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

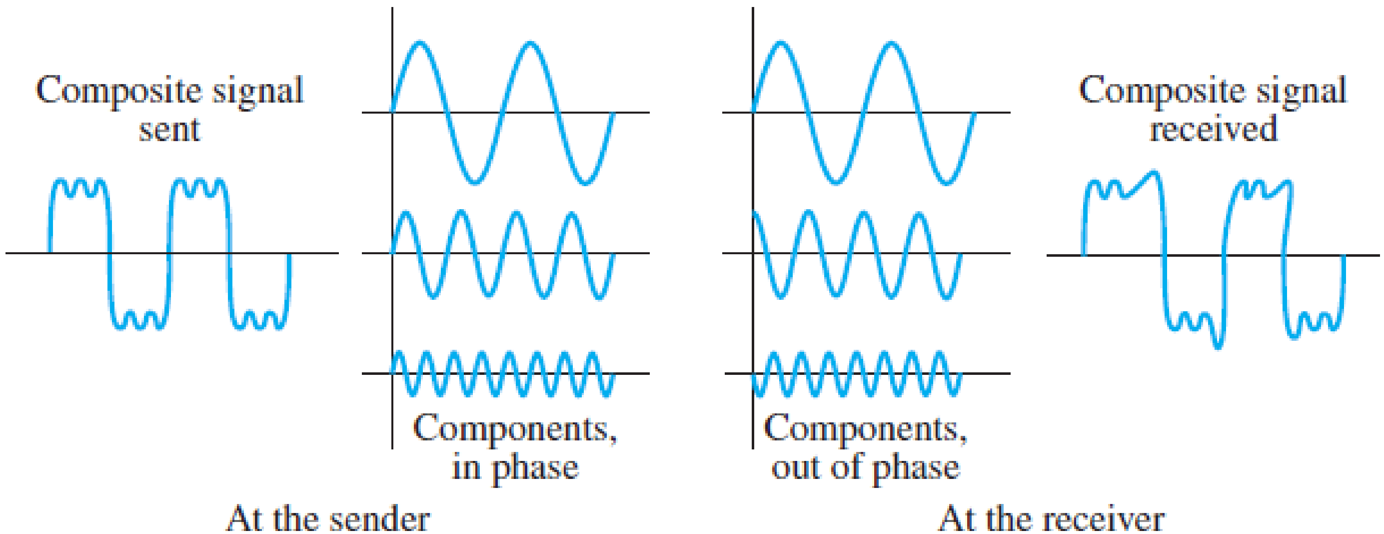
- Signal sent by transmitter may not be the signal received by receiver due to
  - Attenuation
    - Loss of signal strength over distance
  - Attenuation Distortion
    - Different losses at different frequencies
  - Delay Distortion
    - Different speeds for different frequencies
  - Noise
    - Unwanted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



Composite signal sent
Components, in phase
At the sender
Components, out of phase
Composite signal received
At the receiver

