Computer Networks (CSC305)

<u>Course Outline:</u>

√Overview of Data Communication and Networking

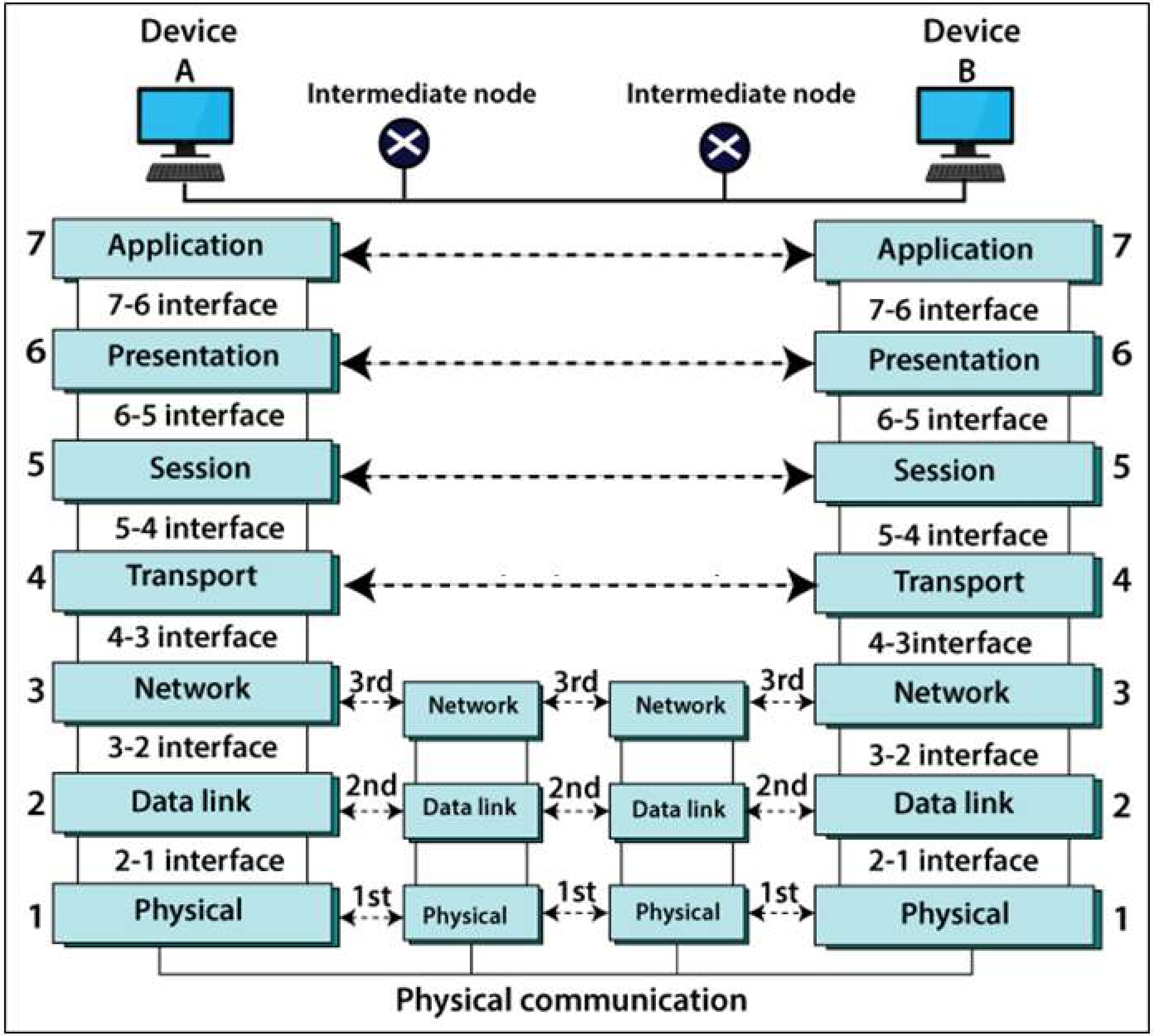
√Physical Layer

- Data Link Layer
  - Logical Link Control (LLC)
  - Medium Access Control (MAC)
- Network Layer
- Transport Layer
- Application Layer

OSI Reference Model

Host Layers	APPLICATION	Network process to Application, User end APIs, resource sharing, remote file access, etc.	DATA
	PRESENTATION	Translation of data like character encoding, encryption/decryption, data compression, etc.	DATA
	SESSION	Establish, maintain and gracefully shut down the session.	DATA
	TRANSPORT	Reliable end to end communication, segmentation, flow-control, acknowledgement, and multiplexing	SEGMENT
Media Layers	NETWORK	Path determination, logical addressing, routing, traffic control	PACKET
	DATA LINK	Reliable node to node transmission of frames, MAC and LLC sublayers, Physical addressing	FRAMES
	PHYSICAL	Transmission/Reception of binary bit streams over physical medium, encoding/decoding at bit level	BITS

OSI Reference Model



Physical Layer

- Connection Types / Line Configuration
  - Point-to-Point
  - Multipoint
- Physical Topology
  - Bus
  - Ring
  - Star
  - Mesh
  - Cellular
- Signalling
  - Analog
  - Digital
- Bit Synchronization
  - Synchronous
  - Asynchronous

- Multiplexing
  - Time-Division Multiplexing (TDM)
  - Frequency-Division Multiplexing (FDM)
  - Wave-Division Multiplexing (WDM)
- Spread Spectrum
  - Frequency Hopping Spread Spectrum
  - Direct Sequence Spread Spectrum
- Switching
  - Circuit Switching
  - Message Switching
  - Packet Switching
- Transmission Media
  - Guided Media
  - Unguided Media

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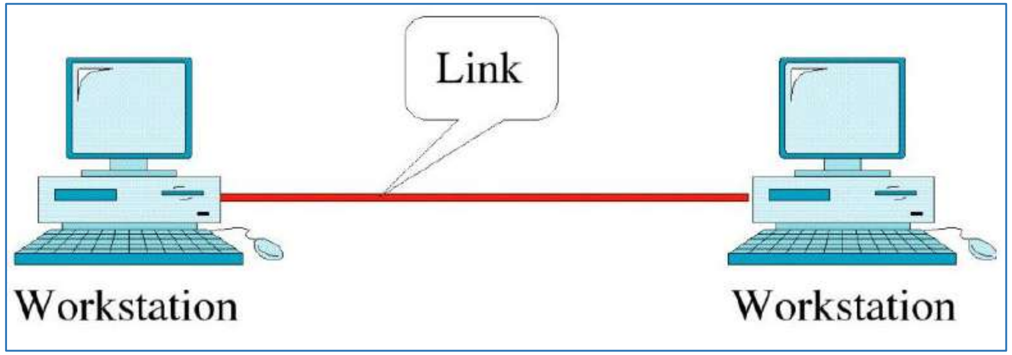
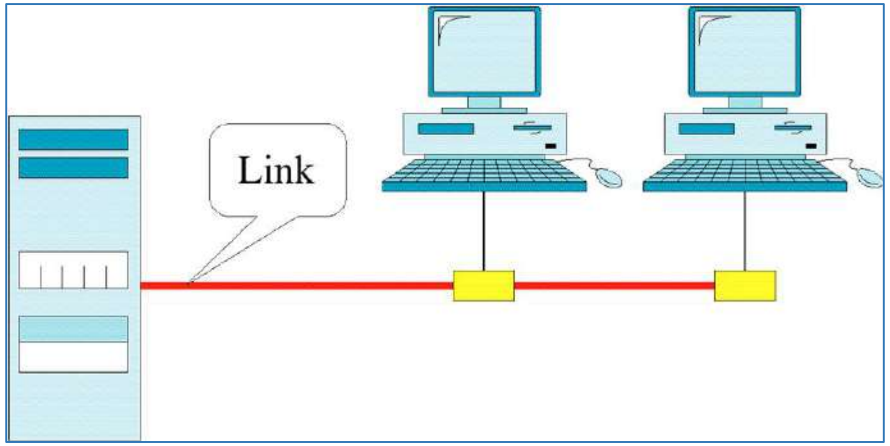
Physical Layer | Connection Types / Line Configuration

- Line configuration refers to the way two or more communicating devices attach to a link.
- Line configuration defines the attachment of communicating devices to a link.

- A link is a physical communication pathway that transfers data from one device to another.



Point-to-Point Line Configuration



Multi-point Line Configuration

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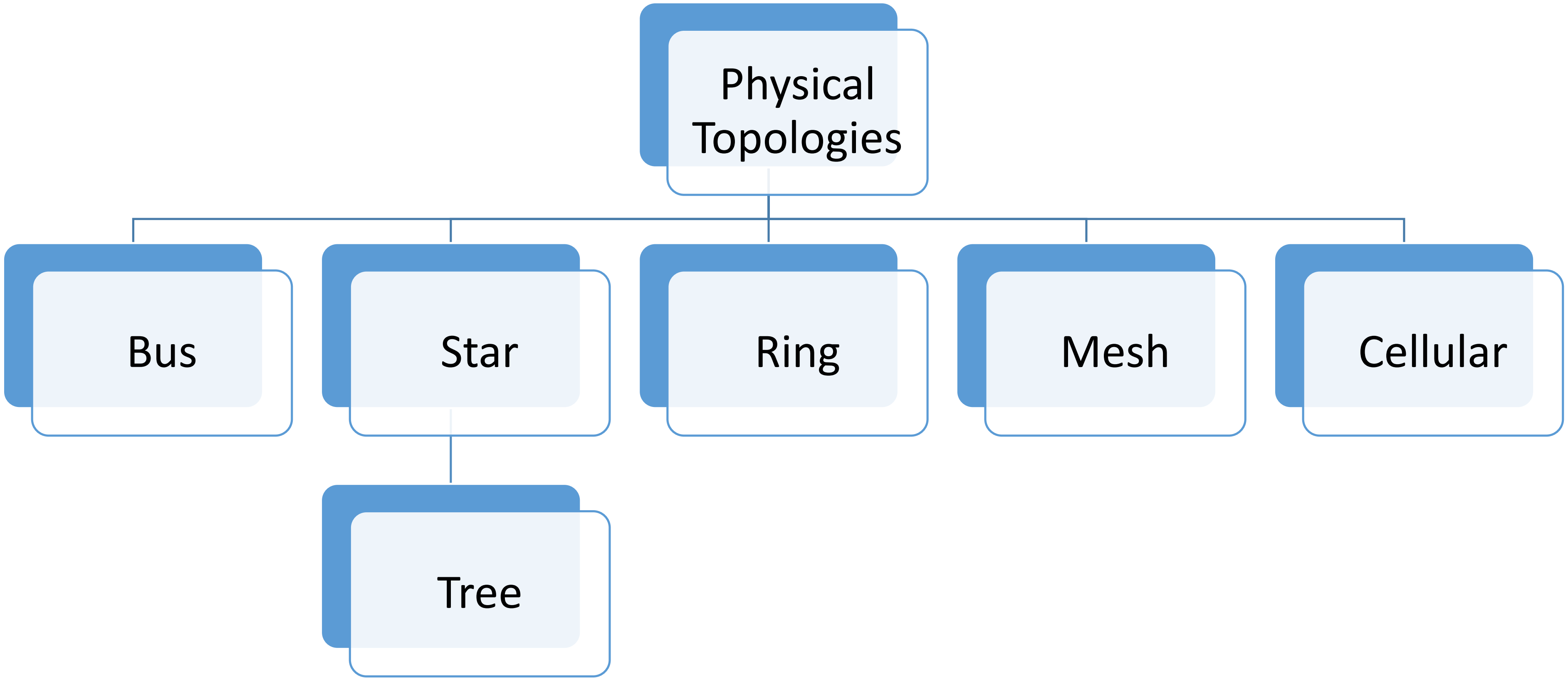
Physical Layer | Physical Topology

- The term topology refers to the way a network is laid out either physically or logically.
- The topology of a network is **the geometric representation of the relationship of all the links and linking devices (usually called nodes) to each other**.

Special attention to the following characteristics is required while choosing physical topology for your network:

- Relative ease of installation
- Relative ease of reconfiguration
- Relative ease of Troubleshooting
- Maximum number of units affected by a media failure.

Physical Layer | Physical Topology

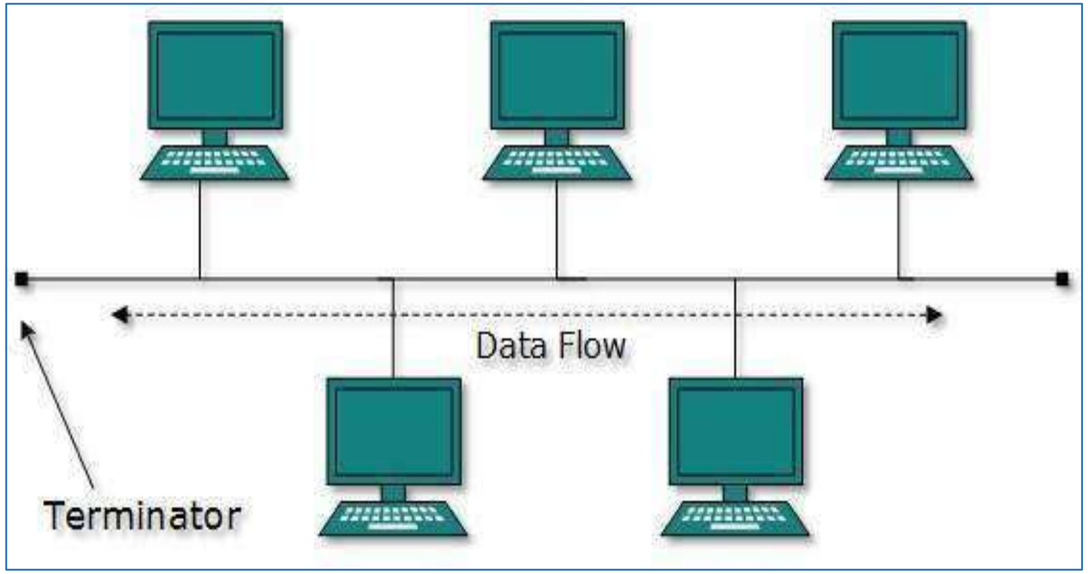


Physical Layer | Physical Topology | Bus Topology

- Relative ease of installation:
  - Relatively easy.

- Relative ease of reconfiguration:
  - Moderately difficult.

- Relative ease of Troubleshooting:
  - Relatively difficult.



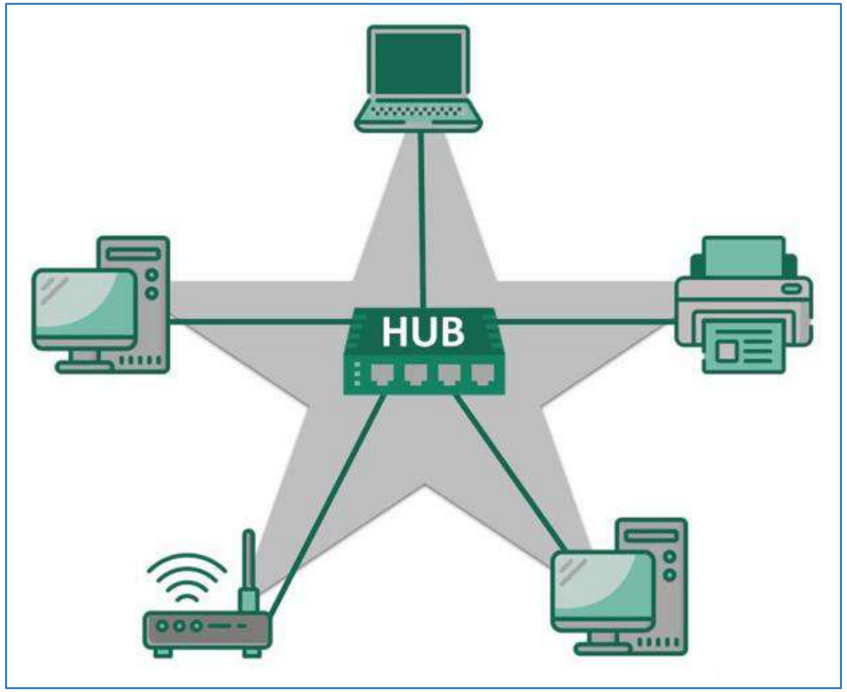
- Maximum number of units affected by a media failure.
  - Bus cable faults or breaks stop all communications.

Physical Layer | Physical Topology | Star Topology

- Relative ease of installation:
  - Moderately difficult.

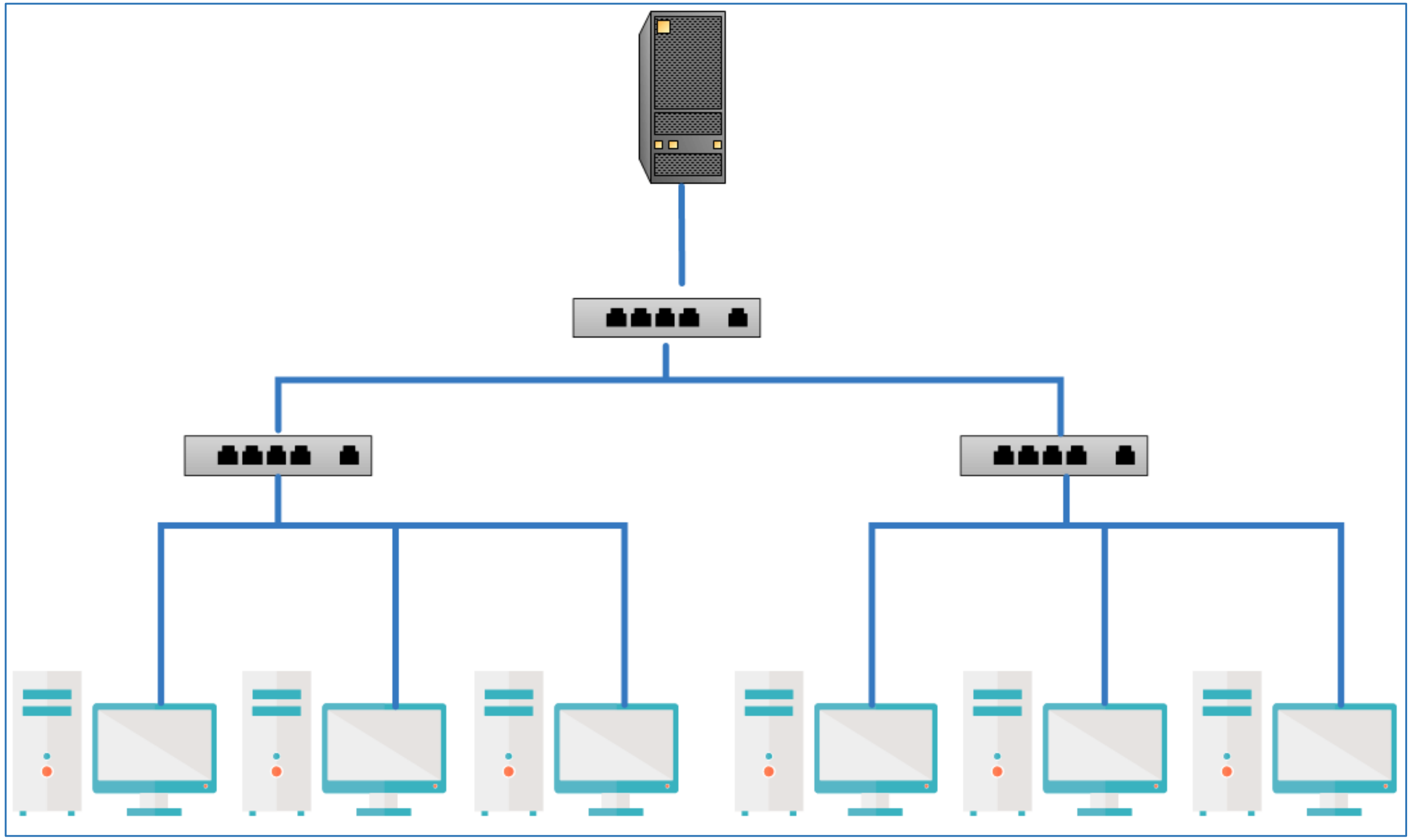
- Relative ease of reconfiguration:
  - Relatively easy.

- Relative ease of Troubleshooting:
  - Easy.



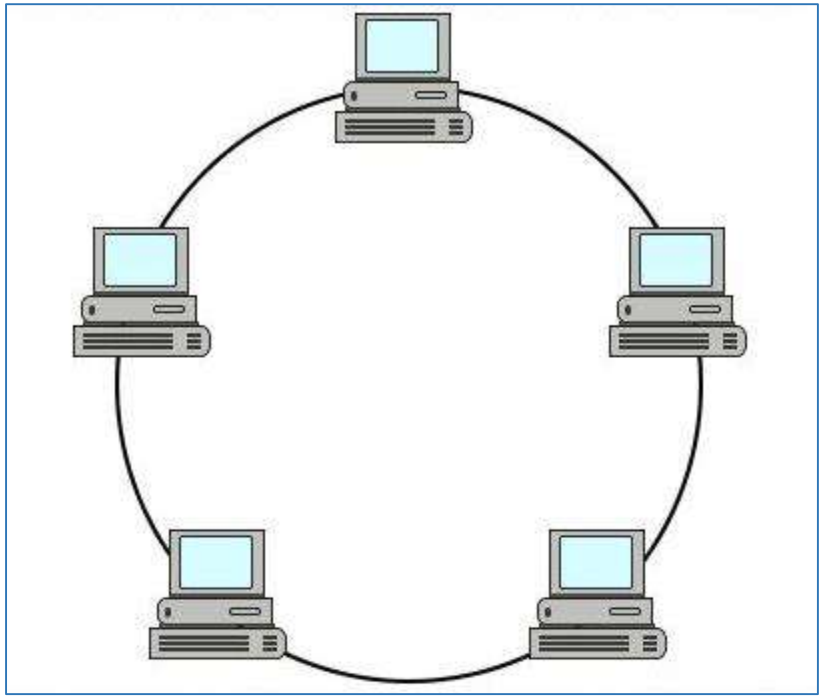
- Maximum number of units affected by a media failure.
  - Handles media faults relatively well. When media segment does fail, only that segments units are affected. However, hub failures can disable large parts of the network.

