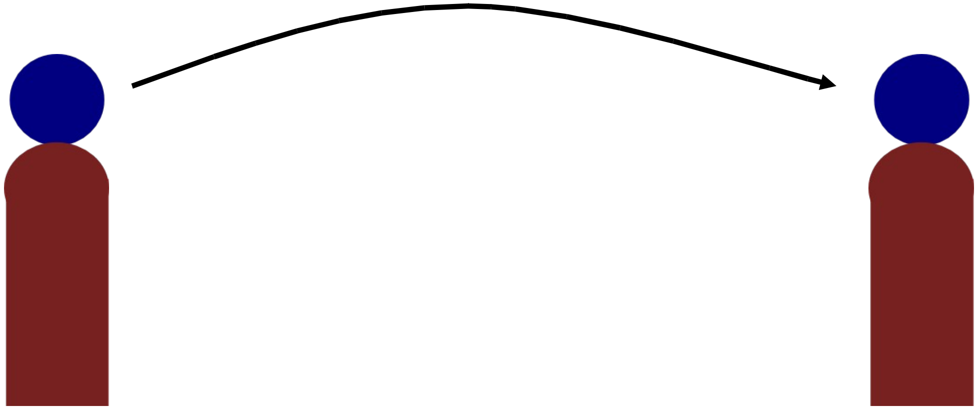
Point-to-Point Communications

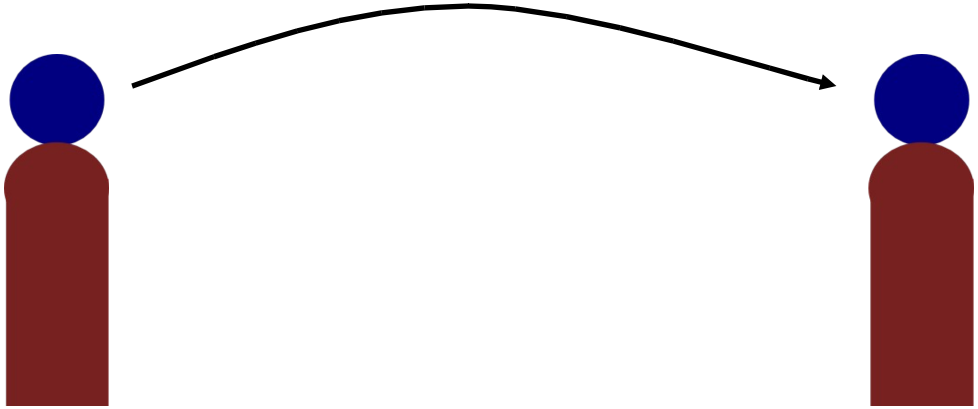
Key Aspects of Communication



- Signals
- Media
- Language

Voice	**Mail**
Tones	Alphabet
Air	Paper
English/Hindi	English/Hindi

Outline of Point-to-Point Communication

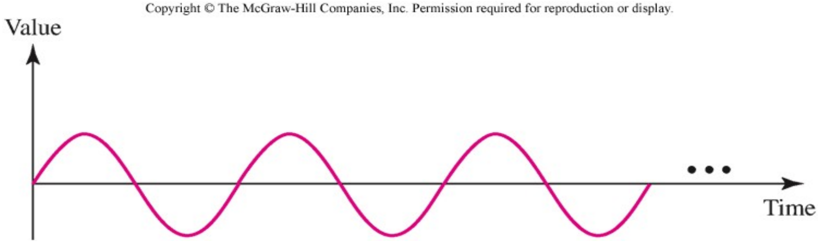


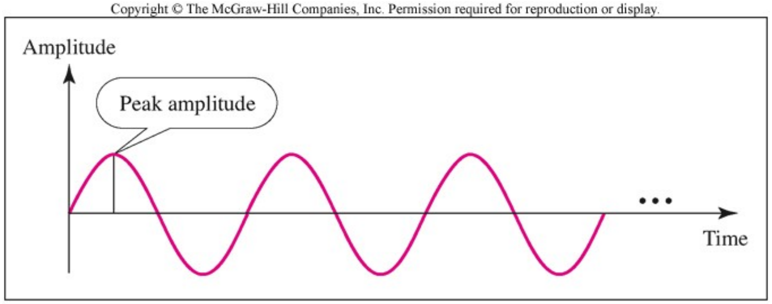
1. Signals – basic signal theory
2. Media – Different transmission media
3. Language – Modulation Techniques

Sinusoids

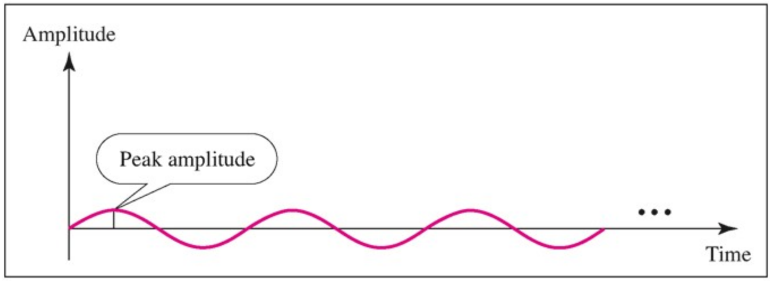
$$A\sin(2\pi f t)$$

amplitude — frequency — time

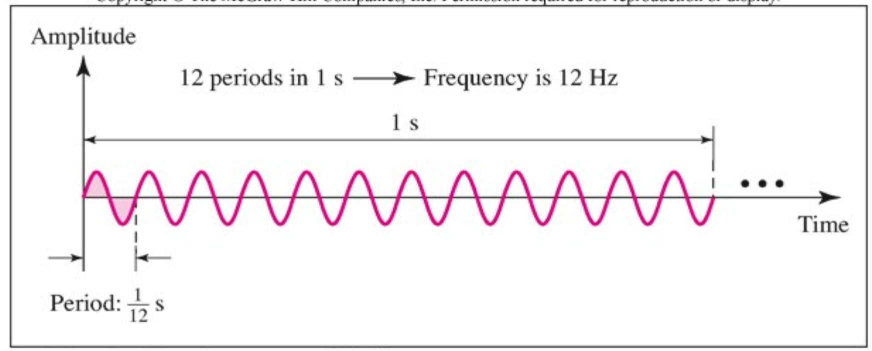




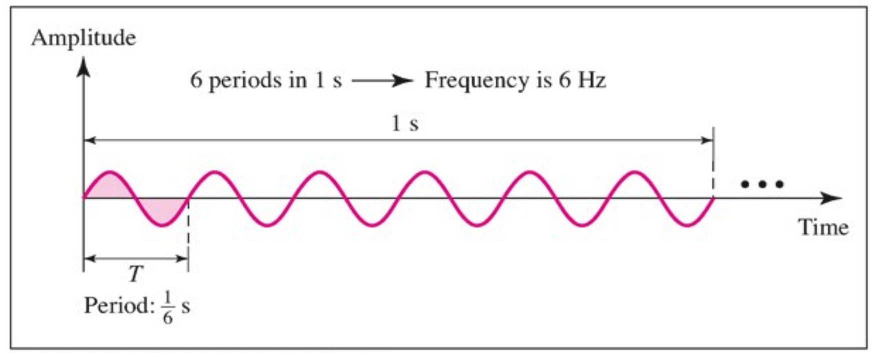
a. A signal with high peak amplitude



b. A signal with low peak amplitude

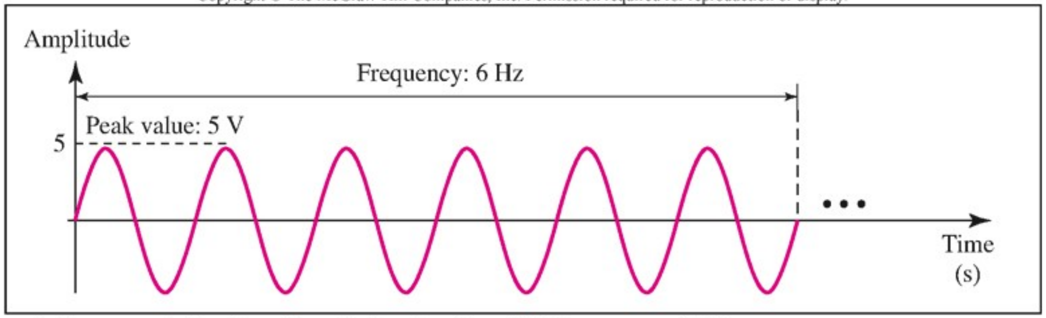


a. A signal with a frequency of 12 Hz

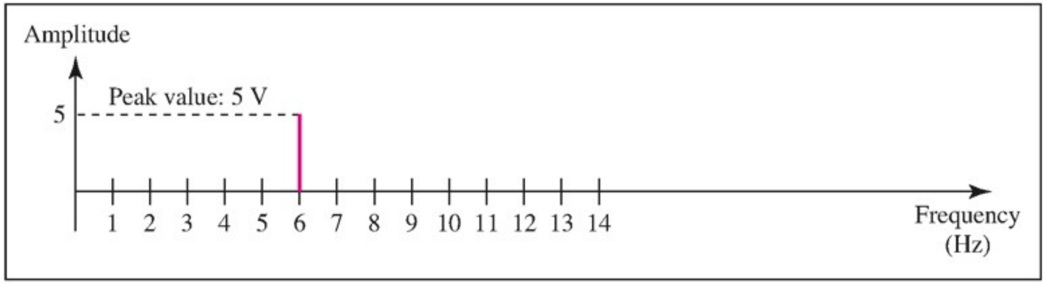


b. A signal with a frequency of 6 Hz

Frequency Domain Representation



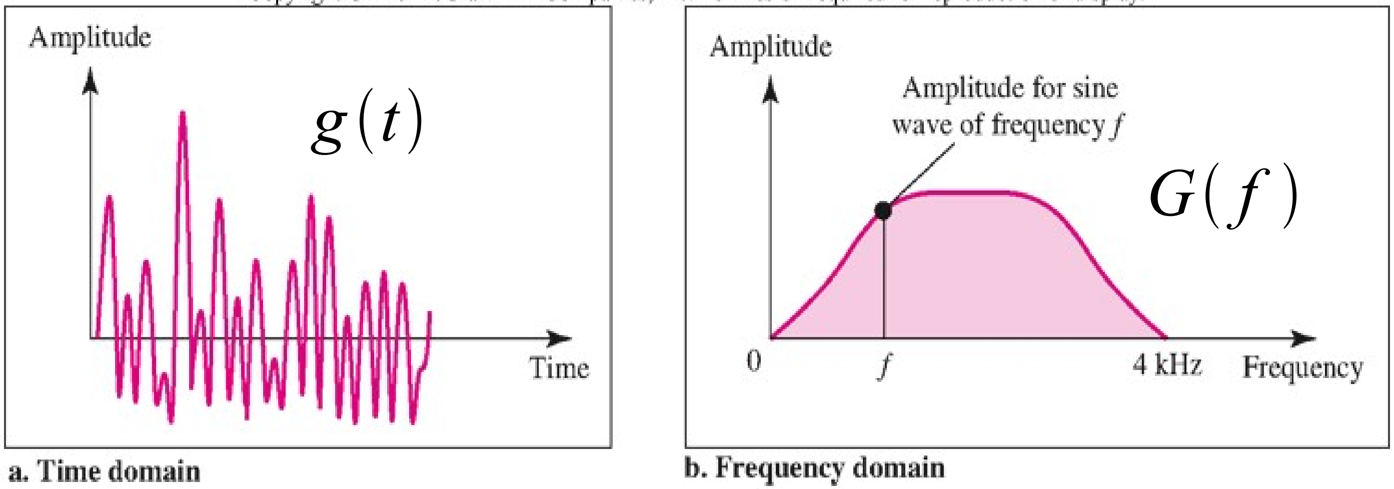
a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

- Sinusoid $A\sin(2\pi f t)$ represented as impulse of height *A* at frequency *f* in frequency domain

Fourier Transform



- Any signal can be represented as linear combination of sinusoids

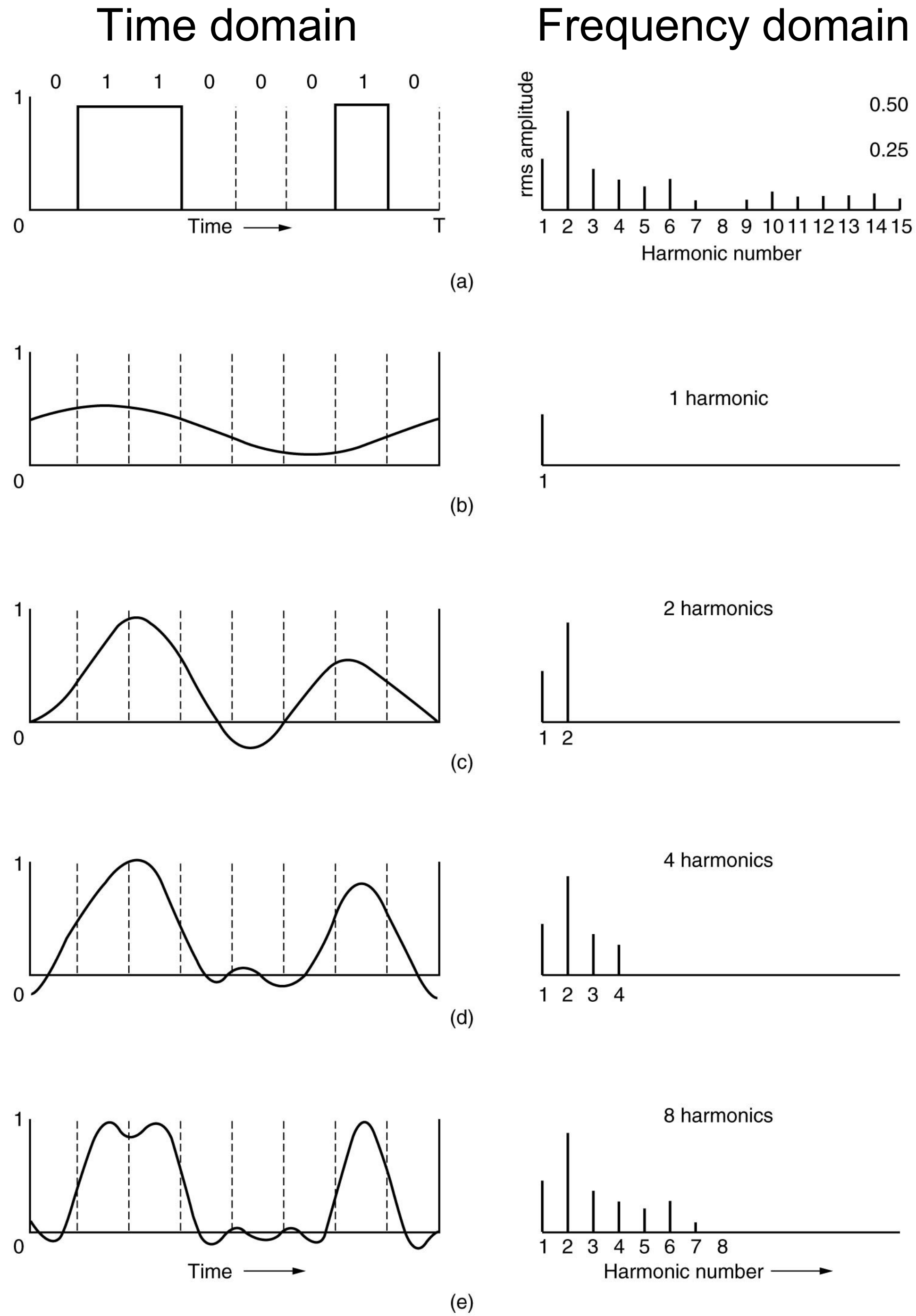
Fourier transform $G(f) = \int g(t) e^{-2\pi j f t} dt$

