Debugging a Current Shunt Monitor circuit – Probe Placement and Soldering

TI Precision Labs – Current Sense Amplifiers

Presented and Prepared by Patrick Simmons

Hello, and welcome to the TI precision labs series on current sense amplifiers. My name is Patrick Simmons, and I’m an applications engineer in the Current & Position Sensing product line. In this video, we will continue our discussion on debug, stressing the importance of probe placement and soldering.

Sources of Error

Device Errors:

$$\varsigma_{RSS}(\%) \approx \sqrt{{e_{Vos}}^2 + {e_{CMRR}}^2 + {e_{PSRR}}^2 + {e_{Gain\_error}}^2 + {e_{Linearity}}^2 + {e_{Shunt\_tolerance}}^2 + {e_{Bias\_current}}^2 + {e_{Other}}^2}$$

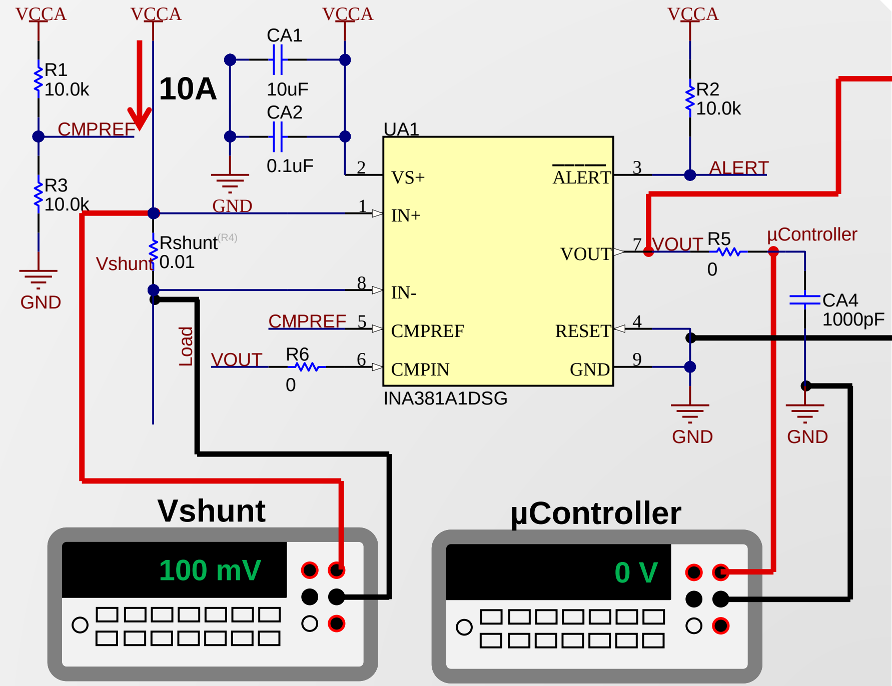
User Errors:

- Improper Layout
- Probe Placement
- Solder issues
- Overlooking device specifications
- Downstream circuitry
- Equipment and Settings
- Actual Fails

In our first video of the user error series we covered layout. In this particular video we will cover some examples relating to probe placement and soldering.

Probe Placement: Case 1

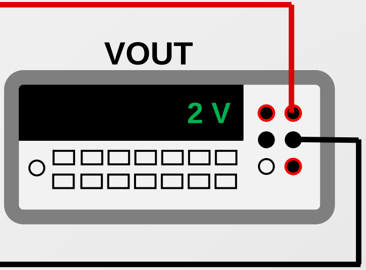
Conditions



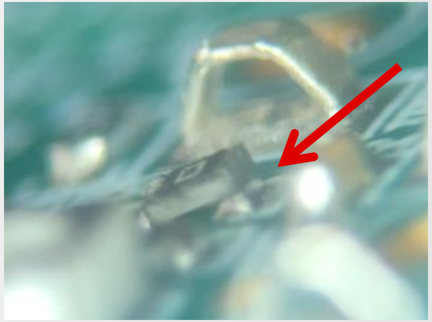
$$\mu Controller_{expected} = 100mV \times 20\frac{V}{V} = 2V$$

