

# Analog and Digital Communications EE 179

*Introduction*

# Today

- Introductions
- Wireless Devices
- Topics
- Class Structure
- Introduction to Communications Systems

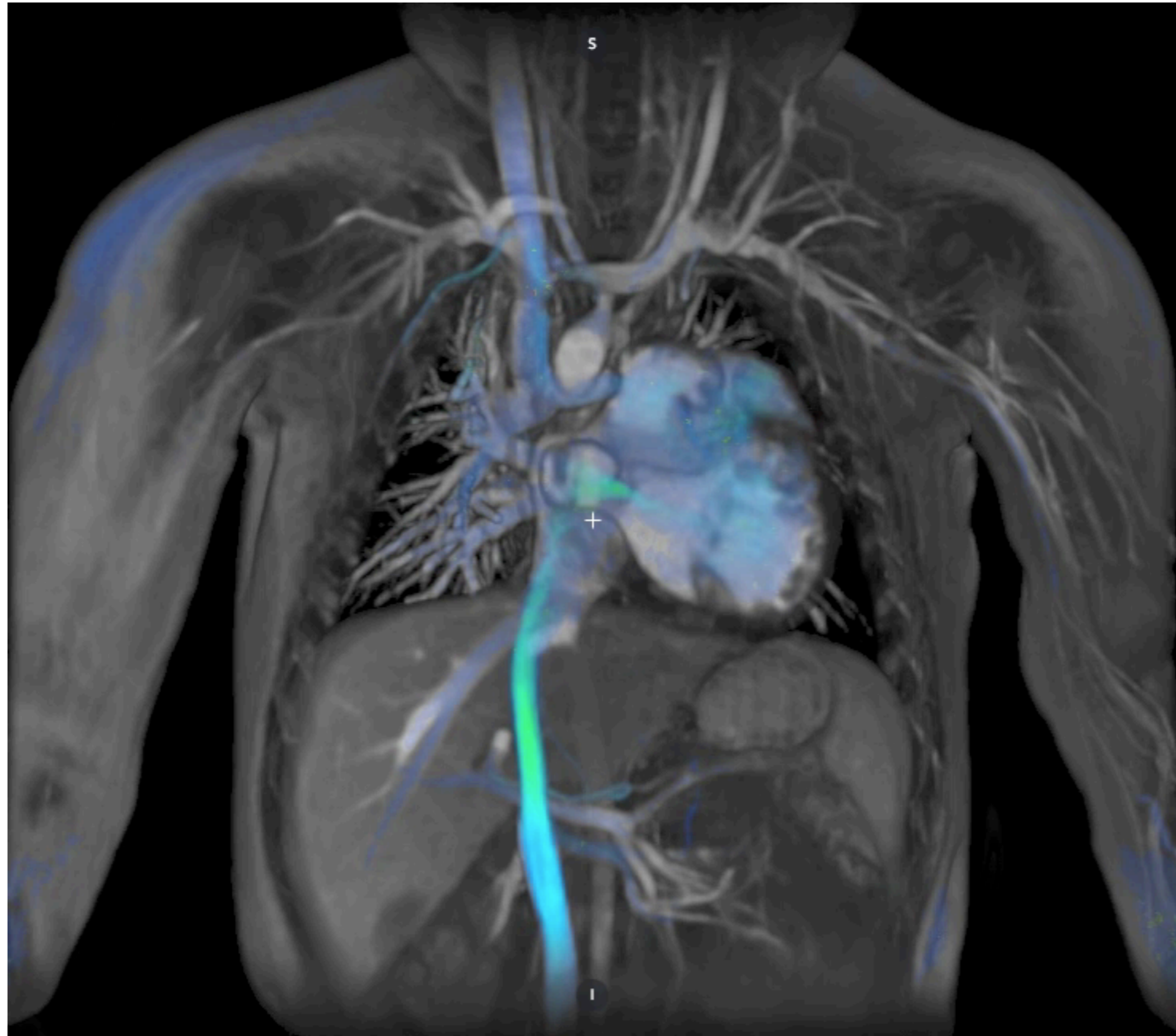
# Introductions

- Name
- Computer, OS, experience (install public domain software, compile code, program, etc)
- Interest in the course
- Any interesting hack you've heard of

# John Pauly



- Medical Imaging
- Magnetic Resonance Imaging (MRI)
- Radio, RF
- Computational Imaging