Inverse Fourier transform $g(t) = \int G(f) e^{2\pi j f t} df$

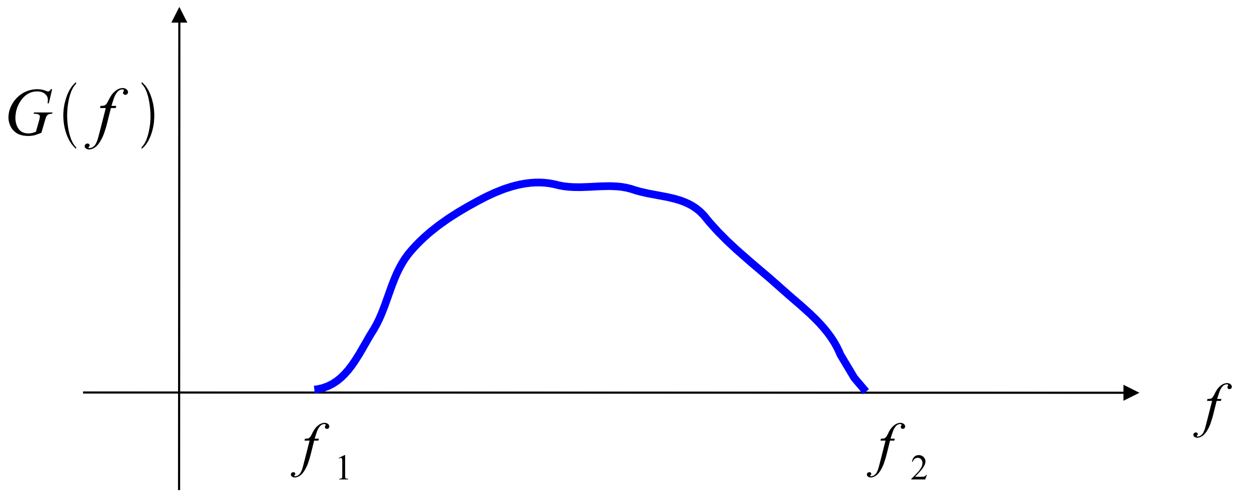
$$e^{2\pi j f t} = \cos(2\pi ft) + j\sin(2\pi ft)$$

Square Wave

- As we add the different frequency components the resultant approaches the square wave

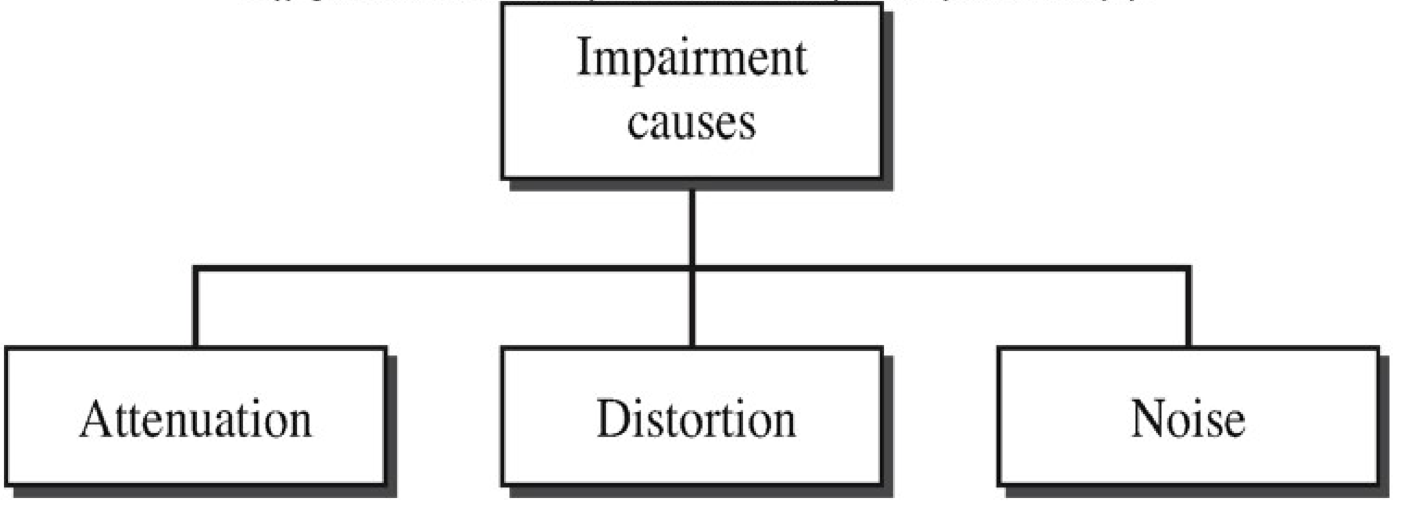


Bandwidth of Signal

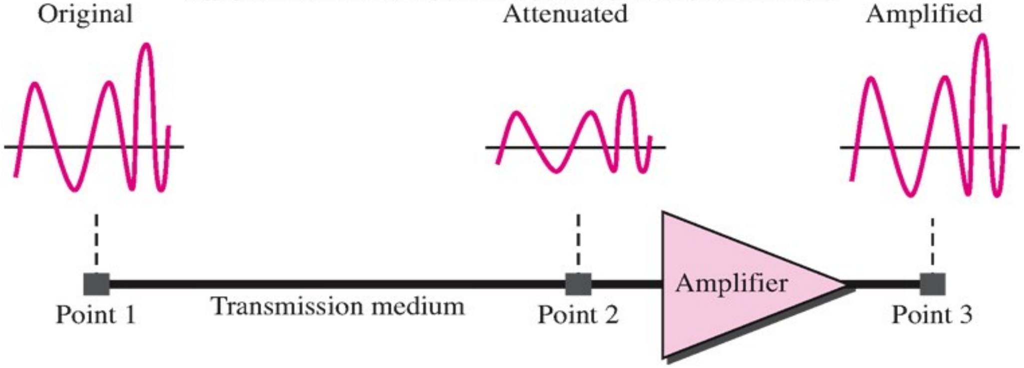


- (3dB??) Bandwidth is difference between maximum and minimum frequency in Fourier transform, $f_2 - f_1$

Impairment of Signals



Attenuation



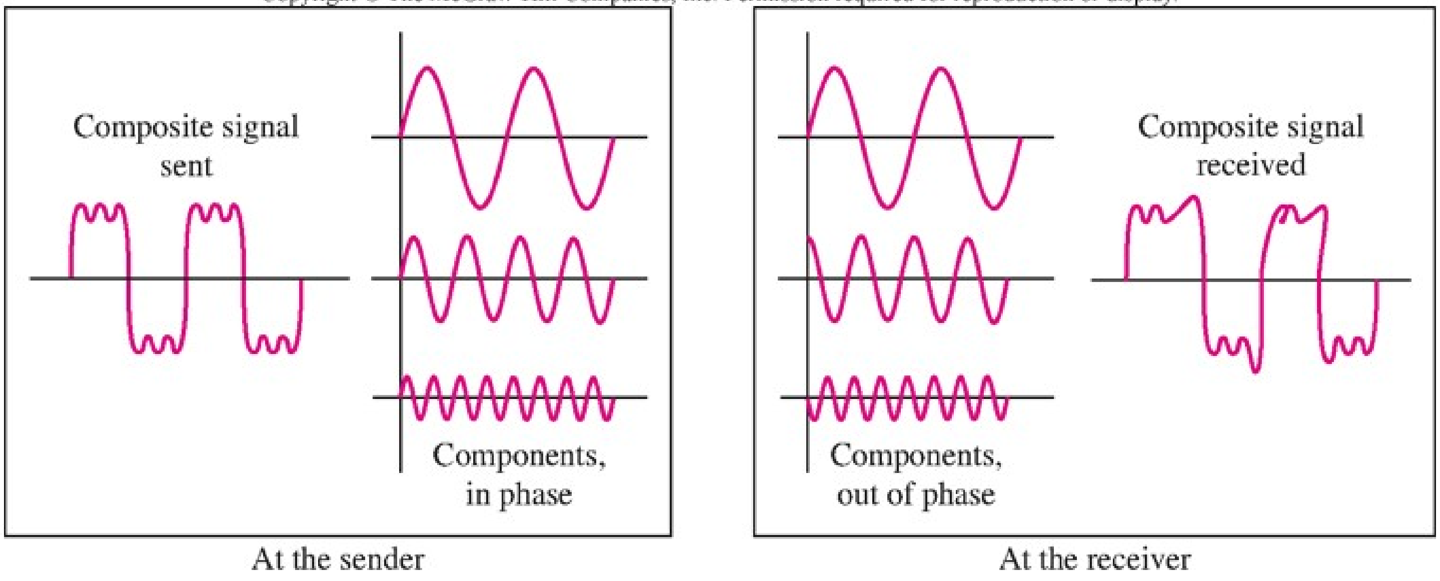
- Signal amplitude decreases because energy gets dissipated in transmission medium
- Attenuation measured in decibels (dB)

$$\text{Attenuation} = 10\log\frac{P_{input}}{P_{out}} \text{ dB}$$

where P_{input} = input power, P_{out} = output power

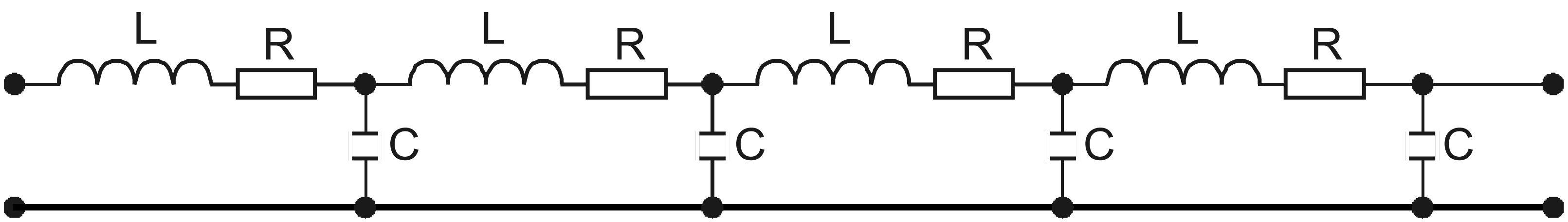
- Need for amplification

Distortion



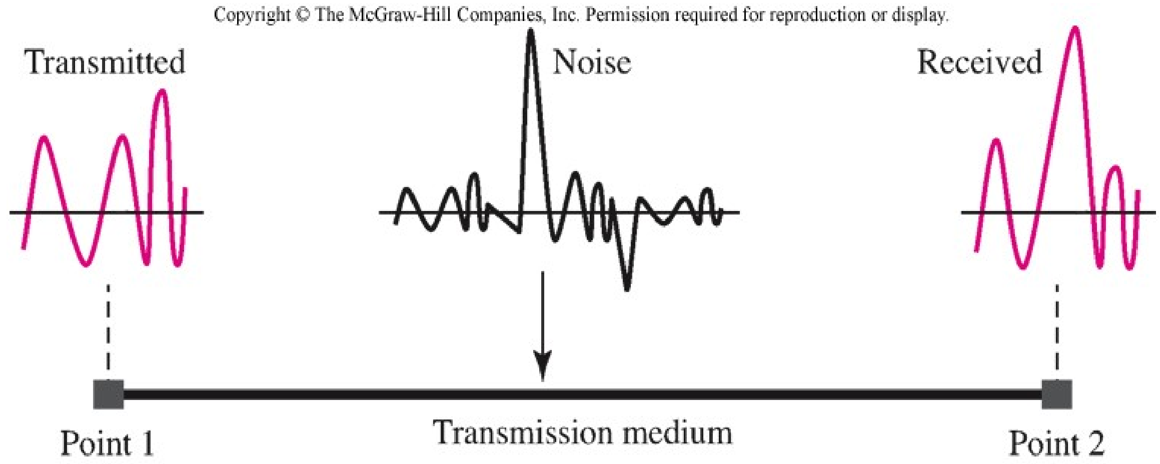
- Different frequency components delayed by different amounts --- misaligned with each other
- Resulting signal at receiver is sum of misaligned sinusoids

