PHYS 252: Analog Electronics I
Spring 2020

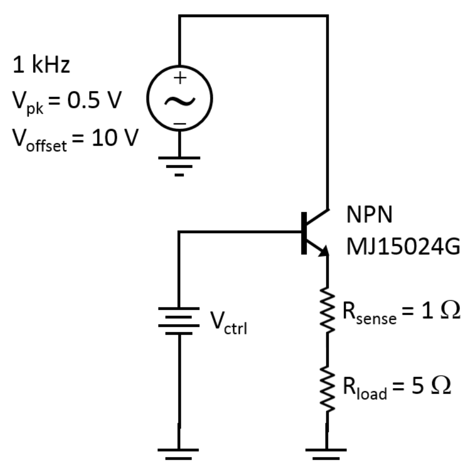
Lab 11: PI Feedback Control

This week's lab focuses on the use of PI feedback control to produce a constant current source using a noisy voltage source. The lab is the simulation version of problem #2 on the homework.

Important: *The free version of Multisim will only allow you to use 25 components (DC/AC voltage sources, op-amps, resistors, capacitors, transistors, etc). Grounds are not considered to be components. Section 4 requires about 25 components, so you will have to be careful to minimize component use so as to not go over the limit. You will only use the 3-terminal ideal op-amp in this lab (use ± 15 V to power it).*

Hint *(for getting started): If you need a resistor, then use a 10 kΩ one. If you need a capacitor, then use a 10 nF one. If you need an amplifier, then choose gain=1 (at least initially).*

1. Basic current controller *(30 minutes)*



This circuit is a basic current controller. The current comes from the AC source, which we are using as a constant voltage source (with voltage V_{offset}) with some sinusoidal "noise" at 1 kHz and amplitude V_{pk}.

a) <u>Construct</u> the circuit adjust V_{ctrl} so that the current through R_{load} is $I_{load} = 1$ A.

b) <u>Measure</u> the amplitude ΔI_{pk} of the 1 kHz oscillations on the main current I_{load} (for 1 A). <u>What</u> is the fractional size of the noise?

c) <u>Derive</u> a formula for I_{load} in terms of R_{load}, R_{sense}, V_{ctrl}, and β. <u>Is this</u> a good current source? <u>Determine</u> β from measurements in the simulation (for $I_{load} = 1$ A). <u>How</u> closely does your formula match the simulation?

2. Sense resistor: Op-Amp current-to-voltage converter *(15 minutes)*

Attach an op-amp (3-terminal, ideal) circuit to the above constant current source to convert the current running through the sense resistor R_{sense} into a voltage in a 1-to-1 manner, such that V_{out}= 1 V for $I_{load} = 1$ A.

<u>Verify</u> that V_{out} has the 1 kHz oscillations present in I_{load}, and that they are the expected amplitude.

3. Error signal circuit *(15 minutes)*

Since your objective is to make a 1 A constant current source, you need to construct an op-amp circuit (single op-amp, 3-terminal, ideal) that will generate an error signal V_{error} that is centered at zero when I_{load} =1 A. You should use a 1 V DC source (i.e. battery) as the source for V_d, the desired target voltage that your feedback circuit will use as reference to produce I_{load} =1 A.

How can you easily modify your circuit to flip the polarity of V_{error}? (polarity flip: $V_{error} \rightarrow -V_{error}$) You may have to flip it in section 4. If it is complicated to flip the polarity of V_{error}, then redesign your circuit.

Verify that for I_{load} =1 A, the 1 kHz oscillations on V_{error} are roughly centered around zero.

4. PI feedback constant current source *(2 hrs … infinite, if not prepared)*

This section is the main part of the lab. You will use proportional and integral feedback (PI) to stabilize the current in the sense resistor R_{sense}, and thus in the load resistor R_{load} as well.

a) Construction

Construct a circuit based on 3 op-amps (3-terminal, ideal) that takes the V_{error} and implements equation 11.1 without the derivative term (i.e. the last term). Your circuit must include sub-circuits or components for each item in the equation: the LHS, the RHS terms, the "+" sign, and the "=" sign. *The hint at the start of the lab instructions will save you some trouble.*

If your circuit works, then you should have I_{load} =1 A, which you can now adjust by changing V_d.

- Verify that V_d = 0.5 V, yields I_{load} =0.5 A, and that V_d = 0.1 V, yields I_{load} =0.1 A.

- Verify that you can change the load resistor to R_{load} = 2 Ω or R_{load} = 7 Ω without changing I_{load} (use 1 A)

Note 2: If you find that V_d controls I_{load}, but the current is only approximately correct, then you should go to part b and make the suggested adjustments to improve the performance of your circuit.

Note 2: If you circuit does not work, e.g. I_{load} =0 A, then it may be incorrectly wired, or the sign of the feedback is incorrect. Try changing the sign of the feedback by flipping the polarity of V_{error}.

b) DC performance

- Change the gain of the integral feedback via the capacitor and see how it affects the accuracy I_{load}. How close can you get to I_{load} = 1 A (use R_{load} = 5 Ω).

- Zoom in to the current plot and measure the size of 1 kHz oscillations on I_{load} (at 1 A). How small can you make the oscillations by adjusting the proportional feedback and the integral feedback.

- Adjust the proportional and integral feedback to minimize the current oscillations, while remaining close to the target desired current of 1 A. Determine the fractional accuracy of your current source (in %), i.e. how close the actual current is to your desired current. Determine the fractional noise on your current source, i.e. the size of the 1 kHz current oscillations with respect to the full 1 A current (in %).

c) Dynamic performance

Replace the DC power source (battery) for V_d with a "clock voltage" source (square wave) at 10 Hz with a 1 V amplitude (Vp) [50 % duty cycle, and rise/fall time = 1 ns]. Measure the response of the actual current to an abrupt change in the target current (by changing V_d) for both an increase and a decrease.