Single-Slope Analog-to-Digital Conversion Technique Using MSP430™ MCUs

TEXAS INSTRUMENTS

Introduction

MSP430™ microcontrollers (MCUs) with an on-chip analog-to-digital (ADC) module are widely used in resistive elements measurement applications such as measuring the resistance of a thermistor in a thermostat, because resistance can be easily digitized by measuring the voltage across it. However, for MSP430 MCUs without an integrated ADC module, resistive elements still can be precisely measured with the on-chip comparator and timer using single-slope analog-to-digital (A/D) conversion technique.

The basic working principle of slope A/D resistance measurement is the charging and discharging of a known value capacitor (C_m) through the resistor to be measured (R_{sense}) and a reference resistor (R_{ref}). By comparing the capacitor discharging time (t_{sense}) through R_{sense} with the discharging time (t_{ref}) through R_{ref}, the value of R_{sense} can be calculated with Equation 1.

$$\frac{R_{sense}}{t_{sense}} = \frac{R_{ref}}{t_{ref}} \tag{1}$$

For more details about slope A/D resistance measurement, see *Implementing An Ultralow-Power Thermostat With Slope A/D Conversion*.

The implementation presented demonstrates the slope A/D conversion resistance measurement using the on-chip comparator and timer of the MSP430 MCUs. It has been optimized for lowest code size, fitting in a low-cost 0.5KB MSP430FR2000 microcontroller. To get started, download project files and a code example demonstrating this functionality.

Implementation

Figure 1 shows the hardware configuration of a slope A/D resistance measurement implementation using the MSP430FR2000 MCU.

R_{ref} is connected to P1.0 and R_{sense} is connected to P1.2. Capacitor C_m is connected to both resistors in series. eCOMP0 is used to monitor the voltage across C_m by connecting C_m to the positive input of eCOMP0. The built-in DAC is used to generate reference voltage (V_{CAREF}) for comparator, and Timer_B0 is configured as capture mode to capture signal from the output of eCOMP0.

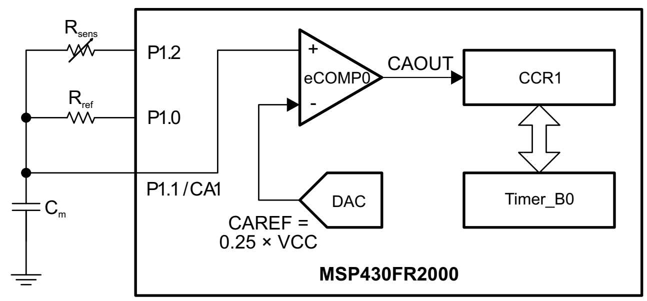

Figure 1. Measurement of Resistors

To measure the resistor value R_{sense}, capacitor C_m is first charged to the digital I/O high voltage ($V_{OH} \approx V_{CC}$) by outputting a high on P1.0. After configuring the Time_B0, the capacitor is discharged through R_{sense} through P1.2 by outputting a low level voltage. At the start of capacitor discharge, register TAR is cleared, and the timer is started. When the voltage across capacitor C_m reaches a comparator reference value V_{CAREF} of 0.25 × V_{CC}, the falling edge of the comparator output CAOUT causes the TAR value to be captured in register CCR1. This value is the discharge time interval t_{sense}. The process is repeated for the reference resistor R_{ref}, which is used to translate t_{sense} into the resistor value R_{sense}. More than one resistive element can be measured with this implementation. Additional elements are also connected to CA1 with available I/O pins and switched to high impedance when not being measured.

The software is designed around a main loop. In each loop, t_{ref} and t_{sense} are measured in sequence and then R_{sense} is calculated. Figure 2 shows voltage across C_m during each loop.

