Lecture 1: Course Overview and Introduction to Linear Analysis

Prof. J. Stephen Smith

Course Information

Instructor:
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Text: Microelectronics, and Integrated Approach
No reading assignment until next week
Teaching assistants

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Course information

The course will include:
- Lectures MWF 9:00-10:00 277 Cory
- Videotapes of lectures available
- Weekly homework sets
- Labs starting February 2
- Midterm
- Final exam

The course web site is:
http://inst.eecs.berkeley.edu/~ee105/spring04/
Grading

Grading is based on
20% Homework
20% Lab writeups
20% Midterm
40% Final exam

Assigned grades are assigned according to the above formula, but also if the class as a whole helps each other, forms study groups, and does well, the average will be raised.

Code of conduct

- It is highly desirable to have collaboration on homework and in study
- Each homework problem is to be your individual work, not copied.
- Labs are to be individual work, and not copied.
- Data should be taken by each student separately.
EECS 105: Course Overview

- Linear design and analysis, Frequency Domain and Phasors (2 weeks)
- Integrated Passives (R, C, L) (2 weeks)
- Semiconductor physics (1 week)
- MOSFET Physics/Model (1 week)
- PN Junction / BJT Physics/Model (1.5 weeks)
- Single Stage Amplifiers (2 weeks)
- Feedback and Diff Amps (1 week)
- Freq Resp of Single Stage Amps (1 week)
- Design → Analysis cycle for linear circuits (2.5 weeks)

Focus of Course

- Understand device physics
- Design and analyze with analog techniques
- Learn electronic prototyping and measurement
  - (LAB)
- Learn simulations tools such as SPICE
- Learning how to design and analyze circuits using linear techniques
EE 105

- EE 105 covers:
  - Understanding and modeling of passives and transistors, particularly integrated devices
  - How to design using simple linear circuits
  - How to implement designs into integrated circuits
  - How to analyze (sort of the reverse of design) linear circuits

Design

- Electrical Engineering often involves very complex systems with millions of interacting components.
- To design such complex systems, we start with simple elements “circuits” “components” which we can understand and model, and then use as parts of the larger system.
- Often, a great deal of effort is put into making the simple elements behave in nice ways, so that we can use them without great effort.
- Two of those possible “nice” ways are:
  - Digital (finite number of input and output states)
  - Linear (the response to \( f_1(t) + f_2(t) \) is the same as the response to \( f_1(t) \) added to the response to \( f_2(t) \) )
Digital

- A digital component has a limited number of possible states for both its inputs and its outputs.
- Good digital design attempts to have small variations in the values for the inputs around the nominal values not change the output.
- For example:
  - Logic low 0 volts to 1 volt
  - Logic high 2 volts to 3 volts
- Each of the outputs would be as close to 0 volts (for a logic low, or 3 volts (for a logic high) as possible, independent of small variations in the inputs.

Digital (timing)

- Timing is a different issue for digital circuits.
- The outputs are discrete, but when they happen is subject to small variations or errors.
- Clocked logic extends all delays to the same time (the clock time), to eliminate that variation.

To get to this behavior, we need to build digital elements, using analog design!
Linear

- Linear systems take a different approach to making systems which can be designed and analyzed.
- Linear design and analysis is often useful:
  - Because Maxwell’s equations are linear (vacuum)
  - Because the signal is a small perturbation
    - Example: currents in metal
  - Because effort was put in to making a device linear or keeping it in a linear range
  - As an (sometimes good, sometimes rough) approximation

Linear techniques

- Are the foundation for understanding digital circuits
- Allow the design of powerful systems with hundreds to thousands of components
  - Example: television, wireless transmitters and receivers, power
- Often include the differentiating elements of an electronic device.
**Wire**

- Voltage same at both ends
- All the current that comes in one end goes out the other
- Neglects:
  - Resistance
  - Charge accumulation
  - Magnetic flux

