Engineering Guidelines for SEN5x

Applicable to following sensors:
SEN50, SEN54 and SEN55

Key content:
- Initial evaluation and testing
- Electrical and mechanical integration
- Algorithm settings customization

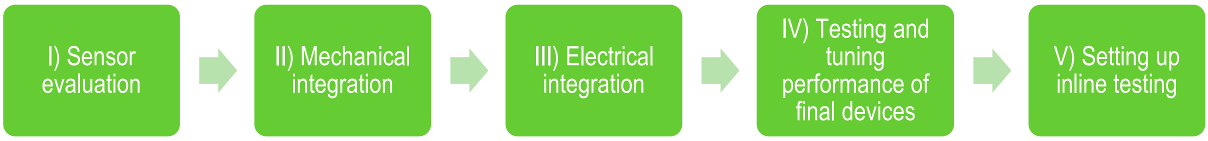
Summary

The SEN5x environmental node is a straightforward, all-in-one sensor solution platform for the accurate measurement of particulate matter, volatile organic compounds, oxidizing gases, as well as humidity & temperature. Each sensing component includes proprietary algorithms that allow an easy integration in various applications.

This application note provides engineers willing to integrate our SEN5x into their product with an overview of sensor evaluation criteria, recommended design-in guidelines, mechanical and electrical configurations, inline test procedures of the finished product, and further background information. This document offers an overview of the available application notes, tools, and datasheet references, please always refer to these documents as a key source of comprehensive information and detailed specifications.

Introduction and Recommended Design-In Process Flowchart

The sensors of the SEN5x family have been specifically designed to allow an easy and handy integration in end-user products. The scope of this guide is to describe all the necessary steps to successfully integrate the sensor in your final product.
At Sensirion we have years of experience in supporting customers integrating our sensors in different applications. The following figure shows our recommendation for an efficient and effective design-in process:



Please note that some process steps will need iterations. Typically, after the first testing of the final device performance, adjustments of the mechanical and electrical integration still need to be done to optimize performance and tune the design for the desired behavior. The following sections will guide you through each process.

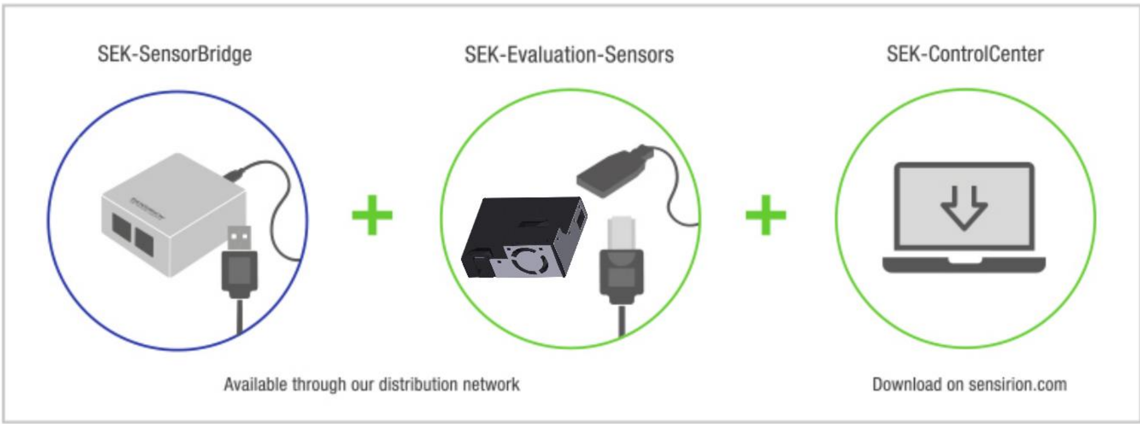
I) Sensor Evaluation

In this section, we guide you through the process of pre evaluating the sensor module for your specific application. As a first step, we recommend to familiarize with measurements in a tabletop setup. Further measurements in specific measurement/lab environments (like climate chambers, dust test setups, gas measurement setups) and the specific user scenario are also possible by using the same test setup.