MRI

with Joseph Cheng, Shreyas Vasawanala

# Wireless Devices



Smart Phone



Laptop



Router

# iPhone 6



<https://www.ifixit.com/Teardown/iPhone+6+Teardown/29213>

# Wireless Devices



Home Automation



Cars



Sensors

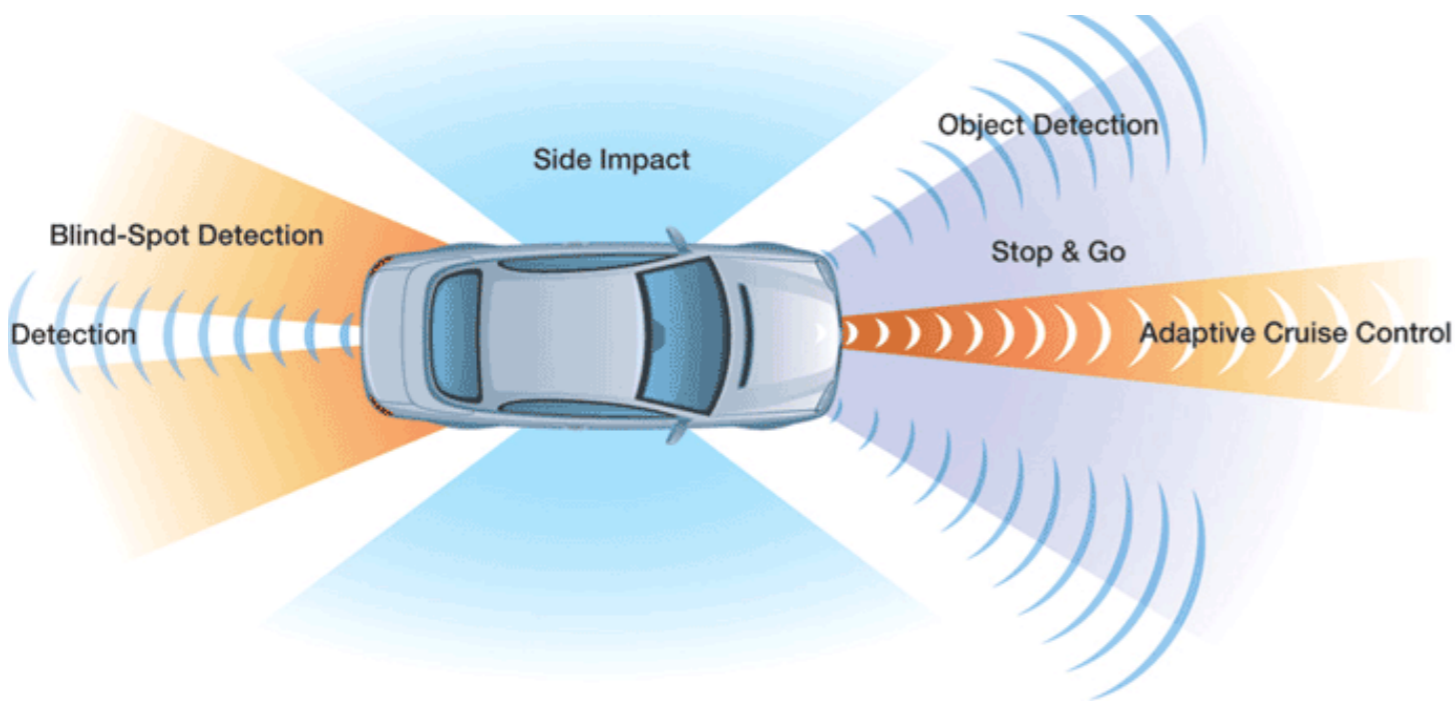


Keys

# Cars



Tire Pressure



Radar



Entertainment/Display

# Communications

- How do these devices communicate
- What frequencies / wavelengths do they use, and why
- How do they encode information
- How can you capture their signals and decode them yourself
- Security?

