


University of Glasgow

# Physical Layer

Networked Systems 3
Lecture 5

# Lecture Outline

- Physical layer concepts
- Wired links
  - Unshielded twisted pair, coaxial cable, optical fibre
  - Encoding data onto a wire
- Wireless links
  - Carrier modulation
  - 802.11 PHY

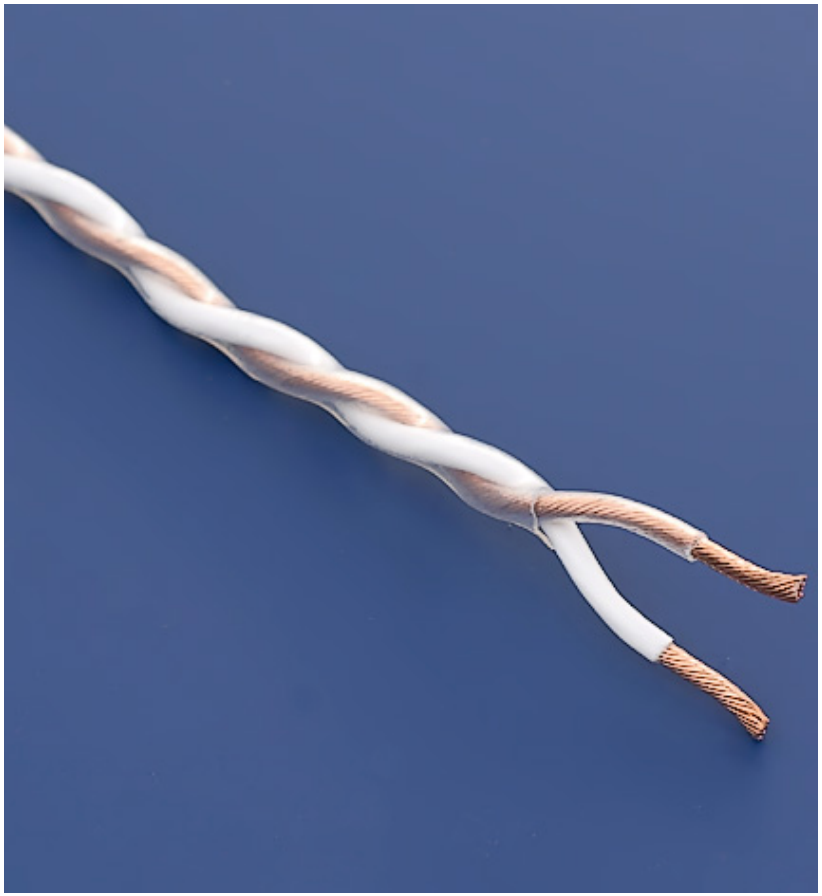
# The Physical Layer

- The physical layer is concerned with transmission of raw data bits
  - What type of cable or wireless link do you use?
  - How to encode bits onto that channel?
    - Baseband encoding
    - Carrier modulation

# Wired Links

- Physical characteristics of cable or optical fibre:
  - Size and shape of the plugs
  - Maximum cable/fibre length
  - Type of cable: electrical voltage, current, modulation
  - Type of fibre: single- or multi-mode, optical clarity, colour, power output, and modulation of the laser

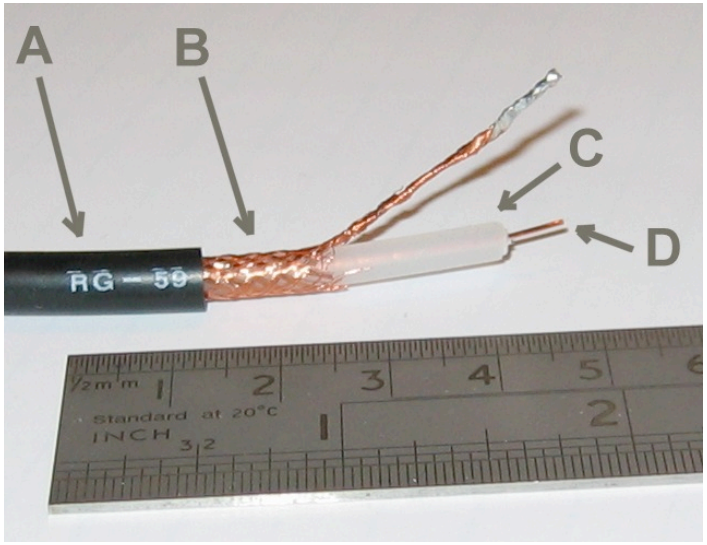
# Unshielded Twisted Pair



- Electrical cable with two wires twisted together in a spiral
  - Unidirectional data: signal and ground
  - Twists reduce interference and noise pickup: more twists → less noise
- Cable lengths of several miles possible at low data rates; 100 metres at high rates
  - Noise increases with cable length
- Extremely widely deployed

