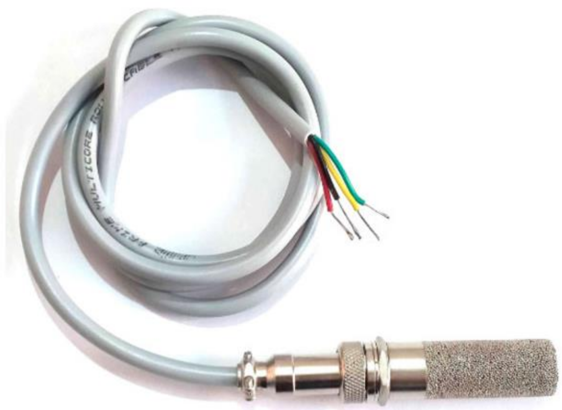
7SEMI ES1351X

High-Accuracy, Ultra-Low-Power, Relative Humidity and Temperature Sensor



General Description

7SEMI ES1351X is a digital sensor platform for measuring relative humidity and temperature at different accuracy classes. Its I2C interface provides several preconfigured I2C addresses and maintains an ultra-low power budget. The power-trimmed internal heater can be used at three heating levels thus enabling sensor operation in demanding environments. The surface of the sensor is covered with a breathable membrane to protect it. A one meter 4-wire cable is attached with the probe for I2C communication and power supply (1.7V to 3.6V).

Device Overview

Products	I2C Address	Humidity Accuracy	Temperature Accuracy
ES13511	0x44	typ ±1.8 max(±3) %RH	typ ±0.2 max(±1) °C
ES13512	0x44	typ ±1.8 max(±2) %RH	typ ±0.2 max(±0.7) °C
ES13513	0x44	typ ±1 max(±1.75) %RH	typ ±0.2 max(±0.6) °C

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1 Quick Start

A typical application circuit for ES1351x is shown on **Figure 1**. After reaching the minimal supply voltage and allowing for the maximal power-up time of 1 ms the sensor is ready for I2C communication. The quickest way to measure humidity and temperature is Sample-code is shown below.

Sample code

```
i2c_write(i2c_addr=0x44, tx_bytes=[0xFD])
wait_seconds(0.01)
rx_bytes = i2c_read(i2c_addr=0x44,
number_of_bytes=6)
t_ticks = rx_bytes[0] * 256 + rx_bytes[1]
checksum_t = rx_bytes[2]
rh_ticks = rx_bytes[3] * 256 + rx_bytes[4]
checksum_rh = rx_bytes[5]
t_degC = -45 + 175 * t_ticks/65535
rh_pRH = -6 + 125 * rh_ticks/65535
if (rh_pRH > 100):
rh_pRH = 100
if (rh_pRH < 0):
rh_pRH = 0
```

