SENSIRION

Design Guide for STC31-C

Design-in guidelines for best performance CO_2 concentration measurement

Key Topics

- Measurement modes
- Sensor integration / Design-in advice
- Evaluation options
- Factory and field calibration options
- Cross-sensitivity considerations
- Specific breath-related considerations

Sensirion STC sensors are accurate and long-term stable thermal conductivity sensors calibrated for concentration measurements. The thermal conductivity measurement principle is not gas selective, and the sensor output depends on environmental conditions.
This Design Guide explains the measurement principle, how to compensate for environmental conditions, and gives recommendations and guidelines for physical sensor integration.

Contents

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1 Introduction

The STC31-C sensor is based on the thermal conductivity measurement principle: the embedded heater heats the gas within the sensor cavity and the embedded temperature sensor measures the temperature change to determine the thermal conductivity of the gas. The thermal conductivity of CO_2 and air/N_2 differ, and the sensor can hence determine the concentration of CO_2 in Air.

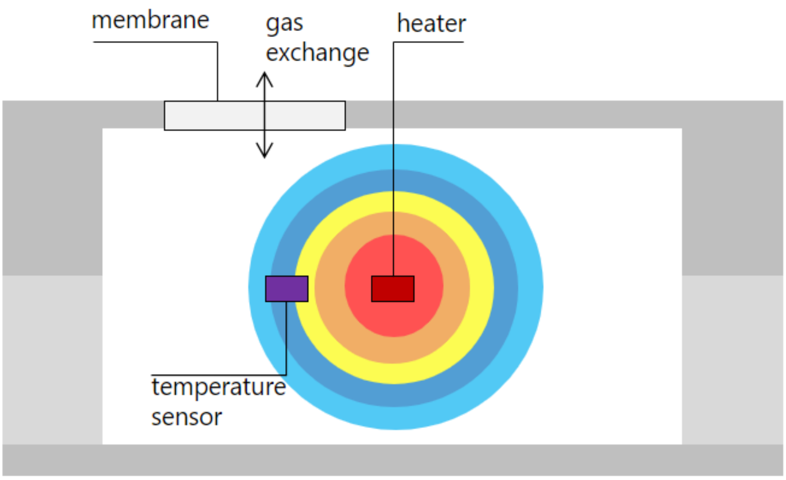

Figure 1. Thermal conductivity sensor schematic

Due to the integration on a single chip and the thermal measurement principle, the STC31-C has multiple advantages over traditional carbon dioxide (CO_2) sensors:

- Individual sensor calibration and compensation for thermal conductivity conversion to accurate gas concentration
- Excellent long-term stability
- Small size
- Robustness to shock and vibration
- Very low power consumption
- SMD soldering
- Fast response time
- Wide measurement range up to 100% CO_2

Note that the thermal conductivity measurement is not selective: a change of thermal conductivity will be translated into a change of concentration in the STC31-C concentration output, independently of the gas or condition responsible for the change in thermal conductivity.

2 Measurement modes

The STC31-C offers two measurement modes:

- **Low-cross-sensitivity: (recommended standard measurement mode)**
  In this measurement mode, the influence of humidity, temperature, pressure, and oxygen on the CO_2 measurement is significantly reduced. Therefore, the low-cross-sensitivity mode is recommended in most cases. It offers a sample frequency of up to 7Hz and the physical response time to gas change is identical to the low-noise mode.

- **Low-noise:**
  The low-noise measurement mode has the advantage of a slightly faster sampling rate (10Hz) and a lower measurement noise but shows significant cross-sensitivities to humidity, temperature, pressure, and oxygen and is therefore not recommended for most use cases. The communication interface for this mode is kept identical to the predecessor sensor STC31 (NRND Mai 2024) for backward compatibility.

Independent of the measurement mode, pressure, humidity (and temperature) need to be provided as inputs to the STC31-C to achieve specified accuracy of the concentration measurement.

3 Sensor integration

Important note: the SHT4x and pressure sensor used for compensation must be exposed to the identical humidity, temperature and pressure condition as the STC31-C sensor and must be integrated next to the STC31-C sensor.

3.1 Compensation of temperature, humidity, and pressure

Temperature, humidity, and pressure affect the thermal conductivity and must be compensated for to accurately measure the gas concentration. Therefore, it is strongly recommended to integrate a SHT4x humidity sensor and a pressure sensor[1] to provide these values as inputs to the STC31-C.
Without these inputs, the STC31-C sensor defaults to a pressure of 1013mbar and a relative humidity of 0% and operates on its internal temperature measurement. Deviating from those default pressure and humidity values without providing the inputs will result in measurement errors.

Regarding temperature, there are two options:

- using the internal temperature measurement of the STC31-C, or
- providing an external value from the SHT4x sensor.

While the SHT4x offers a higher temperature accuracy, the SHT4x might physically have a different local temperature than the STC31-C chip. It is recommended to evaluate both options to determine the better solution in terms of accuracy and robustness/repeatability, which depends on the application.
As a rule of thumb, for measurements with fast temperature transients, the internal temperature (thus no external temperature input) might provide the better result, while for stable temperatures and without gradients, the external SHT4x temperature might be the better choice.

In any case, once one or more compensation parameters are provided, they need to be updated whenever the value changes, otherwise the STC31-C will do the compensation based on the last (outdated) input value.

These compensation parameters are also required in the low-cross-sensitivity measurement mode, despite its lower cross-sensitivity to ambient condition.

[1] For many projects ST Microelectronics' LPS22DF pressure sensor is a good choice

3.2 Thermal coupling

The STC31-C uses a thermal principle to measure gas concentrations. This implies that the sensor is sensitive to external heat sources or other forms of heating or cooling. Consider the following:

- Design the PCB and the sensor surroundings in such a way that thermal gradients and transients are limited as much as possible in the surroundings of STC31-C/SHT4x.
  Thermal gradients and changing thermal gradients need to be avoided![2]
- Keep the sensor away (thermally decouple) from any heat sources like power converters, MCUs, motors, etc., for example by adding holes in the PCB. Also consider thermal decoupling of electrical connections, such as ground and VDD planes, etc."
- It is essential that the STC31-C and SHT4x sensor are thermally well coupled. Placing these sensors on the same PCB and minimizing the distance between them is the best way to achieve this.
- Prevent sources emitting infrared radiation onto the sensor element.
- Prefer a high resistance pull-up resistor to a low resistance pull-up resistor.

Figure 2. Decoupling the sensors from heat sources by adding slits or holes in the PCB design

Consult the *SHTxx Design Guide* and documentation concerning recommendations for the SHT sensors design-in.

3.3 Gas flows and gas exposure

For a good response time, proper exposure to the environment where the gas concentration should be measured is important. On the other hand, it should be considered that exposure to gas flows (e.g. wind, breath) can affect the thermal balance and that gas flow, bursts or turbulence can influence the pressure compensation.

