

Designing a 10-Year Battery Life Smoke Alarm with the TPS8802



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ABSTRACT

This article outlines the design methodology of using the TPS8802 to achieve a 10-year smoke alarm battery life. The TPS8802 smoke alarm analog front end has low power amplifiers, drivers, and regulators specialized for 10-year smoke alarm applications. The system architecture, standby current, and measurement techniques are discussed in relation to power consumption. Detailed calculations estimate system power consumption for two smoke alarm designs and show the breakdown of power consumption between each of the blocks and measurement sequences. The calculations provide the framework for further power optimization. Two smoke alarm designs are tested to verify the accuracy of the calculations, and battery options are selected to provide 10-year battery life for these systems.

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1 Introduction

New smoke alarm regulations often require a 10-year battery life if the battery is the only power source. Battery selection in these alarms is highly dependent on the system power consumption, and lower power alarms have smaller, lower cost batteries. Achieving low power consumption requires low standby currents and careful management of the smoke alarm regulators, drivers, and amplifiers. The TPS8802 smoke alarm analog front end (AFE) integrates configurable regulators, drivers, and amplifiers with low active and standby currents for achieving 10-year battery life with a single lithium primary battery. The TPS8802 supports multi-wavelength photoelectric smoke sensors, carbon monoxide (CO) sensors, and a variety of battery configurations, all of which are explored in the context of power consumption.

2 System Architecture

The external component configuration has a large influence on the system power consumption. In particular, the VCC, MCU, and LED supplies must be selected to minimize power consumption. Different options and their advantages are discussed in this section.

2.1 Battery Voltage

The TPS8802 operates with a battery voltage between 2.0 V and 15.6 V and a VCC voltage between 2.6 V and 15.6 V. When the battery voltage is less than 2.6 V, the boost converter increases the voltage to adequately supply VCC. This allows the TPS8802 to be powered from a variety of batteries, including 3-V lithium, series-connected 1.5-V alkaline, and 9-V alkaline or lithium. Alkaline batteries typically have a shorter shelf life than lithium batteries, making lithium batteries more viable for 10-year smoke alarms. The VCC voltage must be at least 2.6 V for the internal amplifiers to function properly, making the system most efficient when VCC is close to 2.6 V. Therefore, 3-V lithium manganese dioxide (LiMnO₂) batteries and two series-connected 1.5-V lithium iron disulfide (LiFeS₂) batteries provide the best capacity per cost in this application. Other lithium battery chemistries such as lithium ion and lithium thionyl chloride are not considered due to their higher cost. With the battery voltage selected, the system architecture can be designed and current consumption can be calculated. A specific battery size is selected after the capacity requirement is calculated.

2.2 VCC Supply

There are several ways to supply power to the TPS8802 VCC input with a 3-V battery. Two options are explored in detail: connecting VBST to VCC and connecting VBAT to VCC through a switch. These configurations are demonstrated in the example smoke and CO system and smoke-only system.

2.2.1 Connecting VCC to VBST

When using the TPS8802 with a 3-V battery, the boost converter can be used to power the horn, use the battery test load, and power a blue LED. The TPS8802 automatically enables the boost converter on power-up when over 2.0 V is applied to VCC. Connecting VCC to VBST allows the boost converter to provide the minimum 2.6 V required on VCC with a battery voltage as low as 2.0 V. Connecting VCC to VBST increases the usable voltage range of the battery, improving the battery life. During operation, the TPS8802 VCLOW_BST feature can be used to automatically enable the boost converter when the VCC voltage drops below 2.4 V and disable the boost converter when the VCC voltage is above 2.5 V. The VCLOW_BST feature sustains the VCC voltage above 2.4 V with low power consumption. The functional performance is unaffected when the VCC voltage is between 2.4 V and 2.6 V, although parametric performance may be affected.

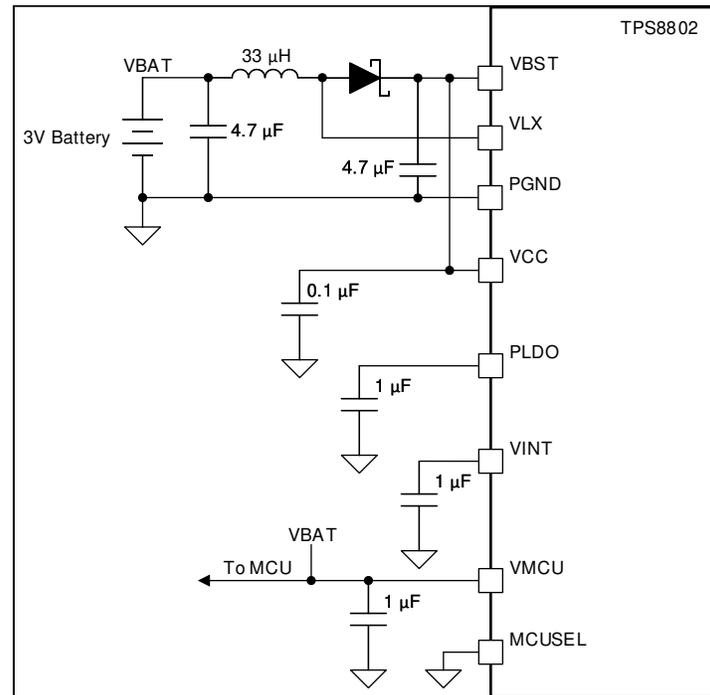


Figure 2-1. TPS8802 Power Connections with VCC Connected to VBST

2.2.2 Connecting VCC to VBAT Through a Switch

In systems where the CO amplifier, MCU LDO, 300-mV reference, VCLOW monitor, interconnect, and sleep timer do not need to be continuously powered, the TPS8802 can be unpowered in between smoke measurements to reduce the system standby current. To achieve this, the MCU controls a load switch between VBAT and VCC to disconnect the TPS8802 in between smoke measurements. This allows the smoke alarm to achieve an idle current less than the TPS8802 typical 3.8- μ A standby current. This configuration provides the best power savings in smoke-only alarms where the CO amplifier is not used. The battery voltage must be above 2.6 V for parametric performance and above 2.4 V for functional performance. While this configuration has a tighter battery voltage range and cannot use the full capacity of the battery, the lower power consumption of this configuration gives it a longer battery life. VCC and PLDO are shorted together to remove the voltage drop caused by the internal PLDO block.

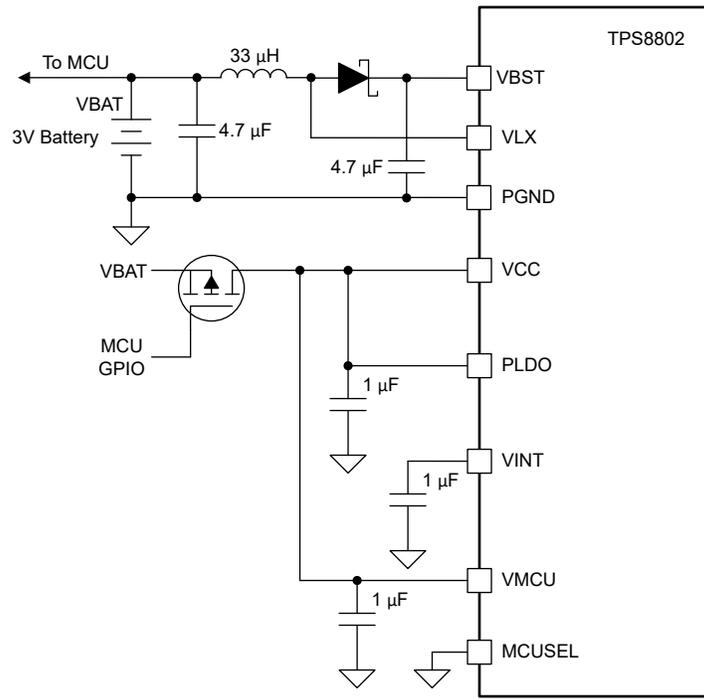


Figure 2-2. TPS8802 Power Connections with VCC Connected to VBAT Through a Switch

2.3 MCU Supply

The MCU can be powered with the TPS8802 MCU LDO, the battery directly, or an external LDO. VMCU sets the voltage of the TPS8802 digital inputs and outputs. VMCU must be the same voltage as the MCU supply to ensure reliable digital communication between the MCU and TPS8802.

