



University  
of Glasgow

# Physical Layer

Networked Systems 3  
Lecture 4

# 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

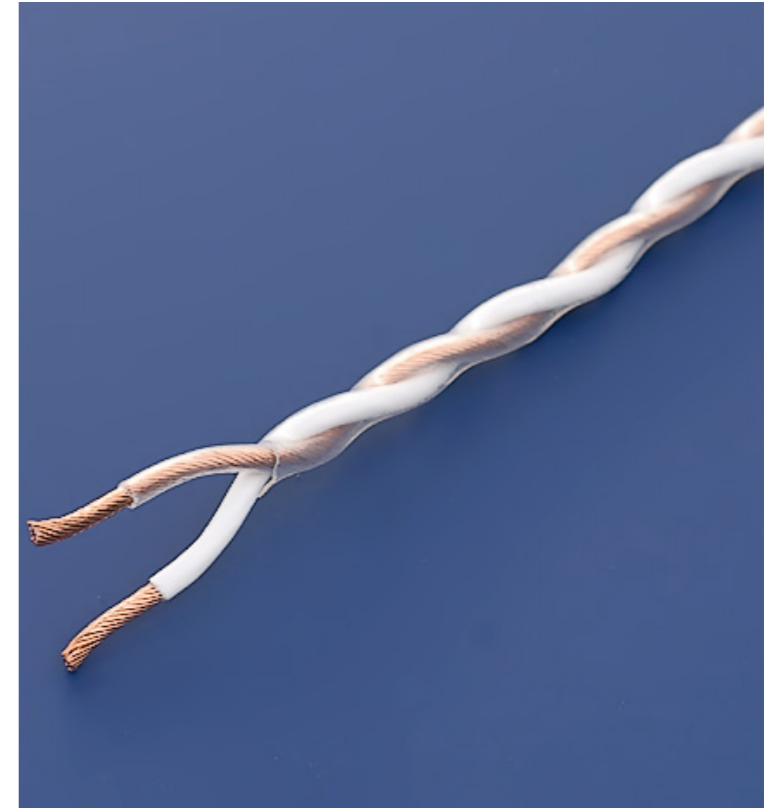
- The physical layer is concerned with transmission of raw data bits
  - What type of cable or wireless link do you use?
  - How to encode bits onto that channel?
    - Baseband encoding
    - Carrier modulation

# 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

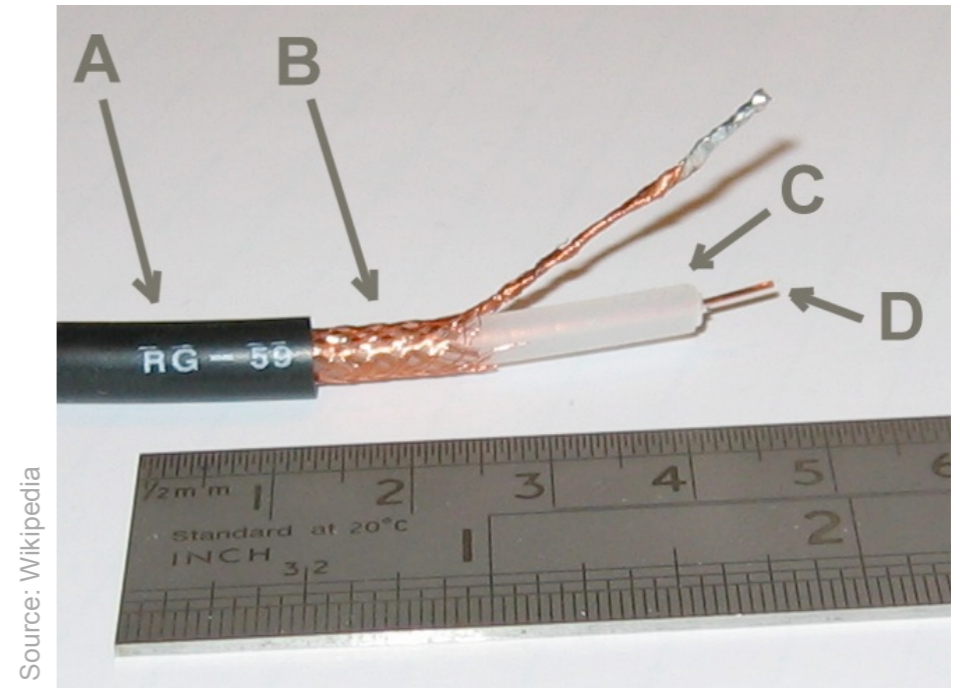
# Unshielded Twisted Pair

- Electrical cable using two wires twisted together in a spiral
  - Each pair is unidirectional: 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
- Susceptibility to noise increases with cable length
- Extremely widely deployed:
  - Ethernet cables
  - Telephone lines



