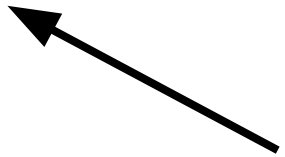
Physical Layer (continued)

10/4/2019

Topics

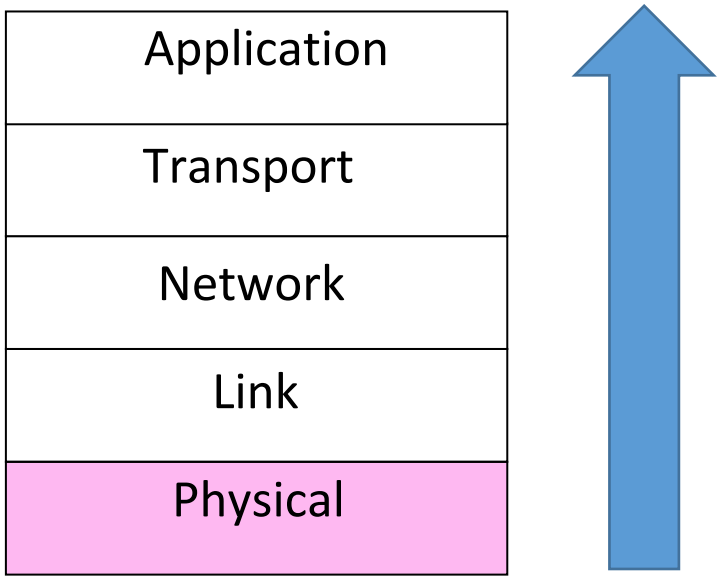
1. ~~Coding and Modulation schemes~~
   - ~~Representing bits, noise~~
2. ~~Properties of media~~
   - ~~Wires, fiber optics, wireless, propagation~~
   - Bandwidth, attenuation, noise
3. Fundamental limits
   - Nyquist, Shannon



Wednesday's Class

Where we are

- Working our way up the stack starting with the Physical layer



Made of up *physical* things

- wires
- fiber
- electromagnetic waves/light

Philosophical Takeaways

- Everything is analog, even digital signals
- Digital information is a *discrete* concept represented in an analog physical medium
  - A printed book (analog) vs.
  - Words conveyed in the book (digital)

Types of Media

- Media propagate analog signals that carry bits of digital information
- We looked at some common types...

  ??? What are some examples???

  - Copper Wires (twisted pair | coax)
  - Fiber (fiber optic cables)
  - Wireless

What is the difference between light, radio waves, and gamma radiation?

