Implementing A Smoke Detector With The MSP430F2012

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ABSTRACT

This application report describes how to implement an ultra-low-power photo-diode-based smoke detector using the MSP430F2012 and an external operational amplifier that is powered from two AAA batteries. The complete schematic is shown, and the solution is discussed. The complete code is downloadable from www.ti.com. In addition, a solution for a piezzo-electric buzzer driver is shown that produces >85-dB sound pressure level at a 10-foot distance.

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1 Introduction

This application report describes how to implement an ultra-low-power photo-diode-based smoke detector. An infrared (IR) diode and IR receiver are used inside a smoke chamber to detect the presence of smoke. The IR diode is pulsed periodically, and the IR receiver signal is examined to determine if smoke is present in the chamber. An operational amplifier is used to magnify the IR receiver current as a transimpedance amplifier, so it can be sampled by the ADC in the MSP430. Between sampling periods, the operational amplifier and IR circuitry are shut down, and the microcontroller is in a standby mode, consuming less then 1-μA current.

When smoke is detected, the buzzer is sounded. The smoke detector implements a loud piezzo-electric buzzer driver circuit capable of producing >85-dB sound pressure level at a measurement distance of 10 feet.

2 Implementation

The smoke detector samples the IR circuitry for the presence of smoke every eight seconds. The MSP430 has an internal RC oscillator called the VLO that is used on conjunction with Timer_A to generate an eight-second interrupt. This interrupt brings the MSP430 out of LPM3. The VLO is calibrated by using the on-chip calibrated DCO oscillator to determine how many VLO clock cycles are required for a one-second interval. This number is used as the rollover period for Timer_A, and Timer_A is clocked from the VLO. The input clock divider for Timer_A is set to ÷8, which gives an eight-second wake-interrupt to the MSP430.

When the MSP430 comes out of LPM3, it turns on the operational amplifier, allows for a settling time, and then samples the IR receiver current with the IR diode off. Then it turns on the IR diode, allows for a settling time, and measures the IR receiver current again. The two measurements are compared to determine if smoke is present.

To prevent false alarms, smoke must be detected three times before sounding the alarm. After the first detection, the clock divider of Timer_A is set to ÷4, giving a four-second interval between the first indication of smoke and the next sampling. If smoke is determined to be present in the second sampling, the Timer_A clock divider is set to ÷1, giving only a one-second interval between the second detection of smoke and the next sampling. If smoke is detected the third time, the alarm is sounded, and the detector continues sampling for smoke at one-second intervals.

The TLV2780 is the operational amplifier chosen for the application. It was chosen for its balance of cost vs settling-time performance. The application is constructed to minimize current consumption. For this reason, the operational amplifier is powered directly from an MSP430 port pin, even though it has a shutdown feature. The TLV2780 can consume up to 1.4 μA at room temperature in shutdown mode. This continuous current consumption is avoided by powering the operational amplifier directly from the MSP430 port pin. In this case, when the operational amplifier is turned off, it consumes no current.

In addition, the power-on time and settling time of the operational amplifier were considered in its choosing. The goal is to keep the operational amplifier and IR circuitry on for a minimum time. Thus, the settling time of the operational amplifier can impact current consumption, if it requires too much time.

The application is powered by two AAA batteries and operates over the full 1.8-V to 3.6-V range of the batteries. To provide the necessary voltage for the loud piezzo buzzer, a TPS61040 low-power dc/dc boost converter is used. The boost converter powers the self-oscillation circuit of the piezzo buzzer. Thus, when the boost converter is on, the buzzer sounds, and when the boost converter is off, the buzzer is off.

The enable pin of the boost converter is tied to the TA1 output of the MSP430. When the alarm is sounded, the period of Timer_A is set to one second, and the CCR1 register of Timer_A is used to automatically generate a 50% duty cycle, 1-Hz signal to enable and disable the buzzer. This automatically gives a half-second on/half-second off cadence for the buzzer, when the alarm is sounding, with no additional software intervention required to generate the alarm timing.

