

## **fischertechnik Simulation and Training Model Information Guide**

Version Two: Revised June 9, 2020



**Using 24V Models with PLCs**

**PLC Input Instructions**

**Component Data Sheets**

**Material to be used in conjunction with PDF documentation for individual models**

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For more information, or to purchase fischertechnik Simulation and Training Models, please visit:

<https://www.studica.com/fischertechnik-industrial-simulation-training-models>

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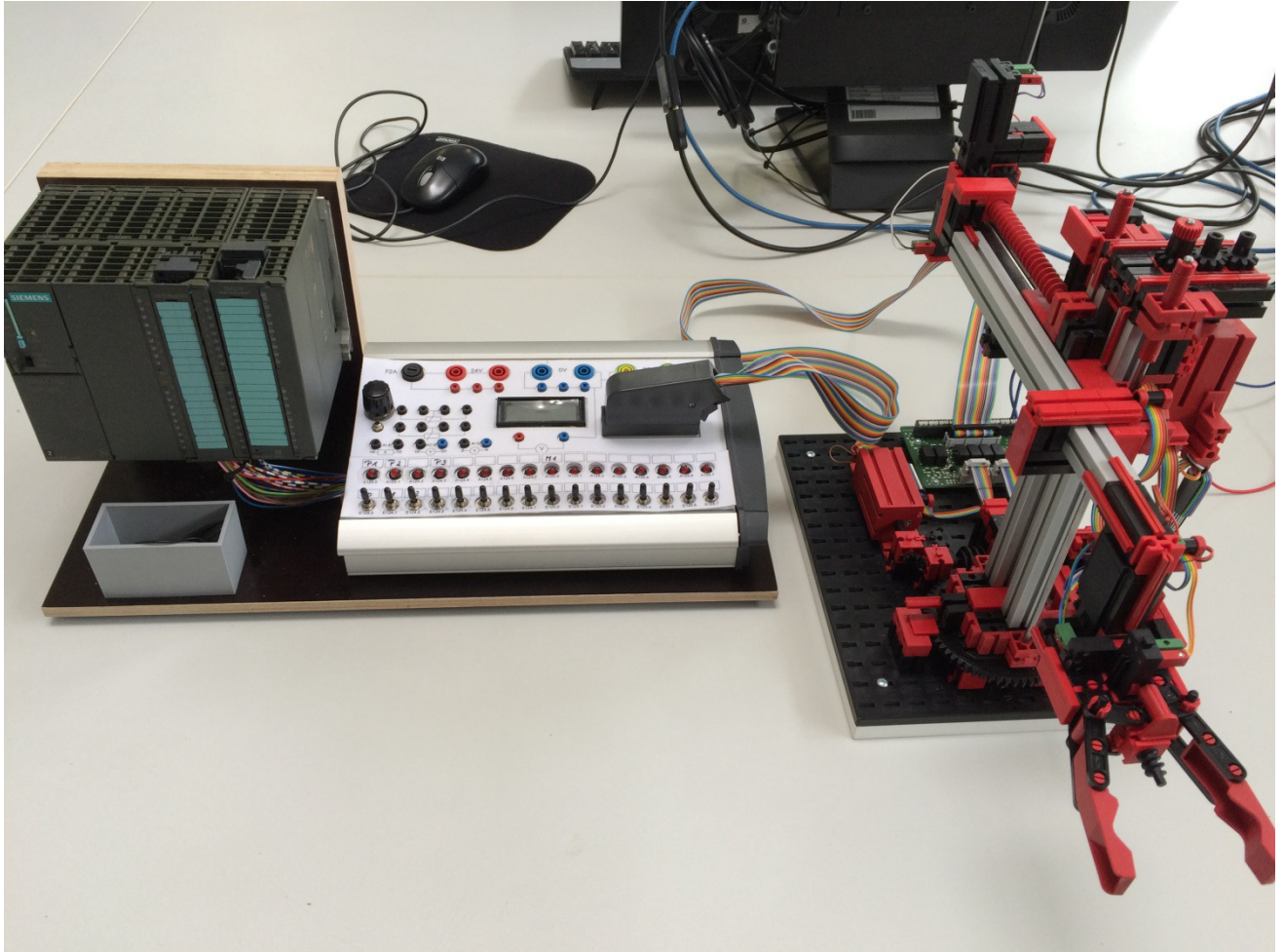
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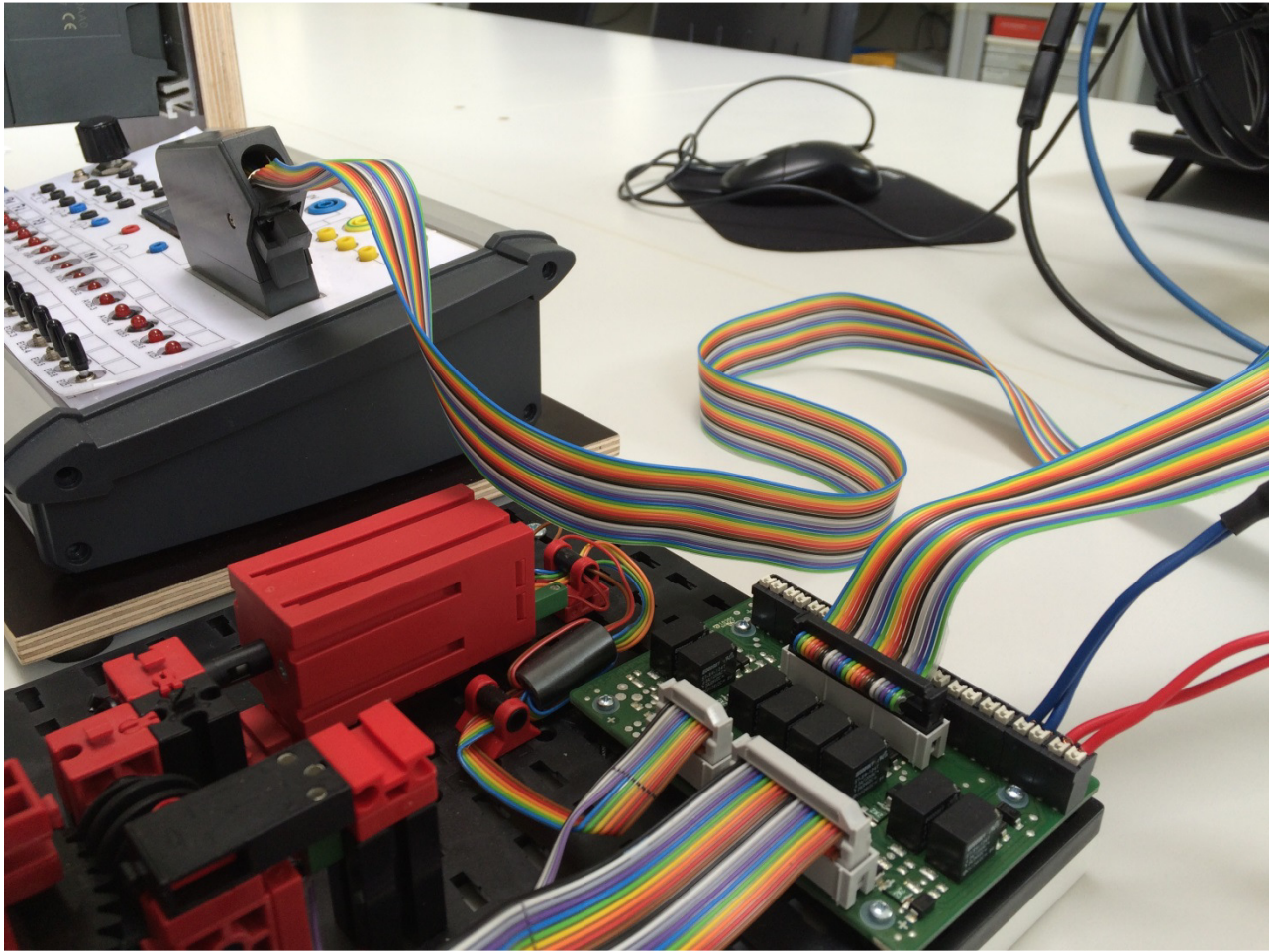
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## Examples for Training models 24V with PLC

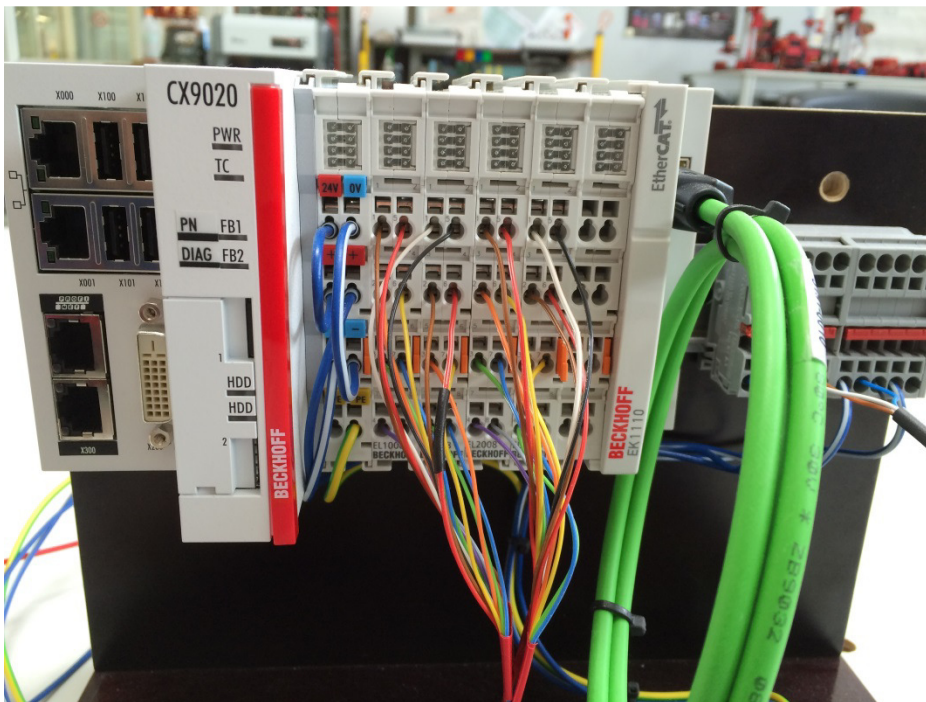
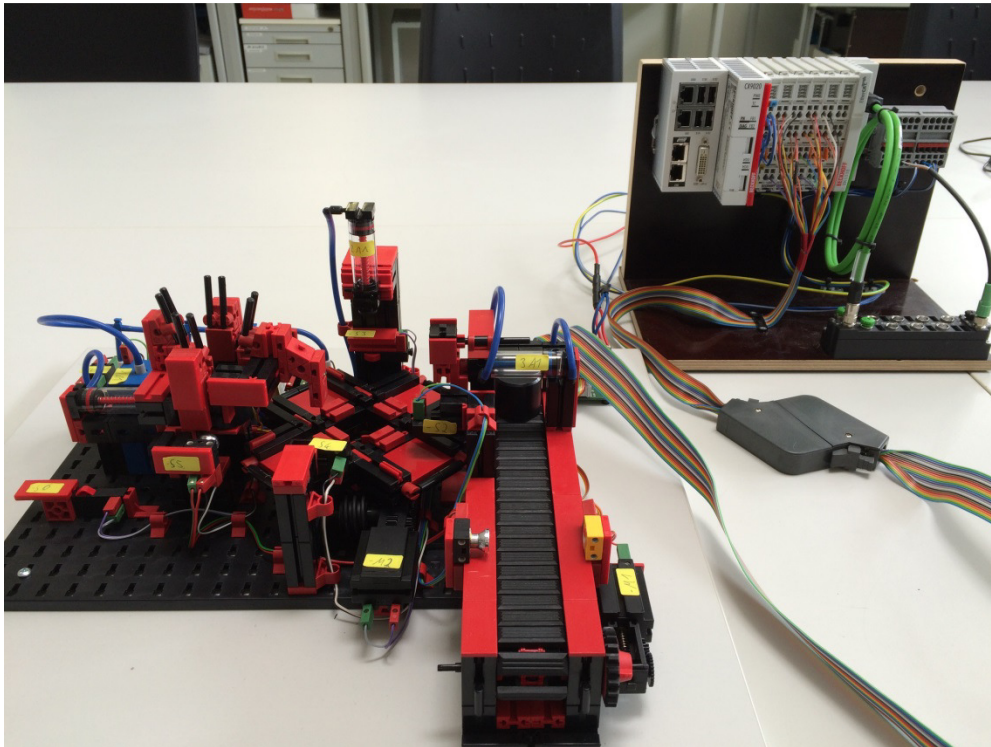
### 1. 3-D-Robot with Siemens S7-300



Inputs and Outputs are directly connected to the adaptor PCB of the 3-D-Robot. No additional components e.g (pullup resistors) necessary. Inputs of the PLC: PNP-sensors



## 2. Pneumatic Processing center with Beckhoff PLC CX 9020



Inputs and Outputs are directly connected to the adaptor PCB of the 3-D-Robot. No additional components e.g. (pullup resistors) necessary. Inputs of the PLC: PNP-sensors.

## PLC-Inputs

Normally PLCs use inputs as "**PNP-sensors**". This means, that a positive potential (24VDC) is switched by the input. This kind of inputs is supported by our adaptor PCB on each training model

|           | Inputs        | Outputs         |
|-----------|---------------|-----------------|
| Type      | Sinking input | Sourcing output |
| Switching |               |                 |

Additional components on the PCB:

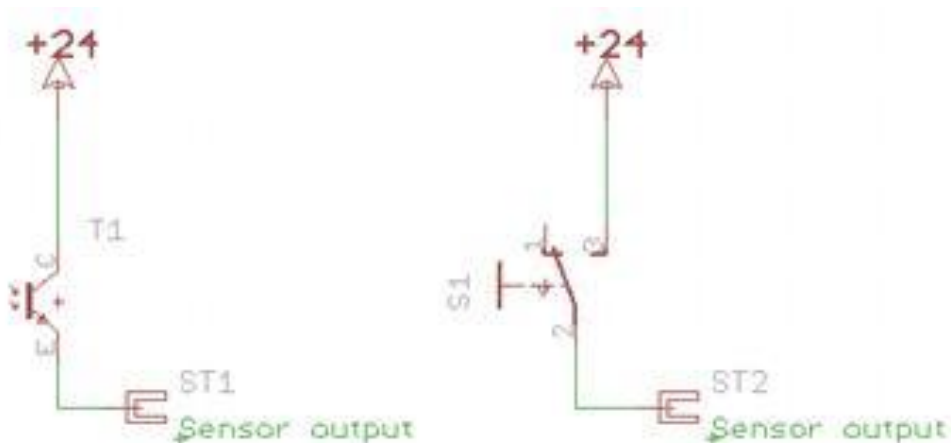
Diode: to avoid damages if + and – will be changed.

Polyswitch to avoid damages in case of shortcuts.


If your PLC uses "**NPN-sensors**": In this case the Input does not use a positive level but ground signal. In this case please contact us, we can tell you how you can adapt PCB to this configuration.

### How to connect a phototransistor to a PLC:

The phototransistor can be connected like a switch. Both can put through +24V. The phototransistor puts through the 24V when it is lighted. The only difference between a switch and a phototransistor is its internal resistance which depends on the lighting. If the internal resistance of the digital inputs of the PLC is too low it might be that the level of the phototransistor is not high enough to switch the digital input of the PLC. In this case it helps to connect a resistor parallel to the phototransistor in order to change the operating point so that the input of the PLC can react. This resistance depends on the threshold level of the PLC and its internal resistance. For the most common PLCs (e.g. Siemens S7-1200) no additional resistance is needed.



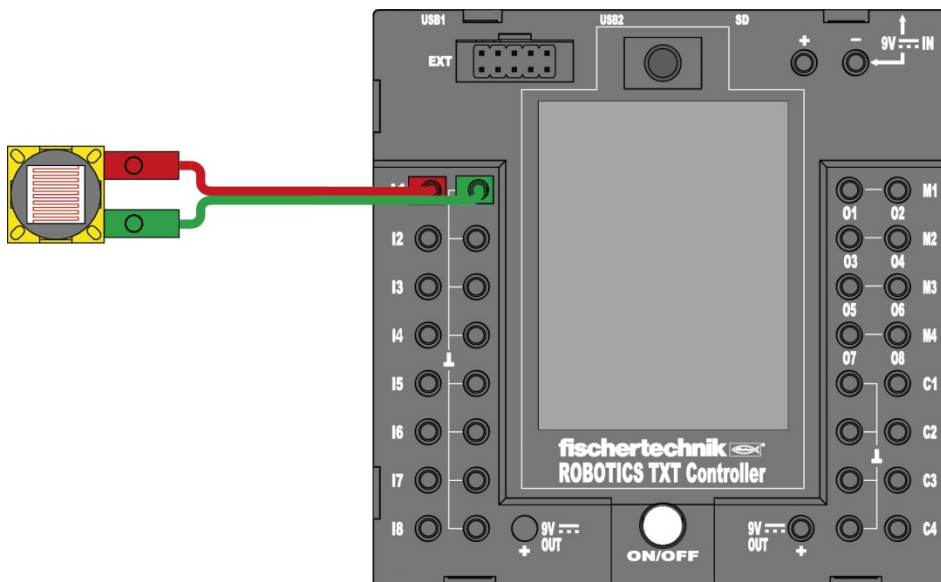
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|                                   |   |   |
|-----------------------------------|---|---|
| Art.-Nr.<br><i>part. no.</i>      | 32698   |  |
| Bezeichnung<br><i>name</i>        | Fotowiderstand LDR03<br><i>Photoresistor LDR03</i>                        |   |
| Abmessungen<br><i>dimensions:</i> | 15x15x15mm<br>(ohne Anschlussdrähte)<br><i>(without connecting wires)</i> |   |
| Gewicht<br><i>weight:</i>         | 2,8g  |   |
| R 10                              | 3-11kΩ  |   |
| R 100                             | 1,2kΩ   |   |
| Wellenlänge:<br><i>wavelength</i> | 600nm   |   |

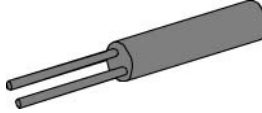
Signal: Widerstandswert 1,2kΩ bei 100Lux und Lichtwellenlänge 600nm  
*Signal: Resistor value: 1,2kΩ at 100Lux and wavelength 600nm,*

Anschlüsse: 2 Buchsen für fischertechnik Stecker Ø 2,5mm  
*Connections: 2 connectors for fischertechnik plugs Ø 2,5mm*

Anschluss an TXT Controller an Eingängen I1-I8, Eingangsart: Analog 5kΩ  
*Connection to TXT Controller at Inputs I1-I8, Input mode: Analogue 5kΩ*



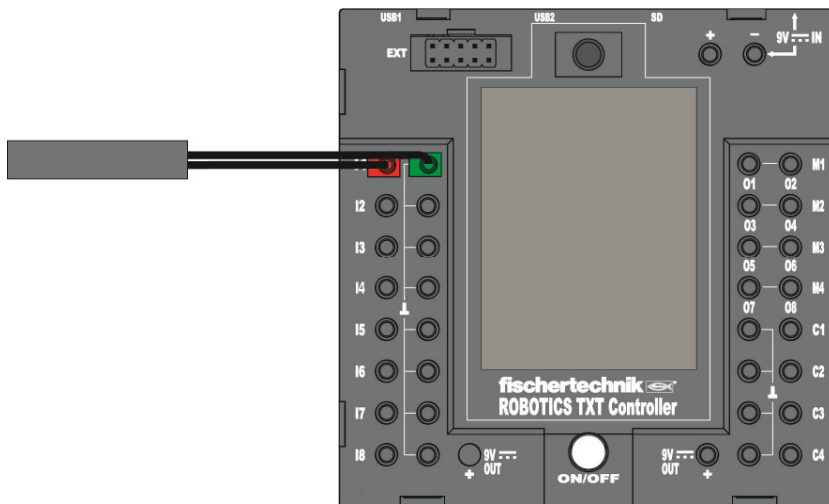
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|   |  |  |
|---|--|--|
| <b>Art.-Nr.</b><br><i>part. no.</i>               | <b>36120</b>                             |  |
| <b>Bezeichnung</b><br><i>name</i>                 | <b>Reedkontakt</b><br><i>Reed switch</i> |  |
| <b>Abmessungen</b><br><i>dimensions:</i>          | 25xØ4 mm                                 |  |
| <b>Gewicht</b><br><i>weight:</i>                  | 3,5g                                     |  |
| <b>Schaltleistung:</b><br><i>Switching power:</i> | max. 0,5A, 50V                           |  |

Signal: Digitaler magnetischer Schalter 0 / 1 für Magnetbaustein Art.-Nr. 108278  
 Signal: Digital magnetic switch 0 / 1, can be used together with magnetic component part no. 108278


Anschlüsse: 2 cables, Schwarz, Länge: 30cm  
 Connections: 2 cables, black, length 30 cm

Anschluss an TXT Controller an Eingängen I1-I8, Eingangsart: Digital 5kΩ  
 Connection to TXT Controller at Inputs I1-I8, Input mode: digital 5kΩ





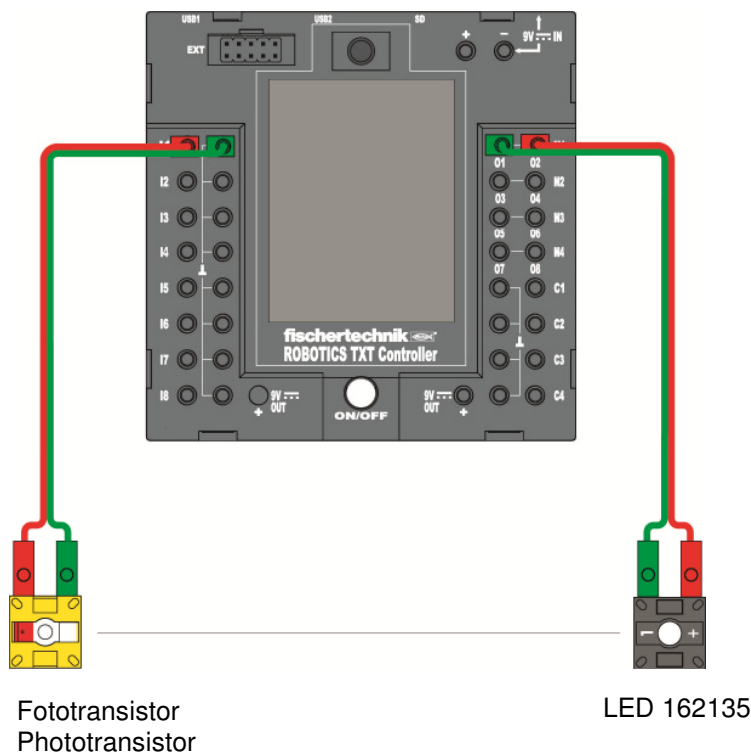
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|                                   |  |   |
|-----------------------------------|--|---|
| Art.-Nr.<br><i>part. no.</i>      | 36134  |  |
| Bezeichnung<br><i>name</i>        | Fototransistor<br><i>Photo-transistor</i>  |   |
| Abmessungen<br><i>dimensions:</i> | 15x15x7,5mm  |   |
| Gewicht<br><i>weight:</i>         | 1,7g   |   |
| Typ:<br><i>Type:</i>              | NPN-Silizium-Fototransistor für Lichtschranke (mit Lichtschranken LED Art. Nr. 162135) |   |

|  |      |
|--|------|
| Kollektor-Emitterspannung $V_{CE}$<br>Collector-emitter voltage $V_{CE}$ | 35V  |
| Kollektorstrom $I_C$<br>Collector current $I_C$                          | 15mA |
| Kollektorspitzenstrom $I_{CS}$<br>Collector surge current $I_{CS}$       | 75mA |
|  |      |

Anschlüsse: 2 Buchsen für fischertechnik Stecker Ø 2,5mm, rote Markierung = +  
 Connections: 2 female connectors for fischeretchnik plugs Ø 2,5mm


Anschluss an TXT Controller an Eingängen I1-I8, Eingangsart: Digital 5kΩ  
 Connection to TXT Controller at Inputs I1-I8, Input mode: digital 5kΩ