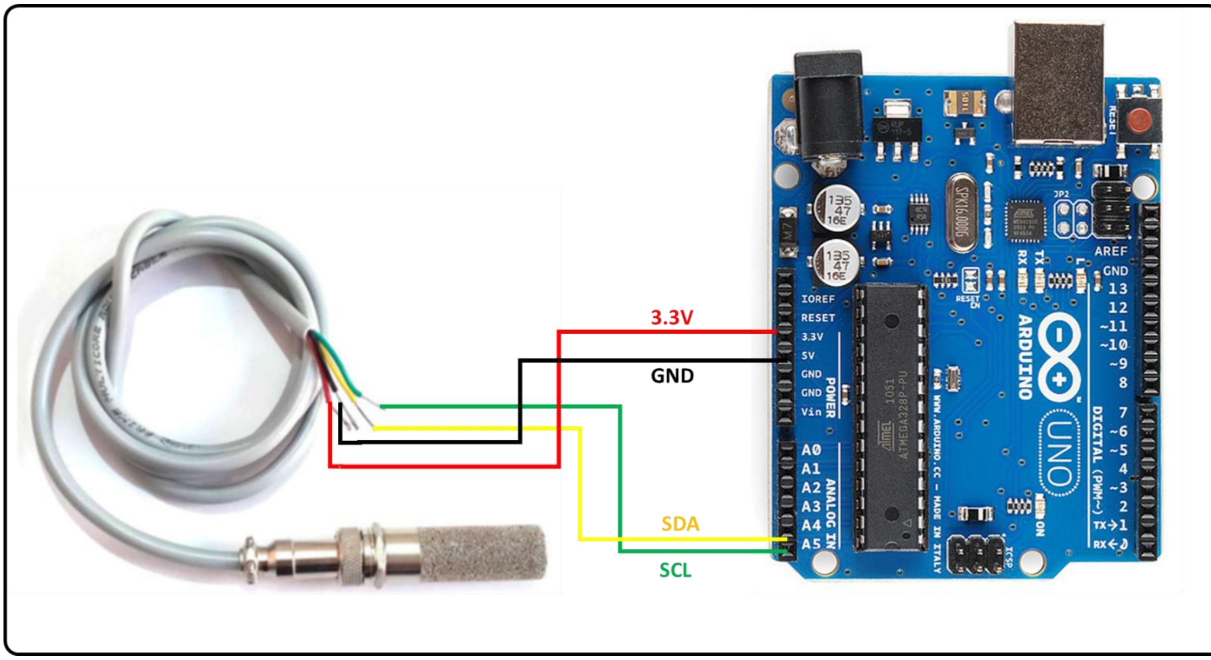

Figure 1 :ES1351X Interfacing with MCU

2 Humidity and Temperature Sensor Specifications

2.1 Relative Humidity

Parameter	Conditions	Value	Units
ES13511 RH accuracy	typ.	±1.8	%RH
	max.	see Figure 2	-
ES13512 RH accuracy	typ.	±1.8	%RH
	max.	see Figure 3	-
ES13513 RH accuracy	typ.	±1.0	%RH
	max.	see Figure 4	-
Repeatability	high	0.08	%RH
	medium	0.15	%RH
	low	0.25	%RH
Resolution	-	0.01	%RH
Hysteresis	At 25°C	±0.8	%RH
Specified range	extended1	0 to 100	%RH
Response time	t63%	4	s
Long-term drift	typ.	<0.2	%RH/y

Table 1 : General relative humidity sensor specifications.

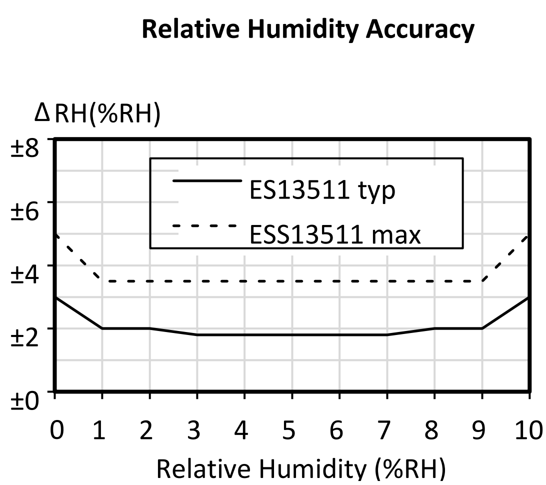

Figure 2 :ES13511 typical and maximal relative humidity accuracy at 25 °C.RH (%RH)

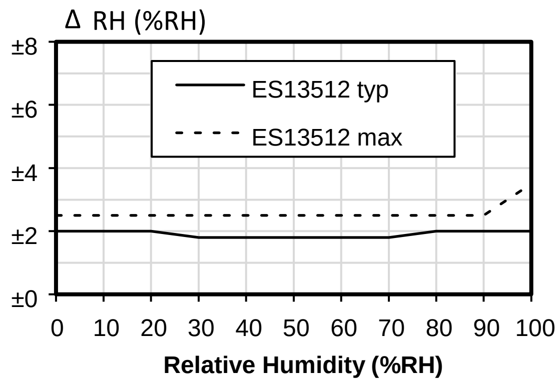

Figure 3 :ES13512 typical and maximal relative humidity accuracy at 25 °C**.**

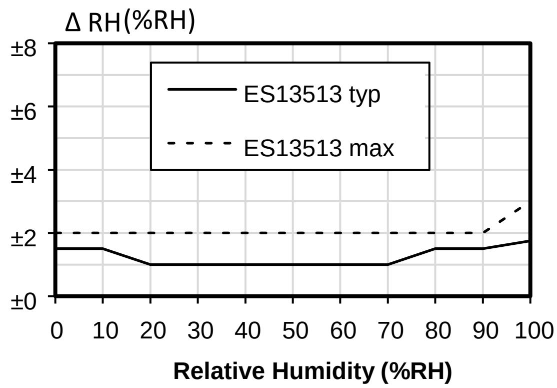

Figure 4 :ES13513 typical and maximal relative humidity accuracy at 25 °C

2.2 Temperature

Table 2 : General Temperature sensor specifications.

