Signals & Systems
Overview & Introduction

ECE 3793

About the Instructor

Dr. Russell Kenney

- Education: B.S. CE, M.S. and Ph.D. in ECE, all from OU
- Assistant Professor of ECE, member of the ARRC
- Research Interests: Distributed and mobile radar systems
- Personal Interests: Fishing, billiards, rock-hounding
- During my time at OU: OU IT, Baptist Collegiate Ministry, undergraduate research, HKN

Left: My only professional headshot from 8 years ago
Right: Me and Sarah

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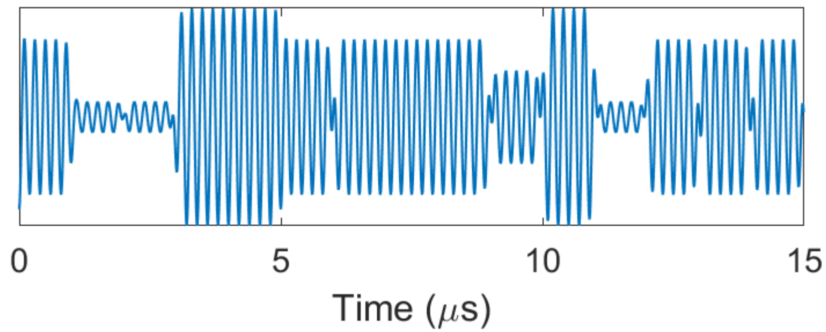
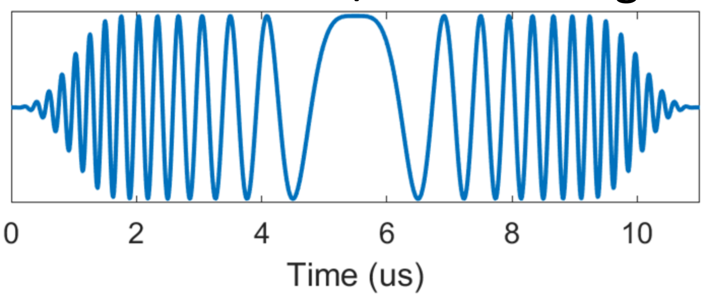
Examples of Signals

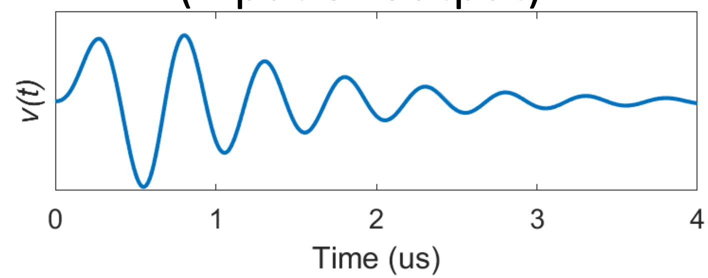
Communication signal: Analog (AM/FM) or digital (CDMA, OFDM, FSK, PSK, WiFi, Bluetooth, …)



Radar waveform/reflected signal

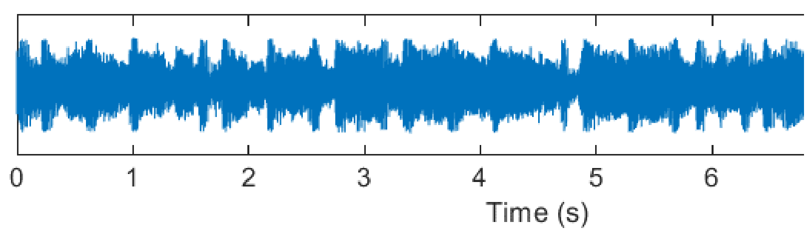


Circuit voltage or current (input or output)



