# TI Designs MSP430FR2311 IR Reflection-Sensing Subsystem Design Guide

# Texas Instruments

## **TI Designs**

This reference design demonstrates the configurable integrated analog of a MSP430<sup>™</sup> FRAM microcontroller (MCU) for sensing and measurement applications. This specific design integrates drive of an infrared LED and simultaneous sensing of an IR receiver useful in a variety of sensor use-cases. As an example implementation, this photoelectric IR reflection solution demonstrates the MCU's ultra-lowpower features with the benefit of FRAM technology and integrated transimpedance amplifier (TIA). A single CR123 battery provides power to the board to make it work more than 10 years.

#### **Design Resources**

TIDM-FRAM-IRREFLECTIONSENSING
MSP430FR2311
TPS61040
TPD2E2U06

TI Design Files Product Folder Product Folder Product Folder

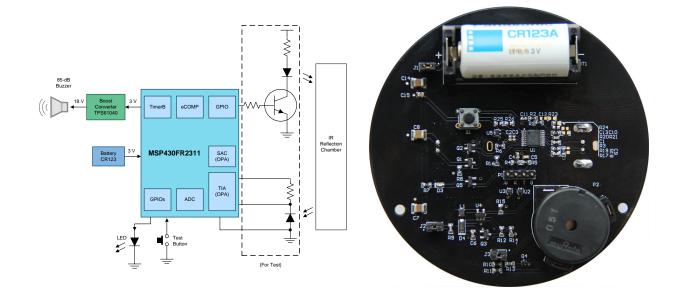
#### **Design Features**

- FRAM-Based MSP430FR2311 Eliminating EEPROM
- Integrated Analog Front End (AFE)
- Amplifier With pA Level Low-Leakage Input
- 10 Year Lifecycle With One CR123 Battery
- Ultra-Low-Average Power (MCU 1 µA)
- High-ESD Performance With Easy Layout

#### **Featured Applications**

IR Reflection Sensing







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#### 1 Application Description

**NOTE:** This subsystem reference design is for IR signal reflection sensing and should not be used for production. The IR reflection chamber for the board is not available. In the block diagram, the sensing circuit in the dot-line rectangle is used only for testing.

This reference design describes the implementation of an IR reflection-sensing subsystem with the following characteristics:

- Photoelectric IR reflection-sensing
- Analog front-end circuit based on integrated amplifiers with pA level low leakage input
- Audio buzzer that alerts when IR reflection is sensed
- Test button to perform self-test mode or silence the alarm
- Low-power consumption (The device enters low-power mode during intervals between checking for IR reflection. MCU average power is approximately 1  $\mu$ A.)
- High-ESD performance with easy layout and board-level protection



# 1.1 MSP430FR2311

The TI MSP430FR2311 is the first device in TI's FRAM technology platform to combine an amplifier with FRAM. FRAM is a new nonvolatile memory that combines the speed, flexibility, and endurance of SRAM with the stability and reliability of Flash at lower total power consumption. The architecture, FRAM, peripherals, and extensive low-power modes are optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and mixed-signal integration. Figure 1 shows the functional block diagram for the MSP430FR2311.

MSP430FR2311 device features include the following:

- 3.75-KB FRAM and 1-KB SRAM
- 8-channel, 10-bit analog-to-digital converter (ADC) with window comparator
- Smart analog combo (SAC-L1), includes one rail-to-rail amplifier
- Trans-impedance amplifier (TIA) with low-leakage input supported in TSSOP16 package
- Enhanced comparator with 6-bit digital-to-analog converter (DAC) as reference voltage
- External 32-kHz crystal oscillator (LFXT)
- External high-frequency crystal oscillator up to 16 MHz (HFXT)
- Two 16-bit timers with three capture and compare registers each
- Two serial interfaces (SPI, UART, or I<sup>2</sup>C)
- Real-time clock (RTC) counter with LPM3.5 support
- 16-bit cyclic redundancy checker
- 32 bytes of backup memory with LPM3.5 support
- All I/Os are capacitive touch I/Os
- Ultra-low-power operation

