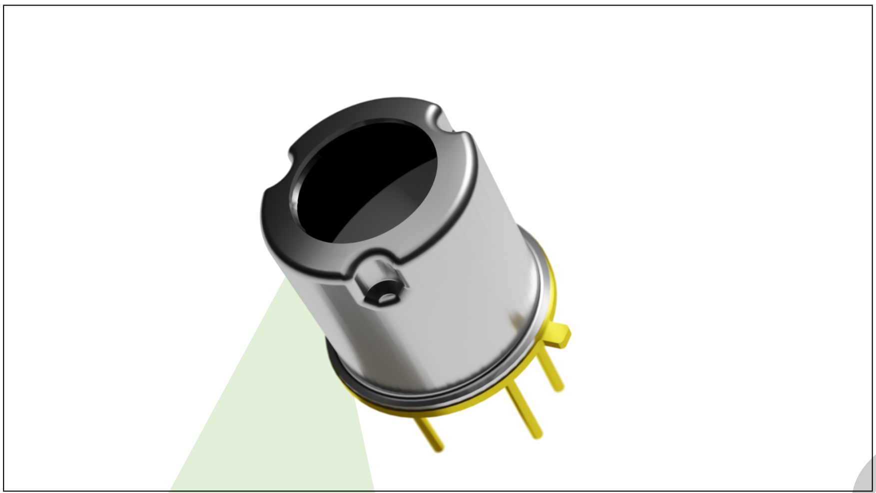
CoolEYE™

Infrared Sensing Solutions

TPiA 4.4T 4766 L5.5 / 4406

Product Specification



Features

- High sensitivity thermopiles
- 4×4 pixel
- 17° field of view
- Calibrated temperature output
- I^2C interface (optional SPI)
- Cap type TO39 L5.5
- 3.3 V supply voltage (optional 1.8 V)

Applications

- Remote temperature measurement
- Body and face temperature measurement
- Room temperature control
- Presence detection
- Fever access control
- (Microwave) oven temperature control
- Fuser roller temperature measurement
- Air conditioning control

Calibrated Thermopile Focal Plane Array

The sensor is a calibrated 4×4 focal plane thermopile array with a digital I^2C interface. It features a temperature calculation at sensor level for all pixels and a measurement of the sensor's temperature itself. The lens provides a small field of view for each pixel. The metal package ensures best possible temperature stability while providing a strong shielding against electromagnetic interference.

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Contents

1 Dimensions and Connections

Figure 1: Mechanical Dimensions (in mm) and Pin Configuration. A short description is given in table 1. The A0 output is bond internally to GND .

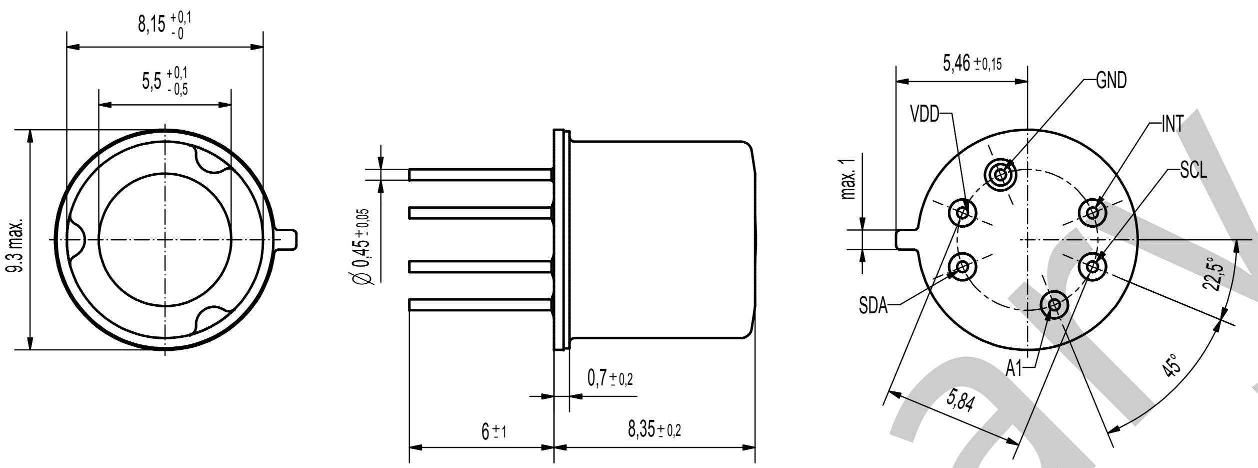

Table 1: Pin descriptions. Further explanations follow in this document.

Pin Symbol	Pin Name and short Functional Description.	Pin Type
A0,A1	**Address Inputs A0, A1:** Setting the last 2 bits of the slave address. Setting a pin to GND corresponds to 0. Setting a pin to VDD corresponds to a 1. The device address with both pins set to GND is **0x0C**.	Input
VSS	**Ground**: The ground (GND) reference for the power supply should be set to the host ground.	Power
VDD	**Power Supply**: The power supply for the device. Typical operating voltage is 3.3 V	Power
SDA	**Serial Data**: The I^{2}C bidirectional data line. Open-drain driven and requires pull-up resistors.	Input/Output
SCL	**Serial Clock Input**: The I^{2}C clock input for the data line. Up to 400 kHz are possible. The device has a time-out feature as described in section 6.2.	Input/Output
INT	**Interrupt Output**: The open drain / active low Interrupt output to indicate a detected event. Reading the chip register out resets this output.	Output

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2 Optical Characteristics

2.1 Field of View

Figure 2 illustrates the measurement of the sensor's field of view (FOV). A hot point like heat source radiates almost parallel infrared light in a distance to the sensor. The sensor's housing is rotated around its sensor plane in all directions while recording the sensor data. A typical measurement result is shown in figure 3. The result is normalized to the peak value of the measurement. The resulting parameters are depicted in table 2.

Figure 2: Illustration of the FOV measurement setup. For details see the text.

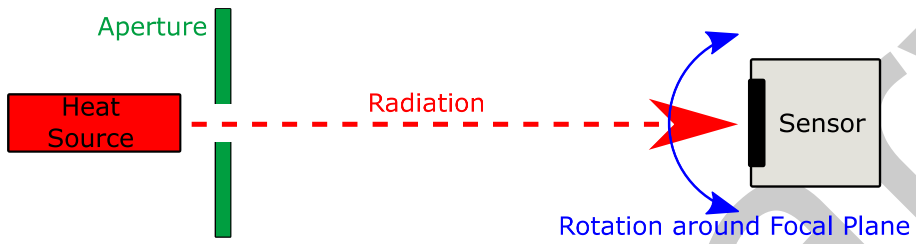

Figure 3: Typical FoV measurement result

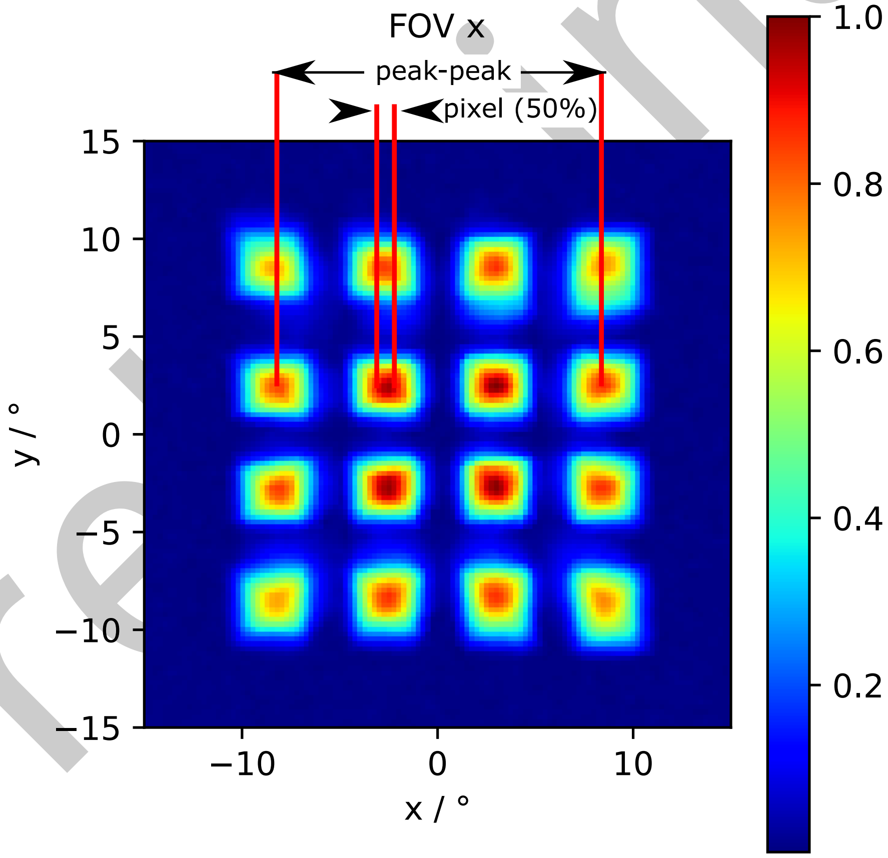

Figure 4 illustrates the definition of the optical axis. It includes all degrees of freedom of the assembly into one parameter, which represents a tilt of the typical field of view center axis in respect to the outer package. The physical pixel orientation is shown in figure 5. Note that the projected image of an object behind a lens appears mirrored.

