

Bits over the Air: Pre-Lab 1

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CornellEngineering

Electrical and Computer Engineering



VLSI Information
Processing Group

IMPORTANT

- You can always ask questions (during pre-labs and labs, or via email after the labs)
- During the labs, you can also ask us if you want to know more about a specific aspect!
- **We are here to help!**

A short introduction

Wireless communication

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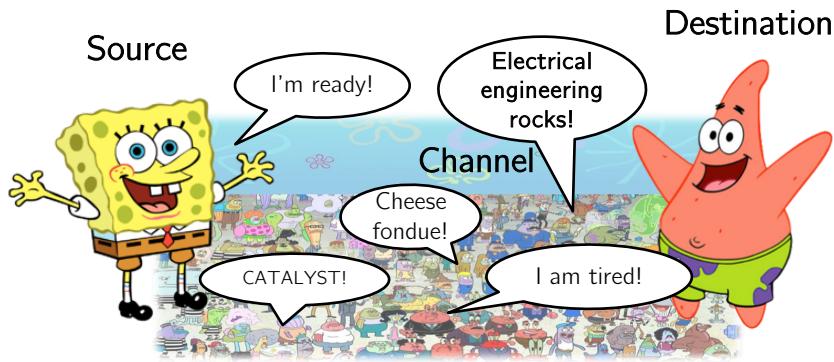
We all communicate!



- **Source:** generates information to be transmitted
- **Channel:** physical medium (air or water)
- **Destination:** entity that receives information

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What could go wrong?



- Real-world channels introduce **noise** and **interference** → unreliable communication

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How can we make communication reliable?

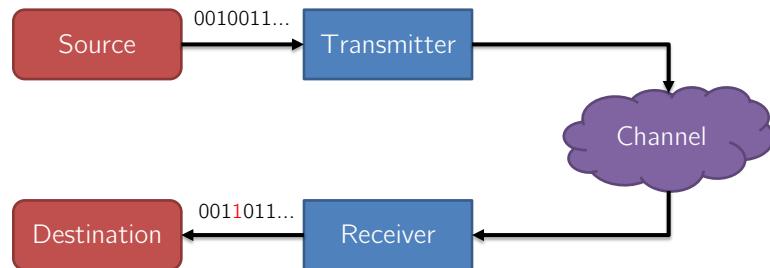
- Speak louder
- Go closer to destination
- Repeat message
- Rephrase message
- Change language
- (Change pitch)
- We are naturally using concepts that modern communication systems are using

} received signal strength
 } modulation and coding

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Abstraction of communication systems

- Simple point-to-point system:

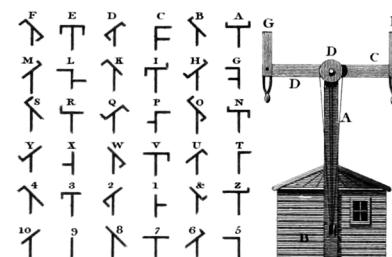
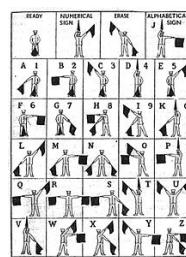


- Almost all possible communication systems (Wi-Fi, LTE, Bluetooth, etc.) look like this!

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Early history of communication

- Optical telegraphy (wireless):
 - Smoke signals, talking drums, homing pigeons, hydraulic semaphore systems (**4BC**), beacons, semaphores (**until about 1880**)



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Wired information transfer

- Electrical telegraphy (wired)
 - 1774 : Georges-Louis Le Sage designed first electrical telegraph with wire for each letter
 - 1800 – 1820 : Different electrical telegraph systems with limited distance
 - 1837 : Samuel Morse developed code and machine to transmit and receive over long distances



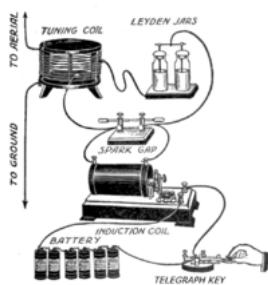
A•-	J•---	S•••
B•••	K•-	T-
C---	L•••	U••-
D--	M--	V•••
E•	N-	W---
F•••	O---	X••-
G---	P•••	Y••--
H•••	Q---	Z---
I••	R•-	



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And then came wireless!

