

# **MSP430F42xA Single-Chip Weight Scale**

*MSP430 Applications*

## **ABSTRACT**

This application report describes how to implement a single-chip pocket weight scale using a resistive full-bridge sensor and a fully integrated MCU solution using low-power design practices. The included software obtains the measurement results using the MSP430™ on-chip sigma-delta analog-to-digital converter (ADC) and displays them on an LCD. A 3-V battery powers the portable device. The design includes a two-point calibration mechanism for offset and gain calibration. The sample code described in this document can be downloaded from [www.ti.com/lit/zip/SLAA220](http://www.ti.com/lit/zip/SLAA220).

## **Contents**

|   |                            |   |
|---|----------------------------|---|
| 1 | Introduction .....         | 1 |
| 2 | Hardware Description ..... | 2 |
| 3 | Software Description ..... | 3 |
| 4 | Application Schematic..... | 6 |
| 5 | References .....           | 7 |

## **List of Figures**

|   |                                      |   |
|---|--------------------------------------|---|
| 1 | Flowchart Main() .....               | 3 |
| 2 | Flowchart Basic Timer ISR .....      | 4 |
| 3 | Flowcharts Port 1 and SD16 ISRs..... | 5 |
| 4 | Schematic.....                       | 6 |

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## **1 Introduction**

Applications for weight, force, torque, and pressure measurement frequently use resistive full-bridge sensors. Most of the bridge sensors require a high excitation voltage (typically in the 10-V range) and output a low full-scale differential voltage in the range of 2-mV/V excitation voltage. The output from the sensor is typically amplified by an instrumentation amplifier. After signal conditioning, the signal is digitized by a high-resolution ADC. Typically, such high-resolution ADCs are not integrated in conventional microcontrollers (MCUs). A general-purpose MCU is then used for further processing and display.

The conventional approach of using a bridge sensor excitation voltage of 10 V and an Instrumentation amplifier to achieve a full-scale ADC input voltage increases chip count and complexity of power management with high power consumption. An energy-efficient and cost-effective solution is to use a microcontroller with an integrated high-resolution ADC and an integrated programmable gain amplifier (PGA). The entire application can then be powered from a 3-V battery. The [MSP430F427A microcontroller](#) (MCU) has integrated 16-bit sigma delta ADCs with differential inputs and PGA with gain up to 32. This device offers a single-chip solution for this application that includes not only high-resolution ADCs with PGA but also an LCD driver and brownout protection.

## 2 Hardware Description

To address the outlined application requirements, an integrated MCU solution is used. The MSP430F42xA ultra-low-power flash-based microcontrollers include 3 integrated 16-bit sigma-delta analog-to-digital converters (SD16). These data converters also feature an on-chip programmable gain amplifier (PGA) that allows the amplification of incoming signals up to 32 times. The bridge sensor is connected directly to the microcontroller. [Section 4](#) shows the schematic of the board that was used to develop this application.

The negative excitation signal of the full-bridge sensor is connected to terminal X1-1, and the positive excitation signal is connected to terminal X1-4. These terminals are powered through MCU port pins P2.0 and P2.1, respectively. The bridge excitation voltage can be disabled to reduce power consumption between measurements or when the weight scale is operated in standby mode. With a bridge resistance of 1200  $\Omega$  (typical) and a supply voltage of 3 V, the sensor consumes 2.5 mA when excited. The bridge sensor output signals are connected to X1-2 and X1-3, passed through two low-pass filters, and fed into the SD16 input channel A0.

The particular full-bridge sensor that is used has a rated full-scale output voltage of 2 mV/V when loaded with its maximum load capacity of approximately 10 kg. The design goal is to resolve the sensor signal with a resolution of 1 g, resulting in a total of 10000 counts, and display the weight on an LCD. The entire application is powered from a 3-V battery source. If the bridge sensor is excited with 3 V, it delivers a full-scale output voltage of 3 V  $\times$  2 mV/V = 6 mV. This also means that 1 g equals a voltage of 6 mV / 10 kg  $\times$  1 g = 0.6  $\mu$ V. To resolve 1 g, the LSB voltage of the ADC should be four times smaller than that, which is 0.6  $\mu$ V / 4 = 0.15  $\mu$ V.

