Oxygen Sensor

SO-100 & 200 Series

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Theory of Operation

The SO series are galvanic-cell type sensors that measure oxygen gas (O_2) in air. Sensors include a lead anode, a gold cathode, an acid electrolyte, and a fluorine resin membrane. The current flow between the electrodes is proportional to the oxygen concentration being measured. An internal bridge resistor is used to provide a mV output linearly proportional to O_2. Unlike polargraphic oxygen sensors, galvanic do not require a power supply.

The mV output responds to the partial pressure of oxygen in air. The standard units for partial pressure are kPa. However, gas sensors that respond to partial pressure are typically calibrated to read out in mole fraction of the gas in air, or units of moles of oxygen per mole of air. These units can be directly converted to % O_2 in air, or ppm O_2 in air. The concentration of oxygen in our atmosphere is 20.95%. This precise percentage has not changed for decades. It is also constant across changing temperatures or pressures. This allows for precise calibration of the instrument.

Being a galvanic cell type sensor, a small amount of oxygen is consumed in the reaction in order to produce the current flow and subsequent mV output. The oxygen consumption was measured to be 2.2 umol O_2 per day when the O_2 concentration was 20.95% at 23 C.

All models are equipped with an internal thermistor or type-K thermocouple for measuring sensor body temperature. All models also come with built-in heaters, designed to warm the sensor body to a temperature slightly above ambient in order to keep condensation from forming on the sensor membrane where oxygen diffusion occurs.

Using the Sensor

For the most stable reading, the sensor should be used with the sensor opening facing down. This facilitates the best contact of the electrolyte and the electronics.

1. Connect the O_2 lead wires to a volt meter or a datalogger capable of measuring small mV signals.

2. To calibrate, measure the mV output in a well-ventilated area. Do not breathe on the sensor as exhaled breath has a lower O_2 concentration compared to ambivalent air (20.95%). The output is approximately 50 mV for the SO-100 series and 12 mV for the SO-200 series in ambient air. To derive the multiplier, divide 20.95 by the mV output minus the zero offset. The zero offset can be measured in pure N_2 gas or approximated as 3.0 mV for the SO-100 series and 0.35 mV for the SO-200 series.

Example: 20.95% / (50 - 3.0 mV) = 0.446% O_2 per mV

To derive the intercept, multiply the measured zero offset by the calibration factor.

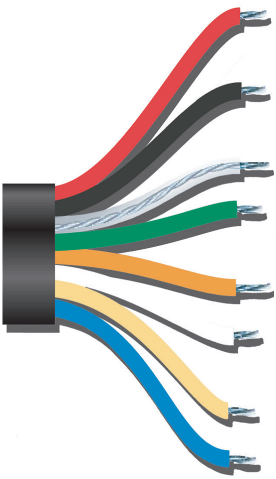
Example: 3.0 mV * 0.446% O_2 per mV = 1.338% O_2

The calibration factor and intercept are correct for the current elevation, pressure, temperature, and humidity.

3. Calibration establishes the multiplier and offset necessary to convert the mV reading to % O_2. Install the multiplier and offset values in your datalogger program.

Wiring Instructions

Sensor with Thermistor



Red High side of differential channel
(positive lead for O_2 sensor)

Black Low side of differential channel
(negative lead for O_2 sensor)

Clear Analog ground (shield wire)

Green Single-ended channel
(positive lead for thermistor)

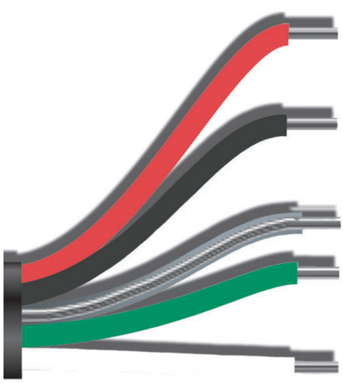
Orange Analog ground
(negative lead for thermistor)

White Excitation channel
(excitation for thermistor)

Yellow 12V port
(positive lead for heater)

Blue Ground
(negative lead for heater)

Sensor with Thermocouple



Red High side of differential channel
(positive lead for O_2 sensor)

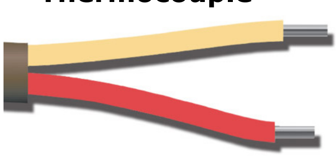
Black Low side of differential channel
(negative lead for O_2 sensor)

