What is ECSE?
&
Applications of Signals and Systems

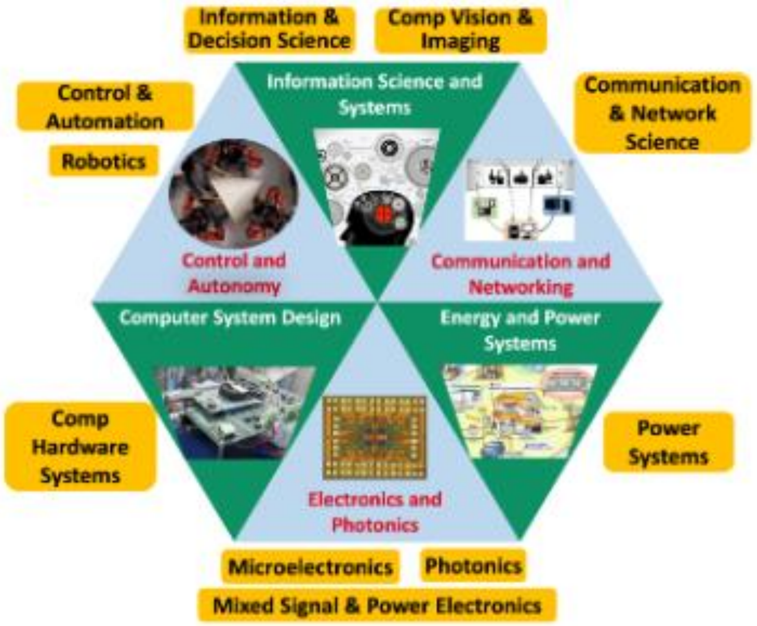
3/31/2023

Prof. Patterson

What is ECSE (at RPI)?

- Artificial Intelligence and Machine Learning
- Computer Vision and Image Processing
- Communications and Computer Networks
- Control Systems
- Robotics and Automation
- Computer Hardware Systems
- Electric Power and Energy
- Microelectronics and Photonics
- Mixed Signal Electronics

https://ecse.rpi.edu/academics/undergraduate-programs



How are EE and CSE different?

https://ecse.rpi.edu/academics/undergraduate-programs/what-are-ee-and-cse

- Where do EE and CSE overlap?

The two majors have many similarities. In either one, you'll get a solid foundation in applied math and physics, computer programming, circuit theory and electronics, engineering design, and professional development. You can take a look at our curriculum and templates for more details.

- How is EE different than CSE?

EEs generally focus more on hardware and physics. This is where you'll learn about machines, devices, and systems that consume a lot of power, and how that power is managed. This is also where you'll build circuits and systems at a small scale, like designing and fabricating your own microchips and sensors.

- How is CSE different than EE?

CSEs generally focus more on algorithms and systems. Compared to an EE, you'll do more computer programming and learn more mathematical theory related to areas like artificial intelligence. This is where you can learn about the Internet of Things, computer vision, communication networks, and robotics.

EE and CSE Core Curricula

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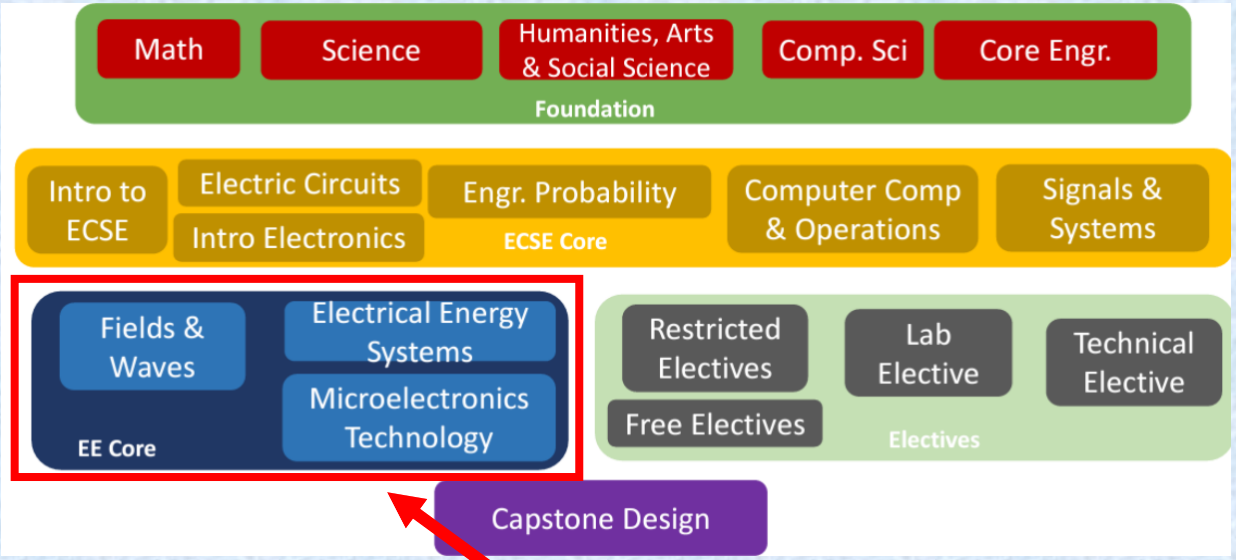
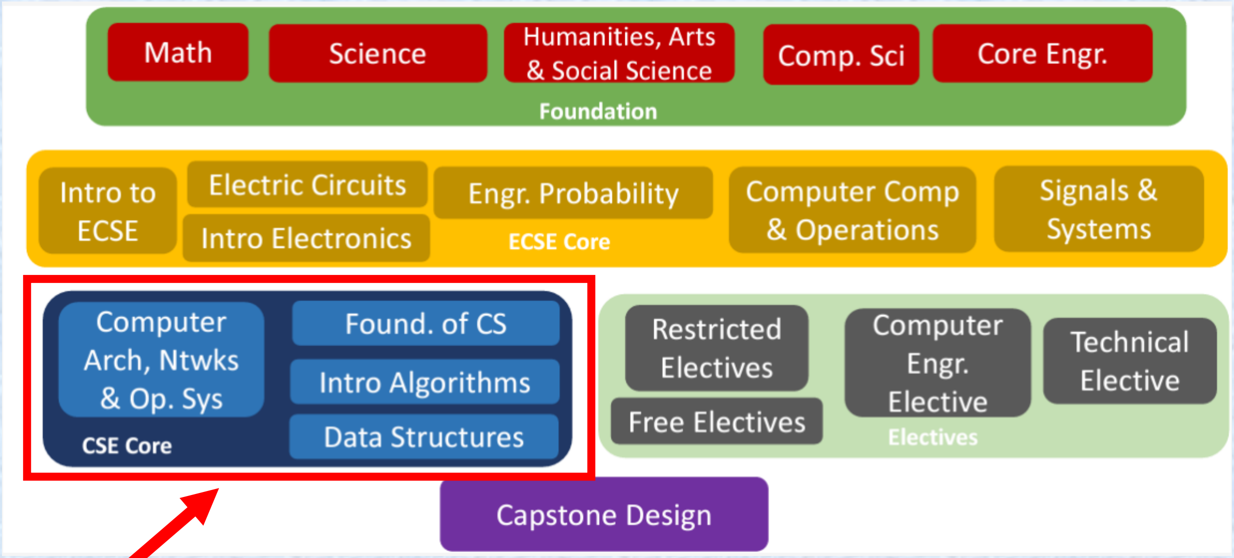
EE Curriculum



CSE Curriculum



Key Differences

How are CSE and CS different?

- Can I do both?

Yes! Many students comfortably get an EE/CSE dual major where you'll get a broad education in both areas. You'll have a lot of freedom to choose electives in your senior year that focus on what you want to learn more about.

- How is CSE different than Computer Science?

A simple answer is that Computer Science is more focused on what computers can do, and Computer Systems Engineering is more focused on how computers are built. You can get a CS degree without taking your hands off the keyboard, but in CSE you will get them dirty with all sorts of sensors and devices! You'll learn a lot of ways of applying math to model the real world in the CSE major that you won't see in a CS degree.

- Can I do both?

Yes! It's extremely common for students to dual major in CSE and CS to get exposed to both ways of thinking.

Focus Areas

Information Science and Systems

The next industrial revolution will largely be driven by Intelligent Technologies (ITs). It will mark with the ubiquitous presence and applications of intelligent algorithms and systems, such as autonomous machines and smart devices. ECSE faculty has a long tradition in developing intelligent technologies. The AI and Machine Learning Systems (AI/ML Systems) group performs fundamental research in AI and machine learning as well as their applications to various physical systems.

