AN4366
Application note

Compensate the input offset of a high-side current sensing

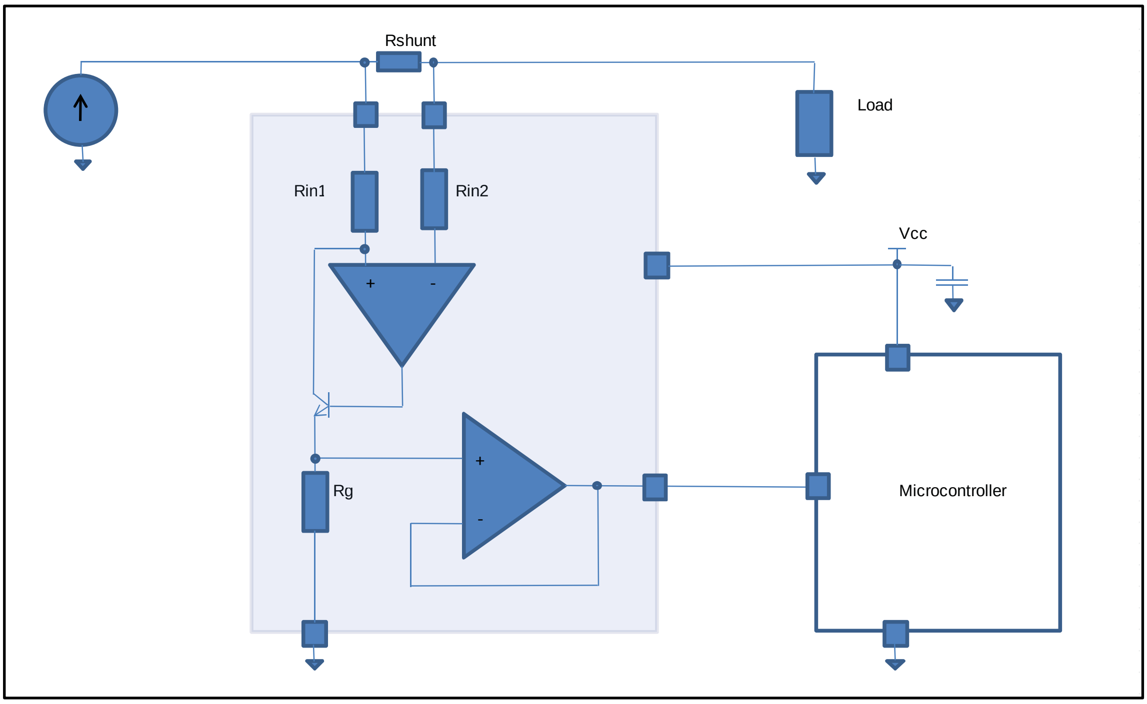
Nicolas Aupetit

Introduction

This application note explains how to configure a high-side current sensing when it is powered in single supply. This approach is especially useful when a low current must be measured.

A high-side current sensing can amplify input differential signals at a common-mode voltage well beyond the power supply rail. This common-mode voltage, in a current-sense amplifier such as the TSC101, can rise to 28 V and can rise even higher in the TSC103. The device amplifies small voltages across a shunt resistor on the high-voltage rail and feeds it to a low-voltage ADC generally embedded into a microcontroller (see *Figure 1*). By construction, all current sensing devices have a small input offset. Depending on whether this input offset voltage is positive or negative, there may be an impact on the measurement of a low current.

