

Data Communication Basics

Assuming that you know...

- Analog / digital signals
- Periodic / aperiodic signals
- Amplitude, frequency, phase of a signal
- Time domain and frequency domain representations of signals
- Spectrum and bandwidth of a signal
- DC component of a signal

Signal Transmission

- Basic entities involved
 - Transmitter – sender of signal
 - Receiver – receiver of signal
 - Transmission Medium – physical path between transmitter and receiver
 - Can be wired or wireless
- Types
 - Simplex – transmission possible only in 1 direction
 - Half-Duplex – transmission in both directions, but at any time, only one direction is possible
 - Full Duplex – simultaneous transmission in both directions is possible

Data and Signal

- Data
 - Entities that has some meaning (carry “information”)
 - We consider only digital data, i.e., the entities consist of sequence of 0's and 1's
 - For ex., 01 may mean the number ‘1’, or the letter ‘a’, or anything else depending on the application
- Signals
 - Electric or electromagnetic representations of data
 - Different signals can be used to represent the same data
 - Signal can be analog or digital

- Encoding
 - Representing data with signals
- Transmission
 - Communication of data by propagation and processing of signals

Thus, we will deal with

Analog signals carrying digital data

and

Digital signals carrying digital data

Signal Strength Specification

- Watts, Milliwatts etc.
 - Ex. typical transmitter power for a 4G base station will be 20-30 Watts
 - Absolute strength specification
- Decibel (dB)
 - Power of a signal P_1 relative to a reference signal power P_0
 - Signal strength in dB = $10\log_{10}(P_1/P_0)$
 - 0 if $P_1 = P_0$
 - +ve if $P_1 > P_0$
 - -ve if $P_1 < P_0$
 - Relative signal strength specification
- dBm: P_0 is taken as 1 milliwatt
 - Absolute strength specification in mW

Transmission Impairments

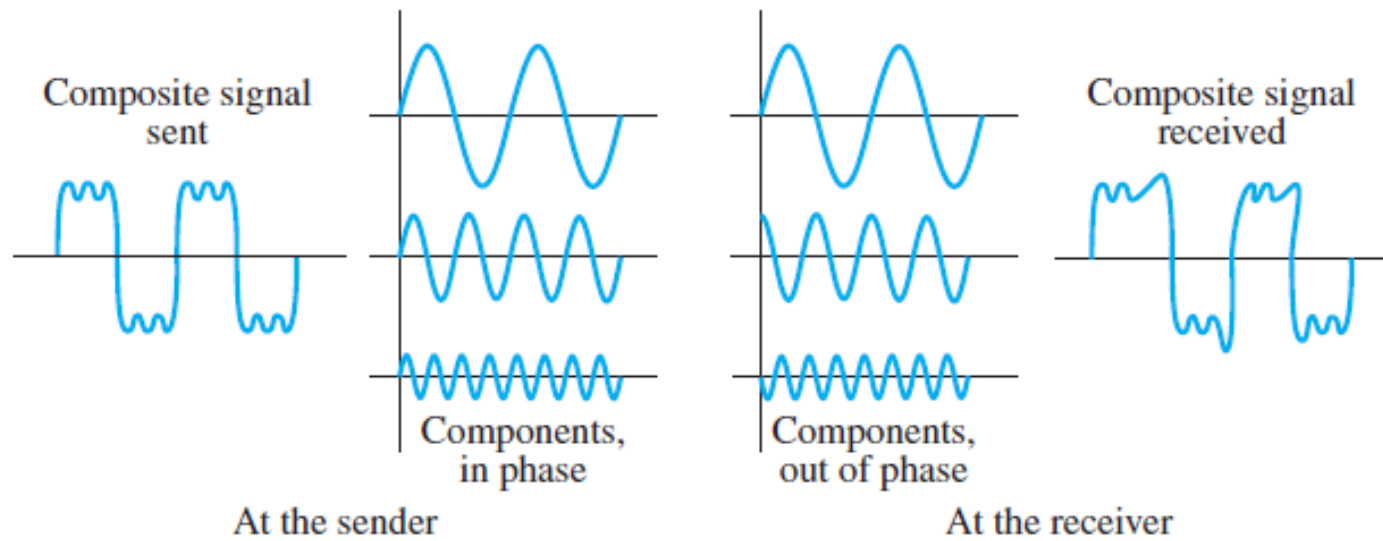
- Signal sent by transmitter may not be the signal received by receiver due to
 - Attenuation
 - Loss of signal strength over distance
 - Attenuation Distortion
 - Different losses at different frequencies
 - Delay Distortion
 - Different speeds for different frequencies
 - Noise
 - Unwanted signals superimposed on the original signal