Artificial Intelligence and Machine Learning

- Required:
  - ECSE 4840 - Introduction to Machine Learning
- ECSE Electives (take two from list)
  - ECSE 4850 – Intro to Deep Learning
  - ECSE 4810 – Intro to Probabilistic Graphical Models
  - ECSE 4740 – Parallel Computing
  - CSCI 4100 - Machine Learning from Data
  - ECSE 4760 – Real Time Control & Communication
  - ECSE 4962 (Spring 2022) - Trustworthy Machine Learning
  - ECSE 4964 (Spring 2022) - Distributed Machine Learning

Computer Vision and Image Processing

- ECSE Electives (take three from list)
  - ECSE 4540 – Introduction to Image Processing
  - ECSE 4620 – Computer Vision for Visual Effects
  - ECSE 4750 - Computer Graphics
  - ECSE 4850 - Intro to Deep Learning
  - ECSE 4961/6650 - Computer Vision

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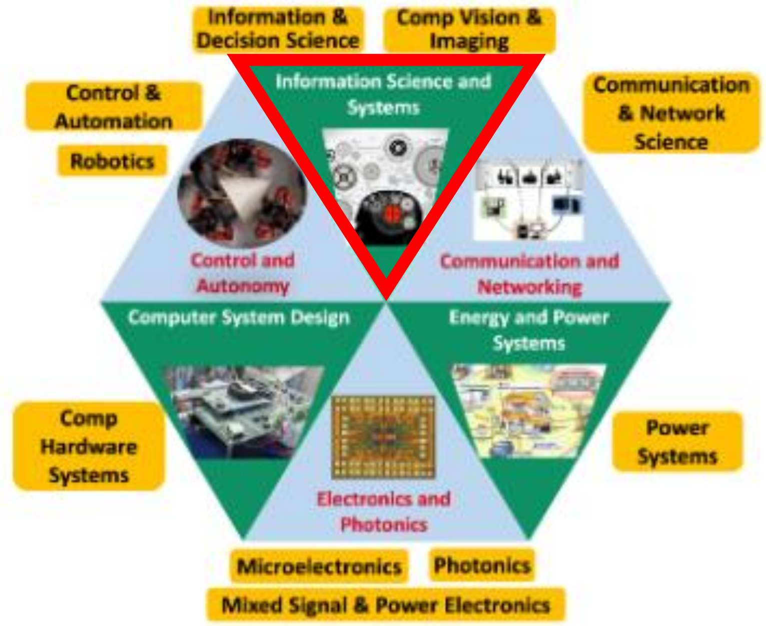

Focus Areas

Communications & Networking

This field deals with the encoding, transmission, retrieval, and interpretation of information in many forms. Students may pursue programs of study focusing on mathematical modeling and analysis, algorithm design, and hardware/software implementation of solutions for efficient information transmission and retrieval.

Communications and Computer Networks

- Required:
  - ECSE 4660 – Internetworking of Things
- ECSE Electives (take two from list)
  - ECSE 4670 – Computer Communication Networks
  - ECSE 4520 – Communication Systems
  - ECSE 4530 - Digital Signal Processing
  - ECSE 4560 - Digital Communications

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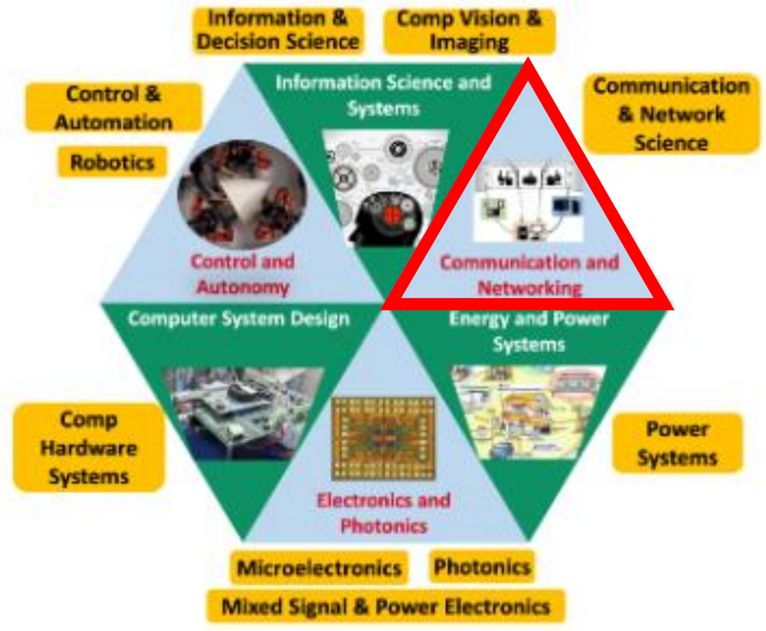

Focus Areas

Energy and Power Systems

The program includes the study of power system dynamics and control, and the role of power electronics in renewable resource integration in large power grids. The programs apply techniques from other disciplines on the various aspects of power system operation, such as cyber security and data analytics.

Electric Power and Energy

- Required:
  - ECSE 4130 – EPE Laboratory
- ECSE Electives (take two from list)
  - ECSE 4080 – Semiconductor Power Electronics
  - ECSE 4110 – Power Engineering Analysis
  - ECSE 4120 – Electromechanics
  - ECSE 4170 – Modeling & Simulation of Cyberphysical Systems

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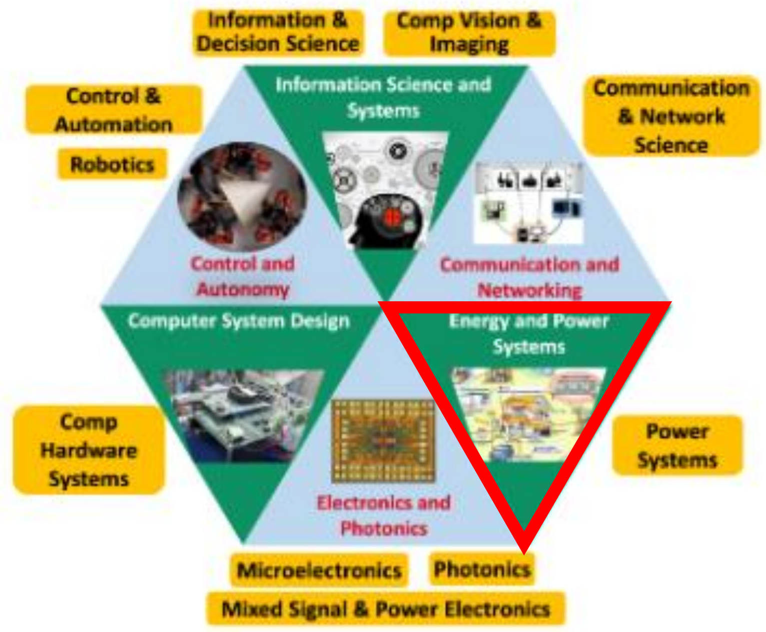
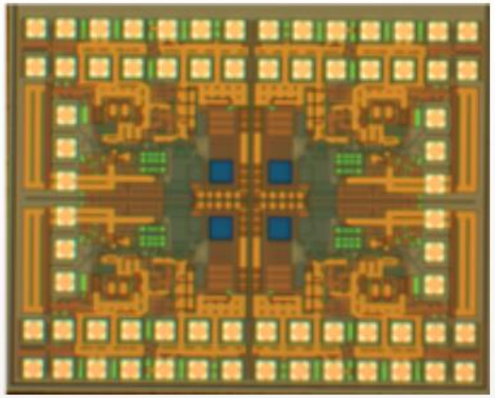


Focus Areas



Electronics & Photonics

Work in this area primarily focuses in developing new devices using cutting edge technology and then employing them in building state of the art systems with the aim of improving the modern electronic industry.