The MSP430 SD16 16-bit sigma-delta ADC can operate using either a built-in reference of 1.2 V or an externally connected reference voltage. This application uses the external reference. An external resistor divider provides the reference voltage. With the bridge sensor powered from the same voltage source, this configuration has the advantage of implementing a  $V_{CC}$ -independent ratiometric measurement principle. If the bridge sensor were to be powered from  $V_{CC}$  and use the internal voltage reference for the SD16 module, the measurement results would change as  $V_{CC}$  changes over the lifetime of the battery. Using the resistor divider and a supply voltage of 3 V, the reference voltage is as follows:

$$V_{REF} = V_{CC} \times \frac{R_{10}}{R_{10} + R_9} = 3 \text{ V} \times \frac{11 \text{ K}}{11 \text{ K} + 15 \text{ K}} = 1.269 \text{ V} \quad (1)$$

The R9/R10 divider ratio was chosen so that the generated reference voltage stays in the allowed VREF(I) range, while  $V_{CC}$  drops from 3 V to 2.7 V. The minimum supply voltage for the SD16 module is 2.7 V. For detailed SD16 voltage ranges and other parameters, see the [MSP430F42xA data sheet](#). The SD16 reference voltage determines the full-scale differential input voltage, which is VREF/2. As the data converter is bipolar, the ADC LSB voltage is:

$$V_{LSB} = \frac{V_{REF}/2}{2^{NrBits}} = \frac{1.269 \text{ V}/2}{2^{16-1}} = 19.36 \text{ } \mu\text{V} \quad (2)$$

By using the maximum PGA gain of 32, the LSB voltage decreases to 0.605  $\mu$ V. This is still approximately 4 times higher than the design goal of 0.15  $\mu$ V. An external op-amp could be used to provide this additional amplification. Another approach without adding external components is to use additional SD16 output bits. The SD16 module is a 16-bit ADC, but it provides access to a total of 24 bits from its internal digital decimation filter. By adding two more of the bits from the digital filter output to the 16-bit conversion result and low-pass filtering this 18-bit output signal by averaging multiple results, the LSB voltage reduces to 0.151  $\mu$ V.

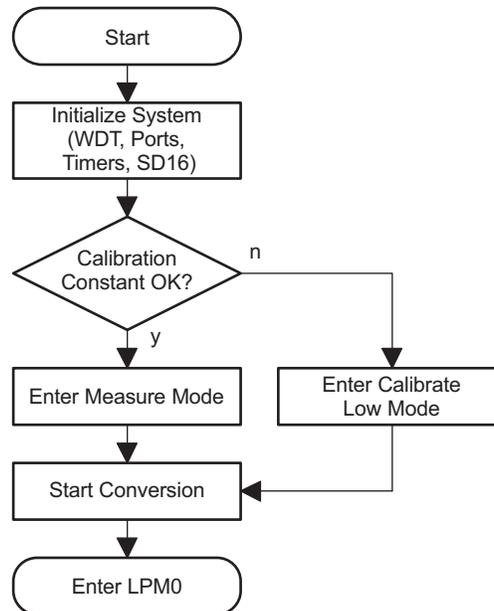
$$V_{LSB} = \frac{V_{REF}/2}{GAIN_{PGA} \times 2^{NrBits}} = \frac{1.269 \text{ V}/2}{32 \times 2^{17}} = 0.151 \text{ } \mu\text{V} \quad (3)$$

With this voltage, the resolution requirement can be fulfilled, even though the full-scale sensor output voltage is only 6 mV and the full input range of the sigma-delta converter is not used.

The MSP430F427A on-chip LCD driver directly interfaces to common LCDs. This application uses the SBLCDA4, a 4-mux 7.1-digit LCD from [SoftBaugh](#). Resistors R5, R7, and R8 provide the voltage ladder for the LCD driver module. A 32-kHz watch crystal is the system clock reference to drive the LCD display and to provide periodic wakeup from low-power modes during application operation. A push button (SW1) to start the weight scale operation connects to P1.0.