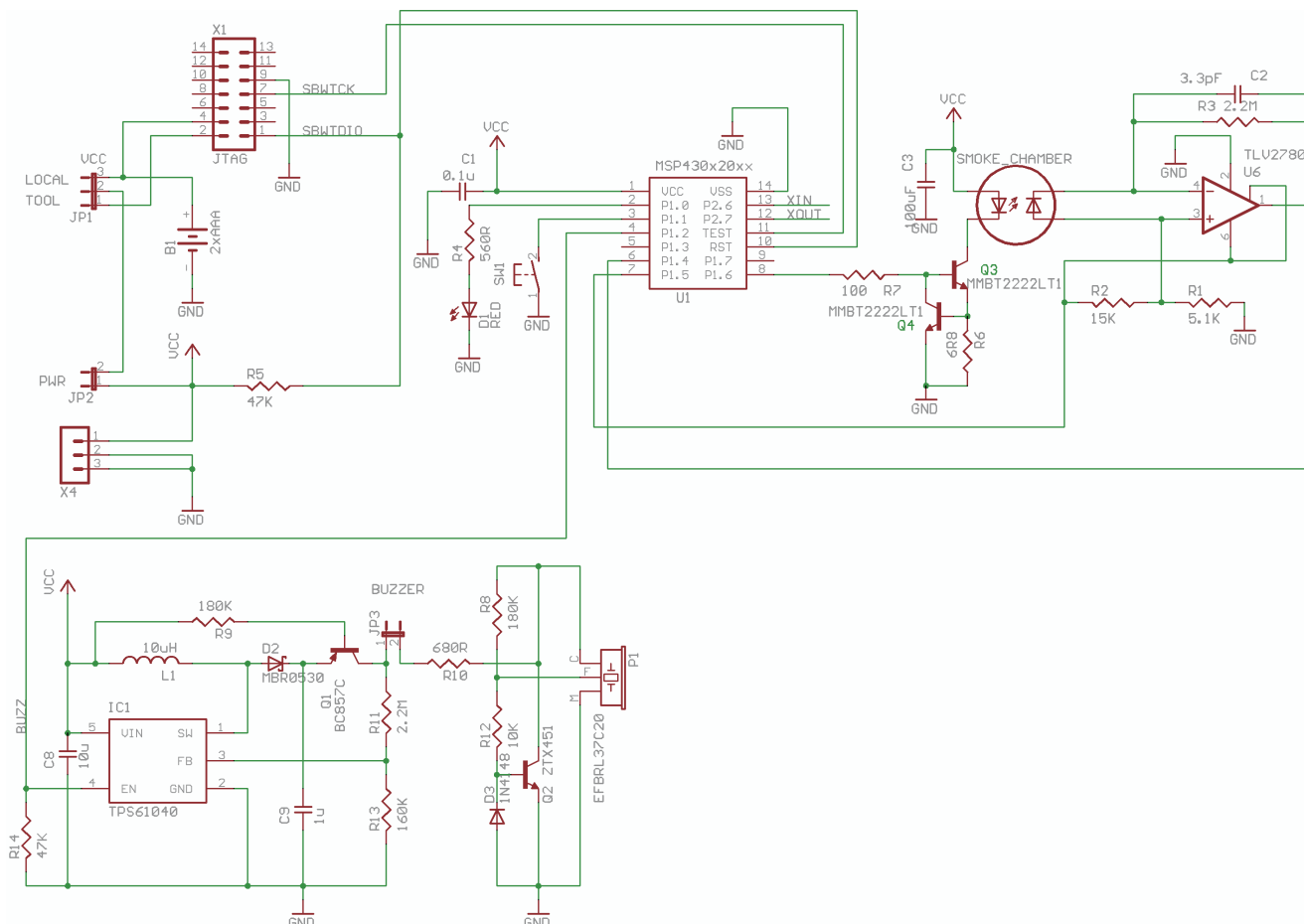The complete schematic is shown in Figure 1.