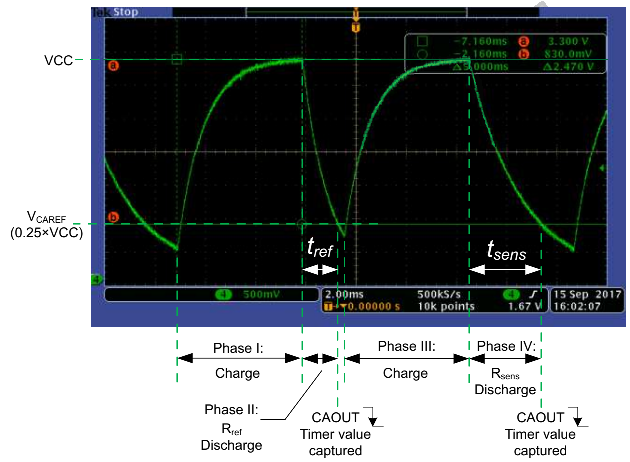

Figure 2. Voltage at C_m During Resistance Measurement

The MSP430 MCU is put to sleep while the capacitor is charging or discharging and the Timer_B0 module is used. During charge phase, auxiliary clock (ACLK) is the source clock, and therefore the sleep mode low-power mode 3 (LPM3) is used. For discharge phase, subsystem master clock (SMCLK) is used (derived from the DCO) because of the higher frequency and greater slope ADC accuracy. Therefore, LPM0 is used in this case. Different timer modes are used in each case: Timer overflow interrupt wake the MCU from LPM3 and CCR1 capture interrupt wake the MCU from LPM0. In the interrupt service routines, the respective low-power mode bits are cleared, so that when the ISR is exited, the device remains active, returning operation to the place where it was put to sleep. Every time the main loop runs, the MSP430 device calculates the resistance value using the discharge times t_{sense} and t_{ref} as previously described.

Notice that the reference resistor is a fixed, precise 10-kΩ resistor. The value of resistor to be measured is in the range of 10 kΩ. Because both resistors use the same capacitor in the RC discharge measurement, assigning similar resistance values results in discharge times within the same range. This allows the implementation to use the same timer clock configuration for each measurement and simple comparison of timer values. The reference resistor can be changed for different applications. For example, select a 1-kΩ reference resistor for PT1000 measurement.

In this design, C_m is 0.1 µF and R_{ref} is 10 kΩ, so the time constant $\tau = R_{ref} \times C_m$ = 1 ms, and the time to charge C_m should be between 5τ (for 1% accuracy) and 7τ (for 0.1% accuracy). The value within this range depends on the accuracy required.

Performance

High accuracy can be obtained with slope A/D resistance-measurement method. A 12-kΩ resistor was measured 100 times with a demonstration board, and the standard deviation of test results was 3.63, which means the accuracy is 0.03%. However, the tradeoff for high accuracy is that the sampling rate is limited due to the relatively long charge and discharge time. The sample rate in this demonstration is approximately 75 Hz, and there are additional code and execution cycles necessary to perform the measurement and calculation. The execution cost of the calculation comes in the form of one multiply and one divide per measurement. The code size of multiply and divide is 122 bytes from the CCS compiler.

This solution provides a slope A/D resistance-measurement solution with minimal external components using optimized software that fits in code-limited devices as small as 0.5KB.

Device Recommendations

The device used in this example is part of the MSP430 Value Line Sensing portfolio of low-cost MCUs, designed for sensing and measurement applications. This example can be used with the devices shown in Table 1 with minimal code changes. For more information on the entire Value Line Sensing MCU portfolio, visit www.ti.com/MSP430ValueLine.

Table 1. Device Recommendations

Part Number	Key Features
MSP430FR2000	0.5KB FRAM, 0.5KB RAM, eComp
MSP430FR2100	1KB FRAM, 0.5KB RAM, 10-bit ADC, eComp
MSP430FR2110	2KB FRAM, 1KB RAM, 10-bit ADC, eComp
MSP430FR2111	3.75KB FRAM, 1KB RAM, 10-bit ADC, eComp

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