EECS 16A Designing Information Devices and Systems I
Spring 2019 Homework 11

This homework is due April 19, 2019, at 23:59.
Self-grades are due April 23, 2019, at 23:59.

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

- `hw11.pdf`: A single PDF file that contains all of your answers (any handwritten answers should be scanned) as well as your IPython notebook saved as a PDF.

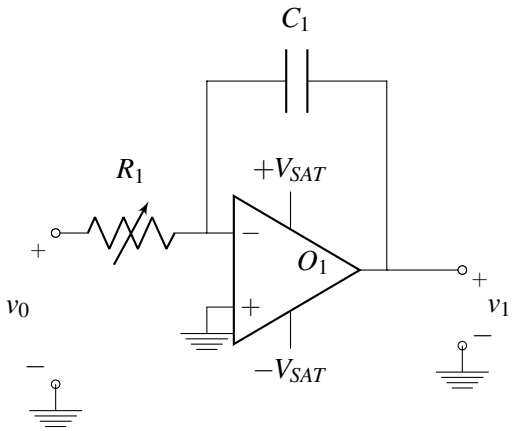
  If you do not attach a PDF "printout" of your IPython notebook, you will not receive credit for problems that involve coding. Make sure that your results and your plots are visible. Assign the IPython printout to the correct problem(s) on Gradescope.

Submit the file to the appropriate assignment on Gradescope.

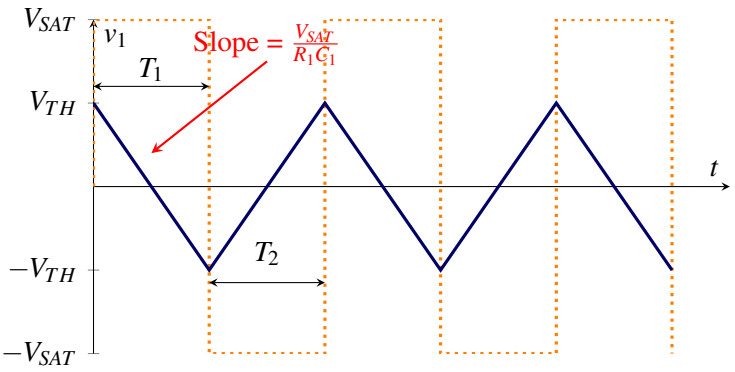
1. Jumpbot

In this problem, you will be designing circuits allowing a robot named Jumpbot to execute a set of commands that will be described below. Specifically, the output voltages produced by your circuits are interpreted by Jumpbot as setting its vertical position in meters in free space (both positive and negative values will be used). You will be generating an oscillating triangular waveform with a controllable time period.

(a) One of the circuit blocks you will use to generate the triangular waveform is the integrator. An integrator integrates the input signal. For the circuit given below express v_1 in terms of R_1, C_1, and v_0. You may assume the capacitor C_1 has $0V$ across it at time $t = 0$.
Hint: You will have to apply KCL, and the current flowing through a capacitor is given by $I = C\frac{dV}{dt}$.



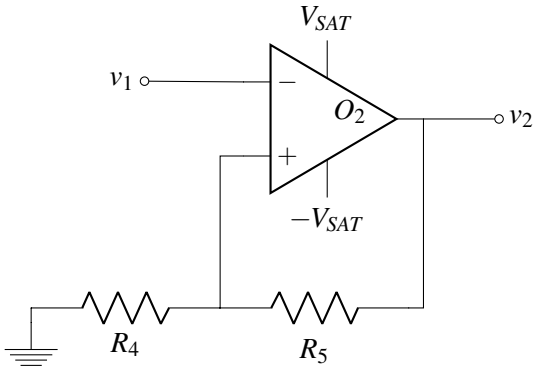
(b) Suppose for a specific v_0, shown by the dotted orange line below, v_1 looks as shown by the blue line. Derive an expression for T_1 and T_2 as a function R_1, C_1, V_{TH}, and V_{SAT}.



