Using oxygen sensors made by **SENSORE**, oxygen can be measured in gaseous media within a concentration range from 10 ppm O_2 up to 96 % O_2 depending on the sensor type. The sensor is thus characterized by the following essential characteristics:

- High accuracy
- For many types a more or less linear characteristic
- Small temperature dependence of the sensor signal
- Low interference with other gases
- Long service life
- In many cases “Single point calibration“ necessary only once

Technical data see in the appendix (specification).

Definition of types

Example SO-B0-250-A100C

- A100C → Customized type completion
- 250 → Measuring range of the sensor (see spreadsheet measuring ranges in the appendix)
- B0 → Housing type (see spreadsheet housing types in the appendix)
- SO → Sign for oxygen sensors

Sensor's function

If a voltage is applied to the sensor then this sensor operates as a current source, whose output current is dependent on the oxygen concentration of the measuring gas. For this the current is at a certain oxygen concentration dependent on the measuring range selected and on the sensor's production tolerances. Due to these production tolerances each sensor must be calibrated individually! The required, type-dependent sensor voltages and output current ranges are listed in the Sensor type table in the appendix.

For all sensor types and for all calibration gas concentrations the following formula is valid:

$$I_s([O_2]) = -k \cdot \ln\left(1 - \frac{[O_2]}{100}\right)$$

$I_s([O_2])$	Sensor current in the measuring medium
$[O_2]$	Oxygen concentration in the measuring medium in %
k	Sensor-specific constant

To determine the sensor-specific constant the sensor must be put in a gaseous medium with a known oxygen concentration (calibration). With the sensor current measured in this gas and the following formula the *k* constant can be calculated

$$k = \frac{-I_k([O_2])}{\ln\left(1 - \frac{[O_{2,k}]}{100}\right)}$$

k	Sensor-specific constant
$I_k[O_2]$	Sensor current at a given oxygen concentration
$[O_{2,k}]$	Given oxygen concentration (calibration gas concentration) in %

For sensor types SO-xx-250 and SO-xx-960 which can be calibrated in air, the sensor current follows as a function of the oxygen concentration the equation:

$$I_s([O_2]) = \frac{-I_s(20.9\%)}{0.2345} \cdot \ln\left(1 - \frac{[O_2]}{100}\right)$$

$I_s[O_2]$	Sensor current at a given concentration
$I_s(20.9\%)$	Sensor current measured in air [20.9 %]
$[O_2]$	Oxygen concentration in %

For small oxygen concentrations the formula can be simplified mathematically and a linear connection results:

$$I_1([O_2]) = k \cdot [O_2]$$

in which k can be determined under the same conditions as described above:

$$k = \frac{I_k([O_2])}{[O_{2,k}]}$$

$I([O_2])$	Sensor current in the measuring medium
$[O_2]$	Oxygen concentration in the measuring medium in %
k	Sensor-specific constant
$I_k[O_2]$	Sensor current at a given oxygen concentration
$[O_{2,k}]$	Given oxygen concentration (calibration gas concentration) in %

The sensor output current can be measured either by using a commercial ammeter or it can be converted into an easily measurable voltage with the help of an operational amplifier circuit. The appendix contains a circuit suggestion for this.

Sensor heater operating modes

In order to operate the sensor it is necessary to heat it. This is carried out using the sensor heater integrated in the sensor. There are two different modes.

Constant heater voltage

If the ambient temperature fluctuations are small (a few degrees °C), then the heating can be operated by means of a constant voltage with current limitation. The necessary heater voltage depends on the sensor housing and is listed with recommended heater current limitation in the appendix. In this heater operation mode the output signal changes by 0.034 % / °C ambient temperature.
The appendix also contains a circuit suggestion for this.

Constant heater resistance

However, if higher variations in temperature (e.g. exhaust gas measurement) or also higher gas flow rates occur, then the sensor temperature must be kept constant to increase the measuring accuracy.
To keep the sensor temperature constant a rheostatic control is used, which always adjusts the sensor heater's resistance and thus the sensor temperature to the same value independent from the ambient temperature. This desired value of the rheostat is calculated as follows starting from the cold resistance of the sensor heater:

$$R_{w,soll} = f \cdot R_{(25°C)}$$

$R_{w,soll}$	Resistance of the sensor heating in operation
$R_{(25°C)}$	Resistance of the sensor heating at 25 °C
f	Temperature factor 2.8; in some applications also 2.65

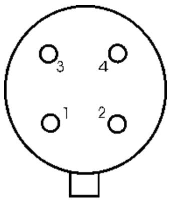
SENSORE offers an electronic circuit (EDAB-M1V2-L) by which the sensor can be operated in the simplest way (see description in the appendix).