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Table 2: Optical Parameters for Cap type TO39 L5.5

Symbol	Parameter	Min	Typ	Max	Unit	Remarks / Conditions
FOV_X	Field of View X Direction		17		°	See fig. 3
FOV_Y	Field of View Y Direction		17		°	See fig. 3
$FOV_{X\ pixel}\ 50\,\%$	Single Pixel FOV		3.5		°	See fig. 3
OA	Optical Axis	−3.7	0	3.7	°	See fig. 4

Figure 4: Illustration of optical axis

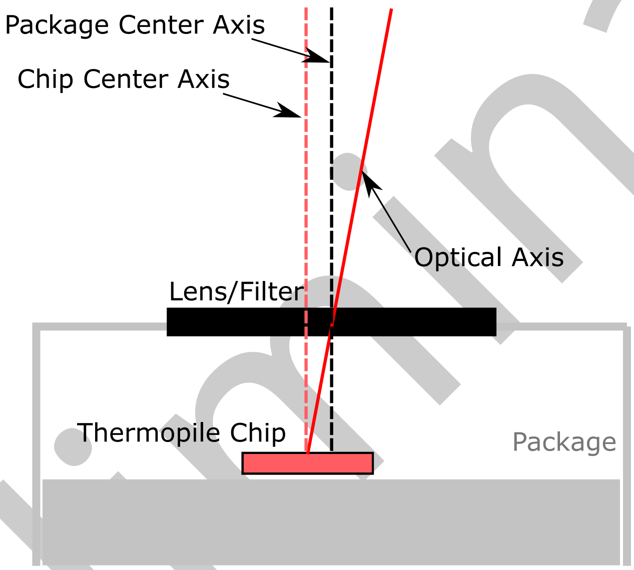
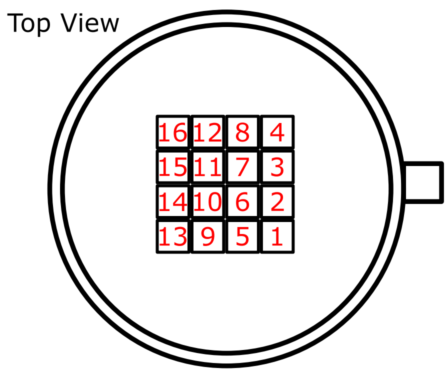


Figure 5: Physical pixel orientation relative to the sensor's cap tab



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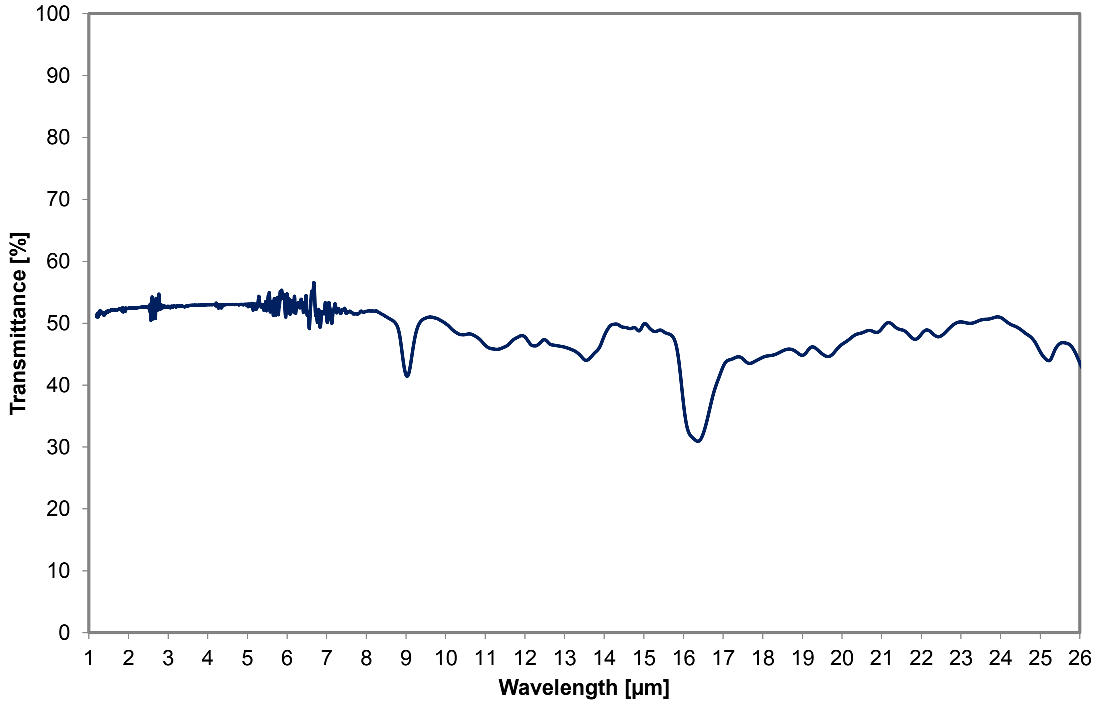
2.2 Filter Properties

Table 3: Filter properties

Parameter	Symbol	Min	Typ	Max	Unit	Remarks / Conditions
Average Filter Transmittance	T_A		50		%	$2\,\mu m < \lambda < 15\,\mu m$

Figure 6: Filter transmittance, typical curve



3 Absolute Maximum Ratings

Table 4: Absolute Maximum Ratings. Data applicable to operation at free-air temperature range.

Parameter	Symbol	Min	Typ	Max	Unit	Remarks/Conditions
Voltage at any pin	V_{DD}	−0.3		3.6	V	
Current into any pin	I_{pin}	-		100	mA	
Storage Temperature		−40		100	°C	< 60 % r.H.
Operating Temperature		−25		85	°C	
Humidity				95	%r.h.	Non-condensing, 60 °C max.
ESD Tolerance [HBM]				2.5	kV	IEC 61000-4-2

Stresses beyond the limits listed in table 4 may cause permanent damage to the device. Exposure to absolute maximum ratings for long time may affect the device reliability and may lead to deterioration of any parameter.

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4 Device Characteristics

Device characteristics are given at 25 °C ambient temperature unless stated otherwise.

Table 5: Power Supply

Symbol	Parameter	Min	Typ	Max	Unit	Remarks / Conditions
V_{DD}	Supply Voltage	2.6	3.3	3.6	V	
I_{DD}	Supply Current		0.65	0.8	mA	Normal Mode (see sec. 6.4)
I_{DD}	Supply Current		0.15	t.b.d.	mA	Deep Sleep (see sec. 6.4)

Table 6: Thermopile

Parameter	Symbol	Min	Typ	Max	Unit	Remarks / Conditions
Sensitive Area	A		0.4×0.4		mm^2	Absorber
Sensitivity	$\Delta counts/\Delta T$		25		counts/K	Tobj=40 °C
Noise(rms)	NETD		160		mK	averaging 5 (sec. 5.4)
Time constant	τ		15		ms	(consider sec. 5.5)
Power up time			590		ms	TP_{OBJ} and TP_{AMB} stable
Resolution			16		Bits	
Max. Object Temp.	$Tobj_{max}$		350		°C	Full FOV, $\epsilon > 99\,\%$

The TPiA 4.4T 4766 L5.5 temperature measurement is specified for a full field-of-view coverage by a black body with more than 99 % emissivity.

Table 7: Ambient temperature sensor (PTAT)

Parameter	Symbol	Min	Typ	Max	Unit	Remarks / Conditions
Resolution			16		Bits	
Slope			230		counts/K	−20 °C to 85 °C
Range		−90		180	°C	
Linearity		−1	0.3	1	%	−20 °C to 85 °C
Offset			−4300		counts	
Noise(rms)			10		mK	averaging 5 (sec. 5.4)

Figure 7 shows the calculated thermopile raw data TP_{object} as a function of the ambient temperature and object temperature based on typical characteristics of TPiA 4.4T 4766 L5.5 . The ASIC typically features a wider dynamic range as compared to the specified values in table 6 and 7. Values out of our specifications are not guaranteed. The measurement of thermopile parameters is described in section 5. The performance in the application may vary due to physical constraints. Please consult our local representative for more information.

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Figure 7: Typical temperature dependence of the raw thermopile output

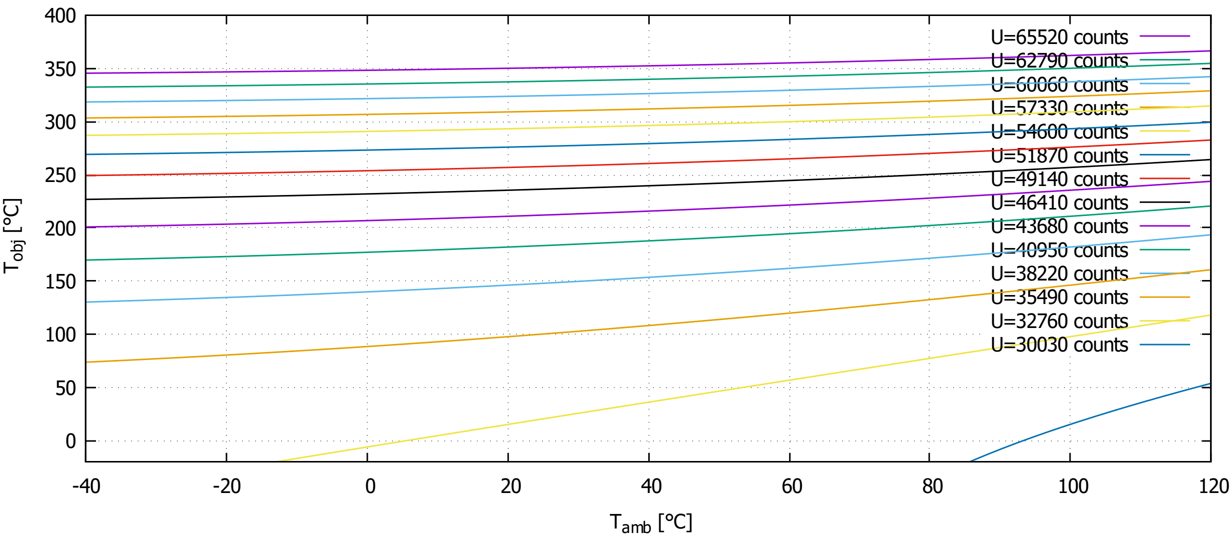

Figure 8: Sensor's minimum accuracy as measured according to section 5.

