2 : Physical Layer

IT 4506 – Computer Networks

Level II - Semester 4

Signals and Their Properties

Signal

“In electronics and telecommunications, it refers to any time varying voltage, current, or electromagnetic wave that carries information. ”

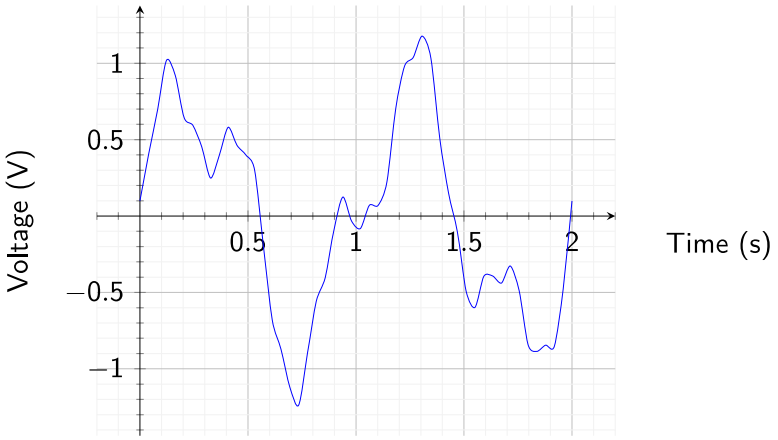
Wikipedia

Analog Signal

"An analog signal is any continuous signal for which the time-varying feature of the signal represents some other time-varying quantity"

Wikipedia

Analog Signal



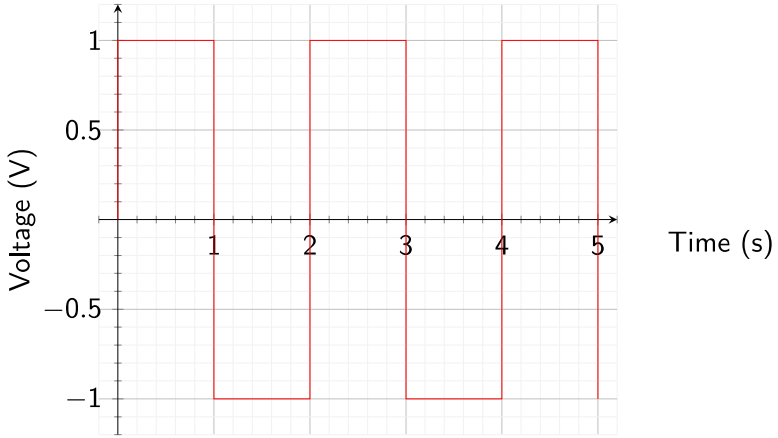
Digital Signal

"A digital signal is a signal that represents data as a sequence of discrete values; at any given time it can only take on, at most, one of a finite number of values."

Wikipedia

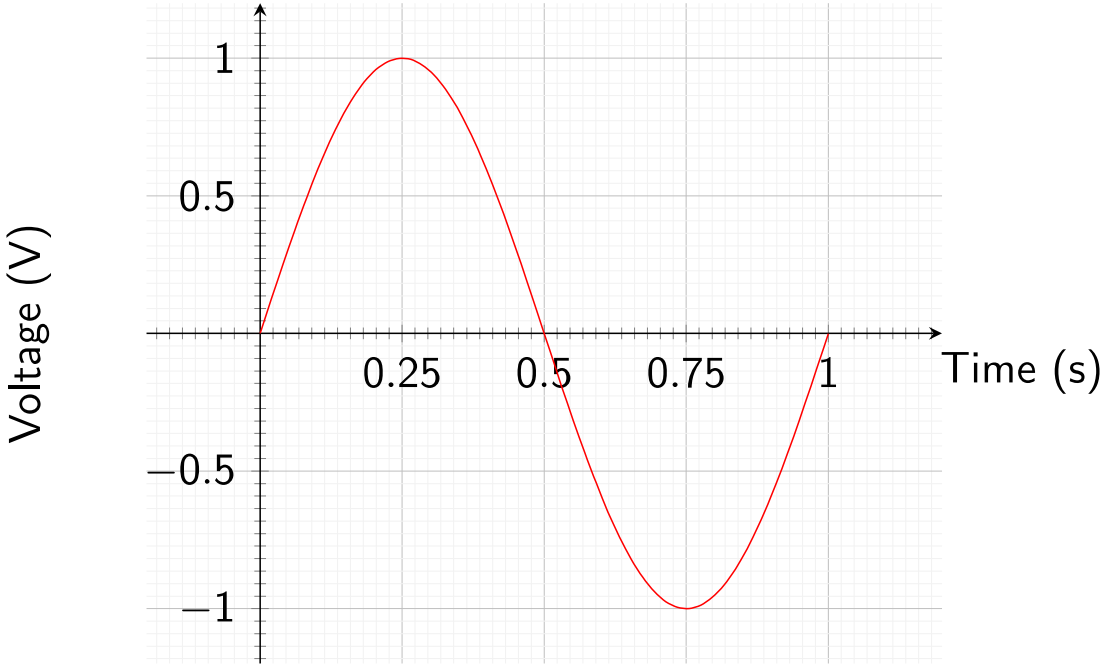
Digital Signal

Square Wave



Properties of Signals

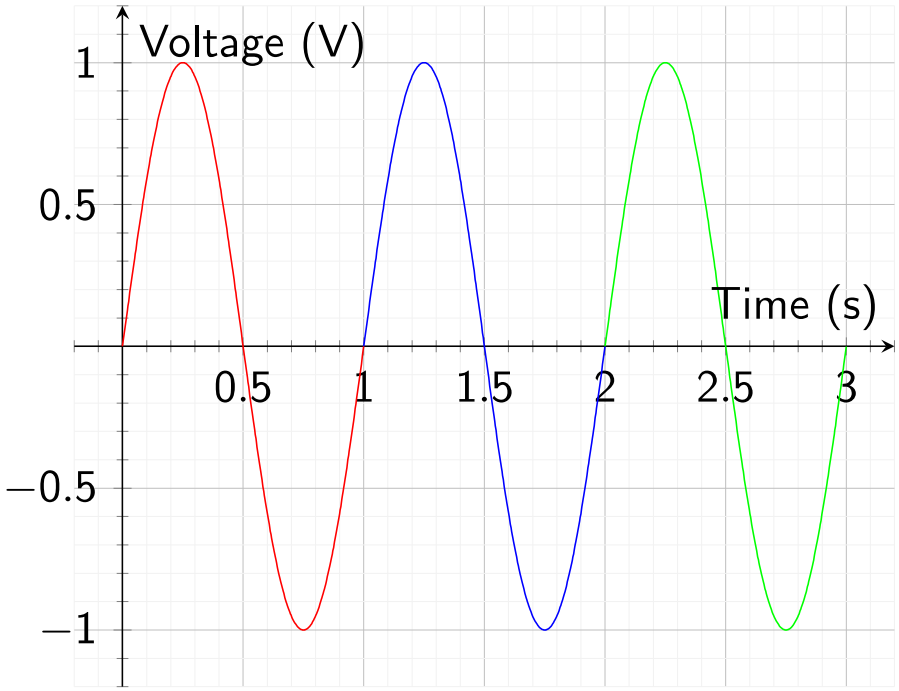
Sine Wave - One Cycle



Sine wave is a very basic time varying voltage signal

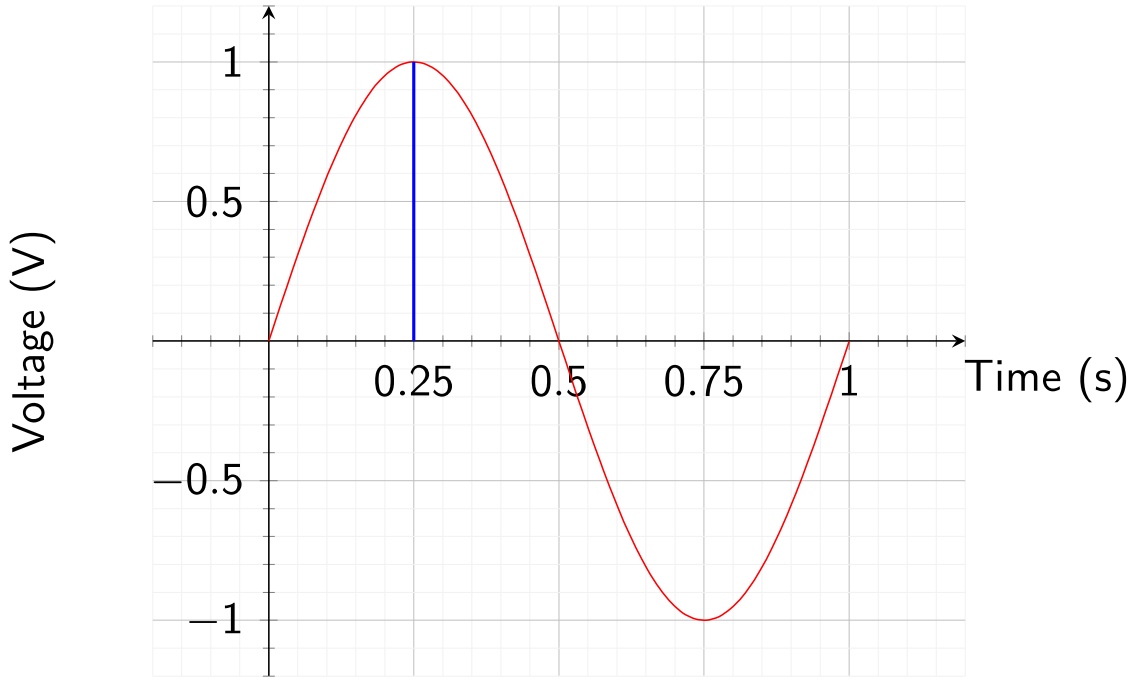
- Voltage varies continuously over time
  - Analog signal

Sine Wave - Three Cycles



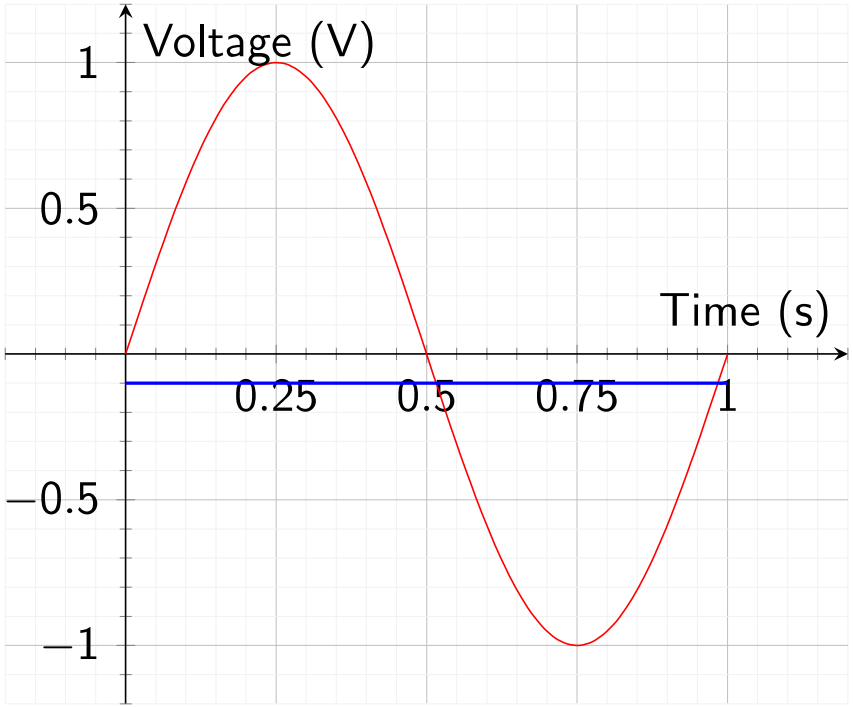
Same pattern repeats – Periodic Signal

Amplitude



Voltage varies with time – Maximum is cosidered as the Amplitude

Periodic Signal - Period



Period is the time it takes for one cycle to complete

Frequency

Number of cycles per second.

$$Period = 1s$$

$$Frequency = 1Hz$$

Frequency

Number of cycles per second.