Pin connection for different sensor types

TO39 (Type SO-A0-xxx), TO8 (Type SO-Bx-xxx)

1 H+ (HS+)
2 H- (HS-)
3 Sen+
4 Sen-

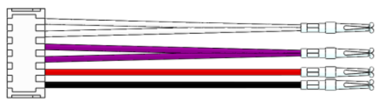
(Pin-side view)



Sensors with connecting cable for 4-wire operation (SO-Bz-xxx-AxxxC, SO-Dz-xxx-AxxxC)

Sensors with connecting leads (teflon isolation with temperature stability up to 250 °C):

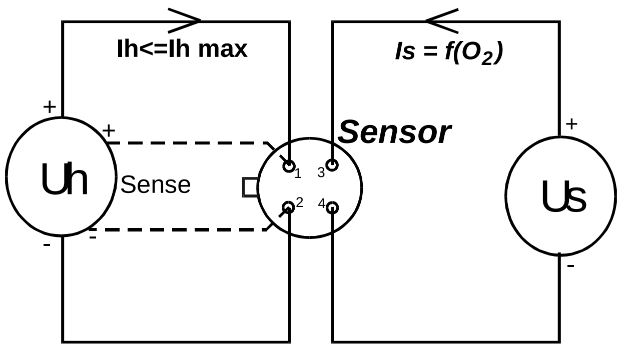
Cable colour	Pin Connection	Connected to pin No.
Violet 1 Violet 2	H+ HS+	1
White 1 White 2	H- HS	2
Red	Sen+	3
Black	Sen-	4



Schematic drawing of sensor connection cable with plug, view from backside of the plug

Basic circuit of the sensor

There are additional leads named sense drawn in the basic circuit shown beside. With this leads the exact heater voltage at the sensor pins can be adjusted. This four wire measuring system is recommended for heater operation with constant voltage. In case of operation with constant heater resistance mode it is absolutely necessary to use this for wire measurement system.



Warning

Permanent damage to the sensor can occur due to the following circumstances:

- Sensor is in the unheated state in exhaust gas which contains H_2S or SO_x
- Contact with water or condensed humidity
- Contact with gases which contains halogens like F, Cl, Br
- Contact with organic vapors

Appendix: Operating parameters

Sensor heater / Constant heater voltage operation mode

Sensor type	**Housing**	**Heater voltage** (*)	**Suggested current limitation**
SO-A0-xxx	TO39	4.0 volt ± 0.05 volt	0.5 ampere
SO-B0-xxx (except 001)	TO8	3.6 volt ± 0.05 volt	0.5 ampere
SO-B0-001-xxxxx	TO8	3.8 volt ± 0,05 volt	0.5 ampere
SO-B1-xxx-xxxxx	TO8 with mounting flange	3.7 volt ± 0,05 volt	0.5 ampere
SO-D0-xxx- xxxxx	Screw mountable housing	4.1 volt ± 0.05 volt	0.5 ampere
SO-D1-xxx- xxxxx	Screw mountable housing	4.1 volt ± 0.05 volt	0.5 ampere
SO-D2-xxx- xxxxx	Aluminium Screw mountable housing	3.8 volt ± 0.05 volt	0.5 ampere
SO-E1-xxx	TO8 with hose connection	3.6 volt ± 0.05 volt	0.5 ampere
SO-E2-xxx- xxxxx	TO8	3.6 volt ± 0.05 volt	0.5 ampere

(*) In case of deviate heater voltage the voltage is listed separately

Sensor heater / Constant heater resistance operation mode

Resistance of sensor heating at 25°C: $R_{(25°C)} = 3.25\ \Omega \pm 0.20\ \Omega$

Sensor type	**Housing**	**Heater resistance during operation**	**Suggested heating limitation**
SO-xx-xxx	All types	R operation = R (25°C)*2.8	0,5 ampere or soft start (PWM)

Temperature dependence of the sensor signal

0.034 % measuring signal / °C ambient temperature in stagnant air(*)

(*) A temperature difference of 200 °C (e.g. exhausted gas measuring) means a raise of the sensor signal of 6.8%.

