Circuit Note
CN-0425

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Devices Connected/Referenced	
ADuCM355	Precision Analog Microcontroller with Chemical Sensor interface
ADT7320	±0.25°C Accurate, 16-Bit Digital SPI Temperature Sensor

Radiated Immunity Compliant Toxic Gas Detection Circuit

EVALUATION AND DESIGN SUPPORT

Circuit Evaluation Boards

CN-0425 Circuit Evaluation Board (EVAL-ADuCM355EMCZ)

Design and Integration Files

Schematics, Layout Files, Bill of Materials

CIRCUIT FUNCTION AND BENEFITS

Toxic gas detection instruments are widely used to alert people of elevated levels of dangerous gases. Many of these instruments use electrochemical gas sensors that contain multiple metal plates, metal pins, and internal metal-based bond wires. These metal components can make the sensor susceptible to picking up energy from nearby RF communication networks, which may result in the instrument reporting an incorrect gas level or even a false gas alarm. An unnecessary workplace evacuation or factory shutdown due to a false alarm can be very costly to an end user.

The European standard EN 50270: 2015, "Electrochemical compatibility – Electrical apparatus for the detection and measurement of combustible gases, toxic gases or Oxygen" specifies the RF frequency range and power levels that a toxic gas detection instrument must be capable of operating in.

The CN-0425 circuit was extensively tested with a number of sensors in an anechoic chamber to prove compliance with the EN 50270 radiated immunity specifications. Additional tests were performed in close proximity to a high power radio transmitter to prove its robustness to near-field RF interference.

Figure 1 shows an electrochemical gas sensor (M1) connected and how to bias and measure the electrochemical toxic gas sensor. This circuit note also shows and explains the filters used to improve radiated immunity of the whole circuit.

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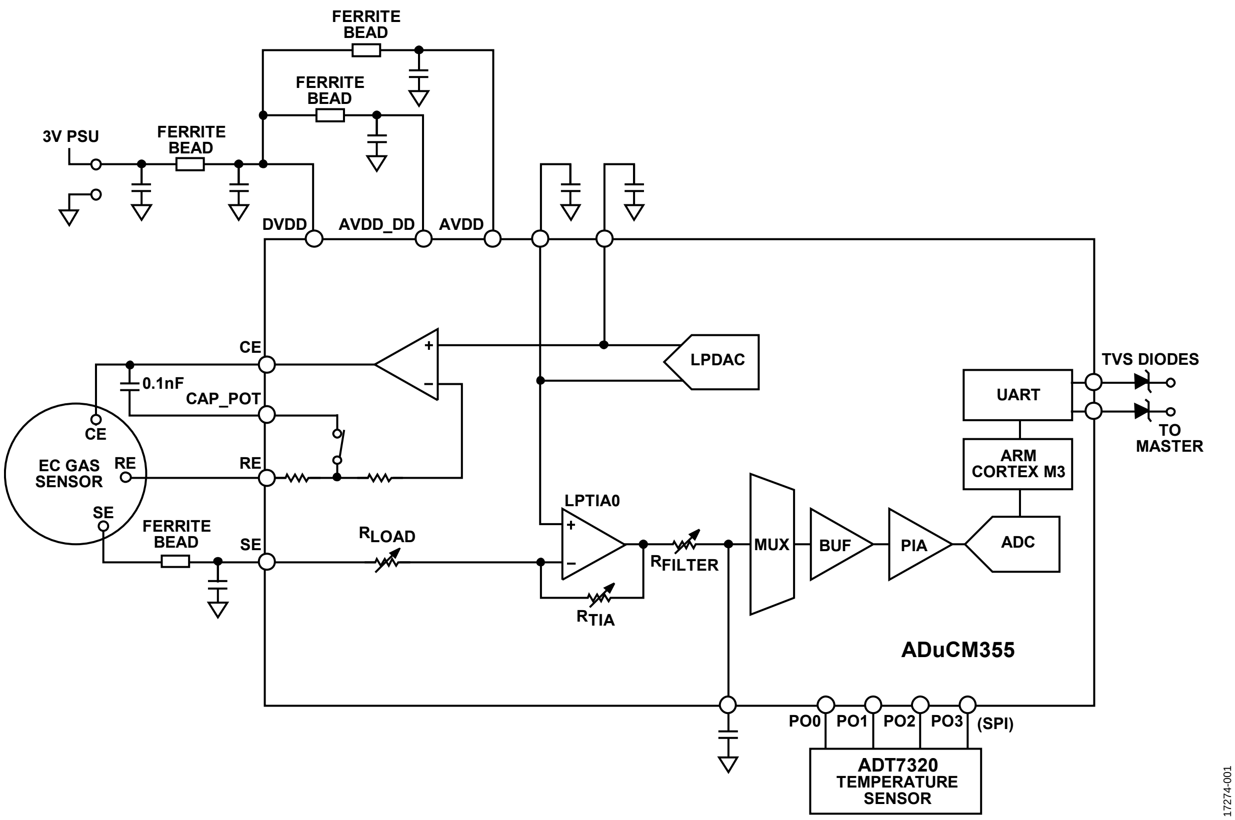

Figure 1. Simplified Circuit Diagram for EVAL-ADuCM355EMCZ

CIRCUIT DESCRIPTION

Figure 1 shows a 3-lead electrochemical (EC) toxic gas sensor connected to the ADuCM355. The ADuCM355 implements the potentiostat function for the gas sensor. It provides a constant, stable bias voltage source between the RE and SE pins of the sensor while sinking/sourcing the current needed for the electrochemical reaction. The current flowing in/out of the sensing electrode (SE) pin of the sensor is proportional to the amount of target gas in the air around the sensor. In the case of the Citicel CO sensor used during testing for this circuit, this is 55 nA/ppm of carbon monoxide gas. The SE pin of the sensor is connected to the low power TIA0 channel of the ADuCM355. This low power TIA0 channel is measured by the analog-to-digital converter (ADC). The ADuCM355 processor is used to convert the measured current to a PPM gas level and periodically sends this result to the UART port for display on a PC.

