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Operational Amplifier for Electrochemical Sensors

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Abstract

This article discusses the applications of an operational amplifier for electrochemical gas sensors such as ethanol and carbon monoxide (CO). It also discusses the desired performance to provide optimum results for accurate measurement of ethanol and CO with the lowest power consumption for portable devices.

Introduction

Electrochemical gas sensing elements require constant bias to operate correctly and accurately, which potentially consumes a tremendous amount of power. Normal power management systems attempt to keep everything shutdown when in idle or sleep mode. However, electrochemical sensors require tens of minutes or even hours to stabilize. Hence, the sensing element and its bias circuitry must constantly be in the always-on power state. Furthermore, the required bias voltage is often quite low for connection to a 1 AA battery cell for consumer applications.

The MAX40108 is a low power, high precision operational amplifier (op amp) that operates with a power supply voltage as low as 0.9 V, which was specifically designed for instrumentation type applications. In addition, the device features rail-to-rail inputs and outputs and consumes only 25.5 µA typical supply current and 1 µV typical zero-drift input offset voltage over time and temperature, making it an ideal device for a wide variety of low power applications for consumer products such as ethanol and CO gas sensors.

Overview

Figure 1 shows the block diagram of an electrochemical sensor such as ethanol or CO. The system consists of a low voltage op amp that operates directly from a 1.5 V AA/AAA battery, providing bias current to the electrochemical sensor while the rest of the system is in sleep mode to save power consumption. The first op amp, U1, powers the electrochemical cell's reference electrode. The second op amp, U2, is configured as a transconductance amplifier, converting the sensor's current output to voltage output to be digitized by a microcontroller after being amplified. This is done by the MAX44260, U3, which is a 1.8 V, 15 MHz low offset, low power, rail-to-rail input/output (I/O) op amp. ES is the electrochemical sensor.

The schematic of the electrochemical sensor is available online here.

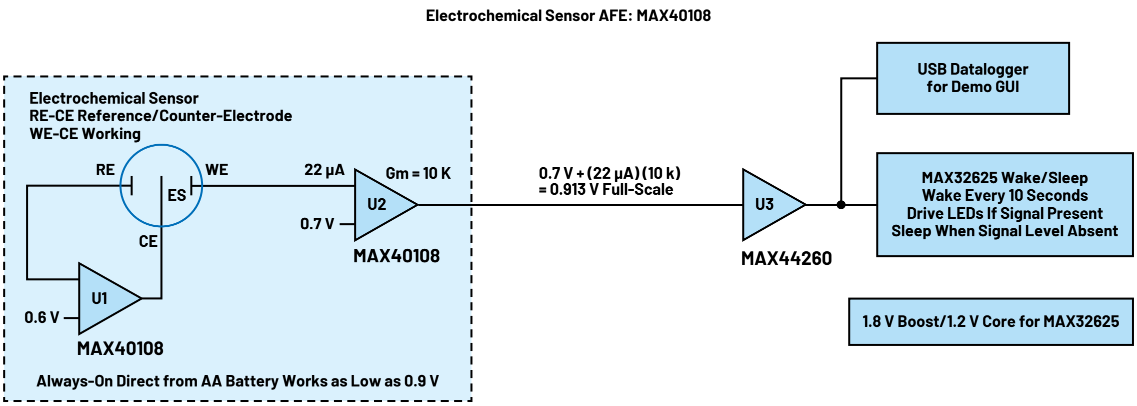

Figure 1. A MAX40108 block diagram of an electrochemical sensor.

Ethanol Sensor Evaluation

In this ethanol sensor evaluation, the sensor used is the SPEC 3SP_Ethanol_1000 package 110-202 shown in Figure 2.

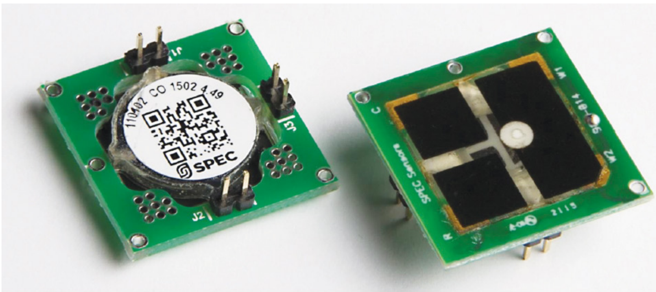

Figure 2. The ethanol sensor SPEC 3SP_Ethanol_1000 package 110-202.

This SPEC ethanol sensor generates a current proportional to the volume of the captured gas. It is a three-electrode device: WE, RE, and CE.

WE: Working electrode. This WE is biased at 0.7 V and used for sensing the gas vapor.

RE: Reference electrode. This RE provides a stable electrochemical potential of 0.6 V bias voltage in the electrolyte, which is not exposed to the gas vapor.

CE: Counter electrode (CE).

The CE conducts when a gas is present. The level of conduction is proportional to the concentration of gas, which can then be electrically measured by the system.

In this gas sensor evaluation, the gas particles need to be physically in contact with the SPEC sensor. In other words, the ethanol sensor is basically measuring only the gas that is present at the exact location of the sensor itself. Therefore, to detect gases such as ethanol and CO accurately and effectively, place the sensors where the concentration of gas is expected to diffuse to the location. In this experiment, a cotton swab was dipped in an ethanol solution and placed right in front of the SPEC sensor.

Figure 3 depicts the capture of the ethanol vapor as shown in a blue curve. The green curve is the current consumption of the entire system including the microcontroller, which is 90 mA typical. However, the current consumption of the MAX40108 itself is a mere 25.5 µA at V_{DD} = 0.9 V and T_A = 25°C as shown in Figure 4.