Physical Layer | Physical Topology | Tree Topology

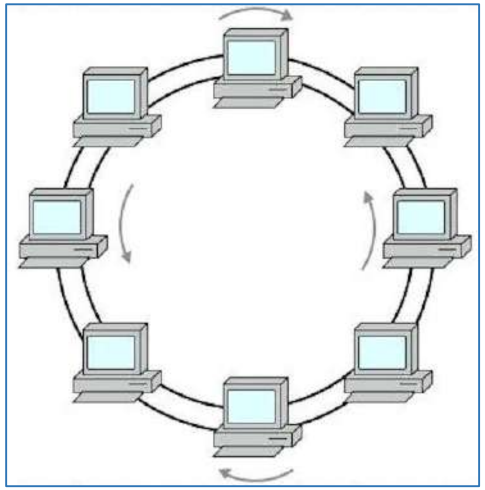


Variation of a Star Topology

Physical Layer | Physical Topology | Ring Topology



- Relative ease of installation:
  - At the initial installation, it is moderately simple.
- Relative ease of reconfiguration:
  - Easy.
- Relative ease of Troubleshooting:
  - Easy.
- Maximum number of units affected by a media failure.
  - Most physical rings use only one loop. Faults in single loop systems affect all devices on the network.
  - In dual loops, the different direction transmission can be used to route around a single cable fault.

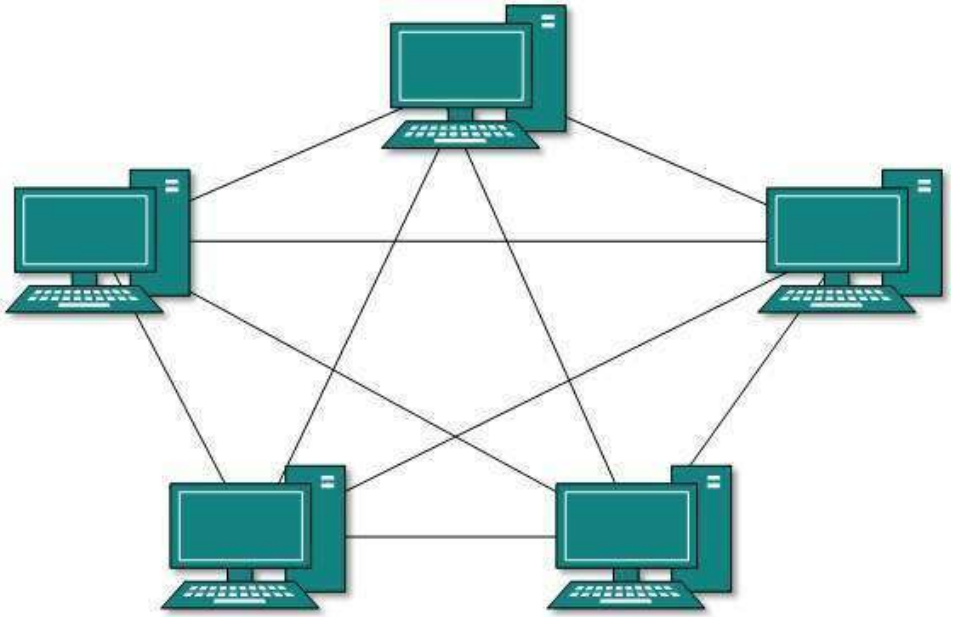


Physical Layer | Physical Topology | Mesh Topology

- Relative ease of installation:
  - Relatively difficult.

- Relative ease of reconfiguration:
  - Difficult.

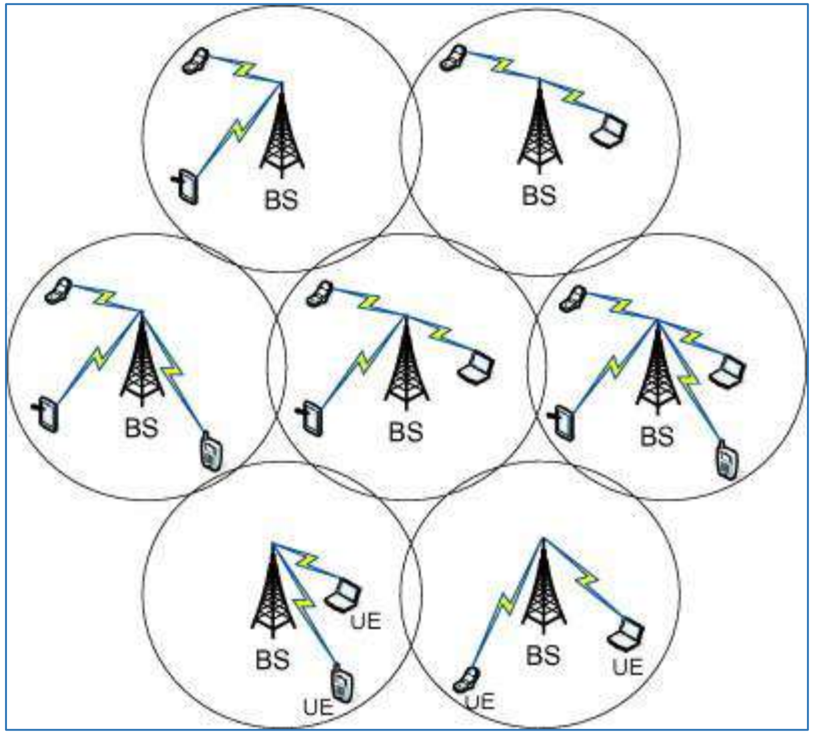
- Relative ease of Troubleshooting:
  - Easy.



- Maximum number of units affected by a media failure.
  - It resists media failure better than other topologies. Theoretically no units are affected by media failure,

Physical Layer | Physical Topology | Cellular Topology

- Relative ease of installation:
  - Easy.
- Relative ease of reconfiguration:
  - Do not require reconfiguration as users move. The network connection exists as long as the device stays within the effective range of any network hub.
- Relative ease of Troubleshooting:
  - Relatively simple to troubleshoot user device to hub links. Hub-to-hub faults is slightly more complicate to troubleshoot.



- Maximum number of units affected by a media failure.
  - When portions of a cellular topology fail, all the units in the cells assigned range are affected.

Physical Layer

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Physical Layer | Signalling

- All forms of information (voice, data, image, video) can be represented by **Electromagnetic Signals**.

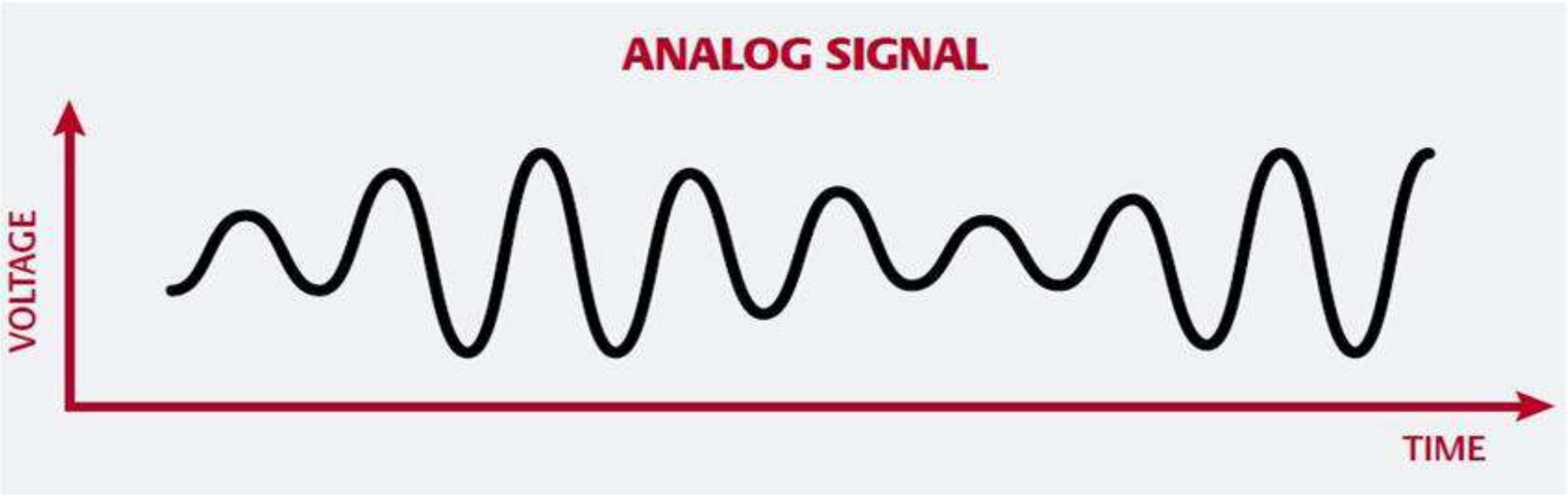
- Depending on the transmission medium and the communication environment, either **analog or digital signals** can be used to convey information.

- A key parameter that characterises the signal is **Bandwidth**, which is the width of the range of frequencies that comprises the signal.

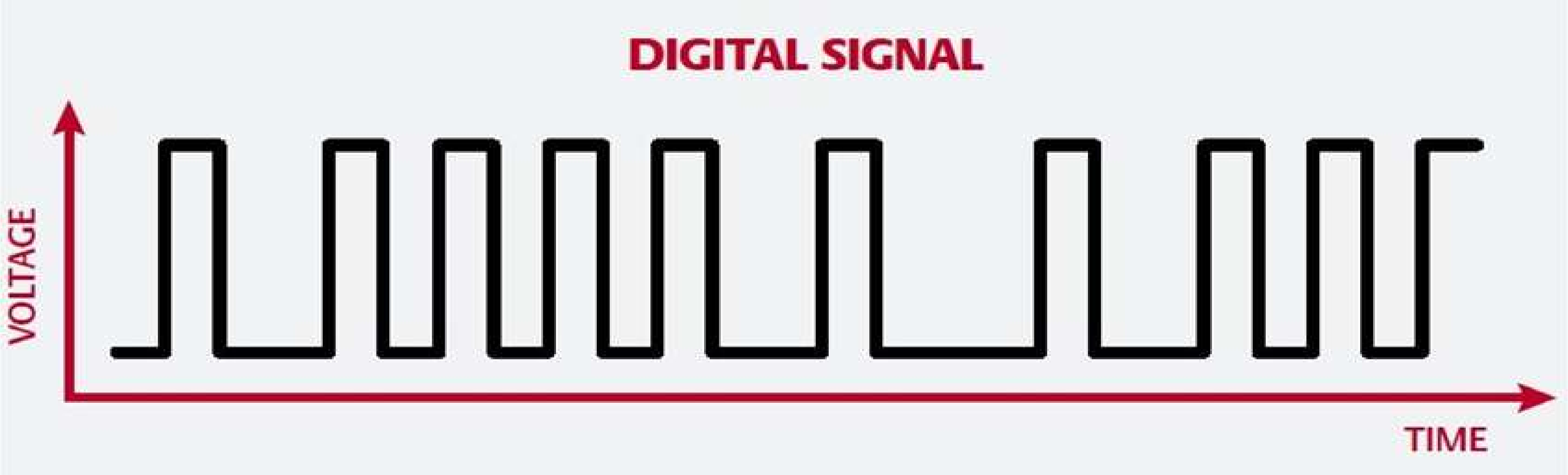
- **The greater the bandwidth of the signal, the greater its information carrying capacity**.

- The successful transmission of data depends principally on two factors:
  - **Quality of signal being transmitted**
  - **Characteristics of the transmission medium**

Physical Layer | Signalling



Continuous Signal: Signal intensity varies in a smooth fashion over time.



Discrete Signal: Signal intensity maintains a constant level for some period of time and then changes to another constant level.

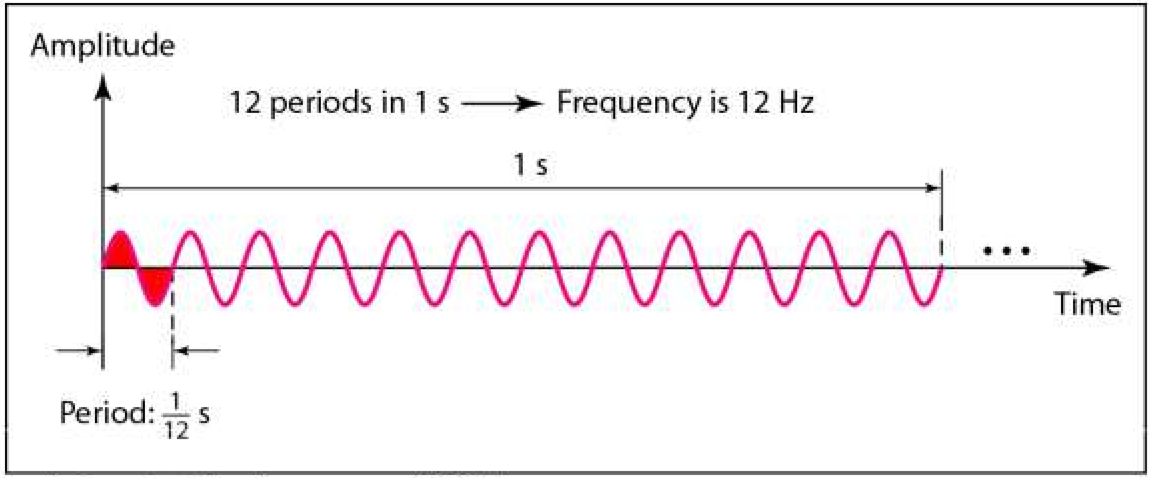
Physical Layer | Signalling

Peak Amplitude – Maximum value or strength of the signal over time (in volts).

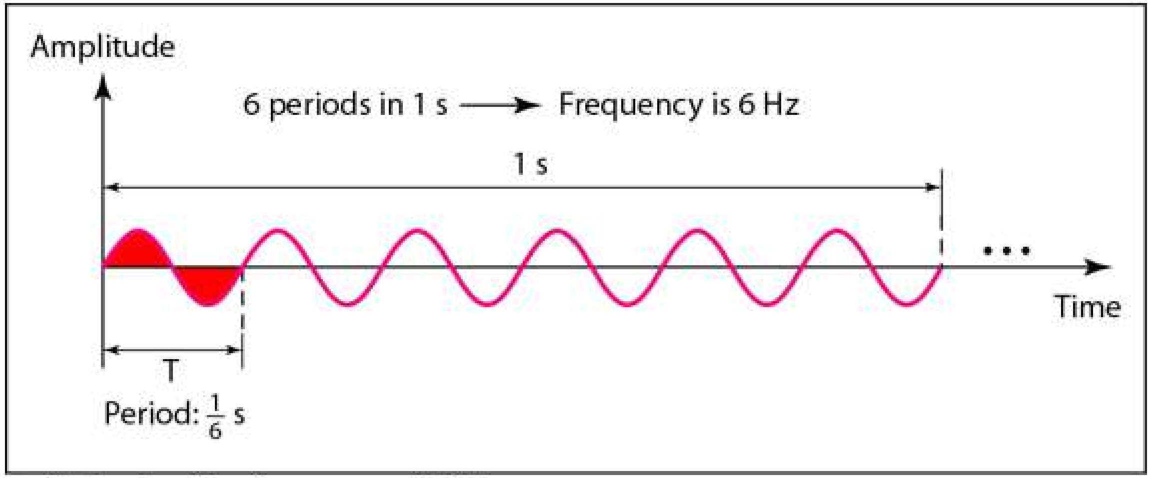
Frequency (f) – Rate at which the signal repeats (Cycles per sec or Hertz)

Period (T) – Amount of time (in sec) it takes for one repetition.

$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$



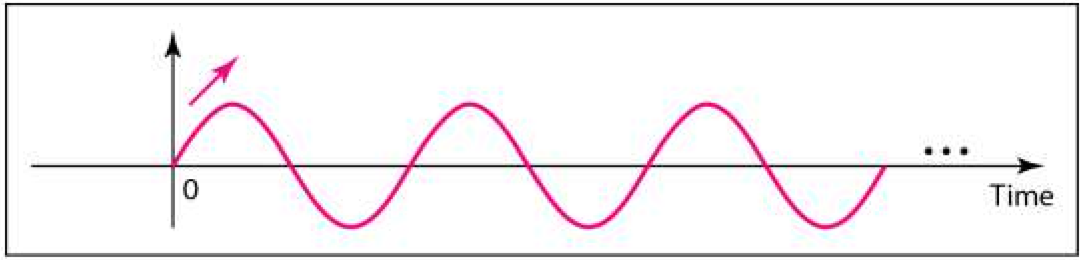
A signal with a frequency of 12 Hz



A signal with a frequency of 6 Hz

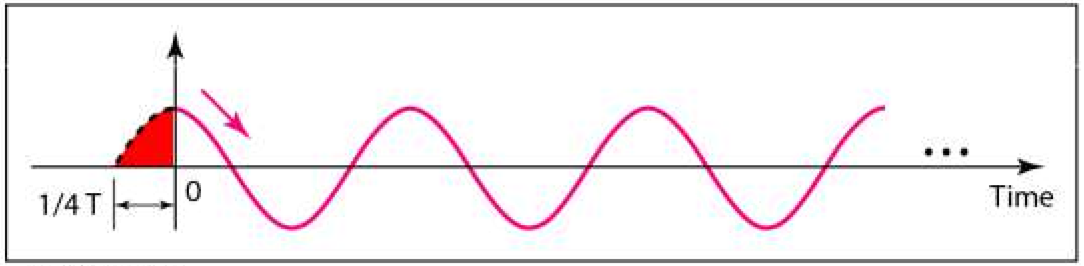
Physical Layer | Signalling

Phase – Describes the **position of the waveform relative to time 0**.



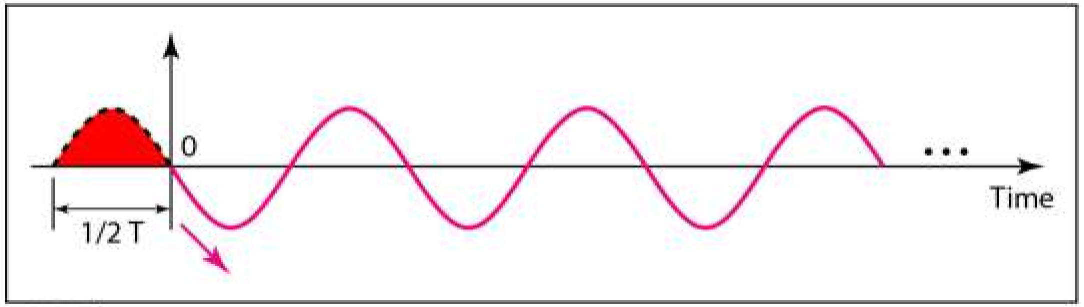
0 degrees

Starts at time 0 with a 0 amplitude. The amplitude is increasing.



90 degrees

Starts at time 0 with a peak amplitude. The amplitude is decreasing.



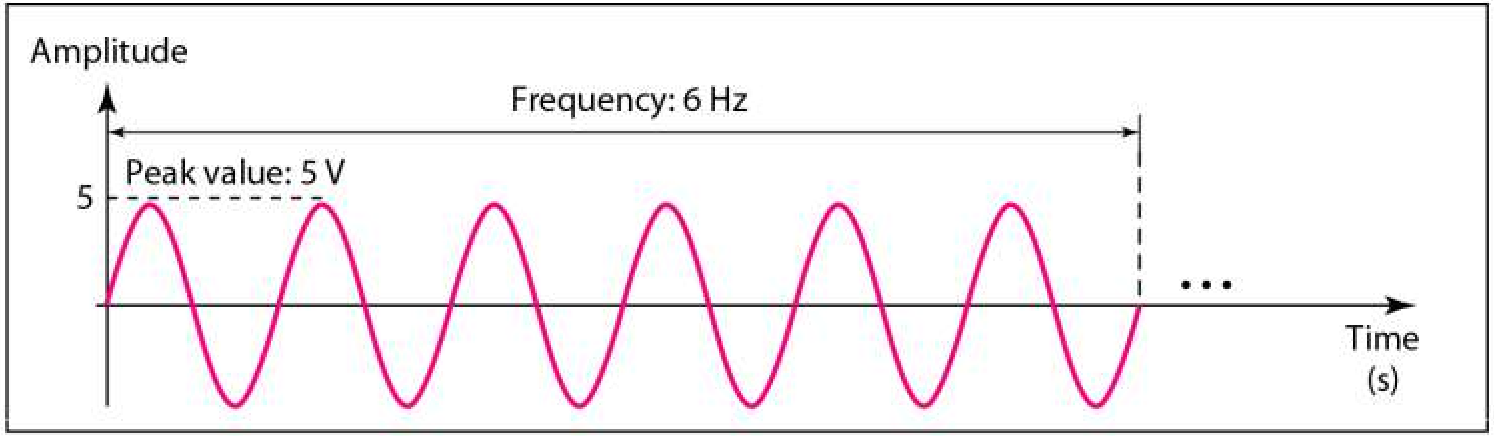
180 degrees

Starts at time 0 with 0 amplitude. The amplitude is decreasing.

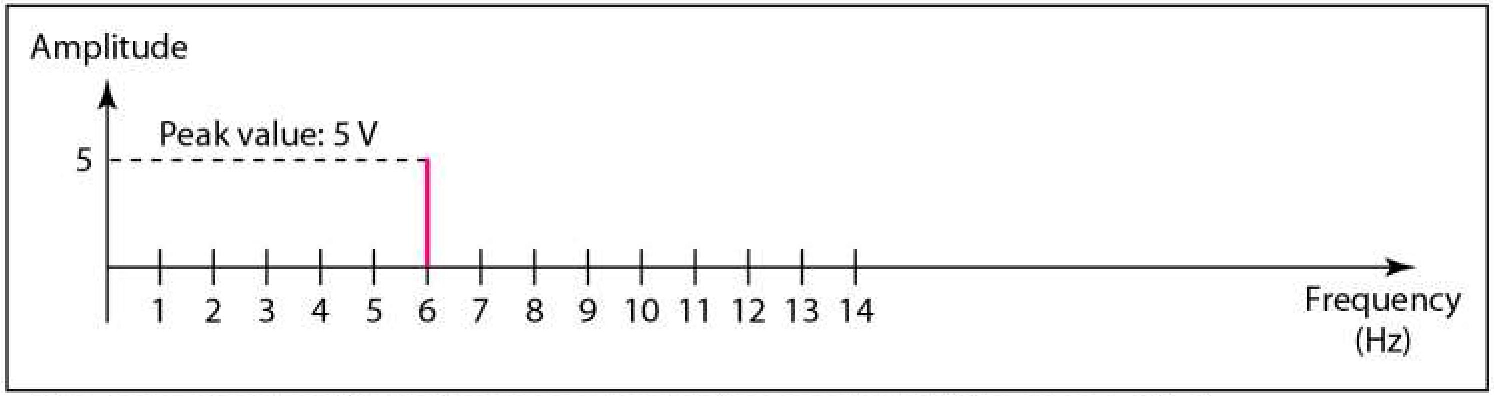
Measured in degrees or radians [360^0 is 2π radian].