### 3 Software Description

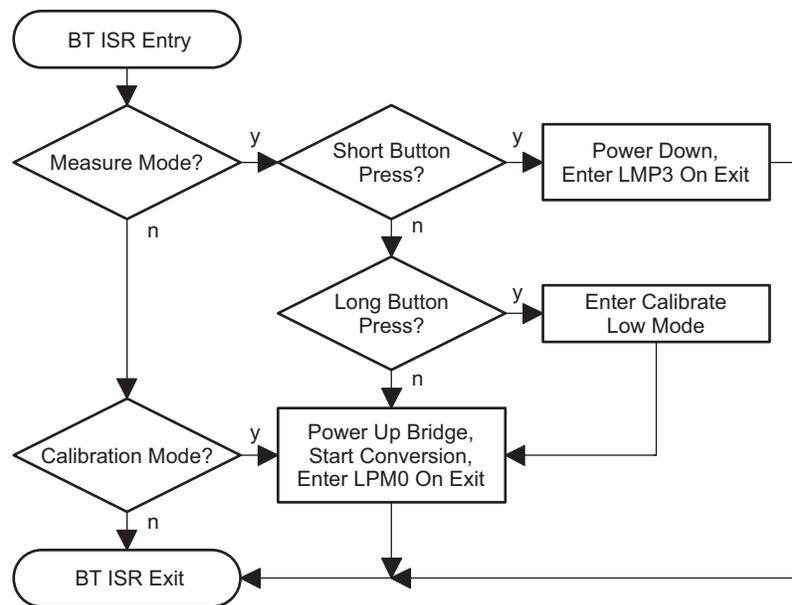
The [MSP430F427A single-chip weight scale software](#) is provided in both C (F42x\_Weigh\_Scale.c) and assembly (F42x\_Weigh\_Scale.s43). The source codes are functionally identical, however, the assembly language version is smaller in terms of code size. On power-on reset, the MSP430 peripherals are initialized. To initialize the peripherals, the software disables the watchdog timer, configures the LFXT1 oscillator load capacitors for the external watch crystal, initializes the LCD controller, the basic timer, and the SD16 sigma-delta ADC module. The software configures SD16 channel 0 to use the input channel pair A0 and amplify the signal with a gain of 32 with the internal PGA. SMCLK provides a 1048567-Hz frequency to the converter, which uses the continuous conversion mode. For more information on SD16 operation, refer to the [MSP430x4xx Family User's Guide](#).



**Figure 1. Flowchart Main()**

In the source code, the two 32-bit words CalMin and CalMax are allocated in the MSP430 flash information memory segment A to hold calibration data. After power on, the software checks if these constants have valid values. If both locations contain the same value (such as 0xFFFFFFFF after device programming), the application enters calibration mode. Otherwise, the application enters measurement mode. The variable ProgramMode keeps track of the current program state (measure mode, calibration mode, power-down mode).

Next, the MCU enters low-power mode 0 (LPM0) with interrupts enabled. LPM0 is used as SMCLK is driving the SD16 and cannot be disabled while the application is actively running and collecting ADC data. The rest of the program flow is interrupt driven. Three interrupt sources are enabled. The basic timer ISR is executed every 0.5 s and is mainly used to trigger the start of the measurement process (see [Figure 2](#)). The Port 1 ISR handles button events and the completion of each analog-to-digital conversion. The SD16 ISR processes the results (see [Figure 3](#)).



**Figure 2. Flowchart Basic Timer ISR**

While in calibration mode, two data points are obtained. The variable CalMin stores the ADC result that equals a display value of 0 g. The variable CalMax stores the ADC result that equals a display value of 10000 g. CAL LO or CAL HI is displayed to indicate which calibration data point is being processed. When the user presses the button, the current SD16 ADC result is read and stored in a temporary variable. After the calibration procedure, these two data points are programmed into the INFO A flash information memory segment using in-system self programming. The software now enters measurement mode.

The SD16 conversion process is started every 0.5 s by the basic timer ISR. During conversions, the bridge sensor is powered up and the DCO is enabled. The MSP430 MCU operates in LPM0. To achieve the needed precision, the software implements a low-pass filter by collecting and summing multiple 18-bit ADC results. After each conversion, the SD16 ISR is executed at the SD16 sample rate (4 kHz). Before actual sample data is collected, the counter variable VoltageSettleCtr is decremented to 0 to allow approximately 12 ms for the voltages to settle after powering up the bridge sensor. When the SD16 ISR has collected 256 results, the sum is then divided by 256 to generate the final 18-bit result. This process can also be described as a 256-to-1 decimation of the sampling data. Including the voltage settling time, the SD16 module operates for approximately 75 ms each 0.5 s.

The calculated value is then compared to the prior value. To avoid unnecessary 32-bit integer multiplications and divisions, a new display value is calculated and the display is updated only if the value has changed.

