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How to Optimize Performance of AMC1304/05M25 in Voltage Sensing

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ABSTRACT

Many applications such as motor drives and power inverters require measurements of both current and voltage to obtain motor information, for example, speed, torque, and power, to control, monitor, and protect the system. Meanwhile, these applications will be operated in harsh, noisy environments and high voltage difference between power stage and control stage. Therefore, this is very important that the device have precise performance and isolation functions simultaneously. In this case, the AMC1304/05M25 can satisfy these criteria. AMC1304/05M25 is optimized for use in current-sensing applications using low-impedance shunts. However, the device can also be used in isolated voltage sensing. In terms of that, this application note will give you an idea of how large a shunt resistor can be used that will not influence device performance and also how to optimize the system performance if you want to use large shunt resistors. In the following content, we will focus on the AMC1305M25 device.

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Consider the input impedance of the AMC1305M25 (R_{ID}: 25 kΩ) in designs with high-impedance shunt resistors that can cause degradation of gain and offset specifications. However, the importance of this effect depends on the desired system performance. Therefore, if AMC1305M25 is designed by such applications, there are important details that need to be remembered when you choose the resistor divider.

First, in order to efficiently use the available linear input range of AMC1305M25, the voltage across R2 must be within ±250 mV, because the linear input range of AMC1305M25 is ±250 mV.

The first inclination to carry out the voltage sensing is to implement the circuit which is shown in Figure 1.
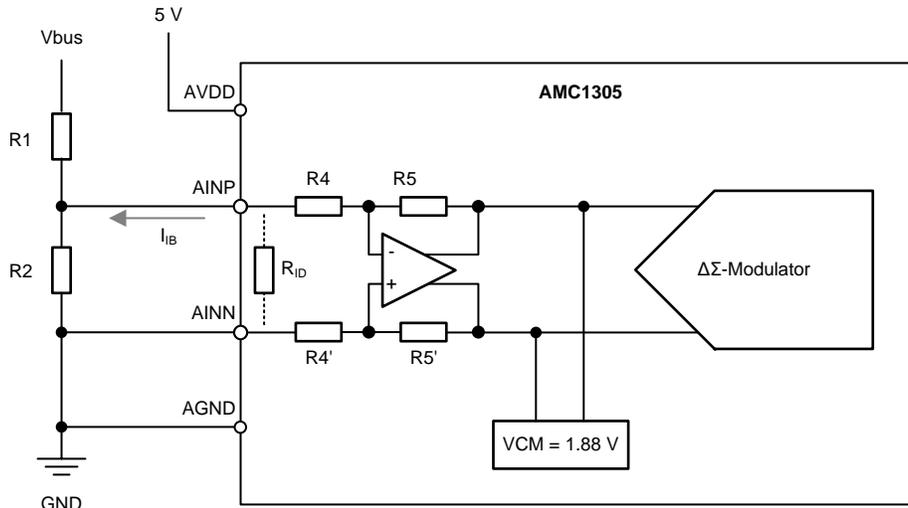
Figure 1. First Rough Solution to Perform Isolated Voltage Monitoring

The resistor divider formed by R1 and R2 in Figure 1 can be governed with Equation 1.

$$V_{R2} = Vbus\ \frac{R2}{R1 + R2}$$

(1)

Where V_{R2} = 0.25 V for AMC1305M25.

For instance, if the system supply is 30 V and shunt resistor is 1 kΩ, then R1 can be calculated which is 119 kΩ for AMC1305M25.

Second, as mentioned before, the larger shunt resistor is used, the larger offset, gain error will be obtained. Equation 2 helps easily estimate offset error.

$$V_{OS} = R2 \times I_{ib}$$

(2)

Where $I_{ib} \approx 30$ µA when Vcm = 0 V for AMC1305M25.

The gain error is calculated with Equation 3:

$$E_G(\%) = \frac{\dfrac{Vbus}{R1 + (R2//R_{IN})} \times (R2\ //R_{IN}) - V_{IN}}{V_{IN}}$$

(3)

Where V_{IN} = 0.25 V for AMC1305M25.

Actual influence of offset error and gain error of different shunt resistors for AMC1305M25 is shown in Figure 2 and Figure 3, Table 1 and Table 2, respectively. When the shunt resistor increases, the offset and gain error will grow linearly. For example, if the shunt resistor is equal to 0.754 Ω, the offset error and gain error is 14 µV and 0.02%. But when the shunt resistor rises to 2.4924 kΩ, the offset error and gain error will become 65.62 mV and –10.65%. That is because input bias current caused by the internal common-mode voltage at the output of the differential amplifier will flow out to shunt resistor, which will cause additional offset error. In addition, with a large shunt resistor, load effect will cause extra gain error.