# Some Systems We'll Talk About

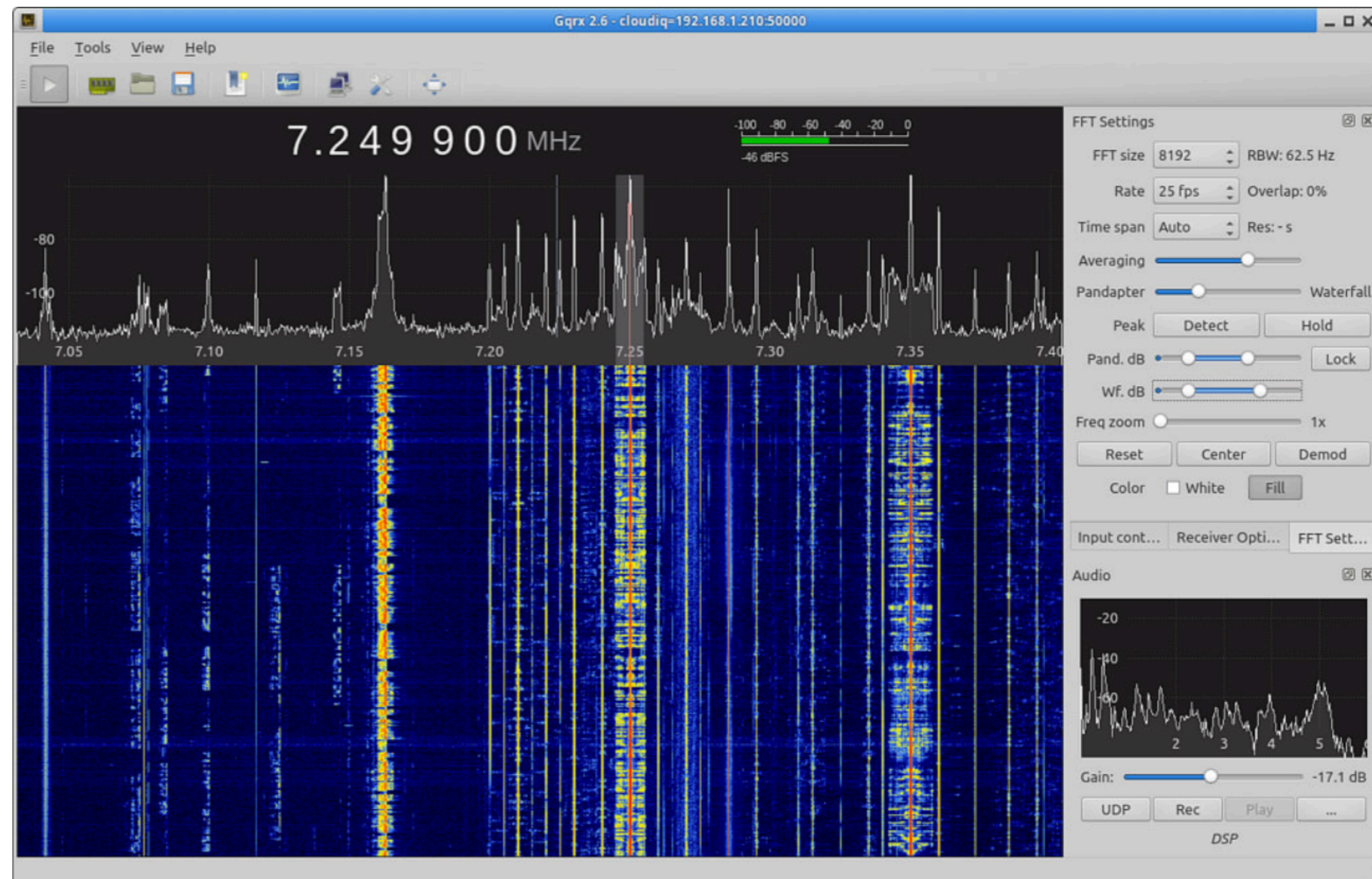
- FM and AM Radio
- Public service radio, Amateur Radio
- ISM bands, Key Fobs, Cars
- ADS-B, airband audio and packet radio
- Cell phones
- Satellites
- WiFi

# Class Structure

- Tuesday, first part of Thursday
  - Technical lectures
  - How does narrowband FM radio work?
- Last part of Thursday:
  - Introduction to this weeks lab
  - In class work time
  - How can I capture and decode narrowband FM radio signals?