To ensure good exposure to the environment, but at the same time minimize the influence of gas flows, it is recommended to place the STC31-C and SHT4x in a 'pocket' with a large enough opening and small enough volume to keep the gas exchange and response time high.

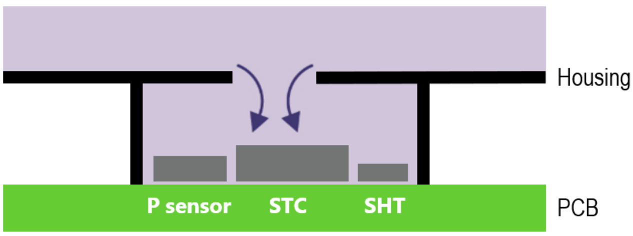

Figure 3. A small pocket with sufficiently large opening and sensors placed close to the opening.

[2] A good way to analyze the performance of the design-in this regard is by recording the temperature outputs of the STC31-C and the SHT4x after start-up and during operation and comparing their behavior. Fluctuations of the difference in their temperature readings can be a sign that temperature gradients and transients are not well managed.

If fast gas exchange is crucial, for example for breath measurements, the sensor must be placed directly in the flow of the sample gas. In this case it is advisable to reduce the flow rate to a minimum and thermalize the gas before reaching the sensors. See the specific section for the breath application.

Sudden ambient pressure fluctuations, that can result from large flow rates fluctuations, should be avoided during the concentration measurement. If possible, a design approach that leaves the STC31-C stable at ambient pressure is preferable.

In most cases the placement of the pressure sensor in this pocket as close as possible to the STC31-C and SHT4x is the best choice. If the pressure sensor is not placed in the same pocket, it must otherwise be assured by design that the pressure sensor and STC31-C are at the same pressure during any measurement.

If during design-in the gas flows still have a notable influence on the measurement signal, a membrane could help to reduce the pressure and temperature influences.

The membrane might also help to protect the electronics from dirt or liquids. However, impact on the response time by adding a membrane must be verified. It might be required to make the hole with membrane bigger.

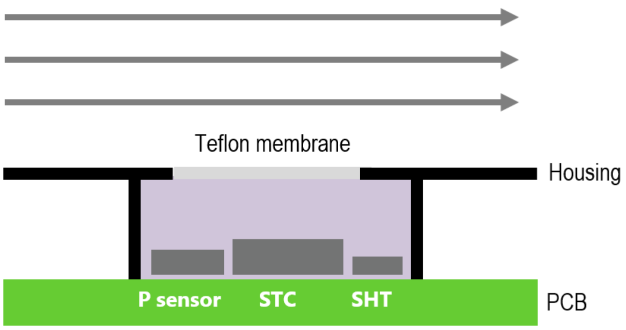

Figure 4. A pocket with a membrane helps reducing the influence of gas flows further.

It is recommended to seal the pocket to decouple it from the device itself. This might further improve response time and can reduce other influences like warm air coming from the device itself.

Figure 5. Pocket sealed from device's inside

3.4 Protection from direct sunlight

Exposing the STC31-C and SHT4x sensor to direct sunlight can lead to undesired heating of the sensors. Therefore, the sensors are to be shielded from direct sunlight.

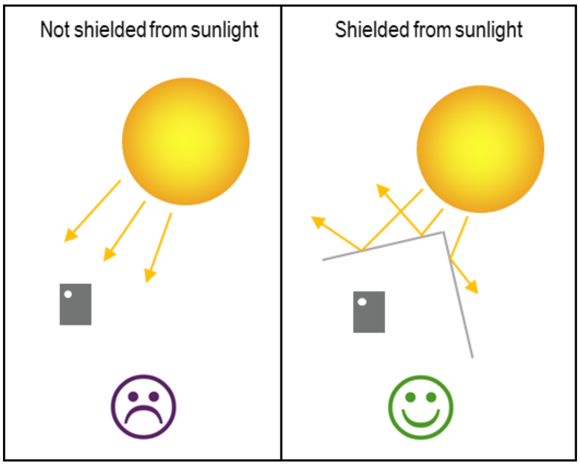

Figure 6. Shield the STC31-C and SHT4x sensors from direct sunlight**.**

3.5 Condensation

Condensation on the sensor or the PCB around the sensor must be avoided for several reasons:

- Condensation on the sensor membrane can hinder or block the gas exchange into the sensor cavity.
- Condensation (and evaporation) is accompanied by heat transfer, which affects the thermal measuring principle of STC31-C and thus the measurement accuracy.
- Condensation can create corrosion of the solder joints and PCB.

For applications in humid environments active heating schemes might be needed.

4 Factory and field calibration

There are two mechanisms on the STC31-C to correct the offset and restore the sensor's accuracy over the entire calibration range: the **Automatic Self-Calibration (ASC)** and **Forced ReCalibration (FRC).**
The concepts behind the ASC and FRC are similar. The main difference is that the FRC uses a value provided by the host and performs an instant offset correction, whereas the ASC assumes a zero-background concentration of CO_2 and continuously lets the output very slowly 'gravitate' towards it.

- In applications where the STC31-C sensor (end device) is exposed to environments where the target gas CO_2 is absent most of the time (i.e. 0% CO_2), we recommend using ASC to ensure accurate readings over long periods of time.
- In all other cases, we recommend executing an FRC at conditions (pressure, humidity, temperature, and concentration) which are as close as possible to the target conditions to be measured.

The FRC and ASC do not change the sensitivity of the sensor but do a smart compensated correction of the offset.
The offset value is not stored in the sensor when the sensor is powered down, reset, or put to sleep mode.

4.1 Forced recalibration (FRC)

For a forced recalibration (FRC), the host feeds a (known) reference concentration value to the STC31-C. This triggers an internal concentration measurement which is compared with the provided reference value and the internal offset value is used for correcting all successive measurements.
This offset value is only stored in the sensor's volatile memory and lost when the sensor is powered down or put to sleep mode. At restart or wake up, it is recommended to execute a new FRC (if the application allows this, i.e. when the sensor is exposed to a known concentration). Alternatively, the host must read out and store the offset value from the sensor before power down/sleep mode and reapply it again after a restart or wake-up. See section 5 for using FRC in combination with sleep mode.
The effect of FRC takes place immediately after the corresponding command and can be executed at arbitrary intervals.
For the best possible performance, the FRC must be executed at the temperature, humidity, pressure, and concentration that are relevant for the application and after receiving accurate compensation parameters.

Typical scenarios for FRC:

- After soldering and assembly
- Before commissioning of a product
- Before placing a product in a controlled environment
- When measurement series start with a known CO_2 concentration (for example for breath measurements where Air can be assumed before measuring an exhalation)

4.1.1 FRC with low-cross-sensitivity mode require a low pass filter

While the low-cross-sensitivity mode has much less cross-sensitivity to other gases and ambient conditions, a single measurement is quite noisy which impacts the effectiveness of the FRC. To overcome this, the following procedure is recommended:

1) Enable weak and/or strong filtering and take several consecutive measurements to have a stable, noise free CO_2 reading (while providing relative humidity, temperature (if external is used), and pressure inputs for compensation – see **Figure 7**: Low-pass filter behavior for low pass filter behavior).
2) Execute FRC command (which is then based on this filtered "noise-free" value).
3) Disable or change the filtering if needed and proceed with the measurements.