Attenuation

- Signal strength falls off with distance
- Depends on medium
- Received signal strength
 - must be enough to be detected
 - must be sufficiently higher than noise to be received without error
- Attenuation is an increasing function of frequency
- If transmitted power = P_1 watts and received power = P_2 watts, attenuation in dB is $10 \log_{10} (P_1/P_2)$

Delay Distortion

- Only in guided media
- Propagation velocity varies with frequency
- Different frequency components of a signal can arrive at different time
 - May cause intersymbol interference
 - For digital data, some components of one bit will arrive later and spill over into the next bit, changing its value



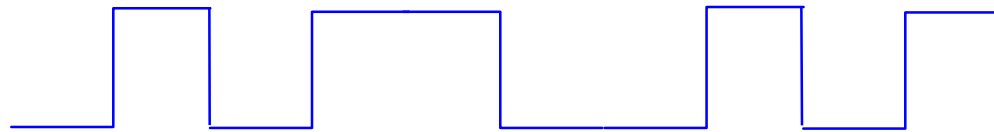
Noise

- Additional signals inserted between transmitter and receiver
- Types of Noise
 - Thermal
 - Due to thermal excitation of electrons
 - Uniformly distributed, cannot be eliminated
 - White noise
 - Intermodulation
 - Signals that are the sum and difference of original frequencies sharing a medium

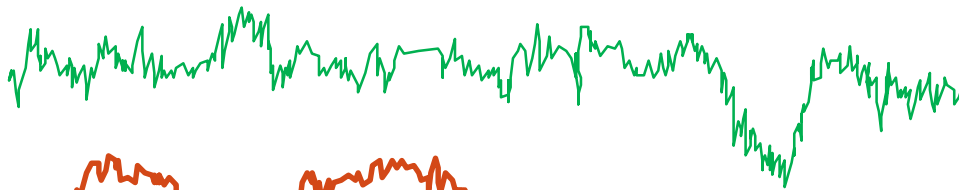
Noise (contd.)

- Crosstalk
 - A signal from one line is picked up by another
- Impulse
 - Irregular pulses or spikes
 - Short duration
 - High amplitude
 - Less predictable
 - Ex. external electromagnetic interferences such as from lightning etc.

