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Inside of the World of IC Design for Sensor Applications

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SENSIRION

Outline

- Sensirion introduction
- SEN6x: indoor air quality sensing platform
- SGP4x: platform for NOx and VOC gas sensing
- SGP4x analog design in sensors for wide range dynamics of physical front ends
- SGP4x analog design in view of limited area and packaging stress
- SGP4x design for calibration
- SGP4x performance
- Conclusion

Sensirion AG

Founded in 1998 as a spin off from ETHZ, the Polytechnical School Zurich, Sensirion now employs around 1,200 people both at its headquarters in Stäfa, Switzerland, and in its numerous international subsidiaries.

Safeguarding health

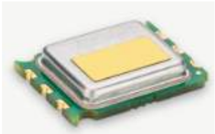
Encouraging innovation

Ensuring safety and comfort

Embodying quality & reliability

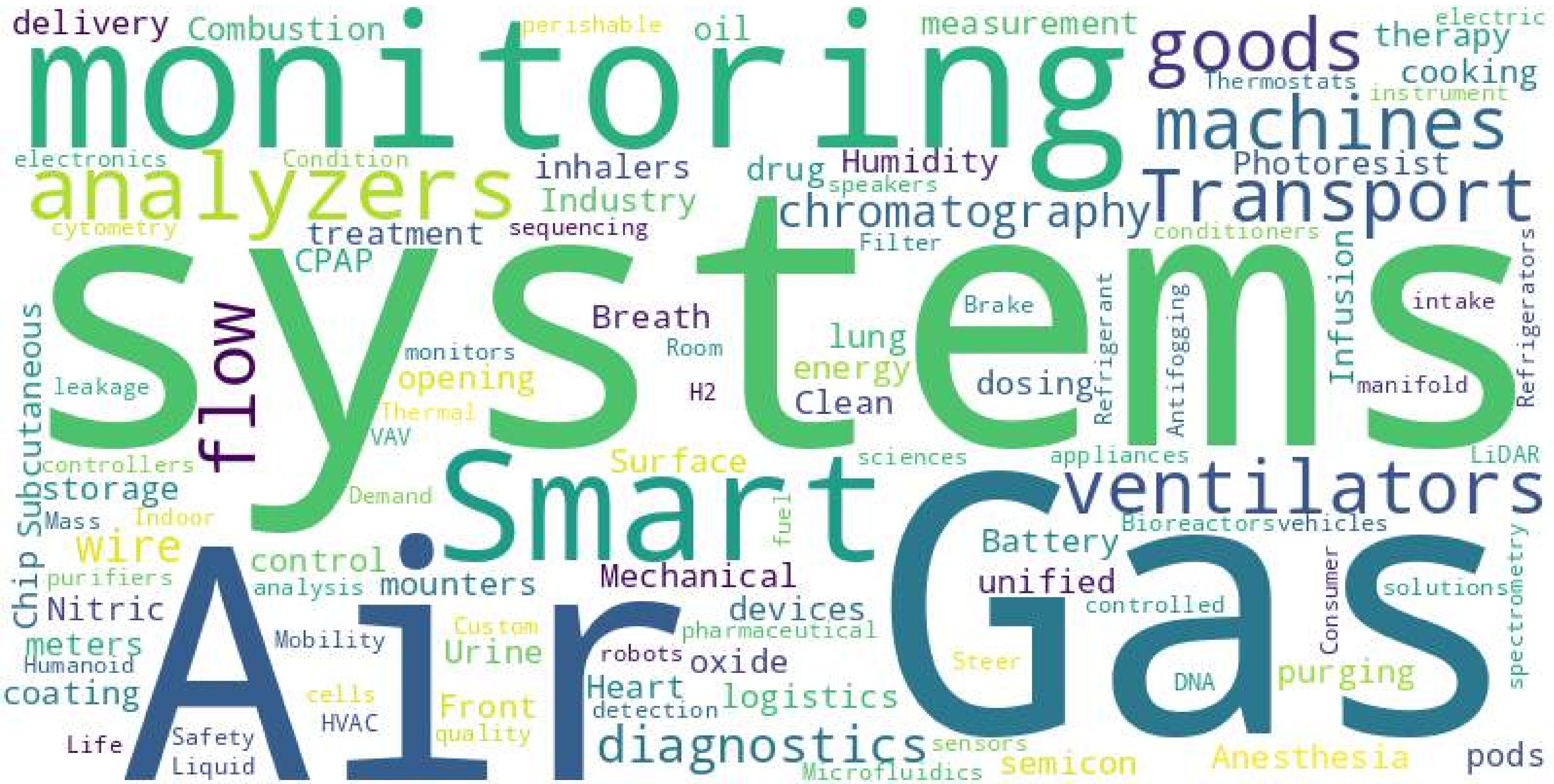
Sensirion main products: smart sensors

- Humidity
- Temperature
- VOCs/NOx
- Formaldehyde
- CO_2
- Particulate matter
- Liquid flow
- Differential pressure
- Gas flow



Sensirion product portfolio: applications

Medical and diagnostics/Semicon Industry/HVAC/ Consumer Electronics/Mobility



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Sensirion newest product: SEN6x for indoor air quality

61%

better cognitive performance

Cognitive scores were found to be higher in good vs. bad indoor air quality settings.

48%

lower disease transmission

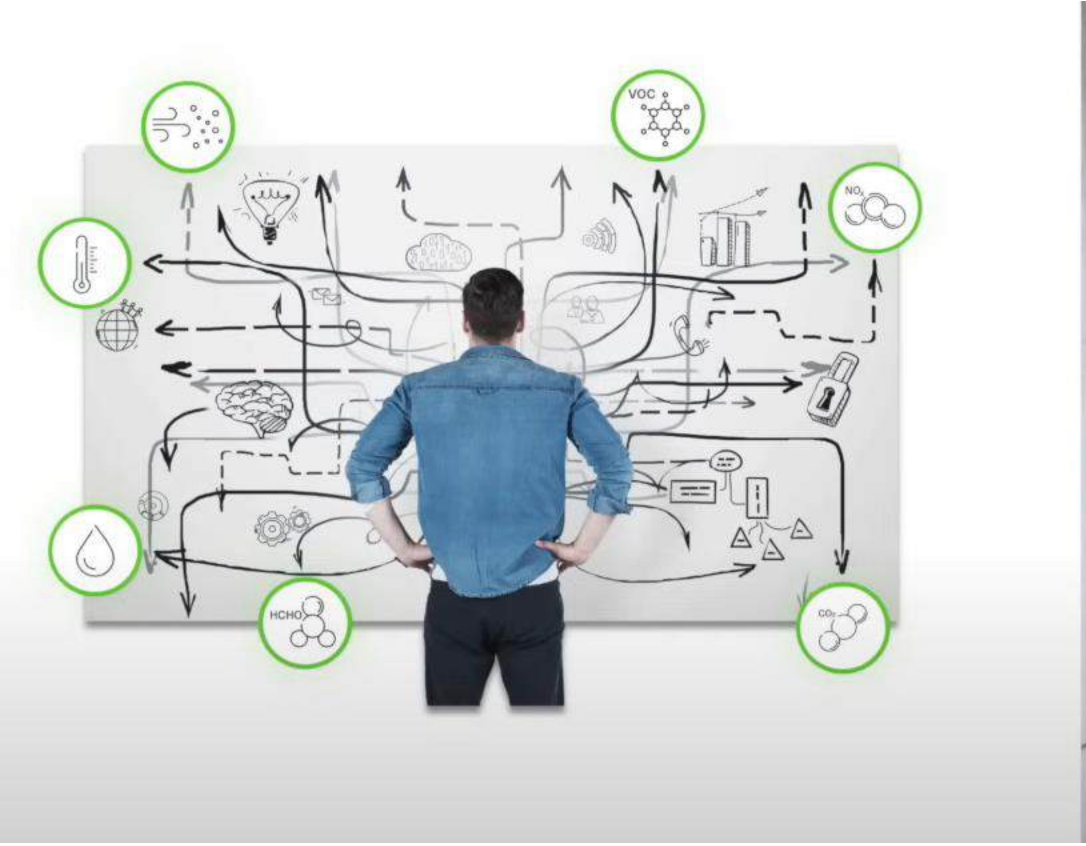
U.S. schools with improved ventilation and air filtration had lower incidence of COVID-19.

3 Mio

potential life savings

Indoor air pollution is associated with three million premature deaths annually.

Measuring Indoor Air Quality is complex…



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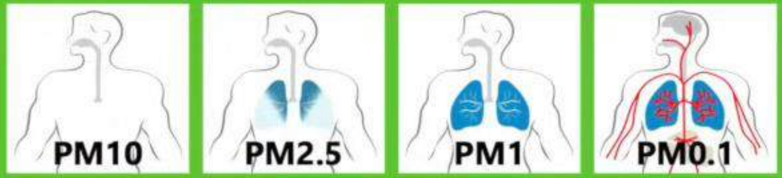
What are the key parameters to measure air quality?

Particulate Matter (PM)

- Mixture of solid particles and liquid droplets
- Can be inhaled and cause serious health issues



Nitrogen Oxides (NOx)

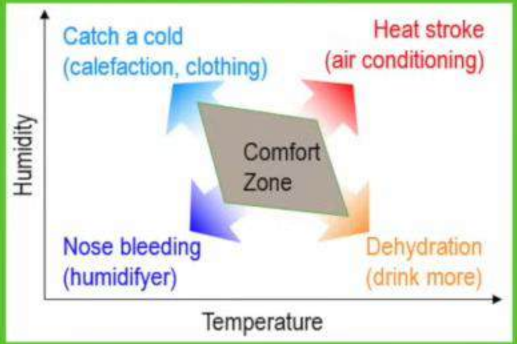
- From burning fuel and as result of combustion
- Irritate airways in the respiratory system

Volatile Organic Compounds (VOCs)

- Some VOCs are dangerous to human health (ie. formaldehyde is a toxic VOC with long-term effects)

Humidity and Temperature (RHT)

- RH and T affect daily performance, comfort, and virus/bacteria transmission.



Carbon Dioxide (CO_2)

- High CO_2 levels cause health symptoms, reduced cognitive performance and compromised well-being