Cause of Distortion



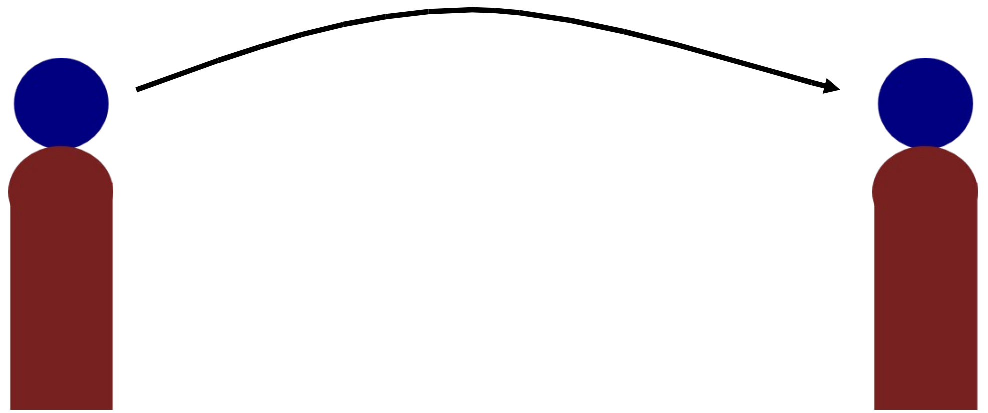
- Can model a transmission medium as a set of
  - resistors (***R***, dissipate energy)
  - inductances (***L***, stores energy in magnetic field)
  - capacitances (***C***, stores energy in electric fields)
- *R*, *L*, *C* together called impedance
- Impedance affects attenuation and distortion

Noise



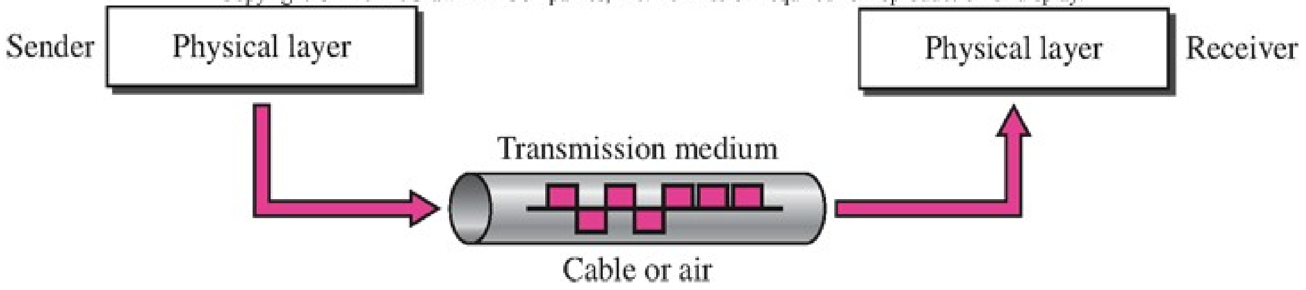
- Received signal = transmitted signal (attenuated, distorted) + noise
- Causes of noise
  - Crosstalk -- interference from other signals being transmitted nearby
  - Thermal noise in circuit at receiver
- Signal to noise ratio (SNR) – ratio of signal power to noise power is crucial factor in performance

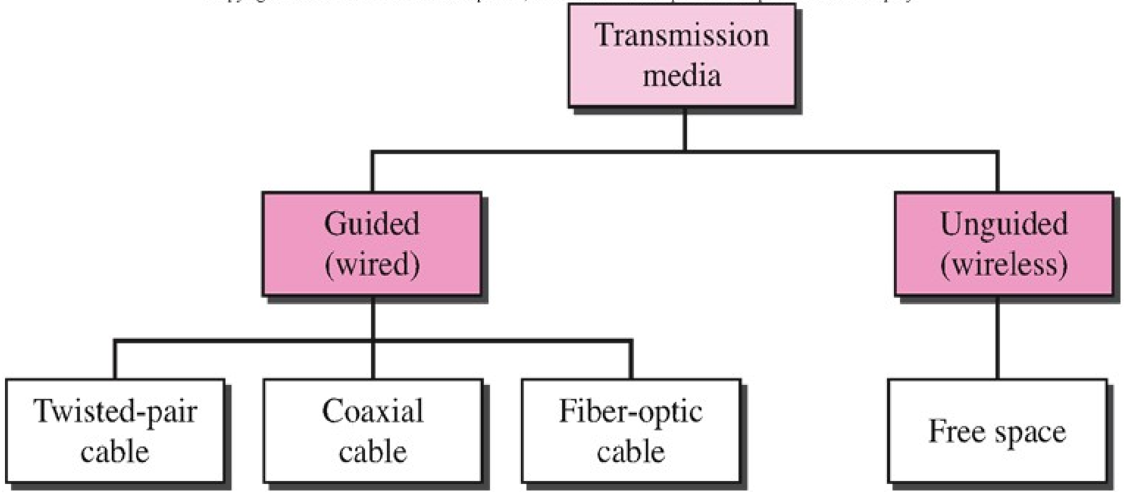
Outline of Point-to-Point Communication



1. Signals – basic signal theory
2. Media – Different transmission media
3. Language – Modulation Techniques

Different Transmission Media

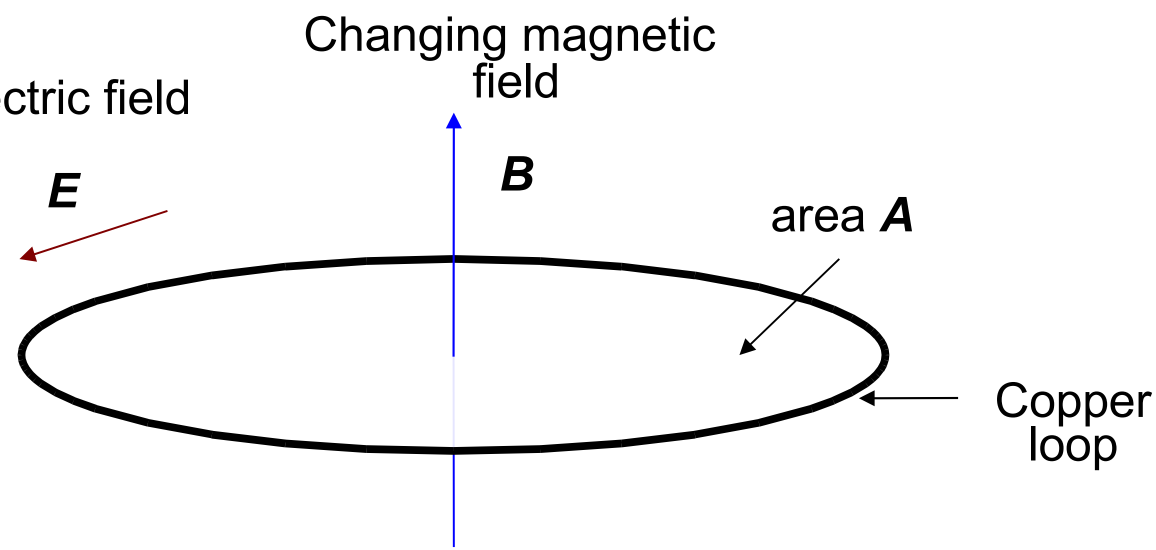




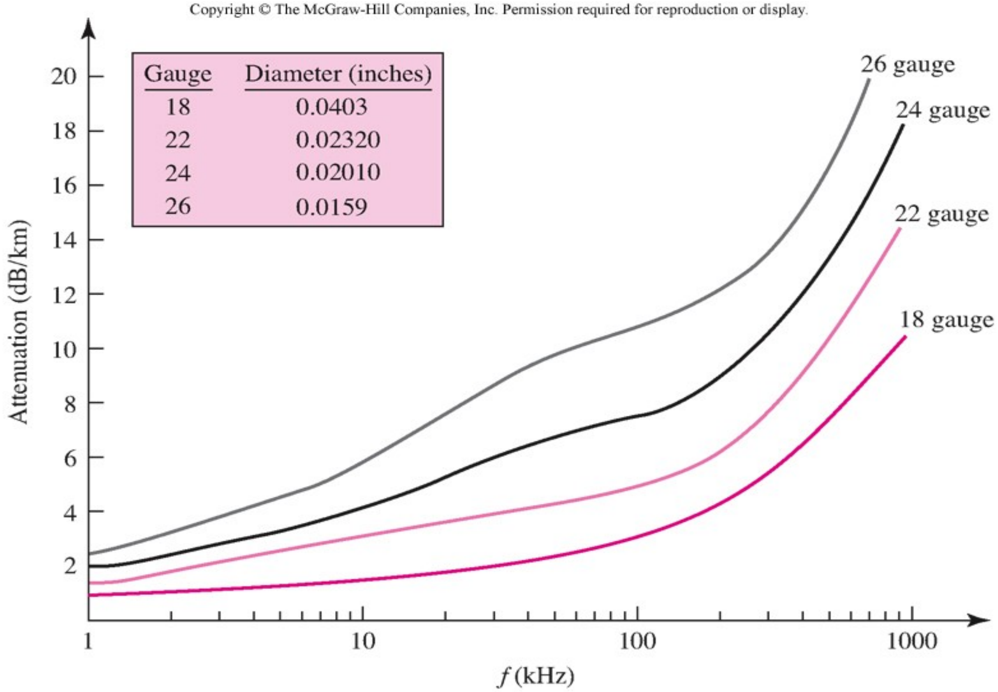
Twisted-Pair Cable

- Telephone lines are usually twisted-pair
- Material: copper
- Intertwining reduces magnetic coupling interference from noise sources

$$E \propto -\frac{dB}{dt} \times A$$

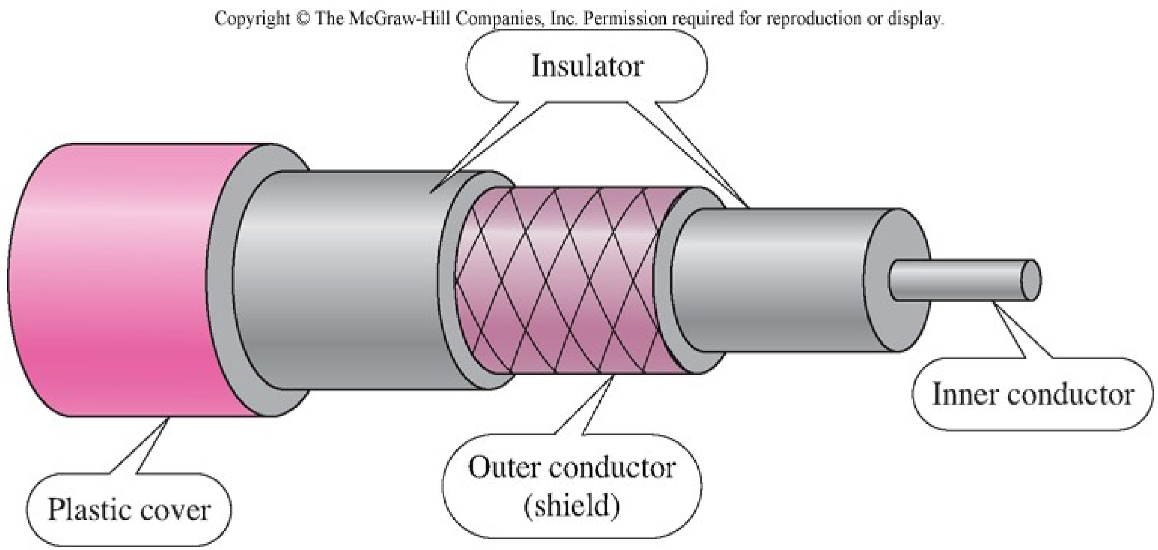


Signal Attenuation - Twisted-Pair



- Signals at higher frequencies have greater attenuation
- Result?
- Attenuation depends on impedance
  - Why is attenuation higher for higher frequencies?

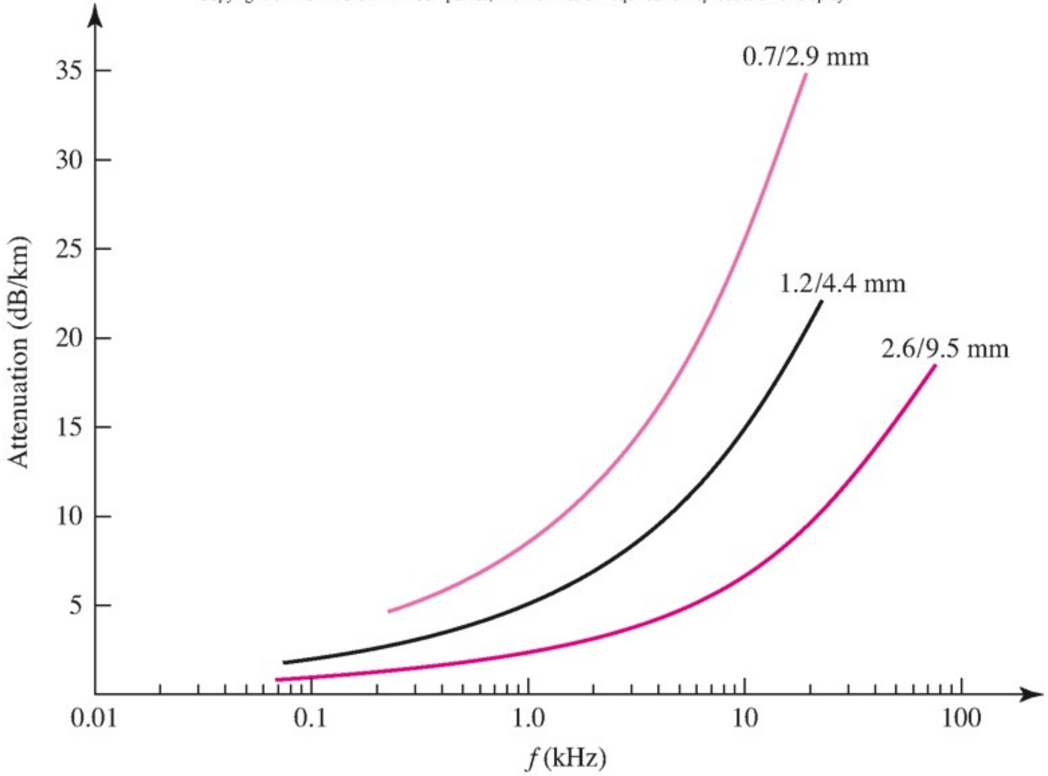
Coaxial Cable



- Current travels in opposite directions in inner and outer conductors
  - In theory, zero loop area --- no magnetic coupling
  - Good shielding from electric coupling
- Material: copper