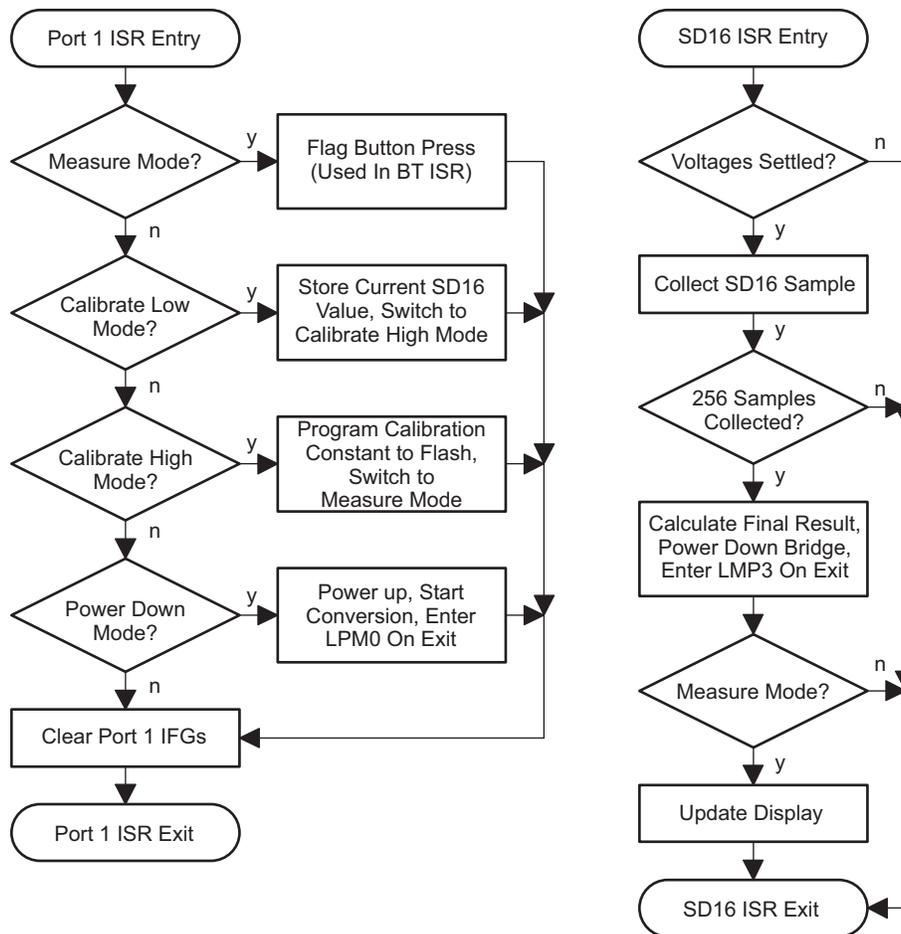


Figure 3. Flowcharts Port 1 and SD16 ISRs

For converting ADC measurement results into actual physical weight values, a two-point calibration mechanism is used. The display value is calculated according to the Equation 4.

$$\text{DisplayValue} = \frac{\text{CurrentADCValue} - \text{CalMin}}{\text{CalMax} - \text{CalMin}} \times \text{CAL\_MIN\_MAX\_SPAN} \quad (4)$$

The range from CalMax to CalMin is projected into a range from 0 to CAL\_MIN\_MAX\_SPAN. CAL\_MIN\_MAX\_SPAN is set by default to 10000, which equals the maximum bridge sensor mechanical load of 10 kg. Due to the differential signal applied to the SD16 module, the 18-bit ADC result is signed, and that signed arithmetic is used throughout the program. This way negative weight values can be displayed. After the measurement process, the SD16 module is disabled, the DCO switches off through entering LPM3 on exit, and the bridge sensor is powered down to reduce current consumption.

Pushing the button disables the conversions immediately, switches off the LCD display, and enters LPM3. In this mode, the application circuit draws less than 1-µA current, with the 32-kHz oscillator still running. LPM4 could be used instead to reduce current consumption even further if required. When the user pushes the button again, the application resumes normal active operation. In this mode, the SD16 module is operated for approximately 75 ms every 0.5 s, the new result is calculated, and the display is updated. During this time, the MCU draws approximately 1 mA of current. Another 3 mA is needed in this period for bridge sensor excitation and reference voltage generation. Between the measurements, the MCU draws approximately 3 µA, which includes the current used by the LCD driver for displaying the calculation result. This results in a total average application current consumption of 600 µA during normal operation.

Calibration mode can be entered any time by holding down the button for at least 5 seconds.