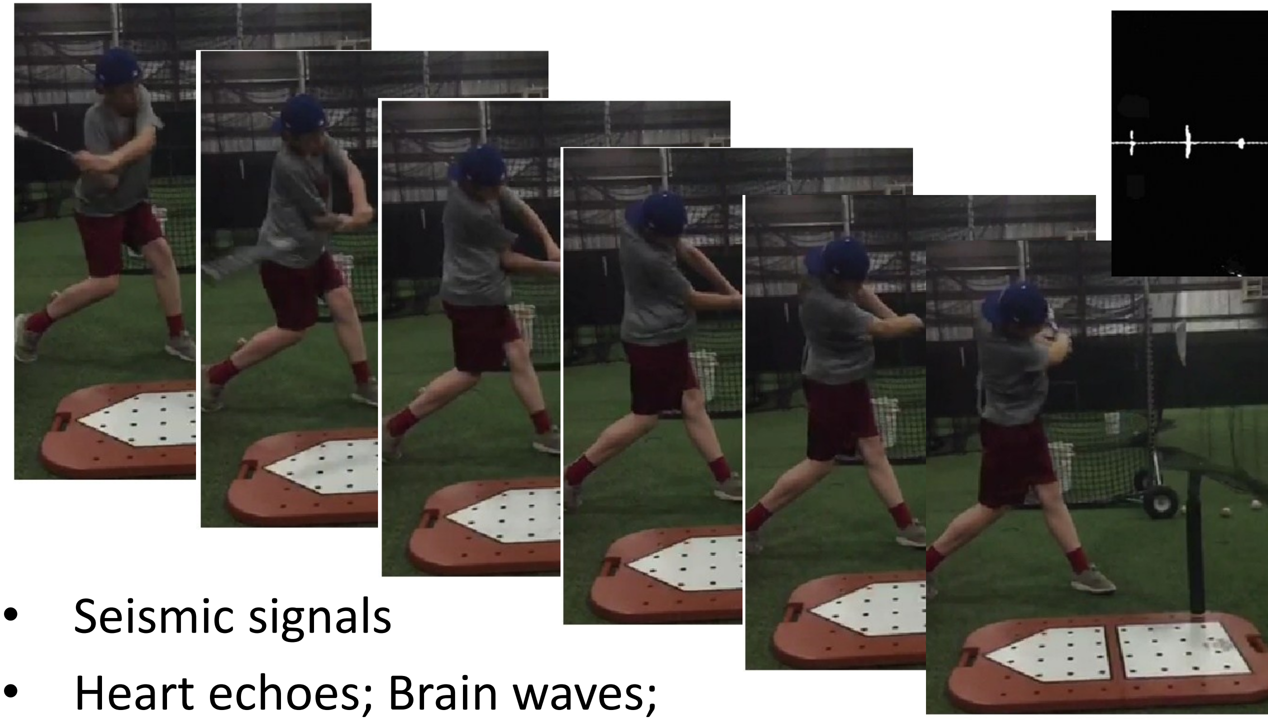
Picture or image; O(x,y) (2-D!)

Music/Audio/Voice



Examples of Signals

Video; O(x,y,t)   (3-D!)



Acoustic (e.g., whale, dolphin, bat,…)

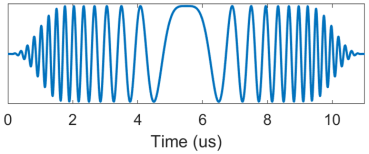
- Seismic signals
- Heart echoes; Brain waves; Medical imaging responses
- Force, velocity, acceleration, …
- …and more…

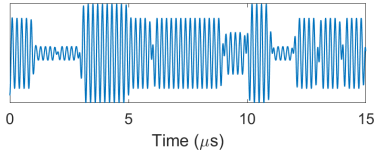
- A "signal is a set of data or information"
- A manifestation of one physical quantity with respect to (w.r.t.) another

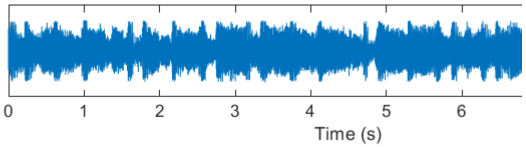
Some Basic Ideas About Signals

- A "signal is a set of data or information"
- A manifestation of one physical quantity with respect to (w.r.t.) another

- For the most part in this class, the independent variable will be time
  - i.e. our signals will be Volts per unit time, Newtons per unit time, etc.
  - Not always the case! e.g. an image contains a signal as a function of pixel position
- In this class, we will mainly focus on 1-D signals