Well… only one makes the Hulk

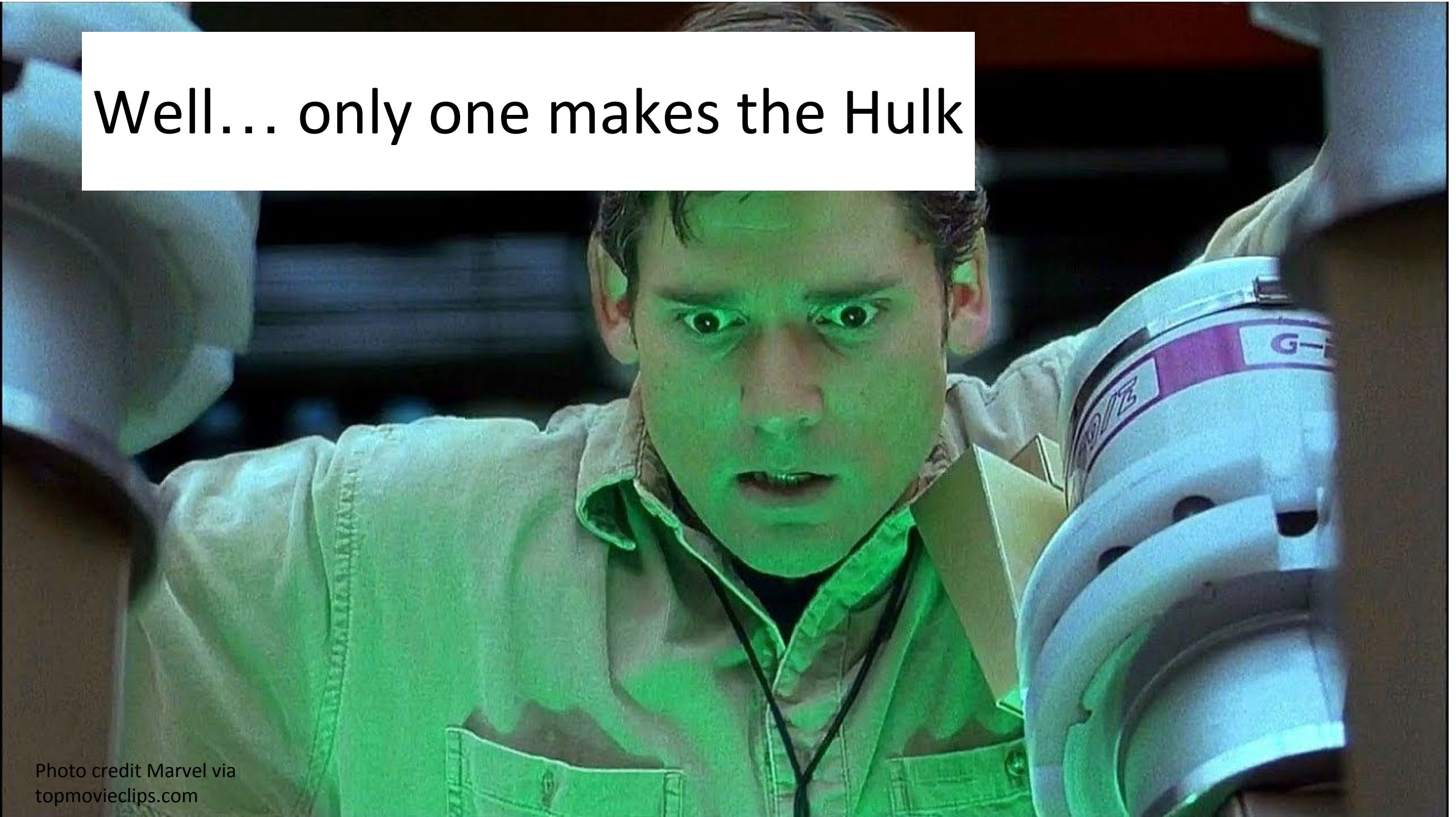
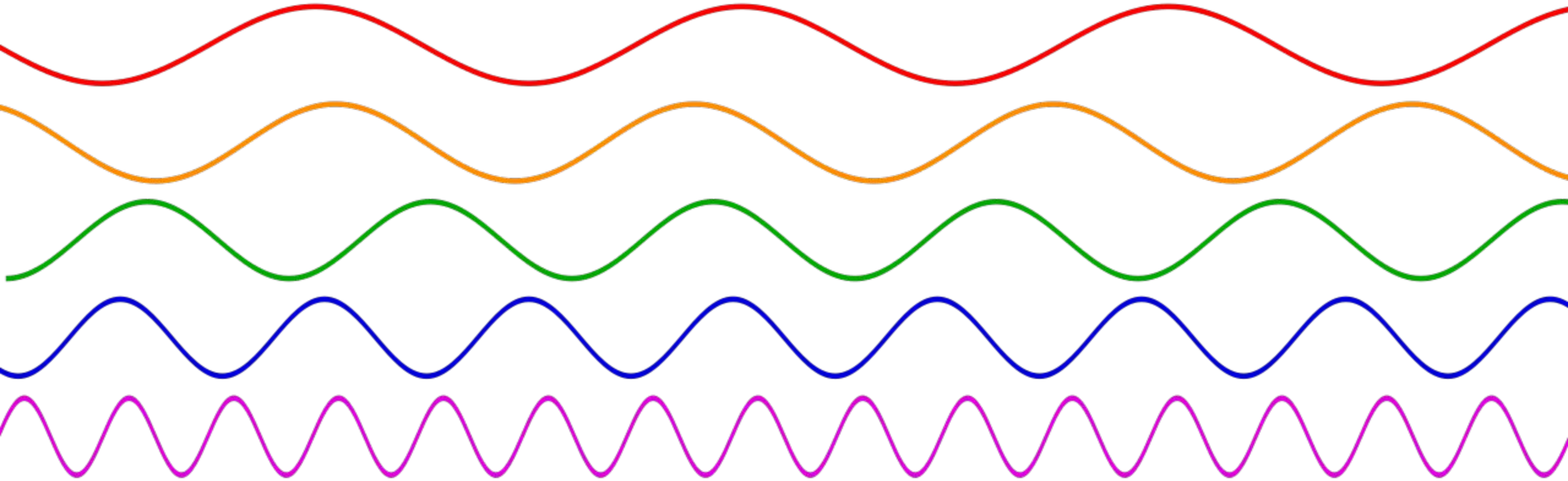


Photo credit Marvel via topmovieclips.com

They are all the same thing (electromagnetic radiation) at different frequencies…