(c) We have a circuit that generates a triangle wave from a square wave. However, we need to create the initial signal (v_0) that helped us to create the triangular waveform (v_1). For the circuit below, draw the waveform (v_2) if we use v_1 from part (b) as the input. Now, draw the waveform (v_2) if we use $-v_1$. Which v_2 (v_1 as input or $-v_1$ as input) matches v_0 from part (b)?

$$+V_{TH} = \frac{R_4}{R_4+R_5}V_{SAT}$$
$$-V_{TH} = \frac{R_4}{R_4+R_5}(-V_{SAT})$$

Hint: read section 9.8.1 of the book "Electronics" by Prof. Ali Niknejad, you can find it on the Resources section on the class website.



(d) Now let's put it all together. The circuit from part (a) generates a triangle wave (v_1) from a square wave (v_0). The circuit above takes an input triangle wave and creates a square wave. Connect the two circuits together so that the circuit keeps generating a triangle wave on it's own. You will use the circuits from part (a) and part (c), in addition you can use any opamps and resistors.

(e) In your circuit, if $\pm V_{SAT} = \pm 10\,\text{V}$, $C_1 = 0.01\,\text{mF}$, and $R_4 = 10\,\text{k}\Omega$, find the values for R_1 and R_5, so that the jumpbot jumps with 10 V peak-to-peak amplitude ($\pm V_{TH} = \pm 5\,\text{V}$) with 1 kHz frequency (period = 1 / frequency).

2. From FA18 Final: A Tool to Help Compute All the Fun You're Having

Starting in the 1950-1960's, the world began a series of missions to get to the moon. Back then though, computers took up entire rooms and could never fit on a spaceship! They needed a better way of computing values on the fly using what they did have: analog circuits.

In class you have seen circuits that can amplify, add, subtract and even integrate voltages, but we're missing a key ingredient to make computational circuits: **multiplication**. Although making a multiplier circuit is not as straightforward as we would like it to be, we can definitely use our now fully-developed EE16A skills to make this a reality.

You may find the following formulas useful throughout the problem:

$$\ln(e^a) = a \qquad \ln(a) + \ln(b) = \ln(ab)$$
$$e^{\ln(a)} = a \qquad \ln(a) - \ln(b) = \ln(\tfrac{a}{b})$$

(a) To start off, your TA Nick suggests that you first draw a block diagram that would do what you want, and then worry about how to implement it later. He starts you off with the following incomplete block diagram and blocks.

You are allowed to use any amount of the following logarithmic, exponential and summer blocks:

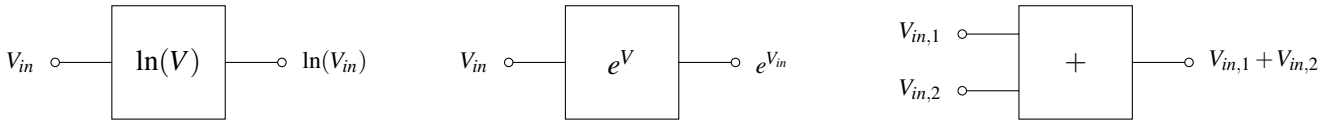
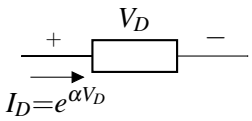


Figure 1: Function blocks you can use

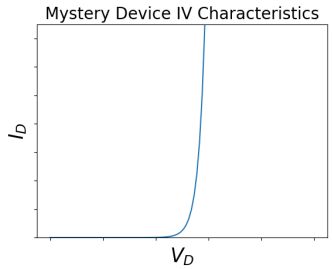
Finish the **block diagram** so that the output is equal to $V_{out} = V_{in,1}V_{in,2}$. **Also provide a mathematical justification for why your block diagram works for full credit!**

While you were making your block diagram, your friend Vlad was watching over your shoulder. With his near-infinite knowledge of circuits, he predicts what you are trying to do and gives you a "magic device" that he claims will help you out.

This device is shown below:



This device has the following IV characteristics:



Numerically, this can be stated as:

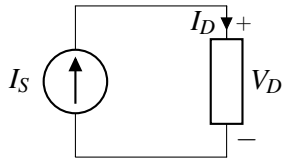
$$I_D = e^{\alpha V_D}$$

where α is some constant and V_D is the voltage across the device as in the above figure.

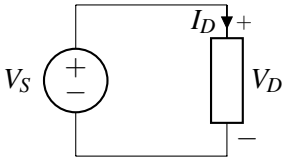
IMPORTANT: Note the passive sign convention.