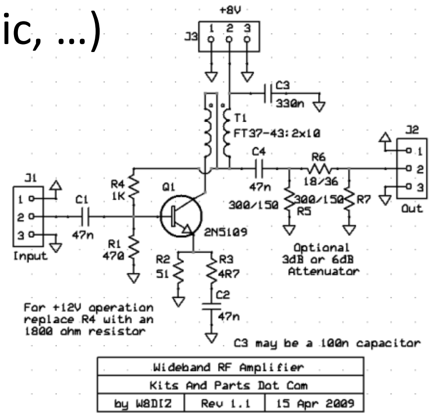




- What do you notice about these signals?
- The interesting part of a signal is generally related to how it **changes with time**
- Many signals of interest are sinusoidal
  - Slow changes → low frequency
  - Fast changes → high frequency
  - Signals are often composed of many sinusoids of different amplitude, phase, and frequency
- Sinusoids show up all the time in nature, so it is nice to have tools for analyzing them
  - Radio waves, sound waves, vibrations, rotations (e.g. motors, planets, etc.)
- Even if it doesn't look sinusoidal, *any* (well, almost any…) function can be treated as if it is composed of many different frequency sinusoids

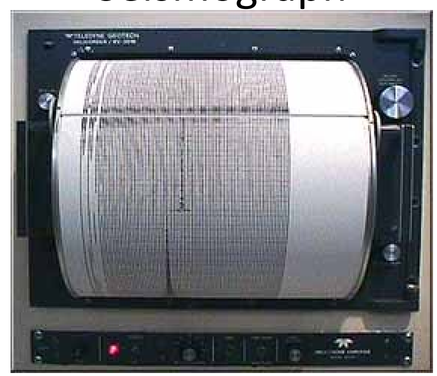
Examples of Systems

Filter/amplifier/mixer (could be electrical, acoustic, …)

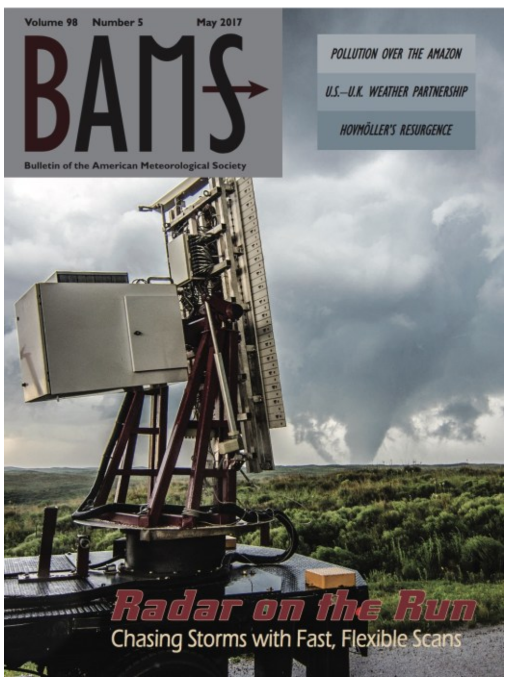


Cardiogram/X-ray/ CT Machine

Seismograph



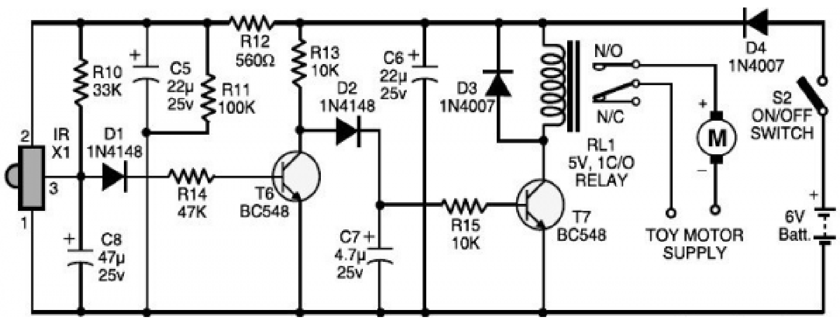
Radar or Sonar



Cell phone, computer, network adapter, router, modem, Ipod

Examples of Systems

Electrical Circuits/Components



Camera/Projector

- Note: Most of these examples are actually systems of systems. For example, a cell phone has a transmitter, receiver, & signal processing sub-systems, which might each have both analog & digital sections

- Systems process signals to modify them or to extract information
  - Systems have an input signal & an output signal