Physical Layer | Signalling

Time Domain and Frequency Domain



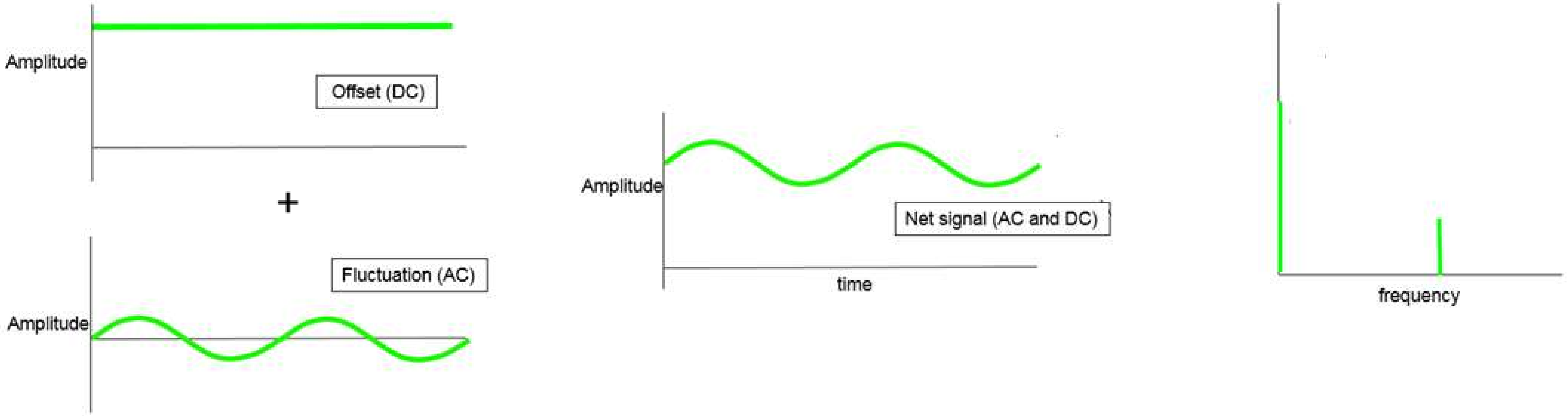
A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



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

Physical Layer | Signalling

- **DC Component** – If a signal includes a component of zero frequency, that component is a Direct current (DC) or Constant component.

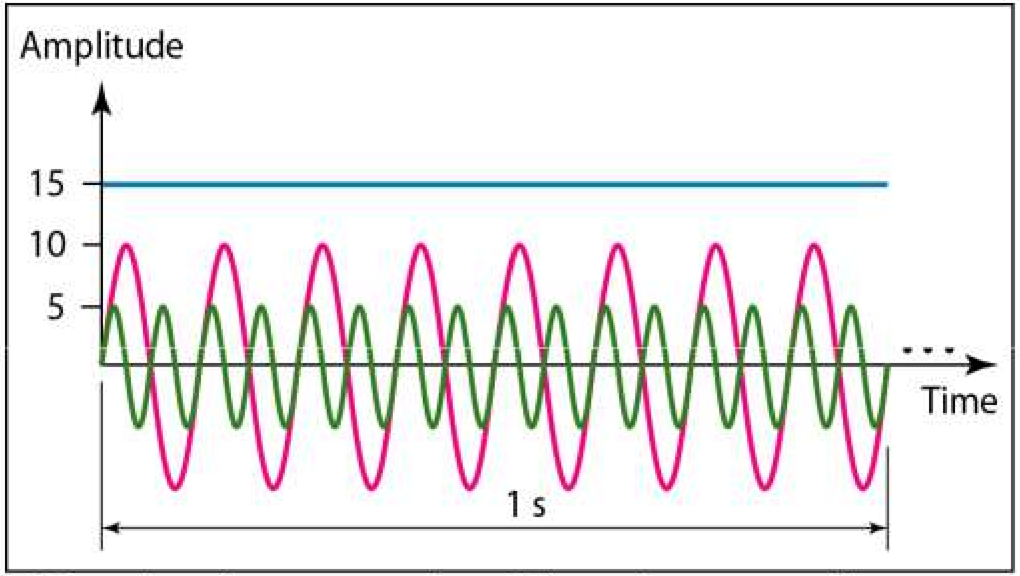


➢ No DC component – Average amplitude will be zero.

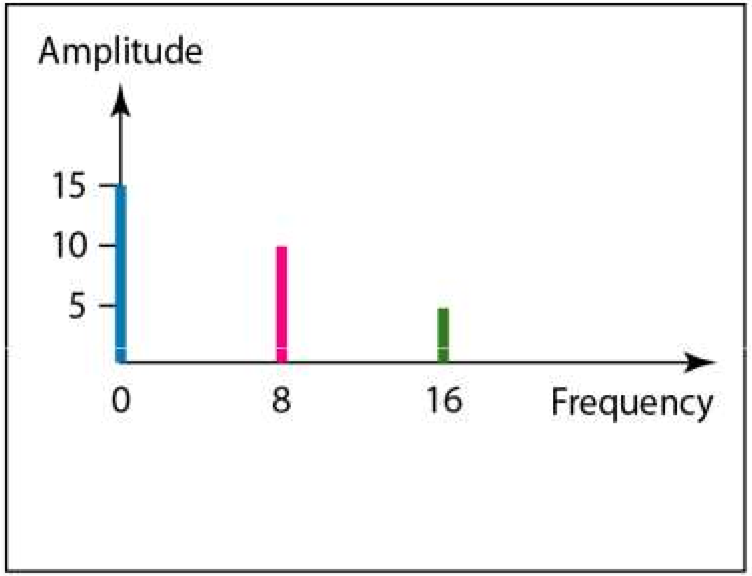
➢ DC Component – Average amplitude will be Non-zero.

Physical Layer | Signalling

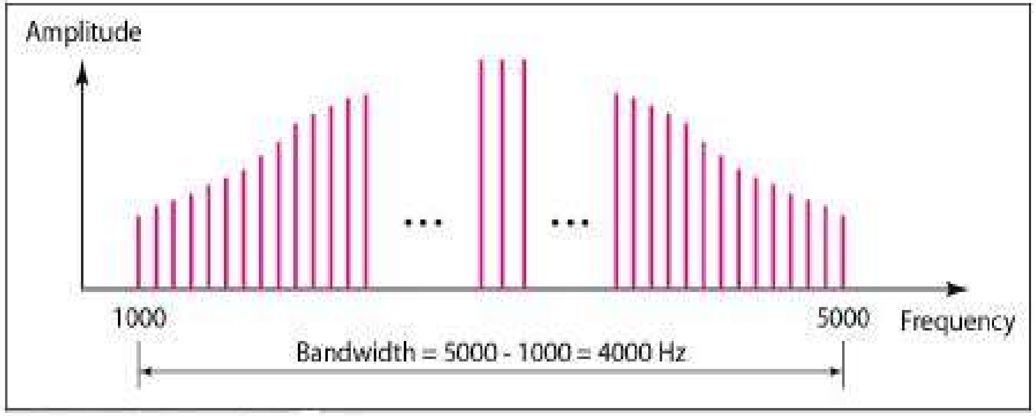
Composite Signal



Time-domain representation of three sine waves with frequencies 0, 8, and 16



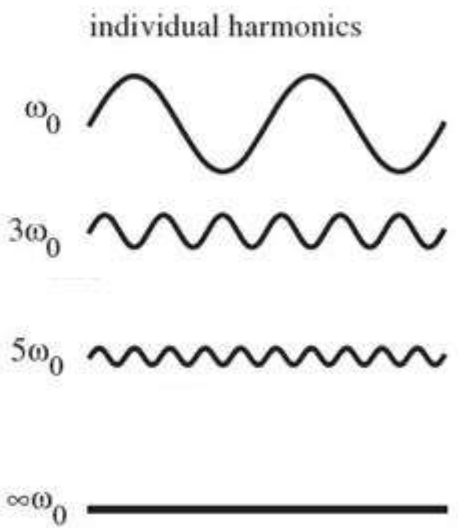
Frequency-domain representation of the same three signals

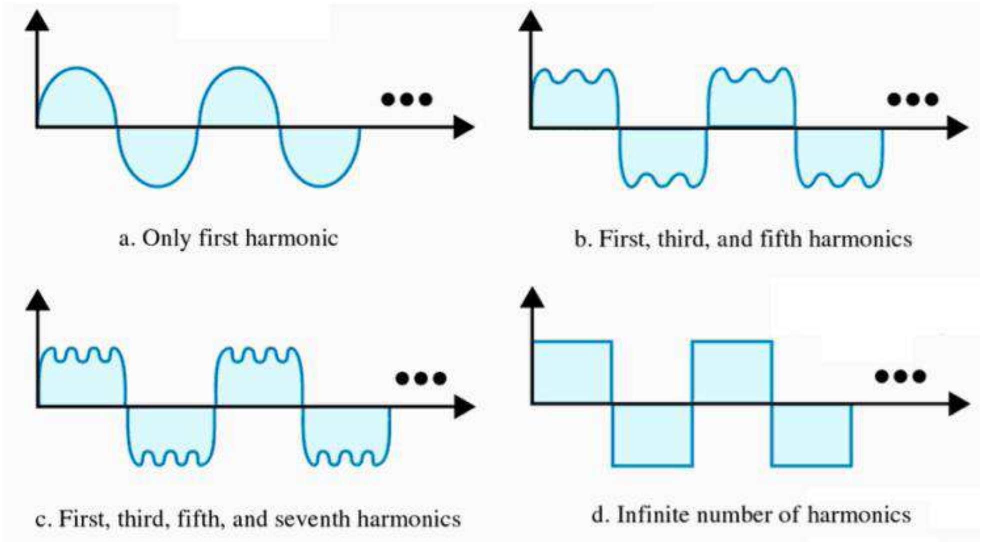


The spectrum of a signal is the **range of frequencies** that it contains.

Physical Layer | Signalling

A digital signal can be decomposed into an infinite number of simple sine waves called **harmonics**, each with a different amp, frequency and phase.





When we send a digital signal along a transmission medium means we are **sending an infinite number of simple signals**.

If some of the components are not passed through the medium, corruption of the signal at the receiver is the result.

Physical Layer | Signalling

Transmission Impairments

The signal that is received may differ from the signal that is transmitted due to various transmission impairments.

The most significant impairments are:

- Attenuation
- Delay Distortion
- Noise

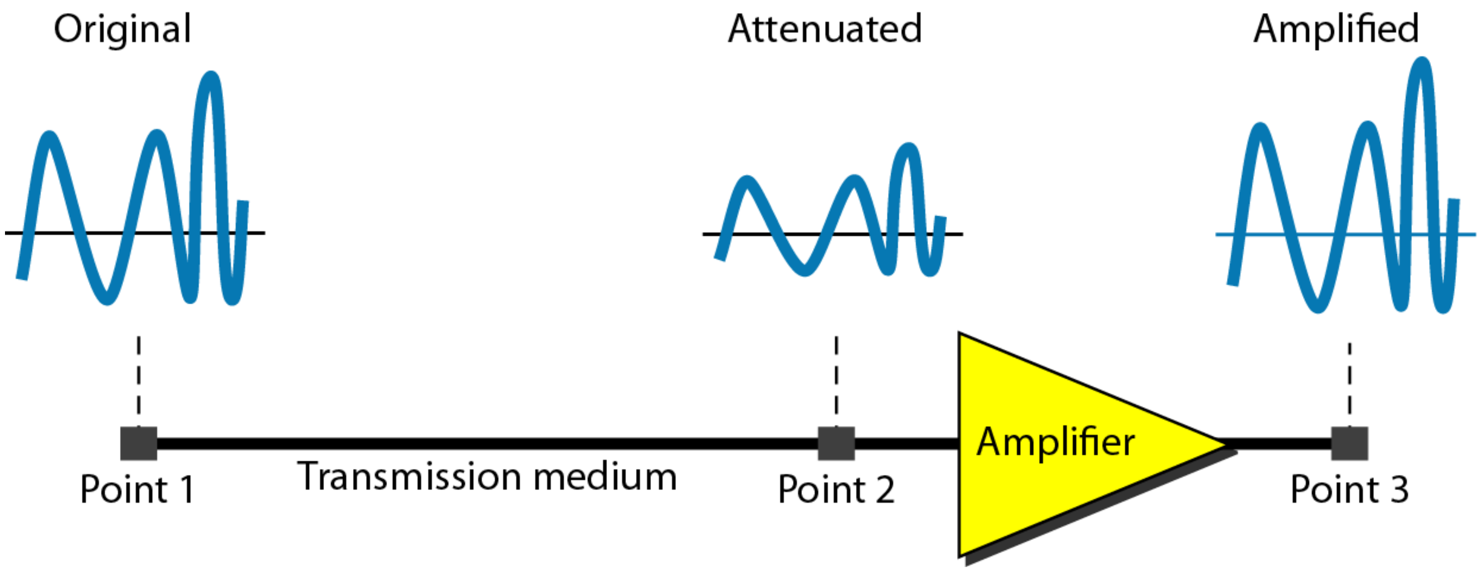
For analog signals, these impairments can **degrade the signal quality**.

For digital signals, **bit error** may be introduced due to impairments. This may change 1 to 0 and 0 to 1.

Physical Layer | Signalling | Transmission Impairments

Attenuation

- The strength of a signal falls off with distance over any transmission medium.
- Progressive decrease in power of signal as it propagates outwards.



$$\boldsymbol{A(dB) = 10\ log_{10}\left(\frac{P2}{P1}\right)}$$

where,
P1 is Transmitted Power, and
P2 is Received Power of signal.

$$\boldsymbol{A(dB) = 20\ log_{10}\left(\frac{V2}{V1}\right)}$$

where,
V1 is Transmitted Voltage, and
V2 is Received Voltage of signal.

Attenuation

Suppose a signal travels through a transmission medium and its power is reduced to one-half.

Attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

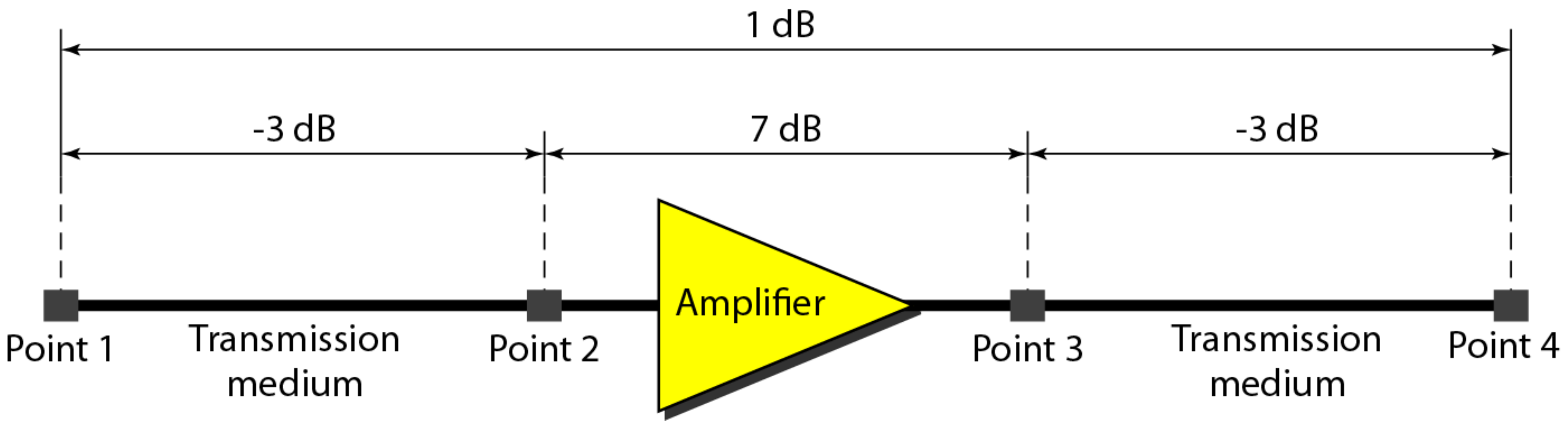
A (dB) = -3dB

A loss of 3 dB halves the power level.

Physical Layer | Signalling | Transmission Impairments

Attenuation

One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two.



$$\boxed{dB = -3 + 7 - 3 = +1}$$

Physical Layer | Signalling | Transmission Impairments

Delay Distortion

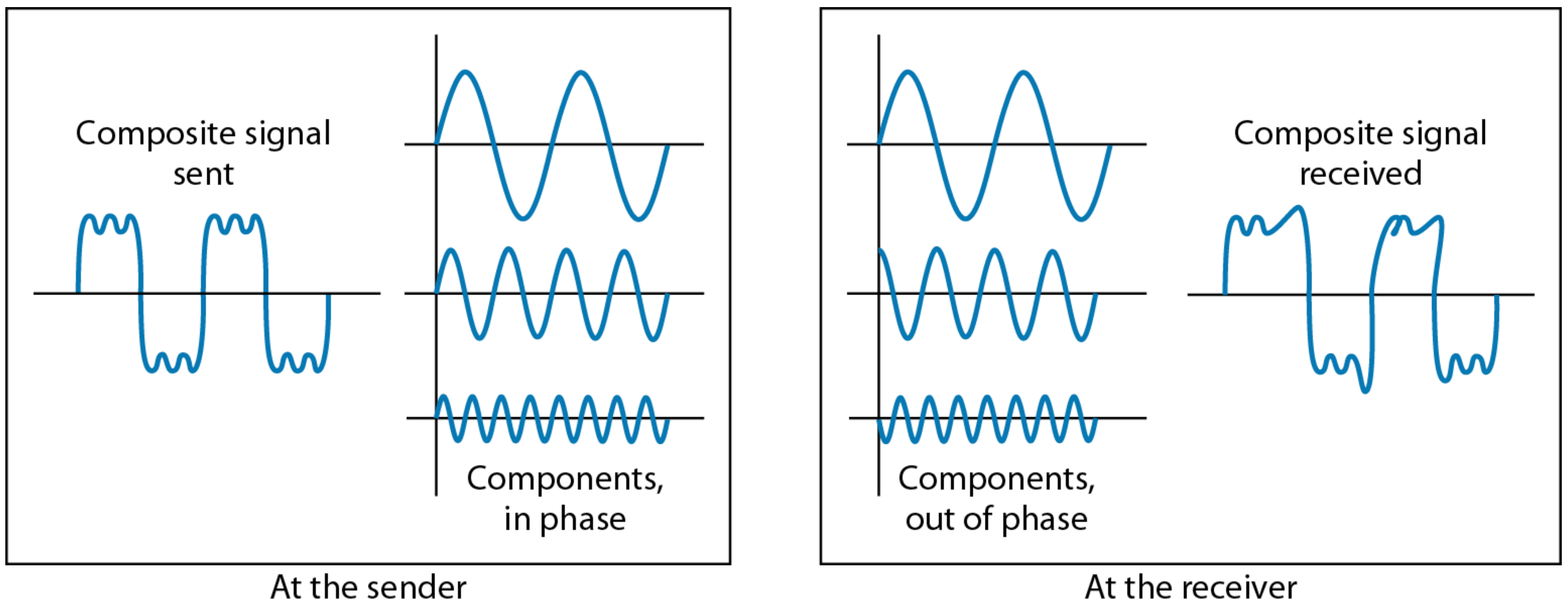
- Means that **the signal changes its form or shape**.

- Distortion occurs in composite signals.
- Each frequency component has its own propagation speed traveling through a medium.
- The different components therefore arrive with different delays at the receiver.

- The signals have different phases at the receiver than they did at the source.

Physical Layer | Signalling | Transmission Impairments

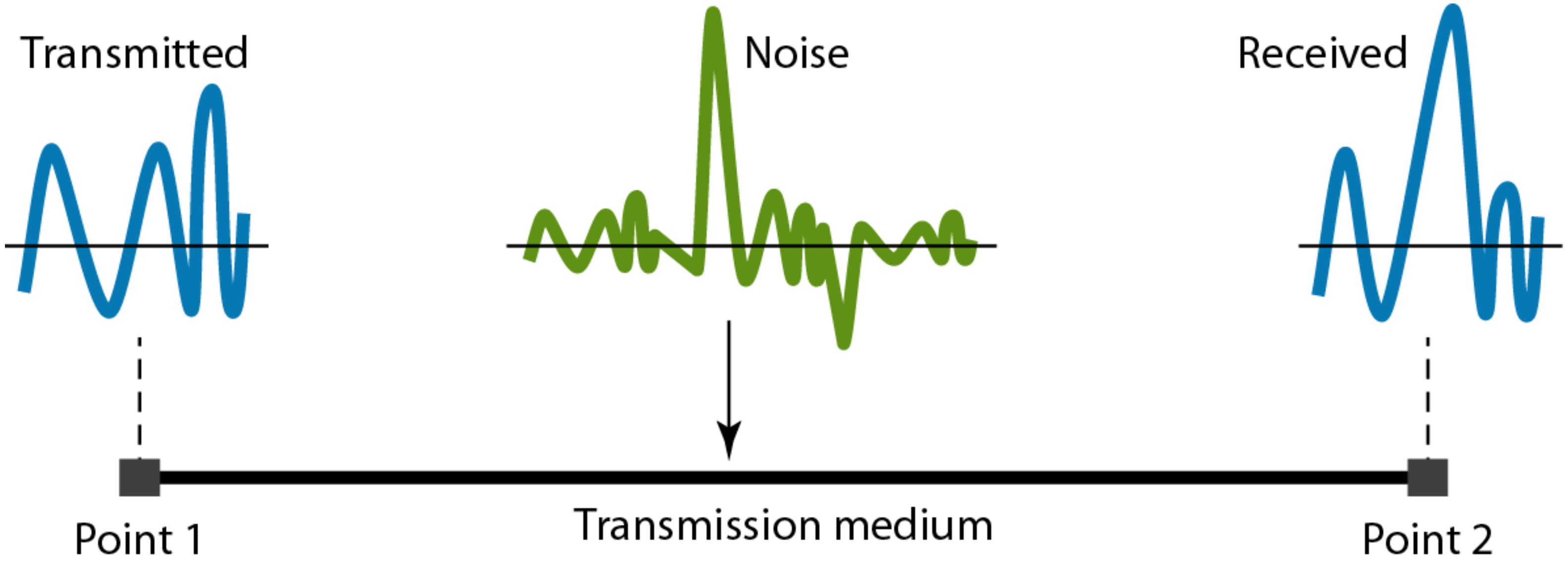
Delay Distortion



Physical Layer | Signalling | Transmission Impairments

Noise

- **Unwanted energy** from sources other than the transmitter.