Fototransistor  
Phototransistor

LED 162135

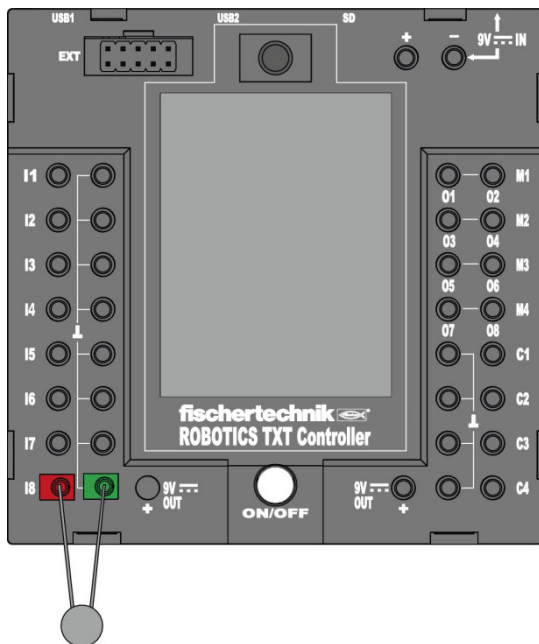
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|                                      |  |  |
|--------------------------------------|--|--|
| Art.-Nr.<br><i>part. no.</i>         | 36437  |  |
| Bezeichnung<br><i>name</i>           | NTC-Widerstand 1,5kΩ<br><i>NTC-resistor 1.5kΩ</i>                        |  |
| Abmessungen<br><i>dimensions:</i>    | 5x5x2,5mm<br>(ohne Anschlussdrähte)<br><i>(without connecting wires)</i> |  |
| Gewicht<br><i>weight:</i>            | 0,4g   |  |
| Max. Leistung:<br><i>Max. power:</i> | 450mW  |  |
| Widerstandstoleranz:                 | +/-10%   |  |
| Nenntemperatur:                      | 25°C   |  |
| R <sub>25</sub>                      | 1,5kΩ  |  |

Signal: Widerstandswert 1,5kΩ bei 25°C, **N**egativer **T**emperatur **C**oefficient. Widerstand sinkt bei steigender Temperatur. R/T-Kennlinie Nr. 1013.  
*Signal: Resistor value: 1,5 5kΩ bei 25°C, Negative Temperature Coefficient, resistance decreases when temperature raises. R/T-curve: No. 1013*

Anschlüsse: 2 Drähte, Länge: ca. 35mm  
*Connections: 2 wires, length: ca. 35mm*

Anschluss an TXT Controller an Eingängen I1-I8, Eingangsart: Analog 5kΩ  
*Connection to TXT Controller at Inputs I1-I8, Input mode: Analogue 5kΩ*

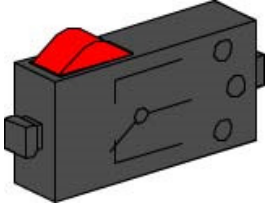


Normierte R/T-Kennlinien  
 Standardised R/T-curves

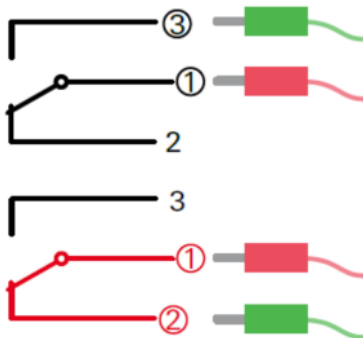
| Nummer                 | 1011                          |                 | 1012                          |                 | 1013                          |                 | 1014                          |                 |
|------------------------|-------------------------------|-----------------|-------------------------------|-----------------|-------------------------------|-----------------|-------------------------------|-----------------|
|                        | $B_{25/100} = 3730 \text{ K}$ |                 | $B_{25/100} = 4300 \text{ K}$ |                 | $B_{25/100} = 3900 \text{ K}$ |                 | $B_{25/100} = 4250 \text{ K}$ |                 |
| $T (^{\circ}\text{C})$ | $R_T/R_{25}$                  | $\alpha (\%/K)$ | $R_T/R_{25}$                  | $\alpha (\%/K)$ | $R_T/R_{25}$                  | $\alpha (\%/K)$ | $R_T/R_{25}$                  | $\alpha (\%/K)$ |
| -55,0                  | 70,014                        | 6,9             | 87,237                        | 6,8             | 77,285                        | 7,0             | 83,935                        | 6,8             |
| -50,0                  | 49,906                        | 6,7             | 62,264                        | 6,7             | 54,938                        | 6,7             | 60,228                        | 6,6             |
| -45,0                  | 36,015                        | 6,4             | 44,854                        | 6,5             | 39,507                        | 6,5             | 43,593                        | 6,4             |
| -40,0                  | 26,296                        | 6,2             | 32,599                        | 6,3             | 28,722                        | 6,3             | 31,815                        | 6,3             |
| -35,0                  | 19,411                        | 6,0             | 23,893                        | 6,1             | 21,099                        | 6,1             | 23,404                        | 6,1             |
| -30,0                  | 14,479                        | 5,8             | 17,654                        | 6,0             | 15,652                        | 5,9             | 17,349                        | 6,0             |
| -25,0                  | 10,903                        | 5,6             | 13,098                        | 5,8             | 11,715                        | 5,7             | 12,946                        | 5,8             |
| -20,0                  | 8,2923                        | 5,4             | 9,8059                        | 5,7             | 8,8541                        | 5,6             | 9,7439                        | 5,7             |
| -15,0                  | 6,3591                        | 5,2             | 7,4266                        | 5,5             | 6,7433                        | 5,4             | 7,3737                        | 5,5             |
| -10,0                  | 4,9204                        | 5,1             | 5,6677                        | 5,4             | 5,1815                        | 5,2             | 5,6247                        | 5,4             |
| -5,0                   | 3,8279                        | 4,9             | 4,3213                        | 5,3             | 4,0099                        | 5,1             | 4,3063                        | 5,3             |
| 0,0                    | 3,0029                        | 4,8             | 3,3208                        | 5,1             | 3,1283                        | 4,9             | 3,3221                        | 5,2             |
| 5,0                    | 2,3773                        | 4,6             | 2,5842                        | 5,0             | 2,4569                        | 4,8             | 2,5779                        | 5,0             |
| 10,0                   | 1,8959                        | 4,5             | 2,0238                        | 4,9             | 1,9438                        | 4,6             | 2,0144                        | 4,9             |
| 15,0                   | 1,5207                        | 4,3             | 1,5858                        | 4,8             | 1,5475                        | 4,5             | 1,5848                        | 4,8             |
| 20,0                   | 1,2280                        | 4,2             | 1,2507                        | 4,7             | 1,2403                        | 4,4             | 1,2547                        | 4,6             |
| 25,0                   | 1,0000                        | 4,1             | 1,0000                        | 4,5             | 1,0000                        | 4,3             | 1,0000                        | 4,6             |
| 30,0                   | 0,81779                       | 3,9             | 0,79640                       | 4,4             | 0,81104                       | 4,1             | 0,79913                       | 4,4             |
| 35,0                   | 0,67341                       | 3,8             | 0,64053                       | 4,3             | 0,66146                       | 4,0             | 0,64287                       | 4,3             |
| 40,0                   | 0,55747                       | 3,7             | 0,51772                       | 4,2             | 0,54254                       | 3,9             | 0,51991                       | 4,2             |
| 45,0                   | 0,46357                       | 3,6             | 0,41958                       | 4,1             | 0,44727                       | 3,8             | 0,42299                       | 4,1             |
| 50,0                   | 0,38740                       | 3,6             | 0,34172                       | 4,1             | 0,37067                       | 3,7             | 0,34573                       | 4,1             |
| 55,0                   | 0,32368                       | 3,5             | 0,27877                       | 4,0             | 0,30865                       | 3,6             | 0,28298                       | 4,0             |
| 60,0                   | 0,27200                       | 3,4             | 0,22861                       | 3,9             | 0,25825                       | 3,5             | 0,23277                       | 3,8             |
| 65,0                   | 0,23041                       | 3,3             | 0,18872                       | 3,8             | 0,21707                       | 3,4             | 0,19262                       | 3,8             |
| 70,0                   | 0,19604                       | 3,2             | 0,15645                       | 3,7             | 0,18323                       | 3,3             | 0,16005                       | 3,7             |
| 75,0                   | 0,16735                       | 3,1             | 0,13012                       | 3,6             | 0,15535                       | 3,3             | 0,13349                       | 3,6             |
| 80,0                   | 0,14342                       | 3,0             | 0,10863                       | 3,6             | 0,13223                       | 3,2             | 0,11175                       | 3,5             |
| 85,0                   | 0,12347                       | 3,0             | 0,091115                      | 3,5             | 0,11302                       | 3,1             | 0,093934                      | 3,5             |
| 90,0                   | 0,10668                       | 2,8             | 0,076700                      | 3,4             | 0,096951                      | 3,0             | 0,079231                      | 3,4             |
| 95,0                   | 0,092734                      | 2,8             | 0,064867                      | 3,3             | 0,083487                      | 3,0             | 0,067054                      | 3,3             |
| 100,0                  | 0,080903                      | 2,8             | 0,055047                      | 3,3             | 0,072139                      | 2,9             | 0,056932                      | 3,2             |
| 105,0                  | 0,070616                      | 2,7             | 0,046797                      | 3,2             | 0,062559                      | 2,8             | 0,048591                      | 3,1             |
| 110,0                  | 0,061826                      | 2,6             | 0,039904                      | 3,1             | 0,054425                      | 2,8             | 0,041605                      | 3,1             |
| 115,0                  | 0,054282                      | 2,6             | 0,034255                      | 3,1             | 0,047508                      | 2,7             | 0,035653                      | 3,1             |
| 120,0                  | 0,047793                      | 2,5             | 0,029498                      | 3,0             | 0,041594                      | 2,6             | 0,030636                      | 3,0             |
| 125,0                  | 0,042249                      | 2,4             | 0,025448                      | 3,0             | 0,036532                      | 2,6             | 0,026454                      | 2,9             |
| 130,0                  | 0,037450                      | 2,4             | 0,022016                      | 2,9             | 0,032175                      | 2,5             | 0,022905                      | 2,9             |
| 135,0                  | 0,033244                      | 2,4             | 0,019038                      | 2,8             | 0,028423                      | 2,5             | 0,019867                      | 2,8             |

| Nummer                 | 1011                          |                 | 1012                          |                 | 1013                          |                 | 1014                          |                 |
|------------------------|-------------------------------|-----------------|-------------------------------|-----------------|-------------------------------|-----------------|-------------------------------|-----------------|
|                        | $B_{25/100} = 3730 \text{ K}$ |                 | $B_{25/100} = 4300 \text{ K}$ |                 | $B_{25/100} = 3900 \text{ K}$ |                 | $B_{25/100} = 4250 \text{ K}$ |                 |
| $T (^{\circ}\text{C})$ | $R_T/R_{25}$                  | $\alpha (\%/K)$ | $R_T/R_{25}$                  | $\alpha (\%/K)$ | $R_T/R_{25}$                  | $\alpha (\%/K)$ | $R_T/R_{25}$                  | $\alpha (\%/K)$ |
| 140,0                  | 0,029582                      | 2,3             | 0,016502                      | 2,8             | 0,025173                      | 2,4             | 0,017274                      | 2,8             |
| 145,0                  | 0,026406                      | 2,3             | 0,014355                      | 2,7             | 0,022358                      | 2,4             | 0,015027                      | 2,8             |
| 150,0                  | 0,023625                      | 2,2             | 0,012514                      | 2,7             | 0,019907                      | 2,3             | 0,013101                      | 2,7             |
| 155,0                  | 0,021193                      | 2,1             | 0,010932                      | 2,6             | 0,017770                      | 2,2             | 0,011453                      | 2,7             |
| 160,0                  | 0,019057                      | 2,1             | 0,0095681                     | 2,6             | 0,015901                      | 2,2             | 0,010031                      | 2,6             |
| 165,0                  | 0,017176                      | 2,1             | 0,0083903                     | 2,5             | 0,014263                      | 2,2             | 0,0088012                     | 2,6             |
| 170,0                  | 0,015516                      | 2,0             | 0,0073706                     | 2,5             | 0,012824                      | 2,1             | 0,0077359                     | 2,6             |
| 175,0                  | 0,014046                      | 2,0             | 0,0065718                     | 2,5             | 0,011556                      | 2,1             | 0,0068109                     | 2,5             |
| 180,0                  | 0,012742                      | 2,0             | 0,0058179                     | 2,4             | 0,010436                      | 2,1             | 0,0060061                     | 2,5             |

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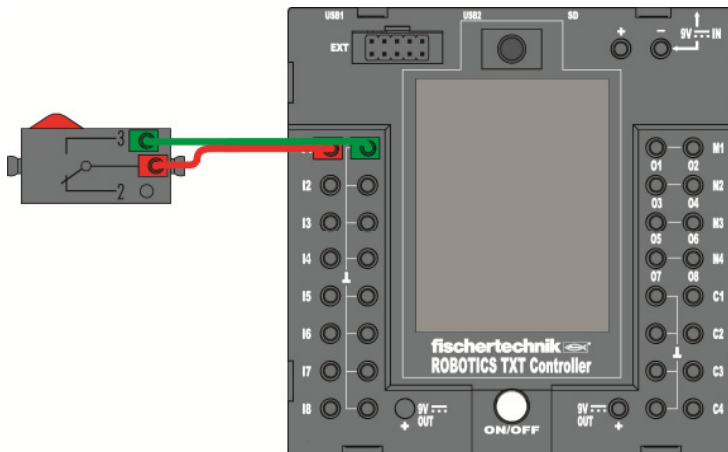
|  |                                   |  |
|--|-----------------------------------|--|
| Art.-Nr.<br><i>part. no.</i>               | 37783                             |  |
| Bezeichnung<br><i>name</i>                 | Mini-Taster<br><i>Mini switch</i> |  |
| Abmessungen<br><i>dimensions:</i>          | 30x15x7,5mm                       |  |
| Gewicht<br><i>weight:</i>                  | 3,4g                              |  |
| Schaltleistung:<br><i>Switching power:</i> | max. 2A, 50V                      |  |

Signal: Digitaler Schalter 0 / 1, als Öffner oder Schließer verwendbar  
 Signal: Digital switch 0 / 1, can be used as "normally open" or "normally closed"

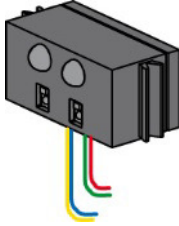


Anschlüsse: Kontakte 1 und 3: "Schließer", Kontakte 1 und 2 angeschlossen: "Öffner"  
 Connections: Contacts 1 and 3: NO (normally open) Contacts 1 and 2: NC (normally closed)

Anschluss an TXT Controller an Eingängen I1-I8, Eingangsart: Digital 5kΩ  
 Connection to TXT Controller at Inputs I1-I8, Input mode: digital 5kΩ



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|   |  |   |
|---|--|---|
| <b>Art.-Nr.</b><br><i>part. no.</i>           | <b>128598</b>                            |  |
| <b>Bezeichnung</b><br><i>name</i>             | <b>Spursensor</b><br><i>Trail sensor</i> |   |
| Abmessungen<br><i>dimensions:</i>             | 30x15x15mm                               |   |
| Gewicht<br><i>weight:</i>                     | 7,3g                                     |   |
| Spannungsversorgung<br><i>Supply voltage:</i> | 6-10 VDC                                 | Stromaufnahme:<br><i>Current consumption:</i> ca.30mA                               |

Signal: Zwei Digitalwerte zum Erkennen einer schwarzen Spur 0=schwarz (0V), 1=weiß (max. 9V abhängig von Eingangsspannung).

*Signal: : Two digital values for recognition of a black trail 0=black (0V), 1=white (max. 9V depending on input voltage)*

Spurbreite: 20mm  
*Track width:*

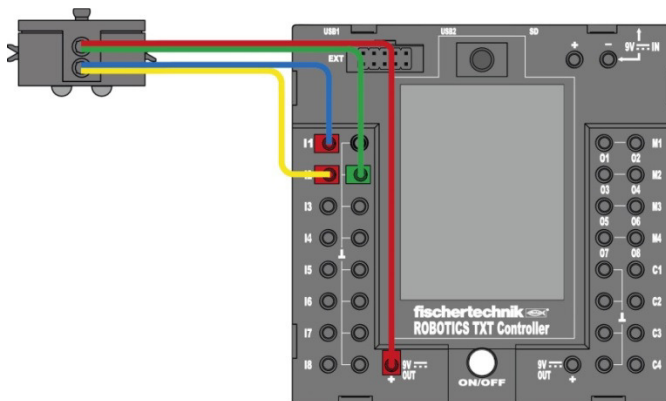
Minimaler Abstand: 8mm  
*Minimum distance:*

Maximaler Abstand: 25mm  
*Maximum distance:*

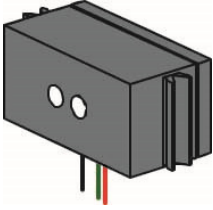
Anschlüsse: rot=9VDC, grün=Masse, gelb, blau=Signal  
*Connection: red=9VDC, green=ground, yellow, blue=signal*

Anschluss an TXT Controller an Eingängen I1-I8, Eingangsart: Digital Spannung  
*Connection to TXT Controller at Inputs I1-I8, Input mode: Digital Voltage*

Anschluss an TXT Controller:  
*Connection to TXT Controller:*



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|  |  |   |
|--|--|---|
| <b>Art.-Nr.</b><br><i>part. no.</i>                  | <b>128599</b>                            |  |
| <b>Bezeichnung</b><br><i>name</i>                    | <b>Farbsensor</b><br><i>Color sensor</i> |   |
| <b>Abmessungen</b><br><i>dimensions:</i>             | 30x15x15mm                               |   |
| <b>Gewicht</b><br><i>weight:</i>                     | 6,8g                                     |   |
| <b>Spannungsversorgung</b><br><i>Supply voltage:</i> | 6-10 VDC                                 | <b>Stromaufnahme:</b> ca. 15mA<br><i>Current Consumption:</i>                       |

Signal: Analogwert 0-2VDC. Ausgabe in mV. Kein RGB-Sensor. Licht wird von einer LED ausgesendet und von unterschiedlichen Farben unterschiedlich stark reflektiert. Das reflektierte Licht wird gemessen. Ähnliche Farben können ähnliche Werte erzeugen. Der Messwert ist abhängig von der Umgebungsbeleuchtung und dem Abstand zum Objekt.

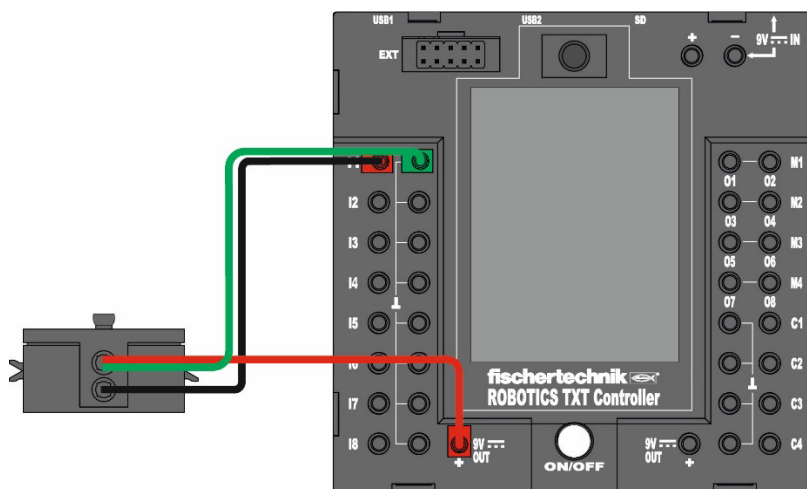
*Signal: Analogue value 0-2VDC. Output in mV. No RGB sensor. Light is sent out by a LED and will be reflected by different colors in a different way. The reflected amount of light will be measured. Similar colors can lead to similar values. The measured value depends on the brightness in the environment and the distance to the object.*

Anschlüsse: rot=9VDC, grün=Masse, Schwarz=Signal  
*Connection: red=9VDC, green=ground, black=signal*

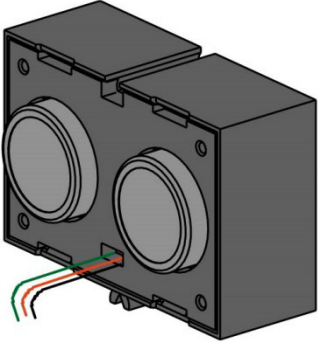
Anschluss an TXT Controller an Eingängen I1-I8, Eingangsart: Analog Spannung  
*Connection to TXT Controller at Inputs I1-I8, Input mode: Analogue Voltage*

Wertebereich 0-2000mV  
*Value range: 0-2000mV*

Anschluss an TXT Controller:  
*Connetction to TXT Controller:*



FT-T-KN  
 2017-07-18

|   |  |  |
|---|--|--|
| Art.-Nr.<br><i>part. no.</i>                  | 133009   |  |
| Bezeichnung<br><i>name</i>                    | Ultraschall-<br>Abstandssensor<br><i>Ultra sonic dis-<br/>tance sensor</i> |  |
| Abmessungen<br><i>dimensions:</i>             | 45x30x15mm   |  |
| Gewicht<br><i>weight:</i>                     | 20,5g  |  |
| Spannungsversorgung<br><i>Supply voltage:</i> | 5-10 VDC   |  |

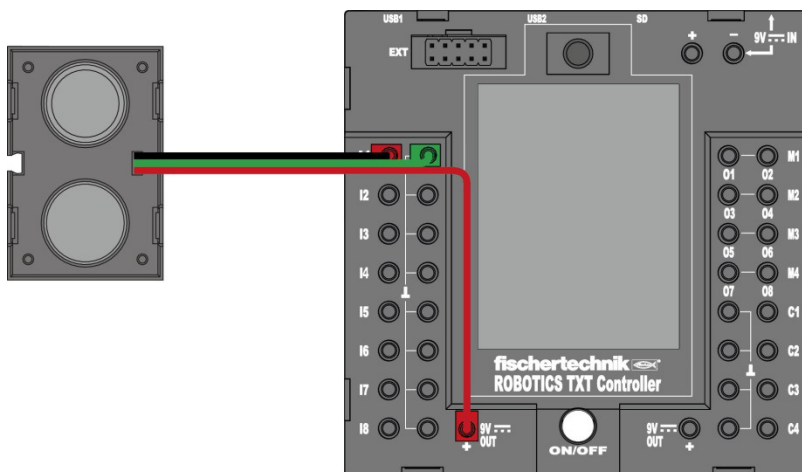
Signal: digital codierte Datenübertragung zwischen ROBO TX Controller/ROBO Interface und Sensor  
*Signal: digital coded data transfer between ROBO TX Controller and sensor*

Anschlüsse: rot=9VDC, grün=Masse, Schwarz=Signal  
 connection: red=9VDC, green=ground, black=signal

Anschluss an TXT Controller an Eingängen I1-I8, Eingangsart: Ultraschall  
 connection to TXT Controller at Inputs I1-I8, Input mode: Ultrasonic

Wertebereich 3-400cm, Ausgabewert entspricht Abstand in cm. Genauigkeit +/- 0,5cm, 1023=unendlich  
 Value range: 3-400cm, value corresponds to distance in cm. Resolution +/-0.5cm, 1023=infinite

Anschluss an TXT Controller:  
 Connection to TXT Controller:



Daten-Protokoll: siehe Anhang "hardware concept"  
 data protocol: see attached file "hardware concept"



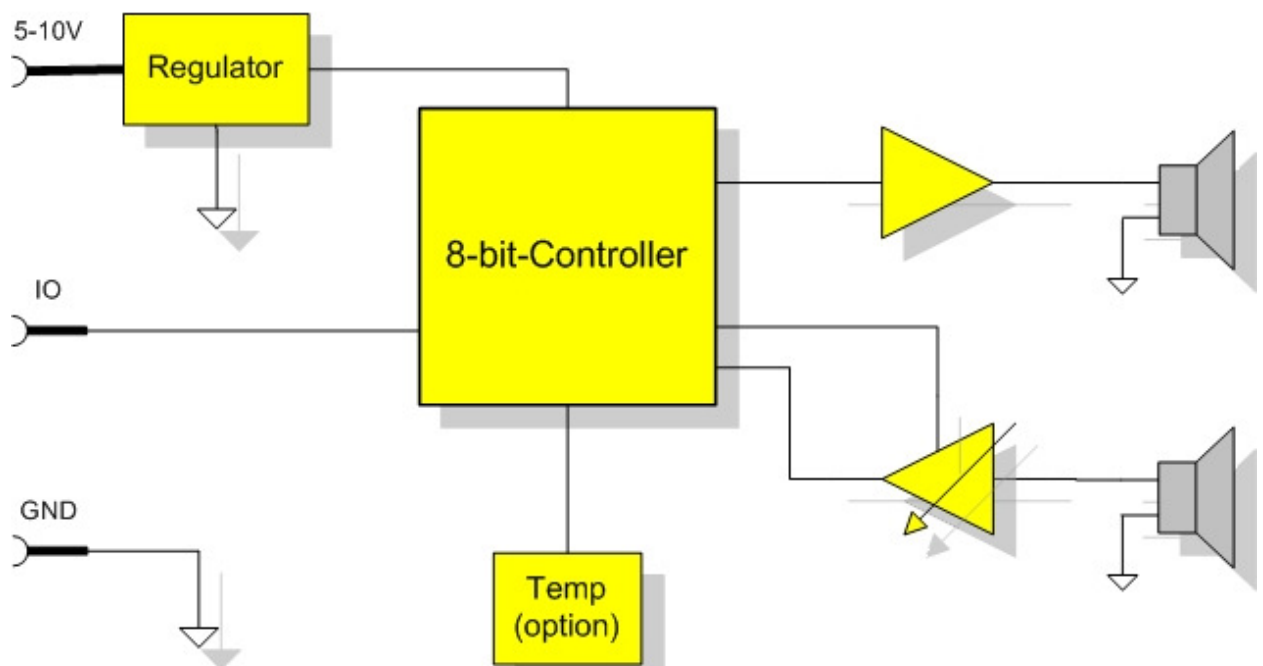
# Hardware - Concept      USONIC2008    RevA

