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

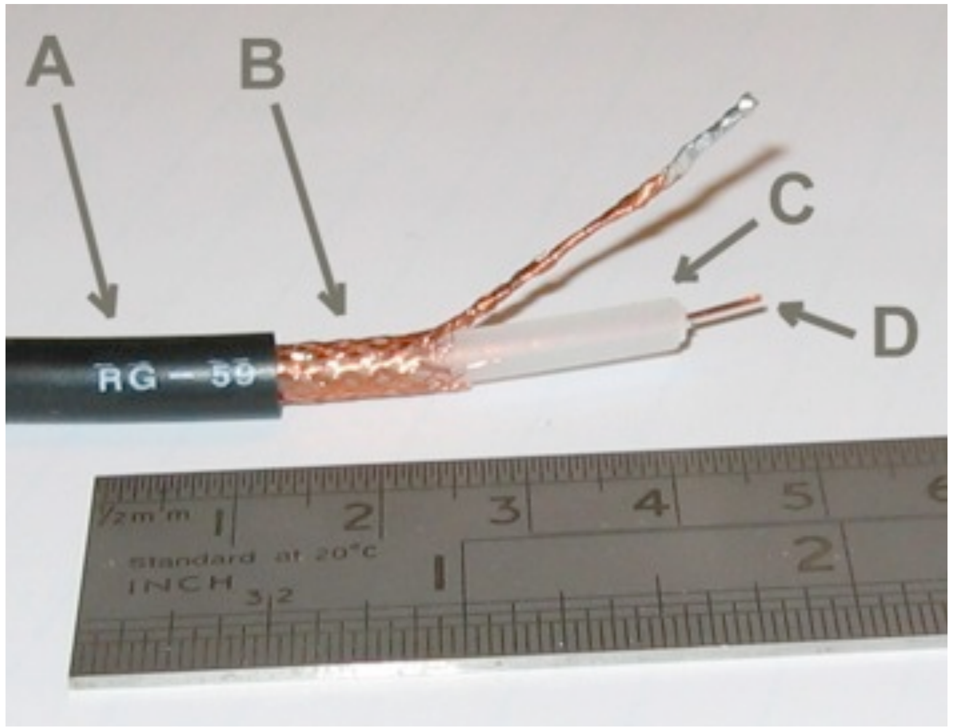
- Physical characteristics of cable or optical fibre:
  - Size and shape of the plugs
  - Maximum cable/fibre length
  - Type of cable: electrical voltage, current, modulation
  - Type of fibre: single- or multi-mode, optical clarity, colour, power output, and modulation of the laser

