APPLICATION NOTE

AN1270: Estimating Total Static Error for Skyworks Si89xx Isolated Amplifiers and Delta-Sigma Modulators

This application note addresses the estimation of total static error for Skyworks' Si89xx series of isolated amplifiers and isolated delta-sigma modulators.

These devices are designed for precisely measuring current or voltage for systems where a sensor must be isolated from the control circuit. For such devices, it is essential to understand their error sources and error margins, which is the purpose of this application note. It covers the three types of static error – offset, gain error, and nonlinearity – and how to combine them to estimate total static error, with example calculations to follow along.

Key Features

- Device specifications
- Device applications
- Error sources
- Error calculations
- Combining errors
- Examples

1. Isolated Amplifiers and Delta-Sigma Modulators for Current Sensing Applications

Skyworks isolated amplifiers and delta-sigma modulators for current sensing applications are designed to measure the voltage across a shunt resistor. The isolated amplifiers for current sensing have differential analog inputs and either single-ended or differential analog outputs. The modulators for current sensing have differential analog inputs and a serial bit-stream digital output.

1.1. Si8921/22 Isolated Amplifier for Current Shunt Measurement

The Skyworks Si8921 and Si8922 devices are isolated amplifiers for current measurement. These devices feature a differential analog input and either a differential analog output (Si8921) or a single-ended analog output (Si8922). Both devices provide two gain options; part numbers with the “A” suffix provide higher gain and correspondingly lower input voltage range than those with the “B” suffix.

Figure 1 shows a typical current sensing application using the Si892x, as seen in the Si8921/22 data sheet. Note that the differential input and output of the Si8921 device allow both positive and negative input voltage swings. However, the single-ended analog output of the Si8922 devices cannot provide a negative output; so, the input voltage range on the Si8922 device is effectively constrained to positive values.

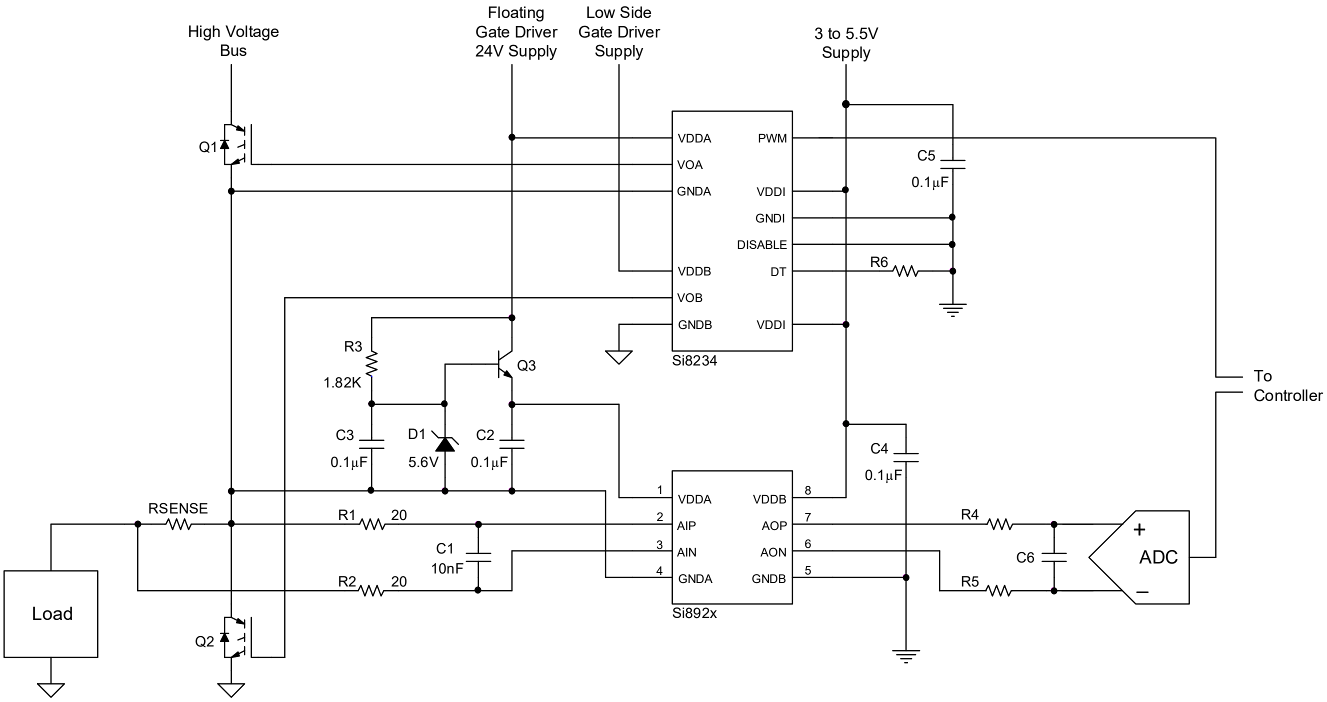

Figure 1. Typical Si892x Current Sensing Application (from Si8921/22 Data Sheet)

1.2. Si8941/46/47 Isolated Delta-Sigma Modulator for Current Shunt Measurement

The Skyworks Si8941/46/47 devices are isolated modulators for current measurement. These devices feature a differential analog input and a digital bit stream output that comes from a second-order, delta-sigma modulator (DSM). The modulator can be clocked either from an on-board oscillator (Si8946/47) or from an external clock (Si8941). The output is typically digitally filtered by an MCU or FPGA in the system. All three parts provide two gain options; part numbers with the "A" suffix provide higher gain and correspondingly lower input voltage range than those with the "B" suffix.