Figure 1. Schematic

3 Software

In the initialization routine, all the MSP430 pins are configured, and unused pins are configured for the lowest power consumption. Next, the calibrated 1-MHz DCO values are loaded to the DCO control registers. The VLO is calibrated against the calibrated 1-MHz DCO clock source, and Timer_A is configured to give an eight-second interrupt as described in Section 2.

The main loop consists of entering LPM3, calling the sampling and averaging routines, and determining if smoke is present. The loop requires smoke to be detected three times before sounding the alarm, as described in Section 2, and adjusts the timing interval of the sampling accordingly.

The VLO calibration procedure is performed only once in the application, but could be performed as often as deemed necessary, given the VLO drift specifications and the timing accuracy requirements of the application. To calibrate the VLO, Timer_A is configured to be clocked from the calibrated 1-MHz DCO clock and to operate in continuous mode. ACLK is configured to be sourced from the VLO divided by eight. ACLK is then used as the capture source for CCR0 of timer, and the number of DCO clock cycles that fit one VLO/8 period is counted. This is equivalent to the ratio of the VLO frequency to 8 MHz; thus 8 000 000 is divided by this number to yield the VLO frequency. The result of the division is used as the period for Timer_A, to provide the 1-s, 4-s, and 8-s timing intervals.

Because a very small MSP430 with limited code space is used in this application, an approximate division routine is implemented directly in the code to determine the VLO frequency, rather than allowing the C compiler to call a complex general-purpose division routine. The timing requirements of the application do not require floating-point math, so a simple subtraction routine approximates the required division.

The sampling routine, shown in Figure 2, samples the IR receiver with the IRLED both on and off. First, the OA and visible LED indicator are turned on, and the ADC10 is configured to take measurements. It is configured to automatically take four ADC conversions, which are automatically moved into RAM using the DTC feature of the ADC10. After a small settling time, the ADC10 is started and the MSP430 is put into LPM3, while the four ADC conversions are taken. The DTC interrupts the MSP430 automatically after four conversions, and the DTC interrupt service routine returns the MSP430 to active mode. Next, the IRLED is turned on and, after a small settling time, the four-conversion process is repeated. At the conclusion of sampling, the operational amplifier, IRLED, ADC, and visible LED are turned off, and the averaging routine is called.

The averaging routine averages the four dark samples and the four light samples for comparison in the main routine.

