
KTU
NOTES

MODULE 2

Data and signals, Analog Signals, Digital Signals - Transmission Impairments, Data Rate Limits: Channel Capacity, Nyquist Bit Rate, Shannon Capacity, Performance parameters - Bandwidth, Throughput, Delay & Jitter.

Digital-To-Digital Conversion: Line Coding Schemes: Unipolar, Polar, Bipolar - Block Coding, Scrambling, Analog-To-Digital Conversion: Pulse Code Modulation, Delta Modulation - Digital-To-Analog Conversion: ASK, FSK, PSK.

Communication model

Data communication is defined as exchange of data between 2 devices over a transmission-medium.

- A communication-system is made up of
  - hardware (physical equipment) and
  - software (programs)
- For data-communication, the communicating-devices must be part of a communication-system
- Four attributes of a communication-system:

  1)Delivery
  - The system must deliver data to the correct destination.

  2) Accuracy
  - The system must deliver the data accurately.
  - Normally, the corrupted-data are unusable.

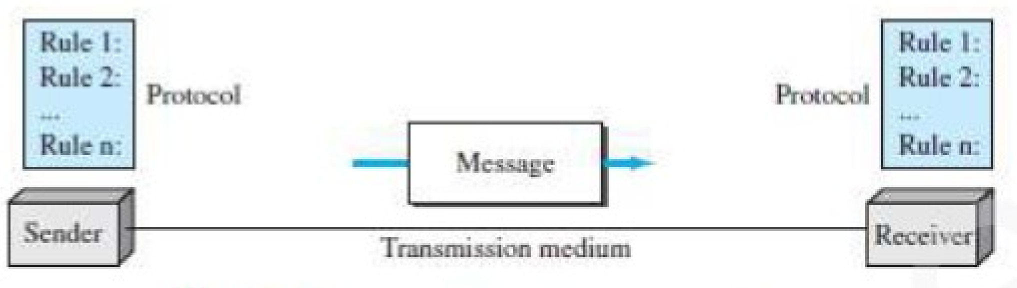
  3)Timeliness
  - The system must deliver audio/video data in a timely manner
  - This kind of delivery is called real-time transmission.
  - Data delivered late are useless.

  4)Jitter
  - Jitter refers to the variation in the packet arrival-time.
  - In other words, jitter is the uneven delay in the delivery of audio/video packets.

Components of Communication System

Five components of a communication-system (Figure 1.1):

1)Message
2)Sender
3)Receiver
4)Transmission-Medium
5)Protocol



1)Message

- Message is the information (or data) to be communicated.
- Message may consist of
  - number/text
  - picture or
  - audio/video

2)Sender

- Sender is the device that sends the data-message.
- Sender can be
  - computer and
  - mobile phone

3)Receiver

- Receiver is the device that receives the message.
- Receiver can be
  - computer and
  - mobile phone

4)Transmission Medium

- Transmission medium is physical-path by which a message travels from sender to receiver.
- Transmission-medium can be wired or wireless.
- Examples of wired medium:
  - twisted-pair wire(used in landline telephone)
  - coaxial cable(used in cable TV network)
  - fiber-optic cable
- Examples of wireless medium:
  - radio waves
  - microwaves
  - infrared waves(ex: operating TV using remote control)

5)Protocol

- A protocol is a set of rules that govern data-communications.
- In other words, a protocol represents an agreement between the communicating-devices.
- Without a protocol, 2devices may be connected but not communicating.

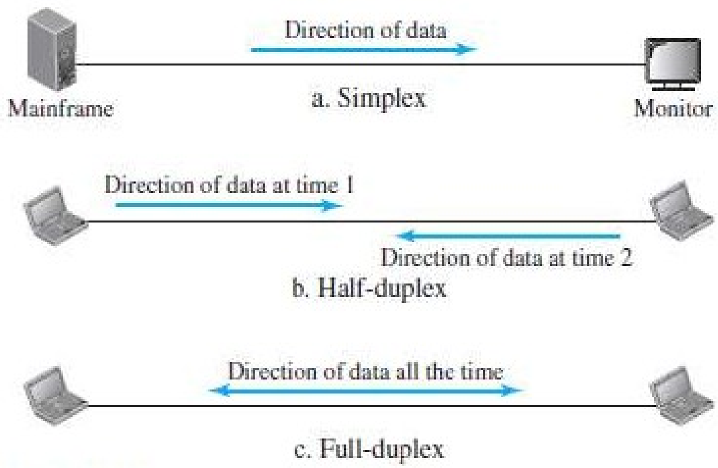
<u>Simplex, half duplex and full duplex transmission</u>

Three ways of data-flow between 2 devices:

1) Simplex
2) Half-duplex
3) Full-duplex

1) Simplex

- The communication is unidirectional
  - (For ex: The simplex mode is like a one-way street).
- On a link, out of 2 devices:
  - Only one device can transmit
  - Another device can only receive.
- For example (Figure 1.2a):
  - The monitor can only accept output.
- Entire-capacity of channel is used to send the data in one direction.