The amount of current flowing in an EC sensor for a given ppm of target gas varies with temperature. Therefore, temperature compensation is required of the gas sensor's current reading to determine the final ppm level. The ADuCM355 has an on-chip temperature sensor. Figure 1 shows the ADT7320, an external temperature sensor connected to the ADuCM355 via an SPI port, which is a more accurate temperature measurement option.

To ensure that the potentiostat circuit and EC sensor are stable in the presence of RF fields, extra external filters were added. This is described in subsequent sections of this circuit note.

Electrochemical Gas Sensor Connections and EMC Filtering

Figure 2 shows the connections between a 3-lead electrochemical gas sensor and the Channel 0 potentiostat circuitry of the ADuCM355.

The data sheet for the gas sensor specifies a bias voltage required for normal electrochemical behavior of the sensor. The bias voltage is the voltage difference between the reference electrode (RE) and the sensing electrode (SE) or working electrode (WE). This differential voltage is set by the outputs of the LPDAC0 (VBIAS0 to VZERO0). The VBIAS0 output is connected to the noninverting terminal of the amplifier PA. The output of the PA amplifier connects directly to the counter electrode (CE) of the sensor. The feedback to inverting terminal of the PA amplifier is from the RE pin of the sensor. Therefore, VBIAS0 determines the RE pin voltage.

The sensing/working electrode of the sensor is connected to the LPTIA0 amplifier of the ADuCM355 via the inverting input. The LPTIA0 amplifier is a transimpedance amplifier with a programmable load resistor (R_{LOAD}) and programmable gain resistor (R_{TIA}). The current flowing in/out of the sensors SE electrode reflects the target gas in the atmosphere around the sensor. The sensor's data sheet reflects this in current/ppm. The LPTIA0 amplifier converts the current to a voltage that is then buffered and measured via the ADC. The microcontroller can calculate the current flowing in/out of the SE0 pin and therefore determine the ppm level of the target gas.