Microelectronics and Photonics

- Required:
  - ECSE 4220 – VLSI Design
- ECSE Electives (take two from list)
  - ECSE 4040 - Digital Electronics OR ECSE 4030 - Analog Electronics
  - ECSE 4250 - IC Processing and Design
  - ECSE 4370 – Optoelectronics Technology
  - ECSE 4380 – Fundamentals of Solid State Lighting
  - ECSE 4080 - Semiconductor Power Electronics
  - ECSE 4720 – Solid State Physics

Mixed Signal Electronics

- Required:
  - ECSE 4220 – VLSI Design
- ECSE Electives (take two from list)
  - ECSE 4030 – Analog IC Design
  - ECSE 4040 – Digital Electronics
  - ECSE 4050 – Advanced Electronics
  - ECSE 4310/ECSE 630 - Fundamentals of RF/Microwave Engineering

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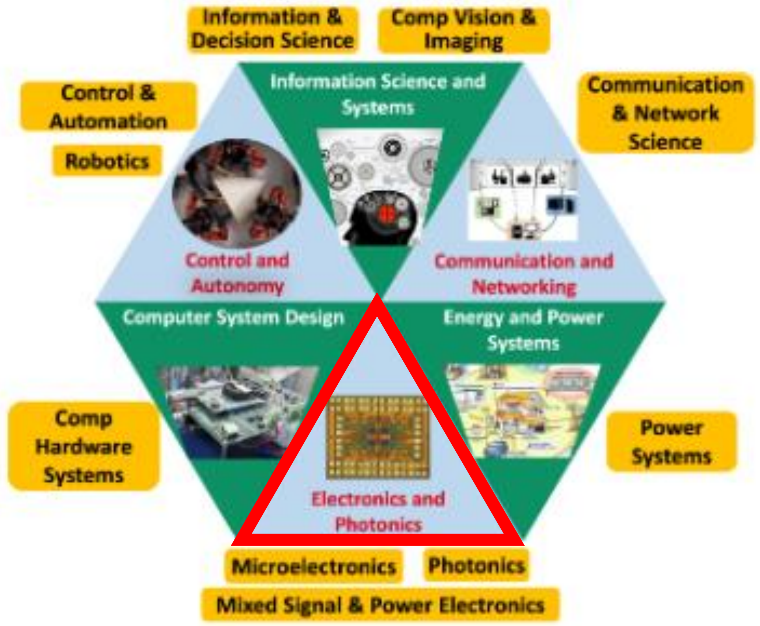
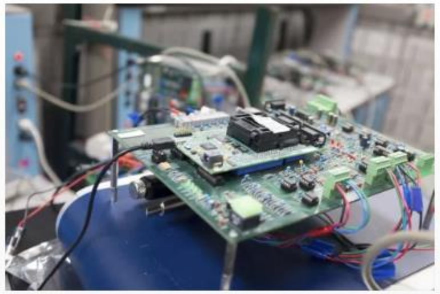


Focus Areas



Computer Systems Design

Computers have become almost as pervasive as food. While there are many users of computer technology and many who write programs, the future of computing depends on the underlying electronic devices that compose them and the digital logic operations they perform. Computers use circuits that connect these devises. While current computers are nearly exclusively fabricated with CMOS, progress has been largely obtained by device scaling. This becomes difficult as the physical dimensions of the devices become so small that only a handful of dopant atoms can be used to define their operation. As such, novel approaches to computing are needed along with new devices.

Computer Hardware Systems

- Required:
  - ECSE 4770 – Computer Hardware Design
- ECSE Electives (take two from list)
  - ECSE 4040 – Digital Electronics
  - ECSE 4220- VLSI Design
  - ECSE 4250 – IC Process & Design

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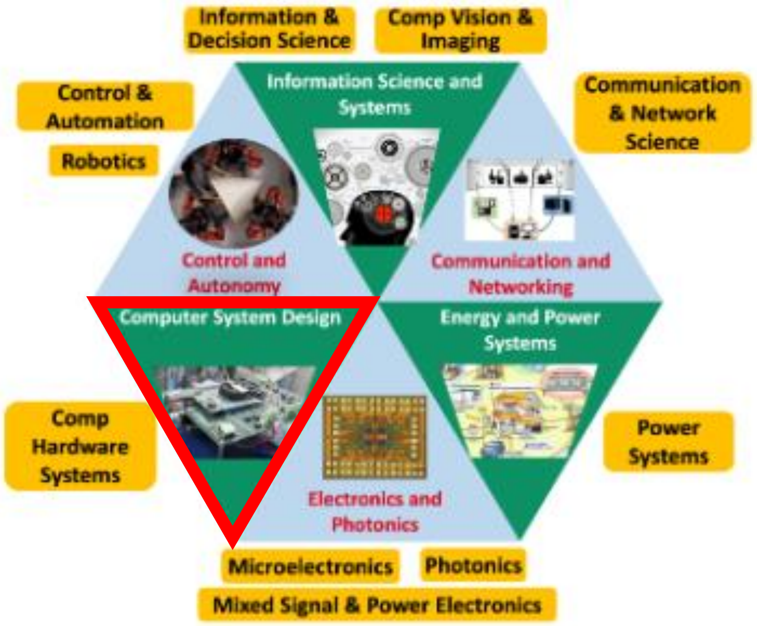

Focus Areas

Control and Autonomy

With focuses on the methodologies and applications in control, robotics, and automation the ECSE faculty in this area conduct multi-disciplinary cutting-edge research with emphasis on high impact applications. Methodological tools include complex large-scale systems, network science, formal methods, machine learning, vision and perception, and cognitive engineering. Applications span human-robot systems, advanced manufacturing, cyber-physical systems, autonomous systems, power systems, thermal management, biological systems, human health, micro-robotics, and materials processing.

Control Systems

- Required:
  - ECSE 4440 - Control Systems Engineering
- ECSE Electives (take two from list)
  - ECSE 4760 - Real Time Control & Communication (Lab or CE Elective)
  - ECSE 4170 – Modeling & Simulation of Cyberphysical Systems
  - ECSE 4090 - Mechatronics (Lab or CE Elective)

Robotics and Automation

- Required:
  - ECSE 4480 - Robotics I
- ECSE Electives (take two from list)
  - ECSE 4490 - Robotics II
  - ECSE 4850 - Intro to Deep Learning
  - ECSE 4170 – Modeling & Simulation of Cyberphysical Systems
  - ENGR 4710 - Manufacturing Process and System Lab I (Lab Elective)

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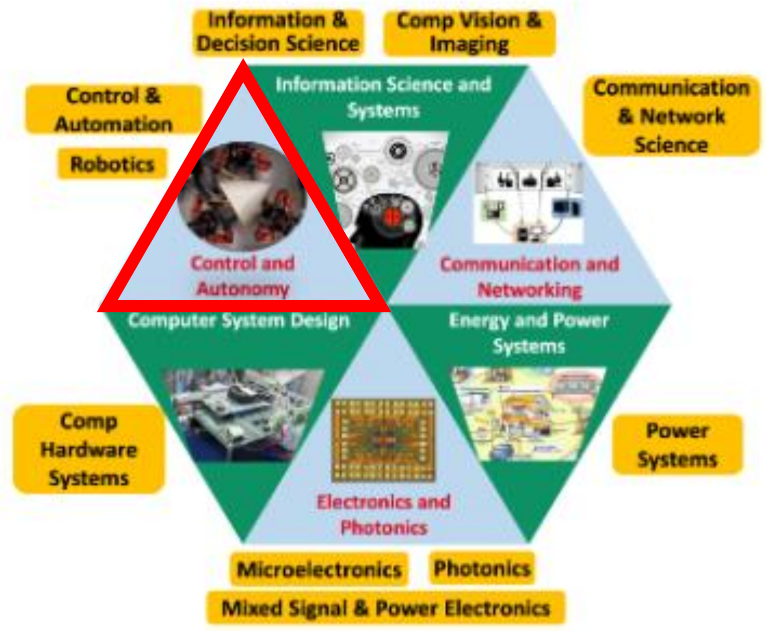

Where do the Labs in ECSE 1010 Fit?