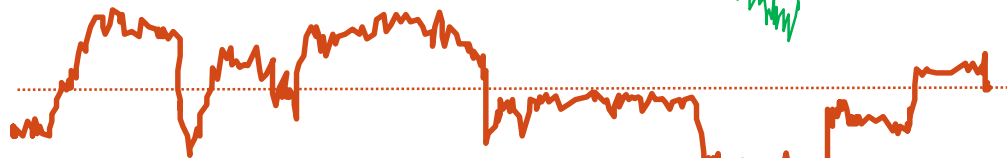
Effect of Noise



Signal

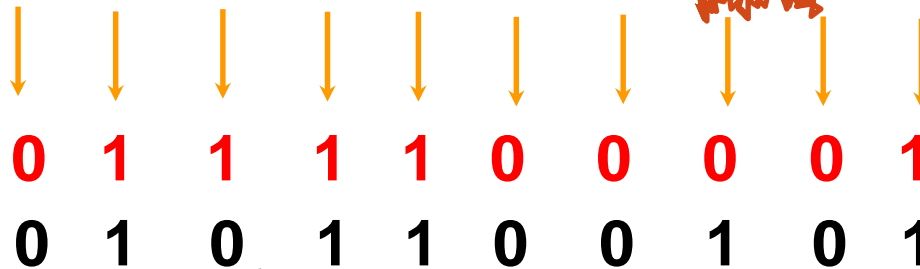


Noise



Signal+Noise

Logic
Threshold →



Sampling times

Data Received

Original data

Bit error

SNR

- Signal-to-Noise Ratio to quantify effect of noise

$$\text{SNR (in dB)} = 10 \log (S/N)$$

S = average signal power

N= noise power

Analog Transmission

- Analog signal transmitted
- May be carrying analog or digital data
- Signal attenuated over distance
- Use amplifiers to boost signal
 - Cascaded amplifiers for longer distance transmissions
 - Problem: also amplifies noise
 - Significant signal distortion possible over long distance

Digital Transmission

- Digital bit pattern transmitted
- Integrity of a bit depends on noise, attenuation etc.
- Usually higher attenuation than analog signals
 - Repeaters used to handle attenuation
 - Repeater receives signal
 - Extracts bit pattern
 - Retransmits bit pattern
 - Attenuation is overcome
 - *Noise is not amplified*

Advantages of Digital Transmission

- Longer distances possible over lower quality lines
- Lower cost
- High degree of multiplexing easier with digital techniques
- Security & Privacy - Encryption

Channel Capacity

- Maximum data rate achievable for transmission over the channel
 - Data rate: Rate at which data can be communicated
 - Measured in bits per second (bps)

Data Rate and Baud Rate

- Data rate — measured in bps (bits per second)
- Signaling rate — no. of signal components per second
- *Each signal component can represent more than one bit, so data rate can be greater than signaling rate*

Nyquist Sampling Theorem

“If the maximum frequency of a signal is f , it can be perfectly reconstructed at the receiver if it is sampled at a rate at least $2f$ ”

Nyquist, 1920

Nyquist Bandwidth

- Theoretical maximum capacity of a noiseless channel

$$C = 2B \log_2 M \text{ bits/sec}$$

B = bandwidth

M = number of discrete signal levels

Example: Channel capacity calculation for voice bandwidth (~ 3100 Hz):

M	Max data rate (C)
2	6200 bps
4	12400 bps
8	18600 bps
16	24800 bps

Shannon's Law

- In the '40s Shannon extended the equation to a channel subject to thermodynamic (thermal) noise