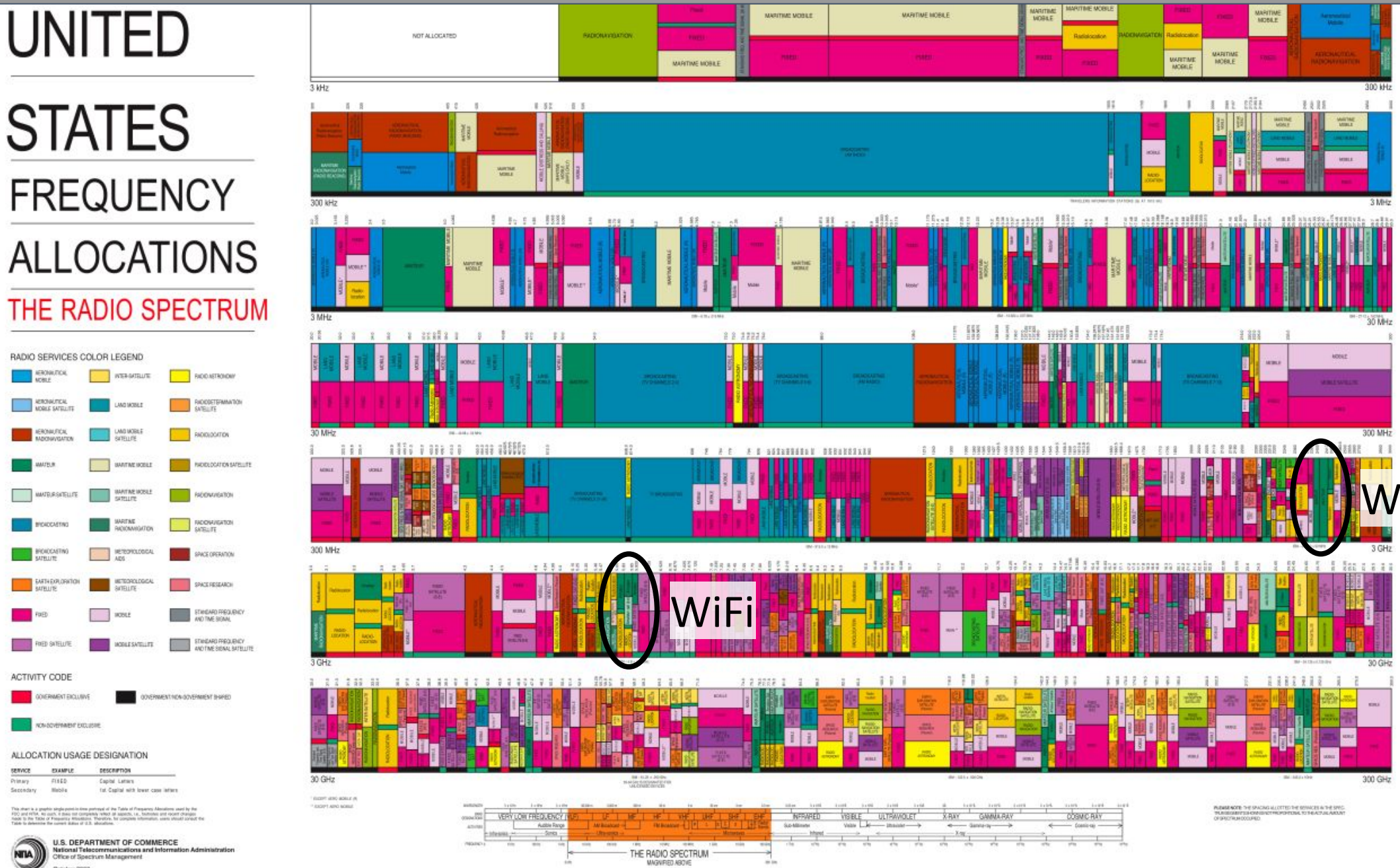


Different frequencies have different properties!

Not all frequencies are created equal...

wikimedia commons

Warning! Brief Review!



Theoretical Limits

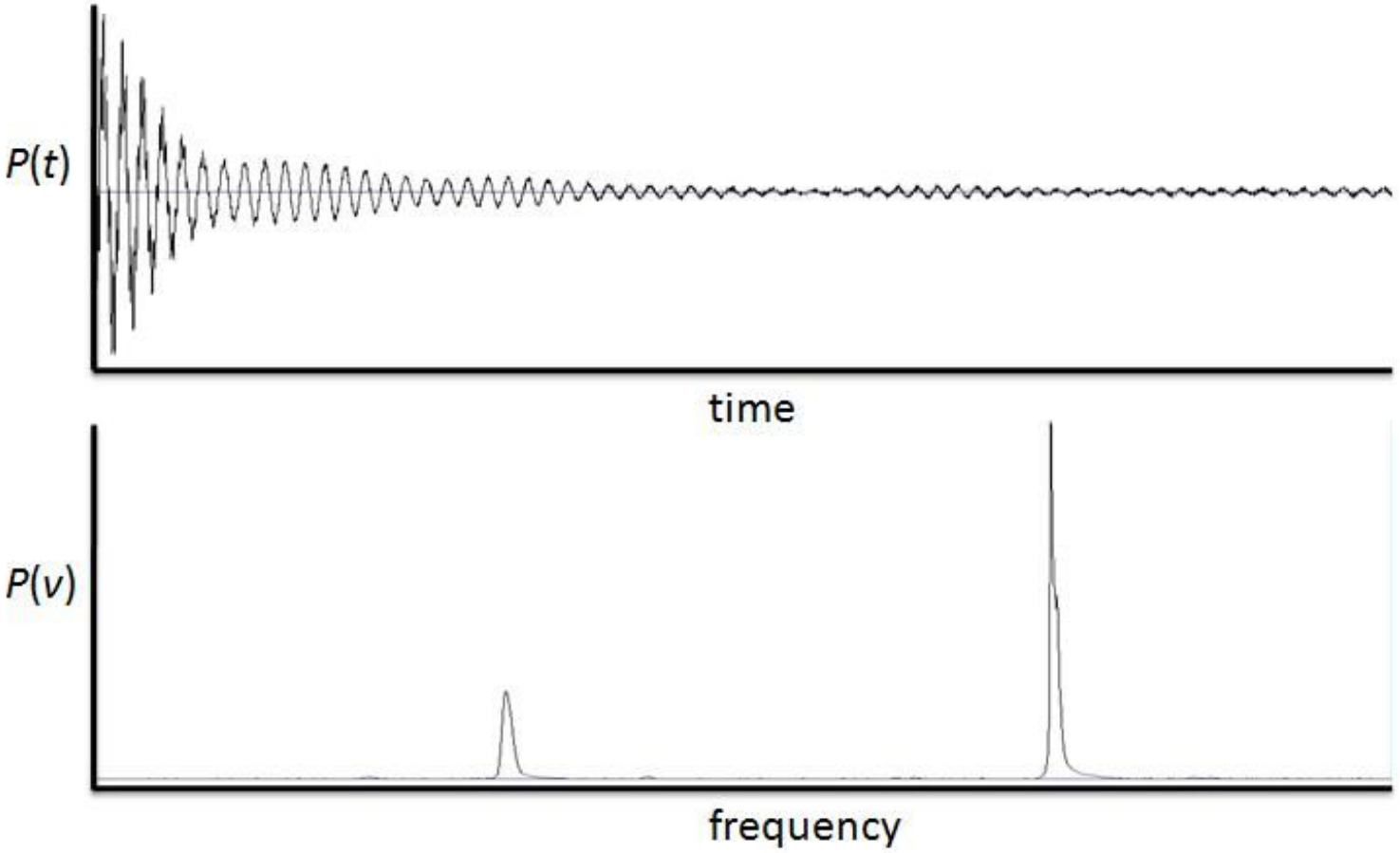
“Information Theory”