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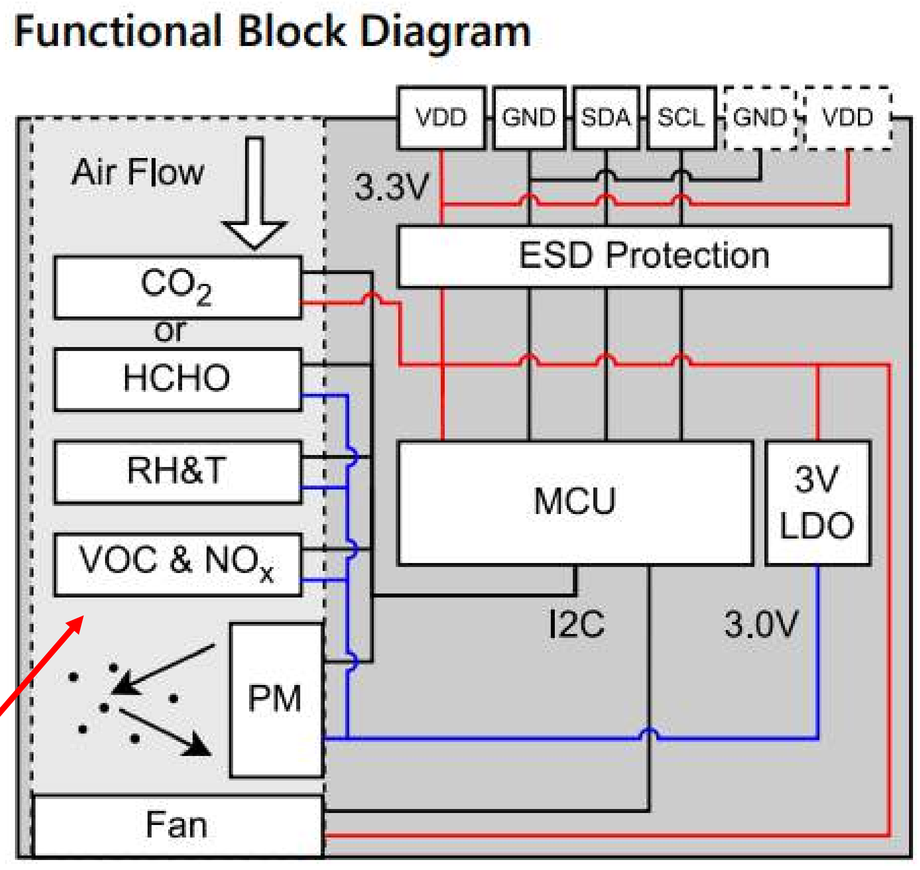
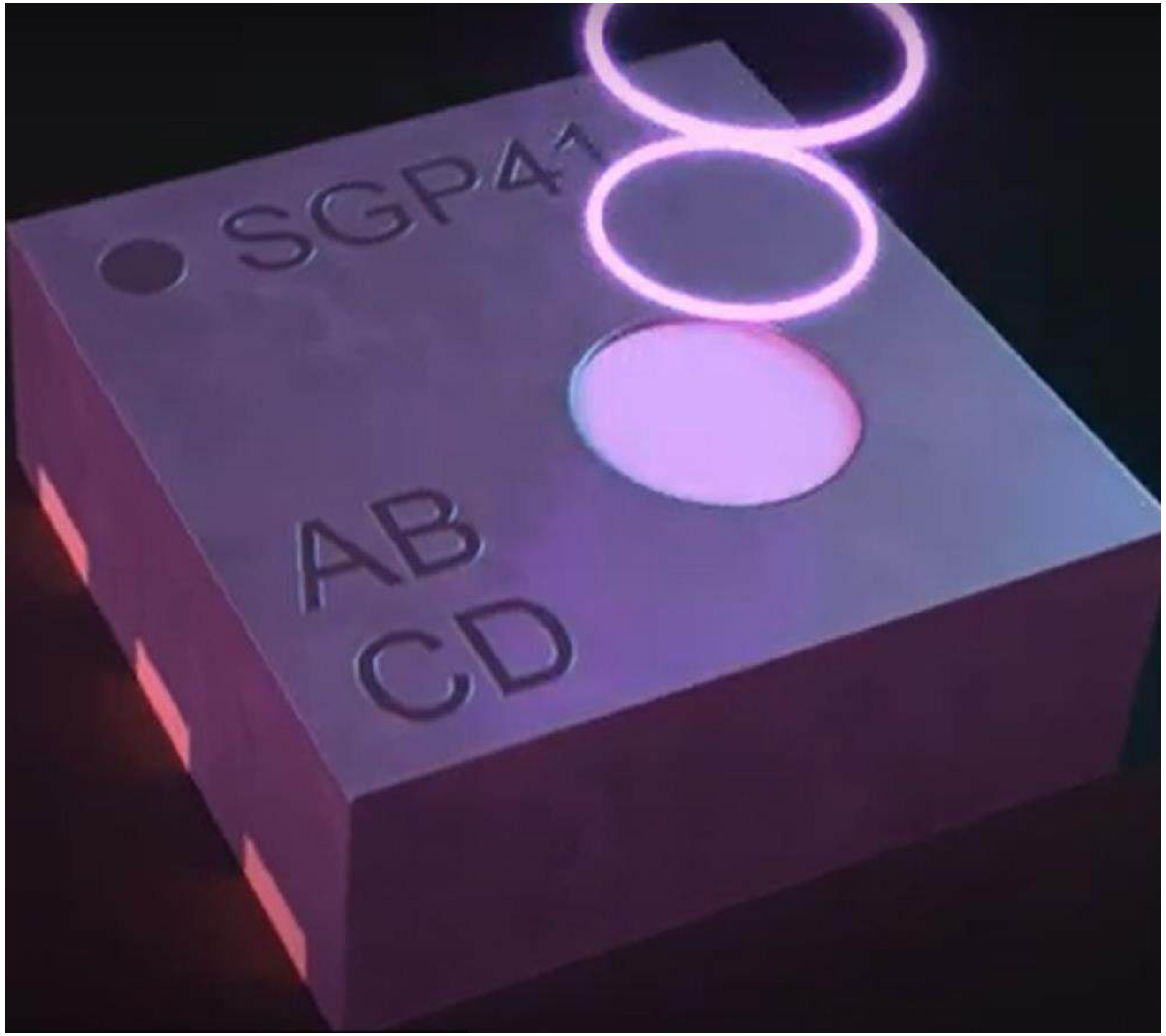
SEN6x block diagram [1]



focus on the IC design of VOC & NOx



NOx/VOC sensor
SGP4x platform
(first all integrated gas sensor on the market)

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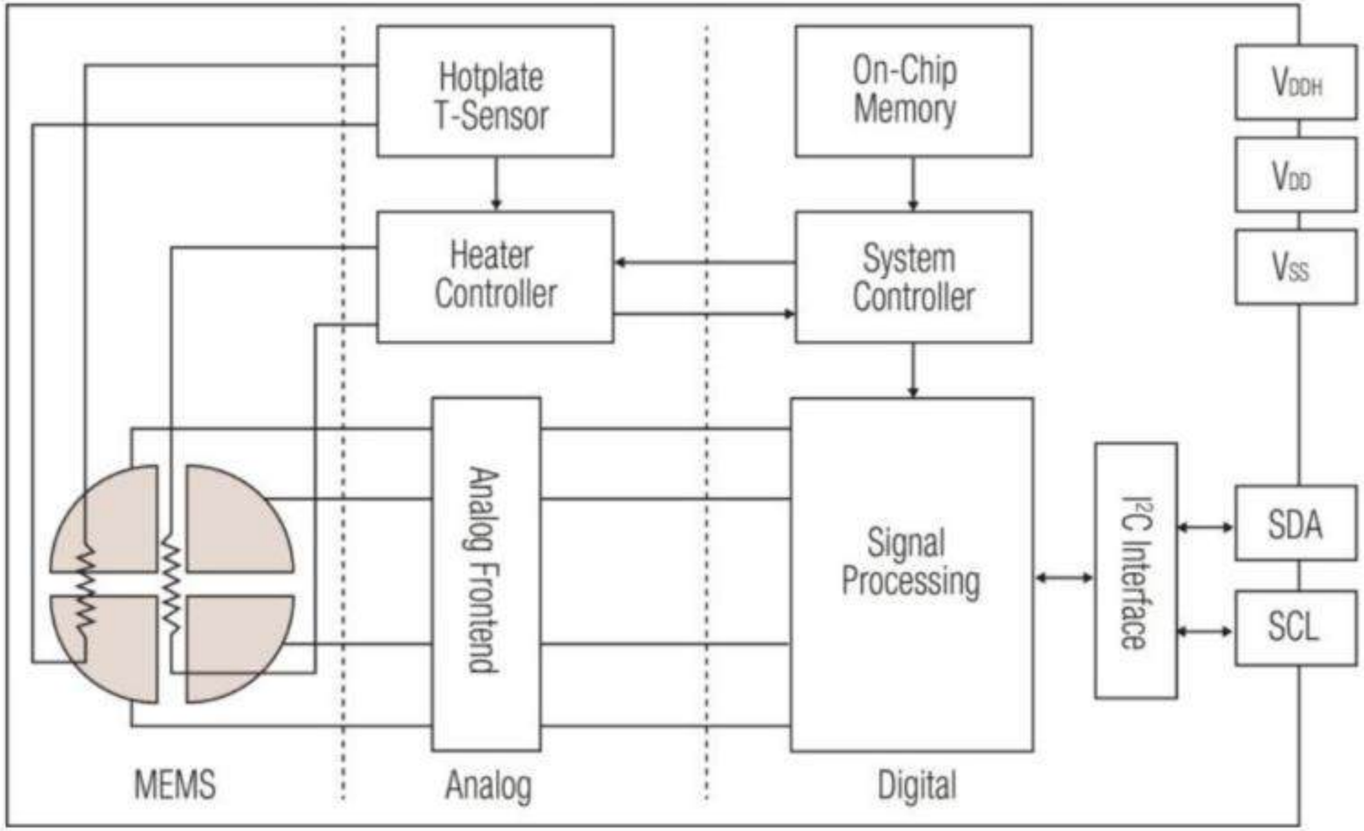
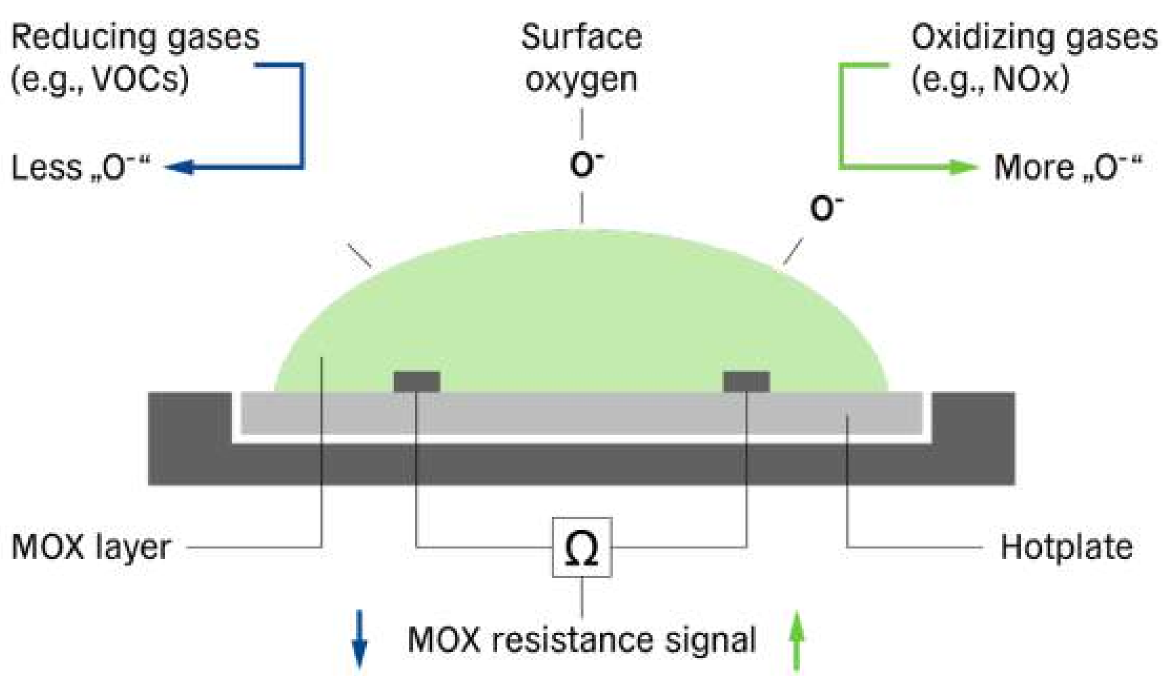
Sensor product design is an interdisciplinary process

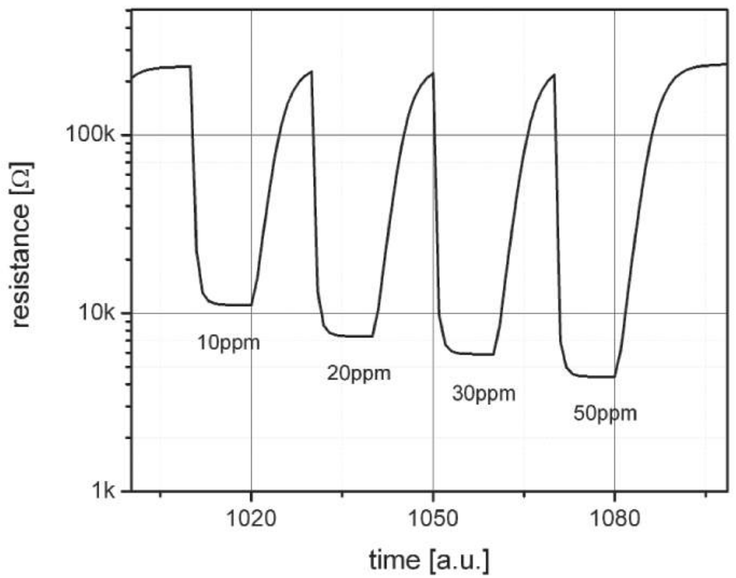
Sensirion Gas Platform, SGP, multi-pixel gas sensor [2]



Block diagram of the SGP multi-pixel gas sensor platform, including the I^2C (inter-integrated circuit) bus interface, consisting of serial data (SDA), serial clock (SCL), supply and ground voltages V_{DD} and V_{SS}. V_{DD} and the hotplate supply voltage V_{DDH} can be shorted.

