Reducing Effects of External RC Filter on Gain Error and Drift in SAR ADC with Integrated AFE

For applications using SAR ADCs with integrated analog front ends (AFE), such as theADS8588S, an external resistor-capacitor (RC) filter at the input may be necessary to eliminate noise pickup and to protect the input from electrical overstress. However, this filter introduces gain error and gain error drift. The purpose of this TechNote is to show how to calculate the gain error and gain error drift added by the external RC filter. Figure 1 shows the integrated AFE in the ADS8588S and the external balanced RC filter. It is very important to understand that the external filter requires a resistor on both the positive and negative inputs as shown; matching the input impedances is required for good common mode and noise rejection.

The selection of the external resistor is designed to limit the input current from an overstress event. A typical value for this resistance is 10k ohms, and for maximum protection an external TVS diode is recommended. The capacitor is selected to set the filter cutoff frequency. For this example the cutoff frequency is set to 320Hz for a system monitoring 50 or 60 Hz power signals. The cutoff frequency can be adjusted according to the design requirements.

Adding the external resistor will affect the room temperature gain of the data converter as the resistance is directly in series with the 1M ohm input impedance of the AFE. Assuming the internal input impedance and external resistors are known, this gain error can be mathematically accounted for. However, the ADS8588S internal impendence has a range of 0.85 Mohm to 1.15 Mohm, which will minimize the effectiveness of this correction. In this example, the corrected gain error would be approximately ±0.15% from internal impedance variation, whereas the uncorrected gain error would be about 1%±0.15%. Depending on the magnitude of the external resistor used, this gain error will differ but for many applications calibration is used to significantly reduce this error.

The room temperature gain error added to the system by the external resistor is given by the equation below. This gain error equation is based on a voltage divider relationship and is the additional uncorrected error from the external resistor. For this example, the uncorrected gain error due to the external resistor is 0.9901%. For comparison, the ADS8588S internal maximum gain error is 64 least significant bits which translates to 0.098% [100*64/(2^16)=0.098%].

$$GainError(R_{EXT})_{RoomTemp} = \frac{1}{1+\frac{R_{IN}}{R_{EXT}}}$$

$$GainError(R_{EXT})_{RoomTemp} = \frac{1}{1+\frac{1M\Omega}{10k\Omega}} = 0.009901 \text{ or } 0.9901\%$$

A simple two point calibration is typically used to correct for gain error in a data converter system. This method will eliminate both the gain error introduced by the external resistor as well as internal device gain error. In this calibration method two test signals are applied and measured at 10% and 90% of the linear range of the input voltage range. These measurements are then used to calculate the slope (m) and offset (b) of the linear transfer function, shown in the equations below.

$$Code = m \cdot V_{in} + b$$

$$m = \frac{Code\_max - Code\_min}{V_{max} - V_{min}}$$

$$b = Code\_min - m \cdot V_{min}$$

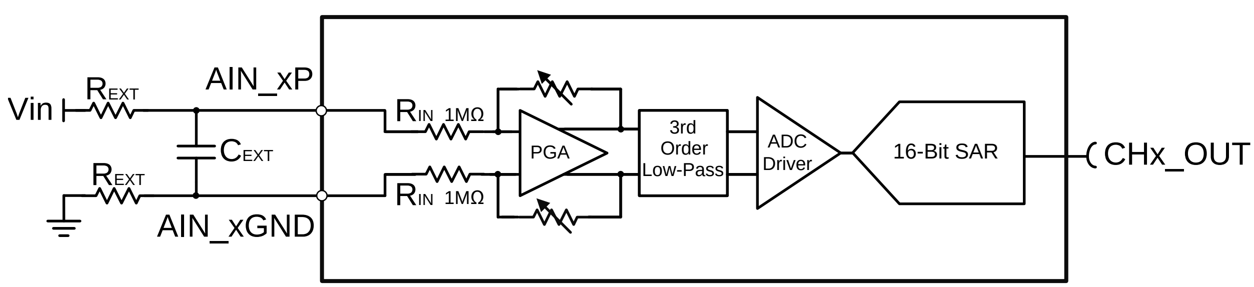

Figure 1. ADS8588S Integrated Analog Front End with external RC filter

Once the calibration coefficients are determined, they are used to correct for the gain and offset of the data converter and external components, using the equation below. Mathematically, this is done by solving the straight line equation for the input signal. Usually the calibration method is executed during a factory automated test, once the coefficients are calculated, they are stored in memory and used in all subsequent measurements to minimize the error.