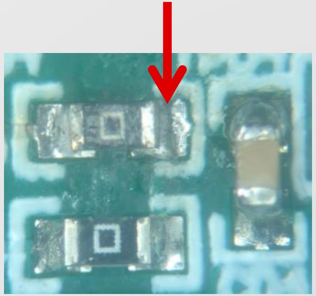
Source of Error

- Probing at the wrong spot



- Solder issue

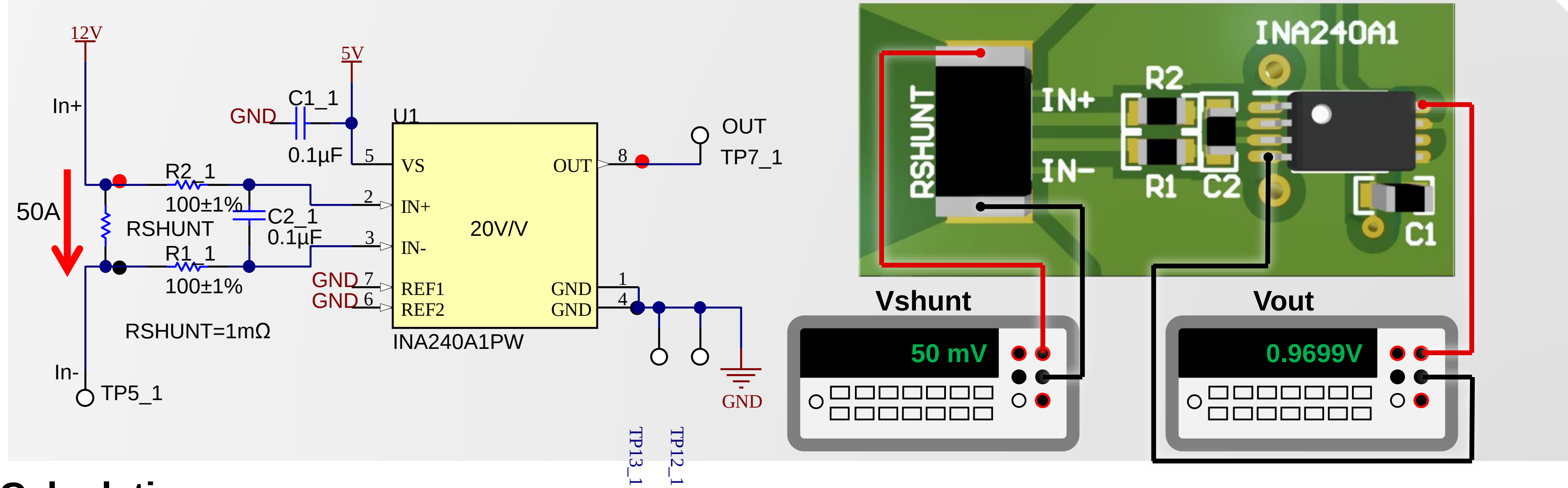




To illustrate the impact of probe placement, lets look at the following example here. In this scenario we have a 10A load passing through a 10mΩ shunt. Measuring across the shunt indicates we have 100mV as we expect. Yet when we probe at our microcontroller input test point, which is shorted to VOUT with a 0Ω resistor, we get roughly 0V. Our initial reaction is ughhh our part is broken. However, is this a valid assumption? Technically we are not probing directly at the device output pin, which is one of the necessary steps for verifying our device is broken. Turns out the output voltage at our pin is 2V as it should be. Closer inspection of our board reveals that R5 is not properly soldered to the board. It should be noted that this was not immediately apparent from an aerial view.

