**ECE4450 - Analog Circuits for Music Synthesis (2-3-3)**

**Prerequisites:** (ECE 3043 [min C] or ECE 3741 [min C]) and ECE 3084 [min C]

**Co-requisites:** None

**Course Description:** Circuits from classic analog synthesizers: nonlinear waveshapers and voltage-controlled oscillators, filters, and amplifiers using operational transconductance amplifiers and the dynamic resistance of semiconductors.

**Textbook(s):** No textbook specified.

**Learning Objectives:** The student will..

1. modify traditional “textbook” circuits, such as oscillators, filters, and amplifiers, so their parameters may be varied by an external control voltage

2. become familiar with the artistic uses of sound generating and processing circuits, including nonlinear waveshapers

3. develop an intuitive approach to analog circuit analysis and design, emphasizing useful approximations and the study of schematics from real musical instruments used by real musicians

4. design and construct a module of a modular music synthesizer, including PCB design and soldering

**Learning Outcomes:** Upon successful completion of this course, the student will be able to:

1. analyze circuits employing operational transconductance amplifiers

2. analyze linear and exponential voltage-to-current converters

3. analyze sawtooth-core and triangle-core voltage controlled oscillators

4. exploit the nonlinearities and dynamic resistance of semiconductor devices

5. analyze various voltage controlled filter configurations, such as Sallen-Key filters, state variable filters, and the Moog ladder filter

**Topical Outline:**

Historical perspective

Demonstration of a modular synthesizer

Circuit theory review (emphasis on operational amplifiers)

Operational transconductance amplifiers (OTAs)

Voltage-controlled amplifiers

Linear current sources

Voltage-controlled oscillators

Sawtooth cores (comparators with resettable integrators)

Temperature-compensated exponential current sources

Triangle cores (comparators and integrators with current switches)

Basic waveshaping circuits

Complex waveshaping circuits for generating time-varying spectra

Voltage controlled filters (VCFs)

Single-pole OTA-C VCFs (resistor replacement and "systems" viewpoints)

Four-pole VCFs with feedback (pole migration and resonance peaks)

Transistor-ladder and diode-ladder VCFs (dynamic resistance)

Second-order filter properties

State-variable VCFs

Sallen-Key VCFs

**Grading:** Final letter grades will be based on a series of written homeworks, three in-class quizzes, and the quality of a final project in which you will design and build a module for a modular synthesizer. The average of your quizzes will be equally weighted with the average of your homework grades. (There will be no “drops” of lowest quiz or homework grades).

**Homeworks**: The homeworks are intended to be instructive and enlightening, and in particular get you looking at schematics of real synthesizers that have been in production, and not “textbook” problems. I try to avoid giving anything resembling “busywork.”

**Quizzes:** All will be closed book. The **first quiz** will focus on basic facts about circuits and electronic facts that a designer needs to have “at their fingertips,” without having to stop and look up, in order facilitate a smooth creative workflow. I will provide extremely detailed information about what I will ask on that quiz. The **second quiz**(roughly covering the first half of the lecture material: OTAs, VCAs, VCOs, waveshapers, and linear and exponential converters) and **third quiz** (roughly covering the second half of the lecture material: VCFs) will probe what kind of intuition you have developed concerning the class material; the questions will be more qualitative in nature (for instance: if the value of resistor X is increased, will the frequency of this oscillator go up or down?), in the sense that they will not require tedious calculations with precise numeric results. There will be no usual written final exam given during final exam week.

**Final Project:** The final project will permit (and encourage) you to make extensive use of various existing schematics you might find on the web, in textbooks, or elsewhere. A project “team” consists of 1, 2, or possibly 3 students (depending on total class size). Projects with two or three will be expected to be somewhat more ambitious than projects with smaller teams..

For the project, you will construct an analog synthesizer module to expand our existing modular system. You could “modularize” part of a complete synthesizer circuit (i.e. build a module based on the VCO, VCF, or whatever of a subcircuit of a complete synthesizer). This may involve adding/modifying input and output circuitry so that the resulting module matches the specifications given below, and also may involve “updating” the circuit to use modern parts. It would be nice if this was relatively “original,” in that a modularized version doesn’t already obviously exist on the web.

I’m allowing you to make such extensive use of existing designs since (a) most of the synth  
designers I know of actually got their start from tinkering around and modifying older designs, and (b) even getting a circuit from a published schematic working can be challenging.

If you would prefer, you can do something more original. If you’re doing a project that is based less on existing proven designs, I will put priority on helping you out during the design process.

You must be sure to give credit to the original inspirations of your designs wherever possible.