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

$S/N = (\text{signal power}) / (\text{noise power})$

$C = \text{Theoretical maximum capacity with noise}$

Transmission Medium

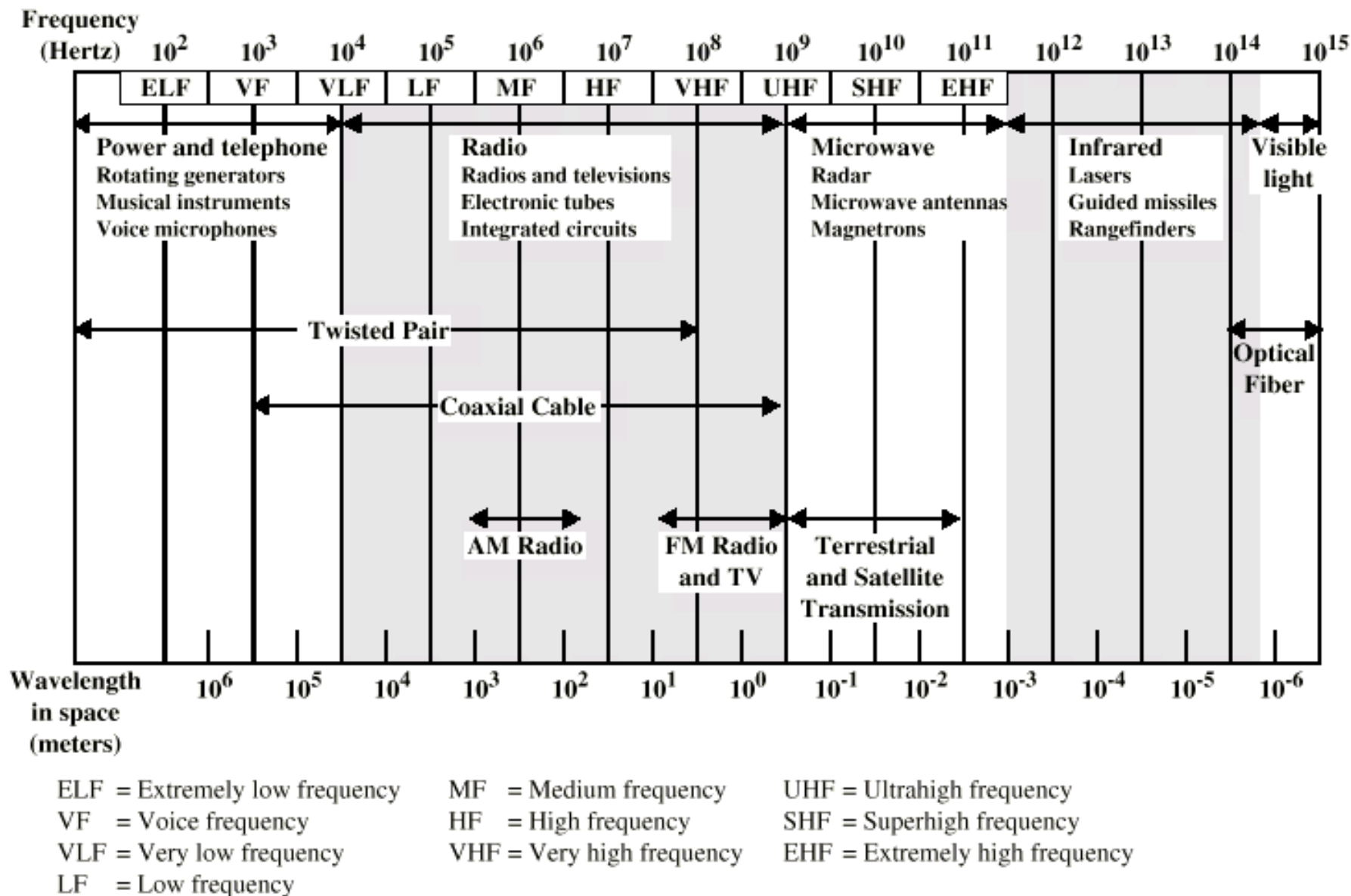
Transmission Medium

- Guided
 - Twisted pair, coaxial etc. (conducting metal)
 - Fibre optic (glass or plastic)
- Unguided
 - Wireless communication
- Key concerns are data rate and distance

Design Factors

- Bandwidth
 - Higher bandwidth gives higher data rate
- Transmission impairments
 - Attenuation (measured in dB/km)
- Interference

Electromagnetic Spectrum



Guided Transmission Media

- Transmission capacity depends on the distance and on whether the medium is point-to-point or multipoint
- Examples
 - Coaxial cable
 - Twisted Pair
 - Optical fiber

Table 4.1 Point-to-Point Transmission Characteristics of Guided Media

	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 μ s/km	2 km
Twisted pairs (multipair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 μ s/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 μ s/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 μ s/km	40 km

THz = terahertz = 10^{12} Hz

Twisted Pair

- Consists of two insulated copper wires arranged in a regular spiral pattern to minimize the electromagnetic interference between adjacent pairs
- Low frequency transmission medium for short distance communication

- Separately insulated
- Twisted together
- Often "bundled" into cables
- Usually installed in building during construction