$$Period = 1ms$$

$$Frequency = 1000Hz = 1KHz$$

Frequency

Number of cycles per second.

$$Frequency = \frac{1}{Period}$$

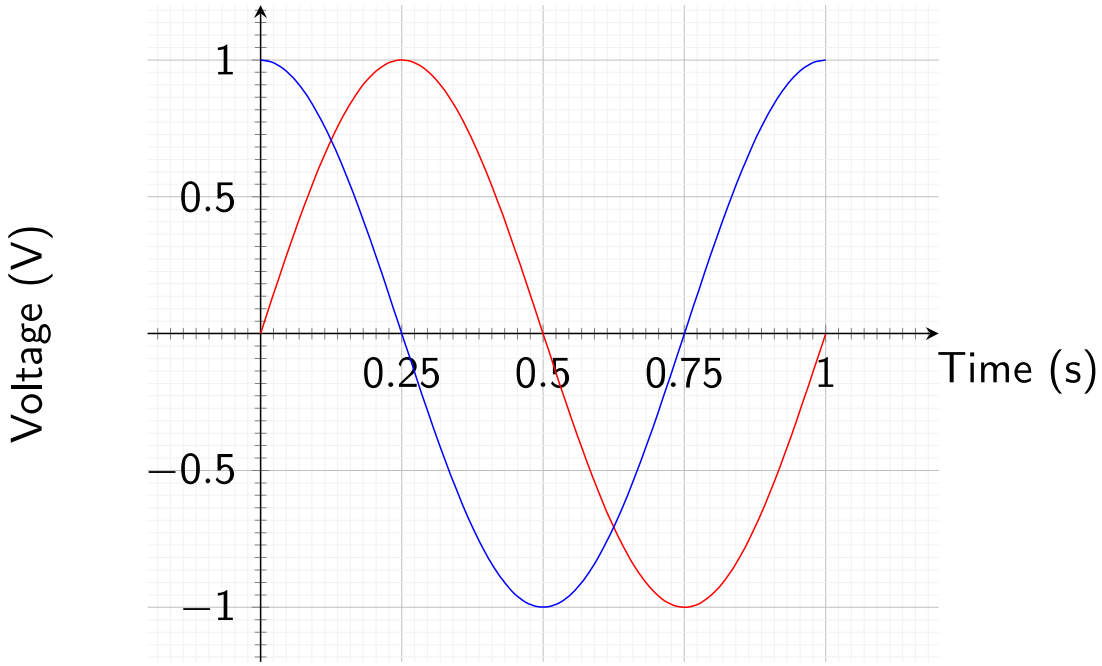
$$f = \frac{1}{T}$$

Frequency $= f$
Period$= T$

Wave Length (λ), Frequency (f), and Propagation Speed of the Signal (c)

$$\lambda = \frac{c}{f}$$

Phase



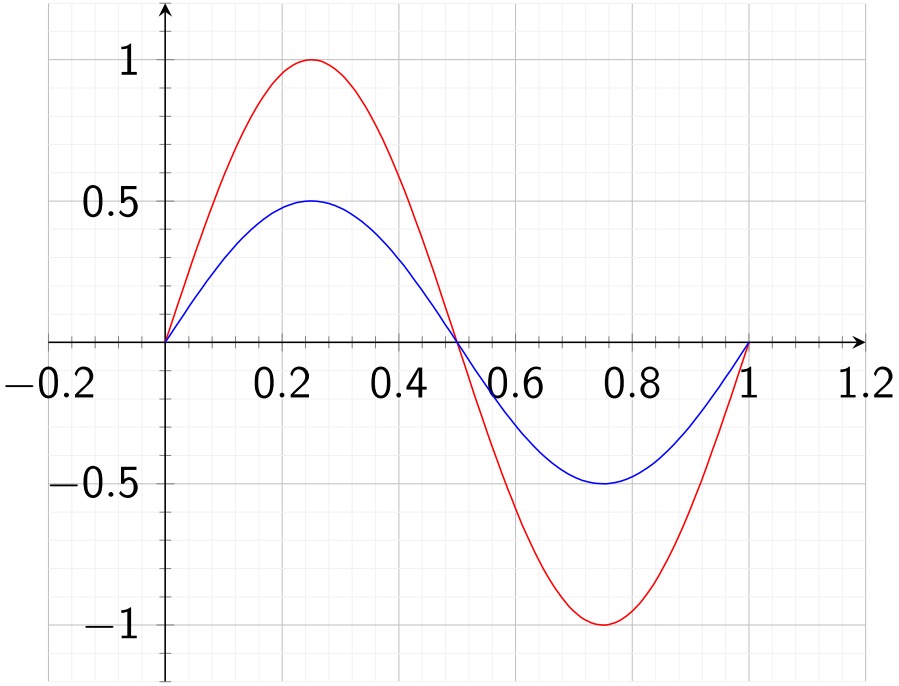
Blue signal is quarter of a cycle ahead of the red signal.

- One cycle is considered as 360 degrees
  - Quarter cycle is 90 degrees
    - These two signals have a 90 degrees phase difference

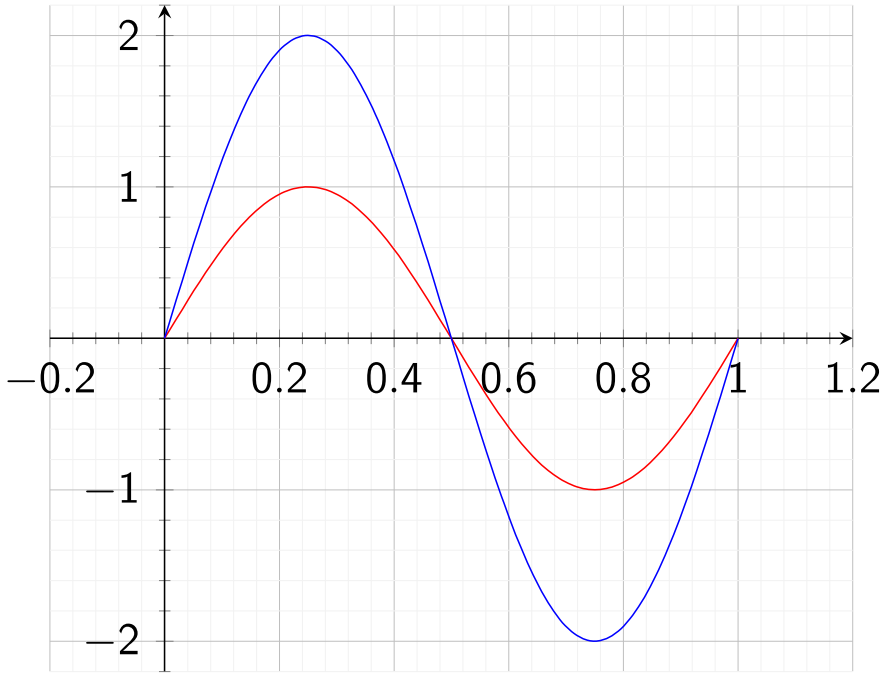
Transmission Impairments

- When a signal travel along a transmiison media it changes due to the imperfections in the mdia
- In the following diagrams
  - Red signal - Signal Transmitted
  - Blue Signal - Signal Received

Attenuation

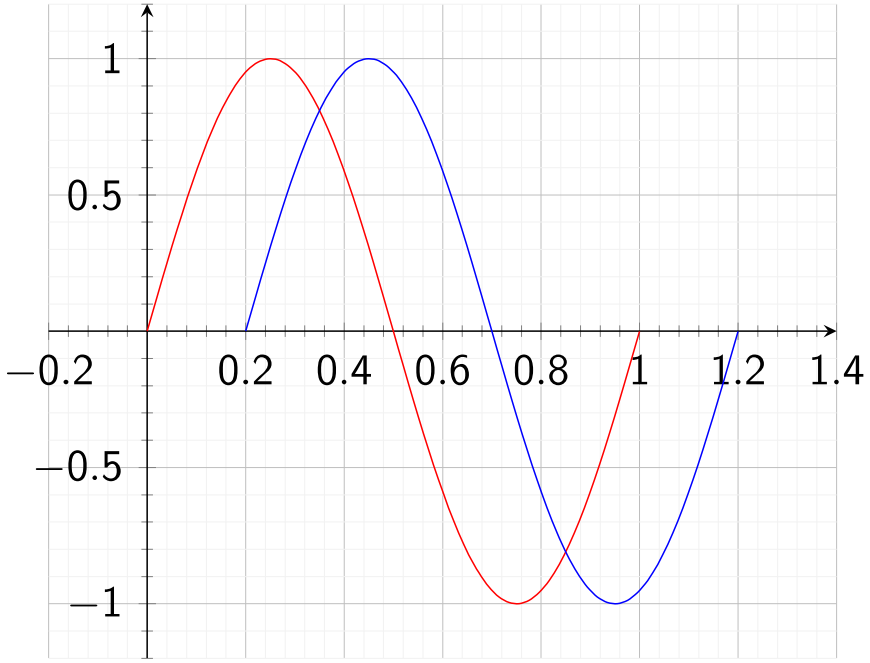


Amplification

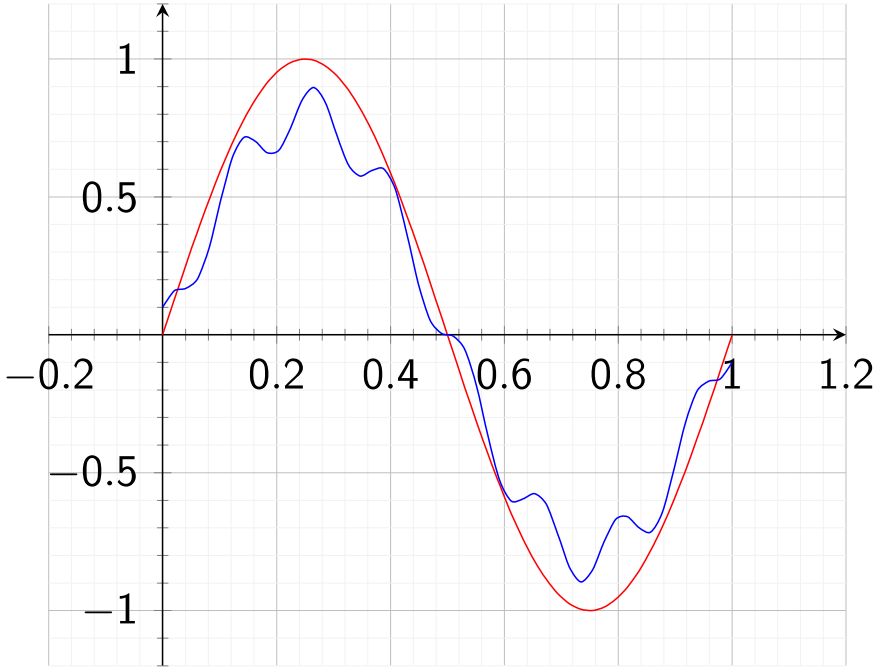


Not actually a problem, but still the output signal iis different from the input

Delay



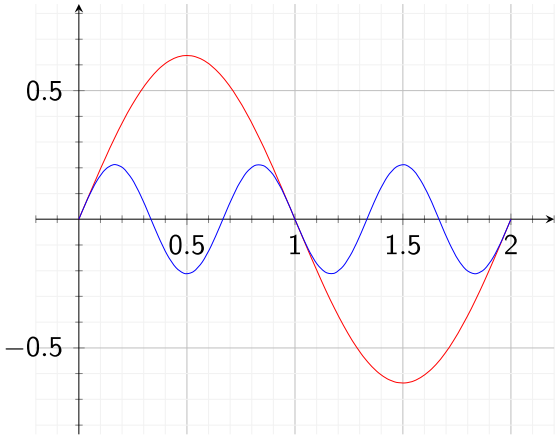
Noise

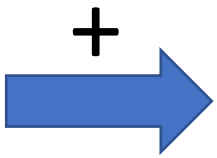


Red signal is distorted due to unwanted signals in the medium to produce the blue signal