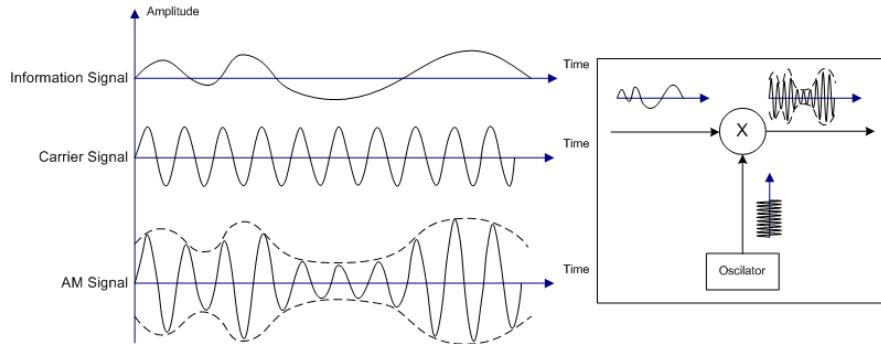
- Wireless telegraphy
 - 1890s : Guglielmo Marconi developed the spark-gap transmitter → send pulses wirelessly



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Analog signal transmission

- 1900 – 1920 : amplitude modulation (AM) for wireless audio transmission



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A digital revolution!

- In 1948, Claude Shannon at Bell Labs developed information theory
 - Digital model for communication
 - Builds the basis of all existing communication systems!
 - Data rates (bits/second) double every 18 months

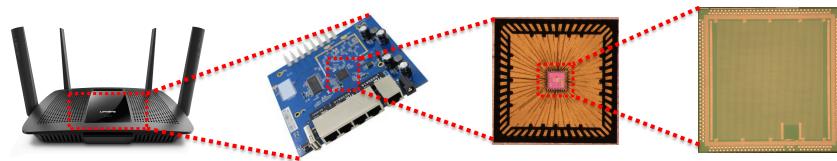


- Since then, digital communication has evolved into Wi-Fi, LTE-A, Bluetooth, DOCSIS, ...

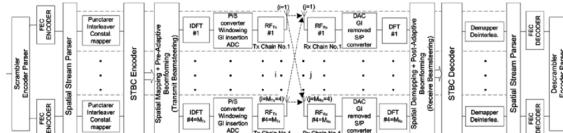
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Modern wireless transceivers

- Transceiver: transmit and receive



- Processing of information is carried out in **digital circuits** at extremely fast rates



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Monday overview

Bits over the air

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How are comm. systems designed?

Mathematical theory of new communication strategies/technologies

Specification of communication system and simulation in software (MATLAB)

Prototype design (transmitter and receiver)

Hardware design (base station, access point, mobile device, etc.)

Deployment in practice

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Today's goals:

MATLAB tutorial

Play audio signals

Amplitude modulation

Build a synthesizer!

Build a simple comm. system!

Transmit data over the air!

Analyze audio signals

Record audio signals

Send text, images, etc.

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Project schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
1pm-2pm	Pre-Lab 1: Introduction to MATLAB and digital communication	Pre-Lab 2: Signal processing, time-domain, spectrum, and spectrogram	Pre-Lab 3: Generating music with MATLAB and communication system basics	Pre-Lab 4: Communication via amplitude modulation and synchronization	Pre-Lab 5: Bits over the air: transmitting text and images over the air (reliably!)
2pm-3pm	Module 1: MATLAB basics 1	Complete previous modules	Complete previous modules	Complete previous modules	Complete previous modules
	15min break	15min break	15min break	15min break	15min break
3pm-4pm	Module 2: MATLAB basics 2	Module 4: Spectrum and spectrogram	Module 6: Generating music in MATLAB	Module 8: Simple communication system 2	Module 10: Transmitting bits over the air
4pm-5pm	Module 3: Play audio in MATLAB	Module 5: Record audio in MATLAB	Module 7: Simple communication system 1	Module 9: Synchronization	Work on presentations

- Scheduled break from 3:15pm to 3:30pm

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Remember: this is group work!

- Groups of 2-3 students (matched by skills)
 - Today's groups are fixed; changes upon request
- Try to help each other (within group)
- **Ask us if you have any questions!**
- Modules contain examples (to explain new concepts) and activities: **do both!**
 - Feel free to explore a certain concept in more detail if you are interested (do not forget time)

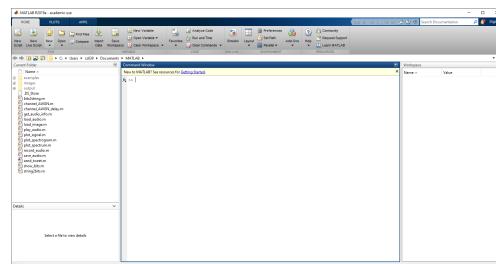
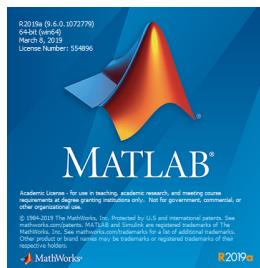
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Modules 1 and 2

MATLAB tutorial

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We will use MATLAB extensively



- The standard software for scientific computing in academia as well as industry
- Used in engineering (**not only ECE!**), computer science, math, physics, etc.

