

Compensate the input offset of a high-side current sensing

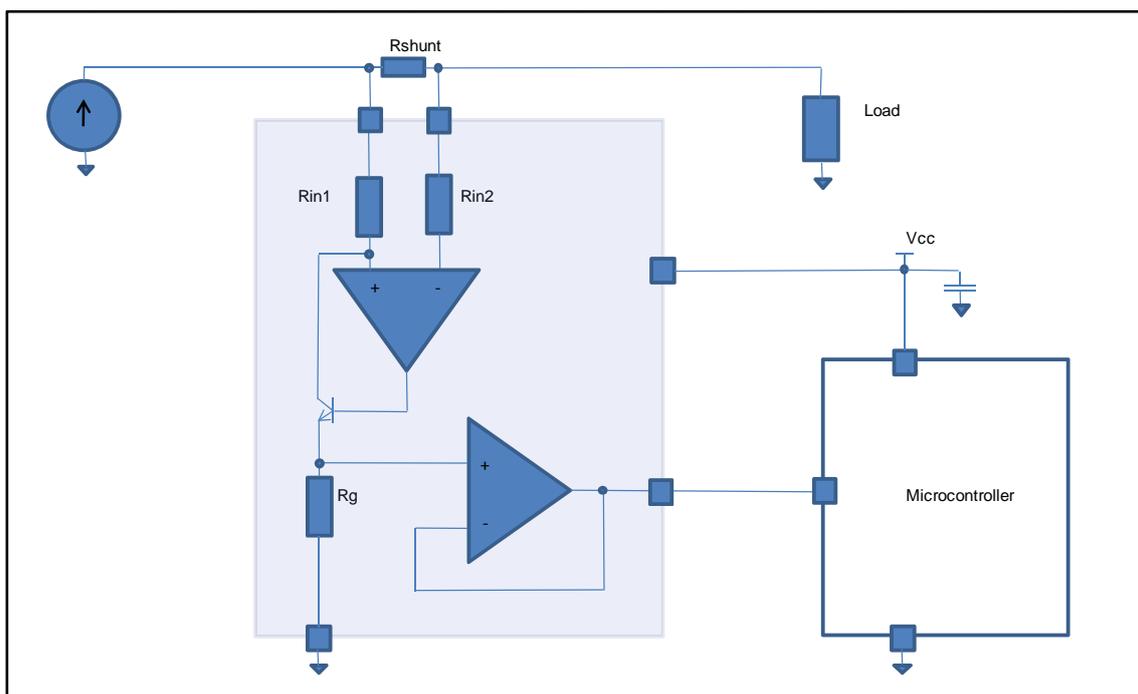
Nicolas Aupetit

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



Contents

1	Definition of input offset voltage (Vos).....	4
2	Saturation problem.....	5
3	How to compensate the input offset voltage.....	7
4	Influence of the external resistances.....	9
5	Current source.....	10
6	Outcome.....	11
7	Conclusion.....	12
8	Revision history	13

List of figures

Figure 1: Typical application schematic.....	1
Figure 2: V_{out} vs V_{sense}	4
Figure 3: Current sensing single supply	5
Figure 4: Schematic to compensate V_{os}	7
Figure 5: Suggested schematic to compensate V_{os}	12

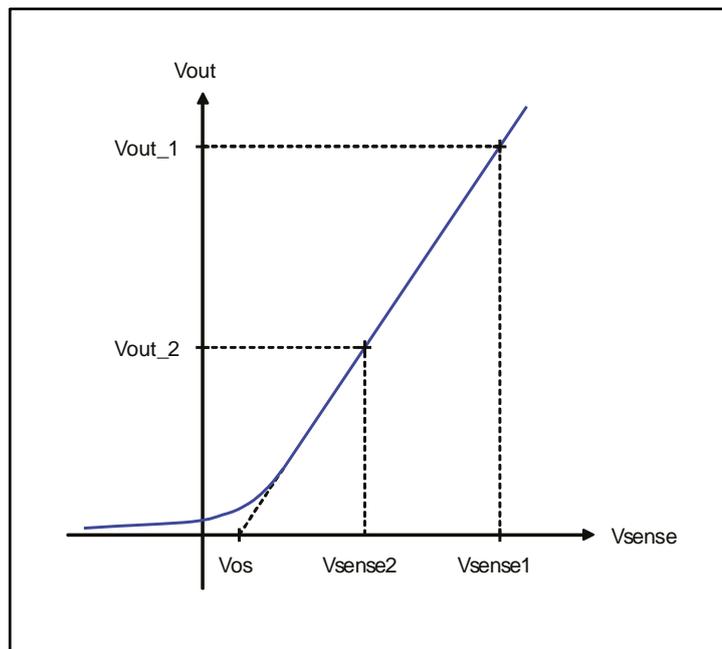
1 Definition of input offset voltage (Vos)