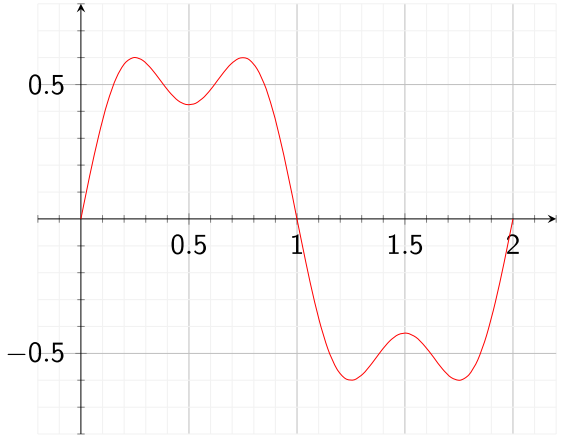
Summing Up Sine Waves

$\frac{2}{\pi}sin(x)$ and $\frac{2}{3\pi}sin(3x)$

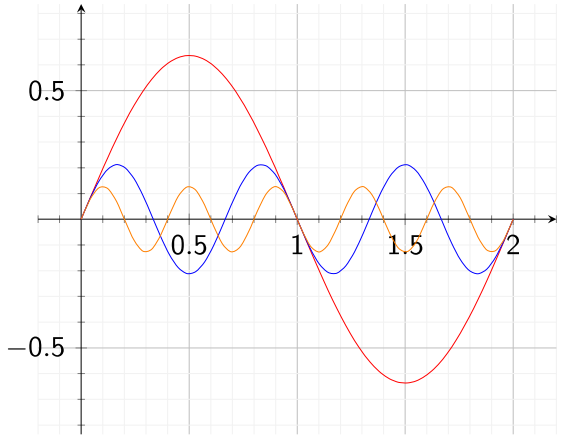


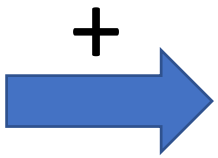


$\frac{2}{\pi}sin(x) + \frac{2}{3\pi}sin(3x)$

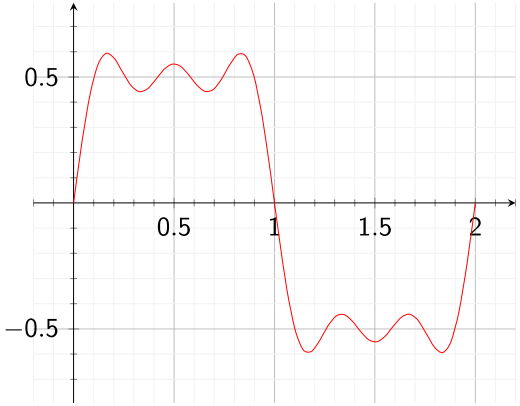


$\frac{2}{\pi}sin(x)$ and $\frac{2}{3\pi}sin(3x)$ and $\frac{2}{5\pi}sin(5x)$



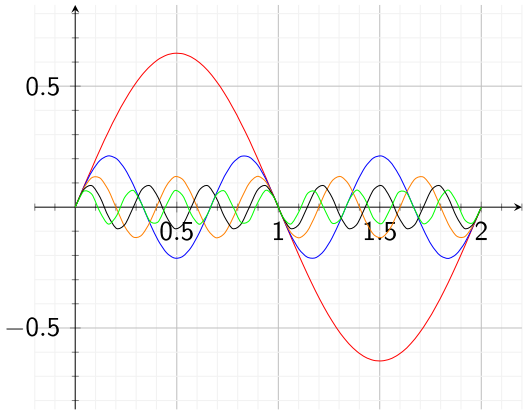


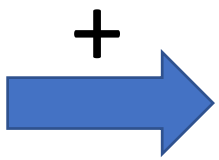
$\frac{2}{\pi}sin(x) + \frac{2}{3\pi}sin(3x) + \frac{2}{5\pi}sin(5x)$

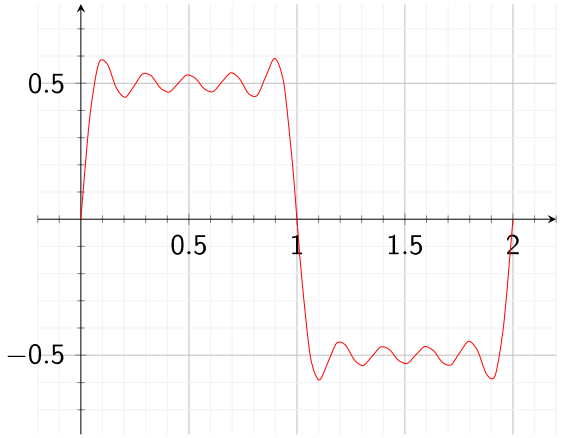


$\frac{2}{\pi}sin(x)$ and $\frac{2}{3\pi}sin(3x)$ and $\frac{2}{5\pi}sin(5x)$ and $\frac{2}{7\pi}sin(7x)$ and $\frac{2}{9\pi}sin(9x)$

$\frac{2}{\pi}sin(x) + \frac{2}{3\pi}sin(3x) + \frac{2}{5\pi}sin(5x) + \frac{2}{7\pi}sin(7x) + \frac{2}{9\pi}sin(9x)$

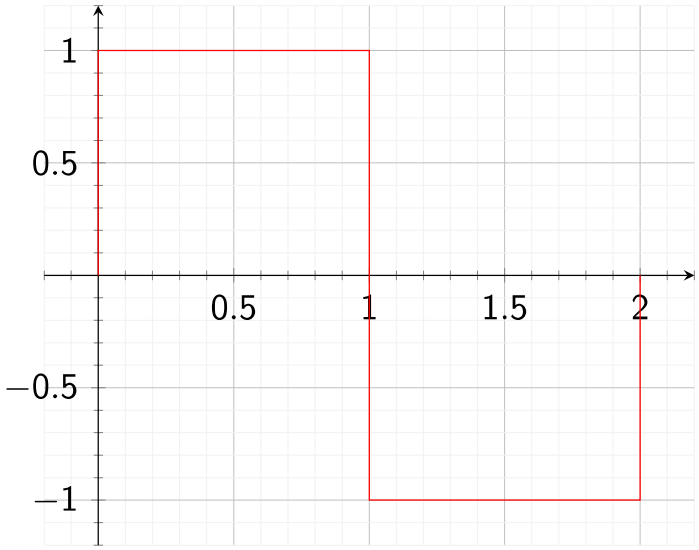






This looks like a square wave !

$$\frac{2}{\pi}sin(x) + \frac{2}{3\pi}sin(3x) + \frac{2}{5\pi}sin(5x) + \frac{2}{7\pi}sin(7x) + \frac{2}{9\pi}sin(9x) + \frac{2}{11\pi}sin(11x) + \frac{2}{13\pi}sin(13x) \ldots \rightarrow \infty$$



Square wave can be produced by adding infinite number of sine waves !

This digital signal is a combination of infinite number of sine waves.

2.1 Transmission Media

"A **transmission medium** is a system or substance that can mediate the propagation of signals for the purposes of telecommunication. Signals are typically imposed on a wave of some kind suitable for the chosen medium. For example, data can modulate sound, and a transmission medium for sounds may be air, but solids and liquids may also act as the transmission medium. Vacuum or air constitutes a good transmission medium for electromagnetic waves such as light and radio waves"

Wikipedia

Channel

"A **communication channel** refers either to a physical transmission medium such as a wire, or to a logical connection over a multiplexed medium such as a radio channel in telecommunications and computer networking."

Wikipedia

2.1.1 Maximum Datarate of a Channel

Bandwidth

- It means different things to Electrical Engineers and Computer Scientists
  - Electrical Engineers
    - Bandwidth is a quantity measured in Hz
      - A range of frequencies that can pass through a channel
      - Analog
  - Computer Scientists
    - Bandwidth is the maximum data rate of a channel
      - maximum data rate of a channel
      - Digital
  - These two are related

Bandwidth

- A channel has a limited bandwidth
  - Only a limited range of frequencies can pass through a channel without a considerable attenuation
- A digital signal is composed of an infinite number of sine waves (frequencies)
  - It requires a channel with an infinite bandwidth to reproduce the digital signal **perefectly** at the receiver
    - Impossible in practice
      - All physical channels are bandwidth limited

Maximum Data rate of a **noiseless** channel

- Bandwidth of the channel = B Hz
- Number of discrete levels in the signal = V

Maximum Data rate of the channel = $2B \log_2 V$ Bits/sec

Signal to Noise Ratio
SNR

- Signal power in the channel = S
- Noise power in the channel = N

$$SNR = S/N$$

- Usually expressed in the logarithmic scale

$$SNR = \log_{10} S/N \text{ Bel}$$

- Bel is a large unit therefore expressed in *decibel (dB)*

$$SNR = 10 \log_{10} S/N \text{ dB}$$

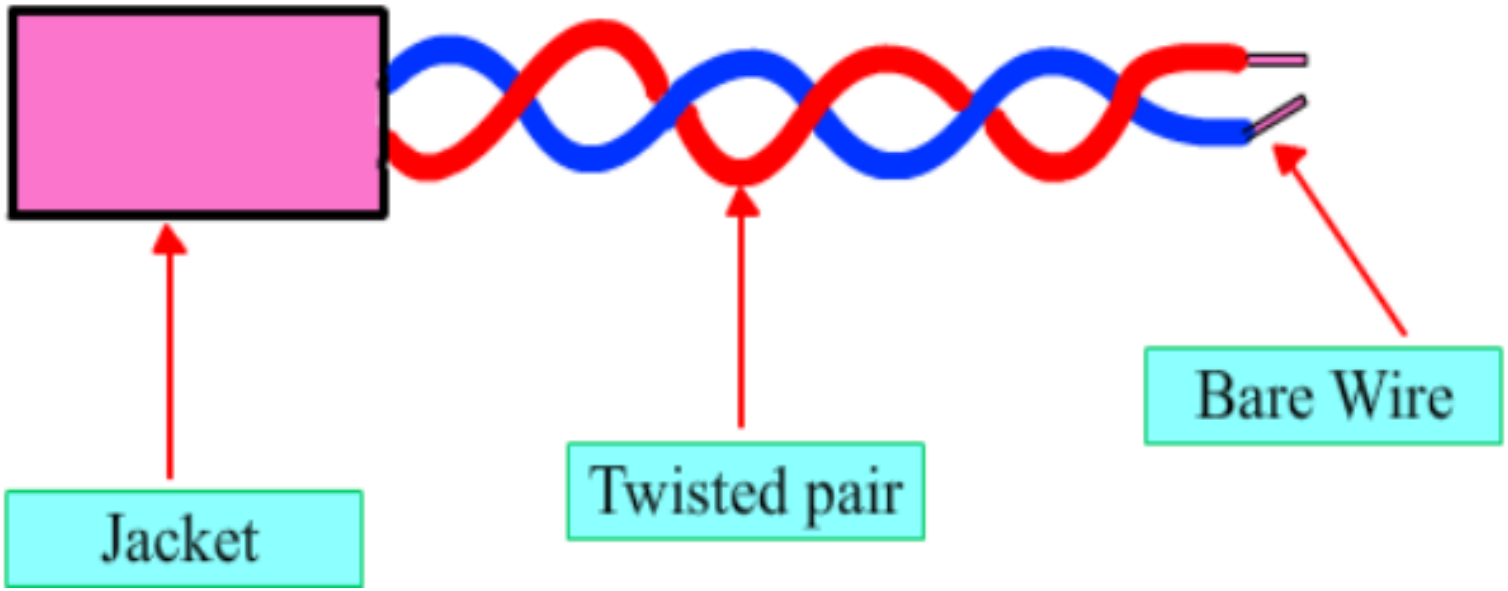
Maximum Data rate of a **noisy** channel

- Bandwidth of the channel = B
- Signal power in the channel = S
- Noise power in the channel = N