Figure 2 shows a typical current sensing application using the Si894x, as seen in the Si8941/46/47 data sheet.

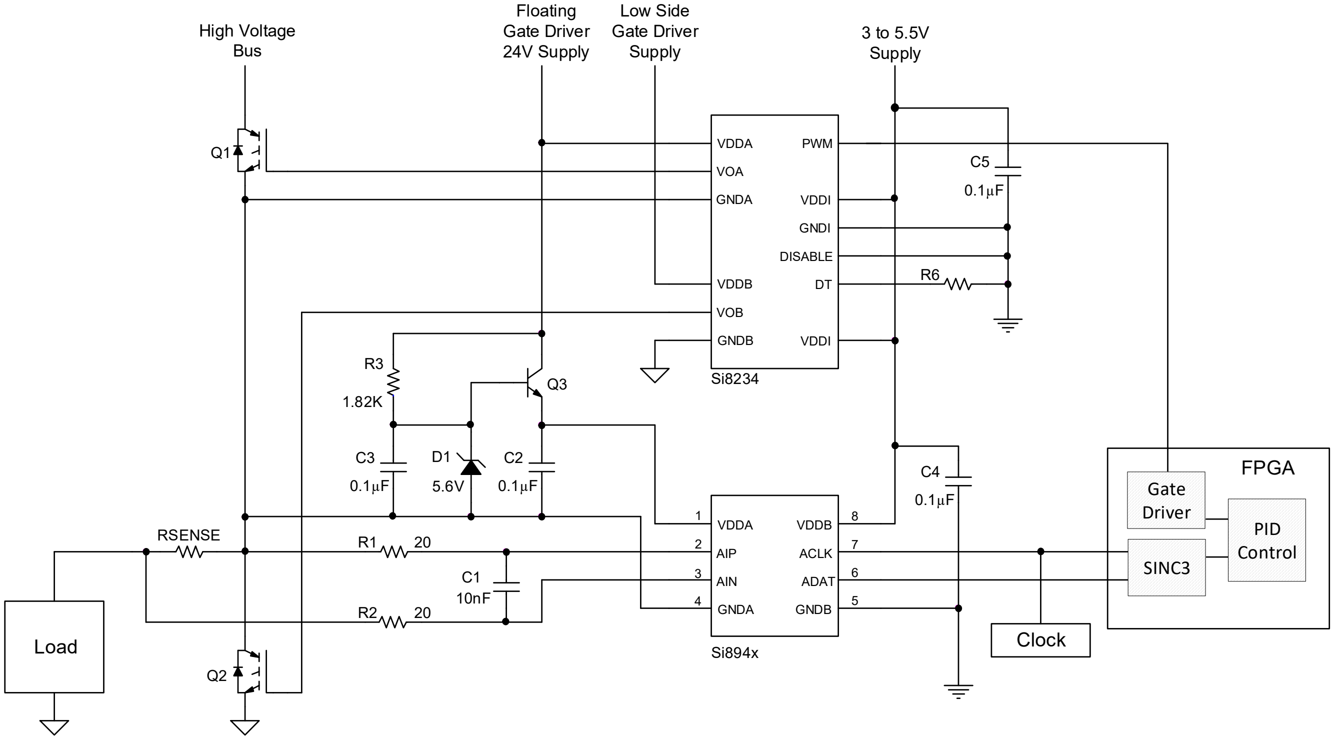

Figure 2. Typical Si894x Current Sensing Application (from Si8941/46/47 Data Sheet)

2. Isolated Amplifiers and Delta-Sigma Modulators for Voltage Measurement Applications

Skyworks isolated amplifiers and delta-sigma modulators for voltage-sensing applications have single-ended analog inputs designed to measure the voltage at the VIN pin, with respect to GNDA. The isolated amplifiers for voltage sensing offer either single-ended or differential analog outputs. The delta-sigma modulators for voltage sensing provide a serial bit-stream digital output. The output functionality of these amplifiers and modulators is equivalent to those for current sensing, as described in 1. Isolated Amplifiers and Delta-Sigma Modulators for Current Sensing Applications .

