μA-level current measurement

Experiment No. 1

$$A_v = 1 + \frac{R_f}{R_g}$$

$$V_{out} = V_{in} \cdot A_v \leq 0.8 \cdot V_{Spp}$$

$$A_V \leq \frac{0.8 \cdot V_{Spp}}{V_{in}}$$

$$V_{in} = I_{test} \cdot R_{sns} = I_{test} \cdot 1.1\Omega$$

$$A_V \leq \frac{0.8 \cdot 8.5}{I_{test} \cdot 1.1}$$

Now comes the unforseen (by me) problem: The test current can range in device testing applications from a few microamperes to hundreds of miliamperes. A 1:100,000 variation in current is far too large.

For the values presented above, A_v would be limited to 618,181 for a current of 10 μA before the opamp reaches saturation. However for 10 mA the gain is limited to only 618. We can't simultaneously have both values for gain

Experiment No. 2

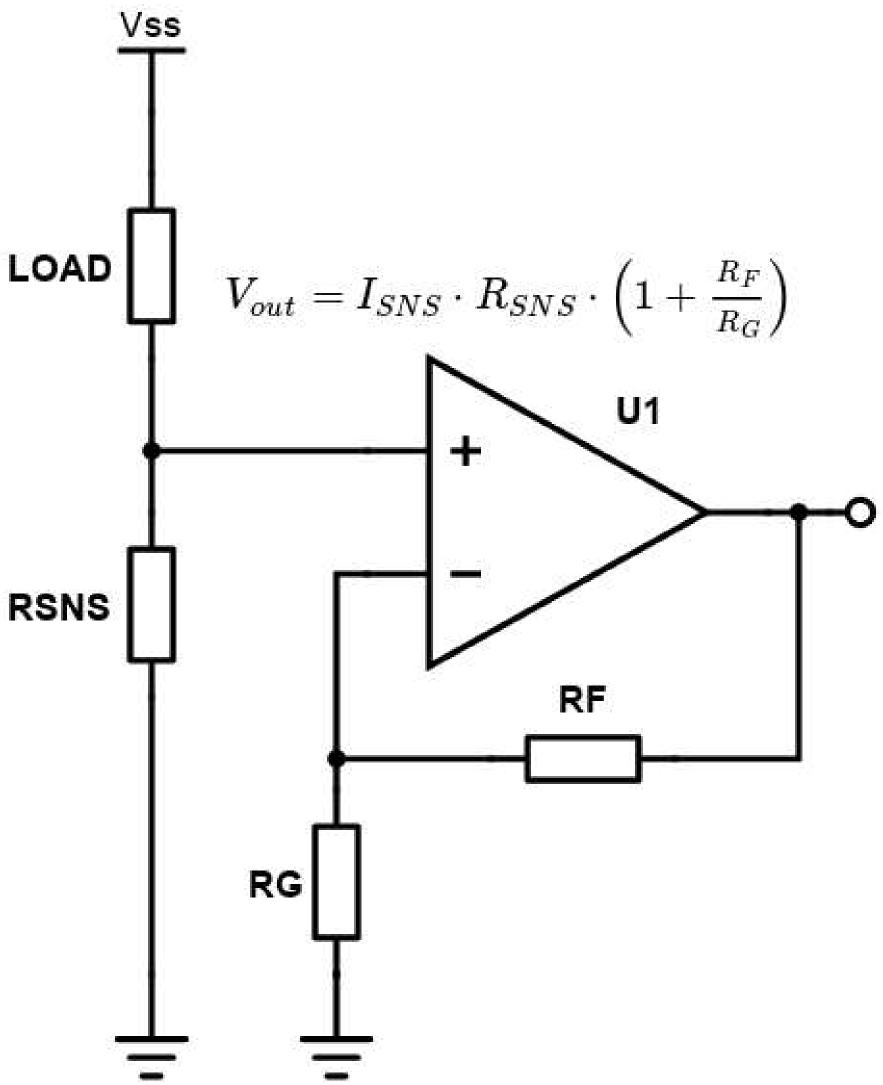
Decided to take a more gradual approach to current sensing. Began to fiddle with a 1.1 Ω as a simple current shunt. I was interesed in seeing how well my DMM would be at measuring the voltage drop over the shunt for currents below 1 miliampere.