# Coaxial Cable

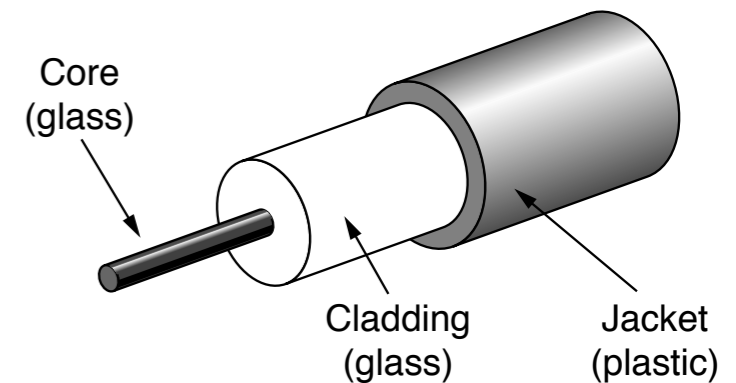
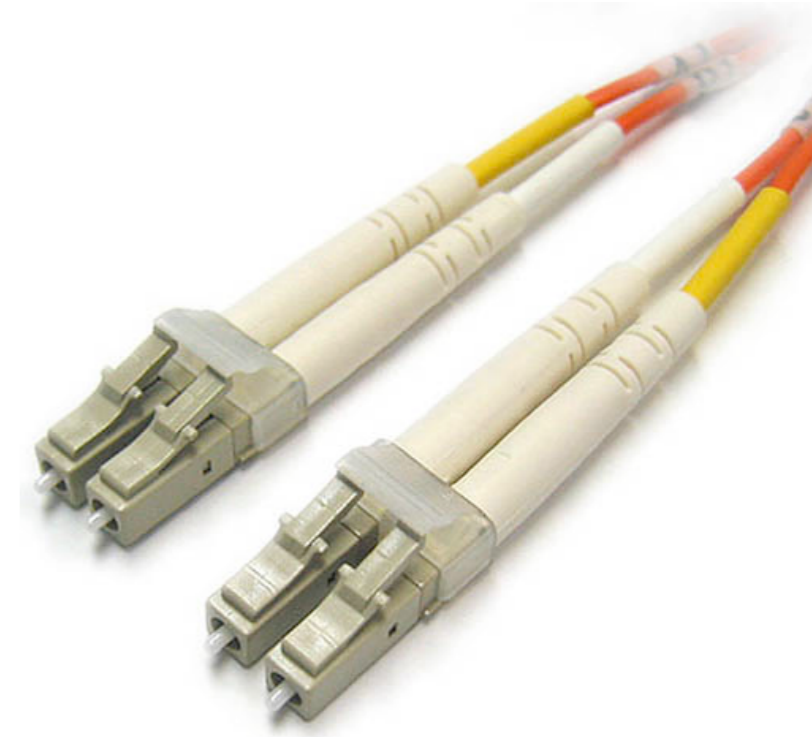
- Wire core surrounded by layer of insulation, with a braided outer conductor
  - Each cable is unidirectional data path
  - Wire core is the signal path; outer conductor provides ground shielding
- **Better noise resilience than twisted pair cables**
  - Longer distance at higher rates: Gbps over several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



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

# Optical Fibre

- Glass core and cladding, contained in plastic jacket for protection
  - Somewhat fragile: glass can crack if bent sharply
  - Unidirectional data: transmission laser at one end; photodetector at the other
    - Laser light trapped in fibre by total internal reflection
  - Very low noise, since electromagnetic interference does not affect light
  - Very high capacity: 10s of Gbps over 100s of miles
  - Very cheap to manufacture
  - Requires relatively expensive lasers to operate



Source: Tanenbaum, Copyright © 1996, Prentice-Hall

# Comparison

- Twisted pair: fast local area networks or slow wide area networks
- Optical fibre: fast wide area networks

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 usually 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