Real World Limits

- How rapidly can we send information over a link?
  - Nyquist limit (~1924)
  - Shannon capacity (1948)
- Practical systems (I.E. your cellphone) approach these limits! Pretty cool :)

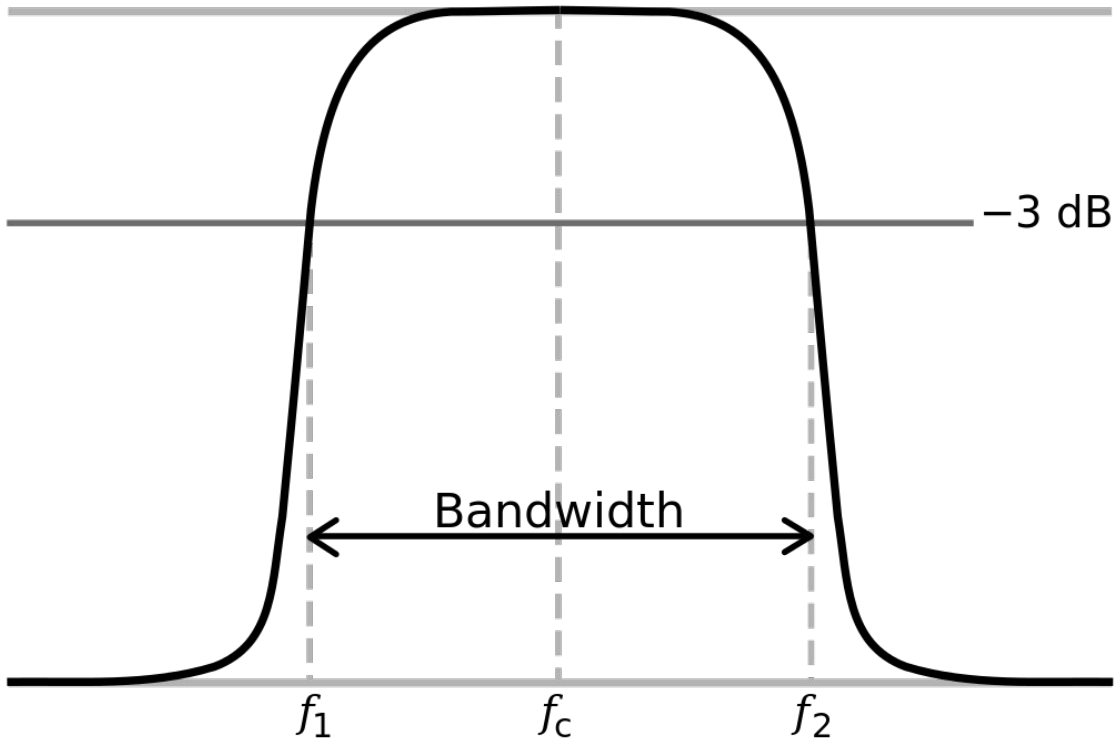
Analog Vocabulary Again

- Often easier to think about ***signals*** in ***frequency***



Important Analog Vocabulary (2)