Finally, the software implements an interrupt handler for the switch. The switch is used in this application to turn the buzzer on and off manually. At initialization, the switch input port pin is configured as an input with its internal pullup resistor enabled and interrupt enabled. The ISR for the switch enacts a software debounce routine and then toggles the buzzer enable. Pressing once turns the buzzer on; pressing a second time turns the buzzer off.
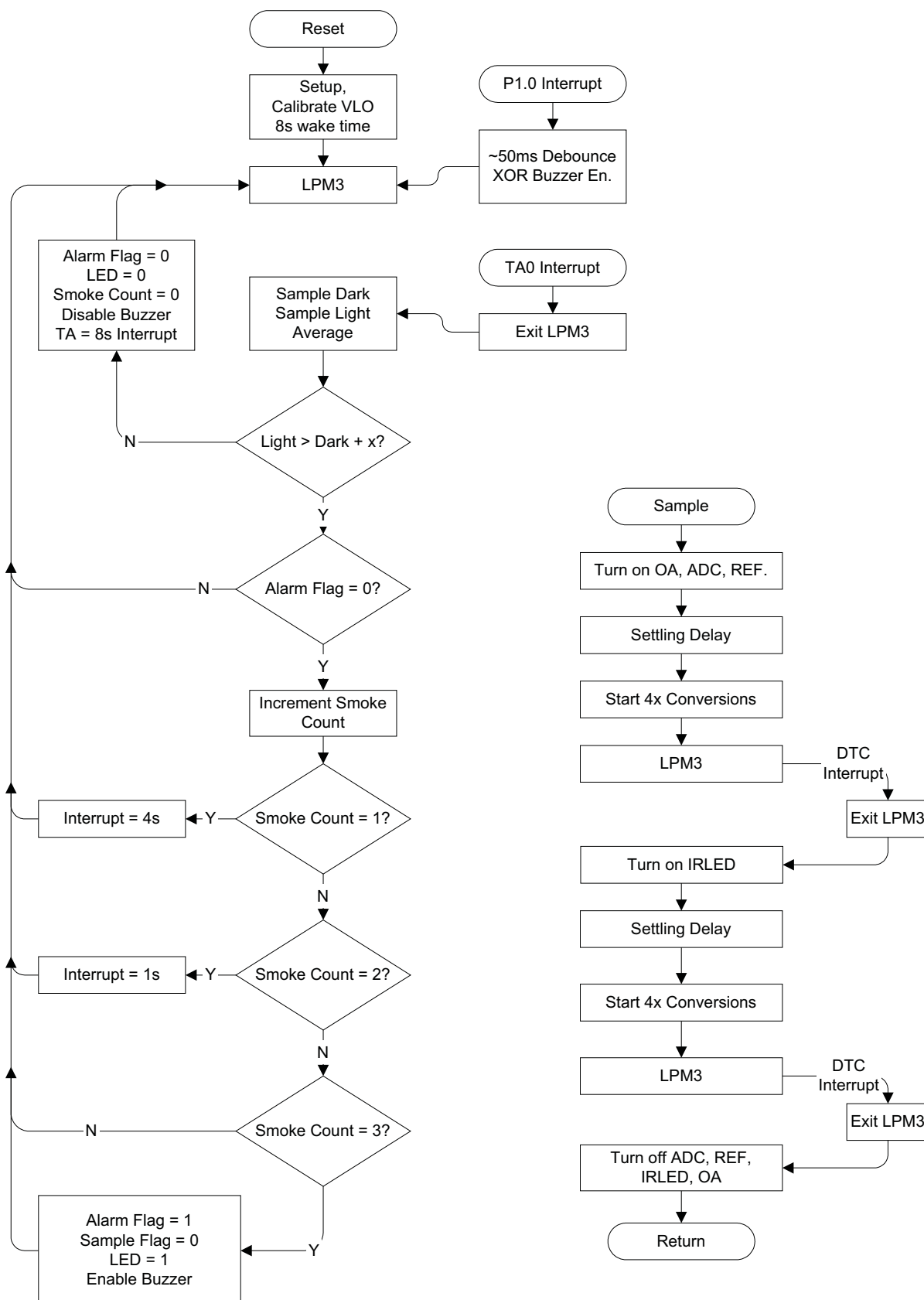
The complete software flow is shown in Figure 2.

Figure 2. Software Flow

4 Power Budget

The typical power budget is shown below in Table 1.

Table 1. Power Budget Normalized For One Second

Function	Duration	Current	Normalized Current
MSP430 active (1 MHz at 3 V)	422.6 µs	300 µA	15.8 nA
MSP430 in LPM3	7.999577 s	0.6 µA	0.6 µA
Operational amplifier	190.6 µs	650 µA	15.5 nA
ADC reference	190.6 µs	250 µA	5.95 nA
ADC core	20.8 µs	600 µA	1.56 nA
IRLED	100.8 µs	100 mA	1.26 µA
TPS61040 in shutdown	Continuous	0.1 µA	0.1 µA
		Total	2.00 µA

5 References

1. *MSP430x2xx Family User's Guide* (literature number SLAU144)
2. *MSP430x20x2 datashseet* (literature number SLAS491)
3. *TLV2780 datasheet* (literature number SLOS245)
4. *TPS61040 datasheet* (literature number SLVS413)

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