

Single Supply, Micropower Toxic Gas Detector Using an Electrochemical Sensor

CIRCUIT FUNCTION AND BENEFITS

The circuit shown in Figure 1 is a single-supply, low power battery operated, portable gas detector using an electrochemical sensor. The Alphasense CO-AX Carbon Monoxide sensor is used in the example.

Electrochemical sensors offer several advantages for instruments that detect or measure the concentration of many toxic gases. Most sensors are gas specific and have usable resolutions under one part per million (ppm) of gas concentration. They operate with very small amounts of current, making them well-suited for portable, battery powered instruments.

The circuit shown in Figure 1 uses the ADA4505-2, dual micro-power amplifier, which has a maximum input bias current of 2 pA at room temperature and consumes only 10 µA per amplifier. In addition, the ADR291 precision, low noise, micropower reference

consumes only 12 µA and establishes the 2.5 V common-mode pseudo-ground reference voltage.

The ADP2503 high efficiency, buck-boost regulator allows single-supply operation from two AAA batteries and consumes only 38 µA when operating in power-save mode.

Total power consumption for the circuit shown in Figure 1 (excluding the AD7798 ADC) is approximately 110 µA under normal conditions (no gas detected) and 460 µA under worst-case conditions (2000 ppm CO detected). The AD7798 consumes approximately 180 µA when operational (G = 1, buffered mode) and only 1 µA in the power-save mode.

Because of the circuit's extremely low power consumption, two AAA batteries can be a suitable power source. When connected to an ADC and a microcontroller, or a microcontroller with a built-in ADC, battery life can be from over six months to over one year.

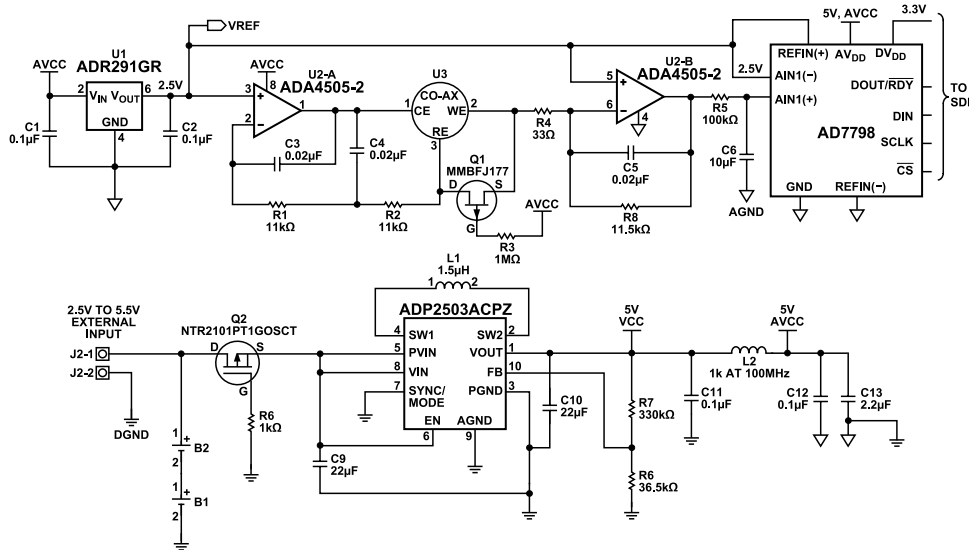


Figure 1. Low Power Gas Detector Circuit

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REVISION HISTORY**12/23—Revision B: Initial Version**

Converted Document from CN-0234 to AN-2565 (Universal).....	1
Deleted Evaluation and Design Support Section.....	1
Deleted Circuit Evaluation and Test Section, Equipment Needed Section, Getting Started Section, Functional Block Diagram Section, Setup Section, Test Section, Learn More Section, and Data Sheets and Evaluation Boards Section.....	4
Deleted Figure 3, Figure 4, and Figure 5; Renumbered Sequentially.....	4