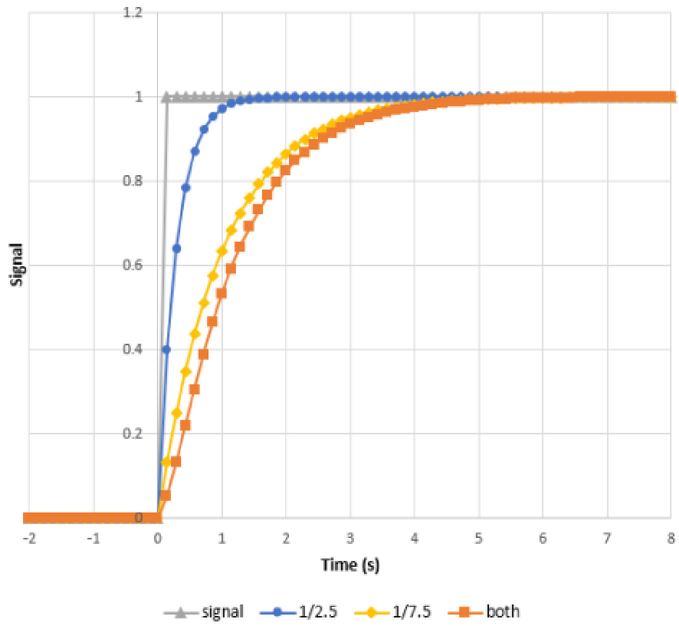

Figure 7: Low-pass filter behavior

4.2 Automatic self-calibration

The STC31-C provides the option of on-chip automatic self-calibration (ASC). This feature is designed for applications where there is zero concentration of target gas (i.e. CO_2) for most of the time. A typical scenario is gas detection to monitor dangerous concentrations of CO_2 due to gas leakage from a storage tank. Here, the sensor will see no CO_2 for most of the time (the atmospheric concentration of 0.04% CO_2 is below the STC31-C accuracy), except in the event where a leak does occur.
When ASC is switched on, the STC31-C will run a zero-point self-calibration that gradually adjusts its output over time. The algorithm is optimized for a measurement interval of 1 s. Significantly different measurement intervals may decrease the performance of ASC.

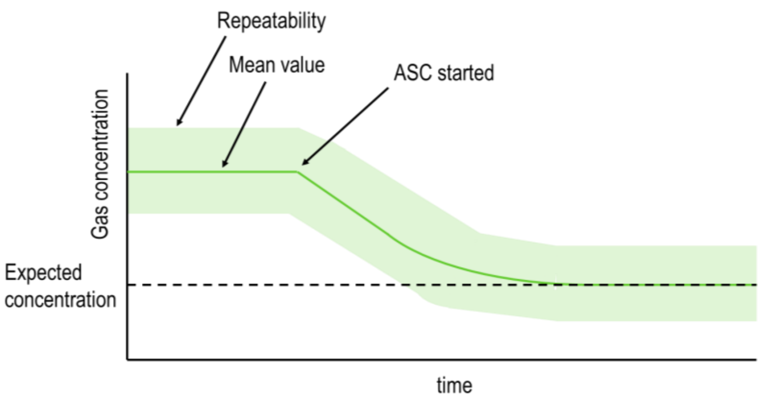

Figure 8: Schematic representation of ASC

5 State retention during sleep, PoR or reset

The STC31-C does not have internal non-volatile memory (NVM) to retain its configured state during power off, sleep or (accidental) reset.
The following information will be lost, and thus must be stored off-sensor in the NVM of the MCU and be written back to the sensor:

- Selected gas model.
- ASC Enable and correction value.
- FRC correction value.
- Compensation inputs: last supplied values of temperature, humidity, and pressure.

The following sections give command sequences for the most common sensor use-cases.

5.1 Post-soldering

After soldering, during assembly, board-test or at a later stage, an FRC must be performed to ensure performance within specifications. After the FRC, the correction value of the FRC must be stored in the NVM of the MCU to be persisted for the next power-up.
The following command sequence is recommended for normal production environments with air. We recommend following the first loop for FRC with a second loop for verification.

