MSP430F42x Single Chip Weigh Scale

Andreas Dannenberg *MSP430*

ABSTRACT

A single chip pocket weigh scale is implemented using a resistive full-bridge sensor and a fully-integrated MCU solution using low-power design practices. The measurement results are obtained using the MSP430 on-chip sigma-delta A/D converter and shown on an LCD display. The portable device is directly powered from a 3-V battery. A two-point calibration mechanism for offset and gain calibration is provided.

1 Introduction

When designing applications for weight, force, torque, and pressure measurement, resistive full-bridge sensors are widely used. Most of the bridge sensors require a high excitation voltage (typically in the 10-V range), while still outputting a rather 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 analog-to-digital converter (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 integrated programmable gain amplifier (PGA). The entire application can then be powered from a 3-V battery. The MSP430F42x 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 with not only high resolution ADCs with PGA, but also LCD driver and brownout protection.

2 Hardware Description

To address the outlined application requirements, an integrated MCU solution is used. The MSP430F42x series of ultra-low power, flash-based microcontrollers comes with three integrated 16-bit sigma-delta analog-to-digital converters (SD16). These data converters also feature an on-chip programmable gain amplifier (PGA) which allows the amplification of incoming signals up to 32 times. The bridge sensor is connected directly to the microcontroller. Appendix A shows the schematic of the demo board that was used to develop this application.

The full-bridge sensor negative excitation signal is connected to terminal X1-1, and the positive excitation signal to terminal X1-4. It gets powered trough MSP430 port pins P2.0 and P2.1. This way, the bridge excitation voltage can be disabled between measurements or when the weigh scale is operated in stand-by mode, thus reducing power consumption. With a bridge resistance of 1,200 Ω (typ.) and a supply voltage of 3 V, the sensor is consuming 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 feed 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 about 10 kg. The goal is to resolve the sensor signal with a resolution of 1g, resulting in a total of 10,000 counts, and show it on an LCD display. The entire application is powered from a 3-V battery source. If the bridge sensor gets excited with 3 V, it delivers a full-scale output voltage of 3 V x 2 mV/V = 6 mV. This also means that 1g equal a voltage of 6 mV / 10 kg x 1g = 0.6 µV. In order to resolve 1g, the LSB voltage of the used ADC should be four times smaller that that, which is 0.6 µV / 4 = 0.15 µV.

The MSP430 SD16 16-bit sigma-delta ADC can operate either using a built-in reference of 1.2 V, or an externally connected reference voltage as used in this application example. Here, an external resistor divider is used to provide the reference voltage. With the bridge sensor powered from the same voltage source, this has the advantage of implementing a VCC-independent, ratio metric measurement principle. If the bridge sensor would be powered from VCC and using the internal voltage reference for the SD16 module, the measurement results would change as VCC changes over the lifetime of the battery. Using the resistor divider as shown in Appendix A and a supply voltage of 3 V, the reference voltage is as follows:

$$V_{REF} = V_{CC} \times \frac{R10}{R10 + R9} = 3\ V \times \frac{11\ K}{11\ K + 15\ K} = 1.269\ V \tag{1}$$

The R9/R10 divider ratio was chosen such that the generated reference voltage stays in the allowed VREF(I) range, while VCC is dropping 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 MSP430F42x data sheet (SLAS421). The SD16 reference voltage determines the full-scale differential input voltage, which is VREF/2. As the data converter is bipolar, the A/D converter LSB voltage is:

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

By using the maximum PGA gain of 32, the LSB voltage decreases to 0.605 µV. This is still about four times higher than the design goal of 0.15 µV. An external op-amp could be used to provide this additional amplification. Another approach without adding external components is using additional SD16 output bits. The SD16 module is a 16-bit A/D converter, 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 such as by averaging multiple results, the LSB voltage reduces to 0.151 µV.

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

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

The MSP430F427 on-chip LCD driver enables direct interfacing to common LCD modules. In this application, the SBLCDA4, a 4-mux 7.1 digit LCD from SoftBaugh is used (http://www.softbaugh.com). Resistors R5, R7, and R8 are providing the voltage ladder used by the LCD driver module. A 32-kHz watch crystal is used as the system clock reference, to drive the LCD display, and to provide periodic wake-up from low-power modes during application operation. Furthermore, a push button (SW1) is provided for the weigh scale operation and connected to P1.0.

