Extend Battery Life and Simplify Calibration in Gas Sensing Applications

Gustavo Martinez and Peggy Liska

In a carbon monoxide (CO) gas sensing application, a gas sensor node must continuously monitor the CO gas concentration and generate an alarm if the concentration exceeds a given limit for a certain amount of time. The required response time of the sensor node can vary depending on the gas concentration. Two challenges of designing a circuit for gas sensing applications are: 1) maximizing the battery life while continually monitoring the gas sensor signal and 2) adjusting for sensitivity differences between individual gas sensors during calibration.

In battery-powered gas sensors, it is imperative that the sensor node operate in low-power mode as much as possible to extend battery life while at the same time ensuring the gas sensing portion of the design is always on. In TIDA-00756, an analog front-end design consisting of a transimpedance and comparator stage continuously monitors the instantaneous gas concentration and generates an interrupt to the microcontroller when the gas concentration has exceeded a given threshold. The microcontroller remains in a low-power mode until an interrupt from the comparator is received or when the nano-power system timer indicates it is time for a system self-test. The system block diagram is shown in Figure 1.

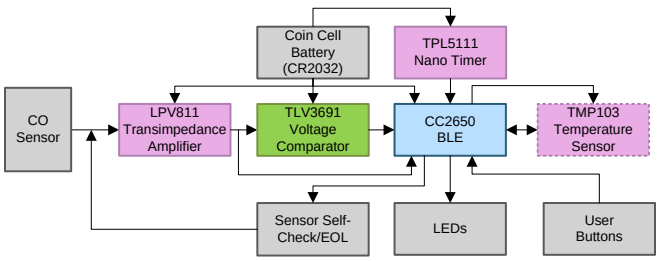

Figure 1. Always-On Gas Sensor Node Design

If the gas concentration rises above a given minimum threshold, the sensor node must closely track the gas concentration and generate an alarm only when a minimum amount of time has transpired, no earlier. If the gas concentration falls below the minimum threshold before the required time, the sensor node can return to its low power mode without generating an alarm. Table 1 lists the response times as required by the Standard for Single and Multiple Station Carbon Monoxide Alarms (UL2034).

Table 1. CO Sensor Response Time per UL2034

Concentration (ppm)	Response time (minutes)
70 ± 5	60 – 240
150 ± 5	10 – 50
400 ± 10	4 – 15

As shown in Figure 2, a reduced battery life can result if the gas sensor node is exposed to an environment where the CO gas concentration often exceeds the minimum gas threshold for short periods of time.

In each case, the microcontroller must come out of low power mode to sample the gas concentration every second and track the amount of time it exceeds the minimum threshold. Since the gas concentration drops to acceptable levels before the minimum amount of time required before generating an alarm is met, no alarm is generated. The microcontroller goes back into low power mode once the concentration drops below the minimum threshold.

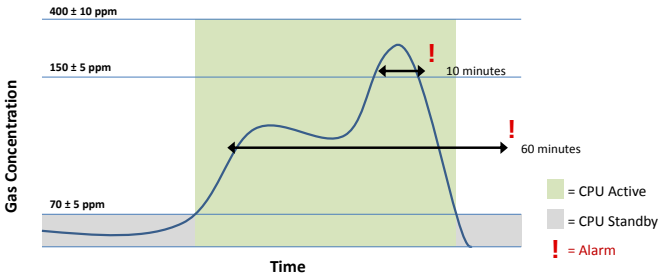

Figure 2. CPU Activity During Non-Alarm Events

Extend Battery Life with Configurable Thresholds

To increase battery life, an ADS7142 analog-to-digital converter (ADC) can replace the comparator in the original design (see Figure 3).

The ADS7142 is a 2-channel sensor monitor that incorporates a windowed digital comparator with programmable high and low thresholds on each channel. The ADS7142 can be configured to trigger an interrupt signal when the input signal is either inside or outside of the window. In other words, the MCU can configure the ADS7142 to send an interrupt signal if the gas level goes above or below a threshold. In the case of a gas sensing application, given normal CO levels, the MCU configures the ADS7142 to send out

Copyright © 2017–2018, Texas Instruments Incorporated

an interrupt signal when the gas sensor voltage exceeds the minimum threshold. At this point, the MCU briefly comes out of its low-power mode to reconfigure the ADS7142 to send out an interrupt signal if the input signal now goes below the minimum threshold (returning to normal operation) or if the signal goes above the next threshold. A timer is also configured to track the amount of time that the gas concentration stays above the minimum threshold.