For 100 μA the sense resistor drops $1.1 \cdot 100 \cdot 10^{-6}$ Volts, which is about 110 μV. Amusingly my DMM quite accurately tracks the voltage even at sub-miliampere currents.

I'm not going to use just the sense resistor to measure current, that would be ill-advised.

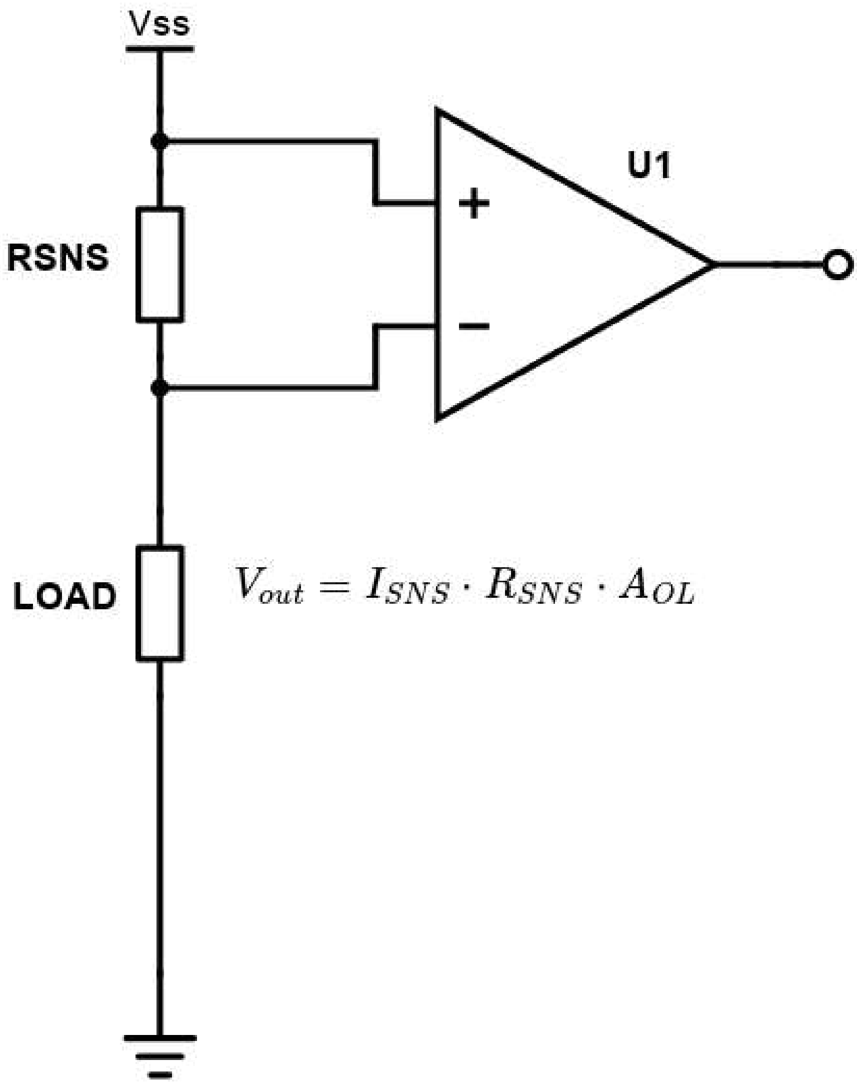
I've come across (until now) two distinct configurations for opamp-based current sense amplifiers:

- Non-inverting amplifier (uses closed loop gain, A_{CL})



Non-inverting amplifier for current sensing

- Bare amplifier (uses open loop gain, A_{OL})