3 Software Description

The MSP430F427 single chip weigh scale demo software is provided in both C (F42x_Weigh_ Scale.c) and assembly language (F42x_Weigh_Scale.s43). Both source codes are functional identical, however, the assembly language version is smaller in terms of code size. On power-on reset, the MSP430 peripherals are initialized. This includes disabling the watchdog timer, configuring the LFXT1 oscillator load caps for the external watch crystal, initializing the LCD controller, the basic timer and the SD16 sigma-delta A/D converter module. The SD16 channel 0 is configured to use the input channel pair A0 and amplify the signal with a gain of 32 using the SD16 module internal PGA. The converter is clocked by SMCLK with a frequency of 1,048,567 Hz and the continuous conversion mode is enabled. Detailed information on the SD16 operation can be found in the MSP430x4xx Family user's guide (SLAU056).

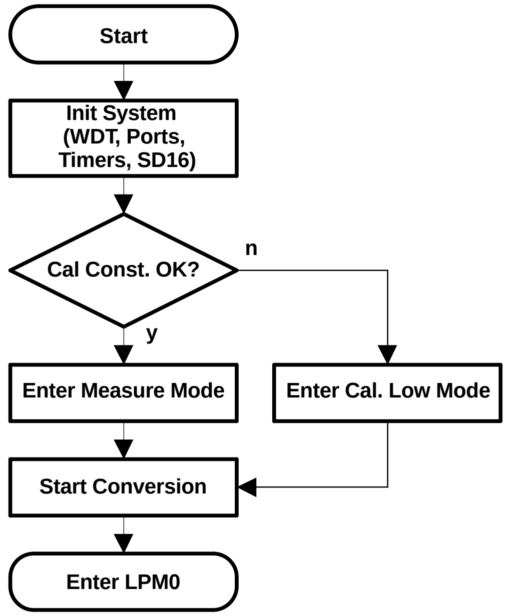

Figure 1. Flowchart Main()

In the source code, the two 32-bit words CalMin and CalMax are allocated in the MSP430 Flash information memory segment A for holding 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 calibration mode is activated. Otherwise, the measurement mode is entered. The variable ProgramMode is used to keep track of the current program state (measure mode, calibration mode, power-down mode) and set accordingly.

Next, the MSP430 enters low-power mode LPM0 with interrupts enabled. LPM0 is used as SMCLK is driving the SD16 and cannot be switched off while the application is actively running and collecting ADC data. From now on, the entire 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 is used for handling button events and after each A/D conversion, and the SD16 ISR is called to process the results (see Figure 3).

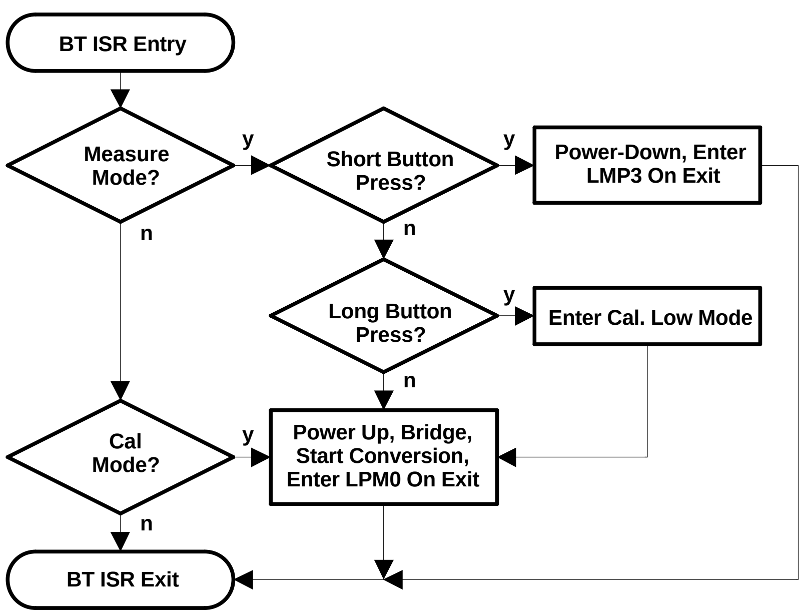

Figure 2. Flowchart Basic Timer ISR

While in calibration mode, two data points are obtained. The variable CalMin is used to store the A/D result that equals later on a display value of 0g, and CalMax is used to store the A/D result that equals a display value of 10,000g. CAL LO or CAL HI is displayed to indicate which calibration data point is being handled. By pressing the button, the current SD16 A/D conversion result is read out and stored into a temporary variable. After the calibration procedure, these two data points are programmed into the INFOA flash information memory segment using in-system self programming. The software now enters measurement mode.