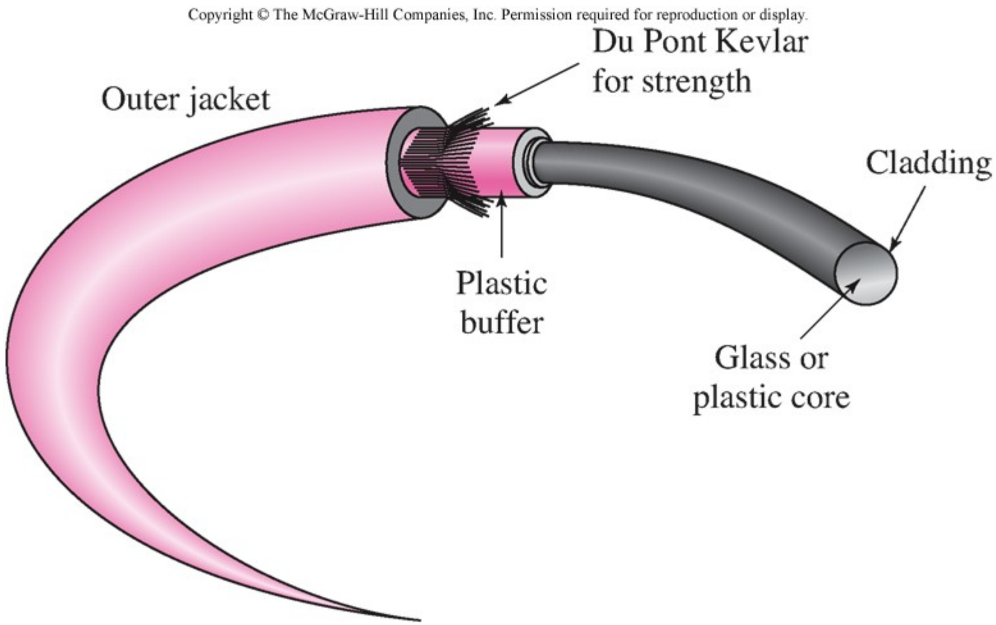
- Used for Ethernet LANs, Cable TV
- Not as flexible as twisted-pair

Signal Attenuation – Coaxial Cables



- Attenuation increases with frequency
- Larger signal attenuation than twisted-pair
- More robust to noise

Optic Fibre

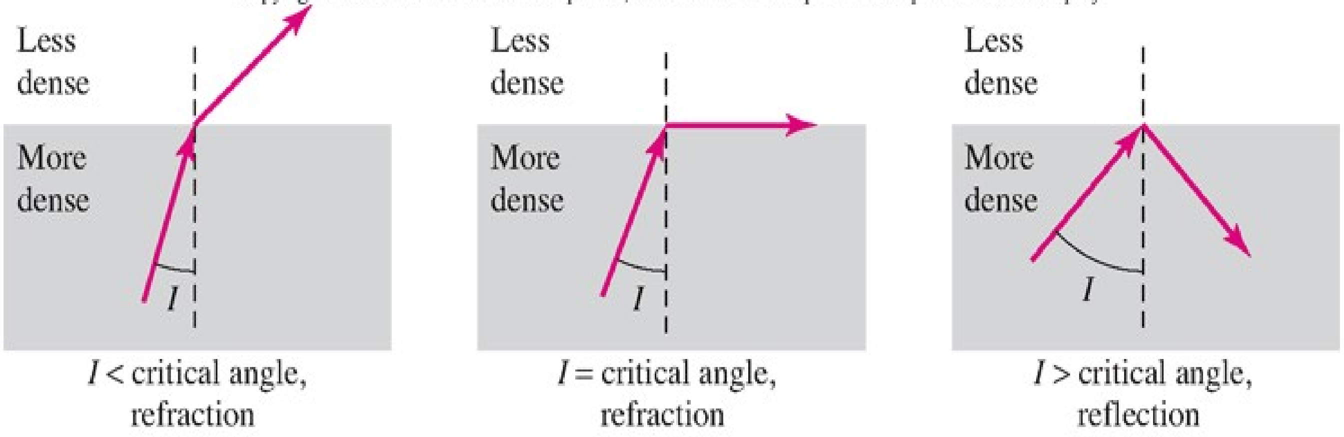


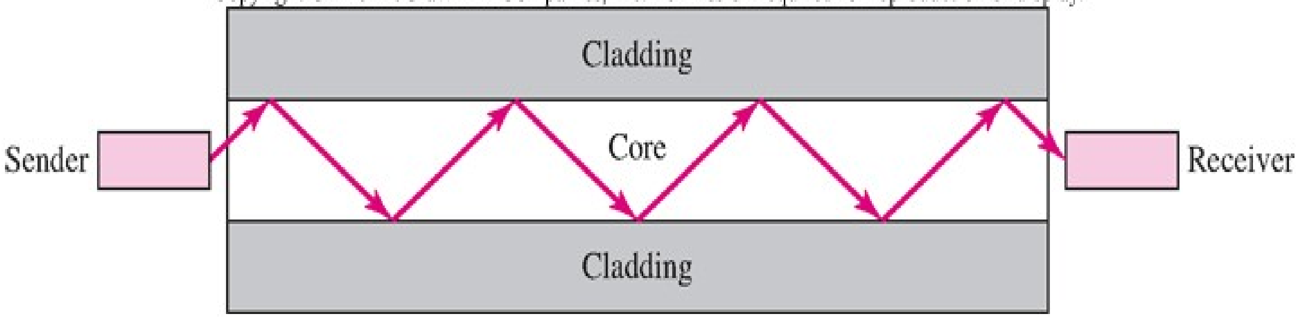
- Information sent as light signals unlike coaxial/twisted-pair

- Material: glass
- SONET, some cable TV, 1000Base-X Gigabit Ethernet

- Light travels in straight lines. How to transmit over bent cable?

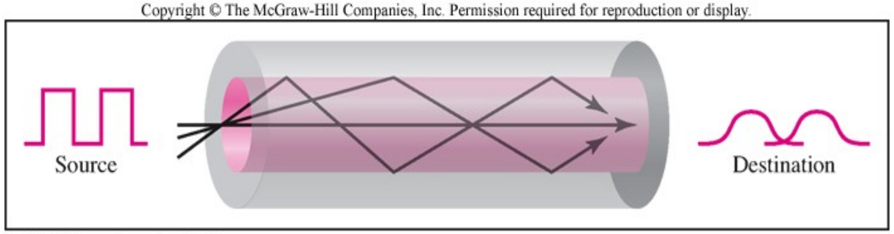
Light Propagation in Optic Fibre



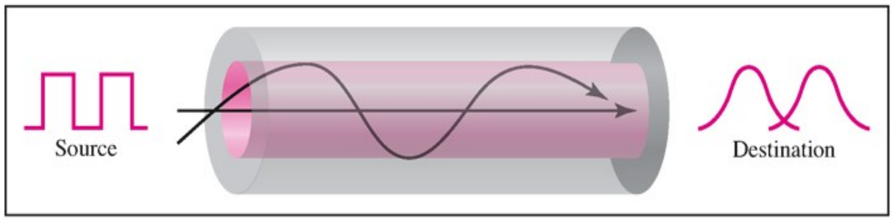


- Total internal reflection to the rescue

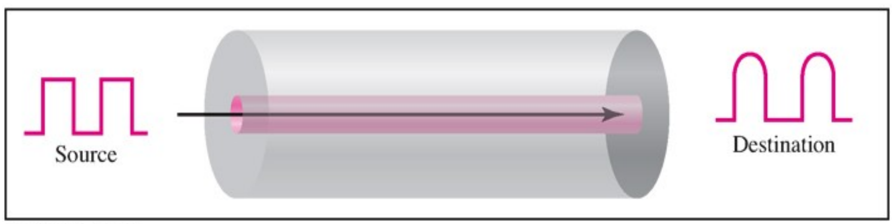
Single Mode and MultiMode Fibre



a. Multimode, step index



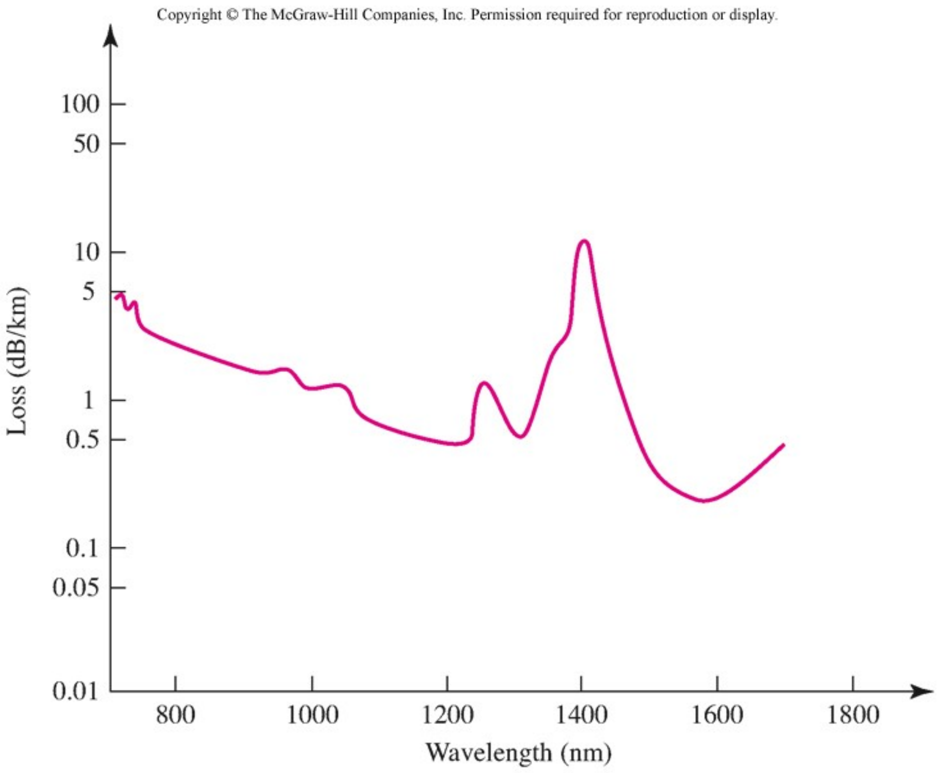
b. Multimode, graded index



c. Single mode

- mode – wave with particular angle of reflection
- Different modes have different delays
- Multimode fibre – signal gets spread out over time, more distortion
- Graded index – refractive index changes gradually with distance from center

Signal Attenuation – Optic Fibre

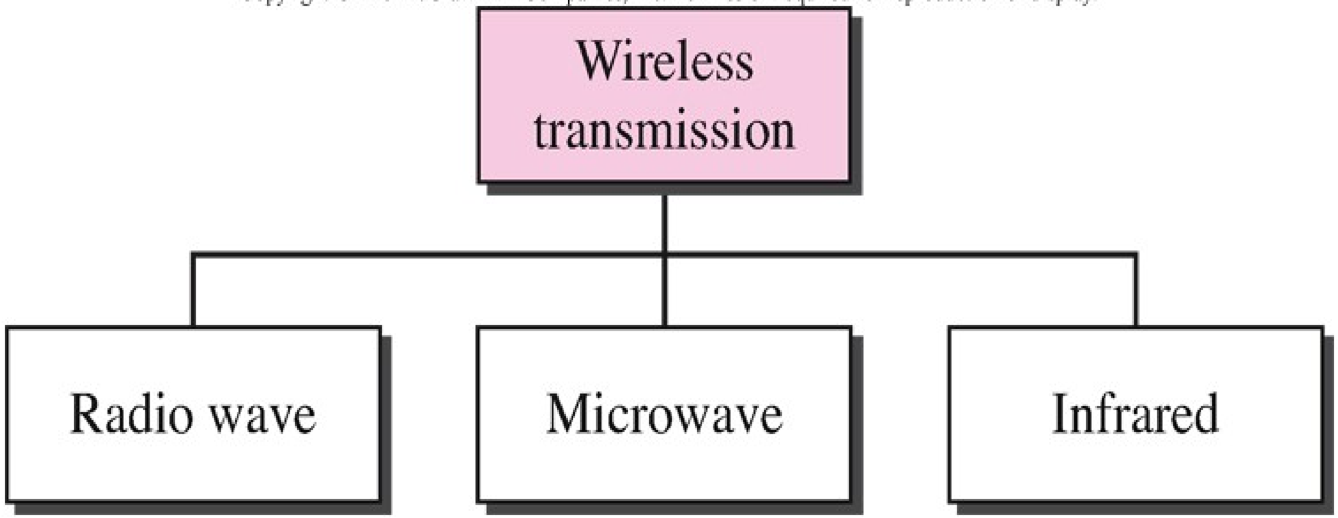


- Attenuation does not vary by much with frequency
- Advantages (vs. twist/coax)
  - Very high bandwidth
  - Corrosion resistant
  - Immunity to EM interference, tapping
  - Light weight
- Disadvantages
  - High cost
  - Requires expertise for operation