2.1. Si8931/32 Isolated Amplifier for Voltage Measurement

The Skyworks Si8931/32 devices are isolated amplifiers for voltage measurement. These devices feature a single-ended analog input and either a differential analog output (Si8931) or a single-ended analog output (Si8932).

Figure 3 shows a typical voltage sensing application using the Si8931, as seen in the Si8931/32 data sheet. These devices have single-ended inputs that support only VIN input voltages that are positive with respect to the GNDA pin.

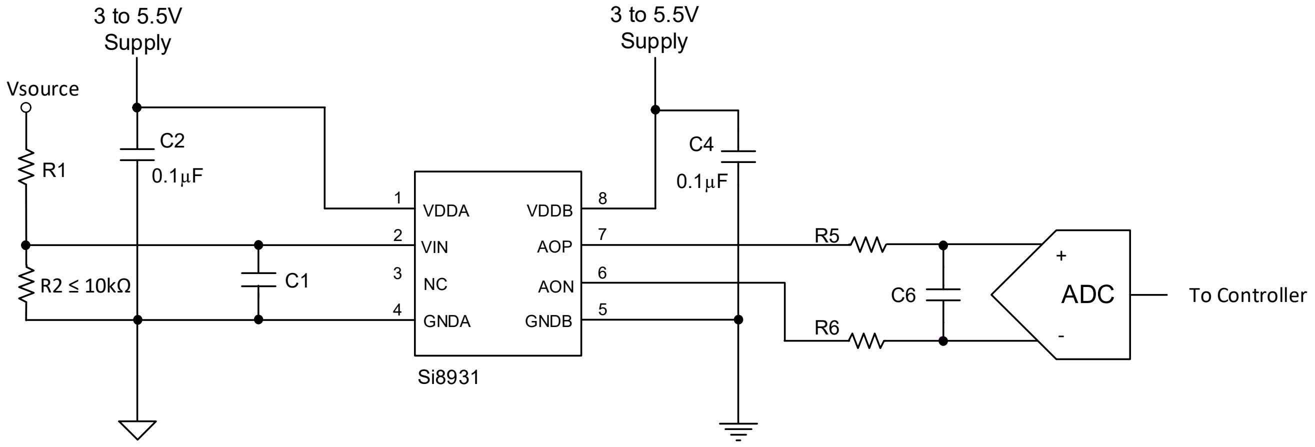

Figure 3. Typical Si8931 Voltage Sensing Application (from Si8931/32 Data Sheet)

2.2. Si8935/36/37 Isolated Delta-Sigma Modulator for Voltage Measurement

The Skyworks Si8935/36/37 devices are isolated modulators for voltage measurement applications. These devices feature a single-ended analog input and a digital bitstream output that comes from a second order delta-sigma modulator (DSM). The modulator can be clocked either from an on-board oscillator (Si8936/37) or from an external clock (Si8935). The output is typically digitally filtered by an MCU or FPGA in the system.

Figure 4 shows a typical voltage sensing application using the Si8935/36/37, as seen in the Si8935/36/37 data sheet.

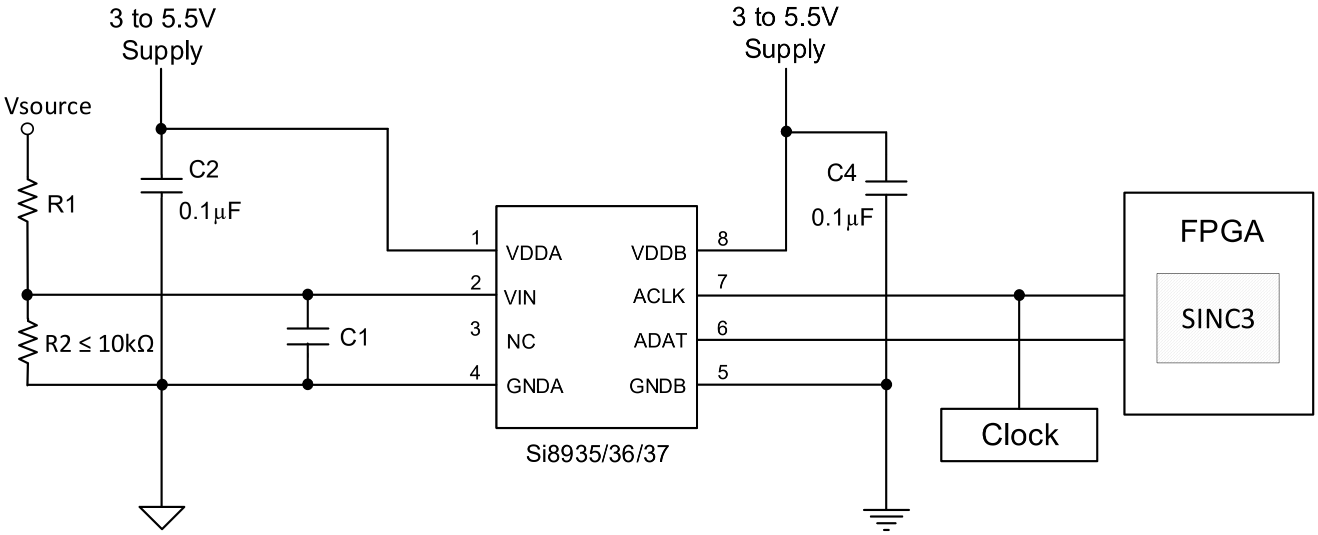

Figure 4. Typical Si8935/36/37 Voltage Sensing Application (from Si8935/36/37 Data Sheet)