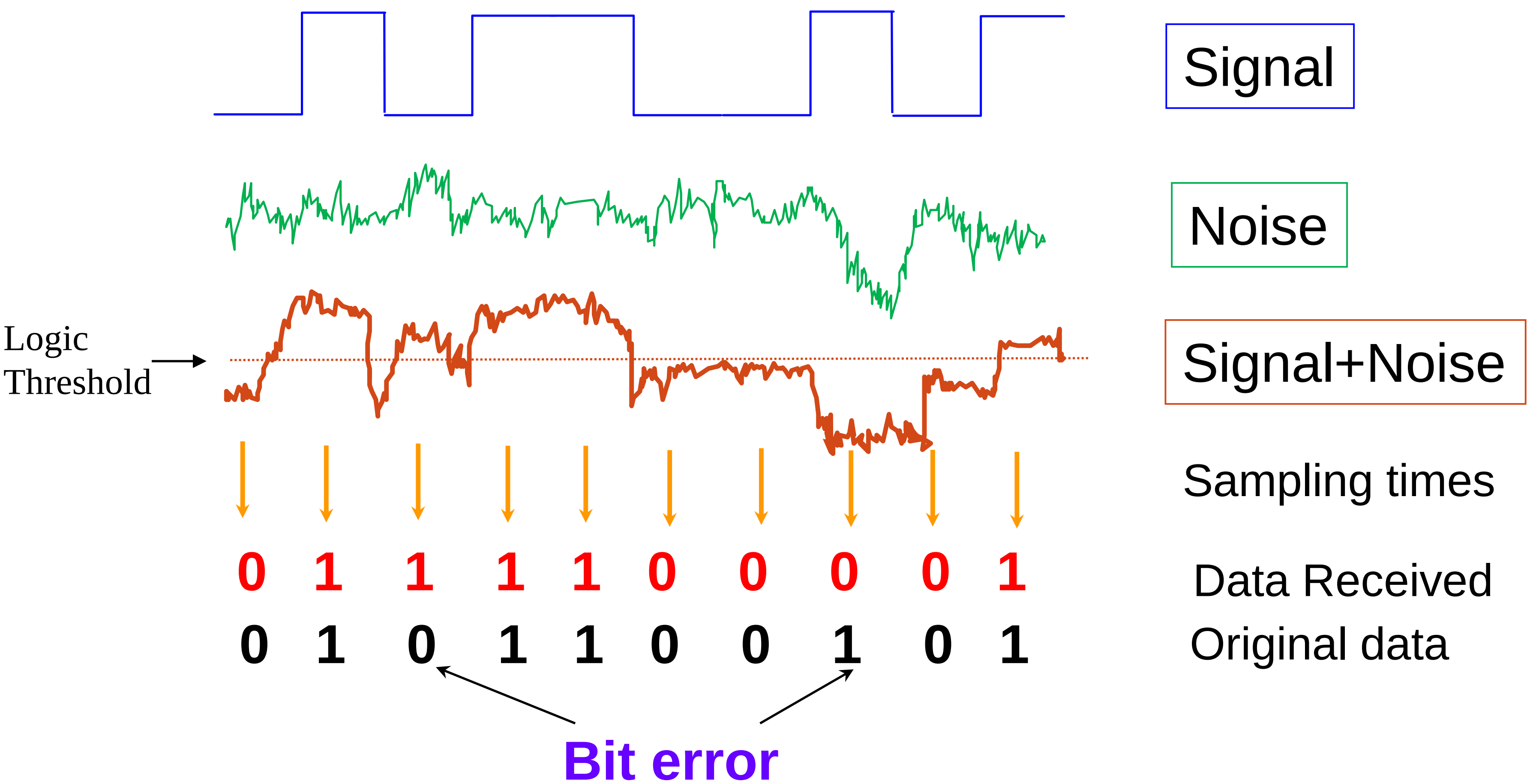
Noise

- 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



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 SamplingTheorem

"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 = (signal power)/(noise power)