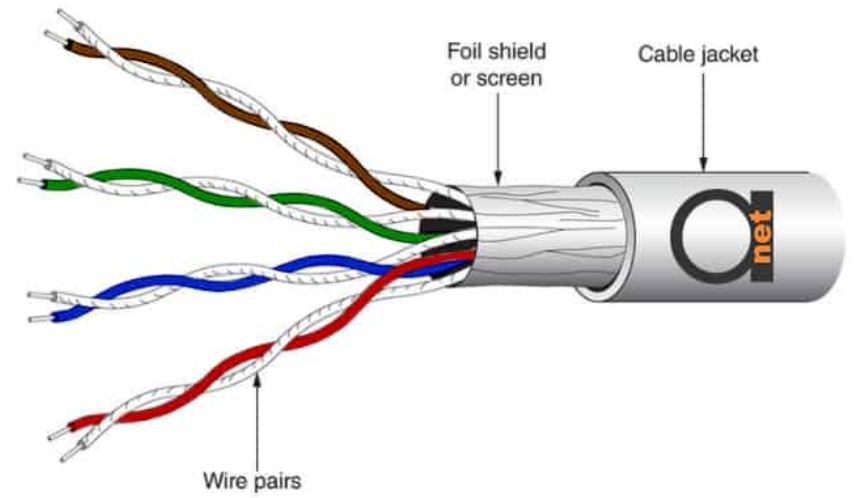
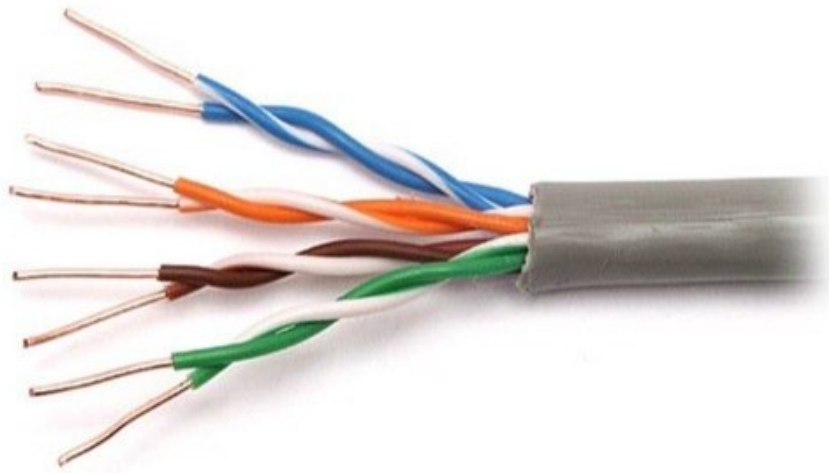
(a) Twisted pair

Twisted Pair - Pros and Cons

- Pros
 - Cheap
 - lightweight
 - Easy to work with
- Con
 - Relatively low bandwidth/data rate
 - Shorter range
 - Susceptibility to interference and noise
 - Attenuation problem

Unshielded and Shielded TP

- Unshielded Twisted Pair (UTP)
 - Ordinary telephone wire
 - Cheapest
 - Easiest to install
 - Suffers from external electromagnetic interference (EM)
- Shielded Twisted Pair (STP)
 - Metallic foil and/or braid over pairs or a group of pairs to insulate the pairs from electromagnetic interference
 - More expensive than unshielded



