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# BME680

Low power gas, pressure, temperature & humidity sensor



## BME680 – Datasheet

Document revision	1.0
Document release date	July 2017
Document number	BST-BME680-DS001-00
Technical reference code(s)	1 277 340 511
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 ±5	%r.H./V 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% ±15		
Durability to siloxanes <sup>6,7,8</sup>	IAQ <sub>s2s</sub>	Sensor-to-sensor deviation		±15% ±15		
	IAQ <sub>drift</sub>	Drift at low & high concentrations		±1% ±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 <sub>A</sub>	operational	-40	25	85	°C
		full accuracy	0		65	
Operating pressure range	P	full accuracy	300		1100	hPa
Supply current	I <sub>DD,LP</sub>	<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 <sub>P</sub>	25–40 °C, 900 hPa		±1.3		Pa/K
				±10.9		cm/K
Absolute accuracy pressure	A <sub>p, full</sub>	300–1100 hPa 0–65°C		±0.6		hPa
Relative accuracy pressure	A <sub>rel</sub>	700–900hPa, 25–40 °C, at constant humidity		±0.12		hPa
	A <sub>rel</sub>	900–1100hPa 25–40 °C, at constant humidity		±0.12		hPa
Resolution of pressure output data	R <sub>P</sub>	Highest oversampling		0.18		Pa
Noise in pressure	N <sub>P,fullBW</sub>	Full bandwidth, highest oversampling		1.4		Pa
				11		cm
		Reduced bandwidth, highest oversampling		0.2		Pa
				1.7		cm
Solder drift		Minimum solder height 50µm	-0.5	1.2	+2.0	hPa
Long-term stability <sup>16</sup>	P <sub>stab</sub>	per year		±1.0		hPa
Possible sampling rate	f <sub>sample_P</sub>	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×TCO<sub>P</sub>).

<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, temperature measurement 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<sub>0</sub> – G<sub>9</sub>. Figure 1 illustrates the handling of these measurement sequences and the gas sensor hot plate is heated for the forced mode.

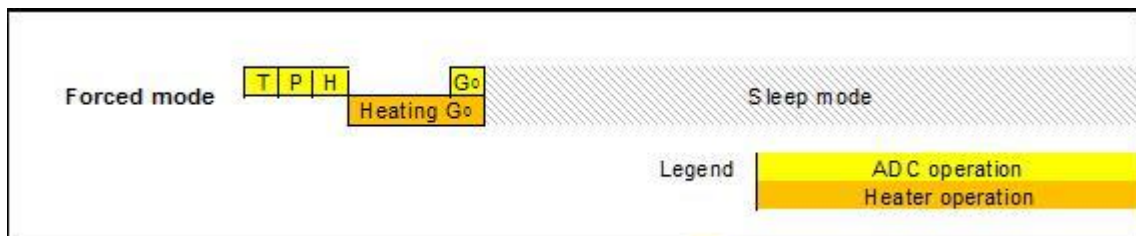


Figure 1: Sequence of ADC and gas sensor heater operation

## 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

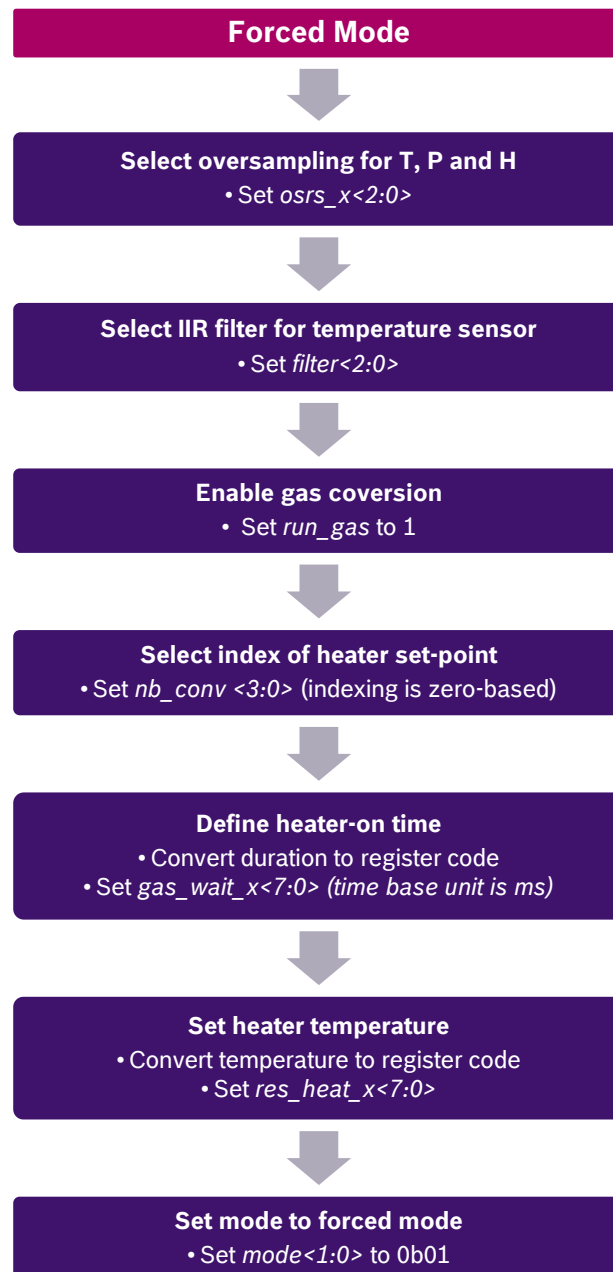
Now, a single forced mode measurement with the above settings can be triggered by writing 0b01 to *mode<1:0>*. For more details on data readout, please see Section 5.3.1.3.

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