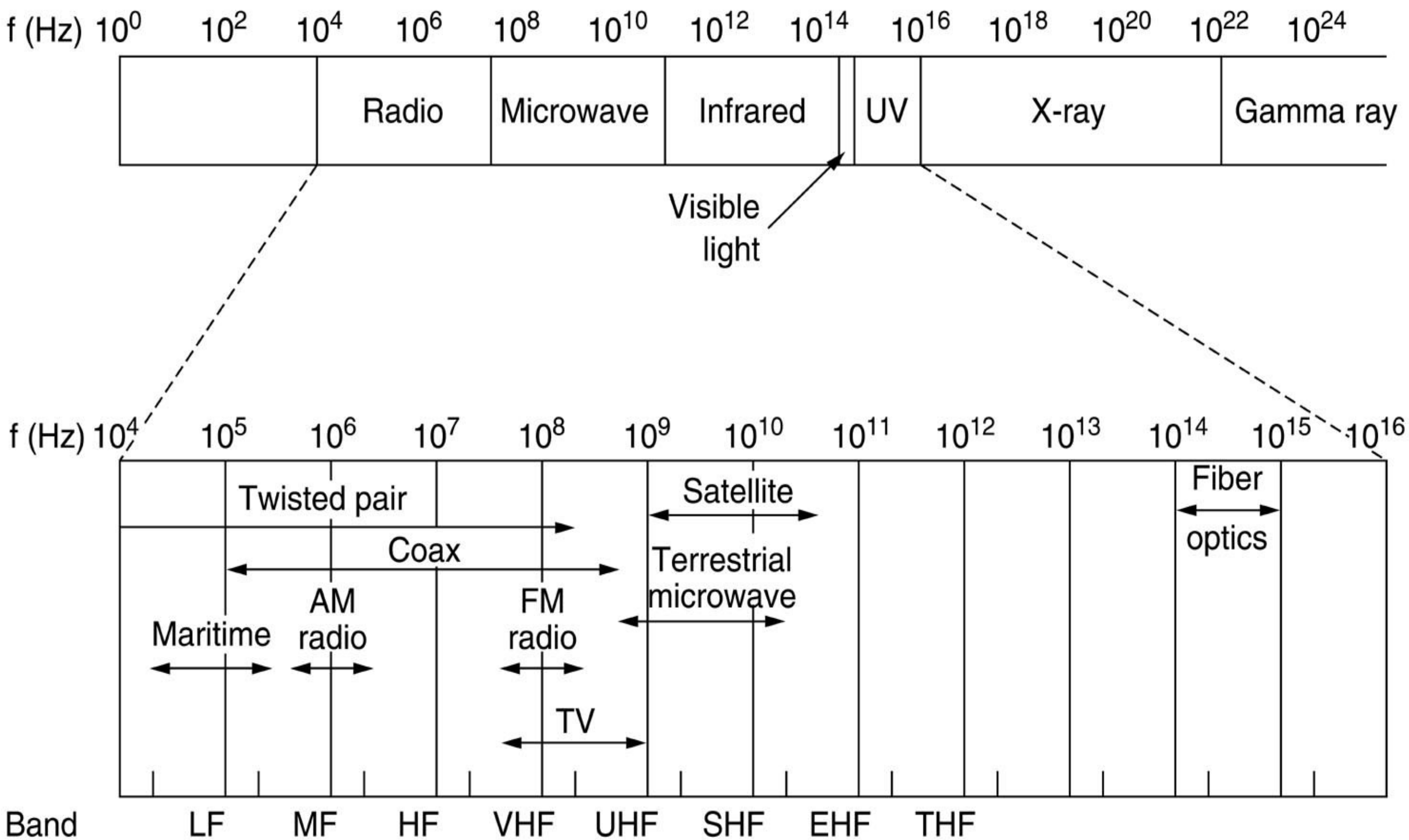
Practical Data Rates with Wired Media

- Very high-rate DSL – 26Mbps for 300m long wire
- Gigabit Ethernet – 1Gbps
- Synchronous Optical Networking (SONET) – upto 10Gbps

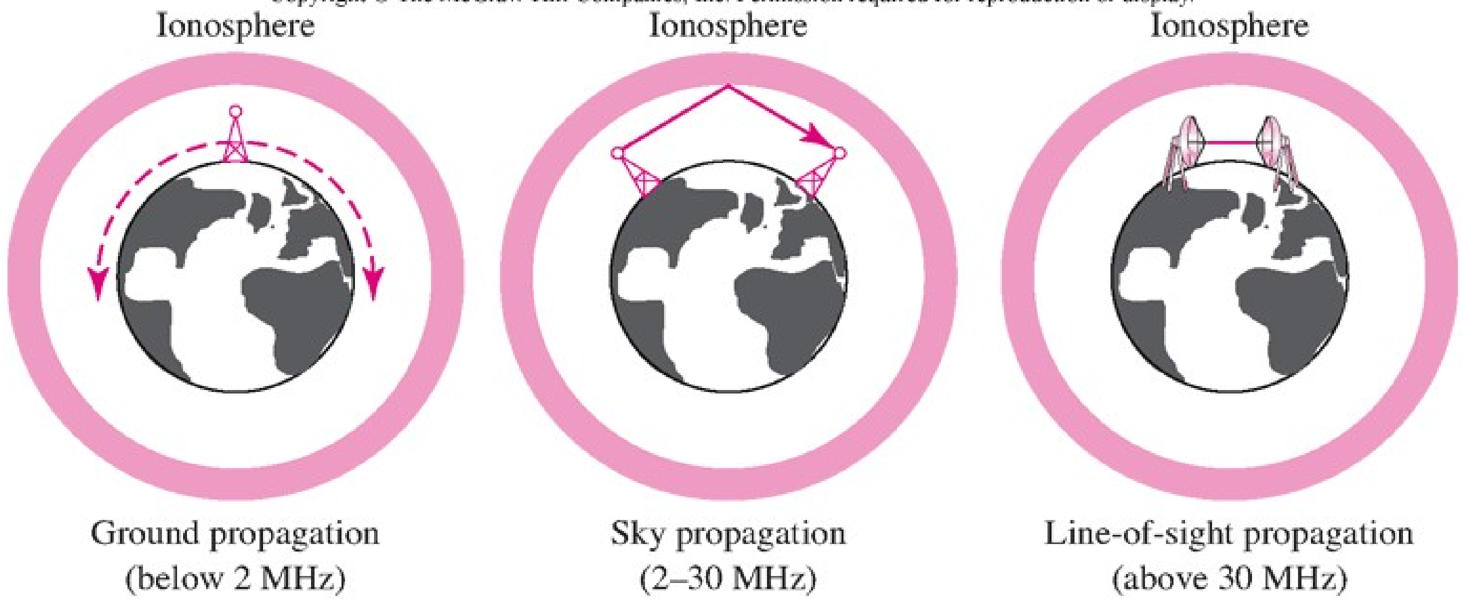
Wireless Transmission



Electro-Magnetic Spectrum



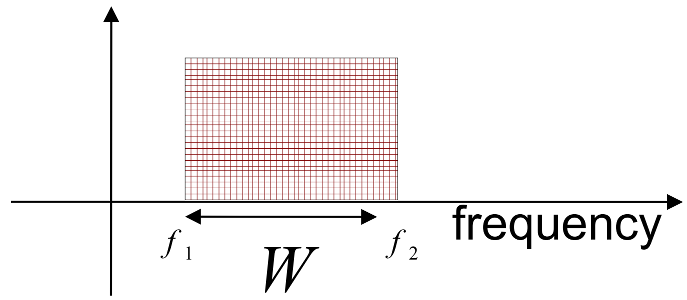
Types of Propagation

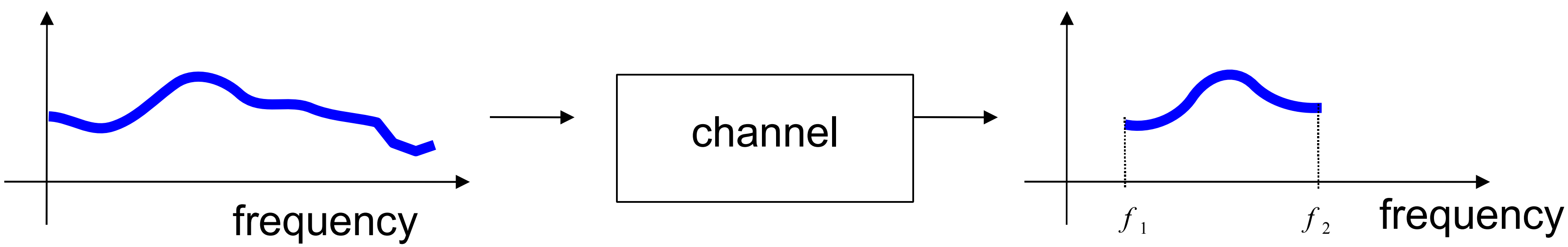


- Low frequency (LF) waves (<2MHz) travel around objects
- High frequency (HF) bounce off the ionosphere
- Microwaves travel in straight lines, permit line-of-sight propagation
- Infrared does not pass through objects, good for short distance indoor (remote controls)

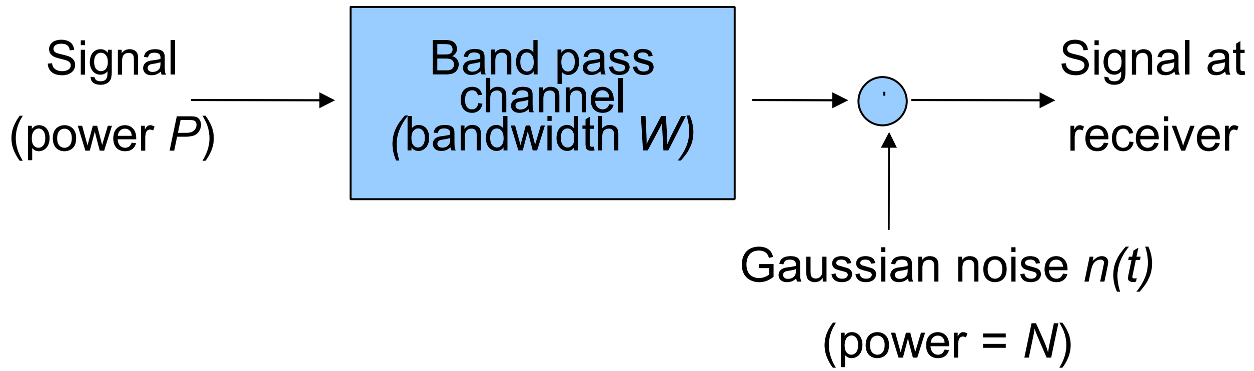
Revisit of Shannon Capacity

- Suppose media (channel) acts as a band pass filter
- Band pass filter --- removes all frequencies of a signal outside a frequency band of width *W*



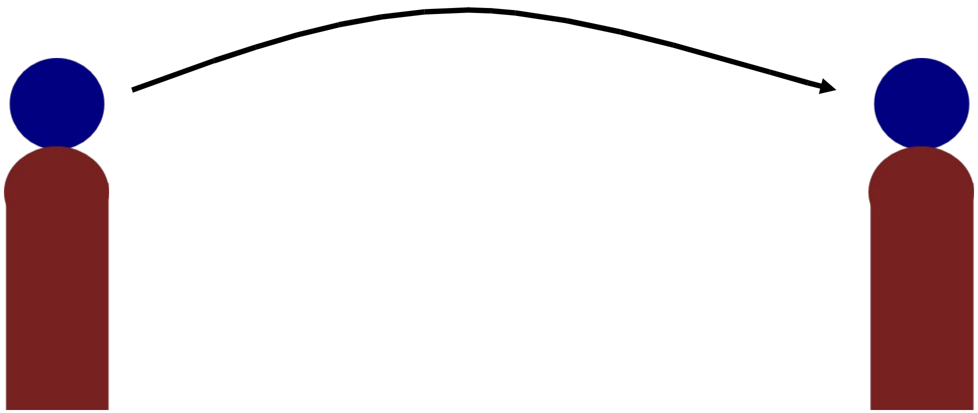


Capacity of Channel with Gaussian Noise



- Gaussian noise – at each time *t*, noise *n(t)* is a Gaussian random variable
- Capacity = $W \log\left(1 + \frac{P}{N}\right) = W \log(1 + SNR)$
- Shannon does not tell us how to achieve capacity

Outline of Point-to-Point Communication



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Modulation

- How would you send information over channel?

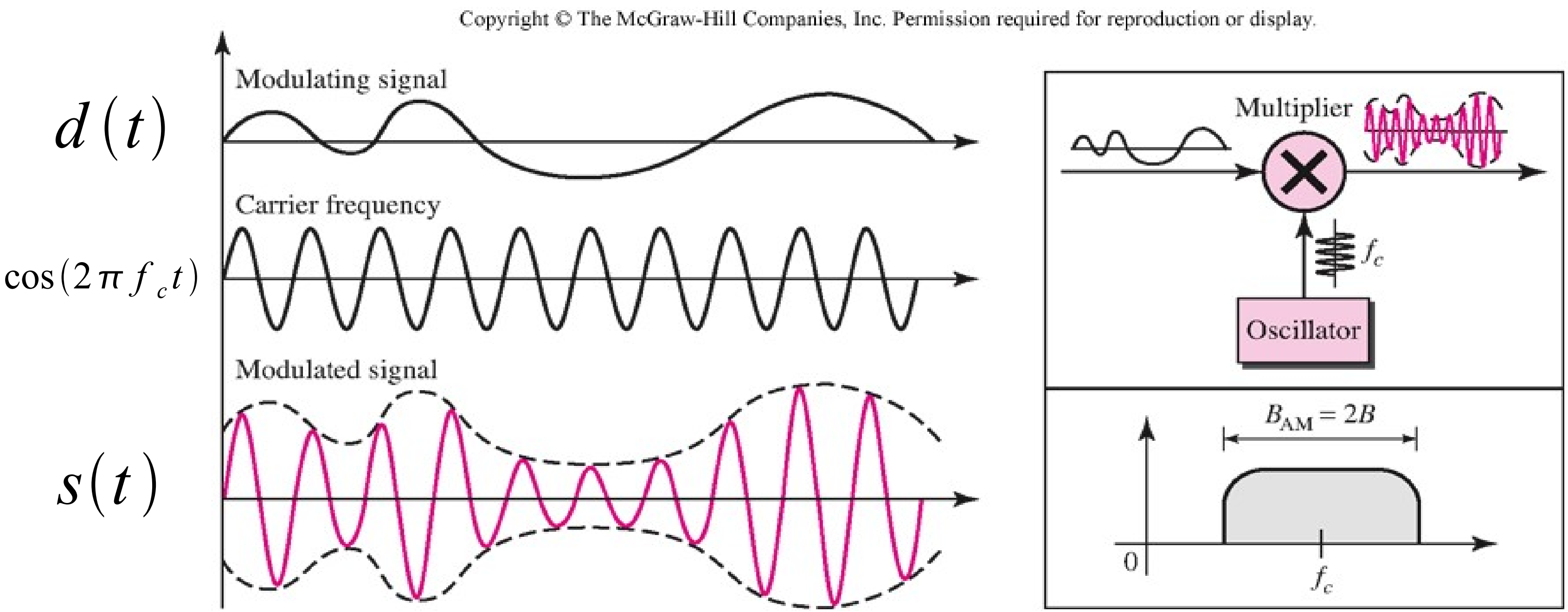
- What if information signal cannot be sent “as is” over the channel?