MEMS: MOx gas dependent resistors & hot plate resistor[2]





$$\frac{c(R_{SENS})}{c(R_0)} = \left(\frac{R_{SENS}}{R_0}\right)^{\frac{1}{n}}$$

T_hotplate = 200 °C to 600 °C

R0: baseline MOX resistance

Technical download (sensirion.com)

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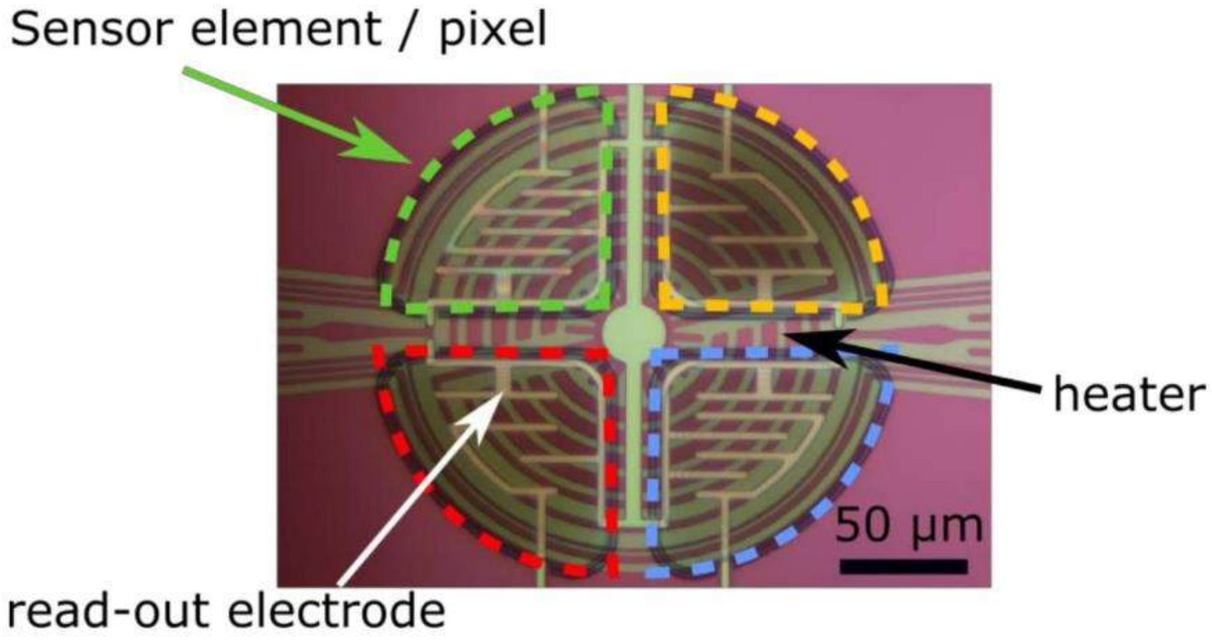
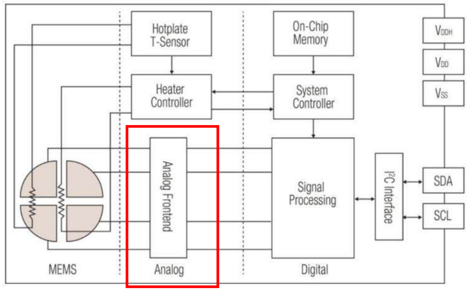
Heater, temperature sensor and MOx electrodes on a membrane (MEMS team design)



Micrograph showing the four sensing elements (indicated by colored shapes), the read-out electrodes and the heater element.

CMOS Design: Analog front end ??



Resistor dynamic range 1k to 40 Gohm/ 152 dB dynamic range (one hardware platform ??) over materials, geometries and T/RH

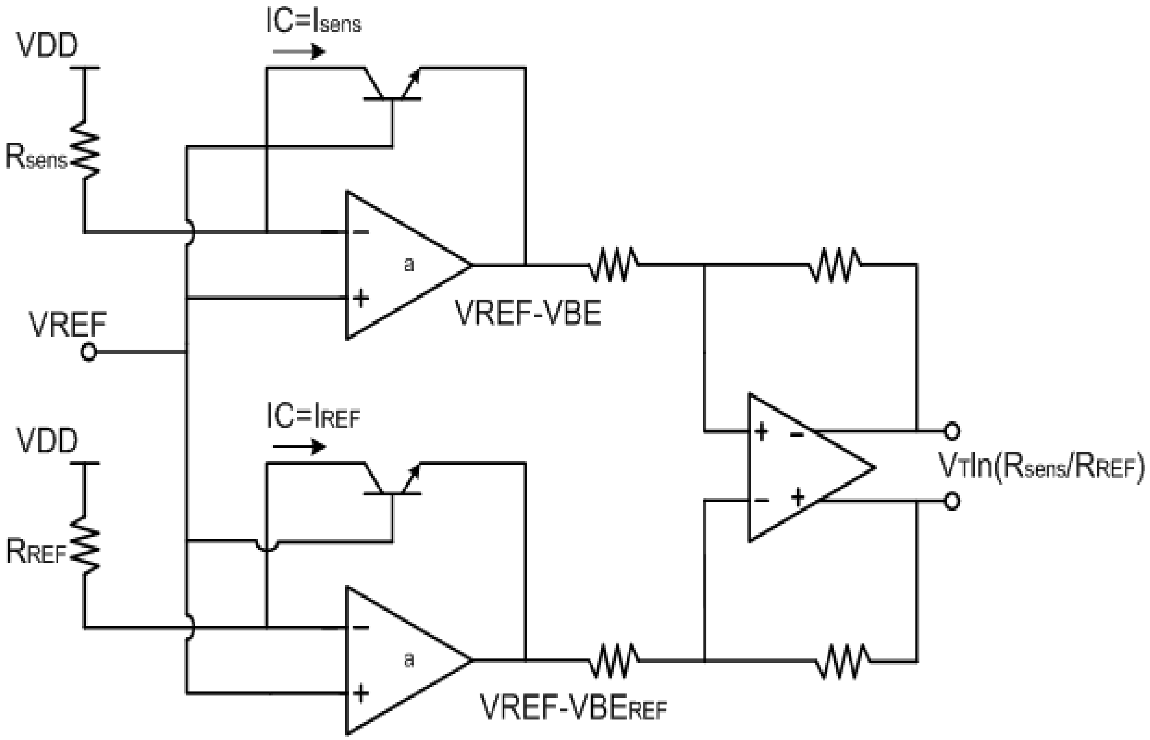
Simple and easy to scale up to allow high number of pixels

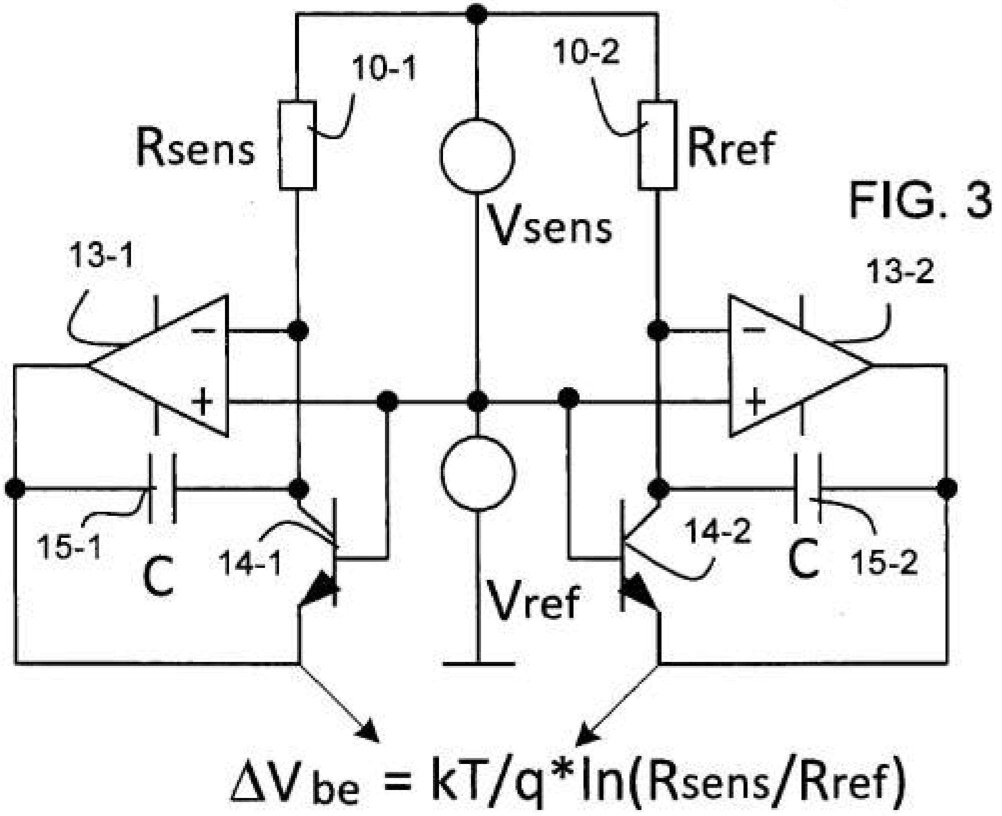
1% resolution up to 40 Gohm = very low noise

“I have loved analog design because it deals with compromises, as does life itself. It forces you to do your best.”

