

EE 140/240A Linear Integrated Circuits

Spring 2020

Homework 1

This homework is due Thursday January 30, 2020 (late Friday at 9am).

Submission Format

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

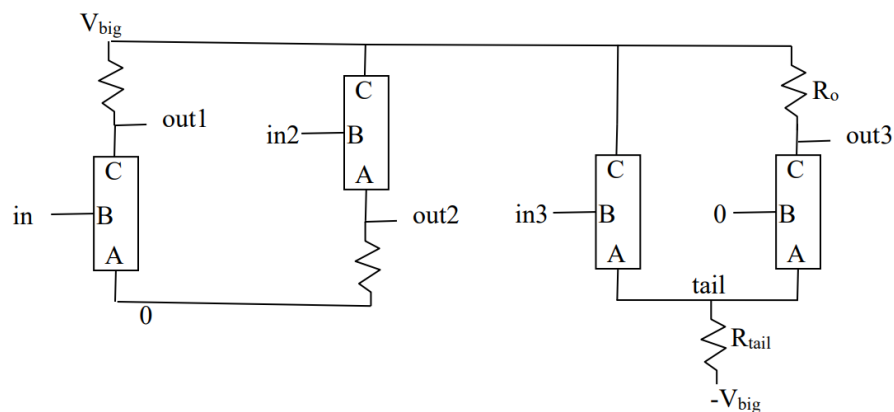
- `hw1.pdf`: A single PDF file that contains all of your answers (any handwritten answers should be scanned).

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)



- Sketch V_{out1} as V_{in} varies from 0 to V_{big}
- 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 .
- 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) **Use MATLAB or some equivalent to plot 3D surfaces of current vs. control and output voltages for an NPN transistor with $I_S = 10^{-10}\text{A}$ and $V_A = 100\text{V}$. Zoom in so that you aren't just showing a big flat plane with a wall next to it. At a given bias point (dot on the surface) think about how much the control voltage or the output voltage needs to change in order to increase the current by one percent. How does that relate to intrinsic gain?**

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!)

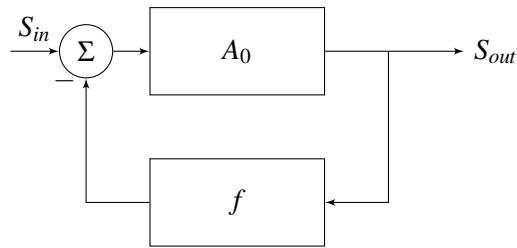
- (a) If you walk 10 steps east and put a stake in the ground labeled (10,0), what is your elevation?
- (b) If you walk 10 steps north from (0,0) and put a stake in the ground labeled (0,10), what is your elevation?
- (c) After walking 10 steps north, how far east do you have to walk in order to go back 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. Impedance Plotting

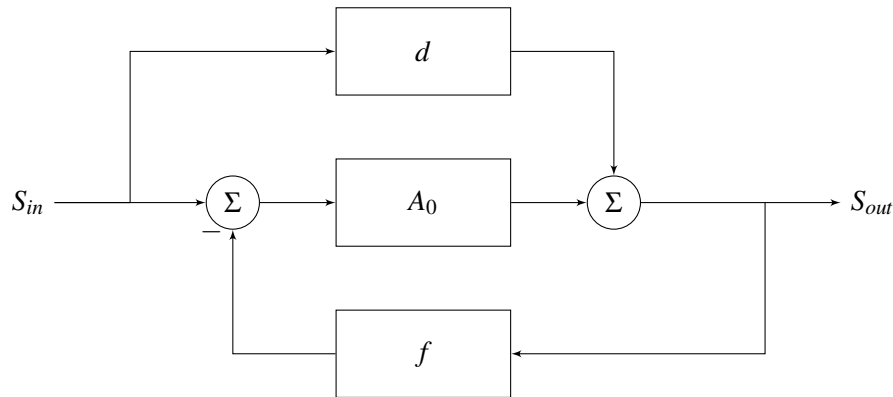
Graph the magnitude of the impedance of the following elements and circuits by hand. Use a log/log scale, with the frequency axis varying from 100 to $10^{12} \frac{\text{rad}}{\text{s}}$, and the impedance axis varying from 1Ω to $10\text{G}\Omega$.

- (a) Resistors of magnitude $1\text{k}\Omega$, $1\text{M}\Omega$, $1\text{G}\Omega$ and capacitors of 1nF , 1pF , and 1fF ; and inductors of magnitude 1mH , $1\mu\text{H}$, 10nH (all 9 of these components should be on the same plot)
- (b) On the previous plot, add a vertical line with a frequency and label for each of the following frequency bands: the electric power grid, audio amplifier lower and upper bound, fluorescent lightbulb electronic ballast, AM radio, FM radio, 802.11bg, 802.11a, modern automotive radar.
- (c) What is the frequency at which a $1\text{M}\Omega$ resistor has the same magnitude impedance as a 1pF capacitor? If the two are in parallel, what is the exact formula for the complex impedance at that frequency (which is called the pole frequency)? If the two are in parallel, and you use the straight-line approximation for impedance, what is the percent error in your magnitude calculation at one tenth of the pole frequency, and ten times the pole frequency?
- (d) The following three impedances should be on a single plot:
- The series combination of $10\text{M}\Omega$ and 10pF
 - The parallel combination of $10\text{M}\Omega$ and 10pF
 - The series combination of 100Ω and 100nH (real inductors always have series resistance)

4. Feed This Way and That



- (a) For the system above, find $\frac{S_{out}}{S_{in}}$



- (b) For the system above, find $\frac{S_{out}}{S_{in}}$

5. PN Junction

An abrupt PN junction $N_D = 10^{18} \text{ atoms/cm}^3$, $N_A = 10^{17} \text{ atoms/cm}^3$, and is held at 300K. For these problems do not use a calculator. You won't have one on the midterm.

- What is the minority carrier concentration on each side of the junction?
- What is the built-in potential?
- With no external bias, draw three sketches aligned vertically to the junction: fixed charge density, electric field, and potential.
- If an external bias triples the width of the depletion region, sketch the same three curves, clearly indicating the change in the width of each depletion regions, the peak electric field, and the potential on each side of the junction.
- What value of reverse bias is needed to cause the depletion region width change above? What is the relative magnitude of the junction capacitance between your two sets of figures, and which is bigger?