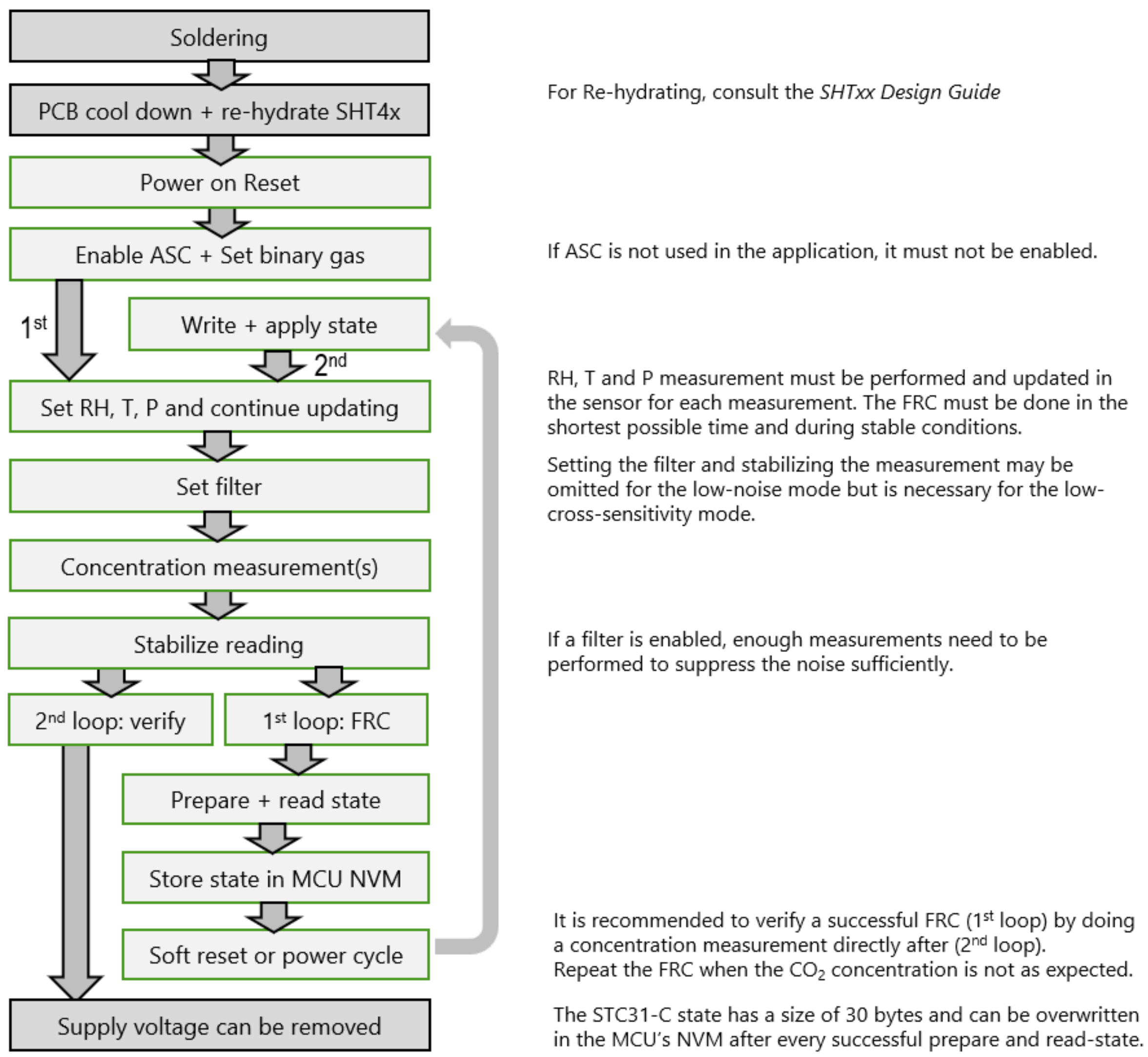

Figure 9: State retention sequence post-soldering in air

During the post-soldering phase, the RH, T and P values should come from the sensors on the same PCB, but should also be compared with references, so that PCBs with faulty pressure and relative humidity sensors can be sorted out, or abnormalities in the production process can be detected. The FRC function of the STC31-C must not be used to correct out-of-specification offsets of the sensors measuring the pressure, humidity, and temperature.

5.2 Continuous Sensor operation without sleep mode

In some applications the sensor will run 24 hours a day, seven days a week, possibly for years without the power supply being removed and without being reset or going to sleep mode.
However, it cannot be excluded that the supply is interrupted accidentally, or an unexpected reset of the sensor occurs. In this case the sensor state with latest ASC correction value will be lost, and it is important that a recent ‘back-up can be restored. The following sequence proposes how such back-up sequence can be integrated in continuous sensor operation.

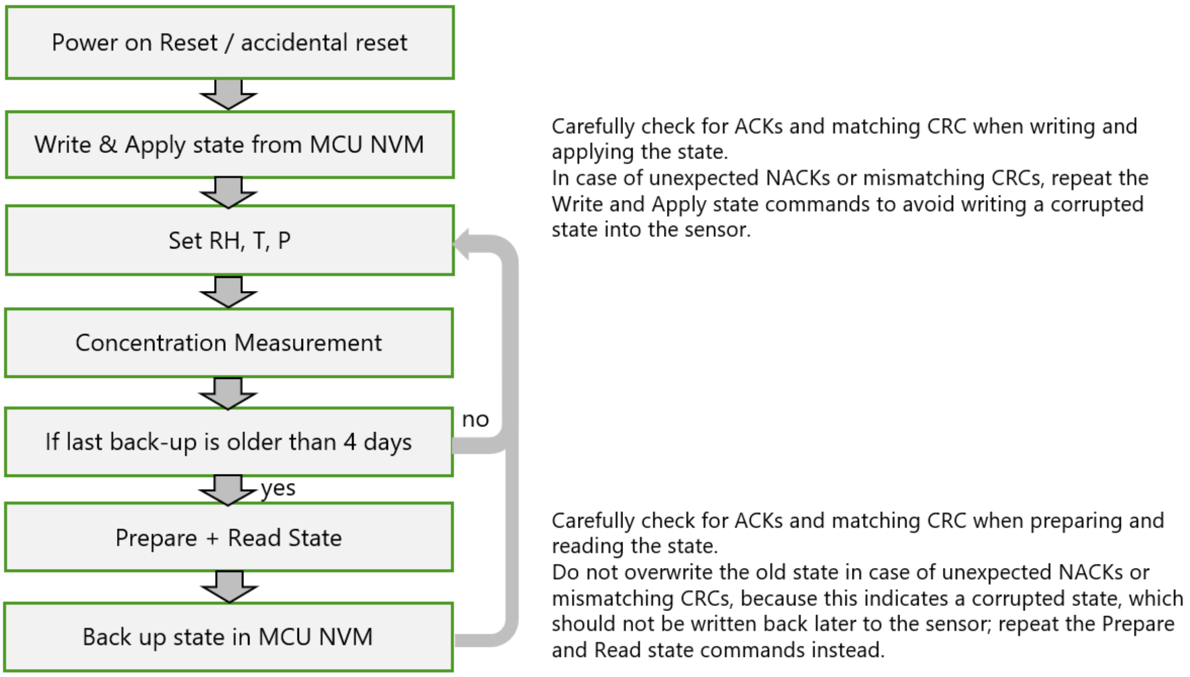

Figure 10: Continuous sensor operation without sleep mode or regular resets

A back-up every four days is an adequate interval where the loss of an ASC correction value loss would only be small and well within sensor specifications. With a lifetime of 10 years, this would result in approximately 1000 write cycles to the NVM of the MCU, which is supported by most Flash memories on common MCUs. It assumes of course that accidental power cycles or resets don’t occur regularly with intervals shorter than four days. If there is a risk this could happen, the back-up frequency must be adjusted.

5.3 Sensor operation with sleep mode

The following sequence is the recommended use of the sensor when the sensor is put into sleep mode frequently, at least every four days. If the time between sleep modes is more than four days, it is recommended to study the previous section, and implement the 'regular back-up' into this sequence.

The first time this sequence is executed, the state saved in the MCU NVM during the *post-soldering sequence* is written to the sensor in the 'Write & Apply state'.