From now on, 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 enabled. The MSP430 is now operated in LPM0. To achieve the needed precision, the software implements a low-pass filter by collecting and summing up multiple 18-bit A/D conversion 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 until 0 to allow about 12 ms time 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 settle time, the SD16 module is operated for about 75 ms each 0.5 s.

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

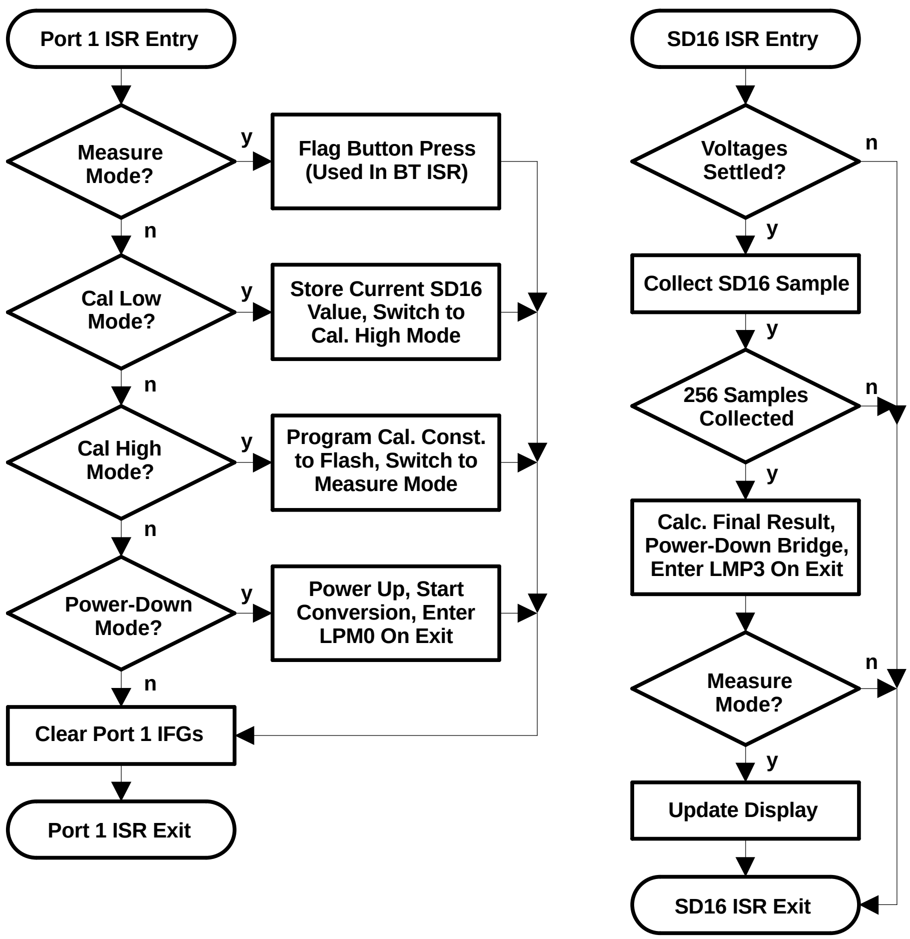

Figure 3. Flowcharts Port 1 and SD16 ISRs

For converting A/D measurement results into actual physical weight values, a two-point calibration mechanism is used. The display value is calculated according to the following formula:

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

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 10,000, which equals the maximum bridge sensor mechanical load of 10 kg. Note that due to the differential signal applied to the SD16 module, the 18-bit A/D conversion 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 switched 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 pushing the button again, the application resumes normal active operation. In this mode, the SD16 module is operated for about 75 ms every 0.5s, the new result is calculated, and the display gets updated. During this time, the MSP430 draws about 1 mA of current. Another 3 mA is needed in this period for bridge sensor excitation and reference voltage generation. Between the measurements, the MSP430 draws only about 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.

