Shunt Resistor Tolerance Error

TI Precision Labs – Current Sense Amplifiers

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Hello, and welcome to the TI precision labs series on current sense amplifiers. My name is Benjamin Damkroger, and I’m a product marketing engineer in the Current & Position Sensing product line. In this video, we will take a closer look at Shunt Resistor Tolerance error.

RSS total error equation

- The root-sum-square (RSS) total error is given by the following equation:

$$\varsigma_{RSS}\ (\%) \approx \sqrt{Vos^2 + CMRR^2 + PSRR^2 + Gain\_Error^2 + Linearity^2 + Shunt\_tolerance^2 + Bias\_Current^2}$$

In previous videos, we introduced the root-sum-of-squares, or RSS, total error equation for current sense amplifier circuits, as shown here. Note that not all error terms may be shown.

The rest of this video focuses on shunt tolerance.

Shunt tolerance is the only error term that has nothing to do with the current sense amplifier itself, but is a key contributor to the system error.

Its effect on system performance bares the same characteristics of gain error of the current sense amplifier itself.

Definition of shunt resistor tolerance

Definition

The percentage deviation of the actual resistance value from its advertised nominal value.

Resistance	Tolerance	TC
10 Meg	±0.20%	±10 ppm/°C
20 Meg	±0.20%	±10 ppm/°C

RESISTANCE RANGE Ω	RATED POWER $P_{25\,°C}$ W	LIMITING ELEMENT VOLTAGE V	TOLERANCE ± %	TEMPERATURE COEFFICIENT ± ppm/°C
0.04 to 2.2K	1	50	0.5, 1, 2, 5	25, 50, 100
0.04 to 4.7K	2	120	0.5, 1, 2, 5	25, 50, 100
0.04 to 13K	2.5	200	0.5, 1, 2, 5	25, 50, 100
10 to 332K	0.5	300	0.5, 1	25, 50
10 to 1M	1	350	0.5, 1	25, 50

Note: % = ppm / 10,000

Shunt resistor tolerance is defined by the shunt resistor manufacturer and can be found on the product data sheets for the resistors. It is usually specified in percent.

A 5% shunt can be up to 5% from its ideal value, directly contributing up to 5% error to the gain error of the system. Shunts with a tighter tolerance will contribute less error to the system with more predictability.

Another thing to note about resistors is the temperature coefficient. This specification, often referred to as “tempco,” describes the variance in the resistor over its standard operating temperature range.

Tempco is usually reported in ppm per degree C. Divide this number by ten thousand to get the variation in percent per degree C.

A tempco of 100 can contribute an additional .5% error over a 50 degree change in temperature, whereas a tempco of 10 would contribute significantly less at just .05% over the same 50 degree change.

Shunt resistors often have high currents flowing through them or are near components on the board that generate heat, so be sure to keep this in mind when designing your system if you expect large temperature variations.

Shunt resistor tolerance error equation

Error equation

$$e_{Shunt} = \frac{V_{Shunt\_Ideal} \times (ShuntTol)}{V_{Shunt\_Ideal}} = ShuntTol$$

- Error is calculated with respect to the ***ideal*** shunt voltage
- Error due to shunt tolerance is equal to total shunt tolerance itself.

The equation to calculate shunt tolerance error is shown here. It is simply the percentage deviation of actual input shunt voltage from ideal shunt voltage. Vshunt_ideal is the product of the load current and ideal shunt resistor value – ignoring the tolerance and temperature drift of the resistor itself.

It turns out the error contribution due to shunt is equal to the total shunt tolerance. The total shunt tolerance includes the initial tolerance plus temperature drift when temperature effect needs to be considered. The total shunt tolerance is expressed in percent. Unless otherwise stated in this presentation, “shunt tolerance” and “total shunt tolerance” are interchangeable.

Shunt resistor tolerance error example

Conditions

- I_{Load} = 1 to 20A;
- R_{Shunt} = 1 mΩ; $ShuntTol$ = 1%; TC = 100ppm
- Temperature Range=50ºC

Calculations

$$e_{Shunt} = ShuntTol + TC \times T$$

→

$$e_{Shunt} = 1.0\% + 100ppm \times 50 = \mathbf{1.5\%}$$

How to minimize

- Choose a shunt with better tolerance and tempco
- System calibration

In this example we wish to measure a load current in the range of 1 to 20 amps. The shunt has the following specification – nominal resistance equals to 1 milliohms; initial tolerance equals to 1%; temperature coefficient equals to 100ppm.

Using our shunt error equation, we calculate that the resulting error is 1.5%. How do we make it better and minimize this error? There are two possible ways to approach this.

First, you can choose a high performance shunt, which means choosing a shunt with low initial tolerance and low temperature coefficient.

Second, you may take advantage of system calibration.