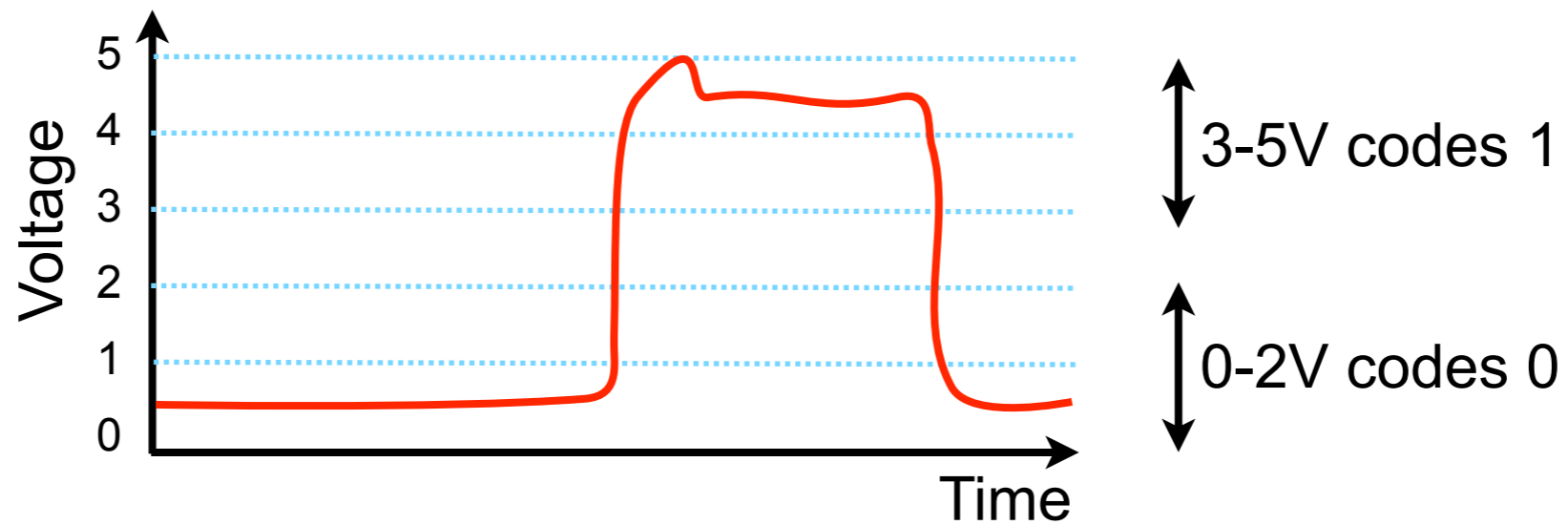
- Signal usually directly encoded onto the channel
  - Signal usually occupies baseband region
    - $H$  is the bandwidth of the signal



