Maintaining Accuracy With Small Magnitude Signals

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In today's embedded system applications, whenever data is read from an interfacing device, somewhere in the data path processing of analog signals certainly comes into picture. Perhaps there is a touch interface detecting changes in current because of variation in the capacitance of the panel. For an industrial application, there may be a need to control the temperature by measuring voltage due to change in thermal or transducer's resistance or by detecting the position of a metal and measuring the EMF because of changing magnetic fields or inductance. The underlying principle in each of these examples is to detect/measure a change in the electrical quantity because of the varying electrical properties like the R, L, or C of transducers.

With the increasing complexity of the design because of shrinking size and increasing integration, the minimum detectable change in electrical quantity has also scaled down. Therefore, a system must not only measure the signal but maintain the accuracy as well.

This article discusses how to maintain the accuracy for an analog signal with a very small magnitude. A weighing scale system is used as an example where a full scale change in the weight changes the voltage or current by only a few mV or mA.

In a weighing scale, tensile and compression forces due to the weight of the object are measured. Depending on the type of materials used for detecting these forces, a weighing scale can be of various types like a pneumatic weighing scale (which measures the amount by which air is compressed), spring scale (which the tension on springs to determine weight), or strain gauge scale (which measures the factor by which metal foil is deformed), among others. The strain gauge scale is the most widely used type of weighing scale and will be used for discussion in this article.

Strain Gauges

Before starting with the implementation of a strain gauge scale, first we will discuss the basic idea of strain gauges and how they are arranged to form a load cell as used in weighing scale applications.

As the name suggest, strain gauges are used to measure how much an object is strained. It works on the physical property of a material, that when it is stretched or compressed within its operational limits, its electrical resistance changes. Thus, stress can be measured by measuring the change in resistance.

Change in temperature has a very severe effect on strain gauges because of thermal expansion of the material which changes its resistance. This resistance change due to temperature will be falsely detected as part of the strain measurement.

By arranging gauges of similar material in each arm of a Wheatstone bridge, change in temperature can be easily compensated for. In this arrangement, temperature will have a similar effect on all the arms of the bridge, which will nullify the change in resistance, thus providing self-compensation for temperature.

However, strain gauges arranged in the format of a wheat-stone bridge have the major disadvantage of a zero offset. This occurs when one of the gauges is not mounted properly or gets deformed. This can be tackled by using a shunt resistor to balance the bridge. However, balancing the bridge in the field is not practical as the gauges deforms due to aging as well.

Load Cells

Load cells are the type of strain gauges which are used specifically for measuring weight. In a load cell, strain gauges are connected in the form of wheat-stone bridge as shown in figure 1.

Published in EE Times Design (http://www.eetimes.com/design) January 2011

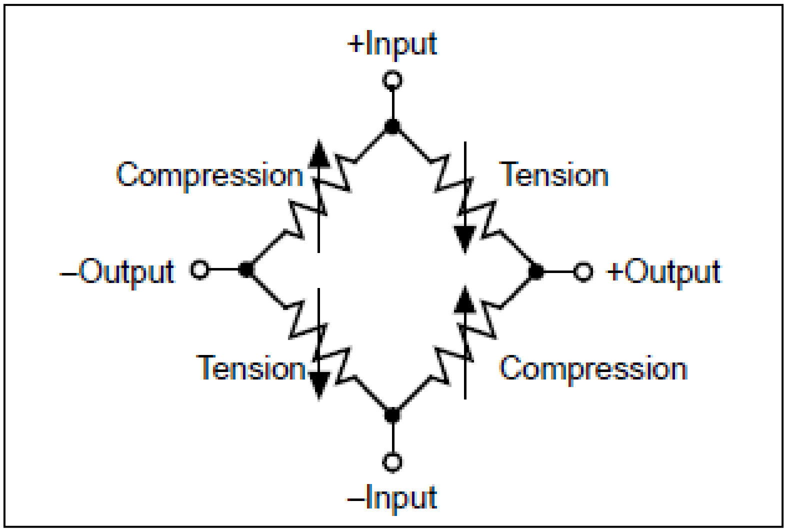

Figure 1: Strain Gauge Bridge

Load cells can be classified based on the arrangement of the gauges:

1. *Full Bridge* – In this type of load cell, strain gauges are used in all the arms of the bridge. Since all the arms of this bridge are active, they provide the highest output when strained. This type of bridge is the least prone to noise because noise gets coupled on all the four arms and canceled out. Another significant advantage of a full bridge is best-in-class performance when it comes to temperature compensation.