Physical Layer | Signalling | Transmission Impairments

Noise

- Thermal noise is caused by the **random motion of the electrons in a wire** and is unavoidable. It is uniformly distributed across the frequency spectrum and hence is often referred to as *White Noise*.

- Induced Noise comes from sources such as motors and appliances.

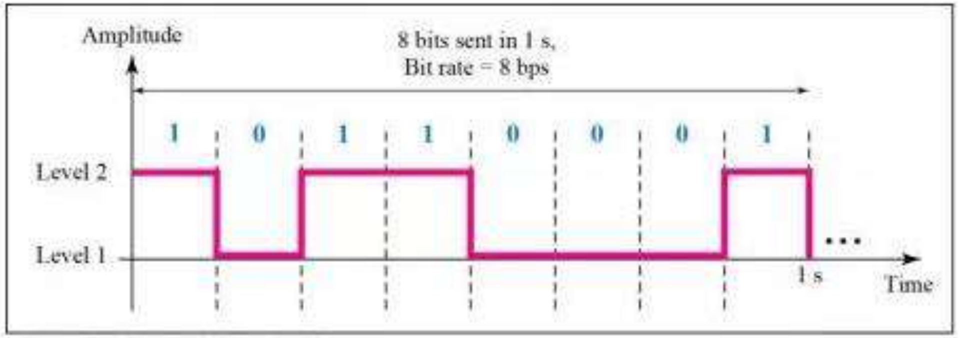
- Crosstalk is caused by **inductive coupling between two wires** that are close to each other.

- Impulsive noise is caused **by spikes on the power line**. It wipe out one or more digital bits. Can be generated because of lightning, fault in the communication systems.

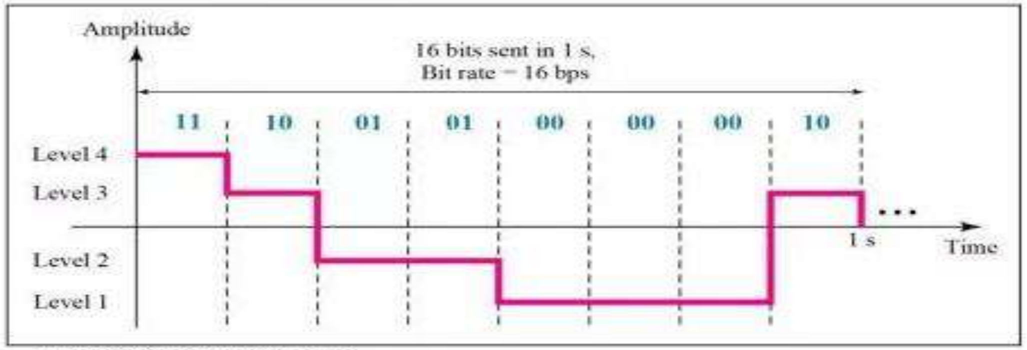
Physical Layer | Signalling

Bit Rate [*Frequency*]

- The bit rate defines the number of bits sent per sec. Is used to describe a digital signal.



A digital signal with two levels



A digital signal with four levels

If a signal has L levels, each level needs **$\log_2 L$ bits**.

Bit Length [*Wavelength*]

- The bit length is the distance one bit occupies on the transmission medium.

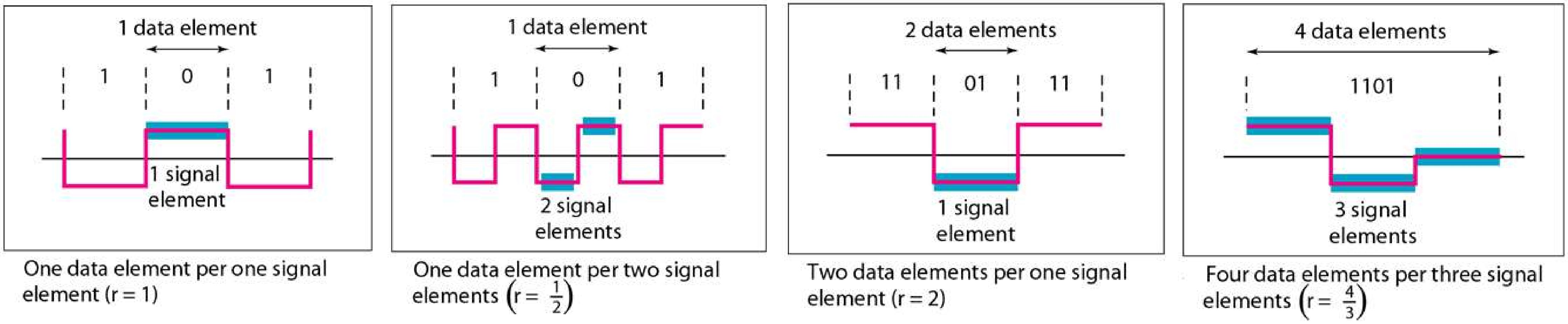
$$Bit\ Length = Propagation\ Speed\ * Bit\ Duration$$

Physical Layer | Signalling

Goal is to increase the data rate while decreasing the baud rate.

Baud or Signal Rate

- The signal rate is the number of signal elements sent in a second and is measured in **bauds**. It is also referred to as the modulation rate.



The **baud or signal rate (S)** can be expressed as: $S = c \times N \times 1/r$ bauds

Where,
N is data rate, c is the case factor (worst, best & average), r is the ratio between data element & signal element.

Physical Layer | Signalling

A very important consideration in data communication is **how fast we can send data, in bits per second, over a channel**.

Data rate depends upon 3 factors:

- **Available Bandwidth**
- **Number of levels in digital signal**
- **Quality of the channel i.e., Level of noise**

Two theoretical formulas were developed to calculate the data rate:

- **By Nyquist for a noiseless channel**
- **By Shannon for a noisy channel**

Physical Layer | Signalling

Filtered signal can be completely reconstructed by making only 2*Bandwidth (exact) samples per second.

Nyquist Bit Rate

An expression for the maximum bit rate (Channel Capacity) for a finite bandwidth in **noiseless channel**.

Given a bandwidth of B, the *highest signal rate that can be carried is 2B*

$$\boxed{\textbf{Bit rate (C)} = 2 \cdot B \cdot \log_2 L}$$

where, L is the number of discrete signal or voltage levels.

Trade-offs:

Increase the Bandwidth (B), increases the Bit rate (C).

Increase the Signal Levels (L), increases the Bit rate (C).

Increase the Signal Level (L), harder the receiver to interprets the bits. May reduce the reliability of the system.

Physical Layer | Signalling

Shannon Capacity

Gives the capacity of a system in the presence of noise.

An expression for the maximum data rate for a finite bandwidth in **noisy channel**.

Maximum Capacity of Channel (in bps) = B*$\log_2$(1 + SNR)

where, C is the capacity of the channel (in bps).

B is the bandwidth of channel (in hertz).

SNR is signal-to-noise ratio (power ratio i.e., unit less).

$$\boxed{(SNR)_{dB} = 10 * log_{10} \frac{Signal\ Power}{Noise\ Power}} \quad \boxed{(SNR)_{dB} = 10 * log_{10}(SNR)}$$

Trade-offs:

Increase the Bandwidth (B) or Signal power (S), increases the data rate (C).

Increase of noise (N), decreases the data rate (C).

Increase Bandwidth (B), allows more noise (N).

Physical Layer | Signalling

Performance of a Network

- **Bandwidth**
  - Range of frequencies (in Hertz) that a channel can pass.
  - Speed of bit transmission (bps) in a channel.

- **Throughput**
  - How fast the data can be sent through network?

- **Latency (or Delay)**
  - How long it takes for an entire message to completely arrive at the destination from the time the first bit sent out from the source?

Latency = Propagation Time + Transmission Time + Queuing Time + Processing Delay

Physical Layer | Signalling

Performance of a Network

- **Latency (or Delay)**

Latency = Propagation Time + Transmission Time + Queuing Time + Processing Delay

- Propagation Time – The time required for a bit to travel from the source to the destination.

Propagation Time = Distance / Propagation Speed

Propagation speed of light is 3×10^8m/sec in vacuum. It is lower in air and much lower in cable.

- Transmission Time – It depends on the size of message and the bandwidth of the channel.

Transmission Time = Message Size / Bandwidth

Physical Layer | Signalling

Performance of a Network

- **Latency (or Delay)**

Latency = Propagation Time + Transmission Time + Queuing Time + Processing Delay

  - Queuing Time – The time needed for each intermediate or end devices to hold the message before it can be processed.
  - Processing Delay – It is a time it takes the intermediate devices to process the received packet.

- **Jitter**
  - It is a problem if different packets of data encounter different delays and the application using the data at the receiver site is *time-sensitive*.

Physical Layer | Signalling

Line Coding

Goal:

Increase the data rate while decrease the signal rate.

Increase the data rate while increase the speed of transmission.

Decrease the signal rate while decrease Bandwidth (BW) requirements.

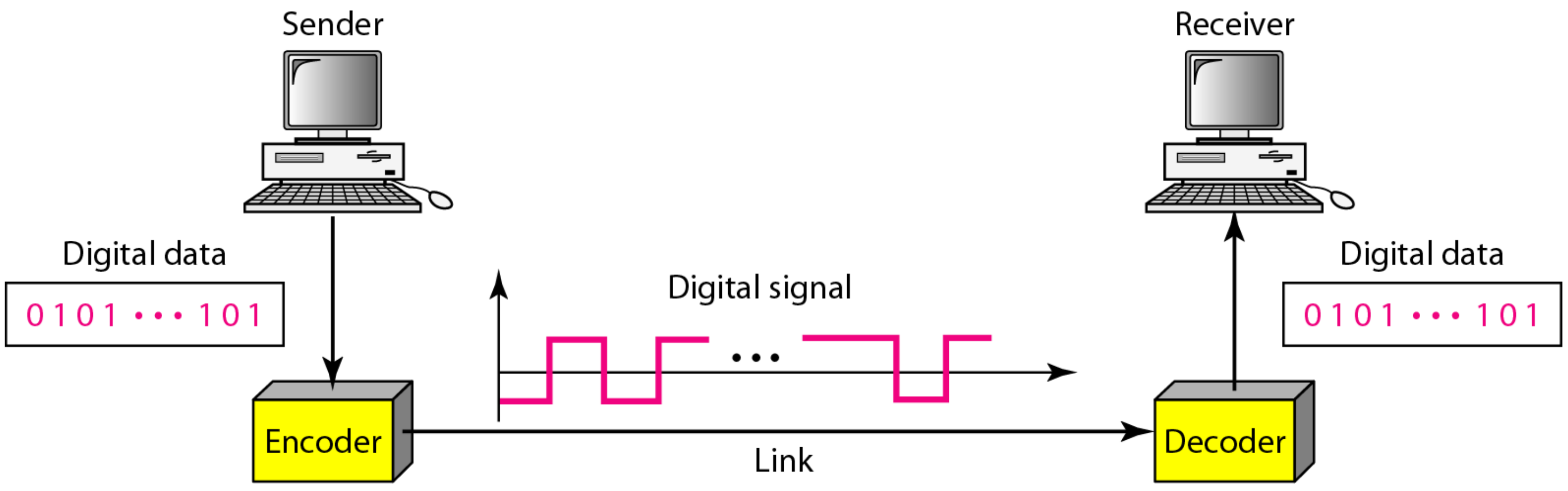
Data	Signal	Approach
Digital	Digital	Encoding
Analog	Digital	Encoding
Analog	Analog	Modulation
Digital	Analog	Modulation

BW requirement is MORE.

BW requirement is LESS.

BW of transmission media plays very important role. The BW of signal should match the BW of transmission media. This requires good encoding scheme.

Physical Layer | Signalling | Line Coding



- Digital Data
  - Digital Signal
  - Analog Signal
- Analog Data
  - Digital Signal
  - Analog Signal

Physical Layer | Signalling | Line Coding

Considerations for choosing **a good signal element** referred to as line encoding:

- **Baseline Wandering**

  A receiver **evaluates the average power of the received signal** (called the **baseline**) and use that to determine the value of the incoming data elements. If the incoming signal does not vary over a long period of time (a long series of 0s or 1s), the **baseline will drift and thus cause errors in detection of incoming data elements**. A good line encoding scheme will prevent long runs of fixed amplitude.

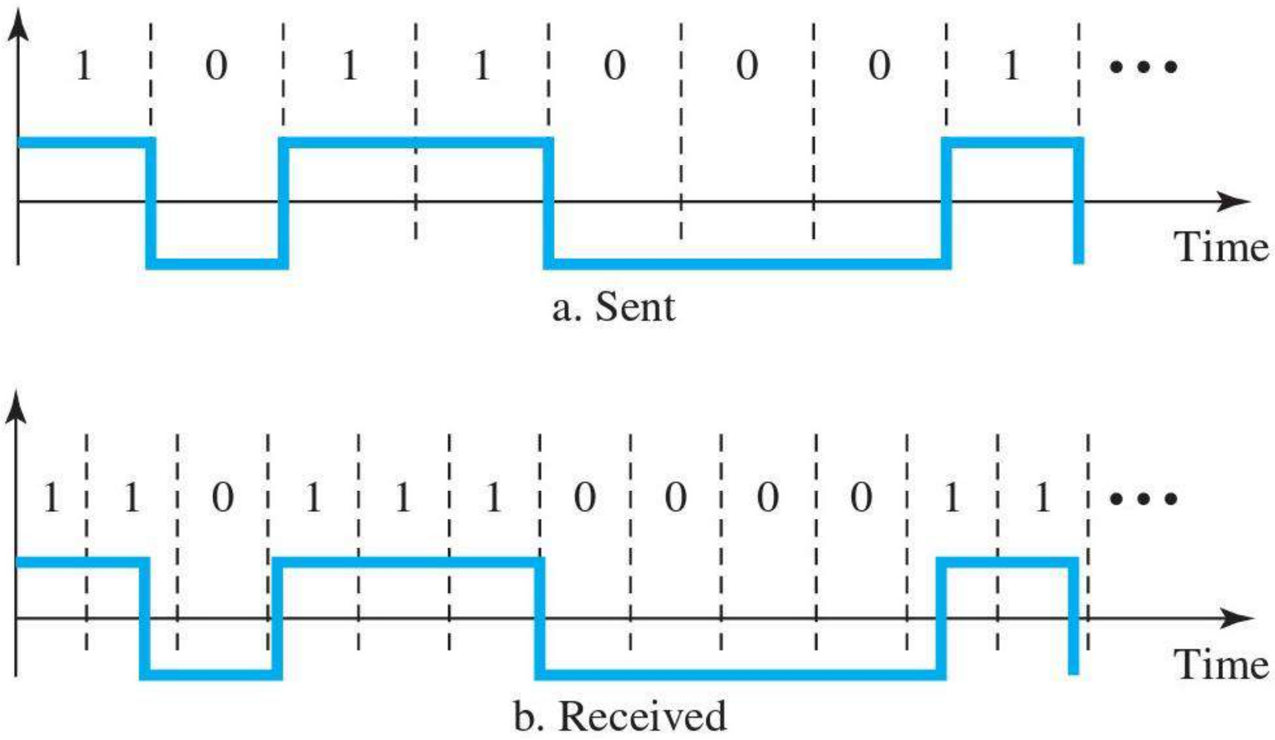
- **DC Components**

  When the voltage level remains constant for long periods of time, there is **an increase in the low frequencies of the signal**. Most channels are band-pass and may not support the low frequencies. This will require the removal of the DC component of a transmitted signal.

Physical Layer | Signalling | Line Coding

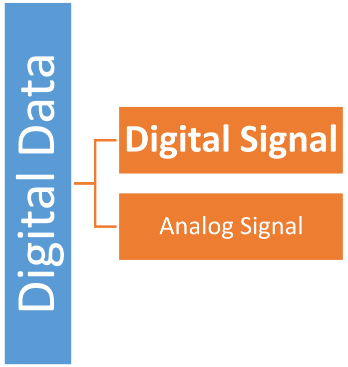
- **Self Synchronization**

The clocks at the sender and the receiver must have **the same bit interval**. If the receiver clock is faster or slower it will misinterpret the incoming bit stream.

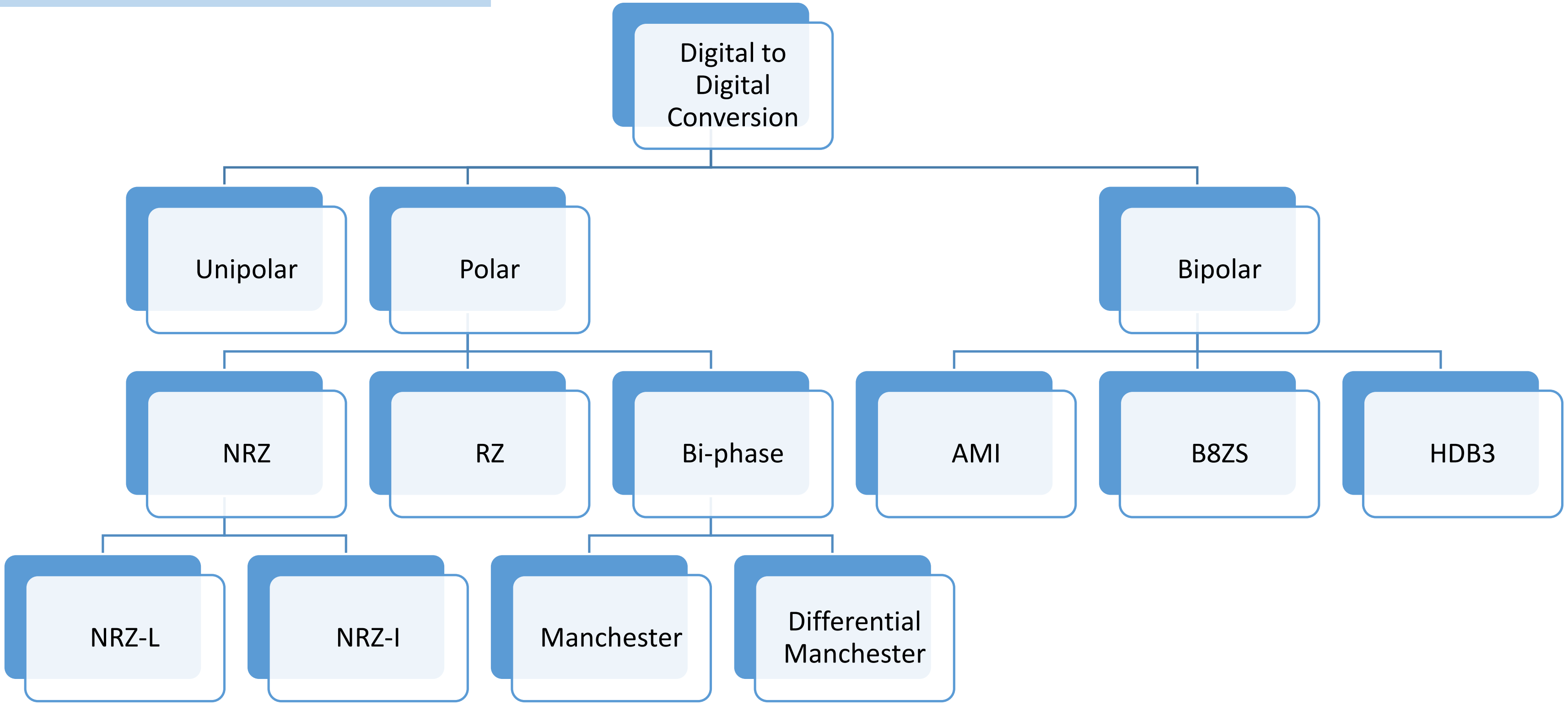


Effect of lack of Synchronization

Physical Layer | Signalling | Line Coding



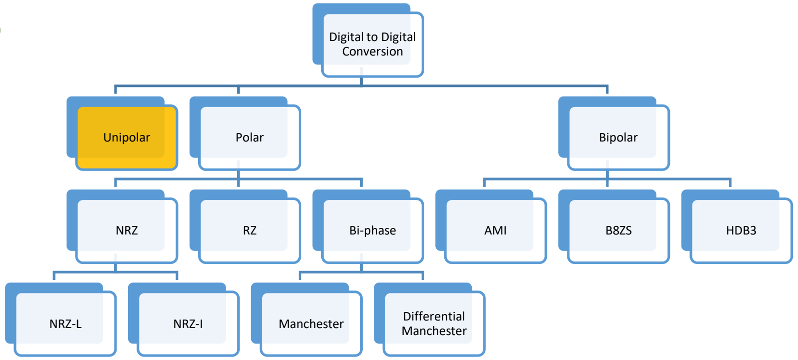
Digital Data to Digital Signal



NRZ : Non-return to Zero
NRZ-L : Non-return to Zero, Level
NRZ-L : Non-return to Zero, Invert
RZ : Return to Zero

AMI : Alternate Mark Inversion
B8ZS : Bipolar 8-zero Substitution
HDB3 : High Density Bipolar 3

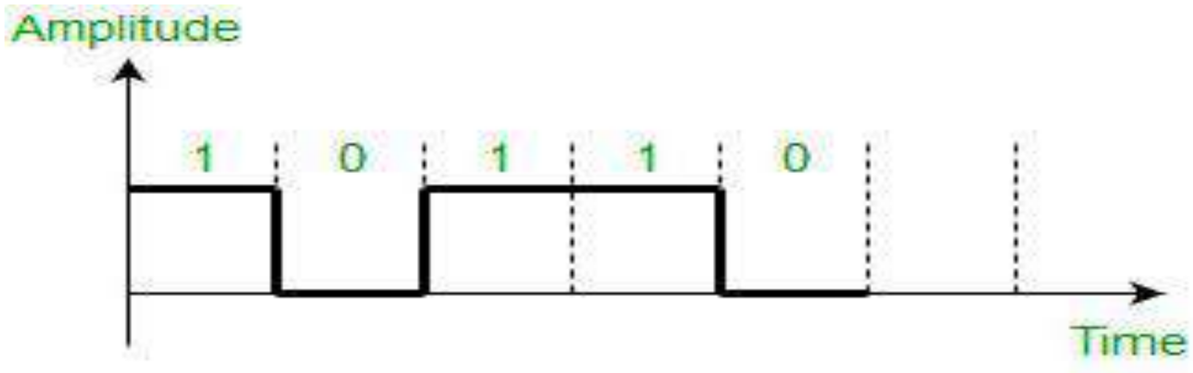
Physical Layer | Signalling | Line Coding



Digital Data to Digital Signal

Unipolar

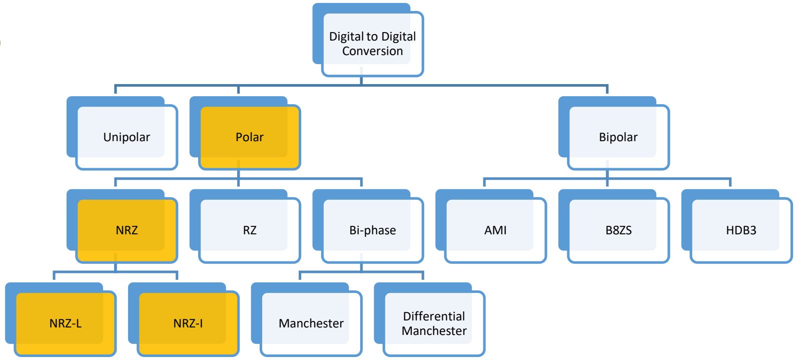
Uses only one level of value (either above or below the time axis).