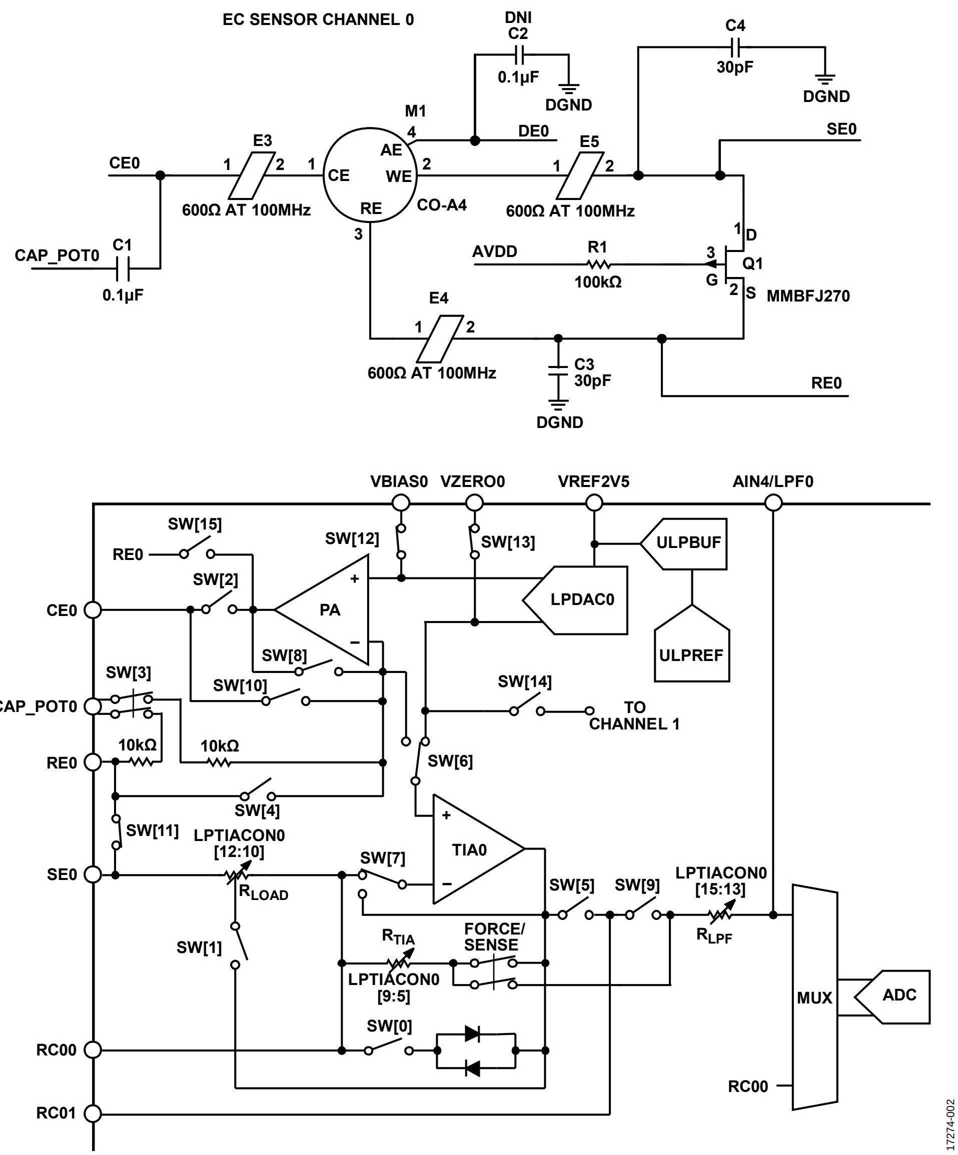

Figure 2. Gas Sensor Connections to ADuCM355 Potentiostat Circuits

The problem that this circuit solves is ensuring no disturbance of the sensor's bias voltage due to RF interference. If the bias voltage is disturbed from its settled steady voltage, extra current flows in/out of the SE electrode and can cause a false alarm or a missed alarm condition.

The following filtering is provided:

- An external 100 nF capacitor (C1) is connected to the CAP_POT0 pin of the ADuCM355. The other side of the C1 capacitor is connected to the CE pin of the sensor via a bead marked E3. The programmable internal switch labelled SW3 allows the CE0 terminal to be connected to RE0 via this capacitor. This means at low frequencies, the connection between CE0 and RE0 is open; however, at high frequencies, the 100 nF capacitor behaves as a short. Also, at high frequencies, the resistive properties of the bead dominate, as shown in Figure 7. This helps to protect the sensor from a disturbance through the counter electrode (CE).
- The sensing/working electrode of the sensor is connected to the SE0 pin of the ADuCM355 via a bead labelled E5 in Figure 2. A 30 pF capacitor (C5) to GND is also shown. This capacitor and bead form an RC filter against high frequencies. The performance of the capacitor up to 2.7 GHz is important, and therefore a capacitor like the GJM0225C1C220JB01 from Murata is recommended. In the printed circuit board (PCB) placement, it is important to place the bead and capacitor as close as possible to the SE pin of the sensor. Figure 5 shows some details of this capacitor's behavior versus frequency.
- A similar bead and capacitor (≤30 pF) is placed near the RE electrode of the sensor. The bead and capacitor are labelled E4 and C3 in Figure 2.
- The output of the LPTIA0 has a programmable low pass, RC filter. The capacitor is an external 100 nF capacitor connected to the AIN4_LPF0 pin of the ADuCM355.

The resistor, R, is labelled R_{LPF} and is programmable from 0 Ω (bypass option) to 1 MΩ.