Willy Sansen

Differential logarithmic amplifier





Read-out circuit for resistive sensor, EP2921850B1, Inventors: Mirjana Banjevic, Ralph Steiner Vahna, Zhenhua Wang; current assignee Sensirion AG

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Block diagram of the analog front end

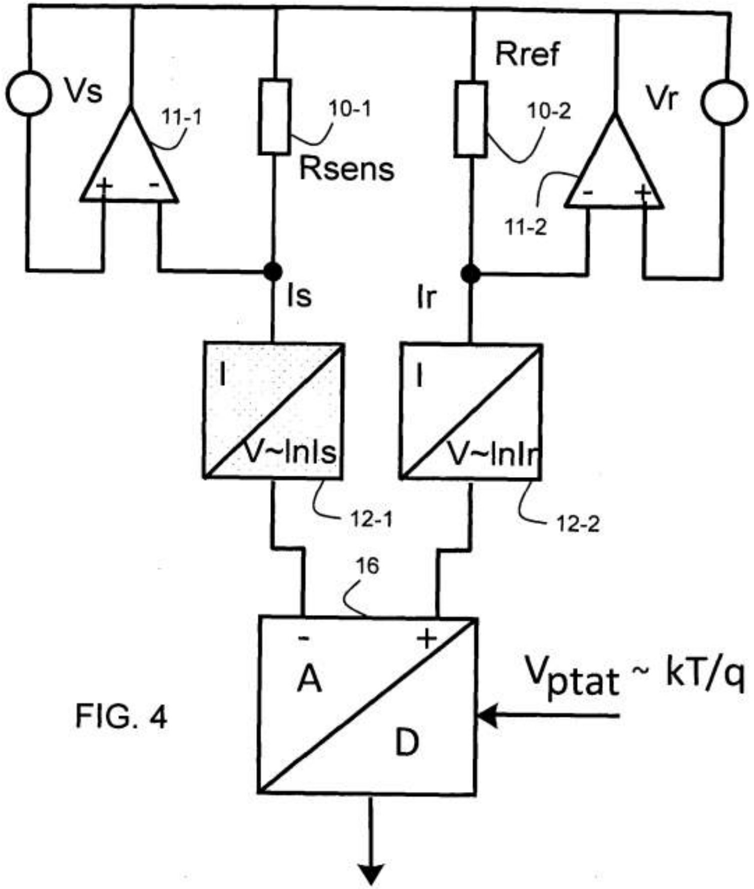


FIG. 4

$DOUT$

$$VSIG_{ADC} = \frac{kT}{q} \ln\left(\frac{R_{SENS}}{R_{REF}}\right)$$

&

$$VREF_{ADC} = \frac{nkT}{q}$$

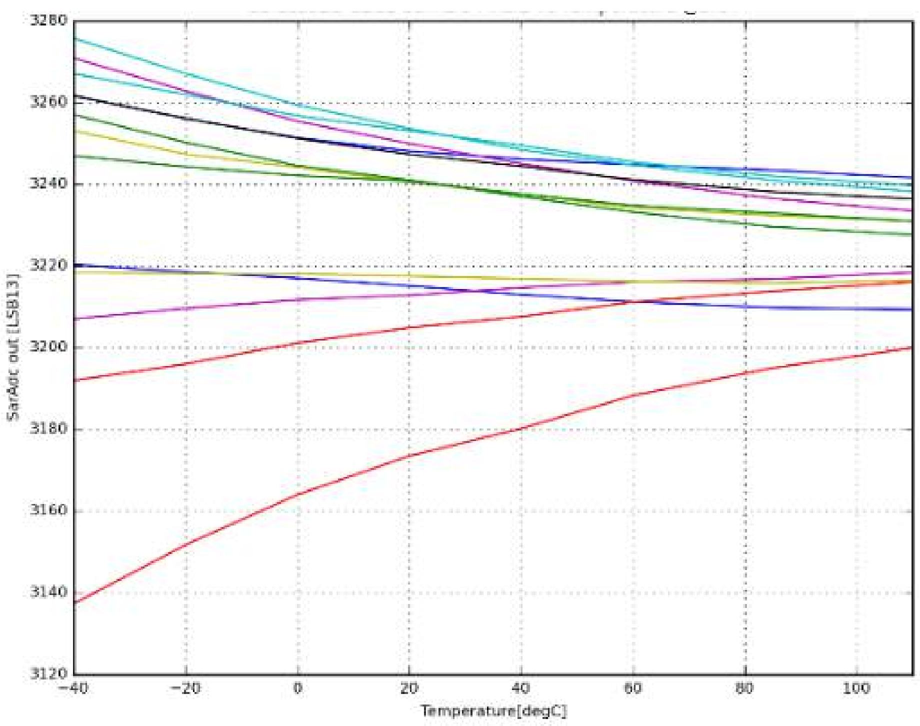
$\rightarrow$

$$DOUT \sim \ln\left(\frac{R_{SENS}}{R_{REF}}\right)$$

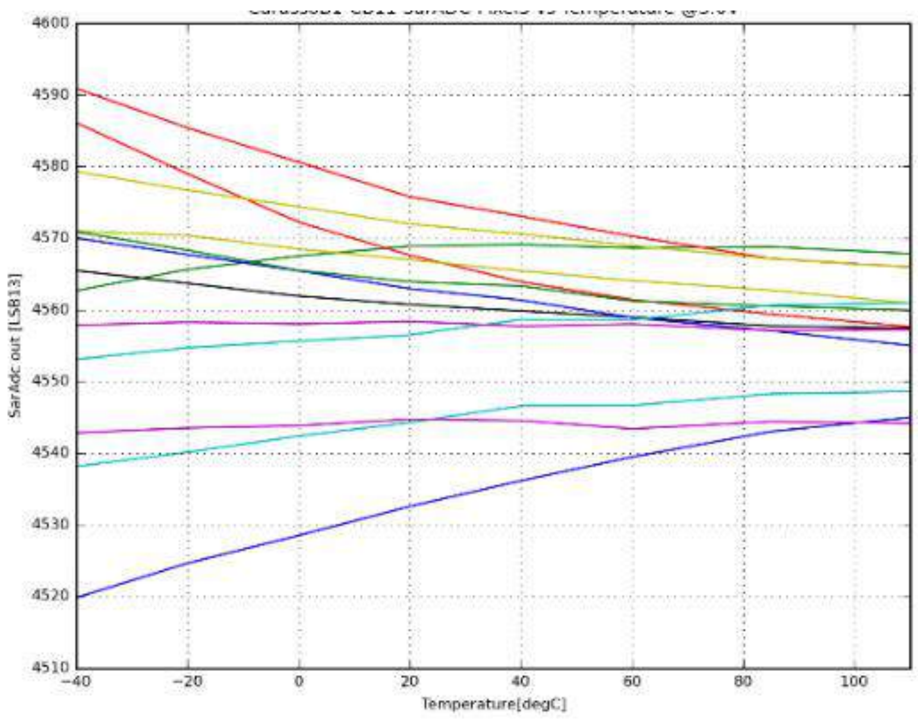
Ratiometric design: choose ADC reference to be derived from the same reference as the measured signal!

CMOS Evaluation of dies in DIL (dual in line package)

Laboratory evaluation of 64-128 dies: Process spread of the reference resistor RREF causes the spread!



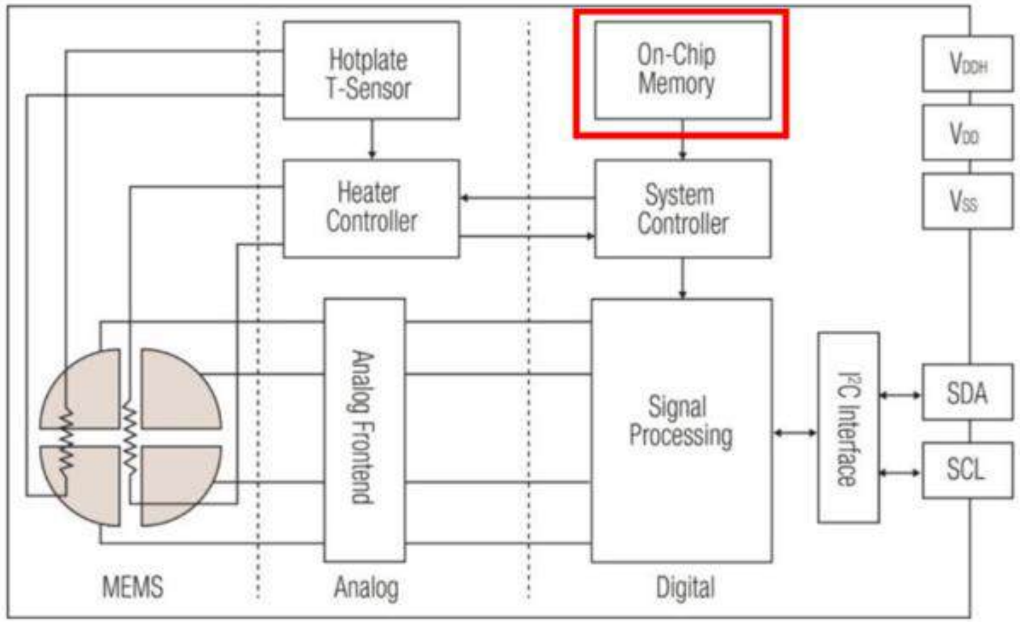
Raw Pixel 1 output (LSB 13)



Raw Pixel 3 output (LSB 13)

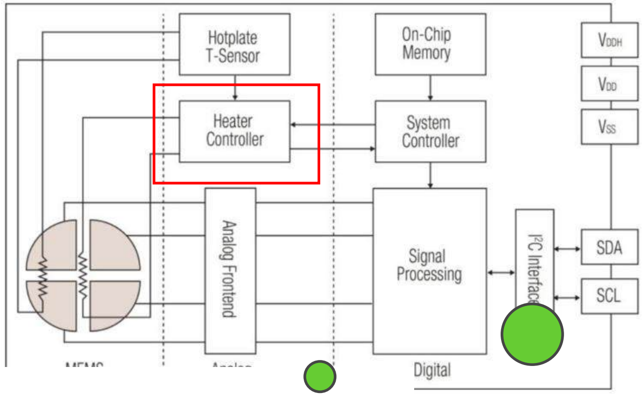
Holy grail of the CMOS design: circuits that do not require trimming?

On chip memory for trim bits and sensor output calibrated values



- Process technology variations call for CMOS trimming and calibration of the sensor output to ensure low spread
- **What do we trim**: CMOS circuits such as oscillator & voltage and current references
- **Why do we trim**: both R and C have huge tolerances due to the manufacturing tolerances (doping and geometrical deviations from the drawn devices due to masks misalignments)

Control system for stabilisation of the hot-plate temperature

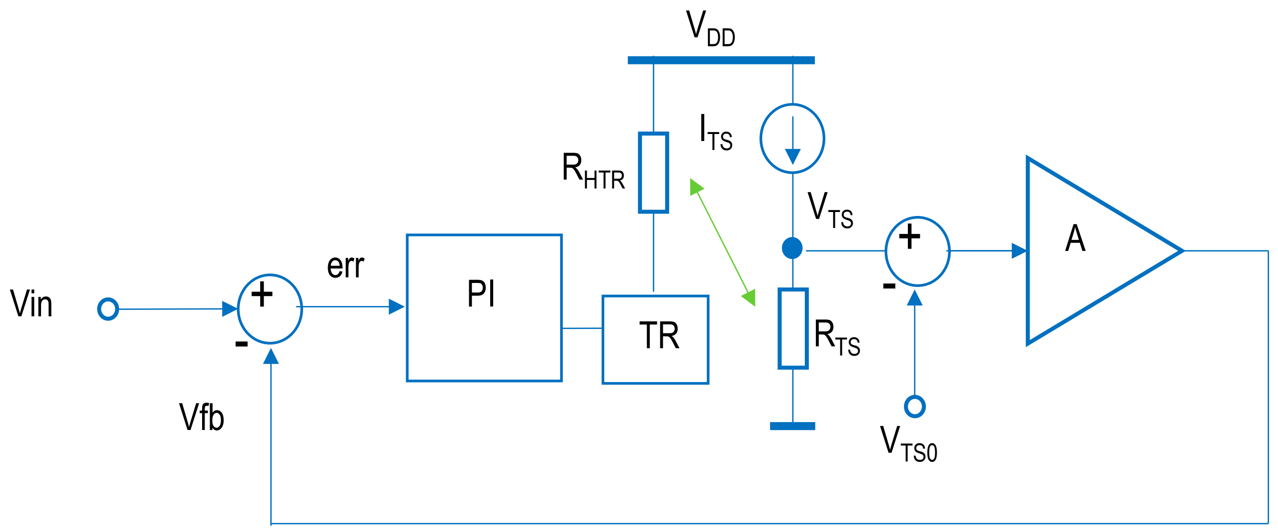


Constant current to bias the resistor serving as the temperature sensor on the hotplate
(VGB to IREF converter)

Stable temperature for the MOX resistor= constant hot plate temperature in the range 200 to 600 deg C
(PI controller)