Problems:

- It uses only one voltage level, so having the problem of DC component.
- Synchronization Problem.

Physical Layer | Signalling | Line Coding



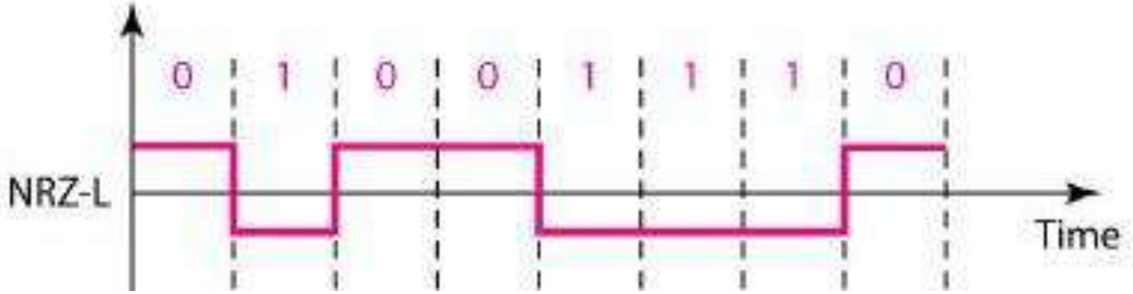
Digital Data to Digital Signal

Polar

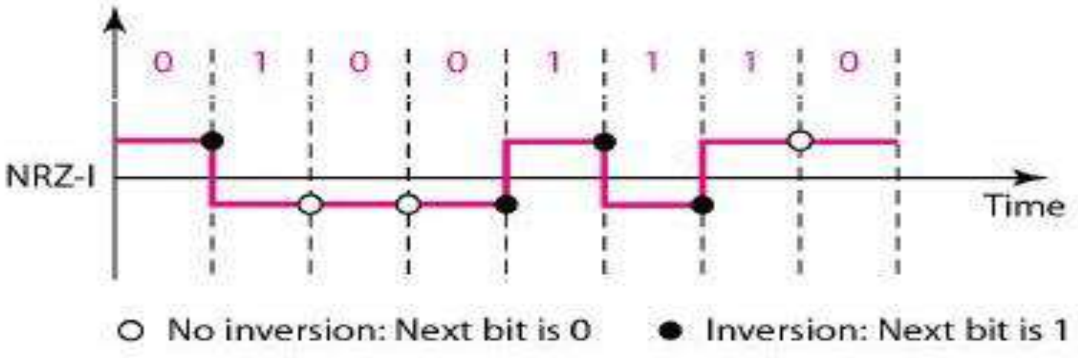
Uses two levels of value (+ve and –ve).

Non-Return-to-Zero (NRZ):
The level of the signal is always either +ve or –ve.

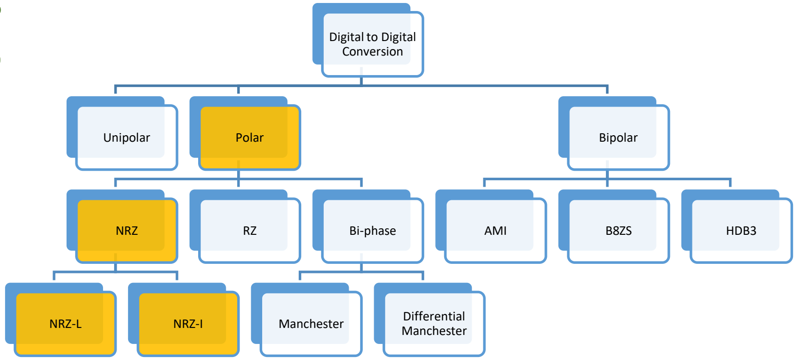
NRZ-Level (NRZ-L):
The level of the signal is dependent upon the state of the bit.



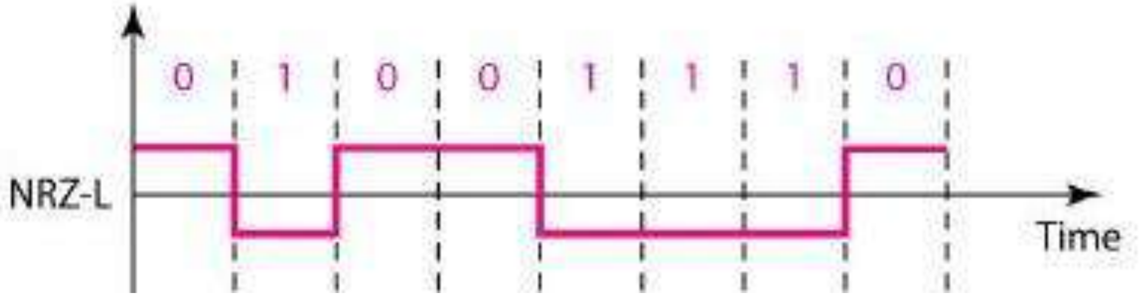
NRZ-Invert (NRZ-I):
The signal is inverted if a 1 is encountered.



Physical Layer | Signalling | Line Coding

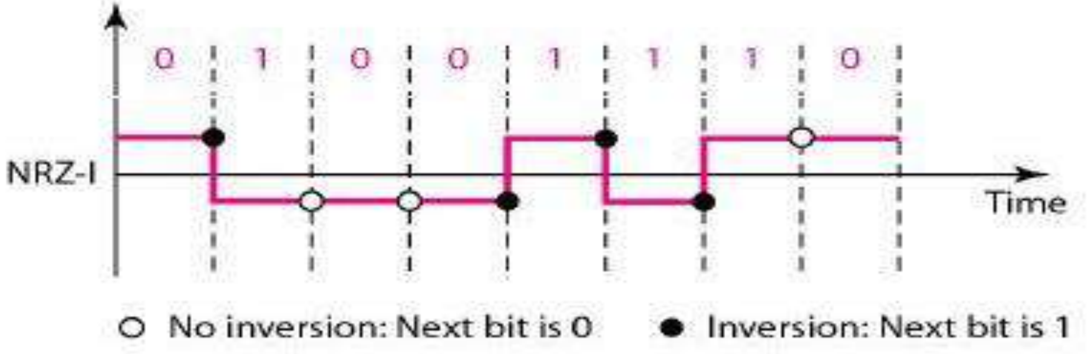


Digital Data to Digital Signal



Problems:

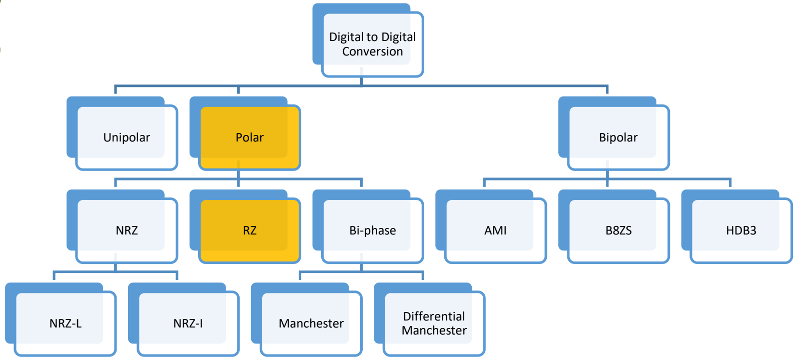
- Baseline wandering (more severe – both for 0s & 1s).
- Presence of DC Component.
- Synchronization Problem (more serious).
- A sudden change of polarity in the system results in all 0s interpreted as 1s and all 1s interpreted as 0s.



Problems:

- Baseline wandering (only for 0s).
- Presence of DC Component.
- Synchronization Problem.
- A sudden change of polarity in the system results in all 0s interpreted as 1s and all 1s interpreted as 0s.

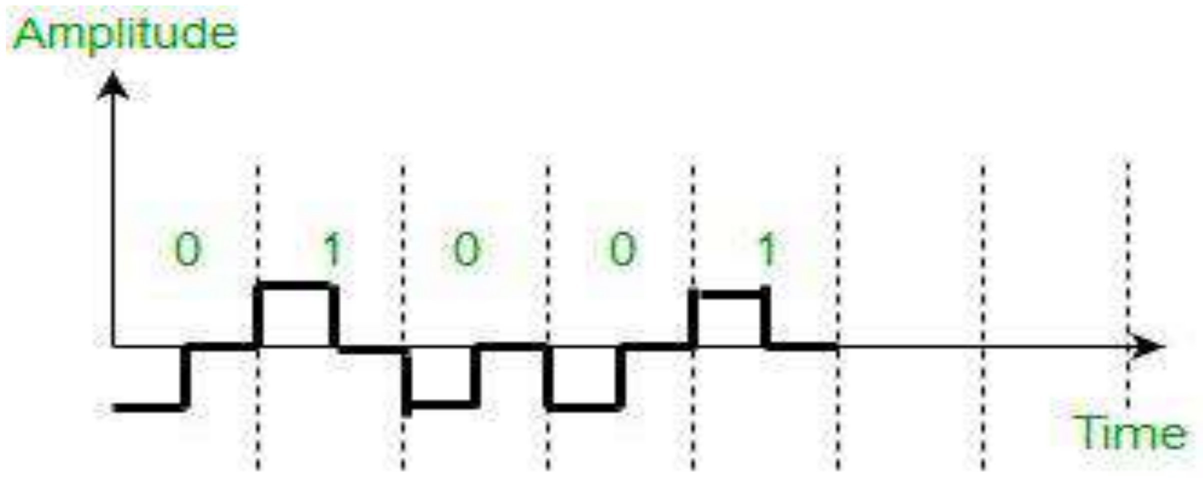
Physical Layer | Signalling | Line Coding



Digital Data to Digital Signal

Return-to-Zero (RZ):

- Uses three values: positive, negative and zero.
- The signal changes not between bits **but during each bit**.



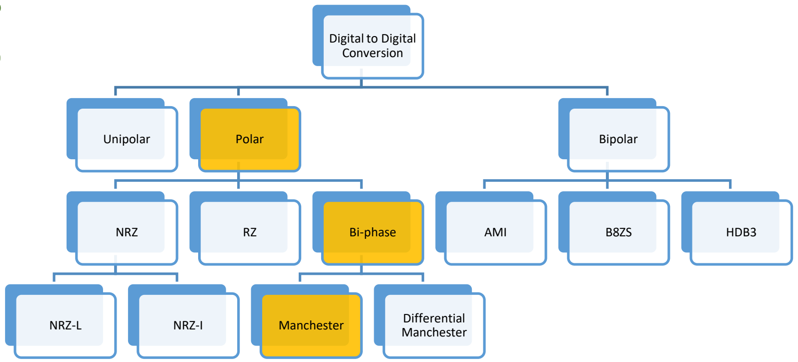
No DC Component problem.

Perfectly synchronized.

Problems:

- It requires two signal changes to encode a bit and thereafter occupies greater BW.
- Complexity (3 voltage level).
- A sudden change of polarity in the system results in all 0s interpreted as 1s and all 1s interpreted as 0s.

Physical Layer | Signalling | Line Coding



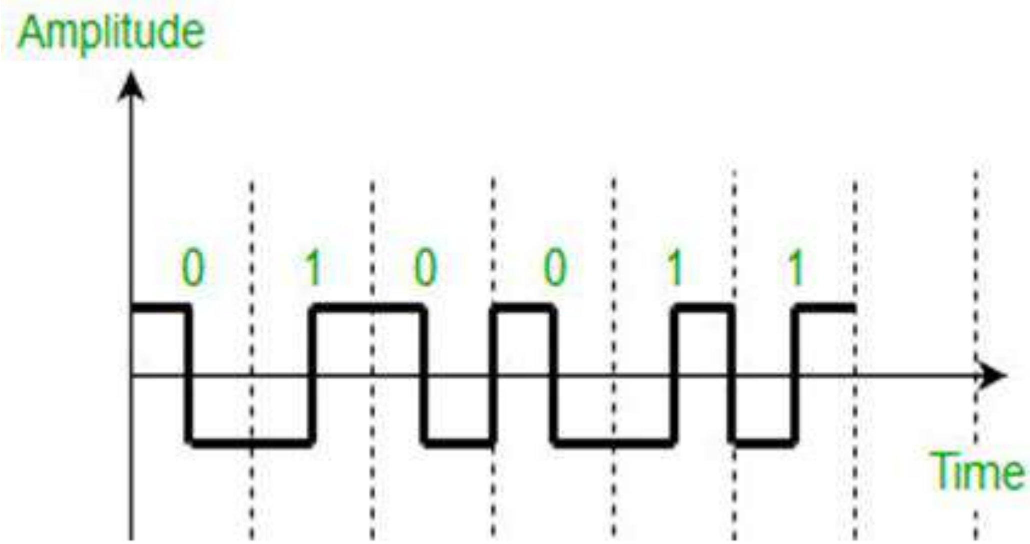
Digital Data to Digital Signal

Bi-phase

Uses two levels of value (+ve and –ve).

Manchester

- The idea of RZ (transition at the middle of the bit) and the idea of NRZ-L are **combined**.
- The duration of the bit is divided into two halves (two voltage levels).



The transition at the middle of the bit is used for both synchronization and bit representation.

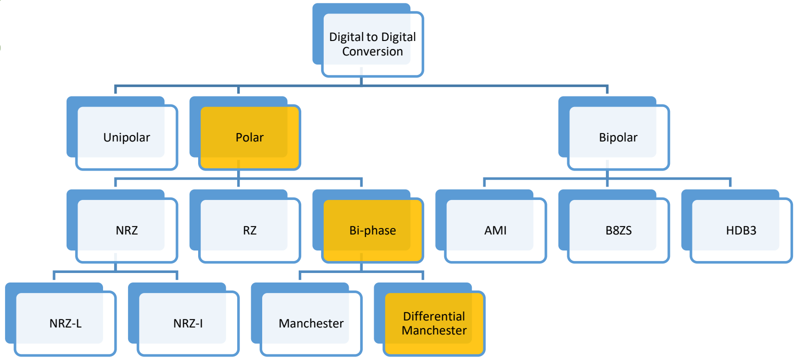
No Baseline wandering.

No DC Component problem.

Problems:

- Signal rate is double that for NRZ.

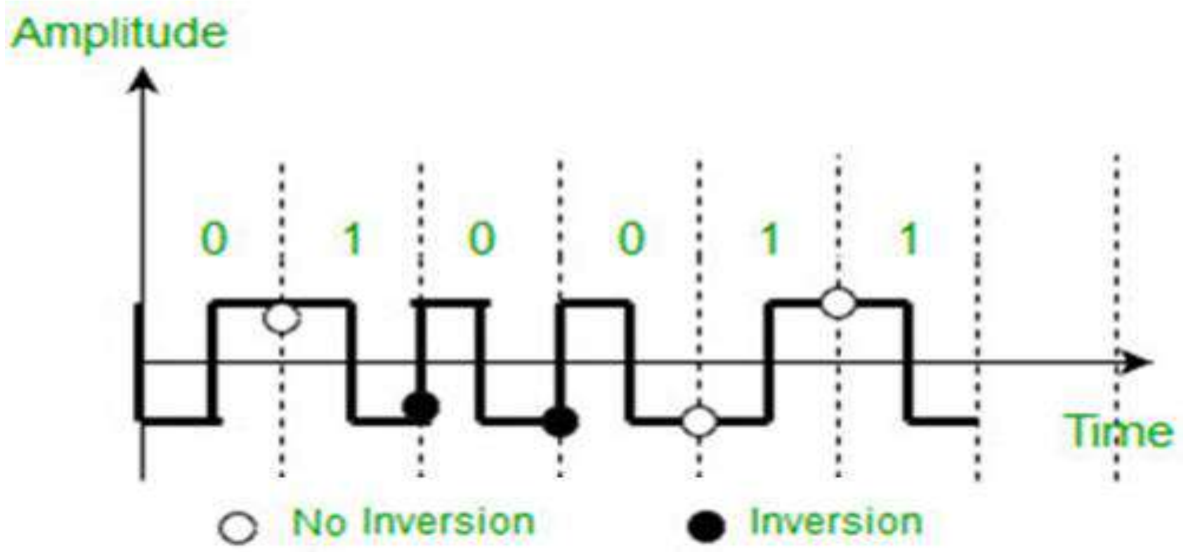
Physical Layer | Signalling | Line Coding



Digital Data to Digital Signal

Differential Manchester

- The idea of RZ (transition at the middle of the bit) and the idea of NRZ-I are **combined**.
- **If the next bit is 0**, there is transition.
- **If the next bit is 1**, **there is no transition**.



The transition at the middle of the bit is used **only for synchronization**. The bit representation is shown by the inversion or non-inversion at the beginning of the bit.

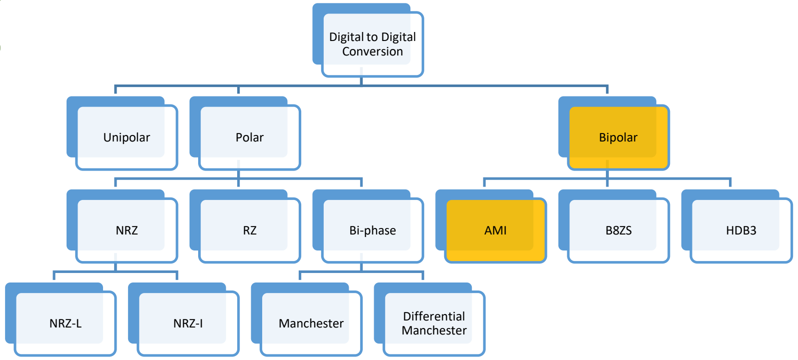
No Baseline wandering.

No DC Component problem.

Problems:

- Signal rate is double that for NRZ.

Physical Layer | Signalling | Line Coding



Digital Data to Digital Signal

Bipolar

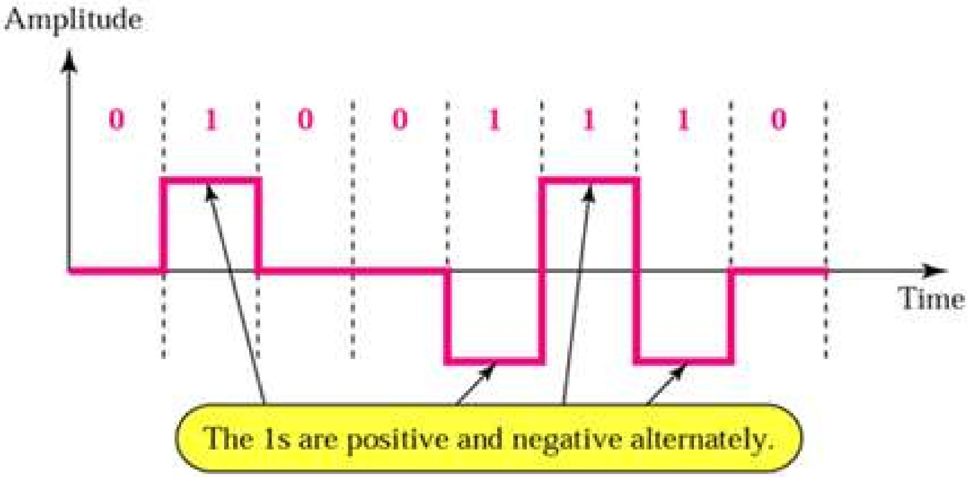
Uses three levels of value (+ve, 0, and –ve).

Multilevel binary is another name.

Alternate Mark Inversion (AMI)

Inverting occurrence of each 1.

On mechanism to ensure the synchronization of a long string of 0s.



Same signal rate as that of NRZ.

No DC Component problem.

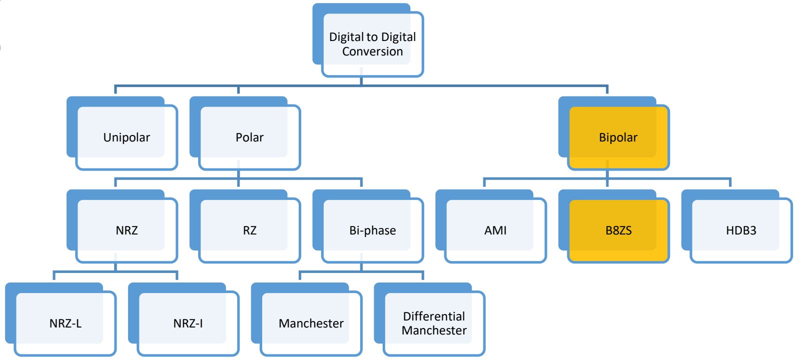
Used for long-distance communication.

Pseudoternary - Inverting occurrence of each 0.

Problems:

- Synchronization problem (long sequence of 0s).