Some Basic Ideas About Systems

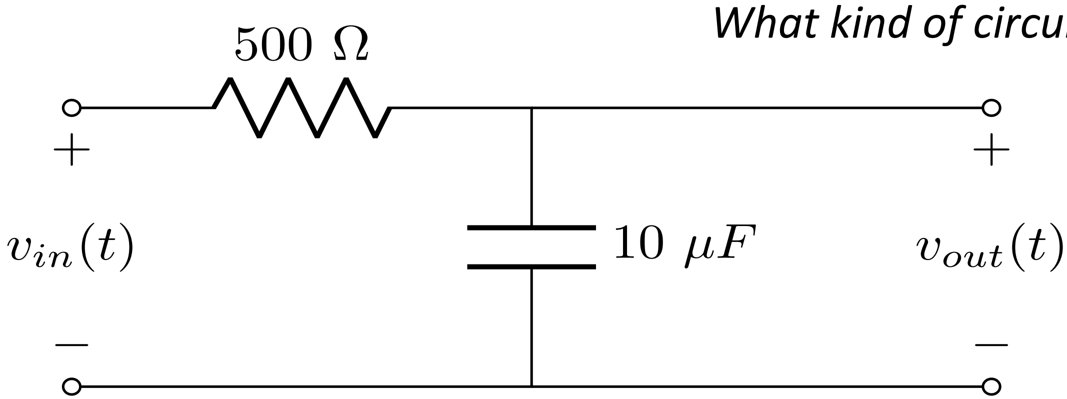
- Systems process signals to modify them or to extract information
  - Systems have an input signal & an output signal

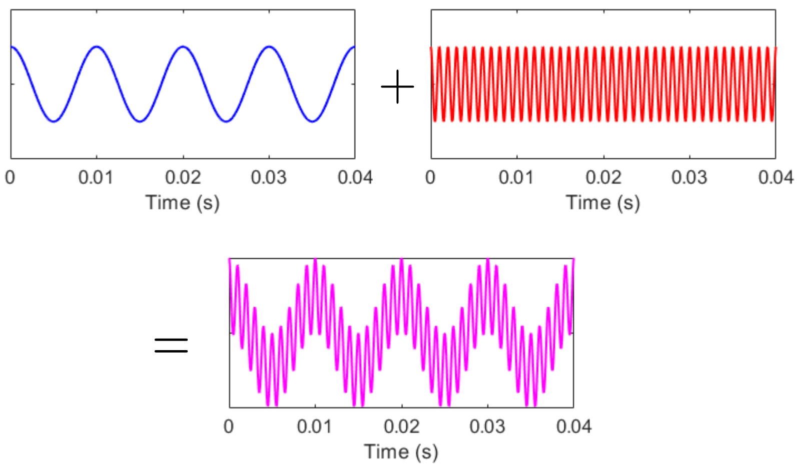
- In this course, we will generally focus on a special class of systems called *linear time-invariant* (LTI) systems
  - We will discuss the mathematical definition of LTI soon
  - Many useful systems are LTI or can be approximated as LTI
  - e.g. Any system described by a linear ODE (all RLC circuits, simple mechanical systems), amplifiers (sometimes), optical systems (lenses, fiber optics)
- LTI systems respond in very "nice" ways when signals are sinusoidal or exponential and can be analyzed in different "domains"
  - More specifically, the complex exponential function is the *eigenfunction* of an LTI system
  - What this means: a complex exponential input to a LTI system will have the same frequency at the output but with a shift in phase and amplitude
  - A signal that is the sum of sinusoids of different frequencies will have the same set of frequencies at the output, but each individual sinusoid will undergo a separate but predictable shift in phase and amplitude
  - Many signals/systems may appear to not be sinusoidal or exponential… but they can be analyzed as if they are if we have an LTI system

Examples of Signals and Systems

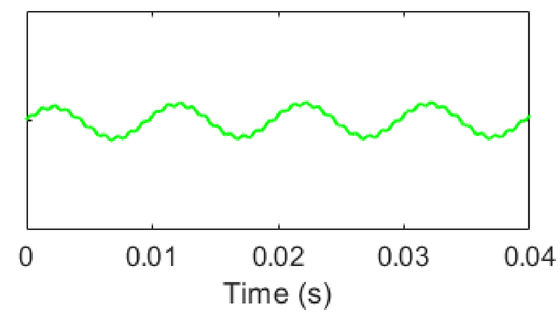
- Simple RC circuit is a system
- Input and output voltages are both signals

What kind of circuit is this?





$$v_{in}(t) = \cos(2\pi \times 100t) + \cos(2\pi \times 1000t)$$



Note the phase and amplitude shifts but that *both frequency sinusoids are present*

Examples of Signals and Systems

- More complicated example: cruise control
- What is the input signal? The output?

$$e(t) \longrightarrow \boxed{\text{Cruise Control}} \longrightarrow u(t)$$

Error function – how far off from the desired speed are we currently?