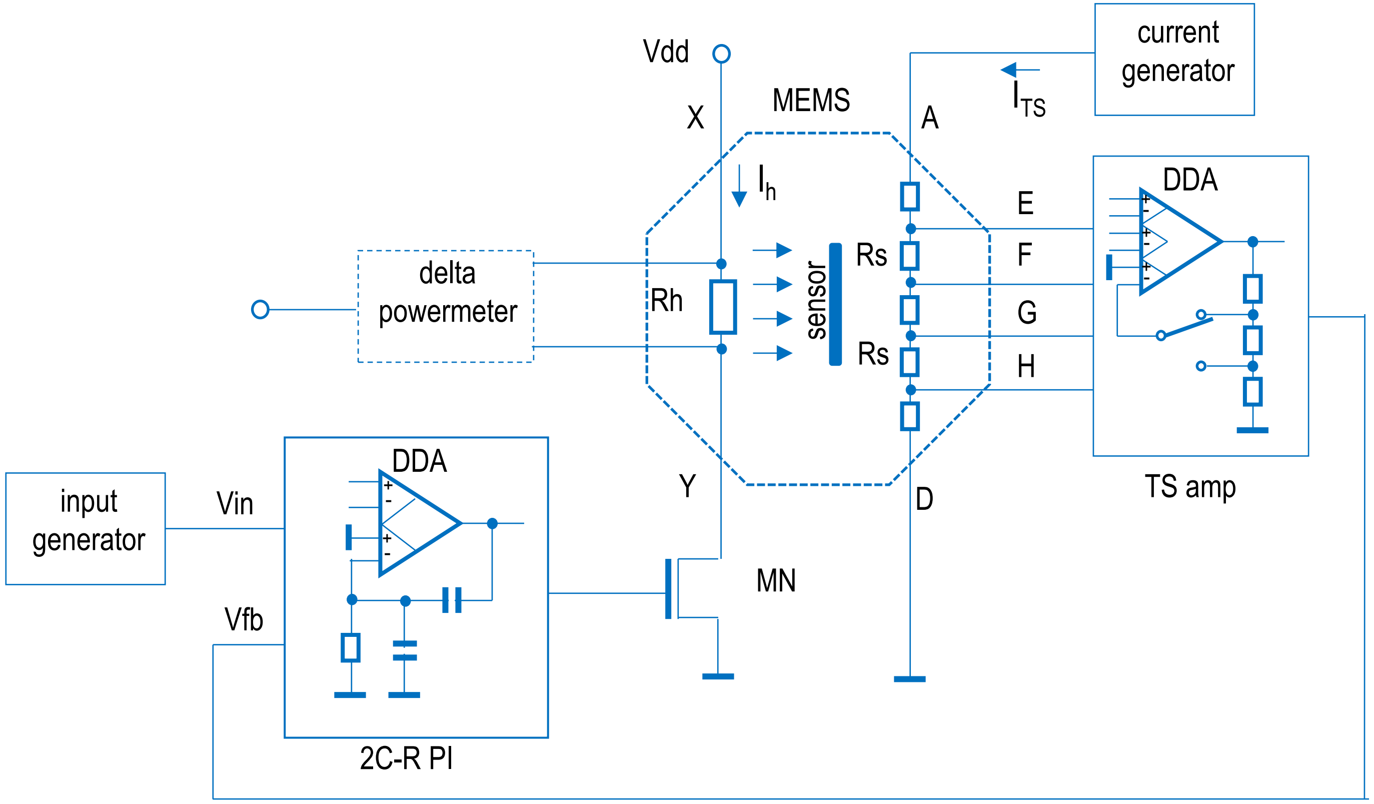
Temperature sensor: calibration & long term stability
(2 Temperature calibration & extrapolation)

Proportional and integral electro-thermal control system, PI, to keep the membrane temperature constant: concept



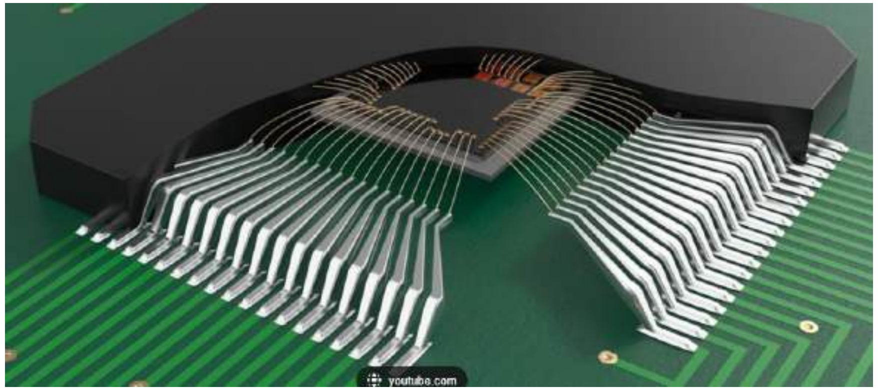
- **Vin** – analog equivalent of the set/wanted temperature of the hotplate
- **RTS** – temperature sensor resistor whose temperature coefficients determines the change of resistance
- when the hotplate is heated
- **RHTR** – heater resistor, the resistor which is heated to deliver the heat to the membrane = hotplate
- **TR** -driving transistor, MOSFET or JFET acting as a current source
- **Vfb** - feedback signal; if the loop gain is high enough Vin= Vfb that is to say the membrane is on the desired temperature!

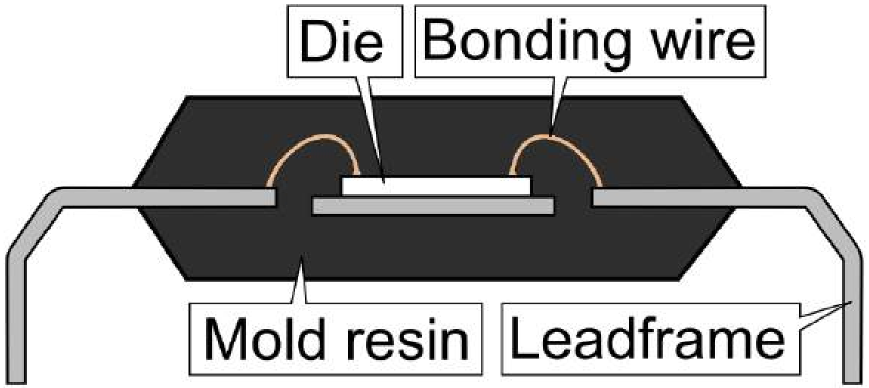
Proportional and integral electro-thermal control system, PI, to keep the membrane temperature constant: block diagram



Temperature / Power controller for MEMS sensor, Wang, Zhenhua; Banjevic, Mirjana; Mrcarica, Zeljko; Steiner Vanha, Ralph CH-8712 Stäfa (CH)

Packaging stress and its temperature dependence affect hot plate temperature stability and spread

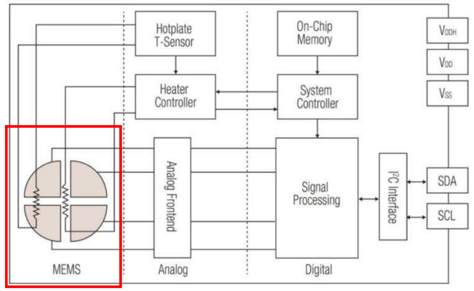




The first silicon showed high spread of the calibrated membrane temperature

- Calibration is not all powerful, especially in our case where we extrapolated the 2-point calibrated temperature at 20/80 deg to 600 deg C!
- Root cause: packaging stress evolution over temperature in a **minimum area** die induced additional offset in a critical amplifier -> back to design -> new floorplan ->new tapeout !

MEMS Design Challenges



Design of the hotplate; hotplate efficiency; hotplate stability

Heater resistor & maximum achievable temperature for 1.8 V supply

MOx electrodes and MOx material deposition

Temperature sensor: calibration & stability

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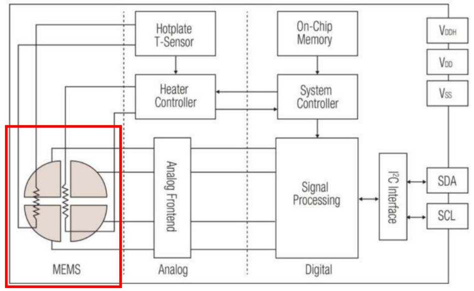
MEMS Design Reliability: lifetime 1 year? 3-10 years required!



First generation hotplates failed reliability tests - > back to the MEMS design phase

Calibration curve for gas concentration

- **What do we calibrate** to arrive at low device-to-device D2D spread: the sensor output including deviations in the physical front end signal processing electronics

$$DOUT \sim \ln\left(\frac{R_{SENS}}{R_{REF}}\right) \quad \rightarrow \quad DOUT1 - DOUT2 \sim \ln\left(\frac{R_{SENS1}}{R_{SENS2}}\right)$$

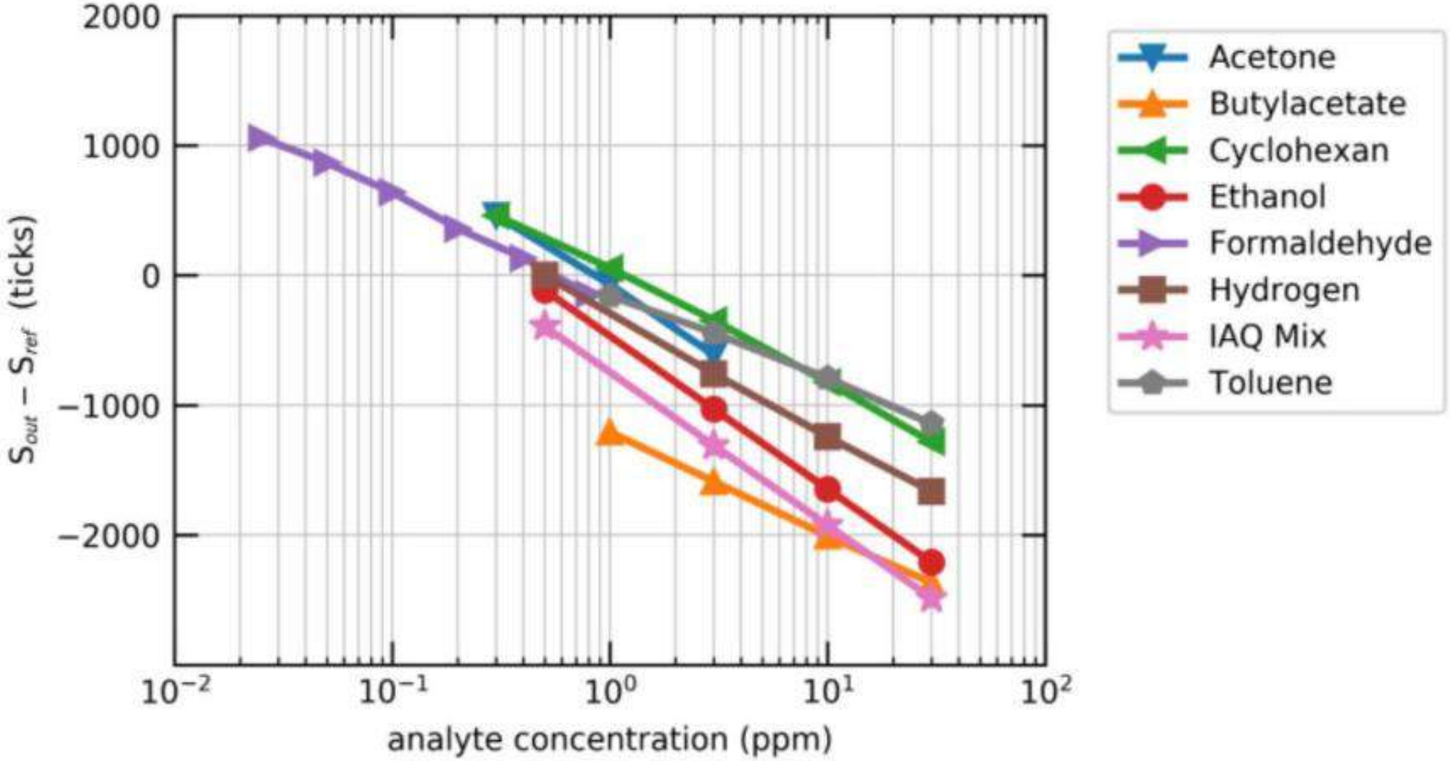
&

$$\frac{c(R_{SENS})}{c(R_0)} = \left(\frac{R_{SENS}}{R_0}\right)^{\frac{1}{n}}$$

If RSENS2 is the baseline/reference concentration *c(R0)*, then:

$$DOUT - DOUT0 \sim n * \ln\left(\frac{c(R_{SENS})}{c(R_0)}\right) = 2.3 * \mathrm{n} * \log\left(\frac{c(R_{SENS})}{c(R_0)}\right)$$