Maximum Data rate of the channel = $B \log_2 (1 + S/N)$ Bits/sec

2.1.2 Guided Transmission Media

Twisted Pairs

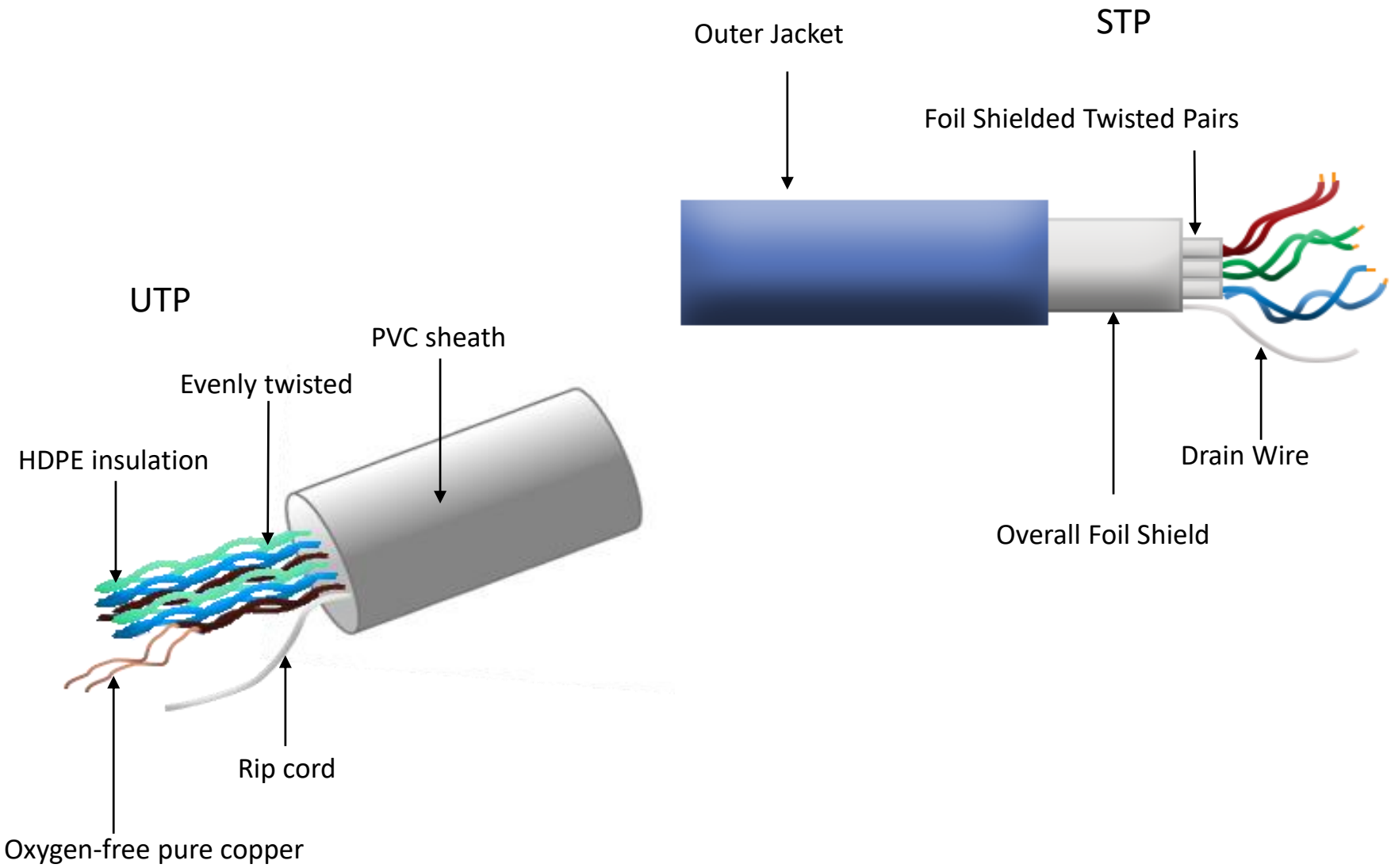


Twisted Pairs

- Two insulated copper wires twisted like a DNA molecule
  - Waves from different twists cancel out
    - Less radition
  - Difference in voltages of the two wires represents the signal.
    - Due to twists external noise affects both wires equally
      - Noise cancels out when the difference is measured

Twisted Pairs - Shielding

- Shielded Twisted Pair – STP
  - Shields around individual twisted pairs
  - Shields around the entire cable
    - shielding reduces the susceptibility to external interference and crosstalk with other nearby cables
- Unshielded Twisted Pair – UTP
  - No shields



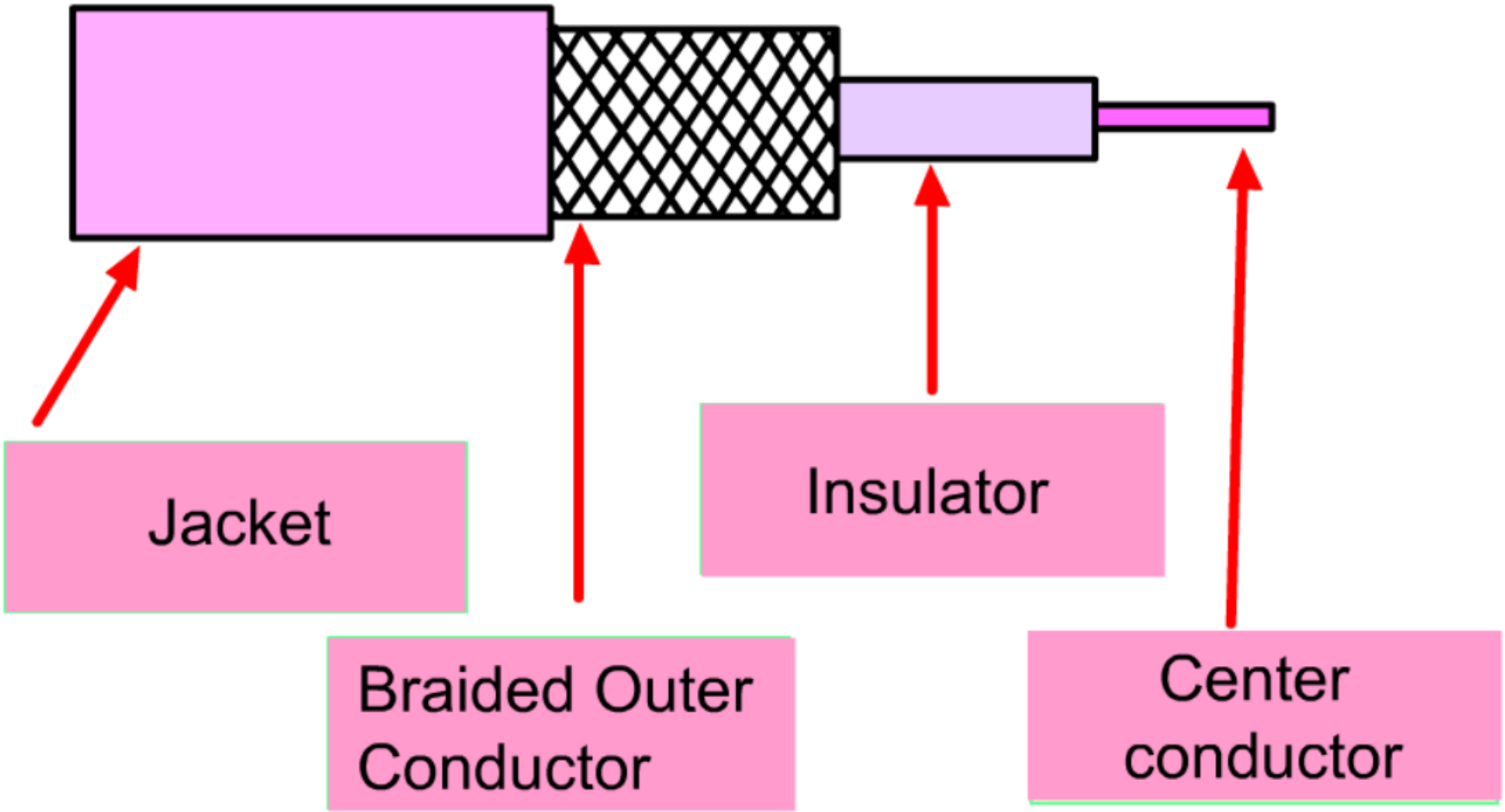
Twisted Pairs - Varieties

- Category 3 – Cat 3
  - UTP
  - Bandwidth 16 Mhz
  - Used in 10BaseT Ethernet
  - Telephone cables
- Category 5 – Cat 5
  - UTP
  - Bandwidth 100 Mhz
  - More twists than Cat 3
  - Used in 100 Mbps and 1 Gbps Ethernet
- Category 6 – Cat 6
  - UTP
  - Bandwidth 250 Mhz
  - Bandwidth 500 Mhz
  - Supports up to 10 Gbps

Twisted Pairs - Varieties

- Category 7 – Cat 7
  - STP
    - shielding on the individual twisted pairs, as well as around the entire cable
  - Bandwidth – Up to 1000 Mhz

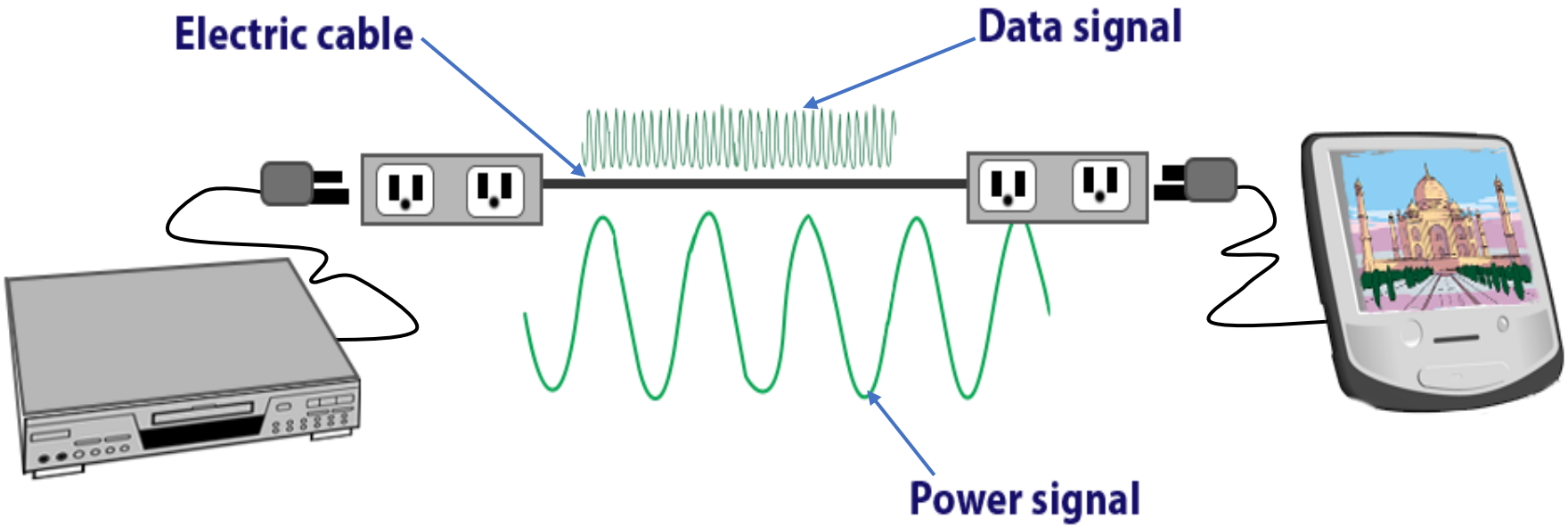
Coaxial Cables



Coaxial Cables

- Stiff copper wire (core), surrounded by an insulating material
- Insulator is encased by a cylindrical conductor
  - often a closely woven braided mesh
- Outer conductor is covered in a protective plastic sheath
- Two types
  - 75 Ohm cable
  - 50 Ohm cable
- The cable running from the Antenna to the TV
- Bandwidth – few Giga Hertz

Powerline Communication



A network that uses household electrical wiring.