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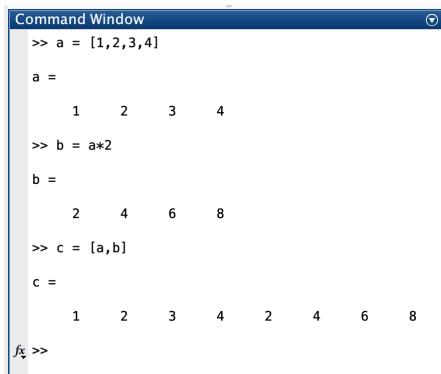
What is MATLAB?

...a powerful and expensive calculator!

- Proprietary programming language developed by MathWorks
- Particularly useful for matrix operations, **digital signal processing**, data analysis and visualization, and algorithm design
- Used by virtually every communication system engineer in the world!

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MATLAB is very simple



A screenshot of the MATLAB Command Window. The window title is "Command Window". The command history shows:

```

>> a = [1,2,3,4]
a =
    1     2     3     4
>> b = a*2
b =
    2     4     6     8
>> c = [a,b]
c =
    1     2     3     4     2     4     6     8
f5 >>

```

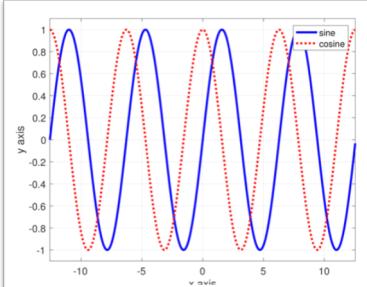
- Example:
 - Define variable **a** containing a row vector **[1 2 3 4]**
 - Create new vector **b** = **a*2** = **[2 4 5 6]**
 - Concatenate vectors **a** and **b** to create new vector **c**

- A great programming language for beginners (Cornell course CS1112)

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Modules 1 and 2 teach...

- basic calculations with scalars and vectors
- function plotting (display graphs)
- How to write MATLAB scripts & functions

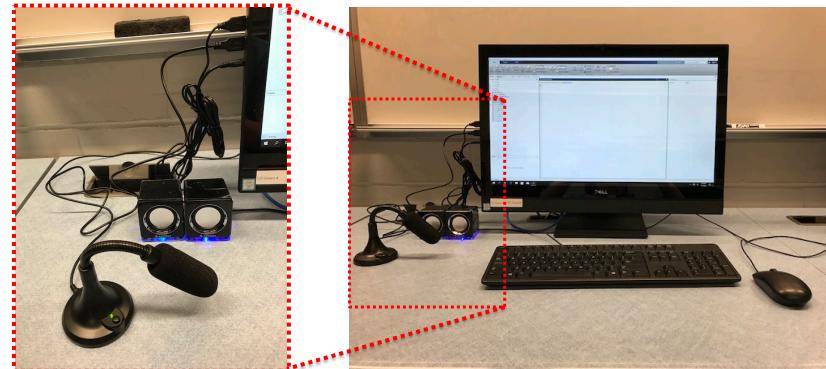


```
function [ z,w ] = test_function( x,y )
%test_function that computes x+y and x*y
% [z,w] = test_function(x,y)
% x : input1
% y : input2
% z : output1 (z=x+y)
% w : output2 (w=x*y)
z = x+y;
w = x.*y;
end
```

Module 3

Play audio signals with MATLAB

First steps with signal processing

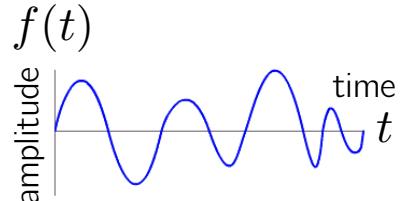


- We will use loudspeakers to play back **digitized signals** with MATLAB

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What is signal processing?