3. Static Error Sources, Specifications, and Calculations

Static error is the difference between a signal's true value and its measured value. It is most applicable to the measurement of dc signals, or signals that vary slowly.

The following sections of this application note will discuss the three types of static error that the data sheet presents and demonstrate how to estimate static errors over a wide temperature range. An example calculation using Si8922B is provided for each error type, and the final section describes how to combine them to find the total static error. The error types and their methods of calculation are the same for all devices in the Si89xx family.

Table 1 shows the relevant information needed to calculate the total static error of the Si8922B devices. They are compiled from the Si8921/22 data sheet.

Table 1. Si8922B Static Error Specifications

Parameter	Symbol	Test Condition	Min	Typ	Max	Units
Specified Linear Input Range	VAIP – VAIN	—	30	—	250	mV
Input Referred Offset	VOS	T_A = 25 °C, AO = 0.25 V	–0.35	±0.07	0.35	mV
Input Offset Drift	VOS_T	—	–0.3	0.5	3	µV/°C
Gain Error	—	T_A = 25 °C	–0.2	±0.06	0.2	%
Gain Error Drift	—	—	–24	–9	0	ppm/°C
Nonlinearity	—	T_A = 25 °C	–0.04	0.01	0.04	%
Nonlinearity Drift	—	—	–16	—	16	ppm/°C

3.1. Specified Linear Input Range and Common-Mode Operating Range

The specified linear input range of a device is the input voltage range over which performance characteristics such as gain error, input-referred offset error, and nonlinearity can be precisely accounted for. For devices with differential inputs (Si8921/22, Si894x), the input voltage is typically defined to be the difference in voltage between the differential input pins (VAIP – VAIN). For devices with single-ended inputs (Si893x), the input voltage is simply the voltage on the input pin (VIN) with respect to the voltage on the input-side ground pin.

3.2. Input-Referred Offset and Offset Drift

In an ideal world, an amplifier input voltage of 0 V will result in an output voltage of 0 V. In a non-ideal situation, the input-referred offset, VOS, of an amplifier is the true input voltage that results in an output voltage of 0 V. The Si89xx datasheets provide a margin for this source of error, which is measured in mV. The input offset drift, in µV/°C, must also be considered for operating temperatures besides 25 °C.

For parts with a differential output, such as the Si8922A devices, 0 V is within the linear input range.
The input-referred offset for devices with a differential output has a test condition of AIP = AIN = 0 V.

For parts with a single-ended output, as seen with the Si8922B example, 0 V is not within the linear input range. 30 mV, the minimum of the linear input range, is the test condition for VOS. The resultant output is AO = 0.25 V, the minimum output voltage in the device's linear range.

3.2.1. Total Input Offset Error for an Isolated Current Sensing Application

The data sheet provides the minimum and maximum offset, as well as minimum and maximum offset drift. With this information, calculating just four lines can provide a great visualization of the input offset error boundaries, as seen in Figure 5 below. The minimum and maximum offset can be thought of as the 25 °C intercept. Each of the intercepts has two slopes, defined by the minimum and maximum drift.