2. *Half Bridge* – These load cells have 2 strain gauges connected in opposite arms. Because all the arms are not active, the change in signal is halved for the same amount of strain as compared to the full bridge. The performance of a half bridge is not accurate when temperature changes because of the different temperature coefficients of resistors connected on other two arms. Also, fixture limitations may prevent resistors from being connected at the same place where the gauges are mounted, so additional error is introduced because of differences in temperature of the gauges and resistors.

3. *Quarter Bridge* – This is the least expensive of the three types of bridges. However, it generates the least amount of signal when strained, and so noise generated becomes a potential problem in this kind of system. Apart from these errors, all the errors faced by a half bridge apply to a quarter bridge as well.

In most weighing scale applications, a fully active or full bridge configuration is used. In this type of configuration, full scale change in the signal is on the order of a few mVs. Thus, the efficiency of the underlying hardware used to determine the change becomes critical to accuracy. The following sections provide conventional and advanced methodologies to accurately measure signal change.

Conventional Methodology

In the conventional methodology, strain gauges arranged in a bridge format are excited using a voltage source, and the voltage at the output terminal is measured. A typical arrangement of the gauges in the form of a bridge along with driving and measuring circuitry is shown in figure 2.

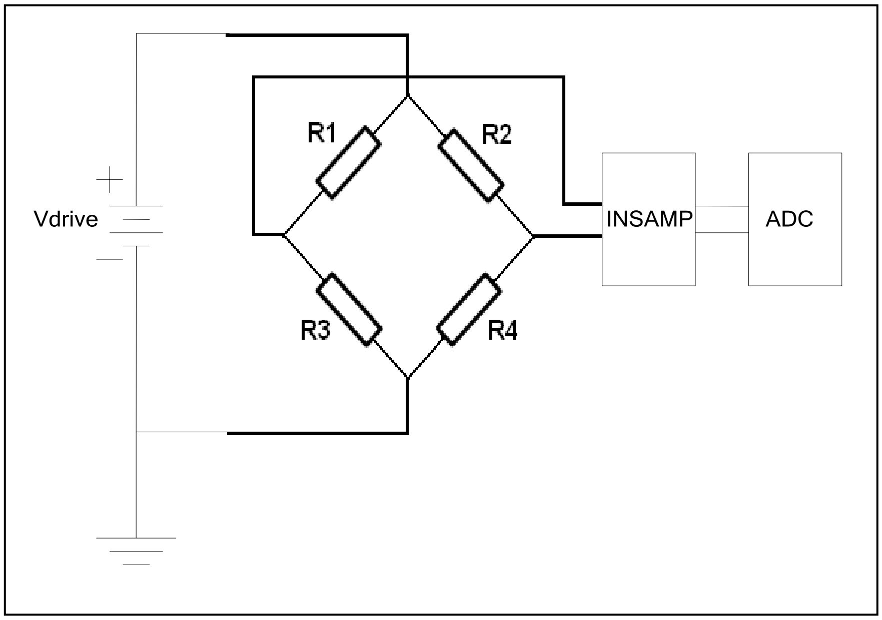

Figure 2: Strain Gauge Bridge measurement circuitry

When the bridge is stressed, depending on the placement of the gauges, tensile or contraction forces will develop. The magnitude of the change in resistance is directly proportional to the amount by which the gauges are strained. Depending on the excitation voltage, the signal can be measured at the output terminal (see Equation 1).

$$V_{OUT} = \left(\frac{R4}{R3+R4} - \frac{R3}{R1+R3}\right)V_{DRIVE} \qquad \text{Equation 1}$$

However, as discussed above, gauges arranged in the form of a Wheatstone bridge face the problem of zero offset and that this offset changes over time. This makes the usage of a shunt resistor an ineffective technique because of the increased cost of maintaining the bridge.

This problem can be resolved by using a simple microcontroller and correcting the offset in firmware. When the load cell is not loaded, the signal obtained can be considered as the offset and subtracted or added in every subsequent reading obtained from the ADC. By providing an "Autocorrect" switch accessible to the user, aging effects can also be dealt with fairly easily. Whenever this switch is pressed, the ADC output can be considered as offset.

Some of the other problems faced by the conventional methodology include:

1. Voltage sources used for the excitation of the bridges are generally located a distance from the assembly. Therefore, the resistance of the wires used to connect the bridge's input terminals to the voltage source also introduce an error into the system.