C = Theoretical maximum capacity with noise

Transmission Medium

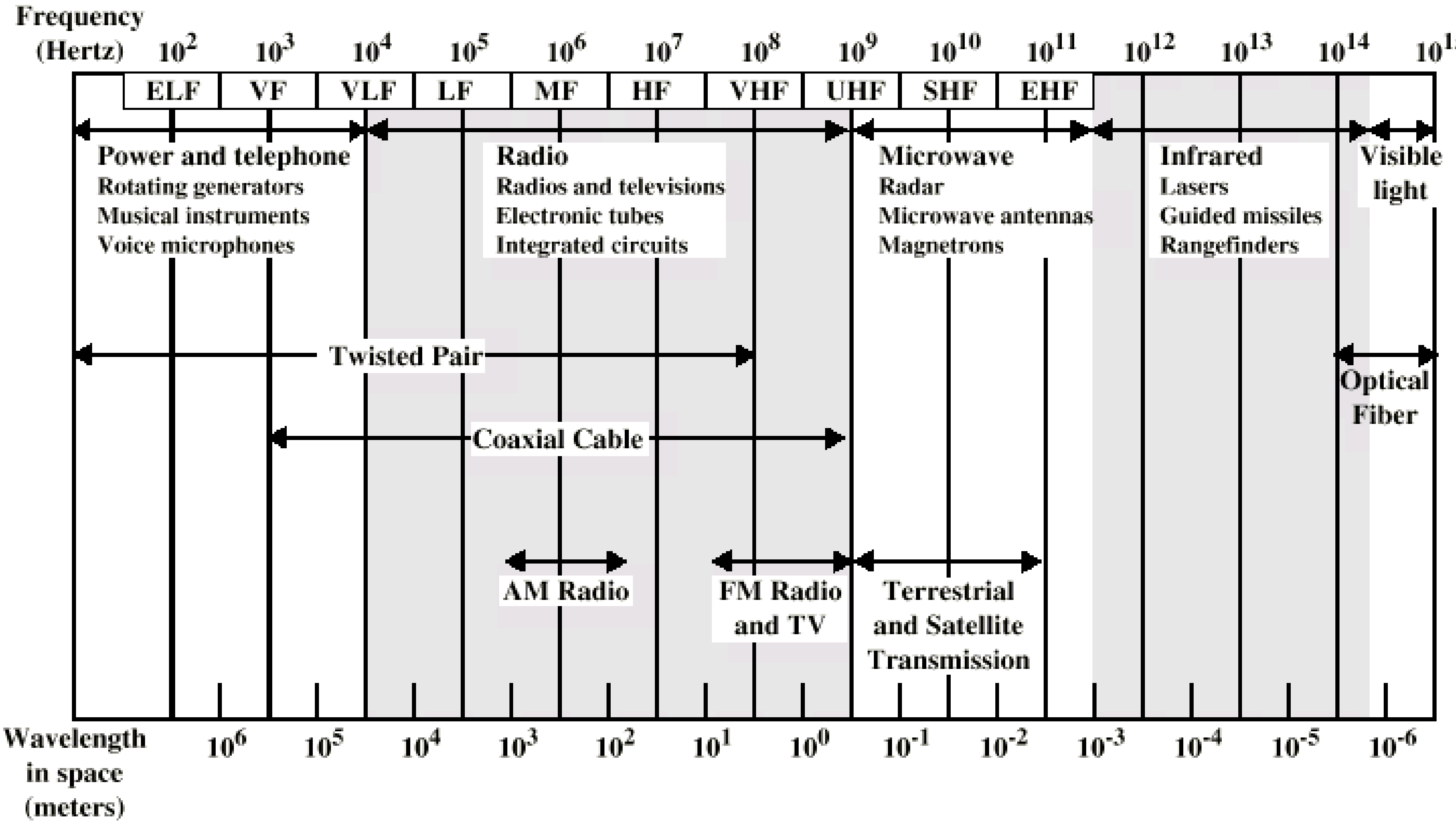
Transmission Medium

- Guided
  - Twisted pair, coaxial etc. (conducting metal)
  - Fibre optic (glass or plastic)
- Unguided
  - Wireless communication
- Key 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



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

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 μs/km	2 km
Twisted pairs (multipair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 μs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 μs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 μs/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