- Artificial Intelligence and Machine Learning
- Computer Vision and Image Processing **Lab03**
- Communications and Computer Networks **Lab03**
- Control Systems **Lab02** **Lab03**
- Robotics and Automation **Lab03**
- Computer Hardware Systems **Lab01**
- Electric Power and Energy **Lab01**
- Microelectronics and Photonics **Lab02***
- Mixed Signal Electronics **Lab01** **Lab02**

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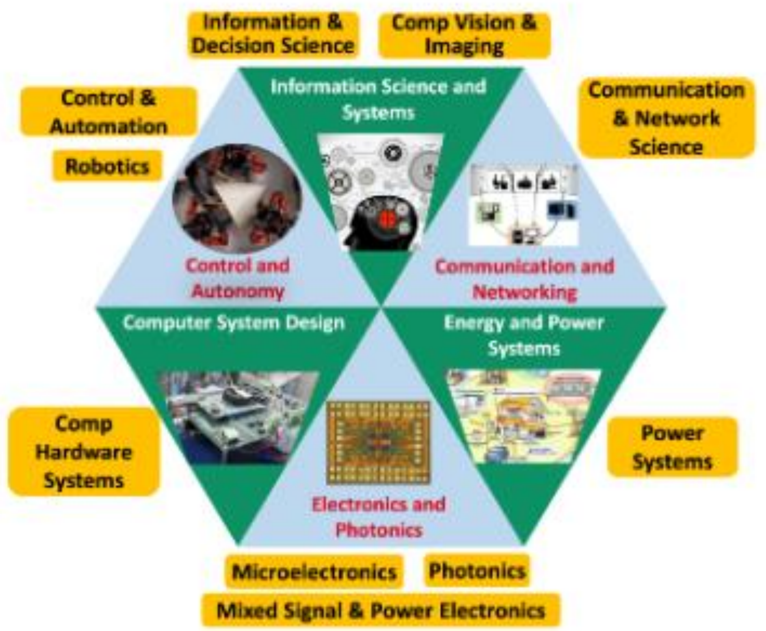


Lab01 – Basics of Electric Circuits

Lab02 – Linear Systems and Op-Amps

Lab03 – Signals (Frequency & Time Domain)

***Diode Omega Lab**

Examples of Projects in Signals and Systems

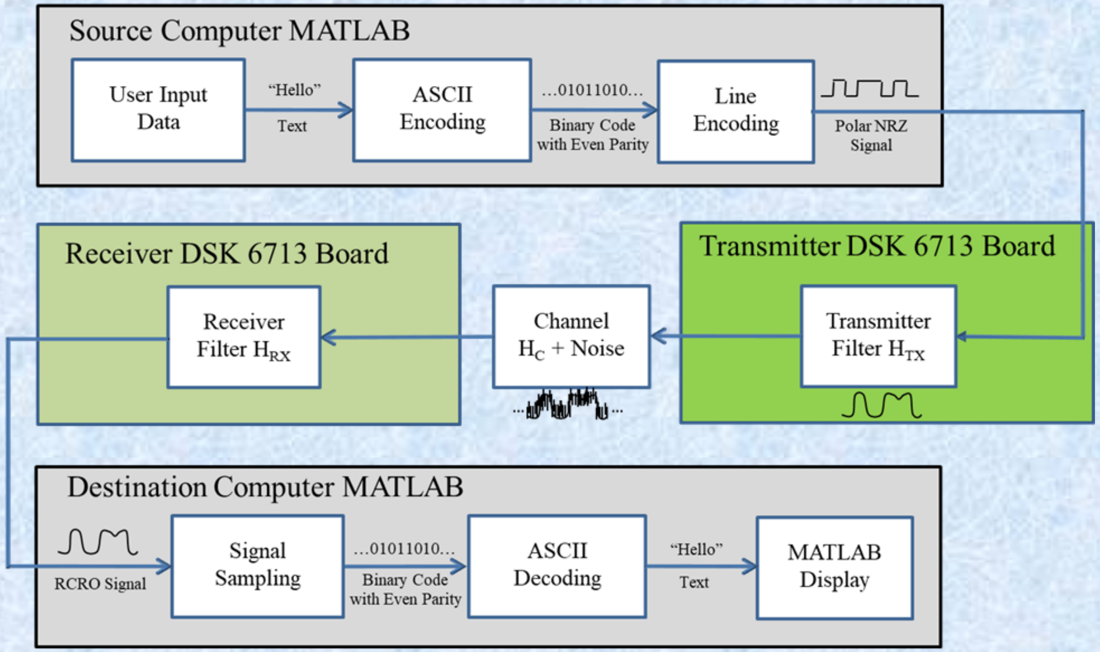
- Although EE and CSE deal more with hardware, they are not limited to building hardware hands-on

- Often the systems that EE's and CSE's deal with are virtual, and are designed on computers in software packages (Matlab, Simulink, Ltspice, Comsol Multiphysics, etc.)

- Instead of physically building these systems to test them, the experiment can actually be a simulation run in one of these programs

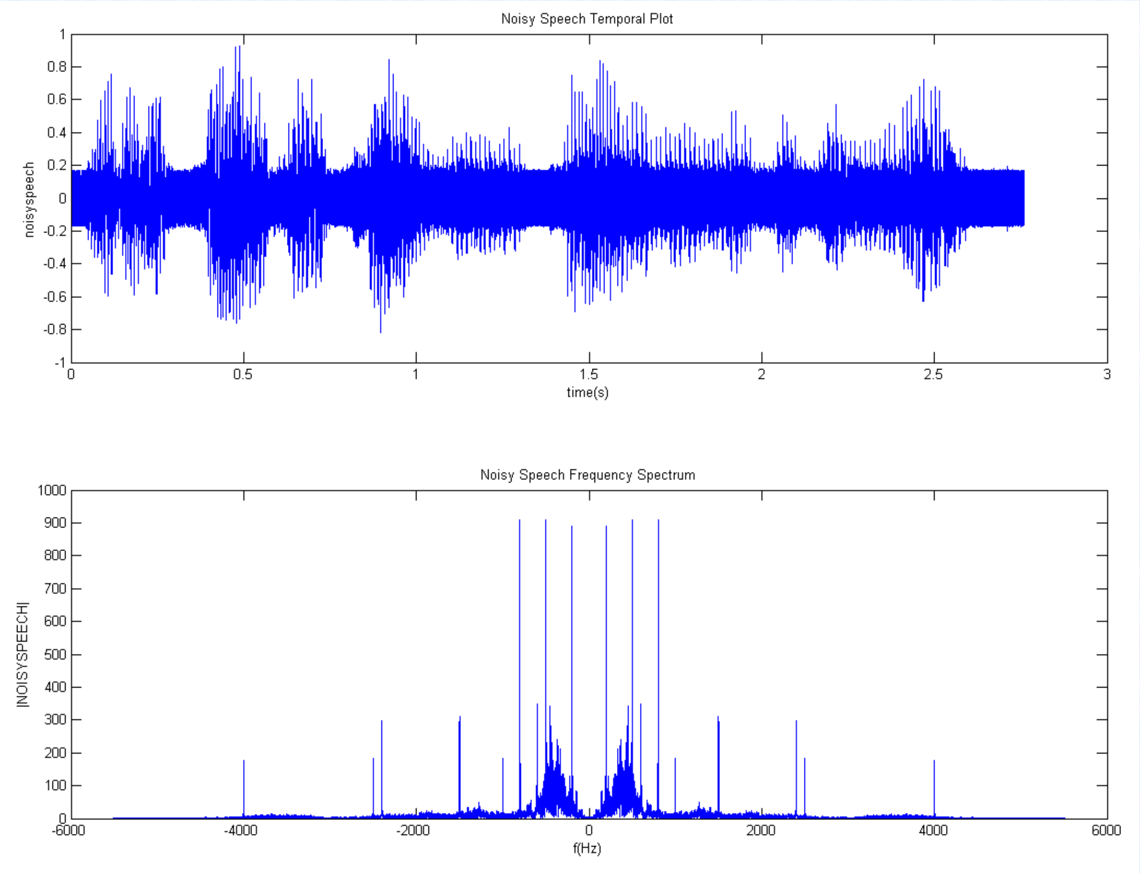
- The fields of signal processing (topic of lab 03) and control systems are examples of this

