Keywords: A/D converters, ADCs, A/D converter calibration, offset flipping, handheld devices

APPLICATION NOTE 4539

Precise Calibration of Dual-Slope ADCs

Jan 13, 2011

Abstract: This circuit calibrates ADCs on-the-fly, using analog switches to configure the setup properly for obtaining the zero and span output codes.

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Handheld devices for measuring toxic gas, blood glucose, etc. are increasingly popular, and their low cost has made them throwaway devices, to be discarded when the battery or the sensor expires. Typical devices include a lithium (Li) primary cell, a sensor, an A/D converter (ADC), conditioning circuitry, a microcontroller unit (MCU), and an LCD. To minimize cost, the design often employs simple LED indicators, a low-cost 8-pin MCU, and a discrete dual-slope ADC. This note explains the use of "offset flipping" for on-the-fly calibration of the ADC.

A block diagram of the circuit (**Figure 1**) includes a single primary Li cell, a millivolt-output bridge sensor, a differential amplifier, and the dual-slope ADC, plus correction circuitry for offset, zero, and span. Component values are selected on assumption that the Li-cell voltage ranges from 2.2V to 3.6V. Because that voltage serves as bias for the bridge and also as reference for the ADC, the ADC input and its full-scale output (span) move together as the cell voltage changes. This ratiometric configuration minimizes error and eliminates the need for a precision voltage reference.
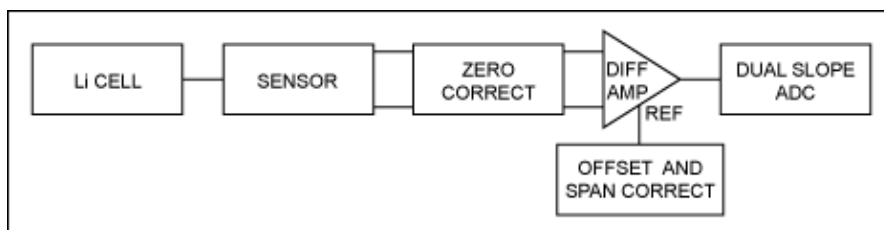

Figure 1. Block diagram of the slope-ADC calibration circuit.

The sensor (S1) produces 20mV/V at full scale (**Figure 2**). For a 3.6V Li cell, therefore, the output is 20mV/V × 3.6V = 72mV. The dual op amp (U2, MAX4242) draws only 18µA of quiescent current per amplifier. Its outputs swing rail-to-rail, and operate down to 1.8V. U2A is configured as a standard differential amplifier with gain of 30. Operating with a 3.6V lithium cell, it achieves a full-scale output of 2.160V. (Note that the resistor network around a differential amplifier loads the input-signal source (sensor), so the sensor should have a low output impedance. If not, you should buffer the sensor with an instrumentation amplifier or equivalent.)
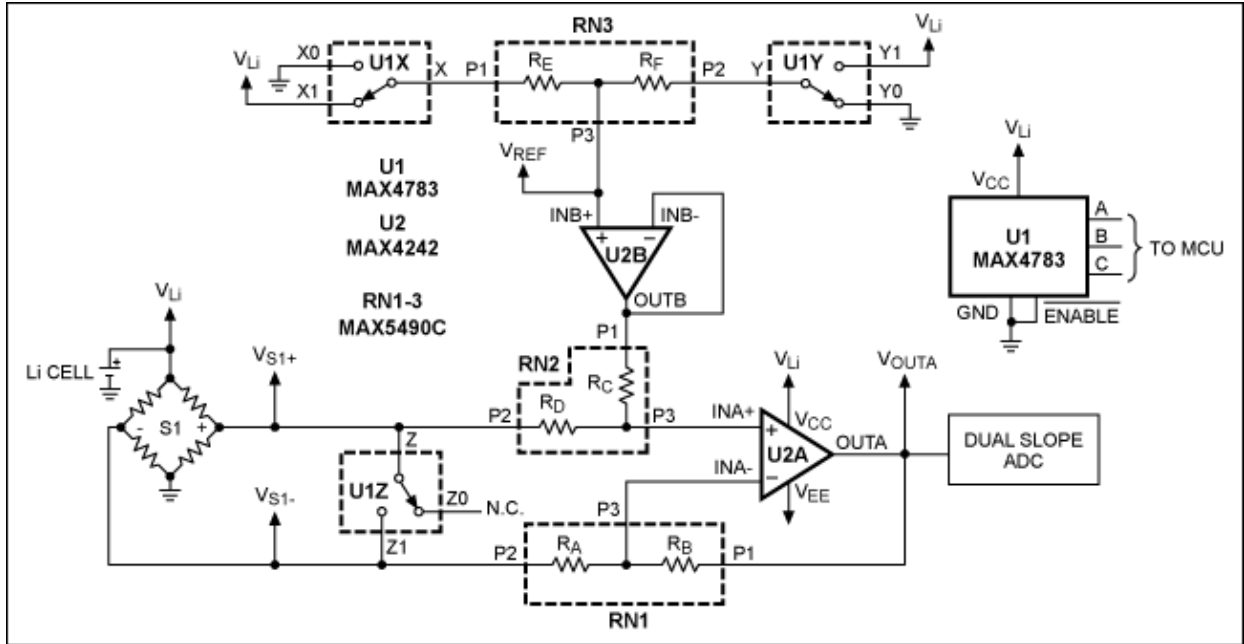
Figure 2. This circuit (depicted in Figure 1) produces offset and span readings, to be stored and used for on-the-fly calibrations of a dual-slope ADC.