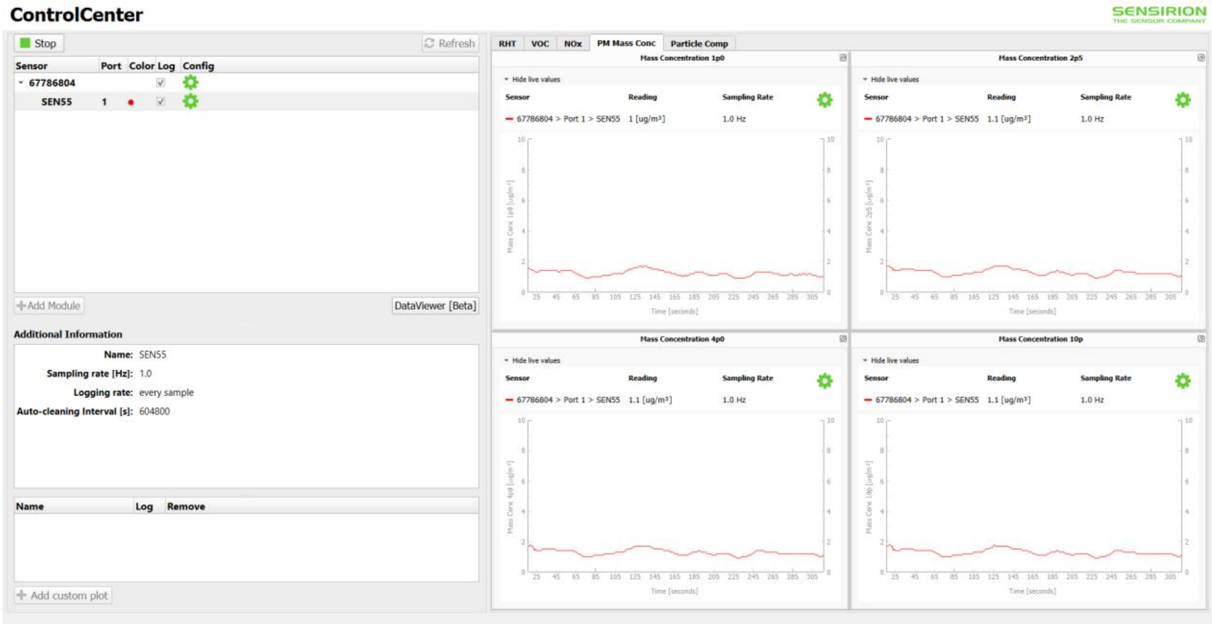
For electrical and laser safety, the reader is referred to the documents on RoHS/REACH declaration and Laser certification of the sensor.

Procedure

The fastest way for starting an experiment is by using the evaluation kit (SEK-SEN5x) combined with the SEK-SensorBridge (to be purchased separately from the evaluation kit), and the Sensirion *ControlCenter* Software. *ControlCenter* can be downloaded at https://www.sensirion.com/en/controlcenter/. Connect the sensor to your computer using the Sensirion SEK-SensorBridge, run ControlCenter, and you are ready to start your experiment.



In the ControlCenter you can access all the data that are measured by the different sensors and visualize them as presented in the following screenshots:



At first, we recommend to test the individual sensors responses in small and easy experiments:

- Blowing into the inlet one can observe a raise in the humidity.
- Holding the SEN5x between your closed hands will result in an increase of the temperature signal.
- Tearing a paper close to the inlet produces a fine particulate matter dust, which is detected by the PM sensor.
- Let gas from a gas lighter stream into a glass positioned bottom up on a table. Placing SEN5x inside the as created gas atmosphere will create a detectable increase in the VOC signal of the sensor. More information on the working principle of the VOC sensor can be found in the document “What is a MOX sensor?” and “What are reducing gases?”.
- Use the same setup as for the VOC experiment, but this time ignite the lighter so instead of streaming gas into the glass, the atmosphere consists of combustion residues. Placing SEN5x in this atmosphere, a signal in the NO_x reading is observed. More information on the working principle of the NO_x sensor can be found in the document “What is a MOX sensor?” and “What are oxidizing gases?”.
- The VOC can also be tested by exposing the module to low concentration liqueur vapor for a short time.

More quantitative testing guidelines, such as instructions for lab setup-based testing, can be found in the testing guides for the various integrated sensors (PM, VOC, NO_x, RH, T).