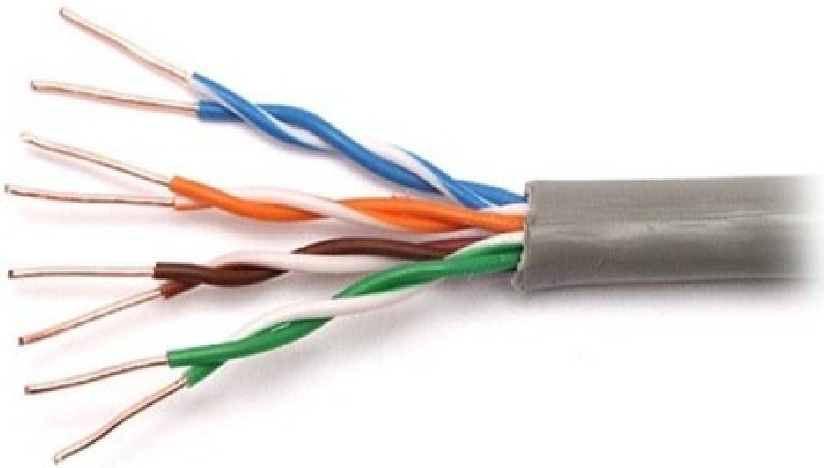
(a) Twisted pair

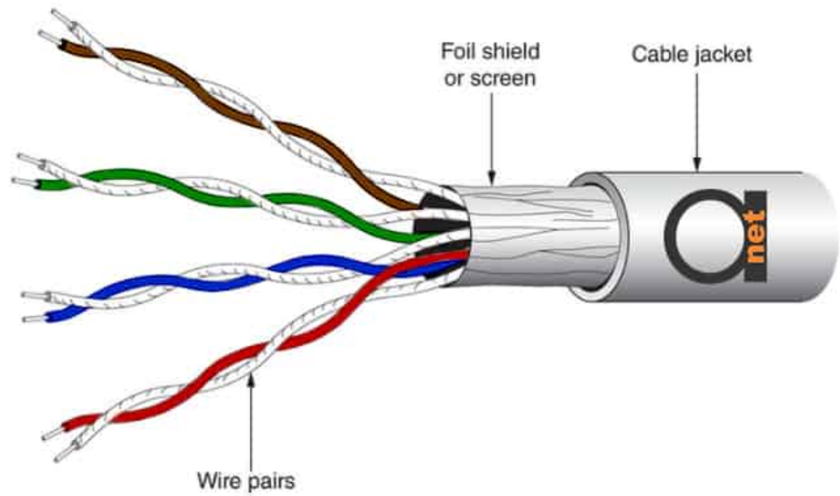
Twisted Pair - Pros and Cons

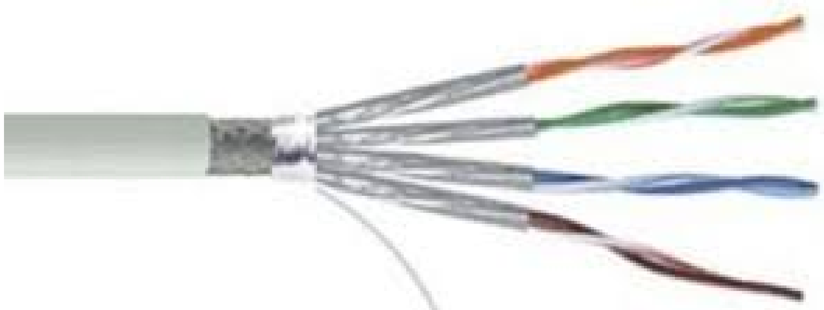
- Pros
  - Cheap
  - lightweight
  - Easy to work with
- Con
  - Relatively low bandwidth/data rate
  - Shorter range
  - Susceptibility to interference and noise
  - Attenuation problem

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




Foil shield
or screen
Cable jacket
Wire pairs



Important UTP Categories

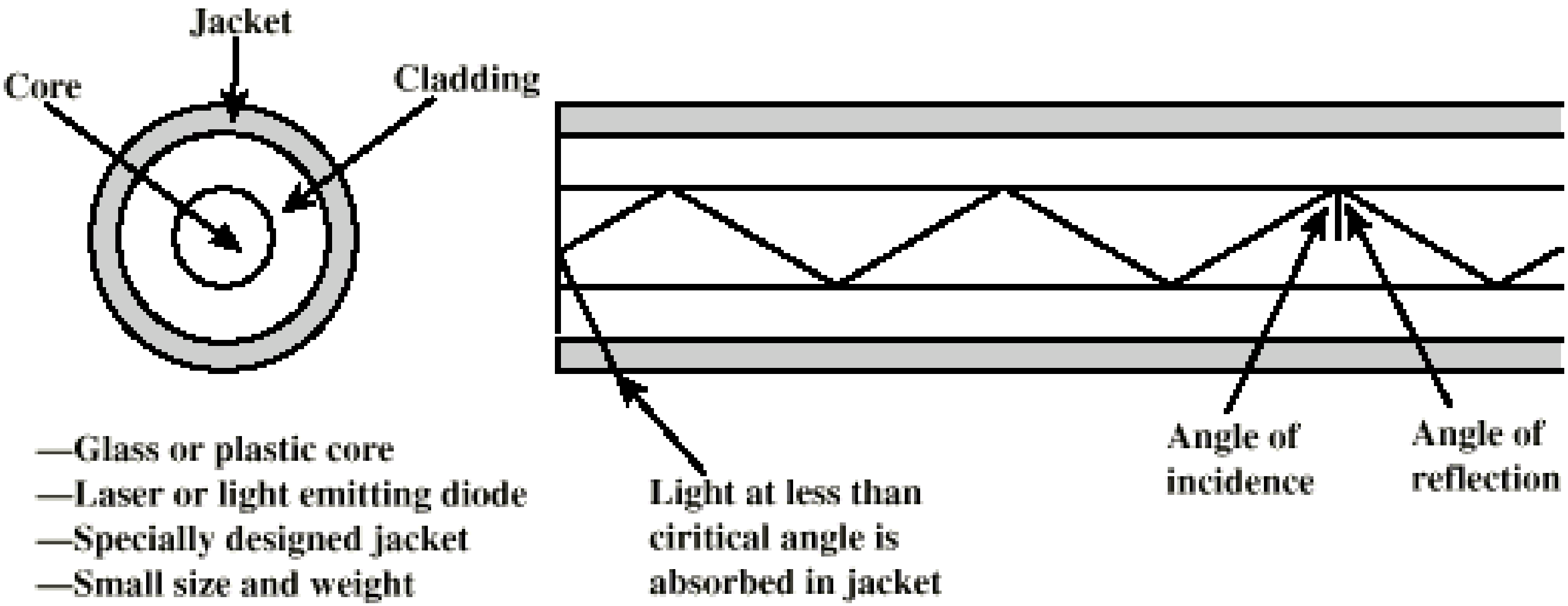
- Cat 3 (not used for computer networks anymore)
  - up to 16MHz
  - Voice grade found in many offices
  - Max distance of 100m
- Cat 5/5e (common in LANs upto 1 Gigabit)
  - up to 100MHz
  - Smaller twist length gives less crosstalk interference
  - Max distance of 100m

