ECEN 2260 - Spring 2016
Circuits as Systems
Syllabus and Introduction

The
“Complex Frequency Domain”
Semester

Laplace – Bode - Fourier
The Giants of Electrical Circuit Analysis in the Complex Frequency Domain
What you will learn

• How analog circuits function as signal processors
• The language of electrical engineering: The Laplace transform (Complex Frequency Domain)
• Frequency-dependent behavior of circuits
  – Bode diagrams - filter frequency response
• Representation of signals with sinusoids.
• Second-order circuit response
  – Resonance, damping, overshoot
• Design of filter circuits
• Effect of negative feedback on circuit behavior
• Block Diagrams – Equations in real world format
Pre-requisite knowledge 1 of 2

• Basic mathematics
  – Trigonometric identities, logarithms, complex numbers with Euler's Identity

• Calculus
  – Integration by substitution and by parts, evaluation of definite integrals, differentiation

• Differential equations
  – Solution of first and second order linear differential equations having initial values and/or forcing functions
Pre-requisite knowledge 2 of 2

• Basic circuits
  – Loop and node analysis
  – Analysis of circuits by methods other than loop and node analysis:
    • Thevenin and Norton equivalents, voltage and current division, op-amp inverting amplifier, superposition
  – Resistors, capacitors, inductors, transformers, independent & dependent voltage and current sources
  – Other elements: the ideal op amp, the comparator
  – Step response of first and second order R-L-C circuits
  – Phasor analysis, Impedance

1/10/2016
Course Vitals 1 of 5

• Instructor: Harry Hilgers
  – Email: See ECEN webpage
    • [http://ecee.colorado.edu/~ecen2260/](http://ecee.colorado.edu/~ecen2260/)
    • Office: OT435
    • Office hours: See ECEN webpage
• Teaching Assistant: See ECEN webpage
  – Email: See ECEN webpage
    • Office hours: See ECEN webpage
Course Vitals 2 of 5

• Homework review sessions
  – One session per homework.
    • Location: EE Wing 1B32
    • Time: Wednesday 8:00 am
  – Other forms of homework help:
    • Discussion folders on D2L
Course Vitals 3 of 5

• Lecture Attendance is mandatory
  – I will help those who help themselves.

• Therefore: If you do not attend lectures, please see a classmate for help and lecture notes.

• Exception: Missing lectures due to documented illness or documented emergency circumstances.
Course Vitals 4 of 5

Grading “formula” (this may change)

• Exams (80% total)
  – Two 50 minute Mid-Term Exams (25% each) and a 2.5 hr. Final Exam (30%)
  – Unless indicated otherwise, ALL EXAMS ARE CLOSED BOOK, CLOSED NOTES, ONLY “DUMB” CALCULATORS, NO COMPUTERS, NO PHONES.

• Homework (20%)
  – One per week (more-less)
  – Due date/time: See D2L
    • No late HW will be accepted
    • No HW will be dropped.

1/10/2016
Course Vitals 5 of 5

• Final grade
  – Computed based on the above percentages but maybe adjusted **upward** if I notice an upward trend.

• Class website
  – D2L for HW assignments, announcements, calendar, etc. It will also contain a discussion folder for each HW.

• Textbook
  – Additional materials will be lectured. Most of these are not published. **So taking lecture notes is vital and therefore class attendance is critical.**
Additional Notices 1 of 2

• If you qualify for accommodations because of a disability, please submit to me a *letter from Disability Services in a timely manner so that your needs may be addressed*. **Disability Services** determines accommodations based on documented disabilities.

• Every effort will be made to reasonably and fairly deal with students who have serious religious observances that conflict with scheduled exams, assignments, etc. Please notify me well in advance, so that there is time to make adequate arrangements. The Boulder campus policy can be read at [http://www.colorado.edu/policies/fac_relig.html](http://www.colorado.edu/policies/fac_relig.html)
Additional Notices 2 of 2

• All students will be expected to comply with the Boulder campus honor code. This honor code can be viewed at http://www.colorado.edu/academics/honorcode/

• Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with differences of race, culture, religion, politics, sexual orientation, gender, gender variance, and nationalities. The campus policy can be read at http://www.colorado.edu/policies/classbehavior.html
Class Attendance

• Class attendance: I view class attendance as a primary requirement.

• Typically the students with the higher grades are also the students that do not miss lectures.

• During lectures, please only one discussion at a time.