The precision resistor dividers (RN1, RN2, and RN3, all MAX5490C) are available with accuracies from 0.035% to 0.1% (0.1% was selected for this design), and with divider ratios that exhibit a very low temperature coefficient. The resulting differential-amplifier output is:

$$V_{OUTA} = V_{REF} + R_B/R_A[(V_{INA-} - V_{S1-})] - R_C/R_D[(V_{INA+} - V_{S1+})]$$

Where
V_{INA-} is the negative input of amplifier U2A
V_{INA+} is the positive input of amplifier U2A
V_{S1-} and V_{S1+} are the sensor outputs

Since $R_B/R_A = R_C/R_D = 30$, the equation simplifies to:

$$V_{OUTA} = V_{REF} + 30[(V_{S1+} - V_{S1-})]$$

Precision divider RN3 is connected between V_{Li} and ground (GND) to generate the offset voltage (V_{REF}). $R_E = 30R_F$. Note that you can alter the magnitude of V_{REF} (from $V_{Li}/31$ to $30V_{Li}/31$) by toggling the switches U1X and U1Y, which swaps the divider connections to V_{Li} and GND. For $V_{Li} = 3.6V$, V_{REF} is:

$$V_{REF} = [R_F/(31R_F)](V_{Li}) = V_{Li}/31 = 0.116V$$

This offset voltage simplifies calibration by ensuring that the U2A output remains positive at $V_{Li}/31$. V_{REF} is buffered by U2B to eliminate the effects of RN2 loading. Thus, we have a millivolt sensor amplified by a difference amplifier with a gain of 30 and zero offset of $V_{Li}/31$. Now to calibrate the ADC: Section U1Z of the triple SPDT switch (MAX4783) is used to short sensor outputs V_{S1+} and V_{S1-} together. Its low impedance (1.2Ω maximum) is negligible compared to that of the sensor bridge (300Ω to 500Ω). Otherwise, the resistor network of the differential amplifier would impose an excessive load on the sensor. The output of U2A therefore equals V_{REF} plus the net effect of offset and gain errors.

To zero the ADC, configure U1Z (via its digital input "C") to connect Z to Z1, and set V_{REF} in the normal operating mode by connecting X to X1 (using "A") and Y to Y1 (using "B"). An ADC conversion now provides

a zero reading.

To obtain a full-scale reading (span), reverse the resistor divider RN3 by toggling the U1X and U1Y switches. Z remains connected to Z1. V_{REF} now becomes:

$V_{REF} = (30/31)V_{Li}$. For $V_{Li} = 3.6V$, $V_{REF} = 3.484V$

The output of amplifier A now "flips" to $V_{REF} = 3.484V$, plus the net effect of offset and gain errors. An ADC conversion in this configuration provides a span reading of $(30/31)V_{Li}$.

Following the span measurement, return the reference to its normal state by connecting X to X1 and Y to Y1, and remove the sensor short by connecting Z to Z0. You have now calibrated the ADC by generating a code for zero and a code for span. This technique can be executed on-the-fly, at any time a calibration is needed. The use of low-cost, off-the-shelf, precision resistor dividers provides good accuracy and temperature stability.

Related Parts		
MAX4242	Single/Dual/Quad, +1.8V/10µA, SOT23, Beyond-the-Rails Op Amps	Free Samples
MAX4783	High-Speed, Low-Voltage, 0.7Ω CMOS Analog Switches/Multiplexers	Free Samples
MAX5490	100kΩ Precision-Matched Resistor-Divider in SOT23	Free Samples

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