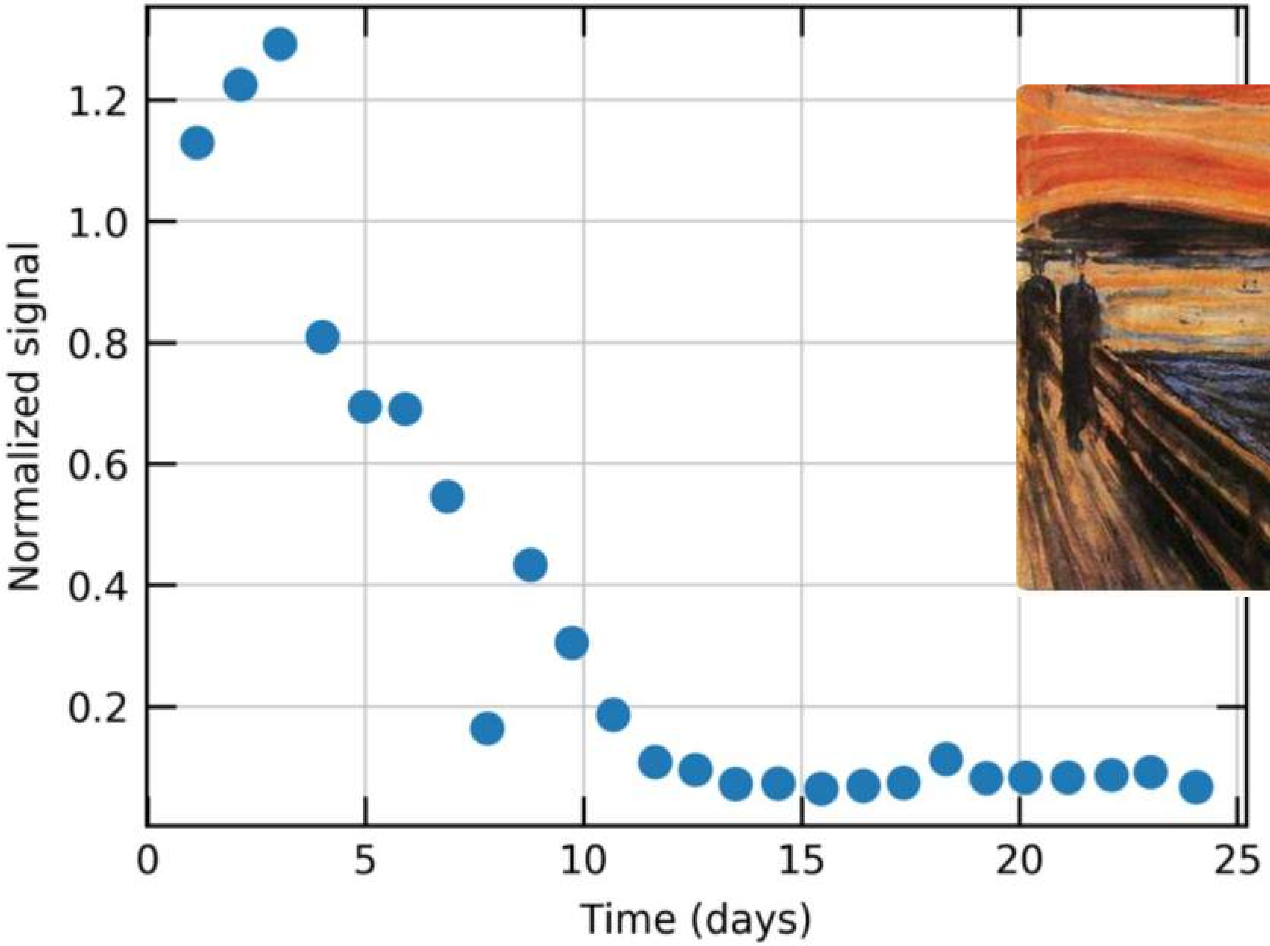
Gas calibration curve [3]

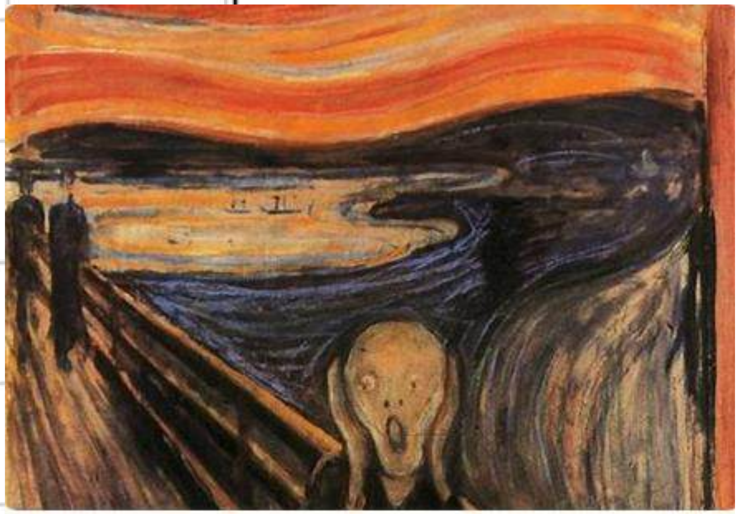


Sensor output (S_{out}) normalized to the sensor signal at 0.5 ppm H_2 (S_{ref}) as function of the analyte concentration for various gases. Indoor air quality (IAQ) Mix refers to a gas mixture proposed by Mølhave et al. representing a typical mixture of volatile organic compounds (VOCs) found in indoor environments.

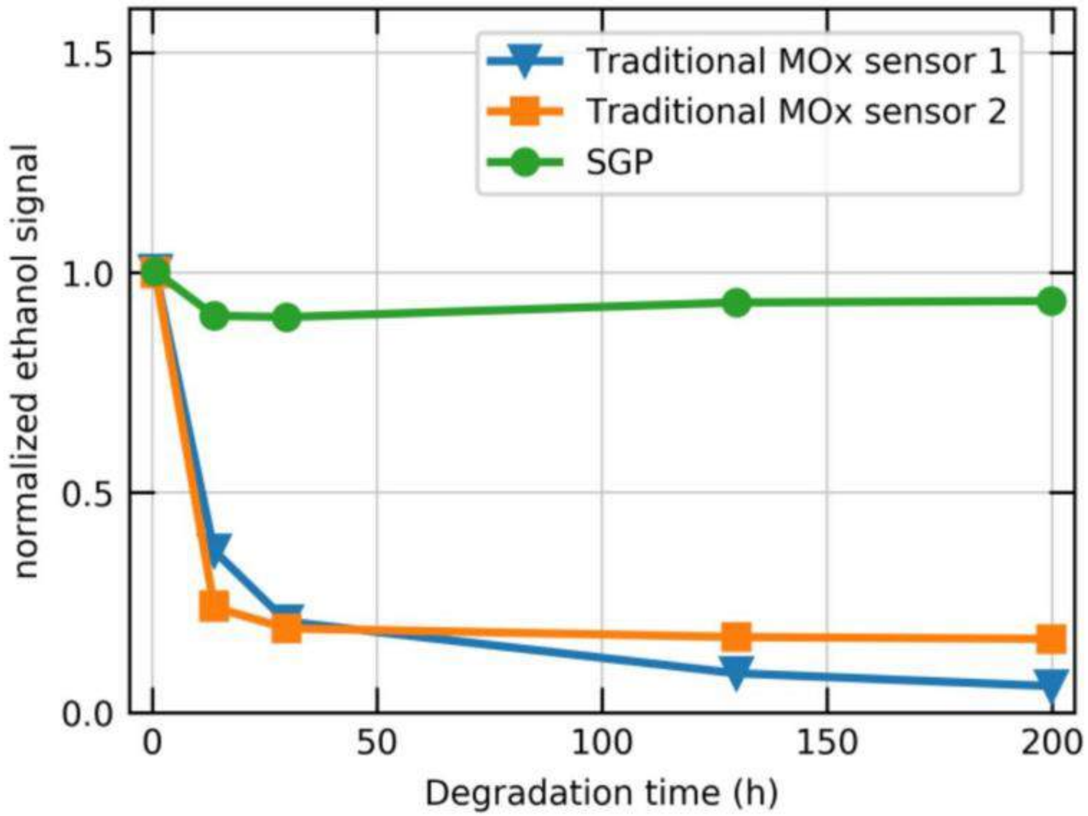
Sensor integration revealed siloxane sensitivity: show stopper ??

Total loss of sensitivity due to siloxanes present in plastic upon integration in the mobile phone





Sensirion found solution ! (4)



Long-term stability in an accelerated life-time test. The normalized ethanol concentration for different degradation time intervals is plotted for two commercially available sensors (blue and orange) and one Sensirion SGP sensor (green). The sensors have been calibrated before the accelerated lifetime test. The signals are normalized to their respective values before the test.

SGP Performance summary [4]

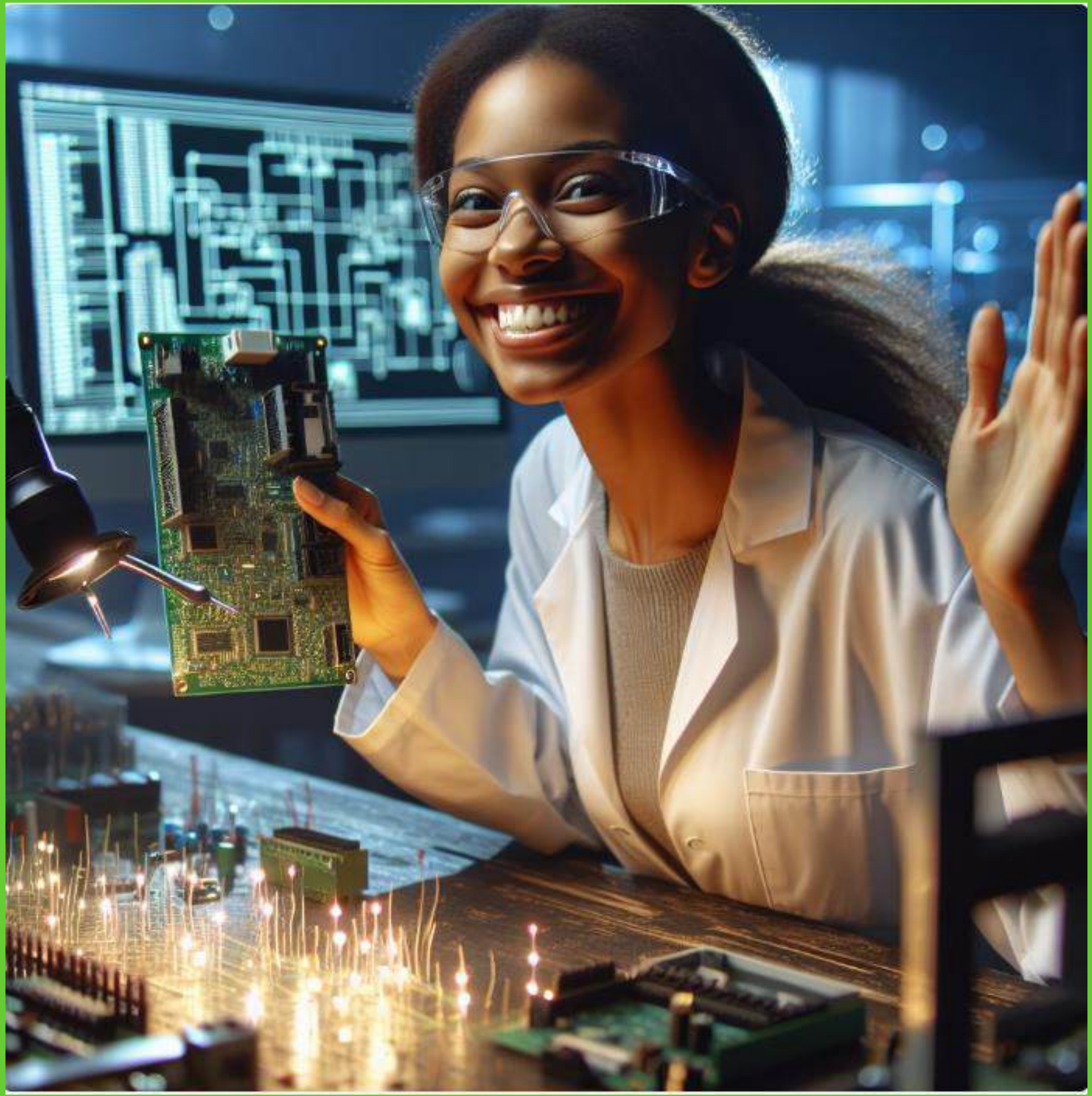
VOC Sensing for Better Indoor Air Quality with Sensirion's SGP40 VOC Sensor - YouTube