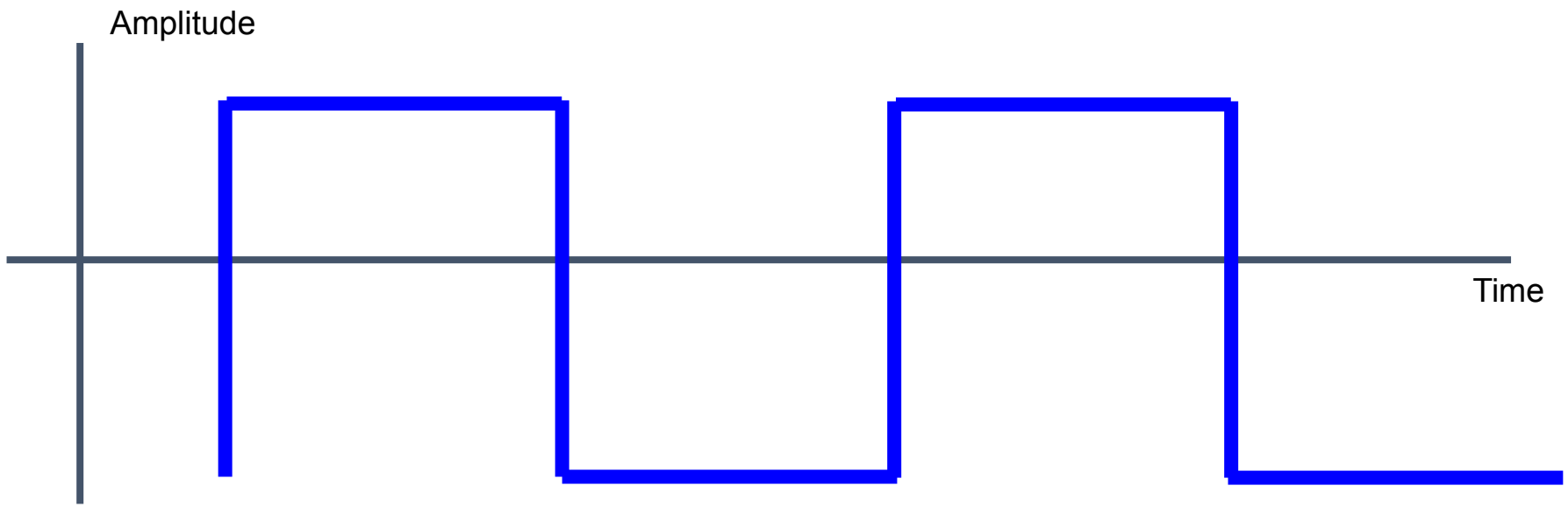
- Every analog ***signal*** has a given ***bandwidth***



Key Channel Properties

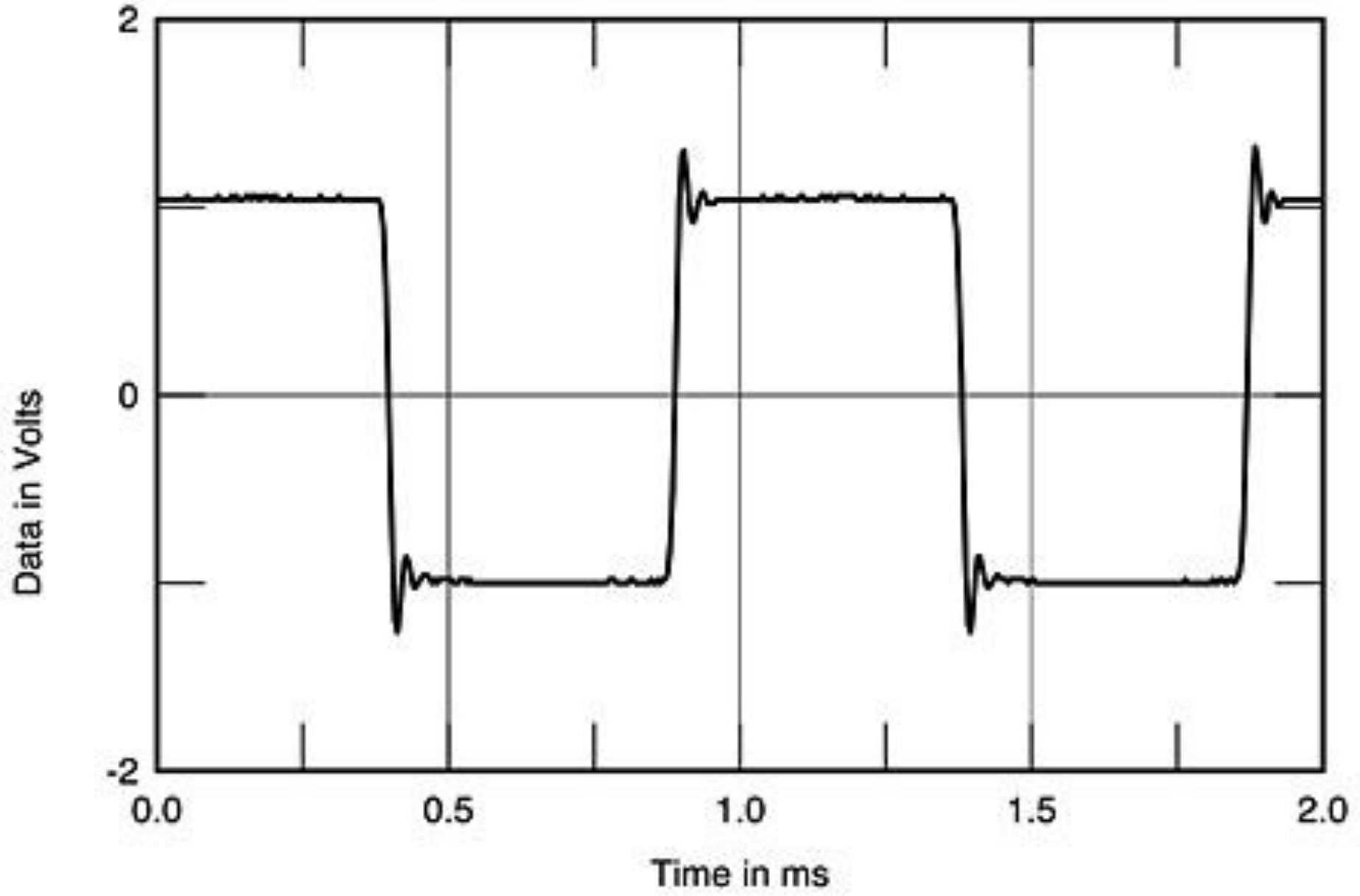
- The bandwidth (B), signal power (S), and noise power (N)
  - B (in hertz) limits the rate of transitions
  - S and N (in watts) limit how many signal levels we can distinguish

What is the bandwidth of a square wave?