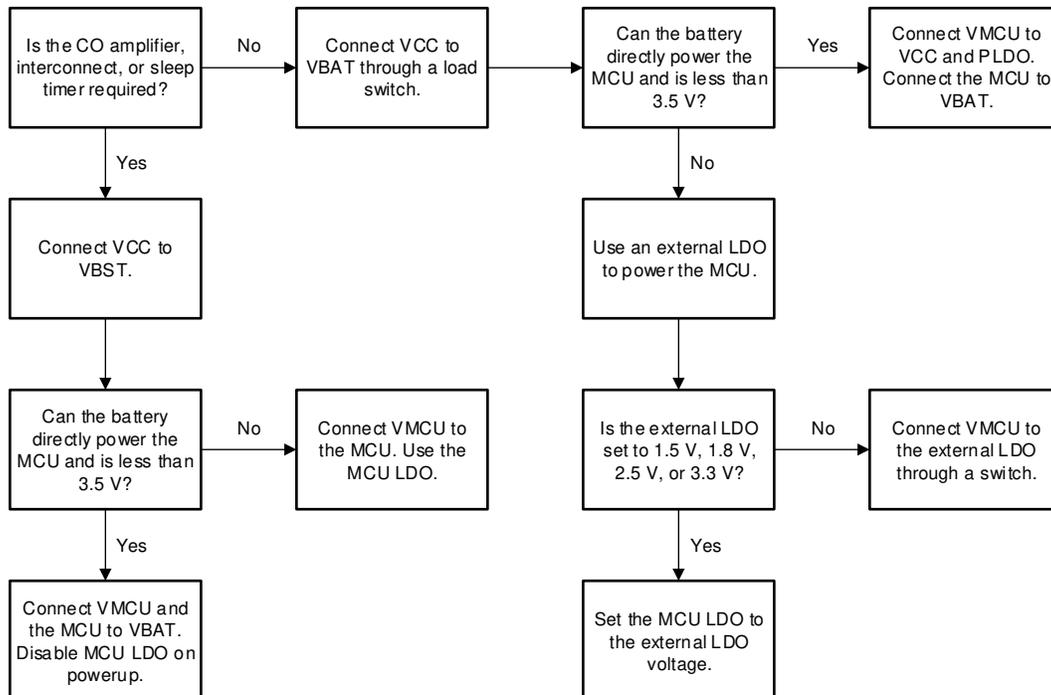


Figure 2-3. VCC and VMCU Connection Guide for Maximum Power Savings.

2.3.1 MCU Connected to VBAT

It is most efficient to connect the MCU directly to the battery if the MCU can withstand the full battery voltage range. Connect MCUSEL to GND to set the MCU LDO to 1.8 V during the power-up sequence. The battery voltage overrides VMCU without drawing significant current. When the system is powered up, disable the MCU LDO to save power. Ensure the battery voltage does not exceed 3.5 V when connected to VMCU.

2.3.2 MCU Connected to MCU LDO

If the MCU cannot be directly connected to the battery, the MCU LDO can be enabled to output 1.5 V, 1.8 V, 2.5 V, or 3.3 V to the MCU while consuming 2.0 μ A of current. Using a 3.3 V microcontroller requires the boost converter to be periodically enabled, greatly increasing the system current consumption. For this reason it is recommended to use a 1.5 V, 1.8 V, or 2.5 V microcontroller with the MCU LDO. Because the MCU LDO is register programmable, the LDO can be set to different voltages during the smoke alarm operation; for example, 3.3 V during measurements and 1.8 V between measurements.

2.3.3 MCU with VCC Connected to VBAT Through a Switch

If VCC is connected to VBAT through a switch, the MCU LDO cannot be used to power the MCU because the MCU LDO is not powered when the switch disconnects power to VCC. There are three options to power the MCU:

- Connect the MCU to the battery and VMCU to VCC.
- Use an external LDO to power the MCU and the MCU LDO to power VMCU. The MCU LDO is programmed nearest to the value of the external LDO: 1.5 V, 1.8 V, 2.5 V, or 3.3 V. The 2.0 μ A MCU LDO current is consumed only while the TPS880x is powered.
- Use an external LDO to power the MCU and a switch to connect the external LDO to VMCU while the VCC switch is enabled.

2.4 Photoelectric Smoke Sensor LED Supply

The photoelectric smoke sensor LED can be powered by the battery, PLDO, or LEDLDO. For maximum power savings, the LED should be supplied directly from the battery if the voltage supports it. If direct battery voltage is not supported, use the boost converter with VBST set to the minimum required voltage. Before selecting how to power the LED, the minimum LED supply voltage $V_{LED(min)}$ must be calculated using Equation 1. V_F is the LED forward voltage, $V_{DINA(drop)}$ is the LED driver dropout voltage (300 mV at 150 mA and 500 mV at 500 mA), V_{CSA} is the voltage at the CSA current sense pin, and ΔV_{LED} is the voltage drop caused by the capacitive voltage supply on the LED. Using a higher capacitance on the LED supply decreases the supply voltage drop when pulsing the LED as shown in Equation 2.

$$V_{LED(min)} = V_F + V_{DINA(drop)} + V_{CSA} + \Delta V_{LED} \quad (1)$$

$$\Delta V_{LED} = \frac{I_{LED} \times T_{LED}}{C_{VLED}} \quad (2)$$

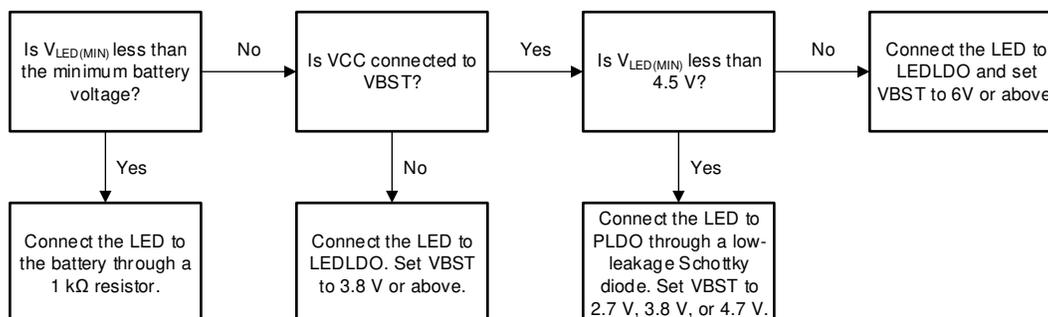


Figure 2-4. LED Supply Selection Guide

2.4.1 LED Connected to VBAT

A low current infrared LED can be powered directly from the battery through a current-limiting resistor and large capacitor. This is the most efficient way to power the LED. Ensure the minimum battery voltage is greater than $V_{LED(MIN)}$.

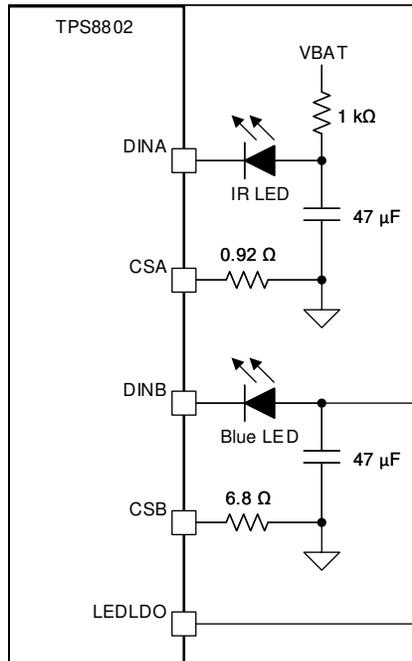


Figure 2-5. IR LED Connected to VBAT Through a Current-Limiting Resistor

2.4.2 LED Connected to PLDO

An infrared LED or low current blue LED can be powered through PLDO with a low-leakage Schottky diode. PLDO is supplied by VCC and can supply a voltage higher than VBAT if VCC is connected to VBST. PLDO has two operating modes: a pass-through mode when VCC is less than 5 V (typical), and a regulation mode when VCC is greater than 5 V (typical). The pass-through mode shorts PLDO to VCC. The regulation mode has a minimum 1 V drop between VCC and PLDO. Therefore, PLDO is most efficient when it is operating in the pass-through mode. The Schottky diode must be low-leakage, approximately 0.1 μA, to prevent the LED capacitor from discharging into PLDO when the boost converter is disabled. A silicon diode can be used instead of a Schottky diode if the higher voltage drop is tolerable.

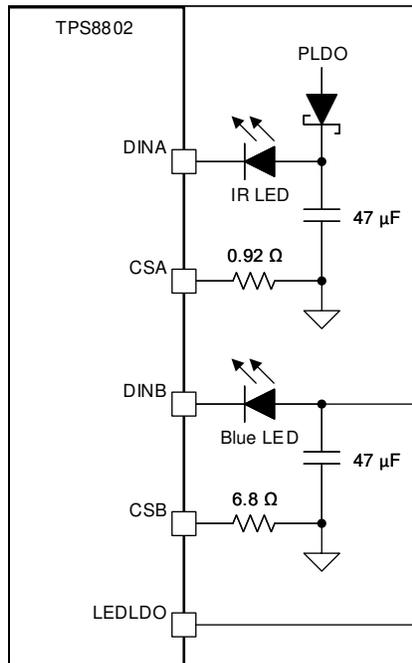


Figure 2-6. IR LED Connected to PLDO Through a Low-Leakage Schottky Diode

2.4.3 LED Connected to LEDLDO

Any LED can be powered through the LED LDO. The LED LDO is current limited and has a series diode to block reverse current. The LED LDO is supplied by VBST and regulates to a programmable voltage between 7.5 V and 10 V, but does not require regulation in order to charge the LED supply capacitor. When the LED LDO is enabled and VBST is less than the programmed voltage, the LED LDO outputs the VBST voltage with a typical 1 V diode drop and 3 mA current limit. If VCC is connected to VBST, the LED LDO output is lower than PLDO in the pass-through mode and higher than PLDO in the regulation mode. For this reason, the LED LDO is best used when $V_{LED(MIN)}$ is above 4.5 V.