# Coaxial Cable

- Wire core surrounded by a layer of insulation, and a braided outer conductor
  - Wire core is the signal path; outer conductor provides shielding
- Better noise shielding than twisted pair
  - Longer distance at higher rates: Gbps over several miles
  - But much more expensive cables

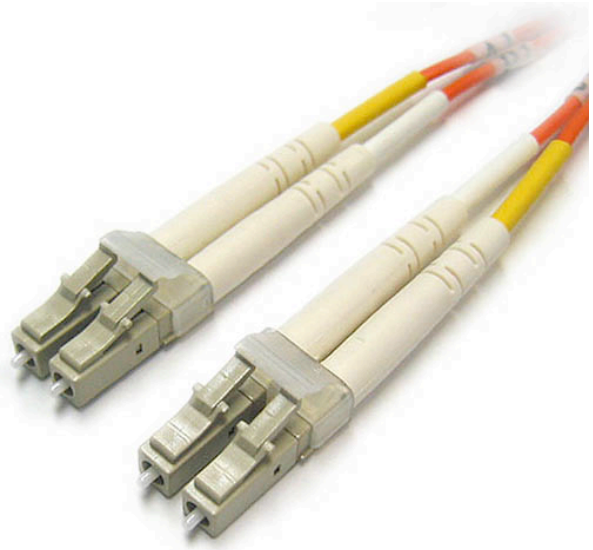


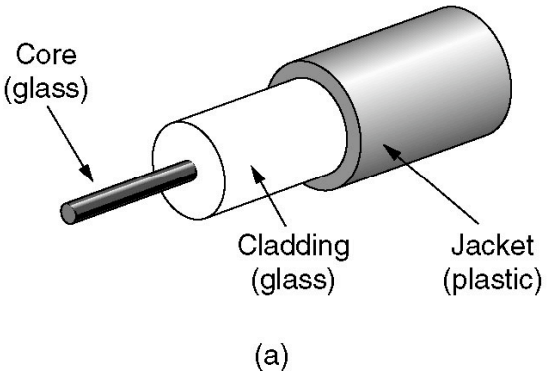

Source: Wikipedia

A: Protective outer coating
B: Braided outer conductor
C: Insulating material
D: Inner conductor

# Optical Fibre

- Glass core and cladding, plastic jacket for protection
  - It's made of glass: fragile – don't try to bend the fibre!
- Unidirectional data: transmission laser at one end; photodetector at the other
  - Laser light trapped in fibre by total internal reflection
- Cheap to manufacture; very low noise: 10s of Gbps over 100s of miles

