How to Extend the Performance of a Low Voltage Precision Op Amp to a High Voltage High Side Current Sensing Application

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Introduction

Dedicated devices that support extended common mode voltage are generally used for high side current sensing. But dedicated devices have their own limitations. What about when the common mode voltage exceeds 100V? Is it possible to precisely measure a current then? A classic 5V Op amp seems totally inappropriate for this kind of measurement. But with just a few external components, we are going to see that low voltage amplifiers are absolutely appropriate for sensing a current accurately without any of the common mode voltage limitations.

Schematic & description

The main goal of this application is to measure the current of an industrial motor control, powered with 150V, as illustrated by figure 1, thanks to a shunt resistor. In order to get a precise measurement for low current, a 5V precision Op amp is used.

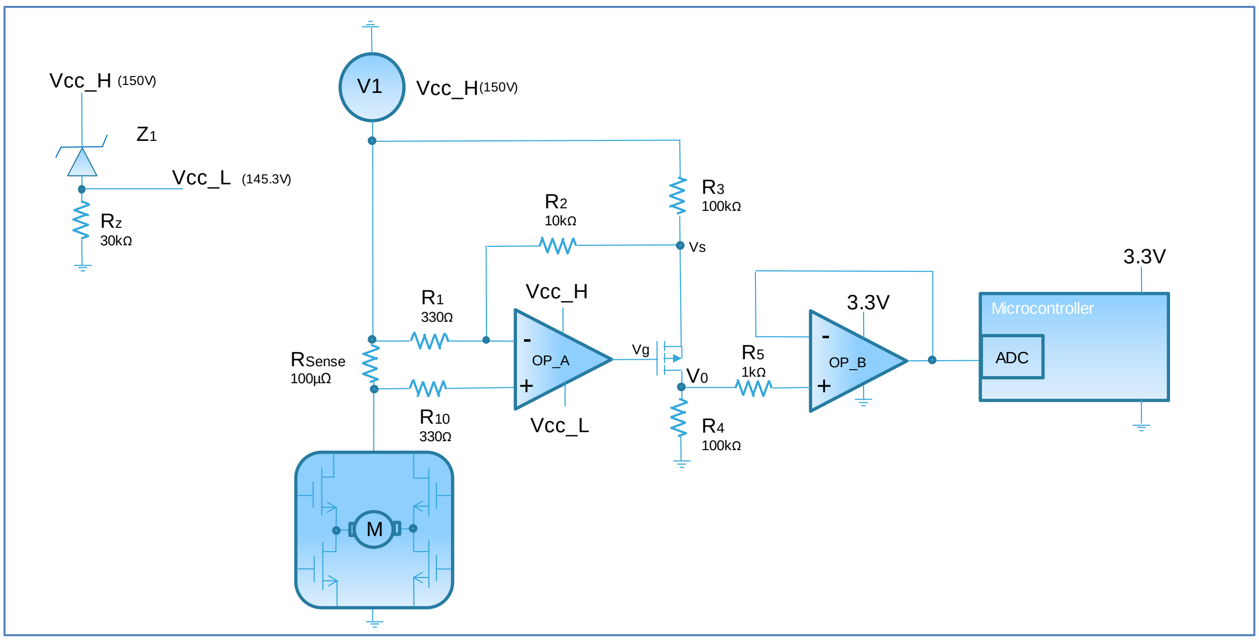

Figure 1: Typical application

Won't 150V input burn up the Op amp? Not if the V1 voltage is used to generate the positive power supply (Vcc_H) for the first Op amp, OP_A.

If we use a Zener diode (BZT52C4V7S) with a 4.7V breakdown voltage, the negative power supply (Vcc_L) of the OP_A is generated. In this way, the OP_A is powered with 4.7V, from Vcc_L=145.3V to Vcc_H=150V.

The resistance Rz is used to bias the zener diode (~5mA) and provide a return path for the bias current of the Opamp (~40µA).

The voltage, Vsense, is the result of the current flowing through Rsense, and it is amplified by R1, R2, R3 and R4 resistances.

The P-MOSFET (BSP2220) sources an accurate output current proportional to the current flowing into Rsense, and with the R4 resistance, it generates a voltage Vo with respect to ground, which is proportional to the high side current. The voltage output of the first stage can be given by equation 1:

$$Vo = \frac{Vsense}{R1}\frac{R4}{R3}.(R1 + R2 + R3) \qquad (1)$$

The second Op amp, OP_B, is necessary to buffer Vo voltage. A R5 resistance may be added in order to protect the intrinsic ESD diode of the OP_B in case of a high current that might flow in the input pins at start up.

The maximum current drawn by the motor control is 100A. So with a 100µΩ shunt resistor, the maximum Vsense is 10mV.The maximum output voltage is dependent on Vsense voltage, and the resulting output current across R4. And as it is treated by an ADC of the microcontroller, this maximum output voltage Vo must not exceed 3.3V.

The values of the components must be chosen carefully to make the system work properly. The main goal is to work with a low |Vgs| in order to not saturate the output of OP_A.

Because keeping a low current Ids helps, we choose a high value for R4.