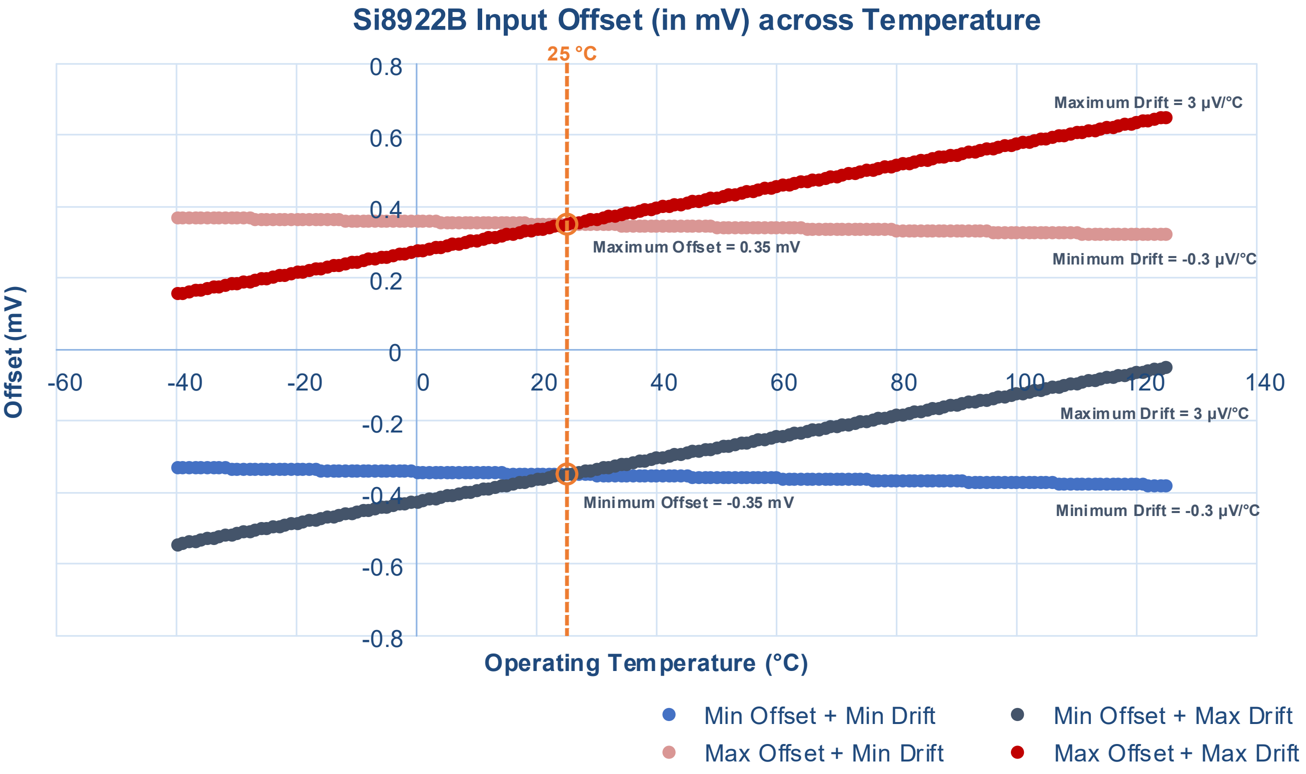

Figure 5. Si8922B Four-Line Offset Graph

As shown in Figure 5 above, 25 °C represents an inflection point where the lines meet and cross each other. The maximum of the two red lines at a given temperature represents the maximum offset error at that temperature. Conversely, the minimum of the two blue lines represents the minimum offset error at any given temperature. The four lines together form the offset error boundary across temperature, as shown below in Figure 6.