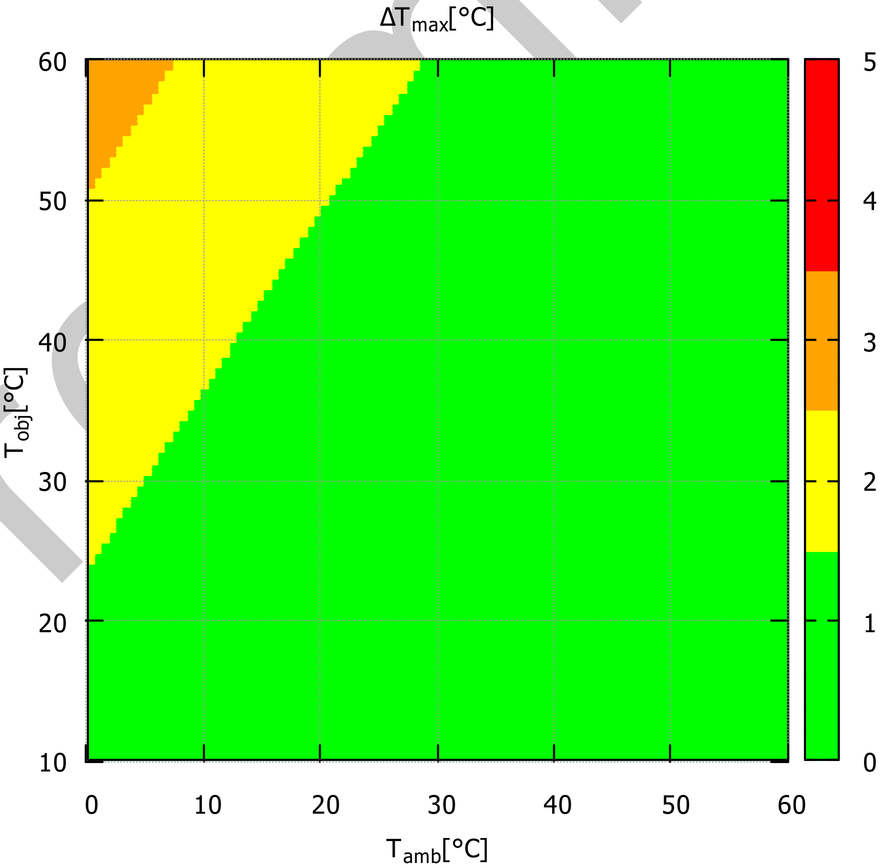

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Table 8: Digital Interface (SCL, SDA). See sec. 6.2 for details.

		Standard Mode		Fast Mode			
Parameter	**Symbol**	**Min**	**Max**	**Min**	**Max**	**Unit**	**Remarks**
Input low voltage	V_{IL}	−0.5	0.8	−0.5	0.8	V	
Input high voltage	V_{IH}	2	$V_{DD} + 0.3$	2	$V_{DD} + 0.3$	V	
Output low voltage	V_{OL}	-	0.4	-	0.4	V	$I_{OL} = 3$ mA
Output high voltage	V_{OH}	-	VDD	-	VDD	V	Open Drain
Input leakage current	I_{LI}	-	2	-	2	µA	$V_I = V_{DD/GND}$
Output leakage current	I_{LO}	-	2	-	2	µA	V_O = VDD
SCL Frequency	f_{SCL}	0	100	0	400	kHz	see sec. 6.2
START Cond. Hold Time	$t_{HD:STA}$	4.0	-	0.6	-	µs	
START Cond. Setup Time	$t_{SU:STA}$	4.7	-	0.6	-	µs	
STOP Cond. Setup Time	$t_{SU:STO}$	4.0	-	0.6	-	µs	
Bus Free Time	t_{BUF}	4.7	-	1.3	-	µs	
Data In Hold Time	$t_{HD:DAT}$	0	-	0	-	µs	
Data In Setup Time	$t_{SU:DAT}$	250	-	100	-	ns	
SCL high time	t_{HIGH}	4.0	-	0.6	-	µs	
SCL low time	t_{LOW}	4.7	-	1.3	-	µs	
SDA/SCL Rise Time	t_r	-	1000	$20 + 0.1C_b$	300	ns	
SDA/SCL Fall Time	t_f	-	300	$20 + 0.1C_b$	300	ns	
Capacitive Load per line	C_b	-	400	-	400	pF	see sec. 7.2
Data Out Hold Time	$t_{VD:DAT}$	-	3.45	-	0.9	µs	
Power-up to Ready Mode	t_{PU}	-	7	-	7	ms	
Noise Pulse at SCL/SDA	t_{SP}	-	$0.1V_{DD}$	-	$0.1V_{DD}$	V	

Table 9: EEPROM

Symbol	**Parameter**	**Min**	**Typ**	**Max**	**Unit**	**Remarks / Conditions**
	Data retention time	10			Years	Max T_{AMB} at 85 °C
t_{WR}	Write cycle time	25			ms	

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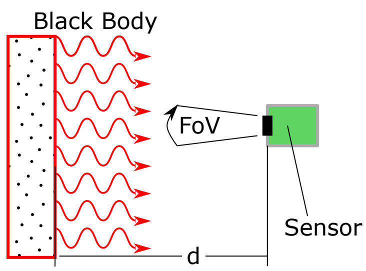
5 Temperature Measurement

5.1 Calibration Conditions

The thermopile output is related to the net IR-radiation. The net IR-radiation can be correlated with the object temperature for a specific fixed set-up. The set-up valid for the factory calibration constants is shown in sketch 9.

Figure 9: Measurement conditions



A fluid heated plane black body with an outer dimension covering at least 4 times the sensors field-of-view (FoV) and an emissivity of better than 95 % has a surface temperature T_{obj} of 60 °C. The surface temperature uniformity is better than 0.2 °C. The ambient temperature T_{amb} is at (25 ± 3) °C. The TPiA 4.4T 4766 L5.5 sensor is mounted at a distance d of 120 mm to the black body. The sensor's temperature may differ from the controlled ambient temperature due to the BB's heat.
Conditions other than described in this document generally require a customized object calibration. Otherwise sensor performance may be different than specified here. Please contact our local representative for more details.

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5.2 Calculation of the Ambient Temprature

For a correct object temperature calculation the ambient temperature must be known. The temperature should be calculated in Kelvin and not °C. To calculate the ambient temperature out of $TP_{ambient}$ the following formula is evaluated.

$$T_{Amb}[K] = TP_{Amb} \cdot (T_{Amb\ PS}) + T_{Amb\ PO} + 273.15$$

using the calibration constants $T_{Amb\ PS}$ and $T_{Amb\ PO}$ from the EEPROM.

5.3 Calculation of the Object Temperature

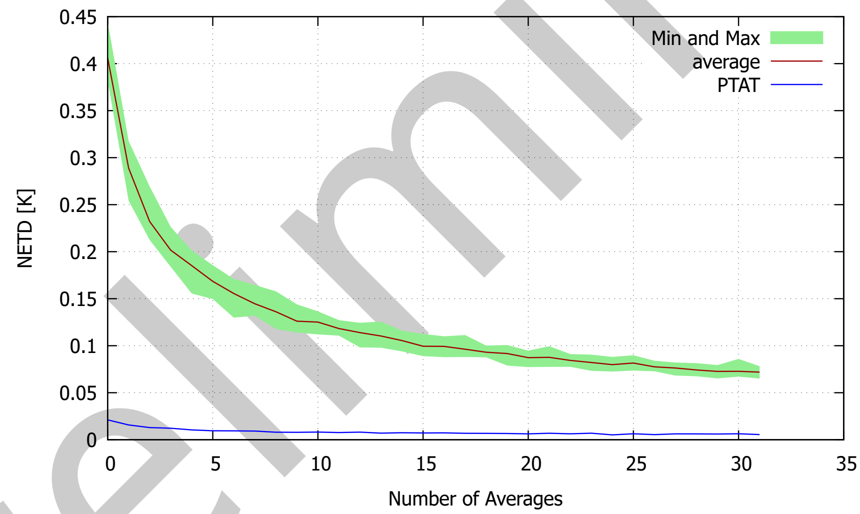
The thermopile output signal TP_{Obj} is not only depending on the objects temperature but also on the ambient temperature T_{Amb} as demonstrated in figure 7. To obtain the object temperature T_{Obj} for pixel i the sensor is calculating

$$T_{Obj\ i}[K] = \left[\frac{TP_{Obj\ i} - U_{0i}}{SCtyp \cdot \sigma \cdot \epsilon} + (T_{Amb})^4\right]^{\frac{1}{4}}$$

where T_{Amb} is obtained as discussed in section 5.2.

5.4 NETD Dependence on Averaging

Figure 10: Sensor's NETD as a function of averaging setting



The sensor's NETD depends on the averaging setting of the sensor. Figure 10 is a typical measurement in thermal equilibrium. The sensor's NETD improves with increasing object temperatures. The averaging setting can be set in volatile as well as the non-volatile memory as described in section 6.6 and section 6.7. Consider also the update time of the temperature measurement as described in section 5.5.