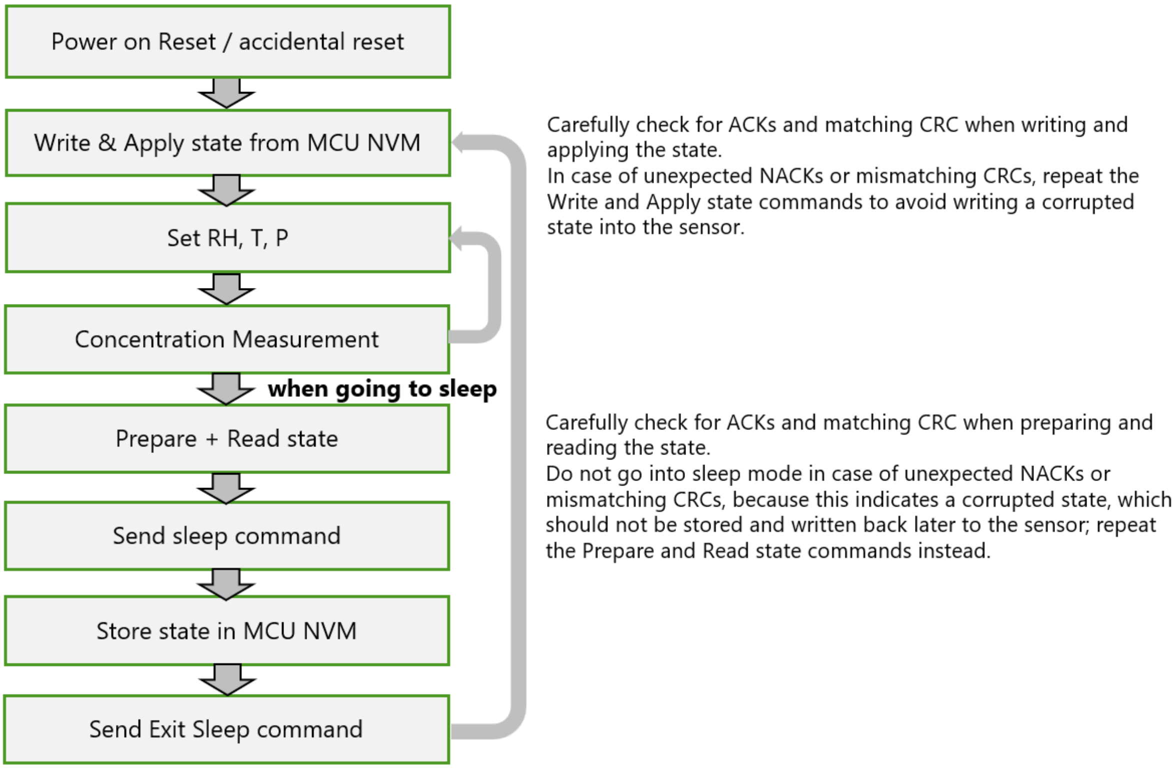

Figure 11: Sensor operation with sleep mode

If during this sequence an FRC is desired, this must then be done in between the 'Write & Apply state' and 'Prepare and read state'.

6 Important considerations about cross-sensitivities

6.1 Environmental uncertainties

Environmental conditions affect the STC31-C output because they change the thermal conductivity of the gas. Section 3.1 explains in detail how to compensate for these effects. Inaccuracy of the compensation inputs (pressure, humidity, and temperature) leads to an error of the STC31-C output, as specified in the datasheet.

6.2 Background gas

The STC31-C sensor measures thermal conductivity and translates this to a gas concentration. This measurement principle relies on the assumption that there is a known background gas, to which the target gas is added (binary gas mixture).
For the CO_2 in air measurement, the background gas is air which is diluted by the target gas CO_2, thus it assumes a mixture of air and CO_2. Changes in the composition of the background gas will influence the measurement.
This is for example relevant when using synthetic air during testing (which often does not contain argon), see the section about argon below.

Since the STC31-C measures in the percent range (1% = 10'000 ppm), only gases that are present in this range are relevant:

Gases in air	c [vol%]	TC @25°C [mW/m/K]
Nitrogen	78.08	25.6
Oxygen	20.95	26.1
Argon	0.93	17.8
Carbon Dioxide (CO_2)	0.04	17.0
Others	Very low, not relevant	

Table 1: Composition of air and thermal conductivity at 25°C of the individual gases

6.2.1 Argon

The amount of argon in air is relatively small but it plays a significant role for the thermal measurement principle of STC31-C in both measurement modes: low-cross-sensitivity, and low-noise.
Reducing (or omitting) the Argon content will affect the CO_2 measurement by approximately the same amount. For example, if the Argon content is reduced to 0%, the CO_2 reading will decrease by about 1%.

This is particularly important for the use case of CO_2 measurement in breath. As real breath is not repeatable, artificial breath and air mixtures are frequently used for test purposes and oftentimes these gas mixtures omit argon for simplicity. While for other measurement principles like NDIR, this approximation might work well, the thermal measurement principle requires this 0.93% of argon for proper outputs. Please note that this is not a limitation for the use case, only a constraint for test gas mixtures containing the argon content.

Example of recommended gas mixtures for test purposes of breath applications:

- Composition of inhaled air (artificial or ambient):
  78.08% N_2, 20.95% O_2, 0.93% argon (and 0.04% CO_2)
- Exhaled air contains the same amount of argon since it is not metabolized but some O_2 is exchanged roughly 1:1 by CO_2 (assuming an RER of 1) thus the composition could for example be:
  78.08% N_2, 17.0% O_2, 0.93% argon and 4.0% CO_2

6.2.2 Oxygen

Changes in O_2 are compensated automatically by the low-cross-sensitivity mode but play a role when using the low-noise mode. For applications where oxygen concentration differs significantly from the air content, the following compensation formular can be used for measurements in low-noise mode.

Low-noise mode	Low-cross-sensitivity mode
$\mathrm{C_{corr}} = 1.032\ \mathrm{C_{meas}^{CO2}} - 0.151(21\ \mathrm{vol.\%} - \mathrm{C_{meas}^{O2}})$	no correction needed

Table 2: Compensation formular for oxygen deviations in air

Where:

- C_{corr}^{CO2} is the corrected CO_2 concentration in vol%
- C_{meas}^{CO2} is the measured CO_2 concentration in vol%
- C_{meas}^{O2} is the measured O_2 concentration in vol%

The correction formula assumes that the STC31-C is operated using the "CO_2 in air" gas model in low-noise mode. Knowledge of the O_2 concentration is required to apply this correction.

6.2.3 Trace gases

Changes that do **not** significantly influence the thermal conductivity include:

- Changes in VOC concentration in the order of 500 ppm or less
- Absence of noble gases other than argon

7 Use case: measurement of CO_2 in breath

7.1 Measurement mode

For breath applications, only the low-cross-sensitivity mode should be used. In this mode, the sensor can sample at up to 7Hz and has a low cross-sensitivity to changes in:

- temperature
- humidity
- pressure
- oxygen

While the maximal sampling rate is slightly reduced, the response time of the STC31-C is not affected by the low-cross-sensitivity measurement mode.

7.2 Offset correction for repetitive breath applications

In applications with repetitive breathing, a subject breathes through a device, alternating between in-breath and out-breath for a series of multiple breath cycles. The STC31-C measures the CO_2 concentration of this alternating stream of ambient air and human breath.

First, the sensor's offset should be corrected with the FRC function before the series of measurements is started. For the best possible performance, the FRC must be performed at the ambient air conditions (temperature, humidity, pressure, and concentration) that are maintained during the measurement series. A possible solution can be that the device (with the STC31-C sensor inside) must be allowed to acclimate to the environment and the user must draw fresh air through the device.

During the measurement series, the conditions at the STC31-C will however still slightly change. This change can affect the offset of the sensor slightly and affect the measured concentrations.
For best performance, it is necessary to correct for this measurement offset. Since breath is a dynamic process, it is not possible to use the sensor's FRC function as it requires setting noise filter and performing many measurements. Instead, this must be performed in the devices MCU.