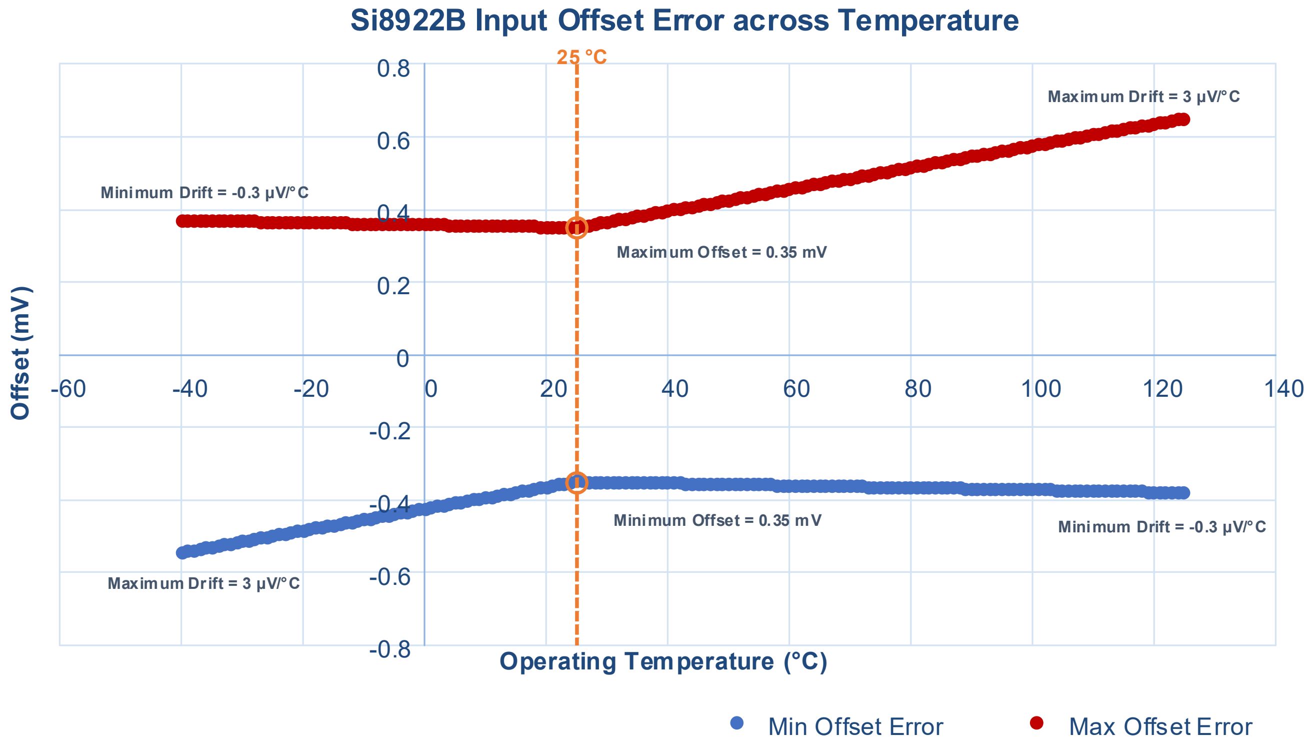

Figure 6. Si8922B Input-Offset Error across Temperature

Figure 5 and Figure 6 illuminate how simple the error calculations are. When calculating the exact error value at any given temperature, one common misstep is to not account for the intercept of 25 °C. The drift value should be multiplied by the temperature difference from 25 °C. Here is an example calculation for the minimum offset at –40 °C.

$$-40\ ^\circ\mathrm{C} - 25\ ^\circ\mathrm{C} = -65\ ^\circ\mathrm{C}$$

Equation 1.

$$-0.350\ \mathrm{mV} + (-65\ ^\circ\mathrm{C}) \times 3\ \mu\mathrm{V}/^\circ\mathrm{C} = -0.545\ \mathrm{mV}$$

Equation 2.

–65 °C represents the temperature difference, and the negative sign must be kept when multiplying with the drift value. As seen in Figure 5 and Figure 6, the minimum offset at –40 °C is a result of the 3 µV/°C drift component, which is used in Equation 2. For the maximum offset at –40 °C, the –0.3 µV/°C drift component is combined with the maximum offset at 25 °C, as shown in Equation 3 below.

$$0.350\ \mathrm{mV} + (-65\ ^\circ\mathrm{C}) \times -0.3\ \mu\mathrm{V}/^\circ\mathrm{C} = 0.370\ \mathrm{mV}$$

Equation 3.

Table 2 depicts the minimum and maximum offset at 25 °C, -40 °C, and 125 °C, and across the entire temperature range. This table can serve as an accuracy check for these error calculations.

Table 2. Si8922B Minimum and Maximum Offset

Temperature	Minimum Offset	Maximum Offset
25 °C	–0.350 mV	0.350 mV
–40 °C	–0.545 mV	0.370 mV
125 °C	–0.380 mV	0.650 mV
Global (–40 °C to 125 °C)	–0.545 mV	0.650 mV

Lastly, the offset error must be converted into the same units as the other error terms, in %. The best method is to convert this millivolt unit into a percentage of the full-scale linear input voltage of 250 mV, simply by dividing the offset values by 250 mV. As specified in the datasheet, 250 mV is specifically for Si8922B, and other OPNs have different ranges. Table 3 shows the minimum and maximum offset for Si8922B in percent-full-scale (% FS).

Table 3. Si8922B Minimum and Maximum Offset (% FS)

Temperature	Minimum Offset	Maximum Offset
25 °C	–0.140%	0.140%
–40 °C	–0.218%	0.148%
125 °C	–0.152%	0.260%
Global (–40 °C to 125 °C)	–0.218%	0.260%

These converted numbers will be used to calculate the combined static error due to all three error types in "3.5. Estimating Total Static Error" on page 12.

3.3. Gain, Gain Error, and Gain Error Drift

Nominal gain and gain error are typically determined by measuring the device's output signal level for multiple input voltages that span the specified linear input voltage range. The nominal gain is defined as the slope of a linear least squares regression line fit to the resulting set of (input voltage, output voltage) data points, and the gain error is defined as the difference between the measured gain and the nominal gain for the stated operating conditions (e.g., temperature, supply voltage), expressed as a percentage of the input voltage.

For devices with differential outputs, the output signal is generally defined as the difference between the non-inverting output, AOP, and the inverting output, AON (VOUT = AOP – AON). For devices with a single-ended output, the output voltage is simply the voltage on the output pin with respect to the output-side ground pin (VOUT = AO – GNDB). For Skyworks parts that have a Delta-Sigma Modulator bit-stream output (Si8941/46/47), the output signal level is defined in terms of the ones-density of (the percentage of ones in) the serial bit stream output.

3.3.1. Total Gain Error for an Isolated Current Sensing Application

The method of calculating gain error is the same as calculating offset error. There is minimum and maximum gain error, as well as minimum and maximum gain error drift. Figure 7 represents the gain error boundary across temperature for the Si8922B devices. The four lines are processed to only show the true boundary points at each temperature.