Parameter	Conditions	Value	Units
ES13511 *T* Accuracy	typ.	±0.2	°C
	max.	see **Figure 5**	-
ES13512 *T* Accuracy	typ.	±0.2	°C
	max.	see **Figure 6**	-
ES13513 *T* Accuracy	typ.	±0.1	°C
	max.	see **Figure 7**	-
Repeatability	high	0.04	°C
	medium	0.07	°C
	low	0.1	°C
Resolution	-	0.01	°C
Specified range	-	–40 to +125	°C
Response time	$t_{63\%}$	2	s
Long-term drift	typ.	<0.03	°C/y

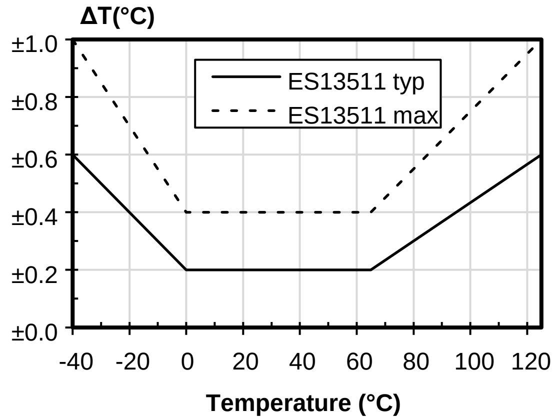

Figure 5 :ES13511 typical and maximal temperature accuracy

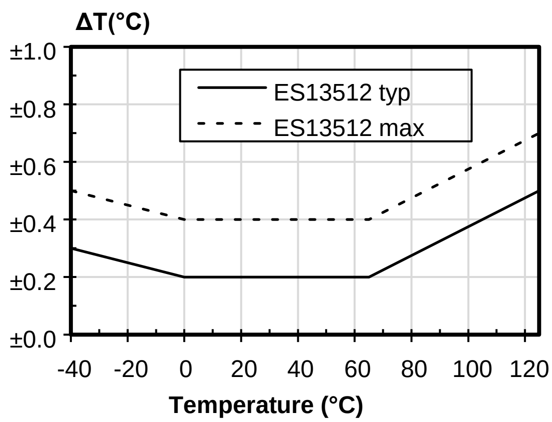

Figure 6 :ES13512 typical and maximal temperature accuracy.

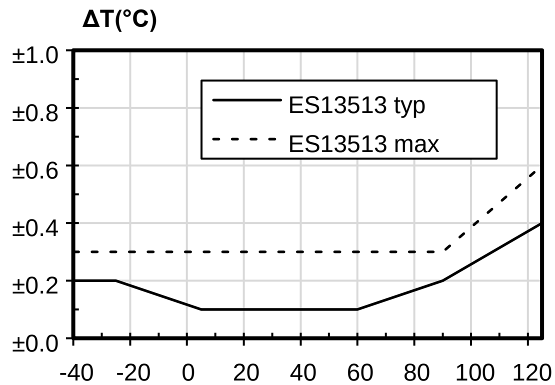

Figure 7 :ES13513 typical and maximal temperature accuracy.

2.3 Recommended Operating Conditions

The sensor shows best performance when operated within the recommended normal temperature and humidity range of 5 °C … 60 °C and 20 %RH … 80 %RH, respectively. Long term exposure to conditions outside recommended normal range, especially at high relative humidity, may temporarily offset the RH signal (e.g. +3 %RH after 60 h at > 80 %RH). After returning into the recommended normal temperature and humidity range the sensor will recover to within specifications by itself. Prolonged exposure to extreme conditions may accelerate ageing. Please note as well that this does apply not only to transportation and manufacturing, but also to operation of the ES1351x.

3 Electrical Specifications

Valid for all electrical specifications: Typical values correspond to V_{DD} = 3.3 V and T = 25 °C. Min. and max. Values are valid in the full temperature range -40 °C … 125 °C and at declared V_{DD} levels and are based on characterization.

