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APPLICATION NOTE 4170

Improve Current Measurement Accuracy by Skewing the Input Offset Voltage on Current-Sense Amplifiers

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Abstract: Some applications require that the input offset voltage (V_{OS}) of current-sense amplifiers be calibrated to enhance measurement accuracy. This is not a straightforward task because of interactions between the output voltage low (V_{OL}) and the input V_{OS}. This application note outlines a simple method to artificially "skew" the input V_{OS} of unidirectional current-sense amplifiers. The method allows measurement of total-input V_{OS} without the normal limitations from V_{OL}, and improves the overall accuracy of current measurements. The MAX4080 current-sense amplifier serves as the example of the technique.

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Introduction

Current-sense amplifiers are sophisticated ICs, popular in electronic equipment that monitors load currents in real time. System controllers use this load information to implement power-management algorithms that modify the load-current characteristic itself, and to implement flexible overcurrent protection schemes.

Current-sense amplifiers magnify a small differential voltage while rejecting the input common-mode voltage. In this role they operate like traditional op amp-based differential amplifiers. There is, however, an important difference between these two amplifier architectures. The input common-mode voltage for current-sense amplifiers is allowed to exceed the power-supply (V_{CC}) voltage. When, for example, the MAX4080 current-sense amplifier is powered from V_{CC} = 5V, it can still withstand an input common-mode voltage of 76V. By using unique amplifier architectures, current-sense amplifiers are not hampered by the common-mode rejection limitations (CMRR) that arise from mismatched resistors. The MAX4080, for example, has 100dB (min) DC CMRR. In contrast, the performance of traditional op amp-based differential amplifiers is negatively impacted by CMRR, and their effective input V_{OS} is magnified through the signal chain.

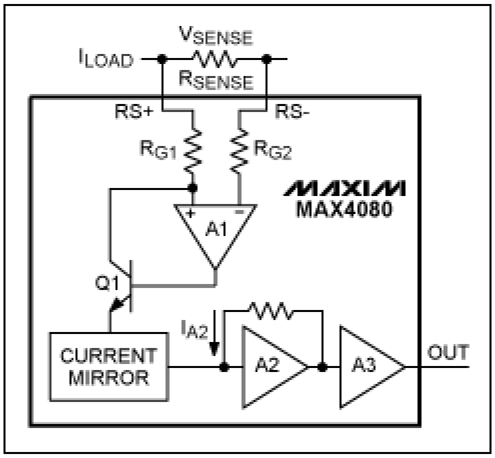

Figure 1. The MAX4080 is a precision unidirectional current-sense amplifier.

Using Calibration to Improve Precision

The MAX4080 has a precision ±0.6mV (max) input offset voltage (V_{OS}) at 25°C, and ±1.2mV (max) V_{OS} over the -40°C to +125°C temperature range. Some applications, however, need to further calibrate input V_{OS} to enhance precision of the final current measurement. To do this calibration, V_{OS} is typically measured during production and stored in firmware. This V_{OS} is then adjusted digitally in real time when the equipment is in the field and in use.

A preferred method of calibration, intended for the convenience of manufacturing, would measure the V_{OS} when there is zero load current (zero input differential voltage). In this approach one could measure the output V_{OS} and subtract this voltage from all future measurements. Unfortunately, this method has a drawback. The V_{OL} (output voltage low) and input V_{OS} specifications interact, causing the output voltage not to reflect the input V_{OS} accurately. This interaction is, in fact, characteristic of all single-supply amplifiers.

Consider the example of the MAX4080T with a gain of 20, and hypothetical zero input V_{OS}. One would then expect to measure a true zero at the amplifier's output. However, even at zero input differential voltage, the amplifier is not guaranteed to output a voltage below 15mV (with 10µA sink current). In fact, if the output voltage measurements were used directly for V_{OS} calibration, the amplifier would appear to have a 0.75mV input V_{OS} (15mV/20 = 0.75mV).

Similarly, if a MAX4080T did have V_{OL} = 0, then a positive input V_{OS} will produce a positive output V_{OS} as expected. However, a negative input V_{OS} will not be "reflected" in the output voltage measurement, since the amplifier cannot really output a voltage below ground. Thus to summarize, one cannot "directly" use an output voltage measurement with zero input differential voltage to calibrate the input V_{OS}.

There are two methods typically used to calibrate V_{OS} during production:

1. A bidirectional current-sense amplifier like the MAX4081 is used with a reference voltage of about 1.5V. This effectively translates the output voltage measurements by 1.5V, so a zero input differential voltage will output 1.5V ±V_{OS}-induced errors. Since this 1.5V voltage is well above the amplifier's V_{OL}, it does not affect error analysis. V_{OS} errors can thus be calculated by measuring the difference between the output voltage and the ideal 1.5V input reference voltage. There is a drawback to this method: reduced dynamic range. The 0V–5V input range of the ADC is now reduced by 30% to 1.5V–5V. Additionally, the method requires a more expensive bidirectional

current-sense amplifier to be used for unidirectional measurements. Finally, generating a low-drift 1.5V reference voltage or spending a second channel to measure this 1.5V reference voltage is not attractive.

