Application Note

Dual-Ray Smoke Detector with the TPS8802 and MSPM0 MCUs

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ABSTRACT

Currently available, threshold based, smoke alarms do not have the capability to distinguish between certain types of smoke particles (for example, flaming polyurethane) and nuisance sources like from cooking, steam from a shower, and so on. This application report describes a dual chip design, using the TPS8802 analog front end (AFE) ASIC, which is a UL recognized UTGT2.S36499 smoke alarm component, and the Arm Cortex-M0+ MSPM0L1306 microcontroller. This design enables making the distinction between real sources of smoke and nuisance sources to satisfy new UL217 requirements for smoke alarms. This document also includes test data showing measurements under simulated smoke and water vapor conditions.

Demo source code for this design is available in the latest MSPM0 SDK. An optional graphical user interface (GUI) allows developers to configure the AFE and observe the system response in real-time. The GUI is published in the TI Cloud Tools gallery.

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1 Introduction

The latest changes to the UL217 standard (eighth and ninth editions) mandate that smoke alarms have the ability to distinguish between smoke from real fire and smoke from nuisance sources such as cooking, steam from showers, and so on. Smoke from these nuisance sources tend to contain particles sizes much smaller than those found in sources from real fires. However, flaming polyurethane is an exception, where the particle sizes in this type of smoke consists of sizes in the upper range as those found in nuisance sources. This causes a change to the typical single wavelength, threshold-based detection algorithms for reliable smoke detection and reduced false alarms.

Two prevalent photoelectric sensing techniques that are used for particle size estimates and smoke type determination are LED wavelength and scattering angles. The signal response of light scattering configurations in smoke detection follow Mie scattering physics. It follows that LED’s with low wavelength, such as blue, allow for increased signal response and therefore higher signal-to-noise ratio (SNR) for sensing smaller particle sizes typically found in nuisance sources. In order to detect particle sizes in the range of 50nm average diameter to approximately 1μm or larger average diameter, it is advantageous to use LED’s with different wavelengths to cover the range of particles sizes expected, typically IR and Blue. Measurement of the scattering response at different scattering angles, such as back scatter (scattering angle <90°) and forward scatter (scattering angle >100°), allows the estimation of particle size. These two techniques together allow for a robust, multi-criteria approach to distinguish between real sources of smoke and nuisance sources.

A solution that includes the necessary hardware for distinguishing between real sources of smoke and nuisance sources is shown in Figure 1-1. The two LED drivers allow for use of LED’s with different wavelengths as well as different scattering angles depending on the optical chamber design.

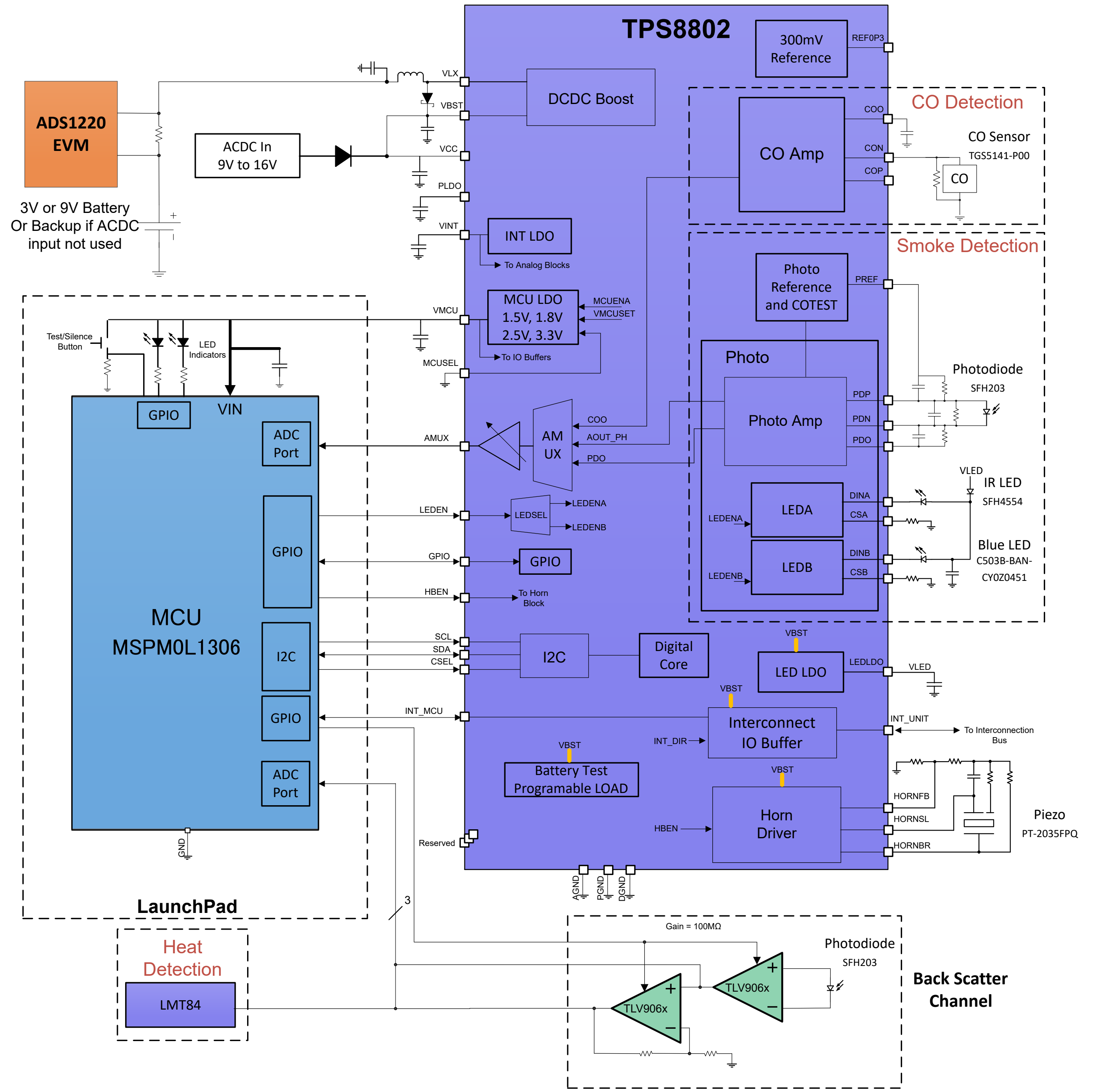

Figure 1-1. TPS8802 + MSPM0 Demo Hardware Block Diagram

The optical chamber used in this design is configured for forward scattering measurements of both LED's with a single broad-spectrum photo diode (PD). However, the TPS8802 PCB accommodates different optical chamber designs so that different combinations scattering angles and wavelengths can be used with the same hardware.