Data flow (simplex, half-duplex, and full-duplex)

2) Half Duplex

- Both the stations can transmit as well as receive but not at the same time.
  (For ex: The half-duplex mode is like a one-lane road with 2 directional traffic).
- When one station is sending, the other can only receive and vice-versa
- For example(Figure 1.2b): Walkie-talkies
- Entire-capacity of a channel is used by one of the 2 stations that are transmitting the data.

3) Full Duplex

- Both stations can transmit and receive at the same time.
  (For ex: The full-duplex is like a 2-way street with traffic flowing in both directions at the same time).
- For example(Figure 1.2c):
  Mobile phones (When 2 people are communicating by a telephone line, both can listen and talk at the same time)
- Entire-capacity of a channel is shared by both the stations that are transmitting the data.

Data and signals

In communication system a signal is generated by the transmitter and transmitted over a medium. The signal is a function of time, but it can also be expressed as a function of frequency.

Analog and digital Data and Signals

Analog &Digital Data

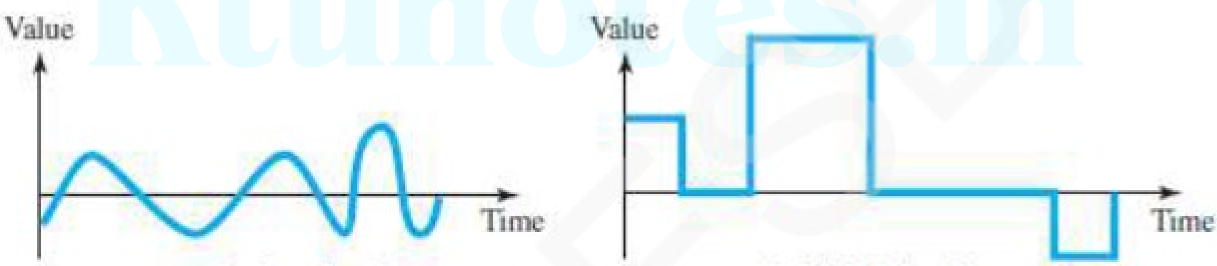
- To be transmitted, data must be transformed to electromagnetic-signals
- Data can be either analog or digital.

1) **Analog Data** refers to information that is continuous.
   For example: The sounds made by a human voice.
2) **Digital Data** refers to information that has discrete states.
   For example: Data are stored in computer-memory in the form of 0s and 1s

Analog &Digital Signals

- Signals can be either analog or digital (Figure 3.2).

1) Analog Signal has infinitely many levels of intensity over a period of time.
2) Digital Signal can have only a limited number



a. Analog signal　　b. Digital signal

Periodic &Non-Periodic Signals

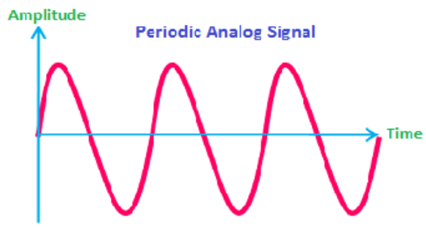
The signals can take one of 2 forms: periodic or non-periodic.

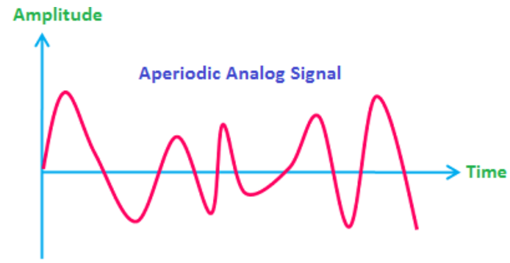
1)Periodic Signal

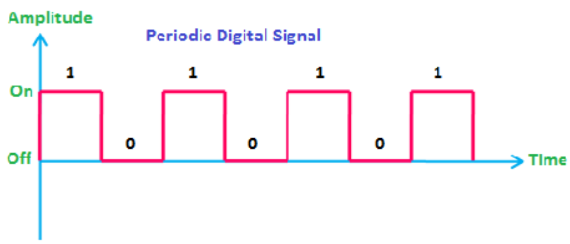
- ➢ Signals which repeat itself after a fixed time period are called Periodic Signals.
- ➢ The completion of one full pattern is called a cycle.

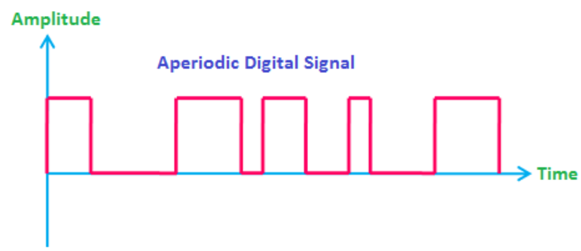
2)Non-Periodic Signal

- ➢ Signals which do not repeat itself after a fixed time period are called Non-Periodic Signals.









For periodic signals, time and frequency are the inverse of each other. Specifically, a periodic signal can be quantified by its period which is how long it takes for the signal to repeat itself or by its frequency which is how many times the signal repeats itself in a given time.:

$$period = \frac{1}{frequency}$$

and

$$frequency = \frac{1}{period}$$

Since period and frequency are inverses of each other, time domain analysis and frequency domain analysis are, in a way, inversely related as well.