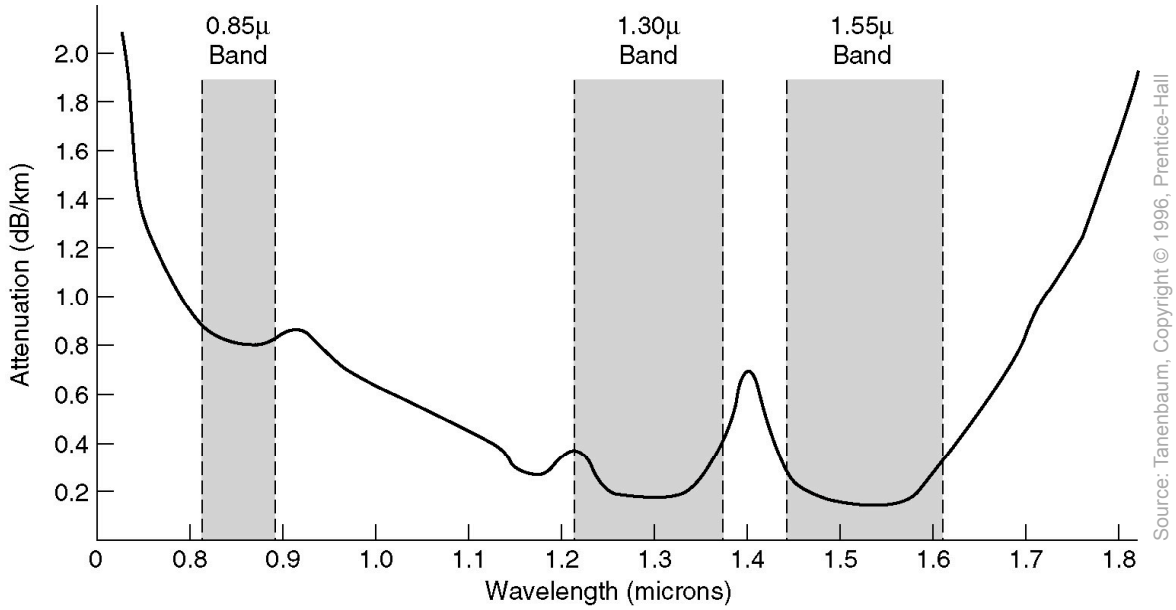





(a)

Source: Tanenbaum, Copyright © 1996, Prentice-Hall

# Optical Fibre




0.85μ laser easy to build in GaAs semiconductor

1.30μ and 1.55μ lasers give higher performance

Colour of transmission laser determines attenuation in the fibre → affects maximum possible fibre length

# Comparison

| Twisted Pair | Coaxial Cable | Optical Fibre |
|---|---|---|
| Cheap | Expensive | Cheap |
| Robust | Robust | Fragile |
| Good local area performance | Good local area, okay wide area | Good wide area performance |

# Wired Data Transmission

- Signal directly encoded onto the channel
  - Vary voltage in an electrical cable, intensity of light in an optical fibre
    - Analogue signals directly coded
    - Multiple digital coding schemes: NRZ, NRZI, Manchester, 4B/5B, etc.
    - Different complexity, resilience to noise

# Wired Data Transmission

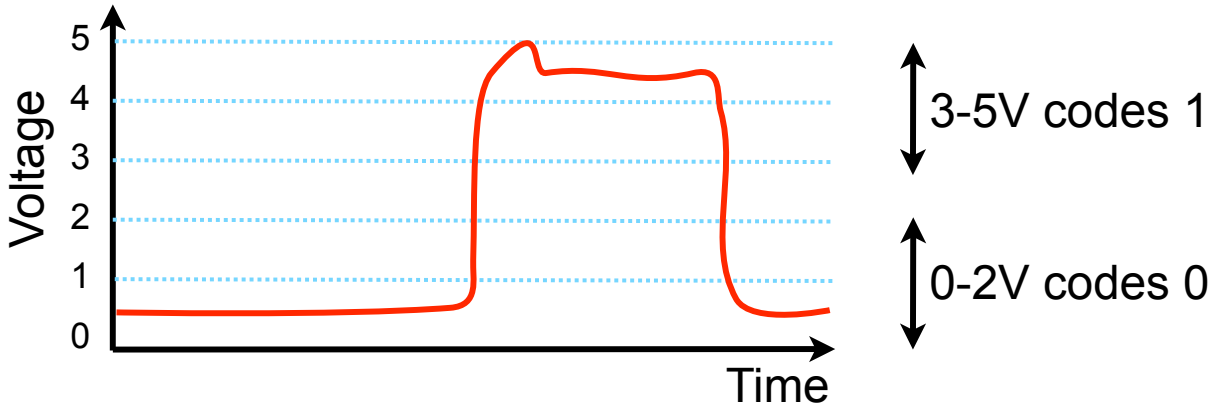
- Signal directly encoded onto the channel
  - Signal occupies baseband region
    - *H* is the bandwidth of the signal




    - Not suitable for wireless since all share a single baseband channel (use of modulated carrier waves allows several signals to coexist)

# Non-Return to Zero Encoding

- Encode a 1 as a high signal, a 0 as a low signal

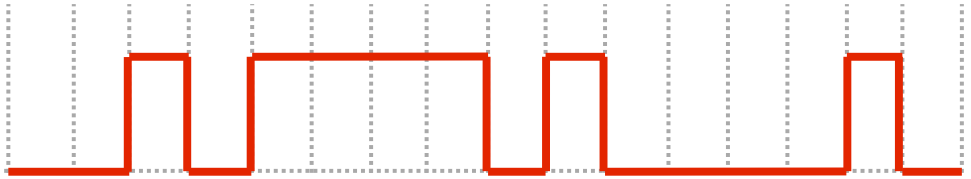


# Non-Return to Zero Encoding

- Encode a 1 as a high signal, a 0 as a low signal

Bits: 0 0 1 0 1 1 1 1 0 1 0 0 0 0 1 0

NRZ:



- Limitations with runs of consecutive same bit:
  - Baseline wander
  - Clock recovery

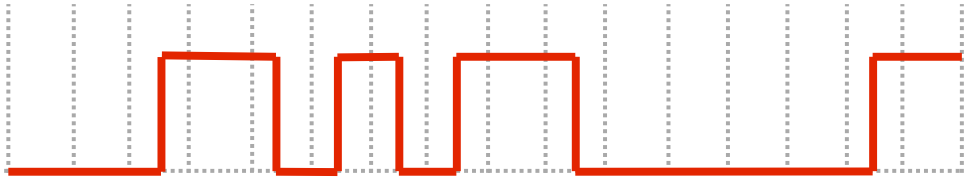
Average signal level provides boundary between 1 and 0. Runs of consecutive same bit cause the average to drift, and confuse the receiver

# NRZ Inverted Encoding

- Encode a 1 as a change in signal value, a 0 as a constant signal

Bits: 0 0 1 0 1 1 1 1 0 1 0 0 0 0 1 0

NRZI:

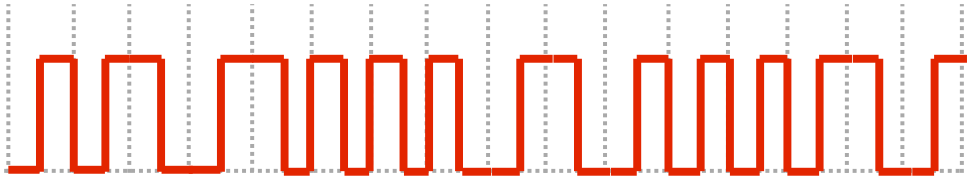


- Solves problems with runs of consecutive 1s, does nothing for runs of consecutive 0s

# Manchester Encoding

- Encode a 1 as a high-low signal transition, a 0 as a low-high signal transition

Bits: 0 0 1 0 1 1 1 1 0 1 0 0 0 0 1 0

Manchester: 

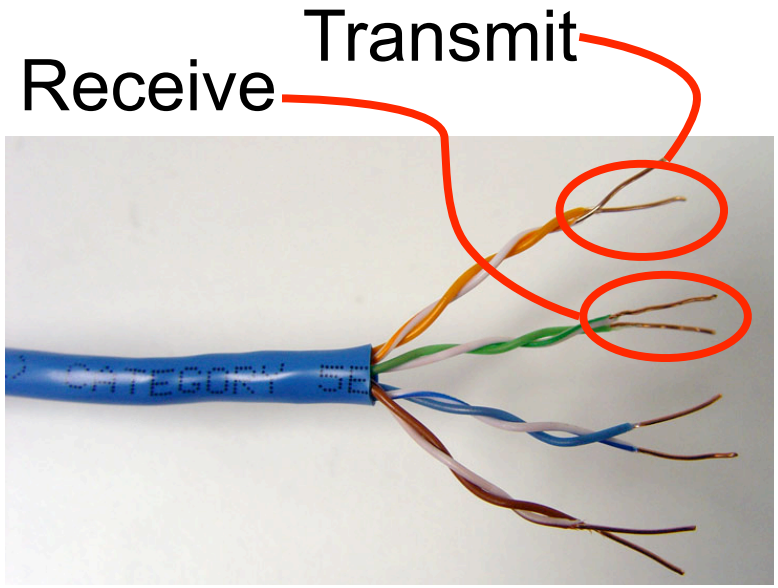
- Doubles the bandwidth needed, but avoids the problems with NRZ encoding

