

# 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  $10 \log_{10} (P_1/P_2)$



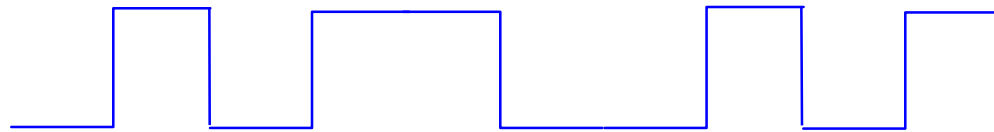
# Noise

- 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

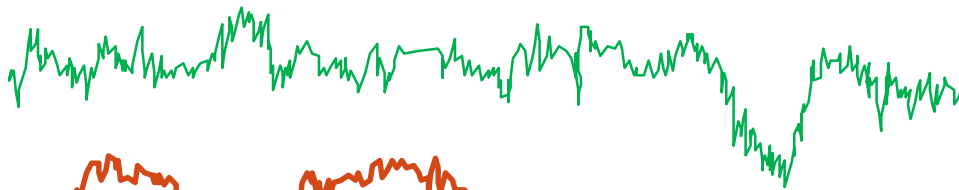
# Noise (contd.)

- 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.

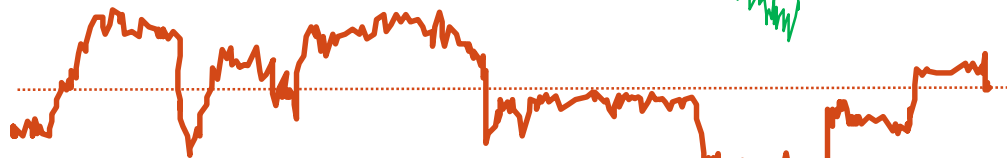
# Effect of Noise



Signal

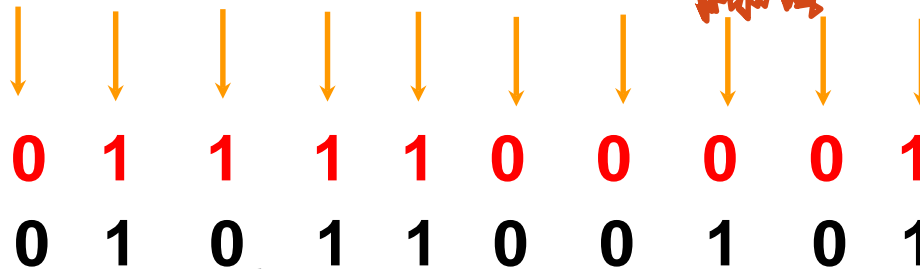


Noise



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

# Data Rate and Signalling rate

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



# 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 ( $\sim 3100$  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

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

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

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

# 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

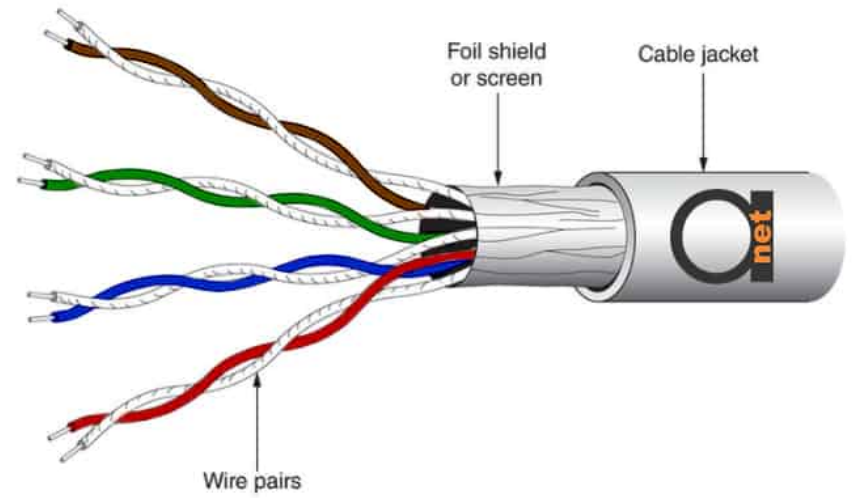
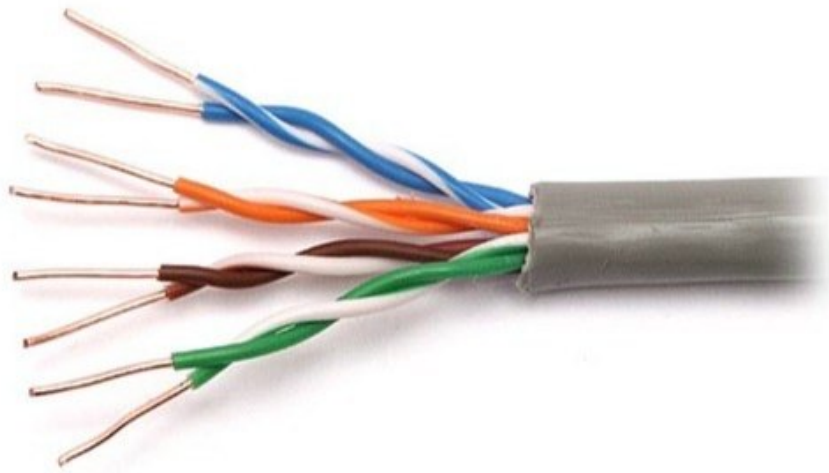
# Twisted Pair - Pros and Cons