2.5 Example Schematics

Schematics for the smoke-only system and smoke and CO system are shown. The power consumption of these systems are calculated and measured.

2.5.1 Smoke and CO Schematics

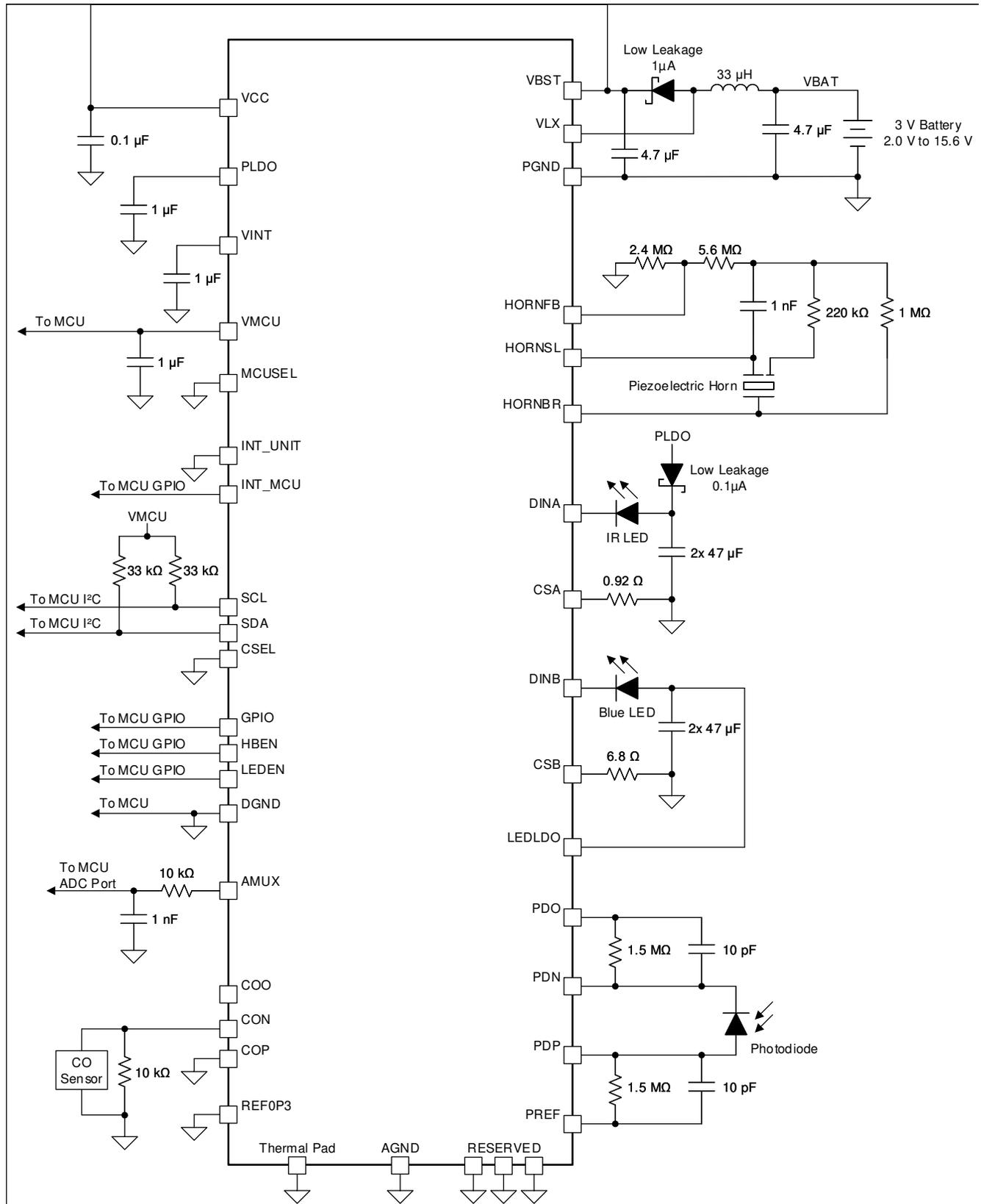


Figure 2-7. Smoke and CO System Schematics for Minimum Power Consumption

The smoke and CO system connects VBST to VCC to allow battery voltages down to 2.0 V. Here the MCU LDO is set to 1.8 V, a low voltage that can be powered without the boost converter being enabled. The boost converter can be enabled to 2.7 V, 3.8 V, or 4.7 V to supply the IR LED through PLDO with a low-leakage (0.1 μ A) Schottky diode. The blue LED is supplied by the LED LDO to support the higher blue LED forward voltage. The CO amplifier is continuously enabled to track the slowly-varying CO concentration signal.

2.5.2 Smoke-Only Schematics

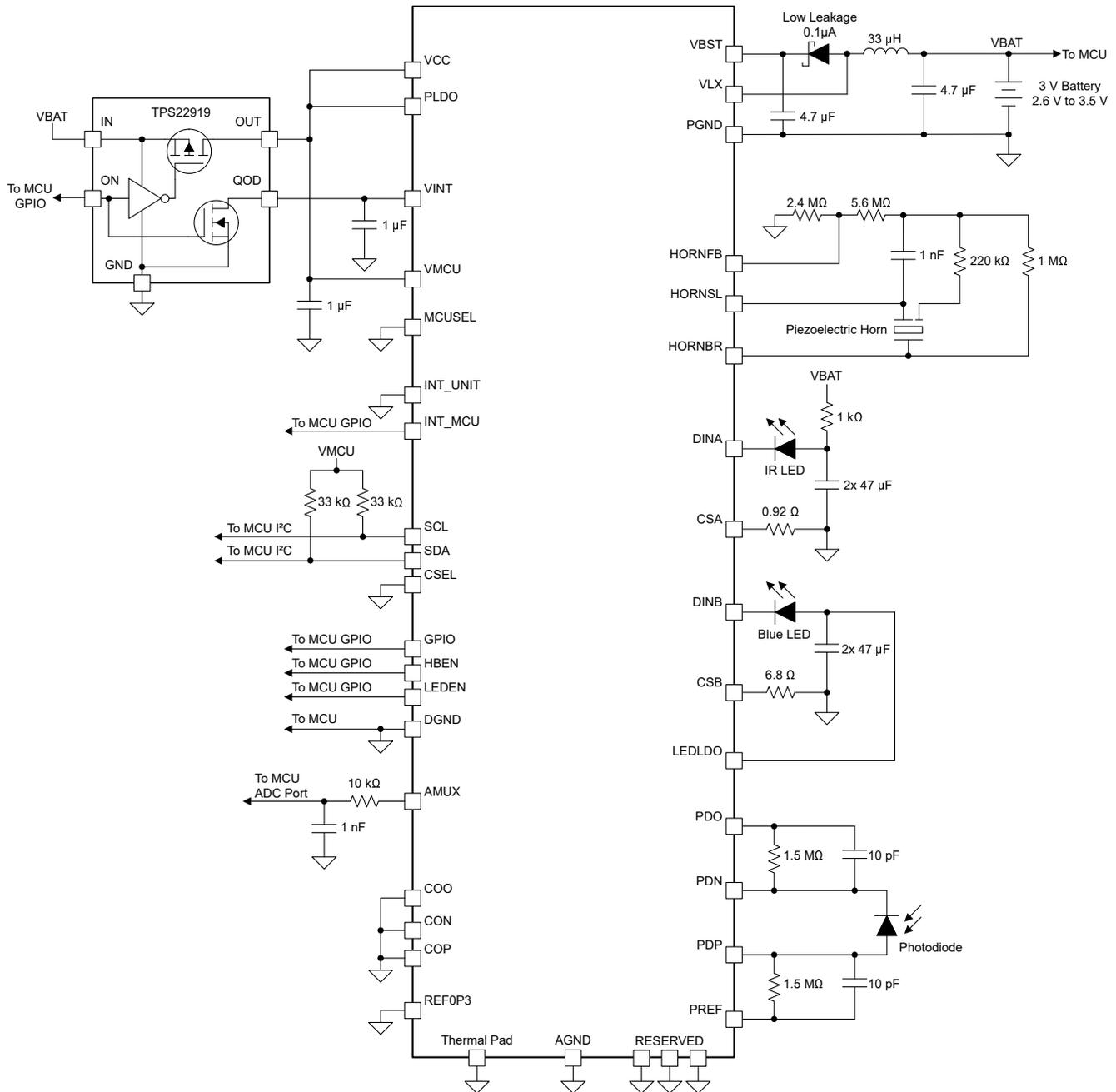


Figure 2-8. Smoke-Only Alarm Schematics for Minimum Power Consumption

The smoke-only system uses a microcontroller that connects directly to the battery. Because the TPS8802 MCU LDO is not required, the TPS8802 can be unpowered between measurements. A TPS22919 load switch is used to connect the battery to VCC during measurements and discharge VINT between measurements. VCC and PLDO can be shorted because of the low battery voltage. VMCU is connected to VCC to set the TPS8802 digital logic level equal to the microcontroller's supply voltage. With the battery voltage used to supply VCC, the minimum battery voltage is limited by the 2.6 V minimum VCC voltage. The IR LED is driven at a low enough

current such that 2.6 V is sufficient. The blue LED has a higher voltage that requires the boost converter, thus the LED LDO is used.