# Tools

- RTL-SDR
- SDR Apps
- Matlab



# Midterm and Final Projects

- Midterm will be a short project (essentially a lab you do on your own).
  - Designing a system for stereo AM radio.
- The final project topic will be given to you.
  - Decoding a digital packet radio system (planes, satellites, ships, etc)

# Labs

- Labs will be about capturing and decoding some of the many different signals around us.
- Coding will be in Matlab, so make sure you have this, as well as Simulink
- Pre-acquired data will be available if you need it
- Bring your computers (and headphones) on Thursdays

# Course Outline

- Section 1: Introduction and Background
  - Review of signals using  $2\pi f$  transforms (as opposed to the  $\omega$  transforms used in 102A)
  - Finding your way around the RF spectrum
  - Overview of the different modulation schemes and mediums that are used for communications

# Course Outline

- Section 2: Analog Communications
  - Amplitude modulation schemes, including commercial AM radio, SSB, and QAM
  - Angle modulation schemes, such as commercial FM, as well as PM, PSK, and FSK
  - Pulse modulation, such as PAM, PWM, and PPM
  - Receiver design

# Course Outline

- Section 3: Digital Communications
  - Sampling, and the basis for digital communications
  - Up and down conversion
  - Quantization, PCM, line coding, and reducing ISI
  - Synchronization and Phase-Locked Loops
  - Digital carrier modulation, including PAM, ASK, FSK, PSK, QPSK, and QAM
  - Error Correction

# Amateur Radio

- FCC license class this quarter
- 5 classes, followed by FCC exam
- Exam will be online
- License to play in the RF spectrum



# Communication Systems

- Information Representation
- Communication systems block diagrams
- Analog vs digital systems
- Performance metrics
- Data rate limits

# Analog Communications

- As humans, everything we see and do is analog
  - Speech: sound pressure
  - Sight: colors and spatial distribution
- Analog communication converts these into other analog values that can be transmitted
  - Speech: amplitude of an RF carrier
  - Sight: amplitude of a raster scan, again modulating the amplitude of an RF carrier

# Analog Communications

- Examples
  - AM and FM Radio
  - NTSC television
  - Vinyl records

# Digital Communications

- Analog signals can be represented digitally
  - Sampled
  - Transmitted
  - Reconstructed
- Images: JPEG's and TIFF's
- Speech: AMBE encoder
- These digital signals can then be transmitted over an analog channel

