Extend Battery Life and Simplify Calibration in Gas Sensing Applications

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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.

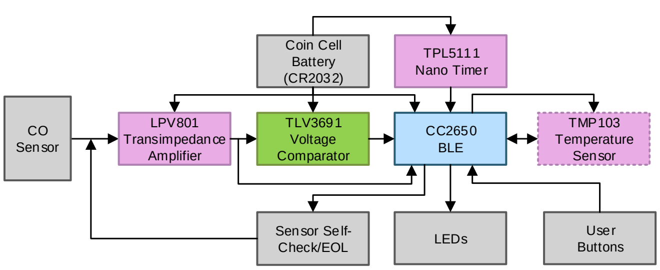

Figure 1. Always-On Gas Sensor Node Design

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.

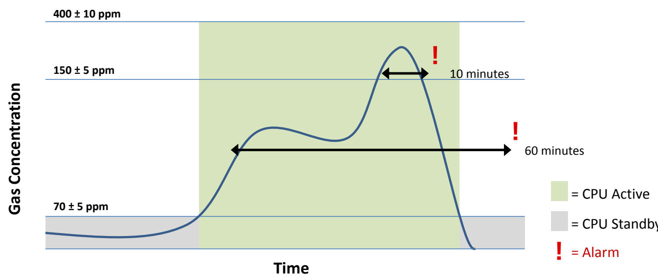

Figure 2. CPU Activity During Non-Alarm Events

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 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.

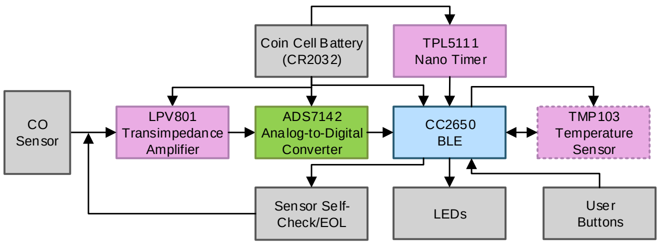

Figure 3. Gas Sensor Node Using ADS7142

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.

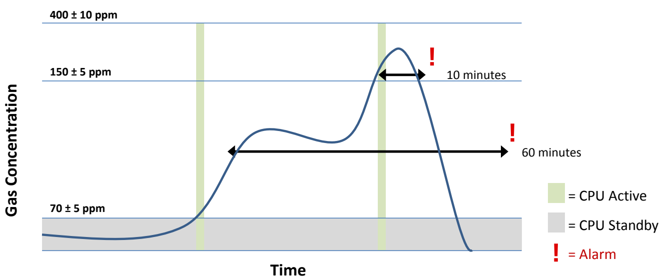

Figure 4. CPU Activity Using the ADS7142

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.

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