While set up for demo purposes, the hardware is intended to show the capabilities of TPS8802 together with the MSPM0 micro controllers. As such, the firmware and GUI for this demo does not include the use of the discrete back scatter photo diode channel shown in Figure 1-1. However, these can both be customized for more advanced sensing and algorithm implementations.

In addition to smoke detection, the TPS8802 AFE includes circuitry for sensing Carbon Monoxide (CO) which is necessary for combination detectors required in residential installations or can be used as part of a multi-criteria smoke sensing algorithm together with the photoelectric sensing.

2 Demo Hardware

The block diagram for a demo board based on the TPS8802 and LP-MSPM0L1306 is shown in Figure 1-1. This demo board includes a coin cell CO sensor, a basic 3D printed smoke chamber and a 3 terminal piezo element for alarm notification as well as commonly found functions such as status LED's and push-to-test / silence button. The hardware board also includes an LMT84 for ambient air temperature measurements which can be used in combination with the internal temperature sensor of the MSPM0L1306 on the launchpad for rudimentary heat detection. In the simplest use case of the demo hardware, power is applied using 2 AA batteries and the launchpad is plugged into a PC using a USB cable for data capture or display using the GUI described in this report.

Although the basic 3D printed smoke chamber is designed for multi-wavelength forward scatter only measurements, the PCB includes alternative locations for LED's and PD's as shown in Figure 2-1. These alternate locations allow, but is not limited to the following chamber designs: forward scatter only (single or multi-wavelength), multi-angle (single or multi-wavelength) with 3 LED's and 1 PD or 2 LED's + 2 PD's. In this way, customers can use this hardware together with their own chamber and optical design or evaluate multiple designs.

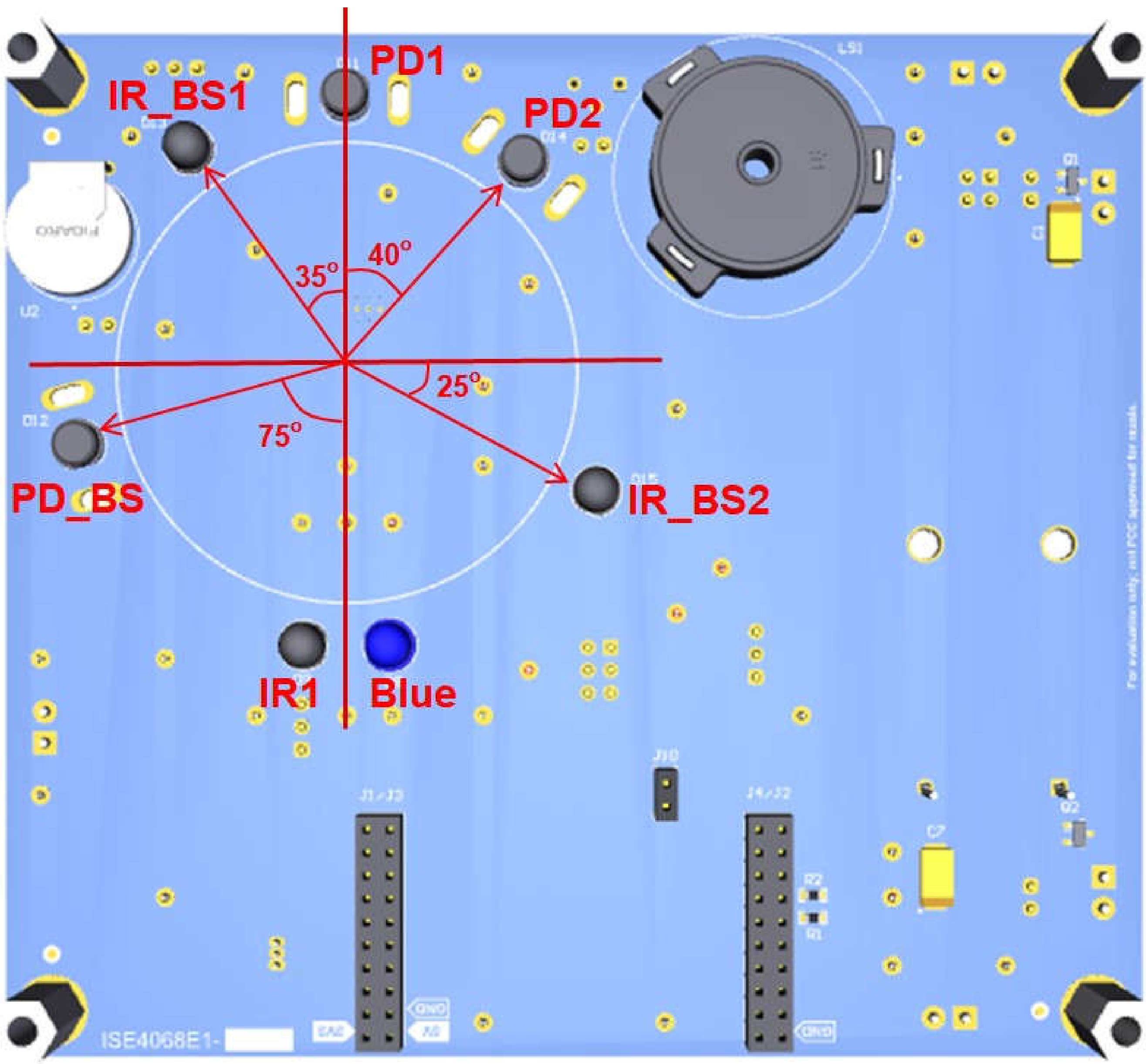

Figure 2-1. PCB Locations and Angular Information for Alternate LED and PD Configurations

Figure 2-2 and Figure 2-3 show the details of the photoelectric front-end implementation for the LED driver and the 2-stage trans-impedance amplifier receiver, respectively. The demo software and GUI allow modifications on the fly for the LED drive strength and temperature coefficient setting. The LED drive strength is controlled with an 8-bit DAC using the PDACx registers in the TPS8802. The CSA and CSB pins are connected to ADC channels on the MCU with the results shown in the GUI. Using this information together with the sliders found in the GUI for the LED DAC settings, instant feedback for the actual LED drive strength based on the temperature coefficient setting, external current setting resistor, and the programmed LED DAC value is received. Similarly, for the trans-impedance amplifier, the PGAIN register can be modified on the fly with the GUI. Separate PGAIN settings are provided for each LED so that the receiver gain is different depending on which LED is being flashed. This is necessary to tune the response for different wavelength LED's or LED's with different scattering angle configuration. The input amplifier stage of the TPS8802 is an ultra-low input offset (voltage and current), wide bandwidth design, designed for amplifying low-level photo diode currents. With the photoelectric front-end fully configurable with software, different configurations and optimizations in hardware can be measured and analyzed with ease. Lastly, since the TPS8802 does not include the ADC, the analog to digital conversion takes place in the MCU where signal processing can take place or be immediately stored instead of using an additional serial interface and delays to get the data from the TPS8802. This saves both power and cost for the sub-system. In this demo, the photoelectric receiver is sampled 5 times by the ADC for each LED flash. These ADC samples are averaged to reduce noise of the measurement.

