Harvard University
School of Engineering and Applied Sciences

ENG-SCI 156: Signals and Systems
Spring 2018

Course information

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Lecture:
T-Th 10-11:30 AM (MD 119)

Problem Solving (Section) Times: TBD

Course Website:
`https://canvas.harvard.edu/courses/37342`

1 Course overview

Signals model the World. Broadly speaking, a *signal* is a set of data/information that describes a given phenomenon. Examples of signals include the output of a WiFi router, heartbeat samples recorded by a fitness tracker, daily closing prices of the stock market (e.g. S&P 500 index), the position of an airplane as detected by a radar, and light intensity/color values captured by a camera sensor. Signals usually represent measurements of some phenomenon that is a function of an independent variable, such as time or space. Over the past century, an array of powerful mathematical and computational tools have been developed to analyze and interpret signals. These tools stem from functional analysis, statistics, the study of differential equations, machine learning, and related areas.

Electrical engineers go beyond simply analyzing signals: they design and deploy *systems* that manipulate signals for a given purpose. These systems have changed the technological landscape of the 20th century. For example, reliable communication schemes manipulate the signal transmitted by a WiFi router in order to overcome channel noise. Vehicle control systems compute the signals that determine acceleration and direction of self-driving cars. Audio systems sense variations of acoustic pressure in a microphone, and convert these variations into digital signals that can be efficiently processed by computers. Many (but not all) of these systems share a set of common features: they are linear and time-invariant. As we shall see in the course, this enables us to study them through a common mathematical lens. This theory, in turn, serves as a *design driver* for modern digital systems.

This is a first course on signals and linear systems. Throughout the semester, we shall weave part of the elegant mathematical tapestry that underlies modern communication, control and digital signal processing systems. You should think of this course as an important step towards a deeper understanding of control theory (ES 158), manipulating biological signals (ES 155), computer vision (CS 283), information theory (ES 250), and related areas. Please note that this class is mathematical in spirit, but practical at heart. As a consequence, you will spend a lot of time manipulating equations, understanding proofs, and exploring fundamental mathematical concepts. However *always keep in mind* that this math will help you design the next generation of EE systems.

By the end of the semester, you should be able to:

1. Describe and analyze *linear systems* using powerful mathematical tools. Linear systems enjoy a very elegant theory, and this will help you recognize why mathematicians and physicists try to simplify (sometimes oversimplify) natural phenomena through linear models.

2. Analyze signals in *frequency domain*. Spectral analysis is a powerful tool that provides "a different look" at a signal. In many applications signals may appear complicated or noisy in time domain, but have a simple description in frequency domain.

3. Apply *Fourier Transform Theory* to problems in engineering. We will study many facets of the Fourier transform within different contexts. This may seem redundant at first, but keep in mind that it took nearly four centuries for this theory to be fully developed — so a bit of repetition will be helpful.

4. Understand *sampling of bandlimited signals*. The conversion from analog to digital (and back) is at the center of most electrical and computer engineering systems. You will appreciate why this conversion is possible without significant loss of generality, and learn how it drives modern communication and signal processing systems.

5. Examine systems in terms of their *impulse/frequency response*, and explain concepts such as "high pass", "low pass", and bandwidth.

The tools you will learn are applicable in many different areas of EE, and will appear in classes on circuit design, communication systems, controls, imaging, finance, and beyond.

2 Course Topics

Below is a list of topics that will be covered in class. This is an *approximate/tentative* schedule, and the pacing may vary during the term. Nevertheless, the outline below will serve as a good study guide.

1. Modeling and analyzing linear time-invariant (LTI) systems ($\approx$ 4 weeks).

    - Introduction to signals and their properties;
    - Exponential signals;
    - Impulse signals;
    - The convolution theorem in continuous and discrete time;

- LTI systems given by differential and difference equations;
- Step response of LTI systems.

2. All things Fourier ($\approx$ 4 weeks).
   - Fourier series;
   - Fourier transform
   - Discrete-time Fourier transform;
   - Frequency shaping filters.
3. Understanding signals and systems via their transforms ($\approx$ 2 weeks).
   - Bode plot representation of frequency response systems;
   - Linear filters in practice, first and second-order systems;
   - Bode plot of systems described by differential and difference equations.
4. Sampling: from digital to analog and back ($\approx$ 2 week)
   - Sampling, Nyquist rate and the Shannon-Nyquist theorem;
   - Discrete-time implementation of continuous-time signals
   - Discrete-time sampling, interpolation, decimation.
5. Signals and systems in practice: a case study based on communication systems ($\approx$ 1 week).
   - Modulation, demodulation;
   - AM, FM, PAM, PCM;
   - A gentle introduction to noise and SNR.
6. From Fourier to Laplace ($\approx$ 1 week).
   - The Laplace transform;
   - The z-transform.