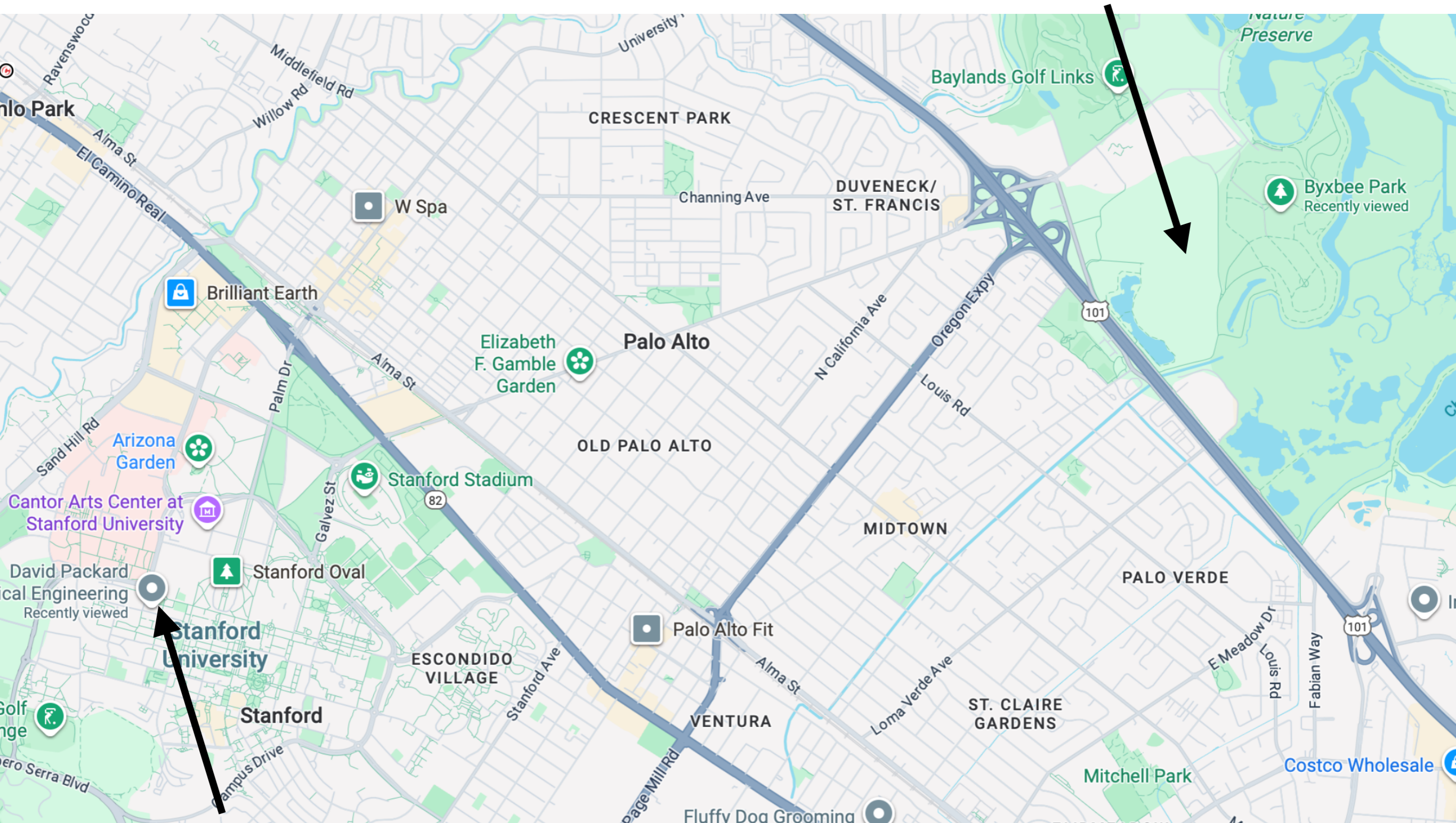
# Digital Communications

- Digital communications are considered “Modern”, which is true
- Digital systems go way back
  - Baudot code: 5 unit alphabet code, 1874
  - Teleprinters: 1924
  - Fax machines: 1843
- Most systems were analog until 1980’s or so
- Now everything is going digital