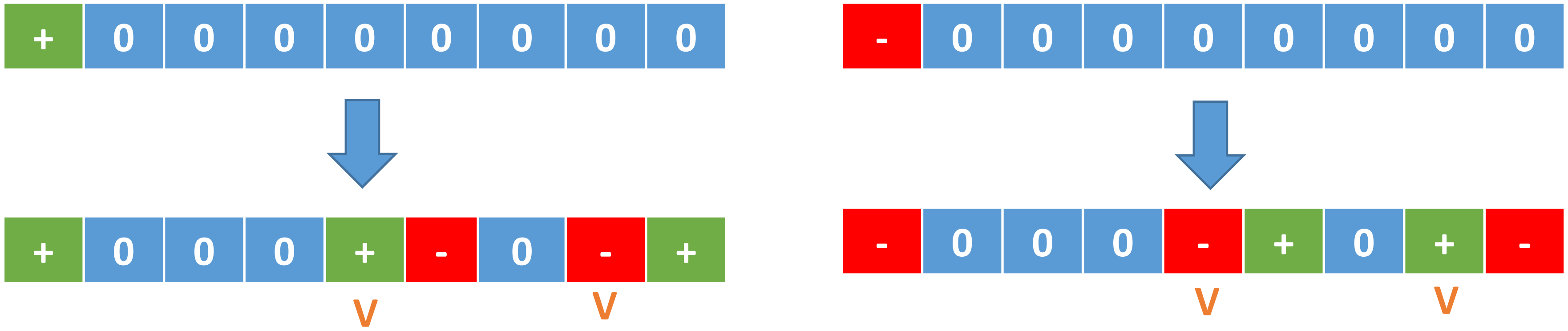
Physical Layer | Signalling | Line Coding



Digital Data to Digital Signal

Bipolar 8-Zero Substitution (B8ZS)

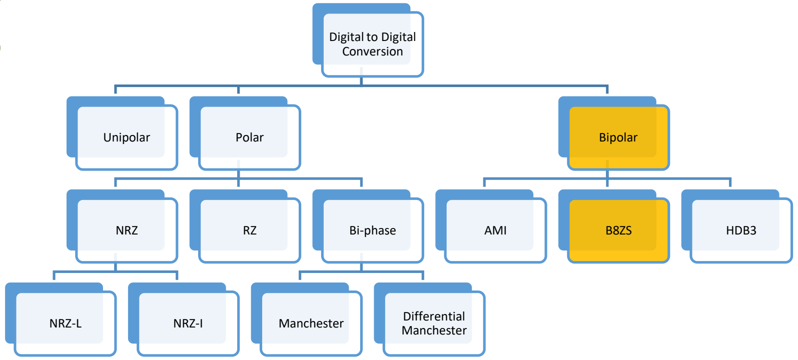
If eight 0s come after another, we change the pattern in one of two ways based on the polarity of the previous 1 (just before the 0s). It will be replaced by the sequence **000VB0VB**.



Forces **artificial signal changes**, called violations (V), within the 0 string.

Process is called Scrambling.

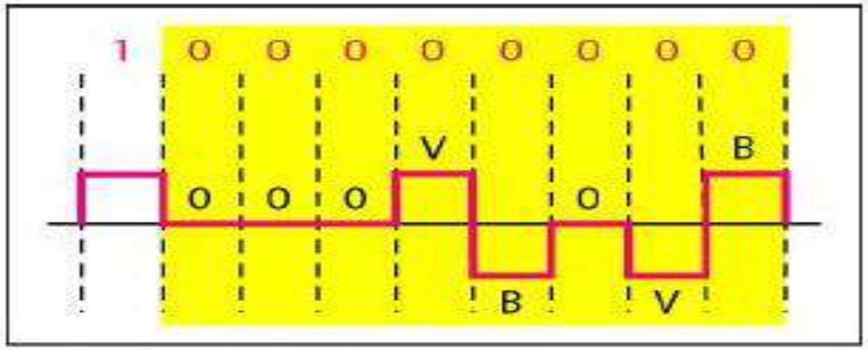
Physical Layer | Signalling | Line Coding



Digital Data to Digital Signal

+	0	0	0	0	0	0	0	0

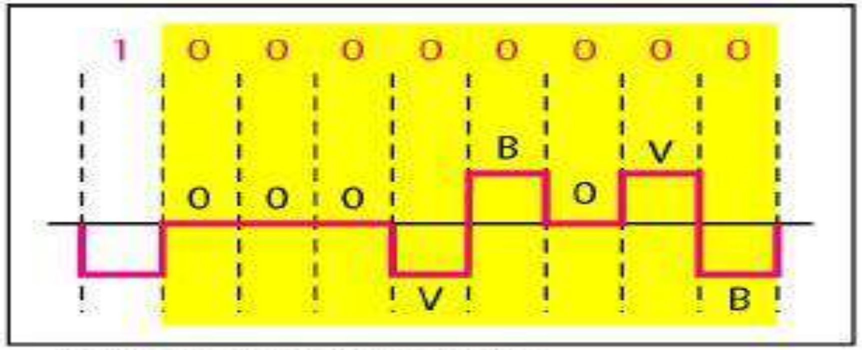
+	0	0	0	+	-	0	-	+



Previous level is positive.

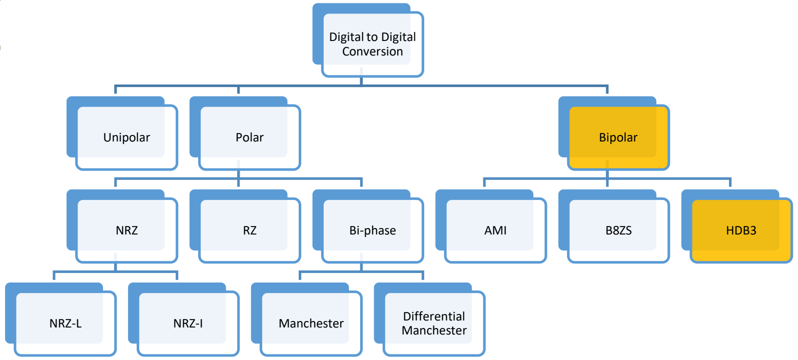
-	0	0	0	0	0	0	0	0

-	0	0	0	-	+	0	+	-



Previous level is negative.

Physical Layer | Signalling | Line Coding



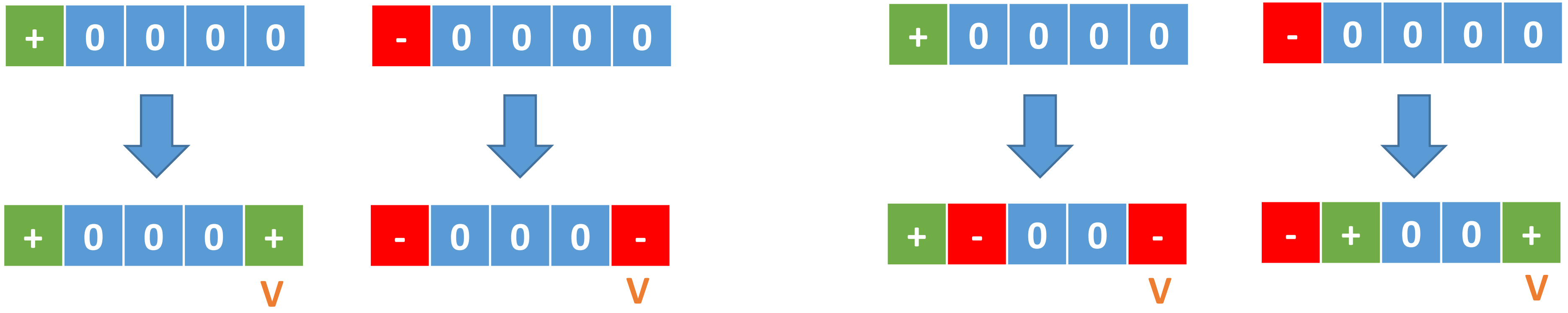
Digital Data to Digital Signal

High-Density Bipolar 3 (HDB3)

If four 0s come one after another, we change the pattern in one of four ways based on the polarity of the previous 1 and the number of 1s since the last substitution. It will be replaced by the sequence **000V or B00V.**

If the number of 1s since last substitution is ODD.

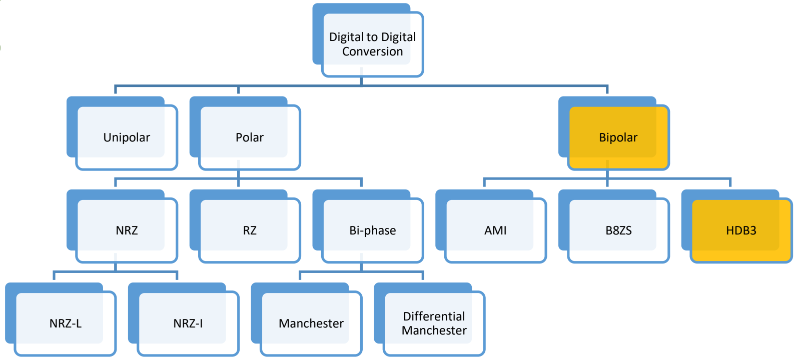
If the number of 1s since last substitution is EVEN.



To maintain the EVEN number of Non-Zero pulses.

Process is called Scrambling.

Physical Layer | Signalling | Line Coding



Digital Data to Digital Signal

If the number of 1s since last substitution is ODD.

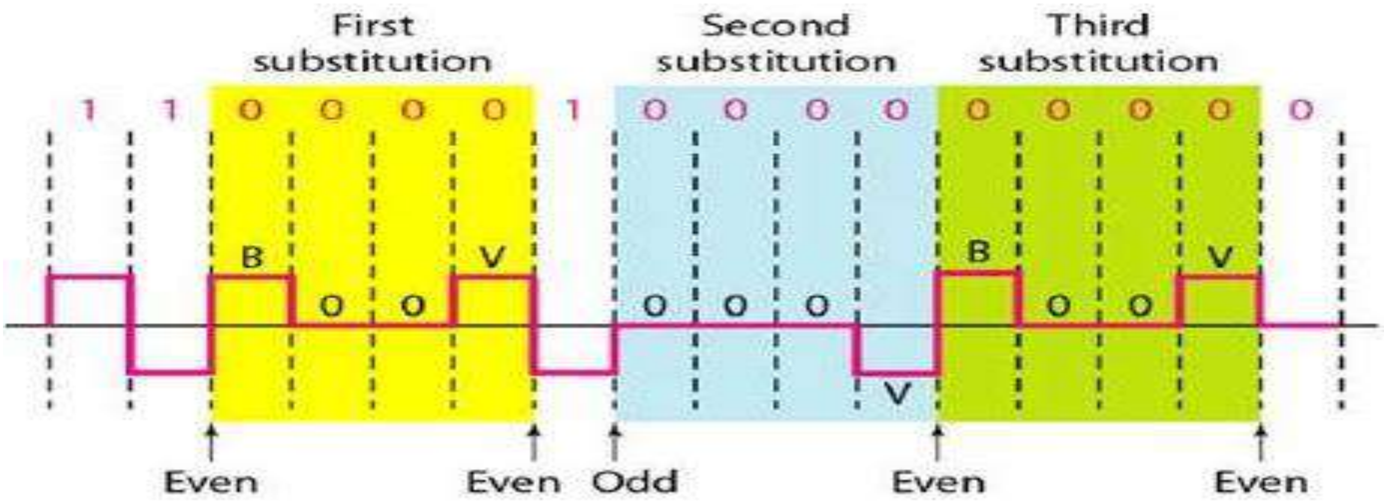
+	0	0	0	0
+	0	0	0	+

-	0	0	0	0
-	0	0	0	-

If the number of 1s since last substitution is EVEN.

+	0	0	0	0
+	-	0	0	-

-	0	0	0	0
-	+	0	0	+

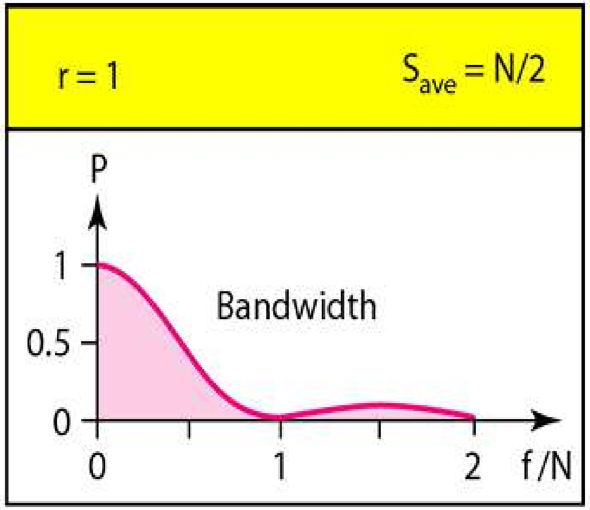


Physical Layer | Signalling | Line Coding

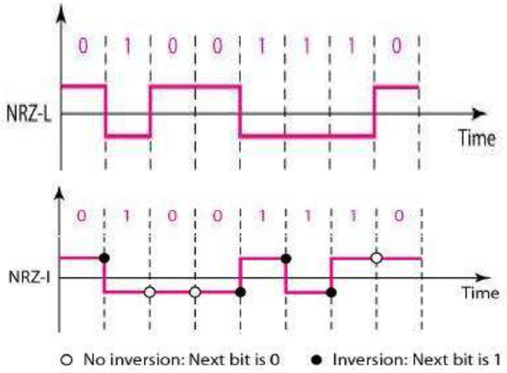
Digital Data to Digital Signal

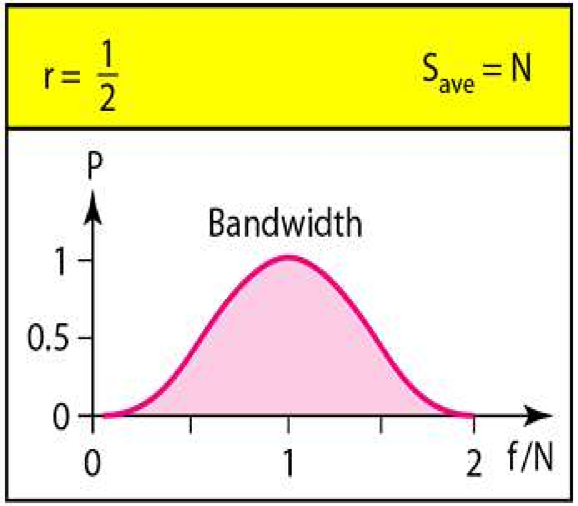
Normalized Bandwidth

S = c x N x 1/r bauds

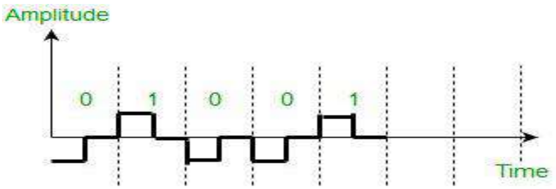


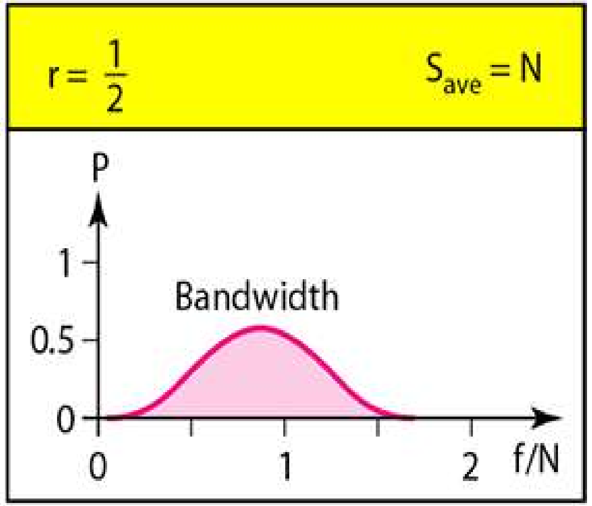
Polar NRZ-L and NRZ-I



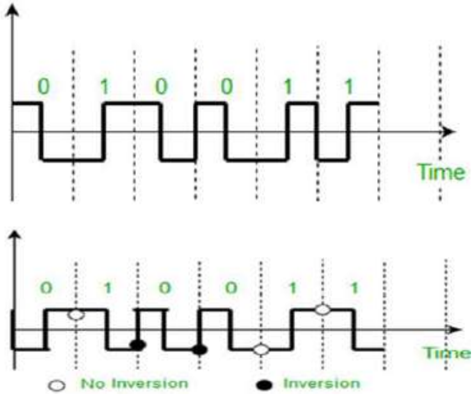


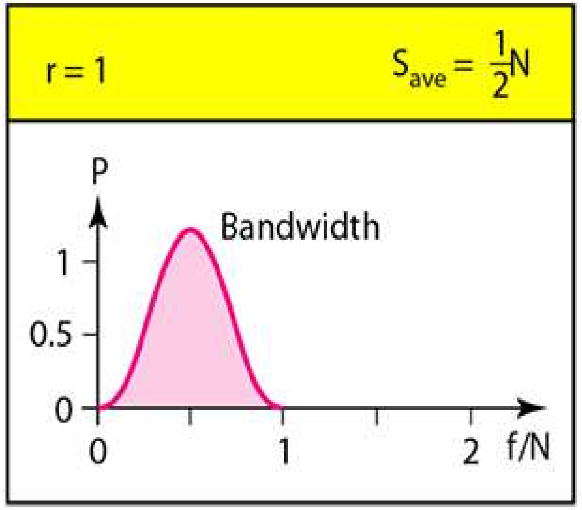
Polar RZ



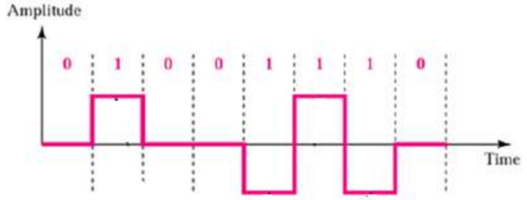


Polar biphase

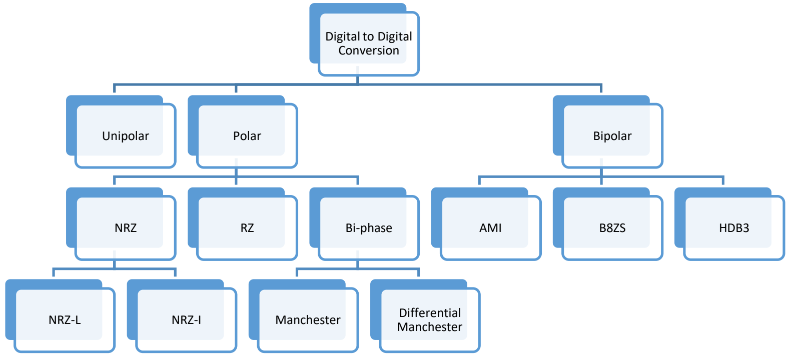




AMI



Physical Layer | Signalling | Line Coding



Digital Data to Digital Signal

Applications of Line Coding

- NRZ encoding: *RS232 based protocols*
- Manchester encoding: *Ethernet networks*
- Differential Manchester encoding: *Token-ring networks*
- NRZ-I encoding: *Fibre Distributed Data Interface (FDDI)*

Physical Layer | Signalling | Line Coding

Analog Data

- Digital Signal
- Analog Signal

Analog Data to Digital Signal

Analog signal created by a microphone or camera.

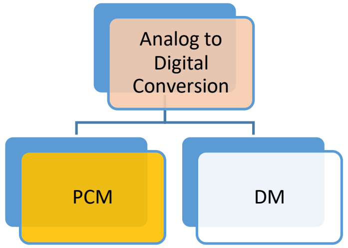
Analog to Digital Conversion

- PCM
- DM

PCM: Pulse Code Modulation

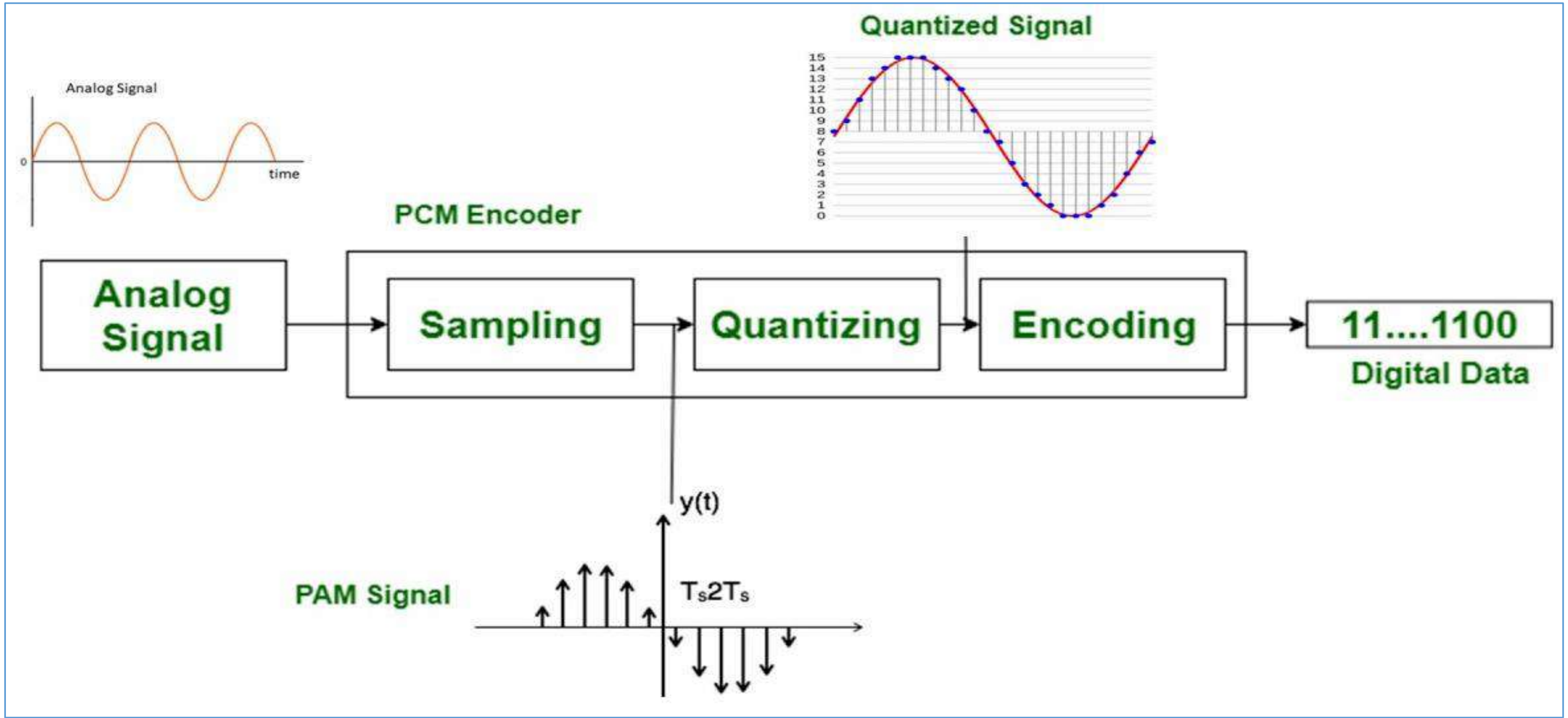
DM: Delta Modulation

Physical Layer | Signalling | Line Coding

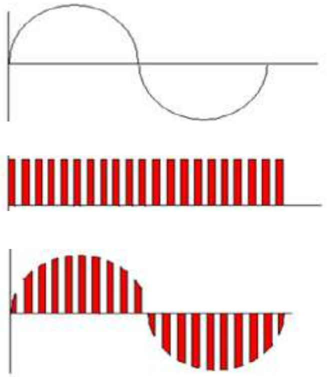


Analog Data to Digital Signal

Pulse Code Modulation (PCM)



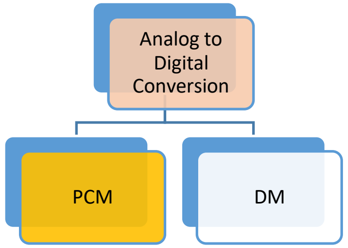
Sampling means measuring the amplitude of the signal at equal intervals.