3.1 Electrical Characteristics

Table 3: Electrical specifications.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit	Comments
Supply voltage	V_{DD}		1.08	3.3	3.6	V	-
Powerup/down level	V_{POR}	Static power supply	0.6	-	1.08	V	-
Slew rate of the supply voltage	$V_{DD, slew}$		-	-	20	V/ms	Voltage changes on the supply between $V_{DD, min}$ and $V_{DD, max}$. Faster slew rates may lead to a reset
Supply current (no heater)	I_{DD}	Idle state	- -	0.08 -	1.0 3.4	µA	At 25°C At 125°C
		Power up	-	50	-	µA	-
		Measurement	-	320	500	µA	Current while sensor is measuring
		Aver., high repeatability Aver.,med. repeatability Aver., low repeatability	- - -	2.2 1.2 0.4	- - -	µA	Aver. current consumption (continuous operation with one meas. per second)
Power consumption at VDD=1.2V (no heater)	-	Aver., high repeatability Aver.,med. repeatability Aver., low repeatability	-	2.6 1.4 0.5	- - -	µW	Aver. power consumption (continuous operation with one meas. per second)
Low level input voltage	V_{IL}	-	0	-	0.3* V_{DD}	V	-
High level input voltage	V_{IH}	-	0.7* V_{DD}	-	V_{DD}	V	-
Pull up resistors	R_p	V_{DD} < 1.62 V	820	-	-	Ω	-
		V_{DD} ≥ 1.62 V	390	-	-	Ω	-

Low level output voltage	V_{OL}	V_{DD} < 1.62V, R_{pullup} > 820 Ω	-	-	0.2* V_{DD}	V	-
		V_{DD} = 1.62V … 2.0V, R_{pullup} > 390 Ω	-	-	0.2* V_{DD}	V	-
		V_{DD} > 2.0V, R_{pullup} > 390 Ω	-	-	0.4	V	-
Capacitive bus load	C_b	R_P ≤ 820 Ω: fast mode	-	-	400	pF	Capacitive bus load can be determined from $C_b < t_{rise}/(0.8473 * R_p)$. Rise times are t_{rise} = 300 ns for fast mode and t_{rise} = 120 ns for fast mode plus
		R_p = 390 Ω, VDD > 1.62 V: fast mode plus	-	-	340	pF	

3.2 Timings

Max. Values are measured at -40°C and 1.08 V supply voltage (based on characterization).

Table 4: System timing specifications.

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units	Comments
Power-up time	t_{PU}	After hard reset, $V_{DD} \geq V_{POR}$	-	0.3	1	ms	Time between V_{DD} reaching V_{POR} and sensor entering idle state
Soft reset time	t_{SR}	After soft reset	-	-	1	ms	Time between ACK of soft reset command and sensor entering idle state. Also valid for I2C general call reset.
Measurement duration	$t_{MEAS,l}$	Low repeatability	-	1.3	1.6	ms	Including t_{PU}: The three repeatability modes differ with respect to measurement duration, noise level and energy consumption
	$t_{MEAS,m}$	Med. repeatability	-	3.7	4.5	ms	
	$t_{MEAS,h}$	High repeatability	-	6.9	8.3	ms	
Heater-on duration	t_{Heater}	Long pulse	0.9	1	1.1	s	After that time the heater is automatically switched off
		Short pulse	0.09	0.1	0.11	s	After that time the heater is automatically switched off

3.3 Absolute Maximum Ratings

Stress levels beyond those listed in Table 5 may cause permanent damage or affect the reliability of the device. These are stress ratings only and functional operation of the device at these conditions is not guaranteed. Ratings are only tested each at a time.

Table 5: Absolute maximum ratings.

Parameter	Rating
Max. voltage on any pin	V_{SS} - 0.3 V … V_{DD} + 0.3 V
Operating temperature range	-40 °C … 125 °C
Storage temperature range	-40 °C …150 °C
ESD HBM	2 kV
ESD CDM	500 V
Latch up, JESD78 Class II, 125°C	+-100 mA

4 Sensor Operation

4.1 I2C communication

I2C communication is based on NXP's I2C-bus specification and user manual UM10204, Rev.6, 4 April 2014. Supported I2C modes are standard, fast mode, and fast mode plus. Data is transferred in multiples of 16-bit words and 8-bit checksum (cyclic redundancy check = CRC). All transfers must begin with a start condition (S) and terminate with a stop condition (P). To finish a read transfer, send not acknowledge (NACK) and stop condition (P). Addressing a specific slave device is done by sending its 7-bit I2C address followed by an eighth bit, denoting the communication direction: "zero" indicates transmission to the slave, i.e. "write", a "one" indicates a "read" request. Schematics of the I2C transfer types are sketched in **Error! Reference source not found.**. The sensor does not support clock-stretching. In case the sensor receives a read header and is still busy with e.g. measurement or heating, it will return a NACK. Measurement data can only be received once and will be deleted from the sensor's register after the first acknowledged I2C read header.