Probe Placement: Case 2

Conditions



Calculations

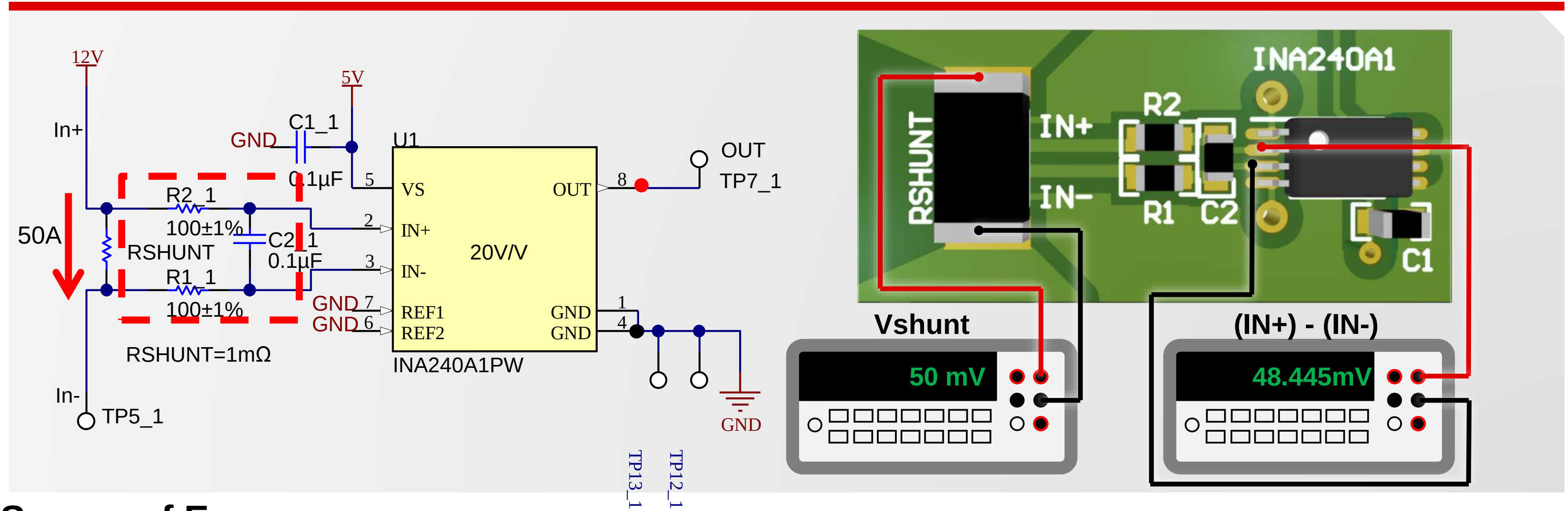
$$V_{out\_ideal} = Load \times R_{SHUNT} \times Gain = 50A \times 1m\Omega \times 20\frac{V}{V} = 1V$$

$$Load_{measured} = \frac{V_{out\_measured}}{R_{SHUNT} \times Gain} = \frac{0.9699V}{1m\Omega \times 20\,V/V} = 48.495A$$

Now lets consider a different case involving the INA240 with a 20V/V gain. In this instance we are trying to measure a 50A load. Based upon our calculations, we expect the output to be 1V. Yet we measure a value that is 30.1mV lower, suggesting our measured load is 48.495A. The schematic looks fine, and our layout indicates symmetric kelvin connections to the shunt. Obviously, this part is broken! Or is it…?

Probe Placement: Case 2

Conditions



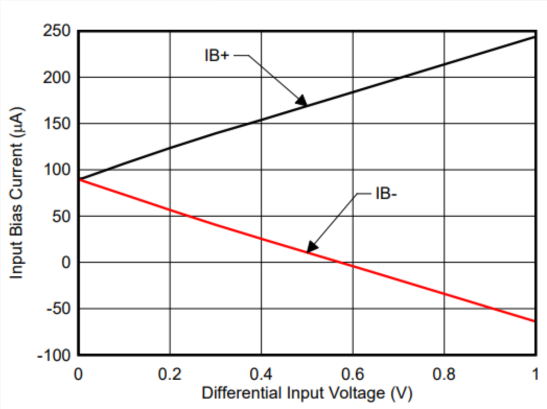
Source of Error

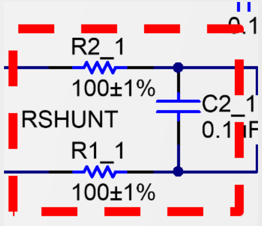
- Probing at the wrong spot
- Input Filter introduces error

We decide do some further probing and discover that right at the device input pins we measure a different differential voltage. It turns out that the differential between IN+ and IN- is 48.445mV, a little lower than our ideal 50mV. We now have determined the source of ire to be the filter. But why?

