

**Circuits
from the Lab®**
Reference Designs

Circuits from the Lab® reference designs are engineered and tested for quick and easy system integration to help solve today's analog, mixed-signal, and RF design challenges. For more information and/or support, visit www.analog.com/CN-0395.

Devices Connected/Referenced	
ADN8810	12-Bit High Output Current Source
AD7988-1	16-Bit Lower Power PuLSAR ADC in MSOP/LFCSP
ADG758	3 Ω, 4-/8-Channel Multiplexer in Chip Scale Package
ADG884	0.5 Ω CMOS, Dual 2:1 MUX/SPDT Audio Switch
ADR4540	Ultralow Noise, High Accuracy Voltage Reference
ADP124-2.5	5.5 V Input, 500 mA, Low Quiescent Current, CMOS Linear Regulator
AD8628	Zero-Drift, Single-Supply, Rail-to-Rail Input/Output Operational Amplifier
ADP196	5 V, 3 A, Logic Controlled High-Side Power Switch

Volatile Organic Compound Detector for Indoor Air Quality Measurement

EVALUATION AND DESIGN SUPPORT

Circuit Evaluation Boards

[CN-0395 Circuit Evaluation Board \(EVAL-CN0395-ARDZ\)](#)

[ADICUP360 Evaluation Board \(EVAL-ADICUP360\)](#)

Design and Integration Files

[Schematics, Layout Files, Bill of Materials](#)

CIRCUIT FUNCTION AND BENEFITS

The circuit shown in Figure 1 measures indoor air quality by using a metal-oxide sensor to detect gases composed of volatile organic compounds. The sensor is composed of a heating resistor

and a sensing resistor. When the sense resistor is heated, its value changes as a function of the concentrations of different gases.

The circuit uses a 12-bit, current output digital-to-analog converter (DAC) for precision control of the heater current, and the flexible software allows the heater to operate in one of the following four modes: constant current, constant voltage, constant resistance, and constant temperature.

The circuit is able measure a wide range of sense resistance values by using a software-selectable, five range resistor divider. The board also includes a temperature and humidity sensor that is used for compensating the gas concentration value.

Rev. 0

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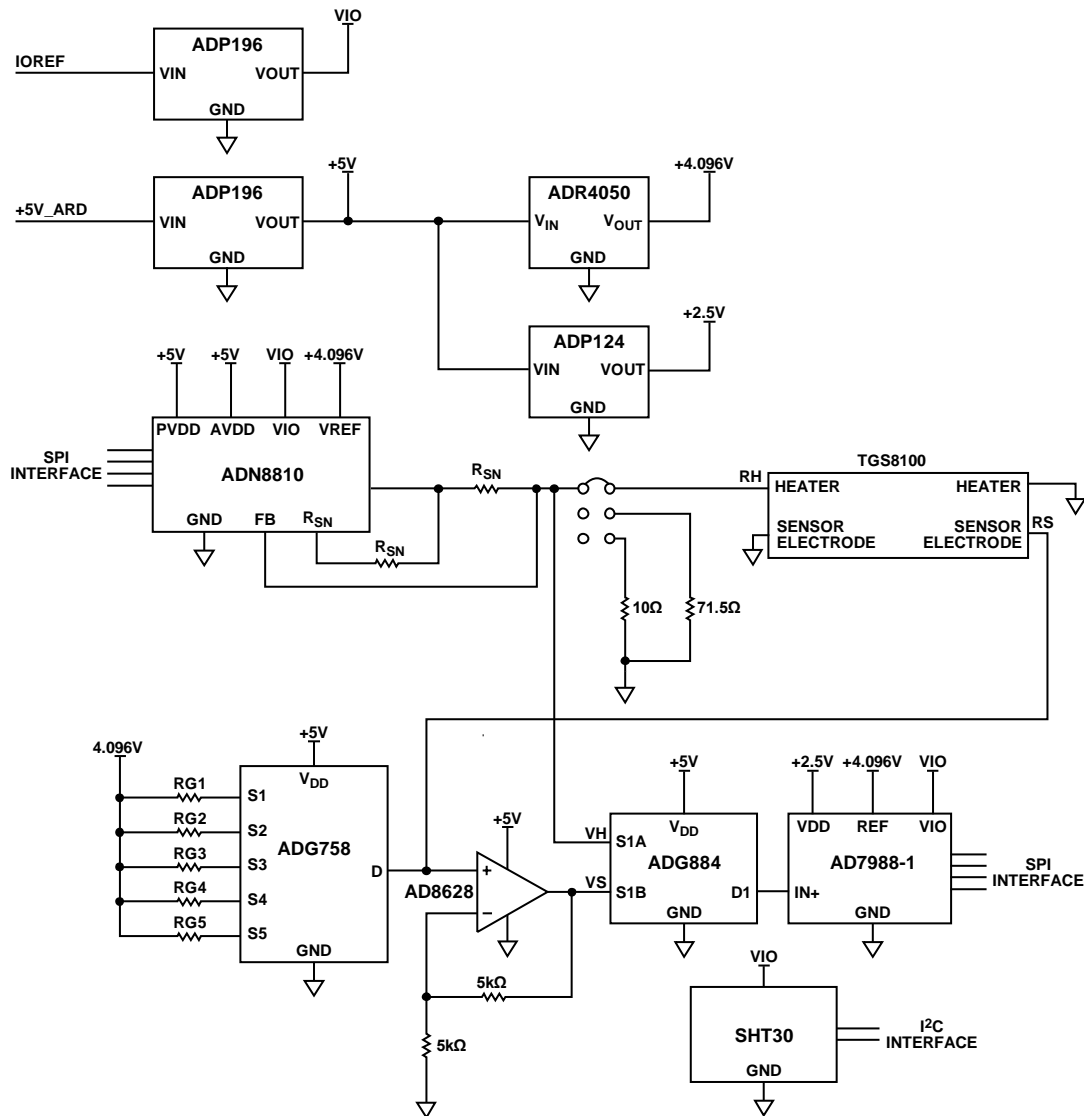