## 4 Application Schematic

Figure 4 shows the schematic.

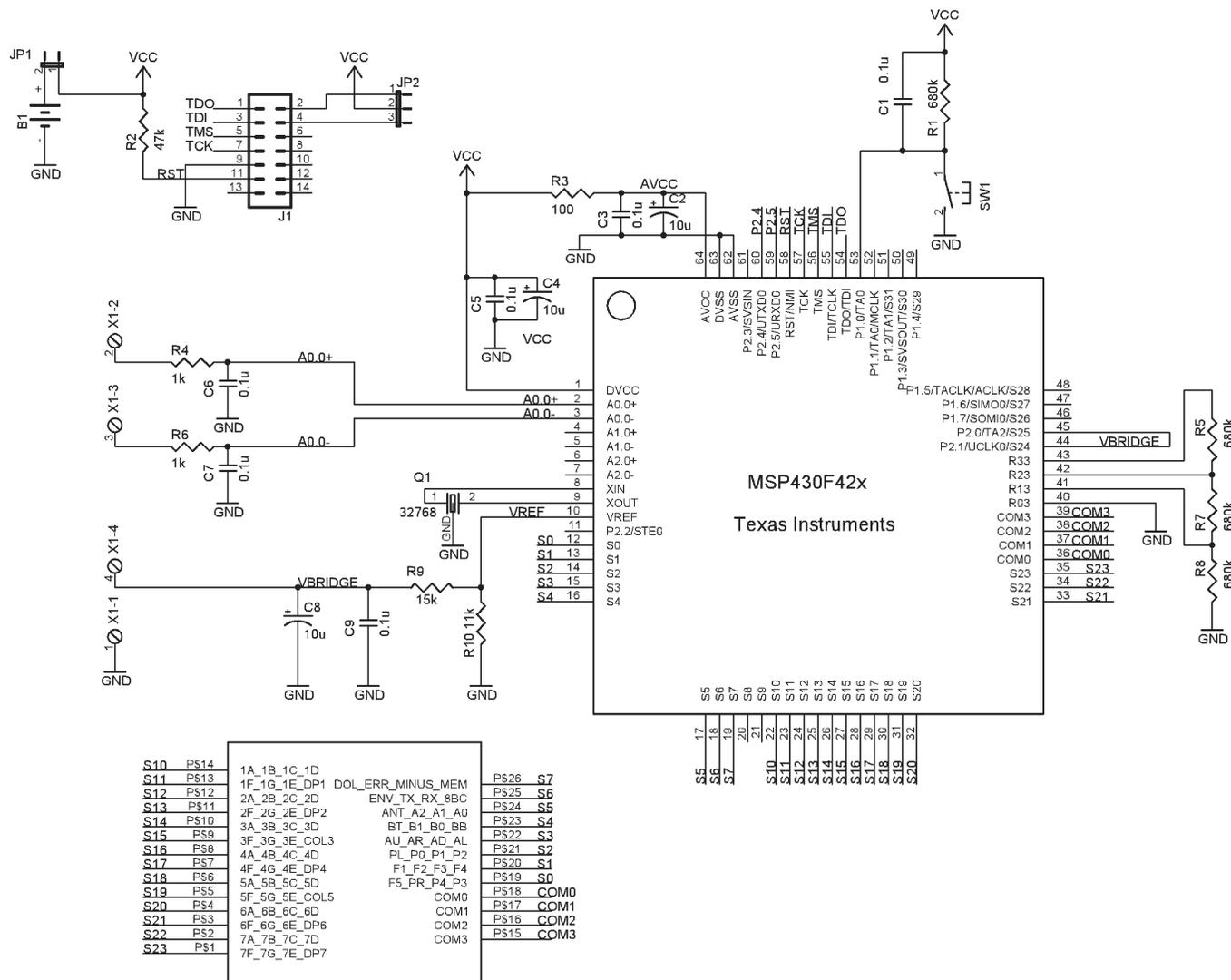


Figure 4. Schematic

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## 5 References

1. [MSP430F42xA Mixed-Signal Microcontrollers data sheet](#)
2. [MSP430x4xx Family User's Guide](#)

### Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

#### Changes from November 15, 2004 to August 6, 2018

**Page**

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- |   |   |
|---|---|
| • Editorial and formatting changes throughout document..... | 1 |
| • Changed all instances of MSP430F42x to MSP430F42xA .....  | 1 |
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