3 Current Consumption

Various blocks and measurement timing have an impact on the system power consumption. These blocks will be discussed in the context of the system power consumption.

3.1 Standby Current

In this report, standby current is the current consumption if no measurements are taken. The two primary contributors to standby current are from the TPS8802 and microcontroller.

3.1.1 TPS8802 Standby Current

The TPS8802 typically consumes 3.8 μA current when 3 V is applied to VCC. This current is always drawn when VCC is supplied with 3 V. The TPS8802 standby current supplies the power LDO (PLDO), 2.3 V INT LDO analog supply, and digital core. I²C communication and the sleep timer are active and do not require additional current to use. The primary blocks in the TPS8802 that add to system standby current consumption are the MCU LDO, CO amplifier, and VCCLOW monitor. The MCU LDO uses 2.0 μA current, CO amplifier uses 0.6 μA current, and the VCCLOW monitor uses 0.9 μA current. Other blocks such as the photo amplifier and boost converter consume several hundred microamps of current and are strategically enabled for a short amount of time during measurements to make their overall contribution to total power negligible.

3.1.2 Microcontroller Standby Current

The microcontroller standby and active currents contribute to the total system power consumption. While there is no specific requirement for the microcontroller, a microcontroller in the range of 1 μA standby and 1 mA active current is generally sufficient to not dominate the total power consumption. It is critical that the microcontroller enters its standby mode in between smoke measurements. Some microcontrollers are able to enter an ultra-low power mode, less than 100 nA, if the microcontroller clocks are disabled.

The TPS8802 sleep timer allows the ultra-low power mode to be entered in between measurements. This can be done by writing the sleep time duration to the TPS8802 registers SLPTMR1 and SLPTMR2, then writing 1 to SLP_EN to start the sleep timer. The MCU can enter the ultra-low power mode while the TPS8802 keeps track of time. When the sleep timer finishes, the TPS8802 wakes up the MCU by sending a pin interrupt to the microcontroller.

The microcontroller supply voltage range has a large influence on the microcontroller current. If the boost converter is required to power the microcontroller, all of the microcontroller current is scaled by the boost converter efficiency and input-to-output voltage ratio. If an LDO is required to power the microcontroller, the LDO standby current adds to the total system current. For this reason it is most efficient to use a microcontroller that can be directly powered by the battery. The options for powering the microcontroller are discussed in [Section 2.3](#).

3.2 Measurement Current

In this report, measurement current is the current consumption from taking measurements. These measurements include smoke, CO, battery voltage, and the horn functionality.

3.2.1 Smoke Measurement Current

Taking a smoke measurement generally follows the procedure:

1. Enable the photo amplifier and analog multiplexer (AMUX) buffer.
2. Take an ADC measurement after the photo amplifier and AMUX settles. This measures the ambient light entering the photo chamber.
3. Enable the LED driver.
4. Take an ADC measurement after the photo amplifier and AMUX settles. This measures the ambient light and smoke concentration in the photo chamber.
5. Disable the LED driver, photo amplifier, and AMUX buffer.
6. Process the ADC measurements to determine the smoke concentration.

The power consumed from taking a smoke measurement is dominated by the LED driver current. The average LED current is shown in [Equation 3](#), where I_{LED} is the LED pulse current, T_{LED} is the LED pulse duration, and f_{MEAS} is the measurement frequency.

$$I_{LED (avg)} = I_{LED} \times T_{LED} \times f_{MEAS} \quad (3)$$

If the LED is supplied by the boost converter, the average LED current is scaled by the boost input-output voltage ratio and efficiency. The average LED current draw from the battery is calculated in [Equation 4](#). Connecting the LED directly to the battery is the most efficient method of powering the LED.

$$I_{LED (bat)} = \frac{I_{LED (avg)} \times V_{BST}}{V_{BAT} \times \eta_{BST}} \quad (4)$$

Secondary sources of power dissipation during the smoke measurement are the MCU active current and boost charging current. The MCU active current is drawn during the length of a measurement while the MCU is not in standby. Optimizing measurements for speed is essential to reducing the MCU active current. Boost charging current is caused by charging and discharging the VBST capacitor. Boost charging is further discussed in [Section 3.3.1](#).

3.2.2 CO Measurement Current

The CO amplifier is continuously powered to amplify the electrochemical CO sensor current. Current is consumed from powering the CO amplifier and taking measurements of the CO amplifier output. Measuring the CO concentration requires enabling the AMUX buffer to output the COO voltage and taking an ADC measurement. The majority of power consumption from taking the CO measurement comes from the MCU active current. To take the CO measurement as fast as possible, take the CO measurement directly before the smoke measurement.

The CO sensor connectivity test is not a significant contributor to total power consumption due to the infrequency of the test.

3.2.3 Battery Test Current

The high current draw required for the battery test can make it a significant contributor to total power consumption. The average test load current is calculated in [Equation 5](#), where $I_{BATTEST}$ is the battery test load current, $T_{BATTEST}$ is the battery test duration, and $f_{BATTEST}$ is the battery test frequency.

$$I_{BATTEST (avg)} = I_{BATTEST} \times T_{BATTEST} \times f_{BATTEST} \quad (5)$$

When using the TPS8802 battery test load, the load current is scaled by the boost input-output voltage ratio and efficiency. The average battery current draw caused by the battery test load is calculated in [Equation 6](#).

$$I_{BATTEST (bat)} = I_{BATTEST (avg)} \times \frac{V_{BST}}{V_{BAT} \times \eta_{BST}} \quad (6)$$

3.2.4 User Alarm Test Current

The last standard test that contributes to the total power consumption is the weekly or monthly alarm testing. In this test, the horn driver and boost converter are enabled by the end user for several seconds. The average current draw from this test can be estimated based on the horn driver current using the following equation:

$$I_{ALARMTEST (avg)} = I_{HORN} \times T_{HORN} \times f_{ALARMTEST} \times \frac{V_{BST}}{V_{BAT} \times \eta_{BST}} \quad (7)$$

3.3 Other Current Consumption

3.3.1 Boost Charge Current

Any time the boost converter is enabled, charge is transferred from the battery to the VBST capacitor. When the boost converter is disabled, the VBST capacitor charge supplies power to any circuitry connected to VBST. This energy transfer dissipates power because the boost capacitor cannot be charged or discharged with 100% efficiency. The TPS8802 boost converter typically operates between 65% and 85% efficiency when the load current is much higher than the boost converter active current. Using a lower inductor peak current limit BST_CLIM improves the efficiency with the tradeoff of decreased maximum output current. The majority

of circuitry connected to VBST consumes constant current independent of the VBST voltage. Therefore, an increase in the VBST voltage directly increases the power consumption of the connected circuitry.

$$I_{\text{CHARGE}} = \frac{f_{\text{CHARGE}}}{V_{\text{BAT}}} \times \left(\frac{C_{\text{BST}}}{2 \times \eta_{\text{BST}}} \times (V_{\text{BST}}^2 - V_{\text{LOW}}^2) - C_{\text{BST}} \times V_{\text{BAT}} \times (V_{\text{BST}} - V_{\text{LOW}}) \right) \quad (8)$$

The extra current from boost charging is calculated using [Equation 8](#), where:

- f_{CHARGE} is the boost charge frequency
- V_{BAT} is the battery voltage
- C_{BST} is the capacitance
- V_{LOW} is the voltage before charging and after discharging
- V_{BST} is the boost converter output voltage
- η_{BST} is the boost converter efficiency

[Equation 8](#) is derived by taking the difference of the energy used to charge the VBST capacitor and the energy used from discharging the VBST capacitor. The boost charging current is in addition to all other currents.