Shunt resistor tolerance error example - better shunt

Conditions

- I_{Load} = 1 to 20A;
- R_{Shunt} = 1 mΩ; $ShuntTol$ = 0.25%; TC = 10ppm
- Temperature Range=50ºC

Calculations

$$e_{Shunt} = ShuntTol + TC \times T \longrightarrow e_{Shunt} = 0.25\% + 10ppm \times 50 = \mathbf{0.3\%}$$

Note: high performance shunt resistor can be expensive

Lets take the same example on previous slide, but substitute the shunt with one that is much more accurate – here the initial shunt tolerance equals to 0.25%; and temperature coefficient equals to 10ppm.

As you can see the resulting shunt error is only 0.3%.

It should be noted that high performance shunt resistors can be significantly more expensive.

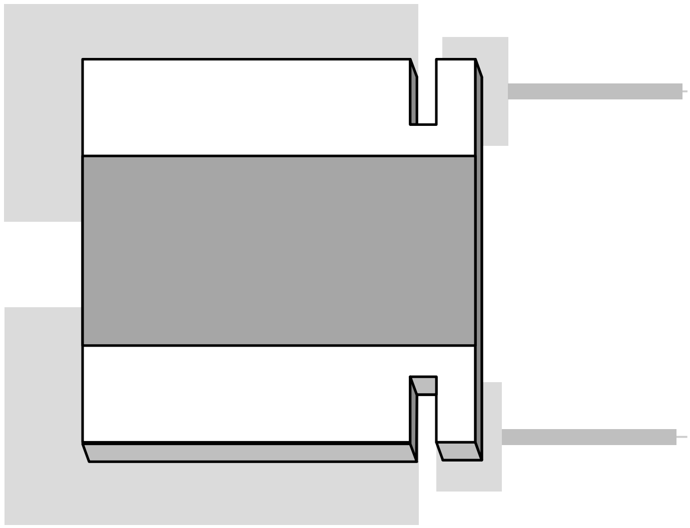
Shunt resistor tolerance error – select R_{SHUNT}

- Shunt resistors come in many packages and with different ratings.
- Current shunt monitors typically need resistors that are:
  - Low resistance
  - Low tolerance
  - High power dissipative
  - Low inductance

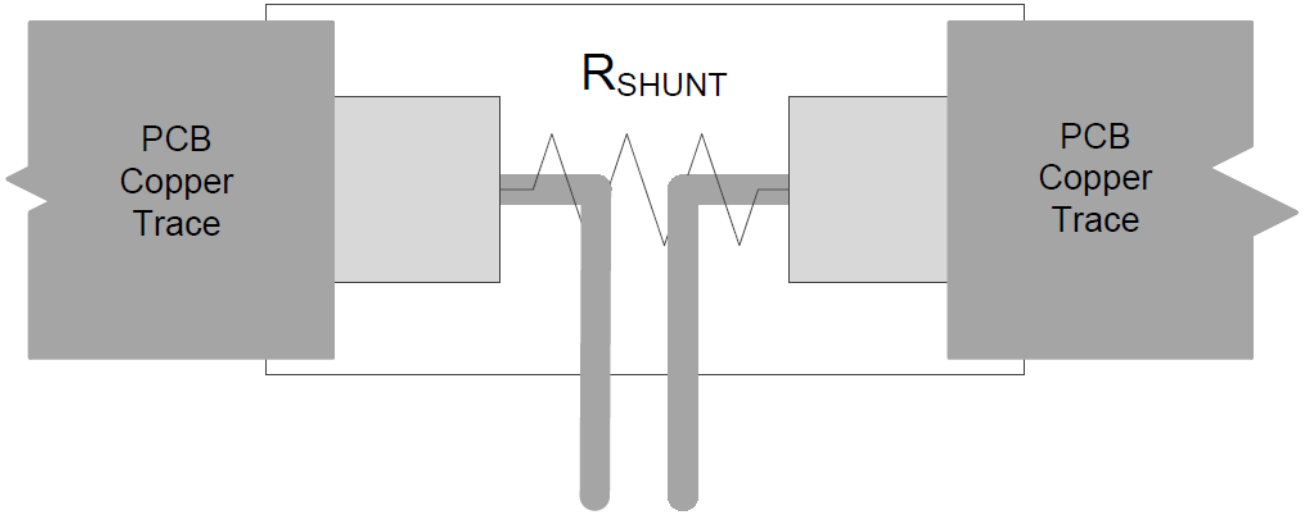
There are a variety of shunt resistors available for current sensing applications. The most common use cases involve low resistance, low tolerance, high power resistors to handle tens of amps with little voltage drop from the supply.

Larger resistors give a better signal at the low end of the dynamic range where offset error dominates, but smaller resistors give less voltage drop and dissipate less power, often making them the better choice for applications measuring large current. See the other videos in this series for more help on selecting an appropriate shunt resistance.

Shunt resistor tolerance error – R_{SHUNT} layout



Four-terminal resistor



Chip resistor

Note: Follow the resistor manufacturer recommended layout guidelines

For resistors with Kelvin connection leads or atypical geometries, follow the manufacturer guidelines regarding layout. Sometimes these resistors have a tolerance based on where they were measured when they were fabricated and trimmed at the factory. If you don’t follow their guidelines, you may end up well outside the stated tolerance of the resistor.

See the other videos in this series for more help on shunt resistor layout.