Figure 1. Complete, Single-Supply, 16-Bit Volatile Organic Compound Detector Using a Metal-Oxide Sensor with a 12-Bit Current Output DAC (Simplified Schematic, All Connections and Decoupling Not Shown)

CIRCUIT DESCRIPTION

The circuit is optimized for the Figaro TGS8100 sensor, which is comprised of a MOS sensing chip and an integrated heater formed on a silicon substrate using MEMS technology. Other MOS sensors can be used by making appropriate changes in the hardware and software.

Testing was done using carbon monoxide in a gas chamber. The results were correlated to the data sheet specifications of the sensor.

Heater Driver

The [ADN8810](#) is a 12-bit current source with adjustable output current of up to 300 mA. The full-scale current is set with the two output sense resistors. Choosing these resistors and setting the full-scale current is crucial to the design specifications for the sensor installed on the board. The full-scale current must be

set not to violate the maximum ratings of the sensor to avoid possible failures.

Using 41.2 Ω sense resistors, the full-scale current of the board is set to approximately 9.94 mA, which is a safe upper limit for the TGS8100 sensor where the recommended operating current is 8 mA. The calculation for the full-scale current as a function of the sense resistor values is given by

$$I_{FS} \approx \frac{V_{REF}}{10 \times R_{SN}} \quad (1)$$

where:

V_{REF} is the voltage reference of the circuit (4.096 V).

R_{SN} is the value of the sense resistors.

The full-scale accuracy of the [ADN8810](#) without calibration is 1%. If greater accuracy is required, the full-scale current output can be calibrated using the 71.5 Ω or 10 Ω precision resistors and the P2 jumper.

All operations (constant current, constant voltage, constant resistance, and constant temperature modes) maintain the values of the specified parameter by controlling the amount current passing through the heating element and measuring the heater voltage with the [AD7988-1](#) analog-to-digital converter (ADC).

Relationship Between Heater Resistance and Heater Temperature

The heater resistance, RH_T , is related to the heater temperature, TH , by the following equation:

$$RH_T = RH_0 \times [1 + ALPHA \times (TH - T_0)] \quad (2)$$

where:

RH_0 is the heater resistance at ambient temperature, T_0 .

TH is the heater temperature.

$ALPHA$ is the sensor dependent constant.