Figure 1: Typical application schematic



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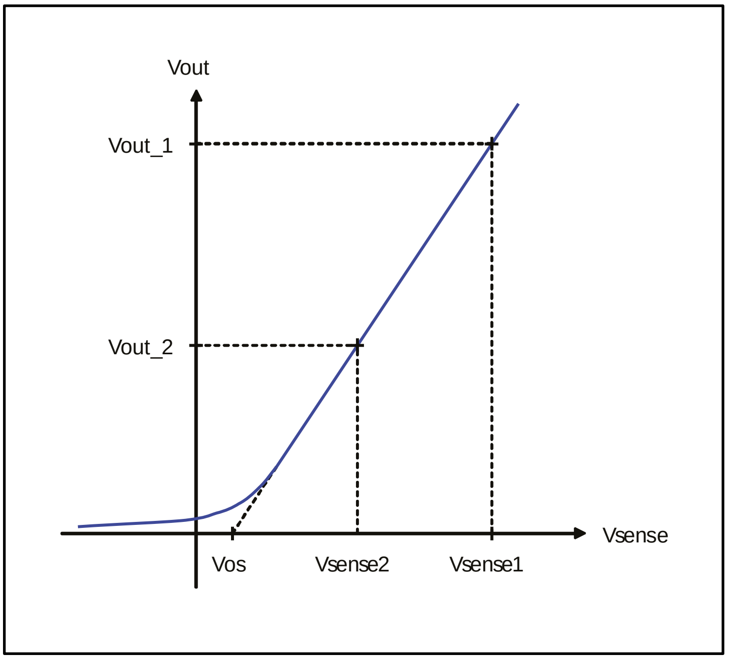
1 Definition of input offset voltage (Vos)

The input offset voltage (Vos) is defined as the intersection between the linear regression of the Vout vs. the Vsense curve with the X-axis (see *Figure 2*).

If Vout1 is the output voltage where Vsense = Vsense1, and if Vout2 is the output voltage where Vsense = Vsense2, then Vos can be calculated using following equation 1:

$$\mathrm{Vos} = \mathrm{Vsense1} - \left(\frac{\mathrm{Vsense1} - \mathrm{Vsense2}}{\mathrm{Vout}_1 - \mathrm{Vout}_2} * \mathrm{Vout}_1\right) \quad (\mathbf{1})$$

Figure 2: Vout vs Vsense

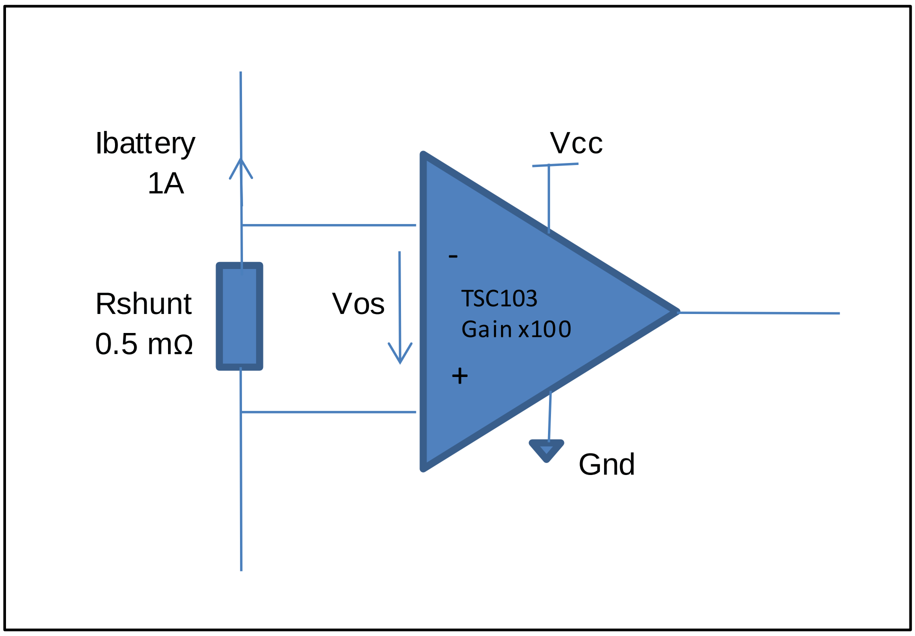


2 Saturation problem

If the TSC103 is used in single supply with a positive Vos (see Figure 2 in *Section 1: "Definition of input offset voltage (Vos)"*) and zero current through the shunt, it becomes saturated and the output is clamped to the Vol. Unfortunately, this phenomenon also holds true with a positive Vos and low current. In such a case, a voltage drop through the shunt, lower than the Vos of the current sensing, gives an incorrect output value.

