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# 1- and 2-Channel, No Latency $\Delta\Sigma$ , 24-Bit ADCs Easily Digitize a Variety of Sensors

by Michael K. Mayes  
and Derek Redmayne

## Introduction

Since its introduction, the LTC2400's performance and ease-of-use have transformed the method of designing analog-to-digital converters into a variety of systems. Some key features that separate the LTC2400 from conventional high-resolution ADCs and enable direct digitization of many sensors include:

- Ultralow offset (1ppm), offset drift (0.01ppm/°C), full-scale error (4ppm) and full-scale drift error (0.02ppm/°C) without user calibration
- Absolute accuracy typically less than 10ppm total (linearity + offset + full-scale + noise) over the full operating temperature range
- Ease-of-use (eight pins, no configuration registers, internal oscillator and latency-free conversion)
- Low noise and wide dynamic range (0.3ppm<sub>RMS</sub> with  $V_{REF} = V_{CC} = 5V$ —21.6 effective bits of resolution)

This article introduces two new products based on the technology used in the LTC2400. Both parts come

in tiny 10-pin MSOP packages. They include full-scale and zero-scale set inputs for removing systematic offset/full-scale error. The LTC2401 is a single-ended 1-channel device. The LTC2402 is a 2-channel device with automatic ping-pong channel selection.

The absolute accuracy and near zero drift of these devices enable many novel applications, of which four are presented here. The first application uses the full-scale and zero-scale set inputs of the 1-channel device (LTC2401) to digitize a half-bridge sensor. The second is a thermocouple digitizer with a digital cold-junction compensation scheme using the automatic ping-pong channel selection of the LTC2402 for simplified optocoupled isolation. The third combines the LTC2402's ping-pong channel selection, absolute accuracy and excellent rejection into a pseudo-differential bridge digitizer. The final application uses the LTC2402 to digitize an RTD temperature sensor and remove voltage drop errors due to long leads using the second channel and underrange capabilities.

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LTC2401/LTC2402, continued from page 1

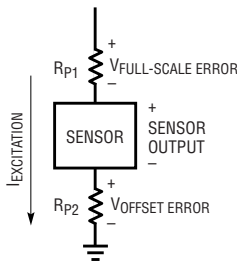


Figure 1. Errors due to excitation currents

## Single-Ended Half-Bridge Digitizer with Reference and Ground Sensing

Sensors convert real world phenomena (temperature, pressure, gas levels and others) into voltages. Typically, the voltage is generated by passing an excitation current through the sensor. This excitation current also flows through wiring parasitics  $R_{P1}$  and  $R_{P2}$  (see Figure 1). The voltage drop across these parasitic resistances leads to systematic offset and full-scale errors.

In order to eliminate the errors associated with these parasitic resistances, the LTC2401/LTC2402 include a full-scale set input ( $FS_{SET}$ ) and a zero-scale set input ( $ZS_{SET}$ ). As shown in Figure 2, the  $FS_{SET}$  pin acts as a full-scale sense input. Errors due to parasitic resistance  $R_{P1}$  in series with the half-bridge sensor are removed by the  $FS_{SET}$  input to the ADC. The absolute full-scale output of the ADC (data out =  $FFFFF_{HEX}$ ) will occur at  $V_{IN} = V_B = FS_{SET}$  (see Figure 3). Similarly, the offset errors due to  $R_{P2}$  are removed by the ground sense input,  $ZS_{SET}$ . The absolute zero output of the ADC (data out =  $00000_{HEX}$ ) occurs at  $V_{IN} = V_A = ZS_{SET}$ .

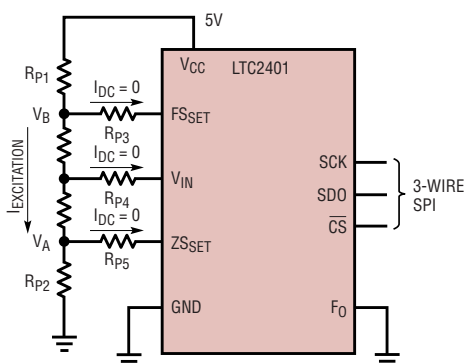


Figure 2. Half-bridge digitizer with zero-scale and full-scale sense

Parasitic resistances  $R_{P3}$ – $R_{P5}$  have negligible errors due to the 1nA (typ) leakage current at pins  $FS_{SET}$ ,  $ZS_{SET}$  and  $V_{IN}$ . The wide dynamic input range ( $\sim 300mV$  to  $5.3V$ ) and low noise ( $0.6ppm_{RMS}$ ) enable the LTC2401 to directly digitize the output of a bridge sensor.