## Ultrasonic distance sensor modul

### 1. Features

- Distance measurement from 4 – 400 cm
- Double ultrasonic speaker for low distance recognition
- accuracy better than 2% or 1 cm (partly temperature compensated)
- bidirectional digital interface, resolution 0,5 cm (10bit)
- 3-wire interface, connectable to universal Interface2008 inputs
- Multi sensor use without influence (up to 8)
- Voltage supply 5 – 10 Volt

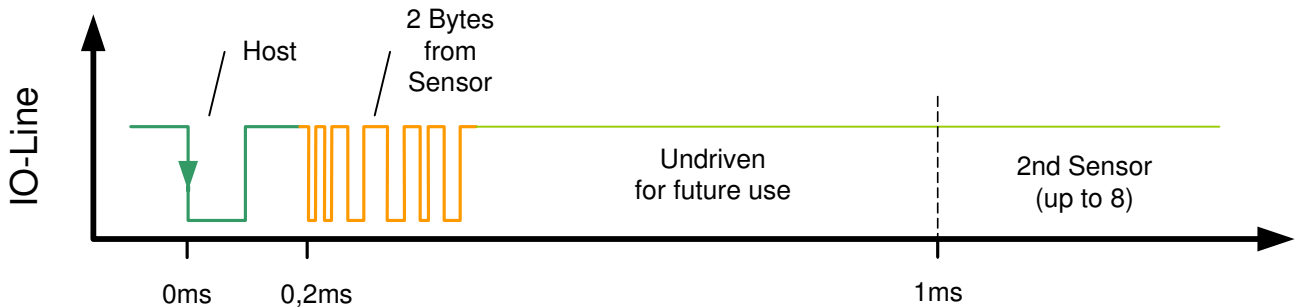
### 2. Diagram



## 2. Protocol

### 2.1 Single bidirectional IO-Line

- Ultrasonic sensor waits for host trigger pulse to synchronize all sensors



### 2.2 Host query

- low pulse with 78,125us duration ( = '0'-Byte with 115200 Baud, 8N1)
- tristate after 90us
- repeated every 10ms

### 2.3 Sensor answer

- sensor synchronizes to falling edge
- 2 Byte answer in 0.2 – 1 ms timeslot
- Asynchron, 115200 Baud, 1 Startbit, no parity, 1 Stopbit
- Output: open collector, 100K-Pullup to Vin (5-10V)
- answer is not mandatory
- without host trigger sensor goes into standby
- weak pullup at sensor side (avoids floating during undriven states)
- protocol expandable to ASN1 protocol chain

### 2.4 Sensor answer: 2 Bytes

- First Byte

| D7 | D6     | D5   | D4  | D3  | D2 | D1 | D0 |
|----|--------|------|-----|-----|----|----|----|
| 1  | Valid# | W/D# | ID1 | ID0 | L9 | L8 | L7 |

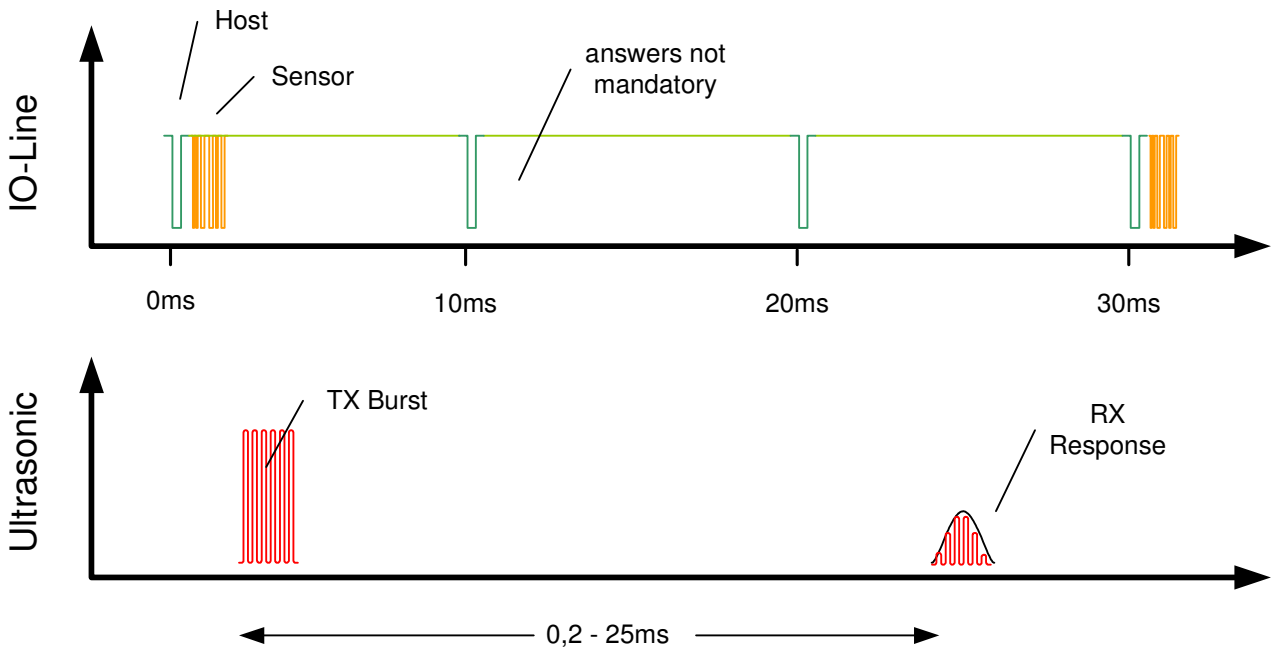
- Second Byte

| D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|----|----|----|----|----|----|----|----|
| 0  | L6 | L5 | L4 | L3 | L2 | L1 | L0 |

- Bit Definition
- Valid#: 0 = valid, 1 = invalid
- W/D#: 0 = distance, 1 = weight
- ID: 0 = first echo, 1 = second echo, 2 = third echo
- L9..0: 10 bit, distance (0.5 cm), weight in range from 0 - 64
- Val=0x000 distance lower than 4 cm
- Val=0x3FF distance higher than 400 cm

### 2.5 IO protocol vs. Ultrasonic timing

- Ultrasonic burst should start after data transmit
- Sequential procedure for easy firmware timing

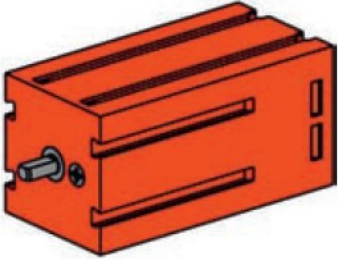


### 2.6 Options

- Further protocol options on request
  - e. g. firmware update via IO-line
  - multi echo recognition
  - controller frequency adjustment by triggersensing

FT-T-KN  
2018-10-25

**Datenblatt Encodermotor 9V Art.-Nr. 135484**  
**Datasheet Encoder motor 9V Art. No. 135484**

|   |   |
|---|---|
|  | <p>Maße/dimensions: 60x30x30mm</p> <p>Abtriebswelle/output shaft: D=4mm, L=7,5mm,<br/>2 Abflachungen je 0,7mm/ 2 bevels 0.7mm each</p> <p>Stromversorgung: 9VDC über 2 fischertechnik Anschlussbuchsen<br/>D=2,5mm/<br/>Power supply: 9VDC with 2 fischertechnik connection sockets D=2.5mm</p> |
|---|---|

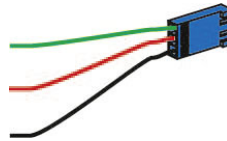
**Motordaten/motor data:**

Constant voltage: 9V DC  
reduction ratio: 25:1  
No load speed: 320 (+/-33) rpm  
No load current: 0,16A max.  
Rated speed: 230 (+/-26) rpm  
rated torque: 0,25 Kgcm min  
rated current: 0,35A max  
Stall torque: 0,70Kgcm min (not allow the torque)  
Stall current: 1,1A max.

**Encoderdaten/encoder data:**

Magnetencoder  
Stromversorgung/power supply: 9VDC  
Signal: Encodersignal, Push-Pull Output (0/9V), max. 10mA  
Frequenz/frequency: max 1kHz.

Anschlüsse/connector: 3-pol Stiftleiste,  
passendes Kabel/fitting cable: Art.No. 137125  
rot/red=+9V, grün/green=0V,  
schwarz/black=Encodersignal/encoder signal



Versorgungsspannung Encoder/supply voltage encoder: 9V DC  
Signal: NPN Open Kollektor Ausgang, max. 2mA belastbar/signal: npn open collector output, max. 2mA

Bei Anschluss an einen digitalen Eingang einer Steuerung (nicht fischertechnik-Controller): Pull-up-Widerstand 4.7-10kOhm notwendig zwischen Encodersignal und Prozessorstromversorgung (bei 3,3-5V)

When the encoder motor is connected to a digital input of any control units (not fischertechnik controllers) a pull-up resistance of 4.7-10kOhms is needed between the encoder signal and the processor power supply (3.3V or 5V).

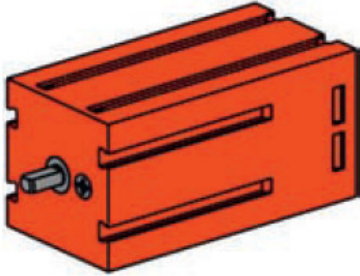
Pins (Encoderkabel): grün: Masse (-), rot: 9V+, schwarz: Encodersignal  
Pins (encoder cable): green: 0V (-), red: 9V+, black: encoder signal

Auflösung des Encoders: 3 Impulse (6 Impulse wenn 0-1 und 1-0-Flanke gezählt wird) pro Umdrehung des Motors. 63,3/126,6 Impulse pro Umdrehung der Getriebe-Abtriebsachse

Resolution of encoder: 3 pulses (6 pulses when counting 0-1 and 1-0 edge) per round of motor. 63.9/127.8 pulses per round of the gear shaft.

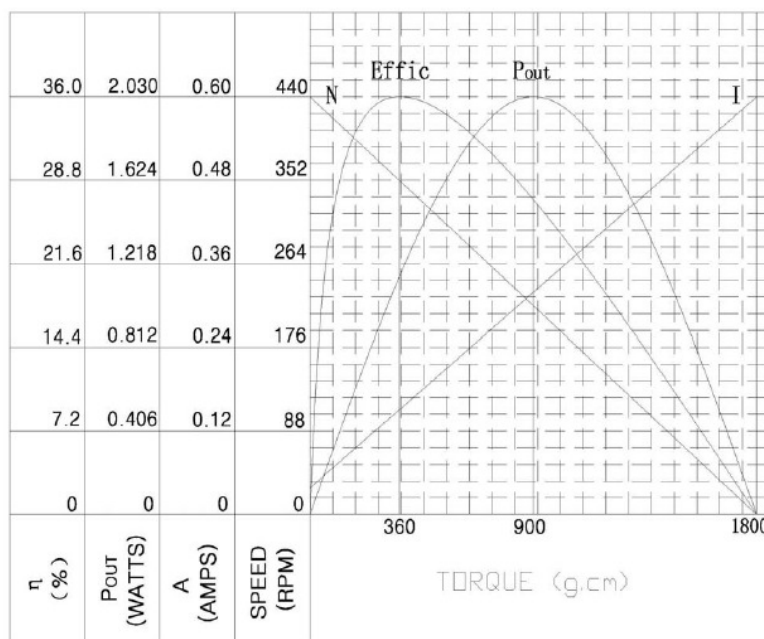
FT-T-KN  
 11.04.2017

**Datenblatt Encodermotor 24V Art.-Nr. 144643**  
**Datasheet Encoder motor 24V Art. No. 144643**

|   |  |
|---|--|
|  | Maße/dimensions: 60x30x30mm  |
|   | Abtriebswelle/output shaft: D=4mm, L=7,5mm,<br>2 Abflachungen je 0,7mm/ 2 bevels 0.7mm each  |
|   | Stromversorgung: 24VDC über 2 fischertechnik Anschlussbuchsen D=2,5mm/<br>Power supply: 24VDC with 2 fischertechnik connection sockets D=2.5mm |

**Motordaten/motor data:**

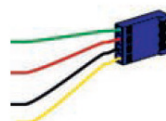
T-N-I CHARACTERISTICS



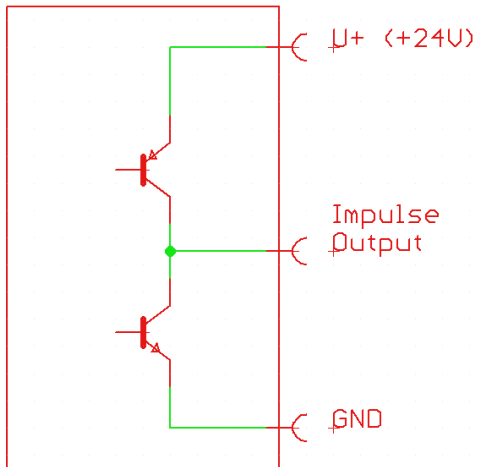
**Encoderdaten/encoder data:**

Quadraturencoder,  
 Stromversorgung/power supply 24VDC  
 Signal: Quadratur Encoder, Push-Pull Output (0/24V), max. 10mA  
 Frequenz/frequency: max 1kHz.

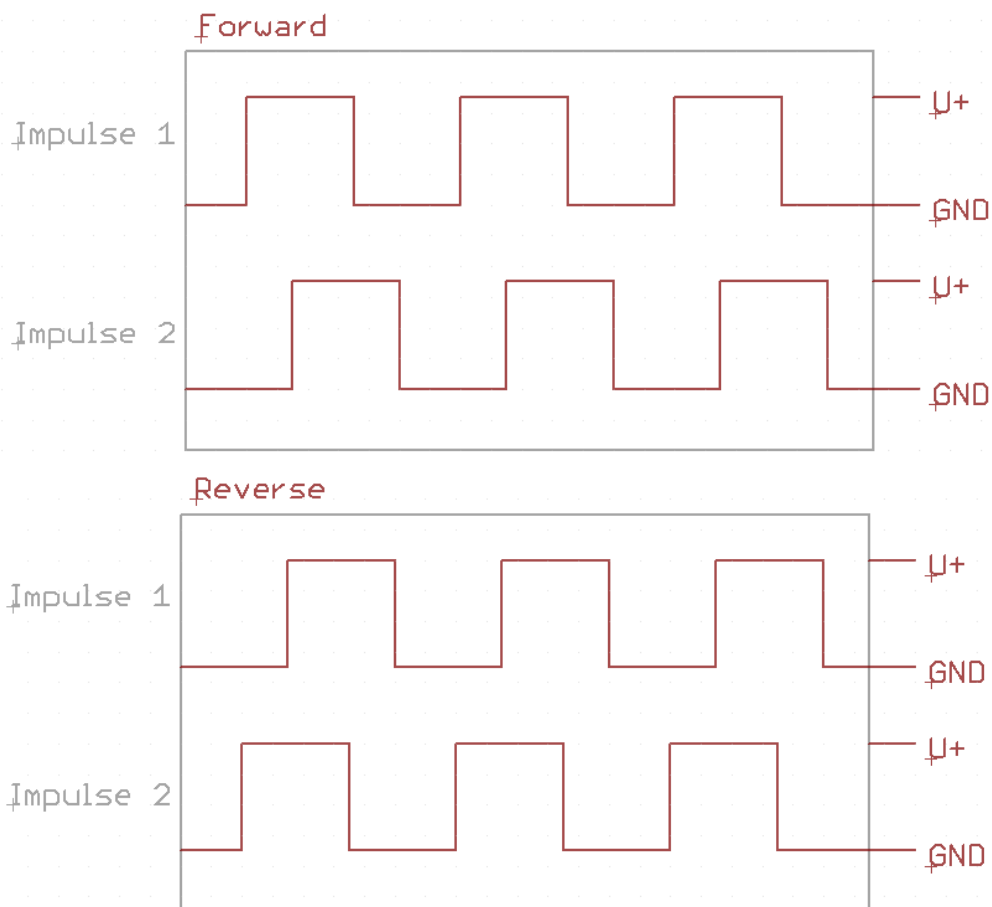
Anschlüsse/connector: 4-pol Stiflleiste,  
 passendes Kabel/fitting cable: Art.No. 119785  
 rot/red=+24V, grün/green=0V, schwarz/black=Puls1,  
 gelb/yellow=Impuls2



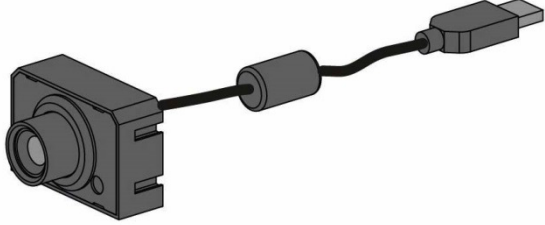
Ersatzschaltbild eines 24V Encoder-Ausgangs (2 pro Motor)  
*Equivalent circuit diagram of 24V encoder output (2 per motor)*



Ausgangssignal des 24V-Encoders für verschiedene Drehrichtungen.  
*Output signal of 24V-encoder for different directions of rotation*



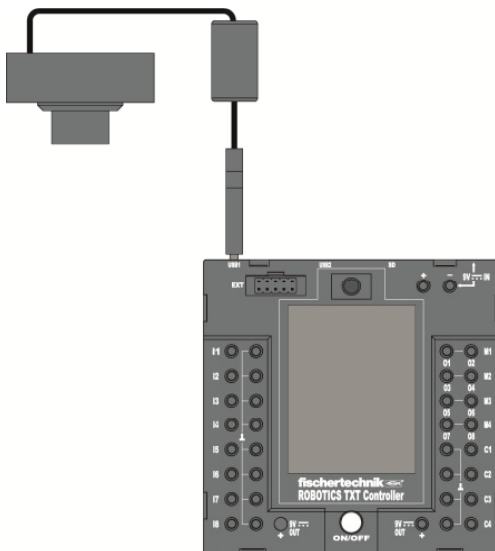
FT-T-KN  
2017-08-15

|  |   |  |
|--|---|--|
| <b>Art.-Nr.</b><br><i>part. no.</i>      | <b>152522</b>   |  |
| <b>Bezeichnung</b><br><i>name</i>        | <b>USB-Kameramodul</b><br><i>USB-Cameramodule</i>                   |  |
| <b>Abmessungen</b><br><i>dimensions:</i> | 45x30x30,5mm<br>(ohne Anschlusskabel)<br>(without connecting cable) |  |
| <b>Gewicht:</b><br><i>weight:</i>        | 47,8g   |  |
| <b>Auflösung:</b><br><i>resolution:</i>  | 1MPixel, RGB  |  |
| <b>Fokus:</b><br><i>Focus:</i>           | Manuell<br>manually   |  |

Signal: USB-Protokol, 15 fps (frames per second) QVGA über TXT Controller  
*Signal: USB-Protocoll, 15fps (frames per second QVGA via TXT Controller*

Anschlüsse: USB-Kabel, Länge 80cm, USB-A-Stecker  
*Connections: USB-cable, length 80cm, USB-A-plug*

Anschluss an TXT Controller an USB1  
*Connection to TXT Controller at USB1*



Verfügbare Bildverarbeitungsrountinen in ROBOPro:

Bewegungserkennung, Farberkennung, Spurerkennung (farbig), Ballerkennung

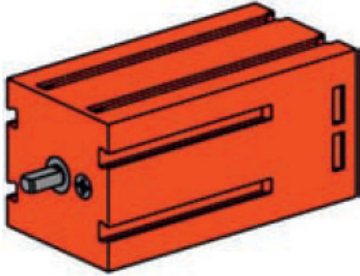
*Available Image processing routines in ROBOPro:*

*motion recognition, color recognition, trail recognition (color), ball recognition*



FT-T-KN  
2017-08-15

**Datenblatt Encodermotor 9V Art.-Nr. 153422**  
**Datasheet Encoder motor 9V Art. No. 153422**

|   |  |
|---|--|
|  | Maße/dimensions: 60x30x30mm  |
|   | Abtriebswelle/output shaft: D=4mm, L=7,5mm,<br>2 Abflachungen je 0,7mm/ 2 bevels 0.7mm each  |
|   | Stromversorgung: 9VDC über 2 fischertechnik Anschlussbuchsen<br>D=2,5mm/<br>Power supply: 9VDC with 2 fischertechnik connection sockets<br>D=2.5mm |

**Motordaten/motor data:**

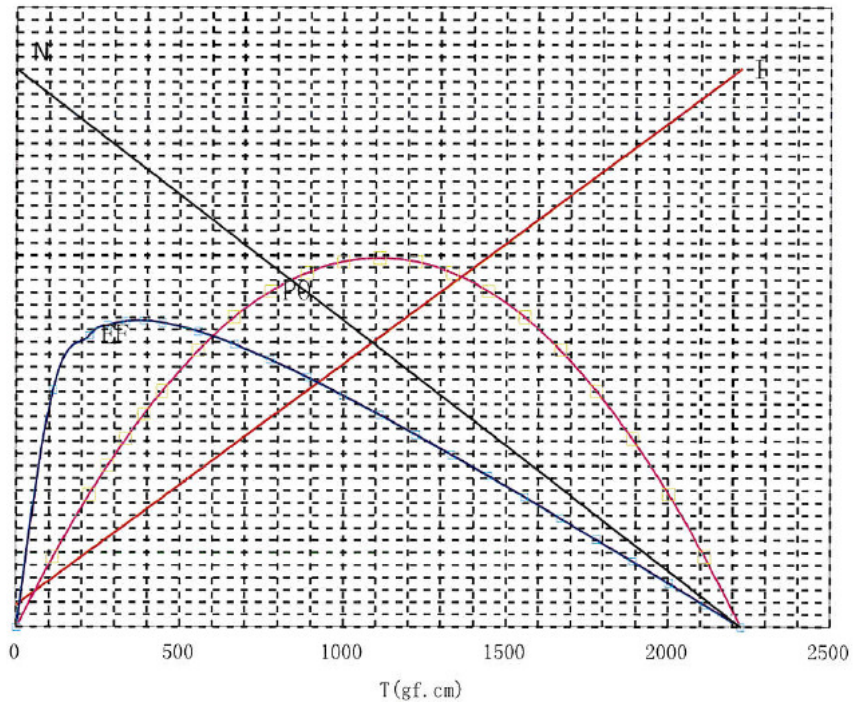
Constant voltage (额定电压) : 9V

Rotation (转向) : CCW

| P <sub>0</sub> | EF  | I    | N     |
|----------------|-----|------|-------|
| 2              | 100 | 824  | 232   |
| 1              | 50  | 412  | 116   |
| [W]            | [%] | [mA] | r/min |

T: torque: 力矩

— N: Speed: 转速                      — I: Current: 电流  
— P: Out power: 输出功率            — EF: Efficiency: 效率  
— 线性 (N: Speed: 转速)

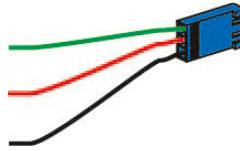


Nennspannung Motor/rated voltage motor: 9V DC  
Max. Leistung/max. power: 1,2 W  
Drehzahl bei max. Leistung/ speed at max. power: 105 U/min (rpm).  
Drehmoment bei max. Leistung/torque at maximum power: 109 mNm  
Stromaufnahme bei max. Leistung/current at max. power: 386 mA  
Getriebeuntersetzung: 21,3:1 /gear reduction: 21,3:1

**Encoderdaten/encoder data:**

Magnetencoder  
Stromversorgung/power supply: 9VDC  
Signal: Encodersignal, Push-Pull Output (0/9V), max. 10mA  
Frequenz/frequency: max 1kHz.