• The only dumb question is the one not asked.
Syllabus – More-Less

• Review of complex numbers and phasors.
• The Laplace Transform, Circuit Analysis with Laplace Transform
• 2\textsuperscript{nd} Order Transient Response using the Laplace Transform
  ➢ Many dynamic systems show a dominant 2\textsuperscript{nd} order behavior
  ➢ Newton’s Law, RLC circuits, mass-spring-damping system (car shock absorbers)
• Dominant and non-dominant poles
• Convolution
• Frequency Response and Bode Diagrams
• Filter circuits
• Fourier Series
• Fourier Transform
• Feedback, stability, gain and phase margins
• Block diagrams
The Laplace Transform

• The language of analog electrical engineering
• A method of turning linear differential equations into algebraic equations
• It gives insight into the frequency contents of a signal.
• Can be thought of as a generalization of the phasor method
• We can transform a circuit from the time domain to the complex frequency domain and then solve using manipulation techniques learned in Intro to Circuits. This solution method is much simpler then solving the differential equations in the time domain.
• Works with arbitrary waveforms (sinusoidal, transient, etc.)
Bode Diagrams

A widely-used way of plotting the frequency response of a circuit.

We will develop a simple set of rules that allow easy construction of theoretical Bode plot.

Relatively easy to obtain a physical interpretation of the frequency response of a circuit.
Bode Diagrams
Bode Diagrams
Feedback Circuits and Systems

Learn rules for manipulating block diagrams
Negative feedback is widely used in all fields of engineering, to obtain high-performance control of an output signal
How to construct the Bode plots of feedback circuits and systems
Feedback Systems - Block Diagrams

Note the minus sign to create Negative Feedback

\[
\frac{E(s)}{R(s)} = \frac{1}{1 + G_1(s)G_2(s)H(s)} \quad \text{and} \quad \frac{Y(s)}{R(s)} = \frac{G_1(s)G_2(s)}{1 + G_1(s)G_2(s)H(s)}
\]
Filter Circuits
Remove unwanted frequency components

- Low-Pass, High-Pass, Band-Pass, Band-Stop, Notch
- State Variable Filters
- Chebychev
- Bessel
- Butterworth
- An application of Laplace Transforms and Bode Plots.
Fourier Analysis

- How circuits and filters having a known frequency response operate on a nonsinusoidal waveform
- Decompose periodic waveform into a sum of sinusoidal components. Put each component through the circuit frequency response.
- Spectrum of a waveform
Introduction to Design and Engineering Analysis

• Real Circuits that do useful things.
  – They are more complicated than the circuits in the Introductory Course.

• High-level thinking.
  – Learn to look at upper level requirements from which the lower level requirements are derived.

• Circuit Manipulation instead of Algebra
  – To solve larger circuits, break them into functional blocks
  – Loop and node equations can easily lead to algebraic mistakes. However, if you are not sure about your answers, you can always double check your functional expressions with these methods.
Introduction to Design and Engineering Analysis

• Approximations instead of exact numerical solutions
  – The equivalent resistance for a $10\Omega\pm10\%$ resistor in parallel with a $100\Omega\pm10\%$ resistor still “equals” around $10\Omega$
  – Estimate the ORDER OF MAGNITUDE of your expected calculator/simulation output.
    ✓ A $10^6$ Henry Inductor ??? Maybe you meant $10^{-6}$ !!!!!
    ✓ A $2^6$ Farad Capacitor? At a high voltage this would be a huge capacitor. I wonder if this cap would fit inside the Grand Canyon
  – Once I saw a value of $33k\Omega \pm 0.87563 \, \Omega$ for a $10\%$ resistor.
    ✓ The moral: Don’t just write what your calculator tells you; THINK about your answer.
How to learn this material? (1 of 2)

• A 50 minute lecture is just that: ONLY 50 minutes
  ▪ Therefore only the highlights can be lectured. You are expected to fill-in the remainder with self study.
  ▪ The real learning comes from many focused hours of “burning-the-midnight-oil”.
  ▪ Studying with pencil/paper increases the slope of your knowledge acquisition curve.
How to learn this material? (1 of 2)

- The more frequently you are exposed to new topics, the better the chance that they stay with you.
- Make use of the D2L discussion folders.
- During the semester there are six exposures to new material:
  1. Preparation for lectures by reading your text book and other material.
  2. Come to class to listen to the lecture.
  3. Study the material after the lecture.
  4. Do the homework
  5. Review the homework solution sets.
     ➢ I fully expect you to do this.
  6. Study the material for the exams.
- Come to office hours as needed.