Bixby Park in Palo Alto  
AT&T Wireless Telegraph Station  
1920's



# AT&T Telegraph Site

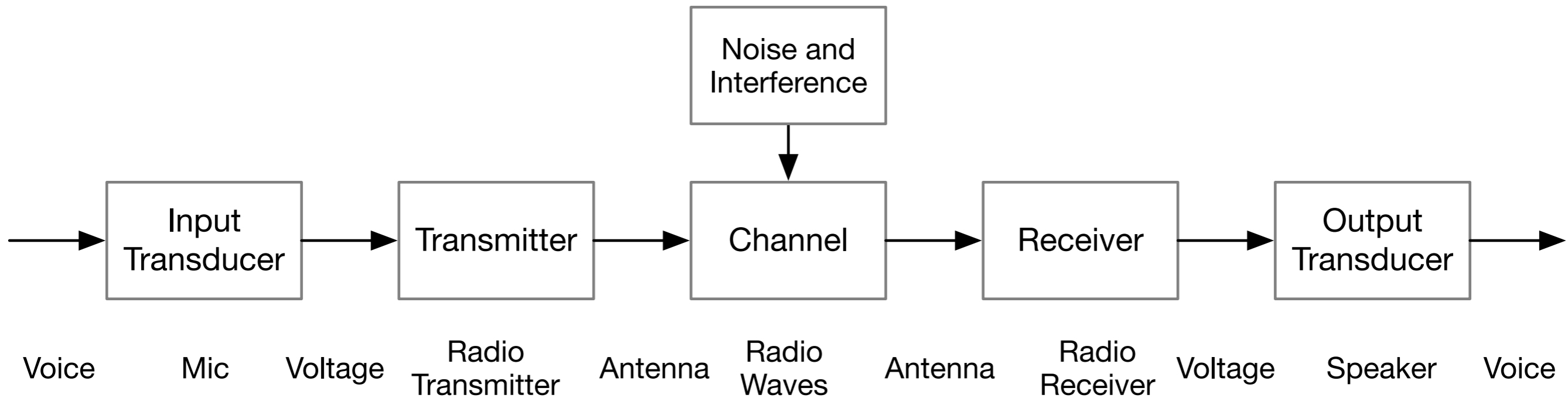


Packard EE

# Analog vs Digital

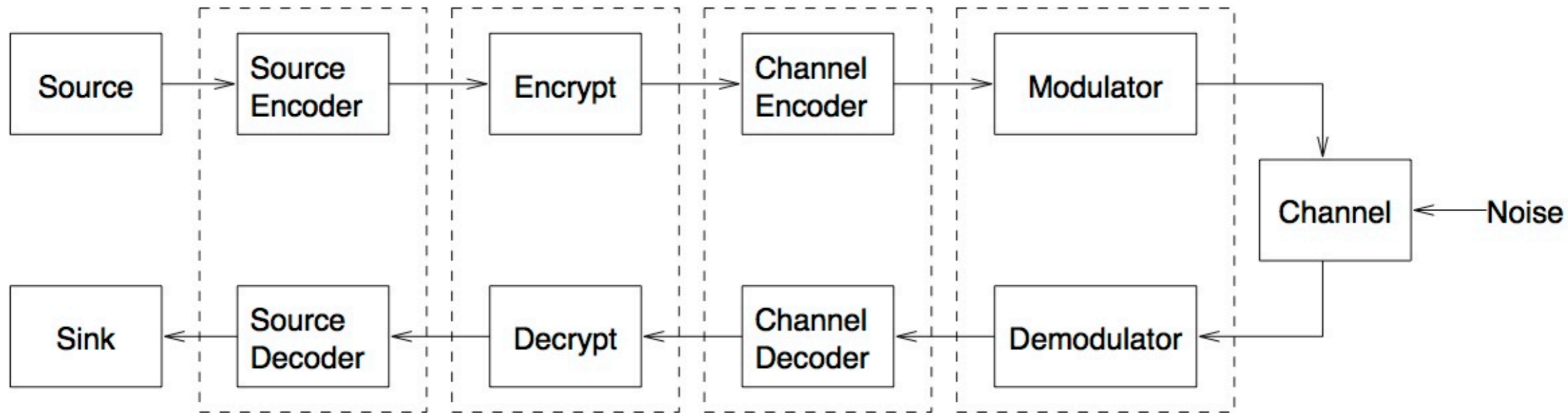
- Analog systems can be stunningly simple
  - Crystal radio
- Intuitively appealing
  - Transmitting exactly the waveform you are interested in
- Digital seems much more complex
  - A/D's, D/A's, gate arrays, computation
  - Lots more components
- Why bother with digital?

# Simple Communication System



- This is an analog system
- A digital system would transmit bits
  - Input and output transducers would produce bits instead of voltages
  - Transport is still fundamentally analog