Infinite! *No true square wave exists in the real world*

Warning! Brief EE Moment!

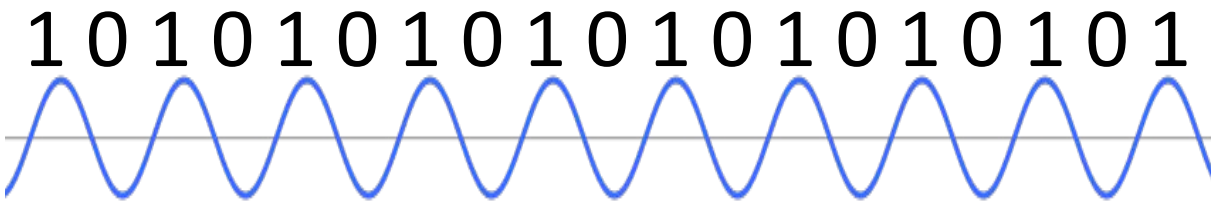


Attribution: captainprog at dsp.stackexchange.com

Brief Activity...

Nyquist Limit

- The maximum symbol rate is 2*Bandwidth



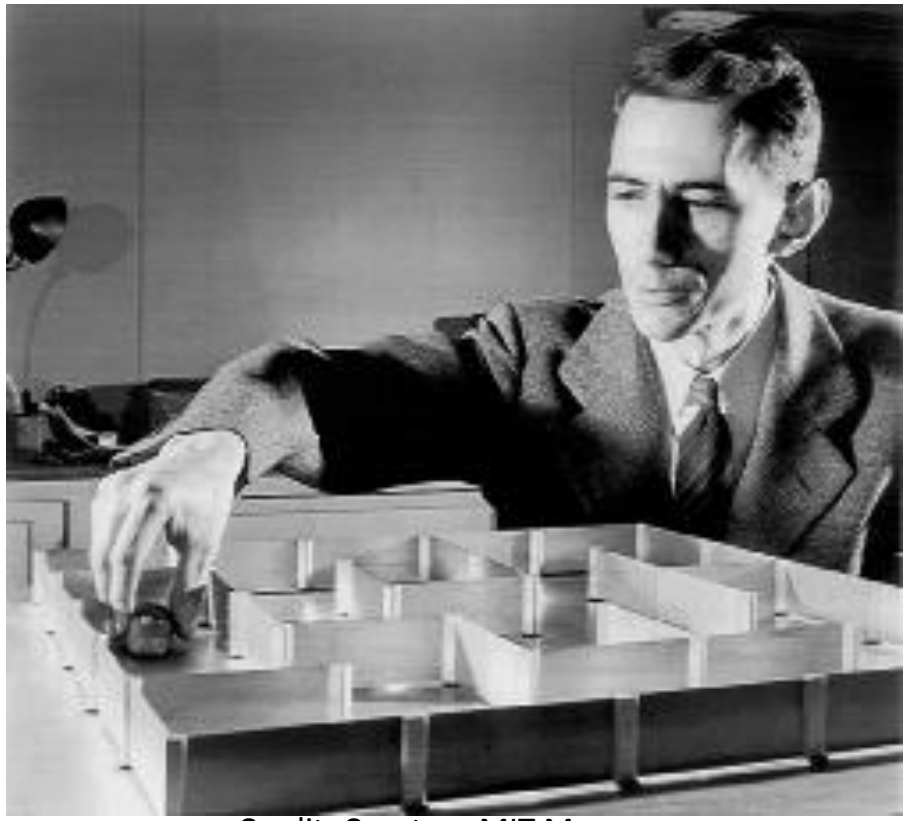
- Thus if there are V signal levels, ignoring noise, the maximum bit rate is:

$$R = 2B \log_2 V \text{ bits/sec}$$

Claude Shannon (1916-2001)

- Father of information theory
  - "A Mathematical Theory of Communication", 1948
- Fundamental contributions to digital computers, security, and communications

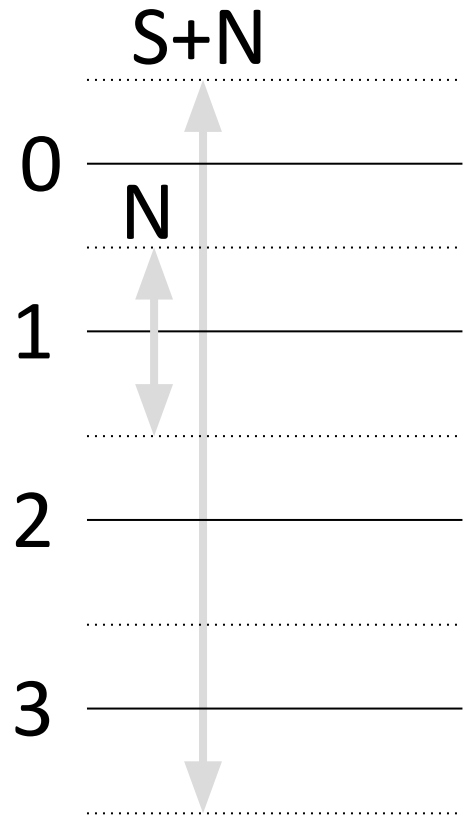
Electromechanical mouse that "solves" mazes!