From the TGS8100 data sheet, the following nominal values are obtained: $VH = 1.8$ V, $RH_0 = 110$ Ω at $T_0 = 20^\circ\text{C}$. For $T_H = 360^\circ\text{C}$, $RH_T = 225$ Ω . The constant, $ALPHA$, is then determined by substitution and solving the previous equation yielding $ALPHA = 0.003074$.

The equation can be rearranged and solved for TH as a function of RH :

$$TH = T_0 + (1/ALPHA) \times [(RH_T/RH_0) - 1] \quad (3)$$

Before setting the mode values, the actual heater resistance, RH_A , at ambient temperature, T_A , is first determined. This value is determined by applying 8 mA to the heater and measuring the heater voltage, VH_A , within 20 μs of the application of the current. At this point the heater is still at ambient temperature. The ambient heater resistance is calculated from $RH_A = VH_A/8$ mA. The ambient temperature, T_A , and the humidity, HUM , is also recorded.

The previous equations must be modified slightly, because the actual ambient temperature, T_A , can be different from the data sheet value, $T_0 = 20^\circ\text{C}$. With the correction factor added, the two equations become

$$RH_T = RH_A \times [1 + ALPHA \times (RH_0/RH_A) \times (TH - T_A)] \quad (4)$$

$$TH = T_A + (1/ALPHA) \times (1/RH_0) \times (RH_T - RH_A) \quad (5)$$

Heater Modes of Operation

The following sections describe the heater modes of operation in more detail.

Constant Heater Voltage

Constant heater voltage mode is the most common mode of operation. The recommended voltage for the TGS8100 sensor is 1.8 V \pm 2%. An iterative program adjusts the heater current, I_H , until the measured heater voltage is 1.8 V. The corresponding heater resistance, RH_T , is then calculated from $RH_T = VH/I_H$. The corresponding heater temperature can then be calculated from Equation 5.

Constant Heater Current

The desired heater current, I_H , is set in the [ADN8810](#) DAC. The heater voltage, VH , is measured. The heater resistance is calculated from $RH_T = VH/I_H$. The corresponding heater temperature is then calculated from Equation 5.

Constant Heater Temperature

The heater resistance, RH_T corresponding to the desired heater temperature, TH , is calculated using Equation 4. An iterative program adjusts the heater current, I_H , and measures the heater voltage, VH , until the desired heater resistance of $VH/I_H = RH_T$ is reached.

Constant Heater Resistance

An iterative program adjusts the heater current, I_H , and measures the heater voltage, VH , until the desired heater resistance of $VH/I_H = RH_T$ is reached. The corresponding heater temperature is then calculated using Equation 5.

Sense Resistor Measurement

The resistance value of the sensing element of the sensor can be determined using the following equation:

$$RS = \frac{RG \times VS}{VREF - VS} \quad (6)$$

where:

RS is the resistance of the sensing element.

VS is the voltage across RS with respect to ground.

RG is the range setting resistor used in the voltage divider.

$VREF$ is the value of the reference voltage (4.096 V).

To cover RS ranges from 30 Ω to 30 M Ω , one of five RG resistors are selected using the [ADG758](#) low voltage, CMOS, analog multiplexer. The circuit uses the S1 to S5 channels with corresponding RG resistor values of 8.87 k Ω , 39.2 k Ω , 110 k Ω , 2.74 M Ω , and 33 M Ω , respectively.

Using the RG resistors in a voltage divider with RS and $VREF$, the value of the RS sense resistor can now be determined using Equation 6.

The output voltage from the voltage divider of the sense resistor is amplified by a factor of 2 to match the input range of the [AD7988-1](#) ADC using the [AD8628](#), an ultralow offset, drift and bias current op amp.

The [AD7988-1](#) is a low power, 100 kSPS 16-bit, successive approximation ADC used to convert the voltage readings from the heating and sensing element of the sensor.

The [ADG884](#) is a software selectable low voltage CMOS dual single pole, double throw switch used to switch between voltage readings from the heating and sensing element of the sensor.

The [ADR4540](#) is an ultralow noise, low power voltage reference. It produces a high accuracy 4.096 V reference voltage to the [ADN8810](#), [AD7988-1](#), and the RG divider network with excellent temperature stability and low output noise, consuming only a maximum of 950 μA .