5.5 Update Time Dependence

The sensor's update time of the temperature output depends on the number of averages. Figure 11 shows a typical measurement of update times. Pulling the data with sampling speeds shorter than the update time will lead to repetitive values. Consider also the NETD dependence on averaging as described in section 5.4.

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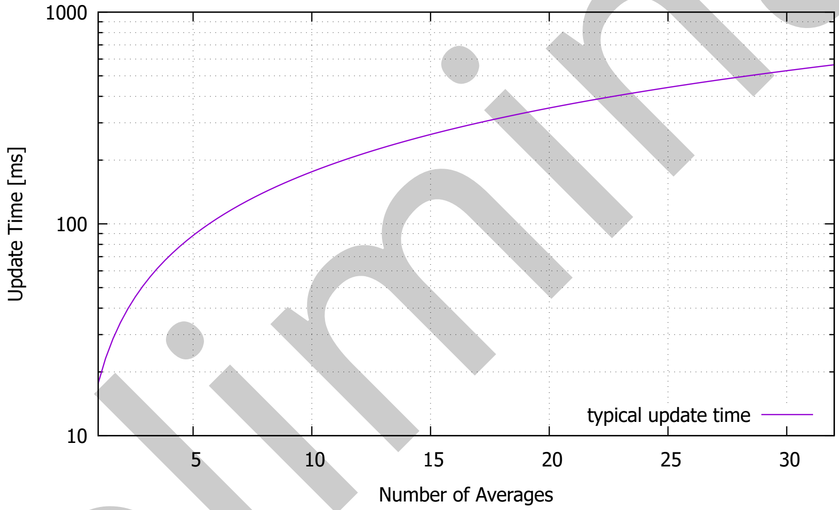
Figure 11: Update time of temperature output as a function of averaging



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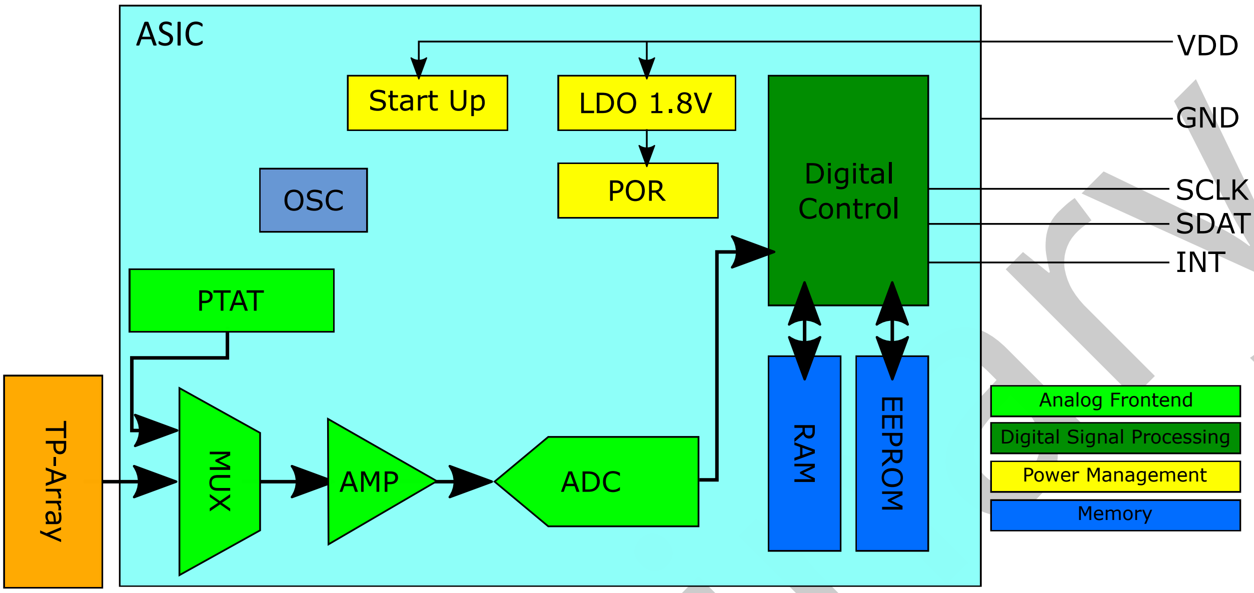
6 Interface Characteristics

6.1 Interface Overview

Figure 12: Block Diagram



The functional diagram 12 illustrates the functional blocks of the sensor. The ASIC consists of two main parts, the analog/mixed-signal block and the digital signal processor. The analog/mixed-signal part represents the front-end and consists in general of the low-noise amplifier, the analog-to-digital-converter and some power management blocks like bandgap, reference voltage generation, power-on-reset, oscillator and a low-drop-out-regulator. The digital signal processor is a hard-wired digital circuit with some programming capabilities. Its main purpose shall be the digital signal conditioning based on the calibration settings and the calculation of the object temperature. A random-access memory (RAM) and a non-volatile E2PROM memory (NVM) are included.

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6.2 I²C Interface

An I²C serial interface is provided to read out the sensors data and for read and write access of configuration and status registers and to obtain calibration data from the EEPROM.
The following chapters give detailed instructions to understand and to operate the I²C interface. For the complete I²C specifications (version 2.1) refer to: `www.i2c-bus.org`.
The SCL is a bidirectional input and output used as synchronization clock for serial communication. The SDA is a bidirectional data input and output for serial communication. The SCL and SDA outputs operate as open drain outputs only. External pull-up resistors are required. The pull-up resistor does all the work of driving the signal line high. All devices attached to the bus may only drive the SDA and SCL lines low.
The I²C interface allows connection of a master device (MD) and one or more slave devices (SD). This device can be operated as a SD only. The MD provides the clock signals and initiates the communication transfer by selecting a SD through a slave address (SA) and only the SD, which recognizes the SA should acknowledge (ACK), the rest of SDs should remain silent.
The general data transfer format is illustrated in figure 13.

Figure 13: Illustration of voltages during I²C communication

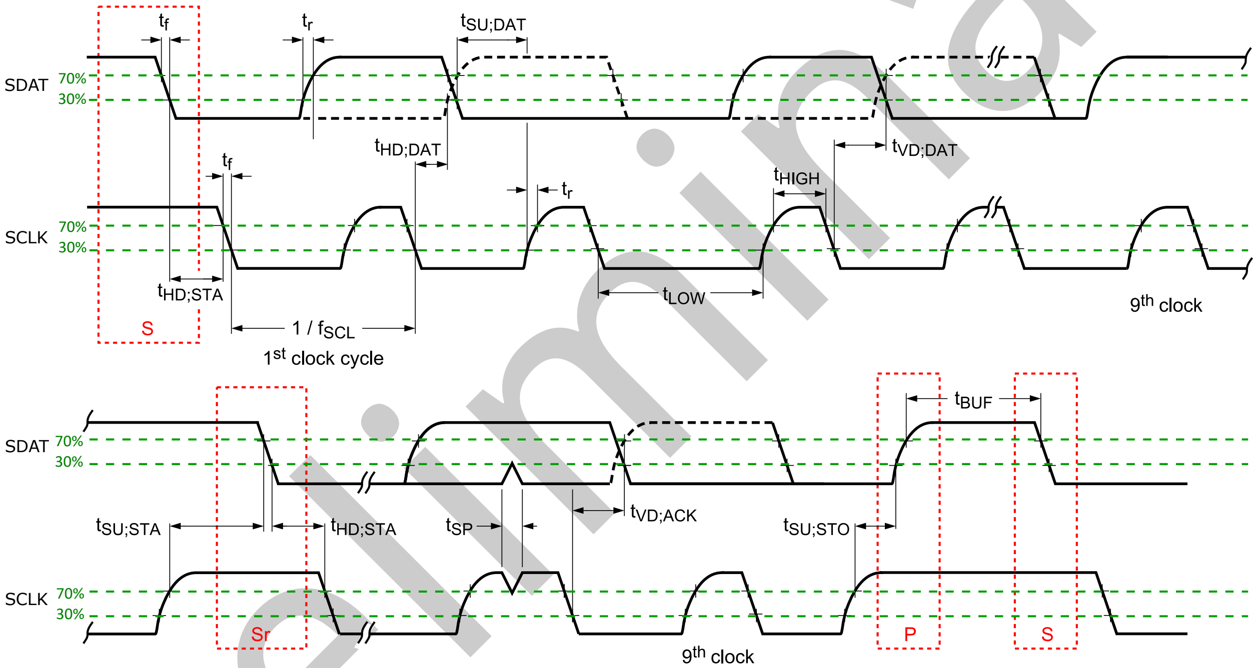

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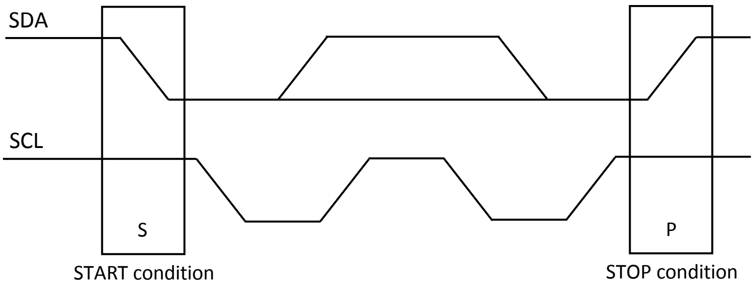
Figure 14: START and STOP Condition



START and STOP conditions Two unique bus situations define a message START and STOP condition which is shown in figure 14.