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

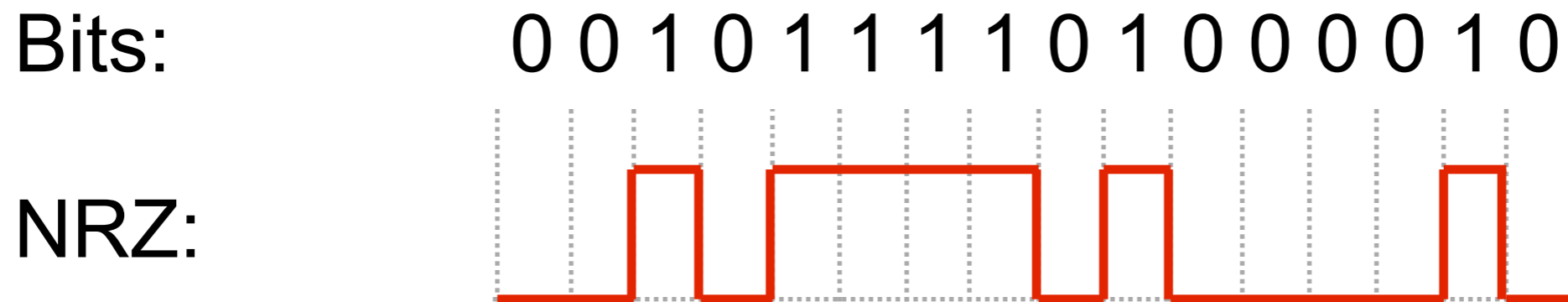
# Non-Return to Zero Encoding

- 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



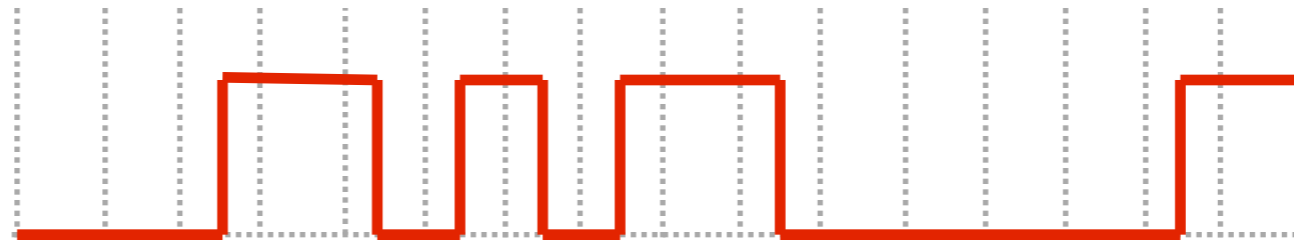
- Limitations with runs of consecutive same bit:
  - Baseline wander
  - Clock recovery

# 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:

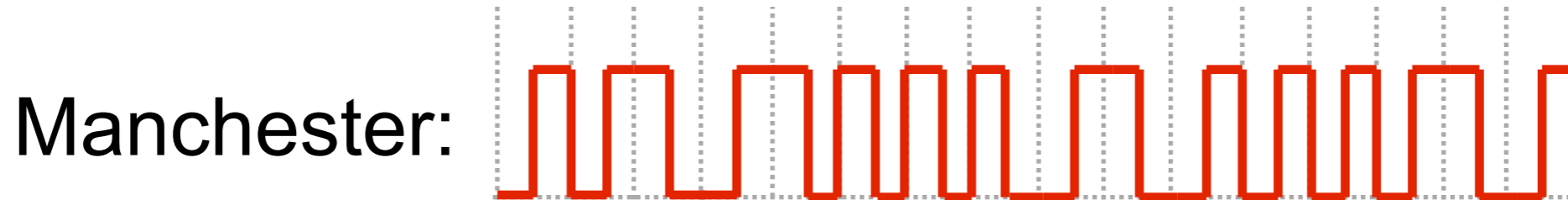


- Solves problems with runs of consecutive 1s, does nothing for runs of consecutive 0s

# 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



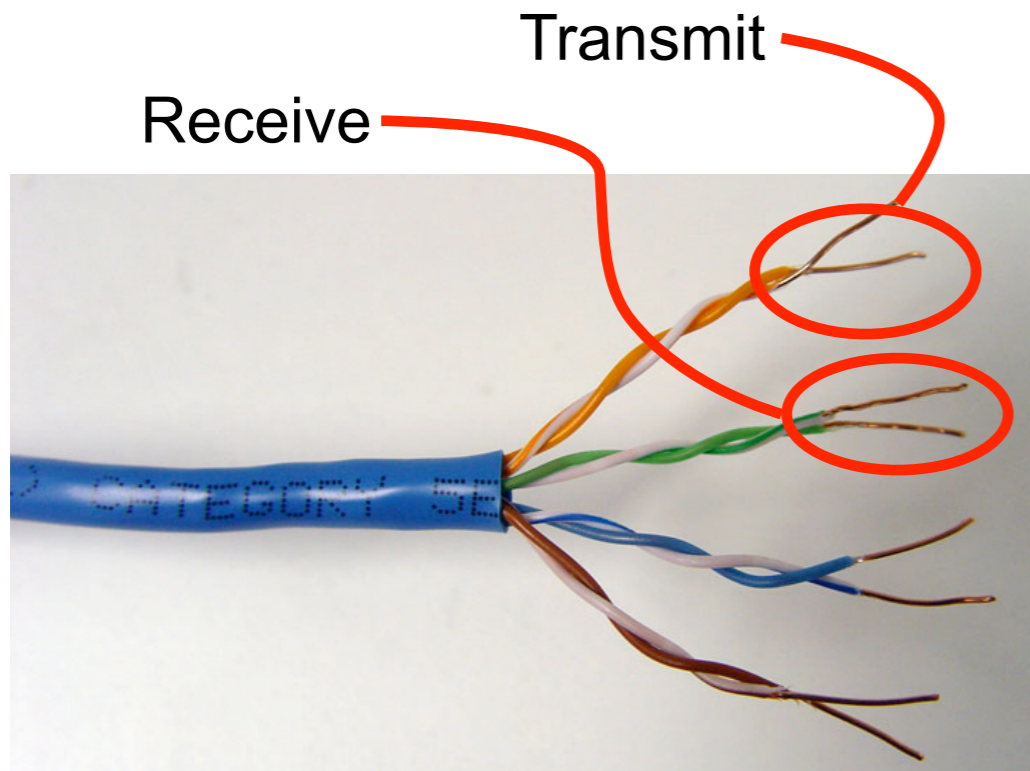
- Doubles the bandwidth needed, but avoids the problems with NRZ encoding