The [ADP196](#) is a logic-controlled high side power switch that is used to fully shut down the whole circuit using the digital input/output pins from the [ADICUP360](#), dropping the consumption of the circuit to 400 μW. This feature allows a power down function for the board by using a digital input/output pins, making it an excellent candidate for a low power solutions.

The [ADP124](#) is a low quiescent current, low dropout linear regulator that is used as the 2.5 V supply voltage for the [AD7798-1](#).

The circuit also has an on-board temperature and humidity sensor, SHT30, from Sensirion, which is used for compensation in making the calculations for the concentration of gasses.

The combinations of these ICs create a low power solution for measurement of volatile organic compounds in indoor applications.

Conversion of Sensor Resistance to Gas Concentration

The TGS8100 sensor data sheet shows typical concentration curves as a function of R_s/R_0 , where R_0 is the sense resistance value with no gas present. The curve for carbon monoxide (CO) gas can be approximated by two equations depending on the R_s/R_0 ratio. The equations apply with CO concentration levels from 1 ppm to 100 ppm.

For R_s/R_0 between 0.05 and 0.6,

$$C = 2.61 \times \left(\frac{R_s}{R_0} \right)^{-2.63} \tag{7}$$

For R_s/R_0 between 0.6 and 0.95,

$$C = 0.550 \times \left(\frac{R_s}{R_0} \right)^{-5.68} \tag{8}$$

Heater Control Software

The demo software for the [CN-0395](#) displays the modes of heater operation, the resistance of sense resistance readings at T_0 or clean air, current sense resistance reading for calculations, and calculated gas concentrations.

There are four different heater modes of operation: constant voltage, constant current, constant resistance, and constant temperature.

In constant voltage mode, it is assumed that the initial heater resistance is at 225 Ω, and the desired heater voltage is maintained to a 0.5% accuracy by calculating the error voltage and adjusting the output current accordingly.

$$IH1 = VH/225 \tag{9}$$

where:

VH is the user input of the voltage to be maintained.

$IH1$ is the initial current that is set of the [ADN8810](#).

$VH1$ is read across the heating resistor, and the error calculation is as follows:

$$E1 = \frac{(VH - VH1)}{VH} \tag{10}$$

where:

VH is the desired heater voltage.

$VH1$ is the voltage read across the heating resistor.

If the error does not fall within the specified tolerance, a new heater current is set to the [ADN8810](#). The new heater current is calculated using the following equation:

$$IH2 = IH1 + 0.5 \times IH1 \times E1 \tag{11}$$

where:

$IH2$ is the heater current for the second iteration.

$IH1$ is the heater current for the first iteration.

$E1$ is the voltage error from the first iteration.

Multiple iterations may be needed to fall within the range of desired voltage; however, if the error falls within 0.5%, the iterations stop.

Sensor Resistance Measurement Software

The software measures the sensor resistance, R_s , using Equation 6. The algorithm steps through the gain resistor ranges, starting with the highest range ($RG1 = 33 \text{ M}\Omega$), until the correct range is reached. After R_s is determined, it is converted into gas concentration using the equation described in the following section.

Test Results

The circuit was tested in a gas test vessel, being exposed to various concentrations of CO gas. To achieve various concentrations, carbon monoxide is mixed with synthetic air at a specified ratio. The gas mixture is passed through a humidifier and is purged to the gas test vessel at a constant rate of 1 l/min, as shown in Figure 2.

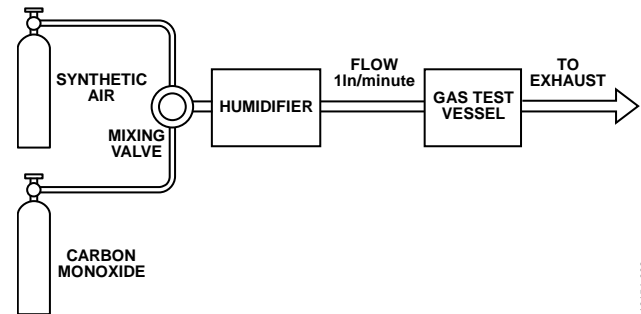


Figure 2. Gas Test Setup

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The R_s/R_0 vs. gas concentration results for the test using the setup are shown in Figure 3 in blue. The red trace shows the typical concentration values predicted by the approximations using Equation 7 and Equation 8. The difference in R_s/R_0 at 100 ppm is approximately 25%.