Powerline Communication

- Used by electricity companies for low-rate communication
  - remote metering
- It is practical to send at least 100 Mbps over typical household electrical wiring

Optical transmission systems

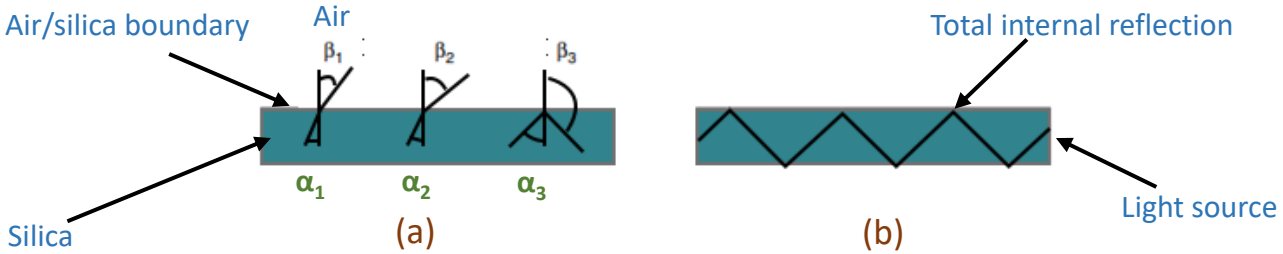
- Components
  - Light source
  - Transmission medium
  - Detector
- Light pulses are used to encode bits
  - Example
    - Pulse 1 bit
    - Absence of pulse 0 bit

Light Sources

Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multi-mode	Multi-mode or single-mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

Transmission Medium
Fiber Cables

- Made of glass
  - Made of sand
    - Inexpensive and abundant



Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

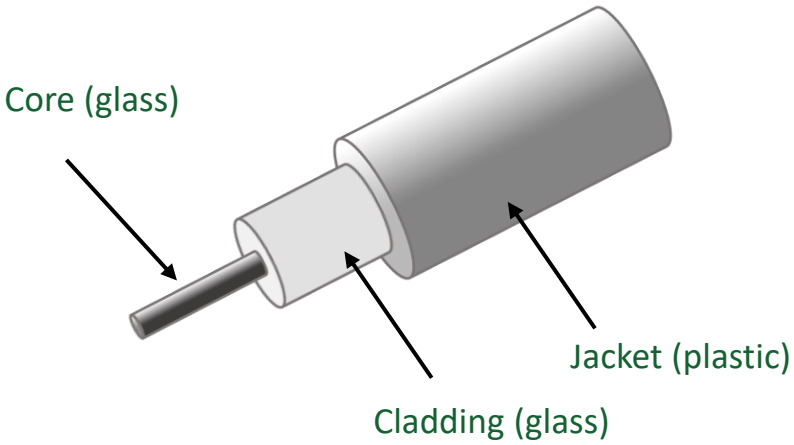
Light trapped by total internal reflection.

- Light ray is trapped inside the fiber due to total internal refraction
  - Can propagate many kilometres without a substantial loss

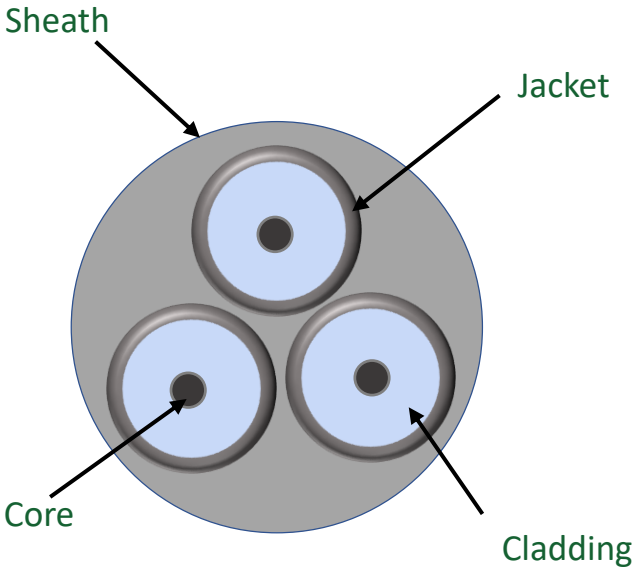
Fiber Cables
Modes

- Multimode
  - Different rays bounce around in the fiber at different angles
  - Less expensive
- Single Mode
  - Diameter of the fiber is just few wavelengths of the light
  - Light propagates in straight line without bouncing
  - Expensive
  - Used for longer distance communication

Fiber Cables



Side view of a single fiber



End view of a sheath with three fibers

Detector

- Photodiode
  - Gives an electric pulse when struck by light
    - Light pulse must carry enough energy to be detected
  - Response time limits the data rate

Fiber Vs Copper

- Activity
  - Compare and contrast fiber and copper
  - Create a table to show the advantages and disadvantages

2.1.3 Wireless Transmission Media

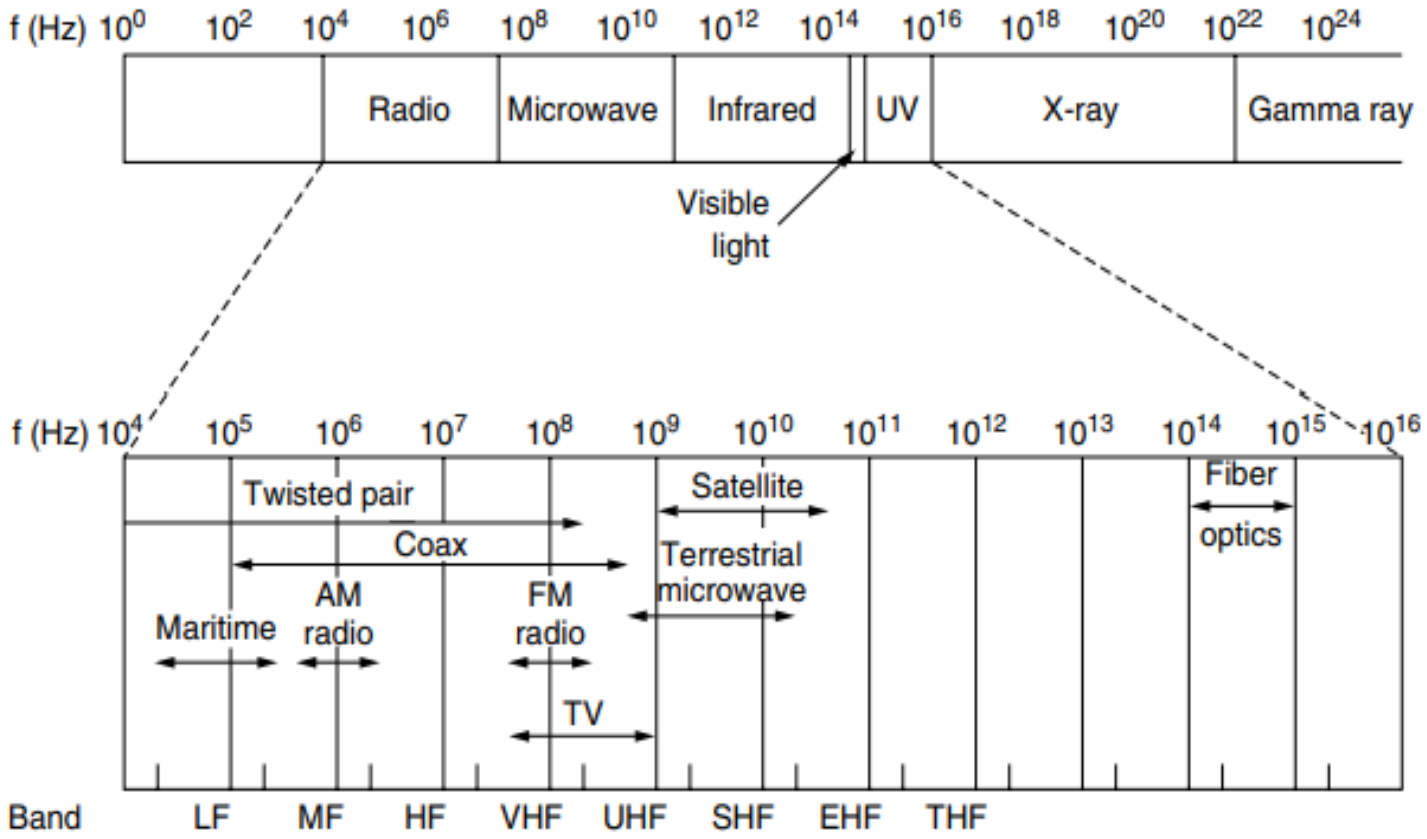
Electromagnetic Waves Basics

- Frequency - f
  - Number of oscillations per second of a wave
  - Measured in Hertz – Hz
- Wavelength – **λ**
  - The distance between two consecutive maxima (or minima) of a wave
  - Measure in meters
- Propagation Speed in a medium – c
  - Light is also an electromagnetic wave
    - Propagation speed of light in a vacuum – 3×10^8 m/sec

Electromagnetic Waves Basics

$$c = f \lambda$$

Electromagnetic Spectrum

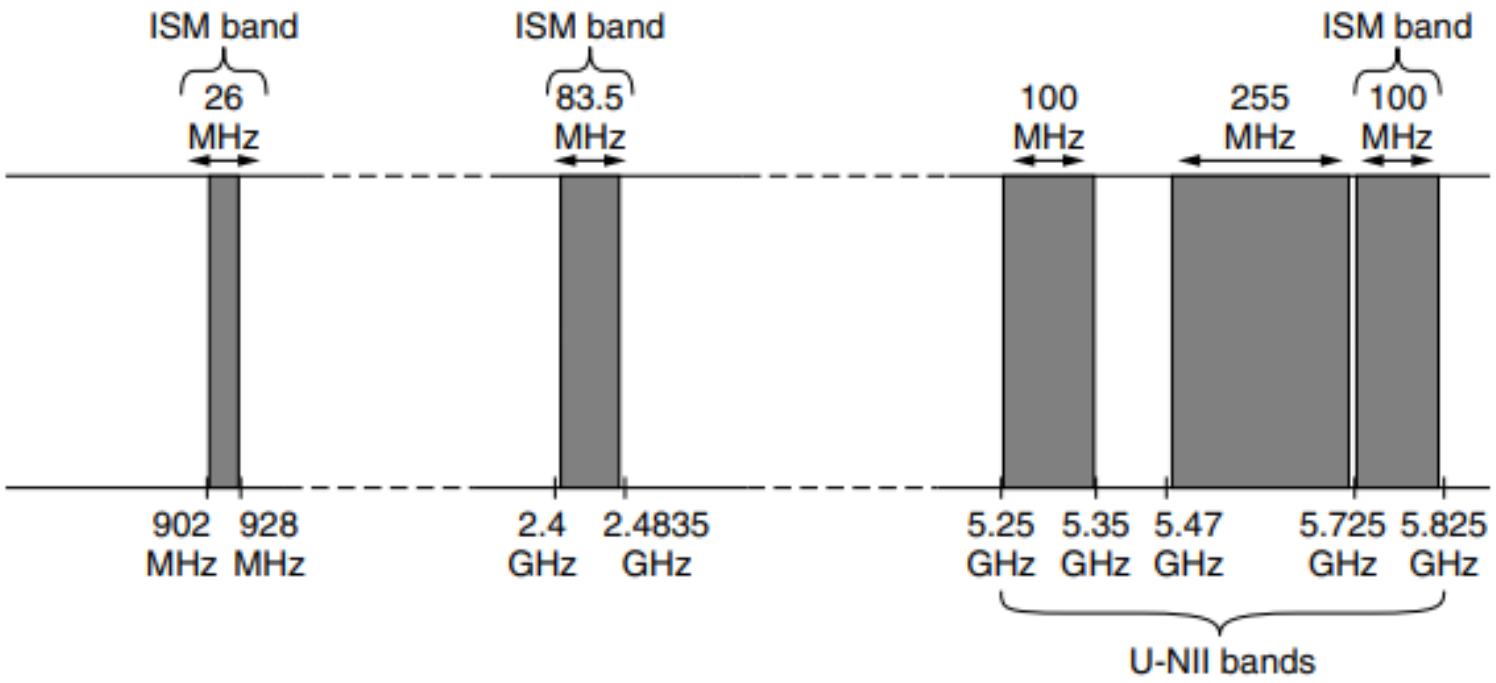


The electromagnetic spectrum and its uses for communication.

Electromagnetic Spectrum Regulations

- Regulations to prevent chaos
  - In Sri Lanka the regulatory body is the Telecommunications Regulatory Commission of Sri Lanka (TRCSL)
  - In USA - Federal Communication Commission (FCC)
  - International Telecommunication Union (ITU)
    - The ITU Radiocommunication Sector (ITU-R)
- License is required to use most of the electromagnetic spectrum
- Some frequency bands are set aside for unlicensed usage
  - Industrial, Scientific, Medical (ISM) bands

ISM Bands



ISM and U-NII bands used in the United States by wireless devices.