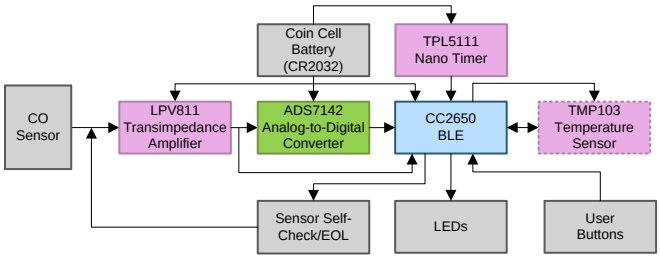

Figure 3. Gas Sensor Node Using ADS7142

Figure 4 illustrates this concept in practice. The MCU receives an interrupt from the ADS7142 when the gas concentration exceeds 70 ppm. The MCU comes out of low power mode to configure the ADS7142 to generate an interrupt if the gas concentration drops below 70 ppm or goes above the next threshold of 150 ppm. The MCU also configures a timer to generate an interrupt after 60 minutes and goes back to a low-power mode. When the gas concentration exceeds 150 ppm, the ADS7142 generates another interrupt. The MCU again wakes up and configures the ADS7142 window comparator to detect if the gas concentration drops below 150 ppm or goes above 400 ppm. The MCU configures the timer for 10 minutes and goes back to a low-power mode. Using the ADS7142 allows the MCU to stay in a low power mode longer, thereby increasing battery life.

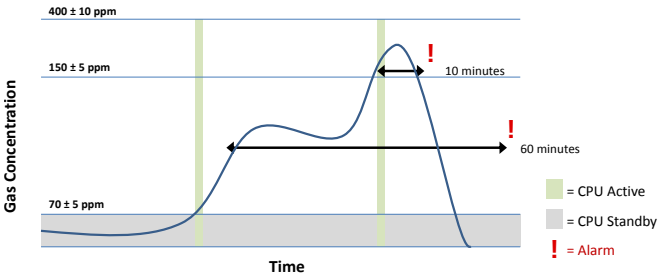

Figure 4. CPU Activity Using the ADS7142

By keeping the MCU in a lower power mode longer, the ADS7142 can help achieve an energy savings as shown in Equation 1.

$$(I_{MCU_ACTIVE} - I_{MCU_STANDBY}) \times \delta t \times V_{BAT} \quad (1)$$

In this equation, I_{MCU_ACTIVE} and $I_{MCU_STANDBY}$ are the current consumption of the MCU in active mode and standby mode respectively. The reduction in MCU Active time is given by δ_t. Multiplying the current savings over time by the voltage of the battery, V_{BAT}, equates to the total energy savings.

Given that the TLV3691 comparator used in TIDA-00756 consumes a typical 150 nA during operation, it might be argued that the ADS7142 with its power consumption of 500 nA could actually increase overall power consumption. However, the current consumed by the MCU when in low-power mode vs monitoring mode differs on the order of 500 µA. This proves that the keeping the MCU in its low-power mode as much as possible provides significant system-level power savings.

Simplify Calibration with Configurable Thresholds

In the original TIDA-00756 design, the comparator threshold is fixed using a voltage divider. The voltage for the divider is calculated using Equation 2.

$$V_{THRESH} = GasCon \times Sensitivity \times TempCorr \times A_{TIA} \quad (2)$$

In this equation, *GasCon* is the minimum gas concentration at which to wake up the microprocessor, e.g. 70ppm, *Sensitivity* is the sensitivity of the sensor, *TempCorr* is an optional correction factor for temperature, and A_{TIA} is the gain of the trans-impedance stage. The resulting V_{THRESH} is used to adjust the voltage divider accordingly through a potentiometer. There are two limitations with this approach. First, manual adjustment of the voltage divider requires an operator and can increase costs during production. Second, once the threshold is set, it cannot be varied to account for changes in the sensor output based on temperature. This can be mitigated by setting the threshold assuming the worst case conditions. However, this comes at an expense of battery life since the comparator will wake up the microcontroller at lower than necessary gas concentration levels.

In the ADS7142 design, the microcontroller can easily adjust the threshold using an I2C command. This allows for automatic, configurable calibration at the time of production as well as when the product is out in the field. By utilizing the programmable thresholds of the comparator inside the ADS7142, the system is calibrated for a specific sensor sensitivity vs the "worst" case sensor sensitivity. In addition, the system is able to self-correct for changing sensor sensitivity due to temperature variations by reprogramming the comparator threshold levels based on ambient temperature readings.

Copyright © 2017–2018, Texas Instruments Incorporated

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ('TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2018, Texas Instruments Incorporated