Probe Placement

Source of Error





$$V_{os-filter-max} = \left(100\Omega \times \left(1 + \frac{1\%}{100}\right) \times I_{B+} - 100\Omega \times \left(1 - \frac{1\%}{100}\right) \times I_{B-}\right)$$

$$V_{os-filter-max} = \left(100\Omega \times \left(1 + \frac{1\%}{100}\right) \times 90\mu A - 100\Omega \times \left(1 - \frac{1\%}{100}\right) \times 90\mu A\right)$$

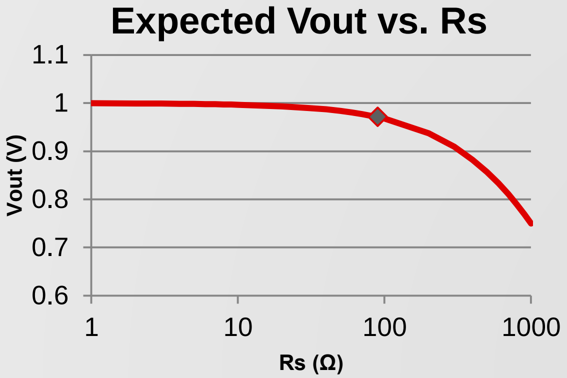
$$V_{os-filter-max} = 180\mu V$$

$$V_{os-filter-max} \times Gain = 180\mu V \times 20\tfrac{V}{V} = 3.6mV$$

$$\text{Gain Error Factor} = \frac{3000}{R_S + 3000} = 0.968$$

$$\text{Gain Error (\%)} = 100 - (100 \times \text{Gain Error Factor})$$
$$= 100 - (100 \times 0.968) = 3.2\%$$

$$V_{out} = V_{shunt} \times \text{Gain} \times \frac{(100\% - \text{Gain Error \%})}{100}$$
$$= 0.05V \times 20\tfrac{V}{V} \times \frac{(100 - 3.2)}{100} = 0.968V$$



Recalling from our layout video that trace symmetry can influence measurement error due to input bias current, we turn back to the schematic and realize that while our traces are symmetric, the filter resistors may not be. The tolerances are 1% on 100Ω resistors. In the extreme case where the resistors have the greatest difference between them, we find the INA240 output could be offset by as much as 3.6mV from the ideal output. While for precision measurements this is significant, it is still almost 10x smaller than the error we are observing, so what else could be our issue? Well we are actually quite close now. Further digging into the datasheet reveals gain error formulas. After putting our filter resistance values into the formula, we see that our output could be as low as 968mV neglecting all other sources of error.   It is because of this gain error issue, we typically recommend all filter resistors be no greater than 10Ω for most of our devices. Aside from using small filter resistors with tight tolerances, the key takeaway from this case and the prior case is to probe at multiple points along your signal path starting at the device input and output pins. By doing so you will be able to determine if the signal is reaching the device and thereby discern if the device is indeed broken or you may be able to discover some solder issues.

Solder Issues

Error	Source
Noisy output	• Decoupling capacitor not properly connected to ground our device supply
Output Floating	• Filter resistor not properly connected • Device supply not properly connected • Device ground not properly connected • Reference pin not properly connected
Output zero or near zero	• Supply shorted to ground • Output shorted to ground • Input pins shorted together
Unexpectedly high leakage	• Residual flux and other contaminants from lack of proper board cleaning

With regards to solder issues, here is a non-exhaustive list of solder issues along with some of their symptoms. One case where these issues may arise is when you use a reflow oven and the silkscreen is not flush with your pads. As for avoiding various leakage issues, be sure to use the appropriate cleaning solution for the solder and flux used on your boards.

Summary

- May need to probe at multiple points along a path to pinpoint the issue
- Voltage across shunt pads does not equal voltage at sense input pins
- Asymmetric input traces and filter resistors can produce offset and gain errors
- Solder issues can disrupt signal path.

In summary, you may need to probe at multiple points along a signal path to find the source of error. From the start, you should probe directly at the device pins to validate the assumption that a device is broken. Inconspicuous solder flaws can open or short signal paths thereby leading to what appear to be device failures.

Additionally as current shunt monitors have input bias currents and due to their sense inputs not being buffered, resistances between the shunt and input pins will influence the offset and gain error of the device.

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

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