  Example: Suppose allotted 1-2GHz radio frequencies (channel), want to send voice signal (<4kHz)

- Must somehow convert a 4kHz signal into a 1-2GHz signal for transmission.

- How?

Amplitude Modulation (AM)



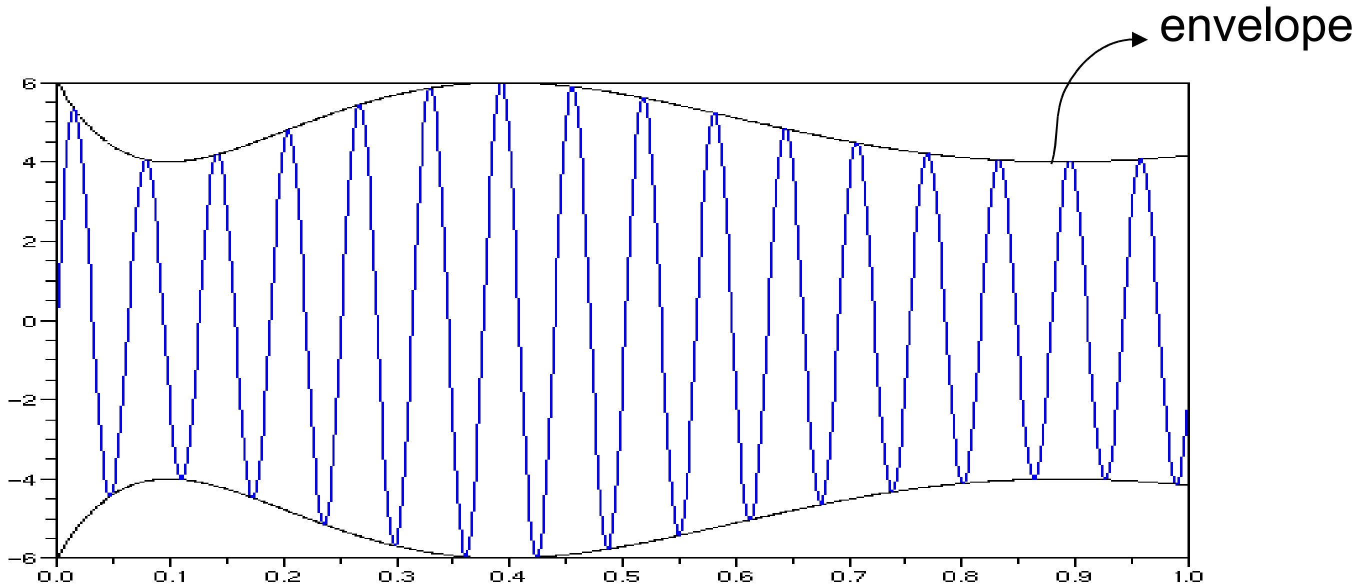
$$s(t) = d(t)\cos(2\pi f_c t)$$

- Multiply carrier frequency (e.g. 1GHz sinusoid) with information bearing signal (e.g. 4kHz voice)

bandwidth *d(t)* ⟶ *B* Hz
bandwidth *s(t)* ⟶ *2B* Hz.

Demodulating AM

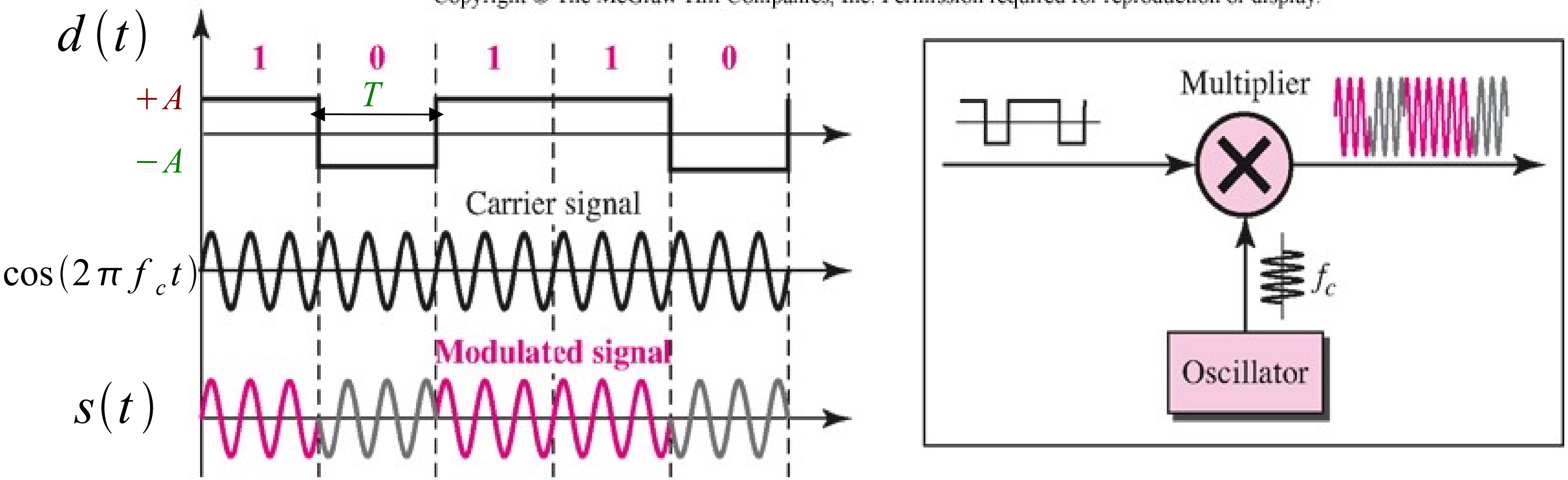
- How do we recover *d(t)* from *s(t)* at receiver?



- Envelope detection: receiver ignores fast changes and only keeps track of envelope

Binary Phase Shift Key (BPSK)

- Information signal is digital (ones and zeros)

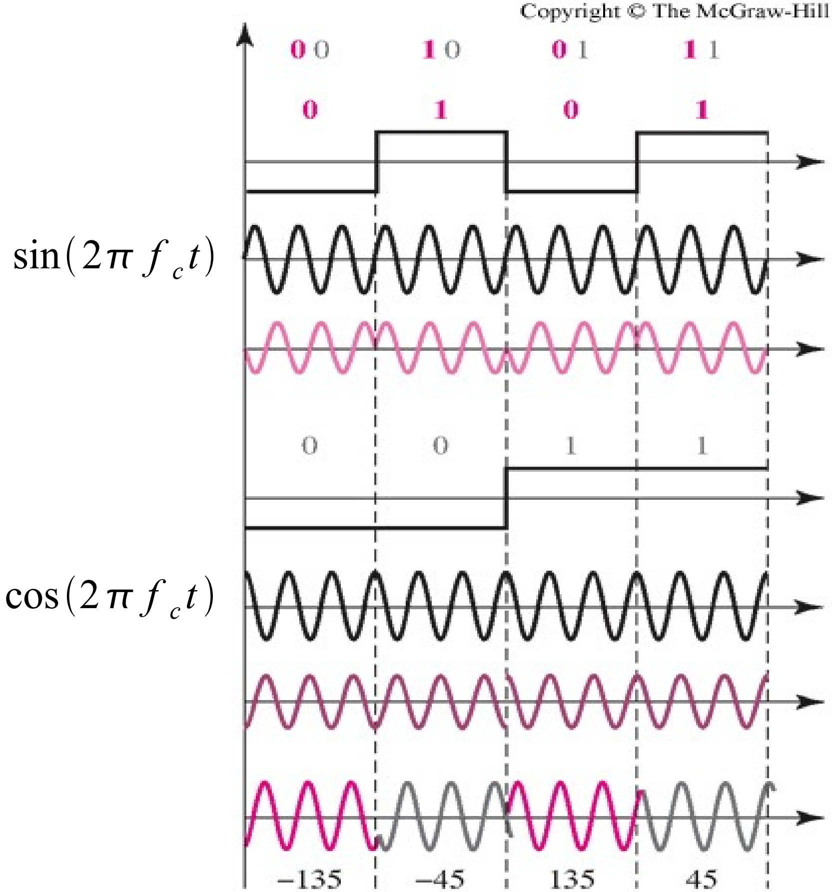


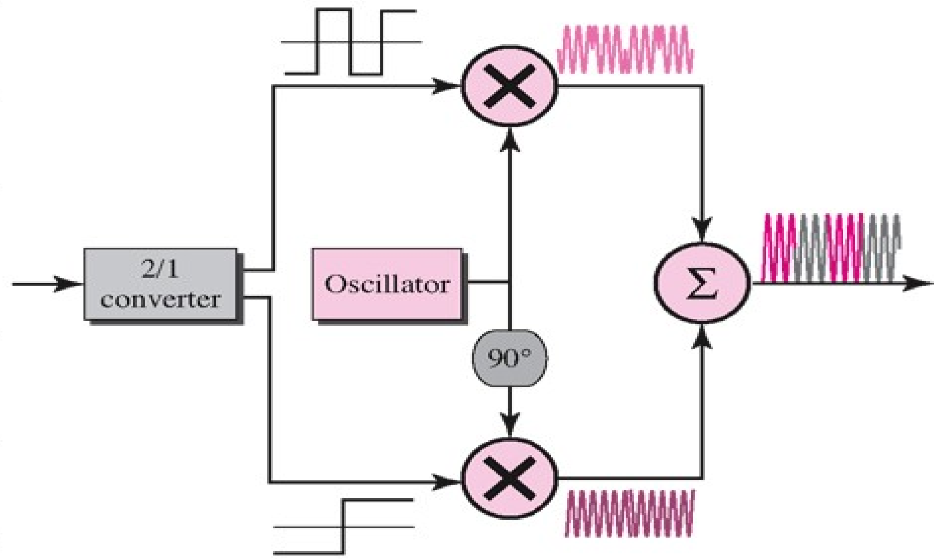
- Bit 1 ⟶ constant, amplitude A, duration T sec
- Bit 0 ⟶ constant, amplitude $-A$, duration T sec

data rate= 1/T bits/sec

Demodulation – detect abrupt change in phase

Quadrature Phase Shift Key (QPSK)

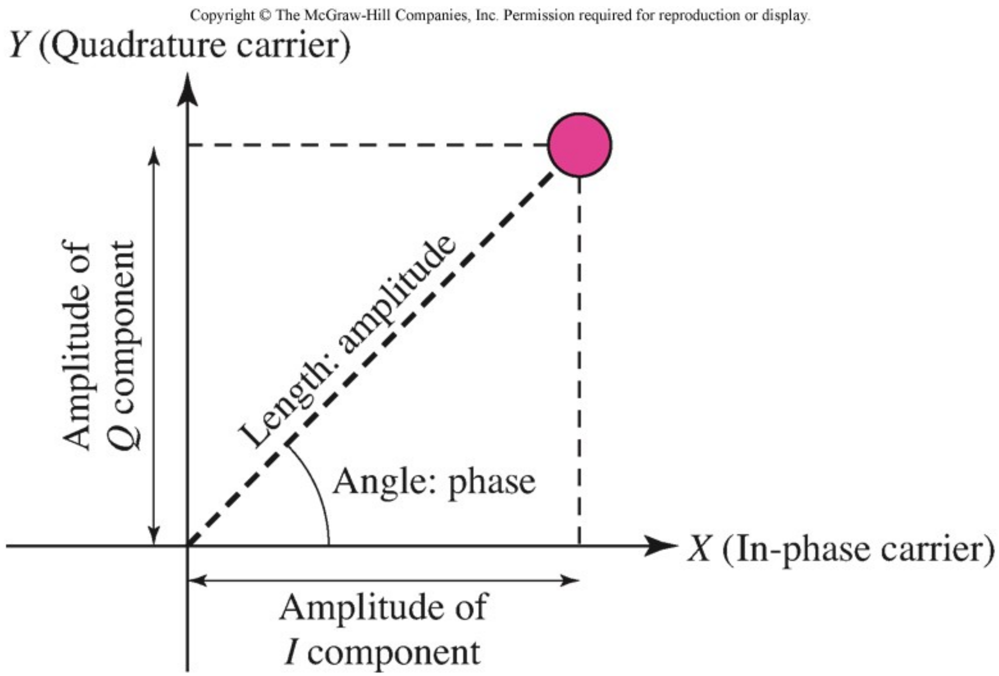




Data-rate 2 times rate of BPSK

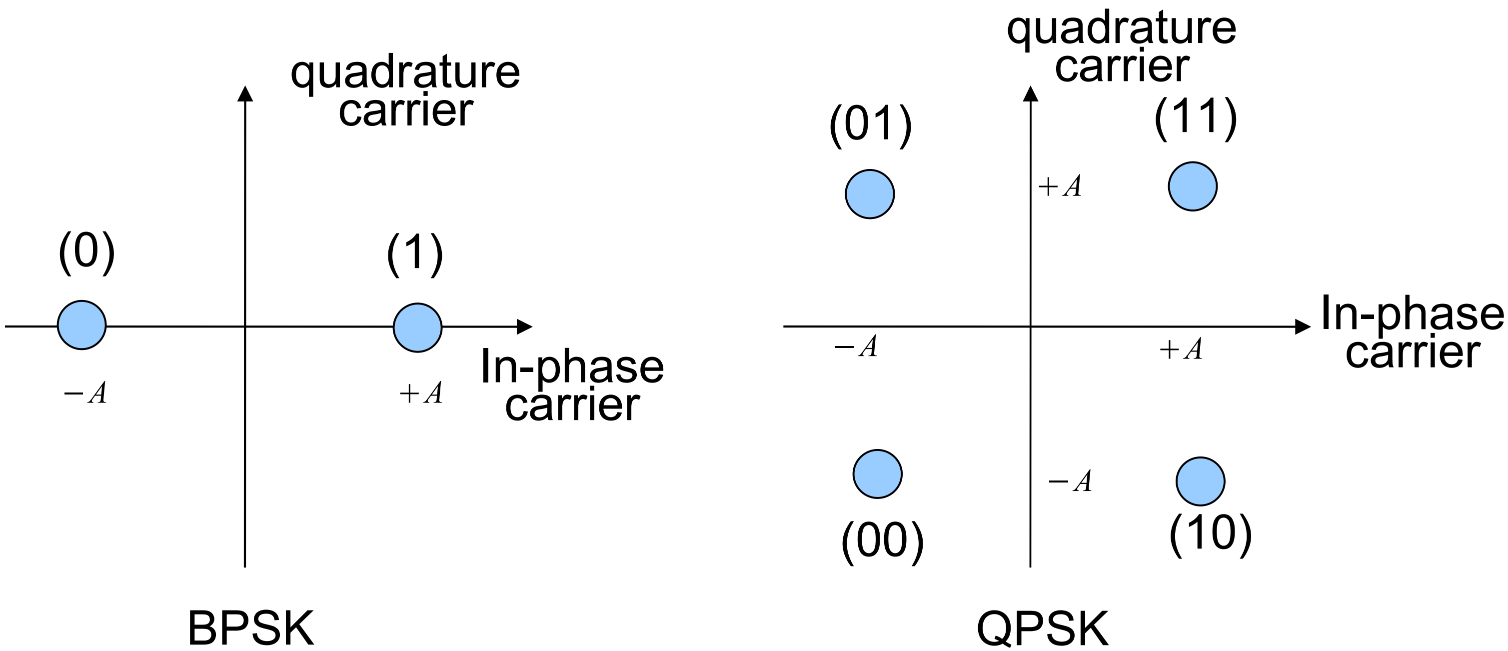
- Use two carriers
- Modulate $\sin(2\pi f_c t)$ with odd bits -- quadrature component
  $\cos(2\pi f_c t)$ with even bits – in-phase component