Tools

- SEK-SEN5x evaluation kit
- SEK-SensorBridge
- Control Center Software

Documentation

- SEN5x Datasheet
- SEN5x Handling Instructions
- Testing guides
  - PM2.5
  - RH/T
  - VOC and NO_x: **SGP41 Quick Testing Guide (sensirion.com)**
- Documentation MOX sensor

- Document: What is a MOX sensor?
- Document: What are reducing gases?
- Document: What are oxidizing gases?
- Youtube video VOC and NO_x experiment: **SGP41 Gas Sensor Evaluation Kit: Introduction - YouTube**

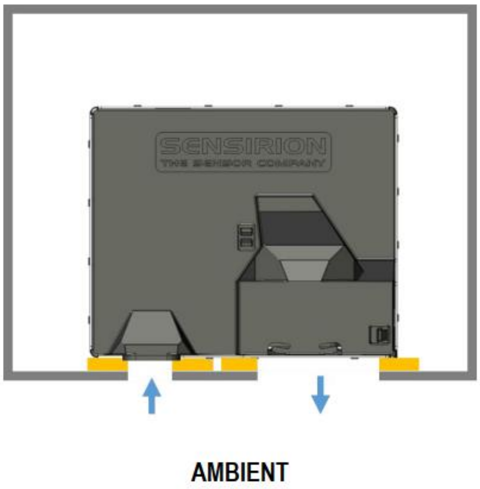
- Statement on Sensor Specification
  - PM2.5
  - RH/T
  - VOC and NO_x
- Additional documentation
  - RoHS/REACH declaration
  - Laser certification

II) Mechanical Integration

A good mechanical design-in is a key requirement for optimal performance of your device. Design-in can however be a lengthy time-consuming process when different sensors need to be combined. SEN5x is designed to revolutionize this process and the customer can benefit from Sensirion's expertise in providing solutions for implementations in different applications areas.

Procedure

SEN5x's air channel geometry is designed for optimal performance of each sensor component. Active ventilation helps speed up reaction times. Complex compensation and acceleration algorithms are part of SEN5x's firmware. Lastly, we provide a tested design-in example which includes a brief description and a CAD file with the actual design. An example of a best practice design is presented in the figure:



The most important aspects in designing in the module are:

- Decoupling in- and output via insulation
- Installing the module in the correct orientation
- Isolation from airflow
- Decoupling from external heat and radiation sources

For a more thorough understanding about design-in we recommend using the Mechanical Design and Assembly Guidelines "SEN5x Mechanical Design-In Instructions".
Choice of material is key towards optimal performance of the sensor in your device. This is particularly important for VOC sensing as some kinds of plastics are prone to emitting VOCs themselves. We strongly recommend to test plastics around the sensor, especially soft plastics, and foams. If you require assistance with material selection, connect with your Sensirion contact and request material testing for your potential product.

Tools

- SEN5x Module

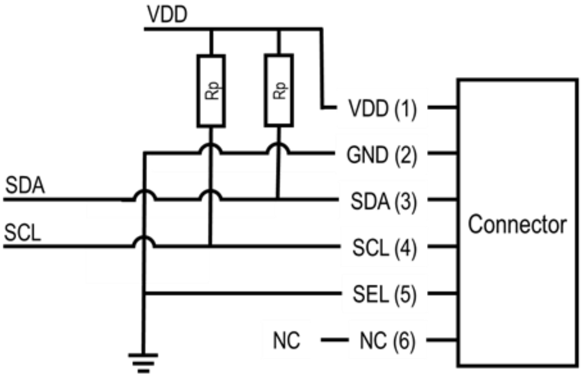
Documentation

- SEN5x Mechanical Design-In Instructions
- CAD model (STEP)
- SEN5x Mechanical Design-In Example

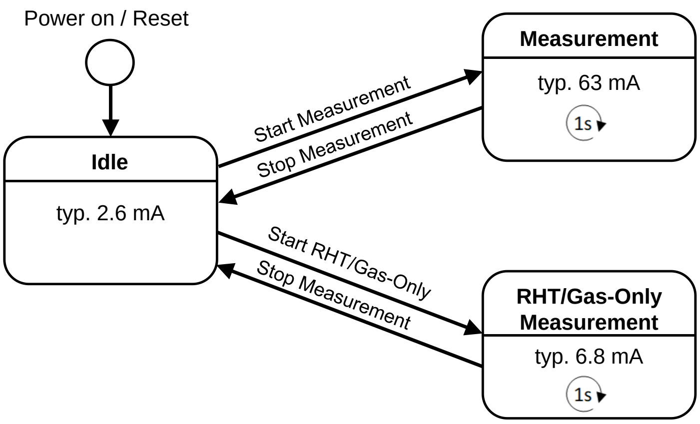
III) Electrical Integration

Besides the mechanical integration, the electrical and software integration are major steps in designing a product. In this section we provide you with information about electrically requirements such as the software we provide for integration.