# Modern Communications System



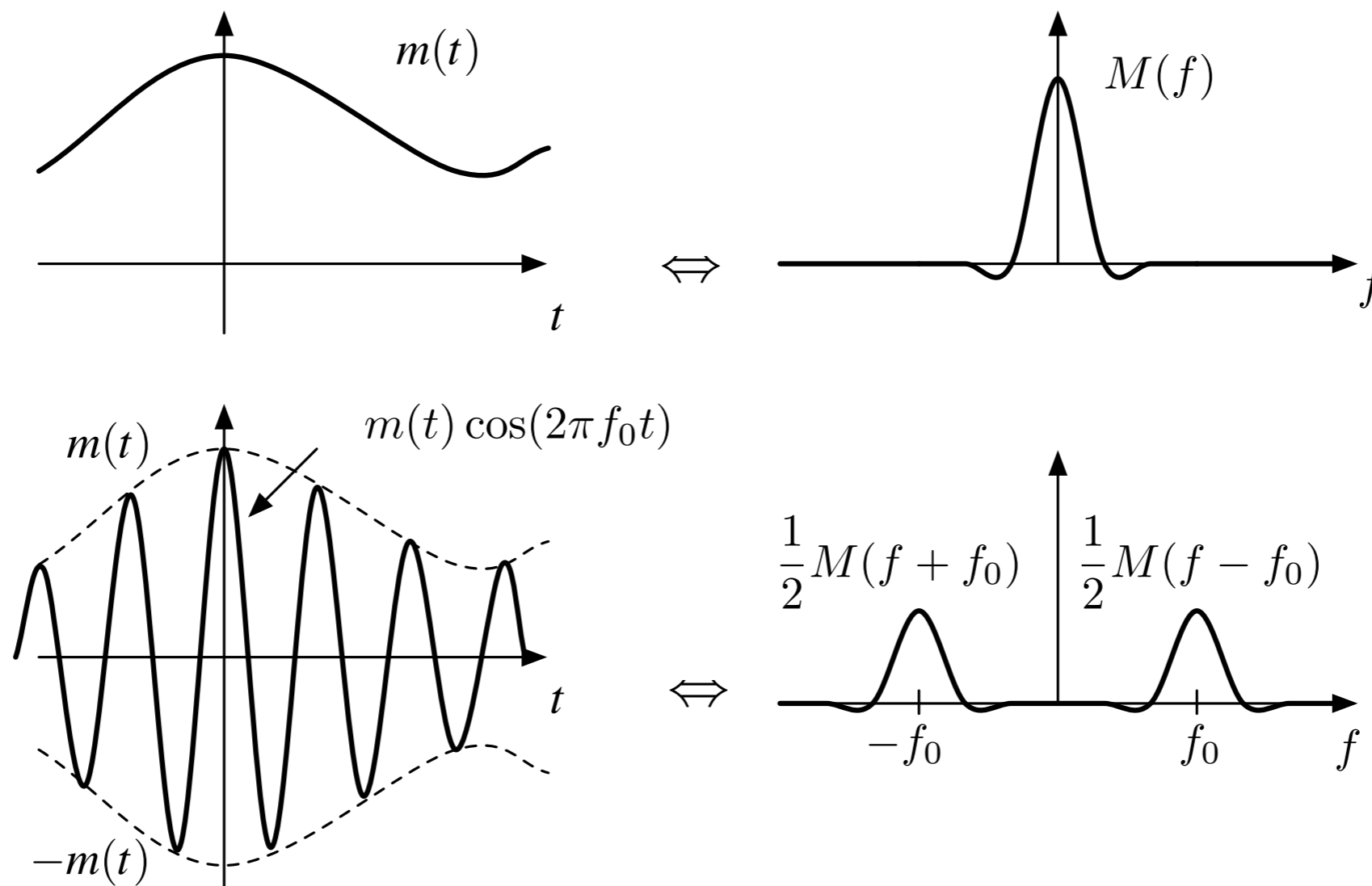
- Data is compressed, encrypted, and channel encoded for error correction
- Secure link insures privacy
- Guarantees perfect reception (until it doesn't)
- Tremendously more computation (this is essentially free now)
- Modulator / Channel / Demodulator are all analog (transport layer)

# Channels

- The channel is the medium used to carry the signal
  - Radio waves (radio, WiFi, Cell Phones, IoT devices)
  - Optical Fibers (deep sea cables, optical interconnects)
  - Line of sight lasers (between satellites)
  - Sound (audio or ultrasound, submarines, students)
- Same basic ideas
  - Each have specific issues, like temperature in optical fibers
  - All have the same basic structure
  - We'll focus on RF for this class