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

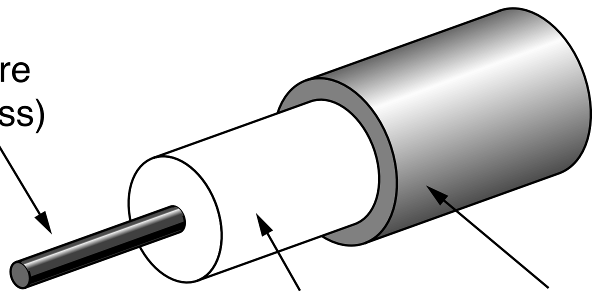
B: Braided outer conductor

C: Insulating material

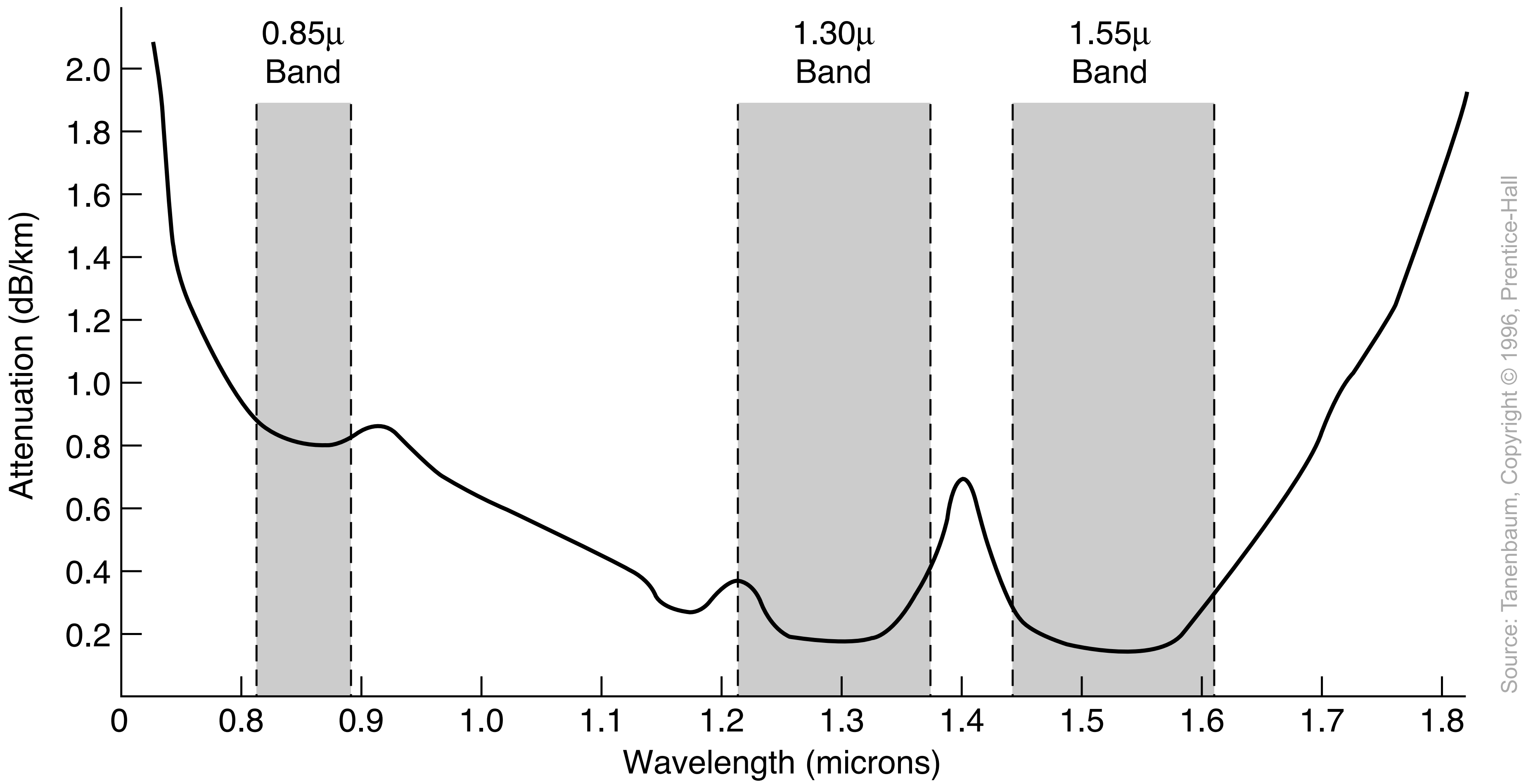
D: Inner conductor

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



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

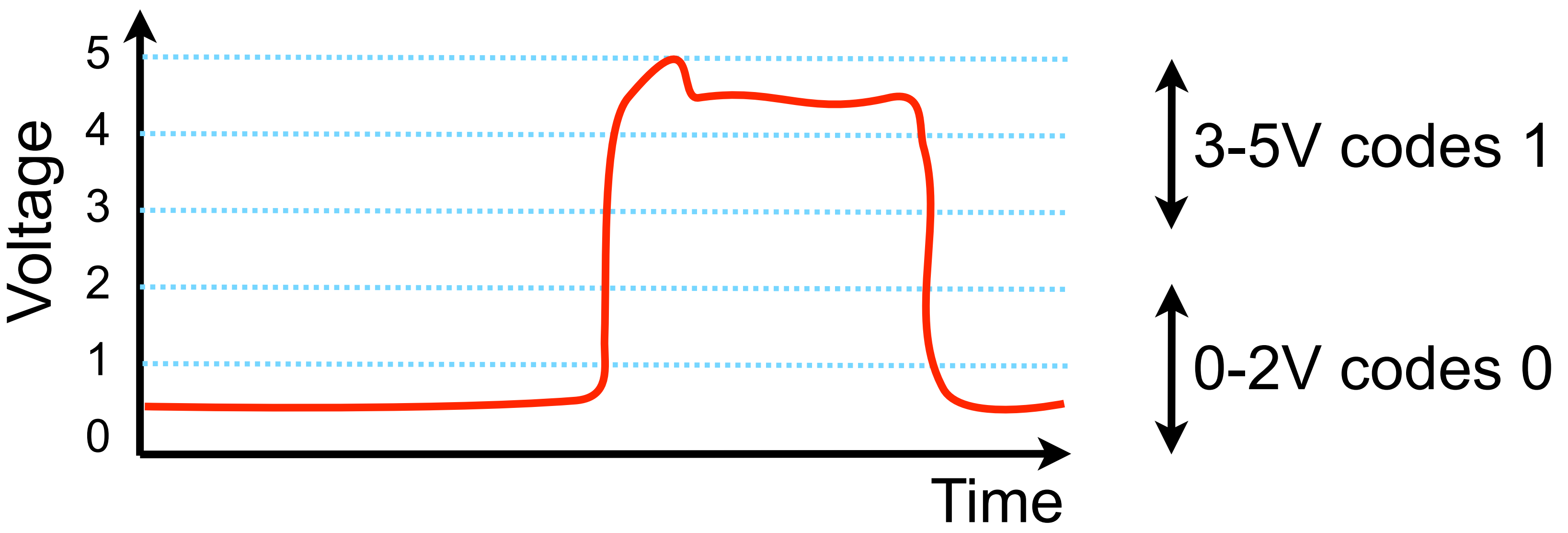
Wired Data Transmission