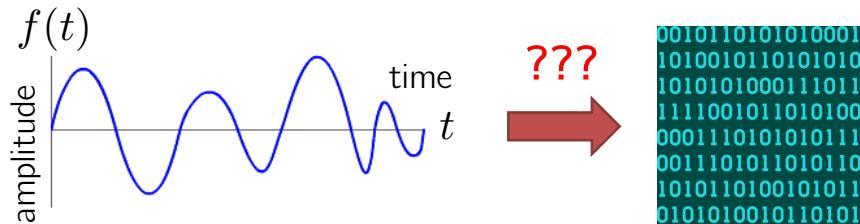
- Signals are functions that convey information, e.g., $f(t) = \sin(t)$ where $t \in \mathbb{R}$
- Examples: Music, speech, temperature, FM radio, painting, etc.
- **Signal processing:** analyzing, modifying, & synthesizing signals



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Digital signal processing

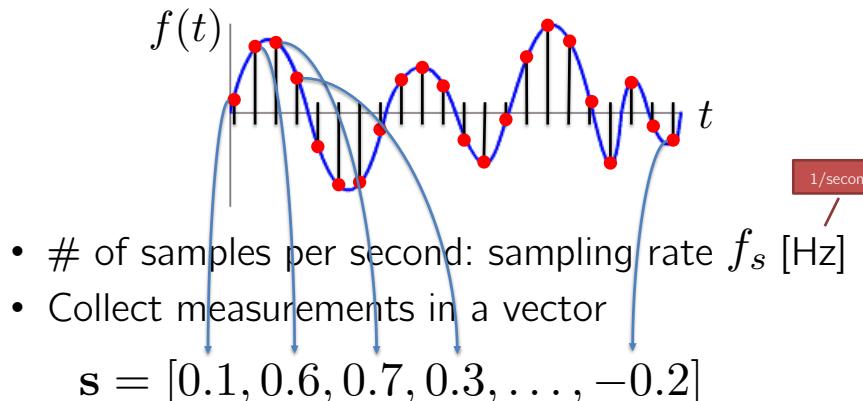
- Our world is analog (continuous), computers **cannot** store or process analog signals
- Digital signal processing requires **conversion** of continuous signals into digital information (bits)



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Solution: sampling!

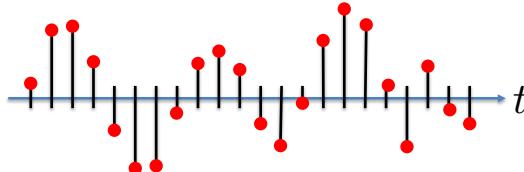
- Take a subset of measurements (samples) of the continuous signal $f(t)$



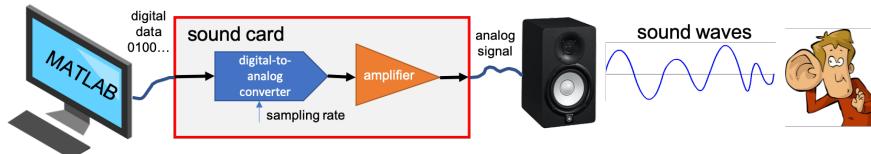
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Sampling enables digital processing

- Sampled signals can be processed in software



- Samples can be played back at sampling rate f_s



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Project website: catalyst2019.github.io

- Copy MATLAB files
(in a zip-folder)
- Extract to computer
- These functions
simplify a lot of the
repeating tasks!

Bits over the Air
Exploring Wireless Systems

This week-long CATALYST design project will provide a unique hands-on-experience in wireless system design and expose the scholars to the broad range of fields covered by Electrical and Computer Engineering (ECE) with the goals of (i) learning how digital information is transmitted over the air and (ii) building a networked wireless communication system.

With the acquired knowledge, scholars will then work in groups in order to build a robust wireless communication system that either maximizes the data rate or the communication range of their sensors and without causing interference to the other groups' systems. In a final presentation, the groups will demonstrate the capabilities of their communication systems.

Modules

[PDF file](#)
Module 1: MATLAB Tutorial, Part I
Module 1: MATLAB Tutorial, Part II
Module 2: Listen to Audio Signals with MATLAB
Module 3: Spectrum and Spectrogram of Signals
Module 4: Record Audio Signals in MATLAB
Module 5: Generating Music with MATLAB
Module 6: Design of a Single Communication System, Part I
Module 7: Design of a Single Communication System, Part II
Module 8: Synchronization
Module 10: Bits over the Air

Software

The following ZIP file includes all the MATLAB files that you will need to start your adventure of sending bits over the air!
[ZIP file](#)
[MATLAB Software](#)

Team

• Christoph Studer (Assistant Professor)
• Alessandro Sartori Bernhardi (Ph.D. Student)
• Brian Rappoport (Ph.D. Student)
• Oscar Castañeda (Ph.D. Student)
• Ryan Gao (Ph.D. Student)
• Sevdet Hedi Mirzibablu (Ph.D. Student)

VLSI Information Processing (VIP)
Cornell University

Learn more about us here! [Look at the tweets you have posted using your communication system here!](#)