[Equation 8](#) is particularly useful in calculating power consumption with the TPS8802 VCCLOW_BST feature enabled. VCCLOW_BST automatically enables the boost converter when the VCCLOW monitor is enabled and a low VCC voltage is detected. In this scenario, the boost charge frequency depends on the capacitance, standby current, boost Schottky diode leakage current, boost converter voltage, and VCCLOW detection voltage. The standby current here is the current continuously drawn from the VBST capacitor. The frequency and current are calculated in [Equation 9](#) and [Equation 10](#). [Equation 10](#) highlights the importance of using a low-leakage Schottky diode. The Schottky diode leakage effectively adds to the standby current. Using a Schottky diode with 1 μA leakage current reduces the power drawn when VCCLOW_BST is active. Low leakage Schottky diodes generally have a higher forward voltage and reduce the boost converter efficiency. Using a Schottky diode with less than 1 μA leakage current can reduce the total system battery life because of the higher forward voltage.

$$f_{\text{VCCLOW}} = \frac{I_{\text{STANDBY}} + I_{\text{SCHOTTKY}}}{C_{\text{BST}} \times (V_{\text{BST}} - V_{\text{VCCLOW}})} \quad (9)$$

$$I_{\text{VCCLOW}} = (I_{\text{STANDBY}} + I_{\text{SCHOTTKY}}) \times \left(\frac{V_{\text{BST}} + V_{\text{VCCLOW}}}{2 \times \eta \times V_{\text{BAT}}} - 1 \right) \quad (10)$$

3.3.2 Initialization Current

In systems where a load switch periodically applies power to VCC, power is dissipated during the TPS8802 initialization. The initialization current has several components: VCC charging, VINT charging, MCUSEL sensing, and VBST charging. The VCC, VINT, and VBST waveforms and battery current draw during the TPS8802 initialization are shown in [Figure 3-1](#).

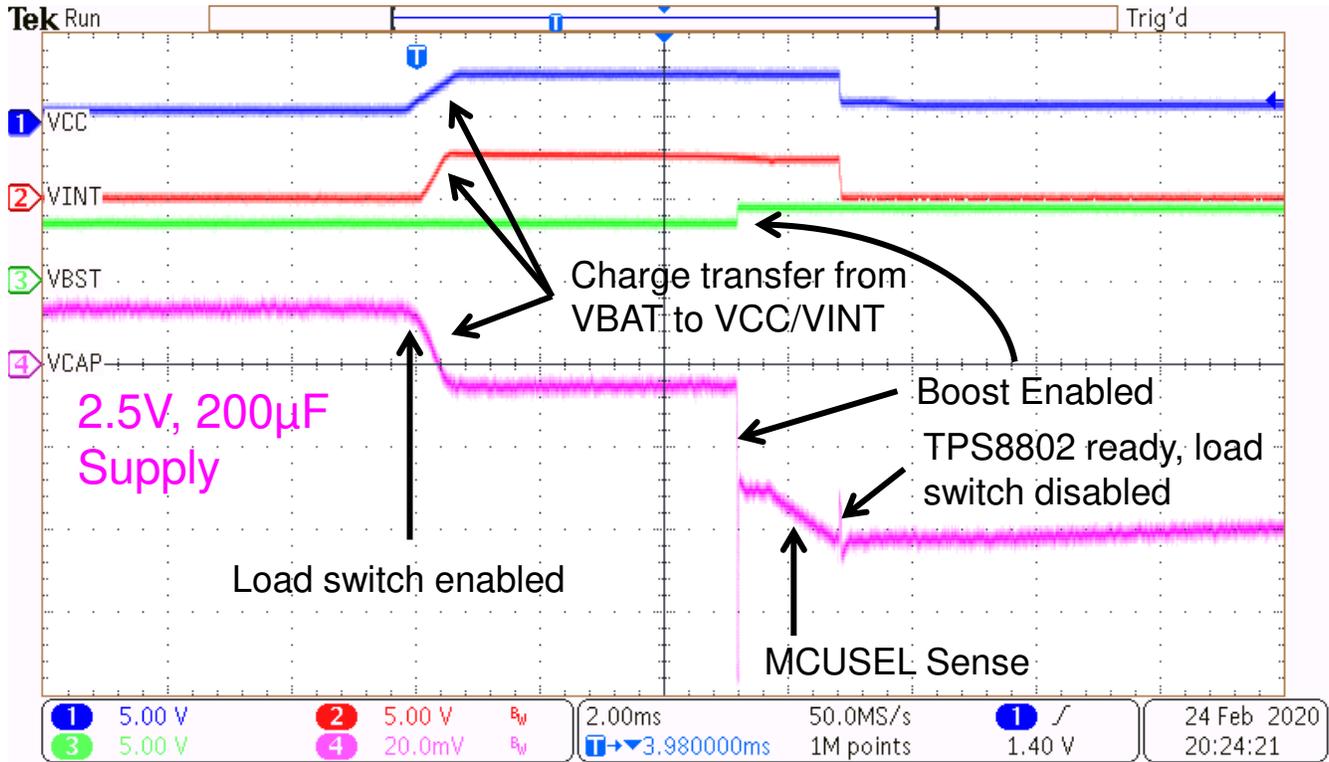


Figure 3-1. TPS8802 Initialization Waveforms

The VCC and VINT capacitors are charged when the load switch is enabled. The amount of power required to charge these capacitors depends on the capacitance, voltage, and frequency of initialization. The MCUSEL pin is sensed during initialization to determine the default MCU LDO voltage. Sensing the MCUSEL pin typically draws 2.2 mA current for 1.2 ms. The initialization current is calculated in Equation 11.

$$I_{INIT} = (C_{VCC} \times V_{VCC} + C_{VINT} \times V_{VINT} + I_{MCUSEL} \times T_{MCUSEL}) \times f_{INIT} + I_{CHARGE (init)} \quad (11)$$

The initialization current caused by boost charging depends on the charging frequency and VBST voltage change. During initialization, the boost converter is automatically enabled to 3.8 V with 500 mA peak inductor current. If VBST is below 3.8 V, the boost converter switches until VBST is above 3.8 V. If the VBST load is low between measurements, the boost converter does not switch during every initialization.

The VBST voltage change depends on the VBST load between measurements. The minimum VBST voltage change is the boost converter ripple, and the maximum VBST voltage change is VBST minus VBAT. In Figure 2-8, the only load on VBST between measurements is the Schottky diode leakage. Therefore the Schottky diode leakage has a large impact on the boost charge current. The boost converter ripple is calculated in Equation 12, the charging frequency is calculated in Equation 13, and the boost charging initialization current is calculated in Equation 14.

$$\Delta V_{CHARGE} = \text{Max} \left(\text{Min} \left(\frac{I_{SCHOTTKY}}{C_{BST} \times f_{INIT}}, V_{BST} - V_{BAT} \right), \sqrt{\frac{L_{BST}}{C_{BST}} \times I_{PEAK}^2 + V_{BST}^2 - V_{BST}} \right) \quad (12)$$

$$f_{CHARGE (init)} = \text{Min} \left(f_{INIT}, \frac{I_{SCHOTTKY}}{C_{BST} \times \Delta V_{CHARGE}} \right) \quad (13)$$

$$I_{\text{CHARGE (init)}} = f_{\text{CHARGE (init)}} \times \Delta V_{\text{CHARGE}} \times C_{\text{BST}} \times \left(\frac{2 \times V_{\text{BST}} - \Delta V_{\text{CHARGE}}}{2 \times \eta_{\text{BST}} \times V_{\text{BAT}}} - 1 \right) \quad (14)$$

4 System Power Calculation and Measurements

4.1 Power Calculation Spreadsheet

All of the identified sources of current consumption are tabulated in a spreadsheet to calculate the system power consumption. The spreadsheet uses a set of system parameters and measurement subroutines to break down the power consumption block-by-block for each measurement subroutine. The decomposition allows users to identify the biggest sources of power consumption when testing their system and further reduce the system power.

The power calculation is based on the schematics in [Section 2.5](#). These schematics and associated power calculation can be modified based on the system requirements. One of the key calculation parameters is that the IR LED is the primary method of smoke detection. When the smoke concentration is low, the IR LED is used to measure the smoke level. When the smoke concentration rises, the IR and blue LED are used to measure the smoke level. Because only the IR LED is pulsed most of the time, only the IR LED power consumption is considered.

4.1.1 Power Consumption Overview Page

Smoke Alarm System Parameters		Subroutine	System	
Parameter	Value		Smoke Only, Load Switch	Smoke + CO + MCU LDO
Battery Voltage:*	3 V	Standby:	1.00 μ A	6.60 μ A
MCU Standby Current:	1 μ A			
MCU Standby, Timers Disabled:	0.1 μ A			
MCU Active Current:	1000 μ A	Smoke Measurement:	3.63 μ A	1.92 μ A
Smoke LED Current:**	100 mA			
Smoke LED Pulse Length:	75 μ s			
Smoke LED Pulse Rate:	5 seconds	Battery Test:	0.17 μ A	0.17 μ A
Battery Test Boost Voltage:	15 V			
Battery Test Load (10-20mA):	20 mA			
Battery Test Length:	50 ms			
Battery Test Rate:	12 hours	User Alarm Test:	0.28 μ A	0.28 μ A
User Alarm Test Boost Voltage:	15 V			
User Alarm Test Current:	20 mA			
User Alarm Test Length:	5 seconds			
User Alarm Test Rate:	30 days	Low Battery Boost:	- μ A	1.35 μ A
Boost Schottky Leakage:***	1 μ A			
Numbers in yellow can be modified		Total Current:	5.09 μ A	10.33 μ A
* Battery voltage must be between 2.6V and 3.5V for smoke-only system and 2.0V to 15.6V for smoke + CO system.				
** Photoelectric chamber LED forward voltage must be less than 2.2 V. Modify the power calculation if otherwise.				
*** For smoke and CO system				

Figure 4-1. Power Consumption Overview

The power calculation overview page highlights the key parameters that affect the power consumption. The current consumption for each subroutine is calculated, and by adding together each subroutine current, the total current is calculated. The detailed calculations for each subroutine total are performed in the **Smoke and CO Power** and **Smoke Only Power** pages.