- 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

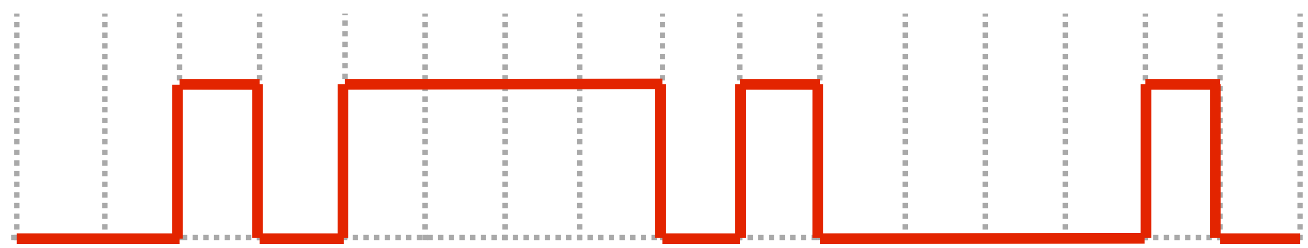


Non-Return to Zero Encoding

- 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

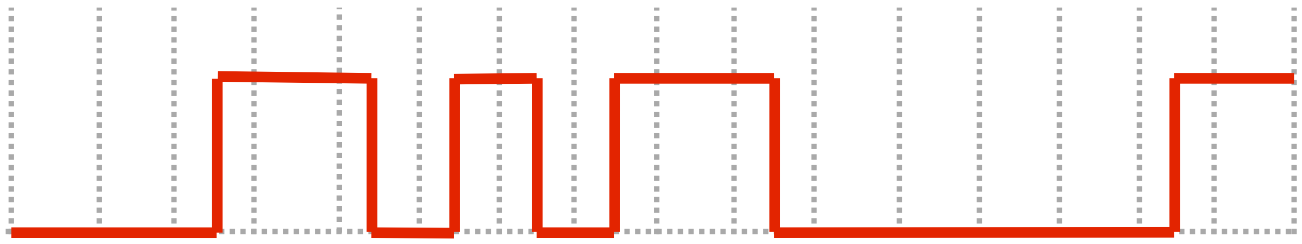
Average signal level provides boundary between 1 and 0. Runs of consecutive same bit cause the average to drift, and confuse the receiver

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:



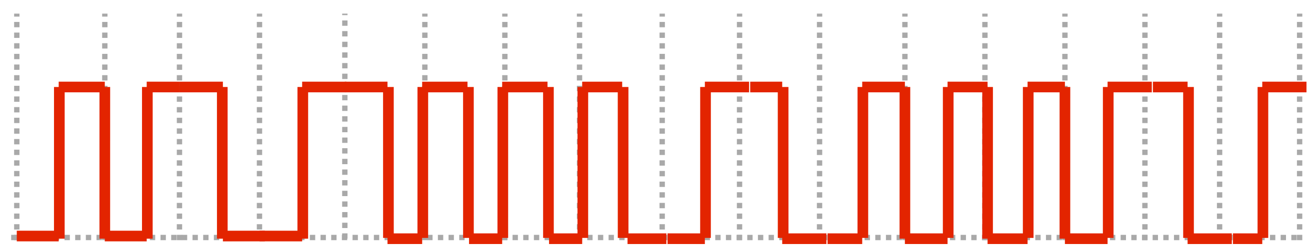
- Solves problems with runs of consecutive 1s, does nothing for runs of consecutive 0s

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:



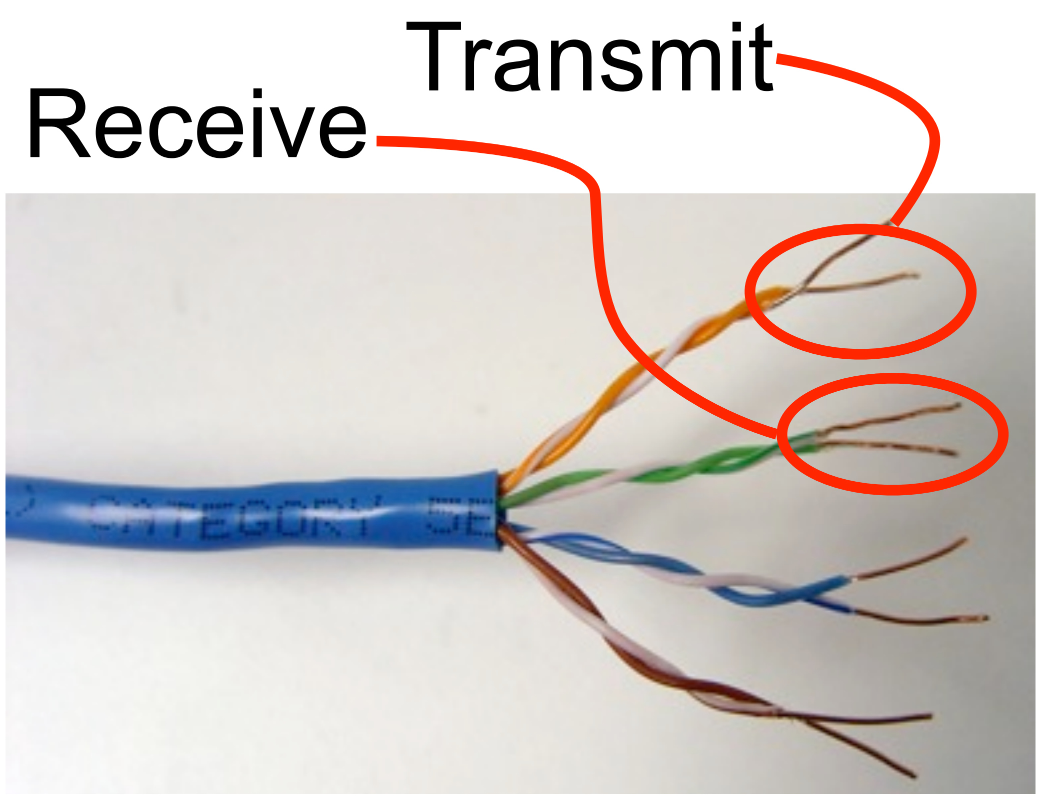
- Doubles the bandwidth needed, but avoids the problems with NRZ encoding