Credit: Courtesy MIT Museum

Shannon Capacity

- How many levels we can distinguish depends on S/N
  - Or SNR, the Signal-to-Noise Ratio
  - Note noise is random, hence some errors
- SNR given on a log-scale in deciBels:
  - $SNR_{dB} = 10\log_{10}(S/N)$



Shannon Capacity (2)

- Shannon limit is for capacity (C), the maximum ***lossless*** information carrying rate of the channel:

$$C = B \log_2(1 + S/N) \text{ bits/sec}$$

- Deriving this is outside the scope of this course, but it is an elegant result with incredible implications...

Shannon Capacity Takeaways

$$C = B \log_2(1 + S/N) \text{ bits/sec}$$

- There is some rate at which we can transmit data **without loss** over a random channel
- Assuming noise fixed, increasing the signal power yields diminishing returns : (
- Assuming signal is fixed, increasing bandwidth increases capacity linearly!

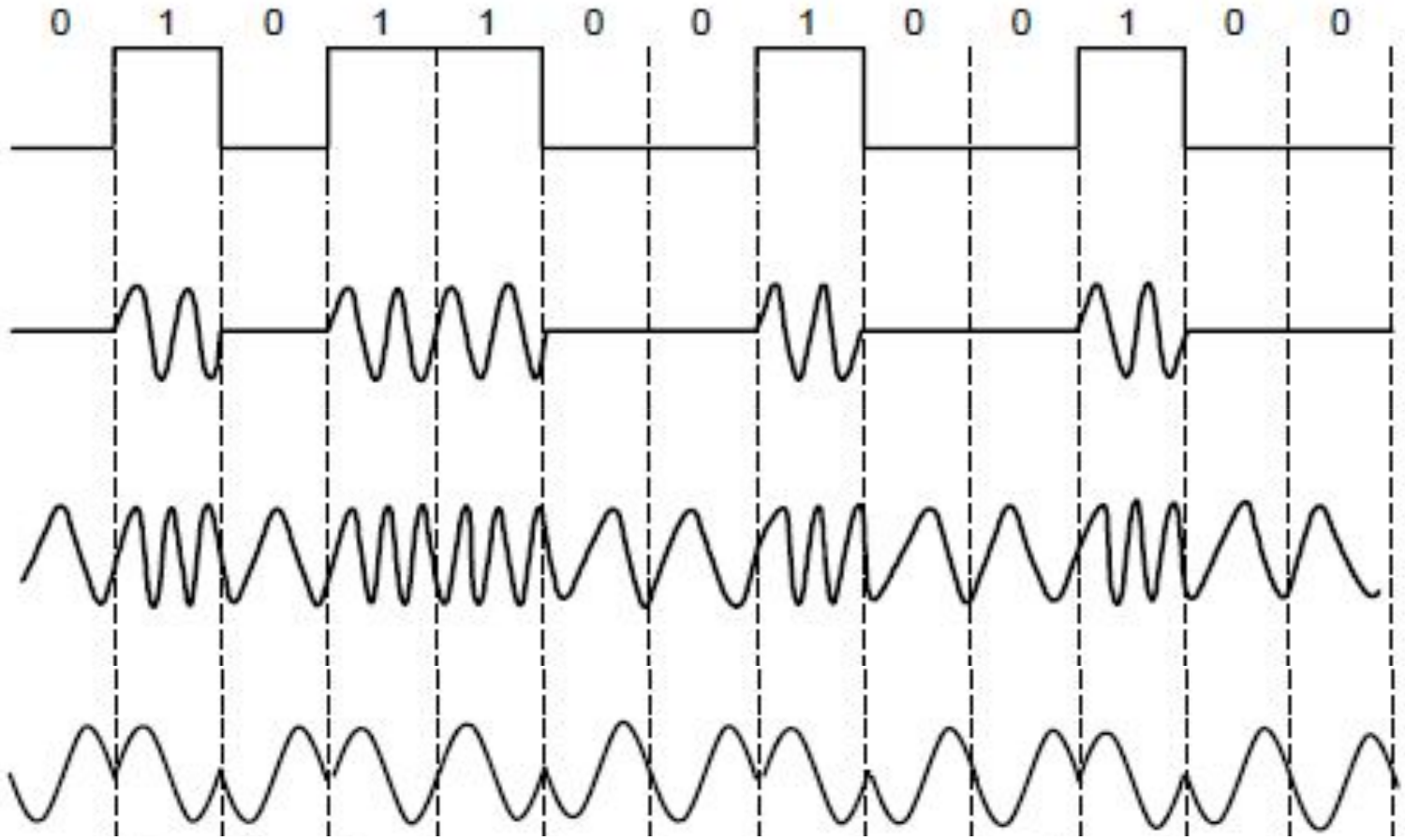
No matter what fancy code you use, you can't beat Shannon (in AWGN)

NRZ signal of bits

Amplitude shift keying

Frequency shift keying

Phase shift keying



Wired/Wireless Perspective

- Wires, and Fiber
  - Engineer link to have requisite SNR and B

→ Can fix data rate

Engineer SNR for data rate

- Wireless
  - Given B, but SNR varies greatly, e.g., up to 60 dB!

