PHYS 252: Analog Electronics I
Spring 2020

Homework 11: PI Feedback Control

Problem 1: Square wave to triangle wave converters

Consider a square wave signal that flops back and forth between +1 V and – 1 V at 1 kHz. Design an op-amp circuit that takes the square wave as an input and outputs a triangle wave centered 0 V at 1 kHz.

Calculate the slope and amplitude (V_{pk}) of the triangle wave for your component values.

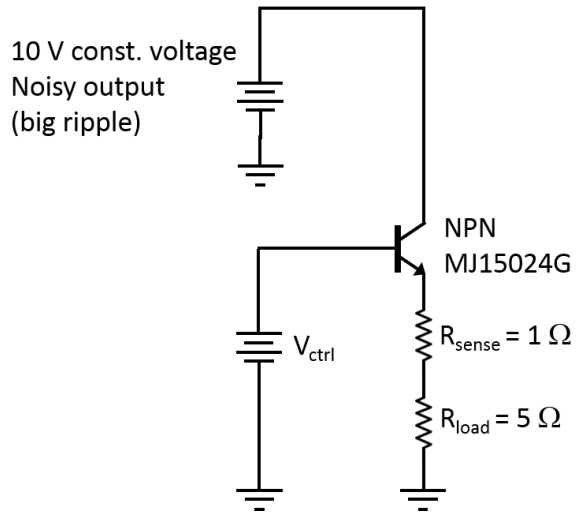
Hint: *Watch the last 10 minutes of the week 9 lecture again.*

Problem 2: Constant current source design using PI feedback control

This problem focuses on helping you design the circuits that you will need for the lab this week on using PI feedback control to produce a constant current source.

Note 1: You do not need to simulate any circuits for this problem.
Note 2: 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.

1. Basic constant current source



This circuit is a basic constant current source. The current comes from the low quality 10 V "constant" voltage source, which is similar to the one you built in lab 4: bridge rectifier.

a) Derive a formula for I_{load} in terms of R_{load}, R_{sense}, V_{ctrl}, and β. Does it depend on the exact voltage coming out of the 10 V power supply?

b) Is this a good current source? Explain.

2. Sense resistor: Op-Amp current-to-voltage converter

Design an op-amp (3-terminal, ideal) circuit that you can attach to the above constant current source to measure the current running through the sense resistor R_{sense} by converting it into a voltage in a 1-to-1 manner, such that V_{out}= 1 V for I_{load} =1 A.

3. Error signal circuit

Since the final objective of this exercise is to design a constant current source (nominally for 1 A), in this section you will design an op-amp circuit (single op-amp, 3-terminal, ideal) that will generate an error signal V_{error} from the V_{out} in section 2, which is centered at zero when I_{load} =1 A. You can use an external 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.

Make sure that your error signal circuit can be easily modified so that you can flip the sign of V_{error} (i.e. polarity). If it is complicated to flip the polarity of V_{error}, then redesign your circuit.

4. PI feedback circuit

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) PI gain circuit

Design a circuit based on 3 op-amps (3-terminal, ideal) that takes the V_{error} and implements the RHS of 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, including the "+" sign.

Note: You may find it useful to review the last 10 minutes of the week 9 lecture.

b) Full PI feedback circuit

Take the circuit in section 1, and attach the circuit in section 2, then attach the circuit from section 3, and then finally attach the circuit in section 4(a). Next, implement the LHS of equation 11.1, including the "=" sign (note: you will have to modify the circuit in section 1).

<u>Problem 3:</u> Basic Op-Amp constant current sources

(This problem is independent of problem 2.)

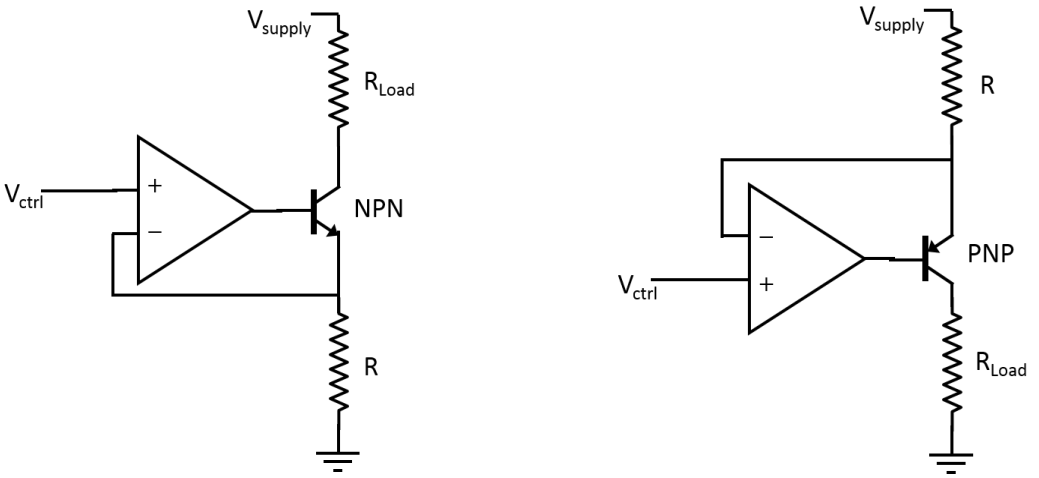


Figure: Basic unipolar op-amp current sources. *Left:* Constant current source with a high side load resistor, based on a NPN transistor. *Right:* Constant current source with grounded load resistor, based on a PNP transistor. N-type and P-type MOSFET or JFET transistors can be used in place of the NPN and PNP BJT transistors, respectively.

a) <u>Derive</u> a formula for the current in the load resistor in the NPN-based circuit in the figure (left) above.

b) <u>Derive</u> a formula for the current in the load resistor in the PNP-based circuit in the figure (right) above.

c) <u>Which circuit</u> is more immune to power supply noise on V_{supply} ?