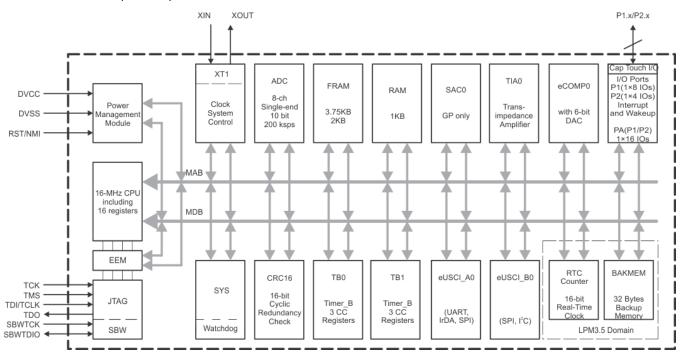


Figure 1. Functional Block Diagram—MSP430FR2311



Application Description

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#### 1.2 TPS61040

The TPS61040 device is a high-frequency boost converter dedicated for small to medium LCD bias supply and white LED backlight supplies. The device is ideal to generate output voltages up to 28 V from a dual cell NiMH or NiCd or a single-cell Li-Ion battery. The part can also be used to generate standard 3.3-V or 5-V to 12-V power conversions.

The TPS61040 device operates with a switching frequency up to 1 MHz. This feature allows the use of small external components using ceramic and tantalum output capacitors. With the thin SON package, the TPS61040 device has a small solution size. The TPS61040 device has an internal 400-mA switch current limit that allows for low-output voltage ripple and the use of a smaller form factor inductor for low-power applications. With an optimized control scheme, the low-quiescent current lets the device operate at high efficiencies over the entire load current range.

This reference design uses the TPS61040 boost converter to generate sufficient voltage to drive the buzzer.

#### 1.3 TPD2E2U06

The TPD2E2U06 is a dual-channel, low-capacitance transient-voltage-suppression (TVS) diode ESD protection device. The device offers  $\pm$ 25-kV contact and  $\pm$ 30-kV air-gap ESD protection in accordance with the IEC 61000-4-2 standard. The 1.5-pF line capacitance of the TPD2E2U06 optimizes the device for a range of applications, such as water meter or IR reflection-sensing applications. This reference design uses the TPD2E2U06 ESD-protection device to enhance board-level ESD performance of IR reflection-sensing application.



# 2 Block Diagram

Figure 2 shows the MSP430FR2311 IR reflection-sensing subsystem.

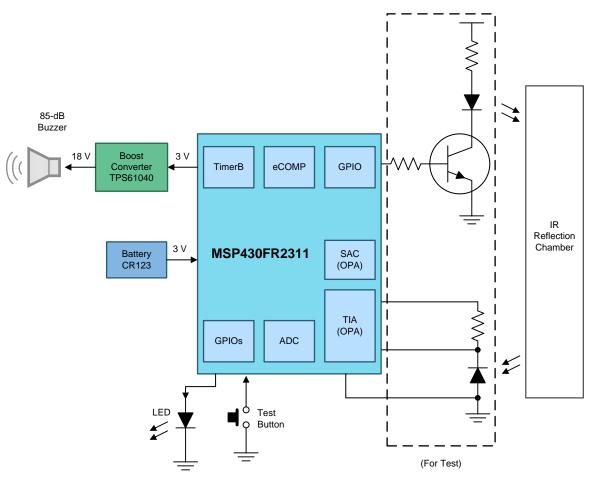


Figure 2. Block Diagram of the MSP430FR2311 IR Reflection-Sensing Subsystem

#### 3 Theory Operation

Theory Operation

#### 3.1 IR Reflection-Sensing

An infrared (IR) light receiver and an IR LED are used in the IR reflection chamber.

#### **NOTE:** There is no IR reflection chamber in this design.

In the chamber, there should be a plastic divider between the LED and the IR receiver to prevent the LED from shining directly on the receiver. The MSP430 device takes a measurement with the IR LED off and another is taken with the IR LED powered. When no particles are in the chamber, IR light on the receiver changes minimally. When IR reflection particles are in the chamber and the IR LED is powered, the IR light reflects from the particles to the IR receiver. This reflection causes the reading to vary compared to the scenario with the IR LED off.

The MSP430 device samples the IR signal every eight seconds. The MSP430 has an internal lowfrequency RC oscillator called the VLO. The VLO is used with the RTC to generate an 8-second interrupt. This interrupt brings the MSP430 out of its idle state of LPM4 to measure the IR receiver current. Using the on-chip trimmed low-frequency oscillator REFO to measure VLO frequency, the VLO is calibrated. Based on calculated VLO frequency, the RTC with VLO as a clock source is set to give an 8-second wake interrupt to the MSP430.

When the MSP430 comes out of LPM4 state, it turns on the op amp, allows for a settling time, and samples the IR receiver current with the IR diode off. The MSP430 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 IR reflection is present.