# 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

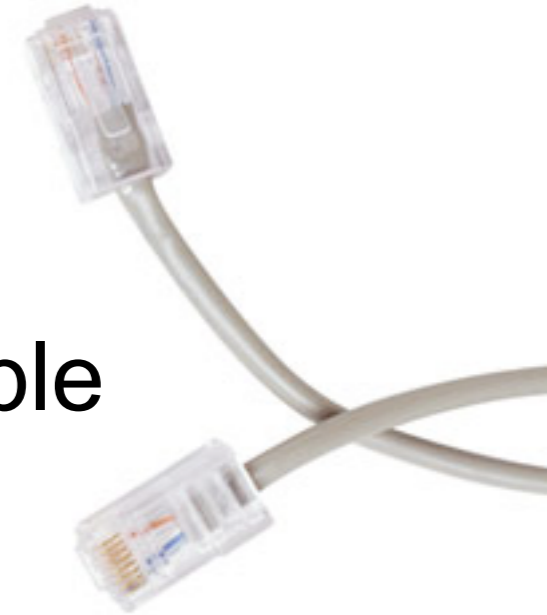


4 twisted pairs per cable

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



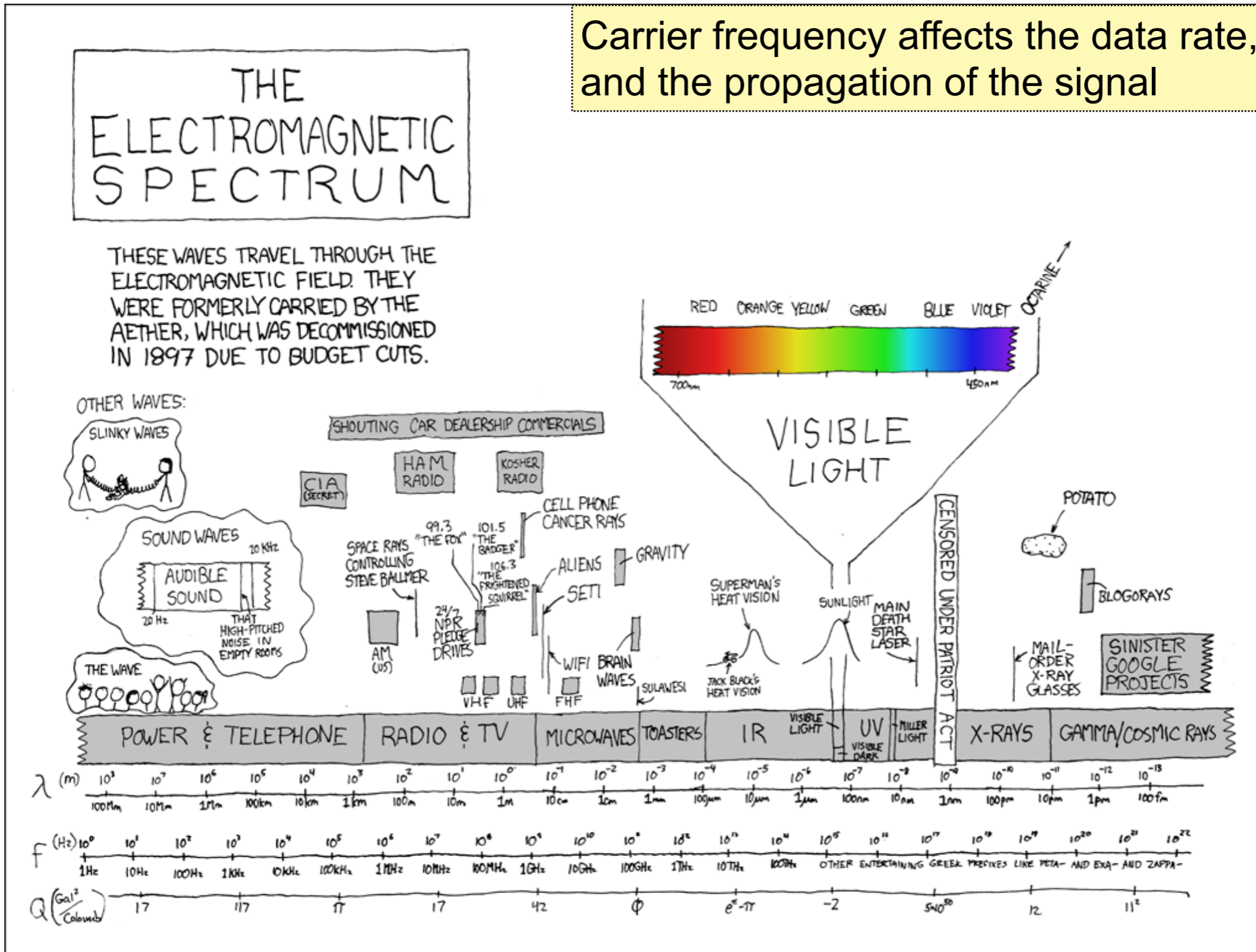
# Wireless Links

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

<sup>\*</sup> Ignoring ultra-wideband, for now...