The SEN module comes with an ACES 51451-0060N-001 connector which is used for power supply and communication with the sensors. The circuit diagram below shows both the I2C communication interface and the power supply setup :



The sensor needs to be supplied with 5 V +/- 10%. Constant supply values are desired for optimal performance. When the sensor is in measurement mode (after first 60 seconds) the typical average supply current is 63mA, while 70 mA at maximum. Considering the start, and the other operation modes, the maximum peak current is 110 mA.
The operation of the sensor follows the flowchart:



More details on the operation modes and how to switch between them are presented in the datasheet.
For experiments using Arduino, or other prototyping platforms and common microcontrollers, our drivers for the desired platforms can be found on Github. In the corresponding repositories you also find dedicated installation guides.
A full description of the communication protocols and interfaces can be found in the datasheet.

Tools

- SEN5x Module
- Jumper wire cable contained in SEK-SEN5x
- Electronic prototyping boards

- Desired software tools

Documentation

- Datasheet
- Driver repositories (https://github.com/sensirion?q=SEN5)
  - Arduino diver repository
  - Raspberry Pi driver repository
- Tutorials

IV) Testing and tuning performance of final devices

For testing our specifications, we have developed specialized setups that require the support of a reference which has an accuracy at least 10 times higher than the sensor's tested limits. In general, for the product testing, we instead recommend testing more use-case-oriented procedures.

Procedure (RH/T)

To optimize the temperature reading performance of a specific product, it is possible to tune the compensation changing the offset parameters. Place the device with the built-in sensor next to a reference sensor and compare the steady state temperature with the one provided by the reference. If an offset is observed, this can be corrected via the offset value with the I2C command (0x60B2).

SEN5x comes with an already tuned set of parameters for the Sensirion temperature acceleration routine (STAR) allowing for a quick temperature acceleration of stand-alone modules, and two use cases: Air Purifiers and Air Quality Monitors. Three different predefined settings for the use of the standalone module and the built-in scenarios are available with the corresponding I2C command (0x60F7).

In addition, it is possible to define a warm-start scenario, this is done with the command (0x60C6).

The application note "Temperature Acceleration and Compensation Instructions for SEN5x" gives explanation about all the temperature measurements and procedures for the customization.

Tools

- SEN5x based prototype device

Documentation

- Datasheet
- Temperature Acceleration and Compensation Instructions for SEN5x
- Testing guides
  - PM2.5
  - RH/T **Testing Guide (sensirion.com)**

Procedure (PM)

While there are certainly gases and aerosols well suited for simulating real life PM events in a controlled lab environment, the necessary equipment is typically bulky and expensive. Instead, we recommend placing a batch of devices into a typical end-use environment and operating it for a week. This will give the most relevant information about device performance for applications like Air Purifiers and Air Quality Monitors. There is no tunability for PM.

Tools

- SEN5x based prototype device

Documentation

- Datasheet
- Testing guides
  - PM2.5

Procedure (VOC and NOx)

Sensirion's powerful Gas Index Algorithm is ideal for the visualization and interpretation of the VOC and NO_x sensor readings. Its working principle is based on the human perception of smell and explained in the document "What is Sensirion's VOC/NO_x Index?" in greater detail. The exact implementation can be found in the repository listed in the documentation section. The algorithm by default maps the VOC readings to a VOC scale from 1 to 500 where 100 refers to the average condition (see "What is the VOC Index?" for more information) and the NO_x values are mapped to a NO_x scale from 1 to 500, where everything above 1 is an event (see "What is the NO_x Index?" for more information).

Generally, the algorithms are tuned in such a way that the default output is useful for a wide range of applications. The response of the VOC Algorithm can however be tuned to specific applications by adjusting up to six different parameters as stated in the datasheet:

1. Index Offset: By default, the average VOC condition is mapped to VOC Index = 100. In this way, it is possible to discriminate between fresh-air (VOC Index < 100) and VOC events (VOC Index > 100). This mapping can be changed to values from 1 to 250 to decrease/increase the visual focus on fresh-air events on the VOC Index scale.
2. Learning Time Offset Hours: This parameter defines the range of the rolling window used by the algorithm to learn its offset from the history of sensor data. Due to the exponential decay function, sensor data older than twice the learning time become almost insignificant. The default value is 12 h. We recommend setting this parameter to the same value as "Learning Time Gain Hours".
3. Learning Time Gain Hours: This parameter defines the range of the rolling window used by the algorithm to learn its gain from the history of sensor data. Due to the exponential decay function, sensor data older than twice the learning time become almost insignificant. The default value is 12 h. We recommend setting this parameter to the same value as "Learning Time Offset Hours". In the case of indoor air quality monitoring, a time of 72h works optimal.
4. Gating Max Duration Minutes: This parameter is referred to as the gating time, which is the time, at which the learning mechanism is deactivated after triggering a VOC event, when the VOC Index is above the gating threshold of 230. Without this feature, a high VOC event lasting for several minutes or longer would look like as if the event is already over because the VOC Index is decreasing again due to the learning. By using this feature, VOC events with a duration below the gating time will be displayed like they are. If an event takes longer than the gating time, it is considered a change in the environmental condition. The default value is set to 180 minutes. If only single events should be traced, it is recommended to set the value to zero, for portable applications it is recommended to perform individual tests.
5. Standard Deviation Initial: This refers to the sensor behavior during the fast learning phase. Choosing high values reduces the gain of the learning algorithm but increases the device-to-device variation, low values increase the gain to VOC events in the initial learning but lower the device-to-device variation.
6. Gain Factor: This parameter directly amplifies/attenuates the entire VOC Index output in both directions (fresh-air and VOC events) at the same time. Note: this parameter may interfere with the gating behavior. The gating threshold is fixed at VOC Index = 230 and thus, any event reaching this threshold will be treated according to the setting of the "Gating Max Duration Minutes" or, in case the VOC Index output is always below 230, the learning of offset and gain will always be active even during long VOC events.

Additionally, it is possible to apply the "Read/Write the VOC Algorithm State" function, which can be used to gain back the original state of the algorithm after short power cycling of the device. This function reads/writes the whole learning sequence to the memory, reproducing the initial value before power cycling to avoid the algorithm entering the fast-learning phase again. In this way, the VOC Index output behaves approximately as if the sensor would not have been shut down. The read function is recommended for power cycling times below 10 minutes and can only be applied if the write function was triggered decently close before the shutdown. At default settings of the algorithm, we recommend triggering the writing procedure every two hours.

The response of the NO_x Algorithm can also be tuned to specific applications by adjusting four different parameters, like described for the VOC Algorithm. However, the two parameters 'Learning Time Gain Hours' and 'Standard Deviation Initial' have no impact on the NO_x Index output. Still, they must be set to the default values in the tuning interface.

Tools

- SEN5x based prototype device

Documentation

- Datasheet
- Testing guides
  - VOC and NO_x **SGP41 Quick Testing Guide (sensirion.com)**
- Documents:
  - What is Sensirion's VOC/NO_x Index?
  - What is the VOC Index?
  - What is the NO_x Index?
- Repositories
  - Gas Index Algorithm: GitHub - Sensirion/gas-index-algorithm: Sensirion's Gas Index Algorithm provides a VOC and NOx Index output signal calculated from the SGP40/41 raw signals

Multiple iterations of the previously described processes are recommended to fine-tune the parameters in the testing phase.

V) Setting Up In-line Testing

Once the design iterations are finished and the product goes into production, in-line testing is another step towards guaranteeing a stable quality of the final product. As all sensor components are tested at Sensirion production sites, we recommend keeping the in-line testing procedure lean, examples for possible procedures are listed in this section.

Procedure
As the most important in-line testing procedure, we recommend the read device status register command for checking functionality of all components and returns 0 for pass. As indicated previously testing specifications is a difficult, time-consuming task which is why we recommend using the self-test command only.

If a functional test is absolutely required, we recommend generating brief “events” using bursts of ethanol for VOC or smoke for particulate matter testing. If further testing is required, please contact Sensirion for further advice.

After specifying the performance of the final device, we advise to reiterate and adjust the mechanical and electrical integration with respect to the fabrication processes in production to optimize performance and tune the design for the desired behavior.

Documentation

- Datasheet

Revision History

Date	Version	Page(s)	Changes
January 2022	1	-	Initial version

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 does not assume any liability arising out of any application or use of any product or circuit and specifically disclaims any and all liability, including without limitation consequential or incidental damages. All operating parameters, including without limitation recommended parameters, must be validated for each customer's applications by customer's technical experts. Recommended parameters can and do vary in different applications.
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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