With the power calculated, the required battery life is then calculated. The result of the power calculation at each battery voltage is entered into the **3V Battery Life** table shown in [Figure 4-2](#). The table lists the percentage of a LiFeS₂ and LiMnO₂ battery capacity at each voltage. These capacity percentages are derived

from battery manufacturer's datasheets. The power consumption and capacity percentage data calculates the required battery capacity for a given battery life.

Battery voltage	Battery Chemistry		System Current	
	2x LiFeS2 Batteries	LiMnO2 Battery	Smoke Only, Load Switch	Smoke + CO + MCU LDO
3.5	0.2%	0.0%	5.10 μ A	8.91 μ A
3.4	20.1%	0.0%	5.10 μ A	8.93 μ A
3.3	26.7%	0.0%	5.10 μ A	8.94 μ A
3.2	7.9%	0.2%	5.10 μ A	8.95 μ A
3.1	14.7%	0.1%	5.10 μ A	8.97 μ A
3	15.6%	8.7%	5.10 μ A	8.98 μ A
2.9	9.5%	49.6%	5.10 μ A	9.00 μ A
2.8	1.5%	12.8%	5.10 μ A	9.24 μ A
2.7	1.2%	9.8%	5.11 μ A	9.33 μ A
2.6	0.7%	5.6%	5.11 μ A	9.42 μ A
2.5	0.4%	3.2%	- μ A	12.67 μ A
2.4	0.3%	2.8%	- μ A	13.23 μ A
2.3	0.3%	2.0%	- μ A	13.84 μ A
2.2	0.1%	1.7%	- μ A	14.51 μ A
2.1	0.1%	1.5%	- μ A	15.24 μ A
2	0.2%	1.5%	- μ A	16.04 μ A
Required LiFeS2 Capacity:			506 mAh	881 mAh
Required LiMnO2 Capacity:			572 mAh	932 mAh
Battery Life:		10	years	
Battery Derating:		10.0%		
Battery voltage must be 2.6V to 3.5V for smoke only alarm				

Figure 4-2. Battery Life Calculation Table

Using a TPS8802 with a 1- μ A standby current microcontroller (0.1 μ A with timers disabled), 100-mA IR LED current, 75 μ s IR LED pulse length, and 5 second measurement interval, the required battery capacity is calculated. The smoke and CO system achieves a 10 year battery life using a single CR123 battery (typical capacity 1500 mAh) with 61% margin or two lithium AAA batteries (typical capacity 1250 mAh) with 42% margin. The smoke-only system achieves a 10 year battery life using a single CR2 battery (typical capacity 800 mAh) with 40% margin.

4.1.2 Detailed Calculation Pages

Parameter	Value
Battery Voltage	3 V
LED Propagation Delay	0.02 ms
Boost Low Power Efficiency*	85%
Boost High Power Efficiency*	70%
VBST Cap (at VBST bias)	4.7 μ F
Boost+Bias+8MHz Current	339 μ A
Photo Input Amp Current	175 μ A
Photo Gain Amp Current	41 μ A
AMUX Current	8.3 μ A
LEDLDO Current	31 μ A
8MHz Current	175 μ A
Bias Current	63 μ A
I2C pulldown Current	54 μ A
TPS8802 Standby	3.8 μ A
MCULDO Current	2 μ A
COAMP Current	0.7 μ A
VCCLOW Current	0.9 μ A
300mV Reference	0.4 μ A
MCU Standby	0.1 μ A
MCU Active	1000 μ A
VCCLOW Threshold	2.45 V
I2C Clock Speed	0.13 MHz
I2C Write Length	230.77 μ s
BST_CHARGE Min Time	0.141 ms
Boost Schottky Leakage	1 μ A
Boost Schottky Drop	0.15 V

* Efficiency depends on BST_CLIM setting

Figure 4-3. System Specifications Table

ADC measurements. The MSP430F5529 is programmed using the Energia open-source electronics prototyping platform, version 1.8.11E23. The MSP430F5529 is powered from a separate power supply to allow precise measurements of the TPS8802 power consumption. By measuring the power consumption of the TPS8802 device in this system, the calculation accuracy is verified.

4.2.1 Power Measurement Method

The power consumption measurements are taken using a Keithley 2400 to supply power and measure the output current. A 1 k Ω resistor is installed between the Keithley 2400 output and VBAT on the EVM, and a 2200 μ F capacitor is installed between VBAT and GND. The resistor and capacitor filter the current draw from the Keithley 2400. This resistor and capacitor is required for two reasons: to lower the maximum current draw out of the Keithley 2400 for more accurate measurements, and to anti-alias the current waveform. The TPS8802 current draw can have large 500-mA spikes from the boost converter that would greatly diminish the accuracy of the microamp average current measurement if the Keithley 2400 was set to measure up to 500 mA.

The Keithley 2400 has an adjustable integration time for each measurement that is best set to an integer multiple of a power line cycle (PLC) to reject power line noise. However, due to the nature of the instrumentation, there is time between each measurement sample where the current draw is not included in the measurement. This means that the large 500-mA current spikes may be missed if no anti-aliasing filter is used. One approach is to set the integration time to the maximum value supported by the instrument for the best accuracy, but this would require a very large anti-aliasing filter due to the low sample rate. Therefore, the optimal integration time is 1-PLC.

The last step is to take multiple measurements and average them together. This is performed using the Keithley 2400 repeating filter function. This digital filter averages a programmed number of measurements and outputs the value when a new set of measurements is taken. Ideally, the total time taking the set of measurements should equal an integer multiple of the smoke alarm measurement interval (the amount of time between each smoke measurement in the smoke alarm).

It was experimentally determined that the Keithley 2400 sample rate for 1-PLC integration time is 3-PLC, and the sample rate for 2-PLC integration is 6-PLC. Therefore, it was chosen to set the smoke alarm measurement interval to 3.333 seconds (200-PLC), the integration time to 2-PLC, and the number of averages to 100. A set of 100 current measurements takes 10 seconds (600-PLC), equal to three smoke alarm measurements.

4.2.2 Smoke and CO System Measurements



```

TPS8802_Smoke_CO | Energia 1.8.11E23
File Edit Sketch Tools Help
TPS8802_Smoke_CO
void setup()
{
  Wire.begin(); // join i2c bus
  Wire.setClock(400000); // Set I2C speed to 400kHz
  pinMode(GPIOpin, INPUT);
  pinMode(LEDPINpin, OUTPUT);

  I2Cwrite(addr, 0x03, 0x7E); // mask all error flags but SLP_DONE
  I2Cwrite(addr, 0x04, 0x2A); // Set VMCUSET=1.8V, SLP_ANALOG=1
  I2Cwrite(addr, 0x05, 0x1A); // set HORN_SEL=1, HORN_THR=10
  I2Cwrite(addr, 0x06, 0x00); // Set BST_EN=0
  I2Cwrite(addr, 0x07, 0x04); // write LEDPIN_EN=1
  I2Cwrite(addr, 0x08, 0x01); // set VCLOW_DIS=0, VCLOW_BST=1
  I2Cwrite(addr, 0x09, highByte(slptime)); //program sleep timer duration
  I2Cwrite(addr, 0x0A, lowByte(slptime)); //program sleep timer duration
  I2Cwrite(addr, 0x0B, 0x02); // set GPIO to output STATUS1
  I2Cwrite(addr, 0x0C, 0x70); // set CO switches to internal components
  I2Cwrite(addr, 0x0D, 0x01); // enable CO amp
  I2Cwrite(addr, 0x0E, 0x50); // IBST, VBST set to 100mA, 2.7V
  I2Cwrite(addr, 0x10, 0x1F); // write TEMPCOA==11, PREF_SEL=1, PGAIN=35
  I2Cwrite(addr, 0x11, 0x31); // write PDACA to 0x31 for 100mA current
  delay(1000); // wait for VCLOW to check voltage
  STATUS1 = I2Cread(addr, 0x01); //read STATUS1 to reset SLP_DONE and VCLOW
  if (!bitRead(STATUS1, 6)) { //if VCLOW=0
    I2Cwrite(addr, 0x08, 0x11); //set VCLOW_DIS=1, VCLOW_BST=1
  }
}

void loop()
{
  STATUS1 = I2Cread(addr, 0x01); // read STATUS1 to reset SLP_DONE and VCLOW
  I2Cwrite(addr, 0x07, 0x44); // write BST_CHARGE=1 and LEDPIN_EN=1
  I2Cwrite(addr, 0x0B, 0x12); // write AMUX_SEL=COO, GPIO=STATUS1
  COval = analogRead(AMUXpin); // read the CO sensor output
  I2Cwrite(addr, 0x06, 0x0C); // write PAMP_EN=1 and PGAIN_EN=1
  I2Cwrite(addr, 0x0B, 0x22); // write AMUX_SEL=AOUT_PH, GPIO=STATUS1
  floorval = analogRead(AMUXpin); // read the ambient light level
  digitalWrite(LEDPINpin, 1); // enable photo LED
  smokeval = analogRead(AMUXpin); // read the LED signal level
  digitalWrite(LEDPINpin, 0); // disable photo LED
  I2Cwrite(addr, 0x07, 0x05); // write LEDPIN_EN=1 and SLP_EN=1

  // process collected data here (not implemented)

  while (!digitalRead(GPIOpin)); // Wait until sleep done
}

Done compiling.
Sketch uses 5090 bytes (10%) of program storage space. Maximum is 48128 bytes.
Global variables use 286 bytes (3%) of dynamic memory, leaving 7906 bytes for local variables. Maximum is 8192 bytes.
1 MSP-EXP430F5529LP on COM7
    
```