Digital Communication System



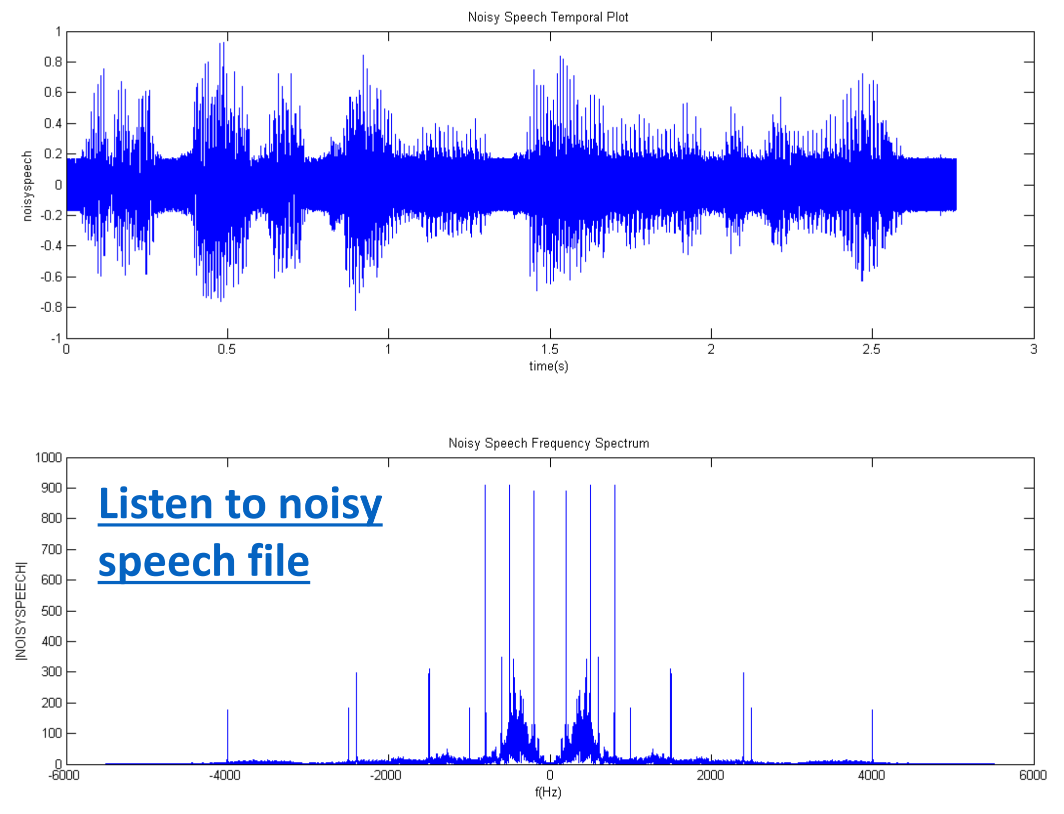
Example: Filtering Noisy Signals

- Signals are functions that convey information
- Signals, such as a recording of speech, often contain noise that make it more difficult to understand that information
- It is possible to use a representation of a signal in the frequency domain to gain a different perspective on the information in the signal
- If we know which frequencies of the signals contain the information, we can use filters to keep only those parts of the signal
- The manipulation of signals is called signal processing



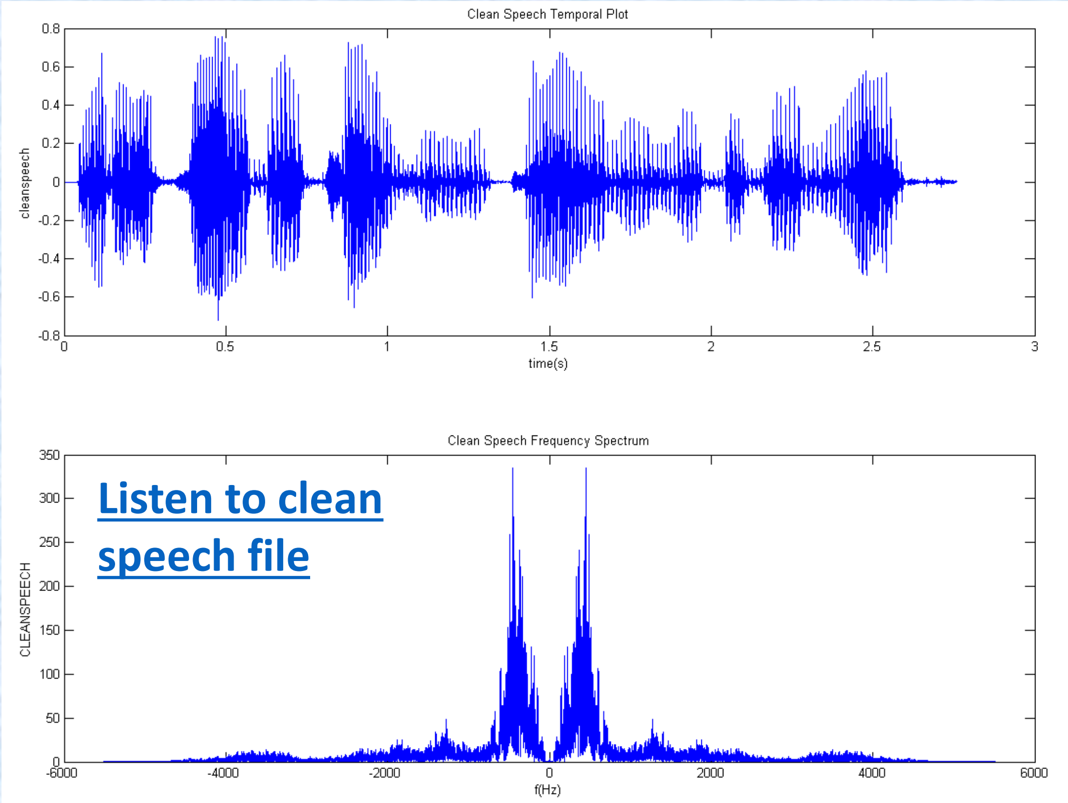
Example: Filtering Noisy Signals

- The top plot shows a noisy signal in the time domain; the bottom plot, the frequency domain



[Listen to noisy speech file]

- The top plot shows the "clean" signal in the time domain; the bottom plot, the frequency domain



[Listen to clean speech file]

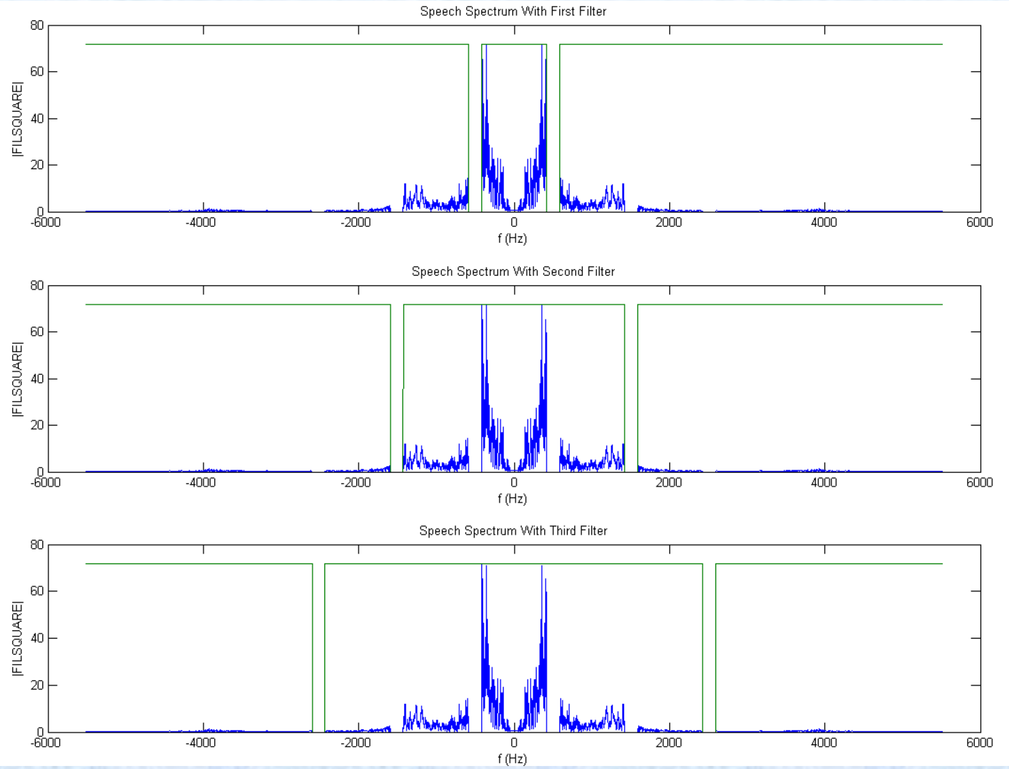
Notice that the frequency spectrum of the noisy signal has large spikes that the clean signal does not

→ These spikes are the noise and the goal is to remove them from the signal

Example: Filtering Noisy Signals

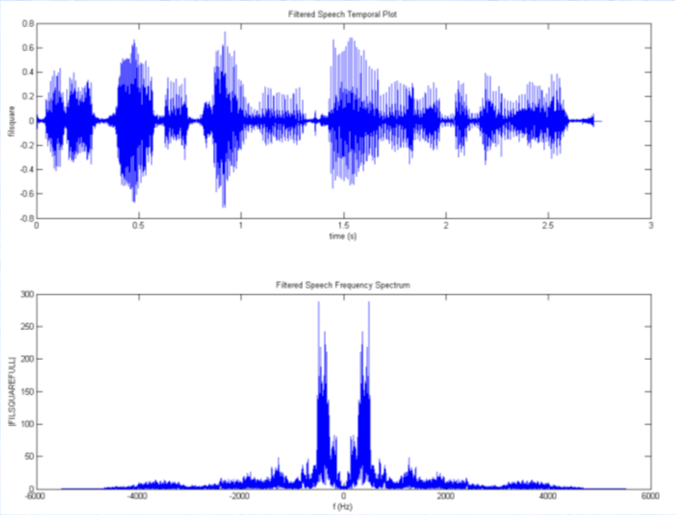
- We can design filters (green lines) that eliminate a certain range of frequencies to remove the spikes (noise)