ISM Bands

- Garage door openers
- cordless phones
- radio-controlled toys
- WiFi
- Bluetooth
- Microwave

Infrared

- Shot range communication
  - TV remote controls
- Cheap
- Cannot penetrate walls
  - Does not interfere with neighbouring systems
    - No government license is required

Free-space optical communication

- LiFi
  - High speed data transmission using – up to 100Gbps
    - Visible light
    - Ultraviolet
    - Infrared
  - Useful in environments susceptible to electromagnetic interference
    - Aircrafts
    - Hospitals

2.2. Modulation and Multiplexing

Modulation

> "… modulation is the process of varying one or more properties of a periodic waveform, called the carrier signal, with a separate signal called the modulation signal that typically contains information to be transmitted. "
>
> Wikipedia

- Properties that can be changed
  - Amplitude
  - Frequency
  - Phase
- Inverse process - Demodulation

Modulation

- The process of converting between bits and signals that represent them is called ***digital modulation***
- Directly convert bits into a signal
  - Baseband transmission
    - signal occupies frequencies from zero up to a maximum
- Regulate the amplitude, phase, or frequency of a ***carrier signal*** to convey bits
  - Passband transmission
    - Signal occupies a band of frequencies around the frequency of the carrier signal.

Baseband Transmission

(A) Bit stream

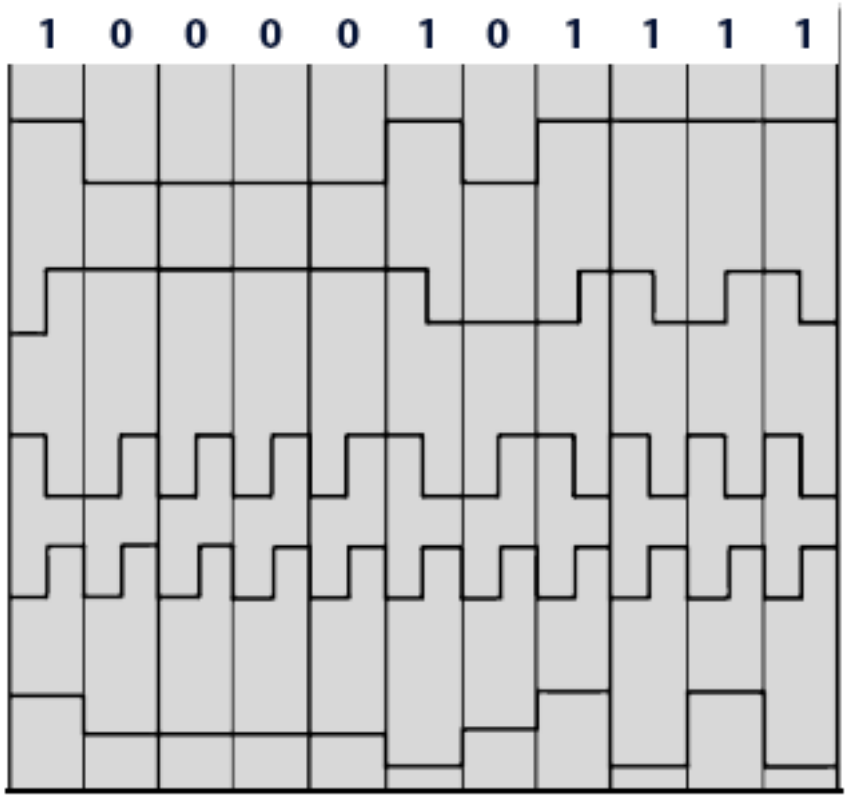
(B) Non-Return to Zero (NRZ)

(C) NRZ Invert (NRZI)

(D) Manchester

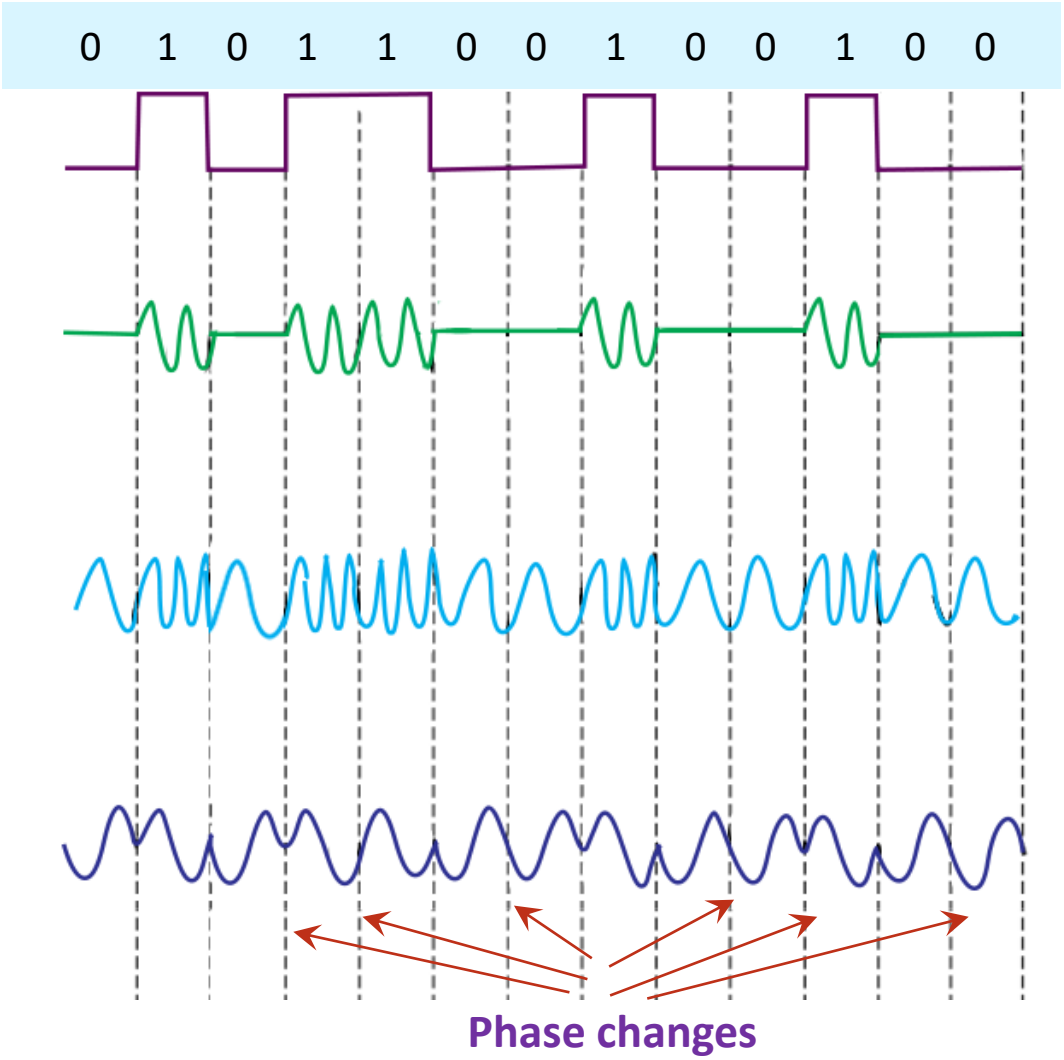
(Clock that is XORed with bits)

(E) Bipolar encoding (also Alternate Mark Inversion, AMI)



Line codes: (A) Bits, (B) NRZ, (C) NRZI, (D) Manchester, (E) Bipolar or AMI.

Passband Transmission



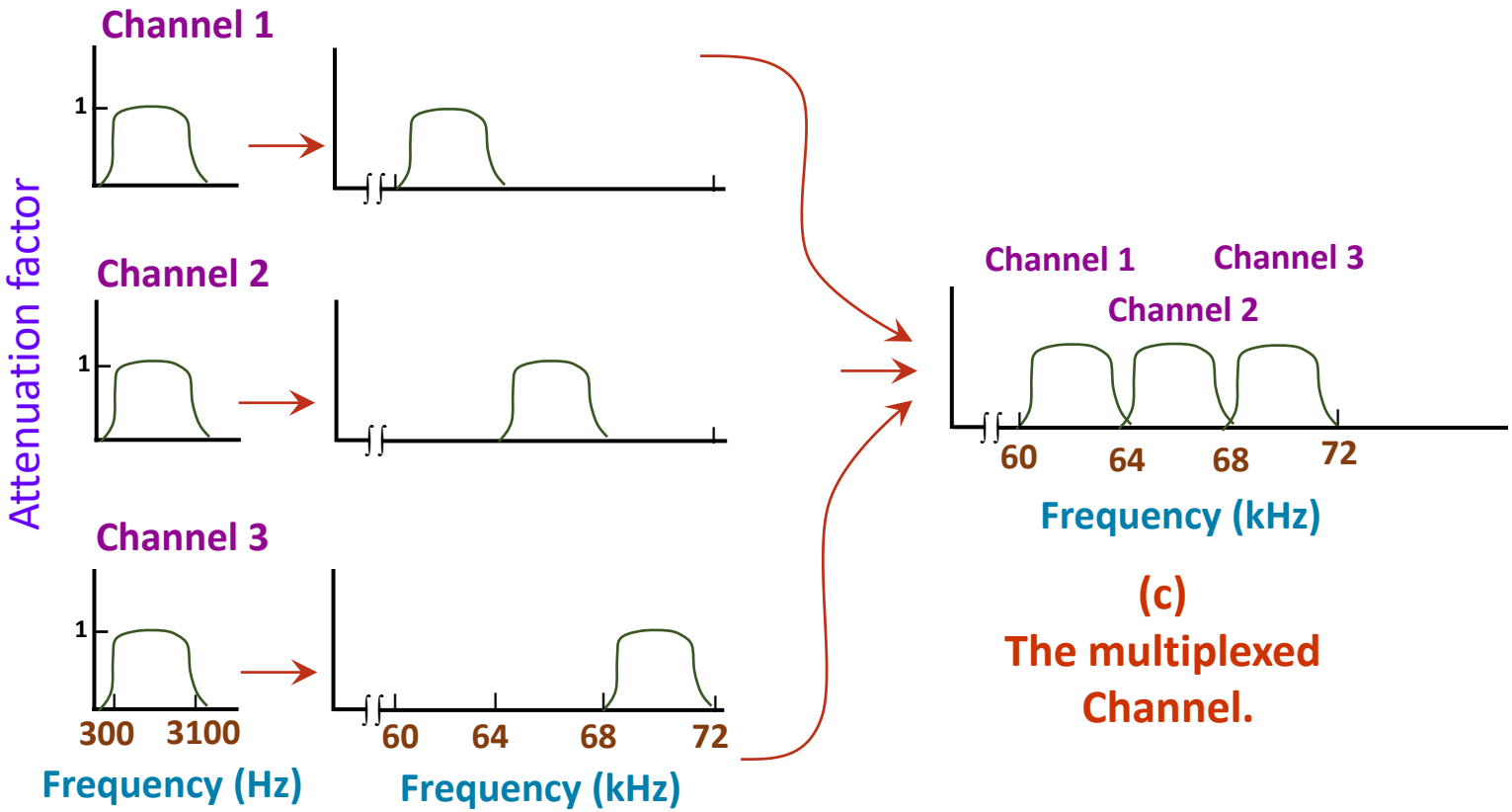
Multiplexing

- Multiple signals are combined into one signal over a shared medium
  - Divides the channel capacity into several logical channels
  - The device that does the multiplexing – Multiplexer (MUX)
- Demultiplexing
  - Extracts the original channels
    - Device – Demultiplexer – (DEMUX)

2.2.2.Frequency Division Multiplexing

- Takes advantage of the passband transmission to divide the available bandwith of a channel
  - Divides the spectrum into frequency bands
    - Guard bands are placed to avoid interference
  - A carrier frequency from each band (subcarrier) is used to modulate the data stream

Frequency Division Multiplexing



(a)
The original bandwidths

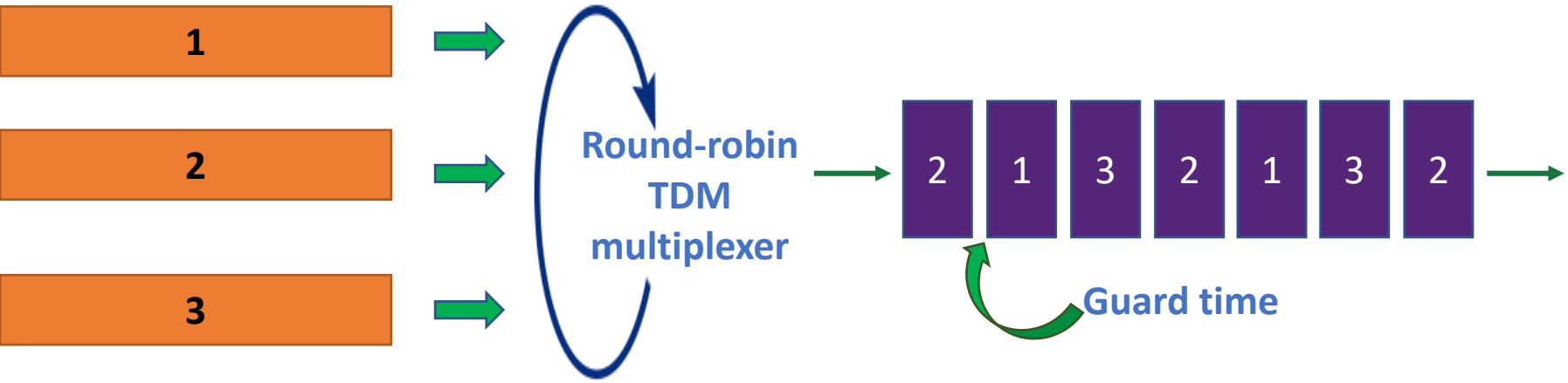
(b)
The bandwidths raised in frequency.