Figure 4-6. Energia Code Excerpt for Taking Smoke and CO Measurements

The smoke and CO measurement subroutine controls the TPS8802 and collects the data required to determine the smoke and CO concentration. Here the TPS8802 sleep timer is used to disable blocks in the TPS8802 and send a signal to the microcontroller to wake up. The VCLOW monitor is read after all the registers are initialized to determine whether the VCLOW monitor and VCLOW_BST need to be active. If the VCLOW status flag is low, the VCLOW monitor is disabled. This implementation is used in place of a periodic battery check to simplify the power measurements. The waveforms verify that the Energia code is correctly written.

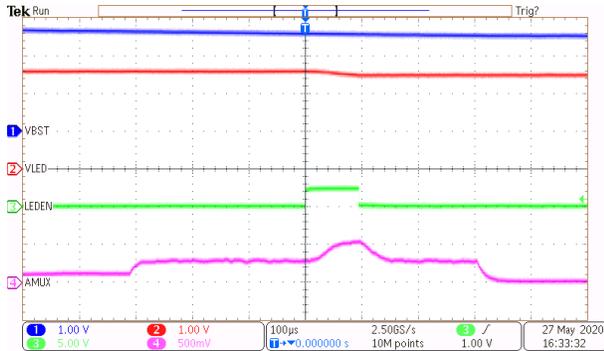


Figure 4-7. Smoke Measurement Signals in the Smoke and CO System

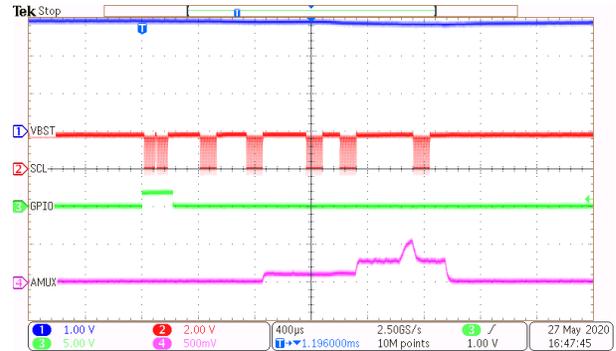


Figure 4-8. Power and Signal Waveforms with VBAT=3 V

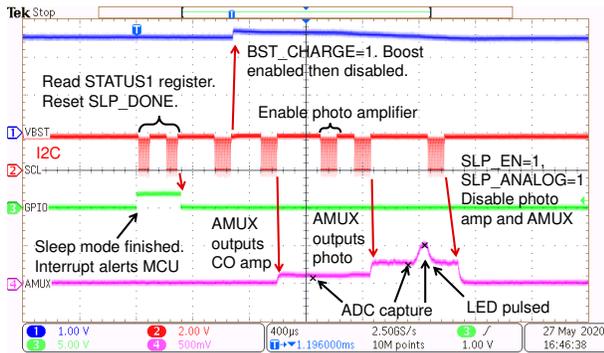


Figure 4-9. Power and Signal Waveforms with VBAT=2.6 V

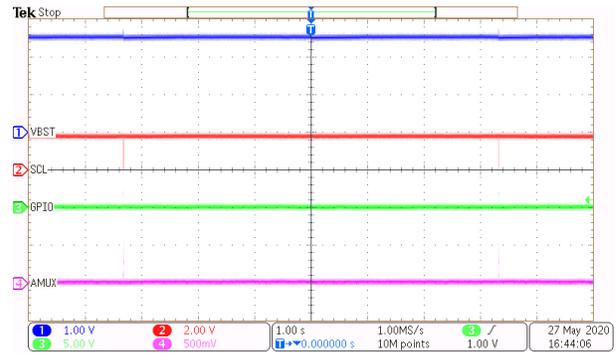


Figure 4-10. Multiple Smoke and CO Measurements Waveforms with VBAT=2.6 V

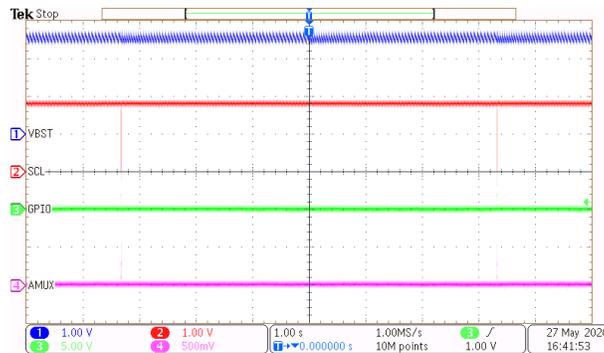


Figure 4-11. Multiple Smoke and CO Measurements Waveforms with VBAT=2.0 V

The supply current with the photoelectric sensor LED connected and disconnected is measured at three voltages, shown in Table 4-1. Four sets of measurements are taken at each condition, making the total measurement time 40 seconds for each condition. The photoelectric sensor LED is connected and disconnected to measure the current consumption caused by the LED. This provides more datapoints to correlate the measurements with the calculation.

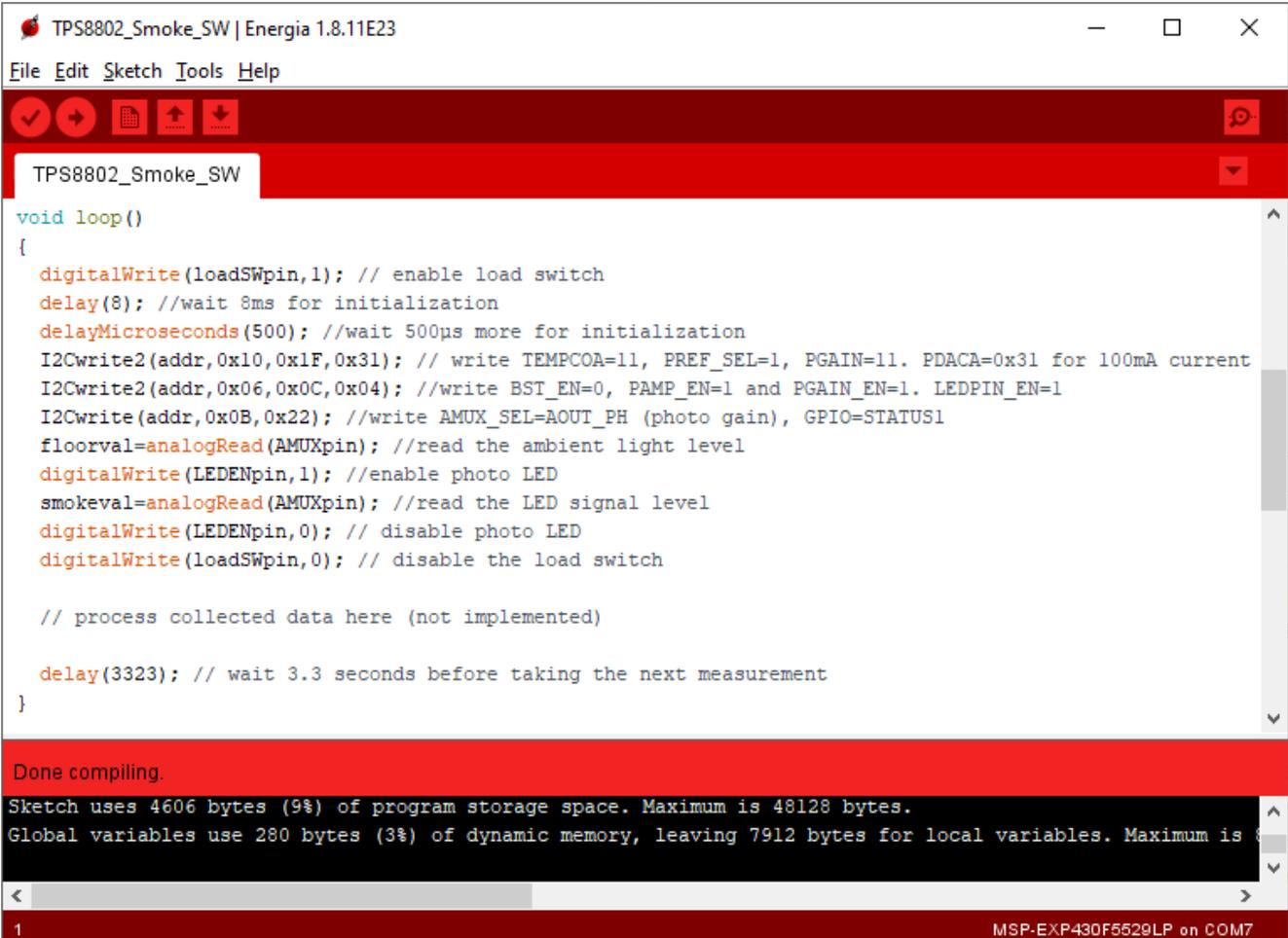
The largest discrepancy between the measurement and calculation is 0.58 μA at the $\text{VBAT}=2.0\text{ V}$, LED on condition. The source of discrepancy was found to be caused by above-average currents for the TPS8802 standby, MCU LDO, and CO amplifier, totaling 0.48 μA . After adjusting the TPS8802 standby, MCU LDO, and CO amplifier currents in the calculation, the measurement much more closely matches the calculation. For this calculation, the MCU standby, MCU active, battery test, and user alarm test currents are set to zero because they are not implemented in the test system. The boost Schottky leakage is set to 4 μA in the calculation to match the Schottky diode leakage on the TPS8802EVM. The power consumption at lower voltages can be improved with a lower leakage Schottky diode.