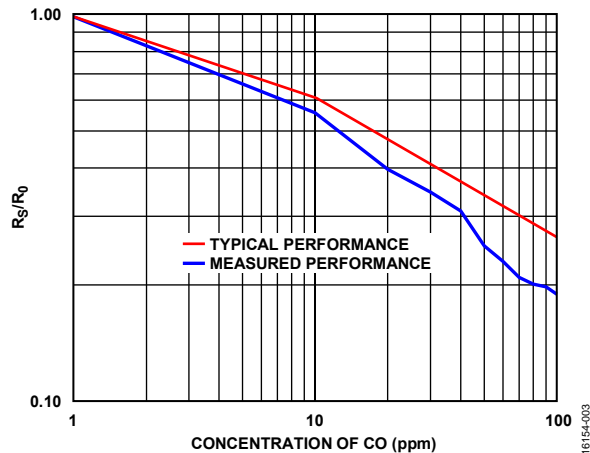


Figure 3. Measured R_s/R_0 Ratio vs. CO Gas Concentration

To achieve more accurate concentration results, calibrate the system in a chamber using known concentrations of the target gas. Variations between sensors, sensor contamination due to exposure to impurities, aging effects, temperature, relative humidity, stabilization time, and purity of the synthetic mixing air all affect the final results.

An important factor in obtaining consistent results is to let the sensor stabilize in ambient air for at least 30 minutes with power applied to the heater before taking the R_0 measurement. Sufficient stabilization time must also be allowed at each concentration level. For the results shown in Figure 3, the R_0 stabilization time was 1 hour, and the stabilization time at each concentration level was 10 minutes. Additional stabilization time may improve accuracy.

Board Layout Considerations

It is important to carefully consider the power supply and ground return layout on the board. Design the printed circuit to have separate analog and digital sections. If the circuit is used in a system where multiple devices require an analog ground to digital ground connection, make the connection at only one point. Bypass the power supplies to all components with at least 0.1 μF capacitors. These bypass capacitors must be as physically close as possible to the device, with the capacitor ideally right up against the device. Choose the 0.1 μF capacitor to have low effective series resistance (ESR) and low effective series inductance (ESL), such as ceramic capacitors. This 0.1 μF capacitor provides a low impedance path to ground for transient currents. The power supply line must also have as large a trace as possible to provide a low impedance supply path. Use proper layout, grounding, and decoupling techniques to achieve optimum performance (see the [MT-031 Tutorial, Grounding Data Converters and Solving the Mystery of AGND and DGND](#), and the [MT-101 Tutorial, Decoupling Techniques](#)).

A complete set of documentation for the [EVAL-CN0395-ARDZ](#) including schematics, layouts, and bill of materials can be found at www.analog.com/CN0395-DesignSupport.

COMMON VARIATIONS

With the trade-off of complexity and cost, the [ADN8810](#) can be replaced with a current source controlled by a DAC.

For a higher resolution ADC, use the [AD7989-1](#). For a higher sampling rate ADC, use the [AD7988-5](#) or [AD7989-5](#).

Another good candidate for an 8:1 multiplexer is the [ADG5208F](#), which has added features of latch-up immunity and overvoltage detection and protection.

For a lower offset voltage with the tradeoff of power, use the [ADA4528-1](#).

For a faster enable time, use the [ADP195](#) instead of the [ADP196](#).

For a higher accuracy 2.5 V supply, use the [ADP7156](#) or [ADP7158](#).

For a lower power consumption 4.096 V reference voltage with lower initial accuracy, use the [ADR4530](#).

CIRCUIT EVALUATION AND TEST

This circuit uses the [EVAL-CN0395-ARDZ](#) circuit board and the [EVAL-ADICUP360](#). The [EVAL-CN0395-ARDZ](#) is stacked on top of the [EVAL-ADICUP360](#) board using the Arduino-compatible pins.

Equipment Needed

The following equipment is needed:

- PC with a USB port and Windows® 7 (64-bit), Windows 8 (64-bit), or Windows 10 (64-bit)
- [EVAL-CN0395-ARDZ](#) circuit evaluation board
- [EVAL-ADICUP360](#) evaluation board or equivalent Arduino interface
- USB A to USB micro cable
- [EVAL-ADICUP360](#) software (IDE)
- [EVAL-CN0395-ARDZ](#) sample code

Getting Started

Load the sample code onto the [EVAL-ADICUP360](#) IDE by following the [EVAL-ADICUP360 Tool Chain Setup User Guide](#).