Level	Hygenic Rating	Recommendation	Exposure Limit	TVOC Concentration [ppb]
5 Unhealthy	Situation not acceptable	• Use only if unavoidable • Intense ventilation necessary	hours	2000 - 5000
4 Poor	Major objections	• Intensified ventilation / airing necessary • Search for sources	< 1 month	600 - 2000
3 Moderate	Some objections	• Intensified ventilation / airing recommended • Search for sources	< 12 months	200 - 600
2 Good	No relevant objections	• Ventilation / airing recommended	No limit	60 - 200
1 Excellent	No objections	• Target value	No limit	0 - 60

Conclusion

- Sensor design is a multidisciplinary project
- IC design has to find solution for demanding specifications of the physical front end where the limits of detection are pushed every day
- IC design for minimum area (packaging stress influence) to reduce the chip price and minimum power to extend the battery lifetime
- IC design has to facilitate calibration of the sensed physical value
- IC design for sensors is an exciting field where the contact with the physical front end/MEMS asks for novel and creative solutions

THESE SOLUTIONS ARE YOURS TO FIND AND HAVE FUN ALONG THE WAY!



SENSIRION

References

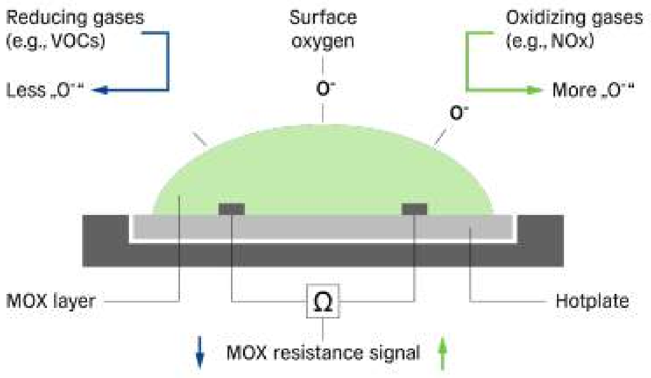
1. Datasheet on SEN6x (sensirion.com)
2. Technical download SGP4x (sensirion.com)
3. Daniel Ruffer, Felix Hoehne, Johannes Buhler, *New Digital Metal-Oxide (Mox) Sensor Platform*, Sensors (Basel), 2018, doi: 10.3390/s18041052
4. *Siloxane-resistant MOX gas sensor brings smartphones one step closer to Star Trek's tricorder* - Electronic Products by Andrea Orzati, Sensirion AG

ADDITIONAL SLIDES

MOX Sensor’s Application Notes

What is a MOX sensor?

Learn about the possibilities and limitations of MOX sensors and the strength of Sensirion's SGP4x products



A MOX sensor reacts to most changes in gas composition

In a nutshell, a MOX sensor is a heated surface of a metal oxide that changes its electrical resistance depending on the oxygen content on its surface. Oxidizing gases like NO_x (providing more oxygen than ambient air) increase the resistance, whereas reducing gases like VOCs (consuming oxygen by being combusted on the metal oxide surface) reduce the resistance. Humidity also impacts the MOX sensor signal, as water vapor usually behaves as a reducing gas. This can be compensated for by using a humidity sensor such as Sensirion's SHTxx. Sensirion's SGP4x sensors feature on-chip humidity compensation.

> MOX sensors are excellent devices to detect relatively short-term changes in gas compositions and better understand the activities associated with gas events in indoor environments.

MOX sensors are semiquantitative and broadband-sensitive

By calibrating the MOX resistance to a specific target gas, under laboratory conditions the absolute concentration of the target gas in air can be measured. However, under field conditions, two aspects hamper MOX sensors' ability to provide absolute concentration outputs.

Firstly, a well-defined baseline is required. A baseline is a reference point for a well-known concentration of the target gas. Since the signal of a MOX sensor usually drifts over time, this must be compensated for in the field. However, under field conditions, it cannot be ensured that the sensor is exposed to the exact same concentration it has been calibrated for, leading to an erroneous concentration output.

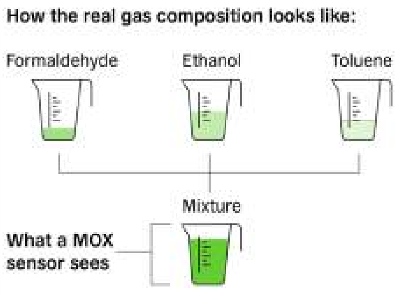
Secondly, a MOX sensor is a broadband-sensitive device, meaning that it reacts to multiple gases and cannot distinguish between them. Thus, calibrating such a sensor to a specific gas or gas mixture – as it is usually the case with digital MOX sensors – does not make these devices selective to this particular gas (mixture). For instance, a calibrated sensor could show 1000 ppb as the output, whether it is related to 500 ppb of ethanol or 2000 ppb of toluene. However, through material design and operation mode engineering, it is possible to enhance the selectivity to specific gas groups – namely, reducing and oxidizing gases – to distinguish between VOC and NO_x events, as it was done with Sensirion's SGP41.

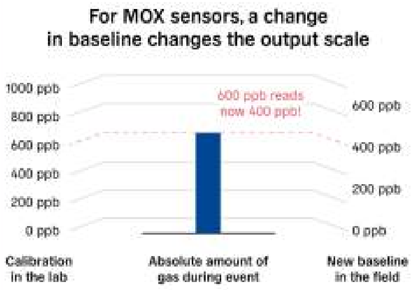
Nevertheless, because MOX sensors are sensitive and fast, they can reliably report short-term changes in the gas composition relative to a certain period in history (e.g., the past 24 hours).

Further reading

[What are reducing gases?](#)

[What are oxidizing gases?](#)

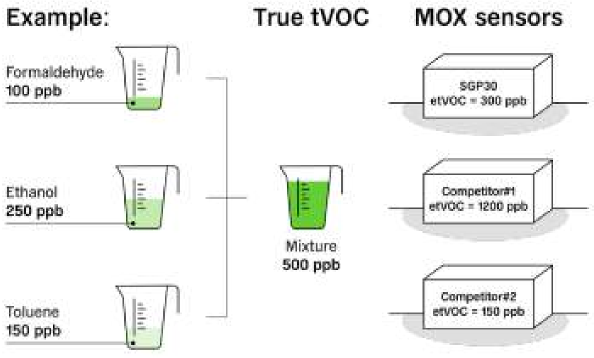




Figures above demonstrate the limitation to provide a concentration output for a specific target gas by a MOX sensor due to broad band sensitivity (top) and varying baseline conditions in the field (bottom).

Is it possible to map the output of a MOX sensor to a norm?

Learn why a MOX sensor output maps only under laboratory conditions to a norm



To measure tVOC, a sensor must be capable of measuring each individual VOC

tVOC stands for total volatile organic compounds. It is by definition the sum of all VOCs present in a given environment. Most health-related indoor air quality levels, such as those published by the German Federal Environmental Agency or the WHO, as well as building norms such as RESET or LEED, refer to tVOC. To measure this accurately, an analytical device is needed that can selectively quantify hundreds of VOCs individually at the same time, such as a gas chromatograph. These devices are large and expensive and are not suited for consumer devices such as indoor air quality monitors or air purifiers; however, they are state-of-the-art.

In the lab, MOX sensors can be used with concentration outputs for the gas (mixture) they were calibrated for. In the field, MOX sensors are semiquantitative indicators (e.g., for VOCs), but not concentration detectors for tVOC.

Limitations of MOX technology

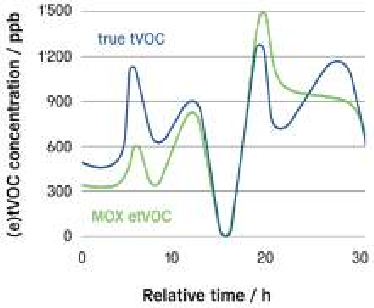
The MOX sensors which are currently available on the market (including Sensirion's SGP4x) can be calibrated for one specific gas or gas mixture in the laboratory. This allows a MOX sensor to accurately measure the concentration of the calibrated gas (mixture) in a controlled environment. However, the gas composition of VOCs in the field constantly and widely varies; therefore, all VOC compounds must be measured individually, as stated above. This means that an etVOC (where "e" stands for "equivalent") output from a MOX sensor may deviate from the true value by a factor of two (corresponding to −50/+100 %) or more. It also can happen that the sensor output moves in the opposite way compared to the true tVOC value. This behavior is called broadband sensitivity because the sensor is reacting to multiple gases at the same time, but cannot distinguish which gas is causing the signal change.

Furthermore, under field conditions it cannot be guaranteed that the reference gas conditions used for calibration (which is called baseline) are also exactly present in the field. This is necessary to compensate for the drift which almost every MOX sensor faces over time. This adds an additional, substantial error to the concentration readings. It is therefore important to understand that current MOX sensors can only work as semiquantitative VOC indicators, not as true tVOC detectors. The same arguments also are valid for the NO_x output.

These facts also explain why etVOC concentration outputs from MOX sensors by different manufacturers often do not match.

Further reading

What is a metal oxide (MOX) sensor?



The plot above shows a typical field situation for VOCs. Due to its nature, the etVOC output of a typical MOX sensor deviates significantly from the true tVOC concentration. Some events may even not be detected by the MOX sensor if it is not sensitive enough to this particular VOC.

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What are reducing gases?

Harmless VOC sources	Harmful VOC sources
breath, cosmetics, perfumes, drinks and food	carpets, furniture, building materials, paints, lacquers, solvents, cleaning supplies, cooking, plastics, adhesives, glues, arts and craft supplies

Reducing gases like to react with oxygen

Simply speaking, reducing gases are compounds which react with atmospheric oxygen catalyzed on heated surfaces, such as the metal oxide layer of SGP4x sensors. Some examples of reducing gases are hydrogen (H_2), volatile organic compounds (VOCs), carbon monoxide (CO) and methane (CH_4). Typical VOC MOX sensors, like the SGP4x products, react only to H_2 and VOCs.

