EE 140/240A Linear Integrated Circuits
Fall 2019 Homework 1

This homework is due September 4, 2019, at 23:00.

Submission Format
Your homework submission should consist of **one** file submitted via bCourses.

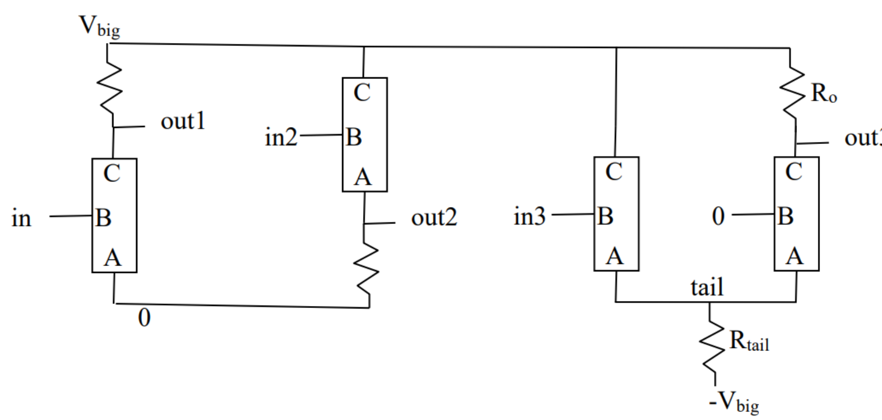
- `hw1.pdf`: A single PDF file that contains all of your answers (any handwritten answers should be scanned).

1. Three-Terminal Devices

In the figure below, there are four identical three-terminal devices. These devices all have the properties:

- The current from C to A is a strong function of the voltage from B to A and a weak function of the voltage from C to A.
- There is negligible current into node B.
- If the voltage from B to A is less than V_X, that the current is zero.
- If the voltage from B to A is more than $V_X = \frac{V_{\text{big}}}{10}$, the current goes up really fast.
- The voltage from C to A doesn't have much effect, as long as it is greater than 0, but if it is 0 or less, the current is 0.

(Note: Seen from far away, this describes JFETs, BJTs, Darlingtons, MOSFETs, MESFETs, vacuum tubes, IGBTs, HEMTs, and virtually every other three terminal electronic device ever made)



(a) Sketch V_{out1} as V_{in} varies from 0 to V_{big}

(b) When V_{out1} is $\frac{V_{\text{big}}}{2}$, write an expression for the V_{out1} using the derivative of the current with respect to V_{in} and the resistor R.

(c) Sketch V_{out2} as the V_{in2} varies from 0 to V_{big}.

(d) Sketch V_{tail} as V_{in3} varies from 0 to V_{big}.

(e) **(EE240A)** Use MATLAB or some equivalent to plot 3D surfaces of current vs. control and output voltages for several of the types of 3-terminal devices listed above, preferably showing constant-current projections onto the XY plane. Comment on the gain vs. bias point.

2. Berkeley Hills

You're standing on a big smooth hillside. Directly North the hill climbs up quite steeply, rising 10cm for every step you take. Directly East the hill climbs gently, rising only 1mm for every step you take. You put a stake in the ground where you are standing and call it $(0,0)$. You measure the elevation to be E. If you want to be 10 steps further north than you currently are, but don't want to change your altitude (current source!)

(a) If you walk 10 steps east and put a stake in the ground labeled $(10,0)$, what is your elevation?

(b) If you walk 10 steps north from $(0,0)$ and put a stake in the ground labeled $(0,10)$, what is your elevation?

(c) After walking 10 steps north, how far east do you have to walk in order to go back to your original altitude? (You can have a negative answer!)

(d) (Note: altitude is current. East/west is drain/source voltage. North/south is gate/source voltage. The first stake is the DC operating point, the origin of the local coordinate systems. Step counts are small signal voltage changes. What is the intrinsic gain?

(e) Do any of the previous answers depend on E, or the GPS location of the stake that you labeled (the specific values of the DC operating point)?

3. Linearizing Gold Mining

You live in an area with a lot of gold mines. Everyone knows that the amount of gold G that has been extracted from a mine as a function of the time the mine has been open H is given by

$$G(H) = \frac{G_{\text{total}}}{2}\left(1-\cos\left(\frac{H}{T}\pi\right)\right)$$

from the time that people first start excavating the mine (when $H=0$) until the time that all of the gold is gone, $H=T$. In other words, G is strictly increasing over since no one's putting gold back into the mine.

(This is about linearization. You get more bang for your buck (more g_m per µA) with transistors that are biased just right. There's a low bias where you get nothing, a high bias where everything is maxed out, and a sweet spot somewhere in the middle.)

(a) If you only get to work for one hour in the mine, does it matter if you work at the beginning, vs. the middle or the end? Why or why not?

(b) When should you work to mine the most gold, and how much will you get?

(c) Let $T=100$ years. If you start working at $H=\frac{T}{4}$ and work for a year, does your gold mining rate change much from month to month?

4. Impedance Plotting

Graph the magnitude of the impedance of the following elements and circuits by hand. Use a log/log scale, with the frequency axis varying from 1 to $10^{11}\,\frac{\text{rad}}{\text{s}}$, and the impedance axis varying from 1Ω to $10\text{G}\Omega$.

(a) Resistors of magnitude 1kΩ, 1MΩ, 1GΩ and capacitors of 1nF, 1pF, and 1fF; and inductors of magnitude 1mH, 1μH, 1nH (all 9 of these components should be on the same plot)

(b) The following three impedances should be on a single plot:

- The series combination of 1MΩ and 100fF
- The parallel combination of 1MΩ and 100fF
- The series combination of 10Ω and 10nH (real inductors always have series resistance)