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:

$$V_{os} = V_{sense1} - \left(\frac{V_{sense1} - V_{sense2}}{V_{out1} - V_{out2}} * V_{out1} \right) \quad (1)$$

Figure 2: Vout vs Vsense

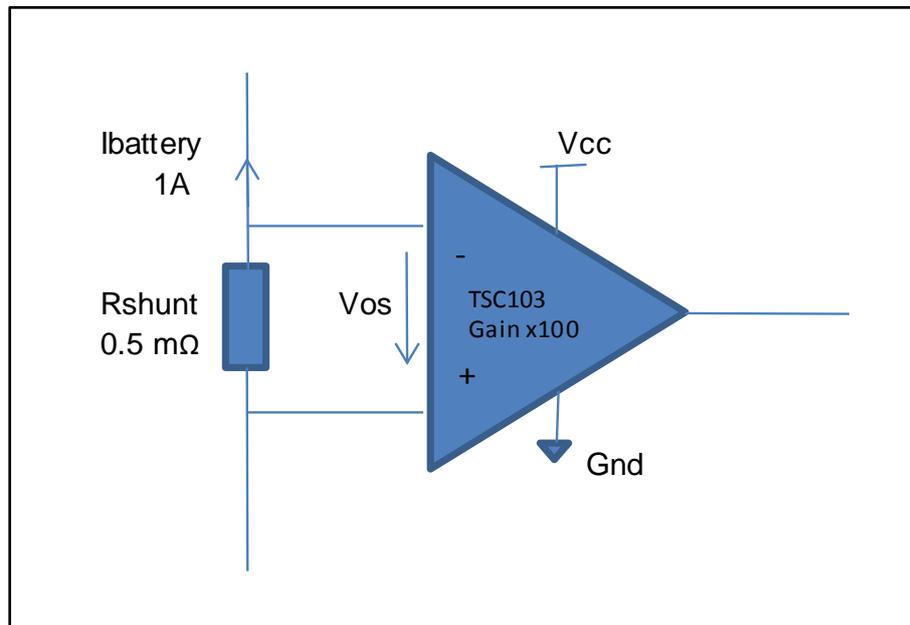


2 Saturation problem

If the TSC103 is used in single supply with a positive V_{os} (see Figure 2 in [Section 1: "Definition of input offset voltage \(\$V_{os}\$ \)"](#)) and zero current through the shunt, it becomes saturated and the output is clamped to the V_{ol} . Unfortunately, this phenomenon also holds true with a positive V_{os} and low current. In such a case, a voltage drop through the shunt, lower than the V_{os} 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 m Ω 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 V_{ol} might be 125 mV. The output voltage of the TSC103 is given by equation (2):

$$V_{out} = (I_{battery} \cdot R_{shunt} - V_{os}) \cdot \text{Gain} \quad (2)$$

To obtain a valuable measurement, the V_{out} must be higher than the output stage, low-state saturation voltage i.e. $V_{out} > V_{ol}$.

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: $V_{out} = (1 \text{ A} * 0.5 \text{ m}\Omega + 1.1 \text{ mV}) * 100 = 160 \text{ mV}$. 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: $V_{out} = (1 \text{ A} * 0.5 \text{ m}\Omega - 1.1 \text{ mV}) * 100 = -60 \text{ mV}$. As the TSC103 is powered in single supply the output in this case is saturated and $V_{out} = Vol$. 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.

$$I_{min} = \frac{\frac{Vol}{Gain} + Vos_{max}}{R_{shunt}} \quad (3)$$

3 How to compensate the input offset voltage

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

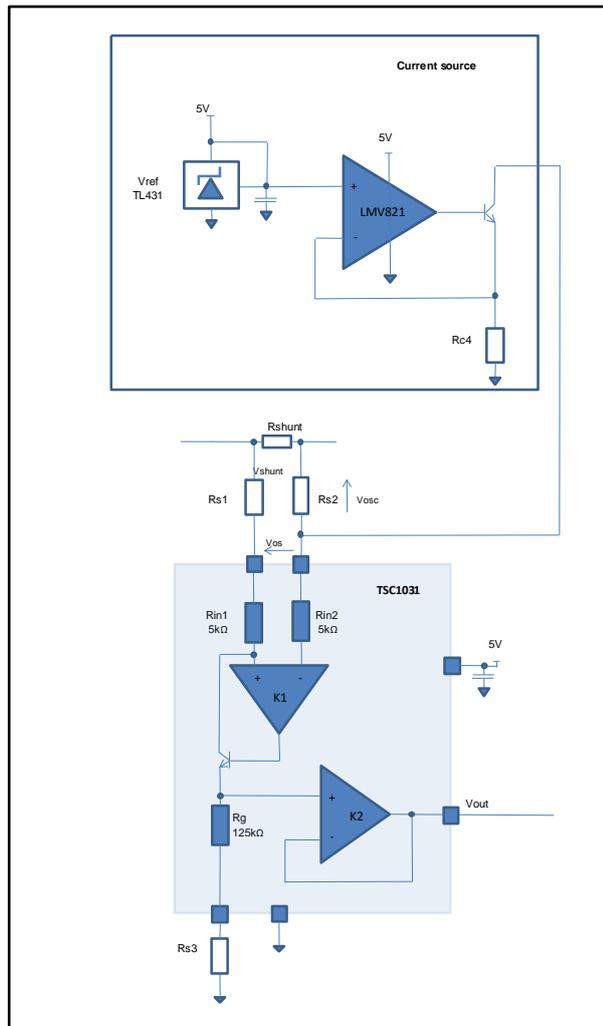
- an external current source
- added resistances