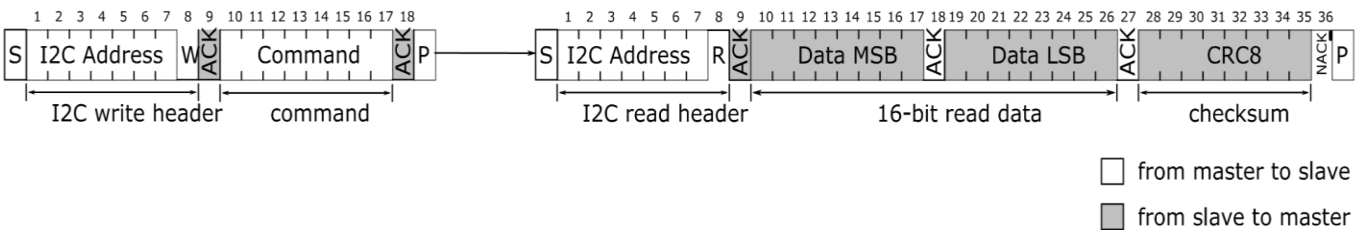

Figure 8 :I2C transfer types

First a write header is sent to the I2C slave, followed by a command, for example "measure RH&T with highest precision". After the measurement is finished the read request directed to this I2C slave will be acknowledged and transmission of data will be started by the slave.

4.2 I2C Communication Timing

All details on the timing are following the interface specification of NXP's user manual UM10204, Rev.6, 4 April 2014. Please follow mandatory capacitor and resistor requirements given in **Table 3**.

4.3 Data type & length

I2C bus operates with 8-bit data packages. Information from the sensor to the master has a checksum after every second 8-bit data package.

Humidity and temperature data will always be transmitted in the following way: The first value is the temperature signal (2 * 8-bit data + 8-bit CRC), the second is the humidity signal (2 * 8-bit data + 8-bit CRC).

4.4 Checksum Calculation

For read transfers each 16-bit data is followed by a checksum with the following properties

Table 6: Data checksum properties.

Property	Value
Name	CRC-8
Message Length	16-bit
Polynomial	0x31 ($x^8 + x^5 + x^4 + 1$)
Initialization	0xFF
Reflect Input/Output	false/false
Final XOR	0x00
Examples	CRC(0xBEEF) = 0x92

The master may abort a read transfer after the 16-bit data if it does not require a checksum.

4.5 Command Overview

Table 7: Overview of I2C commands.

Command (hex)	Response length incl. CRC (bytes)	Description [return values]
0xFD	6	measure T & RH with high precision (high repeatability) [2 * 8-bit T-data; 8-bit CRC; 2 * 8-bit RH-data; 8-bit CRC]
0xF6	6	measure T & RH with medium precision (medium repeatability) [2 * 8-bit T-data; 8-bit CRC; 2 * 8-bit RH-data; 8-bit CRC]
0xE0	6	measure T & RH with lowest precision (low repeatability) [2 * 8-bit T-data; 8-bit CRC; 2 * 8-bit RH-data; 8-bit CRC]
0x89	6	read serial number [2 * 8-bit data; 8-bit CRC; 2 * 8-bit data; 8-bit CRC]
0x94	-	soft reset [ACK]
0x39	6	activate heater with 200mW for 1s, including a high precision measurement just before deactivation [2 * 8-bit T-data; 8-bit CRC; 2 * 8-bit RH-data; 8-bit CRC]
0x32	6	activate heater with 200mW for 0.1s including a high precision measurement just before deactivation [2 * 8-bit T-data; 8-bit CRC; 2 * 8-bit RH-data; 8-bit CRC]
0x2F	6	activate heater with 110mW for 1s including a high precision measurement just before deactivation [2 * 8-bit T-data; 8-bit CRC; 2 * 8-bit RH-data; 8-bit CRC]
0x24	6	activate heater with 110mW for 0.1s including a high precision measurement just before deactivation [2 * 8-bit T-data; 8-bit CRC; 2 * 8-bit RH-data; 8-bit CRC]

0x1E	6	activate heater with 20mW for 1s including a high precision measurement just before deactivation [2 * 8-bit T-data; 8-bit CRC; 2 * 8-bit RH-data; 8-bit CRC]
0x15	6	activate heater with 20mW for 0.1s including a high precision measurement just before deactivation [2 * 8-bit T-data; 8-bit CRC; 2 * 8-bit RH-data; 8-bit CRC]

If the sensor is not ready to process a command, e.g. because it is still measuring, it will response with NACK to the I2C read header. Given heater power values are typical and valid for VDD=3.3V.