Filters

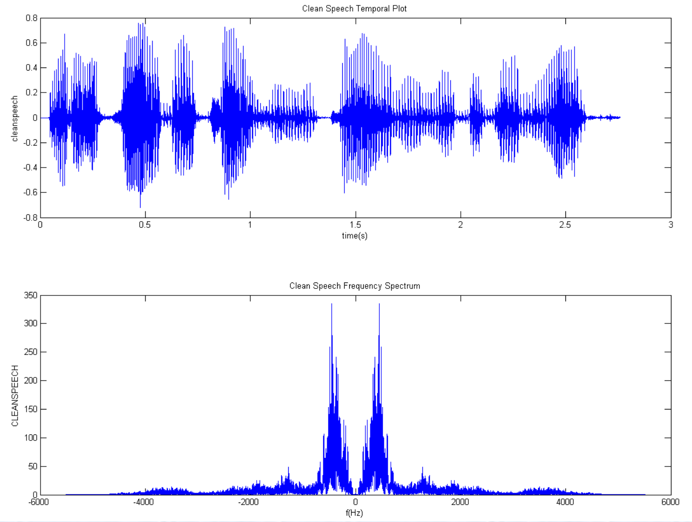


- After filtering, the filtered noisy signal closely resembles the original clean signal

Filtered Noisy Signal



Original Clean Signal



[Listen to filtered speech file]

[Listen to clean speech file]

Example: Digital Communication System

- Signals contain information, but to convey that information, they need to be transported from one place to another: this is the purpose of a communication system. How do they work?

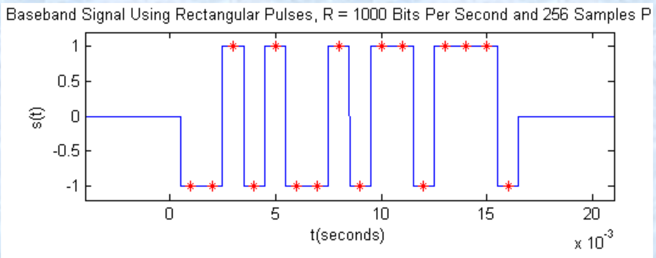
1. User inputs data (text): “hello”

2. User data converted to binary (0’s and 1’s) via ASCII encoding.

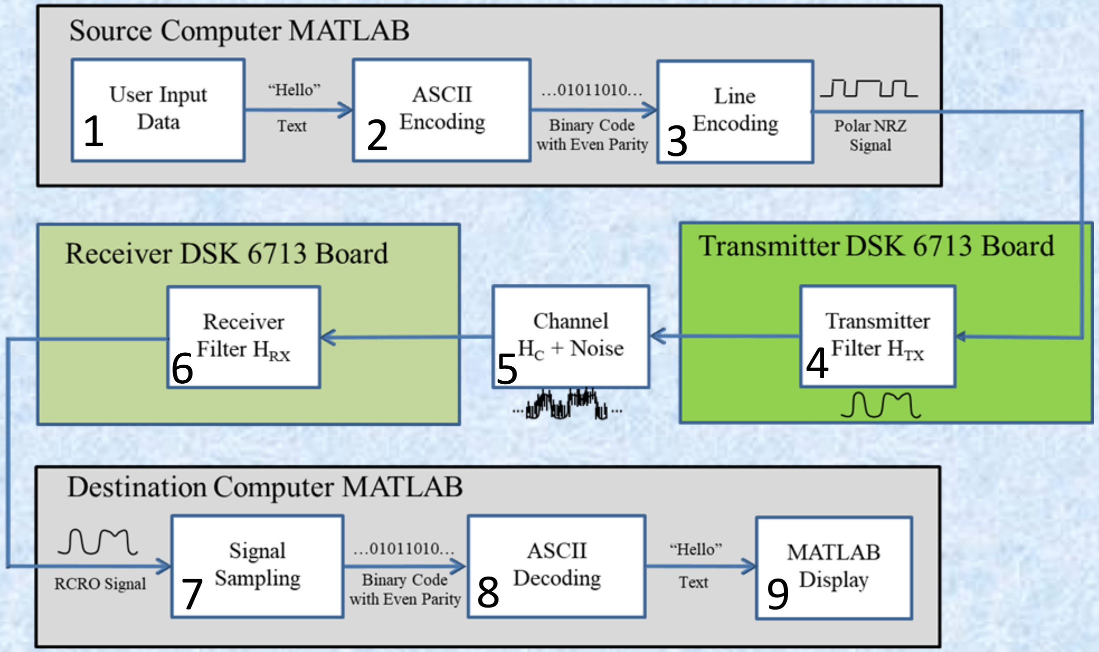
01101000 01100101 01101100 01101100 01101111

H E L L O

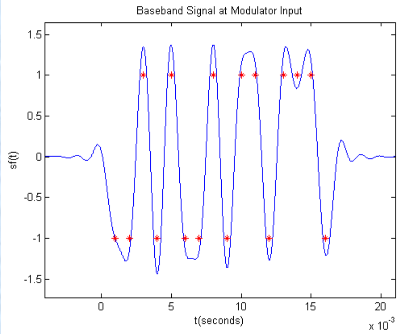
3. Binary data converted to digital voltage signal, such as:



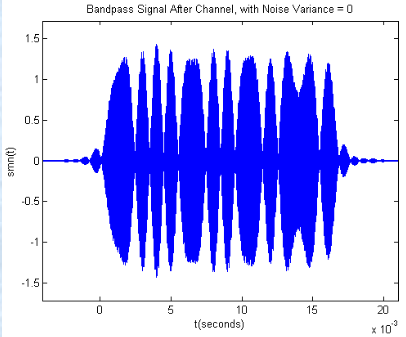
Text-to-Text Digital Communication System



4. Filter the voltage signal to ensure it keeps its shape while being transmitted through wire



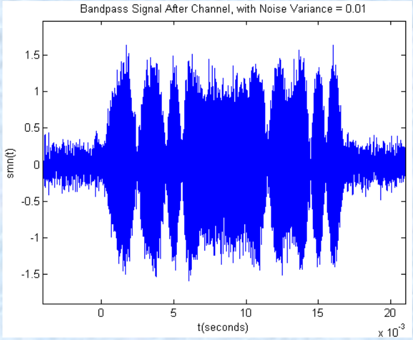
Modulate signal for transmission



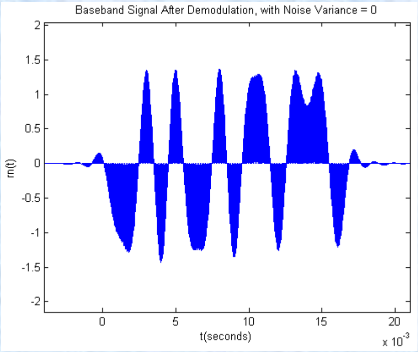
Example: Digital Communication System

- Signals contain information, but to convey that information, they need to be transported from one place to another: this is the purpose of a communication system. How do they work?