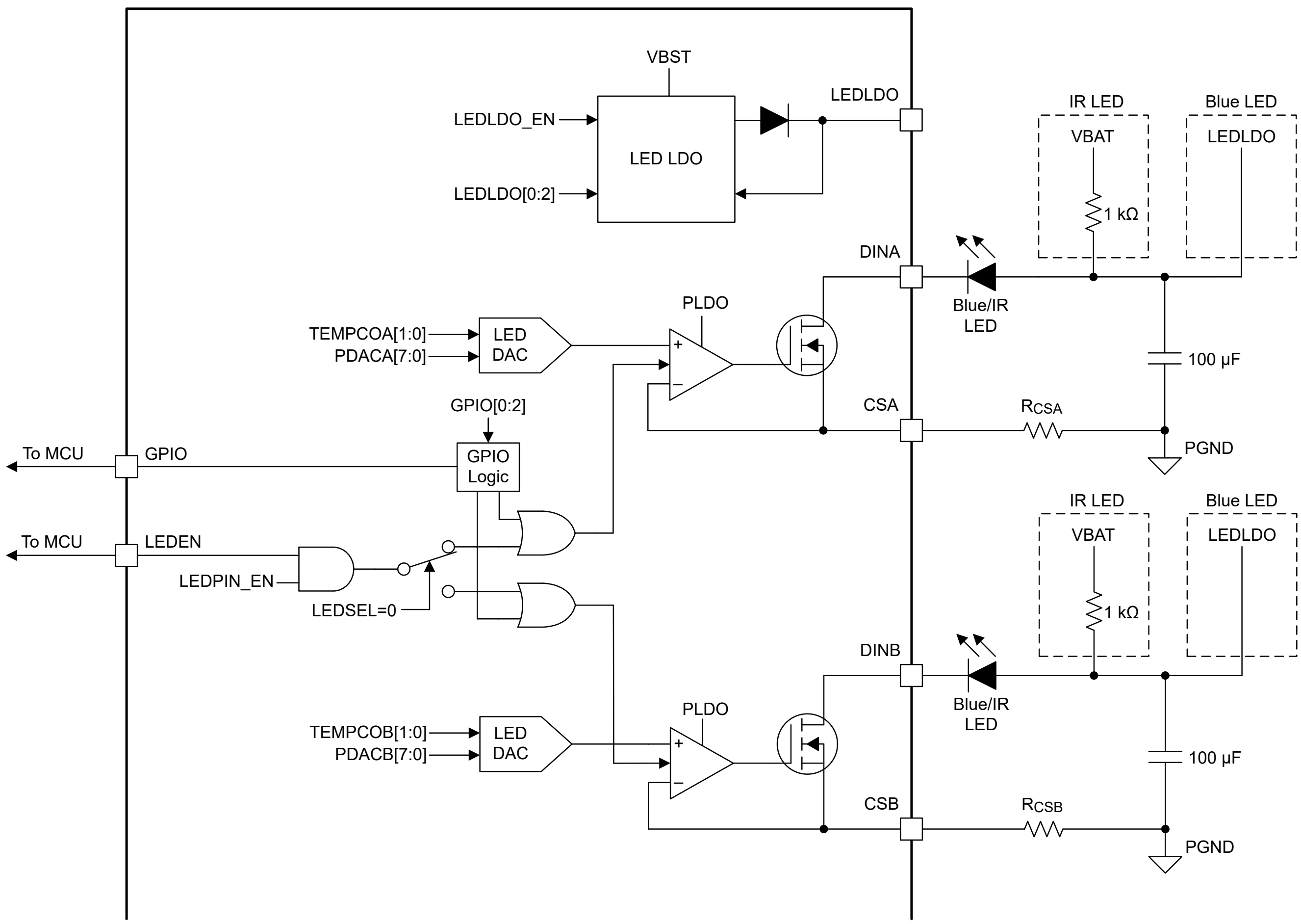

Figure 2-2. TPS8802 LED Driver

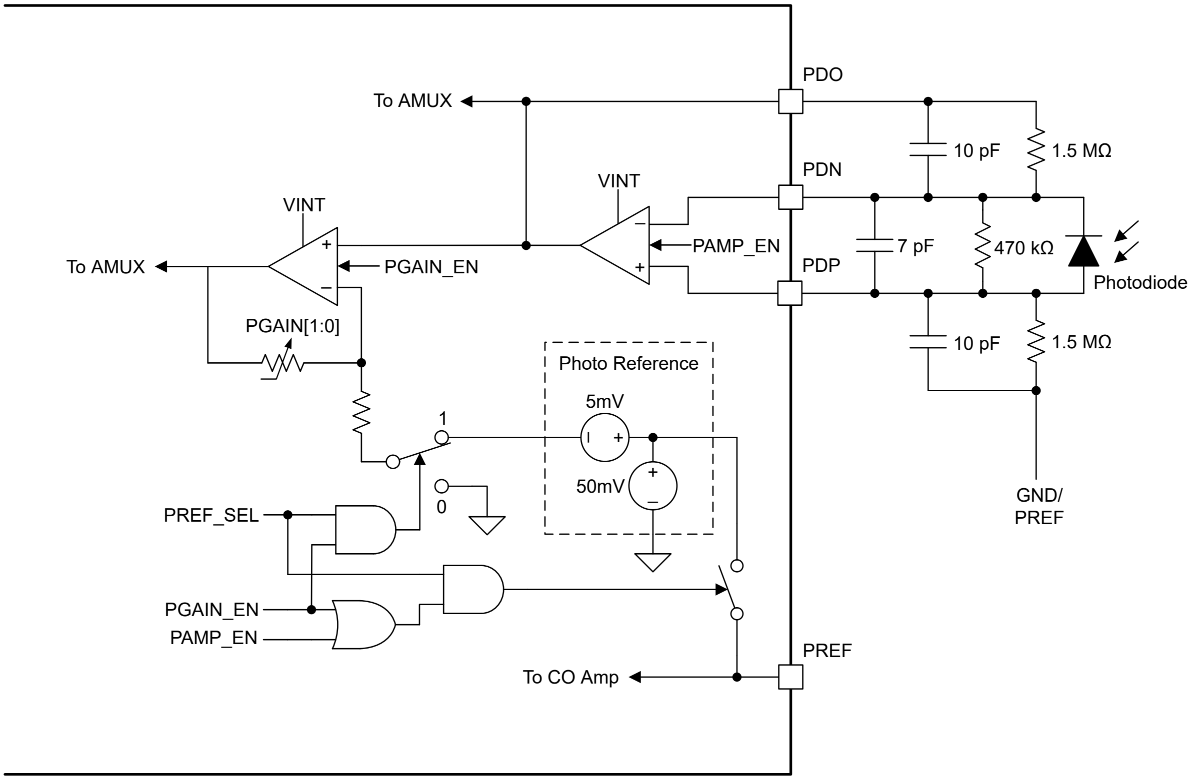

Figure 2-3. TPS8802 Photoelectric Receiver Trans-impedance Amplifier

Additionally, the TPS8802 integrates a boost converter, analog supply LDO, microcontroller supply LDO, photoelectric chamber analog front end (AFE), carbon monoxide sensor AFE, interconnect driver, piezo horn driver, analog multiplexer, and digital core. The high integration greatly reduces component count in smoke alarms and carbon monoxide alarms. The TPS8802 can be powered from a variety of sources:

- 9-V battery
- 3-V battery
- 2-V to 15-V DC supply
- DC supply with battery backup

The two LED drivers have highly configurable temperature compensation to support IR and blue LEDs over a wide range of currents. The wide bandwidth of the photo-amplifier saves power due to reduced LED on-time. The CO amplifier has integrated gain resistors. The horn driver is compatible with two-terminal or three-terminal piezo horns, and the three-terminal self-resonant mode is tunable to maximize piezo loudness. The wired interconnection driver allows multiple smoke alarm units to communicate alarm conditions. Each block is highly configurable with the digital core I2C interface, supporting on-the-fly adjustment of amplifier gains, regulator voltages, and driver currents. Digital features such as sleep mode, under-voltage boost enabling, and one-time boost charging are designed to reduce power consumption for the 10-year battery alarms. Configurable status and interrupt signal registers alert the MCU of fault conditions such as under-voltage, over-temperature, and interconnection alerts.

The MSPM0 microcontrollers are part of MSP's highly-integrated, ultra-low-power 32-bit MSPM0 MCU family based on the enhanced Arm® Cortex®-M0+ core platform operating at up to 32-MHz frequency. These cost-optimized MCUs offer high-performance analog peripheral integration, support extended temperature ranges from -40°C to 125°C, and operate with supply voltages ranging from 1.62 V to 3.6 V. The MSPM0L devices provide up to 64KB embedded flash program memory with up to 4KB SRAM. These MCUs incorporate a high-speed on-chip oscillator with an accuracy up to ±1.2%, eliminating the need for an external crystal. Additional features include a 3-channel DMA, 16- and 32-bit CRC accelerator, and a variety of high-performance analog peripherals important for use in smoke detector applications such as:

- One 12-bit 1.68-MSPS ADC with configurable internal voltage reference (1.4V or 2.5V)
- One high-speed comparator with built-in reference DAC

- Two zero-drift zero-crossover operational amplifiers with programmable gain
- One general-purpose amplifier
- An on-chip temperature sensor for use as part of heat detection or for compensation of LED current strength and photo diode temperature drift.

These devices also offer intelligent digital peripherals such as four 16-bit general purpose timers, one windowed watchdog timer, and a variety of communication peripherals including two UARTs, one SPI, and two I^2Cs.

3 Demo Software

This application note includes source code for libraries and a demo application intended to accelerate the development of a smoke detector application. This software is only a part of a complete system and is intended to be used only as a reference.

Figure 3-1 shows the architecture of the demo software.

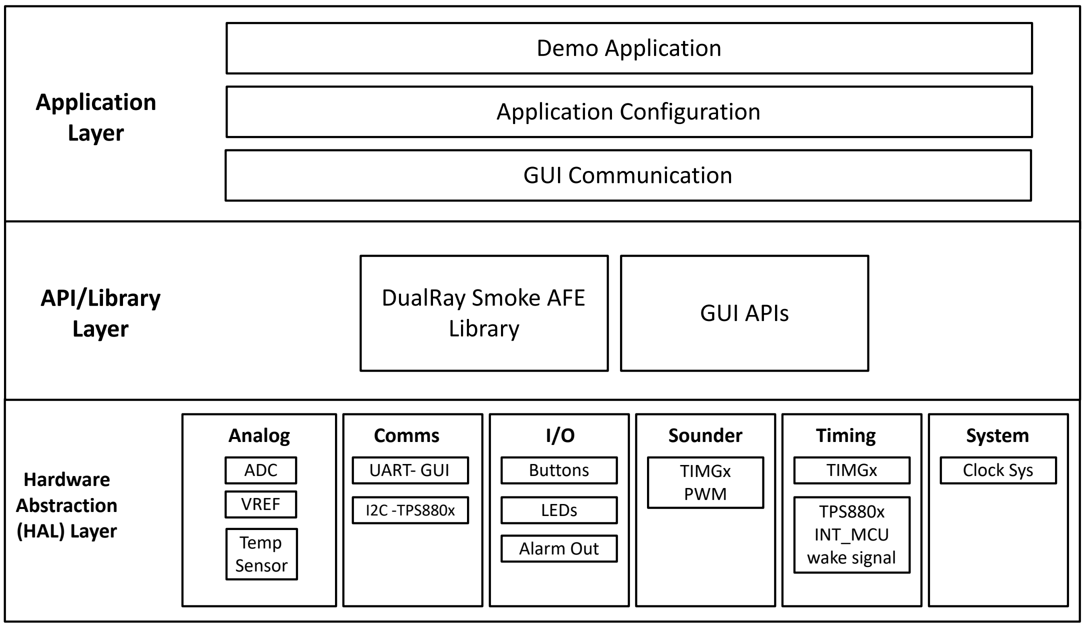

Figure 3-1. Software Architecture

The software was designed in three layers:

- The application layer implements the demo functionality, defines the default configuration, and handles the commands to and from the GUI.
- The API/Library layer defines a set of APIs to take AFE measurements, perform calculations, and interface with the GUI.
- The HAL layer provides hardware-abstraction to interface with different peripherals and allow for a modular, flexible and portable design.

3.1 Dual-Ray Measurements and Alarm Detection

The demo application performs periodic measurements of the Dual-Ray AFE and implements a simple threshold algorithm to detect if an alarm can be triggered. SysConfig is used to generate the ti_msp_dl_config.c and .h files, which fully configure all peripherals of the MSPM0. The main clock is configured to run from the internal SYSOSC and is running at 32 MHz. No RTC is implemented in this example, instead a low power timer is configured in the TPS880x is used to wake the MSPM0 from sleep using an external GPIO. These files also configure the GPIOS, Timers, Comms, and power policy for the application.

The main loop includes the sampling routine, averaging routines, determining if IR or blue LED thresholds have been reached, sending and receiving information from GUI if enabled, and entering low-power modes. The loop requires either IR or blue reflection to exceed the set threshold three times consecutively before sounding the alarm (see Figure 3-2.) As the warning level rises, the time between measurements is reduced.