Anschlüsse/connector: 3-pol Stiftleiste,  
passendes Kabel/fitting cable: Art.No. 137125  
rot/red=+9V, grün/green=0V,  
schwarz/black=Encodersignal/encoder signal



Versorgungsspannung Encoder/supply voltage encoder: 9V DC  
Signal: NPN Open Kollektor Ausgang, max. 2mA belastbar/signal: npn open collector output, max. 2mA

Bei Anschluss an einen digitalen Eingang einer Steuerung (nicht fischertechnik-Controller): Pull-up-Widerstand 4.7-10kOhm notwendig zwischen Encodersignal und Prozessorstromversorgung (bei 3,3-5V)

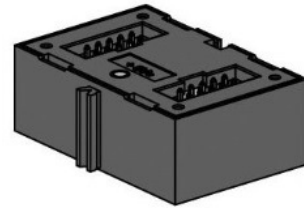
When the encoder motor is connected to a digital input of any control units (not fischertechnik controllers) a pull-up resistance of 4.7-10kOhms is needed between the encoder signal and the processor power supply (3.3V or 5V).

Pins (Encoderkabel): grün: Masse (-), rot: 9V+, schwarz: Encodersignal  
Pins (encoder cable): green: 0V (-), red: 9V+, black: encoder signal

Auflösung des Encoders: 3 Impulse (6 Impulse wenn 0-1 und 1-0-Flanke gezählt wird) pro Umdrehung des Motors. 63,3/126,6 Impulse pro Umdrehung der Getriebe-Abtriebsachse

Resolution of encoder: 3 pulses (6 pulses when counting 0-1 and 1-0 edge) per round of motor. 63.9/127.8 pulses per round of the gear shaft.

**Combi Sensor part no. 158402**  
**3-in-1 absolute-orientation sensor**



### Quick reference guide

The fischertechnik 3-in-1 absolute-orientation sensor contains an acceleration sensor, a gyroscope and a geomagnetic sensor which can be addressed by the I<sup>2</sup>C interface of the ROBOTICS TXT Controller as three independent devices. The connection of the sensor is made by a ribbon cable (117336), which is attached to the TXT controller via the extension port (EXT) and a single power line (9V), which is plugged into the 9V OUT connector of the TXT controller. The correct connection can be seen in Figure 1. A detailed description of the sensor can be found in the manual of the used MEMS sensor by Bosch Sensortec BMX055, which can be found here:

<https://ae-bst.resource.bosch.com/media/tech/media/datasheets/BST-BMX055-DS000-02.pdf>

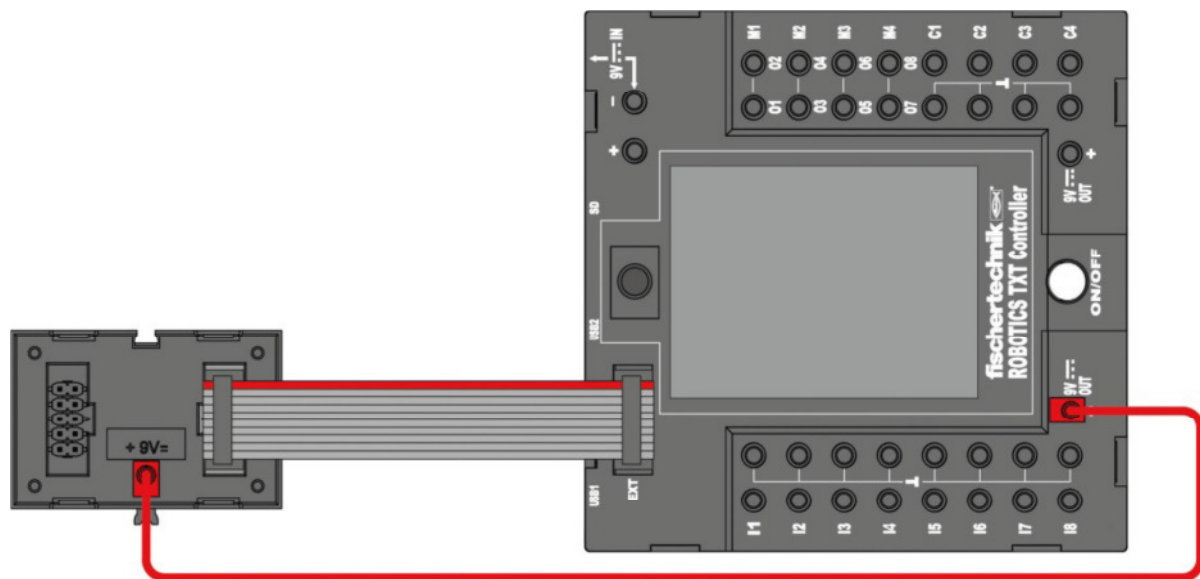


Fig.1: Connection of the fischertechnik 3-in-1 absolute-orientation sensor to the ROBOTICS TXT Controller.

### Specifications:

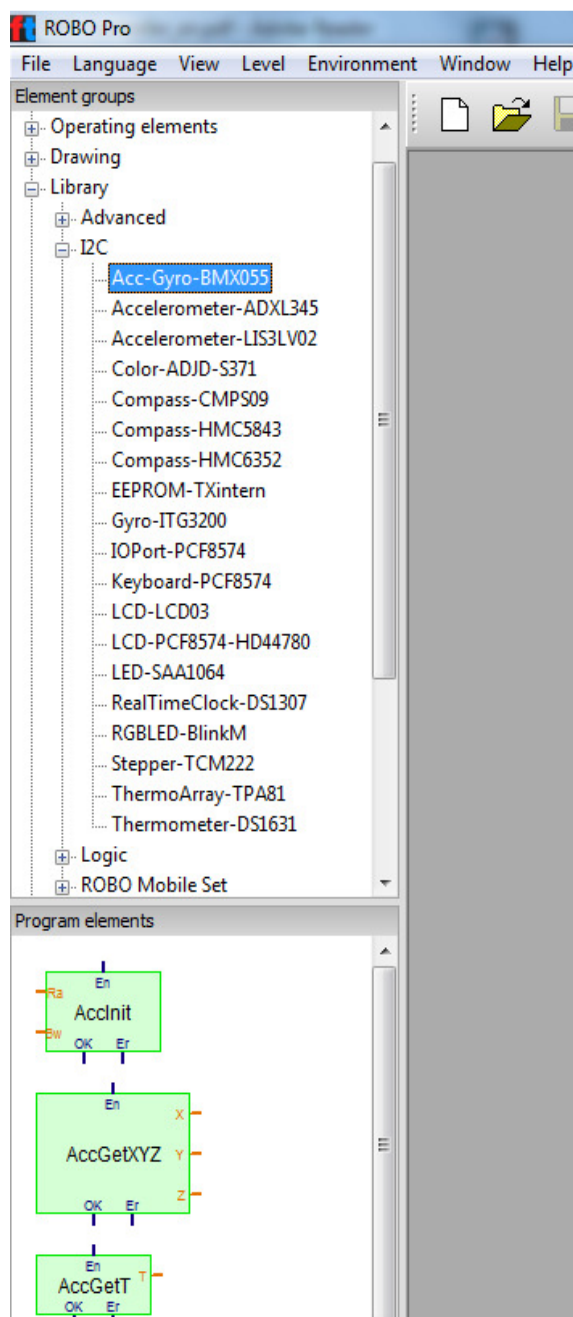
- Integrated 3-axis gyrosensor / 3-axis acceleration sensor
- resolution: up to 12 bit
- measurement range acceleration: +-2/+-4/+-8/+-16g
- measurement range gyroscope: +-125/+-245/+-500/+-1000/+-2000°/s
- sample rate 1k/s
- I<sup>2</sup>C-port

## I<sup>2</sup>C addresses of the devices

- Acceleration sensor: 0x18
- Gyroscope: 0x68
- Geomagnetic sensor: 0x10

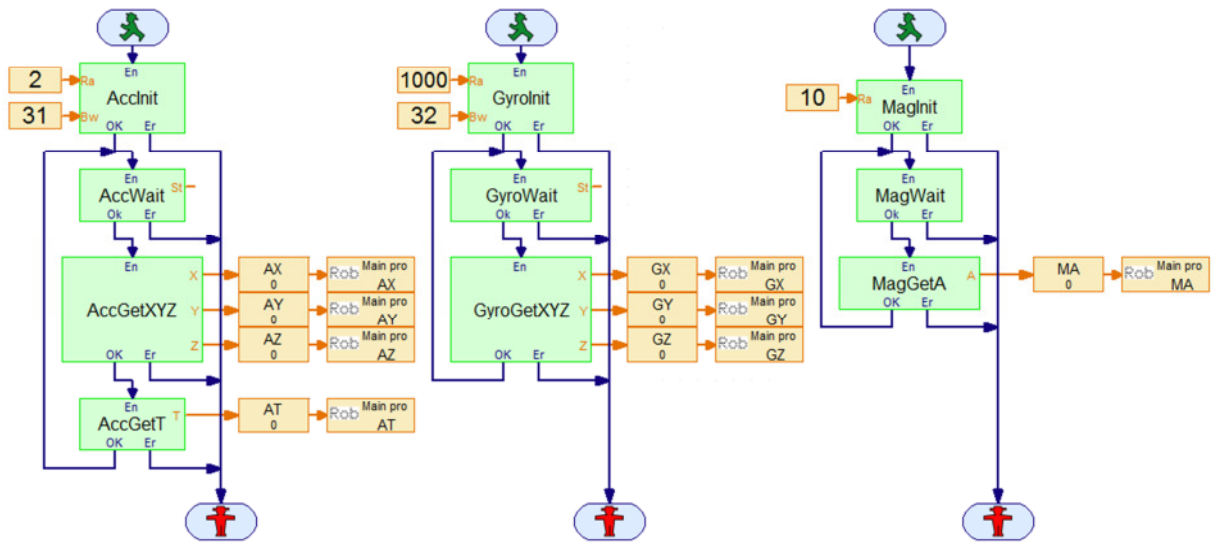
## Assignment in ROBOPro (Version 4.2.4)

The three units of the 3-in-1 sensor have to be assigned independently in ROBOPro. For each sensor unit, there are three important blocks, which have to be used in order to obtain sensor values. They are available as subprograms in the element groups – Library – I2C – BMX055



On the one hand, these are the initialization blocks, which have to be called at the beginning of the program and on the other hand, the waiting blocks and the actual reading blocks, which have to be called continuously. These blocks can be found under 'Library->I2C->Acc-Gyro-BMX055'. In case of the acceleration sensor, these blocks are called 'AccInit', 'AccWait' and 'AccGetXYZ'. The gyroscope can be assigned by the functions 'GyroInit', 'GyroWait' and 'GyroGetXYZ'. The functions of the geomagnetic sensor are called 'MagInit', 'MagWait' and 'MagGetA'. The initialization blocks are also used to configure the sensor units. Thereby, it is possible to set the bandwidth and the range of the sensor.

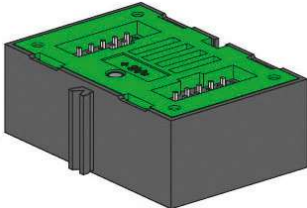
A typical configuration can be seen in the example program 'Acc-Gyro-BMX055.rpp', which can be seen in the figure below.



This sample is available in the folder ROBOPro\Library\I2C\Acc-Gyro-BMX055.rpp

The program reads all the values from the sensor and displays them in download mode on the display of the TXT Controller.

FT-T-KN  
2019-10-23

|  |  |  |
|--|--|--|
| Art.-Nr.<br><i>part. no.</i>                       | 167358   |  |
| Bezeichnung<br><i>name</i>                         | Umweltsensor<br><b>BME 680</b><br><i>Environmental-sen-<br/>sor BME680</i> |  |
| Abmessungen<br><i>dimensions:</i>                  | 45x30x15mm   |  |
| Gewicht<br><i>weight:</i>                          | 14,2g  |  |
| Spannungsver-<br>sorgung<br><i>Supply voltage:</i> | 9 VDC  |  |

Signal: I2C-Schnittstelle über 10-polige Stiftleiste  
*Signal: I2C-port 10-pole male connector*

Anschlüsse: rot=9VDC, grün=Masse, Schwarz=Signal  
*connection: red=9VDC, green=ground, black=signal*

**Messwerte:**  
***measured values:***

Lufttemperatur (-40 - +85°C)  
*air temperature (-40 - +85°C)*

Luftdruck (300-1100hPa)  
*air pressure (300-1100hPa)*

Luftfeuchtigkeit 0-100% r. H.  
*humidity 0-100% r. H.*

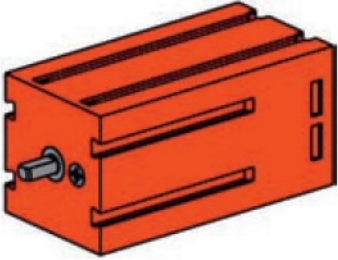
Luftqualität, Messung durch Gassensor, Auswertung nach Indoor air quality (IAQ)  
*air quality (measurement with gas sensor, evaluation according to Indoor air quality (IAQ))*

| IAQ Index | Air Quality        |
|-----------|--------------------|
| 0 – 50    | good <sup>10</sup> |
| 51 – 100  | average            |
| 101 – 150 | little bad         |
| 151 – 200 | bad                |
| 201 – 300 | worse <sup>2</sup> |
| 301 – 500 | very bad           |

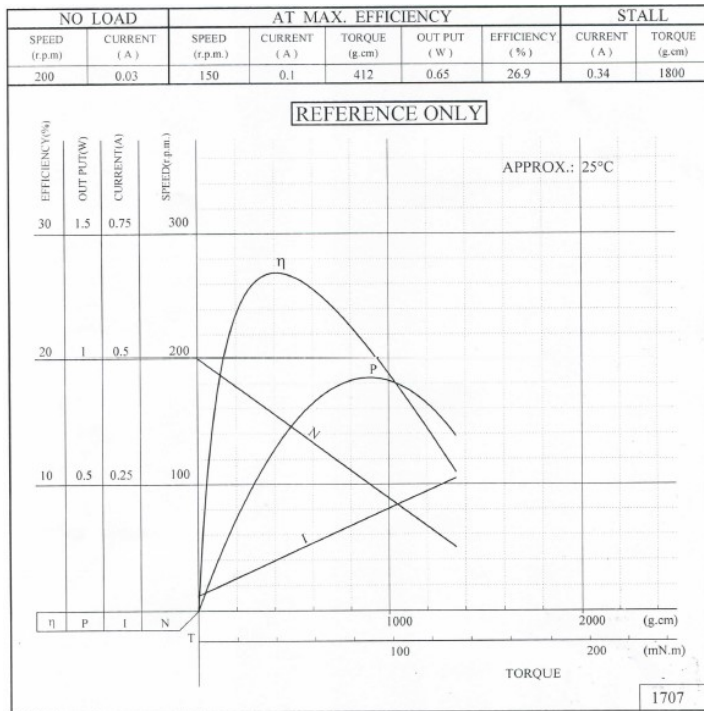
Weitere Details siehe Datenblatt Bosch BME680  
 Further details see data sheet Bosch BME680

FT-T-KN  
12.05.2020

**Datenblatt Encodermotor 24V Art.-Nr. 168988**  
**Datasheet Encoder motor 24V Art. No. 168988**

|   |  |
|---|--|
|  | <p>Maße/dimensions: 65x30x30mm</p>   |
|   | <p>Abtriebswelle/output shaft: D=4mm, L=7,5mm,<br/>2 Abflachungen je 0,7mm/ 2 bevels 0.7mm each</p>  |
|   | <p>Stromversorgung: 24VDC über 2 fischertechnik Anschlussbuchsen D=2,5mm/<br/>Power supply: 24VDC with 2 fischertechnik connection sockets D=2.5mm</p> |

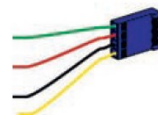
**Motordaten/motor data:**



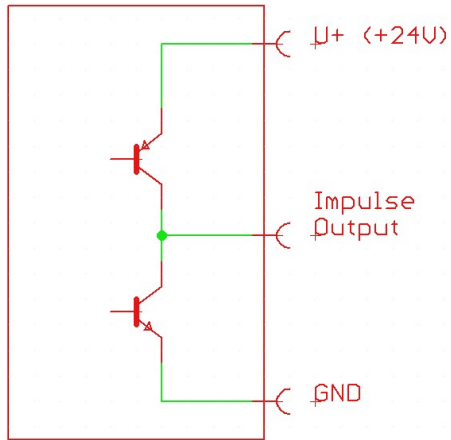
**Encoderdaten/encoder data:**

Quadraturencoder,  
 Stromversorgung/power supply 24VDC  
 Signal: Quadratur Encoder, Push-Pull Output (0/24V), max. 10mA  
 Frequenz/frequency: max 1kHz.

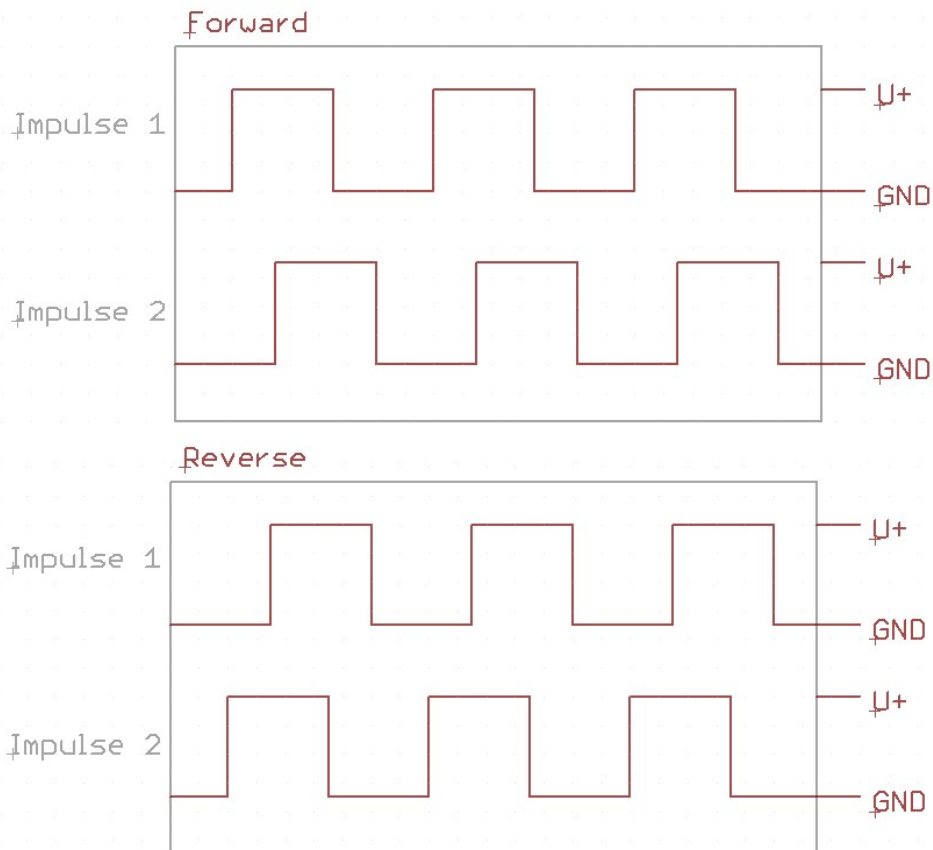
Anschlüsse/connector: 4-pol Stifteleiste,  
 passendes Kabel/fitting cable: Art.No. 119785  
 rot/red=+24V, grün/green=0V, schwarz/black=Puls1,  
 gelb/yellow=Impuls2



Ersatzschaltbild eines 24V Encoder-Ausgangs (2 pro Motor)  
 Equivalent circuit diagram of 24V encoder output (2 per motor)



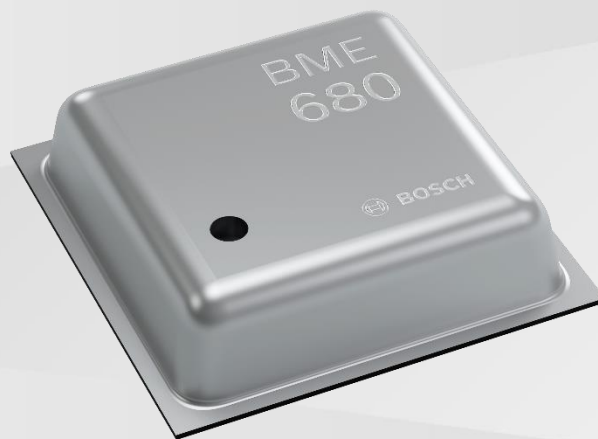
Ausgangssignal des 24V-Encoders für verschiedene Drehrichtungen.  
 Output signal of 24V-encoder for different directions of rotation





# BME680

Low power gas, pressure, temperature & humidity sensor



## BME680 – Datasheet

|                             |  |
|-----------------------------|--|
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| Notes                       | Data and descriptions in this document are subject to change without notice. Product photos and pictures are for illustration purposes only and may differ from the real product appearance. |



## BME680

### Low power gas, pressure, temperature & humidity sensor

The BME680 is a digital 4-in-1 sensor with gas, humidity, pressure and temperature measurement based on proven sensing principles. The sensor module is housed in an extremely compact metal-lid LGA package with a footprint of only  $3.0 \times 3.0 \text{ mm}^2$  with a maximum height of 1.00 mm ( $0.93 \pm 0.07 \text{ mm}$ ). Its small dimensions and its low power consumption enable the integration in battery-powered or frequency-coupled devices, such as handsets or wearables.

#### Typical applications

- Indoor air quality
- Home automation and control
- Internet of things
- Weather forecast
- GPS enhancement (e.g. time-to-first-fix improvement, dead reckoning, slope detection)
- Indoor navigation (change of floor detection, elevator detection)
- Outdoor navigation, leisure and sports applications
- Vertical velocity indication (rise/sink speed)

#### Target Devices

- Handsets such as mobile phones, tablet PCs, GPS devices
- Wearables
- Home weather stations
- Smart watches
- Navigation systems
- Gaming, e.g. flying toys
- IOT devices

## Key features

- Package 3.0 mm x 3.0 mm x 0.93 mm metal lid LGA
- Digital interface I<sup>2</sup>C (up to 3.4 MHz) and SPI (3 and 4 wire, up to 10 MHz)
- Supply voltage V<sub>DD</sub> main supply voltage range: 1.71 V to 3.6 V  
V<sub>DDIO</sub> interface voltage range: 1.2 V to 3.6 V
- Current consumption 2.1  $\mu$ A at 1 Hz humidity and temperature  
3.1  $\mu$ A at 1 Hz pressure and temperature  
3.7  $\mu$ A at 1 Hz humidity, pressure and temperature  
0.09–12 mA for p/h/T/gas depending on operation mode  
0.15  $\mu$ A in sleep mode
- Operating range -40–+85 °C, 0–100% r.H., 300–1100 hPa
- Individual humidity, pressure and gas sensors can be independently enabled/disabled
- The product is RoHS compliant, halogen-free, MSL1

## Key parameters for gas sensor

- Response time ( $\tau_{33-63\%}$ ) < 1 s (for new sensors)
- Power consumption < 0.1 mA in ultra-low power mode
- Output data processing direct indoor air quality (IAQ) index output

## Key parameters for humidity sensor

- Response time ( $\tau_{0-63\%}$ ) ~8 s
- Accuracy tolerance  $\pm 3\%$  r.H.
- Hysteresis  $\pm 1.5\%$  r.H.

## Key parameters for pressure sensor

- RMS Noise 0.12 Pa, equiv. to 1.7 cm
- Offset temperature coefficient  $\pm 1.3$  Pa/K, equiv. to  $\pm 10.9$  cm at 1 °C temperature change

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# 1. Specification

If not stated otherwise,

- all values are valid over the full voltage range,
- all minimum/maximum values are given for the full accuracy temperature range
- minimum/maximum values of drifts, offsets and temperature coefficients are  $\pm 3\sigma$  values over lifetime,
- typical values of currents and state machine timings are determined at 25 °C,
- minimum/maximum values of currents are determined using corner lots over complete temperature range, and
- minimum/maximum values of state-machine timings are determined using corner lots over 0–+65 °C temperature range.

Besides the general electrical specifications, the following tables are separated for the gas, pressure, humidity and temperature functions of the BME680.