Clear Analog ground (shield wire)

Green 12V port
(positive lead for heater)

White Ground
(negative lead for heater)

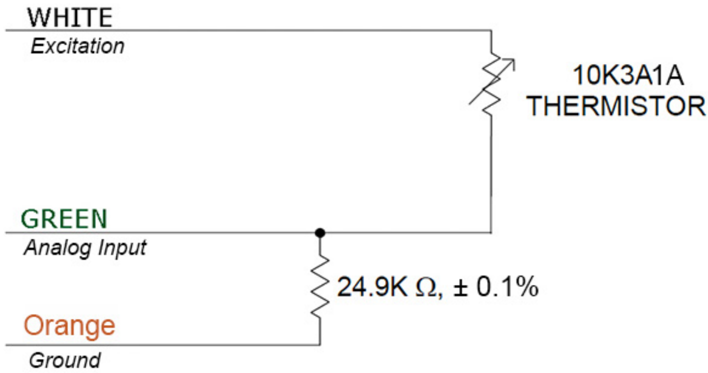
Thermocouple



Yellow High side of differential channel
(positive lead for thermocouple)

Red Low side of differential channel
(negative lead for thermocouple)

Convert Thermistor Output to Temperature



The models SO-110 and SO-210 incorporate a thermistor to directly measure sensor body temperature. The resistance of the thermistor (R_T) changes with temperature. Because most dataloggers do not measure resistance directly, a half-bridge measurement is used to determine resistance from the ratio of the measured voltage (V_{OUT}) and excitation voltage (V_{EX}):

$$R_T = 24900\left(\frac{V_{ex}}{V_{OUT}} - 1\right)$$

From resistance, temperature is calculated with the Steinhart-Hart equation and thermistor-specific coefficients.

$$T_K = \frac{1}{A + B\ln(R_T) + C(\ln(R_T))^3}$$

Where Tk is temperature in Kelvin. The Steinhart-Hart coefficients are:

$A = 1.129241 \times 10^{-3}$

$B = 2.341077 \times 10^{-4}$

$C = 8.775468 \times 10^{-8}$

Note: The thermistor is considered a passive device and requires no warm-up time once a voltage is applied. A 2.5 V excitation is recommended to minimize self-heating and power draw.

Characteristics

Zero Offset

The mV output in ultra-pure nitrogen gas (0.000% O_2) is typically 6% of the ambient (20.95%) output for the SO-100 series and 3% of the ambient output for the SO-200 series. Precise measurements of hypoxic and anaerobic conditions can be made by making a periodic zero calibration of the sensor with ultra-pure nitrogen gas.

Life Expectancy

The life expectancy of the sensor is expressed in %-years as follows:

[Oxygen Concentration (%) * Exposure Time (years)]

The life of the SO-100 series is approximately 10 years of continuous use at 21% oxygen and 20 C. Under the same conditions the life of the SO-200 series is approximately 5 years.

Storage Temperature

The life of the sensor can be extended by storage at a lower temperature. For example, a sensor stored at 0 C will have a life expectancy approximately twice that of a sensor stored at 20 C. The minimum storage temperature is -20 C. Below -20 C, the electrolyte will freeze. This does not damage the sensor, but to resume measurement the electrolyte must be thawed. Maximum storage temperature is 60 C.

Shock and Vibration

The sensor is resistant to 2.7 g of shock. However, vibration may influence the sensitivity of the sensor and should be minimized.

Factors Affecting Output

Influence from Various Gases

The sensor is unaffected by CO, CO_2, NO, NO_2, H_2S, H_2, and CH_4. There is a small effect (approximately 1%) from NH_3, HCI, and C_6H_6 (benzene). The sensor is sensitive to SO_2 and can be damaged by O_3.

Temperature Sensitivity

A change in temperature changes the amount of O_2 available to the sensor and therefore changes the mV output that correlates to the atmospheric constant of 20.95%. Additionally, the sensor electronics have a small temperature dependence. To eliminate temperature effects, simply recalibrate or use the correction equations detailed in the write-up, "Understanding Oxygen in Air", located in the Knowledge Base of the Apogee website.