## Digital Cold-Junction Compensation

In order to measure absolute temperature with a thermocouple, cold-junction compensation must be performed. The LTC2402 enables simple digital cold-junction compensation. One channel measures the output of the thermocouple while the other measures the output of the cold-junction sensor—diode, thermistor or the like (see Figure 4).

The selection between CH0 (the thermocouple) and CH1 (the cold junction) is automatic. The LTC2402 alternates conversions between the two input channels and outputs a bit corresponding to the selected channel in the data output word. This simplifies the user interface by eliminating a channel-select input pin. As a result, the LTC2402 is ideal for systems that perform isolated measurements; it only requires two optoisolators (one for serial data out and one for the serial data output clock).

Alternating conversions between two input channels is difficult with conventional  $\Delta\Sigma$  ADCs. These devices require 3–5 conversion cycle settling every time the input channel is switched. On the other hand, the LTC24xx family uses a completely different architecture than other  $\Delta\Sigma$

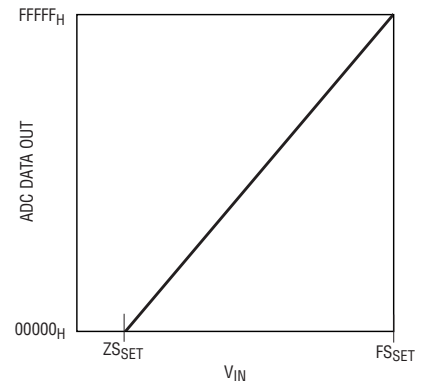


Figure 3. Transfer curve with zero-scale and full-scale set

converters. This results in latency-free, single-cycle settling. The LTC2402 enables continuous conversion between two alternating channels without the added complexity associated with conventional  $\Delta\Sigma$  converters.

## Pseudodifferential Applications

Generally, system designers choose fully differential topologies for several reasons. First, the interface to a 4- or 6-wire bridge is simple (it has a differential output). Second, good rejection of line frequency noise is required. Third, the output of the sensor is typically a small differential signal sitting on a large common mode voltage; as a result, accurate measurements of the differential signal independent of the common mode input voltage is needed. Many applications currently using fully differential analog-to-digital converters for any of the above reasons can migrate to a pseudodifferential conversion using the LTC2402.

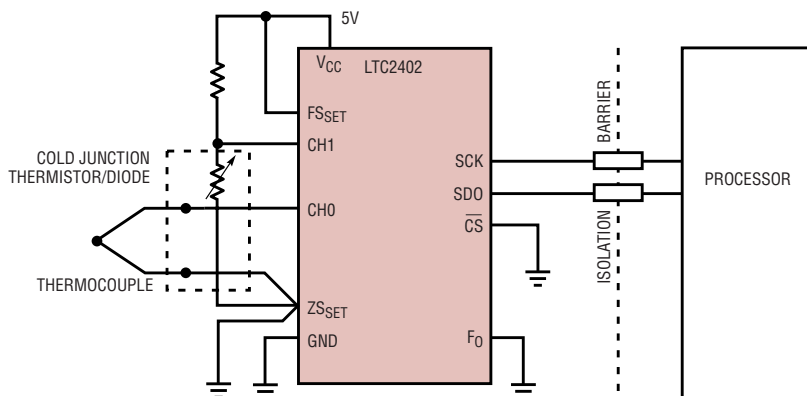
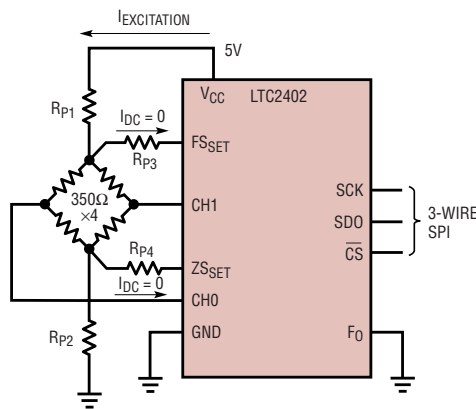