When in idle mode, the microcontroller wakes up every 10 seconds to monitor the ethanol vapor. When the vapor is present, the microcontroller starts measuring the vapor concentration as shown in the blue curve. The red line shows the AA battery voltage at approximately 1.5 V, and the yellow line is the CE voltage.

To see the effect of the ethanol sensor's response to the vapor concentration, the cotton swab was moved farther away from the sensor. The result was captured as shown in Figure 5. As expected, the amplitude of the vapor concentration blue curve was reduced accordingly.

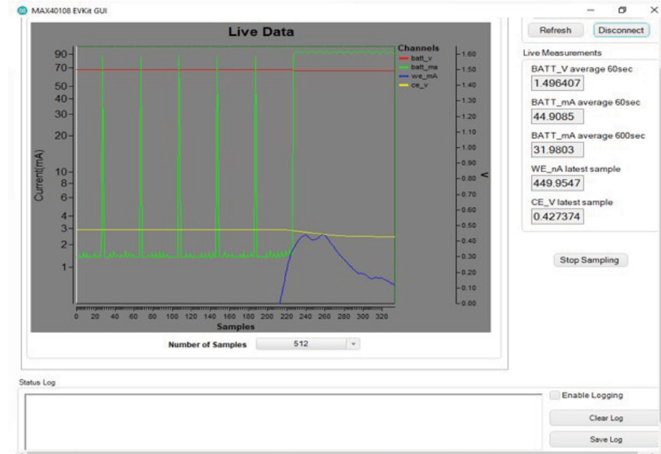

Figure 3. Performance of the ethanol sensor.

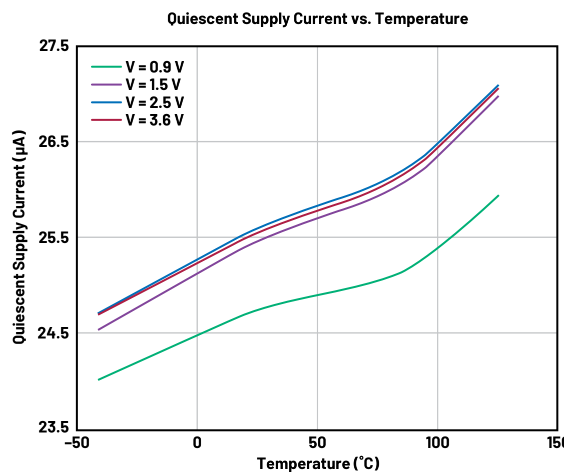

Figure 4. Current consumption at various power supply voltages and over the operating temperature range.

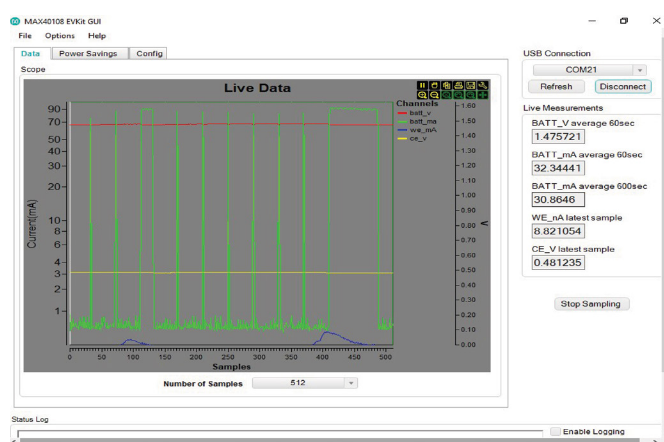

Figure 5. Performance of the ethanol sensor as vapor was moved far away from the SPEC sensor.

CO Sensor Evaluation

Unlike ethanol, CO is a potentially poisonous gas resulting from the incomplete combustion processes from gasoline or even a harmless candle. So, it's important that proper ventilation be implemented to ensure health and safety when conducting this CO gas experiment. In this evaluation, a candle was used to produce the CO gas in a concealed jar, and the same sensor SPEC 3SP_Ethanol_1000 Package 110-202 was used to capture the CO gas concentration.

Figure 6 portrays the capture of the CO gas as shown in the blue curve. The green curve is the current consumption of the entire system including the microcontroller, which is typical 90 mA.

As in the ethanol evaluation, when in idle mode, the microcontroller wakes up every 10 seconds to monitor the CO gas. When the gas is detected, the microcontroller starts measuring its concentration as shown in the blue curve. The red line shows the AA battery voltage of approximately 1.5 V, and the yellow line is the CE voltage.

Figure 6. Performance of the MAX40108 CO sensor.

Conclusion

To measure the ethanol and CO gases accurately for consumer and industrial applications, a low power, high precision operational amplifier that operates with a power supply voltage as low as 0.9 V is needed. The MAX40108 device is specifically designed to capture and measure the commonly encountered gases such as ethanol and CO effectively as it possesses not only a low current consumption of 25.5 µA but also a tiny dimension of 1.22 mm × 0.92 mm in the 8-ball WLP package. The amplifier features a shutdown mode for saving power further, which is imperative for wearable devices, portable medical systems, and industrial internet of things (IIoT) such as pressure, flow, level, temperature, and proximity measurements.

About the Author

Tom has been with Maxim (now part of Analog Devices) for more than 20 years. His experience is in RF/wireless and analog technology such as mixers, amplifiers, power amplifiers, voltage controlled oscillators, ADCs, and DACs.

He holds a B.S.E.E degree from California Polytechnic State University in San Luis Obispo, CA, and an M.S. degree in electrical engineering from Santa Clara University in Santa Clara, CA.