Best performance is achieved with a dynamic offset correction that uses the clean air measurement during in-breath before, after or an average of both for the compensation of each out-breath. Additionally, to temperature effects, this also accounts for elevating CO_2 levels in the ambient air over the course of a measurement series.

The experimental data in section 7.5 uses this approach. The measurements during seconds 0 to 3 are used as the offset for the measurement during second 4 to 6. In other words, the difference between these two averaged measurement intervals is used as the final CO_2 concentration result for each breath cycle.

7.3 Design-In recommendations for breath measurements

The STC31-C offers a fast response time and a wide measurement range suitable for CO_2 measurements in breath. For best performance, it requires a careful design-in because of its thermal measurement principle. While the sensor has a temperature compensation algorithm on the chip, the challenge lies in accurately determining the gas temperature. Since the internal temperature measurement or external temperature measurements are strongly coupled to the PCB temperature, inaccuracies arise if the gas temperature differs from the PCB temperature. Since the temperature of exhaled air is close to the body temperature, thermalization is the key for a good design-in.

A good thermalization means that the air going to the sensor gets cooled down/heated up to the temperature at the STC31-C sensor. This is achieved by increasing the surface area in proportion to the gas volume that gets to the sensor. Possible solutions are using a pump that samples a small portion of the exhaled gas or using a passive side stream that only allows a small volume of the air to pass by the sensor.

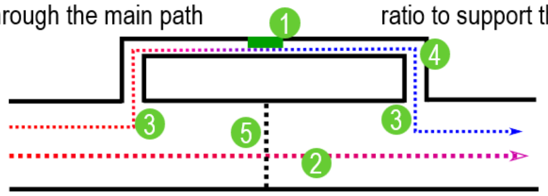

Figure 12. Bypass flow for optimal breath gas thermalization

Since breath also has rapid changes in CO_2 concentration the response time of the system is another important design-in consideration. A balance must be found where the thermalization is good enough while keeping an adequate gas exchange for short response time.

7.4 Breath measurement procedure

To design your own breath measurement procedure, consider the following steps to achieve the best measurement performance:

1. Temperate sensor environment for optimal FRC and measurement conditions and to avoid condensation during breath sampling.
2. Ensure that sensor environment is filled with fresh air (for example, user inhales through device).
3. Run FRC with 400 ppm CO_2 level (if the device may be used in an indoor environment with higher CO_2 levels make sure that 400 ppm is realistic). The ambient humidity should be determined with an SHT4x as the input for the FRC measurements.
4. Perform single or series of breath tests and dynamically correct the offset (section 7.2)
5. Humidity input for the compensation:
   a. For a single captured breath, use a SHT4x sensor in proximity to the STC31-C
   b. For continuous breathing, choose the best available estimate. For example, use a SHT4x measurement for the ambient air for the in-breath in and estimate/measure the humidity for the out-breath. The humidity profile of an outbreath can, for example, be determined during the device development and may be modelled with available flow, concentration, and slow humidity inputs.
6. Keep the elevated temperature around the sensor until the humidity has dropped enough if you are concerned about condensation.

7.5 Typical performance example

As a guidance of the possible performance that can be achieved, we provide results from Sensirion internal evaluations.

The test setup switches in < 100 ms between the two gases passing over the sensor chip, as described above:

- Air[3], 21 °C, dry, 0% CO_2
- Air[3], 37 °C, RH > 90%, 5% CO_2

The test setup achieves a response time of τ_{90} of < 0.5 s and we averaged the sensor readouts between the 1st and 3rd second after the gas switching. **Figure 13** shows the measurement data of 100 repetitions and the calculated concentration values in the histogram. The CO_2 concentration is determined from the difference between the two stable gas states (red), seconds 4-6 versus seconds 1-3. The concentration average is 4.94 with a sigma of 0.06 This means 95% of all measurements measured between 4.82 and 5.06

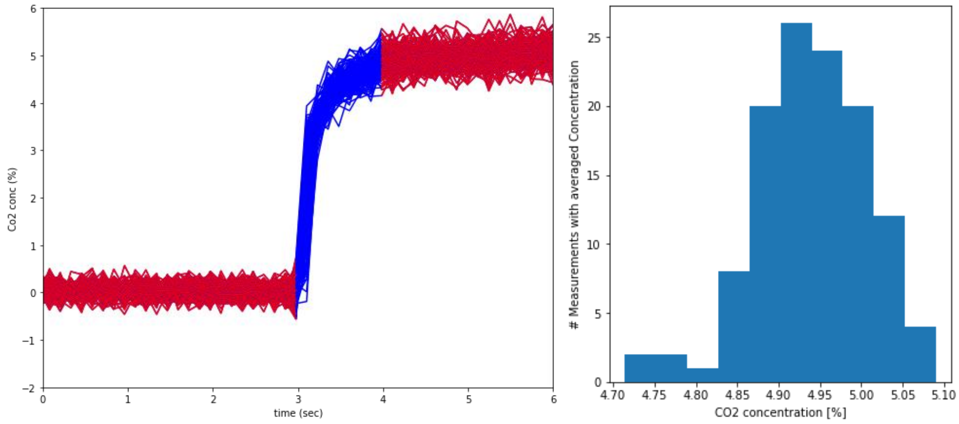

Figure 13. Typical breath measurement performance in Sensirion's test design

Due to the signal noise the statistical distribution can be improved when longer averaging is possible by e.g. capture of the breath or if multiple breaths are averaged for continuous breathing (see 7.6).

The low-cross-sensitivity measurement mode is strongly preferred for breath applications. **Figure 14** shows the performance difference between the low-cross-sensitivity mode (gray) and the low-noise mode (blue) when the humidity value is not provided to the sensor.

[3] Air is defined as 78.1% nitrogen, 21.0% oxygen and 0.9% argon

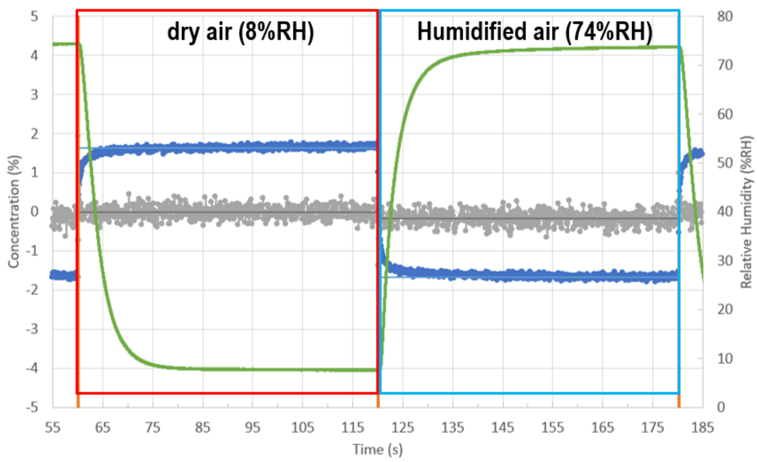

Figure 14. Humidity cross effect without compensation: low-cross-sensitivity (gray) vs. low-noise mode (blue)