In this calculation only the effect from the differential amplifier is considered, whereas both input filter and Delta-sigma modulator error are not. By contrast, the simulation considers the effect from differential amplifier and input filter, but it does not include Delta-sigma modulator error. So these will have slight differences with measurement. The simulation result is done with TI-TINA.
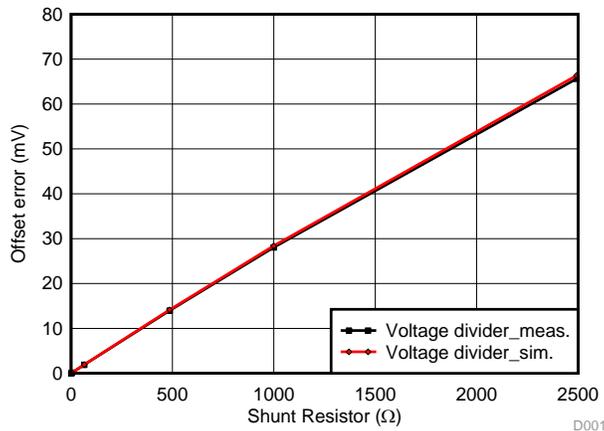
Figure 2. Offset Error vs Different Shunt Resistor (AMC1305M25)

Table 1. Offset Error vs Different Shunt Resistor (AMC1305M25)

Offset Error-Shunt Resistor (Ω)	Voltage divider_cal. (mV)	Voltage divider_meas. (mV)	Voltage divider_sim. (mV)
0.754	0.022620	0.013876	0.022467
64.88	1.946400	1.892609	1.925176
486.1	14.58300	13.97162	14.14728
999	29.97000	28.05624	28.39243
2492.4	74.77200	65.61527	66.35166
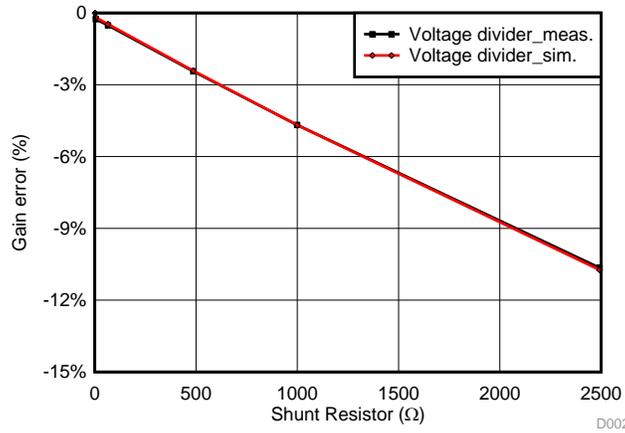
Figure 3. Gain Error vs Different Shunt Resistor (AMC1305M25)

Table 2. Gain Error vs Different Shunt Resistor (AMC1305M25)

Gain Error- Shunt resistor (Ω)	Voltage divider_cal. (%)	Voltage divider_meas. (%)	Voltage divider_sim. (%)
0.754	−0.003586%	0.02%	−0.003587%
64.88	−0.307846%	−0.52%	−0.466670%
486.1	−2.262164%	−2.44%	−2.414913%
999	−4.539821%	−4.68%	−4.685772%
2492.4	−10.608349%	−10.65%	−10.736764%

The INL will not be influenced by different shunt resistors. No matter how large shunt resisters will be, INL will always be within specification (max: ±4 LSB). The measurement result is shown in Figure 4 for AMC1305M25.
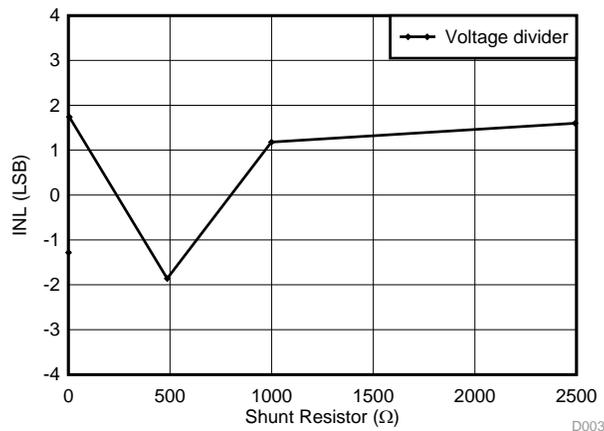
Figure 4. INL vs Different Shunt Resistor (AMC1305M25)

If the voltage sensing system is not allowed to add additional compensated circuits, but AMC1305M25's performance is desired such as offset, gain error within datasheet specification, then the shunt resistor, R2, must be lower than 0.75 Ω.