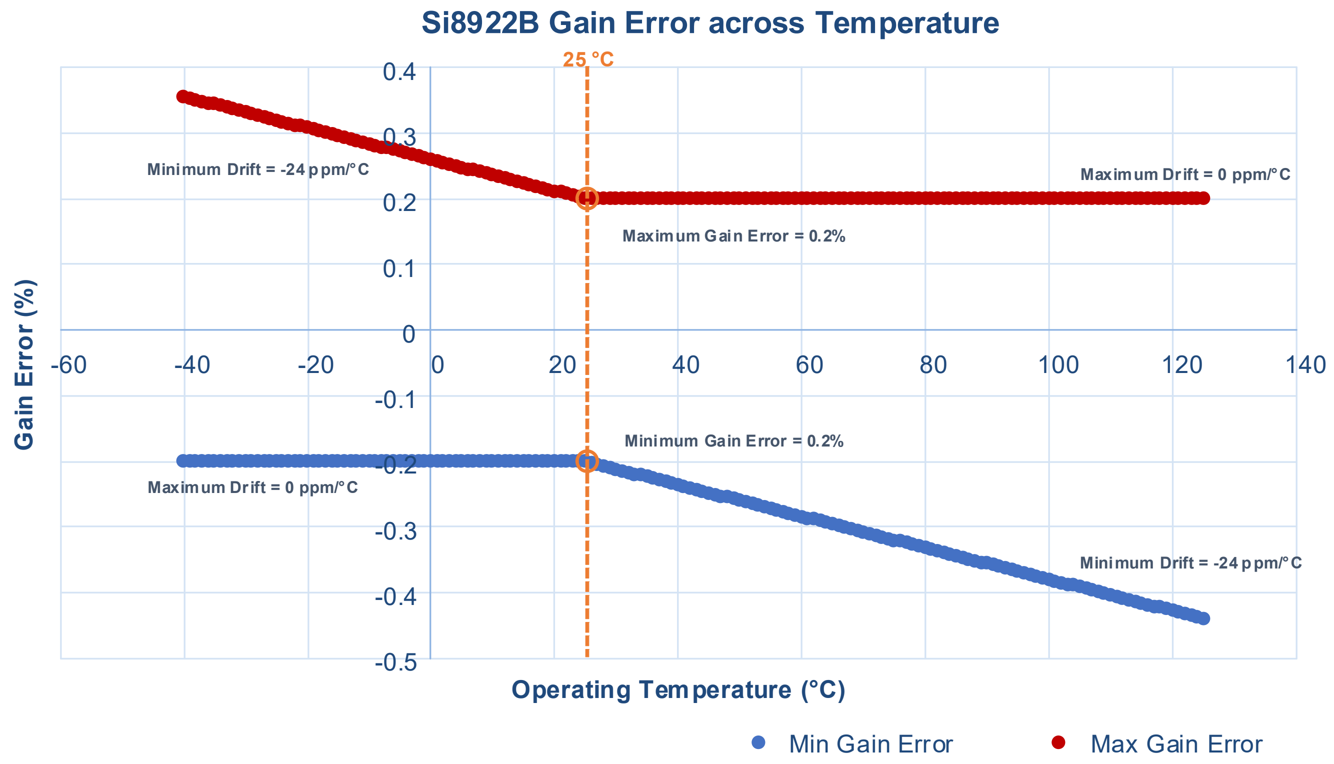

Figure 7. Si8922B Gain Error across Temperature

Table 4 depicts the minimum and maximum gain error at 25 °C, –40 °C, and 125 °C, and across the entire temperature range.

Table 4. Si8922B Minimum and Maximum Gain Error

Temperature	Minimum Gain Error	Maximum Gain Error
25 °C	–0.200%	0.200%
–40 °C	–0.200%	0.356%
125 °C	–0.440%	0.200%
Global (–40 °C to 125 °C)	–0.440%	0.356%

3.4. Nonlinearity and Nonlinearity Drift

Nonlinearity is a measure of the deviation of the actual device output at 25 °C from that predicted by the linear gain equation implied by the nominal gain and offset specifications. The data sheet minimum and maximum nonlinearity values specify the worst-case output deviation from the ideal gain line over the specified linear input range, expressed as a percentage of the input voltage.

Nonlinearity drift specifies how nonlinearity may vary over the operating temperature.

3.4.1. Total Nonlinearity for an Isolated Current Sensing Application

Figure 8 represents the nonlinearity boundary across temperature for the Si8922B devices, followed by Table 5, which shows the minimum and maximum error values.

Note: This is the calculated nonlinearity error over the specified linear input range. Refer to the data sheet "Nonlinearity vs. Input Signal Amplitude" plot to see typical behavior outside this range.