(c)
The multiplexed Channel.

2.2.3 Time Division Multiplexing

- Each user (sender) gets a time burst in a round robin fashioon
  - Whole bandwidth is allocated for that user for that time period
  - A guard time is there in between time slots as a safeguard against timing errors

Time Division Multiplexing



Statistical Time Division Multiplexing (STDM)

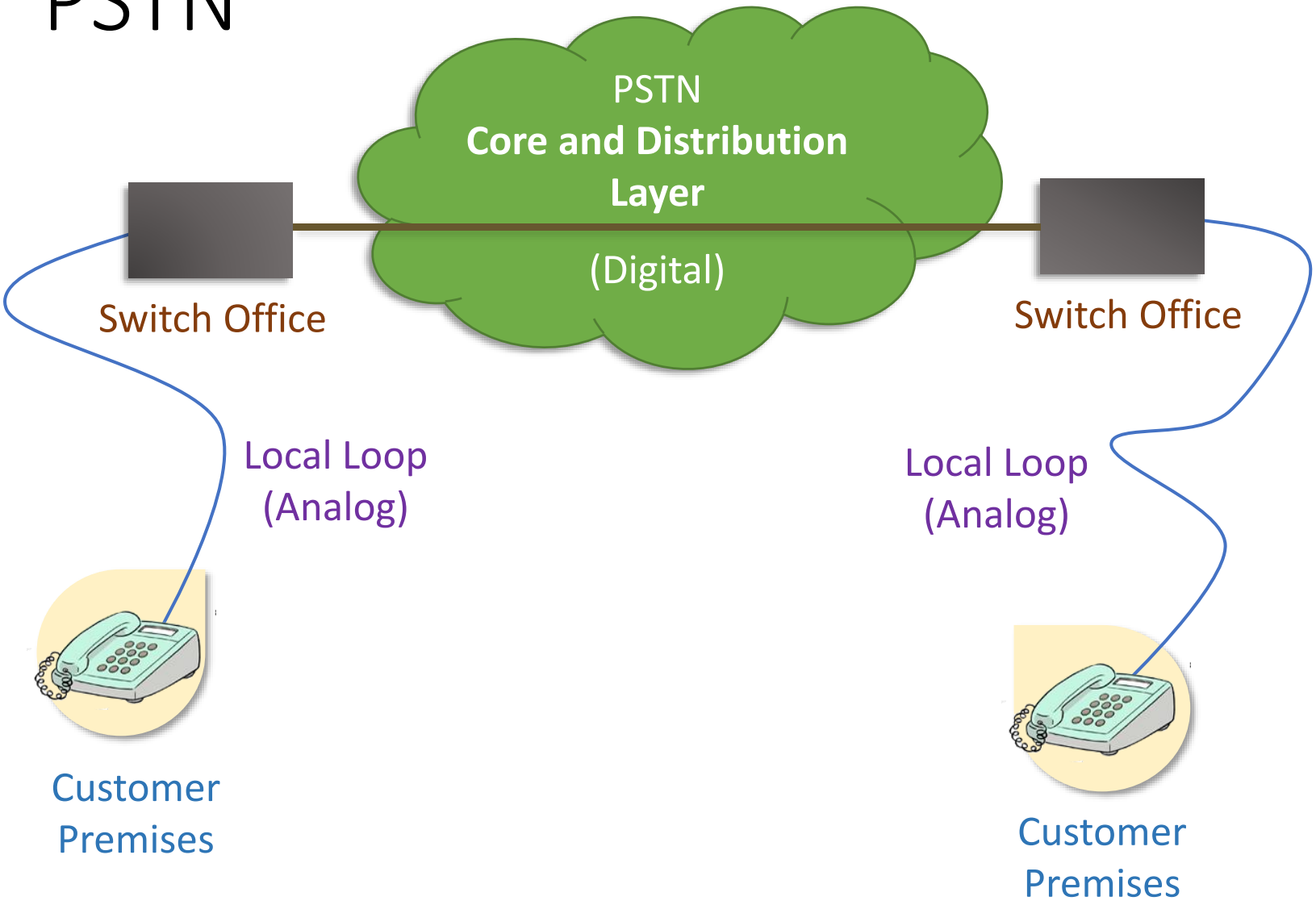
- There are no fixed time slots
  - Slots are allocated on demand
  - Packet Switching → STDM

2.3. Modems, ADSL and Fiber to Home

Public Switched Telephone Network - PSTN

- Originally designed to carry voice
- Local Loop
  - analog twisted pairs going to subscribers (houses and businesses)
  - Bandwidth of the voice-grade telephone line is limited to 3100 Hz (4000 Hz including the guard bands)
- Trunks
  - digital fiber optic links connecting the switching offices
- Switching offices
  - calls are moved from one trunk to another

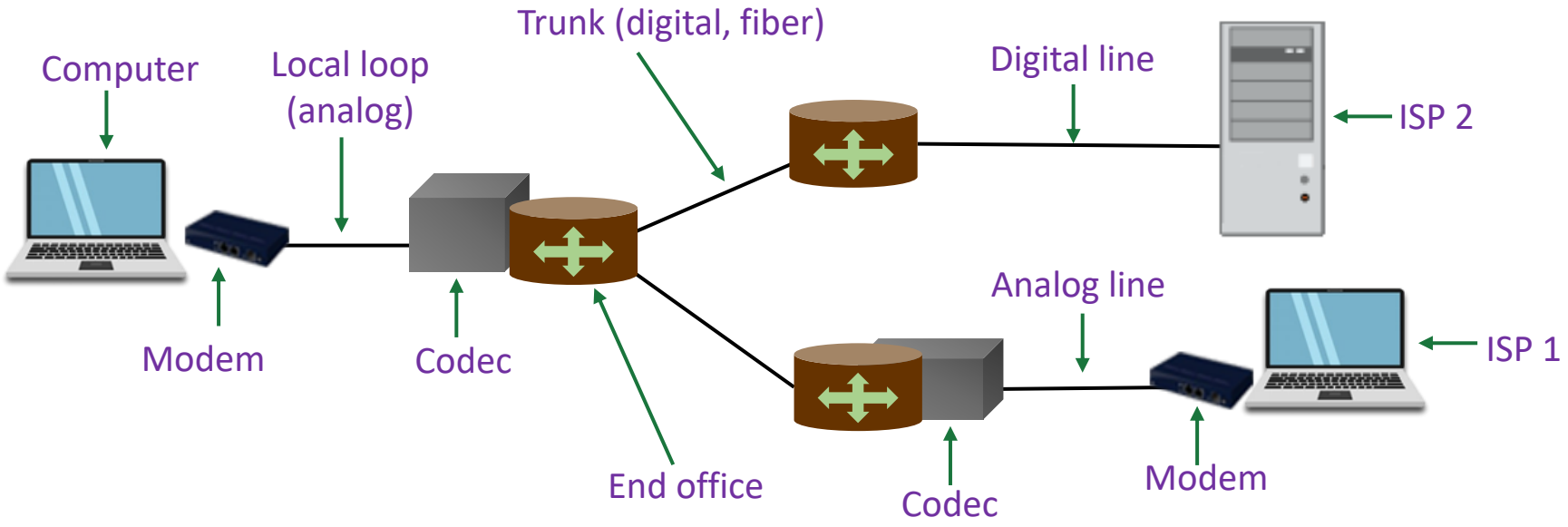
PSTN



Modems

- Local loop is an analog line
- Bits should be converted to analog signals using digital modulation
  - Use demodulation at the receiver
  - The device that does the modulation and the demoulation → Modem
- Local loop bandwidth is 3100 Hz
  - Low datarates

Modems



The use of both analog and digital transmission for a computer-to-computer call. Conversion is done by the modems and codecs.

Digital Subscriber Line (DSL)

- The bandwidth of the local loop is limited to 4000 Hz using filters at the end office
  - The twisted pair has much more bandwidth than 4000 Hz
    - About 1.1 MHz
      - Depends on the distance from the end office and the quality of the wires
- Remove the filter and use the full bandwidth for subcribers of DSL

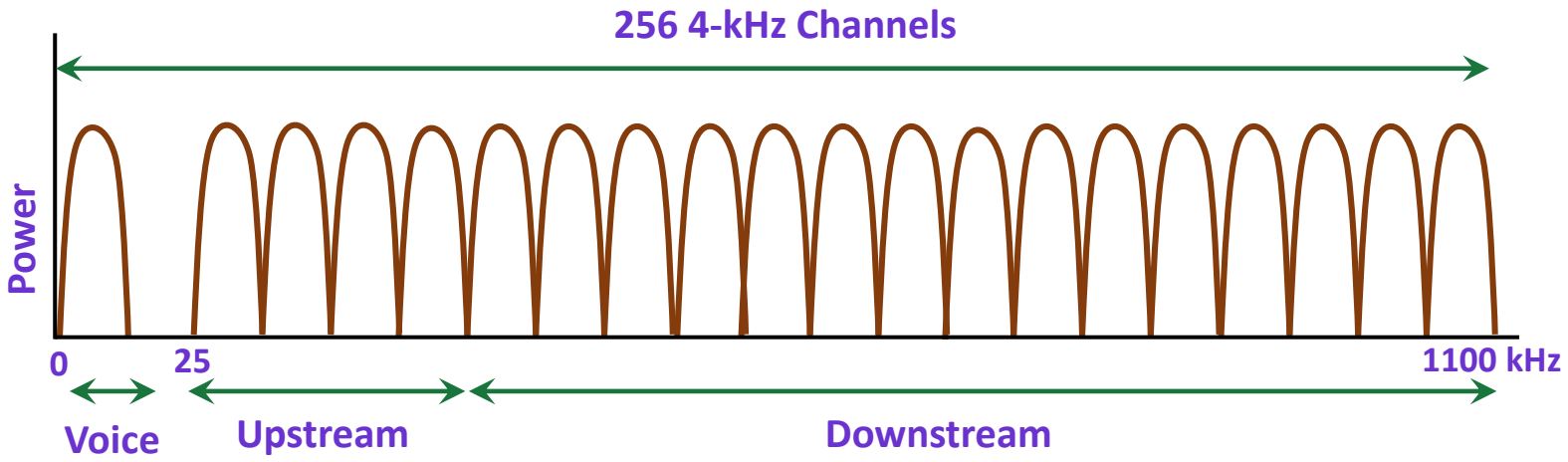
Digital Subscriber Line (DSL)

- The bandwidth of 1.1 MHz local loop is divided in to 256 channels each with a bandwidth of 4312.5 Hz
- One channel (0) is reserved for the Plain Old Telephone Service (POTS)
- Channels 1-5 are not used
  - To avoid interference between data and voice
- 250 channels are allocated for data and control signals

Asymmetric Digital Digital Subscriber Line (ADSL)