**Resistors**

- Voltage linearly proportional to current
  \[ v_r(t) = i_r(t) \cdot r \]
- Neglects:
  - Nonlinearity due to temperature changes
  - Magnetic flux
  - Charge accumulation
Capacitors

- Voltage proportional to charge
- Charge is conserved, and current is moving charge, so voltage is integral of current.
- Or, current is proportional to the rate of change in the voltage

\[ i_c(t) = C \frac{dv_c(t)}{dt} \]

Neglects:
- Resistance
- Inductance

Inductors

- Voltage proportional to rate of change of current with time

\[ v_L(t) = L \frac{di_L(t)}{dt} \]

Neglects:
- Resistance
- Interwinding capacitance
Perfect amplifiers

- Voltage out equal to voltage in times a constant
- Current out equal to voltage in times a constant
  - Transconductance (FET transistors)
- Current out equal to current in times a constant
  - Beta (Bipolar transistors)

Nearly linear amplifiers are obtained by limiting the range of transistors, or are designed to be that way (like your stereo)

Other linear components

There are other approximately linear components: Transformers, antennas, transmission lines, etc., but these basic components will take us quite a way to understanding a lot of basic electronics.
components

- All of these elements, with the approximations made, are completely determined for their input and output by their terminal voltages and currents. (The physics stays in the box!)
- This is done deliberately, to the extent possible, to make design and analysis easier (possible)

For example:
- Wires run too near each other couple inductively and capacitively
- Transistors built too near each other can change their characteristics
- Parasitic (unintentional) capacitances will exist anyway, and you will often need add them to the circuit diagram
- Active devices sometimes remember what you did to them, change over time, react to temperature or light, etc.

Circuit diagrams

- A circuit diagram is often similar to a physical circuit, because the wire, resistors, capacitors etc. are close to ideal
- A circuit diagram is, however, is more like a mathematical representation, after approximations, limited range of voltage, etc.
Example: low pass filter

- Lets say you are adding a base speaker to your car, and you are cheap (or a clever tinkerer) How do you keep the high frequencies out of the woofer?

What happens to a base drum hit?

\[ v_{in} \]

\[ v_{out} \]
What circuit could we use for the tweeter?

What happens to a base drum hit?

\[ V_{in} \]

\[ V_{out} \]
Capacitors

- The voltage won’t change rapidly across a capacitor (the charge on the plates must have time to build up with a finite input capacitance)
- If the input doesn’t change, eventually the current into the capacitor will fall to zero, (the charge is fully built up)

► A capacitor looks like a short for high frequencies
► A capacitor looks like an open for low frequencies

The time scale for low or high frequencies is the RC time constant

Linear Circuit model ↔ set of linear differential equations

\[
\begin{align*}
  v_r(t) &= i_r(t) \cdot r \\
  i_c(t) &= C \frac{dv_c(t)}{dt} \\
  v_L(t) &= L \frac{di_L(t)}{dt}
\end{align*}
\]

The wires convey the variables (voltages and currents) between the equations (components!)

For the low pass example, applying Kirchoff’s laws:

\[
\begin{align*}
  v_{out}(t) &= v_c(t) \\
  v_{in} &= v_r + v_c \\
  i_{in} &= i_r = i_c + i_{out}
\end{align*}
\]
\[ v_{\text{out}}(t) = L(v_{\text{in}}(t)) = \]
\[ a v_{\text{in}}(t) + b_1 \frac{d}{dt} v_{\text{in}}(t) + b_2 \frac{d^2}{dt^2} v_{\text{in}}(t) + \cdots \]
\[ + c_1 \int v_{\text{in}}(t) + c_2 \int \int v_{\text{in}}(t) + c_3 \int \int \int v_{\text{in}}(t) + \cdots \]

Here, \( L \) represents a Linear operator, that is, if you apply it to a function, you get a new function (it maps functions to functions), and it also has the property that:

\[ L\{a \cdot f(t) + b \cdot g(t)\} = a \cdot L\{f(t)\} + b \cdot L\{g(t)\} \]