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

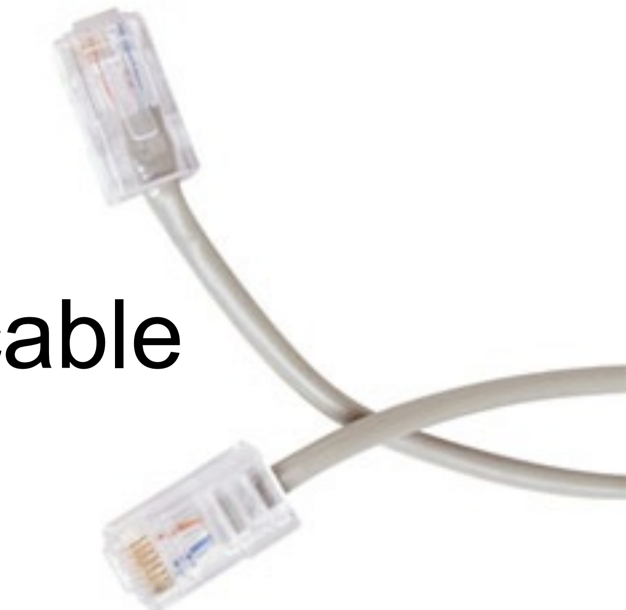


4 twisted pairs per cable

3 twists per inch

24 gauge (~0.5mm) copper

100m maximum cable length



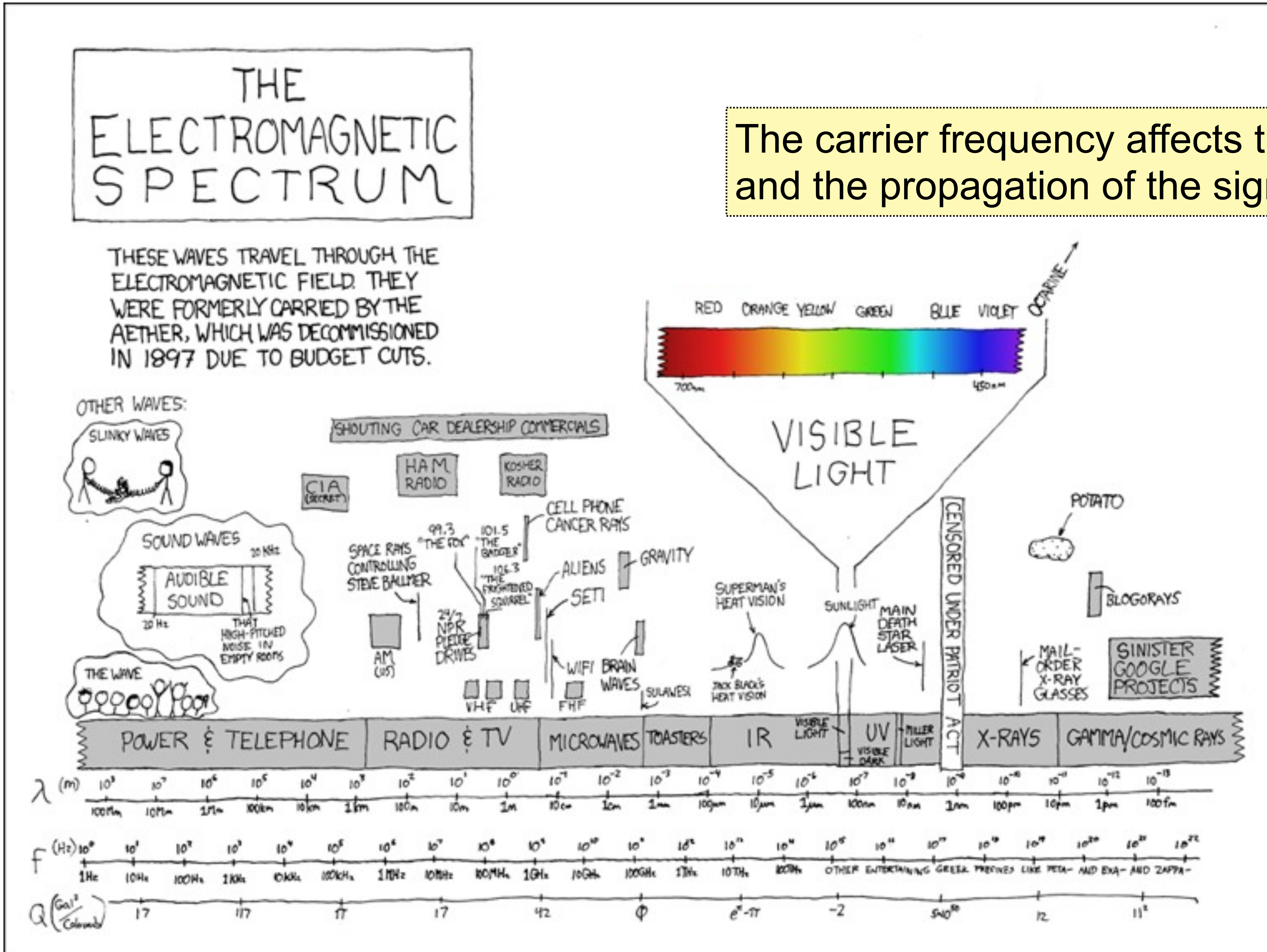
Baseband data with Manchester coding at 10 Mbps;
4B/5B coding at 100 Mbps

