Technical Article

Ratiometric Measurement - Improving Bridge Sensor Sampling Accuracy

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The Wheatstone bridge sensor is a common sensor type for various industrial equipment, often used to sense changes in physical quantities such as strain, pressure, and temperature. This article will introduce how ratiometric measurement reduces the sampling error of the Wheatstone bridge sensor and improves system sampling accuracy.

As shown in Figure 1, it is a typical Wheatstone bridge - quarter-bridge resistor sensor, which consists of two parallel resistor branches, including three static resistor elements R and a variable resistor sensor R + ΔR. Changes in physical parameters can be converted into the resistance change of the variable resistor sensor.

When the change in physical parameters is 0, ΔR = 0Ω, and the bridge output V_{out} = 0; when the physical parameters change, ΔR ≠ 0Ω, and the bridge output Vout is as shown in Equation 1;

$$V_{out} = V_{excitation} \times \left[\left(\frac{R + \Delta R}{R + R + \Delta R}\right) - \left(\frac{R}{R + R}\right)\right] = V_{excitation} \cdot \left[\left(\frac{\Delta R}{2(2R + \Delta R}\right)\right] \quad (1)$$

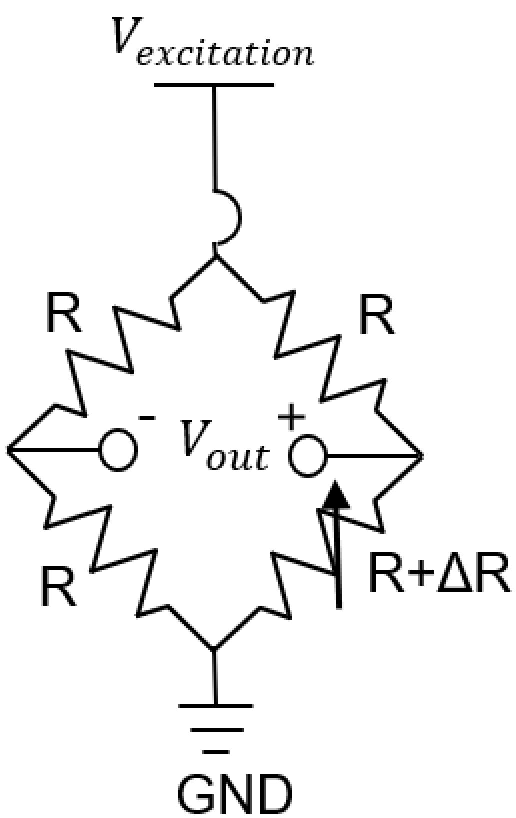

Figure 1. Quarter-Bridge Resistor Sensor

A traditional sampling system for the bridge output is usually shown in Figure 2.

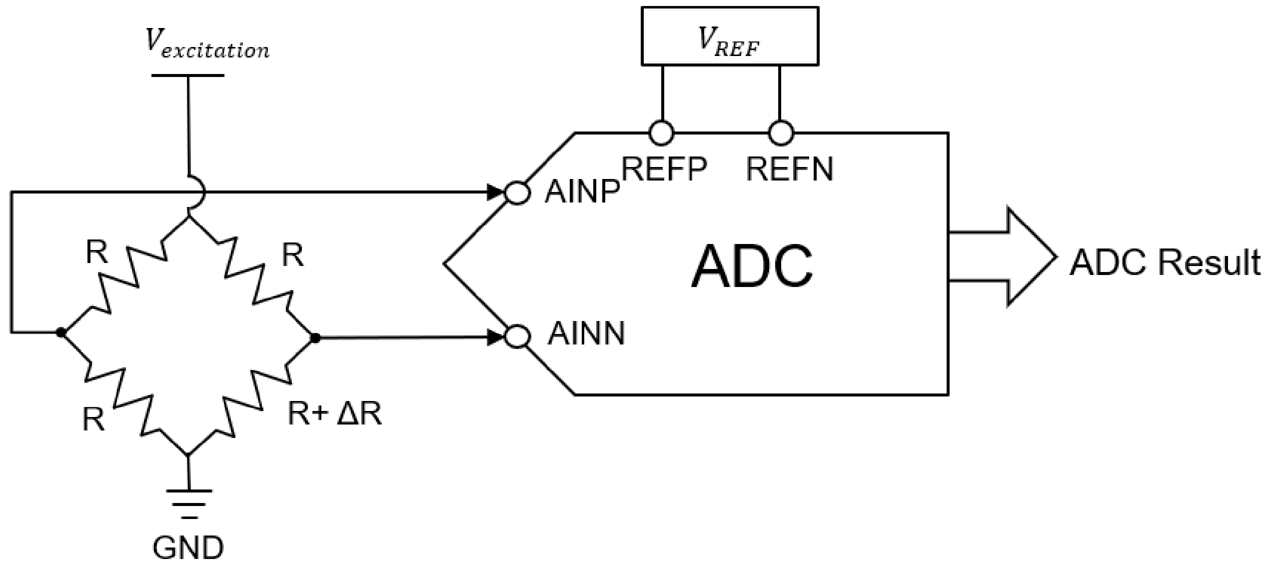

Figure 2. Bridge Sensor - Traditional Sampling Circuit

By substituting the bridge output voltage in Equation 1 into the ADC output code formula, the ADC conversion code of the bridge voltage can be obtained as follows:

$$ADCresult = \left(V_{excitation} + V_{exc\_noise}\right) \cdot \left[\left(\frac{\Delta R}{2(2R + \Delta R)}\right)\right] \cdot \frac{2^N}{V_{REF} + V_{REF\_noise}} \quad (2)$$

It can be seen that when there is any error such as noise or temperature drift in the ADC reference voltage and the bridge excitation voltage, they will be included in the ADC conversion code error of the bridge voltage, and such errors are usually a larger contribution to the error of the ADC conversion result.

