GEORGIA INSTITUTE OF TECHNOLOGY

SCHOOL of ELECTRICAL and COMPUTER ENGINEERING

ECE 4893A: Analog Circuits for Music Synthesis Spring 2018

Problem Set #4

Assigned: 9-Mar-18
Due Date: 16-Mar-18

Your homework is on **Friday, March 16** by 4:30 PM in my Van Leer 431C office. If I am not there, please slip it under my office door. Note that we will not have class on Friday.

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 4.1:

The Mutron III is a state-variable filter that uses light-dependent resistors to vary the cutoff frequency. The original Mutron III schematics I've found on the web are difficult to read, so let's take a look at a modern clone called the Neutron. You can find the schematic of the Neutron in the Neutron Filter construction guide:

`http://www.geofex.com/PCB_layouts/Layouts/neutronpub.pdf`

(a) Find the f_n, the natural frequency of the 2nd-order filter in Hz, for the following four conditions:

- Caps C5 and C7 switched "out"; LDRs = infinite Ω
- Caps C5 and C7 switched "out"; LDRs = 5KΩ
- Caps C5 and C7 switched "in"; LDRs = infinite Ω
- Caps C5 and C7 switched "in"; LDRs = 5KΩ

(b) Take a look at the VTL5C3/2 datasheet:

`https://www.thonk.co.uk/wp-content/uploads/2013/08/vtl5c3c4.pdf`

What control current would generate a 5KΩ LDR resistance? Use curve #4 on the graph (you'll see what I mean when you look at the datasheet). (Note I haven't actually analyzed the control circuit in detail, so I'm not sure such a current could be produced by this circuit, but my intuition says it's plausible.)

(c) Consider the "Peak" 150K pot. As the wiper is moved to the left on the schematic, does the Q increase or decrease? Explain your reasoning.

PROBLEM 4.2:
Let's check out the ASM-1 State Variable VCF:

`http://home.swipnet.se/cfmd/synths/friends/stopp/asm1vcf.new.pdf`

For the purpose of this analysis, ignore (i.e. "open") the 30 pF caps C1 and C3. You should be able to find the OTAs that are taking the place of resistors in the variable gain integrators. You should also be able to find the capacitors that the output currents of the OTAs are being sent into, as well as the op amps that buffer the resulting voltages. Finally, you should be able to look at the inputs of the OTA and find what resistor you will want to call R_{big} and what resistor you will want to call R_{small} to form the R_{small}/R_{big} gain factor that you will want to combine with the gain of the OTA when computing the natural frequency (in Hertz), f_n. Real OTAs have some non-ideal offset; P2 and P3 are trim pots that can help compensate for this offset. We will assume the OTAs are ideal so you can assume the positive inputs of the OTAs are grounded.

(a) Are the variable-gain integrators forming this SVF inverting or non-inverting?

(b) Find f_n (the natural frequency in Hertz) as a function of the current fed to the control current inputs of the OTAs. This should be a simple calculation once you find the component values you need.

(c) If R16 was increased, would the Q of this filter increase or decrease? Briefly explain your reasoning.

PROBLEM 4.3:

Problems 1 and 2 on Homework 3 dealt with a fairly popular lowpass filter configuration, namely a cascade of *four* identical single-pole lowpass filters with negative feedback.

The VCF in the `Elka Synthex` (see `this demo` by Paul Wiffen, one of the original Synthex sound programmers) permits this configuration, but it also allows the musician to select a configuration with a cascade of *two* identical single-pole lowpass filters with negative feedback. We will mathematically explore this configuration. Assume each single-pole filter stage has a transfer function of $\omega_c/(s+\omega_c)$, where ω_c is the half-power cutoff point of a single stage (in radians).

(a) Assuming a negative feedback factor of k, find the closed-loop transfer function of the complete filter. Write your answer so that it has ω_c^2 in the numerator and a quadratic polynomial in s in the denominator. Make sure the highest power of s has unit coefficient, i.e. a coefficient of 1.

(b) In class, we looked at a canonical lowpass 2nd-order filter transfer function of the form $\omega_n^2/[s^2+(\omega_n/Q)s+\omega_n^2]$, where ω_n was the "natural frequency" and Q was the "quality factor." If you put your answer to (a) in this form, what are ω_n and Q in terms of ω_c and K?

(c) What are ω_n and Q for the special case of $K=0$ (i.e. no feedback)?

(d) For what values of K does the filter exhibit a resonance bump, i.e. for what values of K is $Q>1/\sqrt{2}$?

(e) Using the quadratic formula, find the locations of the poles of this filter as a function of ω_c and K.

(f) Where are the poles for the special case of $K=0$?

(g) Describe how the poles move as K increases.

(h) Can this filter be made to self-oscillate like the four-pole-casade-with-feedback filter explored in the pervious problems? In other words, is there a value of $K>0$ for which the poles can be made to lie on the imaginary axis?