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: $(-V_{os} + V_{osc} + V_{shunt}) * Gain > V_{ol}$.

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 V_{osc} is calculated using equation 4:

$$V_{osc} = \frac{R_{s2} * V_{ref}}{R_{c4}} \quad (4)$$

Note: adding the resistances R_{s1} , R_{s2} , and R_{s3} 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 R_{s1} and R_{s2} 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).

$$K1 \text{ gain (with } R_s) = \frac{R_g}{R_{in} + R_s} \quad (5)$$

Where R_{in} is the specified amplifier input resistance.

Assuming that $R_s = 100 \Omega$, the gain, $K1$, becomes:

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

Therefore, to keep the gain as close as possible to 25, ensure that the input series resistors, R_{s1} and R_{s2} , are small compared to R_{in} . Using a resistor that is less than 10Ω is strongly recommended.

To balance the contribution of R_{s1} and R_{s2} in the current sense amplifier gain, an output resistor R_{s3} should be connected between pin A1 and the Gnd of the TSC1031. The value of R_{s3} should be chosen according to equation 6:

$$K1 = 25 = \frac{R_g}{R_{in}} = \frac{R_{s3}}{R_{s1}} \quad (6)$$

To keep the gain constant (i.e. $K1 = 25$), let $R_{s3} = 250 \Omega$ for $R_{s1} = 10 \Omega$.

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

- keep the value of the external resistances, R_{s1} and R_{s2} , 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 V_{os} should be high enough not to be impacted by the gain error and low enough to allow reasonable values of R_{s1} and R_{s2} 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:

- $R_{s1} = R_{s2} = 10 \Omega$
- $R_{s3} = 250 \Omega$ which maintains $K1 = 25$
- $K2 = 4$ by setting $SEL = V_{cc+}$

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 V_{os} 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:

$$I_{source} = \frac{V_{source}}{R_{s2}} = \frac{2 \text{ mV}}{10 \Omega} = 200 \mu\text{A} \quad (7)$$

The current delivered by the current source is mainly fixed thanks to the reference voltage TL431 (2.5V) and the resistance R_{c4} . So,

$$R_{c4} = \frac{2.5 \text{ V}}{200 \mu\text{A}} = 12.5 \text{ k}\Omega \quad (8)$$

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

6 Outcome

If finally, the native V_{os} of the TSC1031 is +1.1 mV with the current source compensation, the equivalent input offset V_{os} becomes -0.9 mV. If finally, the native V_{os} of the TSC1031 is -1.1 mV with the current source compensation, the equivalent input offset V_{os} 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 m Ω , 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.