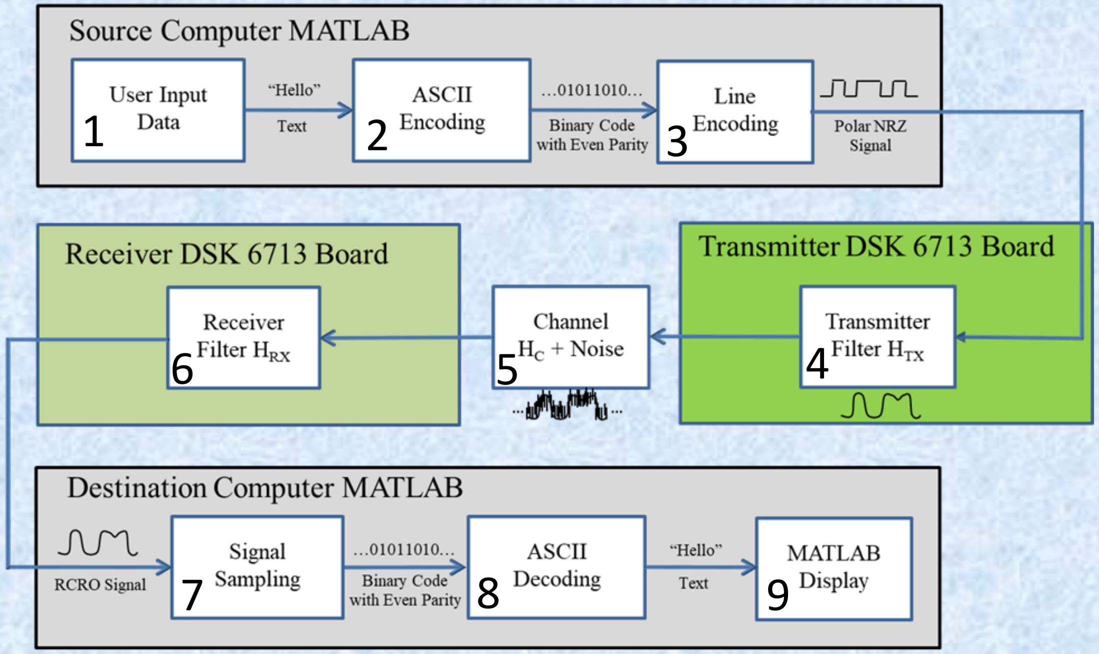
5. Signal is transmitted through a channel, gains noise



6. Receiver filters demodulates signal

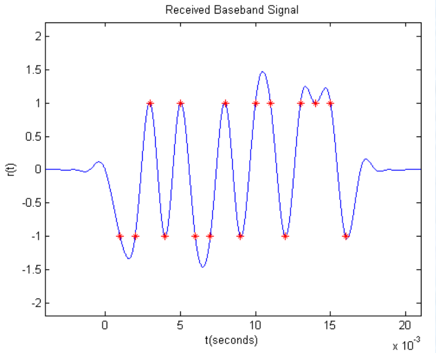


Text-to-Text Digital Communication System



Note: steps 1-4, 6-9 implemented via software!

7. Signal is sampled



8. Sampled values converted to binary

01101000 01100101 01101100 01101100 01101111

9. Binary converted to text via ASCII

H E L L O

10. Message displayed on screen

Note: although all of these examples are done in software (digital signal processing), they are also done in hardware (analog and digital signal processing)

Example: Audio Engineering

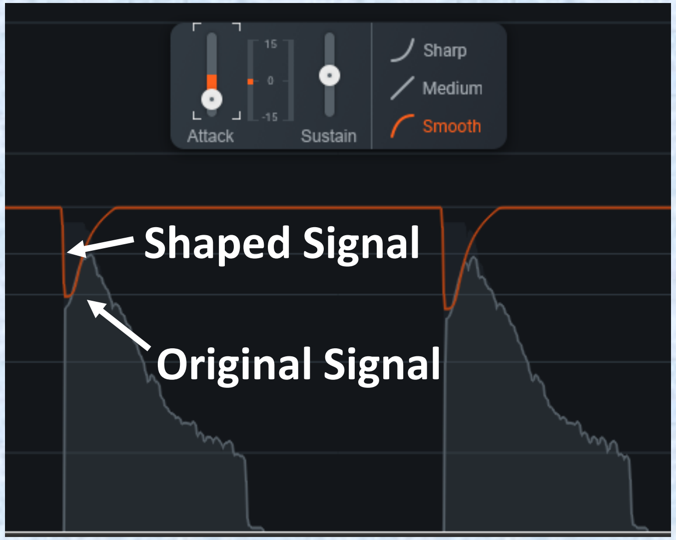
- Another area rich in signal processing applications is audio engineering & music production. Think of signal processing as a set of tools for creating auditory art (music). Examples:
  - **Transient shaping**: reduce/enhance an initial sound (attack) or the lingering sound after (sustain)

https://www.artplacer.com/essential-art-tools-every-artist-should-have/

Original Sample

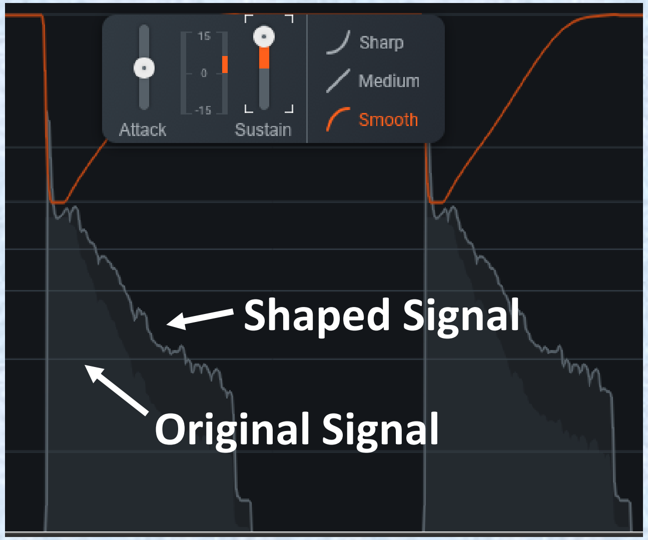
[Listen to original snare sample]

Reduced Attack



[Listen to reduced attack snare sample]

Enhanced Sustain



[Listen to enhanced sustain snare sample]

Example: Audio Engr.: Sound Effects

- **Sound Effects/Simulating Hardware**: changing the character of a signal's sound, by adding effects such as distortion (amplifiers), reverb, delay, chorus, flanger, phaser (guitar pedals), etc.

Digital signal processing methods used to emulate hardware (analog circuits)