Constellation Diagrams



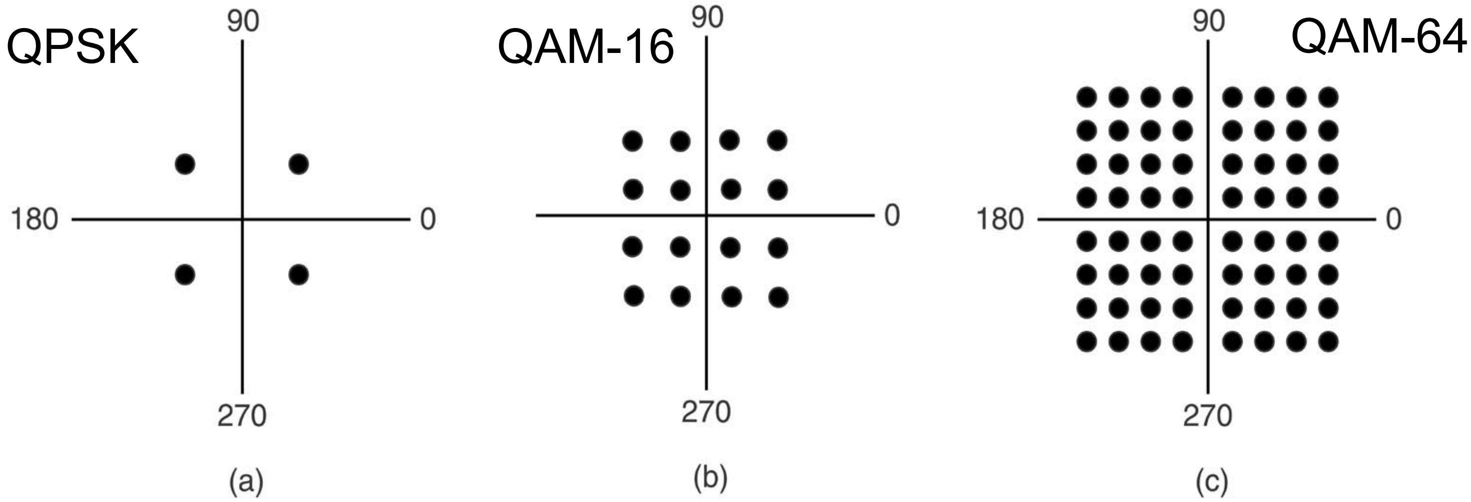
- X-axis – in-phase component
- Y-axis – quadrature component
- Each *signal element* represented by point in constellation diagram
- Signal element – transmitted signal corresponding to a binary information signal (1 bit for BPSK, 2 bits for QPSK)

Constellations of BPSK, QPSK



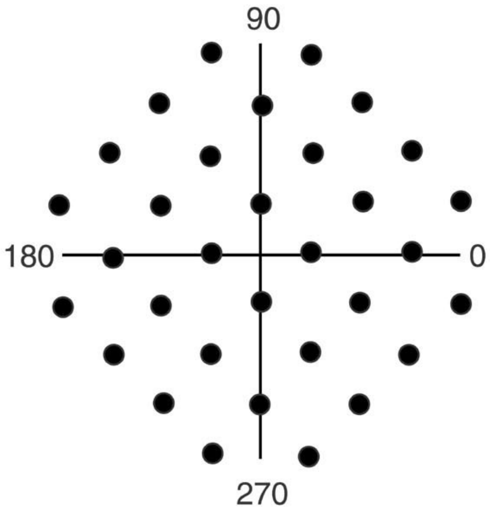
- BPSK has 2 signal elements
- QPSK has 4 signal elements

Quadrature Amplitude Modulation (QAM)

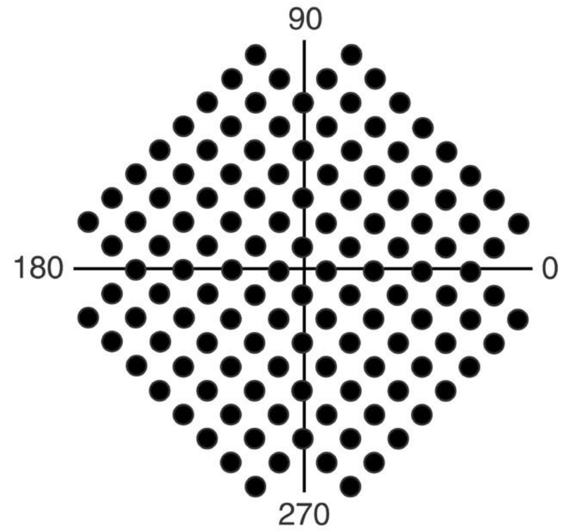


- Signal elements have different amplitude and phase
- Each signal element of QAM-2^n corresponds to *n*-bits of information

Constellations of Telephone Modems



V.32

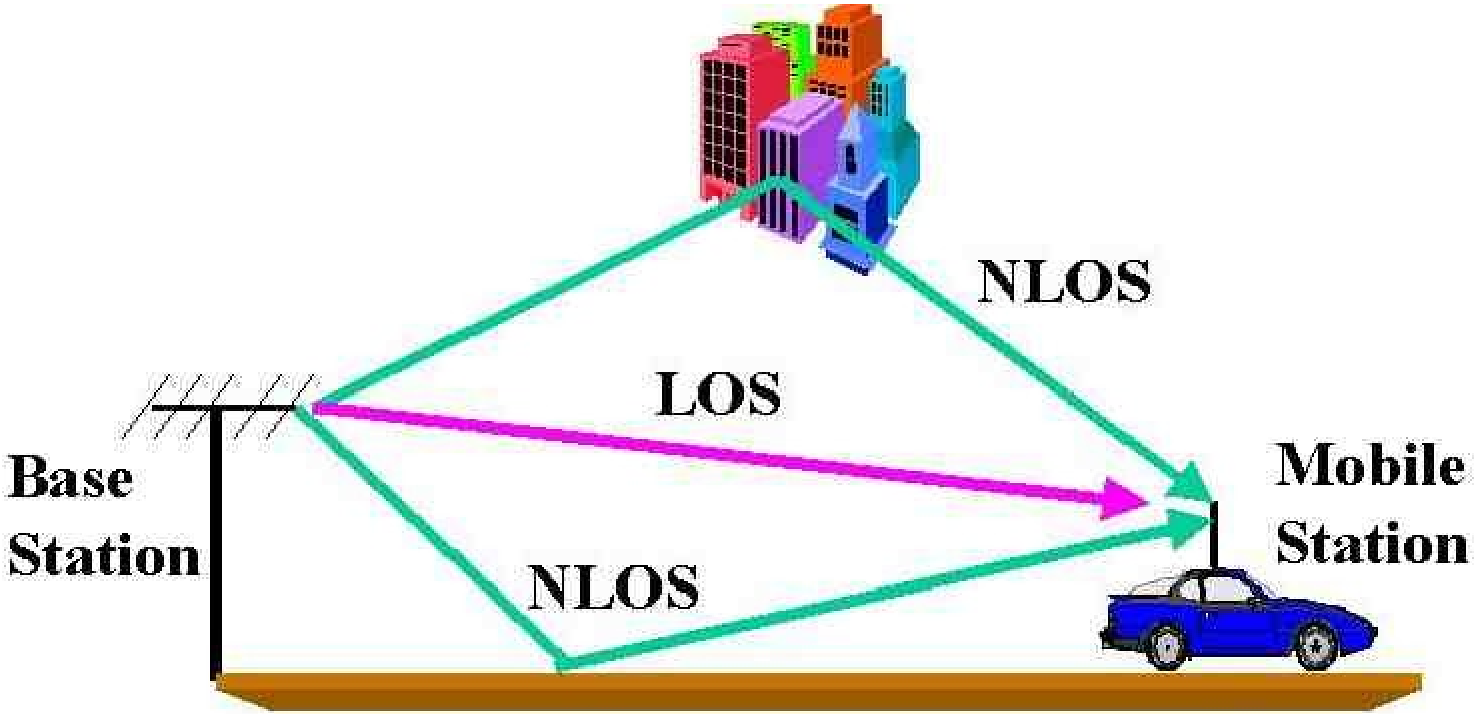


V.32 bis

- Why do modems make squeaky noise when turned on?

Multipath Fading

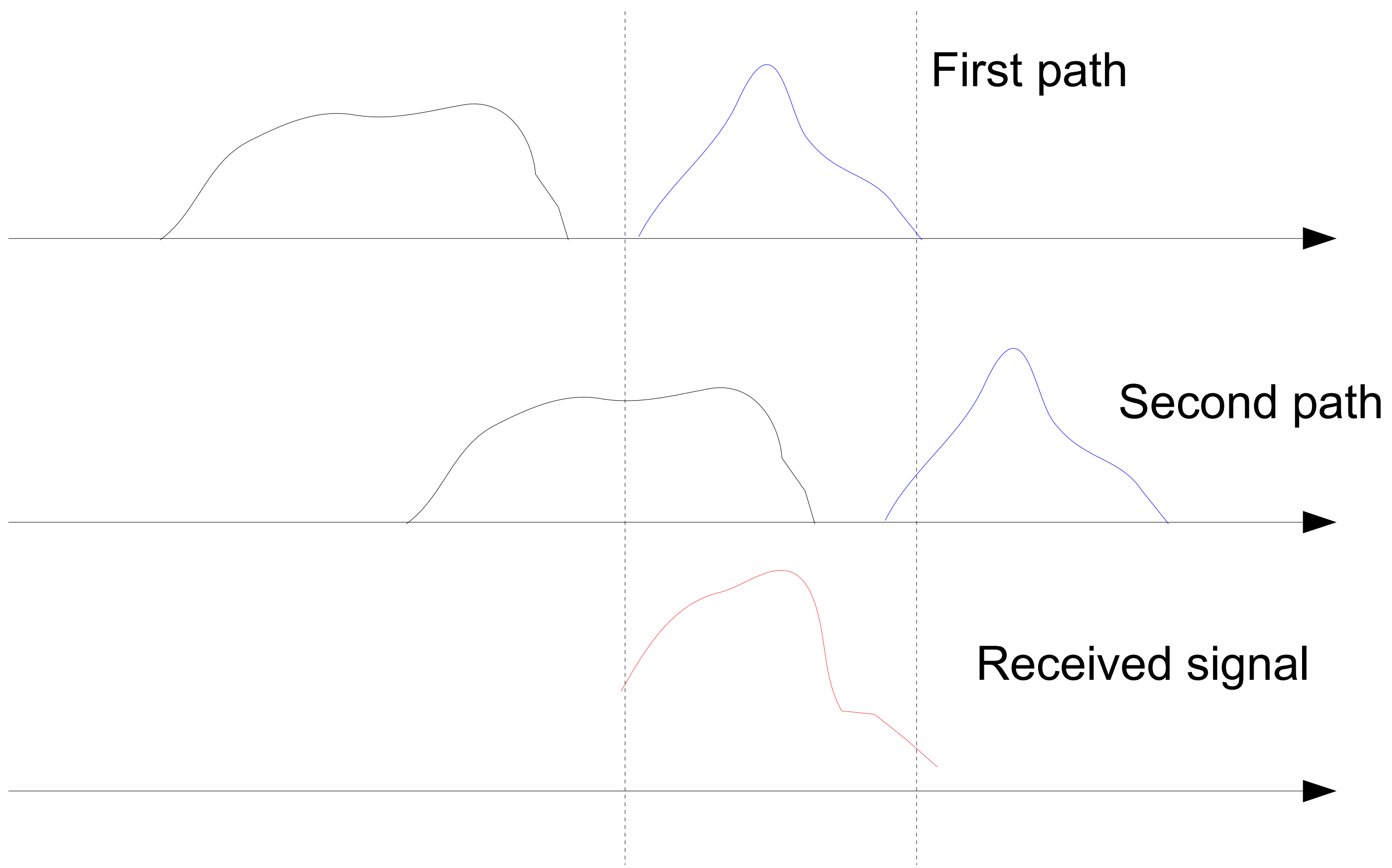
- Wireless channel – signal can take multiple paths to receiver, different delays