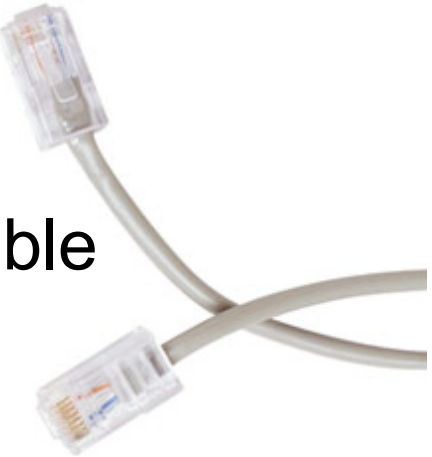
# 4B/5B Encoding

| 4-Bit Data Symbol | 5-Bit Encoding |
|---|---|
| 0000 | 11110 |
| 0001 | 01001 |
| 0010 | 10100 |
| 0011 | 10101 |
| 0100 | 01010 |
| 0101 | 01011 |
| 0110 | 01110 |
| 0111 | 01111 |
| 1000 | 10010 |
| 1001 | 10011 |
| 1010 | 10110 |
| 1011 | 10111 |
| 1100 | 11010 |
| 1101 | 11011 |
| 1110 | 11100 |
| 1111 | 11101 |

- Manchester encoding inefficient – only 50% of link capacity used
- Alternative – insert extra bits to break up sequences of same bit
  - Each 4 bit data symbol is changed to a 5 bit code for transmission; reversed at receiver
  - Transmit 5 bit codes using NRZI encoding
  - 80% of link capacity used for data

# Example: Ethernet



4 twisted pairs per cable

3 twists per inch

24 gauge (~0.5mm) copper

100m maximum cable length

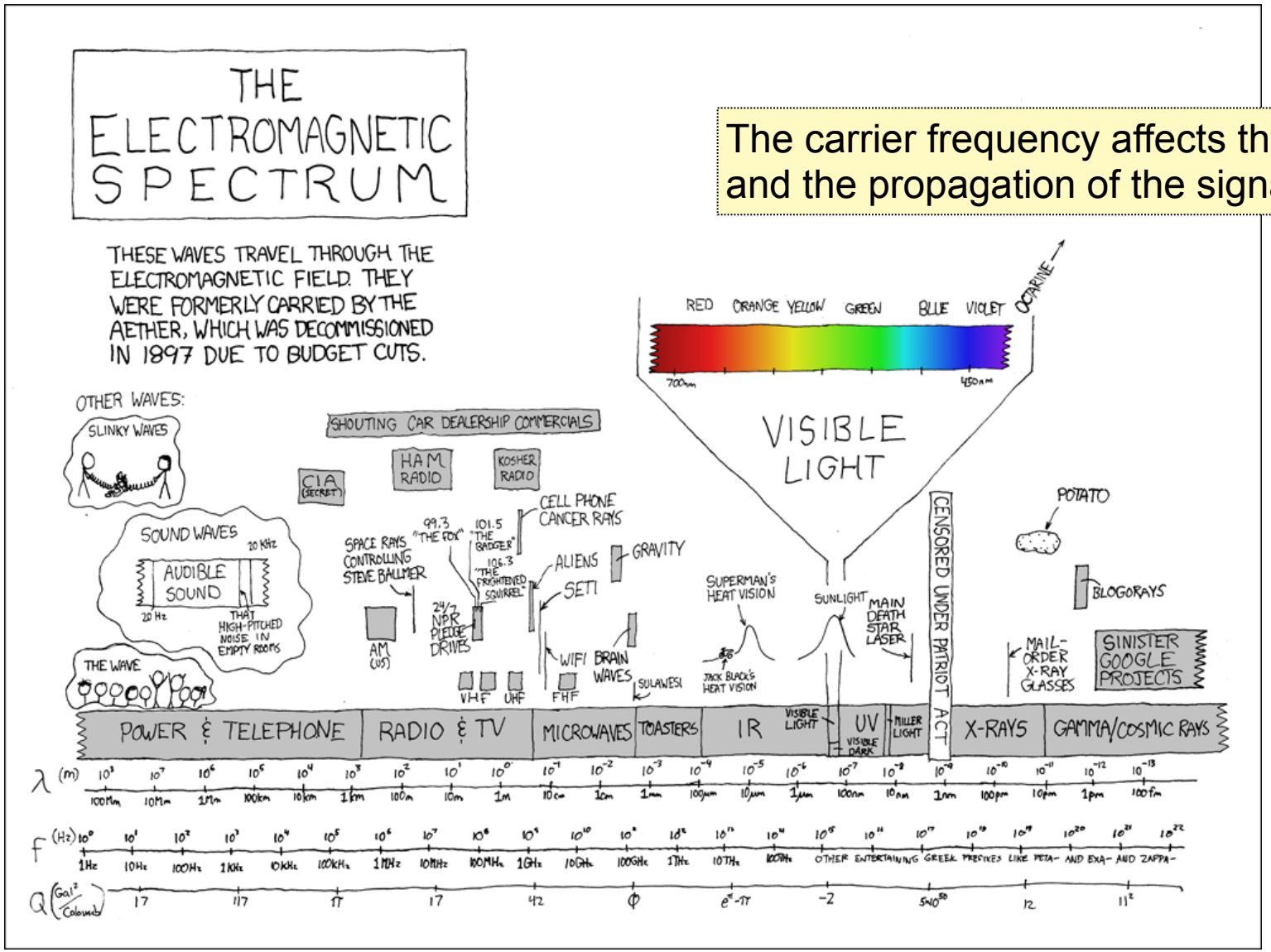
Baseband data with Manchester coding at 10 Mbps; 4B/5B coding at 100 Mbps