1. A high to low transition of the SDAT line while SCLK is high indicates a message START condition.
2. A low to high transition of the SDAT line while SCLK is high defines a message STOP condition. START and STOP conditions are always generated by the bus master. After a START condition the bus is considered to be busy. The bus becomes idle again after certain time following a STOP condition or after both the SCLK and SDAT lines remain high for more than $t_{HIGH:MAX}$.

Slave Address The CoolEYE™responds to the base slave address of dec8 + the logic state of A1 and A0 bits. The voltage applied to A1 and A0 can be either LOW (V_{SS}) or HIGH (V_{DD}). This results in 4 possible addresses ranging from dec8 to dec11 as illustrated in table 10.

Table 10: Examples for the interplay between configuration pins and the EEPROM

Base Address<7:1>	<A1:A0> state	I^2C slave address
0001 000	L:L	0001 000
0001 000	H:L	0001 010
0001 000	L:H	0001 001
0001 000	H:H	0001 011

Timeout The CoolEYE™ provides a time-out mechanism for the bus communication self recovery in the event that the protocol sequence is interrupted or disturbed. Every time a new transaction is recognized by a slave address match, a timer is activated. If the subsequent protocol events do not occur within a span of 30 ms, a time-out occurs and as a consequence, the communication sequence will be reset to be ready for a new transaction.

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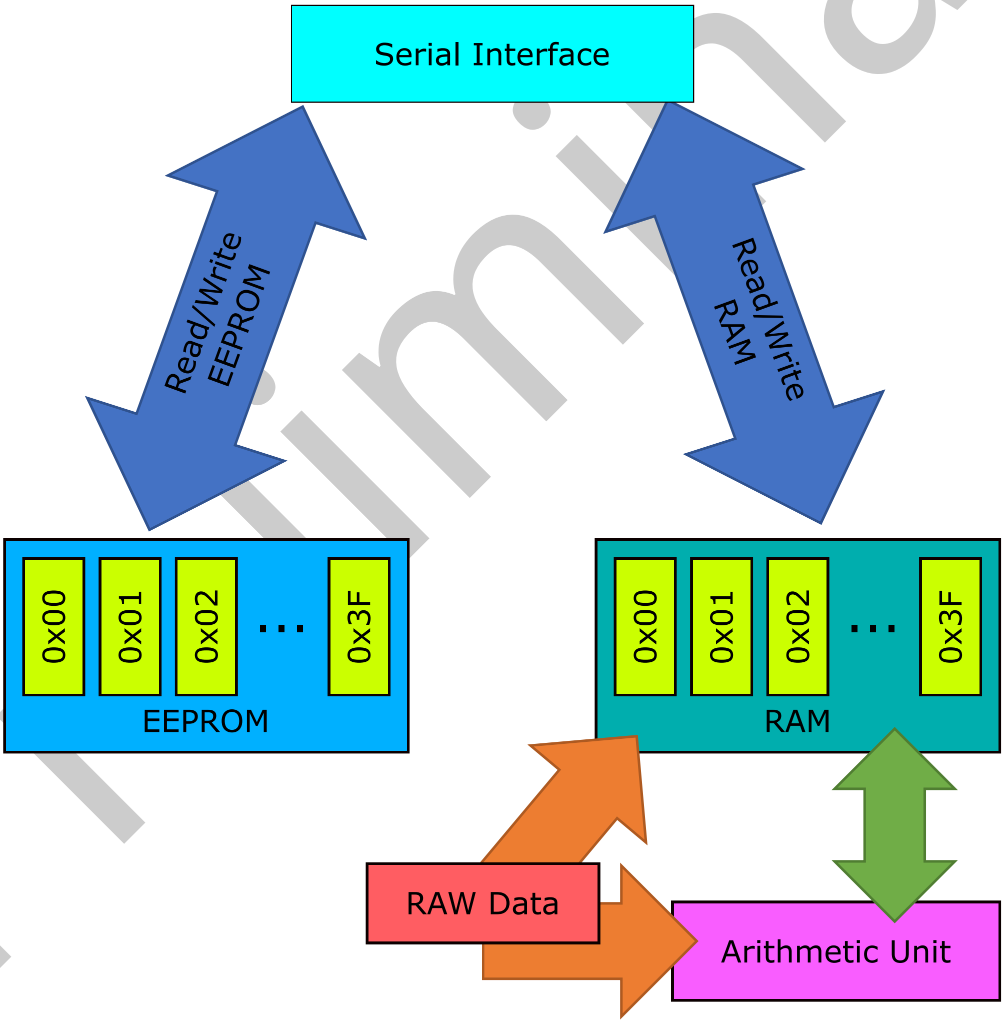
6.3 Protocol

Figure 15 is an illustration for the access to the raw and calculated data as well as the sensor's configuration. The interface consists of a volatile RAM and non-volatile EEPROM. The serial interface is generally accepting read and write operations. The contents of RAM and EEPROM can be individually accessed by an address from 0x00 (dec 0) to 0x3F (dec 63). Each address represents 1 word which in turn consists of 16 bits.
The volatile RAM is the interface to raw and calculated data as well as the configuration parameters for the calculations in the arithmetic unit of the sensor. On power-up basic configuration parameters are loaded from the sensor's non-volatile EEPROM.
The access to EEPROM space is steered through a combination of a privilege setting and mode selection which is described in a later section. Some configuration parameters are mapped to the same addresses and can be modified in a volatile manner by accessing the RAM space or in a non-volatile manner by writing into the EEPROM space.
Access to the RAM space requires a so-called Read or Write RAM command sequence. Access to the EEPROM space requires a so-called Read or Write EEPROM command sequence.
Both are described in the following sections.

Figure 15: Illustration of access to EEPROM and RAM through the Serial Interface.



Read and Write Word Figure 16 is a legend to the following protocol illustrations. A write word squence is shown in figure 17 and a read word sequence in figure 18.

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The sequence is initiated by a start condition, followed by a slave address with the bus write bit. When the sensor acknowledges, the protocoll sends the command which defines the access type. The command is described in a separate section below.
According to the serial interface specifications, data is transferred in 8 bit chunks. Actual transferred values consists of words (2 x 8bit). It is transferred in the big endian format in case it is representing one value. In order to ensure data integrity, each sequence is finalized with a byte for cyclic redundancy check (CRC).

Figure 16: Legend for Protocol illustrations

S	START Condition
Sr	Repeated START Condition
Rd	READ (bit value 1)
Wr	WRITE (bit value 0)
A	ACKNOWLEDGE (ACK)
Ā	NOT ACKNOWLEDGE (NACK)
P	STOP Condition
PEC	Packet Error Code (CRC: Cyclic Redundancy Check)
(white box)	Data Direction: MASTER send to SLAVE
(green box)	Data Direction: SLAVE send to MASTER

Figure 17: Protocol illustration for WRITE Word

S	Slave Address	Wr	A	Command	A	Data Lo Byte	A	Data Hi Byte	A	
PEC	A	P								

Figure 18: Protocol illustration for READ Word

S	Slave Address	Wr	A	Command	A	Sr	Slave Address	Rd	A	Data Lo Byte	A	
Data Hi Byte	A	PEC	A	P								

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Command The command is a byte used by the master device to tell the CoolEYE™ which operation is requested or executed. The command has the format as shown in figure 19. It is devided into two parts. The highest two bits define if RAM or EEPROM is accessed. The lowest six bits represent the register address. The command types are listed in table 11.

Important: The command alone is not sufficient to grant write access to RAM or EEPROM. Depending on the requested operation, the ASIC must be pre-configured to a certain operation state. See section 6.4 for details.

Figure 19: Command Structure

Table 11: Command Types

Command	Descriptions
00 XXXXXX$_{bin}$	Read RAM, XXXXXX= 6 LSBits of address of RAM cell to be read
01 XXXXXX$_{bin}$	Read/Write EEPROM, XXXXXX = 6 LSBits of address of E2P cell to be read/written

Content of RAM is explained in section 6.6 and EEPROM content in section 6.7.

Block Read Protocol In addition to the above READ Word, a BLOCK READ protocol can be activated in order to output in one sequence the data refreshed from RAM Addresses 18 to 34 (T_{AMB}, $T_{OBJ\ PIX1}$, $T_{OBJ\ PIX2}$ ... $T_{OBJ\ PIX16}$) by providing a single COMMAND byte 11 XXXXXX$_{bin}$. The BLOCK READ can output the data of up to 16 pixels. The actual output will stop after the actual number of available pixels in this module.

Figure 20: Command for Block Read

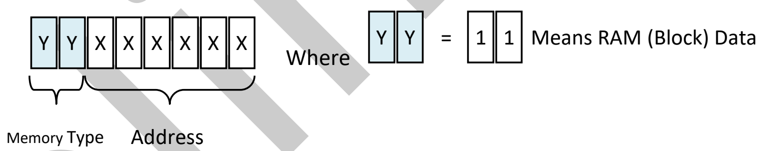
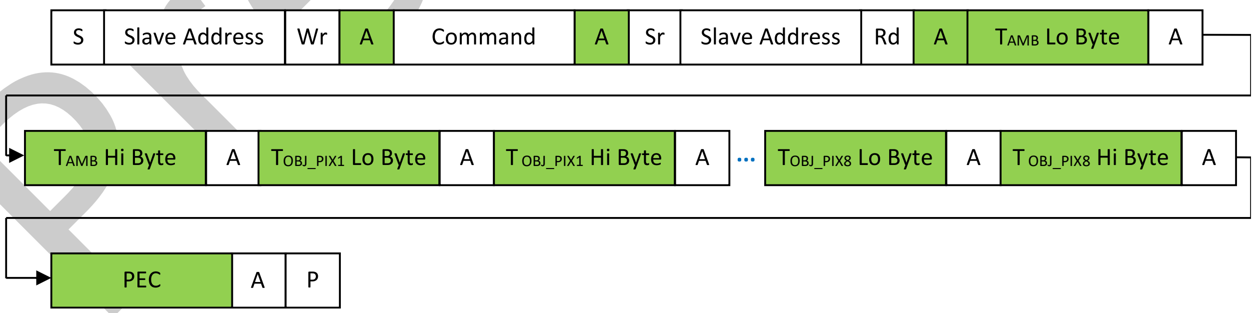


Figure 21: Protocol illustration for Block Read



PEC: Cyclic Redundancy Check Each bus transaction requires a Packet Error Code (PEC) calculation by both the MASTER and the SLAVE devices to ensure physical correctness of transmitted data. The PEC includes all bits of a transaction except the START, REPEATED START, STOP, ACK, and NACK bits.