(b) Your friend Gireeja sees you looking confused, and reads what you've done so far. She decides to help push you in the right direction. She reminds you that if you know how a device reacts when you put current through it or apply a voltage across it, then you are in a good spot to understand how it would behave in any circuit.

i. **In the following circuit, express the voltage across the device, V_D, as a function of the source current, I_S.**

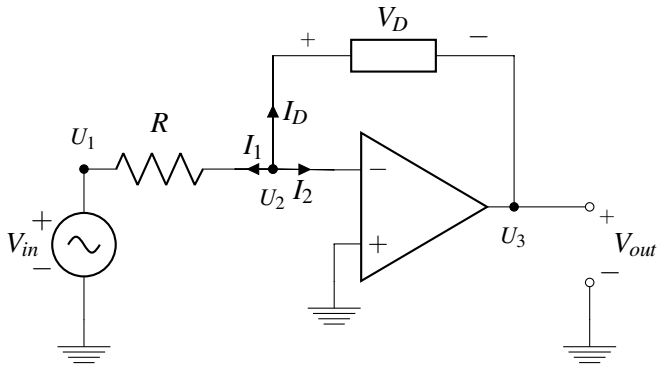


ii. **In the following circuit, express the current through the device, I_D, as a function of the source voltage, V_S.**



(c) By now we have all the tools necessary to make this a reality. Unfortunately, as you may remember from the touchscreen lab, ideal current sources don't exist. As such, we will use an op-amp to create the behavior we are interested in. Let's analyze the circuit below in steps.

Hint: *Your answers for some parts of this problem will not perfectly match with the ideal scenario in part (a). Don't be afraid of getting different answers! After all, a block diagram is just a starting point.*



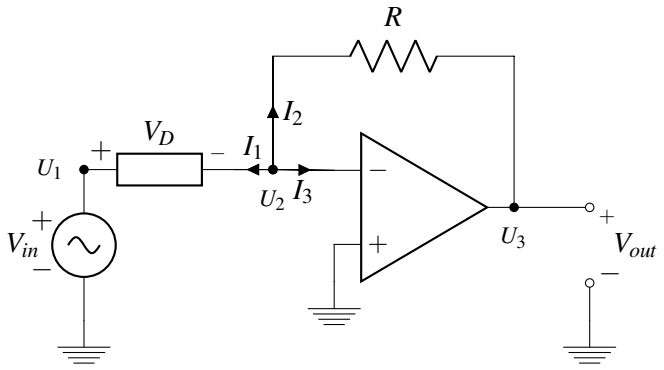
i. **write V_D in terms of V_{out} only. You may assume the circuit is in negative feedback.**

ii. **Now write out the KCL expression at the U_2 node in terms of the three currents I_D, I_1 and I_2.**

iii. **Use the IV relations for each device and the KCL expression above to find V_{out} as a function of V_{in}.**