To prevent false alarms, IR reflection must be sensed three times before the alarm sounds. After the first detection, the RTCMOD value is divided by 4, giving a 2-second interval between the first indication of IR reflection and the next sampling. If IR reflection is determined to be present in the second sampling, the RTCMOD value is divided by 8, giving only a 1-second interval between the second sensing of IR reflection and the next sampling. If IR reflection is sensed the third time, the alarm sounds and the MSP430 device continues sampling for IR reflection at 1-second intervals. After the button is pressed, it turns the alarm off and sets the RTCMOD value for an eight-second interval.

#### 3.1.1 Considerations for Implementing an IR Reflection System

This design is the subsystem of IR reflection applications. For the complete IR reflection system, an IR reflection chamber must be ready on the board. The chamber is used for IR signal reflection when there are IR reflection particles in the chamber. There must be a divider in the chamber to avoid direct receiving of the IR signal. The experience software for the design is also just for IR detection sensing reference. Many things must be done to use it as a complete system and many tests and calibrations must be completed.



#### 3.1.2 IR Detection and Signal Amplification

The output current of the IR receiver runs through a transimpedance amplifier to convert output current of IR receiver into analog voltage. This analog voltage is amplified by the second-stage amplifier and then measured by the analog-to-digital converter (ADC) on the MSP430. As Figure 3 shows, these two amplifiers are integrated in MSP430FR2311 and the external resistors determine the amplification factor. The transimpedance amplifier supports pA level low-leakage input that improves accuracy of current measurement.

If pA level current must be detected, the feedback resistor R20 should be larger (for example, R20 = 10  $M\Omega$ ). The amplifier in smart analog combo (SAC-L1) supports rail-to-rail input and output. Transimpedance amplifier output is internally connected to SAC-L1 positive input. The application is constructed to minimize current consumption. The op amps are disabled with internal control registers when IR detection is finished for this reason. When the op amps are turned off, they consume no current.

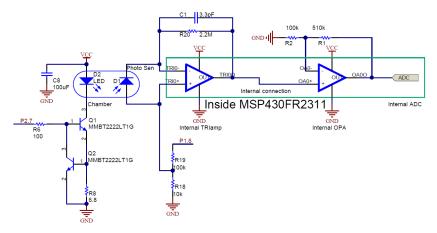


Figure 3. AFE Circuit

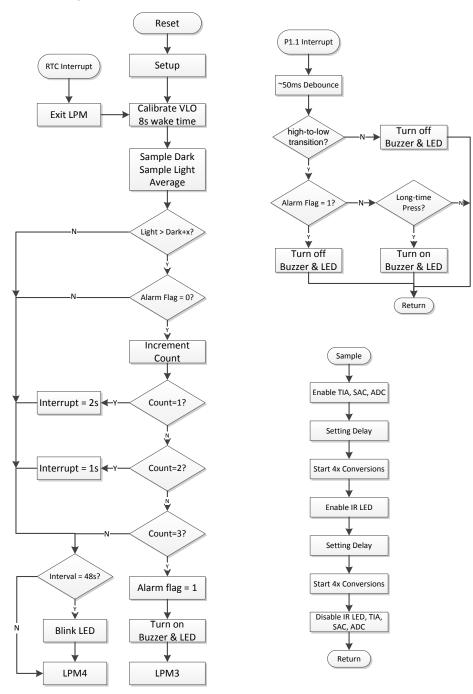
## 3.2 Piezo Alarm

A TPS61040 low-power DC-DC boost converter provides the voltage for the loud piezo buzzer. The boost converter powers the self-oscillation circuit of the piezo buzzer. When the boost converter is on, the buzzer sounds. When the boost converter is off, the buzzer is silent.

The enable pin of the boost converter is tied to the TB1.1 output of the MSP430. When the alarm sounds, the period of Timer\_B1 is set to 1 millisecond and the CCR1 register of Timer\_B automatically generates a 50% duty cycle, 1-kHz PWM signal to drive the buzzer.

#### 3.3 Software

Figure 4 shows the experience software flow chart.





In the initialization routine, DCO is configured to 1 MHz and stabilized by the FLL. The internal trimmed REFO with 32768-Hz typical frequency is selected as a clock reference into FLL. The MSP430 pins are configured and unused pins are configured for the lowest power consumption. After the initialization, LED is fast-blinked and then enters the main loop. If the MSP430 is reset, LED fast-blinking occurs. The main loop includes VLO calibration, RTC setting, calling the sampling, averaging routines, determining if IR reflection is present, and entering low-power mode. The loop requires IR reflection to be detected three times before sounding the alarm (as described in Section 3.1) and adjusts the timing interval of the sampling.