CIRCUIT DESCRIPTION

Figure 2 shows a simplified schematic of an electrochemical sensor measurement circuit. Electrochemical sensors work by allowing gas to diffuse into the sensor through a membrane and interacting with the working electrode (WE). The sensor reference electrode (RE) provides feedback to maintain a constant potential with the WE terminal by varying the voltage at the counter electrode (CE). The direction of the current at the WE terminal depends on whether the reaction occurring is oxidation or reduction. In the case of carbon monoxide, oxidation takes place; therefore, the current flows into the working electrode, which requires the counter electrode to be at a negative voltage (typically 300 mV to 400 mV) with respect to the working electrode. The op amp driving the CE terminal should have an output voltage range of approximately ± 1 V with respect to V_{REF} to provide sufficient headroom for operation with different types of sensors (Alphasense Application Note AAN-105-03, *Designing a Potentiostatic Circuit*, Alphasense, Ltd.).

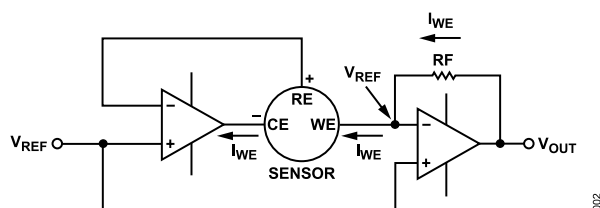


Figure 2. Simplified Electrochemical Sensor Circuit

The current into the WE terminal is less than 100 nA per ppm of gas concentration; therefore, converting this current into an output voltage requires a transimpedance amplifier with a very low input bias current. The ADA4505-2 op amp has CMOS inputs with maximum input bias current of 2 pA at room temperature, making this op amp a very good fit for the application.

The 2.5 V ADR291 establishes the pseudo-ground reference for the circuit, which allows for single-supply operation while consuming very little quiescent current.

Amplifier U2-A sinks enough current from the CE terminal to maintain a 0 V potential between the WE and RE terminals on the sensor. The RE terminal is connected to the inverting input of U2-A; therefore, no current flows in or out of it. This means that the current comes from the WE terminal, and it changes linearly with gas concentration. Transimpedance Amplifier U2-B converts the sensor current into a voltage proportional to gas concentration.

The sensor selected for this circuit note is an Alphasense CO-AX Carbon Monoxide sensor. Table 1 shows typical specifications associated with carbon monoxide sensors of this general type.

Warning: Carbon monoxide is a toxic gas, and concentrations higher than 250 ppm can be dangerous; therefore, exercise extreme care when testing this circuit.

Table 1. Typical Carbon Monoxide Sensor Specifications

Parameter	Value
Sensitivity	55 nA/ppm to 100 nA/ppm (65 nA/ppm typ)
Response Time (t_{90} from 0 ppm to 400 ppm CO)	<30 sec
Range (ppm CO, Guaranteed Performance)	0 ppm to 2,000 ppm
Overrange Limit (Specifications Not Guaranteed)	4,000 ppm

The output voltage of the transimpedance amplifier is

$$V_O = 2.5 \text{ V} + I_{WE} \times R_F \quad (1)$$

where I_{WE} is the current into the WE terminal, and R_F is the transimpedance feedback resistor (shown as R8 in Figure 1).

The maximum response of the CO-AX sensor is 100 nA/ppm, and its maximum input range is 2000 ppm of carbon monoxide. This results in a maximum output current of 200 μ A and a maximum output voltage determined by the transimpedance resistor, as shown in Equation 2.

$$V_O = 2.5 \text{ V} + 2000 \text{ ppm} \times 100 \frac{\text{nA}}{\text{ppm}} \times R_F$$

$$V_O = 2.5 \text{ V} + 200 \mu\text{A} \times R_F \quad (2)$$

Operating the circuit with a 5 V supply results in a usable range of 2.5 V at the output of the transimpedance amplifier, U2-B. Selecting a 11.5 k Ω resistor for the transimpedance feedback resistor gives a maximum output voltage of 4.8 V, which allows for approximately 8% overrange capability.