Important UTP Categories

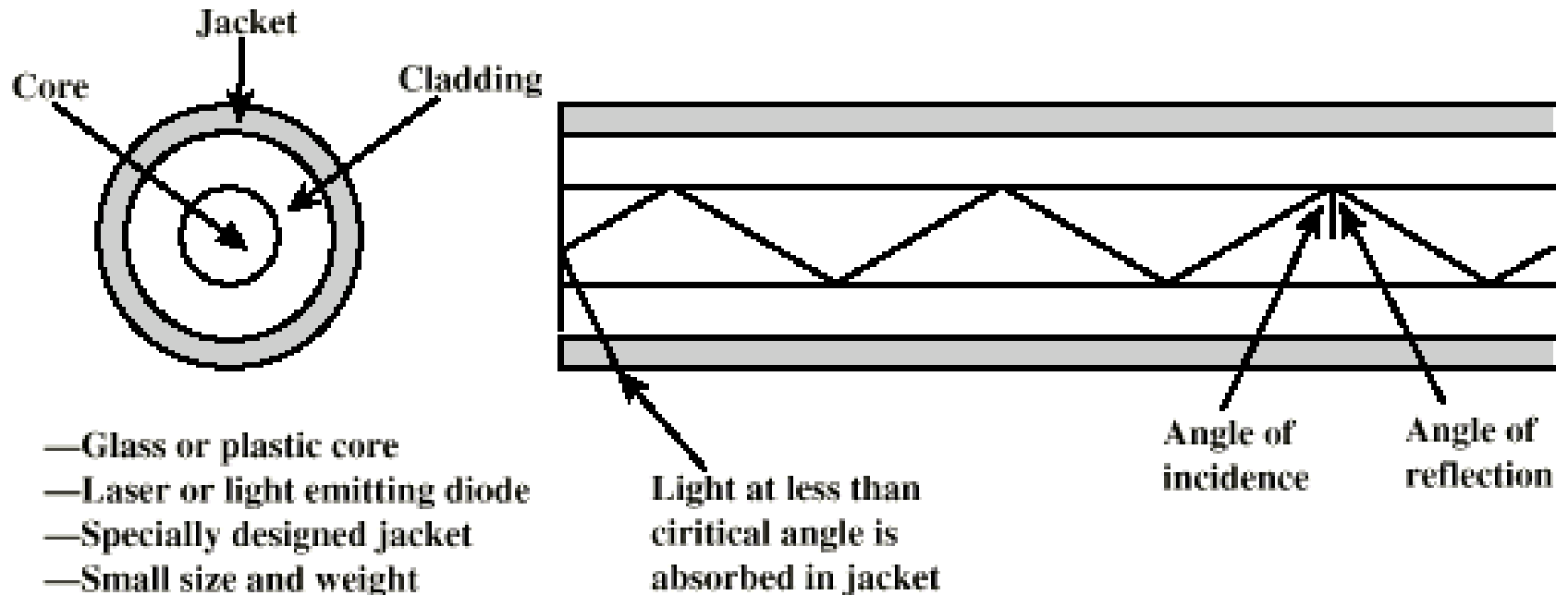
- Cat 3 (not used for computer networks anymore)
 - up to 16MHz
 - Voice grade found in many offices
 - Max distance of 100m
- Cat 5/5e (common in LANs upto 1 Gigabit)
 - up to 100MHz
 - Smaller twist length gives less crosstalk interference
 - Max distance of 100m

- Cat 6
 - Up to 250 MHz
 - Max distance 55m for 10G communication
- Cat 6a
 - Up to 500 MHz
 - Max distance 100m for 10G communication
- Cat 7/7A/8 also there
- Higher the category, higher the bandwidth, and therefore higher the maximum data rate supported

Optical Fiber

- Thin (2-125 micrometer), flexible medium capable of conducting an optical ray
 - Made of ultrapure fused silica, glass fiber or plastic
- Cylindrical shape with three concentric sections: the **core**, the **cladding**, and the **jacket**
 - Core consists of one or more very thin strands, or fibers, made of glass or plastic
 - Cladding is a glass or plastic coating that has optical properties different from that of the core
 - Jacket surrounds one or a bundle of cladded fibers

