Wide Common-Mode Differential Analog Input Module Solutions for Factory Automation and Control

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TEXAS INSTRUMENTS

In Factory Automation and Control, Programmable Logic Controllers (PLC) have Analog Input Modules which receive up to ±10-V differential inputs with varying common-mode. Three different solutions to capture differential inputs with wide common mode are tested and compared to offer a solution trade-off.

Solution 1: AFE Design With Operational Amplifier in Differential Configuration

Figure 1 shows the first solution using a differential amplifier configuration with the TLV9062 rail-to-rail input-output operational amplifier. The single-ended output is captured using an analog-to-digital converter (ADC) such as the ADS8686S device. The amplifier uses the 5-V analog supply of the ADC for its own positive power supply and has its negative power supply connected to ground. The gain is set to 0.25 V/V and the bias voltage is set to 2.5 V to convert the ±10-V input differential signal to a 0- to 5-V single-ended output signal. The gain is calculated with the input resistors set to 1 MΩ to have lower loading on the input, which is a common system requirement for PLCs. However, these high resistor values add the need for a 16-pF capacitor in parallel to the 250-kΩ feedback resistor to stabilize the operational amplifier as well as another 16-pF capacitor in parallel to the other 250-kΩ resistor to match the impedance ratio.

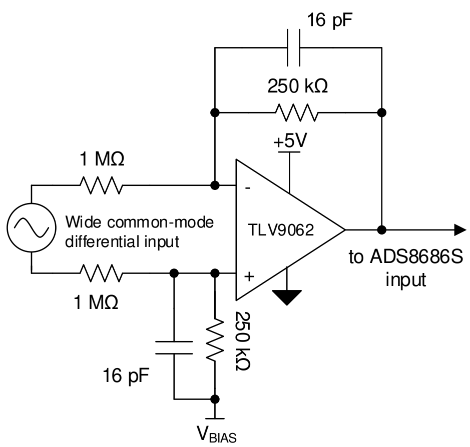

Figure 1. Converting True Differential Signals to Single-Ended Signals Using an Operational Amplifier in Differential Configuration

The tests are performed on the circuit in Figure 1 with the output of the TLV9062 device captured using the first SAR ADC of the ADS8686S device. The results in Figure 2 show that the total error is proportional to the common-mode of the input. In fact, the discrete resistor matching impacts the common-mode rejection ratio (CMRR) of the AFE. This can be reduced by using better matched components. On top of that, the CMRR is not constant over the operational amplifier input common-mode range which leads to additional errors for common-mode voltages below –10 V and above 7.5 V.

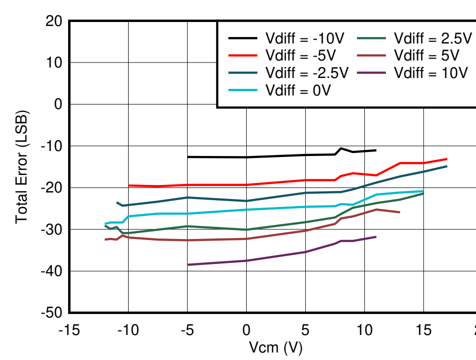

Figure 2. Total Error (LSB) for Different V_{cm} and V_{diff} When Using Solution 1

Solution 2: Difference Amplifier as AFE

Figure 3 shows the second solution using the INA149 difference amplifier. The output is captured using a SAR ADC such as the ADS8686S device. The amplifier has an internal resistance of 300 kΩ and is capable of handling wide common-mode voltages using +15- and –15-V supply rails.

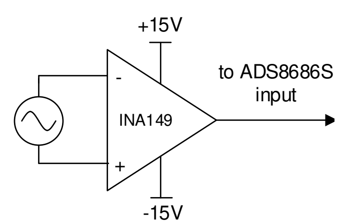

Figure 3. Converting True Differential Signals to Single-Ended Signals Using a Difference Amplifier