- 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

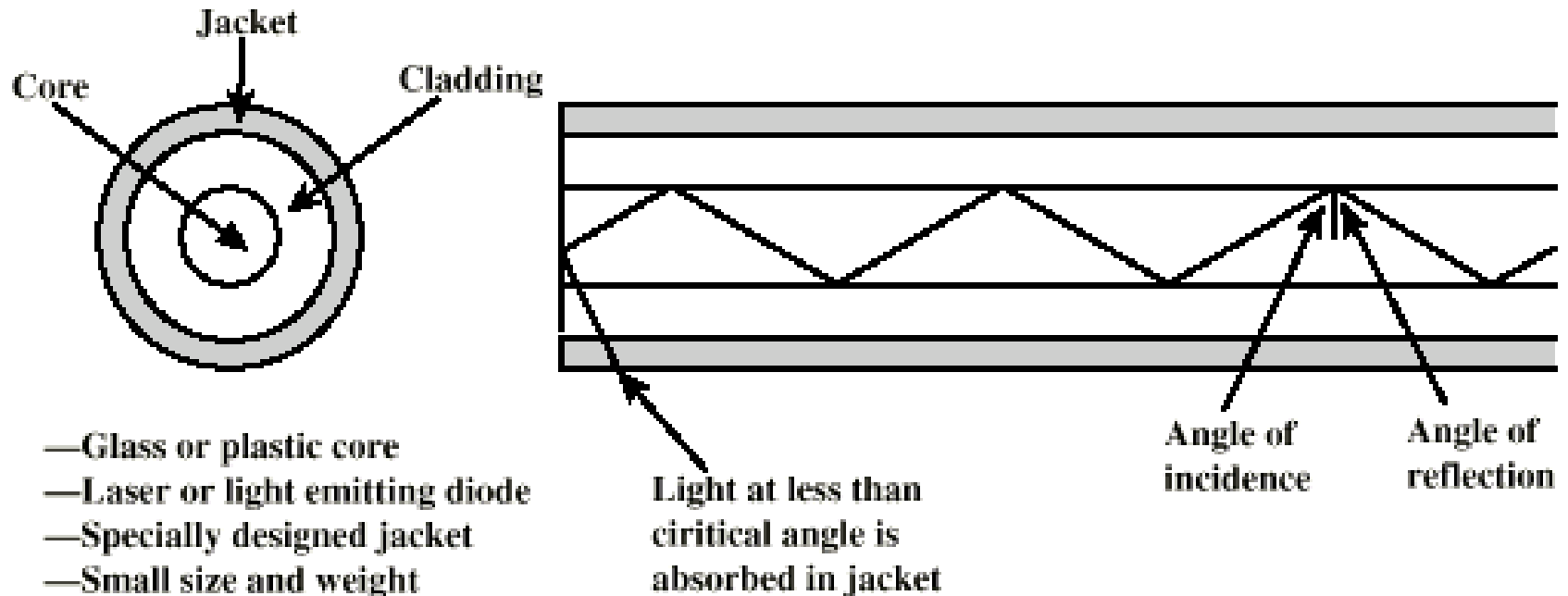
- Cat 3 (not used for computer networks anymore)
  - up to 16MHz
  - Voice grade found in many offices
  - Max distance of 100m
- Cat 5/5e (common in LANs upto 1 Gigabit)
  - up to 100MHz
  - Smaller twist length gives less crosstalk interference
  - Max distance of 100m