# Electromagnetic Spectrum

Carrier frequency affects the data rate, and the propagation of the signal

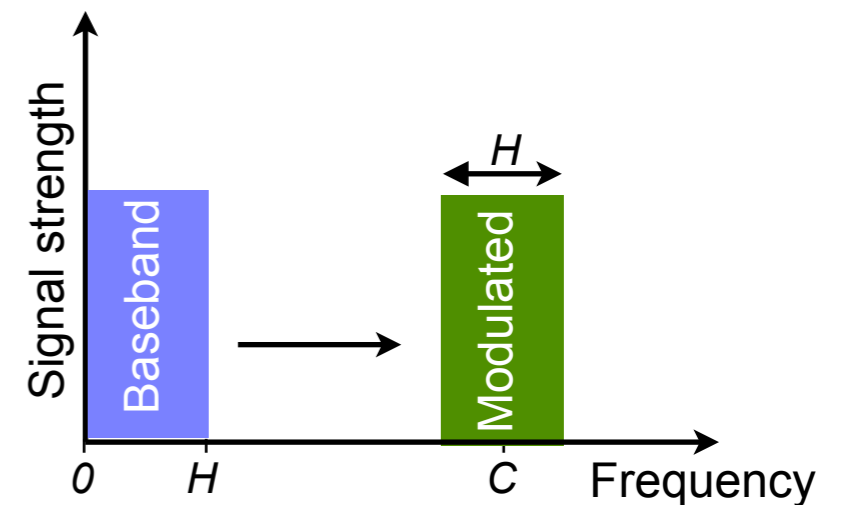


Frequency → antenna size

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

# Carrier Modulation

- Carrier wave applied to channel at frequency,  $C$
- Signal 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)