2. A two-point measurement method is employed in which two known values of a differential input voltage (load currents) are applied to the current-sense amplifier. First, straight-line approximation is applied to the output voltage measurements to calculate the input V_{OS} by extrapolating to a zero-sense voltage. Secondly, that voltage measurement is then used for calibration. This method has its drawback: it uses two "known" exact values of currents during production, which is inconvenient and increases test time. Finally, accurate measurements close to a zero input differential voltage are still not achieved because V_{OL} limitations will cause errors at small sense voltages.

Using Input Resistors to Introduce Input V_{OS}

This application note presents a third method for measuring the input V_{OS} of a current-sense amplifier. Once again, the MAX4080 serves as the example. This approach applies a zero input differential voltage and overcomes the interactions between V_{OL} and V_{OS}—making it easy to use on the production line.

All current-sense amplifiers have input bias currents. Therefore the use of input resistors (for input filtering, as an example) should be carefully studied since the resistors can introduce unplanned gain and offset errors. These issues are detailed in application note 3888, "Performance of Current-sense Amplifiers with Input Sense Resistors." The method presented here uses similar techniques, but in this case, the input resistors are intentionally mismatched. In this manner an intentional output V_{OS} is introduced. The MAX4080 has a temperature-compensated bias current of 5µA (typ) and 12µA (max) over process variation. Using a 2kΩ resistor in series with RS- (**Figure 2**) thus produces a typical input V_{OS} of 10mV and 24mV, respectively, over process variation. This additional input V_{OS} then causes an output offset of 200mV (typ) and 480mV (max), which is adequate to override any V_{OL} and V_{OS} limitations in the basic MAX4080. Error in this input-resistor-induced V_{OS} will have a temperature dependence based both on the drift characteristics of the input resistor (usually 100ppm) and on the bias current (negligible).

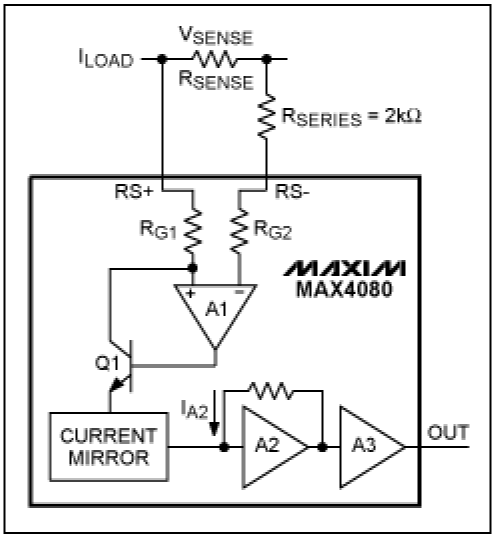

Figure 2. The MAX4080 configured to use an external 2kΩ resistor in series with RS-.

The resistor drift characteristic of +100ppm causes a +1% change in the resistance value over a 100°C change (i.e., +20Ω). Additional input V_{OS} drift from the input resistor is then typically about +0.1mV, and

+0.24mV max across the process variation of bias current. This drift is still only 20% of the ±0.6mV bidirectional error in input V_{OS} that one would usually expect from process variation if no calibration were used.

To account for the 15mV V_{OL} and the ±1.2mV input V_{OS} over temperature, the additional input V_{OS} would need to be a minimum of 1.2mV + 15mV/20 = 1.95mV ≈ 2mV, approximately. **Table 1** shows the test results over temperature. Here, the MAX4080 has negligible drift in V_{OS}, and so all measured drift in V_{OS} is due to the use of input resistor and its ppm drift.

Table 1. Results of Temperature Tests With and Without Input Resistors

V_{OS}	-40°C	+25°C	+85°C	+125°C
No Input Resistors	-0.015mV	0mV	-0.005mV	-0.01mV
2kΩ in Series with RS-	9.69mV	9.73mV	9.76mV	9.80mV

Conclusion

This application note presents a method that introduces known input V_{OS} by suitably sizing input resistors for current-sense amplifiers like the MAX4080. Equipment manufacturers can thus use this methodology for production-line calibration of V_{OS} with zero input current to enhance the accuracy of real-time measurements.

Related Parts		
MAX4080	76V, High-Side, Current-Sense Amplifiers with Voltage Output	Free Samples
MAX4081	76V, High-Side, Current-Sense Amplifiers with Voltage Output	Free Samples

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