Let us consider an automotive application where it is necessary to sense the current of the battery. The minimum current that must be measured is 1 A. To limit the power dissipation, a 0.5 mΩ shunt resistor is used. The current sensing, TSC103, powered in single supply and set with a gain of 100 is used to measure the current (see *Figure 3*).

Figure 3: Current sensing single supply



The native input offset of the TSC103 might be, in the worst case, +1.1 mV or -1.1 mV, and the maximum Vol might be 125 mV. The output voltage of the TSC103 is given by equation (2):

$$\text{Vout} = (\text{Ibattery}.\text{Rshunt} - \text{Vos}).\text{Gain} \quad (\mathbf{2})$$

To obtain a valuable measurement, the Vout must be higher than the output stage, low-state saturation voltage i.e. Vout > Vol.

Negative Vos (Vos of the TSC103 = -1.1 mV)

When it is necessary to measure 1 A, the voltage output of the TSC103 using equation 2 is: Vout = (1 A * 0.5 mΩ + 1.1 mV) * 100 = 160 mV. This value is acceptable as it is above the maximum Vol of the TSC103.

Positive Vos (Vos of the TSC103 = +1.1 mV)

When it is necessary to measure 1 A, the voltage output of the TSC103 using equation 2 is: Vout = (1 A * 0.5 mΩ -1.1 mV) * 100 = -60 mV. As the TSC103 is powered in single supply the output in this case is saturated and Vout = Vol. In this case, a current lower than 4.7 A (see equation 3 below), cannot be measured correctly by the current sensing due to the Vos and Vol limitation.

$$\mathrm{Imin} = \frac{\frac{Vol}{Gain} + \mathrm{Vos\ max}}{\mathrm{Rshunt}} \quad \mathbf{(3)}$$

3 How to compensate the input offset voltage

The input offset can be compensated and output saturation can be avoided thanks to:

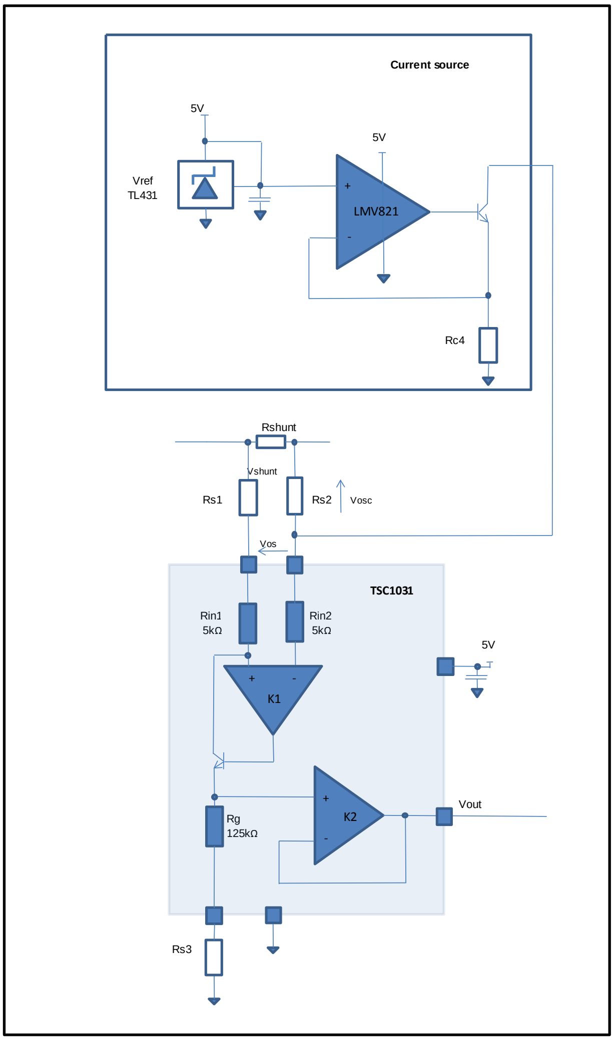
- an external current source
- added resistances

To realize this compensation, it is recommended to use the TSC1031 rather than the TSC103. Both devices are very similar in terms of their electrical characteristic, but the TSC1031 is a more flexible current sensing solution as it allows the Rg internal resistors values to be externally changed.