And in order to avoid any saturation of the output of the Op amp, the gain relative to the Op amp OP_A, given by the ratio R2/R1, should not be too high.

We have to compromise in the choice of components' values, which must follow equation 2:

$$|Vgs\ \mathrm{max}| < Vzener - \frac{R3.(R1+R2)}{R4.(R1+R2+R3)}.Vo\_max \qquad (2)$$

- Where Vgmax is the Vgs needed to allow a current into the transistor of $Id_{max} = \frac{Vo\_max}{R4}$
- And Vzener=Vcc_H - Vcc_L

Let's now have a look to the precision of such a system. The inaccuracy is mainly due to the mismatch of the resistances as well as the offset of amplifiers.

Error analysis

Impact of the mismatch of the resistances

Equation 1 gave the result of the output voltage by considering that the resistances used are perfectly matched. Unfortunately, this is not the case, as the resistances have their own precision.

The error done on the gain, due to the mismatch of the resistances is given by the following formula:

$$V0 = \frac{Isense*Rshunt}{R1}.\frac{R4}{R3}.(R1+R2+R3).[1+\left(\frac{2R1+4R2+2R3}{R1+R2+R3}\right).\ \varepsilon\alpha\ +\ \varepsilon Rshunt\ ]\ (3)$$

- Where $\varepsilon\alpha$ is the precision of any of the resistances, and εRshunt is the accuracy of the shunt resistor.

From equation 3, we can see that the R2 resistance has a bigger impact on the error than the other resistances. And so its value must be chosen to be as low as possible (10kΩ). Note also that the sum of R1 and R3 should be high and unbalanced in order to achieve the gain, with R1 ideally low to limit the noise.

Impact of the Vio

Another error must be taken into consideration: the input voltage offset. In this application, we have chosen the TSZ121, a chopper amplifier, because it exhibits a very low Vio, 8µV over temperature. This error becomes predominant especially when very small current has to be measured.

The transfer function taken into account the Vio can be written as follows:

$$Vout = \frac{(Vsense \pm Vio1)}{R1}.\frac{R4}{R3}.(R1+R2+R3) \pm Vio2\ (4)$$

Where Vio1 is the input offset of the first Op amp (OP_A), and Vio2 is the input offset of the second Op amp (OP1_ B). As the TSZ121 has an extremely low input offset voltage, Vio2 can be neglected.

Total error

In order to have an idea of the total error on the output, we add the mismatch of the resistances and the offset of the Op amp. Finally, the output voltage can be written as equation 5:

$$Vo = \frac{(Isense*Rshunt)}{R1}.\frac{R4}{R3}.(R1+R2+R3).\left[1+\left(\frac{2R1+4R2+2R3}{R1+R2+R3}\right).\ \varepsilon\alpha\ +\ \varepsilon Rshunt\ \right] \pm \frac{Vio}{R1}.\frac{R4}{R3}.(R1+R2+R3)$$

(5)

The graphs in figures 2 and 3 represent the maximum error expected over temperature, by taking into account the shunt accuracy.

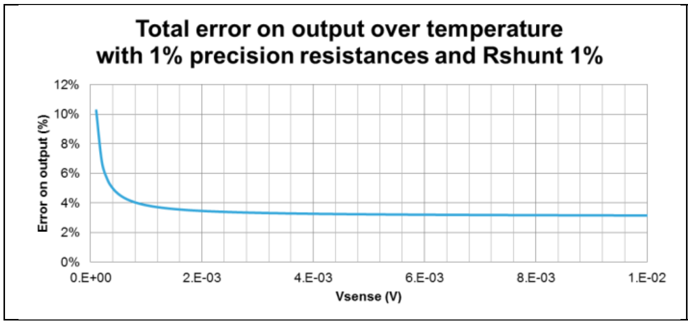

Figure 2: Total error assuming 1% resistances with Rshunt 1%

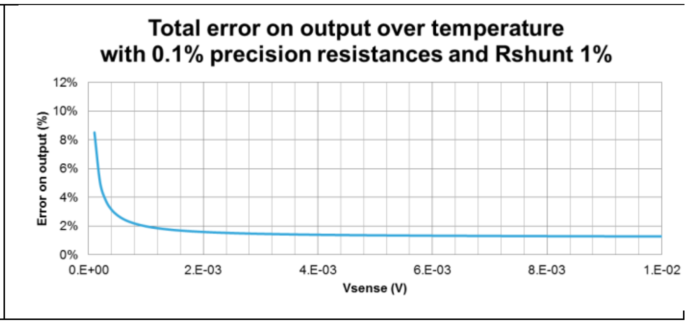

Figure 3: Total error assuming 0.1% resistances with Rshunt 1%

Conclusion

Dedicated amplifiers are commonly used to realize high side current sensing measurement. But in applications where the common mode is higher than 70V, we've seen that this kind of measurement should be done with a conventional 5V Op amp.

We've shown that high side current sensing can be achieved using a precision Op amp such as the TSZ121 amplifier, combined with a zener diode in order to work in a 5V range and level shift transistor.

We've taken some errors due to the resistances and amplifiers used into account. We advise using 0.1% precision resistances to obtain a good accuracy for the current measurement.