Courtesy: users.ece.gatech.edu/~mai

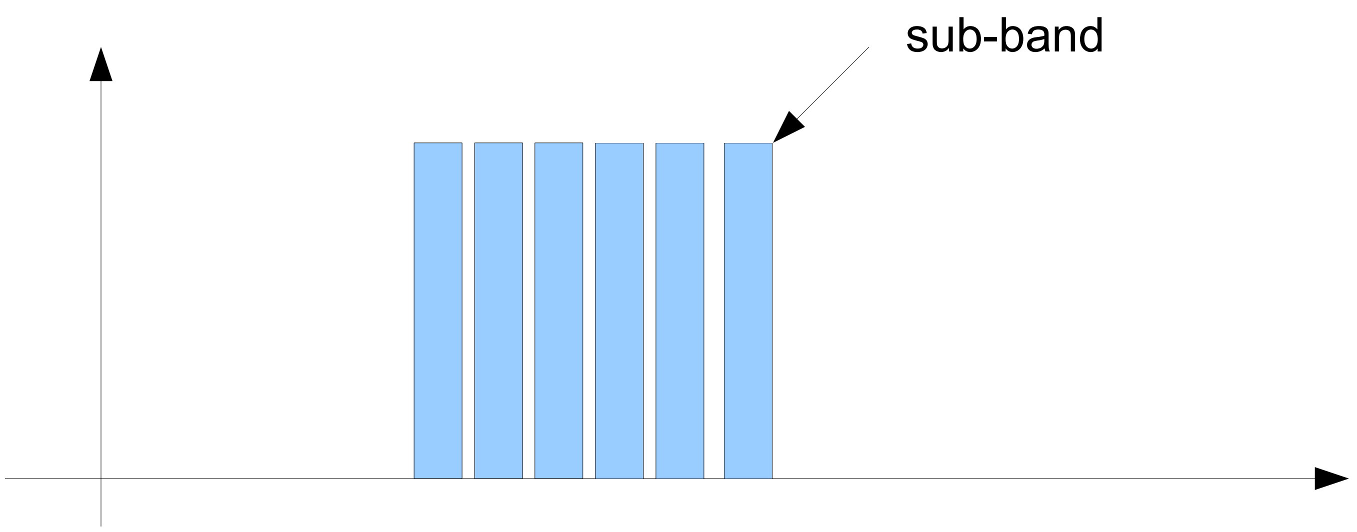
Inter-Symbol Interference (ISI)

- Signals from different paths interfere with each other



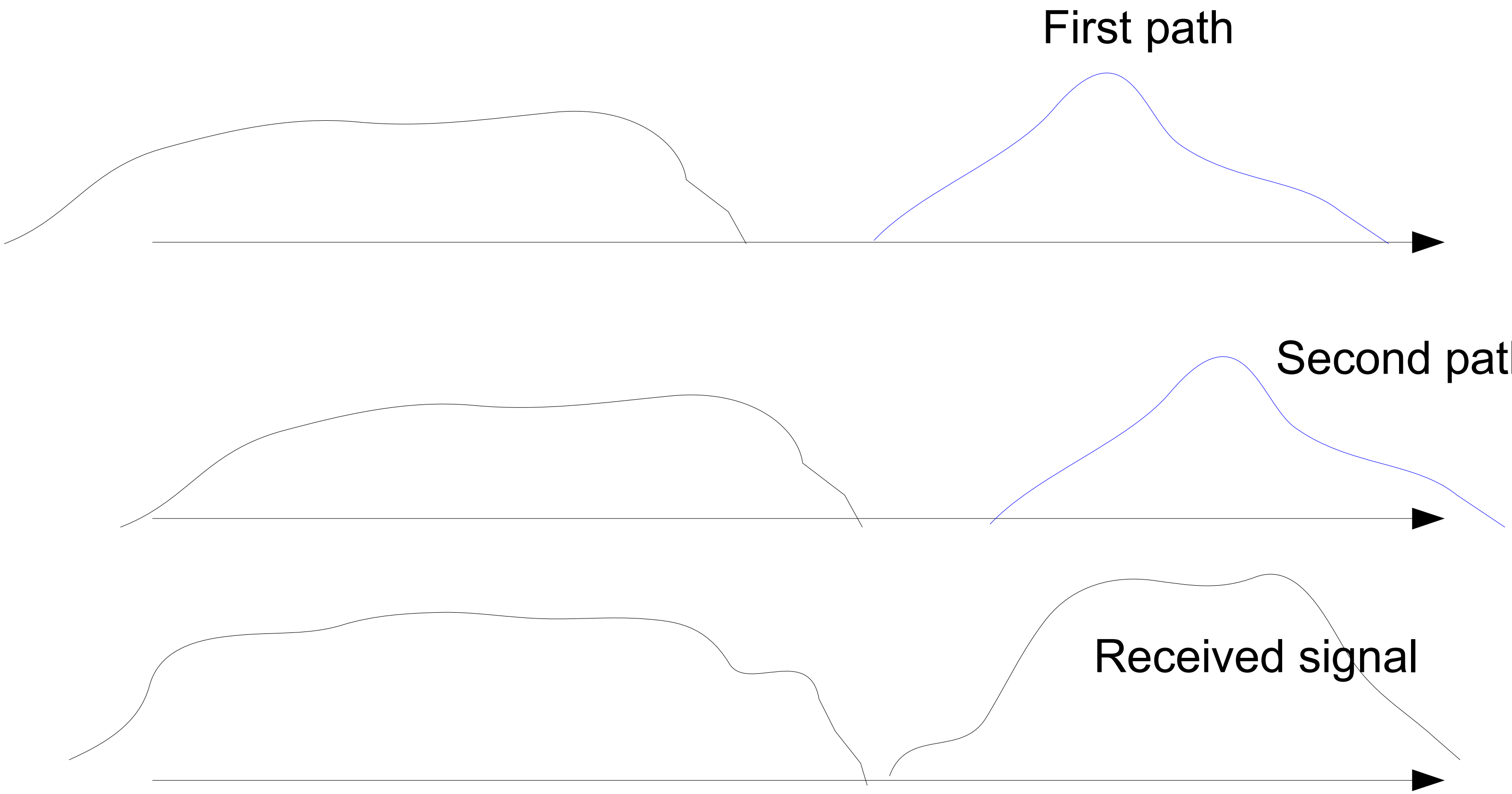
Orthogonal Frequency Division Multiplexing (OFDM)

- Reduce effect of multipaths
- Divide frequency band into narrow sub-bands which are orthogonal to each other
- Spread data over different sub-bands



OFDM

- Symbols used in each sub-band are long, hence ISI does affect any particular sub-band by much



Modulations Used

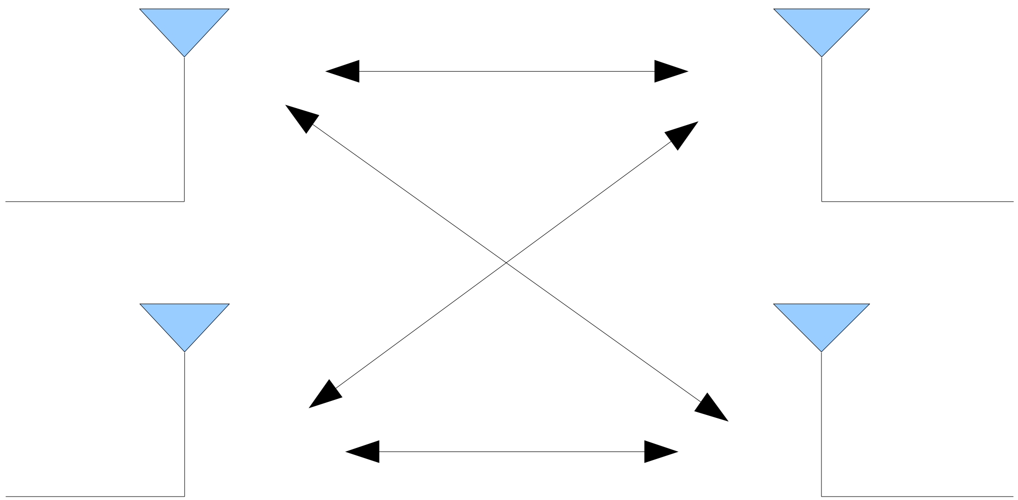
- ADSL -- OFDM
- Ethernet -- Manchester encoding (similar to BPSK)
- GSM -- Gaussian-filtered Minimum Shift Keying

State of the Art

- MIMO technology
- Ultra-wide band
- Software-defined radio
- Photonics

MIMO Technology

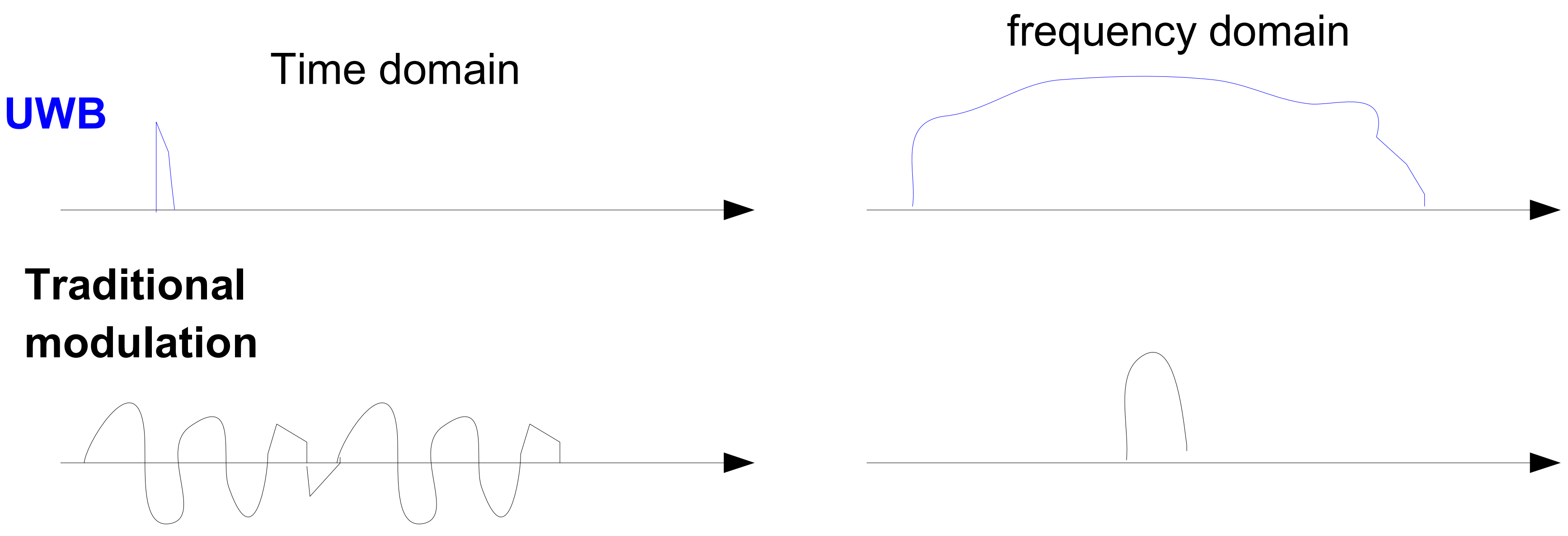
- Multiple Input Multiple Output (MIMO) – use multiple transmit and receive antennas



- If antennas are far-enough apart, they see independent channels

Ultra-Wide Band

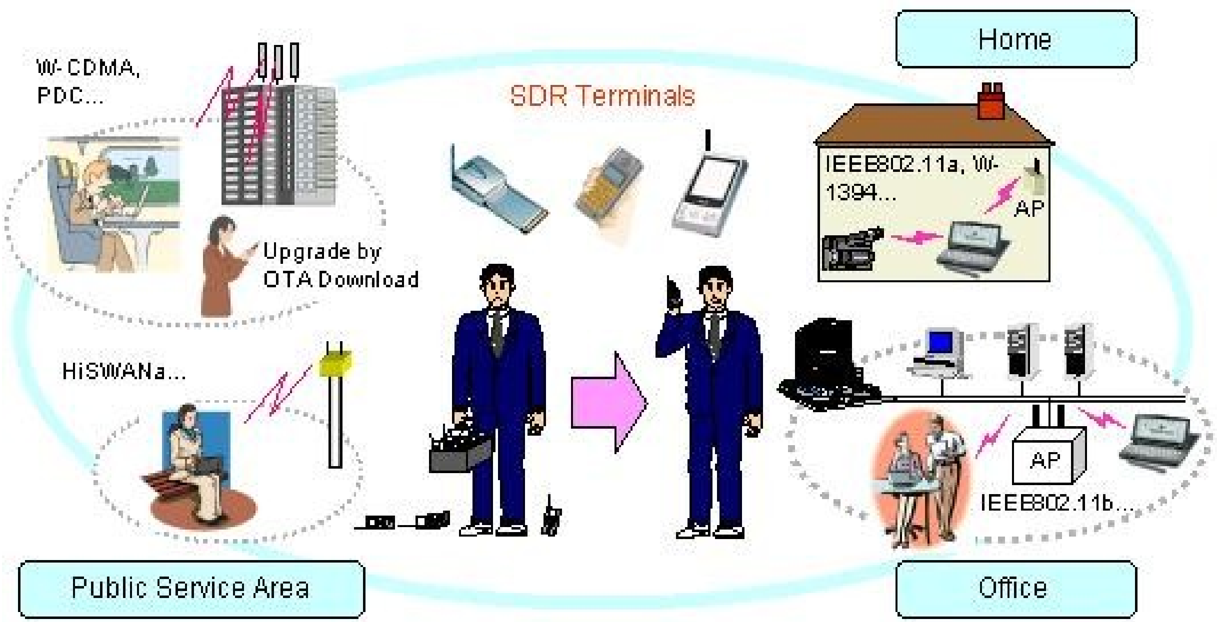
- Use large bandwidth (>500MHz)
- Low power, not interfere with other users
- Transmission range short
- Very high bit rates (100's of Mbps)



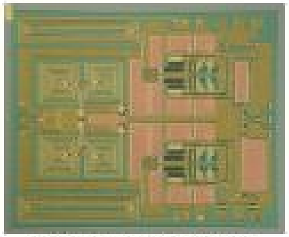
Software Defined Radio

- Programmable hardware controlled by software

- tune to any frequency band and receive any modulation across a large frequency spectrum




SDR Prototype


Direct-conversion
Multi-band MMIC

Photonics for Communications

- Goal: move to optical domain from electronic domain
- Do signal processing, routing etc in optical domain

Courtesy: wikipedia.org