## 1.1 General Electrical Specification

Table 1: Electrical parameter specification

| OPERATING CONDITIONS BME680                      |                       |  |      |      |             |                 |
|--|-----------------------|--|------|------|-------------|-----------------|
| Parameter  | Symbol                | Condition  | Min  | Typ  | Max         | Unit            |
| Supply Voltage Internal Domains <sup>1</sup>     | V <sub>DD</sub>       | ripple max. 50 mVpp  | 1.71 | 1.8  | 3.6         | V               |
| Supply Voltage I/O Domain                        | V <sub>DDIO</sub>     |  | 1.2  | 1.6  | 3.6         | V               |
| Sleep current                                    | I <sub>DDSL</sub>     |  |      | 0.15 | 1           | μA              |
| Standby current (inactive period of normal mode) | I <sub>DDSB</sub>     |  |      | 0.29 | 0.8         | μA              |
| Current during humidity measurement              | I <sub>DDH</sub>      | Max value at 85 °C   |      | 340  | 450         | μA              |
| Current during pressure measurement              | I <sub>DDP</sub>      | Max value at -40 °C  |      | 714  | 849         | μA              |
| Current during temperature measurement           | I <sub>DDT</sub>      | Max value at 85 °C   |      | 350  |             | μA              |
| Start-up time                                    | t <sub>startup</sub>  | Time to first communication after both V <sub>DD</sub> > 1.58 V and V <sub>DDIO</sub> > 0.65 V |      |      | 2           | ms              |
| Power supply rejection ratio (DC)                | PSRR                  | full V <sub>DD</sub> range   |      |      | ±0.01<br>±5 | %r.H./V<br>Pa/V |
| Standby time accuracy                            | Δt <sub>standby</sub> |  |      | ±5   | ±25         | %               |

<sup>1</sup> The power efficiency, performance and heat dissipation scales with the applied supply voltage. The BME680 is optimized for 1.8 V.

## 1.2 Gas sensor specification

Table 2 lists the gas sensor specification. All the parameters are deduced from lab measurements under controlled environmental conditions, which are compliant to the ISO16000-29 standard “Test methods for VOC detectors”. Detailed procedure to measure the gas sensor is available in the Application Note: Measurement Instructions for Lab Environment.

Referring to Chapter 4, a software solution (BSEC: Bosch Software Environmental Cluster) is available for the BME680. The software is carefully engineered to seamlessly work with the 4-in-1 integrated sensors inside the BME680. Based on an intelligent algorithm, the BSEC provides an indoor air quality (IAQ) output. In principle, this output is in an index that can have values between 0 and 500 with a resolution of 1 to indicate or quantify the quality of the air available in the surrounding. Table 4 lists the IAQ system specification. The detailed classification and color coding of the IAQ index is described in Table 4. Furthermore, the BSEC solution supports different operation modes for the gas sensor to address the necessary power budget and update rate requirements of the end-application.

Unless mentioned otherwise, the specifications are deduced from new sensors that have been operated for at least five days mainly in ambient air and consequently have the same history (i.e. same power mode and exposed to the same environment).

Besides ethanol (EtOH) as a target test gas, the sensors are also tested with breath-VOC (b-VOC). The b-VOC mixture, as listed in Table 5, represents the most important compounds in an exhaled breath of healthy humans. The values are derived from several publications on breath analysis studies. The composition does not contain species which would chemically react to ensure that the mixture is stable for at least 6 months. Furthermore, the composition is also limited to species which can be manufactured in one mixture.

Table 2: Gas sensor parameter specification

| Parameter  | Symbol              | Condition  | Min  | Typ  | Max  | Unit   |
|--|---------------------|--|------|------|------|--------|
| Operational range <sup>1</sup>                         |                     |  | -40  |      | 85   | °C     |
|  |                     |  | 10   |      | 95   | % r.H. |
| Supply Current during heater operation                 | I <sub>DD</sub>     | Heater target temperature 320 °C, constant operation (V <sub>DD</sub> ≤ 1.8 V, 25°C) | 9    | 12   | 13   | mA     |
| Peak Supply Current                                    | I <sub>Peak</sub>   | Occurs within first ms of switching on the hotplate                                  | 15   | 17   | 18   | mA     |
| Average Supply Current (V <sub>DD</sub> ≤ 1.8 V, 25°C) | I <sub>DD,IAQ</sub> | Ultra-low power mode   |      | 0.09 |      | mA     |
|  |                     | Low power mode   |      | 0.9  |      | mA     |
|  |                     | Continuous mode  |      | 12   |      | mA     |
| Response time <sup>2</sup> (brand-new sensors)         | τ <sub>33-63%</sub> | Ultra-low power mode   |      | 92   |      | s      |
|  | τ <sub>33-63%</sub> | Low power mode   |      | 1.4  |      | s      |
|  | τ <sub>33-63%</sub> | Continuous mode  |      | 0.75 |      | s      |
| Resolution of gas sensor resistance measurement        |                     |  | 0.05 | 0.08 | 0.11 | %      |
| Noise in gas sensor resistance (RMS)                   | N <sub>R</sub>      |  |      | 1.5  |      | %      |

<sup>1</sup> The sensors are electrically operable within this range. Actual performance may vary

<sup>2</sup> Response time of unsoldered, brand-new sensors extracted from the sensors' resistance change in response to a 0.6–60 ppm step of EtOH and a 0.5–15 ppm step of b-VOC at 20 °C, 50% r.H. and atmospheric pressure.



Table 3: IAQ system parameter specification<sup>3</sup>

| Parameter                                | Symbol               | Condition                          | Min | Typ         | Max | Unit |
|--|----------------------|------------------------------------|-----|-------------|-----|------|
| Accuracy status <sup>4</sup>             | AX <sub>IAQ</sub>    | Android compatible                 | 0   |             | 3   |      |
| IAQ Resolution                           | IAQ <sub>rs</sub>    |                                    |     | 1           |     |      |
| IAQ Range                                | IAQ <sub>rg</sub>    |                                    | 0   |             | 500 |      |
| Sensor-to-sensor deviation <sup>5</sup>  | IAQ <sub>s2s</sub>   | All operation modes                |     | ±15%<br>±15 |     |      |
| Durability to siloxanes <sup>6,7,8</sup> | IAQ <sub>s2s</sub>   | Sensor-to-sensor deviation         |     | ±15%<br>±15 |     |      |
|  | IAQ <sub>drift</sub> | Drift at low & high concentrations |     | ±1%<br>±4   |     |      |

Table 4: Indoor air quality (IAQ) classification and color-coding<sup>9</sup>

| IAQ Index | Air Quality        |
|-----------|--------------------|
| 0 – 50    | good <sup>10</sup> |
| 51 – 100  | average            |
| 101 – 150 | little bad         |
| 151 – 200 | bad                |
| 201 – 300 | worse <sup>2</sup> |
| 301 – 500 | very bad           |

Table 5: bVOC mixture with Nitrogen as carrier gas

| Molar fraction | Compound                         | Production tolerance | Certified accuracy |
|----------------|----------------------------------|----------------------|--------------------|
| 5 ppm          | Ethane                           | 20 %                 | 5 %                |
| 10 ppm         | Isoprene /2-methyl-1,3 Butadiene | 20 %                 | 5 %                |
| 10 ppm         | Ethanol                          | 20 %                 | 5 %                |
| 50 ppm         | Acetone                          | 20 %                 | 5 %                |
| 15 ppm         | Carbon Monoxide                  | 10 %                 | 2 %                |

<sup>3</sup> IAQ parameters only apply for the combination of BME680 together with the Bosch Software Environmental Cluster (BSEC) solution (available separately, see Chapter 4)

<sup>4</sup> The accuracy status is equal to zero during the power-on stabilization times of the sensor and is equal to 3 when the sensor achieves best performance

<sup>5</sup> Tested with 0.6–90 ppm of EtOH at 5–40 °C, 20–80% r.H. and atmospheric pressure. Condition is valid after the calibration period of the BSEC algorithm.

<sup>6</sup> Siloxanes are present in a typical indoor environment and can in principle perturb the metal-oxide-based gas sensor performance.

<sup>7</sup> 220 hours of 700 mg/m<sup>3</sup> of octamethylcyclotetrasiloxane (D4) in ambient conditions (i.e. 20 °C and 50% r.H.) simulates the amount of siloxanes in a typical indoor environment over more than 10 years.

<sup>8</sup> Tested with 0.5–15 ppm of b-VOC at 20 °C and 50% r.H. using continuous operation mode for 220 hours of 700 mg/m<sup>3</sup> of octamethylcyclotetrasiloxane (D4).

<sup>9</sup> According to the guidelines issued by the German Federal Environmental Agency, exceeding 25 mg/m<sup>3</sup> of total VOC leads to headaches and further neurotoxic impact on health.

<sup>10</sup> The BSEC software auto-calibrates the low and high concentrations applied during testing to IAQ of 25 and 250, respectively.

## 1.3 Humidity sensor specification

Table 6: Humidity parameter specification

| Parameter   | Symbol             | Condition  | Min | Typ   | Max | Unit        |
|---|--------------------|--|-----|-------|-----|-------------|
| Operating Range <sup>11</sup>                       |                    |  | -40 | 25    | 85  | °C          |
|   |                    |  | 0   |       | 100 | % r.H.      |
| Full accuracy range                                 |                    |  | 0   |       | 65  | °C          |
|   |                    |  | 10  |       | 90  | % r.H.      |
| Supply Current                                      | I <sub>DD,H</sub>  | 1 Hz forced mode, temperature and humidity measurement |     | 2.1   | 2.8 | μA          |
| Absolute Accuracy                                   | A <sub>H</sub>     | 20–80 % r.H., 25 °C, including hysteresis              |     | ±3    |     | % r.H.      |
| Hysteresis <sup>12</sup>                            | H <sub>H</sub>     | 10→90→10 % r.H., 25°C                                  |     | ±1.5  |     | % r.H.      |
| Nonlinearity <sup>13</sup>                          | NL <sub>H</sub>    | 10→90 % r.H., 25°C                                     |     | 1.7   |     | % r.H.      |
| Response time to complete 63% of step <sup>14</sup> | τ <sub>0-63%</sub> | N <sub>2</sub> (dry) → 90 % r.H., 25°C                 |     | 8     |     | s           |
| Resolution  | R <sub>H</sub>     |  |     | 0.008 |     | % r.H.      |
| Noise in humidity (RMS)                             | N <sub>H</sub>     | Highest oversampling                                   |     | 0.01  |     | % r.H.      |
| Long-term stability                                 | ΔH <sub>stab</sub> | 10–90 % r.H., 25°C                                     |     | 0.5   |     | % r.H./year |

<sup>11</sup> When exceeding the operating range (e.g. for soldering), humidity sensing performance is temporarily degraded and reconditioning is recommended as described in Section 7.7. Operating range only for non-condensing environment.

<sup>12</sup> For hysteresis measurement the sequence 0→10→30→50→70→90→70→50→30→10 % r.H. is used. The hysteresis is defined as the maximum difference between measurements at of the same humidity up / down branch and the averaged curve of both branches.

<sup>13</sup> Non-linear contributions to the sensor data are corrected during the calculation of the relative humidity by the compensation formulas described in Section 3.5.

<sup>14</sup> The air-flow in direction to the vent-hole of the device has to be dimensioned in a way that a sufficient air exchange inside to outside will be possible. To observe effects on the response time-scale of the device an air-flow velocity of approximately 1 m/s is needed.

## 1.4 Pressure sensor specification

Table 7: Pressure parameter specification

| Parameter                                       | Symbol          | Condition   | Min  | Typ        | Max        | Unit      |
|---|-----------------|---|------|------------|------------|-----------|
| Operating temperature range                     | $T_A$           | operational   | -40  | 25         | 85         | °C        |
|   |                 | full accuracy   | 0    |            | 65         |           |
| Operating pressure range                        | $P$             | full accuracy   | 300  |            | 1100       | hPa       |
| Supply current                                  | $I_{DD,LP}$     | <b>1 Hz forced mode, pressure and temperature, lowest power</b> |      | <b>3.1</b> | <b>4.2</b> | <b>μA</b> |
| Temperature coefficient of offset <sup>15</sup> | $TCO_P$         | 25–40 °C, 900 hPa   |      | ±1.3       |            | Pa/K      |
|   |                 |   |      | ±10.9      |            | cm/K      |
| Absolute accuracy pressure                      | $A_{p,full}$    | 300–1100 hPa<br>0–65°C  |      | ±0.6       |            | hPa       |
| Relative accuracy pressure                      | $A_{rel}$       | 700–900hPa,<br>25–40 °C, at constant humidity                   |      | ±0.12      |            | hPa       |
|   | $A_{rel}$       | 900–1100hPa<br>25–40 °C, at constant humidity                   |      | ±0.12      |            | hPa       |
| Resolution of pressure output data              | $R_P$           | Highest oversampling  |      | 0.18       |            | Pa        |
| Noise in pressure                               | $N_{P,fullBW}$  | Full bandwidth, highest oversampling                            |      | 1.4        |            | Pa        |
|   |                 | Reduced bandwidth, highest oversampling                         |      | 11         |            | cm        |
| Solder drift                                    |                 | Minimum solder height 50μm                                      |      | 0.2        |            | Pa        |
|   |                 |   |      | 1.7        |            | cm        |
| Long-term stability <sup>16</sup>               | $P_{stab}$      | per year  | -0.5 | 1.2        | +2.0       | hPa       |
| Possible sampling rate                          | $f_{sample\_P}$ | Lowest oversampling, see chapter 3.3.2                          | 157  | 182        |            | Hz        |

<sup>15</sup> When changing temperature from 25 °C to 40 °C at constant pressure / altitude, the measured pressure / altitude will change by  $(15 \times TCO_P)$ .<sup>16</sup> Long-term stability is specified in the full accuracy operating pressure range 0–65 °C

## 1.5 Temperature sensor specification

Table 8: Temperature parameter specification

| Parameter                                   | Symbol       | Condition   | Min | Typ        | Max | Unit |
|---|--------------|---|-----|------------|-----|------|
| Operating temperature range                 | $T_A$        | operational   | -40 | 25         | 85  | °C   |
| Supply current                              | $I_{DD,T}$   | <b>1 Hz forced mode,<br/>temperature measurement<br/>only</b> |     | <b>1.0</b> |     | μA   |
| Absolute accuracy temperature <sup>17</sup> | $A_{T,25}$   | 25 °C   |     | ±0.5       |     | °C   |
|   | $A_{T,full}$ | 0–65 °C   |     | ±1.0       |     | °C   |
| Output resolution                           | $R_T$        | API output resolution   |     | 0.01       |     | °C   |
| RMS noise                                   | $N_T$        | Lowest oversampling   |     | 0.005      |     | °C   |

<sup>17</sup> Temperature measured by the internal temperature sensor. This temperature value depends on the PCB temperature, sensor element self-heating and ambient temperature and is typically above ambient temperature.

## 2. Absolute maximum ratings

The absolute maximum ratings are determined over the complete temperature range using corner lots. The values are provided in Table 9.

Table 9: Absolute maximum ratings

| Parameter                    | Condition                                 | Min     | Max                     | Unit |
|------------------------------|---|---------|-------------------------|------|
| Voltage at any supply pin    | V <sub>DD</sub> and V <sub>DDIO</sub> pin | -0.3    | 4.25                    | V    |
| Voltage at any interface pin |   | -0.3    | V <sub>DDIO</sub> + 0.3 | V    |
| Storage temperature          | ≤ 65% r.H.                                | -45     | +85                     | °C   |
| Pressure                     |   | 0       | 20 000                  | hPa  |
| ESD                          | HBM, at any pin                           |         | ±2                      | kV   |
|                              | Machine model                             |         | ±200                    | V    |
| Condensation                 | No power supplied                         | Allowed |                         |      |

### 3. Sensor usage

#### 3.1 Sensor modes

The sensor supports low-level power modes: sleep and forced mode. These modes can be selected using the *mode<1:0>* control register (see Section 5.3.1.3). The key differences between the modes are summarized in Table 10.

After a power-up sequence, the sensor automatically starts in sleep mode. If the device is currently performing a measurement, execution of mode switching commands is delayed until the end of the currently running measurement period. It is important to note that, further mode change commands or other write commands to the control registers are ignored until the mode change command has been executed. All control registers should be set to the desired values before writing to the mode register.

Table 10: Low-level operation modes

| Operation mode | mode<1:0> | Key features  |
|----------------|-----------|---|
| Sleep          | 00        | <ul style="list-style-type: none"> <li>No measurements are performed</li> <li>Minimal power consumption</li> </ul>  |
| Forced mode    | 01        | <ul style="list-style-type: none"> <li>Single TPHG cycle is performed</li> <li>Sensor automatically returns to sleep mode afterwards</li> <li>Gas sensor heater only operates during gas measurement</li> </ul> |

In forced mode, temperature, pressure, humidity and gas conversion are performed sequentially. Such a measurement cycle is abbreviated as TPHG (Temperature, Pressure, Humidity and Gas) in the following descriptions. Up to 10 temperature set-points and heating durations for the gas sensor hot plate can be stored in the sensor registers. In the following, these set-points and the corresponding measurements are identified as  $G_0 - G_9$ . Figure 1 illustrates the handling of these measurement sequences and the gas sensor hot plate is heated for the forced mode.

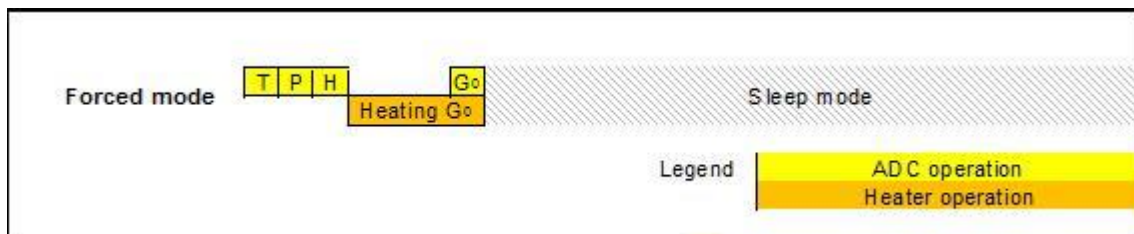


Figure 1: Sequence of ADC and gas sensor heater operation

## 3.2 Sensor configuration

### 3.2.1 Quick start

The sensor is configured by writing to a set of control registers (see Chapter 5 for a detailed list of all available registers and their descriptions). This section illustrates, with the help of a basic step-by-step example, how to configure the sensor for simple forced mode measurements with a single heater set-point. For a more detailed description of the measurement flow, please refer to Section 3.3.

In this example, the sensor will be configured to use 2x oversampling for its temperature measurements, 16x oversampling for the pressure signal, and 1x oversampling for humidity. Moreover, the gas sensor hot plate will be configured to be heated for 100 ms at 300 °C before the gas measurement is performed.

First, the user must configure the oversampling settings for temperature, pressure and humidity by setting the control registers *osrs\_t<2:0>* and *osrs\_h<2:0>*, respectively. Supported settings range from 16x oversampling down to 0x, which is equivalent to skipping the corresponding sub-measurement. See Section 5.3.2 for further details.

1. Set humidity oversampling to 1x by writing 0b001 to *osrs\_h<2:0>*
2. Set temperature oversampling to 2x by writing 0b010 to *osrs\_t<2:0>*
3. Set pressure oversampling to 16x by writing 0b101 to *osrs\_p<2:0>*

It is highly recommended to set first *osrs\_h<2:0>* followed by *osrs\_t<2:0>* and *osrs\_p<2:0>* in one write command (see Section 3.3).

Next, the user shall set at least one gas sensor hot plate temperature set-point and heating duration. Up to 10 heating duration can be configured through the control registers *gas\_wait\_x<7:0>*, where x ranges from 0 to 9. See Section 5.3.3 for definition of register content. The corresponding heater set-points are stored in the registers *res\_heat\_x<7:0>*. Section 3.3.5 explains how to convert the target heater temperature, e.g. 300 °C, into a register code. For forced mode operation, the used heater set point is selected by setting the control register *nb\_conv<3:0>* to the heater profile to be used, e.g. to use *gas\_wait\_0<7:0>* and *res\_heat\_0<7:0>*, *nb\_conv<3:0>* shall be set to 0x0. Finally, gas functionality shall be enabled by setting the *run\_gas\_l* bit to 1.

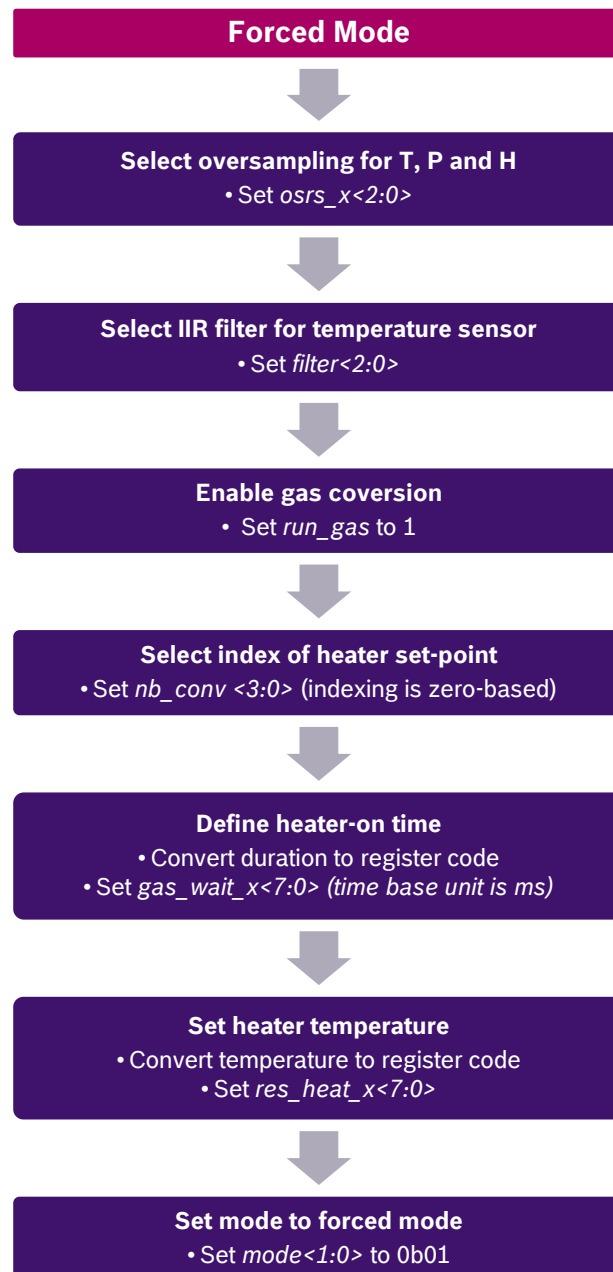
4. Set *gas\_wait\_0<7:0>* to 0x59 to select 100 ms heat up duration
5. Set the corresponding heater set-point by writing the target heater resistance to *res\_heat\_0<7:0>*
6. Set *nb\_conv<3:0>* to 0x0 to select the previously defined heater settings
7. Set *run\_gas\_l* to 1 to enable gas measurements

Now, a single forced mode measurement with the above settings can be triggered by writing 0b01 to *mode<1:0>*. For more details on data readout, please see Section 5.3.1.3.

8. Set *mode<1:0>* to 0b01 to trigger a single measurement.

### 3.2.2 Sensor configuration flow

Picture 2 illustrates which control registers must be set. For details on the individual control registers, please refer to Chapter 5. Moreover, details on the measurement flow for the individual modes can be found in Section 3.3.



Picture 2: Sensor configuration flow



### 3.3 Measurement flow

Referring to Figure 1, the BME680 measurement period consists of a temperature, pressure and humidity measurement with selectable oversampling. Moreover, it contains a heating phase for the gas sensor hot plate as well as a measurement of the gas sensor resistance.

After the measurement period, the pressure and temperature data can be passed through an optional IIR filter, which removes short-term fluctuations. For humidity and gas, such a filter is not needed and has not been implemented.

#### 3.3.1 Temperature measurement

Temperature measurement can be enabled or skipped. Skipping the measurement is typically not recommended since temperature information is used to compensate temperature influences in the other parameters. When enabled, several oversampling options exist. The temperature measurement is controlled by the *osrs\_t*<2:0> setting which is detailed in Section 5.3.2.2. For the temperature measurement, oversampling is possible to reduce the noise. The resolution of the temperature data depends on the IIR filter (see Section 5.3.2.4) and the oversampling setting:

- When the IIR filter is enabled, the temperature resolution is 20 bit
- When the IIR filter is disabled, the temperature resolution is  $16 + (osrs\_t - 1)$  bit, e.g. 18 bit when *osrs\_t* is set to '3'

#### 3.3.2 Pressure measurement

Pressure measurement can be enabled or skipped. When enabled, several oversampling options exist. The pressure measurement is controlled by the *osrs\_p*<2:0> setting which is detailed in Section 5.3.2. For the pressure measurement, oversampling is possible to reduce noise. The resolution of the pressure data depends on the IIR filter (see Section 5.3.2.4) and the oversampling setting:

- When the IIR filter is enabled, the pressure resolution is 20 bit
- When the IIR filter is disabled, the pressure resolution is  $16 + (osrs\_p - 1)$  bit, e.g. 18 bit when *osrs\_p* is set to '3'

#### 3.3.3 Humidity measurement

The humidity measurement can be enabled or skipped. When enabled, several oversampling options exist. The humidity measurement is controlled by the *osrs\_h*<2:0> setting, which is described in detail in Section 5.3.2.1. For the humidity measurement, oversampling is possible to reduce noise. The resolution of the humidity measurement is fixed at 16 bit ADC output.