The calculation accuracy verifies that the calculation can be modified to estimate the power consumption with different system specifications. The result of the power calculation with MCU currents, battery test currents, and user alarm test currents added is shown in [Figure 4-1](#).

Table 4-1. Smoke and CO System Current Consumption

Supply Voltage	VBAT = 3.0 V			VBAT = 2.6 V		VBAT = 2.0 V	
	LED on	LED off	Standby + CO + MCU LDO	LED on	LED off	LED on	LED off
Measurement	9.32 μA	7.15 μA	6.98 μA	9.06 μA	6.96 μA	18.46 μA	14.76 μA
Calculation	8.86 μA	6.61 μA	6.50 μA	9.42 μA	6.67 μA	17.88 μA	14.31 μA
Adjusted Calculation	9.34 μA	7.09 μA	6.98 μA	9.90 μA	7.15 μA	18.64 μA	15.07 μA

4.2.3 Smoke-Only System Measurements



```

void loop()
{
    digitalWrite(loadSWpin,1); // enable load switch
    delay(8); //wait 8ms for initialization
    delayMicroseconds(500); //wait 500us more for initialization
    I2Cwrite2(addr,0x10,0x1F,0x31); // write TEMPCOA=11, PREF_SEL=1, PGAIN=11. PDACA=0x31 for 100mA current
    I2Cwrite2(addr,0x06,0x0C,0x04); //write BST_EN=0, PAMP_EN=1 and PGAIN_EN=1. LEDPIN_EN=1
    I2Cwrite(addr,0x0B,0x22); //write AMUX_SEL=AOUT_PH (photo gain), GPIO=STATUS1
    floorval=analogRead(AMUXpin); //read the ambient light level
    digitalWrite(LEDENpin,1); //enable photo LED
    smokeval=analogRead(AMUXpin); //read the LED signal level
    digitalWrite(LEDENpin,0); // disable photo LED
    digitalWrite(loadSWpin,0); // disable the load switch

    // process collected data here (not implemented)

    delay(3323); // wait 3.3 seconds before taking the next measurement
}
    
```

Done compiling.
 Sketch uses 4606 bytes (9%) of program storage space. Maximum is 48128 bytes.
 Global variables use 280 bytes (3%) of dynamic memory, leaving 7912 bytes for local variables. Maximum is 8192 bytes.

MSP-EXP430F5529LP on COM7

Figure 4-12. Energia Code Excerpt for Taking Smoke and CO Measurements

The smoke-only smoke measurement subroutine controls the TPS8802 and collects the data required to determine the smoke concentration in the chamber. The waveforms verify that the Energia code is correctly written.

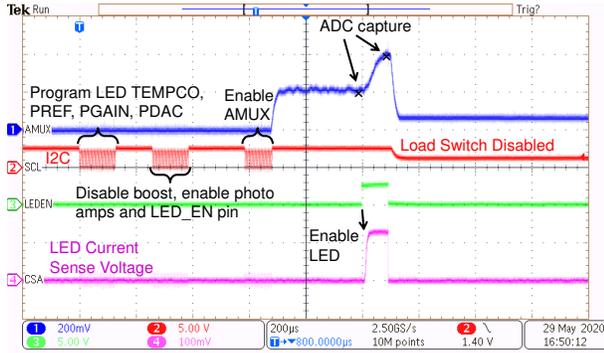


Figure 4-13. Smoke Measurement Waveforms in the Smoke-Only System

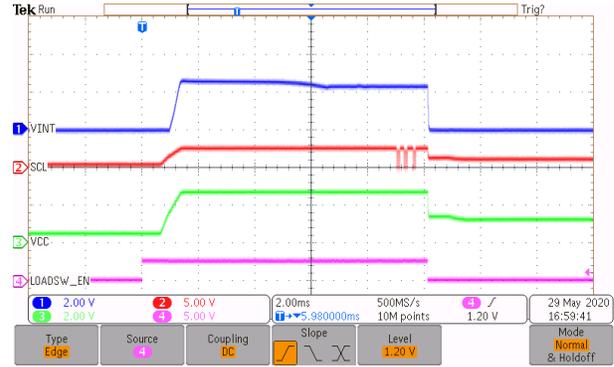


Figure 4-14. Power and Signal Waveforms in the Smoke-Only System

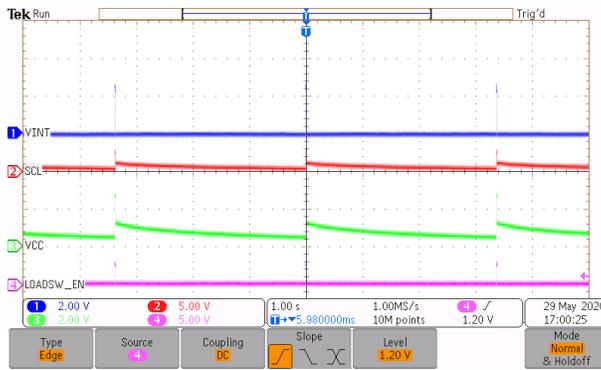


Figure 4-15. Multiple Smoke Measurements Waveforms with VBAT=2.6 V

The supply current with the LED connected and disconnected is measured at two voltages, shown in Table 4-2. Four sets of measurements are taken at each condition, making the total measurement time 40 seconds for each condition. For this calculation, the MCU standby, MCU active, battery test, and user alarm test currents are set to zero because they are not implemented in the Energia code. The measurement matches the calculation within 100 nA.

The calculation accuracy verifies that the calculation can be modified to estimate the power consumption with different system specifications. The result of the power calculation with MCU currents, battery test currents, and user alarm test currents added is shown in Figure 4-1.

Table 4-2. Smoke-Only System Current Consumption

Supply Voltage	VBAT=3.0V		VBAT=2.6V	
Condition	LED on	LED off	LED on	LED off
Measurement	5.21 μ A	2.92 μ A	5.03 μ A	2.78 μ A
Calculation	5.11 μ A	2.86 μ A	5.02 μ A	2.77 μ A

5 Summary

10-year battery life smoke alarm systems are becoming increasingly common in the industry, and the TPS8802 integrates the amplifiers, drivers, and regulators necessary to achieve a 10-year battery life with a single lithium battery. In this report, a smoke detection system and smoke and carbon monoxide (CO) detection system are designed using the TPS8802 with attention on the VCC, MCU, and LED supplies. The current consumption for each system is calculated based on the power configuration, system parameters, and measurement sequences. The calculation breaks down the power consumption block-by-block to further optimize the system. The two systems are built by modifying a TPS8802EVM and using a MSP430F5529 Launchpad to control the TPS8802. Measurements of the system current verify the accuracy of the power calculations. The required battery capacity for achieving a 10-year battery life is calculated from the system power consumption. The calculations show that a CR2 battery provides a 10-year life for a smoke alarm system using the TPS8802, and a CR123 battery provides a 10-year life for a smoke and CO alarm system using the TPS8802.

6 References

- SLVRBG9
- SLVC813

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