→ Can't design for worst case, must adapt data rate

Adapt data rate to SNR

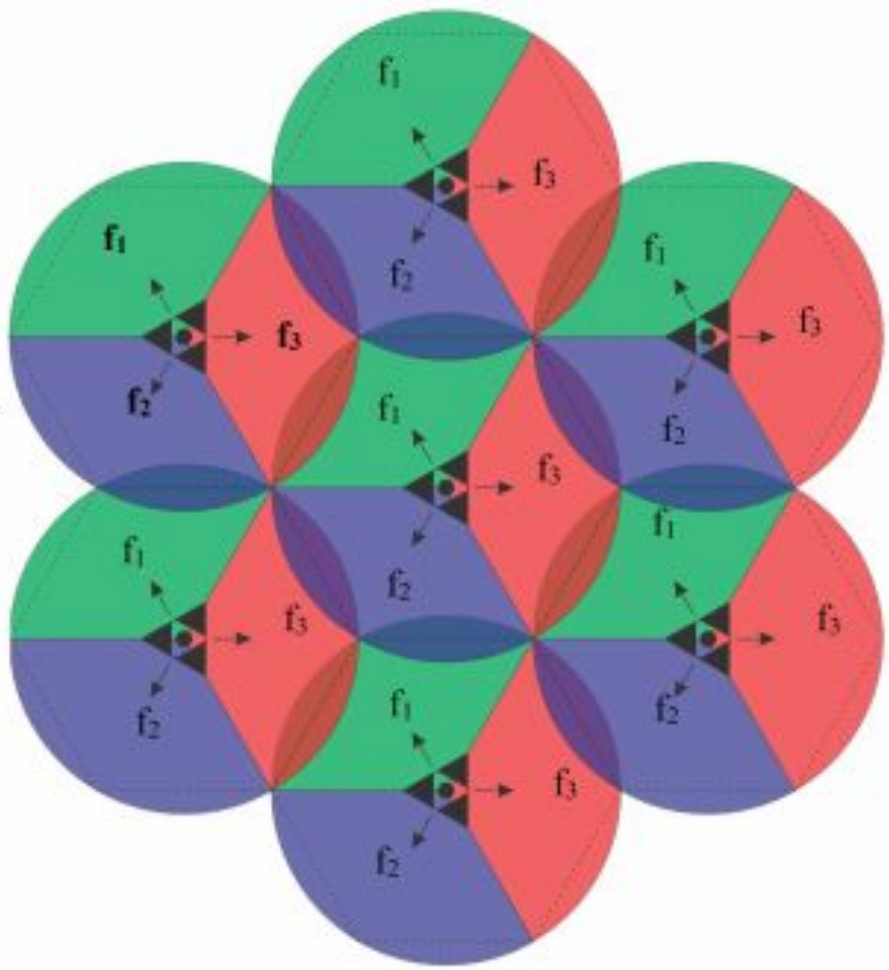
??? Which is better ???

5G… *There is no magic*

- To increase the data rate, you need either more spectrum or more power
- Both are limited by physics… how can we work around it???

Imaged by Heritage Auctions, HA.com

“Spatial Reuse”



Cellular Network

medium.com/@artiedarrell

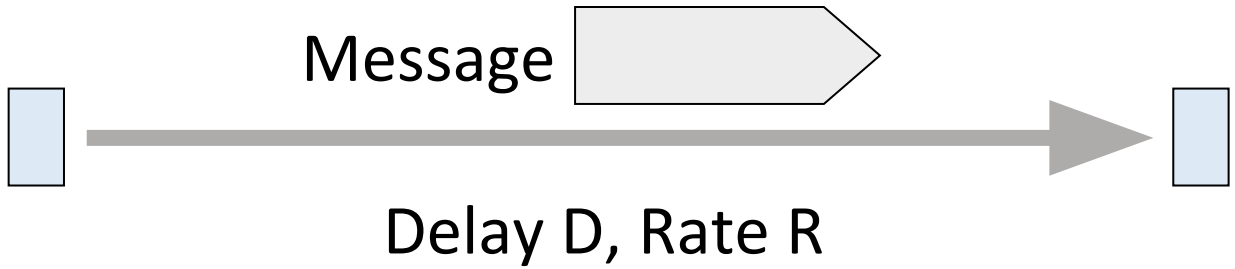
Make the cells smaller… so we can have more of them!

Phy Layer Innovation Still Happening!

- **Backscatter** “zero power” wireless
- **mm wave** 30GHz+ radio equipment
- Free space optical (**FSO**)
- Cooperative **interference management**
- **Massive MIMO** and beamforming
- Powerline Networking
- 100 GbE in datacetners, etc.

All distilled to a simple link model

- Rate (or bandwidth, capacity, speed) in bits/second
- Delay in seconds, related to length



- Other important properties:
  - Whether the channel is broadcast, its error rate, and its stability