The VLO calibration procedure is performed at every execution of the main loop to improve the accuracy of timing for each interval. To calibrate the VLO, Timer\_B is configured to be clocked REFO clock and to operate in capture mode. RTC is configured to be clocked VLO clock that is divided by 10. Each RTC overflow event triggers a high pulse to Timer\_B capture input. Timer\_B counter value is loaded to the CCR0 register each time the capture is performed. The delta value of the CCR0 register at two times is the cycle number of REFO clock. REFO clock frequency is internal trimmed 32768 Hz. The VLO clock frequency can be calculated based on REFO cycle number. The RTCMOD register controls the VLO cycle number between two pulses. Changing the RTCMOD value can change calibration time. To minimize power consumption, the VLO is calibrated in LPM3 where Timer\_B and RTC are in LPM3 during calibration. For more information, see the details in *VLO Calibration on MSP430FR2xx Family* application report (SLAA693). After VLO calibration, RTC is configured to generate an 8-second interval timing.

As Figure 4 shows, the routine samples the IR receiver with the IRLED both on and off. The two amplifiers (TIA and SAC) are turned on and the ADC10 is configured to measure. The ADC10 is configured to automatically take four ADC conversions in repeat single-channel mode. After a brief settling time, the ADC10 starts and takes four ADC conversions in active mode by polling ADCIFG. The IRLED turns on. After a brief settling time, the 4-conversion process repeats. After sampling, IRLED, ADC and amplifiers turn 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. To simplify the calculation, shifting is used in place of division. The software implements an interrupt handler for the button. The button is used in this application to perform self-test mode or silence the alarm. If the alarm is turned on, pressing the button can silence the alarm. If the alarm is off, pressing the button for more than 2 seconds can initiate self-test mode. In self-test mode if the button is pressed, the alarm and LED are on. When the button is released, the alarm and LED turn off. At initialization, the button input port pin is configured as an input with its internal pullup resistor enabled and interrupt enabled. The interrupt service routine (ISR) for the button enacts a software debounce routine and turns the alarm and LED on or off.

Software implemented for this design is only a part of a complete system and is just for reference. For a complete IR reflection sensing system, add more software functions, such as a threshold adjustment, a voltage and temperature monitor, system calibration, and so forth.



#### 4 Getting Started

#### 4.1 Selecting an IR Reflection Chamber

This design does not contain the IR reflection chamber. To get the IR detection work, an IR reflection chamber must to be ready on the board. Users must create their own IR reflection chamber based on detailed application requirements.

#### 4.2 Obtaining a PCB

Download the schematic and layout files from TIDM-FRAM-IRREFLECTIONSENSING. The PCB layout file is for reference and only demonstrates how to layout with MSP430FR2311. For complete applications, users must develop a layout based on their board design requirements.

#### 4.3 Board Configuration

Several jumpers must be connected for correct operation:

- Jumper J1 can be used to measure current into the board.
- Jumper J2 can be used to measure current into buzzer-related circuit.
- Jumper J3 can be used to disconnect the piezo-buzzer during firmware development.
- Connector P1 is Spy-Bi-Wire (SBW) (2-Wire JTAG) used to debug and download firmware.

Before using the reference design board, install one CR123 battery to the battery holder.

#### 5 Getting Started Firmware

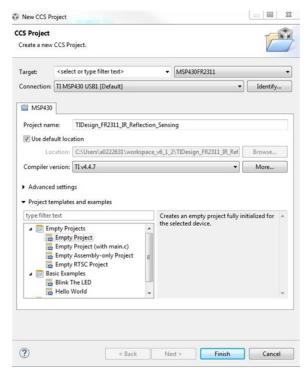
TI used compiler version TI v4.4.6 to build and test the project included in the software package with CCS 6.1.1.00022. The download package includes a single code file, FR2311\_IR reflection\_Sensing.c. This file must be included in a new CCS project for building. The following section describes the procedure to build the project for Code Composer Studio<sup>™</sup> (CCS).



## 5.1 Building Using CCS v6

To build using CCS v6, do as follows:

- 1. Create a new, blank project (File  $\rightarrow$  New  $\rightarrow$  CCS Project).
- 2. Set the Target as MSP430FR2311.
- 3. Name the project (for example, TIDesign\_FR2311\_IR reflection\_Sensing).
- 4. Select Empty Project.
- 5. Click Finish (see Figure 5 for the new CCS project parameters).



