GEORGIA INSTITUTE OF TECHNOLOGY

SCHOOL of ELECTRICAL and COMPUTER ENGINEERING

ECE 4893A: Analog Circuits for Music Synthesis Spring 2018

Problem Set #3

Assigned: 21-Feb-18

Due Date: 2-Mar-18

Your homework is due at the *start* of class on **Friday, March 2**.

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

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 3.1:

In this problem, we'll look at the `Oberheim OB-Mx`. You may listen to it here:

`https://www.youtube.com/watch?v=0CL1e6yvmtk`

Strangely, Tom Oberheim had nothing to do with this synth; Gibson had bought the rights to the Oberheim name. Don Buchla was called in to try to save the project, but it eventually wound up released before it was really ready against Buchla's wishes.

We'll look at the schematic for "Voice A" from one of the voice boards. You may find it on my OB-MX Preservation Page:

`http://lanterman.ece.gatech.edu/obmx`

Click on "Voice A Processing." (Each voice board has circuitry for two voices; an OB-Mx chassis can hold up to six voice boards, for a total of twelve voices.)

If you don't see a specific unit on a capacitor, there's usually an implied "microfarads."

(a) The Moog transistor ladder VCF contains a cascade of four one-pole lowpass filter sections. Using Equation 13 on page 12 of Tim Stinchcombe's `Analysis of the Moog Transistor Ladder and Derivative Filters` (which is the same as the result I hand-wavingly derived in class), find the cutoff frequency (in Hertz) of one of those sections in the OB-Mx's transistor ladder as a function of the control current being pulled from the tied emitters of the transistor pair that feeds the ladder.

Note that when analyzing the Moog VCF, we don't include a resistive divider in the gain as we've done in OTA-C filter cutoff computations; there is typically a resistive divider right at the first input, but it's not important for our frequency analysis.

(b) Let's do some DC analysis. At DC, the caps are open circuits. Supposing that the transistors draw negligible current through the bases, what are the voltages at the bases of the four stages of the ladder? (Number the stages 1 through 4, from bottom to top).

PROBLEM 3.2:
Check out Ray Wilson's Voltage Controlled Low Pass Filter (Four Pole 24db/Oct):

`https://web.archive.org/web/20100823053938/http://www.musicfromouterspace.com/analogsynth/vcf.html`

The input and feedback resistors are 100K; it looks like the divider is made with a 1K to ground. (I find it interesting that he chooses to use TL084 op amps as buffers instead of the buffers built in to the LM13700. Maybe this is to avoid having to deal with the weird 1.4 V drop you get from the LM13700 buffers? The TL084 also are probably better quality than just the simple Darlington pair in the LM13700.) In parts (a) through (g), we will consider the gain of just one of the filter stages, either the second, third, or fourth (they are all the same; I'm not including the first one so we can avoid the effect of resistor coupling in the resonant feedback loop while working (a) and (b)).

(a) Find the voltage at the input terminal of the OTA in terms of the voltage at the output of the buffer and voltage at the input of the filter block. Don't make any approximations concerning the resistors (i.e., if you use superposition, note that you must compute the value of the little resistor in parallel with the big resistor to solve this.)

(b) In class, I attempted to use vigorous handwaving to to convince you that part (a) could be approximated as

$$v_{ota-} = (v_{input} + v_{output})\frac{R_{small}}{R_{small} + R_{big}}$$

Comment on how close this approximation is to what you found in (a).

(c) In class, I used even more vigorous handwaving to attempt to convince you that part (a) could be further approximated as

$$v_{ota-} = (v_{input} + v_{output})\frac{R_{small}}{R_{big}}$$

Comment on how close this approximation is to what you found in (a) and (b).

(d) Assume that the transductance gain of the OTA is $19.2 I_{CON}$, where I_{CON} is the current flowing into the control pin of the OTA. What is the cutoff frequency of the filter block in terms of I_{CON} in Hertz, using the approximation in part (c)? (Remember that the transconductance gain just takes the place of $1/R$ in the usual single-pole cutoff frequency calculation, and for convenience we include the scaling of the resistive divider as part of the transconductance gain.)

(e) Given the result in (d), what value I_{CON} would be needed for the cutoff frequency of one stage to be 3000 Hz?

(f) What single-stage cutoff frequency would you compute if you used the I_{CON} you computed in (e), but you used the no-approximation technique of part (a)?

(g) What single-stage cutoff frequency would you compute if you used the I_{CON} you computed in (e), but you used the approximation in part (b)? Comment on how close the cutoffs computed in (f) and (g) are to 3000 Hz.

PROBLEM 3.3:

In class, we explored the consequences of cascading four one-pole lowpass filter and adding a negative feedback loop with a feedback gain of k. The individual one-pole filters each had the transfer function $H_1(s) = \omega_c/(s + \omega_c)$. We showed that the maximum usable k was k=4, at which point the filter would self-resonate. In this problem, we will take a look at the same structure, except instead of one-pole lowpass filters, we will cascade four **highpass** filters with the transfer function $H_1(s) = s/(s + \omega_c)$.

(a) Find $H_4(s)$, the transfer function of a cascade of four one-pole highpass filters described above.

(b) Find $H_{4F}(s)$, the closed-loop transfer function of $H_4(s)$ with a negative feedback loop with feedback gain k. You need not expand out terms of the form $(s + \omega_c)^4$; that just makes the expression more complicated. (Unlike in the lowpass case, I haven't been able to find a closed-form solution for the pole locations in this highpass case. From my numeric studies, it does seem like the maximum usable k is 4, at which point the filter self-resonances. Also, there are four zeros at the origin in the highpass case, which of course are not present in the lowpass case.)

(c) Asymptotically, what is the value of the frequency response $H_{4F}(j\omega)$ as ω approaches infinity?

(d) Now let's do a numerical experiment with the consider the full four-pole cascade with feedback amount k, Let the cutoff frequency of a single stage be 1000 Hz. Using MATLAB, Mathematica, Maple, or some similar tool, on the same plot, show the magnitude of the frequency response (with the horizontal axis in Hertz), from DC to some value that you think best shows off the curves, for four cases: $k = 0$, k just big enough so that you can just barely see a resonance "bump" in the curve, k close to 4 (but not so big that it swamps your other curves), and a k somewhere between the last two cases that you think is interesting. **Make sure the values at infinity corresponds with the results seem reasonable relative to the results of the simple formula derived in part (c).** Please include your computer code and give me a real printout of your curve, i.e., not something sketched by hand.