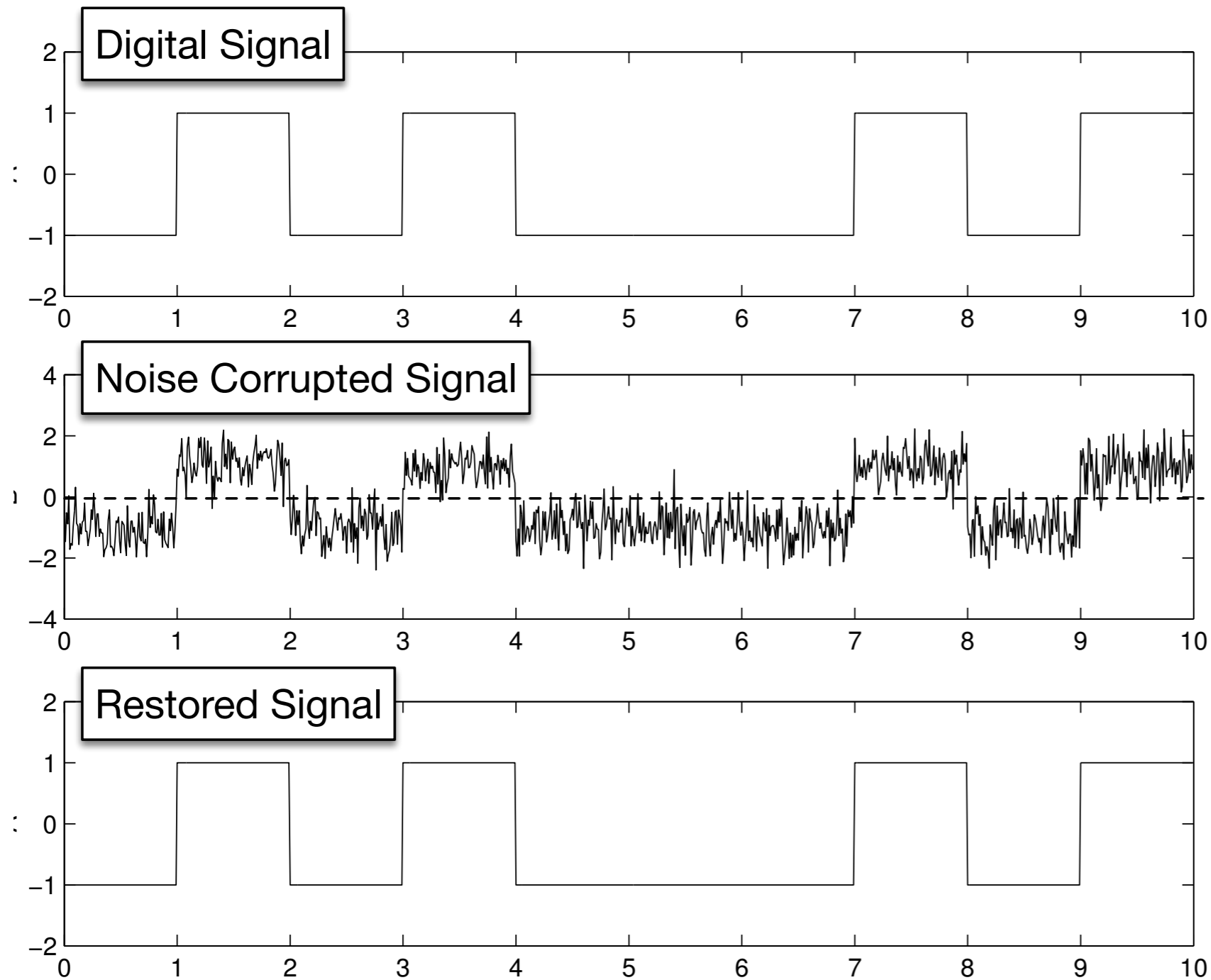
# Modulation

- Modulation encodes information for transmission on a channel



- This is commercial amplitude modulation (AM Radio). There are MANY other ways to do this.

# Signal Regeneration and Noise Suppression



- Comparing to zero restores the original signal
- There will be a limit as the noise level increases, and we start making errors

# Performance Metrics

- For analog systems, we use the fidelity of the output signal to the input
- We want  $\hat{m}(t) \approx m(t)$
- A common metric is the mean squared error (mse)

$$mse = \frac{1}{T} \int_0^T |\hat{m}(t) - m(t)|^2 dt$$

- For a signal with amplitude  $A$  the signal to noise ratio (SNR) is

$$SNR = \frac{A^2}{mse}$$

- This is usually quoted in decibels (dB), which will be covered next class

# Performance Metrics

- For digital systems we usually quote
  - Data rate  $R$  in bits/s
  - Probability of an error

$$P_e = P \{ \hat{b} \neq b \}$$

- Without noise there are no errors
- With noise, errors depend on signal and noise power, data rate, and channel characteristics

# Data Rate Limits

- Without distortion or noise, we could transmit at  $R = \infty$  and error probability  $P_e = 0$ .
- The Shannon capacity is the maximum possible data rate for a system with noise and distortion
  - This maximum rate can be approached with bit probability close to 0
  - For additive white Gaussian noise (AWGN) channels

$$C = B \log_2 (1 + SNR)$$

where  $B$  is the channel bandwidth in Hz and  $C$  is in bits/s

- This theoretical limit does not tell us how to design a system
- We are not near limits in many common systems

# Next Time

- RTL SDR Lab Thursday
  - We'll give you SDR's
  - Bring your laptops, and we'll install the software and get you up and running
- Next week
  - Brief review of EE 102A
  - Fourier transforms in  $2\pi f$
  - Functions and transforms we'll need for communications