2 Optimize the Performance of AMC1305M25 With Large Shunt Resistor

If the system needs to use a large shunt resistor to realize voltage sensing, then there are two methods that can help you minimize system error.

Method 1:

Series resistor at the negative input (AINN) of the AMC1305M25 with a value equal to the shunt resistor R2 (that is R2' = R2 in Figure 5) to eliminate the effect of the bias current. This method can help minimize offset error, but will cause extra gain error. The effect can be calculated using Equation 4 with R5 = R5' = 50 kΩ and R4 = R4' = 12.5 kΩ for AMC1305M25.

$$E_G(\%) = \left(1 + \frac{R4}{R4' + R2'}\right) \times 100\%$$

(4)

The simulation and measurement result of AMC1305M25 is shown in Figure 6 and Figure 7. The offset error can be minimized from 13.97 / 65.62 mV to –0.123 / –0.069 mV when the shunt resistor is equal to 486.1 / 2.492 kΩ, but gain error will increase from –2.44 / –10.65% to –3.87 / –16.44%, respectively.
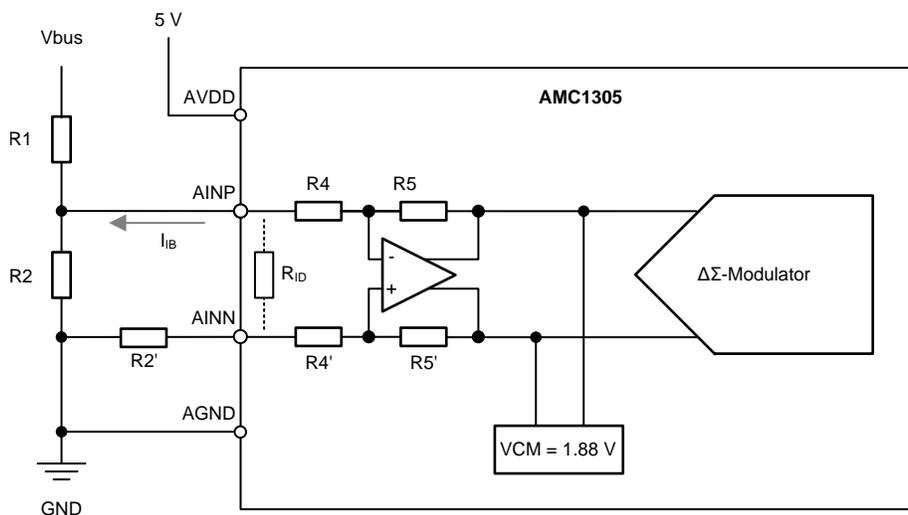
Figure 5. Simplified Circuit With Series Shunt Resistor
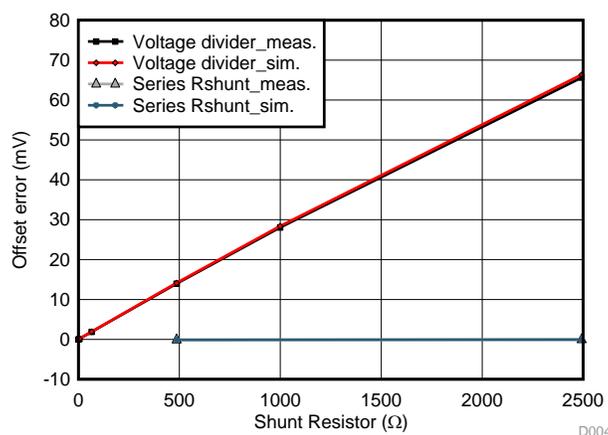
Figure 6. Offset Error vs Different Shunt Resistor With Series Shunt Resistor (AMC1305M25)
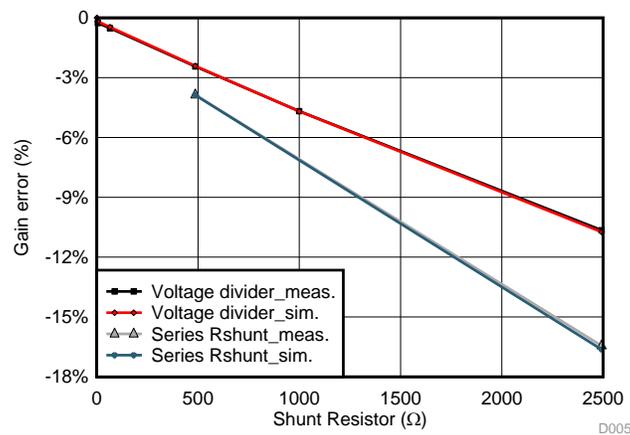
Figure 7. Gain Error vs Different Shunt Resistor With Series Shunt Resistor (AMC1305M25)

