GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL of ELECTRICAL and COMPUTER ENGINEERING

ECE 4893A: Analog Circuits for Music Synthesis Spring 2018
Problem Set #1

Assigned: 2-Feb-18
Due Date: 9-Feb-18

Your homework is due at the *start* of class on **Friday, Feb 9**.

Words in a typewriter-style font are hyperlinks; clicking on them in your PDF reader should open them up in your default web browser.

Suggested references: `National Semiconductor Application Note 31` (or pretty much any textbook that has op amp circuits in it).

Ground rules: You are free to discuss approaches to the problems with your fellow students, and talk over issues when looking at schematics, but your solutions should be your own. In particular, you should *never* be looking at another student's solutions at the moment you are putting pen to paper on your own solution. That's called "copying," and it is bad. Unpleasantness, including referral to the Dean of Students for investigation, may result from such behavior. **In particular, the use of "backfile" of solutions from homeworks and quizzes assigned in previous offerings of this course is expressly forbidden.**

PROBLEM 1.1:

Let's look at the "AUDIO AC IN" of the Serge Lin/Log VCA:

`http://urekarm.tripod.com/synth/serge_vca.pdf`

The input capacitor (470 nF) and the two resistors (68K and 330Ω) form a single-pole highpass filter whose "output" is measured by the positive input terminal of the CA3080. Find its cutoff frequency (the half-power point) **in Hertz** (so don't forget to divide your cutoff in radians/second by 2π). Note that the resistor in series with the cap gives this configuration a non-unity gain DC, so "half-power" should be interpreted in terms of half of the power at DC. As usual, assume that the input is being driven by an ideal voltage source. (Note that the 22K resistor is not relevant to this problem; it's there to make sure the input stays centered at ground so there's not a "pop" when the user plugs in a cord.)

PROBLEM 1.2:
In this problem, we will analyze the PAiA 9710 VCA. The schematic is available here:

`http://www.paia.com/prodimages//9710scha.gif`

It is in squintovision, so I would recommend opening it up in some sort of image viewing program so you can zoom in a little. The `9700 series` runs off a +/- 12V power supply, i.e. V- on the schematic means -12V, and V+ means +12V.

The 9710 actually contains two VCAs, along with a "balanced modulator" (a four-quadrant multiplier, which is good for special effects.) We will look at the "right" VCA. You will find the core of it along the bottom part of the diagram. J2 is the audio input, and J11 is the output. The circuit will we look at uses one-half of a dual OTA, the LM13600; the one of interest to us is labeled IC5:B.

R45 and R43 create a slight voltage bias to compensate for non-ideal characteristics of the LM13600. Real OTAs have an output bias current, which vexingly varies with the control current. The 9710 uses a fixed resistor network to put a small bias voltage to try to correct for a "typical" output bias current. Many other designers use a trim pot for this. In any case, we won't worry about such non-ideal effects here, so you may assume the OTA is an "ideal linear OTA" and that the + terminal of IC5:B is at ground.

The current generating circuitry for the OTA may be found in the upper left corner of the schematic. R14, R16 (at least I think it's R16 - it's the 220K resistor below R14), R12, R18 (at least I think it's R18 - it's a 1500 ohm resistor to ground), IC2:C (an op amp), and Q2 form a current source similar in spirit to the one from Chamberlin, p. 203 that I presented in lecture, so if you have difficulties analyzing it, you will want to review your notes from that day. R44 is a small current limiting resistor to help make sure the OTA doesn't become an ex-OTA. D2 is for protection; we will ignore it in our analysis. Similarly, we will ignore R48, the 18M resistor (consider it to be infinite.)

To simplify our analysis, suppose the "pan" pot is turned all the way towards R, so the wiper is at ground.

J5 is a "normalled" jack, meaning that if nothing is plugged into it, the "signal" part of the jack (the top pin in the schematic, which appears to be labeled with a test point "H") will default to the signal going to the middle pin (which appears on the schematic to be labeled with a test point "B"). We will assume that the user has inserted a control signal into J5, so point "H" (the left side of R14) will be some user-created voltage we will call V_{con}.

(a) Find the voltage at the output of IC3:B. You can do this quickly if you realize that this op amp is acting in a standard "inverting mixer" configuration. (Remember we are assuming the wiper of the "pan" pot is at ground).

(b) Given all the notes above and the assumption that the current through the base of Q2 is negligible, so we may approximate its collector and emitter currents as being equal, find the current input to the OTA (I_{con}) as a function of V_{con}.

(c) Now let's look at the main part of the VCA, with input at J2 and output at J11. Find the gain of the VCA as a function of I_{con}. For now, you may ignore C12 (i.e., open the cap, which is a reasonable assumption for low frequencies).

(d) Suppose $V_{con} = 10$V (from what I understand, the envelope generators in the PAiA 9700 series can generate up to 10V, so that's a reasonable voltage to try). What is I_{con} in this case?

(e) Take a look at the "Absolute Maximum Ratings" section of the `LM13600 datasheet`. What is the maximum rating for the control current (which the data sheet calls I_{ABC})? Is the value you found in part (d) above or below this?

(f) What is the gain of the VCA for $V_{con} = 10$ V?

(g) Without going through extensive calculations - i.e., by just reasoning your way through the circuit - what happens to the VCA gain as the wiper of the "pan" pot is turned away from ground and toward V+.

(h) Previously, we ignored C12. If we now consider it, we see that C12, R52, and IC6:B act as a current-to-voltage single-pole lowpass filter with a cutoff frequency (half-power point) of $1/(2\pi RC)$, in units of Hertz. What is the cutoff frequency of this filter? Is this cutoff frequency above or below the limit of typical human hearing?

(i) What is the input impedance of the VCA?

(j) What is the output impedance of the VCA? (Assume the op amps are all ideal, i.e., they have zero output impedance).

PROBLEM 1.3:

In this problem, we'll keep looking at the same PAiA 9710 schematic as in Problem 2. Here, we will focus on the pan pot, and the notion of "shaping" the curve swept by the pot.

Suppose the leg of the pot between the wiper and ground has resistance R, where R may range from 0 to 10K; then, the other leg (between the wiper and V+) has resistance (10K - R). The voltage at point "C" may be found via a standard voltage divider, where R and the 120K resistor may be simplified as a parallel combination.

On a single graph, plot (a) the voltage at "C" as a function of R, for $0 < \mathrm{R} < 10\mathrm{K}$, and (b) the same thing as (a), except suppose that the 120K resistor is actually a 10K resistor. I recommend using MATLAB to make the graph, but you may use whatever computer program you prefer. (Please actually print out your graph, don't just sketch it in pen or pencil.)

Which graph, (a) or (b), looks more linear?

PROBLEM 1.4:

I've set up an `ECE4893A: Analog Circuits for Music Synthesis site on Piazza`. I posted a "Question" called "Geting to know you." Click on "start a new followup discussion" and leave a brief post about yourself. I'd like to know a bit about you, as it might relate to this class. For instance: How did you find out about the class? Do you play any musical instruments? Do you play in a band? If you make music, have you made any recordings? Do you have any particular interests in using synthesizers and/or audio production more generally, either with or without the use of computers? What related classes are you taking or have taken (such as the senior level audio engineering or operational amplifier design classes, ECE3400, Music Technology classes, etc.)

You can read other people's posts, and maybe find some common interests.

(To be clear, you don't need to play an instrument or anything like that to do well in this class; no previous musical knowledge is needed.)