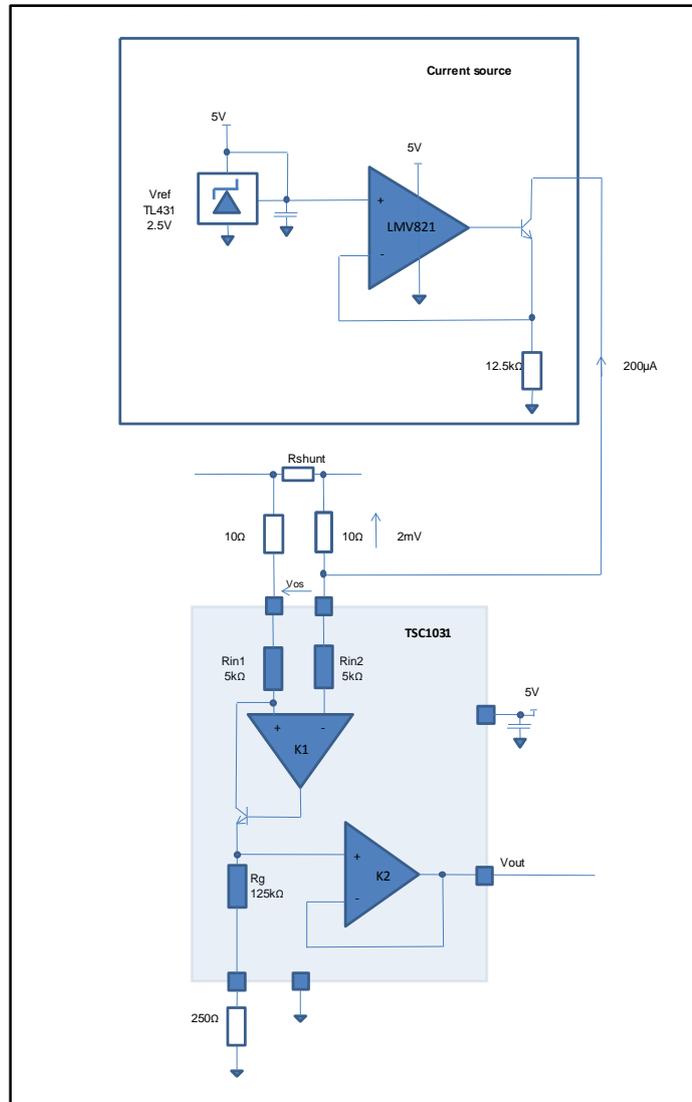
7 Conclusion

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

Please Read Carefully

Information in this document is provided solely in connection with ST products. STMicroelectronics NV and its subsidiaries ("ST") reserve the right to make changes, corrections, modifications or improvements, to this document, and the products and services described herein at any time, without notice.

All ST products are sold pursuant to ST's terms and conditions of sale.

Purchasers are solely responsible for the choice, selection and use of the ST products and services described herein, and ST assumes no liability whatsoever relating to the choice, selection or use of the ST products and services described herein.

No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted under this document. If any part of this document refers to any third party products or services it shall not be deemed a license grant by ST for the use of such third party products or services, or any intellectual property contained therein or considered as a warranty covering the use in any manner whatsoever of such third party products or services or any intellectual property contained therein.

UNLESS OTHERWISE SET FORTH IN ST'S TERMS AND CONDITIONS OF SALE ST DISCLAIMS ANY EXPRESS OR IMPLIED WARRANTY WITH RESPECT TO THE USE AND/OR SALE OF ST PRODUCTS INCLUDING WITHOUT LIMITATION IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE (AND THEIR EQUIVALENTS UNDER THE LAWS OF ANY JURISDICTION), OR INFRINGEMENT OF ANY PATENT, COPYRIGHT OR OTHER INTELLECTUAL PROPERTY RIGHT.

ST PRODUCTS ARE NOT DESIGNED OR AUTHORIZED FOR USE IN: (A) SAFETY CRITICAL APPLICATIONS SUCH AS LIFE SUPPORTING, ACTIVE IMPLANTED DEVICES OR SYSTEMS WITH PRODUCT FUNCTIONAL SAFETY REQUIREMENTS; (B) AERONAUTIC APPLICATIONS; (C) AUTOMOTIVE APPLICATIONS OR ENVIRONMENTS, AND/OR (D) AEROSPACE APPLICATIONS OR ENVIRONMENTS. WHERE ST PRODUCTS ARE NOT DESIGNED FOR SUCH USE, THE PURCHASER SHALL USE PRODUCTS AT PURCHASER'S SOLE RISK, EVEN IF ST HAS BEEN INFORMED IN WRITING OF SUCH USAGE, UNLESS A PRODUCT IS EXPRESSLY DESIGNATED BY ST AS BEING INTENDED FOR "AUTOMOTIVE, AUTOMOTIVE SAFETY OR MEDICAL" INDUSTRY DOMAINS ACCORDING TO ST PRODUCT DESIGN SPECIFICATIONS. PRODUCTS FORMALLY ESCC, QML OR JAN QUALIFIED ARE DEEMED SUITABLE FOR USE IN AEROSPACE BY THE CORRESPONDING GOVERNMENTAL AGENCY.

Resale of ST products with provisions different from the statements and/or technical features set forth in this document shall immediately void any warranty granted by ST for the ST product or service described herein and shall not create or extend in any manner whatsoever, any liability of ST.

ST and the ST logo are trademarks or registered trademarks of ST in various countries.

Information in this document supersedes and replaces all information previously supplied.

The ST logo is a registered trademark of STMicroelectronics. All other names are the property of their respective owners.

© 2014 STMicroelectronics - All rights reserved

STMicroelectronics group of companies

Australia - Belgium - Brazil - Canada - China - Czech Republic - Finland - France - Germany - Hong Kong - India - Israel - Italy
- Japan - Malaysia - Malta - Morocco - Philippines - Singapore - Spain - Sweden - Switzerland - United Kingdom - United
States of America

www.st.com