The main objective is to compensate the input offset by creating an opposite voltage, VosC, thanks to an Rs2 resistance and a current source. In order to compensate the native Vos, it is important that: (-Vos + Vosc + Vshunt) * Gain > Vol.

Figure 4 shows the architecture where the current sensing device always has a negative input offset. The current source is made of few components: a voltage reference (TL431), an op-amp (LMV821) which is used as a buffer, a NPN transistor, and one resistor (Rc4).

Figure 4: Schematic to compensate Vos



The Vosc is calculated using equation 4:

$$\text{Vosc} = \frac{\text{Rs2} * \text{Vref}}{\text{Rc4}} \ (\mathbf{4})$$

Note: adding the resistances Rs1, Rs2, and Rs3 has a direct impact on the whole gain of the TSC1031. The values of these resistances must be chosen carefully.

4 Influence of the external resistances

The values of Rs1 and Rs2 should be equal to balance the contribution on both amplifier inputs. The TSC1031 has several trimmed input resistances. Any external resistances added in series change the value of the original gain, K1 = 25 (see equation 5).

$$\text{K1 gain (with Rs)} = \frac{\text{Rg}}{\text{Rin} + \text{Rs}} \quad (\mathbf{5})$$

Where Rin is the specified amplifier input resistance.

Assuming that Rs = 100 Ω, the gain, K1, becomes:

$$\text{K1} = \frac{125\ \text{k}\Omega}{5\ \text{k}\Omega + 100} = 24.51$$

Therefore, to keep the gain as close as possible to 25, ensure that the input series resistors, Rs1 and Rs2, are small compared to Rin. Using a resistor that is less than 10 Ω is strongly recommended.

To balance the contribution of Rs1 and Rs2 in the current sense amplifier gain, an output resistor Rs3 should be connected between pin A1 and the Gnd of the TSC1031. The value of Rs3 should be chosen according to equation 6:

$$\text{K1} = 25 = \frac{\text{Rg}}{\text{Rin}} = \frac{\text{Rs3}}{\text{Rs1}} \quad (\mathbf{6})$$

To keep the gain constant (i.e. K1 = 25), let Rs3 = 250 Ω for Rs1 = 10 Ω.

To avoid an error on the gain or output offset voltage it is extremely important to:

- keep the value of the external resistances, Rs1 and Rs2, as low as possible
- match resistances

Other parameters, such as the process variation or the temperature coefficient of the resistances must also be taken into consideration regarding the current measurement error. All calculations of the total error due to external resistances are detailed in the application note "AN4369 *Adjustable gain with a current sensing".*

5 Current source

The current necessary to compensate the Vos should be high enough not to be impacted by the gain error and low enough to allow reasonable values of Rs1 and Rs2 to be chosen.

Note that the current is generated by the current source and that gain error may appear in temperature due to the external resistors.

To achieve good accuracy and to maintain the initial gain, the external resistances are set as follow:

- Rs1 = Rs2 = 10 Ω
- Rs3 = 250 Ω which maintains K1 = 25
- K2 = 4 by setting SEL = Vcc+

In this configuration the total gain is: AV = K1.K2 = 100.

If we consider the worst situation, i.e. when the TSC1031 has a positive Vos offset of +1.1 mv, in this case the output of the TSC1031 could become saturated. To avoid this, add a negative offset compensation of 2 mV. Then, we can deduce that the current which must be drawn by the current source is:

$$\mathrm{Isource} = \frac{Vsource}{\mathrm{Rs2}} = \frac{2\ \mathrm{mV}}{10\ \Omega} = 200\ \mu\mathrm{A} \quad (\mathbf{7})$$

The current delivered by the current source is mainly fixed thanks to the reference voltage TL431 (2.5V) and the resistance Rc4. So,

$$\mathrm{Rc4} = \frac{2.5\ V}{200\ \mu\mathrm{A}} = 12.5\ \mathrm{k\Omega} \quad (\mathbf{8})$$

A possible op-amp to drive the NPN transistor is the automotive grade LMV821A (order code LMV821AIYLT).