#### Figure 5. New Project Settings

- 6. Right-click on the project name in the Project Explorer window.
- 7. Select Add Files...
- 8. Browse to where FR2311\_IR reflection.c was saved from the download.
- 9. Select the file.
- 10. Click Open.

NOTE: A popup window appears.

- 11. Select Copy Files to copy the file into the project.
- 12. Click OK.
- 13. Click  $\leq$  to build the project (Ctrl+B, Menu $\rightarrow$ Project $\rightarrow$ Build All).
- 14. Connect the SBW interface of the reference design board to MSP-FET tool.
- 15. Connect the MSP-FET tool to the PC with the USB cable.
- 16. Click <sup>35</sup> to download the project to the device (F11, Menu $\rightarrow$  Run $\rightarrow$  Debug).
- 17. Click to execute the program (or close the debugger and reset the device).

#### 6 Test Data

#### 6.1 Power Consumption

During typical operation, the MSP430 wakes up from LPM4 every 8 seconds to check the IR receiver current.

The timings can be combined with current draw to estimate the total current. Table 1 lists the expected power budget, normalized to 1 second. MSP430FR2311 average current is about 1  $\mu$ A and total board average current is approximately 2.6  $\mu$ A.

FUNCTION		DURATION	CURRENT	NORMALIZED CURRENT
Active Mode (1 MHz at 3 V)	CPU + digital peripherals	2886 µs	223 µA	80 nA
	TIA + SAC	505 µs	206 µA	13 nA
	ADC	350 µs	207 µA	9 nA
VLO calibration in LPM3		80 ms	18 µA	0.18 µA
RTC in LPM4		7917114 µs	0.8 µA	0.79 µA
MCU Average Current	1.072 μA			

#### Table 1. Power Budget Normalized For 1 Second

To measure power consumption of the solution, disconnect the VCC jumper (J1) on the reference design board and connect an ammeter in series. For the power measurement of each function part, the firmware must be updated to enable the part function only.

#### 6.2 Power-On ESD Result

To improve ESD immunity, this reference design adds TVS diode ESD protection device TPD2E2U06 (U2, U3, U5) on the board. The board layout is also optimized for ESD performance that the trace for analog circuit must be as short as possible. Without any trace on the bottom side of board, there is a whole ground plane. One metal shell is added to cover the photodiode because its output current is small. MSP430 and AFE circuit can also be covered by a metal shell to improve ESD performance. In this reference design, there is no metal shell to cover MSP430 and AFE circuit. In the firmware, an LED and a buzzer are used to indicate failure. If the LED is blinking, the MSP430 is reset. If a buzzer is turned on, there is a false trigger.

The IEC 61000-4-2 test was performed to this reference design board. The board was tested in contact discharge mode 1000 times with 20-Hz discharge frequency. Table 2 lists the test results.

DUT	PASS VOLTAGE	FAIL VOLTAGE	FAIL PHENOMENON
FR2311 IR Reflection Sensing –1, without board ESD protection	9 kV	10 kV	Reset
FR2311 IR Reflection Sensing –2, with board ESD protection	11 kV	12 kV	Reset

#### Table 2. Power-On ESD Test Result



#### 7 Design Files

#### 7.1 Schematics

To download the schematics, see the design files at TIDM-FRAM-IRREFLECTIONSENSING.

#### 7.2 PCB Layout

To download the layout prints, see the design files at TIDM-FRAM-IRREFLECTIONSENSING.

#### 7.3 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDM-FRAM-IRREFLECTIONSENSING.

#### 7.4 Altium Project

To download the Altium project files, see the design files at TIDM-FRAM-IRREFLECTIONSENSING.

#### 7.5 Gerber Files

To download the Gerber files, see the design files at TIDM-FRAM-IRREFLECTIONSENSING.

#### 8 Software Files

To download the software files, see the design files at TIDM-FRAM-IRREFLECTIONSENSING.

#### 9 References

- 1. MSP430FR4xx and MSP430FR2xx Family User's Guide, (SLAU445)
- 2. MSP430FR231x Mixed-Signal Microcontrollers, (SLASE58)
- 3. VLO Calibration on MSP430FR4xx and MSP430FR2xx Family, (SLAA693)



About the Author

# 10 About the Author

**DARREN LU** is an applications engineer on the MSP430 applications team at TI. He develops new products for the MSP430 ultra-low-power microcontroller. He also develops reference designs for new MSP430 products. Darren earned his Master of Communication and Information Systems from Xidian University in China.

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