3 Pre-requisites

The official prerequisite for this course is APPLIED MATH 21b or MATH 21b, and a basic level of mathematical maturity is required. There will be a few programming tasks (and a final project) which can be done in MATLAB or your programming level of your choice. These tasks will require only a basic understanding of programming (e.g. loading a file, writing a short script). Knowledge of how to manipulate complex numbers, integrate and differentiate is required, and knowing how to solve differential questions is a plus. **If you have any concerns about pre-requisites please reach out to the teaching staff ASAP.** We are more than happy to help, and are excited to assist you in learning background material that you may not feel confident about. Please do not be shy: we are here to help you learn.

4 Textbook

Main textbook:

- **Signals and Systems, 2nd Edition**, by A.V. Oppenheim and A.S. Wilsky, Prentice Hall Publishers, NJ.

Suggested readings:

- **Signals and Systems using MATLAB, 2nd Edition**, L.F. Chaparro, Academic Press.
- **Foundations of Signal Processing** (available on-line), by M. Vetterli, J. Kovaevi and V.K. Goyal, Cambridge University Press.

5 Grading information

The final grade for this course will be based on your performance on problem sets, one midterm examination, one final examination, and an optional project. **Due dates are listed in section 8.**

5.1 Problem Sets (30%)

There will be **10 problem sets**. Problem set solutions can be hand-written. The **8 highest scores** will jointly count towards **30% of your final grade**. Problem sets will be due **at the beginning of class** on the date stated on the syllabus (with a 10 min grace period). Late homework will be penalized. **For each day late, 25% of the grade will be taken off**. Exceptions will be made if you have to turn in a late problem set due to health or personal issues **as long as you inform teaching staff beforehand**. Late problem sets should be handed to the TFs.

5.2 Midterm (30%)

There will be **one in-class midterm examinations that will each count towards 30% of your final grade**. The midterms will evaluate your mastery of basic concepts seen in class, and will in general be slightly less difficult than the problem sets. Each midterm will cover **all** the material seen up to the second-to-last class before the midterm. The date of the midterm can be found in Section 8.

5.3 Final Exam (40%)

There will be a 3-hour final exam that will be scheduled according to the FAS registrar's office schedule. The final exam will cover all of the material seen in class, including material covered on the midterm.

5.4 Optional Project (Bonus 15%)

There will be a final computational project that will add up to 15% to your final grade. This project will allow you to explore in more detail implementation aspects of signal processing. You can also propose your own project as long as you discuss with the teaching staff the objectives and the scope.

6 Disclaimer

While the above weights are used for computing the final grade, I reserve my right to scale the grades based on the performance of the entire class. Naturally, this possible scaling will not have an adverse effect on the grades and can only increase the raw grades.

7 Policy on collaboration

Problem Sets: Discussion and the exchange of ideas are essential to doing academic work. For assignments in this course, you are encouraged to consult with your classmates as you work on problem sets. However, after discussions with peers, make sure that you can work through the problem yourself and ensure that any answers you submit for evaluation are the result of your own efforts. In addition, you must cite any books, articles, websites, lectures, etc that have helped you with your work using appropriate citation practices. Similarly, you must list the names of students with whom you have collaborated on problem sets.

Exams: The Midterm and the Final will be closed book and solved individually. Absolutely no collaboration is allowed, and electronic devices cannot be used. You will be allowed to bring one **hand-written** cheat sheet (you can write on both sides of the sheet).

8 Important dates

As a reminder, problem sets will be due at the beginning of class on the date stated below. There will be a non-negotiable grace period of 10 minutes. Late homework will be penalized. **For each day late, 25% of the grade will be taken off**.

- **Jan. 25th (Thursday)**: Problem Set 1 out.
- **Feb. 1st (Thursday)**: Problem Set 1 due; Problem Set 2 out.
- **Feb. 8th (Thursday)**: Problem Set 2 due; Problem Set 3 out.
- **Feb. 15th (Thursday)**: Problem Set 3 due; Problem Set 4 out.
- **Feb. 22nd (Thursday)**: Problem Set 4 due; Problem Set 5 out.
- **March 1st (Thursday):** Problem Set 5 due, Problem set 6 out.
- **March 8th (Thursday): Midterm.**
- **March 13th and March 15th (Tuesday/Thursday)**: No lecture – Spring Break! Enjoy!
- **March 22nd (Thursday):** Problem Set 6 due, Problem set 7 out.
- **March 29th (Thursday):** Problem Set 7 due, Problem set 8 out.
- **April 5th (Thursday):** Problem Set 8 due, Problem set 9 out.
- **April 12th (Thursday):** Problem Set 9 due, Problem set 10 out.
- **April 24th (Tuesday):** Problem Set 10 due.
- **May 11th (Friday): Final Exam (tentative date and subject to change)**, according to scheduling for FAS Exam group 15C.