### 3.3.4 IIR filter

The environmental pressure is subject to many short-term changes, caused external disturbances. To suppress disturbances (e.g. slamming of door or wind blowing into the sensor) in the output data without causing additional interface traffic and processor work load, the BME680 features an internal IIR filter (see Section 5.3.2.4). It effectively reduces the bandwidth of the temperature and pressure output signals and increases the resolution of the output data to 20 bit, noting that the humidity and gas values inside the sensor does not fluctuate rapidly and does not require low pass filtering. The output of a next measurement step is filtered using the following formula:

$$x_{filt}[n] = \frac{x_{filt}[n-1] \cdot (c-1) + x_{ADC}}{c}$$

$x_{filt}[n-1]$  is the data coming from the current filter memory, and  $x_{ADC}$  is the data coming from current ADC acquisition.  $x_{filt}[n]$  denotes the new value of filter memory and the value that will be sent to the output registers.

The IIR filter can be configured to different filter coefficients, which slows down the response to the sensor inputs. Note that the response time with enabled IIR filter depends on the number of samples generated, which means that the data output rate must be known to calculate the actual response time.

When writing to the register *filter*, the filter is reset. The next ADC values will pass through the filter unchanged and become the initial memory values for the filter. If temperature or pressure measurements are skipped, the corresponding filter memory will be kept unchanged even though the output registers are set to 0x80000. When the previously skipped measurement is re-enabled, the output will be filtered using the filter memory from the last time when the measurement was not skipped. If this is not desired, please write to the filter register in order to re-initialize the filter.

### 3.3.5 Gas sensor heating and measurement

The operation of the gas sensing part of BME680 involves two steps:

1. Heating the gas sensor hot plate to a target temperature (typically between 200 °C and 400 °C) and keep that temperature for a certain duration of time.
2. Measuring the resistance of the gas sensitive layer.

Up to 10 different hot plate temperature set points can be configured by setting the registers *res\_heat\_x<7:0>*, where  $x = 0 \dots 9$ . The internal heater control loop operates on the resistance of the heater structure. Hence, the user first needs to convert the target temperature into a device specific target resistance before writing the resulting register code into the sensor memory map.

The following code will calculate register code that to be written to *res\_heat\_x<7:0>*. Nevertheless, it is recommended to use the sensor API available on github (Chapter 4) for a friendlier user experience.

```
var1 = ((double)par_g1 / 16.0) + 49.0;
var2 = (((double)par_g2 / 32768.0) * 0.0005) + 0.00235;
var3 = (double)par_g3 / 1024.0;
var4 = var1 * (1.0 + (var2 * (double) target_temp));
var5 = var4 + (var3 * (double) amb_temp);
res_heat_x = (uint8_t)(3.4 * ((var5 * (4.0 / (4.0 + (double)res_heat_range)) * (1.0/(1.0 + ((double)res_heat_val * 0.002)))) - 25));
```

where

- *par\_g1*, *par\_g2*, and *par\_g3* are calibration parameters,
- *target\_temp* is the target heater temperature in degree Celsius,
- *amb\_temp* is the ambient temperature (hardcoded or read from temperature sensor),
- *var5* is the target heater resistance in Ohm,
- *res\_heat\_x* is the decimal value that needs to be stored in register, where 'x' corresponds to the temperature profile number between 0 and 9,
- *res\_heat\_range* is the heater range stored in register address 0x02 <5:4>, and
- *res\_heat\_val* is the heater resistance correction factor stored in register address 0x00 (signed, value from -128 to 127).

Table 11: Variable names and register addresses for *res\_heat\_x* calculation

| Variable name  | Register address (LSB / MSB) |
|----------------|------------------------------|
| par_g1         | 0xED                         |
| par_g2         | 0xEB/0xEC                    |
| par_g3         | 0xEE                         |
| res_heat_range | 0x02 <5:4>                   |
| res_heat_val   | 0x00                         |

For each of the 10 temperature set-points, the heating duration must be specified. Referring to Figure 1, the heating phase starts after the temperature, pressure and humidity measurements are complete. This means there is no heating in parallel to these measurements, which is desirable to minimize undesired cross-influences between the various sensor components.

The heating duration is specified by writing to the corresponding *gas\_wait\_x*<7:0> control register. Heating durations between 1 ms and 4032 ms can be configured. In practice, approximately 20–30 ms are necessary for the heater to reach the intended target temperature.

### 3.4 Data readout

The procedure goes as follows, the *new\_data\_x* bit (see Section 5.3.5.1) can be checked to see if a new data is generated. If gas measurements are performed the *gas\_valid\_r* (see Section 5.3.5.5) and *heat\_stab\_r* (see Section 5.3.5.6) status bits of the respectively field should be checked to ensure that the gas measurement was successful. If *heat\_stab\_r* is zero, it indicates that either the heating time was not sufficient to allow the sensor to reach to configured target temperature or that the target temperature was too high for the sensor to reach.

After the uncompensated values of temperature, pressure and humidity have been read, the actual humidity, pressure and temperature need to be calculated using the compensation parameters stored in the device. Please refer to the BME6xy API for more details.

#### 3.4.1 Gas resistance readout

Readout of gas resistance ADC value and calculation of gas resistance consists of 3 steps

1. Read gas ADC value (*gas\_r*) and gas ADC range (*gas\_range\_r*) (see Section 5.3.4)
2. Read range switching error from register address 0x04 <7:4> (signed 4 bit)
3. Convert ADC value into gas resistance in ohm

The conversion is done as follows:

```
var1 = (1340.0 + 5.0 * range_switching_error) * const_array1[gas_range];
gas_res = var1 * const_array2[gas_range] / (gas_r - 512.0 + var1);
```

### 3.5 Output compensation

The BME680 output consists of the ADC output values. However, each sensing element behaves differently. Therefore, the actual humidity, pressure and temperature must be calculated using a set of calibration parameters. This is implemented in the BME6xy API.

Table 12: List of gas ranges and corresponding constants used for the resistance calculation

| gas_range | Constants (to be integrated in the driver) |              |
|-----------|--|--------------|
|           | const_array1                               | const_array2 |
| 0         | 1  | 8000000      |
| 1         | 1  | 4000000      |
| 2         | 1  | 2000000      |
| 3         | 1  | 1000000      |
| 4         | 1  | 499500.4995  |
| 5         | 0.99                                       | 248262.1648  |
| 6         | 1  | 125000       |
| 7         | 0.992                                      | 63004.03226  |
| 8         | 1  | 31281.28128  |
| 9         | 1  | 15625        |
| 10        | 0.998                                      | 7812.5       |
| 11        | 0.995                                      | 3906.25      |
| 12        | 1  | 1953.125     |
| 13        | 0.99                                       | 976.5625     |
| 14        | 1  | 488.28125    |
| 15        | 1  | 244.140625   |

## 4. Software and use cases

### 4.1 BSEC software

BME680 sensor is intended to be used together with Bosch Software Environmental Cluster (BSEC) solution and BME6xy sensor API to unlock its full potential. The BSEC software features intelligent algorithms which enable use cases such as indoor-air-quality monitoring using the BME680.

Bosch Sensortec BSEC software is available as a closed source binary which will be made available via a Software License Agreement (SLA) on the Bosch Sensortec website ([https://www.bosch-sensortec.com/bst/products/all\\_products/BSEC](https://www.bosch-sensortec.com/bst/products/all_products/BSEC)). Sensor API covers basic sensor communication and data compensation functions and is available as open-source code from Github ([https://github.com/BoschSensortec/BME680\\_driver](https://github.com/BoschSensortec/BME680_driver)).

The key features of the hardware-software system are:

- Calculation of ambient air temperature outside of the device (e.g. phone)
- Calculation of ambient relative humidity outside of the device
- Calculation of indoor air quality (IAQ) level outside of the device

Moreover, the software algorithms handle humidity compensation, baseline as well as long-term drift correction of the gas sensor signal.

Different power modes for the gas sensor and corresponding data rates are supported by the software solution:

- Ultra low power (ULP) mode that is designed for battery-powered and/or frequency-coupled devices over extended periods of time. This mode features an update rate of 300 seconds and an average current consumption of <0.1 mA
- Low power (LP) mode that is designed for interactive applications where the indoor-air-quality is tracked and observed at a higher update rate of 3 seconds with a current consumption of <1 mA
- Continuous (CONT) mode provides an update rate of 1 Hz and shall only be used for use cases that incorporate very fast events or stimulus

Table 13: BSEC gas sensor power-modes

| BSEC power mode                             | Update rate | Average current consumption |
|---|-------------|-----------------------------|
| Ultra-low power mode (ULP)                  | 3.3 mHz     | 0.09 mA                     |
| Low power mode (LP)                         | 0.33 Hz     | 0.9 mA                      |
| Continuous mode (for testing purposes only) | 1 Hz        | 12 mA                       |

BSEC is available in two main variants called solutions: IAQ and ALL solution.

IAQ solution is intended for customers wishing to measure indoor-air-quality, temperature, humidity, and pressure in embedded devices. IAQ solution can be downloaded from the Bosch Sensortec website ([https://www.bosch-sensortec.com/bst/products/all\\_products/BSEC](https://www.bosch-sensortec.com/bst/products/all_products/BSEC)).

ALL solution contains the same features as IAQ solution but also includes more complex ambient temperature and humidity estimation algorithms that will improve temperature and humidity performance in devices that contain many dynamic heat sources in their design. Such devices are, for example, smartphones containing displays, flashlights, large batteries and powerful microprocessors. As these advanced algorithms require tailoring to optimize them to a given customer design, please contact your local Bosch Sensortec representative for support.

The following table describes the available outputs of BSEC. Full descriptions of the outputs and the available interfaces are available in the integration guide shipped together with the BSEC software.

Table 14: BSEC outputs

| Output                               | Included in solution |     | Description  |
|--------------------------------------|----------------------|-----|--|
|                                      | IAQ                  | ALL |  |
| Raw pressure                         | ✓                    | ✓   | Raw data from sensor API bypassed to BSEC output   |
| Raw temperature                      | ✓                    | ✓   | Raw data from sensor API bypassed to BSEC output   |
| Raw relative humidity                | ✓                    | ✓   | Raw data from sensor API bypassed to BSEC output   |
| Raw gas resistance                   | ✓                    | ✓   | Raw data from sensor API bypassed to BSEC output   |
| Sensor-compensated temperature       | ✓                    | ✓   | Temperature which is compensated for internal cross-influences caused by the BME sensor                      |
| Sensor-compensated relative humidity | ✓                    | ✓   | Relative humidity which is compensated for internal cross-influences caused by the BME sensor                |
| Ambient temperature                  |                      | ✓   | Ambient temperature after compensating the influence of device (where BME680 is integrated in) heatsources   |
| Ambient relative humidity            |                      | ✓   | Ambient relative humidity after compensating influence of device (where BME680 is integrated in) heatsources |
| IAQ (0-500)                          | ✓                    | ✓   | Indoor-air-quality   |
| Accuracy status                      | ✓                    | ✓   | Accuracy status of IAQ, ambient tempature/humidity   |
| Stabilization time status            | ✓                    | ✓   | Indicates if the sensor is undergoing initial stabilization during its first use after production            |
| Run in status                        | ✓                    | ✓   | Indicates when the sensor is ready after after switch-on   |

## 4.2 Indoor-air-quality

BME680 is a metal oxide-based sensor that detects VOCs by adsorption (and subsequent oxidation/reduction) on its sensitive layer. Thus, BME680 reacts to most volatile compounds polluting indoor air (one exception is for instance CO<sub>2</sub>). In contrast to sensors selective for one specific component, BME680 is capable of measuring the sum of VOCs/contaminants in the surrounding air. This enables BME680 to detect e.g. outgassing from paint, furniture and/or garbage, high VOC levels due to cooking, food consumption, exhaled breath and/or sweating.

As a raw signal, BME680 will output resistance values and its changes due to varying VOC concentrations (the higher the concentration of reducing VOCs, the lower the resistance and vice versa). Since this raw signal is influenced by parameters other than VOC concentration (e.g. humidity level), the raw values are transformed to an indoor air quality (IAQ) index by smart algorithms inside BSEC.

The IAQ scale ranges from 0 (clean air) to 500 (heavily polluted air). During operation, the algorithms automatically calibrate and adapt themselves to the typical environments where the sensor is operated (e.g., home, workplace, inside a car, etc.). This automatic background calibration ensures that users experience consistent IAQ performance. The calibration process considers the recent measurement history (typ. up to four days) to ensure that IAQ ~ 25 corresponds to “typical good” air and IAQ ~ 250 indicates “typical polluted” air.

## 5. Global memory map and register description

### 5.1 General remarks

Communication with the device is performed by reading from and writing to registers. Registers have a width of 8 bits. If I<sup>2</sup>C is used, 8-bit addressing is utilized. If SPI is used, 7-bit address is only available for register access. For details on the interface, consult Chapter 6.

In SPI mode complete memory map is accessed using page 0 and page 1. Register *spi\_mem\_page* is used for page selection. After power-on, *spi\_mem\_page* is in its reset state and page 0 (0x80 to 0xFF) will be active. Page 1 (0x00 to 0x7F) will be active on setting *spi\_mem\_page* to 1.

Global memory map consists of calibration registers, control registers, data registers, status registers and reserved registers. There are, however, several registers which are reserved. Accordingly, they should not be written to and no specific value is guaranteed when they are read.

Table 15: Memory map page selection

| Digital Interface | Register address range | Register <i>spi_mem_page</i> | Memory Page    |
|-------------------|------------------------|------------------------------|----------------|
| I <sup>2</sup> C  | 0x00 to 0xFF           | Not Applicable               | Not Applicable |
| SPI               | 0x80 to 0xFF           | 0 (default; power on state)  | Page 0         |
| SPI               | 0x00 to 0x7F           | 1                            | Page 1         |



## 5.2 Memory map

The memory map is given in Table 16: Memory map Table 16, noting that not all reserved registers are depicted.

Table 16: Memory map

| Register name | I <sup>2</sup> C | SPI       |    | Bit 7                                    | Bit 6         | Bit 5       | Bit 4        | Bit 3                 | Bit 2       | Bit 1     | Bit 0     | Reset state |
|---------------|------------------|-----------|----|--|---------------|-------------|--------------|-----------------------|-------------|-----------|-----------|-------------|
|               | Adr              | Adr       | Pg |  |               |             |              |                       |             |           |           |             |
| status        | 73h              | 73h       | 1  |  |               |             | spi_mem_page |                       |             |           |           | 01h         |
| Reset         | E0h              | 60h       | 0  | reset<7:0>                               |               |             |              |                       |             |           |           | 00h         |
| Id            | D0h              | 50h       | 0  | chip_id<7:0>                             |               |             |              |                       |             |           |           | 61h         |
| Config        | 75h              | 75h       | 1  |  |               |             |              | filter<2:0>           |             |           | spi_3w_en | 00h         |
| Ctrl_meas     | 74h              | 74h       | 1  | osrs_t<2:0>                              |               |             | osrs_p<2:0>  |                       |             | mode<1:0> |           | 00h         |
| Ctrl_hum      | 72h              | 72h       | 1  |  | spi_3w_int_en |             |              |                       | osrs_h<2:0> |           |           | 00h         |
| Ctrl_gas_1    | 71h              | 71h       | 1  |  |               |             | run_gas      | nb_conv<3:0>          |             |           |           | 00h         |
| Ctrl_gas_0    | 70h              | 70h       | 1  |  |               |             |              | heat_off              |             |           |           | 00h         |
| Gas_wait_x    | 6Dh...64h        | 6Dh...64h | 1  | gas_wait_9<7:0> downto gas_wait_0<7:0>   |               |             |              |                       |             |           |           | 00h         |
| Res_heat_x    | 63h...5Ah        | 63h...5Ah | 1  | res_heat_9<7:0> downto res_heat_0<7:0>   |               |             |              |                       |             |           |           | 00h         |
| Idac_heat_x   | 59h...50h        | 59h...50h | 1  | idac_heat_9<7:0> downto idac_heat_0<7:0> |               |             |              |                       |             |           |           | 00h         |
| gas_r_lsb     | 2Bh              | 2Bh       | 1  | gas_r<1:0>                               | gas_valid_r   | heat_stab_r | gas_range_r  |                       |             |           |           | 00h         |
| gas_r_msb     | 2Ah              | 2Ah       | 1  | gas_r<9:2>                               |               |             |              |                       |             |           |           | 00h         |
| hum_lsb       | 26h              | 26h       | 1  | hum_lsb<7:0>                             |               |             |              |                       |             |           |           | 00h         |
| hum_msb       | 25h              | 25h       | 1  | hum_msb<7:0>                             |               |             |              |                       |             |           |           | 80h         |
| temp_xlsb     | 24h              | 24h       | 1  | temp_xlsb<7:4>                           |               |             |              | 0                     | 0           | 0         | 0         | 00h         |
| temp_lsb      | 23h              | 23h       | 1  | temp_lsb<7:0>                            |               |             |              |                       |             |           |           | 00h         |
| temp_msb      | 22h              | 22h       | 1  | temp_msb<7:0>                            |               |             |              |                       |             |           |           | 80h         |
| press_xlsb    | 21h              | 21h       | 1  | press_xlsb<7:4>                          |               |             |              | 0                     | 0           | 0         | 0         | 00h         |
| press_lsb     | 20h              | 20h       | 1  | press_lsb<7:0>                           |               |             |              |                       |             |           |           | 00h         |
| press_msb     | 1Fh              | 1Fh       | 1  | press_msb<7:0>                           |               |             |              |                       |             |           |           | 80h         |
| eas_status_0  | 1Dh              | 1Dh       | 1  | new_data_0                               | gas_measuring | measuring   |              | gas_meas_index_0<3:0> |             |           |           | 00h         |

| Registers        | Color/Type    |
|------------------|---------------|
| Reserved         | Do not change |
| Status register  | Read only     |
| Data register    | Read only     |
| Control register | Read/write    |

## 5.3 Register description

### 5.3.1 General control registers

#### 5.3.1.1 SPI 3 wire interrupt enable – *spi\_3w\_int\_en*

| Register Name | Address | Content<bit position> | Description  |
|---------------|---------|-----------------------|--|
| ctrl_hum      | 0x72    | spi_3w_int_en <6>     | New data interrupt can be enabled if the device is in SPI 3 wire mode and <i>pi_3w_int_en=1</i> . The new data interrupt is then indicated on the SDO pad. |

#### 5.3.1.2 SPI 3 wire enable – *spi\_3w\_en*

| Register Name | Address | Content<bit position> | Description            |
|---------------|---------|-----------------------|------------------------|
| config        | 0x75    | spi_3w_en<0>          | Enable SPI 3 wire mode |

#### 5.3.1.3 Mode Selection – *mode*

The operation modes of the sensor can be controlled by the register mode as specified below.

| Register Name | Address | Content<bit position> | Description  |
|---------------|---------|-----------------------|--|
| ctrl_meas     | 0x74    | mode<1:0>             | Select sensor power mode as shown in the following table |

| mode<1:0> | Mode        |
|-----------|-------------|
| 00        | Sleep mode  |
| 01        | Forced mode |

#### 5.3.1.4 SPI memory map page selection – *spi\_mem\_page*

In SPI mode complete memory page is accessed using page 0 & page 1. Register *spi\_mem\_page* is used for page selection. After power-on, *spi\_mem\_page* is in its reset state and page 0(0x00 to 0x7F) will be active. Page1 (0x7F to 0xFF) will be active on setting *spi\_mem\_page*. Please refer Table 15 for better understanding.

| Register Name | Address        | Content<bit position> | Description                         |
|---------------|----------------|-----------------------|-------------------------------------|
| status        | 0x73(Page 0/1) | spi_mem_page <4>      | Selects memory map page in SPI mode |

### 5.3.1.5 Reset – reset

Writing 0xB6 to this register initiates a soft-reset procedure, which has the same effect like power-on reset. The default value stored in this register is 0x00.

| Register Name | Address   | Content<bit position> | Description       |
|---------------|---|-----------------------|-------------------|
| reset         | 0x60 (Page 0 in SPI mode)<br>0xE0 in I <sup>2</sup> C | reset<7:0>            | Resets the device |

### 5.3.1.6 Chip id – chip\_id

| Register Name | Address  | Content<bit position> | Description           |
|---------------|--|-----------------------|-----------------------|
| Id            | 0x50(Page 0 in SPI mode)<br>0xD0 in I <sup>2</sup> C | chip_id<7:0>          | Chip id of the device |

## 5.3.2 Temperature, pressure and relative humidity control registers

### 5.3.2.1 Humidity sensor over sampling control – osrs\_h

| Register Name | Address | Content<bit position> | Description   |
|---------------|---------|-----------------------|---|
| ctrl_hum      | 0x72    | osrs_h<2:0>           | Controls over sampling setting of humidity sensor as described in the following table |

| osrs_h<2:0> | Humidity oversampling          |
|-------------|--------------------------------|
| 000         | Skipped (output set to 0x8000) |
| 001         | oversampling ×1                |
| 010         | oversampling ×2                |
| 011         | oversampling ×4                |
| 100         | oversampling ×8                |
| 101, Others | oversampling ×16               |

### 5.3.2.2 Over sampling setting – Temperature data – osrs\_t

| Register Name | Address | Content<bit position> | Description   |
|---------------|---------|-----------------------|---|
| ctrl_meas     | 0x74    | osrs_t<7:5>           | Temperature oversampling settings as shown in the following table |

| osrs_t<2:0> | Temperature oversampling       |
|-------------|--------------------------------|
| 000         | Skipped (output set to 0x8000) |
| 001         | oversampling ×1                |
| 010         | oversampling ×2                |
| 011         | oversampling ×4                |
| 100         | oversampling ×8                |
| 101, Others | oversampling ×16               |

5.3.2.3 Over sampling setting – Pressure data – *osrs\_p*

| Register Name | Address | Content<bit position> | Description  |
|---------------|---------|-----------------------|--|
| ctrl_meas     | 0x74    | osrs_p<4:2>           | Pressure oversampling settings as shown in the following table |

| osrs_p<2:0> | Pressure oversampling          |
|-------------|--------------------------------|
| 000         | Skipped (output set to 0x8000) |
| 001         | oversampling ×1                |
| 010         | oversampling ×2                |
| 011         | oversampling ×4                |
| 100         | oversampling ×8                |
| 101, Others | oversampling ×16               |

5.3.2.4 IIR filter control – *filter*

IIR filter applies to temperature and pressure data but not to humidity and gas data. The data coming from the ADC are filtered and then loaded into the data registers. The temperature and pressure result registers are updated together at the same time at the end of the measurement. IIR filter output resolution is 20 bits. The result registers are reset to value 0x80000 when the temperature and/or pressure measurements have been skipped (*osrs\_x*="000"). The appropriate filter memory is kept unchanged (the value from the last measurement is kept). When the appropriate OSRS register is set back to nonzero, then the first value stored to the result registers are filtered.

| Register Name | Address | Content<bit position> | Description   |
|---------------|---------|-----------------------|---|
| config        | 0x75    | filter<4:2>           | IIR filter settings as shown in the following table |

| filter<2:0> | Filter coefficient |
|-------------|--------------------|
| 000         | 0                  |
| 001         | 1                  |
| 010         | 3                  |
| 011         | 7                  |
| 100         | 15                 |
| 101         | 31                 |
| 110         | 63                 |
| 111         | 127                |

### 5.3.3 Gas control registers

The sensor can have 10 programmable gas sensor heater set-points. A set-point consists of a target heater resistance, heater-on time and optionally an initial heater current.

#### 5.3.3.1 Heater current - *idac\_heat\_x*

BME680 contains a heater control block that will inject enough current into the heater resistance to achieve the requested heater temperature. There is a control loop which periodically measures heater resistance value and adapts the value of current injected from a DAC.