Using the ratiometric measurement method can easily cancel these two error sources of the bridge sampling system, as shown in Figure 3, using the ADC reference voltage as the resistor bridge excitation voltage.

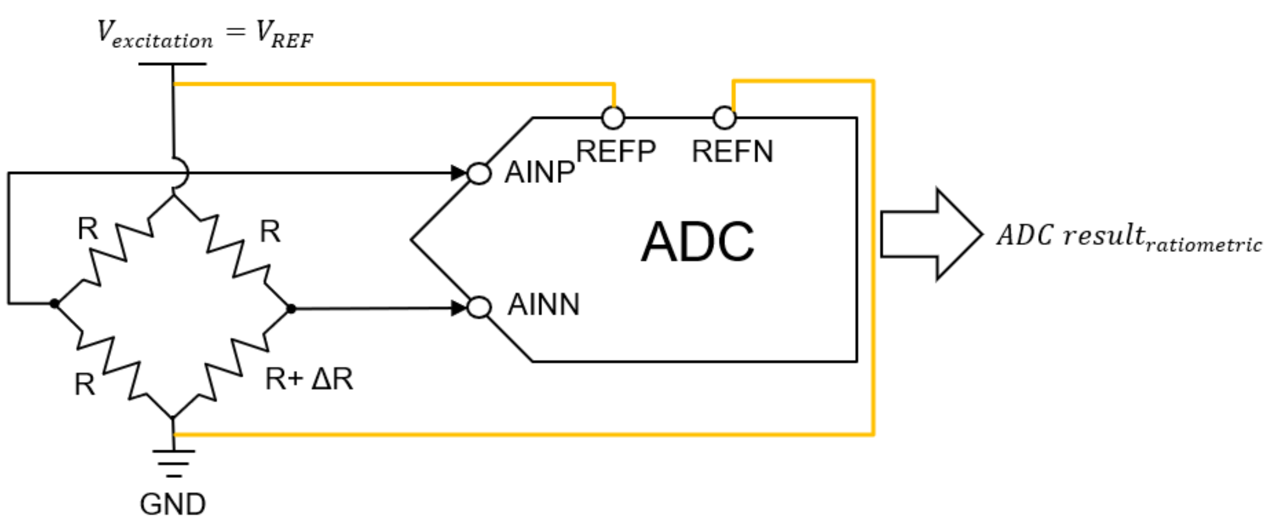

Figure 3. Bridge Sensor - Ratiometric Measurement Sampling

Then $V_{excitation} + V_{exc\ noise} = V_{REF} + V_{REF\ noise}$. By substituting this into Equation 2, the code output of the bridge voltage configured with ratiometric measurement after sampling ADC conversion can be obtained:

$$ADCresult_{ratiometric} = \frac{2^N \Delta R}{2(2R + \Delta R)} \quad (3)$$

It can be seen that the resistor bridge excitation voltage and the ADC reference voltage in the original Equation 2 are canceled out in the ADC results $_{ratiometric}$ Equation 3 of the ratiometric measurement. Correspondingly, the contribution of the excitation voltage and reference voltage to the system error can also be eliminated.

Taking ADS124S06 as an example, use ADS124S06 to perform resistor bridge measurement, and compare the system errors under two configurations: non-ratiometric measurement and ratiometric measurement. If using a non-ratiometric measurement configuration with the lowest BOM cost configuration: the resistor bridge excitation voltage is provided by the 5V of the system power rail Buck, and the ADC reference voltage uses the on-chip reference. After room temperature calibration, under a 350mV resistor bridge voltage, the system error is approximately 552ppm; using a ratiometric measurement configuration, as long as the ADC on-chip reference is simultaneously provided to the resistor bridge excitation, without adding any additional system BOM cost, the errors of the resistor bridge excitation voltage and the ADC reference voltage can be canceled out, and the system error is reduced to 130ppm.

Absolute vs Ratiometric Measurement Accuracy				
Parameter	**Maximum**			
Initial error specs	**VIN = 30 mV**	**VIN = 150 mV**	**VIN=350mV**	**Units**
INL	15	15	15	**ppm**
Offset	66.67	13.33	5.71	**ppm**
Gain Error	200	120	120	**ppm**
RREF initial accuracy	500	500	500	**ppm**
Temperature drift specs				
Offset Drift (no cal)	41.67	8.33	3.57	**ppm**
Offset Drift (cal at 25°C)	21.67	4.33	1.86	**ppm**
Gain Drift (no cal)	250	250	250	**ppm**
Gain Drift (cal at 25°C)	130	130	130	**ppm**
RREF Drift (no cal)	375	375	375	**ppm**
RREF Drift (cal at 25°C)	195	195	195	**ppm**
Total error				
Total error (Absolute measure, cal at 25°C)	552.83	552.42	552.41	**ppm**
Total error (Ratio measure, cal at 25°C)	132.644052	130.9342498	130.8757005	**ppm**

Therefore, using ratiometric measurement can eliminate the largest error source in sampling—the REF reference error—without increasing the original BOM cost, thereby significantly reducing system error and improving bridge sensor sampling accuracy.

References

1. ADS124S06 datasheet
2. Fundamentals of Precision ADC Noise Analysis (Rev. A)