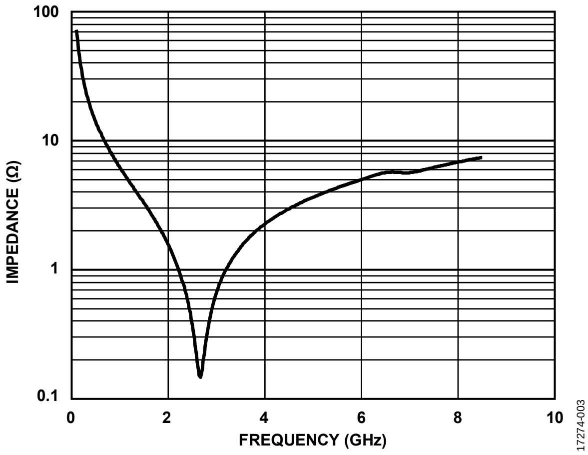

Figure 3. Impedance of GJM0225C1C220JB01 Capacitor Over Frequency

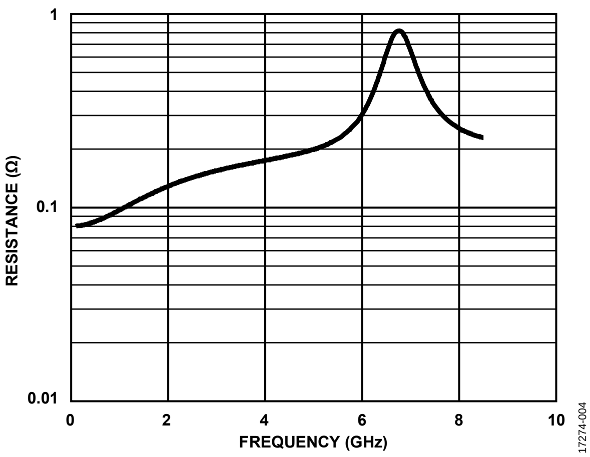

Figure 4. Resistance of GJM0225C1C220JB01 Capacitor Over Frequency

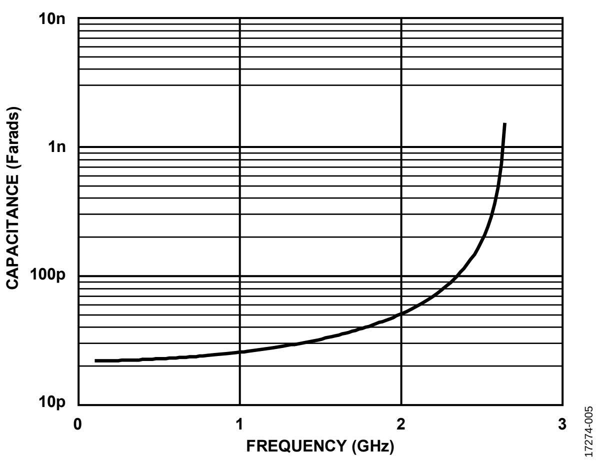

Figure 5. Capacitance of GJM0225C1C220JB01 Capacitor Over Frequency

Power Supply

The circuit is powered from a 3 V source (battery or power supply).

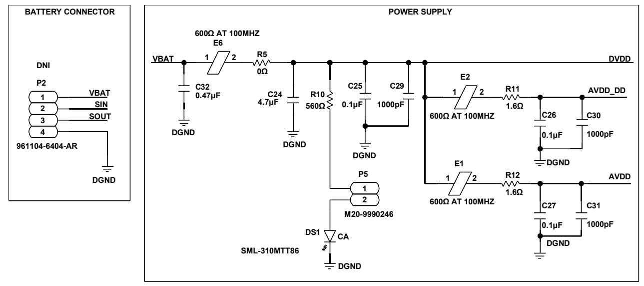

Figure 6. Power Supply Section of the EVAL-ADuCM355EMCZ Board

A filter consisting of a ferrite bead followed by a 0.1 µF capacitor is placed in series with the main supply input. Additional filters are placed in series with the AVDD and AVDD_DD supply voltages.

These filters limit high frequency interference coupling into the power supply because its resistive element becomes dominant at high frequencies, as shown in Figure 7.

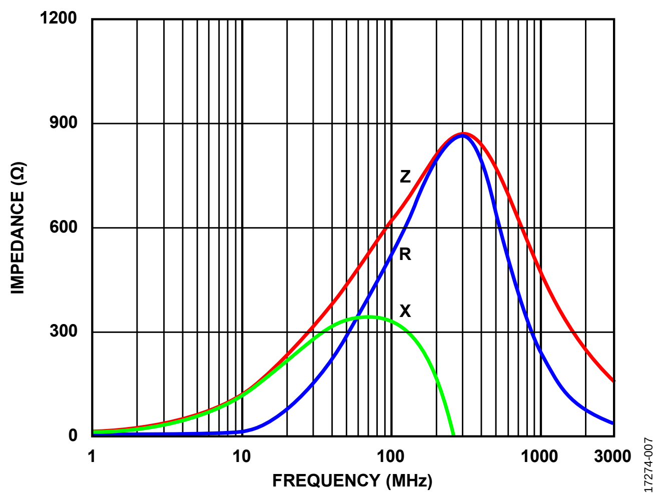

Figure 7. Frequency Response of BLM03AX601SN1

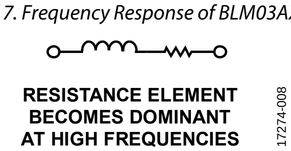

Figure 8. Equivalent Circuit of BLM03AX601SN1

External Temperature Sensor

An external digital temperature sensor, ADT7320 is provided on the board. This connects to the ADuCM355 via an SPI port. Most electrochemical gas sensor's current/ppm of gas varies with temperature; therefore, temperature compensation of the final measurement is required. An internal temperature sensor is provided but the ADT7320 (±0.35°C accurate over the −40°C to +85°C range) has better performance specifications.

Programming and Communications Interface

The 4-lead power connector, P2, also connects to the UART communication signals of the ADuCM355 (SIN, SOUT). The SIN and SOUT signals are each clamped to ground via ESD protection diodes. The transient voltage suppressor (TVS) diodes part number is SESD0201X1UN. These diodes ensure that the UART communication pins meet the Electrostatic Discharge Level 3 tests set by the standard EN 61000-4-2. This standard is quoted in EN 50270 Table 1, and the levels specified are ±6 kV for the ESD contact discharge test and ±8 kV for the air discharge test. The diodes are rated to ±20 kV for both the contact and air discharge tests. ESD testing was not performed on the EVAL-ADuCM355EMCZ board.

The example code with the EVAL-ADuCM355EMCZ sends ADC and gas-sensor measurement results to the UART. This text may be captured and displayed on a PC using a communication-port viewer application like RealTerm.

The ADuCM355 microcontroller can be programmed via the serial wire debug interface. P1 connects to SWDIO and SWCLK pins of the ADuCM355. The EVAL-ADuCM355EMCZ kit provides an adapter board and a programming pod to support programming and debugging of user code as shown in Figure 9.

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Figure 9. Connecting Programming/Debugging POD to the EVAL-ADuCM355EMCZ

COMMON VARIATIONS

The circuit was tested with 3-lead electrochemical gas sensors (CE, RE, WE). However, it can also support 4-lead (CE, RE, WE1, WE2) and 2-lead sensors (CE and WE). For 4-lead sensors with a second working electrode, add the same bead and capacitor to GND on both the WE1 and WE2 sensor pins.