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



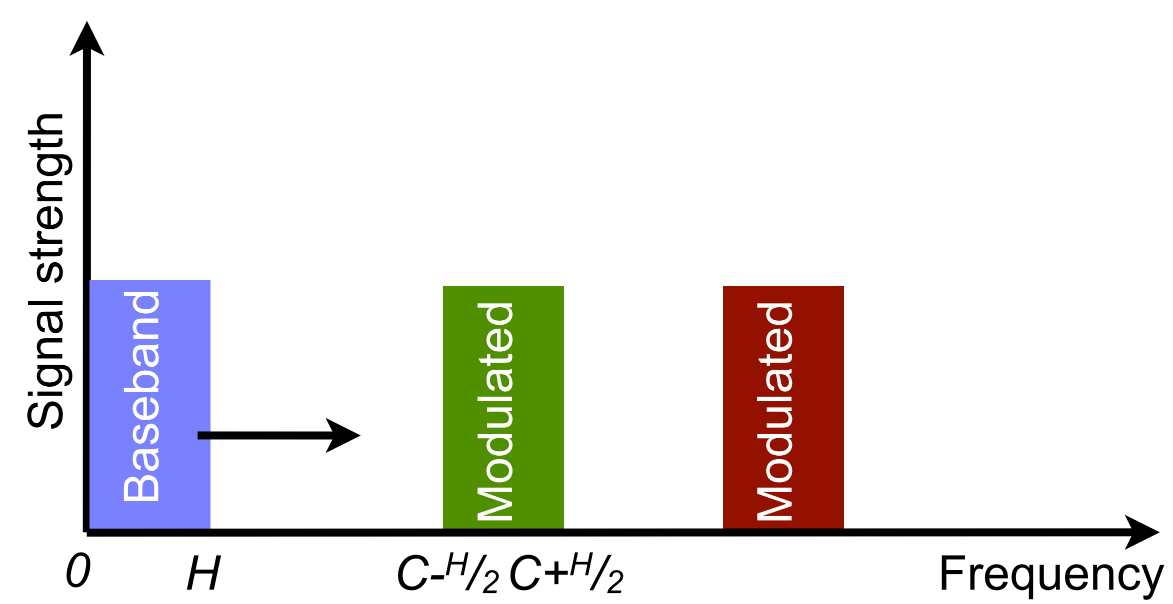
The carrier frequency affects the data rate, and the propagation of the signal

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)