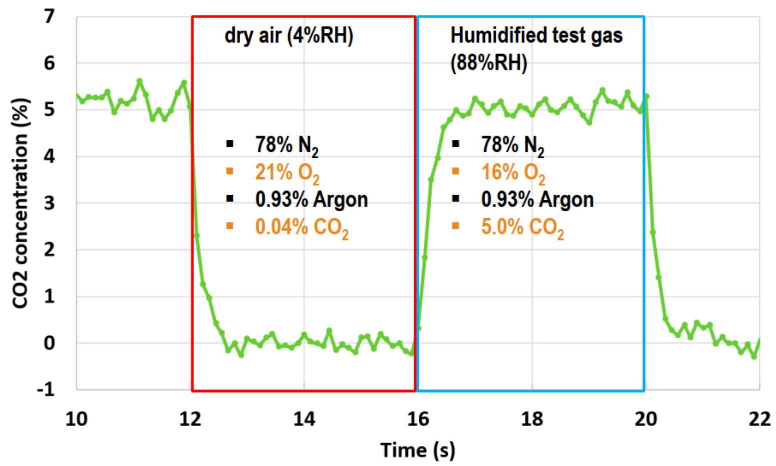

Figure 15. Response time low-cross-sensitivity mode to a medium fast breath pattern

7.6 Accuracy and repeatability of breath measurement:

The attainable accuracy level for breath measurements depends considerably on the design-in of the sensor and the breath measurement procedure. The datasheet provides achievable accuracy; however, it assumes wider ranges than are typical for breath applications. Internal analysis shows that smaller coefficients can be assumed for limited ranges:

- Concentration: 0.0 – 10%
- Temperature: 20 – 40°C
- Relative humidity: 30 – 90%
- Pressure: stable at ~ 1 atm.

With this the following coefficients and calculation results:

Typical base accuracy: 0.2 vol% = 0.2 vol%

additional concentration error: $c_C * \Delta C$ = 0.01 vol% * (5% – 0.04%) = 0.05 vol%

additional temperature error: $c_T * \Delta T$ = 0.01 vol% * (30°C – 25°C) = 0.05 vol%

additional RH error: $c_{RH} * \Delta RH$ = 0.003 vol% * (90% – 50%) = 0.12 vol%

Total typical accuracy (2-sigma) = 0.2 + 0.05 + 0.05 + 0.12 = ± 0.42 vol%

Internal tests, as shown in the previous section, show that even better results can be achieved with careful design-in.

Repeatability between breath measurements depends on the number of measurement points that can be sampled during the exhalation. The 1-sigma noise of a single measurement in low-cross-sensitivity mode is ~0.16 vol% (see section 1.2 in the datasheet) and can be approximated to be normally distributed.

This estimate is reflected in the performance example in section 7.5. The average over 2 seconds corresponds to 14 measurement points and is only 100 ppm or 0.01 vol% larger than expected from the statistical noise calculated for independent normally distributed variables plotted in **Figure 16**: Measurement noise of averaged low-cross-sensitivity measurements.
The same logic can be extended to averaging over multiple breath cycles.

This does not take other variations that can affect the repeatability besides the sensor noise into account.

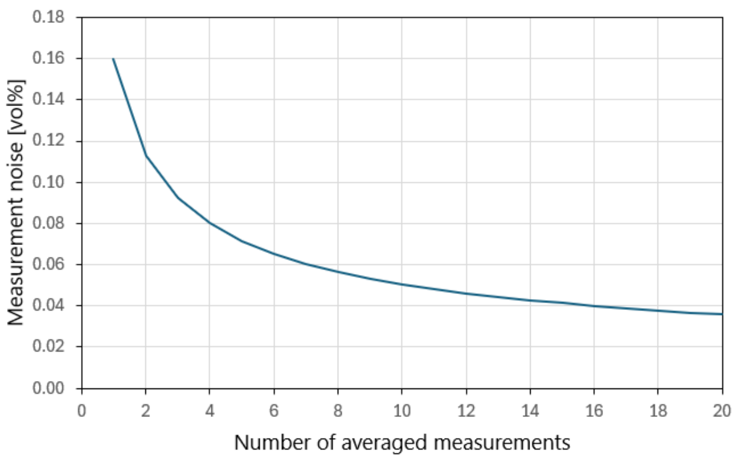

Figure 16: Measurement noise of averaged low-cross-sensitivity measurements

7.7 Summary and guidelines for breath applications

For designing a device to measure CO_2 in breath, the following points should be considered:

- Start from a working starting point (for example STC31-C Evaluation Kit with Sensirion ControlCenter and plain air without breath) and incrementally work towards your product design, checking at each step that the behavior makes sense. If something does not work, go back, and determine at which step the problem arises.
- During evaluation and design tests, the temperature reading of the STC31-C and the SHT4x should be recorded and tracked/plotted against the CO_2 reading to detect fluctuations and other unwanted instabilities.
- Once own firmware is used it is recommended to log all compensation values, measurement values, and commands.
- Special focus needs to be on temperature gradients (changes over space) and temperature transient conditions (changes over time) which need to be managed / limited by a suitable sensor integration. Transients can be compensated to some extend by dynamic offset correction (see section 7.2).
- While CO_2 changes are intended and the value of interest, other transient conditions / changes can influence the measurement accuracy.
  - Oxygen is managed very well by the sensor, very low impact on the measurement.
  - Pressure might have an impact at fast breathing frequency but not devices with slow and long exhalation phases. This can be mitigated by placing the sensor closer to ambient conditions along the sample path.

