ANALOG edge[SM]

Designing with Electro-chemical Sensors

Application Note AN-1798

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As early as 1950, electro-chemical sensors were used for oxygen (gas) monitoring; however, with increasing concerns about personal safety, the demand for portable electro-chemical sensors has dramatically increased. Today, electro-chemical sensors are commonly used in portable equipment to detect different toxic gases.

Electro-chemical sensors operate by reacting with monitored gas and producing an electrical current that is linearly proportional to the gas concentration. Older versions of electro-chemical sensors were based on a two-electrode configuration; however, to achieve superior electro-chemical stability, three-electrode systems are now used. The three electrodes are stacked parallel to each other, separated by a thin layer of electrolyte that provides ionic electrical contact between the electrodes.

Sensor Functionality

When a gas comes in contact with the sensor, it passes through a thin membrane barrier to reach the electrode surface. The first electrode that the gas comes in contact with is the Working Electrode (WE). The WE is designed to optimize the electro-chemical oxidation, (or reduction of the measured gas), and to generate a current flow that is proportional to the gas concentration.

The performance of the sensor deteriorates over time due to the continuous electro-chemical reaction of the changes in WE potential occurring on the electrode. To reduce deterioration while maintaining a constant sensitivity with a good linearity, a Reference Electrode (RE) is placed close to the WE. The reference electrode's purpose is to anchor the working electrode at the correct potential. In order for the RE to maintain a constant potential, no current should flow through it.

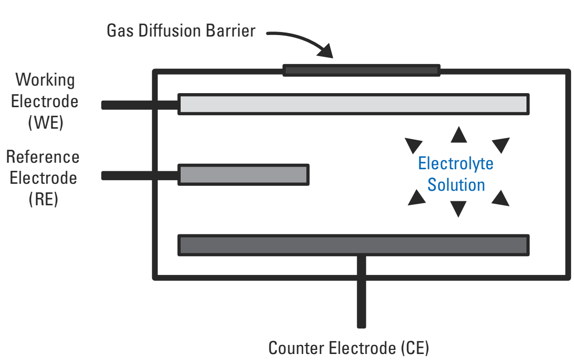

Figure 1. Typical Electro-chemical Sensor

The third electrode, the Counter Electrode (CE), conducts current into or out of the sensor cell. When the WE oxidizes carbon monoxide, the counter electrode reduces other molecules, such as oxygen to generate current. This current exactly balances the current generated at the WE. The ionic current between the working electrodes and counter is transported by the electrolyte.

Potentiostatic Circuit Operation

Electro-chemical sensors require control circuitry to operate. The control circuitry is referred to as the Potentiostatic Circuit. ***Figure 2*** shows a simplified potentiostatic circuit which is comprised of two amplifiers and one JFET transistor. There are small variations in the implementation of this circuit, but the function and the outcome are the same.

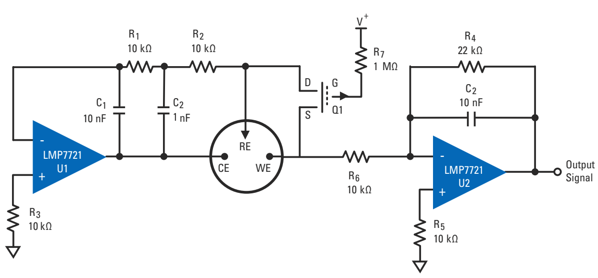

Figure 2. Potentiostatic Circuit

The potentiostatic circuit's main purpose is to maintain a voltage between the reference electrode and the working electrode to control the electro-chemical reaction and to deliver an output signal proportional to the WE current.

When the sensor is exposed to the target gas, such as carbon monoxide, the reaction at the WE oxidizes the carbon monoxide to become carbon dioxide, which diffuses out of the sensor. Hydrogen ions and electrons are generated. The hydrogen ions migrate through the electrolyte towards the counter electrode. This process leaves a negative charge deposited on the working electrode. The electrons flow out from the working electrode through resistor R6 to the inverting input of the amplifier (U2). The amplifier

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is configured as a transimpedance amplifier, which will convert the signal current from the WE into a voltage proportional to the applied gas concentration.

Output Voltage = I_{sensor} (R4+ R6)/R4

For example, a 10 ppm carbon monoxide sample produces a typical signal current of approximately 500 nA, which will give an output voltage of 5 mV. The hydrogen ions that have migrated toward the counter electrode will lift the potential of the RE and the WE. This small rise in potential at the RE is measured by the control amplifier (U1). The amplifier will sink or source adequate current to the CE to balance the current required by the working electrode.

The P-type JFET is used as a switch to prevent the sensor from polarizing when the circuit has no power. If the sensor is polarized, it will take the sensor a long time to stabilize at equilibrium. The JFET is only active when the power is off and at this time it shorts the WE and RE to ensure that the working electrode is maintained at the same potential as the reference electrode.

Amplifier Selection is Critical

The performance of the potentiostatic circuit is greatly dependent on the electrical parameters of the amplifiers chosen. Designing a potentiostatic circuit using a high-bias current amplifier without precision specifications will impact the sensor sensitivity and increase sensor to sensor variation. A precision, ultra-low input bias current amplifier, such as National's LMP7721, improves the potentiostatic circuit's performance, which allows the electro-chemical sensor to detect low-gas concentration with high accuracy.

The LMP7721 is designed with input bias guard driver circuitry to dramatically reduce the input bias current over the common mode voltage range to a typical of 3 fA at room temperature. Guaranteed specifications of 20 fA at room temperature and 900 fA at 85°C makes the LMP7721 the lowest temperature guaranteed bias current amplifier available.

In the potentiostatic circuit, the input bias current of the control amplifier (U1) is one of the critical specifications. The inverting input of U1 which is connected to RE, can-

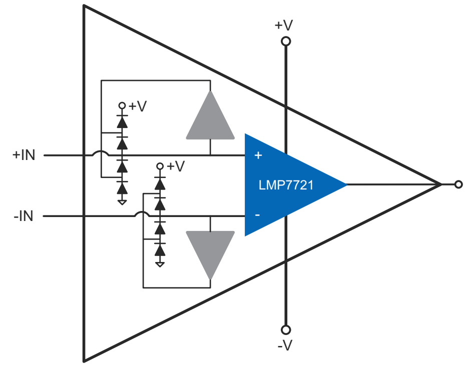

Figure 1. Typical Electro-chemical Sensor

not draw any significant current from the reference electrode. The LMP7721 ultra-low input bias amplifier will assure that the reference electrode will maintain constant potential by having less then 3 fA of bias current.

In addition, gas sensors have large capacitance, so significant currents can flow for small potential shifts; therefore, the offset voltage and offset drift over temperature are critical. A precision amplifier such as the LMP7721 with a maximum input offset voltage of 180 µV, and temperature drift of 4 µV/°C will enable more accurate current measurements. An amplifier with larger offset adds to the bias voltage of the sensor's working electrode causing more error.

In conclusion, the majority of gas sensors are three-electrode electro-chemical cells that generate current that is linearly proportional to the gas concentration. The generated current is measured and converted to a voltage by the potentiostatic circuit. The potentiostatic circuit also provides the current to the counter electrode to balance the current required by the working electrode. The electrical specifications of the amplifiers used in the circuit should be precision with ultra-low bias current, such as National's LMP7721 amplifier.

For more information, visit:
national.com/analogedge

References:

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