Using the button, calibration mode can be re-entered anytime by holding down the button for at least 5 s.

4 References

1. MSP430x42x Mixed Signal Microcontroller Data Sheet (SLAS421)
2. MSP430x4xx Family User's Guide (SLAU056)

Appendix A Application Schematic

Figure A-1 contains the schematic.

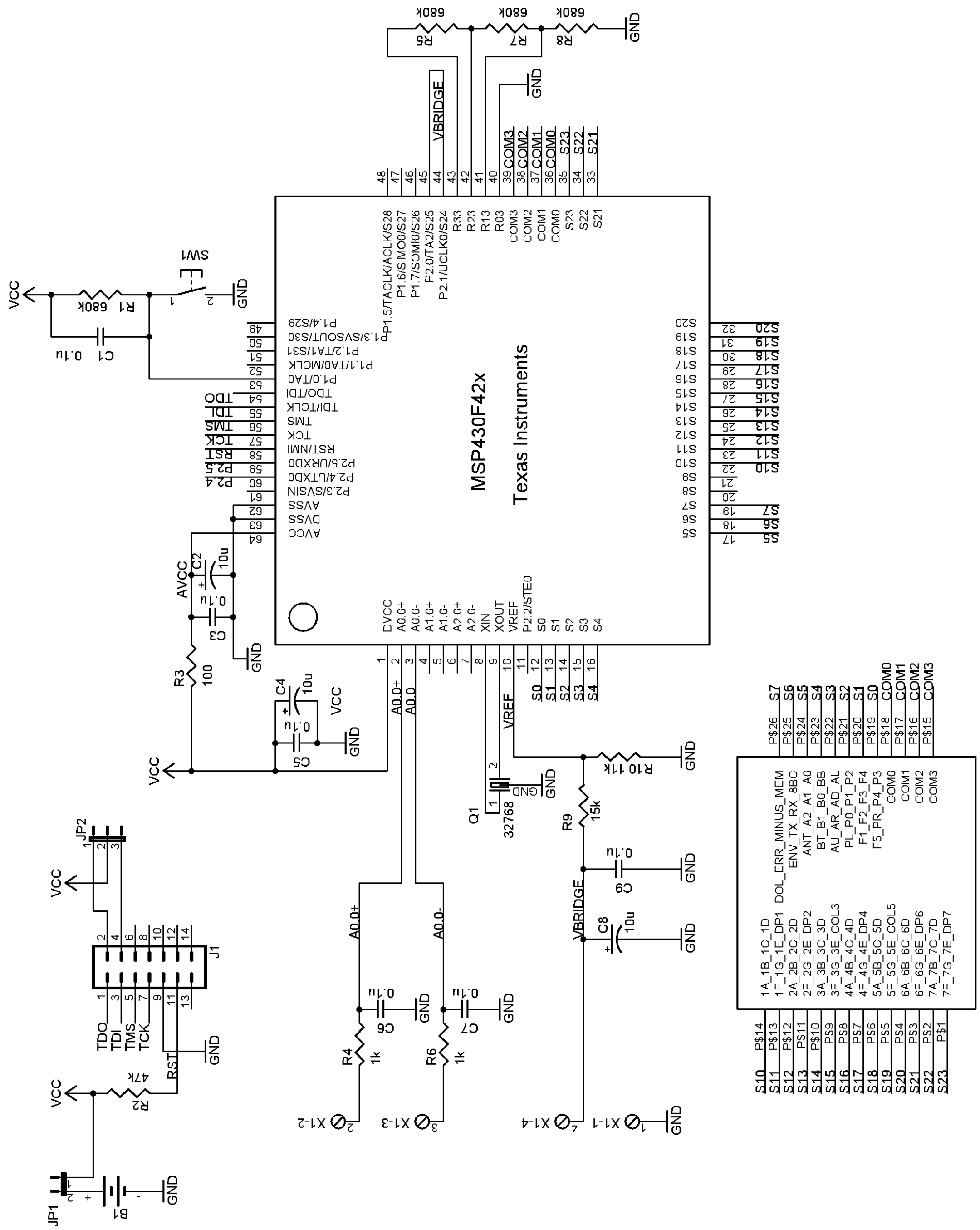

Figure A-1. Schematic

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
		Telephony	www.ti.com/telephony
		Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265