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Table 12: Command Type: Block Read

Command	Descriptions
11 $XXXXXX_{bin}$	Block Read RAM, from Address 18 (T_{AMB}) to Address 34 ($T_{OBJ\ PIX16}$)

The PEC is a CRC-8 with polynomial PEC= $x8 + x2 + x1 + 1 = 107$hex and must be calculated in the order of the bits as received. A possible implementation might look like:

```
#define POLYNOMIAL        (0x107 << 7)
unsigned char calc_crc8(unsigned char inCrC, unsigned char inData)
{
    int i;
    unsigned int data;
    data = inCrC ^ inData;
    data <<= 8;
    for (i = 0; i < 8; i++){
        if ((data &0x8000) != 0)
            data = data ^POLYNOMIAL;
        data = data << 1;
    }
    return(unsigned char) (data >> 8);
}
```


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6.4 Operation Modes

The sensor has 4 different operation modes which are set by writing one or more 16 bit words into register 0 through the write word RAM command. The operation modes are:

Normal Mode This is the default operation mode (when bit 15 in EEPROM cell 49 is set to 1) after power on reset. The device collects data, computes temperatures and manages interrupts to the host system. In this mode RAM cells can be only read.

Idle Mode The Idle mode stops gathering and computing data. This mode is used to write and read RAM cells in order to change the configuration of the sensor in the volatile memory.

Deep Sleep Mode The sensor is powered down and responds only to writing 0xFFFF into register 0. The power consumption is reduced to a minimum. All computation is halted. Exiting this mode equals a power on reset and all configuration is restored to the default as written to the EEPROM.

Programming Mode The programming mode is used to read and write the non-volatile memory in the EEPROM. The programming mode can be exited without the modification of the EEPROM by writing 0xFFFF into register 0. When exiting the mode, the configuration in the volatile memory is overwritten by the current EEPROM content.

Figure 22: Switching between sensor Operation Modes. Valid only when bit 15 is set to 1 in EEPROM Address 49 (default).

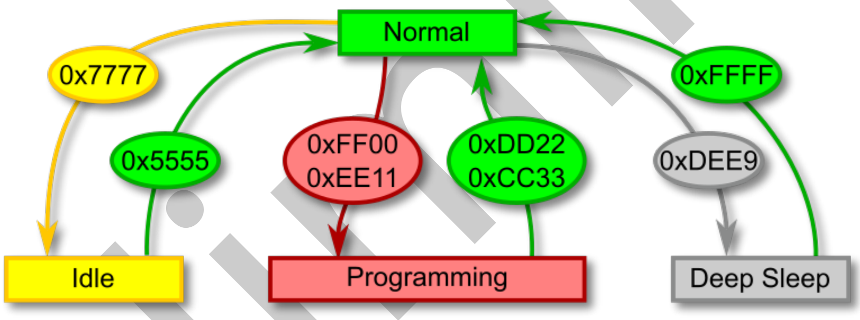

Figure 22 describes switching between different operation modes of the sensor by writing the shown commands into register 0 in the RAM. The current operation mode can be read from register 0 (see sec. 6.6).

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6.5 Number Formats

Table 13: Data Representation. All data is transferred in **big endian** byte order as 16 bit words.

Symbol	Value Range	Example Word Bits [15..0]	Example Value
Int16	−32 768..32 767	1000 0000 000 0010	−126
UInt16	0..65 535	1000 0000 000 0010	32 770
FP S.15	−1.0..0.999 969 482 421 875	1000 0000 000 0010	−0.999 938 964 843 75
FP 1.15	0.0..1.999 969 482 421 875	1000 0000 000 0010	1.000 061 035 156 25

Int16 Signed Integer Data is represented as a signed 16 bit or 2 byte long (word) integer value in the two's complement representation.

UInt16 Unsigned Integer Data is represented as an unsigned 16 bit or 2 byte long (word) integer value.

FP S.15 Signed Fixed Point Data is represented as a fixed point representation (Q-format) where the lowest 15 bits are representing the fractional part of the value, while the first bit is the signed integer value. To obtain a floating point value, calculate

```
float QtoF(unsigned int Q) // 16 bit uint to float convertion
{
    float F = (float) (Q-0.5)/32768.0; // min 16 bit floating point
    return F;
}
```

FP 1.15 Unsigned Fixed Point Data is represented as a fixed point representation (Q-format) where the lowest 15 bits are representing the fractional part of the value, while the first bit is the unsigned integer value. To obtain a floating point value, calculate

```
float QtoF(signed int Q) // 16 bit int to float convertion
{
    float F = (float) (Q-0.5)/32768.0; // min 16 bit floating point
    return F;
}
```

6.6 Sensor Configuration and Data Access through RAM

After power-up, the master may read raw and computed data in RAM. In addition to that, the master can configure the sensor to operate in special modes and to have different user previlidges in order to protect the access of certain registers from unwanted write operations. The address(es) of the RAM Data are shortly described in the Table 14.
Some values are computed and therefore meant to be read-only. If data is present there, depends on the operation mode of the sensor.
Some values were loaded from the EEPROM and can be modified on run-time but modifications are volatile. In order to change them permanently, please refer to section 6.7.
Some values are not-defined or reserved.
The signal processing electronics and the data space in RAM are designed for up to 16 sensor pixels / elements. In case of fewer pixel numbers, only the first npixel Addresses are used.
The data output format is described in section 6.5.

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Table 14: RAM content

Reg Addr [dec]	Reg Addr [hex]	Description	Size [bit]	Access
0	0x00	Operation Mode, Status, Privilege	16	Read/Write
1..16	0x01..0x10	TP_{Obj} raw data of thermopile pixels	16x16	Read
17	0x11	TP_{Amb} raw data of reference temperature sensor	16	Read
18	0x12	T_{Amb} calibrated output of reference temperature sensor	16	Read
19..34	0x13..0x22	T_{Obj} calibrated output of object temperature	16x16	Read
35..37	0x23..0x25	Reserved		
38	0x26	Slope of reference temperature	16	Read/Write
39	0x27	Reserved		
40	0x28	Offset of reference temperature	16	Read/Write
41..44	0x29..0x2C	Reserved		
45	0x2D	Reserved	16	Read/Write
46..47	0x2D..0x2F	Reserved		
48	0x30	Emissivity	16	Read/Write
49	0x31	Data output format, Averaging	16	Read/Write
50	0x32	Interrupt switching	16	Read/Write
51	0x33	Reserved		
52	0x34	Lower interrupt limit	16	Read/Write
53	0x35	Upper interrupt limit	16	Read/Write
54..63	0x36..0x3F	Reserved		

Operation Mode, Status, Privilege This register is used to change the operation modes, read the current status and set/get the current privilege mode for the access to EEPROM and RAM.

Address 0															
Upper Byte								**Lower Byte**							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Mode			reserved						Upper	Lower	reserved				

Mode The current operation mode of the sensor (see sec. 6.4).

Register Content	Current Operation Mode
bin000	DeepSleep
bin001	Normal
bin100	Idle
bin111	Programming
bin010	Reserved

Upper This bit is 1 when the interrupt condition for the undertemperature detection was met.
Lower This bit is 1 when the interrupt condition for the overrtemperature detection was met.
To reset the interrupt, this register must be read together with the PEC. The data transfer must be acknowledged after completion.

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TP_{Obj} Raw Data Those registers give access to the amplified raw voltage value of individual thermopile pixels.The pixel data has the format S.15.

TP_{Amb} Raw Data This register gives access to the raw data of the reference temperature channel. The pixel data has the format S.15.

T_{Amb} This register gives access to the calibrated temperature of the sensor's reference temperature channel. The output format depends on the setting in the 'Data output format' register and is described there in greater detail.
The default output is a 16-bit signed integer value which represents the temperature in °C · 10.

T_{Obj} This register gives access to the calculated object temperature based on the thermopile pixel voltage and the internal reference temperature.
The output format depends on the setting in the 'Data output format' register, averaging as well as the number of enabled pixels and is described there in greater detail.
The default output is a 16-bit signed integer value which represents the temperature in °C · 10.

Emissivity The emissivity is represented as an unsiged integer. The emissivity is given in % · 10. The default value is dec 1000 .

Data Output Format and Averaging This register steers the calculated output format of T_{Amb} and T_{Obj} as well as gives access to averaging options in order to improve the NETD while reducing the update frequency of the temperature output.