Method 2:

Adding an op amp between the voltage divider and the AMC1305M25 can optimize overall system performance. The characteristic of an op amp can help minimize both offset and gain error from bias current and load effect.

2.1 *Choose Suitable Op Amp*

In order to ignore errors which come from the op amp, some specifications must be considered. First of all, the offset error of the op amp must be much lower than ±150 µV. Secondly, the bandwidth of the op amp must be higher than 1 MHz. Third, the input bias current must be smaller to avoid offset error. Last, closed-loop output impedance must be smaller than 0.75 Ω. Some op amp datasheets just provide open-loop output impedance, use Equation 5 to translate or use TI-TINA to simulate.

$$\text{Rout} = \frac{R_O}{1 + \text{Aol}\beta}$$

(5)

Based on this criterion, OPA376 is used.

Vos(max): 25 µV, Vos(typ.): 5 µV

GBW: 5.5 MHz

I_{ib}(max): 10 pA

Rout at DC: 163.5 µΩ
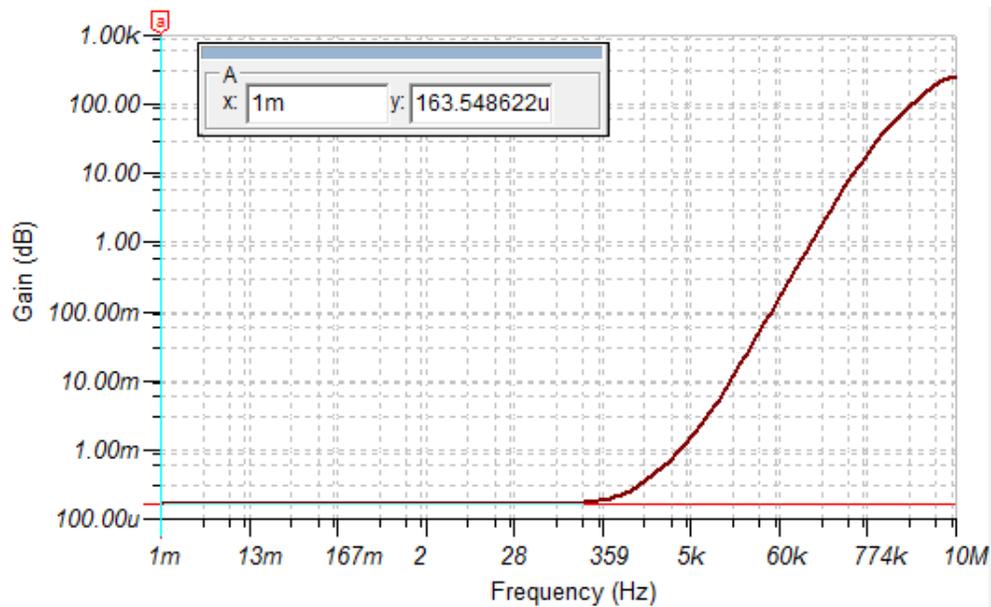
Figure 8. Rout Simulation of OPA376