Listen to Clean Guitar

Guitar Input

Listen to "Plexi" Guitar

Audio Output

Guitar Input

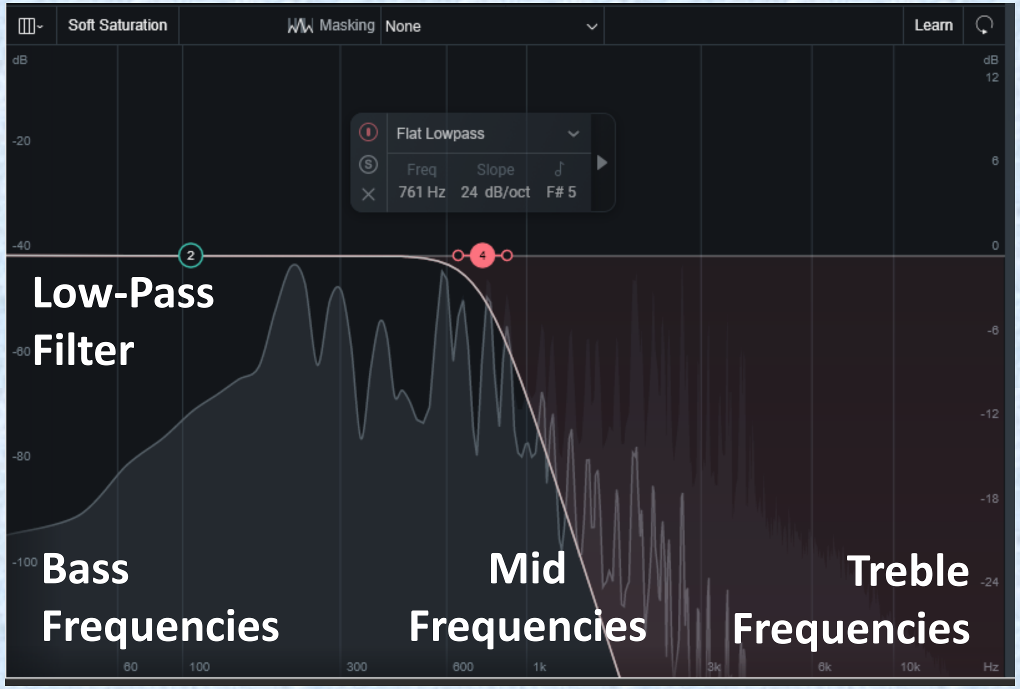
Listen to "Sitar" Guitar

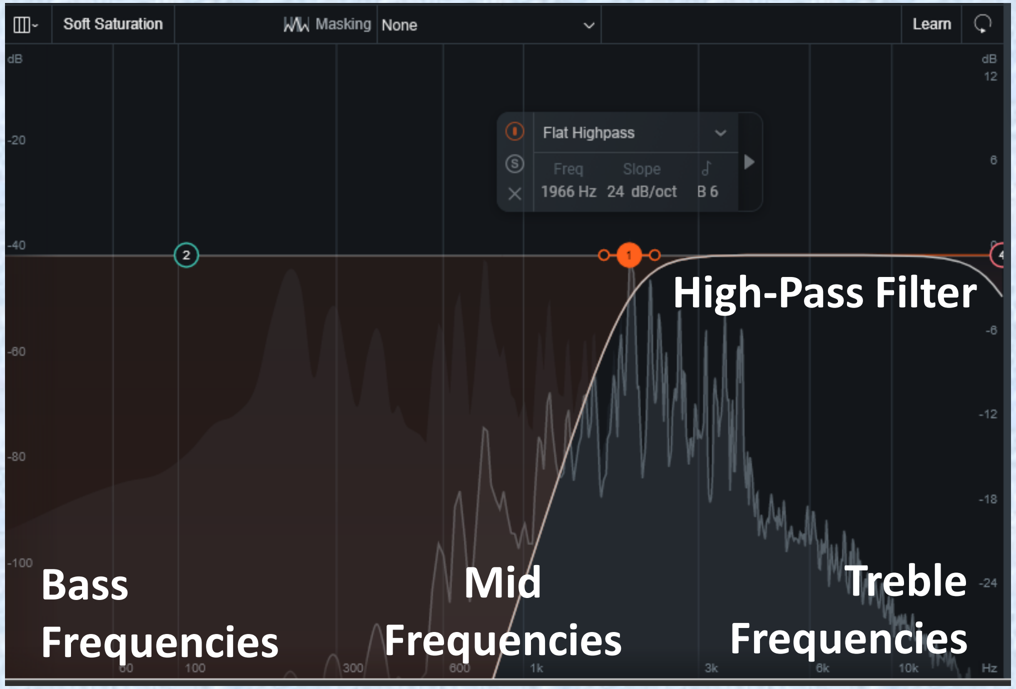
Audio Output

Example: Audio Engr.: Equalization

- **Equalization**: application of filters to reduce/enhance particular ranges of frequency in a signal

Listen to Unfiltered Guitar





Listen to Low-Pass Filtered Guitar (less treble)

Listen to High-Pass Filtered Guitar (less bass)

Example: Audio Engr.: Compression

- **Compression**: makes louder parts of a signal quieter to balance or even out the sound the sound.

- Compression is often a subtle effect and may be difficult to hear, but the compressed signal should sound like the volume level is more even throughout, whereas without compression it seems to get noticeably louder and softer on each strum

Listen to Guitar without Compression

Listen to Compressed Guitar

Example: Audio Engr.: Synthesizers

- With knowledge of manipulating signals, we not only can change sounds but also create (or synthesize) new ones

- Here are a few examples using familiar signals as the fundamental component of the sound

  Listen to Sine Wave Synth

  Listen to Triangle Wave Synth

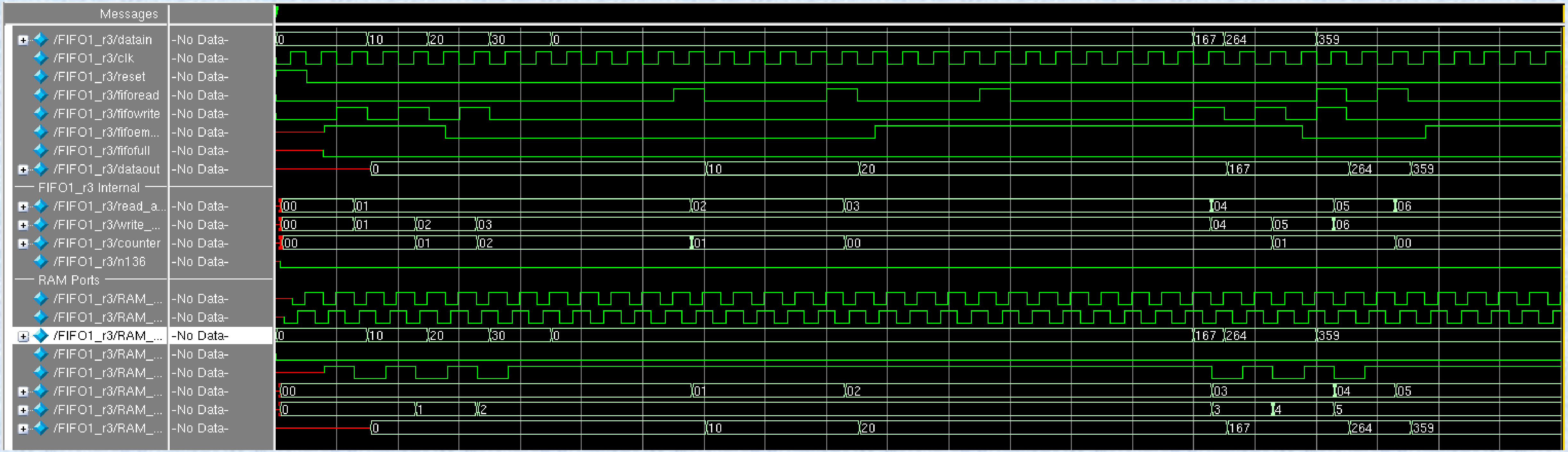
  Listen to Square Wave Synth

- Since additional audio processing techniques can be applied to the synthesizer signal, the possibilities are endless

  Listen to Frequency Modulated (FM) Synth

Example: VLSI Design (Designing Computers)

- Digital circuits in computers make decisions at the frequency of a clock signal
- Each 0 and 1 (information) is represented as a low or high voltage signal
- These signals must be sent from one component to another 1) at the correct time, and 2) with the correct shape & value. Designing such systems also requires a knowledge of signals.



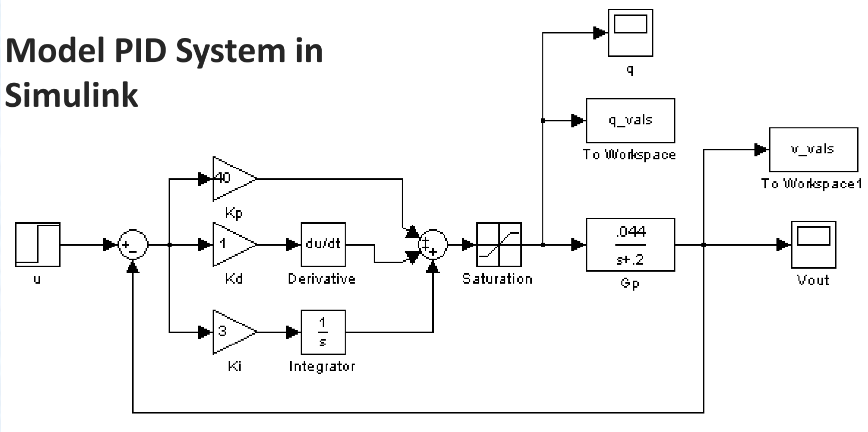
Example: Cruise Control System

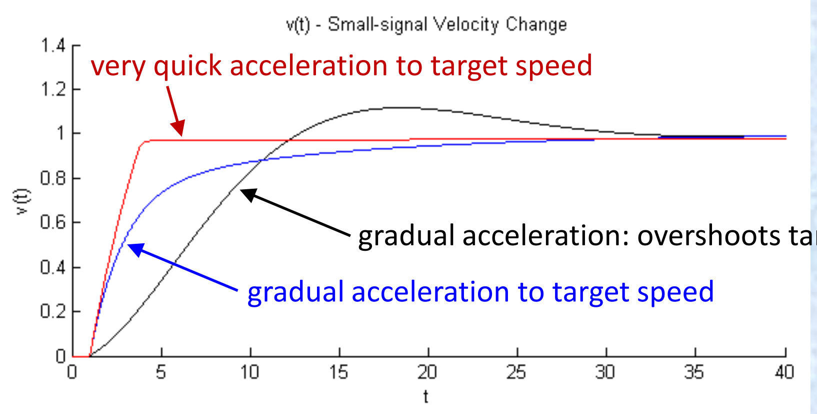
- The cruise control system of a car is an example of a linear control system

- The system takes a new target speed as input and must bring the car to that speed as quickly and smoothly as possible

- The system uses the following feedback to determine how to adjust the car's speed (PID control):
  - Difference between the current speed and target speed (the *error*)
  - Integral of the *error*
  - Derivative of the *error*

- Adjusting feedback parameters produces different velocity curves for reaching target speed





So? Why care about Signals (and Systems)?

- Signals are everywhere and are the basis of **information**
- Systems can **process information to make decisions**
- **Linear systems** (remember Lab02?) are particularly convenient to work with and you will encounter them often
- Signals and systems represents the “other” side of ECSE: the (mostly) hands-off design of systems at a higher level AND the processing of information
- If you like building circuits, don’t worry – the **physical implementations** of these systems are **analog** or **digital circuits**