  - The presence of humidity is well compensated by the sensor; however, condensation (and evaporation) will have a thermal effect which is critical, see next point.
  - Temperature is by far the most critical parameter. To get best performance from the STC31-C sensor, a stable temperature at the STC31-C sensor needs to be achieved. The goal of the design is: zero temperature gradients across the sensors (STC31-C and SHT4x) and zero temperature transients (changes over time) during measurement.
  - Performance can be tweaked by applying the best estimates for the humidity during each part of the breath cycle; this should, however, not be the focus during the initial design-in as it is only a small optimization.
- Avoiding or limiting condensation (and evaporation) can be managed with two strategies:
  - Heating the sensor's surrounding helps to limit condensation. However, this needs to be well designed and avoid temperature gradients and transients/fluctuations around and at the sensor - which need to be avoided.
  - Another strategy is gas thermalization where only a small fraction of the breath is guided through a thin channel to the STC31-C sensor. By the time and distance, the gas has traveled through the thin channel, the gas has thermalized, and all excess humidity has condensed before reaching the sensor.
  - Both strategies can be combined for optimal performance.
- Avoiding temperature gradients around the STC31-C sensor:
  - Avoid point heating sources close to the sensor. (i.e. microcontroller, LDO, etc.)
  - If heating is applied, use a homogeneous heating and work with thermally conducting surfaces/materials.
  - Preheat the sensor and its direct environment before the measurement to reach a stable temperature for the measurement.
- General considerations:
  - At any equilibrium (no transient) the sensor should always indicate the right CO_2 value.
  - If not, there is either:
    - a transient effect (check temperature trends),
    - a gradient (compare STC31-C and SHT4x readings,
    - the sensor gets wrong input data (p, RH, T) or
    - was damaged.
  - As temperature is critical, SHT4x and STC31-C should be placed next to each other and thermally isolated from heating sources close by.
  - You can compare performance of internal temperature compensation by forcing the STC31-C sensor to use its internal temperature by only providing a relative humidity and pressure input (no temperature input). Note that once an input has been provided, this value is used indefinitely until a power cycle of the sensor, i.e. if once a single temperature input was provided to the sensor, this STC31-C will always use the external temperature for calculation, whether that value has been updated or not.
  - All the discussed parameters may influence the measurement accuracy; however, no lasting sensor drift / damage was ever observed.
  - All this information only applies to the "low-cross-sensitivity" measurement mode (the situation is completely different for the low-noise mode). We strongly recommend the low-cross mode for breath applications.

8 STC31-C evaluation

8.1 Evaluation with Sensirion ControlCenter

The initial evaluation of STC31-C can be done with ControlCenter software of Sensirion. For this you need:

1. STC31-C evalkit, including:
    a. Flexible PCB with STC31-C and SHT4x
    b. Connecting cable
2. Sensor bridge
3. ControlCenter software of Sensirion

Connect STC31-C via sensor bridge to a PC and launch the ControlCenter software. Following configurations can be made (see **Figure 17**):

1. Sampling rate
2. Enable humidity compensation
3. Set absolute ambient pressure
4. Select Gas Model and measurement mode. For instance:
    - Air/CO_2 (0-40%)
    - Low-cross-sensitivity
5. Enable a filter (depending on application)
6. Set the calibration value (offset correction, see forced recalibration in STC31-C datasheet

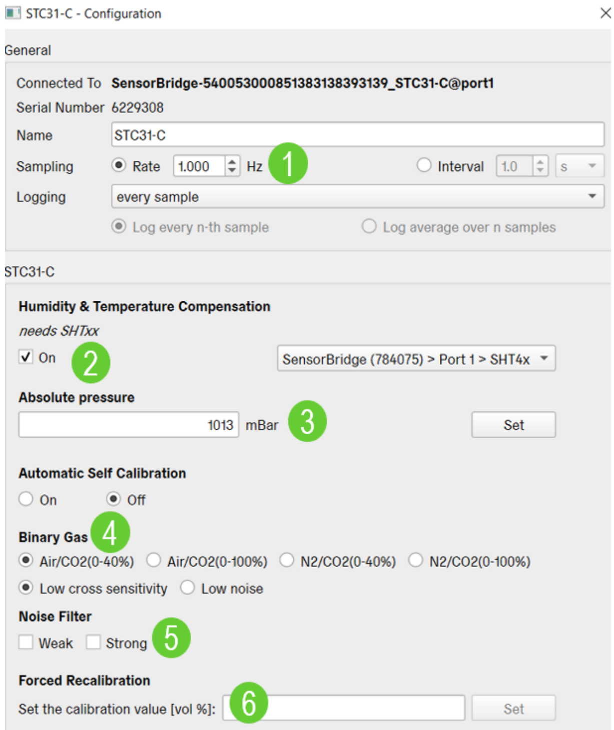

Figure 17: STC31-C configuration

8.2 Evaluation with own embedded software

The STC31-C can also be evaluated by writing a driver following the datasheet's command set description. The order of the I2C commands upon startup is described below:

1. Start sensor up
2. Set measurement mode (see section "Set Measurement Mode and Binary Gas" in STC31-C datasheet)
3. Option: Enable a filter
4. Option: Forced recalibration or enable automatic self-calibration depending on the application (see next paragraph)
5. Read out while updating humidity, temperature, and ambient pressure. Please check maximal recommended readout frequency in the STC31-C datasheet section "Timings".

Note that the sensor will continue using an external temperature input until reset if it was provided even once (for example, for FRC). This can lead to seemingly strange behavior when the temperature changes, but no updates are provided.

If the sleep function should be used to save power consumption, please refer to the datasheet section "Sleep mode".

9 Revision history

Date	Version	Pages	Changes
June 2024	1.0	all	Completely new revision and compilation of relevant design guidance for STC31-C
June 2024	1.1	all	Minor clarifications and corrections

Important Notices

Warning, Personal Injury

Do not use this product as safety or emergency stop devices or in any other application where failure of the product could result in personal injury. Do not use this product for applications other than its intended and authorized use. Before installing, handling, using or servicing this product, please consult the data sheet and application notes. Failure to comply with these instructions could result in death or serious injury.

If the Buyer shall purchase or use SENSIRION products for any unintended or unauthorized application, Buyer shall defend, indemnify and hold harmless SENSIRION and its officers, employees, subsidiaries, affiliates and distributors against all claims, costs, damages and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if SENSIRION shall be allegedly negligent with respect to the design or the manufacture of the product.

ESD Precautions

The inherent design of this component causes it to be sensitive to electrostatic discharge (ESD). To prevent ESD-induced damage and/or degradation, take customary and statutory ESD precautions when handling this product. See application note "ESD, Latchup and EMC" for more information.

Warranty

SENSIRION warrants solely to the original purchaser of this product for a period of 12 months (one year) from the date of delivery that this product shall be of the quality, material and workmanship defined in SENSIRION's published specifications of the product. Within such period, if proven to be defective, SENSIRION shall repair and/or replace this product, in SENSIRION's discretion, free of charge to the Buyer, provided that:

- notice in writing describing the defects shall be given to SENSIRION within fourteen (14) days after their appearance;
- such defects shall be found, to SENSIRION's reasonable satisfaction, to have arisen from SENSIRION's faulty design, material, or workmanship;
- the defective product shall be returned to SENSIRION's factory at the Buyer's expense; and
- the warranty period for any repaired or replaced product shall be limited to the unexpired portion of the original period.

This warranty does not apply to any equipment which has not been installed and used within the specifications recommended by SENSIRION for the intended and proper use of the equipment. EXCEPT FOR THE WARRANTIES EXPRESSLY SET FORTH HEREIN, SENSIRION MAKES NO WARRANTIES, EITHER EXPRESS OR IMPLIED, WITH RESPECT TO THE PRODUCT. ANY AND ALL WARRANTIES, INCLUDING WITHOUT LIMITATION, WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, ARE EXPRESSLY EXCLUDED AND DECLINED.

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SENSIRION reserves the right, without further notice, (i) to change the product specifications and/or the information in this document and (ii) to improve reliability, functions and design of this product.

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