2. Since the output signal from the gauge bridge is very feeble, either a high resolution ADC is required or the signal needs to be amplified before processing via an ADC. Use of an amplifier with DC signals introduces additional gain error and offset error issues.

Use of high-resolution ADCs or amplifiers with low offset and gain error also increase the cost of the complete system.

Advanced Methodology

With the development of SoCs, complex systems can be developed inside a single SoC. These SoCs help in integrating analog components like PGA, Instrumentation Amplifier, ADC, Current or Voltage Source and many more components. This makes the system easy to design, reduces time-to-market, and makes it adaptable to the changing needs of the market. Several methods can be used to measure signals accurately and address the issues faced by conventional methodologies.

CDS Method:

This method is used to measure very low level signals precisely. It automatically takes care of the offset caused by the PGA and thermal noise generated in the system. Figure 3 shows the implementation.

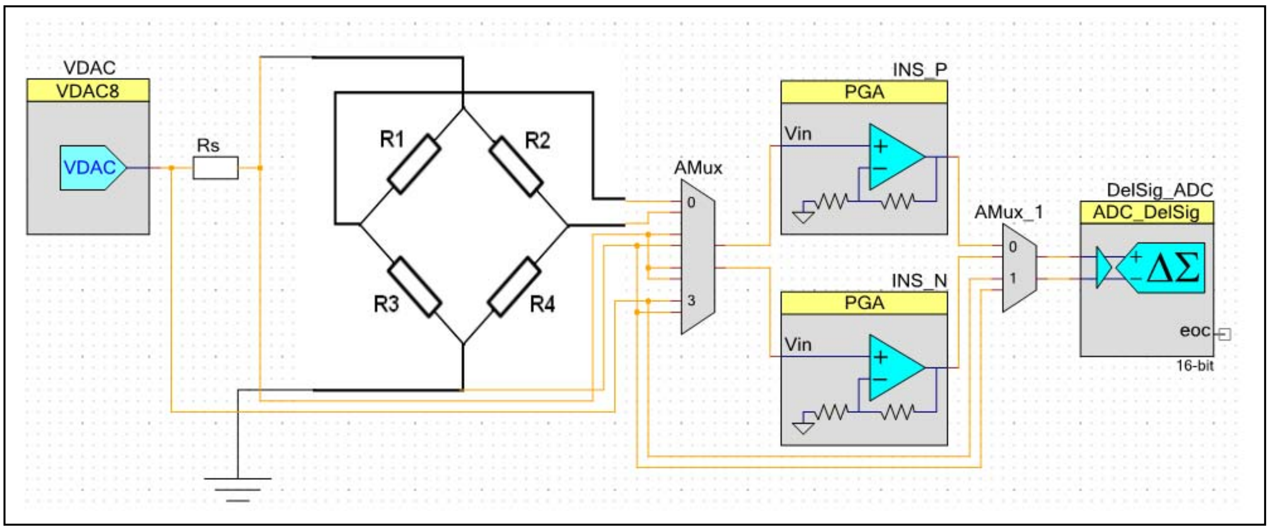

Figure 3: CDS Method

In this methodology, the controller uses an analog mux to switch the input of the ADC between the constant voltage source, the output terminals of the bridge, and the reference voltage.

One of the disadvantages of conventional methods as discussed in the earlier section is the error introduced because of source and wire resistance. This resistance has been modeled as Rs in Figure 3. The effective drive voltage available at the input of the bridge can be given by equation 2.

$$V_{DRIVE} = V_{DAC} - I_{DAC}R_S \qquad \text{Equation 2}$$

In the CDS methodology, by tapping a connection to the drive terminals near the bridge, the drive voltage can be measured. This measured voltage can be used for computing the change in resistance. Since this will not be affected by the source resistance, the computed value will be much more accurate.

Another significant advantage of this method is it automatically takes care of the offset introduced by the electronic circuitry in the hardware itself. In this configuration, the mux switches the input of PGA between the bridge output and the reference voltage source. The signal obtained when the PGAs are connected to reference voltage source will be the offset of the system. Thus, before every reading, the system computes the offset which can be subtracted in the firmware from the signal obtained from the ADC when the PGAs are connected to the bridge output voltage. Apart from the offset, thermal noise generated in the system also gets nullified.

The gain error of the PGA is another limitation which is worth considering while measuring signals where accuracy is the prime concern. This gain error can be calibrated using a simple algorithm in the firmware as shown below.