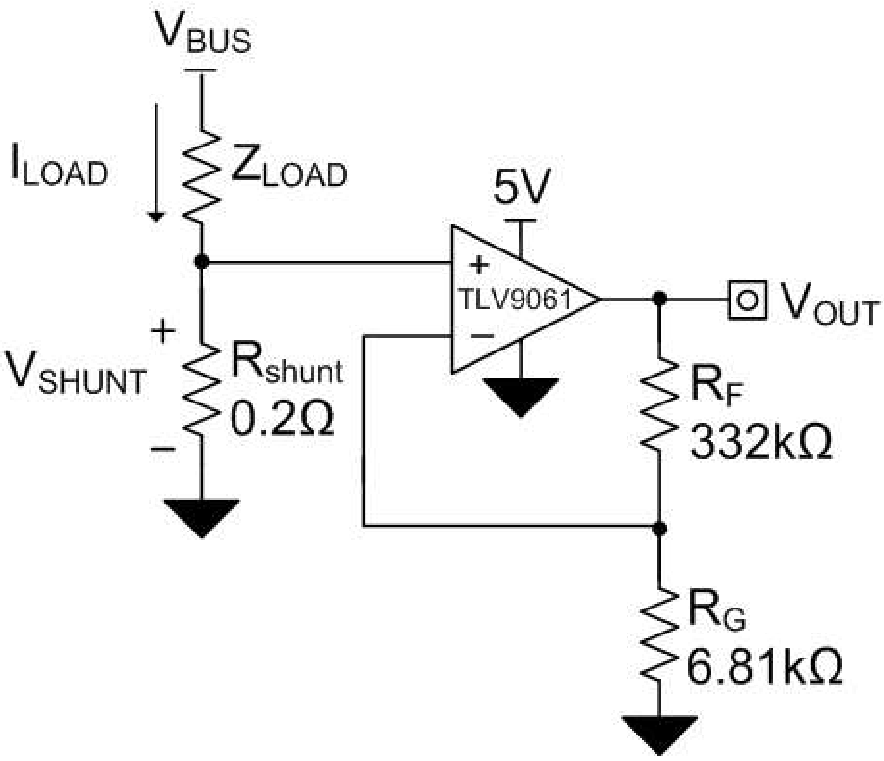


Bare amplifier for current sensing

See this for more current sense amplifier configs: file:///C:/Users/Virgil/Downloads/Selected_Current_Sensing_Circuits_f.pdf

I was initially trying to reach gains of over 1000/10,000/100,000, but as it turns out, opamps have their limits, both in terms of stability, as well as it pertains to effective amplification. In my future breadboard builds I will limit myself to closed loop gains below 100.

My current approach is taken from [this](#) TI forum post:



example of a current amplifier from TI analogwire

I however don't have those weirdly specific resistor values so I will be using either a 300K/6.8K or a 300K/10K combo for a civilized gain.

Variable current source

My current approach to testing the current sensing capabilities of the circuits is to use either a J109 or a J113 JFET as a current regulating diode and a potentiometer to control the magnitude of the generated current. I have encountered problems with not sensible enough potentiometers. I think 1 10K pot would be the perfect middle ground between the 1K and 50K pots.

I might try a CCS similar to the one used for the ramp generator experiment, as it's output current should be easier to control and tweak, when compared to the divergent JFETs.

It came to me that I could use a current mirror with a 1:N ration to amplify the current N times and use a resistor to get a voltage readout. I am not sure that given the theoretically very small collector currents, the current mirror would function as intended.

Phase difference

Phase offset varies for opamp with increasing working frequency. Relevant reading material:

- https://electronics.stackexchange.com/questions/161401/op-amp-datasheet-open-loop-gain-vs-phase

- https://electronics.stackexchange.com/questions/43217/how-do-the-open-loop-voltage-gain-and-closed-loop-voltage-gain-differ

Conclusions and goals for future experiments

Tomorrow I have to build 2 different circuits:

- PNP current source chiplet with 10K potentiometer variable resistor
- LM358-based current amplifier

Other great reads

- http://dicks-website.eu/noisecalculator/index.html
- https://backend.orbit.dtu.dk/ws/portalfiles/portal/3946358/Bruun.pdf
- https://camilotejeiro.github.io/2017/09/18/aic-1-3-4-emitter-resistors-negative-feedback.html