4.6 Conversion of Signal Output

The digital sensor signals correspond to following humidity and temperature values:

$$RH = \left(-6 + 125 \cdot \frac{S_{RH}}{2^{16}-1}\right) \%\mathrm{RH} \qquad (1)$$

$$T = \left(-45 + 175 \cdot \frac{S_{T}}{2^{16}-1}\right) {}^{\circ}\mathrm{C} \qquad (2)$$

$$T = \left(-49 + 315 \cdot \frac{S_{T}}{2^{16}-1}\right) {}^{\circ}\mathrm{F} \qquad (3)$$

N.B.: The RH conversion formula (1) allows values to be reported which are outside of the range of 0 %RH … 100 %RH. Relative humidity values which are smaller than 0 %RH and larger than 100 %RH are non-physical, however these “uncropped” values might be found beneficial in some cases (e.g. when the distribution of the sensors at the measurement boundaries are of interest). For all users who do not want to engage in evaluation of these non-physical values, cropping of the RH signal to the range of 0 %RH … 100 %RH is advised.

4.7 Serial number

The serial number is accessible via I2C command 0x89 and is transmitted as two 16-bit words, each followed by an 8-bit CRC.

4.8 Reset & Abort

A reset of the sensor can be achieved in three ways:

- Soft reset: send the reset command described in **Table 7**.
- I2C general call reset: all devices on I2C bus are reset by sending the command 0x06 to the I2C address 0x00.
- Power down (incl. pulling SCL and SDA low)

Any command that triggers an action at the sensor can be aborted via I2C general call reset or soft reset.

4.9 Heater Operation

The sensor incorporates an integrated on-package heater which can be switched on by the set of commands given in **Table 7**. Three heating powers and two heating durations are selectable. After reception of a heater-on command, the sensor executes the following procedure:

1. The heater is enabled, and the timer starts its count-down.
2. On timer expiration a temperature and humidity measurement with the highest repeatability is started, the heater remains enabled.
3. After the measurement is finished the heater is turned off.
4. Temperature and humidity values are now available for readout.

The maximum on-time of the heater commands is 1 second in order to prevent overheating of the sensor by unintended usage of the heater. Thus, there is no dedicated command to turn off the heater. For extended heating periods it is required to send periodic heater-on commands, keeping in mind that the heater is designed for a maximal duty cycle of less than 10%. To obtain a fast increase in temperature the idle time between consecutive heating pulses shall be kept minimal.

Possible Heater Use Cases

In general, the applications of the on-package heater range around:

1. Removal of condensed / spray water on the sensor surface. Although condensed water is not a reliability / quality problem to the sensor, it will however make the sensor nonresponsive to RH changes in the air as long as there is liquid water on the surface.
2. Creep-free operation in high humid environments. Periodic heating pulses allow for creepfree high-humidity measurements for extended times.

Important notes for operating the heater:

1. The heater is designed for a maximum duty cycle of 10%, meaning the total heater-on-time should not be longer than 10% of the sensor's lifetime.
2. During operation of the heater, sensor specifications are not valid.
3. The temperature sensor can additionally be affected by the thermally induced mechanical stress, offsetting the temperature reading from the actual temperature.
4. The sensor's temperature (base temperature + temperature increase from heater) must not exceed T_{max} = 125 °C in order to have proper electrical functionality of the chip.
5. The heater draws a large amount of current once enabled (up to ~75mA in the highest power setting). Although a dedicated circuitry draws this current smoothly, the power supply must be strong enough to avoid large voltage drops that could provoke a sensor reset.
6. If higher heating temperatures are desired, consecutive heating commands have to be sent to the sensor. The heater shall only be operated in ambient temperatures below 65°C else it could drive the sensor outside of its maximal operating temperature.