<u>Gain Error Calibration:</u>

Output voltage, Y for a given input voltage, X can be given by below equation:

$$Y = mX + C$$

Where, m is the slope of the line equation or the gain of the system and c is the offset. Considering the system is already offset compensated, so the equation can be given as below:

$$Y = mX \text{ and } m = \frac{Y2 - Y1}{X2 - X1} \qquad \text{Equation 4}$$

1. Provide a known input voltage to the PGA and measure the output of PGA (Y1) and voltage source (X1) using the ADC.
2. Increase the voltage and measure it again using an ADC. Voltages obtained in this step will be Y2 and X2.
3. Compute the value of “m” using equation 4.
4. Compute the Gain Correcting Factor (GCF) of the system using equation 5.

   $$GCF = \frac{GAIN_{PGA}}{m} \qquad \text{Equation 5}$$

   Where, $GAIN_{PGA}$ is the gain of the PGA configured in the system.
5. Multiply the output of ADC with GCF to correct the Gain Error of the system.

Current Sourcing Method:
This is another method which is widely used for the measurement of very small signals. In this methodology, a current source is used to drive the bridge instead of a voltage source. This implementation is shown in figure 4.

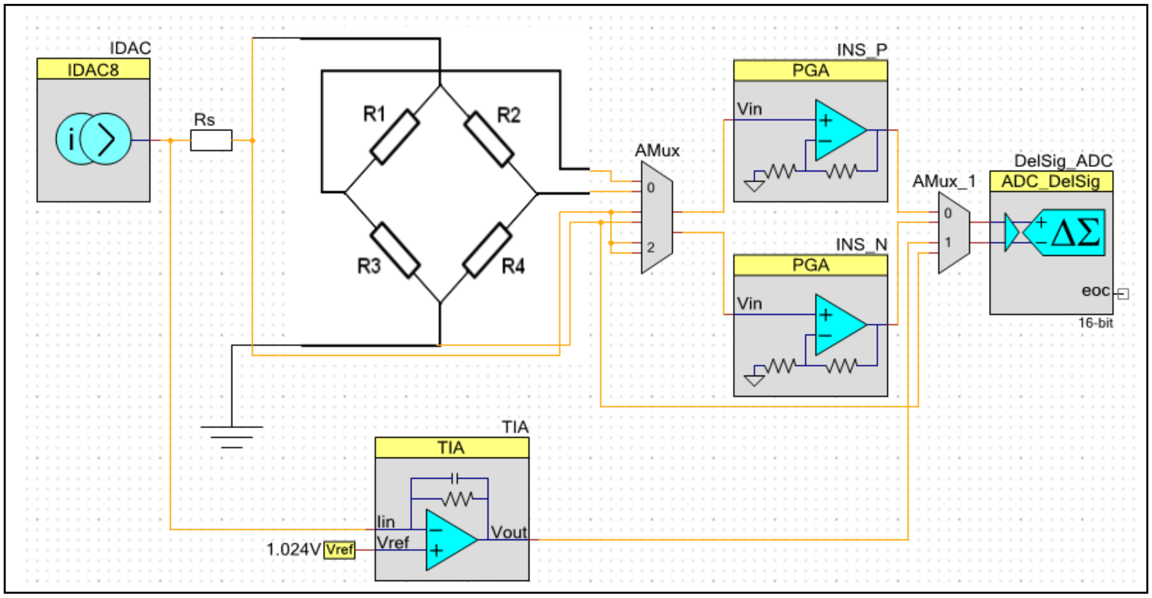

Figure 4: Current Sourcing Method

The biggest advantage of this method is that the resistance of the wire does not introduce any error in the measurement because the current in the branch always remains constant.

One limitation of this methodology is the variation in the current source from the actual value because of device to device variations. However, this problem can be dealt with by calibrating the IDAC using a TIA. For implementing this feature, the IDAC is connected to the TIA which converts the IDAC current into its corresponding voltage, which is given by equation 6.

$$V_{TIA} = I_{DAC} * K \qquad \text{Equation 6}$$

where K is the gain of the TIA.

Measuring the TIA output and dividing the same by the gain of the TIA gives us the value of I_{DAC} used to drive the bridge.

Offset and Gain calibration for this method is the same as discussed in the previous section.

This article provides various methods of measuring low level signals while maintaining accuracy. These methods can be used whether temperature measurements are made using an RTD or thermocouple.

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