$$Vin_{CALIBRATE} = \frac{Code - b}{m}$$

Using calibration can reduce gain and offset errors to almost negligible levels. After calibration, most of the residual error is due to noise and drift. Both the internal 1Mohm resistor and the external filter resistor will contribute to the system drift. From the ADS8588S datasheet, the electrical characteristic lists the input impedance maximum drift at ±25ppm/°C. For this example a precision low drift external resistor (0.1% ±25ppm/°C) was used. Using a precision low drift resistor for the filter will achieve best results. To calculate the effect of the external resistor on drift, first find the gain error at high temperature. This is done by calculating the internal and external effective resistance at high temperature as is shown in the equations below. For worst case analysis, the signs of the drift term of the internal and external impedances must be different. If the signs were to be the same, the drift errors from the internal and external impedances would cancel.

$$R_{IN(-25ppm/°C)} = 1M\Omega \cdot [-25ppm/°C \cdot (125°C - 25°C) + 1]$$

$$R_{IN(-25ppm/°C)} = 0.9975\ M\Omega$$

$$R_{EXT(+25ppm/°C)} = 10k\Omega \cdot [25ppm/°C \cdot (125°C - 25°C) + 1]$$

$$R_{EXT(+25ppm/°C)} = 10.025k\Omega$$

Next, to calculate gain error drift, calculate the gain error at 25ºC, and at125ºC.

$$GainError(R_{EXT})_{RoomTemp} = \frac{1}{1 + \frac{1M\Omega}{10k\Omega}} = 0.009901 \text{ or } 0.9901\%$$

$$GainError(R_{EXT})_{125°C} = \frac{1}{1 + \frac{0.9975M\Omega}{10.025k\Omega}} = 0.009950 \text{ or } 0.995\%$$

Finally, take the difference of the errors over temperature, divide by the temperature range used and multiply by one million to convert to ppm.

$$GainErrorDrift\ (R_{EXT}) = \frac{\Delta GainError}{\Delta Temperature} \cdot 10^6$$

$$GainErrorDrift\ (R_{EXT}) = \frac{.009950 - .009901}{(125°C - 25°C)} \cdot 10^6 ppm$$

$$GainErrorDrift\ (R_{EXT}) = -0.49ppm/°C$$

In the ADS8588s datasheet the gain error temperature drift is listed at a maximum ±14ppm/°C when using an external reference. This is orders of magnitude larger than the calculated additional drift error introduced by the external resistor (-0.49ppm/°C), making the introduced error insignificant. The minimal drift error introduced by the external components is possible because both the internal 1Mohm resistance and the external resistance have low drift. This same calculation can be done using different external resistor values. The absolute worst case drift can be kept relatively low if low drift external resistors (e.g. ±25ppm/ºC or better) are used. For example, the worst case drift introduced by a 1Mohm ±25ppm/ºC external resistor is about ±12ppm/C..

In summary, an external RC filter is a common way to reduce noise as well as protect the input circuit. This circuit will have some impact on the gain error and drift of the system. This paper demonstrated a method for calculating gain error and drift. For best accuracy, calibration can be used. The drift error can be minimized by using precision low drift external resistors; this drift will generally be significantly lower than the device's drift.

Table 1. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
ADS8588S	Input Impedance Max Drift ±25ppm/°C	Simultaneous Sampling, 16 Bit, 200-kSPS
ADS8688	Input Impedance Max Drift ±25ppm/°C	MUX, 16 Bit, 500-kSPS
ADS8681	Input Impedance Max Drift ±25ppm/°C	Single Channel, 16 Bit, 1-MSPS

Table 2. Related Documentation

TIPLADC 3.2	TI Recision Labs ACD 3.2:Understanding and Calibrating the Offset and Gain for ADC Systems
TIDUCO9	High-Accuracy Analog Front End Reference Design Using 16-Bit SAR ADC With ±10-V Measurement Range
TIDU540A	High-Accuracy AC Voltage and Current Measurement AFE for Feeder Terminal Unit Reference Design
TIDU427B	Phase-Compensated, 8-Ch, Multiplexed Data Acquisition System for Power Automation Reference Design

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