Pressure dependence of the sensor signal

in the range of 150 mbar – 800 mbar 2.0 % of measuring signal / 100 mbar
in the range of 800 mbar – 5.0 bar 0.5 % of measuring signal / 1 bar

Drift of sensor current

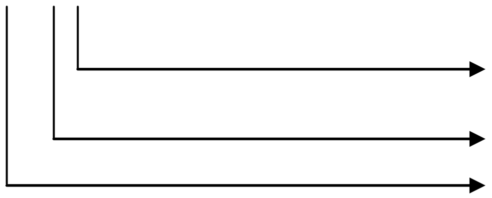
Neglectable

Max. potential difference between heater ground and sensor ground

± 3 Volt

Marking of the sensor

Example 412 3412 D



Code for measuring range (see spreadsheet measuring ranges in the appendix)

Date of production (week / code for the year)

Production order number

Packaging

SO-A0-xxx, SO-B0-xxx   Plastic case
All other types   Single or bounded to 10 pieces

Mounting

SO-A0-xxx, SO-B0-xxx   suitable to solder into a PCB; distance to PCB at least 3 mm
All other types   Mountable in any housing

Cross sensitivities

Gas	**Max. concentration of the checked gas**	**Cross sensitivity [Δ% O_2 / %Gas]**	**at oxygen concentration**
CO_2	40 %	-0.027	20 % O_2
CO_2	40 %	-0.01	5 % O_2
CO	1000 ppm	-0.73	20 % O_2
CO	1000 ppm	-0.83	5 % O_2
NO_2	1000 ppm	1.06	
SO_2	1000 ppm	-0.24	
CH_4	1000 ppm	-1.77	5 % O_2
H_2S	400 ppm	≈ 0.0	
H_2O (humidity) SO-xx-960 excluded	90% abs	≈ 0.0	

Appendix: Change of oxygen content due to humidity

Dalton's law (law of partial pressures)

The total pressure p_{total} exerted by the mixture of non-reactive gases is equal to the sum of the partial pressures p_i of individual gases.

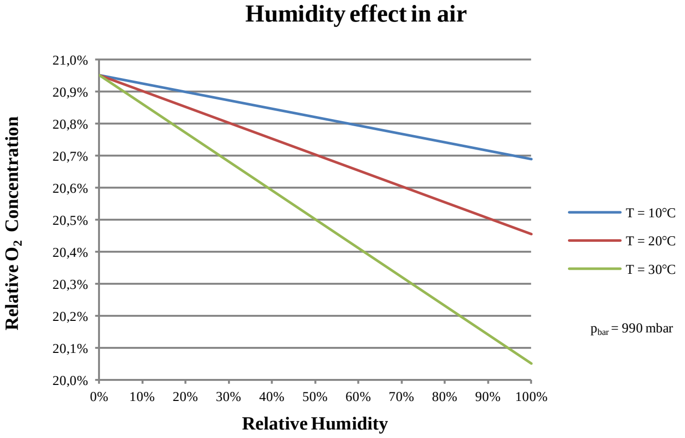
$$p_{total} = p_{bar}\,(h) = \sum_{i=1}^{k} p_i \qquad\qquad p_i = \frac{[X_i]}{100} \cdot p_{bar}\,(h)$$

$[X_i]$	Mole fraction of gas i in %
p_i	Partial pressure of gas i
$p_{bar}\,(h)$	Height-dependent barometric pressure (sea level Vienna ~ 160 m → p_{bar} ~ 990 mbar)

Dry air contains roughly (by volume) 78.084% nitrogen, 20.942% oxygen, 0.934% argon, and small amounts of other gases. Water vapour which is present by an average of 0.4 vol.% (range: 0 – 4 vol.%), is not included in the above composition, because this amount depends on several environmental conditions. When air is humid, the water vapour associated partial pressure displaces the surrounding air, resulting in a reduction of the relative oxygen content. This water vapour pressure is directly proportional to the temperature-dependent saturated vapour pressure.