The heater operation could be speeded up by setting an initial heater current for a target heater temperature by using register *idac\_heat\_x<7:0>*. This step is optional since the control loop will find the current after a few iterations anyway. The current injected to the heater in mA can be calculated by:  $(idac\_heat\_7\_1 + 1) / 8$ , where *idac\_heat\_7\_1* is the decimal value stored in *idac\_heat<7:1>* (unsigned, value from 0 to 127).

| Heater set-point | Register name                                 | Address     | Content  | Description                                     |
|------------------|---|-------------|--|---|
| 0...9            | <i>idac_heat_x</i><br><i>x is from 0 to 9</i> | 0x50...0x59 | <i>idac_heat_x&lt;7:0&gt;</i><br><i>x is from 0 to 9</i> | <i>idac_heat</i> of particular heater set point |

#### 5.3.3.2 Target heater resistance - *res\_heat\_x*

Target heater resistance is programmed by user through *res\_heat\_x<7:0>* registers. The definition of *res\_heat\_x* is given in Section 3.3.5.

| Heater set-point | Register name                                | Address     | Content   | Description  |
|------------------|--|-------------|---|--|
| 0...9            | <i>res_wait_x</i><br><i>x is from 0 to 9</i> | 0x5A...0x63 | <i>res_heat_x&lt;7:0&gt;</i><br><i>x is from 0 to 9</i> | Decimal value that needs to be stored for achieving target heater resistance |

5.3.3.3 Gas Sensor wait time - gas\_wait\_x

Referring to Figure 1, the time between the beginning of the heat phase and the start of gas sensor resistance conversion depends on gas\_wait\_x setting as mentioned below.

| Heater set-point | Register name                  | Address     | Content                             | Description   |
|------------------|--------------------------------|-------------|-------------------------------------|---|
| 0...9            | gas_wait_x<br>x is from 0 to 9 | 0x64...0x6D | gas_wait_x<5:0><br>x is from 0 to 9 | 64 timer values with 1 ms step sizes, all zeros means no wait |
| 0...9            | gas_wait_x<br>x is from 0 to 9 | 0x64...0x6D | gas_wait_x<7:6><br>x is from 0 to 9 | Please refer to the table below for settings                  |

| gas_wait_x<7:6> | Gas sensor wait time multiplication factor |
|-----------------|--|
| 00              | 1  |
| 01              | 4  |
| 10              | 16   |
| 11              | 64   |

5.3.3.4 Heater off - heat\_off

| Register Name | Address | Content<bit position> | Description   |
|---------------|---------|-----------------------|---|
| ctrl_gas_0    | 0x70    | heat_off <3>          | Turn off current injected to heater by setting bit to one |

### 5.3.3.5 Heater profile selection - *nb\_conv*

*nb\_conv* is used to select heater set-points of the sensor. The different heater set-points are described in the sections above.

| Register Name | Address | Content<bit position> | Description   |
|---------------|---------|-----------------------|---|
| ctrl_gas_1    | 0x71    | nb_conv<3:0>          | Indicates index of heater set point that will be used in forced mode as describe in below table |

| nb_conv<3:0> | Heater profile set-point |
|--------------|--------------------------|
| 0000         | 0                        |
| 0001         | 1                        |
| 0010         | 2                        |
| 0011         | 3                        |
| 0100         | 4                        |
| 0101         | 5                        |
| 0110         | 6                        |
| 0111         | 7                        |
| 1000         | 8                        |
| 1001         | 9                        |

### 5.3.3.6 Run Gas - *run\_gas*

| Register Name | Address | Content<bit position> | Description   |
|---------------|---------|-----------------------|---|
| ctrl_gas_1    | 0x71    | run_gas<4>            | The gas conversions are started only in appropriate mode if run_gas = '1' |

### 5.3.4 Data registers

In this section, the data registers for the temperature, pressure, humidity and gas sensors are explained. Shadowing registers are utilized to buffer the data and to ensure stable data in case an update of the data registers occurs simultaneously with the serial interface reading out.

#### 5.3.4.1 Pressure data

| Register Name | Address | Content<bit position> | Description  |
|---------------|---------|-----------------------|--|
| press_msb     | 0x1F    | press_msb<7:0>        | Contains the MSB part [19:12] of the raw pressure measurement output data.   |
| press_lsb     | 0x20    | press_lsb<7:0>        | Contains the LSB part [11:4] of the raw pressure measurement output data   |
| press_xlsb    | 0x21    | press_xlsb<7:4>       | Contains the XLSB part [3:0] of the raw pressure measurement output data. Contents depend on pressure resolution controlled by oversampling setting. |

#### 5.3.4.2 Temp data

| Register Name | Address | Content<bit position> | Description  |
|---------------|---------|-----------------------|--|
| temp_msb      | 0x22    | temp_msb<7:0>         | Contains the MSB part [19:12] of the raw temperature measurement output data.  |
| temp_lsb      | 0x23    | temp_lsb<7:0>         | Contains the LSB part [11:4] of the raw temperature measurement output data.   |
| temp_xlsb     | 0x24    | temp_xlsb<7:4>        | Contains the XLSB part [3:0] of the raw temperature measurement output data. Contents depend on temperature resolution controlled by oversampling setting. |

#### 5.3.4.3 Humidity data

| Register Name | Address | Content<bit position> | Description   |
|---------------|---------|-----------------------|---|
| hum_msb       | 0x25    | hum_msb<7:0>          | Contains the MSB part [15:8] of the raw humidity measurement output data. |
| hum_lsb       | 0x26    | hum_lsb<7:0>          | Contains the LSB part [7:0] of the raw humidity measurement output data.  |

#### 5.3.4.4 Gas resistance data

| Register Name | Address | Content<bit position> | Description   |
|---------------|---------|-----------------------|---|
| gas_r_msb     | 0x2A    | gas_r<7:0>            | Contains the MSB part gas resistance [9:2] of the raw gas resistance. |
| gas_r_lsb     | 0x2B    | gas_r<7:6>            | Contains the LSB part gas resistance [1:0] of the raw gas resistance. |

#### 5.3.4.5 Gas resistance range

| Register Name | Address | Content<bit position> | Description                                    |
|---------------|---------|-----------------------|--|
| gas_r_lsb     | 0x2B    | gas_range_r<3:0>      | Contains ADC range of measured gas resistance. |



## 5.3.5 Status registers

### 5.3.5.1 New data status

The measured data are stored into the output data registers at the end of each TPHG conversion phase along with status flags and index of measurement.

| Register Name | Address | Content<bit position> | Description   |
|---------------|---------|-----------------------|---------------|
| meas_status_0 | 0x1D    | new_data_0<7>         | New data flag |

### 5.3.5.2 Gas measuring status

Measuring bit is set to “1” only during gas measurements, goes to “0” as soon as measurement is completed and data transferred to data registers. The registers storing the configuration values for the measurement (*gas\_wait\_shared*, *gas\_wait\_x*, *res\_heat\_x*, *idac\_heat\_x*, image registers) should not be changed when the device is measuring.

| Register Name | Address | Content<bit position> | Description               |
|---------------|---------|-----------------------|---------------------------|
| meas_status_0 | 0x1D    | gas_measuring<6>      | Gas measuring status flag |

### 5.3.5.3 Measuring status

Measuring status will be set to ‘1’ whenever a conversion (temperature, pressure, humidity and gas) is running and back to ‘0’ when the results have been transferred to the data registers.

| Register Name | Address | Content<bit position> | Description           |
|---------------|---------|-----------------------|-----------------------|
| meas_status_0 | 0x1D    | measuring<5>          | Measuring status flag |

### 5.3.5.4 Gas Measurement Index

User can program a sequence of up to 10 conversions by setting *nb\_conv*<3:0>. Each conversion has its own heater resistance target but 3 field registers to store conversion results. The actual gas conversion number in the measurement sequence (up to 10 conversions numbered from 0 to 9) is stored in *gas\_meas\_index* register.

| Register Name | Address | Content<bit position> | Description           |
|---------------|---------|-----------------------|-----------------------|
| meas_status_0 | 0x1D    | gas_meas_index_0<3:0> | Gas measurement index |

#### 5.3.5.5 Gas valid status

In each TPHG sequence contains a gas measurement slot, either a real one which result is used or a dummy one to keep a constant sampling rate and predictable device timing. A real gas conversion (i.e., not a dummy one) is indicated by the *gas\_valid\_r* status register.

| Register Name | Address | Content<bit position> | Description   |
|---------------|---------|-----------------------|---------------|
| gas_r_lsb     | 0x2B    | gas_valid_r<5>        | Gas valid bit |

#### 5.3.5.6 Heater Stability Status

Heater temperature stability for target heater resistance is indicated *heat\_stab\_x* status bits.

| Register Name | Address | Content<bit position> | Description          |
|---------------|---------|-----------------------|----------------------|
| gas_r_lsb     | 0x2B    | heat_stab_r<4>        | Heater stability bit |

## 6. Digital interfaces

The sensor supports the I<sup>2</sup>C and SPI digital interfaces, where it acts as a slave for both protocols. The I<sup>2</sup>C interface supports the Standard, Fast and High Speed modes. The SPI interface supports both SPI mode '00' (CPOL = CPHA = '0') and mode '11' (CPOL = CPHA = '1') in 4-wire and 3-wire configuration.

The following transactions are supported:

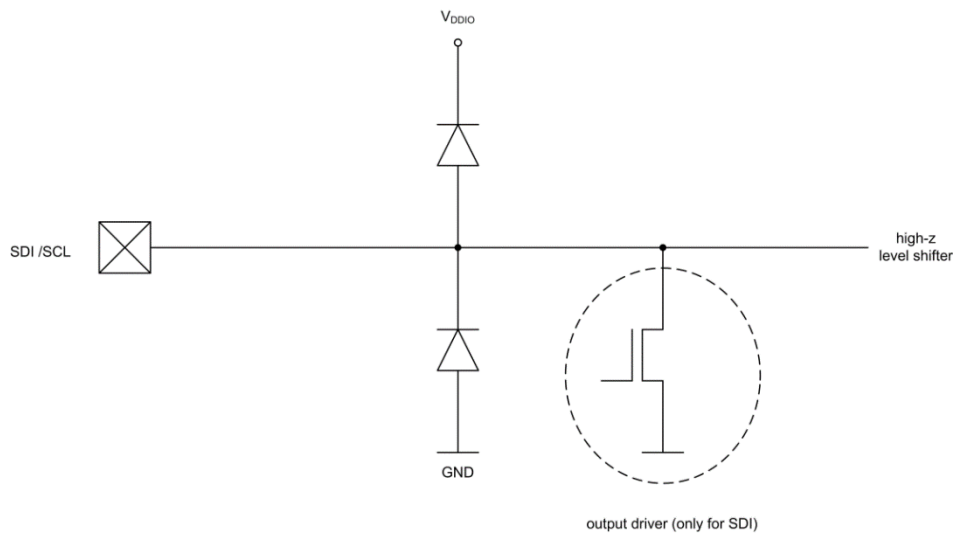
- Single byte write
- multiple byte write (using pairs of register addresses and register data)
- single byte read
- multiple byte read (using a single register address which is auto-incremented)

### 6.1 Interface selection

Interface selection is done automatically based on CSB (chip select) status. If CSB is connected to V<sub>DDIO</sub>, the I<sup>2</sup>C interface is active. If CSB is pulled down, the SPI interface is activated. After CSB has been pulled down once (regardless of whether any clock cycle occurred), the I<sup>2</sup>C interface is disabled until the next power-on-reset. This is done in order to avoid inadvertently decoding SPI traffic to another slave as I<sup>2</sup>C data. Since the device startup is deferred until both V<sub>DD</sub> and V<sub>DDIO</sub> are established, there is no risk of incorrect protocol detection because of the power-up sequence used. However, if I<sup>2</sup>C is to be used and CSB is not directly connected to V<sub>DDIO</sub> but is instead connected to a programmable pin, it must be ensured that this pin already outputs the V<sub>DDIO</sub> level during power-on-reset of the device. If this is not the case, the device will be locked in SPI mode and not respond to I<sup>2</sup>C commands.

### 6.2 I<sup>2</sup>C Interface

For detailed timings, please review Table 18 . All modes (standard, fast, high speed) are supported. SDA and SCL are not pure open-drain. Both pads contain ESD protection diodes to V<sub>DDIO</sub> and GND. As the device does not perform clock stretching, the SCL structure is a high-Z input without drain capability.



Picture 3: SDI/SCK ESD schematic

The 7-bit device address is 111011x. The 6 MSB bits are fixed. The last bit is changeable by SDO value and can be changed during operation. Connecting SDO to GND results in slave address 1110110 (0x76); connection it to V<sub>DDIO</sub> results in slave address 1110111 (0x77), which is the same as BMP280's I<sup>2</sup>C address. The SDO pin cannot be left floating; if left floating, the I<sup>2</sup>C address will be undefined.

The I<sup>2</sup>C interface uses the following pins:

- SCK: serial clock (SCL)
- SDI: data (SDA)
- SDO: Slave address LSB (GND = '0', V<sub>DDIO</sub> = '1')

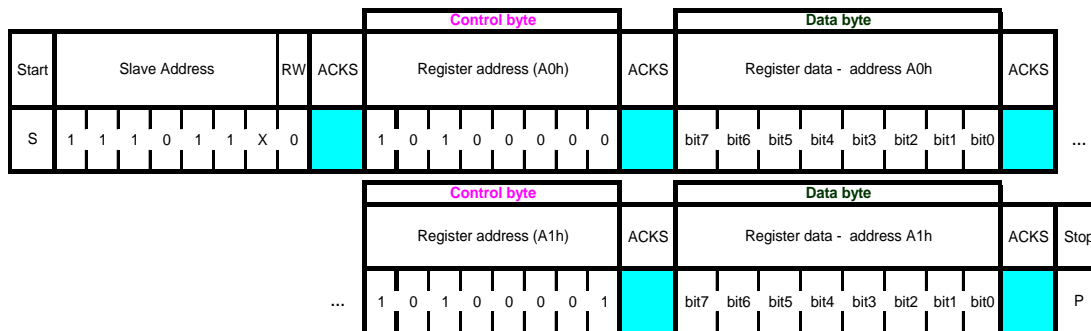
CSB must be connected to V<sub>DDIO</sub> to select I<sup>2</sup>C interface. SDI is bi-directional with open drain to GND: it must be externally connected to V<sub>DDIO</sub> via a pull up resistor. Refer to Chapter 7 for connection instructions.

The following abbreviations will be used in the I<sup>2</sup>C protocol figures:

- S Start
- P Stop
- ACKS Acknowledge by slave
- ACKM Acknowledge by master
- NACKM Not acknowledge by master

### 6.2.1 I<sup>2</sup>C write

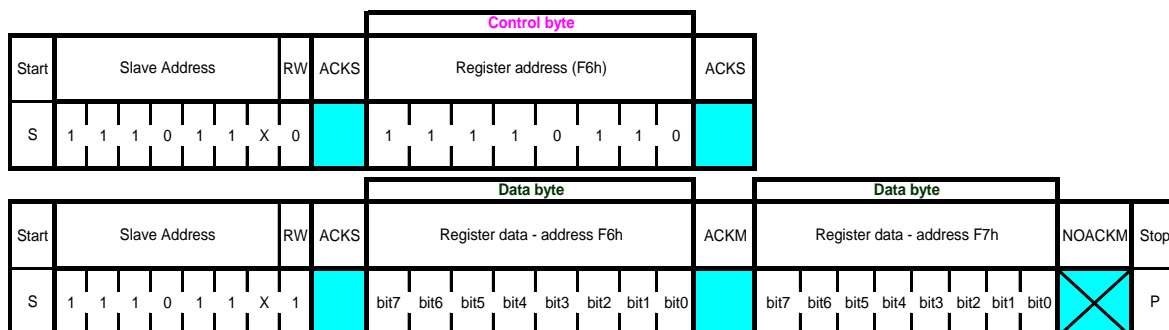
Writing is done by sending the slave address in write mode (RW = '0'), resulting in slave address 111011X0 ('X' is determined by state of SDO pin). Then the master sends pairs of register addresses and register data. The transaction is ended by a stop condition. This is depicted in Picture 4.



Picture 4: I<sup>2</sup>C multiple byte write (not auto-incremented)

### 6.2.2 I<sup>2</sup>C read

To be able to read registers, first the register address must be sent in write mode (slave address 111011X0). Then either a stop or a repeated start condition must be generated. After this the slave is addressed in read mode (RW = '1') at address 111011X1, after which the slave sends out data from auto-incremented register addresses until a NOACKM and stop condition occurs. This is depicted in Picture 5, where register 0xF6 and 0xF7 are read.



Picture 5: I<sup>2</sup>C multiple byte read

### 6.3 SPI interface

The SPI interface is compatible with SPI mode '00' (CPOL = CPHA = '0') and mode '11' (CPOL = CPHA = '1'). The automatic selection between mode '00' and '11' is determined by the value of SCK after the CSB falling edge.

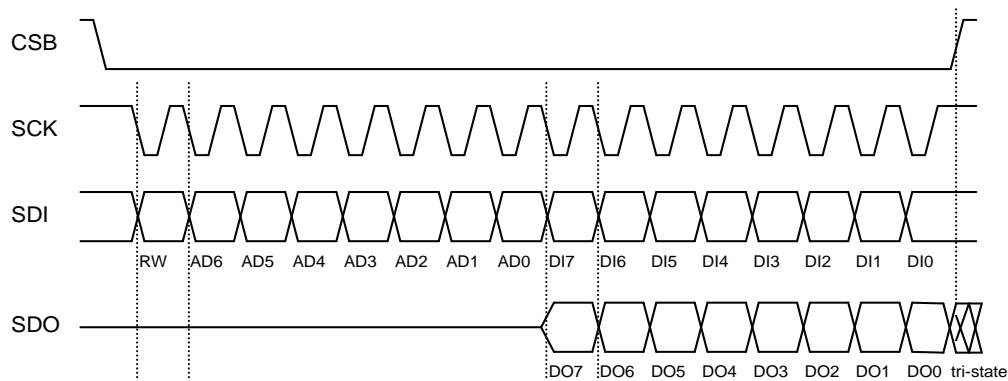
The SPI interface has two modes, namely 4-wire and 3-wire mode. However, the protocol is the same for both. The 3-wire mode is selected by setting '1' to the register spi3w\_en. The pad SDI is used as a data pad in 3-wire mode.

The SPI interface uses the following pins:

- CSB: chip select, active low
- SCK: serial clock
- SDI: serial data input; data input/output in 3-wire mode
- SDO: serial data output; hi-Z in 3-wire mode

For more connection instructions, please refer to Chapter 7.

CSB is active low and has an integrated pull-up resistor. Data on SDI is latched by the device at SCK rising edge and SDO is changed at SCK falling edge. Communication starts when CSB goes to low and stops when CSB goes to high; during these transitions on CSB, SCK must be stable. The SPI protocol is shown in It is important to note that Picture 6. For timing details, please review Table 19.

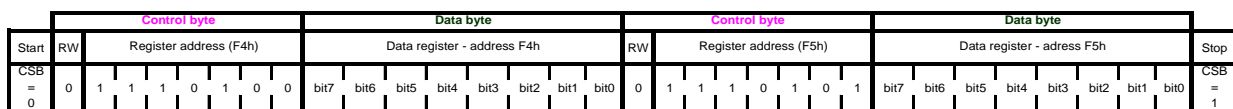


Picture 6: SPI protocol (shown for mode '11' in 4-wire configuration)

It is important to note that in the SPI mode, only 7 bits of the register addresses are used; the MSB of register address is not used and replaced by a read/write bit (RW = '0' for write and RW = '1' for read). For example, address 0xF7 is accessed by using SPI register address 0x77. On the one hand, the byte 0xF7 is transferred for write access, and on the other hand, the byte 0xF7 is transferred for read access.

#### 6.3.1 SPI write

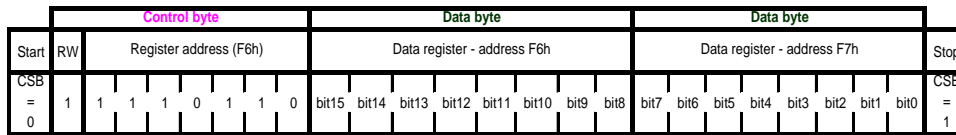
Writing is done by lowering CSB and sending pairs control bytes and register data. The control bytes consist of the SPI register address (= full register address without bit 7) and the write command (bit7 = RW = '0'). Several pairs can be written without raising CSB. The transaction is ended by a raising CSB. The SPI write protocol is depicted in Picture 7.



Picture 7: SPI multiple byte write (not auto-incremented)

### 6.3.2 SPI read

Reading is done by lowering CSB and first sending one control byte. The control bytes consist of the SPI register address (= full register address without bit 7) and the read command (bit 7 = RW = '1'). After writing the control byte, data is sent out of the SDO pin (SDI in 3-wire mode); the register address is automatically incremented. The SPI read protocol is depicted in Picture 8.



Picture 8: SPI multiple byte read

## 6.4 Interface parameter specification

### 6.4.1 General interface parameters

Table 17: Interface parameters

| Parameter                           | Symbol                  | Condition   | Min | Typ | Max | Unit               |
|-------------------------------------|-------------------------|---|-----|-----|-----|--------------------|
| Input low level                     | V <sub>il_si</sub>      | V <sub>DDIO</sub> =1.2 V to 3.6 V                           |     |     | 20  | %V <sub>DDIO</sub> |
| Input high level                    | V <sub>ih_si</sub>      | V <sub>DDIO</sub> =1.2 V to 3.6 V                           | 80  |     |     | %V <sub>DDIO</sub> |
| Output low level I <sup>2</sup> C   | V <sub>ol_SDI</sub>     | V <sub>DDIO</sub> =1.62 V, I <sub>ol</sub> =3 mA            |     |     | 20  | %V <sub>DDIO</sub> |
| Output low level I <sup>2</sup> C   | V <sub>ol_SDI_1.2</sub> | V <sub>DDIO</sub> =1.20 V, I <sub>ol</sub> =3 mA            |     |     | 23  | %V <sub>DDIO</sub> |
| Output low level SPI                | V <sub>ol_SDO</sub>     | V <sub>DDIO</sub> =1.62 V, I <sub>ol</sub> =1 mA            |     |     | 20  | %V <sub>DDIO</sub> |
| Output low level SPI                | V <sub>ol_SDO_1.2</sub> | V <sub>DDIO</sub> =1.20 V, I <sub>ol</sub> =1 mA            |     |     | 23  | %V <sub>DDIO</sub> |
| Output high level                   | V <sub>oh</sub>         | V <sub>DDIO</sub> =1.62 V, I <sub>oh</sub> =1 mA (SDO, SDI) | 80  |     |     | %V <sub>DDIO</sub> |
| Output high level                   | V <sub>oh_1.2</sub>     | V <sub>DDIO</sub> =1.20 V, I <sub>oh</sub> =1 mA (SDO, SDI) | 60  |     |     | %V <sub>DDIO</sub> |
| Pull-up resistor                    | R <sub>pull</sub>       | Internal CSB pull-up resistor to V <sub>DDIO</sub>          | 70  | 120 | 190 | kΩ                 |
| I <sup>2</sup> C bus load capacitor | C <sub>b</sub>          | On SDI and SCK  |     |     | 400 | pF                 |

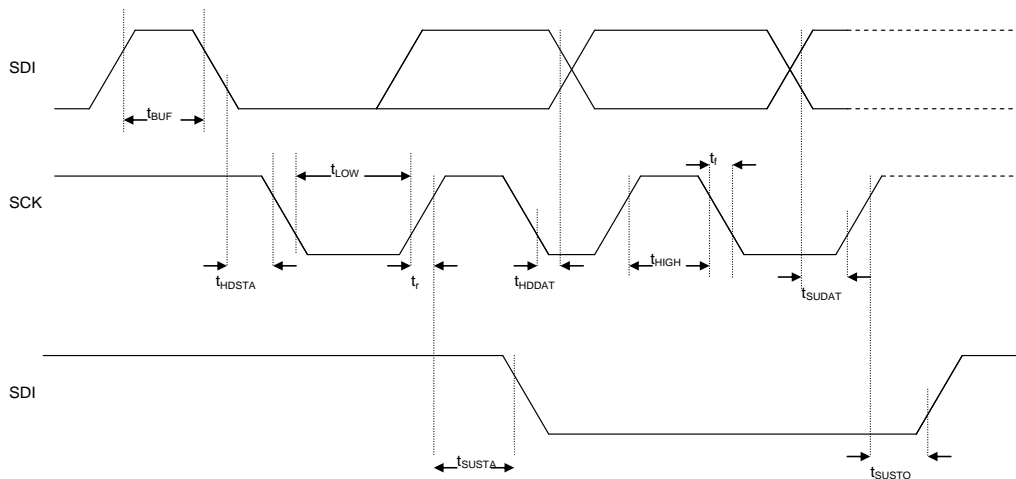
### 6.4.2 I<sup>2</sup>C timings

For I<sup>2</sup>C timings, the following abbreviations are used:

- “S&F mode” = standard and fast mode
- “HS mode” = high speed mode
- C<sub>b</sub> = bus capacitance on SDA line

All other naming refers to I<sup>2</sup>C specification 2.1 (January 2000).