Your module must either make audio (i.e. an oscillator), or process audio (i.e. a filter or nonlinear waveshaper), or sometimes both (i.e. a filter that self-resonates when the Q is turned up really high). Since this will be a component of a synthesizer, in general, some aspect of your module should be controllable via a control voltage; for instance, a filter whose cutoff is solely controlled by a pot won’t do.

Teams are **strongly encouraged** to help other teams out, both with bantering around design ideas and **particularly with debugging**. Often, the mere act of trying to explain what’s on the breadboard to someone else will cause you to discover the source of a bug. You can draft people from outside the class to help you design and debug too. Feel free solicit advice on online. The only caveat on all this is that you must thank the people who aided you and describe how they aided you in your report. (Also, don’t be dishonest about it, i.e. don’t try to con someone online into designing an entire circuit for you.)

In addition to the project, I want a *brief* user’s manual explaining what your module is, what the controls do, etc., and a few basic notes about how you came up with the design, any calculations you made (for instance, to get something to match the MOTM standards), etc. Please include photos of your final built circuit board. (Including a photo of the breadboarded version would be nice, but is optional.) Basically, your report should be sufficiently detailed for someone else to reproduce your work. This should be reasonably slick, i.e. the text should not be handwritten. I’d like to emphasize the word “brief.” **I am more interested in PRODUCT than I am in PROSE.**

I consider the final project to be the most important thing in the class; hence, your course grade will max out at whatever your project grade is, e.g., if you do B work on the homeworks, etc., but turn in an A project, you might get an A for the class, or you might get a B; but if you do A work on everything else but turn in B level project, your grade won’t be an A. I will work with you very closely in helping you with your final project. My general procedure in this class is to push each student until I see what I consider “A” level work.

**Attendance & Absences: I will be taking attendance on most lecture days. If you miss more than 4 lectures or often arrive excessively late or leave excessively early without an appropriate excuse, I am likely to take notice, and reserve the ability to take that into account when assigning grades at the end of the semester. Students with medical or family emergencies should contact the Dean of Students. See http://catalog.gatech.edu/rules/4/ for an articulation of the Institute rules. Students with excused absences will be allowed to make up the work, normally within two days. If you know about an event ahead of time, such as a job interview, or if you are playing a game with an official Georgia Tech sports team, etc., it is your responsibility to turn in your homework ahead of time.**

**Major Emergencies: If you have some sort of major life emergency – serious illness or injury, death in the family, house burns down or is flooded, etc. – that seriously impedes your progress in the class, please let me know as soon as possible so we can work something out. You will find professors can be quite reasonable if you keep us in the loop. Please don’t disappear with no warning half way through, making me think that you dropped the class, and then reappear out of nowhere the week before finals asking what you can do to make things up. (Yes, this has happened quite a bit, in both undergrad and grad classes.)**

**Honor Code:** Georgia Tech aims to cultivate a community based on trust, academic integrity, and honor. Students are expected to act according to the highest ethical standards. This course will be conducted under the rules and guidelines of the Georgia Tech Honor Code; infractions will be reported to the Dean of Students. For information on Georgia Tech's Academic Honor Code, please visit http://www.catalog.gatech.edu/policies/honor-code/ or <http://www.catalog.gatech.edu/rules/18/>. The “ground rules” for each assignment, which may vary from assignment to assignment, will be given in each assignment description. Please ask for clarification if any aspects of the given “ground rules” seem unclear.

**Office of Disability Services:**If you are a student registered with the Office of Disability Services (ODS), please make sure the appropriate forms and paperwork are completed by your instructor. We will abide by all accommodations required by ODS. The date for a quiz will be announced with at least two week’s notice. It is the responsibility of the student to properly arrange test accommodations for each exam with ODS in sufficient time to guarantee space for exam administration. ALL exam accommodations must be handled through ODS. If the student does not register accommodations with ODS for the taking of an exam, then they will have to take the exam at the normally scheduled times without any additional accommodation unless the instructor is given specific directive from ODS on the student’s behalf due to a mitigating circumstance. If you are a student with learning needs that require special accommodation, contact the Office of Disability Services at (404) 894-2563 or <http://disabilityservices.gatech.edu> and <http://disabilityservices.gatech.edu/content/welcome-accommodate> as soon as possible, to make an appointment to discuss your special needs and to obtain an accommodations letter.

**Teacher Commitment:** All of the instructors and graduate teaching assistants commit to dedicating our time and energy to ensure that you have a productive learning environment for this course.

**Student Commitment:**As the student, you agree to commit your time and energy to learn the material by completing all assignments in a timely manner, attending all class sessions, and seeking help when you require it.