6 Outcome

If finally, the native Vos of the TSC1031 is +1.1 mV with the current source compensation, the equivalent input offset Vos becomes -0.9 mV. If finally, the native Vos of the TSC1031 is -1.1 mV with the current source compensation, the equivalent input offset Vos becomes -3.1 mV.

Considering the whole application, with the TSC1031 gain set at x100 and measuring a current of 1 A through a shunt of 0.5 mΩ, the output voltage may vary from 140 mV to 360 mV. In this case, the output of the TSC1031 (used in single supply) is never saturated.

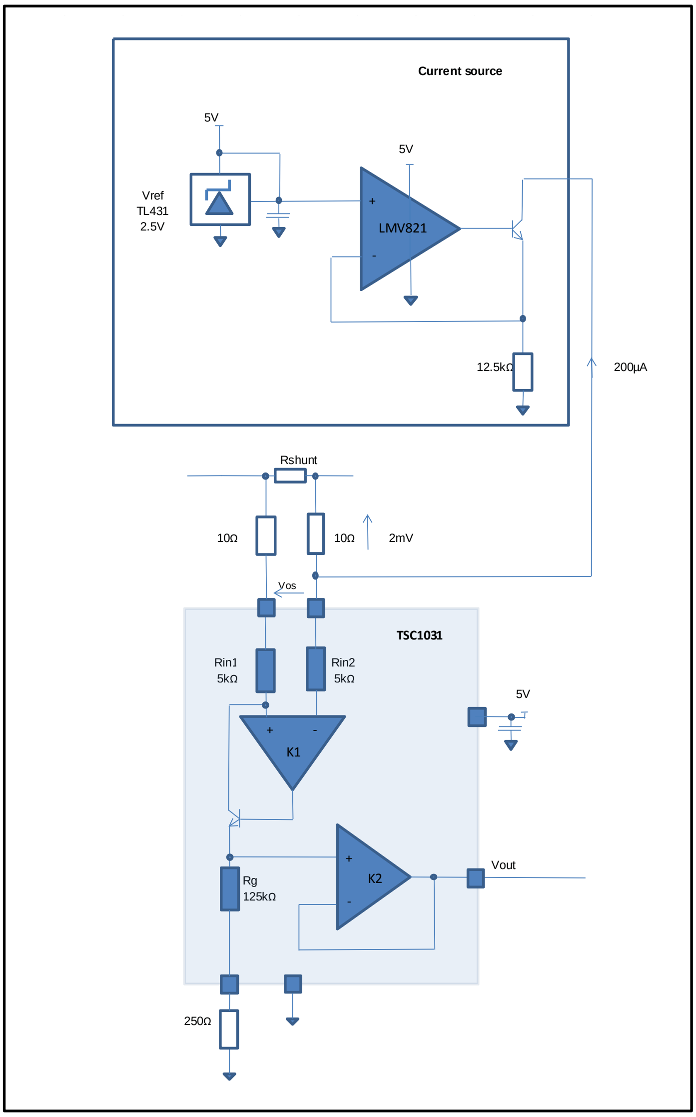
7 Conclusion

A current sensing powered in single supply is able to measure low current. However, if the voltage drop through the shunt is lower than the Vos, it might cause some output saturation problems. In this case, it is important to compensate the Vos by using external resistances and a current source.

The resistances must be as low as possible and must be well matched to avoid inaccurate measurements. The current source must be well dimensioned.

For this kind of compensation, it is important to realize a calibration before starting the measurement. Firstly, measure the output voltage with a minimum current through the shunt, and then used this baseline value as a reference of minimum current. *Figure 5* is a suggested schematic to compensate the Vos. It avoids any output saturation for low current measurements.

Figure 5: Suggested schematic to compensate Vos



8 Revision history

Table 1: Document revision history

Date	Revision	Changes
05-Feb-2014	1	Initial release