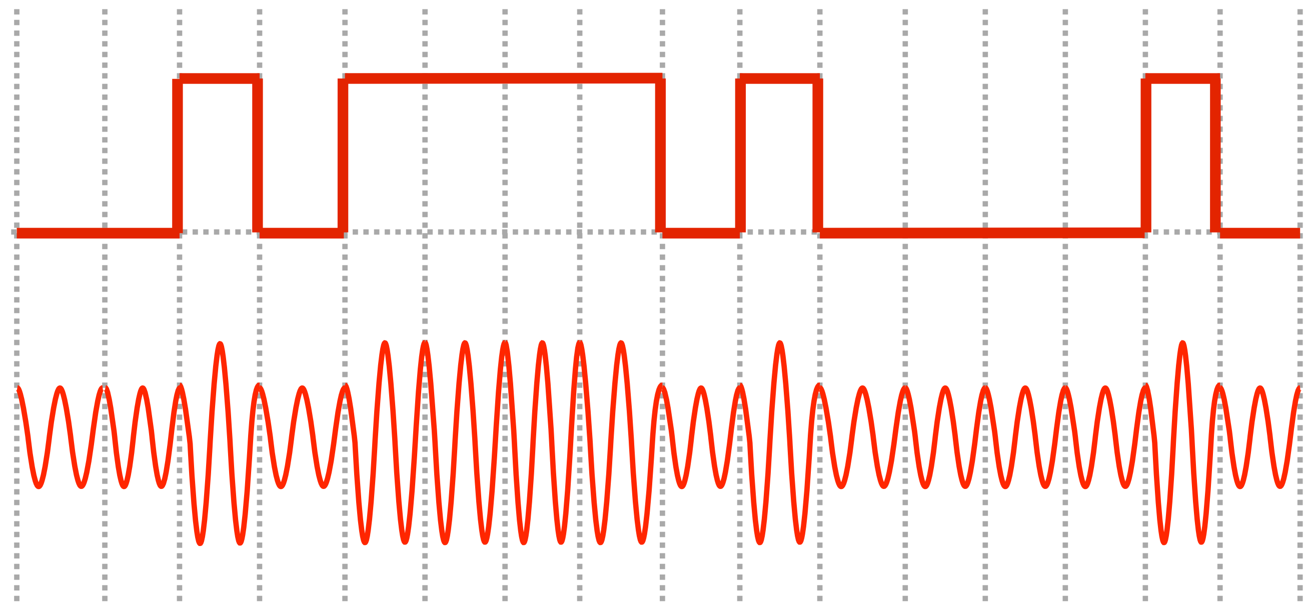
Amplitude Modulation

- 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

Raw signal:

AM:



Simple, but poor resistance to noise

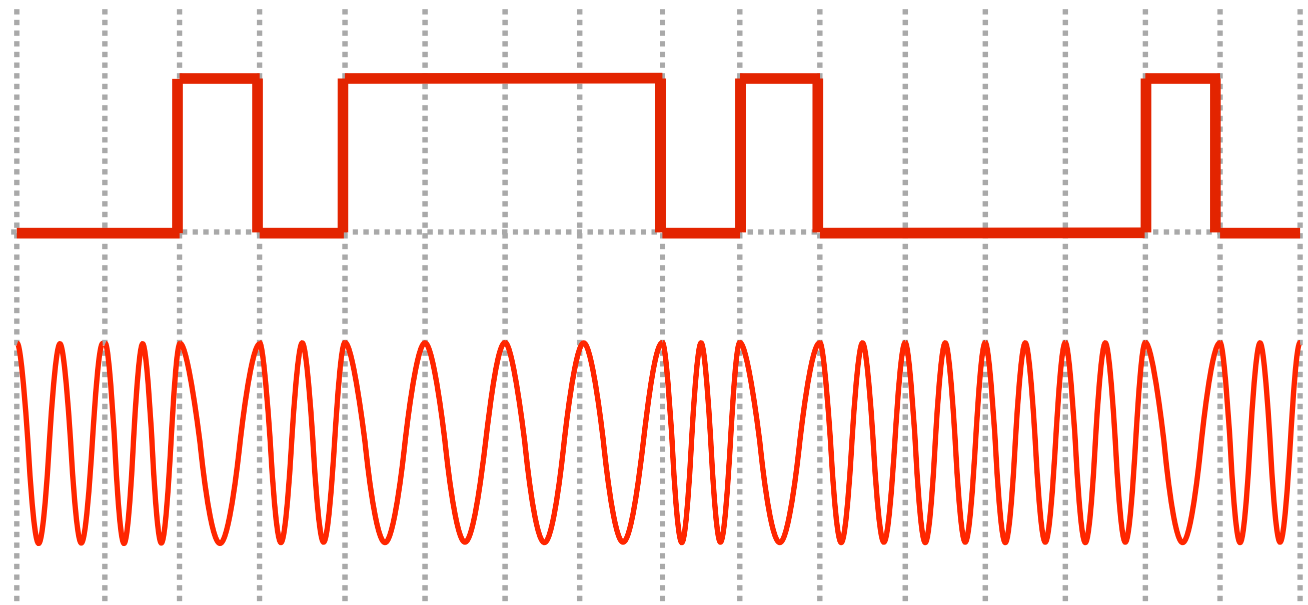
Frequency Modulation

- 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

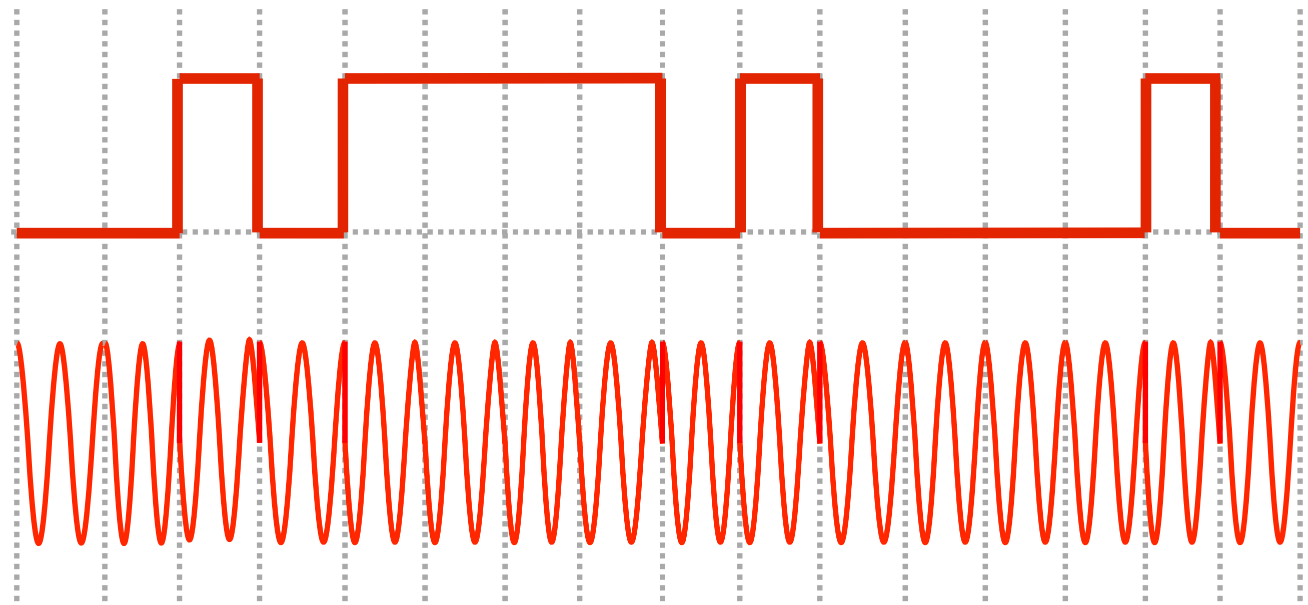
Phase Modulation

- 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:



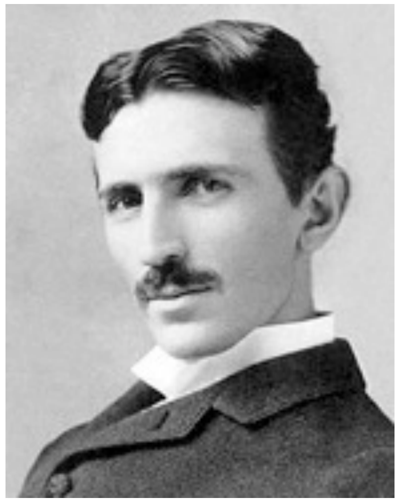
Measure phase shift in degrees: how far ahead in the sine wave the signal jumps

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

Spread Spectrum Communication

- Single frequency communications prone to interference
  - Can be avoiding by repeatedly changing carrier frequency
  - E.g., use a pseudo-random sequence to choose which of a group of carrier frequencies to use for each time slot; make the seed a shared secret between sender and receiver



Nikola Tesla

Originally invented by Nikola Tesla; independently re-invented by Hedy Lamarr and George Antheil.

Hedy Lamarr

George Antheil

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?