The simplified circuit is presented in Figure 9. The offset and gain error can be minimized when you add OPA376 between the voltage divider and AMC1305M25. Simulation and measurement results are shown in Figure 10 and Figure 11. When the shunt resistor is equal to 486.1 / 2.492 kΩ, the offset error can be reduced from 13.97 / 65.62 mV to 0.009 / −0.007 mV and gain error will be also reduced from −2.44 / −10.65% to −0.04 / −0.04%, respectively.
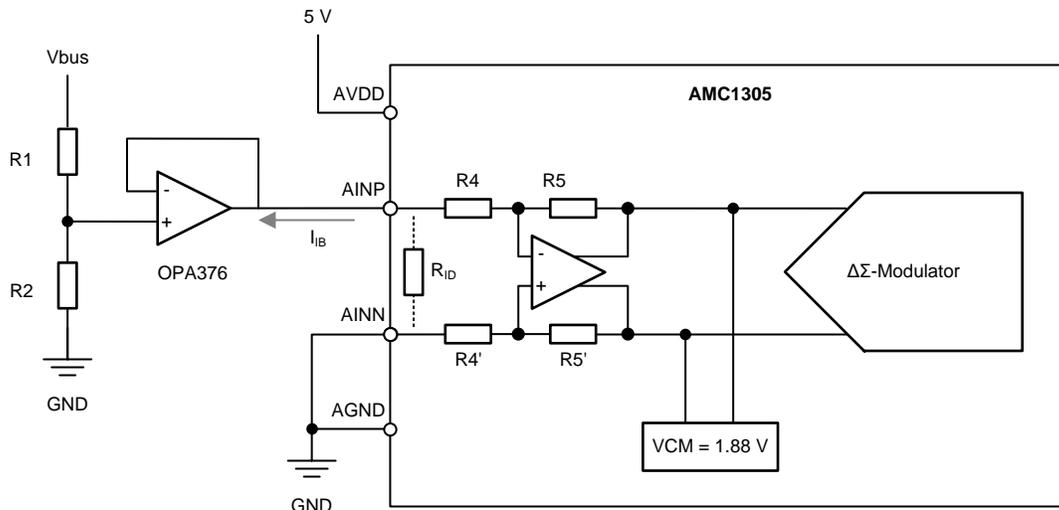
Figure 9. Simplified Circuit With OPA376
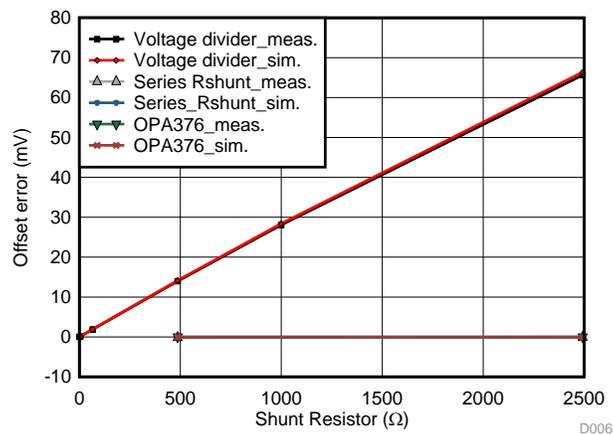
Figure 10. Offset Error vs Different Shunt Resistor With OPA376 (AMC1305M25)
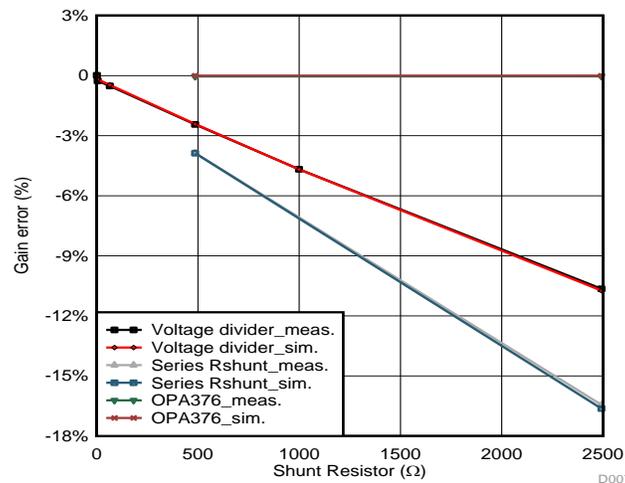
Figure 11. Gain Error vs Different Shunt Resistor With OPA376 (AMC1305M25)

The designer must be aware that if their system does not have suitable power for the op amp, you might need to design other power paths. Therefore, there is a trade-off between performance and cost.

3   Conclusion

This application report provides straightforward equations to evaluate initial performance when you add a large shunt resistor in voltage sensing, and also presents two methods to optimize performance of the AMC1304/05M25. Hence, as long as you add a suitable compensated circuit in these modulators, it can achieve good performance although TI's isolated delta-sigma modulator is optimized by current sensing.

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