- 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

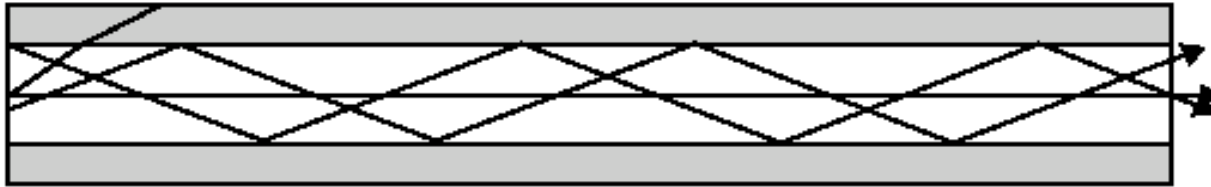
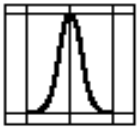
- Greater capacity
  - Data rates of hundreds of Gbps
- Smaller size & lighter weight
- Lower attenuation
- Electromagnetic isolation
- Greater repeater spacing
  - 10s of km at least
- Highly secure due to tap difficulty and lack of signal radiation
- Omnipresent for most long distance communication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

# Optical Fiber Types

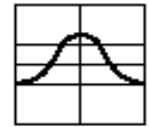
- Single mode fiber
  - The light is guided down the center of an extremely narrow core (only one angle of reflection)
- Multimode fiber
  - Multiple angles of reflection, hence multiple paths
  - Signal elements diffuse over time, causing interference, hence reduced data rate
- Multimode graded-index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

# Optical Fiber Types (contd.)

Input pulse

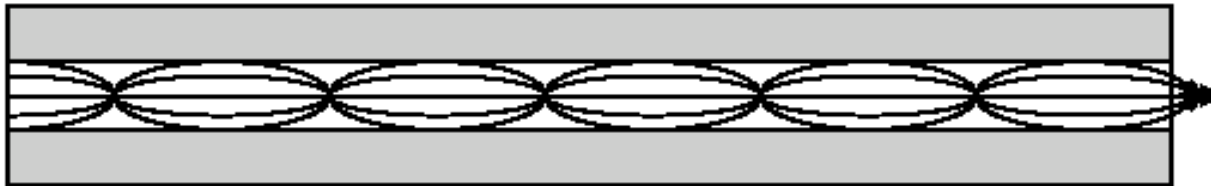


Output pulse

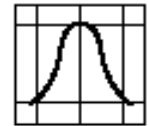


(a) Step-index multimode

Input pulse

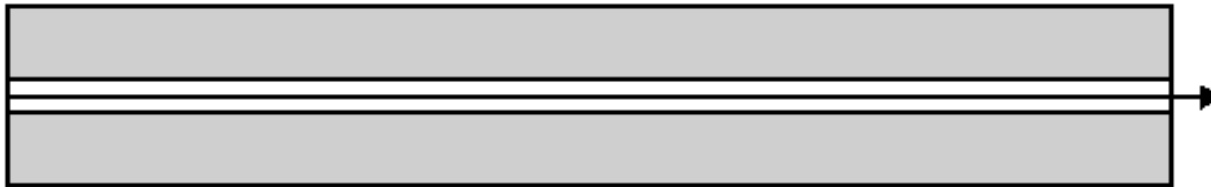


Output pulse

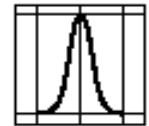


(b) Graded-index multimode

Input pulse



Output pulse



(c) Single mode