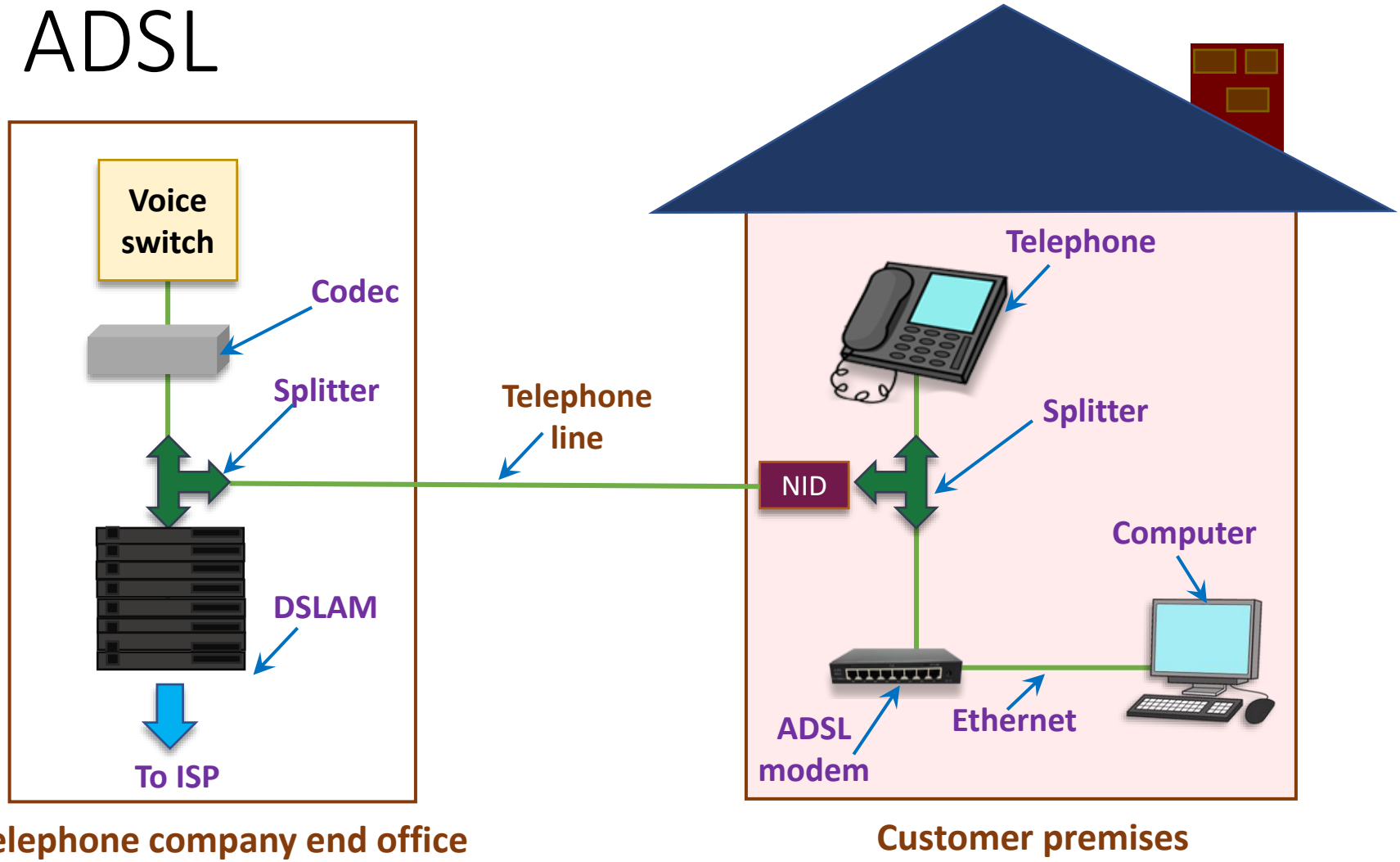
- Majority of the 250 channels are allocated for downstream communication
  - In common use cases users download more then they upload
    - Request for a web page or a vide is very small compared to the response from the servers
  - Asymmetric allocation of bandwidth

ADSL



Operation of ADSL using discrete multitone modulation.

ADSL



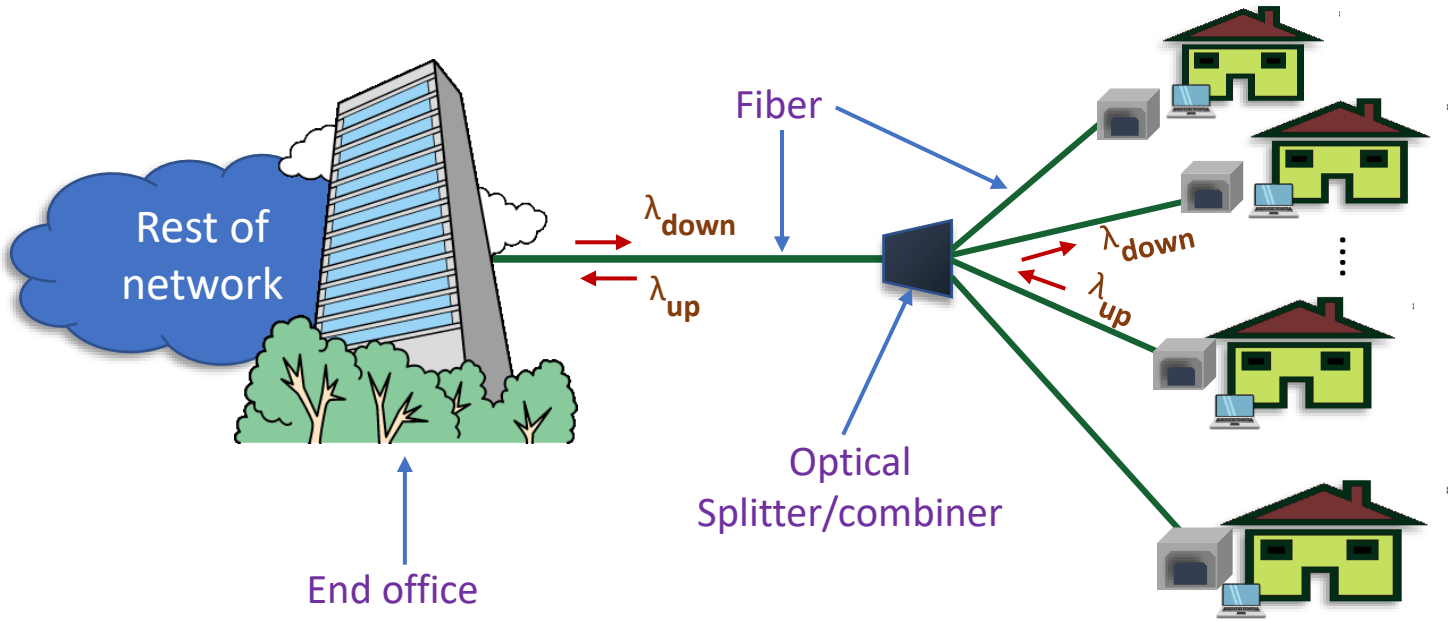
A typical ADSL equipment configuration.

Activity

- What is the reason to connect a the modem and a telephone through a splitter?
- What is DSLAM in a DSL system?

Fiber to the Home (FTTH)

- Passive Optical Networks (PON)



Passive optical network for Fiber To The Home.

PON

- Downstream
  - Data from Fiber from houses are multiplexed into a single fiber running to the end office
- Upstream
  - Optical splitters divide the signal from the end office
- Optical Network Terminal (ONT)
  - Device at the home
  - Converts optical signals to electrical and vice versa
  - Multiplexer/Demultiplexer
    - Multiplexes the signals from the TV, Phone, and Computers etc.
    - Not really modem, but people reffer to it as a modem or a router

Activity

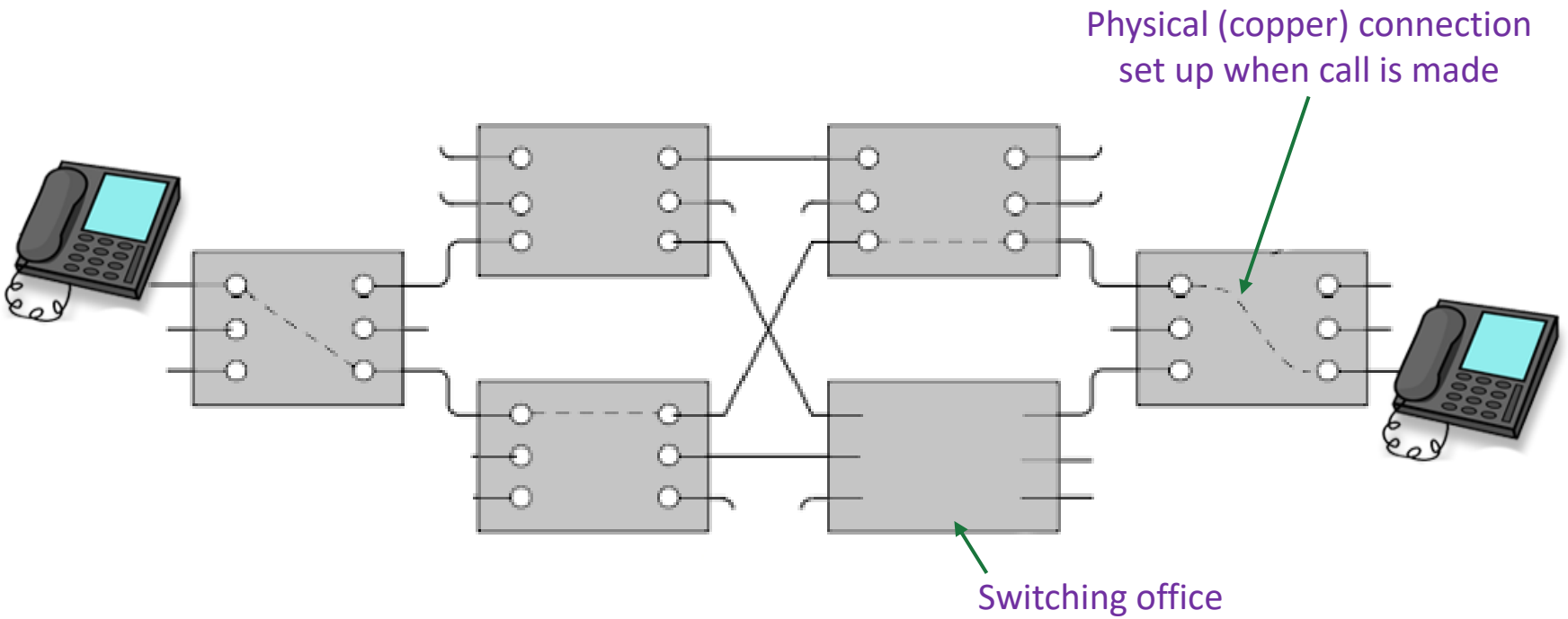
- Find the upstream and downstream data rates of following types of last mile connections in Sri Lanka
  - ADSL
  - FTTH

2.4. Circuit Switching and Packet Switching

Circuit Switching

- A method of implementing a telecommunication network
- A dedicated communication channel is established for communication
  - Circuit
- Full bandwidth of the channel is available for the duration of the communication
  - Session
- Analog telephone network
  - Dedicated electrical circuit between telephones for the duration of a call

Circuit Switching



Circuit Switching

- Advantages
  - Dedicated bandwidth
  - Continous trasfer of messages without the per message overhead in packet switching
- Disadvantages
  - dedicated bandwidth may not be fully utilised
    - Other users cannot use the unutilised bandwidth

Packet Switching

- A packet is a grouping of data and it consists of
  - A header
  - A Payload
- Two types
  - Connectionless packet switching
  - Connection oriented packet switching

Connectionless Packet Switching

- Packet header contains all the information required to forward it to the destination
- No need to pre-establish a path
  - Packets are routed individually
    - Packets from the same source to the same destination may take different paths
    - No guranted bandwidth

Connection-oriented Packet Switching

- Setup phase to setup parameters for communication
- Packet header conatins a connection identifier
  - Very small header compared to conncetionless packet switching
- Path is setup during the connection phase
  - Virtual circuit
    - Not a dedicated circuit as in circuit switching