CIRCUIT EVALUATION AND TEST

Refer to EN 50270:2015 Table 1, which specifies the frequency range and power levels for radio frequency electromagnetic immunity (RF immunity). The RF immunity spec referenced is 61000-4-3. The target specification is 10 V/m (power level) in the frequency ranges of 80 MHz to 1 GHz and 1.4 GHz to 2.0 GHz. The target specification is 3 V/m in the frequency ranges of 2 GHz to 2.7 GHz.

These are the EMC requirements for a gas detection instrument used in European safety applications. The TVS diodes mentioned in the Programming and Communications Interface section cover the EN 50270:2015 Table 1 electrostatic discharge requirement. This circuit note focuses specifically on the RF immunity over the frequency range of 80 MHz to 2.7 GHz.

For the tests, a number of Citytech 4-series sensors were used: carbon monoxide (CO), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), and hydrogen cyanide (HCN). These are 3-lead sensors. For the CO sensor, the maximum disturbance allowed was 3 ppm above the offset measurement. This 3 ppm value is the lower limit of measurement specified in Annex A of the standards document, EN 45544-2:2015. The lowest disturbance allowed for each sensor was taken from this table.

For the radiated immunity tests, a carbon monoxide (CO) sensor was used. The standard EN45544-2 Annex A table specifies a lower limit of measurement of ±3 ppm for CO sensors. This very low gas level was the target specification for an RF disturbance.

EVAL-ADuCM355EMCZ Setup Description

Figure 11 shows four EVAL-ADuCM355EMCZ boards each with a 4-series Citytech CO sensor connected to it. Each is powered by its own 2× AA battery pack, a power supply of 3 V.

Figure 10 shows a block diagram of the high power radio test setup.

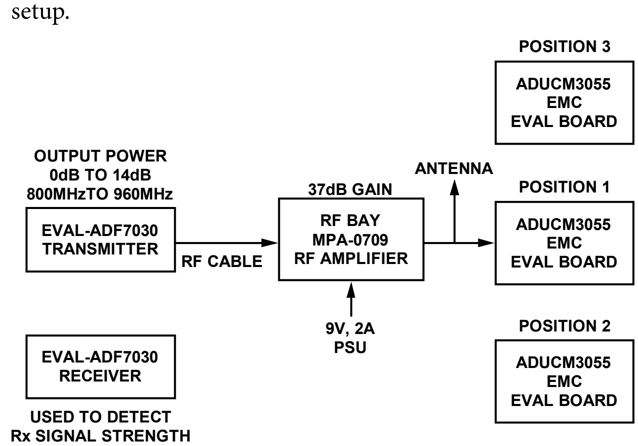

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Figure 10. Block Diagram of Setup Used for High Power Radio Tests

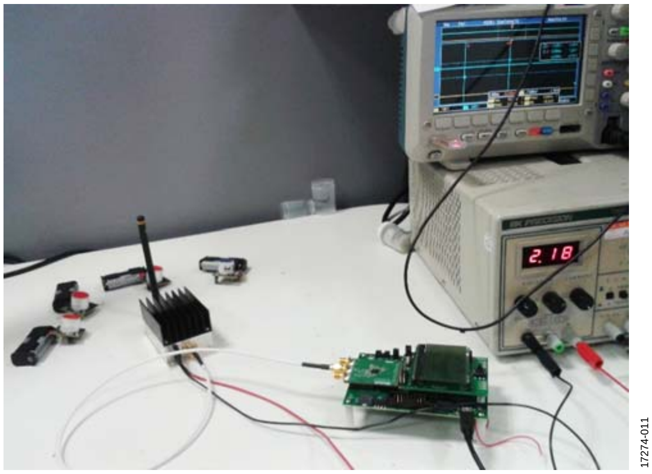

Figure 11. Photograph of Setup Used for High Power Radio Tests

The embedded code running on the ADuCM355 microcontroller configures the Potentiostat 0 channel to set the sensors bias voltage to 0 V with the low power DAC0 outputs (V_{ZERO0} and V_{BIAS0}) both set to 1.1 V. The bias voltage is always enabled to the sensor pins. The microcontroller takes 12× ADC samples of the LPTIA0 channel every 500 ms. These samples are averaged and the results stored to a large array in flash. On completion of the test, the test results can be read off the device via the UART port. Between measurements, the microcontroller enters hibernate mode to save battery power; however, the Potentiostat 0 circuitry remains active.

The embedded code used for the radiated immunity tests is provided as one of the example applications projects with the EVAL-ADuCM355QSPZ and EVAL-ADuCM355EMCZ evaluation software package. It is in the folder **M355_EMC_ DemoBrd_Test** in the **examples** folder. For more details on the evaluation software package, see the EVAL-ADuCM355QSPZ evaluation board user guide.

Anechoic Chamber Tests

The EVAL-ADuCM355EMCZ board was tested in an anechoic chamber where the RF energy transmitted at the board was swept across frequency and the power levels varied.

- 80 MHz to 2 GHz.
  - Repeated for 10 V/m, 20 V/m, and 30 V/m power levels.
  - Tests at each power level were repeated with the board orientation horizontal and vertical to the RF source.
- 2 GHz to 2.7 GHz.
  - Repeated for 6 V/m and 9 V/m power levels.
  - Tests at each power level were repeated with the board orientation horizontal and vertical to the RF source.