Volatile organic compounds are the number one indoor gas pollutant

Volatile refers to compounds that like to be in the gas phase (as opposed to the solid or liquid phase). As a result, they tend to accumulate in indoor air, so VOC concentrations indoors are much higher than outdoors.

There are numerous sources of VOCs in indoor air environments, some – but not all – of which are harmful gases.

Organic in this context means any gaseous compound that contains carbon–hydrogen bonds. Thus, the list comprises hundreds of substances. Prominent examples are ethanol and formaldehyde. Ethanol can be considered a harmless gas in indoor air, but formaldehyde is classified as unhealthy even at very low concentrations. Therefore, the term VOC does not equate to harmful.

Many products in our daily lives off-gas VOCs, so indoor VOC concentrations are higher when more (and newer) off-gassing sources are in the room and the ventilation in the room is poorer. Such sources include cleaning supplies, plastics, paint and lacquers, adhesives and glues, solvents, cosmetics and perfumes, furniture, carpets, building materials and arts and craft supplies – but also fumes from cooking, food and drinks and even the air we exhale. Also note that humans exhale H_2 gas as well, so a typical VOC MOX sensor will also react to this gas even if the concentration of VOCs is low.

SGP4x sensors greatly extend the perception of the human nose

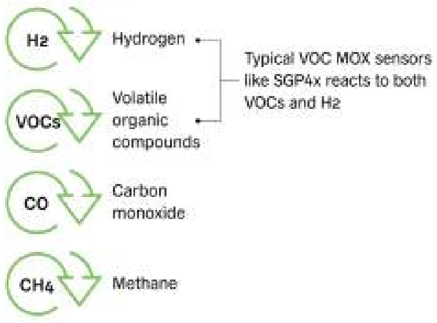
Although the human nose is a great gas detector, it fails at detecting odorless gases or those which are found at low concentrations. In this respect, SGP4x sensors add great value to indoor air quality applications by monitoring most VOCs at the same time with the VOC Index signal. However, the sensors cannot distinguish between individual VOCs. For measuring a specific VOC, Sensirion offers additional solutions, such as the SFA30 for formaldehyde detection.

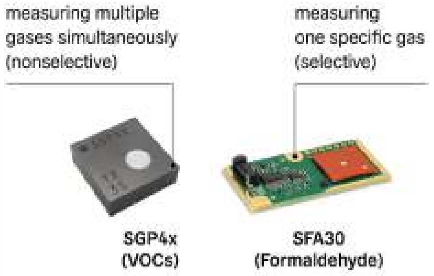
Further reading

[What is Sensirion's VOC Index?](#)

[Is it possible to map the output of a MOX sensor to a norm?](#)

Reducing gases





Typical VOC MOX sensors such as Sensirion's SGPxx sensors are sensitive towards most VOCs and human related H_2 (top). For selective gas detection, products like SFA30 should be used (bottom).

What are oxidizing gases?

NO_x sources

Outdoor NO_x entering house through window (factory emissions and nearby traffic), gas powered cooking stoves, cigarette smoking, gas powered water heaters, candles and wood stoves

NO_x are the main indoor gas pollutants beside VOCs
Simply speaking, oxidizing gases are highly reactive gases that contribute more oxygen to combustion processes than normal air does. The most common examples are nitrogen oxides (NO_x), ozone (O_3) and oxygen (O_2) itself. NO_x mainly refers to nitric oxide (NO) and nitrogen dioxide (NO_2), which both co-exist. Highly reactive means that they are unstable when they come into contact with surfaces. Therefore, oxidizing gases are usually much less abundant indoors compared to volatile organic compounds (VOCs). However, if there is a constant source, indoor concentrations can reach harmful levels.

In indoor air environments, NO_x gases are the most relevant pollutants out of the oxidizing gases. Any long-term exposure at even small concentrations can be considered harmful.

WHO Global Air Quality Guidelines, ISBN 978-92-4-003422-8

Sources of NO_x are always related to combustion processes, such as cooking on a gas-powered stove, smoking a cigarette, burning candles, using a fireplace or heating water in a gas-fired residential boiler. O_3 is usually emitted from devices (e.g., a sterilizer), which either produce O_3 directly (via a spark) or as a by-product (via UV light). In closed rooms, O_3 decomposes rather quickly within 15 minutes, while NO_x gases can remain in the air for several hours, thus posing the higher risk to human health indoors.

Oxidizing gases are hazardous even at small concentrations
Highly reactive also means that oxidizing gases are powerful irritants that harm the lungs and mucous membranes when inhaled – even at low concentrations. In contrast to VOCs, oxidizing gases are also an outdoor problem: human activities (industry or motorized traffic) lead to elevated levels of O_3 and NO_x in outdoor air in or near cities. In this way, oxidizing gases may also enter through an open window. In 2021, the World Health Organization updated its guidelines regarding air quality, greatly lowering the recommended values for exposure to O_3 and NO_x.

SGP41 greatly extends the perception of the human nose
The human nose is not able to reliably warn us when these very low thresholds are exceeded, let alone exceeded for a long time. In this respect, SGP41 adds great value to indoor air quality applications by monitoring mainly NO_x with its NO_x Index signal, in addition to VOCs.

Further reading
What is Sensirion's NO_x Index?

NO_x indoor gas pollutants may cause or facilitate various diseases mainly related to respiratory issues when exposed over a prolonged time.

What is Sensirion's NOx Index

Nose	NO_x Index
Reference = past few minutes /hours	Reference = past 24 hours
Relative intensity (weak, distinct, strong)	Relative intensity NO_x Index 1-500
Different odors distinguishable	Different odors not distinguishable
Sensitive to odors	Sensitive to oxidizing gasses

The NO_x Index is the optimal tool to monitor NO_x conditions

Instead of concentration output, which cannot be properly provided under field conditions, the NO_x Index much better exploits the capabilities of a MOX sensor by being sensitive towards oxidizing gases. For this, the raw signal of the SGP41's NO_x pixel is processed by Sensirion's powerful Gas Index Algorithm on an external microcontroller. The NO_x Index describes the current NO_x condition in a room relative to the sensor's recent history. In this way, the NO_x Index behaves like a human nose. Assuming that we are entering a room from outside, our nose will take the air composition outside the room as an offset (baseline) and provide us with feedback if it recognizes higher or lower levels of gases when entering the room. The NO_x Index performs similarly by applying a moving average over the past 24 hours (called the learning time).

The NO_x Index mimics the human nose's perception of odors with a relative intensity compared to recent history. In combination with the VOC Index, it helps to distinguish different events and user activities.

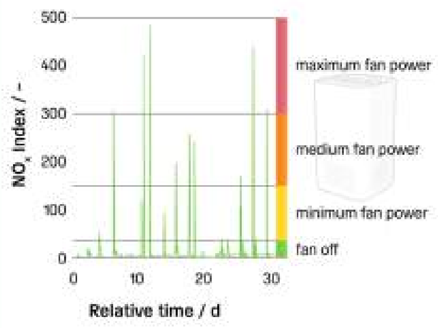
This is a very helpful feature because the NO_x Index thus works in any environment. On the NO_x Index scale, this offset is always mapped to the value of 1, making the readout as easy as possible: an NO_x Index above 1 means that there are more NO_x compounds compared to the average (e.g., induced by cooking on a gas stove), while an NO_x Index close to 1 means that there are (nearly) no NO_x gases present, which is th What is a MOX sensor? (or induced by fresh air from an open window, using an air purifier, etc.).

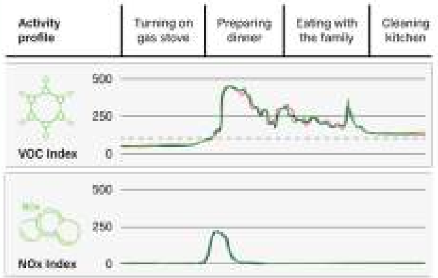
Also, our nose perceives odors on a scale of relative intensity (weak, distinct and strong), but it cannot tell us if the concentration of one odor is truly higher than the concentration of another. Therefore, all NO_x events are quantified on the same limited scale of the NO_x Index, ranging from 1 to 500. In contrast to the VOC Index, there is no gain adaptation for the NO_x Index because the gas composition of NO_x events usually does not vary as much as in VOC events. The NO_x Index scale enables a fixed mapping of the NO_x Index to an action that a device should execute (e.g., triggering an air purifier when the NO_x Index is above 20).

Further reading

What is Sensirion's NO_x Index?

More about Gas Index Algorithm and its tunability: *Sensirion's VOC and NO_x Indices for Indoor Air Applications* (upon request)





The figure at the top demonstrates a possible example implementation of the NO_x Index in an air purifier. At the bottom, one can see a typical activity profile in a kitchen for which the simultaneous monitoring of VOC and NO_x Indices helps distinguishing different types of events.

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What is Sensirion’s VOC Index

Nose	VOC Index
Reference = past few minutes /hours	Reference = past 24 hours
Relative intensity (weak, distinct, strong)	Relative intensity VOC Index 1-500
Different odors distinguishable	Different odors not distinguishable
Sensitive to odors	Sensitive to VOCs and H_2

The VOC Index is the optimal tool to monitor VOC conditions

Instead of etVOC concentration output, which cannot be properly provided under field conditions, the VOC Index utilizes the capabilities of a MOX sensor much more effectively. To achieve this, the raw signal of the SGP4x's VOC pixel is processed by Sensirion's powerful Gas Index Algorithm on an external microcontroller. The VOC Index describes the current VOC status in a room relative to the sensor's recent history. In this way, the VOC Index behaves like a human nose. Assuming that we are entering a room from outside, our nose will use the air composition outside the room as an offset (baseline) and provide us with feedback if it recognizes higher or lower levels of VOCs when entering the room. The VOC Index performs a similar calculation by using a moving average over the past 24 hours (called the "learning time") as offset.

The VOC Index mimics the human nose's perception of odors with a relative intensity compared to recent history. The VOC Index is also sensitive to odorless VOCs, but it cannot discriminate between them.

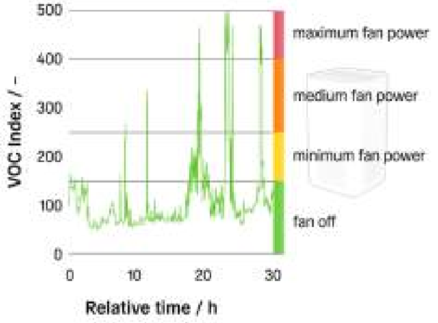
This is a very helpful feature because the VOC Index thus works in any environment regardless of their different VOC backgrounds. Note that every indoor air environment contains a certain VOC background stemming from constantly off-gassing sources. On the VOC Index scale, this offset is always mapped to the value of 100, making the readout as easy as possible: a VOC Index above 100 means that there are more VOCs compared to the average (e.g., induced by a VOC event from cooking, cleaning, breathing, etc.) while a VOC Index below 100 means that there are fewer VOCs compared to the average (e.g., induced by fresh air from an open window, using an air purifier, etc.).

Also, our nose perceives odors on a scale of relative intensity (weak, distinct and strong), but it cannot tell us if the concentration of one odor is truly higher than the concentration of another. Therefore, the VOC Index adapts its gain according to the VOC events of the past 24-hours learning time, leading to different VOC conditions being quantified on the same limited scale: a VOC Index ranging from 1 to 500. In this way, one can use a fixed mapping of the VOC Index to an action the device should execute (for instance, triggering an air purifier when the VOC Index is above 150). Let's assume that in one room an air purifier is exposed to VOC events which the SGP4x is not very sensitive towards, but it is still desired that the air purifier automatically starts cleaning the room. The gain adaption of the VOC Index helps to boost the signal so the air purifier can detect these events and take action.

Further reading

What are reducing gases?

More about Gas Index Algorithm and its tunability: *Sensirion's VOC and NO_x Indices for Indoor Air Applications* (upon request)



The figure above demonstrates a possible example implementation of the VOC Index in an air purifier.

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