Figure 4. Digital cold-junction compensation



**Figure 5. Pseudodifferential strain gauge application**

### Direct Connection to a Full Bridge

The LTC2402 interfaces directly to a 4- or 6-wire bridge (see Figure 5). Like the LTC2401, the LTC2402 includes FS<sub>SET</sub> and ZS<sub>SET</sub> pins for sensing the excitation voltage directly across the bridge. This eliminates errors due to excitation currents flowing through parasitic resistances (R<sub>P1</sub>–R<sub>P4</sub>). The LTC2402 also includes two single-ended input channels that can be tied directly to the differential output of the bridge. The two conversion results can be digitally subtracted, yielding the differential result.

### Noise Rejection

The LTC2402's single-ended rejection of line frequencies (50Hz/60Hz  $\pm 2\%$ ) and their harmonics is better than 110dB. Since the device performs two independent single-ended conversions, each with  $>110$ dB rejection, the overall common mode and differential rejection is much better than the 80dB rejection typically found in other differential  $\Delta\Sigma$  converters.

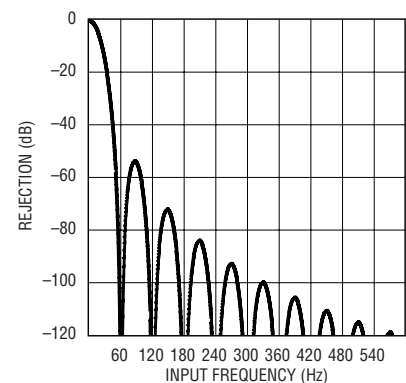
In addition to excellent rejection of line frequency interference, the LTC2402 also exhibits excellent single-ended noise rejection of a wide range of frequencies due to its 4th order sinc filter (see Figure 6). Each single-ended conversion independently rejects high frequency noise ( $>60$ Hz). Care must be taken to ensure that noise at frequencies below 15Hz and at multiples of the ADC sample

rate (15.6kHz) are not present. For this application, it is recommended that the LTC2402 be placed in close proximity to the bridge sensor in order to reduce the noise applied to the ADC input. By performing three successive conversions (CH0–CH1–CH0) the drift and low frequency noise can be measured and compensated digitally.

### Small Differential Signals Sitting on Large Common Mode Voltages

The absolute accuracy ( $<10$ ppm total error) of the LTC2402 enables extremely accurate measurement of small signals sitting on large voltages. Each of the two pseudodifferential measurements performed by the LTC2402 is absolutely accurate independent of the common mode voltage output from the bridge. The pseudodifferential result obtained from digitally subtracting the two single-ended conversion results is accurate to within the noise level of the device times the square root of 2 ( $3\mu\text{V}_{\text{RMS}} \cdot \sqrt{2}$ ), independent of the common mode input voltage.

Typically, bridge sensors output 2mV/V full scale. With a 5V excitation this translates to a full-scale