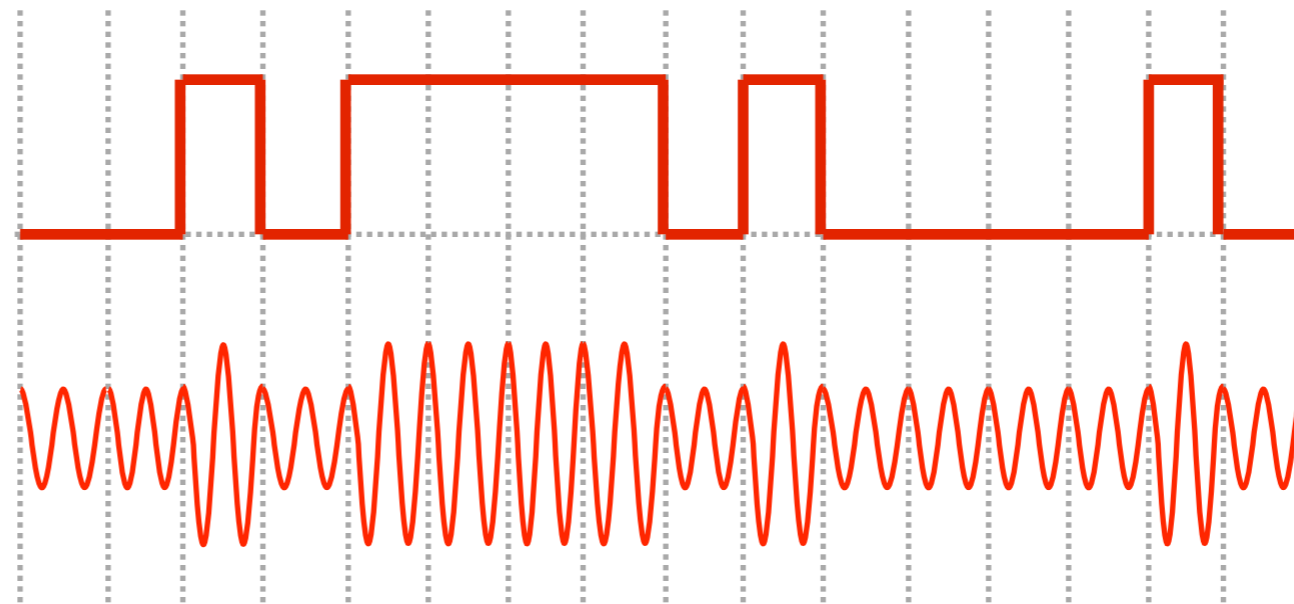
# Amplitude Modulation

- 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:

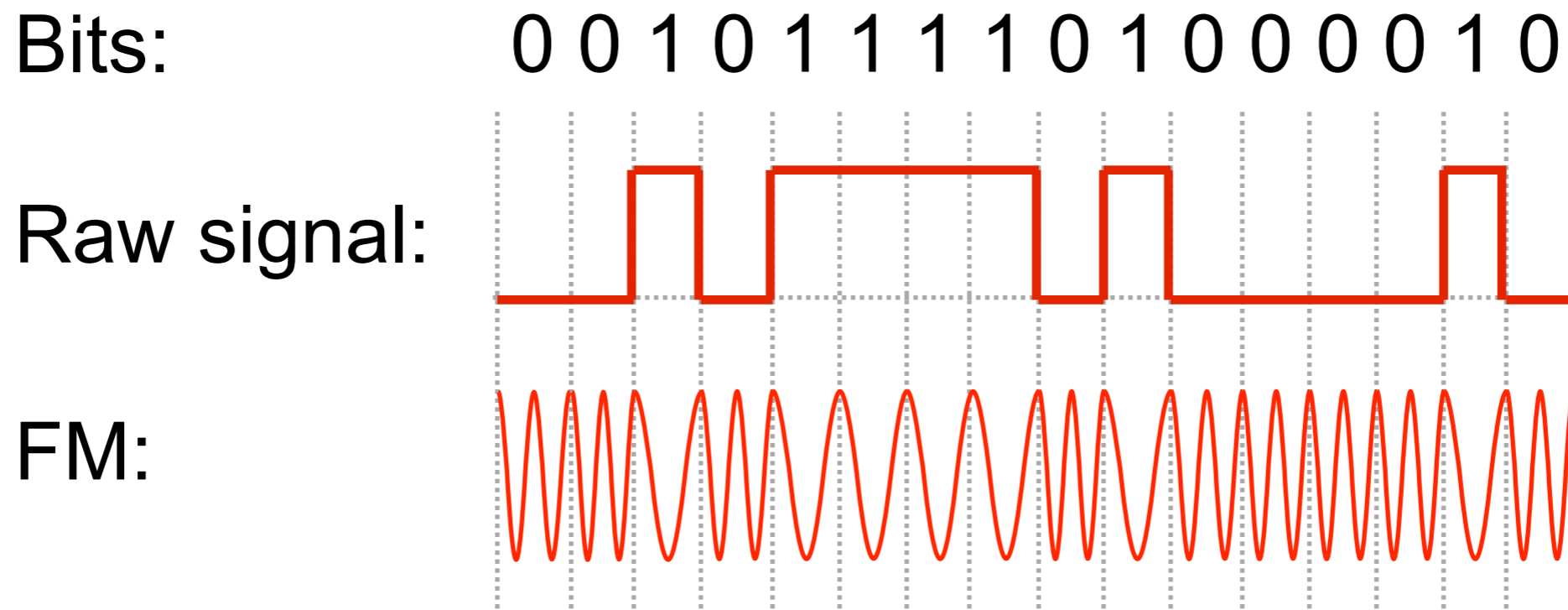
AM:



Simple, but poor resistance to noise

# Frequency Modulation

- Encode signal by varying the frequency of the carrier wave



More complex, but more resistant to noise

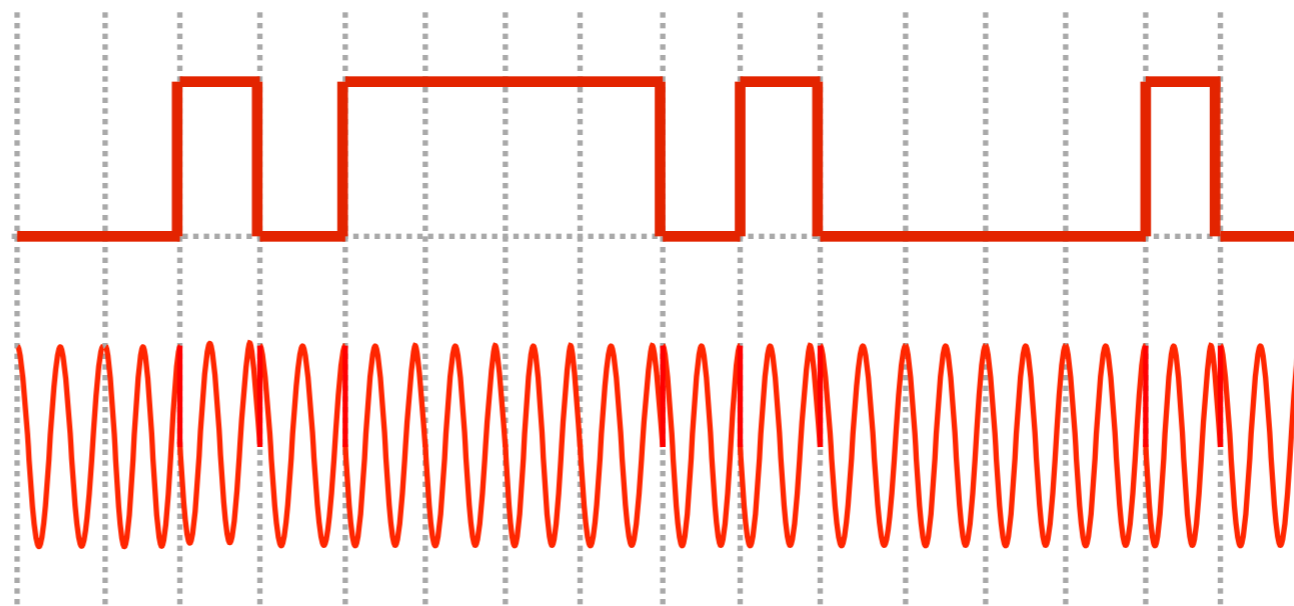
# Phase Modulation

- 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
    - Example: gigabit Ethernet uses amplitude modulation with five levels, rather than binary signalling
  - Combine modulation schemes
    - Vary both phase and amplitude → quadrature amplitude modulation
    - Example: 9600bps modems use 12 phase shift values at two different amplitudes
  - Extremely complex combinations regularly used

# Spread Spectrum Communication

- Single frequency channels prone to interference
  - Mitigate by repeatedly changing carrier frequency, many times per second: noise unlikely to affect all frequencies
  - Use a pseudo-random sequence to choose which of a group of carrier frequencies to use for each time slot; with the seed a shared secret between sender and receiver
    - Hard to eavesdrop if seed is kept secret
- Example: 802.11b Wi-Fi
  - Spread spectrum using several frequencies centred ~2.4 GHz with phase modulation (“CCK modulation”)
  - Range varies with obstacles: ~100m



Hedy Lamarr



# Summary

- Properties of physical layer: twisted pair vs. fibre
- Trade-offs of different modulation schemes
  - Wired: NRZ, NRZI, 4B/5B, Manchester
  - Wireless: AM, FM, phase modulation
- Carrier modulation allows multiple signals to share channel – especially wireless channel
- Spread spectrum gives robustness to noise