**Syllabus - ESE 351 Signals and Systems – Fall 2020**

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**Office hours:** Tues 10-11am Wed 2-3pm or by appt.

**Lecture:** Mon Wed 11:30am-12:50pm, Room TBD

**Course website:** Canvas

**Graders:** TBD

**AIs**: TBD

**Textbook(s)**: TBD (Oppenheim and Willsky follows this syllabus almost exactly)

**Reference texts:** Oppenheim and Willsky, Vetterli et al, Mukai, +

**Course Objective**: This course is designed to introduce engineering juniors to concepts and methodology of discrete- and continuous-time signals and their role and interaction in linear dynamic systems.

**Course description**: (current, from WUCRSL): Introduction to concepts and methodology of linear dynamic systems in relation to discrete- and continuous-time signals. Representation of systems and signals. Fourier, Laplace, and Z-transforms and convolution. Input-output description of linear systems: impulse response, transfer function. State-space description of linear systems: differential and difference equation description, transition matrix. Time-domain and frequency-domain system analysis: transient and steady-state responses, system modes, stability, frequency spectrum. System design: filter, modulation. Continuity is emphasized from analysis to synthesis and implementation. Use of Matlab. Prerequisites: The notion of matrix algebra and Math 217 or equivalent, Physics 117A-118A. Corequisite: ESE 317.

[Draft: Proposed New Course Description] Introduction to concepts and methodology of discrete- and continuous-time signals in relation to linear dynamic systems. Representation of signals and systems. Fourier, Laplace, and Z-transforms. Input-output description of linear systems: impulse response, convolution, transfer function. ~~State-space description of linear systems: differential and difference equation description, transition matrix.~~ Time-domain and frequency-domain system analysis: transient and steady-state responses, stability, frequency spectra and frequency responses. ~~System design: filter, modulation, sampling theorem~~. *Matlab-based case studies highlight the role of this material in key ESE areas of signal processing, control systems, and communication*. Prerequisites: Physics 117A-118A, Math 217, CSE 131, *ESE 105 or ESE 230*, *Matlab*, matrix addition and multiplication; Corequisite: ESE 318.

**Grading:** Letter grades will be assigned on a curved scale. Approximate scale and grade distributions will be announced after the midterm exam.

Homework 15%  
Quizzes (biweekly) 15%  
Case studies 15%  
Mid-term exam 25%  
Final exam 30%

**General notes:**

* **Working together:** In class and for homework, you are encouraged to work with your classmates but you should first try to solve problems on your own. For tests and exams, you may work together before tests and exams but not during tests and exams.
* **Return of graded quizzes and exams: TBD**

**Course Ethics/Academic Integrity**: The statement of the Undergraduate Student Academic Integrity Policy can be found at <http://www.wustl.edu/policies/undergraduate-academic-integrity.html>. Students are encouraged to discuss with one another homework assignments as well as any concepts that underlie the problems. Doing so in groups is encouraged and can be a significant aid in learning the subject, however ***all work submitted for grading must be the effort of the individual submitting it, unless specified otherwise****.* ***Include an acknowledgement of all outside resources used on homework submissions.***

**Course Outline (approximate) 28 lectures + a final (minus a midterm)**

1. Signal representations 3-4+ lectures + a case study?
   1. DT, CT
   2. Applications/examples
      1. 105, 217, 230
      2. Differential/difference equations, systems
      3. Simple filtering CT, DT
   3. Time-domain response of systems? Impulse and impulse response
      1. Other characterization of systems? Step response, etc.
      2. LTI properties, convolution
   4. Signal decomposition -> harmonic series
2. Harmonic Series 3-5 lectures (DT and CT)
   1. Fourier coefficients
   2. Revisit last **Case Study of ESE 2XX: Study effects of Butterworth filter on the Fourier coefficients of the input/output signals. [Alternate: communication case study?]**
3. Fourier/Laplace Transformations 3-5 lectures
   1. Build from the concept of Harmonic series to the formal Fourier/Laplace transformation
   2. Mathematical frameworks and properties
      1. Orthonormal bases, inner product spaces
      2. Convergence properties
      3. Parsevals theorem
   3. **Case Study: Power spectral analysis of EEG data / Eyes-open, eyes-closed EEG lab**
4. Frequency Responses of Linear Systems 3-4 lectures (CT, DT)
   1. as an eigenfunction (should be earlier)
   2. Amplitude and phase characterizations
   3. Bode plots, poles and zeros
   4. **Case Study: Audio signal filtering**
5. Equivalence of time- and frequency-domain representations (CT only?) 4 lectures
   1. Using Laplace transforms to solve differential equations
   2. Preview control systems
   3. Stability
   4. **Case study: Vehicle suspension (i.e., mass spring system)**
6. Sampling and CT-DT conversion, aliasing 1-2 lectures
7. **Integrative case study**: **fNIRS retinotopy (rotating wedge)** 2 lectures
   1. filtering
   2. spectral analysis
   3. Estimation of strongest spatial response to wedge position (retinotopy)?
   4. Lead to image reconstruction (y=Ax w regularized inverse)

Notes on extension to rest of curriculum: 351 leads directly to 471, 482, 520, 523, 524, 582, 589, 5931-5934, 425, 441, 444, 446, 447, 448, 543, 547, 551, 553, etc. and is indirectly used in most others

1. [**skip**?] Introduction to dimensionality reduction
   1. Principal components analysis
   2. Case Study: Some sort of pattern extraction example