Throttle – what power should the engine have to correct the error?

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{\mathrm{d}e(t)}{\mathrm{d}t}$$

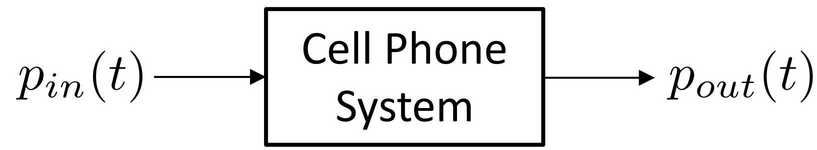
Cruise control and this equation are examples of proportional-integral-derivative (PID) controllers – Learn more about these in Control Systems Engineering (ECE 4413)

On its own, this function is sort of daunting to try to analyze. However, it turns out that the cruise control system described here is LTI, and we can use the tools we will discuss in this class (namely the Laplace transform) to analyze the behavior of this system in a much simpler way!

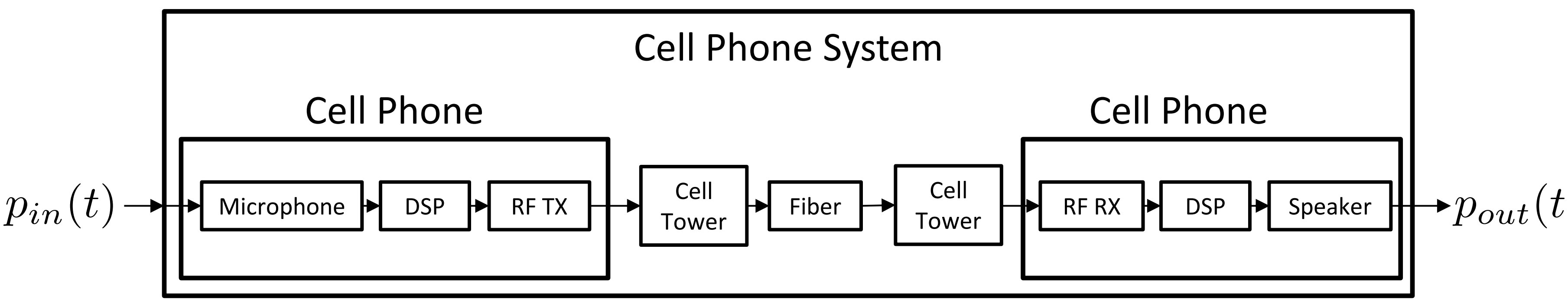
Examples of Signals and Systems

- System of systems example: cell phone call

End-to-end: speech/sound signal in, and speech/sound signal out



Theoretically this entire system can be described mathematically. However, this is nearly impossible in practice. The content of this course will be much simpler to apply to individual systems within the larger system before adding them together



High-Level View of the Semester

I. Foundations: signal descriptions, important signal types, …

II. "Continuous Time": data (time) domain, Fourier analysis (Fourier Series and Fourier Transform), Laplace Transform

III. "Discrete Time": data (sampled time) domain, discrete-time Fourier Series and Transform, z-Transform

Continuous	Discrete
*Laplace (Chap 9)	*z (Chap 10)
Fourier (Chap 3-4)	Discrete Fourier (Chap 3, 5)

- *Should have already seen, or maybe concurrently seeing, in 2713 & 2723
- How to calculate these transforms, fundamental transform pairs & properties

High-Level View of the Semester, cont.

IV. Propagation of signals through LTI systems: impulse response, transfer function, eigenfunction of LTI systems

V. Sampling and Reconstruction (hopefully – if we have time)

VI. Filters (if we have time)

Comments on Course Format

- With the exception of first few lectures, the lectures in this course will be delivered in hand-written notes
  - I will always post both my "original" notes along with the "in-class" notes to Canvas
  - The "original" notes will be available before each lecture, so you can download them and use them to follow along, annotate, etc. if that works better for you
  - **Reviewing posted lecture notes is NOT a substitute for attending and participating in lectures!**
- Each homework (except for HW 1) will have a set of practice problems posted with it
  - The practice problems are similar or harder versions of homework problems with posted solutions
  - Use these to help get unstuck on tricky homework problems, study for exams, etc.