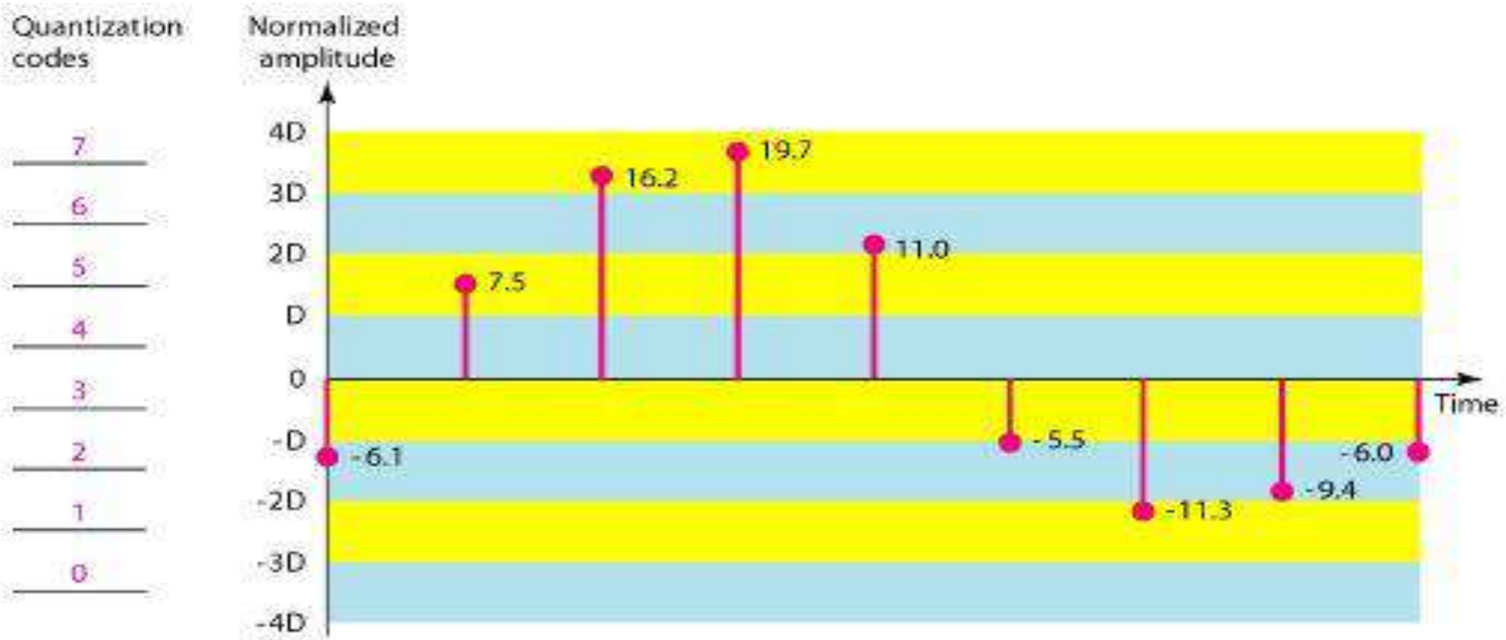
Pulse Amplitude Modulation (PAM)

According to the Nyquist theorem, the sampling rate must be <u>at least 2 times the highest frequency</u> contained in the signal.

Physical Layer | Signalling | Line Coding



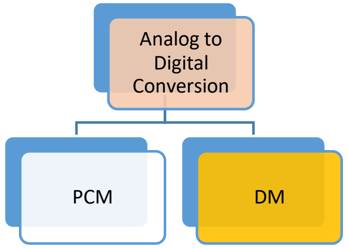
Analog Data to Digital Signal



Normalized PAM values	-1.22	1.50	3.24	3.94	2.20	-1.10	-2.26	-1.88	-1.20
Normalized quantized values	-1.50	1.50	3.50	3.50	2.50	-1.50	-2.50	-1.50	-1.50
Normalized error	-0.38	0	+0.26	-0.44	+0.30	-0.40	-0.24	+0.38	-0.30
Quantization code	2	5	7	7	6	2	1	2	2
Encoded words	010	101	111	111	110	010	001	010	010

Quantization and Encoding of sampled signal.

Physical Layer | Signalling | Line Coding



Analog Data to Digital Signal

Delta Modulation (DM)

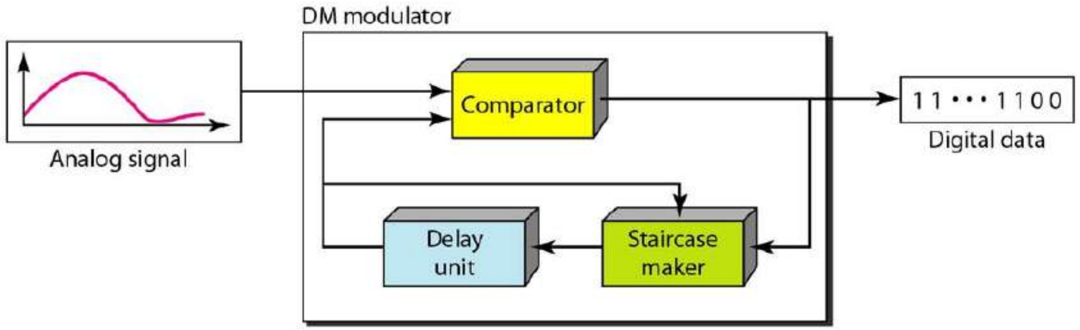
Developed to **reduce the complexity of PCM**.

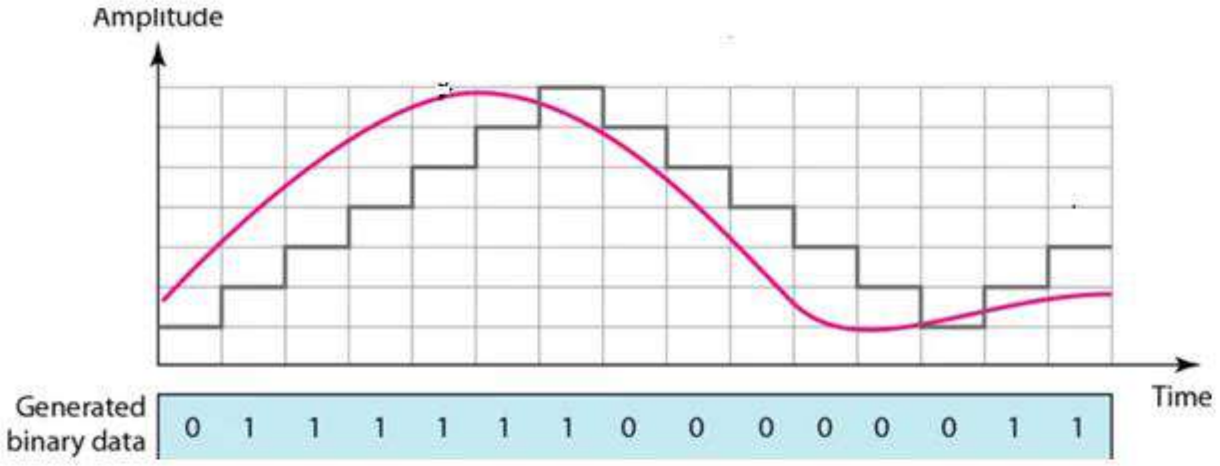
PCM finds the value of the signal amplitude for each sample; **DM finds the change from the previous sample**.

The process records the *small positive or negative changes*, called **delta (Δ)**.

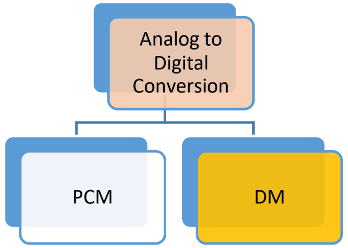
If the Δ is positive, *the process records a 1*; **if it is negative**, *the process records a 0*.

The process needs a base against which the analog signal is compared.





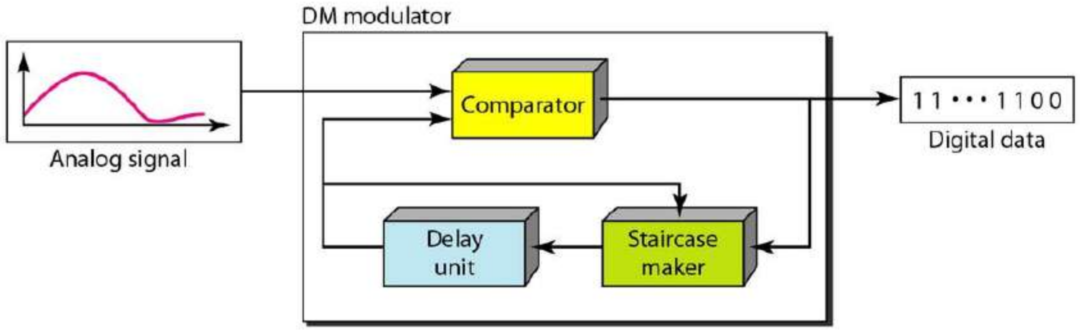
Physical Layer | Signalling | Line Coding



Analog Data to Digital Signal

Delta Modulation (DM)

The modulator builds a **second signal** that **resembles a staircase**. *Finding the change* is then reduced to **comparing the input signal with the gradually made staircase signal**.



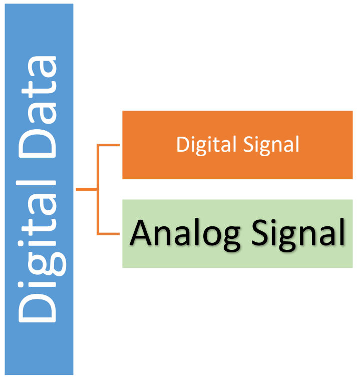
The modulator, *at each sampling interval*, **compares the value of the analog signal with the last value of the staircase signal**.

- **If the amplitude of the analog signal is larger, the next bit in the digital data is 1; otherwise, it is 0.**

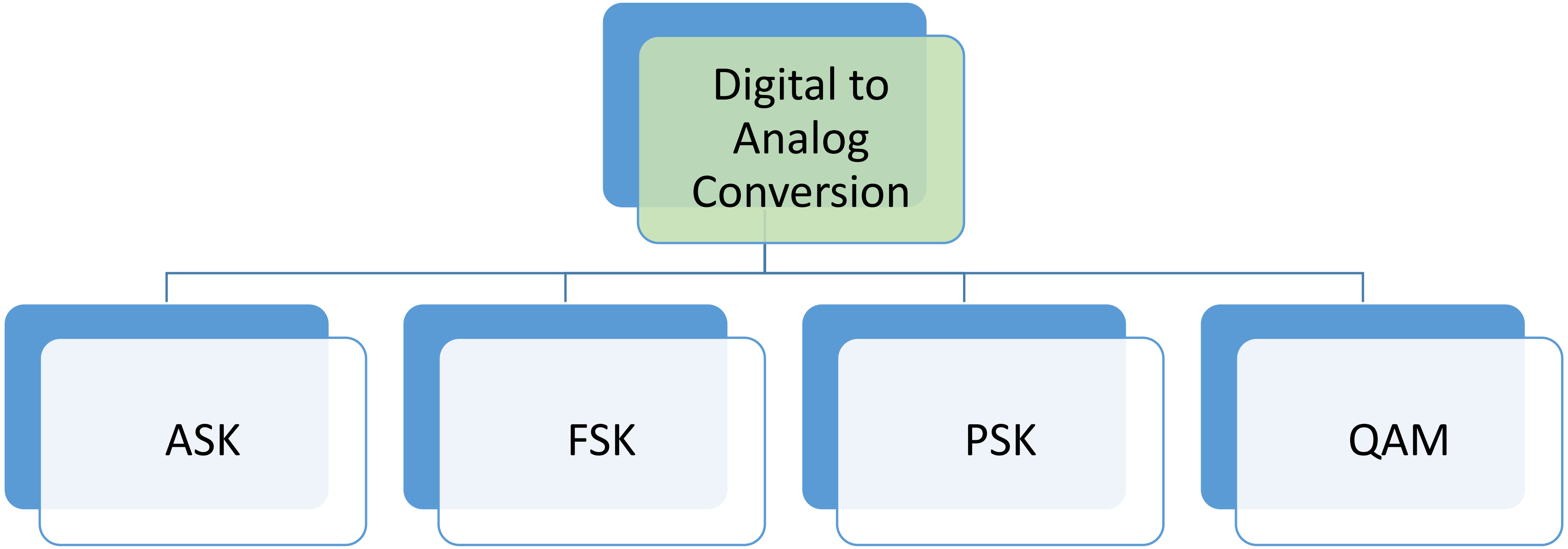
The output of the comparator, however, **also makes the staircase itself**. **If the next bit is 1, the staircase maker moves the last point of the staircase signal Δ up**; **if the next bit is 0, it moves it Δ down**.

The **delay unit** is needed to hold the staircase function for a period between two comparisons.

Physical Layer | Signalling | Line Coding



Digital Data to Analog Signal



ASK : Amplitude Shift Keying
FSK : Frequency Shift Keying

PSK : Phase Shift Keying
QAM : Quadrature Amplitude Modulation

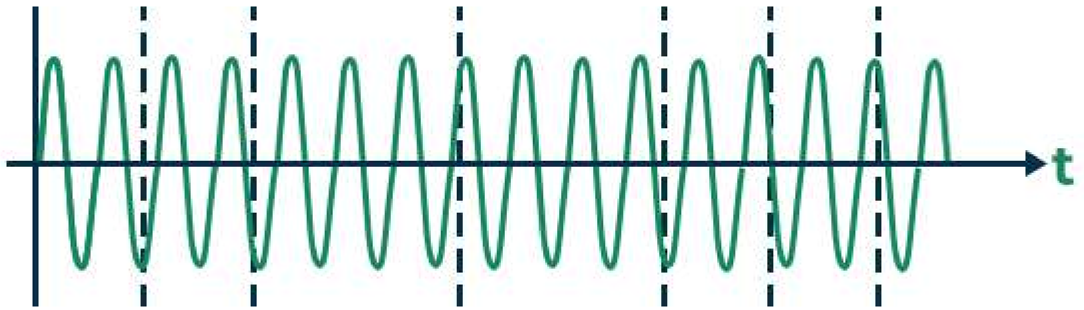
Physical Layer | Signalling | Line Coding

Digital Data
- Digital Signal
- Analog Signal

Digital Data to Analog Signal

Carrier Signal

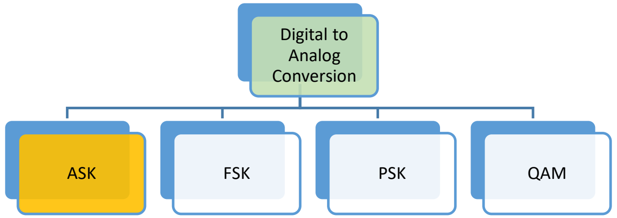
In analog transmission, the *sending device* produce **a high-frequency signal** that acts as a basis for the information signal. This base signal is called **carrier signal** or **carrier frequency**.



The *receiving device* is **tuned to the frequency of the carrier signal** that it expects from the sender.

The digital information is then modulated on the carrier signal by modifying one or more of its characteristics (*amplitude*, *frequency*, *phase*).

Physical Layer | Signalling | Line Coding



Digital Data to Analog Signal

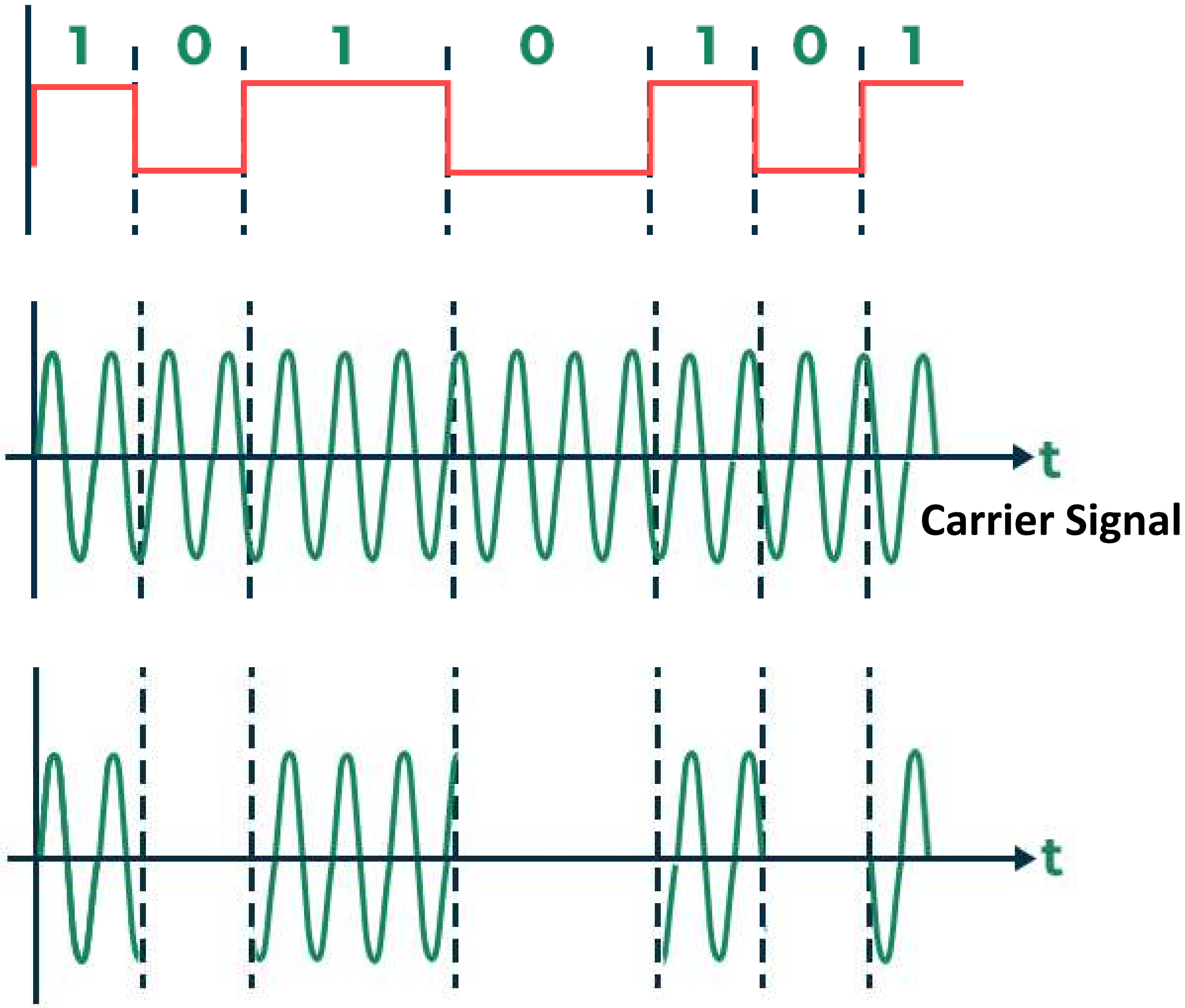
Amplitude Shift Keying (ASK)

The amplitude of the carrier signal is varied to represent binary 1 and 0.

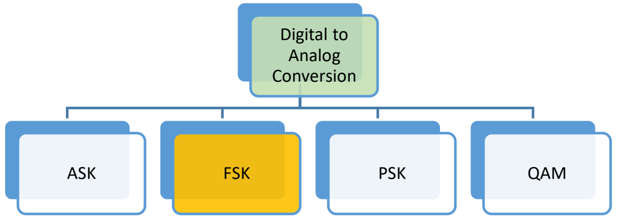
Both frequency and phase remains constant while the amplitude changes.

A popular ASK technique is called **on-off-keying (OOK)**. The advantage is a **reduction in the amount of energy required to transmit information**.

ASK transmission is highly susceptible to noise interference.