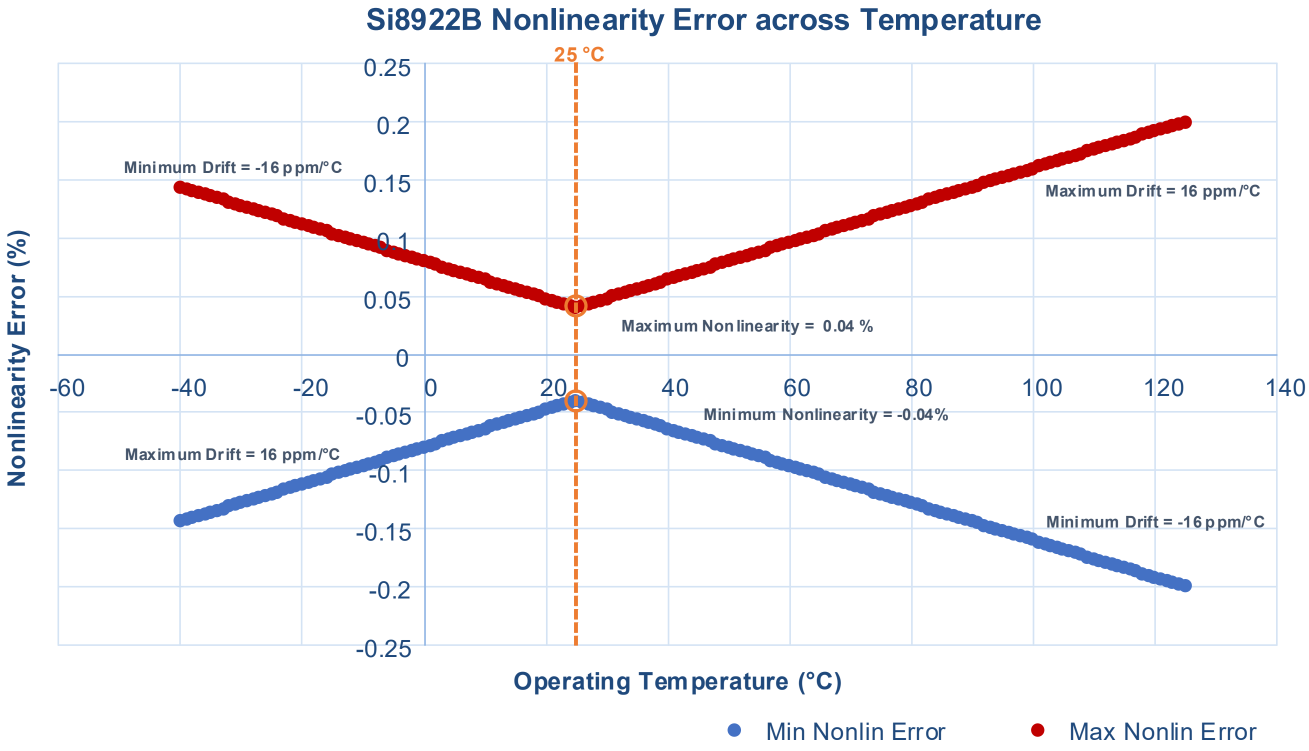

Figure 8. Si8922B Nonlinearity Error across Temperature

Table 5. Si8922B Minimum and Maximum Nonlinearity

Temperature	Minimum Nonlinearity	Maximum Nonlinearity
25 °C	–0.040%	0.040%
–40 °C	–0.144%	0.144%
125 °C	–0.200%	0.200%
Global (–40 °C to 125 °C)	–0.200%	0.200%

3.5. Estimating Total Static Error

For parameters that are perfectly correlated and have the same sign, minimum or maximum values may sum directly as they will reach their limits at the same time. This simple sum of the min and max error terms from various error sources guarantees that the limit will never be exceeded, but often will give an overly conservative estimation of total error if the sources are not well correlated. A less pessimistic approach to uncorrelated values may be found by calculating the square root of the sum of the squares of the values (root-sum-of-squares, or RSS). The RSS approach is based on the statistical notion that when adding two random distributions, the standard deviation of the result is equal to the square root of the sum of the squares of the initial distributions' standard deviations. This is more realistic when the error sources are uncorrelated.

Equation 4 and Equation 5 show the minimum and maximum calculations using the RSS approach.

$$\sqrt{-0.218^2 + -0.440^2 + -0.200^2}\ \% = -0.530\ \%$$

Equation 4.

$$\sqrt{0.260^2 + 0.356^2 + 0.200^2}\ \% = 0.484\ \%$$

Equation 5.

Table 6 presents both direct sum and root-sum-of-squares total error values.

Table 6. Si8922B Total Static Error

Error Term	Minimum	Maximum
Input Referred Offset	–0.218%	0.260%
Gain Error	–0.440%	0.356%
Nonlinearity	–0.200%	0.200%
Sum	–0.858%	0.816%
RSS	–0.530%	0.484%

4. Summary

This application note summarized the different types of static error that can be observed while using Skyworks' Si89xx family of isolated amplifiers and modulators. This document provided application circuits for the different devices and example calculations for each type of error. The root-sum-of-squares method is suggested as the best estimate of total static error for these devices. For more information on these products, refer to the Skyworks web page.

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