Address 49															
Upper Byte								Lower Byte							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
dec 2		Unit	Scaling	Averaging					dec 0						

Unit setting of dec 0 sets the output to Kelvin as unsigned integers. Setting to dec 1 sets then temperature output to degree Celsius as signed integers, The default output format is °C.
Scaling setting of dec 0 sets the output resolution to 10· **Unit**. Dec 1 sets the output resolution to 100· **Unit**. The default resolution is 10.
Averaging determines, how many frames should be accumulated and averaged before updating the temperature output. Dec 0 disables averaging, otherwise up to **Averaging**+1 frames are averaged. Increasing the averaging, improves the signal to noise ratio but increases the update time of the temperature output. The default value is 5 - 1.
The temperature range might be limited by the chosen output format as it is limited to 16 bits.
All other bits must be set to the default values for a proper operation of the device.

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Interrupt switching This register contains the interrupt enable bits.

Address 50															
Upper Byte								Lower Byte							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	Upper	Lower	dec 0												

Upper Setting this bit to 1, enables the interrupt output for the overtemperature feature. Read register 0 to reset the interrupt status. **Lower** Setting this bit to 1, enables the interrupt output for the undertemperature feature. Read register 0 to reset the interrupt status.

Lower interrupt limit Contains the threshold for the undertemperature detection feature. If one of the enabled pixels undercuts this threshold, the interrupt condition is met. The data format is given by the **data output format**. Enable the interrupt in register 50. To reset the interrupt condition, read register 0. No hysteresis is applied.

Upper interrupt limit Contains the threshold for the overtemperature detection feature. If one of the enabled pixels exceeds this threshold, the interrupt condition is met. The data format is given by the **data output format**. Enable the interrupt in register 50. To reset the interrupt condition, read register 0. No hysteresis is applied.

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6.7 Non-volatile Parameters and Calibration Constants in EEPROM

EEPROM contents hold not only calibration constants which are used to compute the output into the RAM section. It also contains configuration parameters, which should be stored non-volatile and therefore loaded each time the sensor is powered up or reset. Therefore some configuration registers, which are described in section 6.6, can be found also in this section. While changes to those registers in the RAM will be lost after sensor power-up or reset, changes in the EEPROM will remain.

Excelitas takes no liability for corrupted or false data in case the EEPROM was modified by the customer!

Table 19: EEPROM content

Reg Addr [dec]	Reg Addr [hex]	Description	Size [bit]	Access
0..15	0x00..0x0F	TP_{Obj} thermopile pixel offsets	16x16	Read/Write
16..31	0x10..0x1F	TP_{Obj} thermopile pixel sensitivities	16x16	Read/Write
32..34	0x20..0x22	Reserved		
35..37	0x23..0x25	Reserved		
38	0x26	Slope of reference temperature	16	Read/Write
39	0x27	Reserved		
40	0x28	Offset of reference temperature	16	Read/Write
41..44	0x29..0x2C	Reserved		
45	0x2D	Reserved	16	Read/Write
46..47	0x2E..0x2F	Reserved		
48	0x30	Emissivity	16	Read/Write
49	0x31	Data output format, Averaging	16	Read/Write
50	0x32	Interrupt switching	16	Read/Write
51	0x33	Reserved		
52	0x34	Lower interrupt limit	16	Read/Write
53	0x35	Upper interrupt limit	16	Read/Write
54..63	0x36..0x3F	Reserved		

Emissivity The emissivity is represented as an unsiged integer. The emissivity is given in % · 10. The default value is dec 1000 .

Data Output Format and Averaging This register steers the calculated output format of T_{Amb} and T_{Obj} as well as gives access to averaging options in order to improve the NETD while reducing the update frequency of the temperature output.

Address 49															
Upper Byte								Lower Byte							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
dec 2		Unit	Scaling	Averaging					dec 0						

Unit setting of dec 0 sets the output to Kelvin as unsigned integers. Setting to dec 1 sets then temperature output to degree Celsius as signed integers, The default output format is °C.

Scaling setting of dec 0 sets the output resolution to 10· **Unit**. Dec 1 sets the output resolution to 100· **Unit**. The default resolution is 10.

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Averaging determines, how many frames should be accumulated and averaged before updating the temperature output. Dec 0 disables averaging, otherwise up to **Averaging**+1 frames are averaged. Increasing the averaging, improves the signal to noise ratio but increases the update time of the temperature output. The default value is 5 - 1.
The temperature range might be limited by the chosen output format as it is limited to 16 bits.
All other bits must be set to the default values for a proper operation of the device.

Interrupt switching This register contains the interrupt enable bits.

Address 50															
Upper Byte								Lower Byte							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	Upper	Lower	dec 0												

Upper Setting this bit to 1, enables the interrupt output for the overtemperature feature. Read register 0 to reset the interrupt status. **Lower** Setting this bit to 1, enables the interrupt output for the undertemperature feature. Read register 0 to reset the interrupt status.

Lower interrupt limit Contains the threshold for the undertemperature detection feature. If one of the enabled pixels undercuts this threshold, the interrupt condition is met. The data format is given by the **data output format**. Enable the interrupt in register 50. To reset the interrupt condition, read register 0. No hysteresis is applied.

Upper interrupt limit Contains the threshold for the overtemperature detection feature. If one of the enabled pixels exceeds this threshold, the interrupt condition is met. The data format is given by the **data output format**. Enable the interrupt in register 50. To reset the interrupt condition, read register 0. No hysteresis is applied.

ID Unique Sensor Identification Number Each sensor is tracable through a unique identification number. This number is stored as

Address 60															
Upper Byte								Lower Byte							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Letter Code					ID number [26..16]										
Address 61															
Upper Byte								Lower Byte							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ID number [15..0]															

Where the letter code A..Z is corresponding to a value of 1..27. The ID number is a 27 byte long number.
This may not apply to engineering samples.

CS Checksum The checksum over all EEPROM cells excluding address 63.

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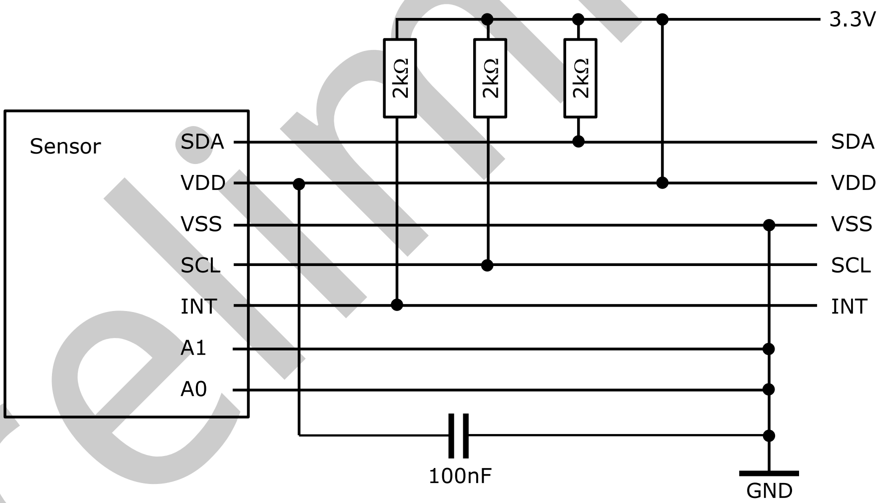
7 Integration instructions and recommendations

7.1 PCB layout and Wiring Patterns

In general, the wiring must be chosen such that crosstalk and interference to/from the bus lines is minimized. The bus lines are most susceptible to crosstalk and interference at the high levels because of the relatively high impedance of the pull-up devices.
If the length of the bus line on a PCB or ribbon cable exceeds 5 cm and includes the VDD and VSS lines, the wiring pattern must be:
SDA - VDD - VSS - SCL
and only if the VSS line is included we recommend
SDA - VSS - SCL
as a pattern. These wiring patterns also result in identical capacitive loads for the SDA and SCL lines. The VSS and VDD lines can be omitted if a PCB with a VSS and/or VDD layer is used.
If the bus lines are twisted-pairs, each bus line must be twisted with a VSS return. Alternatively, the SCL line can be twisted with a VSS return, and the SDA line twisted with a VDD return. In the latter case, capacitors must be used to decouple the VDD line to the VSS line at both ends of the twisted pairs.
If the bus lines are shielded (shield connected to VSS), interference will be minimized. However, the shielded cable must have low capacitive coupling between the SDA and SCL lines to minimize crosstalk.
The PCB design requires, an optimization procedure to achieve the best signal quality. As a starting point sketch 23 is given. Values for pull-up resistors must be replaced by matching ones, fitting the capacitive load of lines. In case of strong EMI observations additional RC-filtering components might be required at the sensor inputs and outputs which is not depicted in the sketch.