Figure 12 shows the worst-case disturbance in the anechoic chamber. All tests in the anechoic chamber were well within the ±3 ppm disturbance level allowed for a CO sensor.

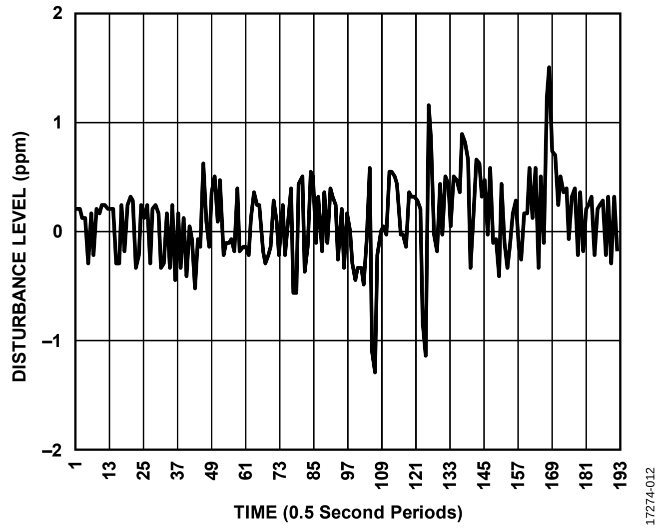

Figure 12. Example Result for 80 MHz to 2 GHz RF Sweep at 30 V/m

Near Field Radio Tests

Many manufacturers of gas detection instruments also test their instruments robustness to near field interferers like high power radios that communicate in the ISM bands around 900 MHz or the Wi-Fi frequency range of 2.4 GHz. In real world applications, a gas detection instrument can be placed beside such a high power transmitter and still be expected to function as normal.

The EVAL-ADuCM355EMCZ board was subjected to two near field tests. First, a frequency sweep using a programmable RF source with an external RF amplifier and then a set of tests using a handy antenna where the transmitted power was measured.

RF Amplifier Tests

In this test, a configurable ISM band RF transmitter (EVAL-ADF7030DB7Z) was connected to a 37 dB RF gain amplifieR.

The EVAL-ADF7030DB7Z was configured to transmit periodically with an output power setting of 0 dB to 5 dB. The antenna connection was connected to an RF amplifier (MPA-0709). This amplifier comes with a fixed 37 dB gain. A number of EVAL-ADuCM355EMCZ boards were placed beside the amplifier. Each ADuCM355 was programmed with the same embedded code as described in the EVAL-ADuCM355EMCZ Setup Description section. A block diagram is shown in Figure 10 for an overview. A photograph of the setup used is shown in Figure 11.

Another EVAL-ADF7030DB7Z ISM radio evaluation board was configured as a receiver to ensure that a valid signal was being transmitted.

The antenna and RF amplifier was set to radiate its maximum of 5 W.

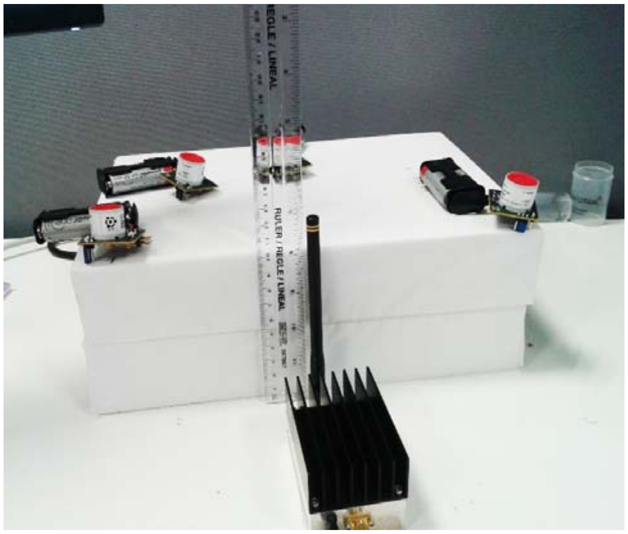

Figure 13. Photograph of Setup used for High Power Radio Tests Showing Distance Between Transmitter and Sensors

A large number of tests were performed with the RF amplifier setup to determine the most robust filter. The frequencies tested were 800 MHz, 900 MHz, and 920 MHz.

The current from the gas sensor was monitored via the ADC. The sensor pin voltages (V_{CE}, V_{RE} and V_{WE}) were also monitored.

One of the early tests applied the RF field to the sensor periodically over a 30 minute period. In this test, there was no bead in series with the sensor pins. E3, E4, and E5 were replaced with 0 Ω links. Figure 14 and Figure 15 show the results.