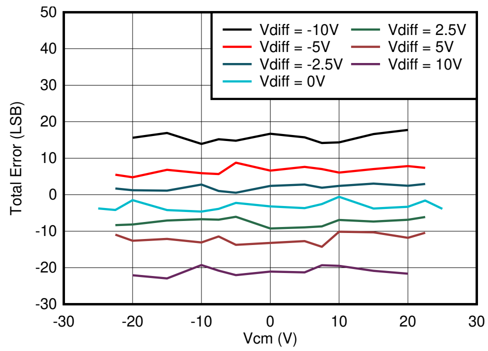

Figure 4. Total Error (LSB) for Different V_{cm} and V_{diff} When Using Solution 2

Figure 4 shows the results of the tests with this solution. The total error is proportional to the differential input signal, but remains relatively constant over the different common-mode voltages. This improvement over the results with the differential amplifier configuration is due to the fact that the difference amplifier uses internal resistors that are trimmed to much higher accuracy as compared to external resistors, which reduces the errors caused by common-mode variation. Additionally, the CMRR is constant over the entire operational amplifier input common-mode range.

Solution 3: Use Dual Simultaneous Sampling SAR ADCs of the ADS8686S

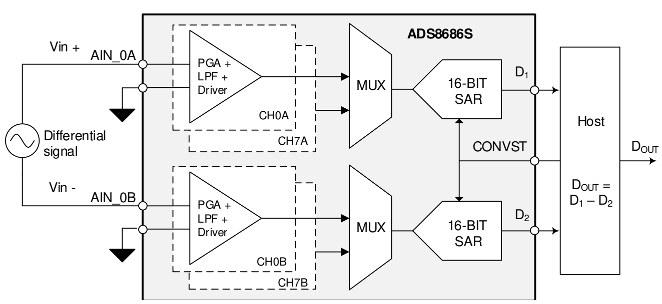

Figure 5. Capturing Differential Signal Inputs as two Single-Ended Signals Using the Dual Simultaneous Sampling SAR ADCs of the ADS8686S

As Figure 5 shows, the last solution uses the ADS8686S device, which is well-fitted for such applications since it can accept signals up to ±10 V, it has a 1-MΩ input impedance, and it has two 8 channel, 16-bit SAR ADCs with 1-MSPS simultaneous sampling. Another option could be to use 2 ADS8688 devices. Each input signal with respect to local ground is converted separately with the two SAR ADCs of the ADS8686S device and then the host subtracts the two digital signals to recover the digital differential signal. No additional components are needed even though some additional digital signal processing is required to perform the subtractions.

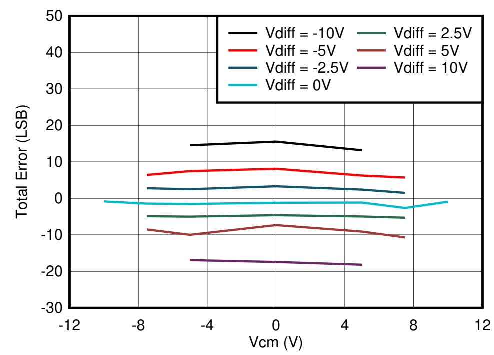

Figure 6. Total Error (LSB) for Different V_{cm} and V_{diff} When Using Solution 3

Figure 6 shows the results of the tests with this solution. The results are similar to the ones of the tests with the difference amplifier since the total error is also proportional to the differential input signal, but remains relatively constant over the different common-mode voltages. The common mode range is limited based on the ADC input range selection.

Solutions Comparison

Each project has its own constraints and requirements where performance is rarely the only criteria. Consequently, there is no ideal solution for dealing with wide common-mode differential input signals for Analog Input Modules of PLCs and each of the discussed implementations can be considered depending on the focus of the project. To help with that decision, the advantages and disadvantages of the three implementations are summarized in Table 1.

Table 1. Solutions Comparison

	Operational Amplifier AFE	Difference Amplifier AFE	ADS8686S Solution
Advantages	• No digital processing required • 1-MΩ Rin • Single 5-V operation	• No digital processing required • Error independent of V_{cm} • Wide common-mode support: ±275 V	• Least expensive solution • 1-MΩ Rin • Error independent of V_{cm} • Single 5-V operation
Disadvantages	• Cost of additional components • Bias voltage needed • Error dependent on V_{cm} • CMRR not constant over opamp input CM	• Most expensive solution • Only 300-kΩ Rin • High bipolar power supplies needed	• Need two channels per signal • Digital processing required • Limited V_{cm}

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