Shunt resistor tolerance error summary

- Shunt tolerance is specified by the resistor manufacturer
- Shunt tolerance can often be the dominant source of error in the circuit
- Typical shunt resistor desired for current sensing:
  - Low resistance
  - Low tolerance and temperature coefficient
  - High power rating
  - Low inductance
- Follow resistor manufacturer’s layout guidelines

Let’s take a minute to summarize what we learned in this video.

Shunt tolerance is specified by the resistor manufacturer
Shunt tolerance can be the dominant source of error in the circuit
The typical shunt resistor desired for current sensing is one that is low resistance, low tolerance, high Power rating and low inductance
Last but not least, always follow the resistor manufacturer’s layout guidelines.

To find more current sense amplifier technical resources and search products, visit ti.com/currentsense

That concludes this video - thank you for watching! Please try the quiz to check your understanding of the content.

For more information and videos on current sense amplifiers please visit ti.com/currentsense.

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Quiz

Shunt resistor tolerance error – quiz

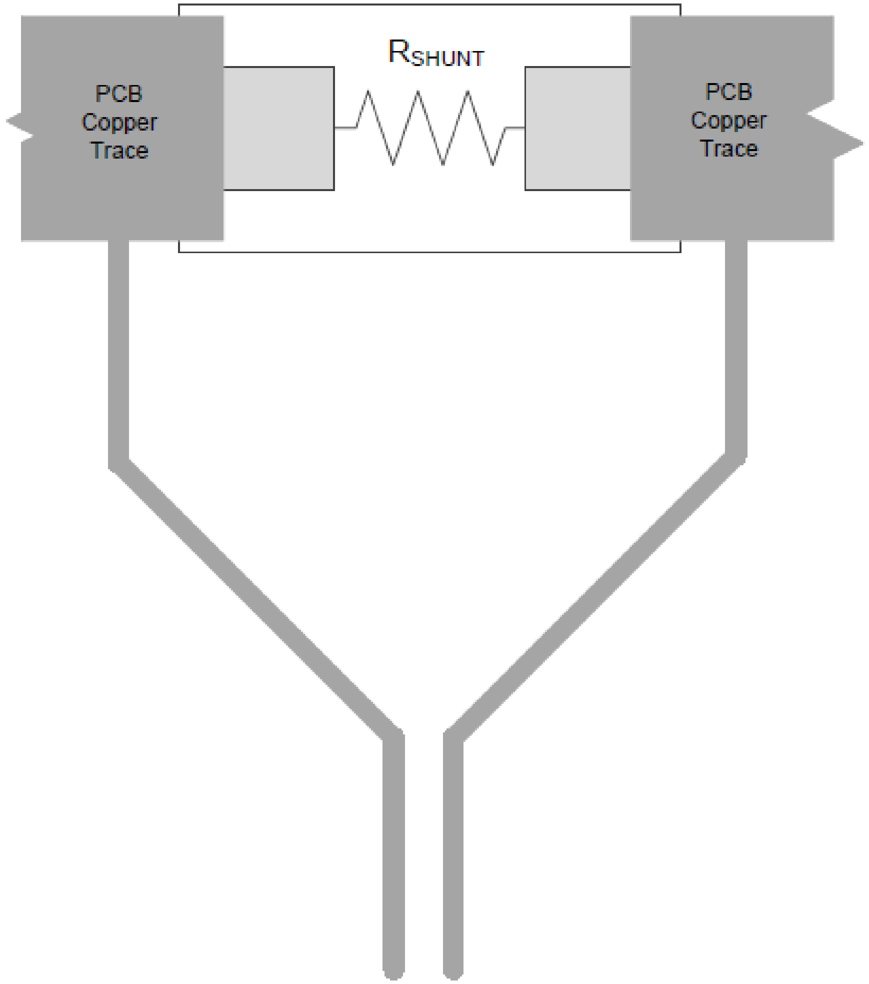
1. The shunt resistor's contribution to system error is very small in a current sensing circuit, therefore you can ignore it.
   a) True
   b) False

2. A super accurate current sense amplifier will compensate for a lousy shunt resistor, therefore I can choose such a combination in order to lower cost even for the high accuracy system that I need.
   a) True
   b) False

Shunt resistor tolerance error – quiz

3. A 1mOhm shunt has a tolerance of <=1%; the current sense amplifier has the following dominant (Max) error sources: Vos=25uV and Gain Error=0.2%. When measuring a 15Amp DC current, the system error upper bound is likely closest to
   a) 0%
   b) 1%
   c) 1.414%
   d) 1.25%

4. This picture to the right shows the best practice of shunt resistor layout recommended by TI.
   a) True
   b) False



Answers

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Shunt resistor tolerance error – quiz

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   c) 1.414%
   d) 1.25%

Explanation: At 15mV Vshunt, Vos can be ignored. Plugging 1% and 0.2% into RSS equation, the answer is about 1%

4. This picture to the right shows the best practice of shunt resistor layout recommended by TI.
   a) True
   b) False

Explanation: Kelvin connections should be used for the sense lines. Layout like this causes errors that are avoidable.