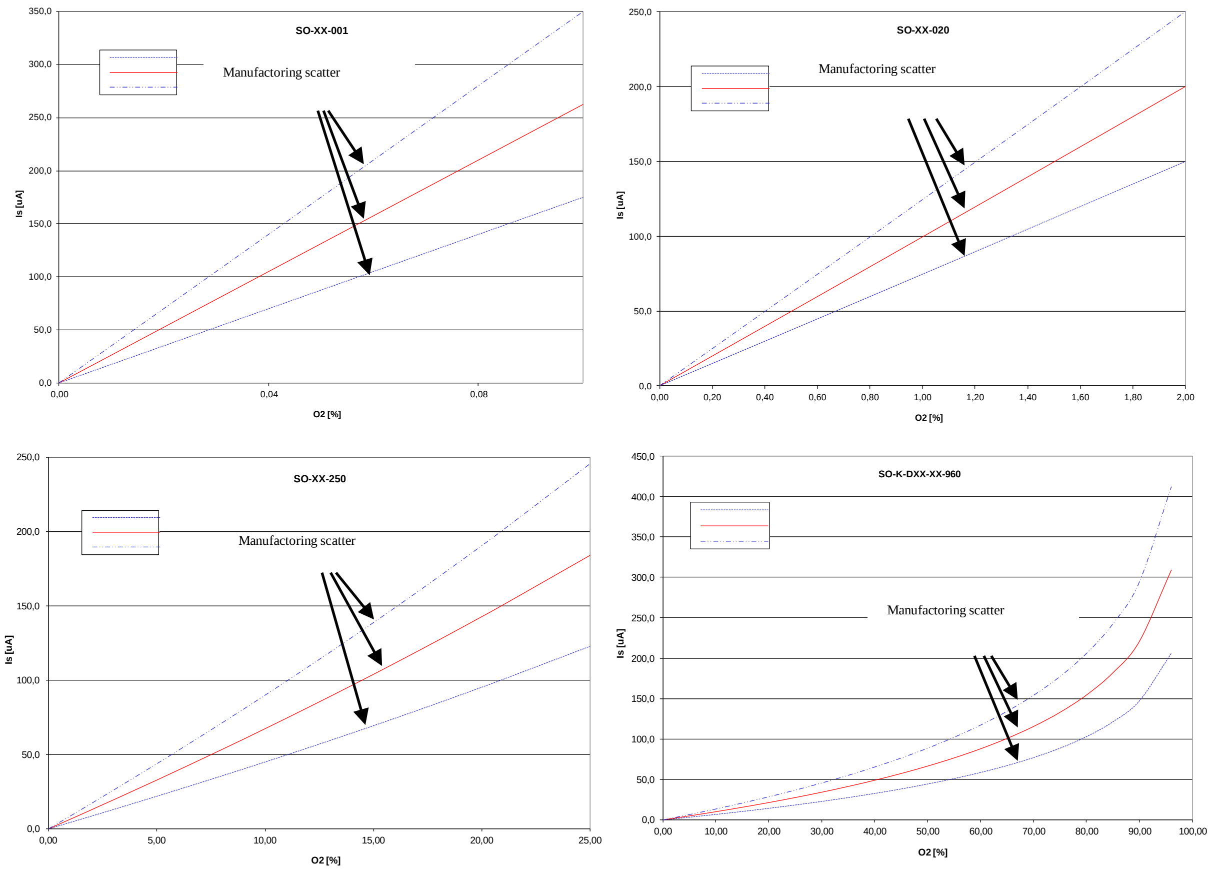
$$[O_{2\,humid}] = [O_{2\,dry}] \cdot \frac{p_{bar} - p_d}{p_{bar}} \qquad\qquad p_d = \frac{\varphi}{100} \cdot p_s(T)$$

p_d	Water vapour pressure [mbar]
φ	Relative humidity in %
$p_s(T)$	Temperature-dependent saturated vapour pressure [mbar]
$[O_{2\,humid}]$	Oxygen content of humid in Vol.%
$[O_{2\,dry}]$	Height independent oxygen content of dry air = 20.942 Vol.%



Attention:
The above-mentioned reduction of oxygen content due to moisture is measurable with all Sensore O_2 sensors except for the SO-xx-960 types. Because of a higher sensor voltage (1.6 V) they are able to split water vapour (H_2O). This additional oxygen causes a positive cross-sensitivity, which leads to an increase of the sensor signal.

Appendix: Sensor characteristics for different sensor types



Different sensor characteristics
ATTENTION: In each case only one characteristic applies per sensor!

Sensor electronics versions from SENSORE

SENSORE offers three electronic versions for easy control of the sensor:

- **CSB:** Electronic sensor board for oxygen sensors.
- **EDAB-M1:** Electronic board with temperature control and linearization of the characteristic sensor curve.
- **GSB:** Compact version of EDAB-N1: temperature control and linearization of the characteristic sensor curve.

The **CSB** (Compact sensor board) provides a plugged/soldered sensor with a fixed heater voltage, is compatible to all SENSORE O_2 sensors of the type SO-xx-xxx and has a current or a voltage output.

EDAB-M1 contains the temperature control specified in the description and in addition to the signal conversion mentioned also a linearization of the sensor characteristic so that a complicated conversion of the output signal to the measured oxygen concentration is not applicable. The GSB is compared to EDAB-M1 more compact, has a current output and can be reprogrammed according to customer requirements.

A more detailed description of the functions is contained in the respective data sheets.

Appendix: Simple circuit suggestion