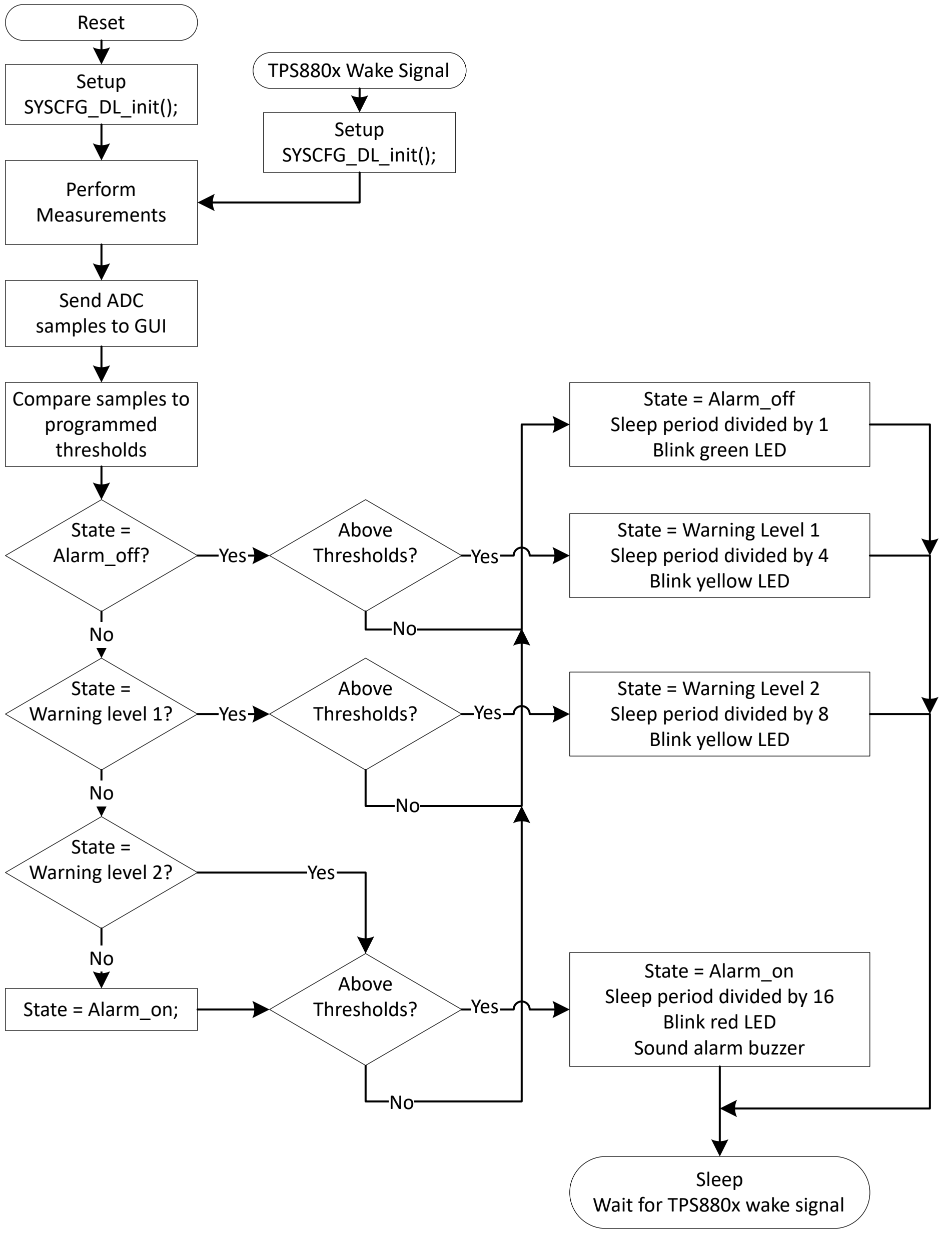

Figure 3-2. Software Flow Chart

As Figure 3-3 shows, the measurement routine first enables the TPS880x AFE, configures it's internal power regulators and analog mux to measure the photo diode and makes sure the LEDs are off. The internal ADC12 is configured to take 4 repeat measurements. After some settling time, takes these measurements without the LEDs on for a *dark* baseline. Then it tells the TPS880x to turn on the IR LED and measures the amount of reflection seen with it on. This process is then repeated with the Blue LED. After both LEDs have been measured, if there is a carbon monoxide sensing enabled in the code, the MCU reconfigures the TPS880x and also reads that sensor.

Once all measurements have been completed, the TPS880x is put in a lower power mode and then the samples are averaged and compensated against any calibration that was done. With this data, the application performs basic dual ray detection by comparing these to thresholds set from the GUI and eventually alarming if they are exceeded.

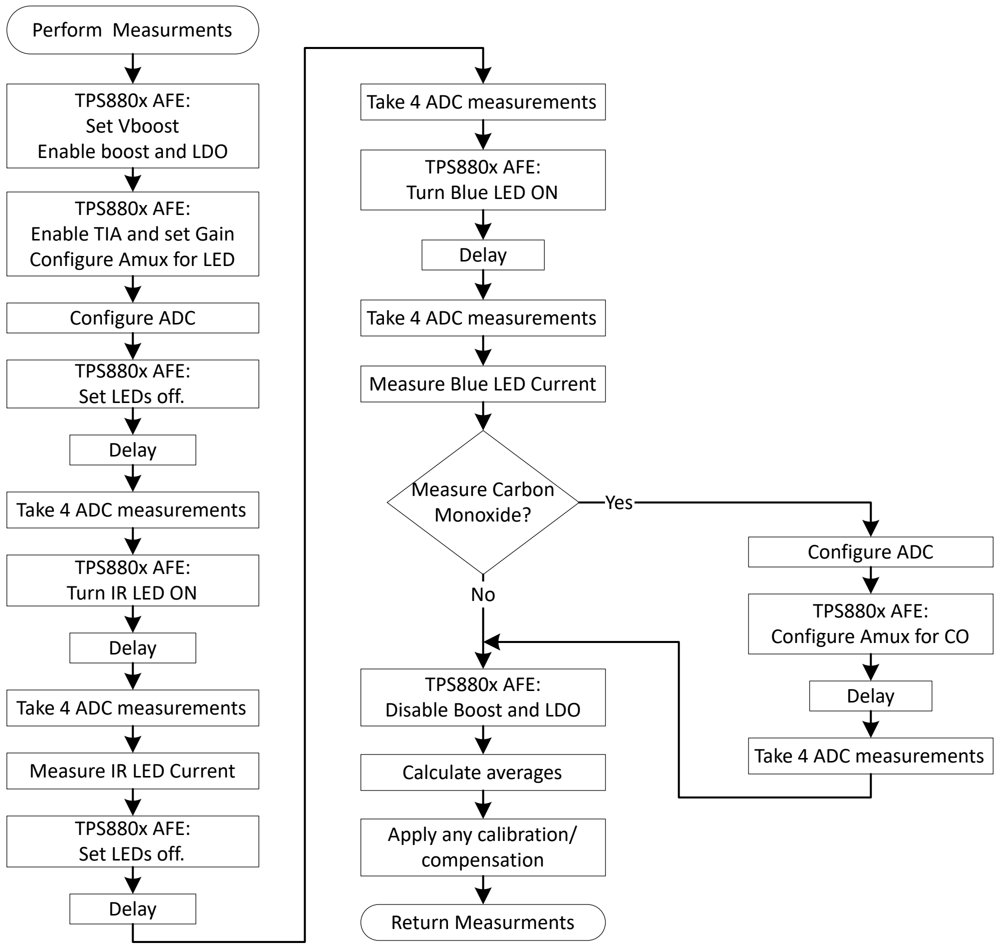

Figure 3-3. AFE Measurement Routine

3.2 Additional Demo Functionality

In addition to measurements of the dual-ray AFE and the basic smoke detection demo algorithm, the software includes the following features:

- **Test button**: a short press turns off the alarm after being activated, while a long-press activates the alarm in self test mode.
- **Temperature sensing**: an external temperature sensor is measured periodically and the information is sent to the GUI. This information can be used by developers to perform temperature calibration of the LED drive current and photodiodes.
- **GUI communication:** provides a visual representation of the measurements, and allows developers to adjust parameters - such as PGA gain, LED drive strength, sampling period, and alarm thresholds in real time.

The software implemented for this design is only a part of a complete system and is intended to be used as a reference. A complete dual-ray reflection detector will require more functionality, such as: algorithms for improved detection of smoke and nuisance rejection, monitoring voltage and temperature, system calibration, and so forth.

4 Demo GUI

To improve the evaluation of dual-ray smoke detection systems, a graphical user interface (GUI) developed with TI GUI Composer is included with this application note.

TI GUI Composer is a tool for rapid development of customer user interfaces to interact with your target application. For more information about the GUID Computer, visit TI Developer Zone.

To use the Dual-Ray Smoke Detector Demo GUI:

1. Visit the TI Cloud Tools Gallery.
2. Click on the DualRaySmoke_FR2355_MSP_TPS Version 2.6.1 GUI.
3. Connect the PC to your MSPM0 design using a UART bridge such as the back-channel UART included in XDS110 or the LP-MSPM0L1306 LaunchPad™.
4. Select the corresponding COM port at 9600 baud.
5. GUI Composer automatically detects when the hardware is connected after receiving data from the device.

Figure 4-1 and Figure 4-2 show the Dual-Ray Smoke Detector Demo GUI and the features:

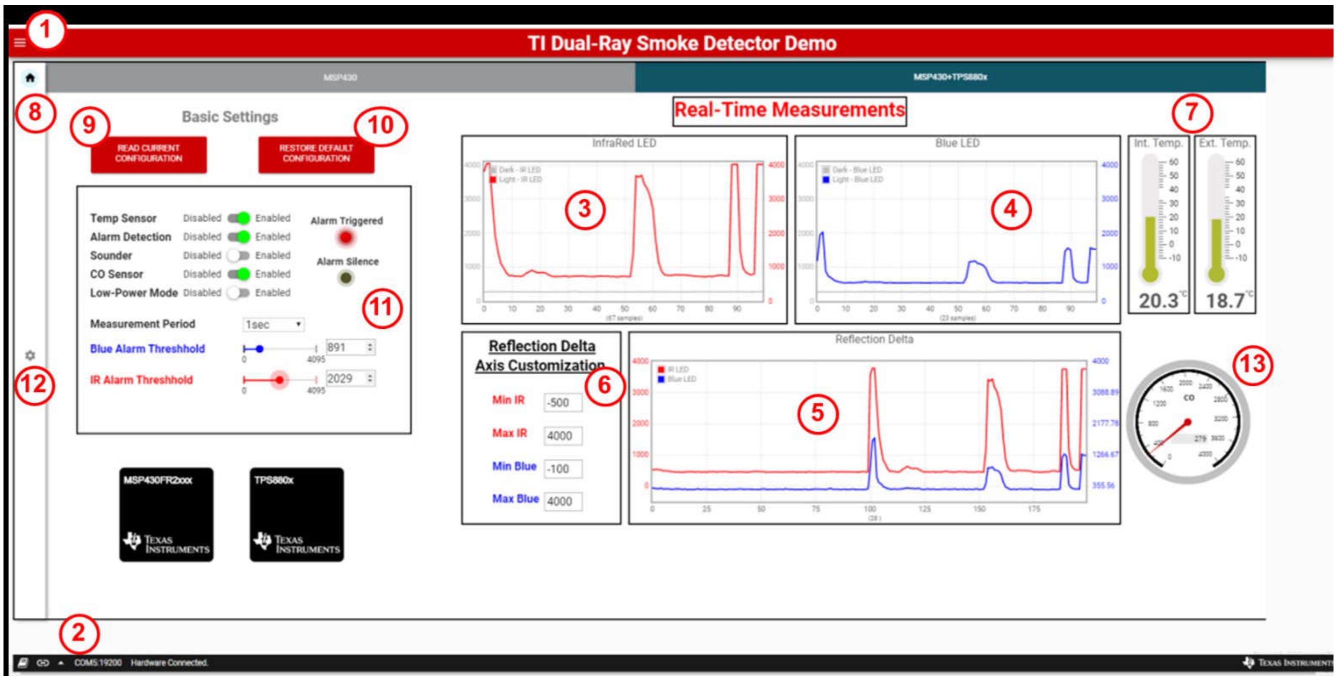

Figure 4-1. Smoke Detector Demo GUI - Basic Settings and Real-time Measurements

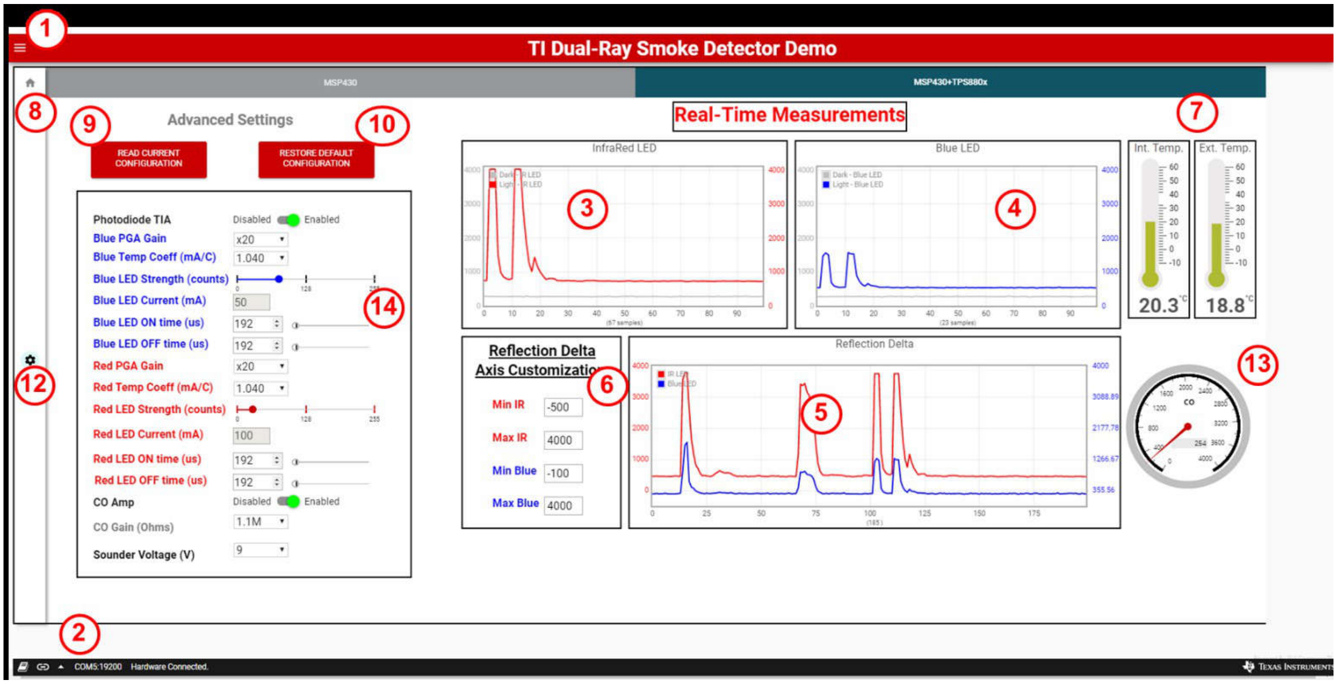

Figure 4-2. Smoke Detector Demo GUI - Advanced Settings

The features included in the GUI are:

1. Menu: used to configure port and baud rate.
2. Connection Status: shows the current hardware connection and status.
3. Infrared LED plot: shows the real time ADC data for the IR LED. The *dark* IR ADC data (measurements taken with the IR LED turned off) are plotted in gray while the *light* IR ADC (taken with the IR LED turned on) are plotted in red.
4. Blue LED plot: shows real time data for the blue LED with the *light* data plotted in blue and *dark* data plotted in gray.
5. Reflection Delta plot: shows the difference between the *dark* and the *light* measurements for both the blue and IR LEDs. Plotting these deltas makes it easy to evaluate how intrusive substances influence the system.
6. Reflection delta axis customization: adjusts the axis of the reflection delta plot.
7. Temperature sensors: shows the temperature measured using the MCU internal sensor and the external LMT84 temperature sensor measurements.
8. Selects the Basic Settings window (default).
9. Read Current Configuration button: press to update the GUI with the current configuration of the device.
10. Restore Default Configuration button: press to restore the default configuration of the device.
11. Basic Settings panel, including:
    a. Temp Sensor: enables or disables reading the temperature sensor.
    b. Alarm Detection: enables or disables the alarm detection functionality. Disable to take measurements without triggering alarm unnecessarily.
    c. Sounder: enables or disables the horn or sounder.
    d. CO Sensor: enables or disables the CO sensor measurements.
    e. Low-Power Mode: enables or disables low power mode for supply current measurements. Enabled mode discontinues UART writes to the GUI.
    f. Alarm Triggered LED: shows if the alarm is activated.
    g. Alarm Silence LED: shows if the alarm has been silenced using the silence button.
    h. Sampling Period: adjusts the period of AFE measurements.
    i. Blue/Red Alarm Threshold: adjusts the threshold at which the blue/IR LED reflection delta triggers the alarm.
12. Advanced Settings tab: select to view advanced settings shown in Figure 4-2.

13. CO Sensor: Displays the ADC result of the CO signal chain output in decimal format, shown in both analog dial and digital display format. ADC result can be converted to PPM level using the calibration code from the sensor mounted to the board.
14. Advanced Settings panel, including:
    a. Photo diode TIA: enables or disables the TPS8802 photoelectric receiver.
    b. Blue/Red PGA Gain: adjusts the PGA gain when measuring each LED.
    c. Blue/Red LED Strength: adjusts the drive strength of each LED.
    d. Blue/Red LED current: ADC measurement result of the CSx sense voltages divided by the CSx resistor values. Provides feedback of LED current drive being set by the LED strength sliders.
    e. Blue/Red LED On/Off time: sets the period allowed for the photo receiver output to settle plus the time needed to take measurements.
    f. CO Amp: enables or disabled the CO amplifier in the TPS8802.
    g. CO Gain: sets the gain of the CO amplifier circuit in the TPS8802.
    h. Sounder Voltage: sets the output voltage of the TPS8802 boost converter when the alarm is active.

5 Test Results

The smoke tests that are performed for agency certification of smoke alarms specify thresholds where the alarm is expected to trigger an alarm within a certain time period after the threshold is crossed. These thresholds are specified in obscuration percentage per foot which is meant as a measure of the density of the smoke in the air and in turn how much the particles of that particular smoke has reduced the visibility in the room. A method used in photoelectric smoke detectors to correlate the signal measurement to obscuration is to compute the current transfer ratio (CTR) of the LED and photo diode pair (for example, photo diode current divided by LED drive current expressed in units of nA/mA).

This demo was tested in a smoke box built to UL specifications as shown in Figure 5-1. The obscuration was measured using a calibrated reference meter.

Figure 5-1. Smoke Box used for Demo Testing

Two separate tests were performed. The first was using water vapor to simulate a nuisance source. The second added salt crystals to produce a simulated smoke signature in the smoke box. For both tests the IR LED drive current was set to 100mA and 50 mA for the Blue LED drive current. The PGA gain was set to 11 for the IR signal and 35 for the Blue signal in both tests. The measurements for these two tests are shown in Figure 5-2 and Figure 5-3, respectively.