Using the sensor's typical response of 65 nA/ppm, Equation 3 shows the circuit output voltage as a function of ppm of carbon monoxide.

$$V_O = 2.5 \text{ V} + 748 \frac{\mu\text{V}}{\text{ppm}} \quad (3)$$

Resistor R4 keeps the noise gain at a reasonable level. Selecting the value of this resistor is a compromise between the magnitude of the noise gain and the sensor settling time errors when exposed to high concentrations of gas. For this example, $R_4 = 33 \Omega$, which results in a noise gain of 349, as shown in Equation 4.

$$NG = 1 + \frac{11.5 \text{ k}\Omega}{33 \Omega} = 349 \quad (4)$$

The input noise of the transimpedance amplifier appears at the output amplified by the noise gain. For this circuit, we are only interested in low frequency noise because the frequency of operation of the sensor is very low. The ADA4505-2 has a 0.1 Hz to 10 Hz input voltage noise of 2.95 μ V p-p; therefore, the noise at the output is 1.03 mV p-p, as shown in Equation 5.

$$V_{\text{OUTPUTNOISE}} = 2.95 \mu\text{V} \times NG = 1.03 \text{ mVp-p} \quad (5)$$

Because this is very low frequency 1/f noise, it is very hard to filter out. However, the sensor response is also very slow; therefore, we can take advantage of this by using a very low frequency low-pass filter (R5 and C6) with a cutoff frequency of 0.16 Hz. Even with such a low frequency filter, its effect on the sensor response time

is negligible when compared to the 30 second response time of the sensor.

One important characteristic of electrochemical sensors is their very long time constant. When first powered up, it can take several minutes for the output to settle to its final value. When exposed to a midscale step in concentration of the target gas, the time required for the sensor output to reach 90% of its final value can be in the order of 25 seconds to 40 seconds. If the voltage between the RE and WE terminals has a sudden change in magnitude, it can take several minutes for the sensor's output current to settle. This also applies when cycling power to the sensor. To avoid very long startup times, P-channel JFET Q1 shorts the RE terminal to the WE terminal when the supply voltage drops below the JFET's gate-to-source threshold voltage (~2.5 V).

Two AAA batteries or a 2.3 V to 5.5 V power supply powers the circuit. Q2 provides reverse voltage protection, and the ADP2503 regulates the input supply to the 5 V required to power the sensor.

COMMON VARIATIONS

If a programmable rheostat, such as the AD5271, is used instead of a fixed transimpedance resistor (R8), the circuit can be used with different gas sensors without changing the bill of materials. The AD5271 is available with nominal resistance values of 20 k Ω , 50 k Ω , or 100 k Ω . There are 256 positions, resulting in steps of 390.6 Ω for the 100 k Ω option. The 5 ppm/ $^{\circ}$ C resistance temperature coefficient of the AD5271 is better than most discrete resistors, and

its 1 μ A supply current is a very small contributor to the system's power consumption.

While two AAA batteries can power the circuit shown in Figure 1 for several months, some applications may be able to run from an external power source. The most efficient way to implement a dual power configuration is to use a power jack with a built-in switch and a mechanical disconnect feature that automatically removes battery power when the external power plug is inserted into the jack.

The circuit discussed here operates with very low power consumption. Using two ADA4528-1 op amps instead of the ADA4505-2 results in much lower noise and better accuracy, but higher power consumption. The ADA4528-1 provides practically zero offset drift with industry-leading low input voltage noise.

Similarly, the ADR3425 can replace the ADR291 for very low drift with temperature; however, at the expense of higher current consumption.

Finally, the circuit as shown in Figure 1 is suitable for interfacing with a 12-bit ADC, such as the built-in converter in most mixed signal microcontrollers.

For applications where measuring fractions of ppm of gas concentration is important, using the ADA4528-1 and the ADR3425 makes the circuit performance suitable for interfacing with a 16-bit ADC, such as the AD7798 or the AD7171.