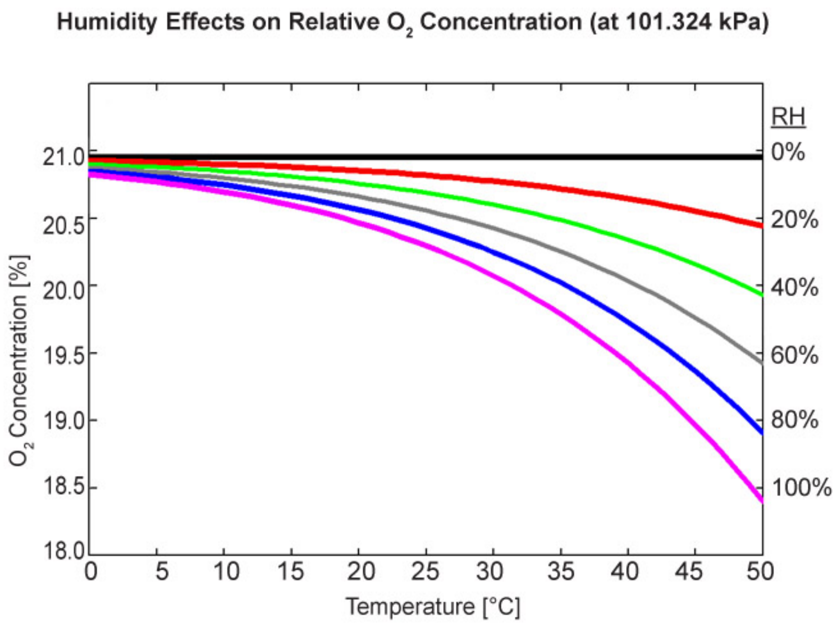
Pressure Sensitivity

A change in barometric pressure changes the amount of O_2 available to the sensor and therefore changes the mV output that correlates to the atmospheric constant of 20.95%. To eliminate pressure effects, simply recalibrate or use the correction equations detailed in the write-up, "Understanding Oxygen in Air", located in the Knowledge Base of the Apogee website. Direct compensation requires a pressure measurement, which can be done with the Apogee barometric pressure sensor, model SB-100 (shown below).

Factors Affecting Output (cont.)

Humidity Sensitivity

The graph below shows the humidity effect on output. The sensor chemistry is not influenced by humidity, but its output decreases because O_2 is displaced by water vapor molecules in the air. The effect of humidity is larger at warmer temperatures because there is more water vapor in the air.

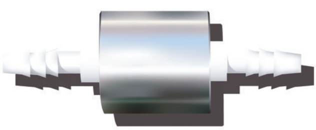


Note: In applications where the relative humidity is at or near 100%, continuous power to the built-in heaters is required. For calibration purposes, take the calibration measurement over water in a sealed container as shown at right. To account for humidity effects, simply recalibrate or use the correction equations detailed in the write-up, “Understanding Oxygen in Air”, located in the Knowledge Base of the Apogee website.

Accessories

The following head attachments for Apogee oxygen sensors can be purchased separately.

AO-001: the Diffusion Head is designed to maintain an air pocket and provide protection for the sensor's O_2 permeable membrane.The attachment is ideal for measurements in soil.



AO-002: the Flow-Through Head is designed for laboratory applications requiring in-line measurements. The head comes with 1/4" barbed Nylon fittings for connecting to a hose.

Specifications

Range
- 0 to 100% O_2

Stability
- ± 0.05% O_2 under stable atmospheric conditions

Repeatability
- ± 0.001% O_2 (10 ppm)

Operating Environment
- -20 to 60 C
- 0 to 100% relative humidity
- 60 to 140 kPa

Mass
- 175 g

Response Time
- SO-100 Series: 60 seconds
- SO-200 Series: 12 seconds

Output (at 20.95% O_2)
- SO-100 Series: 50 mV
- SO-200 Series: 12 mV

Gas Effect
- CO_2, CO, NO, NO_2, H_2S, H_2, CH_4 - No effect
- NH_3, HCI, C_6H_6 (Benzene) - <1%

Power Requirement
- 12 V for heaters (74 mW)
- 2.5 V excitation for thermistor

Diffusion Head (Accessory)
- 3.5 cm long by 3.5 cm diameter
- 125 mesh screen

Flow-Through Head (Accessory)
- 3.2 cm long by 3.2 cm diameter
- 1/4” barbed adapters for hose connections

Cable
- 5 meters of twisted-pair wire
- Foil shield
- Santoprene jacket
- Ending in pigtail leads
- Additional cable is available in multiples of 5 meters

Warranty
- 1 year against defects in materials and workmanship

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