Functional Block Diagram

Figure 4 shows the functional block diagram of the test setup.

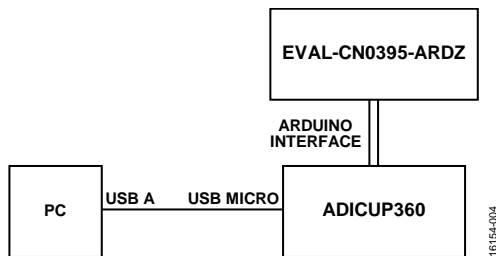


Figure 4. Test Setup Functional Block Diagram

Setup

Connect the [EVAL-CN0395-ARDZ](#) by mounting it on top of the [EVAL-ADICUP360](#) board using the Arduino-compatible headers with their corresponding headers. Then connect the USB cable from the debug port of the [EVAL-ADICUP360](#) to the USB port of the PC.

Test

With the sample code built and loaded onto the [EVAL-ADICUP360](#) and the [EVAL-CN0395-ARDZ](#) mounted on top, the device communicates with the PC and displays the reading from each of the channels. The circuit can be tested by exposing the board in clean air for the initial reading and then exposing it to different concentrations of volatile organic compound gasses.

Figure 5 shows a photo of the [EVAL-CN0395-ARDZ](#) circuit evaluation board.

Information and details regarding test setup and how to use the [EVAL-ADICUP360](#) and the sample code for data capture can be found in the [CN0395 User Guide](#).

Information regarding the [EVAL-ADICUP360](#) board can be found in the [EVAL-ADICUP360 Tool Chain Setup User Guide](#)

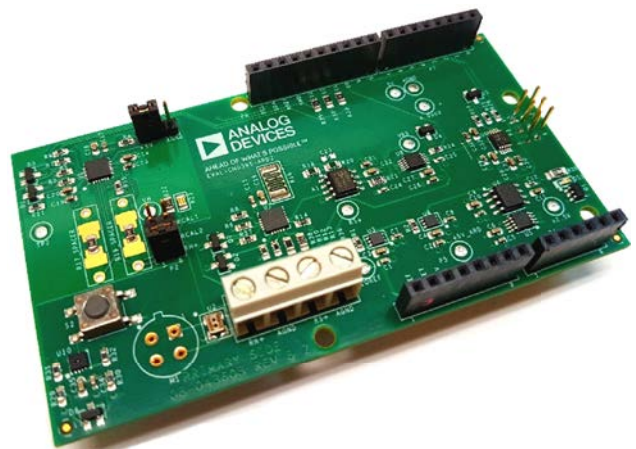


Figure 5. [EVAL-CN0395-ARDZ](#) Circuit Evaluation Board

LEARN MORE

CN-0395 Design Support Package:

www.analog.com/CN0395-DesignSupport

[EVAL-ADICUP360 User Guide.](#)

Kester, Walt. *The Data Conversion Handbook*, Chapter 3 and Chapter 7, Analog Devices. 2005.

MT-015 Tutorial, *Basic DAC Architectures II: Binary DACs*, Analog Devices.

MT-016 Tutorial, *Basic DAC Architectures III: Segmented DACs*, Analog Devices.

MT-031 Tutorial, *Grounding Data Converters and Solving the Mystery of AGND and DGND*. Analog Devices.

MT-035 Tutorial, *Op Amp Inputs, Outputs, Single-Supply, and Rail-to-Rail Issues*, Analog Devices.

MT-101 Tutorial, *Decoupling Techniques*, Analog Devices.

Data Sheets and Evaluation Boards

[ADN8810 Data Sheet](#)

[AD7988-1 Data Sheet](#)

[ADG758 Data Sheet](#)

[ADG884 Data Sheet](#)

[AD8628 Data Sheet](#)

[ADP196 Data Sheet](#)

[ADP124 Data Sheet](#)

[ADR4540 Data Sheet](#)

REVISION HISTORY

7/2017—Revision 0: Initial Version

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