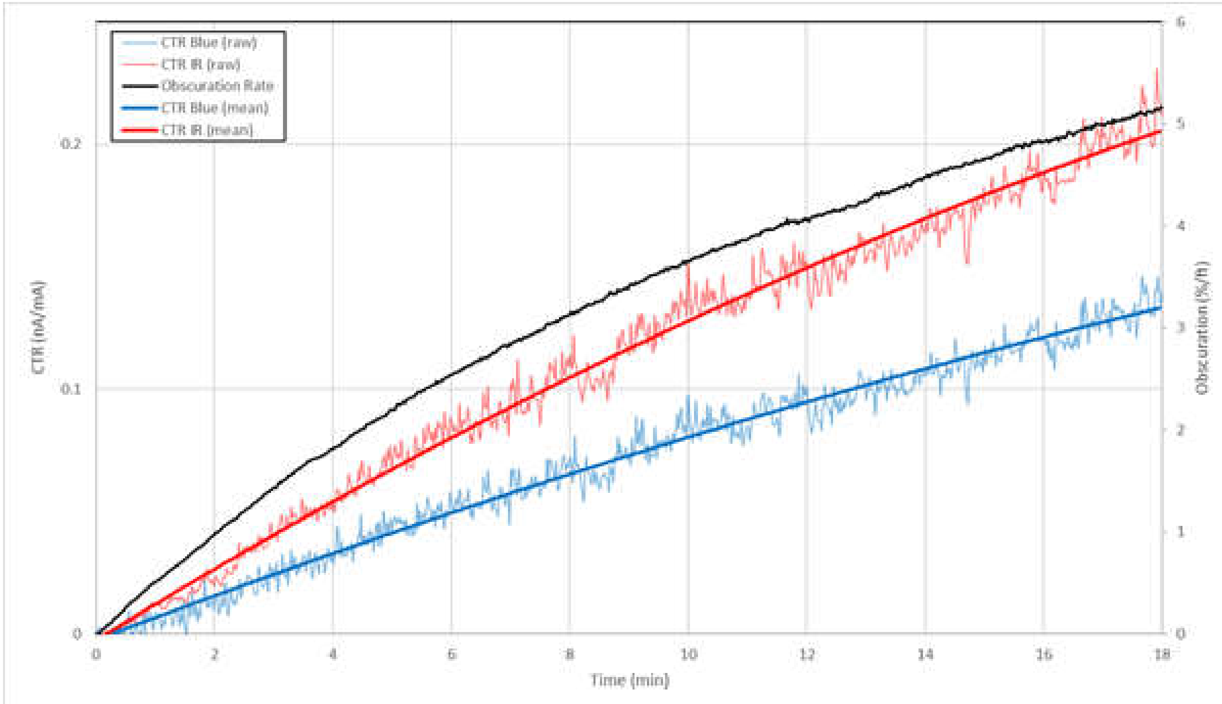

Figure 5-2. Water Vapor Test Results

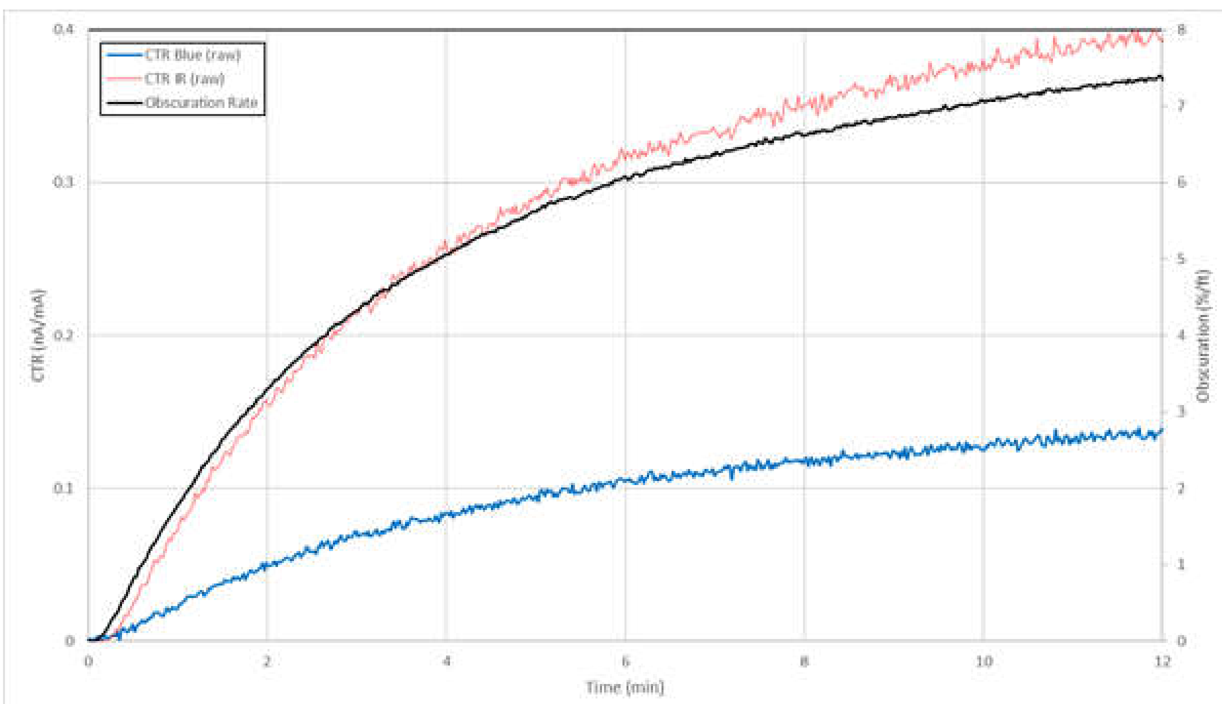

Figure 5-3. Simulated Smoke Test

As shown in these results, this demo is capable of measuring different types of smoke. It is anticipated that the ratio of the IR to Blue photo diode measurements would provide the basis for a method to distinguish between the simulated smoke source and the water vapor source (considered to be a nuisance source, for example, shower steam) as shown in *Designing a Dual-Ray Smoke Detector Analog Front-End With MSP430FR235x MCUs* application note. In fact, an inspection of the results shown in Figure 5-2 and Figure 5-3 at obscuration rates of 2 %/ft and 4 %/ft, indicates ratios of 1.59 and 1.71 for water vapor and 2.93 and 3.08 for simulated smoke.

Also shown in these plots that when comparing the CTR numbers for a given Obscuration rate that the CTR for IR is much higher for the simulated smoke test compared to that of water vapor and also that the opposite is true for the CTR of Blue. This in agreement with theory in that the larger particles sizes in the simulated smoke will produce a larger scattering response for the IR wavelength and the smaller particle sizes in the water vapor will produce a larger scattering response in the Blue wavelength.

6 Summary

This application note describes a cost-efficient, low-power 2-chip design that can be used to accelerate the design of a smoke alarm meeting the requirements of new UL standards. The test results show the ability of this design to detect and the potential to distinguish between sources of real smoke and nuisance sources.

While the design presented in this report is meant for demo purposes, the note provides the foundation in terms of base software routines and configuration, and hardware, to be able to implement more sophisticated algorithms with designed for photoelectric chamber configuration and signal chain parameters needed for full agency compliance.

Other considerations for the 2-chip design presented is in the flexibility of the selection of the MCU as the only requirements are an ADC with the required resolution and sample rate, an I2C interface, the appropriate number of GPIO’s for the application, and the amount of memory space needed to run the algorithms. While the MSPM0L1306 is used for the design shown in this report, the even lower cost MSPM0C device can be used. Additionally, if the need for GPIO’s is low, the MSPM0L series is offered in a small package size 16WQFN with is only 3 mm × 2 mm. These are just a couple examples illustrating the flexibility of TI’s new family of MSPM0 Arm-based micro controllers.

7 References

- Texas Instruments, *Designing a Dual-Ray Smoke Detector Analog Front-End With MSP430FR235x MCUs*, application note.

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