Notes (old)

* Input-output description sufficient (no state space?)
* Could start with review of RC as system – frequency response
* Probably skip dim reduction, PCA for now
* Filter design? Pole/zero placement and freq response
* Any matrix?
* Emphasize orthogonality, basis functions in harmonic series
* Case studies
  + Review+: RC or more – frequency response? DT system? Sampling?
  + Communication (Neal)
  + Control/feedback, Vehicle suspension?: active w feedback? Time and frequency?
  + fNIRS retinotopy (rotating wedge)
    - filtering
    - spectral analysis
    - Estimation of strongest spatial response to wedge position (retinotopy)?
    - Lead to image reconstruction (y=Ax w regularized inverse)

Other topics needed

* Stability
* Sampling and Nyquist
* CT, DT

**Course Outline (Mukai, old)**

1. Mathematical modeling of engineering systems: state-space descriptions for translational and rotational mechanical systems, electrical circuits, thermal systems, fluid-level systems, chemical systems, discrete-time systems (3 classes)

2. Different system representations and conversion among them: input-output descriptions, state-space realization and block diagrams (1 class)

3. Solution of differential and difference equations: annihilators and inhomogeneous equations (2 classes)

4. Impulse response of the system and its input-output description (2 classes)

5. Response of the linear time-invariant system: convolution integrals and summations (1 class)

6. Response of the system in terms of state transition matrices: matrix powers and exponentials (2 classes)

7. Laplace and z transforms: both bilateral and unilateral transforms (2 classes)

8. Response of the system in terms of transforms: transfer functions (2 classes)

9. Modes and different concepts of stability (2 classes): system eigenvalues, system poles, mode functions, asymptotic stability and bounded-input bounded-output stability

10. Fourier series: exponential and trigonometric Fourier series, interpretation of different harmonics, continuous-time only (1 class)

11. Steady-state response to a periodic input: transient, steady-state and frequency responses of the system, steady-state responses to phasor and sinusoidal inputs (3 classes)

12. Fourier transforms: continuous Fourier spectra (2 classes)

13. Filtering and communication systems: filters, frequency shifts, amplitude modulation and demodulation, stereo broadcasting, sampling theorem, aliasing (2 classes)

**THIS IS A WORKING DOCUMENT (from ShiNung)**

Proposal to Revise ESE 351 Signals and Systems

Overall Concept: ESE 351 is revised into a two course sequence integrating a smaller number of fundamental concepts paired with laboratory and computational experience. The sequence will build from the infrastructure of ESE 105, helping students to solidify and enhance their linear algebra, while introducing new mathematical frameworks, more notable differential equations.

Each course will be 4 units (3 units+1 unit for lab/computational experiences)

**Course 1**

**ESE 2XX: Signals and Systems I: Modeling the engineered and natural worlds**

The goal of ESE 2XX is to introduce key concepts relatively low-dimensional settings, to try and build intuition for the major ideas and concepts. The philosophy is to allow students to see the whole picture, first, then break down components as they move through the sequence.

1. First-order autoregressive equations: Build intuition for time evolution in discrete-time setting.
2. First-order differential equations.
   1. Linear first order ode’s. Connect to decay processes. Build intuition regarding time-evolution and asymptotic behavior of a system.
3. Modeling: Higher-order differential equations.
   1. Convert high order differential equations to a system of first-order ode’s. (i.e., introduce the idea of a state-space specification of a dynamical system).
   2. Existence and uniqueness of solutions
   3. Modeling circuits as systems of differential equations
   4. **Case Study: RLC Circuits**
   5. **Case Study:** **Predator-prey model or SIR epidemiological model** (the latter would build on ESE 105).
      1. Introduce the idea of a phase portrait/flow here
      2. Simulating trajectories numerically in MATLAB.
4. Modeling: Systems with exogenous input
   1. Reinforce the idea of a flow of a dynamical system
   2. Introduce the idea of a forced trajectory, i.e., the solution for a differential equation when input is applied.
   3. Convey the concept of the input as ‘signal’ and the dynamical system as transforming the signal.
   4. **Case study:** **Low-order Butterworth filter**
      1. Simulate response to sinusoidal signals of various frequency
      2. Simulate response to square wave.
      3. Use this to build the idea of a frequency response / eigenfunctions

**Course 2**

**ESE 3XX: Signals and Systems II: Analysis and decomposition of signals evolving in space and time**

The goal of ESE 3XX would be to affirm and formally build the concept of frequency domain analysis, and integrate this with prior concepts towards time-series analysis and certain aspects of dimensionality reduction.

1. Harmonic Series
   1. Fourier coefficients
   2. Revisit last Case Study of ESE 2XX: Study effects of Butterworth filter on the Fourier coefficients of the input/output signals.
2. Fourier/Laplace Transformations
   1. Build form the concept of Harmonic series to the formal Fourier/Laplace transformation
   2. Mathematical frameworks and properties
      1. Convergence properties
      2. Parsevals theorem
   3. **Case Study: Power spectral analysis of EEG data / Eyes-open, eyes-closed EEG lab**
3. Frequency Responses of Linear Systems
   1. Amplitude and phase characterizations
   2. Bode plots
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4. Equivalence of time- and frequency-domain representations
   1. **Case study: Vehicle suspension (i.e., mass spring system)**
   2. Using Laplace transforms to solve differential equations
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5. Introduction to dimensionality reduction
   1. Principal components analysis
   2. Case Study: Some sort of pattern extraction example