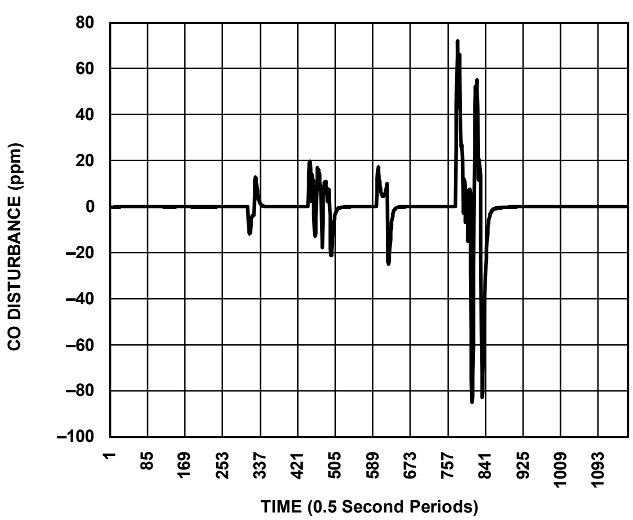

Figure 14. Sensor Current with No Bead in Series with CO Sensor Pins—False Alarm Generated

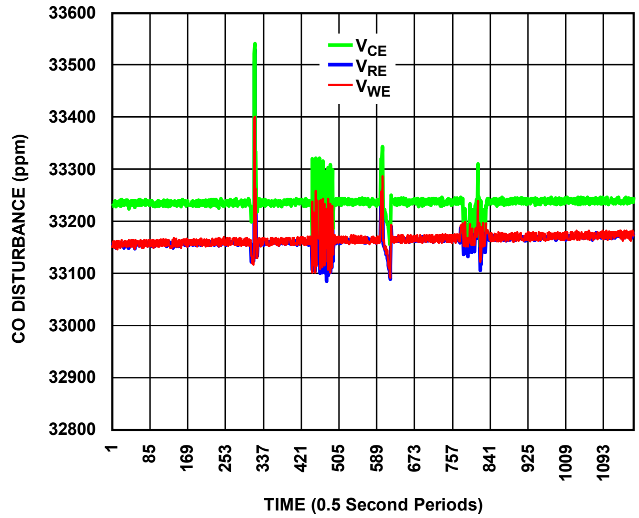

Figure 15. Sensor Pin Voltages with No Bead in Series with CO Sensor Pins—False Alarm Generated

The y-axis of Figure 14 is the ppm level of CO gas, reflective of the current measured from the LPTIA0 channel. As shown, levels greater than 70 ppm were detected. A value of 30 ppm of CO is a threshold for a CO alarm. A 3 ppm maximum disturbance is the target; therefore, a serious disturbance of the sensor and potentiostat circuit occurred. Figure 15 shows the ADC codes for the voltages measured on the sensor's reference electrode (RE), working electrode (WE), and even the counter electrode (CE).

Figure 16 and Figure 17 show the test repeated but this time the each sensor pin has the beads (E3, E4, and E5) in series with the 22 pF capacitors (C3 and C4) to GND. This time the voltages on the sensor pins remain stable as shown in Figure 17. Figure 16 shows a slight disturbance; however, the ppm level is <±2 ppm for the CO sensor.

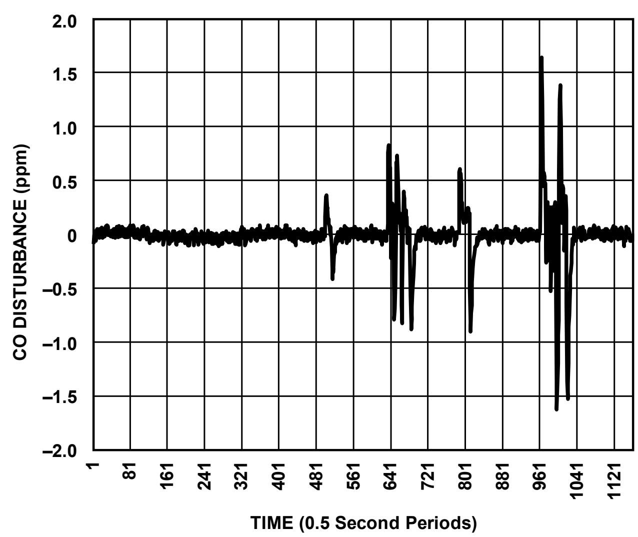

Figure 16. Sensor Current with Bead in Series with CO Sensor Pins and Capacitor to GND on Each Sensor Pin

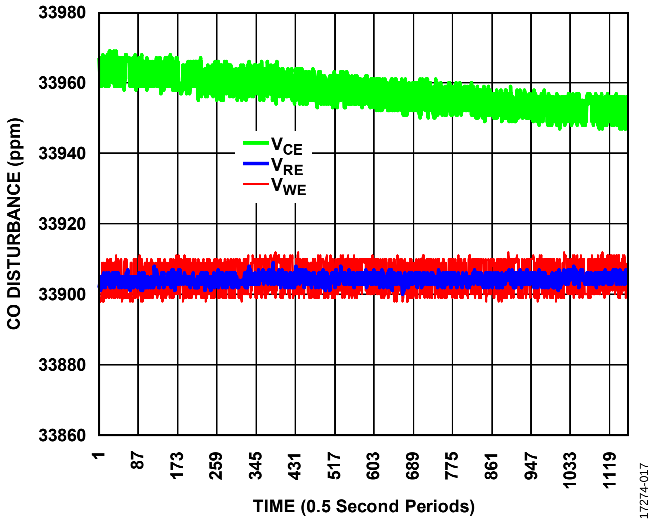

Figure 17. Sensor Pin Voltages with Bead in Series with CO Sensor Pins and Capacitor to GND on Each Sensor Pin

The following are recommendations from the RF transmitter testing:

- If the sensor used has a bias voltage requirement of 0 V, configure SW6 as shown in Figure 2 by setting LPTIASW0[6] = 1 and ensure that the LPTIA0 noninverting pin voltage is the same as the RE sensor pin voltage.
- The ADuCM355 provides a programmable load resistor between the SE/WE pin of the sensor and the inverting input of the LPTIA0. Most electrochemical gas sensors require a load resistor of ≥10 Ω for stability purposes. However, because of the very large internal capacitances of the sensor, the load resistor needs to be ≤47 Ω for optimum settling/response time of the sensor. There was a slight improvement in results when R_{LOAD} was set to 30 Ω in comparison to the 10 Ω setting.
- The ADuCM355 provides programmable gain resistors on its TIA amplifiers. During the tests, there was a slight improvement when using larger RTIA resistor values. Therefore, it is recommended to use as large an RTIA gain resistor as possible.

Handy Antenna RF Amplifier tests

A further set of near field tests were performed using a handy transmitter. This time the tests were performed in an anechoic chamber (ALSE chamber) where the RF output power was controlled and calibrated.

The antenna used was a broad-band miniature Schwarzbeck SBA 9113 with 420NJ elements.

The tested frequency range was 360 MHz to 2620 MHz. The transmitter was placed approximately 50 mm above the EVAL-ADuCM355EMCZ board. The dwell time at each frequency point was 3 sec.

Each test was completed with the EVAL-ADuCM355EMCZ board at 0° and 90° with respect to the antenna. Further details are provided in Table 1.

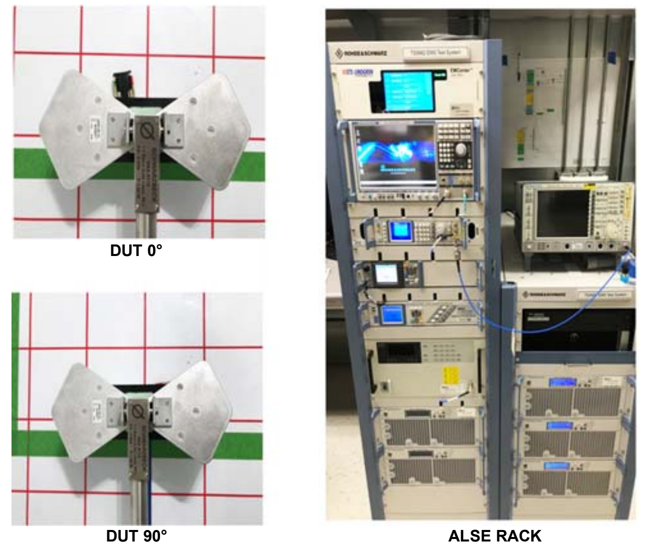

Figure 18. Photograph of Equipment used for Handy Antenna Tests

Table 1. Handy Antenna Test List and Details[1]

Test Number	Frequency (MHz)	Step Size	Level (Watts)
1	360 to 530	2.0%	10
2	410 to 470	N/A	10
3	764 to 960	0.5%	8
4	1240 to 1300	0.5%	3
4	1429 to 1453	N/A	N/A
5	1626 to 2400	0.5%	6
6	1885 to 2025	N/A	2
7	2400 to 2620	N/A	6

[1] N/A means not applicable.

Only the frequency range tests of 764 MHz to 960 MHz reported a CO ppm reading of greater than 3 ppm. When repeated with a power level of 5 W, the readings were less than 3 ppm. All other tests results passed.

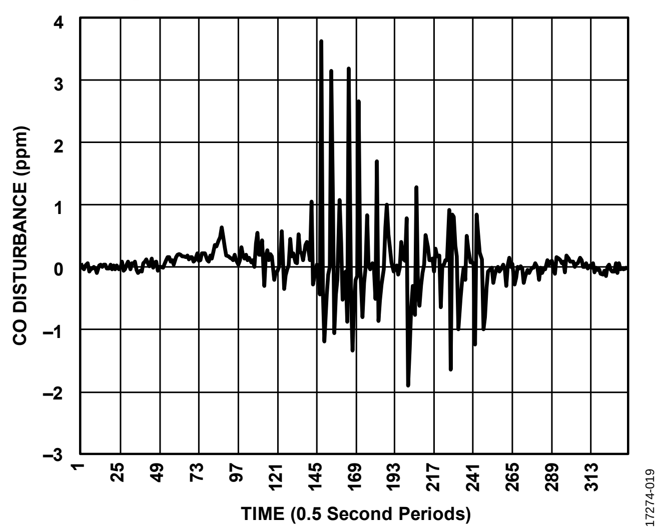

Figure 19. Handy Antenna Result for 764 MHz to 960 MHz, 8 W

When the test was repeated with the bead and capacitor removed from the gas sensor pins, a disturbance of >±15 ppm was detected.

LEARN MORE

CN-0425 Design Support Package:
www.analog.com/CN0425-DesignSupport

EVAL-ADuCM355EMCZ User Guide

Data Sheets and Evaluation Boards

ADuCM355 Data Sheet

ADT7320 Data Sheet

EVAL-ADuCM355QSPZ Evaluation Board

REVISION HISTORY

12/2018—Revision 0: Initial Version

I^{2}C refers to a communications protocol originally developed by Philips Semiconductors (now NXP Semiconductors).

ANALOG DEVICES