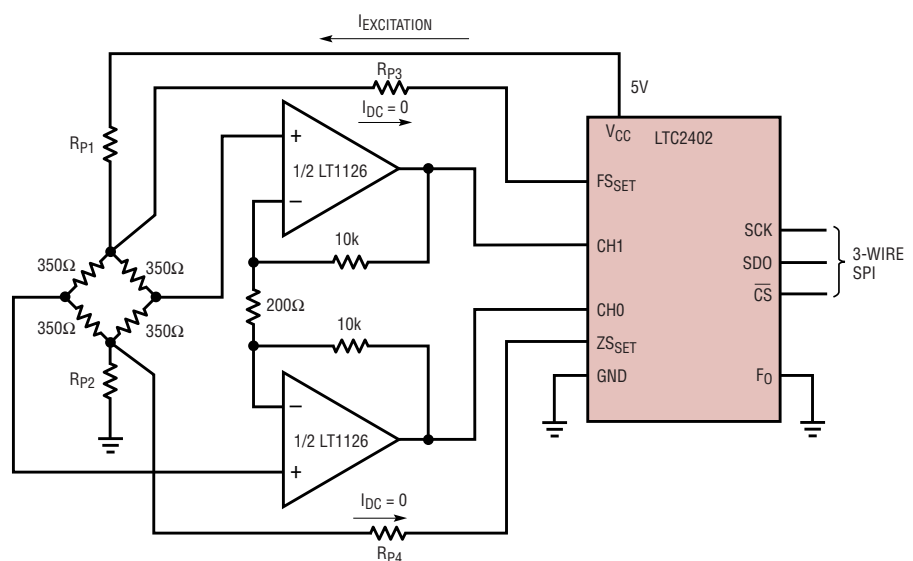


**Figure 6. Single-ended LTC2401/LTC2402 input rejection**

output of 10mV. Divided by the RMS noise of the LTC2402, this circuit yields 2357 counts with no averaging or amplification. If more counts are required, several conversions may be averaged. The number of effective counts is increased by  $\sqrt{2}$  for each doubling of averages. For example, to achieve 10,000 counts sixteen readings should be averaged.

In order to achieve more counts, an LT1126 low noise dual op amp can be placed in front of the LTC2402, see Figure 7. The noise performance of this device is 2.6nV/ $\sqrt{\text{Hz}}$ . With a gain of 100, the input-referred noise contribution of the LTC2402 is less than 50nV<sub>RMS</sub>.

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**Figure 7. 100,000 count pseudodifferential strain gauge application**

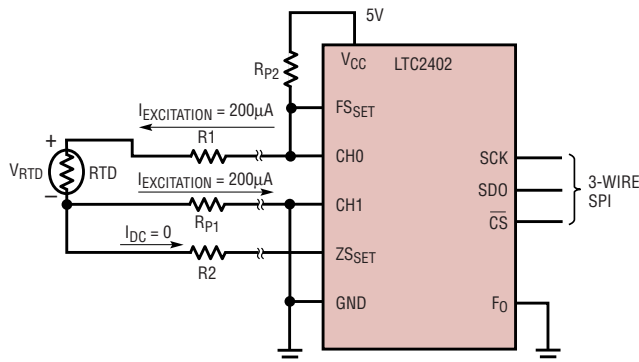


Figure 8. RTD remote temperature measurement

## RTD Temperature Digitizer

RTDs used in remote temperature measurements often have long leads between the ADC and RTD sensor. These long leads result in parasitic voltage drops due to excitation current in the interconnect to the RTD. This voltage drop can be measured and digitally removed using the LTC2402, as illustrated in Figure 8.

The excitation current (typically 200µA) flows from the ADC reference through a long lead to the remote temperature sensor (RTD). This current is applied to the RTD, whose resistance changes as a function of temperature (100Ω–400Ω for 0°C to

800°C). The same excitation current flows back to the ADC ground and generates another voltage drop across the return leads. In order to get an accurate measurement of the temperature, these voltage drops must be measured and removed from the conversion result. Assuming that the resistance is approximately the same for the forward and return paths ( $R1 = R2$ ), the second channel (CH1) on the LTC2402 can measure this drop. These errors are then removed with simple digital correction.

The result of the first conversion on CH0 corresponds to an input volt-

age of  $V_{RTD} + R1 \cdot I_{EXCITATION}$ . The result of the second conversion (CH1) is  $-R1 \cdot I_{EXCITATION}$ . Note that the LTC2402's input range is not limited to the supply rails; it has underrange as well as overrange capabilities. The device's input range is  $-300\text{mV}$  to  $FS_{SET} + 300\text{mV}$  ( $D_{OUT}$  includes a sign bit indicating a negative input). Adding the two conversion results, the voltage drop across the RTD's leads is cancelled and the final result is  $V_{RTD}$ .

## Conclusion

Linear Technology has introduced two new converters to its 24-bit No Latency  $\Delta\Sigma^{\text{TM}}$  converter family. The family consists of the LTC2400 (1-channel, 8-pin SO), LTC2408 (8-channel, 24-bit ADC) and the LTC2401/LTC2402 shown here. Each device features excellent absolute accuracy, ease-of-use and near zero drift. The LTC2401/LTC2402 also include full-scale set ( $FS_{SET}$ ) and zero-scale set ( $ZS_{SET}$ ) inputs for removing errors due to systematic voltage drops. The performance, features and ease-of-use of these devices warrant that designers reconsider the accuracy capabilities of their future system designs. 