# Wireless Links

- Wireless links use carrier modulation, rather than baseband transmission*
- Performance affected by:
  - Carrier frequency
  - Transmission power
  - Modulation scheme
  - Type of antenna, etc.

* Ignoring ultra-wideband, for now...

# Electromagnetic Spectrum



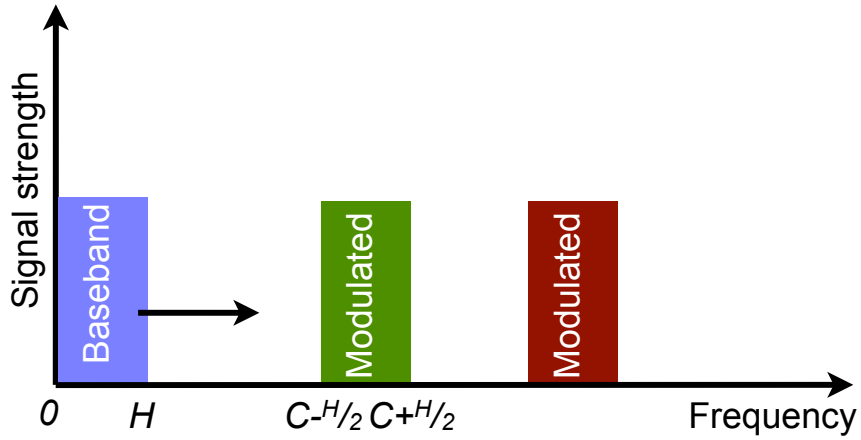

The carrier frequency affects the data rate, and the propagation of the signal

Antenna size → frequency

Source: http://xkcd.com/273/

# Carrier Modulation

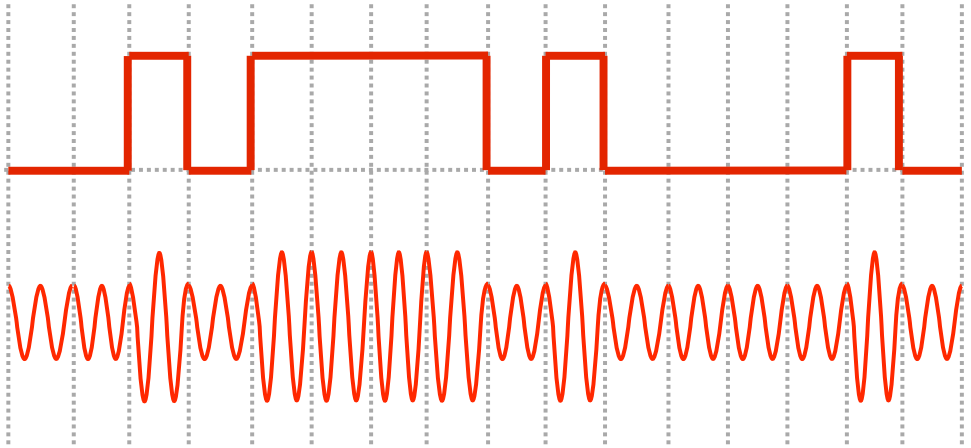
- A *carrier wave* is applied to the channel at some fixed frequency, *C*
- The signal is *modulated* onto the carrier
  - Shifts signal from baseband to carrier frequency
  - Allows multiple signals on a single channel
    - Provided carriers spaced greater than bandwidth, *H*, of the signal
    - (This is how ADSL and speech data share a single phone line)