Optical Fiber



Optical Fiber - Benefits

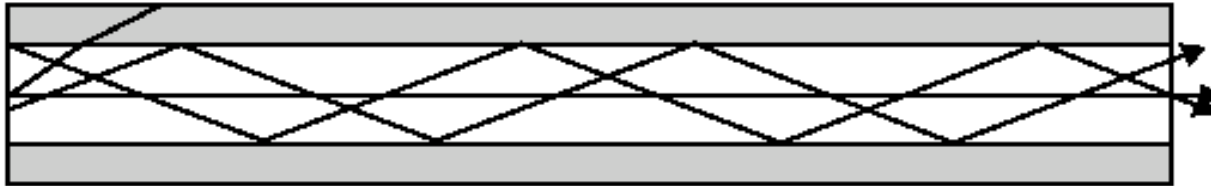
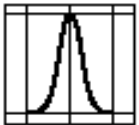
- Greater capacity
 - Data rates of hundreds of Gbps
- Smaller size & lighter weight
- Lower attenuation
- Electromagnetic isolation
- Greater repeater spacing
 - 10s of km at least
- Highly secure due to tap difficulty and lack of signal radiation
- Omnipresent for most long distance communication needs, including telephone

Optical Fiber Types

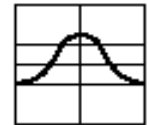
- Single mode fiber
 - The light is guided down the center of an extremely narrow core (only one angle of reflection)
- Multimode fiber
 - Multiple angles of reflection, hence multiple paths
 - Signal elements diffuse over time, causing interference, hence reduced data rate
- Multimode graded-index fiber
 - Acts to refract the light toward the center of the fiber by variations in the density

Optical Fiber Types (contd.)

Input pulse

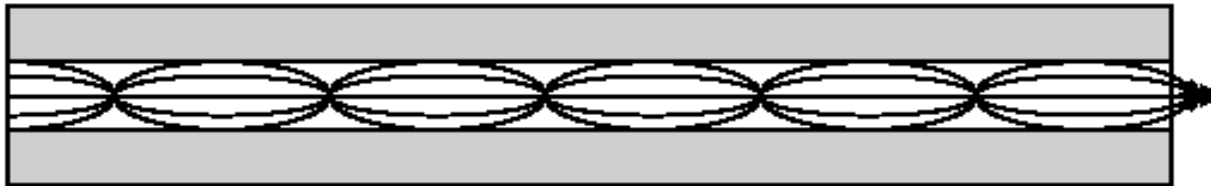
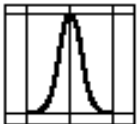


Output pulse

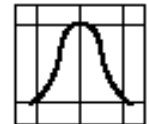


(a) Step-index multimode

Input pulse

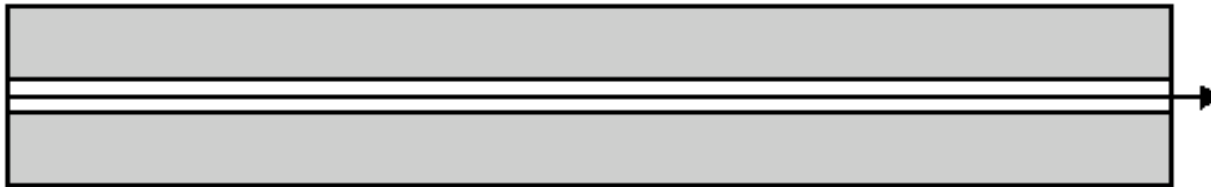
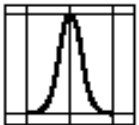


Output pulse

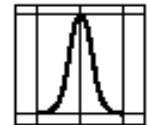


(b) Graded-index multimode

Input pulse



Output pulse



(c) Single mode

Unguided Media

- Wireless transmission
- Transmission and reception via antenna
- Two techniques are used:
 - Directional Antenna
 - Focused beam, longer range
 - Careful alignment required
 - Omnidirectional Antenna
 - Signal spreads in all directions
 - Can be received by many antennas

Frequencies

- 1GHz to 40GHz
 - Microwave
 - Highly directional
 - Point to point
 - Terrestrial microwave, Satellite, wireless LANs (2.4 – 5 GHz)
- 30MHz to 1GHz
 - Omnidirectional
 - Broadcast radio
- 3×10^{11} to 2×10^{14} Hz
 - Infrared