Figure 23: Exemplary wiring layout



7.2 Choice of Passive Components

Passive components must be chosen in such way that specifications are met according to table 8. The maximum pull-up resistance R_p is a function of the maximum rise time t_r and can be calculated as follows

$$R_{p\max} = \frac{t_{r\max}}{0.8473 \cdot C_b} \tag{1}$$

and is shown in figure 24.
The total bus capacitance C_b must take all components into account

$$C_b = C_{\text{Sensor}} + C_{\text{Lines}} + C_{\text{Host}} \tag{2}$$

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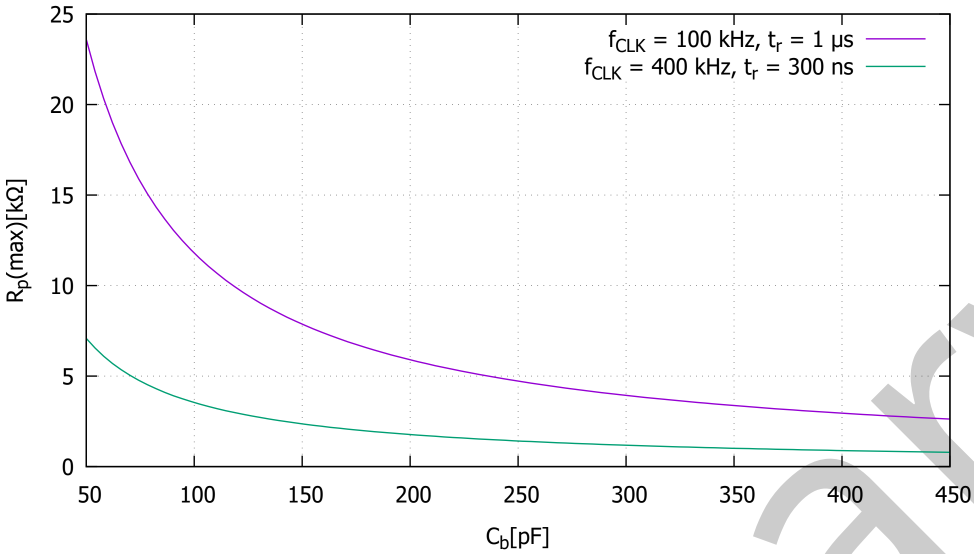
Figure 24: Maximum I2C pull-up resistance over line capacitance.



The total bus capacitance limits the external maximum pull resistance R_p due to to the I2C standard rise time specifications. The actual bus timings must be validated in the final system. If the pull-up resistor value is too high, the I2C line may not rise fast enough to a logical high before it is pulled low.

7.3 Position

In order to obtain the highest possible performance it is possible to operate the sensor without a (protecting) front window. To measure a temperature based on Excelitas calibration constants no window between the sensor and the object must be used. Excelitas calibration values are only valid when the bare sensor is exposed to the object. As the device is equipped with a highly sensitive infra-red detector, it is sensitive any source of heat, direct or indirect. For a proper temperature measurement the device must be at the same temperature as the ambient. Sudden temperature changes will directly affect the behaviour of the internal calculations such as motion, presence and over-/under-temperature recognition. While slow variations of the sensor and ambient temperature may be tolerated for a proper function of the motion and presence features, a drift in the ambient temperature needs to be compensated for the over-/under-temperature feature as mentioned in the corresponding section.
This device is equipped with a highly sensitive ADC and integrated circuits. Common rules of electronics integration apply. We recommend to place strong EMI sources far apart and/or to shield those.

7.4 Soldering

For the soldering of the detectors within PCBs, the typically applied and recommended process is wave soldering. The recommended soldering temperature shall not exceed 300 °C with a maximum exposure time of 5 s.
Other soldering processes are also possible when maintaining similar temperature profiles. Temperatures higher than recommended may affect its performance. Any soldering process should be qualified to avoid damage to the sensor.
For highest accuracy and best temperature compensation, it is recommended to keep a small gap (1 mm) between the PCB and sensor base plate.

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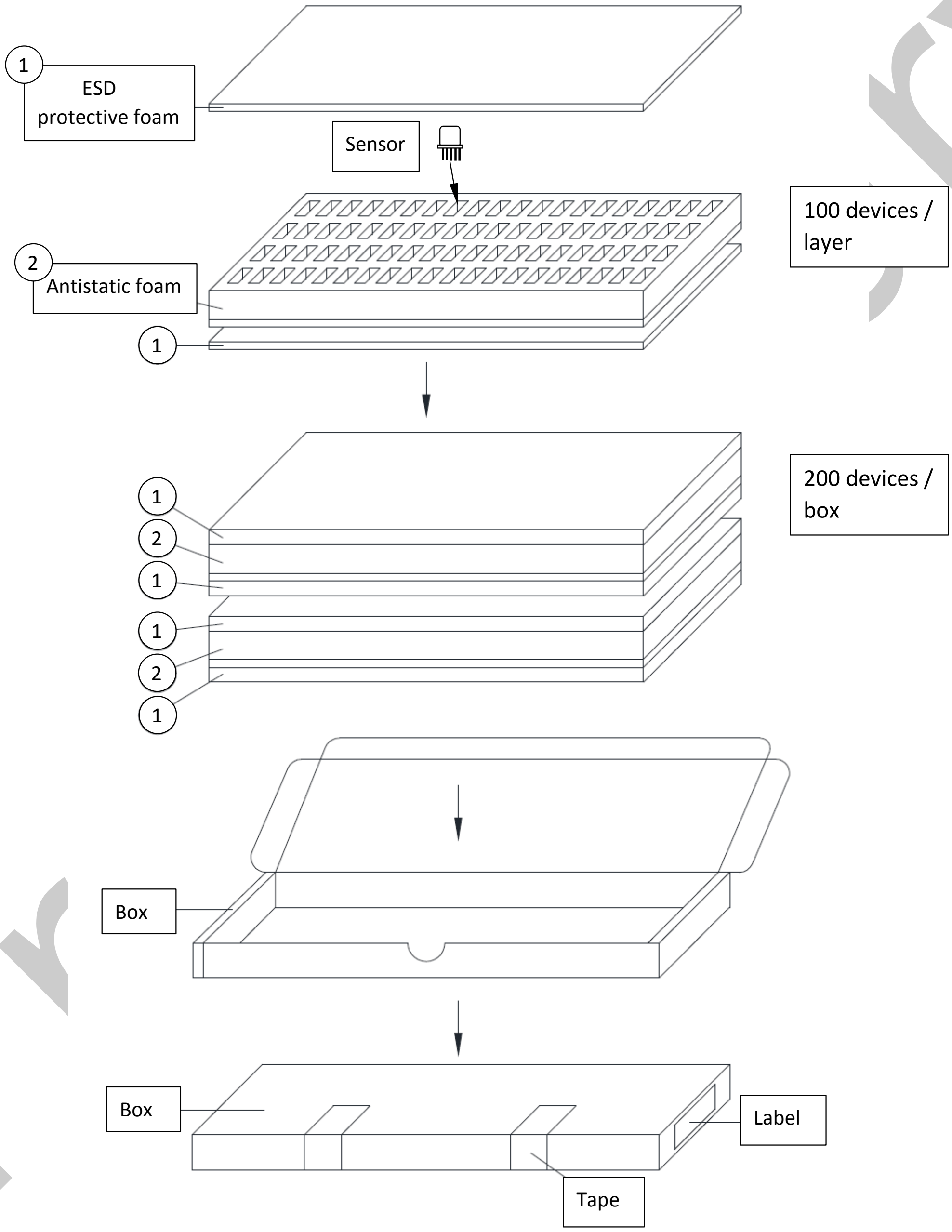
8 Packaging Specification

8.1 General Information

The Excelitas Technologies sponge packaging system protects the product from mechanical and electrical damage and is designed for manual unloading. The system consists of sponges which are protected against ESD. Up to 100 parts are filled into one box. Information labels, ESD labels and bar-code Labels (optional) are placed on the box. Figure 25 shows the basic outline.

Figure 25: Sponge packaging system for manual unload.



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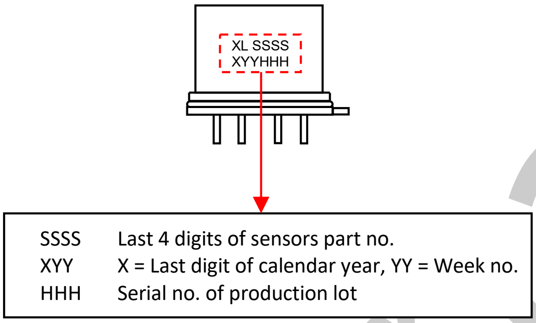
9 Statements

Quality Excelitas Technologies is a ISO 9001:2015 certified manufacturer with established SPC and TQM. Excelitas Technologies is certified for it's Environmental Management System according to ISO 14001:2015 and for the Occupational Safety and Health Management System according to ISO 45001:2018.
All devices employing PCB assemblies are manufactured according IPC-A-610 class 2 guidelines.
The infra-red detection product line is certified for ANSI/ESD S.20.20:2014.

Labeling For manufacturing traceability, each sensor and module is labelled using the following format.

Figure 26: Labeling on Sensors and Modules



Moisture Sensitivity Level Moisture sensitivity level classification does not apply to TO-can products and parts with connectors. Storage at high humidities should be avoided.

Electrostatic Discharge Performance Excelitas standard ESD tests are performed according to IEC 61000-4-2. Tests conducted according to other norms are performed on request. Test results are depicted in table 4.
Please make sure not to confuse applying norms with other norms such as ANSI/ESDA-JEDEC JS-001-2010 (Human Body Model), ESD DS5.3.1 (Charge Device Model) or ESD STM5.2 (Machine Model).

RoHS This sensor is a lead-free component and complies with the current RoHS regulations, especially with existing road-maps of lead-free soldering.

Liability Policy The contents of this document are subject to change. The details of this document are valid by the specified revision date. Excelitas reserves the right to change at any time total or part of the content of this specifications without individual notification. Customers should consult with Excelitas Technologies' representatives to ensure updated specifications before ordering.
Customers considering the use of Excelitas Technologies devices in applications where failure may cause personal injury or property damage, or where extremely high levels of reliability are demanded, are requested to discuss their concerns with Excelitas Technologies representatives before such use.
The Company's responsibility for damages will be limited to the repair or replacement of defective product. As with any semiconductor device, pyroelectric sensors, thermopile sensors or modules have a certain inherent rate of failure. To protect against injury, damage or loss from such failures, customers are advised to incorporate appropriate safety design measures into their product.

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