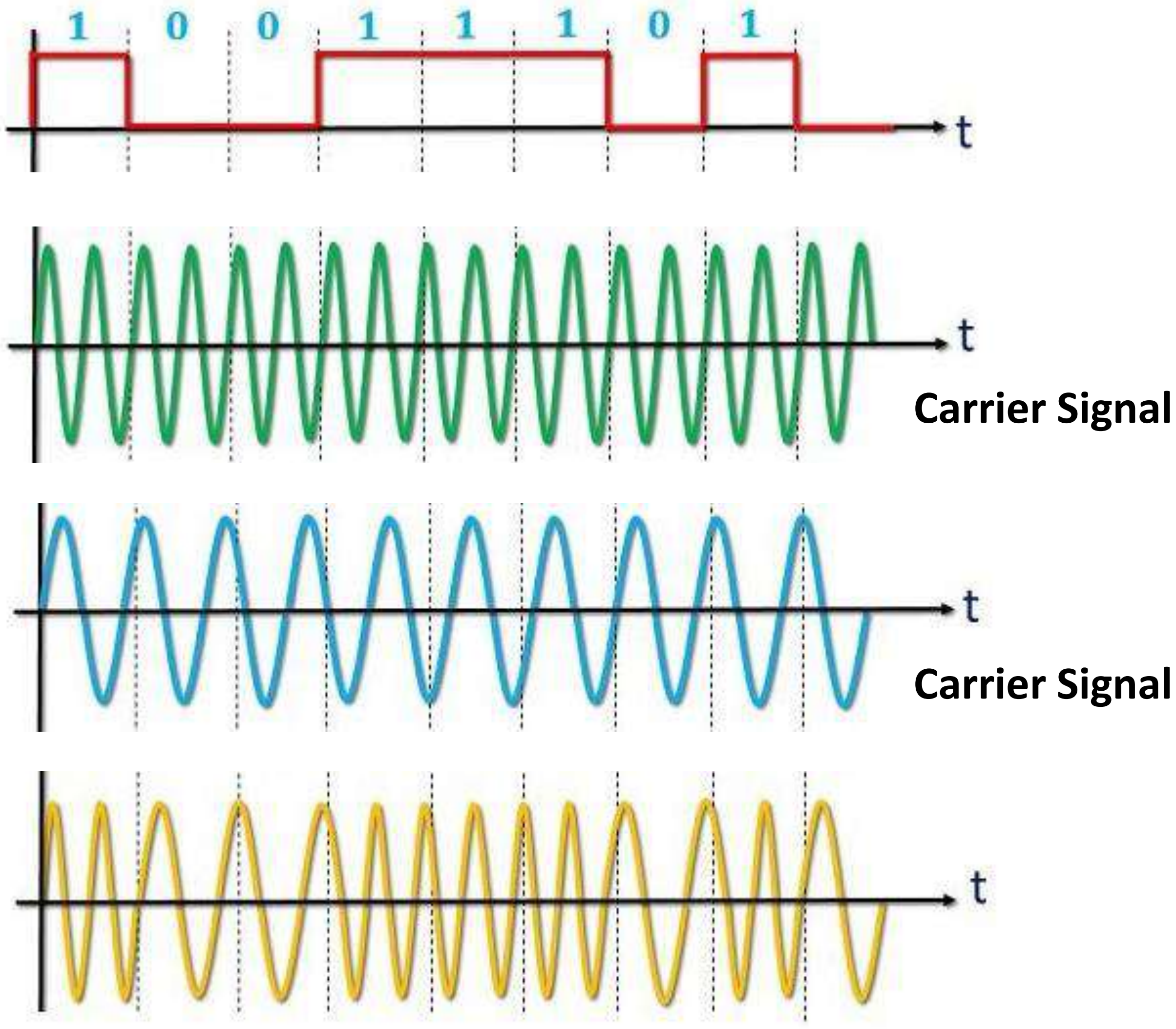


Physical Layer | Signalling | Line Coding



Digital Data to Analog Signal

Frequency Shift Keying (FSK)

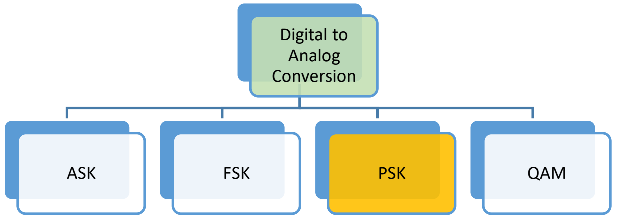


The frequency of the carrier signal is varied to represent binary 1 and 0.

Both amplitude and phase remains constant while the frequency changes.

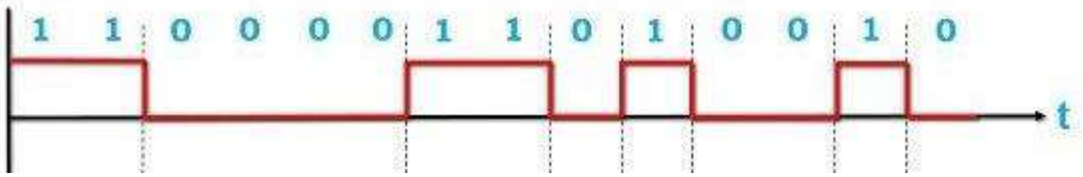
FSK transmission avoids most of the noise problem of ASK.

Physical Layer | Signalling | Line Coding

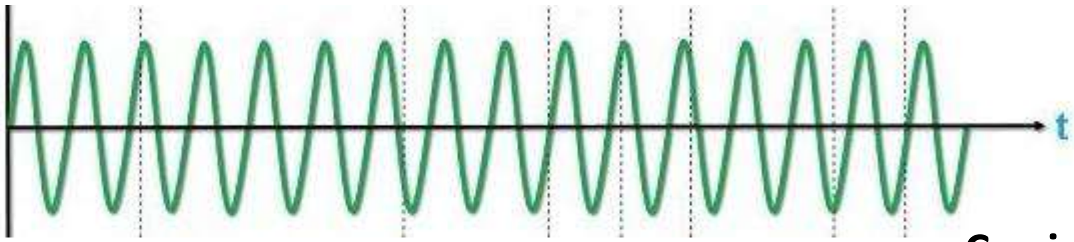


Digital Data to Analog Signal

Phase Shift Keying (PSK)



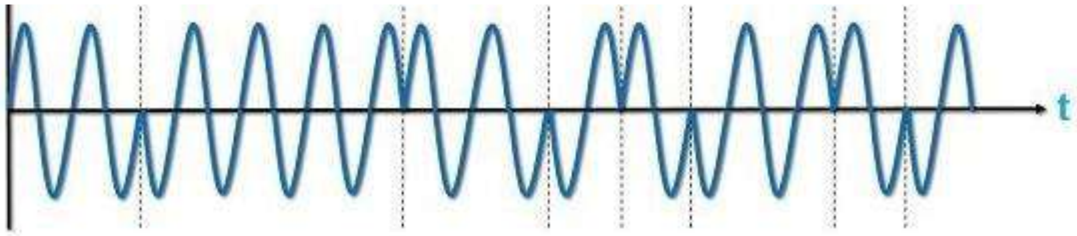
The phase of the carrier signal is varied to represent binary 1 and 0.



Carrier Signal

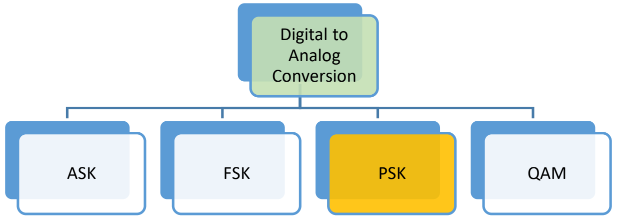
Both amplitude and frequency remains constant while the phase changes.

If we start with phase of 0^0 to represent binary 1, then we can change the phase to 180^0 to send binary 0.

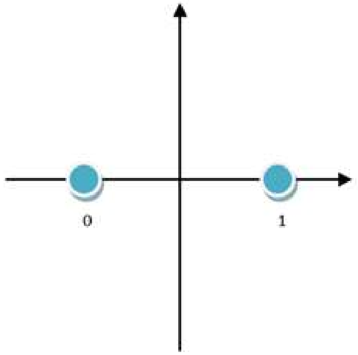


The phase of the signal during each bit duration is constant and its values depends on the bit (1 or 0).

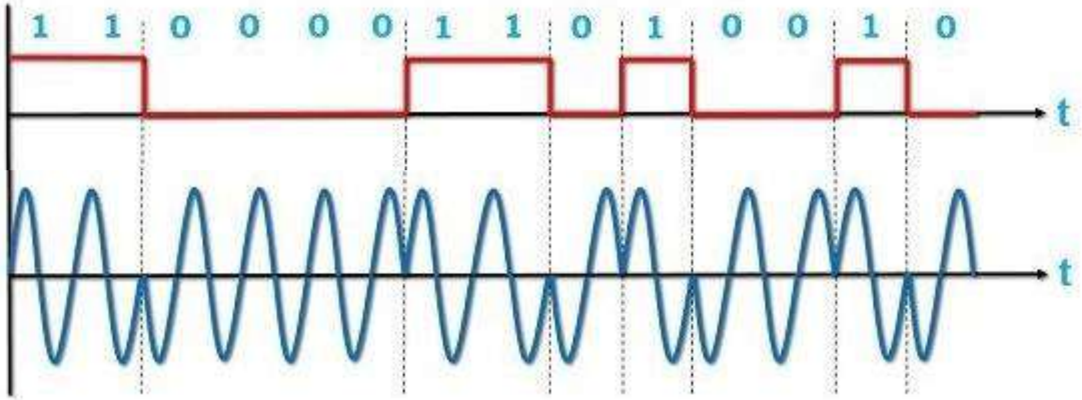
Physical Layer | Signalling | Line Coding

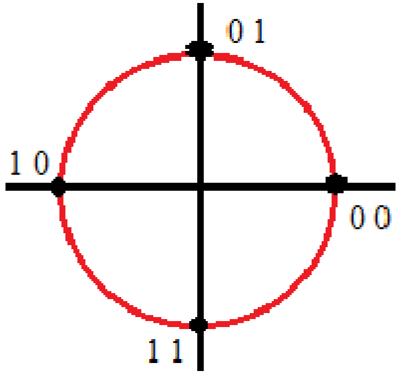


Digital Data to Analog Signal

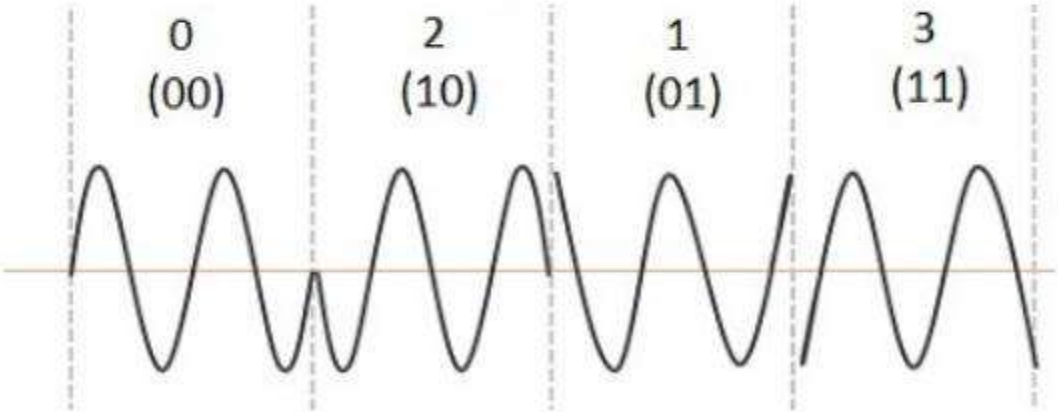


Constellation Diagram (2-PSK or B-PSK)



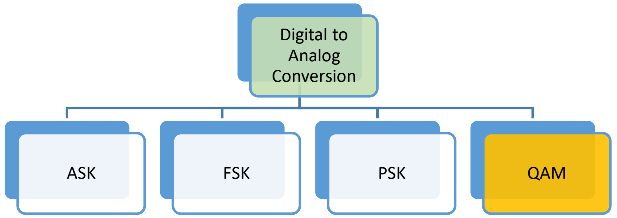


Constellation Diagram (4-PSK or Q-PSK)



Transmit data two times as faster. The bits represented by each phase is called a **dibit**.

Physical Layer | Signalling | Line Coding



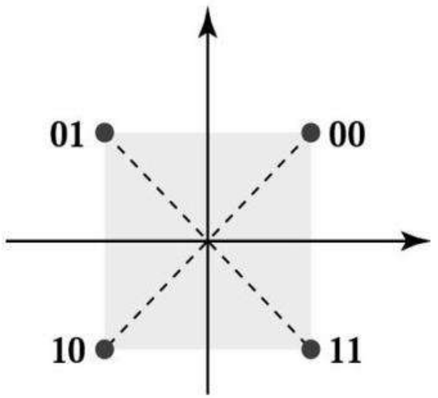
Digital Data to Analog Signal

Quadrature Amplitude Modulation (QAM)

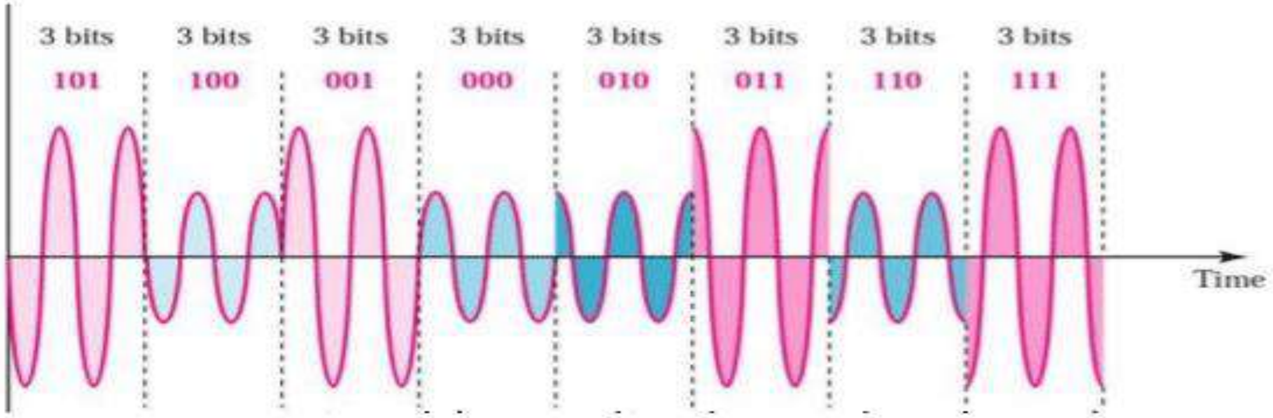
PSK is limited by the ability of the equipment to distinguish small differences in phase. This factor limits its potential bit rate.

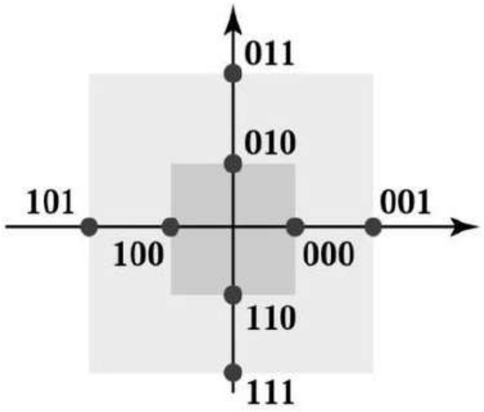
Combines ASK and PSK in such a way that we have *maximum contrast between each bit, dibits, tribit, quadbit and so on*.

Number of phase shifts used by a QAM system is always larger than the number of amplitude shifts.



Constellation Diagram (4-QAM)





Constellation Diagram (8-PSK)

Physical Layer | Signalling | Line Coding

Analog Data
- Digital Signal
- Analog Signal

Analog Data to Analog Signal

Analog to Analog Conversion

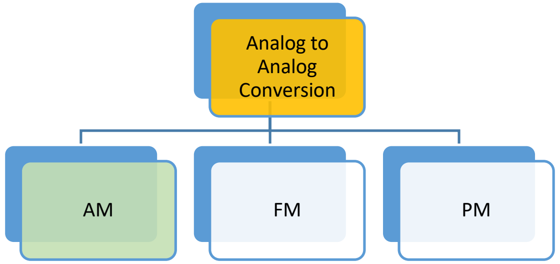
- AM
- FM
- PM

AM: Amplitude Modulation

FM: Frequency Modulation

PM: Phase Modulation

Physical Layer | Signalling | Line Coding



Analog Data to Analog Signal

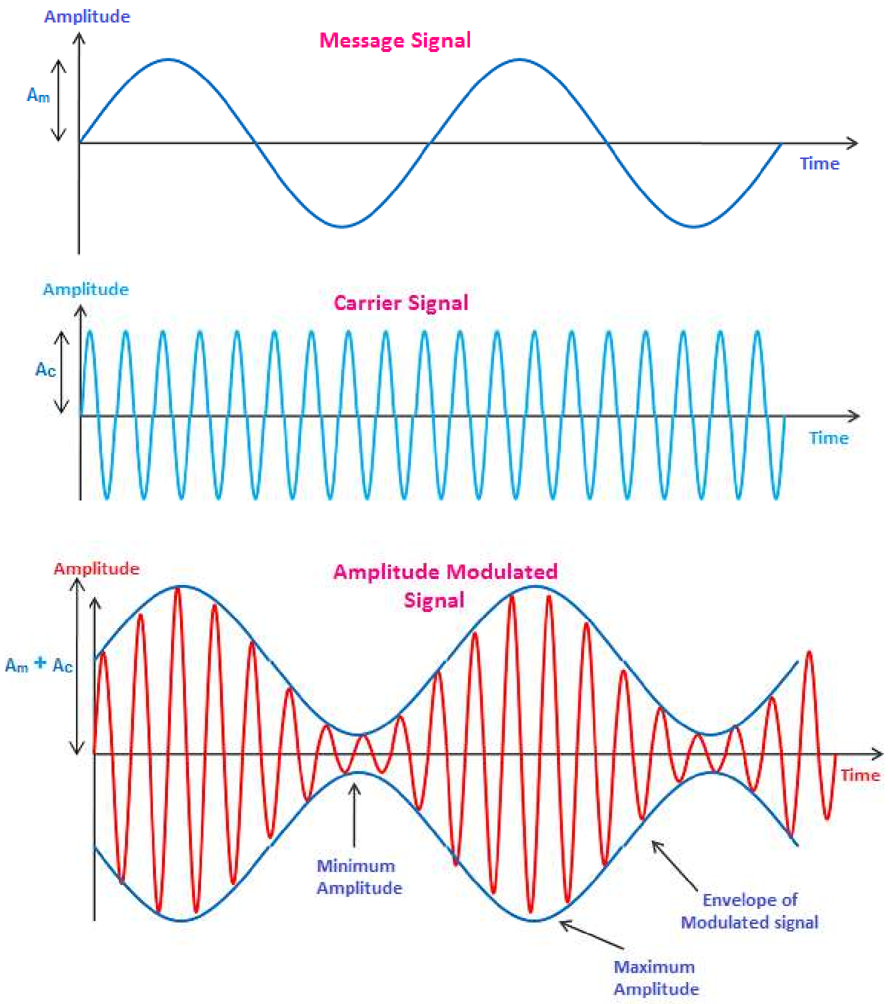
Amplitude Modulation (AM)

The carrier signal is modulated so that its **amplitude varies with the changing amplitudes of the modulating signal**.

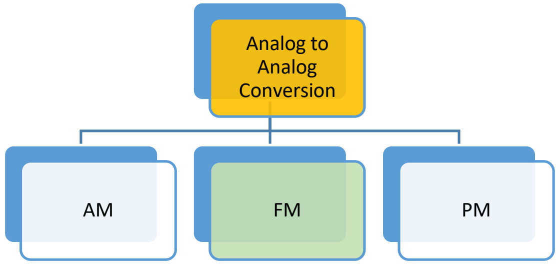
The frequency and phase of the carrier remain the same.

The modulating signal becomes an envelope to the carrier.

The bandwidth of an AM signal is equal to **twice the bandwidth of the modulating signal** and covers a range centered around the carrier frequency.



Physical Layer | Signalling | Line Coding

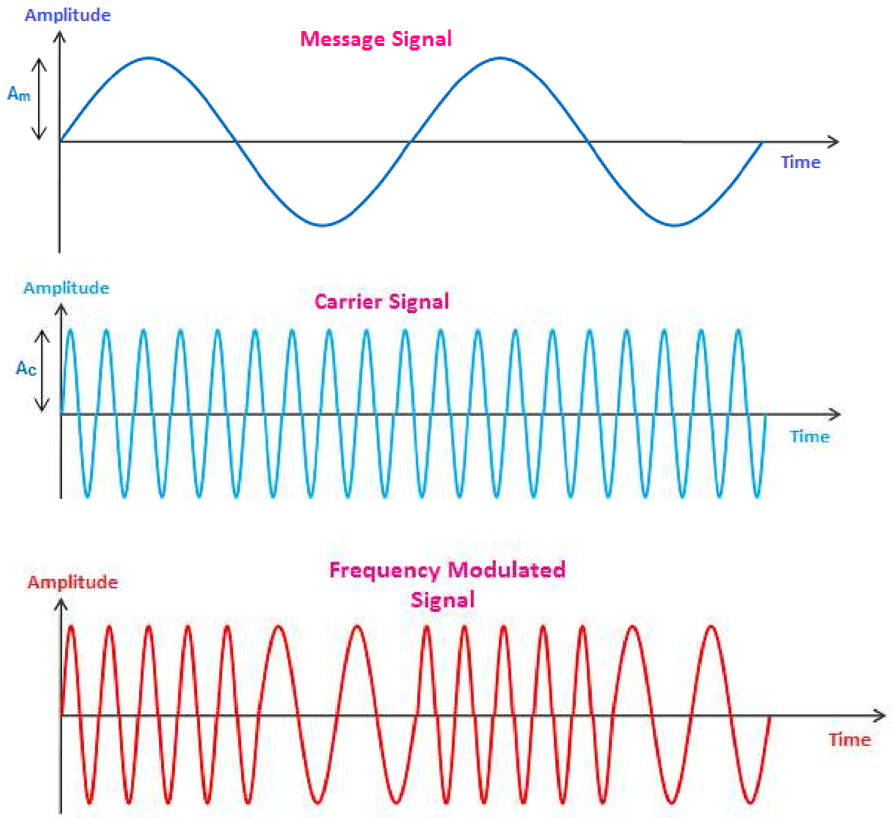


Analog Data to Analog Signal

Frequency Modulation (FM)

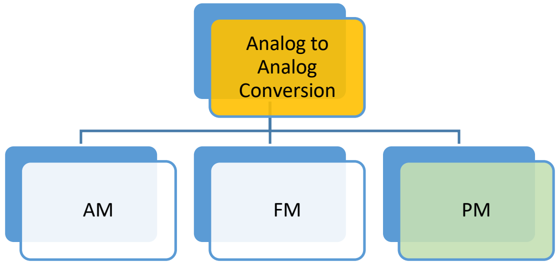
The frequency of the carrier signal is modulated to follow the *changing voltage level (amplitude) of the modulating signal*.

The peak amplitude and phase of the carrier remain the same.



The bandwidth of an FM signal is equal to **several times the bandwidth of the modulating signal** and covers a range centered around the carrier frequency.

Physical Layer | Signalling | Line Coding



Analog Data to Analog Signal

Phase Modulation (PM)

The phase of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal.

In FM, the instantaneous change in the carrier frequency is proportional to the **amplitude of the modulating signal**.

In PM, the instantaneous change in the carrier frequency is proportional to the **derivative of the amplitude of the modulating signal**.