# Amplitude Modulation

- Encode signal by varying the amplitude of the carrier wave

Bits: 0 0 1 0 1 1 1 1 0 1 0 0 0 0 1 0




Simple, but poor resistance to noise

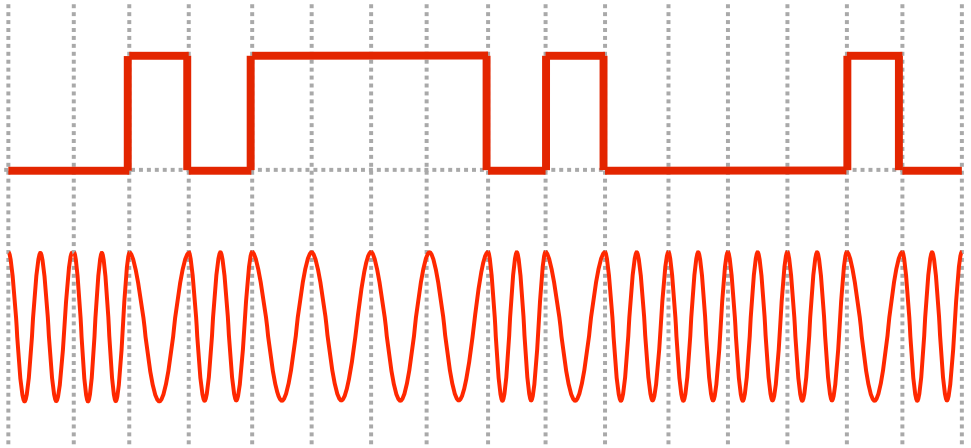
# Frequency Modulation

- Encode signal by varying the frequency of the carrier wave

Bits: 0 0 1 0 1 1 1 1 0 1 0 0 0 0 1 0

Raw signal:

FM:



More complex, but more resistant to noise

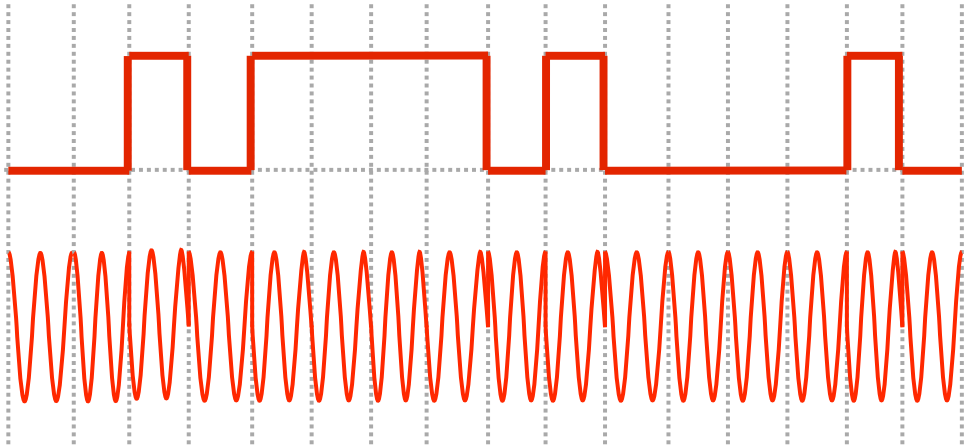
# Phase Modulation

- Encode signal by varying the phase of the carrier wave

Bits: 0 0 1 0 1 1 1 1 0 1 0 0 0 0 1 0

Raw signal:

PM:



Measure phase shift in degrees: how far ahead in the sine wave the signal jumps

# Complex Modulations

- More complex modulation schemes allow more than one bit to be sent per baud
  - Use multiple levels of the modulated component
    - E.g. vary amplitude across four different levels, to transmit 2 bits per baud
  - Combine modulation schemes
    - E.g. vary both phase and amplitude
    - E.g. 9600 bps modems use 12 phase shift values at two different amplitudes
  - Extremely complex combinations regularly used

# Example: 802.11 PHY

- Spread spectrum modulated carrier
  - Carrier frequency continually changes according to a pseudo-random sequence (to avoid interference)
  - Several frequencies centred around 2.4 GHz
- Uses a complex mixture of amplitude and phase modulation (“CCK modulation”)
- Range varies with obstacles: ~100m



# Questions?