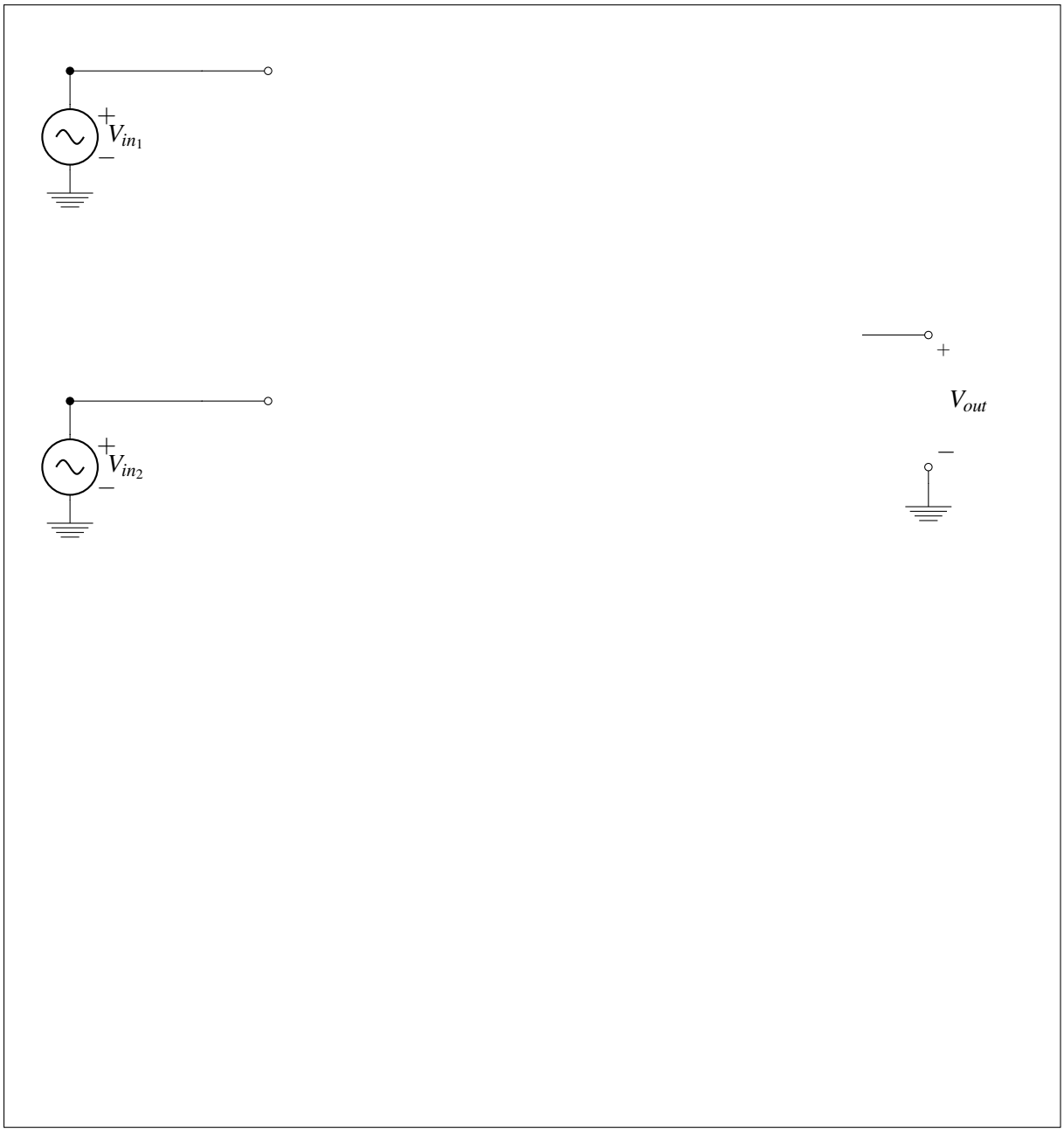
(d) Just one more piece left to analyze. You may assume the circuit is in negative feedback. **In the circuit below, write V_{out} as a function of V_{in}.**

Hint: *Note the direction of the voltage drop, V_D. Be careful when writing your KCL expressions to account for this!*



(e) Given the polarity of circuits in parts (c) and (d), to put everything together, you need to implement **an inverting summer circuit, where $V_{out} = -(V_{in_1} + V_{in_2})$.**

You may use up to 1 op-amp (you do not need to label the power supplies) and as many resistors as you wish. **Any resistors used must be assigned a value. You must mathematically justify your circuit's behavior for full credit.**



And that's it! Now that you have all the individual parts, you can string them together and start selling calculators. You may need to make a few small changes to your original design, but you can do it!

3. APS Prelab - Cross Correlation

Complete the included iPython notebook to prepare for the upcoming APS lab, prob11.ipynb.

4. Midterm Problem 3

Redo Midterm Problem 3.

(a)

(b)

5. **Midterm Problem 4**
   Redo Midterm Problem 4.

   (a)

   (b)

   (c)

6. **Midterm Problem 5**
   Redo Midterm Problem 5.

   (a)

   (b)

7. **Midterm Problem 6**
   Redo Midterm Problem 6.

   (a)

   (b)

8. **Midterm Problem 7**
   Redo Midterm Problem 7.

   (a)

   (b)

9. **Midterm Problem 8**
   Redo Midterm Problem 8.

   (a)

   (b)

   (c)

   (d)

   (e)

10. **Midterm Problem 9**
    Redo Midterm Problem 9.

    (a)

    (b)

11. **Homework Process and Study Group**

    Who else did you work with on this homework? List names and student ID's. (In case of homework party, you can also just describe the group.) How did you work on this homework?