- 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

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



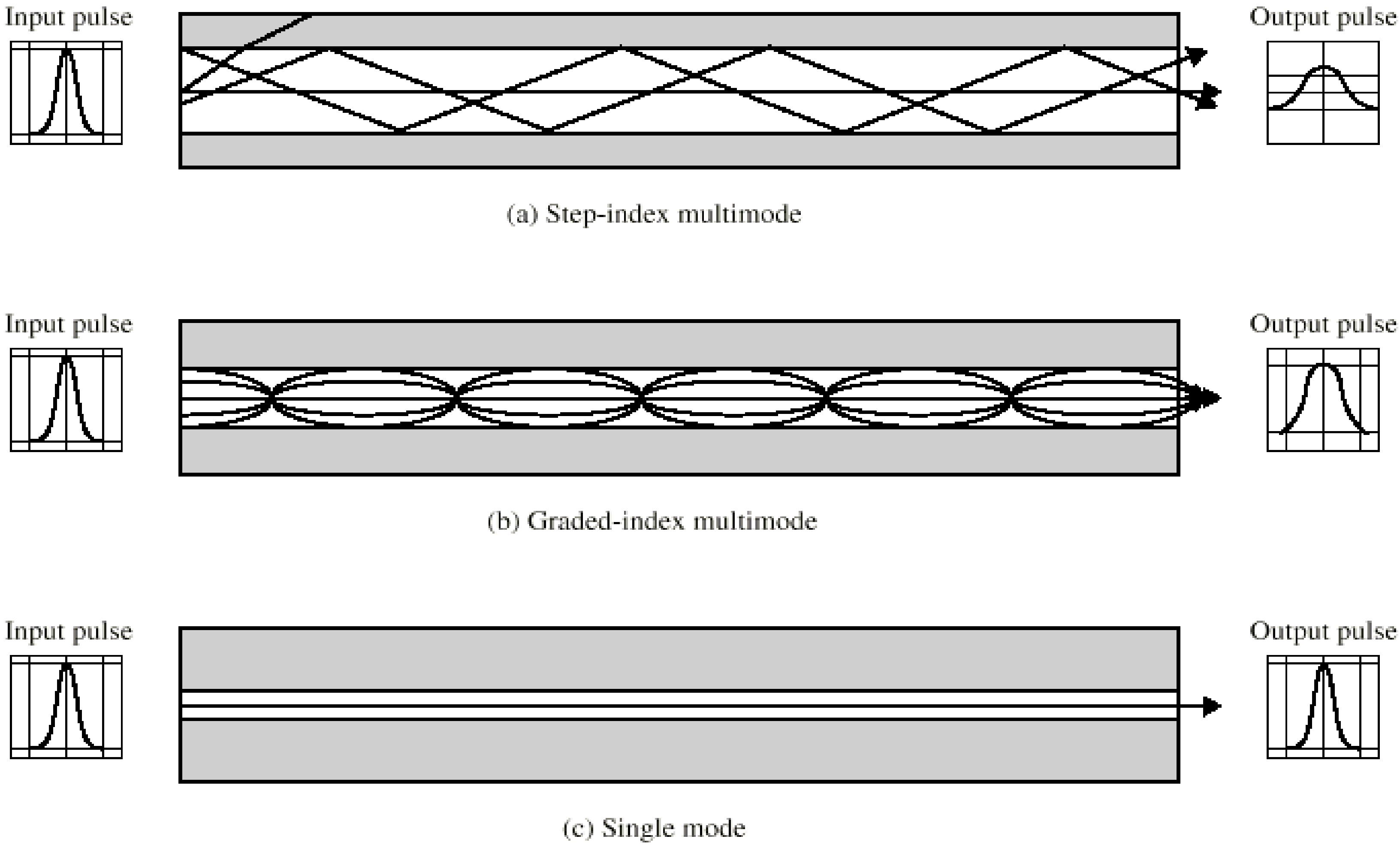
Optical Fiber - Benefits

- 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.)



(a) Step-index multimode

(b) Graded-index multimode

(c) Single mode

Wireless Transmission

- Unguided media
- 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