The I<sup>2</sup>C timing diagram is in Picture 9. The corresponding values are given in Table 18



Picture 9: I<sup>2</sup>C timing diagram

Table 18: I<sup>2</sup>C timings

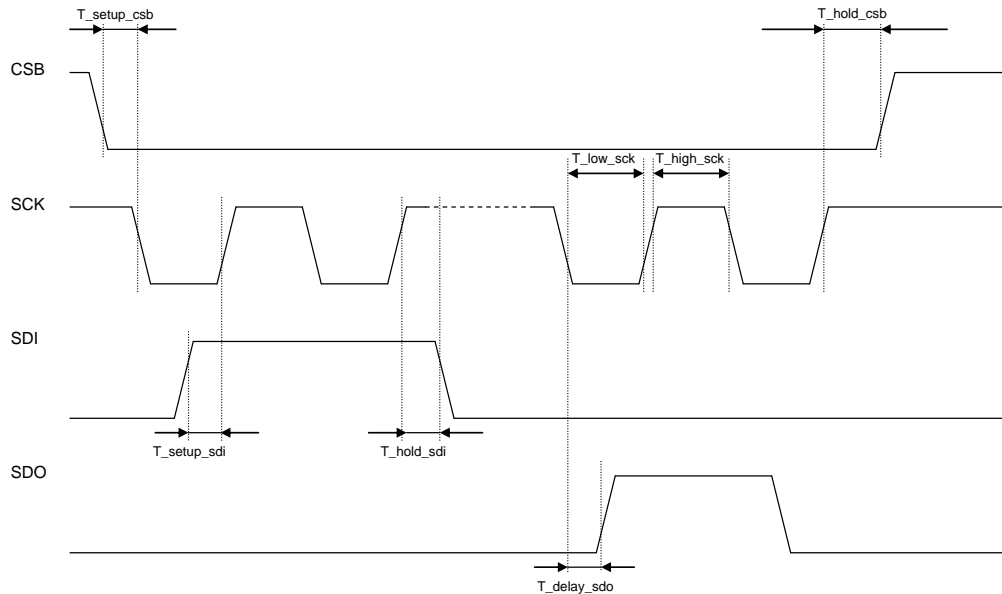
| Parameter      | Symbol              | Condition   | Min | Typ | Max | Unit |
|----------------|---------------------|---|-----|-----|-----|------|
| SDI setup time | t <sub>SU;DAT</sub> | S&F Mode  | 160 |     |     | ns   |
|                |                     | HS mode   | 30  |     |     | ns   |
| SDI hold time  | t <sub>HD;DAT</sub> | S&F Mode, C <sub>b</sub> ≤100 pF                              | 80  |     |     | ns   |
|                |                     | S&F Mode, C <sub>b</sub> ≤400 pF                              | 90  |     |     | ns   |
|                |                     | HS mode, C <sub>b</sub> ≤100 pF                               | 18  |     | 115 | ns   |
|                |                     | HS mode, C <sub>b</sub> ≤400 pF                               | 24  |     | 150 | ns   |
| SCK low pulse  | t <sub>LOW</sub>    | HS mode, C <sub>b</sub> ≤100 pF<br>V <sub>DDIO</sub> = 1.62 V | 160 |     |     | ns   |
| SCK low pulse  | t <sub>LOW</sub>    | HS mode, C <sub>b</sub> ≤100 pF<br>V <sub>DDIO</sub> = 1.2 V  | 210 |     |     | ns   |

The above-mentioned I<sup>2</sup>C specific timings correspond to the following internal added delays:

- Input delay between SDI and SCK inputs: SDI is more delayed than SCK by typically 100 ns in Standard and Fast Modes and by typically 20 ns in High Speed Mode.
- Output delay from SCK falling edge to SDI output propagation is typically 140 ns in Standard and Fast Modes and typically 70 ns in High Speed Mode.

### 6.4.3 SPI timings

The SPI timing diagram is in Picture 10, while the corresponding values are given in Table 19. All timings apply both to 4- and 3-wire SPI.



Picture 10: SPI timing diagram

Table 19: SPI timings

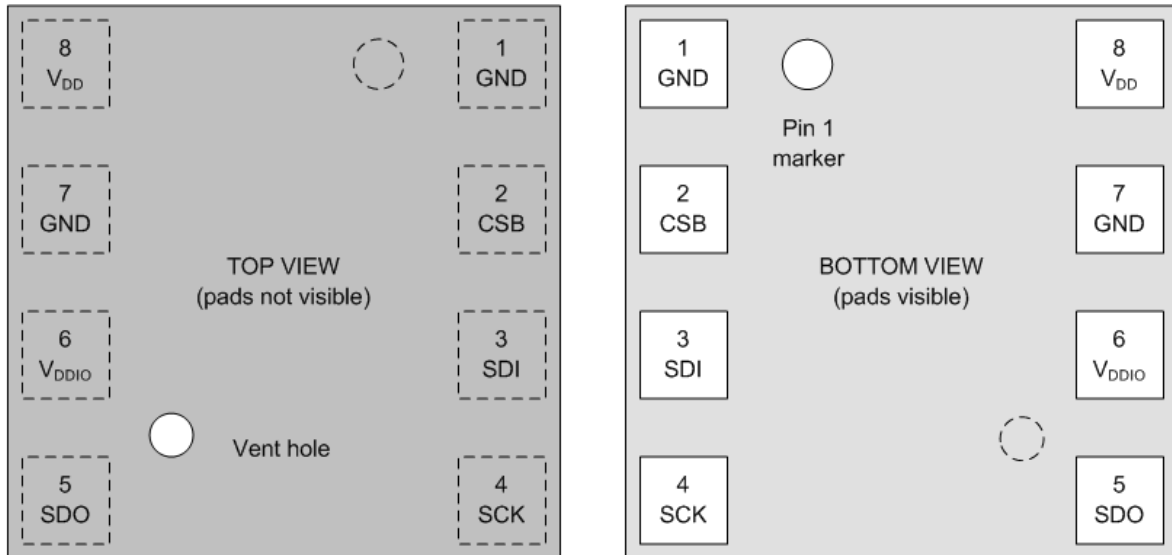
| Parameter                 | Symbol      | Condition                                | Min | Typ | Max | Unit |
|---------------------------|-------------|--|-----|-----|-----|------|
| SPI clock i/p frequency   | F_spi       |  | 0   |     | 10  | MHz  |
| SCK low pulse             | T_low_sck   |  | 20  |     |     | ns   |
| SCK high pulse            | T_high_sck  |  | 20  |     |     | ns   |
| SDI setup time            | T_setup_sdi |  | 20  |     |     | ns   |
| SDI hold time             | T_hold_sdi  |  | 20  |     |     | ns   |
| SDO output delay          | T_delay_sdo | 25 pF load, V <sub>DDIO</sub> =1.6 V min |     |     | 30  | ns   |
| SDO output delay          | T_delay_sdo | 25 pF load, V <sub>DDIO</sub> =1.2 V min |     |     | 40  | ns   |
| CSB setup time            | T_setup_csb |  | 20  |     |     | ns   |
| CSB hold time             | T_hold_csb  |  | 20  |     |     | ns   |
| SPI clock input frequency | F_spi       |  | 0   |     | 10  | MHz  |



## 7. Pin-out and connection diagram

### 7.1 Pin-out

The pin numbering of BME680 is performed in the untypical clockwise direction when seen in top view and counter-clockwise when seen in bottom view. Picture 11 and Table 20 give a detailed description and illustration of the input/output pins.



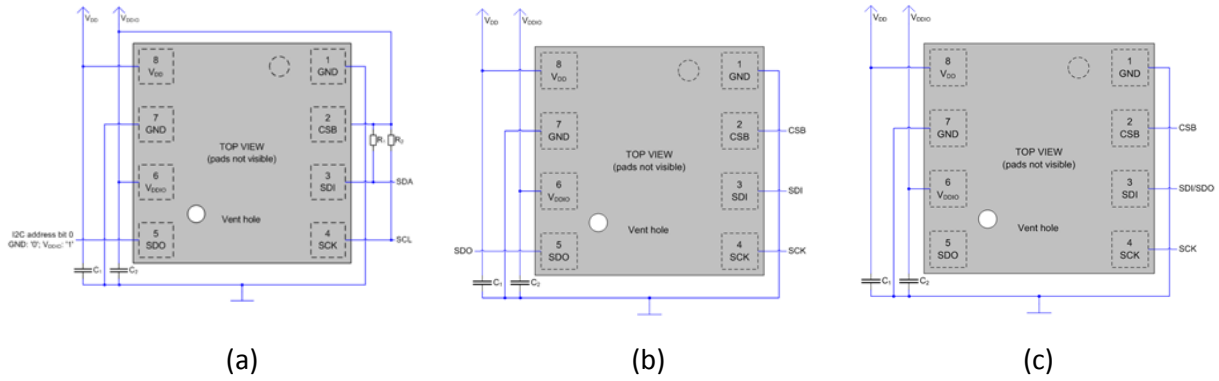
Picture 11: Top (left) and bottom (right) views of the chip with input/output pins

Table 20: Pin description

| Pin | Name              | I/O type | Description                | Connection        |         |                         |
|-----|-------------------|----------|----------------------------|-------------------|---------|-------------------------|
|     |                   |          |                            | SPI 4W            | SPI 3W  | I <sup>2</sup> C        |
| 1   | GND               | Supply   | Ground                     | GND               |         |                         |
| 2   | CSB               | In       | Chip select                | CSB               | CSB     | V <sub>DDIO</sub>       |
| 3   | SDI               | In/Out   | Serial data input          | SDI               | SDI/SDO | SDA                     |
| 4   | SCK               | In       | Serial clock input         | SCK               | SCK     | SCL                     |
| 5   | SDO               | In/Out   | Serial data output         | SDO               | DNC     | GND for default address |
| 6   | V <sub>DDIO</sub> | Supply   | Digital / Interface supply | V <sub>DDIO</sub> |         |                         |
| 7   | GND               | Supply   | Ground                     | GND               |         |                         |
| 8   | V <sub>DD</sub>   | Supply   | Analog supply              | V <sub>DD</sub>   |         |                         |

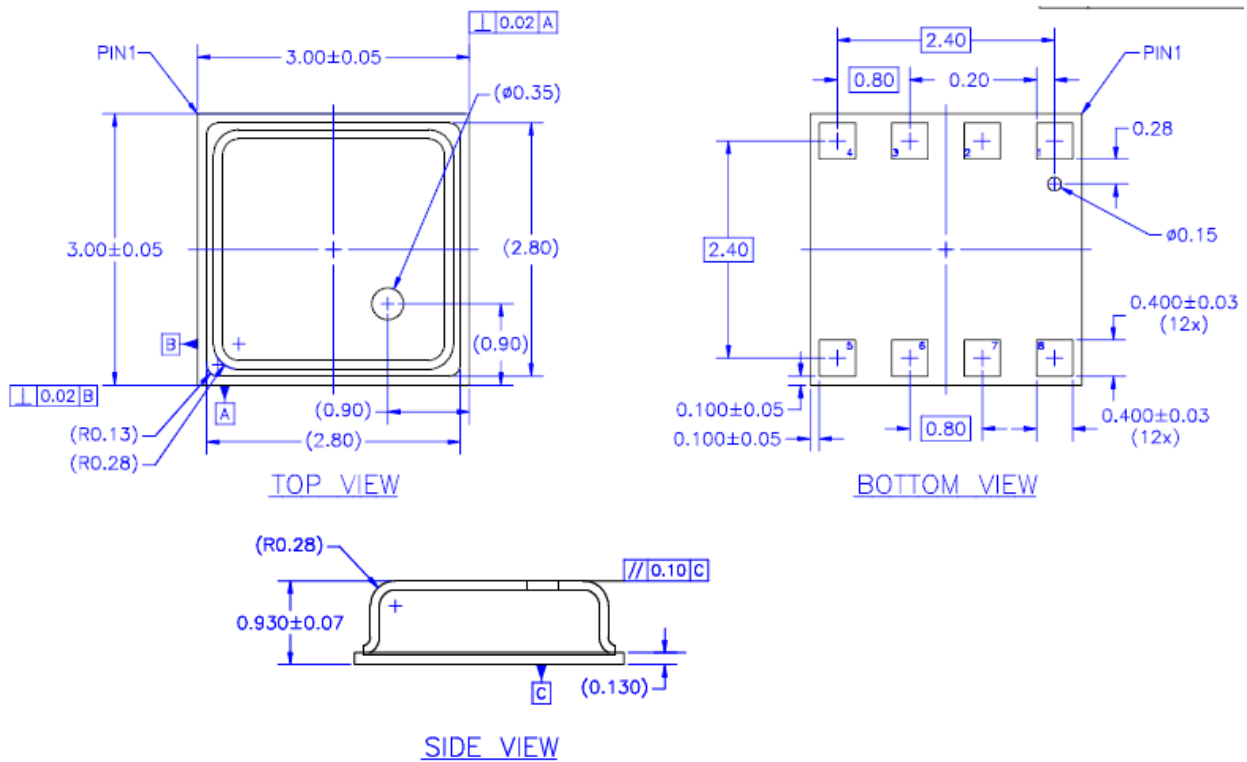
## 7.2 Connection diagrams

For the I<sup>2</sup>C connection, it is recommended to use 100 nF for C<sub>1</sub> and C<sub>2</sub>. Moreover, the value for the pull-up resistors R<sub>1</sub> and R<sub>2</sub> should be based on the interface timing and the bus load; a normal value is 4.7 kΩ. Finally, a direct connection between CSB and V<sub>DDIO</sub> is required. Similarly for the 4- and 3-wire SPI connections, it is suggested to use 100 nF for C<sub>1</sub> and C<sub>2</sub>.



Picture 12: Connection diagrams for (a) I<sup>2</sup>C, (b) 4-wire SPI, and (c) 3-wire SPI

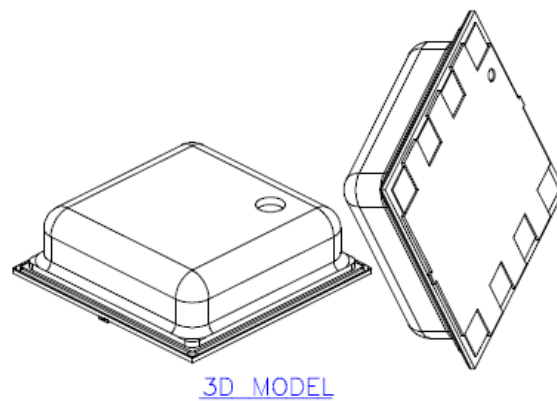
### 7.3 Package dimensions



2. REFERENCE SPECIFICATIONS:
  - A. AWW SPEC #001-0531-2234: PACKING OPERATION PROCEDURE.
  - B. AWW SPEC #001-0519-2062: MARKING.

1. ALL DIMENSIONS AND TOLERANCES CONFORM TO ANSI Y14.5M-1994.

NOTES: UNLESS OTHERWISE SPECIFIED

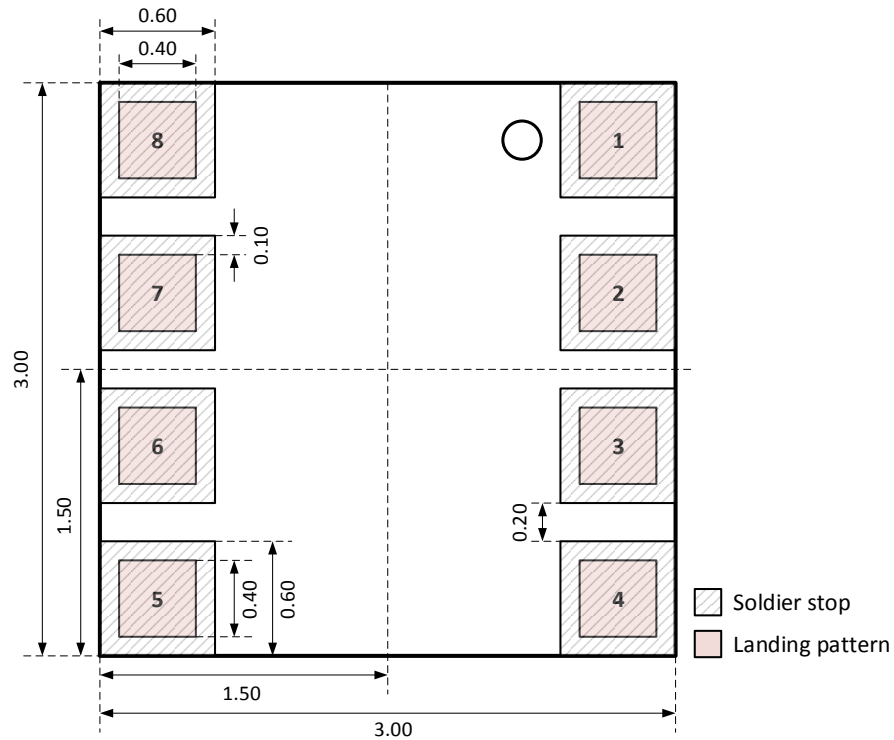


Picture 13: Package dimensions for top, bottom and side view

## 7.4 Landing pattern recommendation

For the design of the landing pattern, the dimensions shown in Picture 14: Recommended landing pattern (top view; dimensions are in milli-meters) are recommended. It is important to note that areas marked in red are exposed PCB metal pads.

- In case of a solder mask defined (SMD) PCB process, the land dimensions should be defined by solder mask openings. The underlying metal pads are larger than these openings.
- In case of a non-solder mask defined (NSMD) PCB process, the land dimensions should be defined in the metal layer. The mask openings are larger than these metal pads.



Picture 14: Recommended landing pattern (top view; dimensions are in milli-meters)

## 7.5 Marking

### 7.5.1 Mass production devices

Table 21: Marking of mass production parts

| Marking | Symbol | Description  |
|---------|--------|--|
|         | CCC    | <u>Lot counter</u> : 3 alphanumeric digits, variable to generate mass production trace-code  |
|         | T      | <u>Product number</u> : 1 alphanumeric digit, fixed to identify product type, T = "S"<br>"S" is associated with the product BME680 (part number 1 277 340 511) |
|         | L      | <u>Sub-contractor ID</u> : 1 alphanumeric digit, variable to identify sub-contractor (L = "P")   |

### 7.5.2 Engineering samples

Table 22: Marking of engineering samples

| Marking | Symbol | Description   |
|---------|--------|---|
|         | XX     | Sample ID: 2 alphanumeric digits, variable to generate trace-code                                 |
|         | N      | Eng. Sample ID: 1 alphanumeric digit, fixed to identify engineering sample, N = "*" or "e" or "E" |
|         | CC     | Counter ID: 2 alphanumeric digits, variable to generate trace-code                                |

### 7.6 Soldering guidelines and reconditioning recommendations

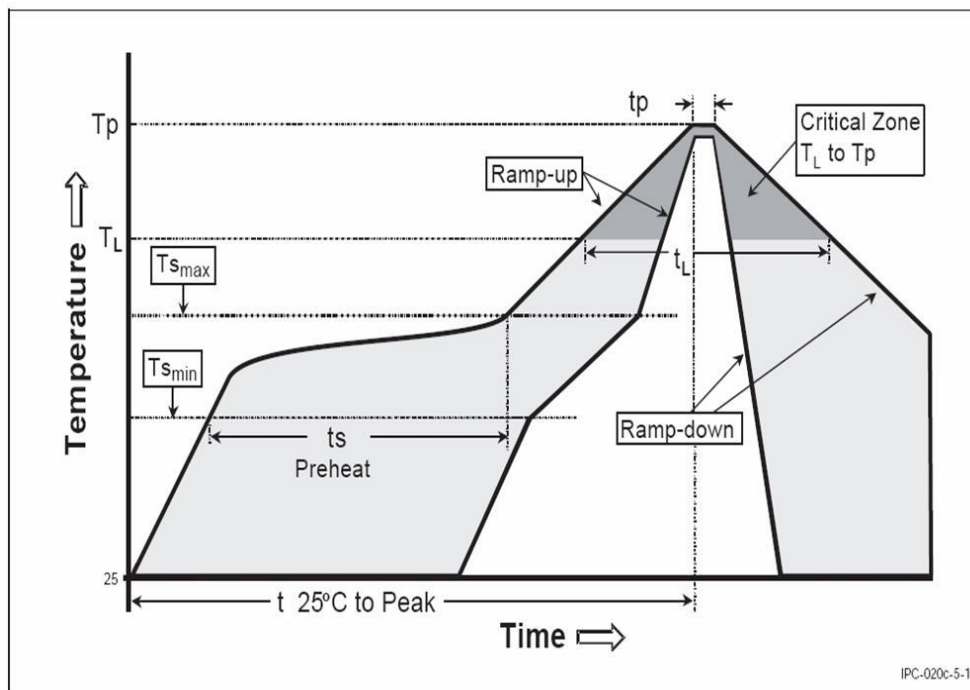
The moisture sensitivity level of the BME680 sensors corresponds to JEDEC Level 1, see also:

- IPC/JEDEC J-STD-020C “Joint Industry Standard: Moisture/Reflow Sensitivity Classification for non-hermetic Solid State Surface Mount Devices”
- IPC/JEDEC J-STD-033A “Joint Industry Standard: Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices”

The sensor fulfils the lead-free soldering requirements of the above-mentioned IPC/JEDEC standard, i.e. reflow soldering with a peak temperature up to 260°C. The minimum height of the solder after reflow shall be at least 50 µm. This is required for good mechanical decoupling between the sensor device and the printed circuit board (PCB).

| Profile Feature   |  | Pb-Free Assembly                   |
|---|--|------------------------------------|
| Average Ramp-Up Rate ( $T_{S_{max}}$ to $T_p$ )   |  | 3° C/second max.                   |
| <b>Preheat</b><br>– Temperature Min ( $T_{S_{min}}$ )<br>– Temperature Max ( $T_{S_{max}}$ )<br>– Time ( $t_{S_{min}}$ to $t_{S_{max}}$ ) |  | 150 °C<br>200 °C<br>60-180 seconds |
| Time maintained above:<br>– Temperature ( $T_L$ )<br>– Time ( $t_L$ )   |  | 217 °C<br>60-150 seconds           |
| Peak/Classification Temperature ( $T_p$ )   |  | 260 °C                             |
| Time within 5 °C of actual Peak Temperature ( $t_p$ )   |  | 20-40 seconds                      |
| Ramp-Down Rate  |  | 6 °C/second max.                   |
| Time 25 °C to Peak Temperature  |  | 8 minutes max.                     |

Note 1: All temperatures refer to top side of the package, measured on the package body surface.



Picture 15: Soldering profile

### 7.7 Mounting and assembly recommendations

This HSMI-document provides all the necessary instructions to handle, solder and mount the environmental sensor BME680. Following the reported guidelines is very important to prevent the damage of the sensor and the resultant loss of warranty.

## 7.8 Environmental safety

### 7.8.1 RoHS

The BME680 sensor meets the requirements of the EC restriction of hazardous substances (RoHS) directive, see also: *Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.*

### 7.8.2 Halogen content

The BME680 is halogen-free. For more details on the analysis results please contact your Bosch Sensortec representative.

### 7.8.3 Internal package structure

Within the scope of Bosch Sensortec's ambition to improve its products and secure the mass product supply, Bosch Sensortec qualifies additional sources (e.g. 2<sup>nd</sup> source) for the packaging and processing of the BME680.

While Bosch Sensortec took care that all of the technical packages parameters are described above are 100% identical for all sources, there can be differences in the chemical content and the internal structural between the different package sources.

However, as secured by the extensive product qualification process of Bosch Sensortec, this has no impact to the usage or to the quality of the BME680 product.

## 8. Legal disclaimer

### 8.1 Engineering samples

Engineering Samples are marked with an asterisk (\*) or (e) or (E). Samples may vary from the valid technical specifications of the product series contained in this data sheet. They are therefore not intended or fit for resale to third parties or for use in end products. Their sole purpose is internal client testing. The testing of an engineering sample may in no way replace the testing of a product series. Bosch Sensortec assumes no liability for the use of engineering samples. The Purchaser shall indemnify Bosch Sensortec from all claims arising from the use of engineering samples.

### 8.2 Product use

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The resale and/or use of products are at the purchaser's own risk and his own responsibility. The examination of fitness for the intended use is the sole responsibility of the Purchaser.

The purchaser shall indemnify Bosch Sensortec from all third party claims arising from any product use not covered by the parameters of this product data sheet or not approved by Bosch Sensortec and reimburse Bosch Sensortec for all costs in connection with such claims.

The purchaser must monitor the market for the purchased products, particularly with regard to product safety, and inform Bosch Sensortec without delay of all security relevant incidents.

### 8.3 Application examples and hints

With respect to any examples or hints given herein, any typical values stated herein and/or any information regarding the application of the device, Bosch Sensortec hereby disclaims any and all warranties and liabilities of any kind, including without limitation warranties of non-infringement of intellectual property rights or copyrights of any third party. The information given in this document shall in no event be regarded as a guarantee of conditions or characteristics. They are provided for illustrative purposes only and no evaluation regarding infringement of intellectual property rights or copyrights or regarding functionality, performance or error has been made.



## 9. Document history and modifications

| Rev. | Chapter | Description of modifications | Date      |
|------|---------|------------------------------|-----------|
| 1.0  |         | Initial release              | July 2017 |

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