Amplitude is a measurement of how large a wave is. It represents the wave's energy.

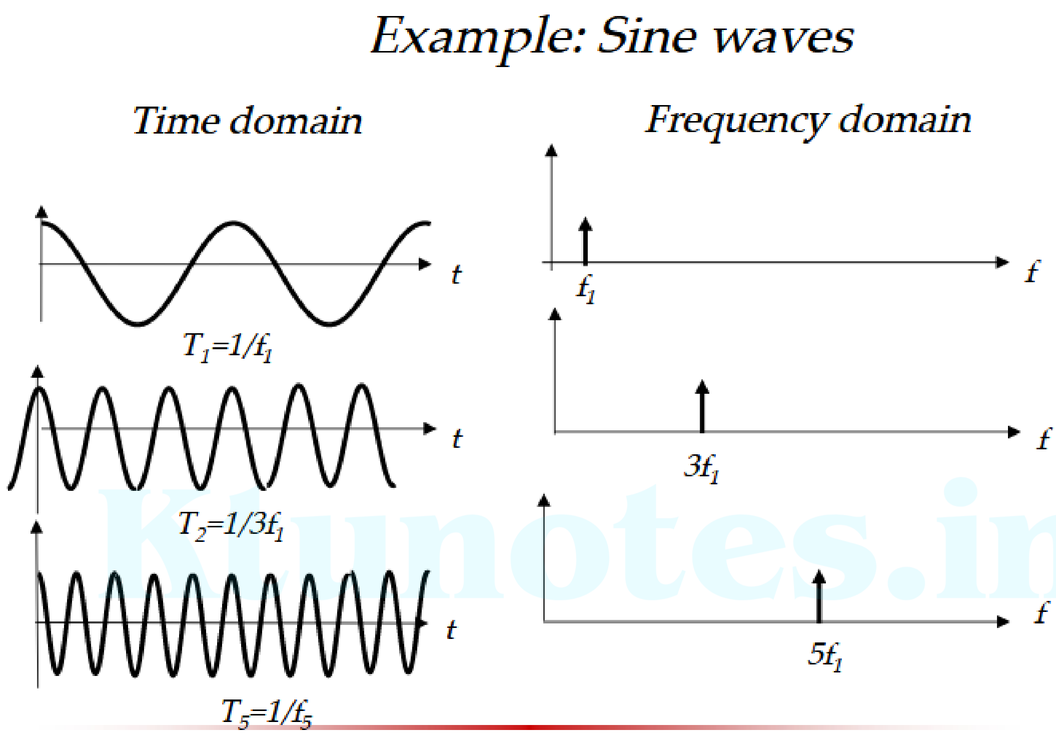
<u>Time Domain and Frequency Domain concepts</u>

Time Domain Concepts

- Viewed as a function of time
- an electromagnetic signal can be either analog or digital.
- Time domain plot shows the changes in signal amplitude with respect to time
- It shows how a signal changes over time

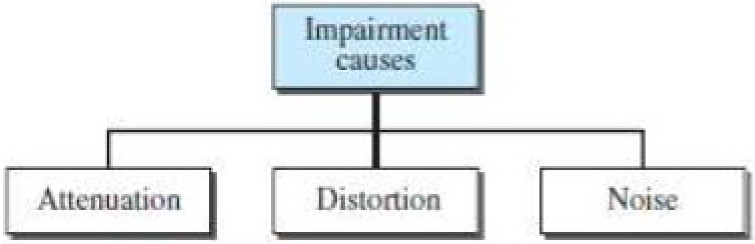
Frequency Domain Concepts

- Refers to the analysis of a signal with respect to frequency
- It shows how much of the signal lies within each given frequency band over arrange of frequencies



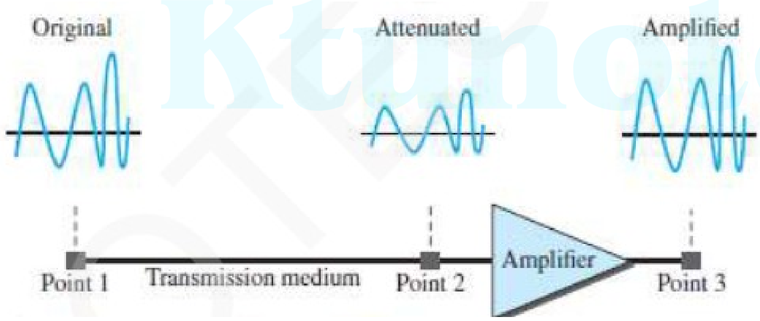
Transmission Impairments

- Signals travel through transmission media, which are not perfect.
- The imperfection causes signal-impairment.
- This means that signal at beginning of the medium is not the same as the signal at end of medium.
- What is sent is not what is received.
- Three causes of impairment are
  1) Attenuation
  2) Distortion &
  3) Noise.



Attenuation

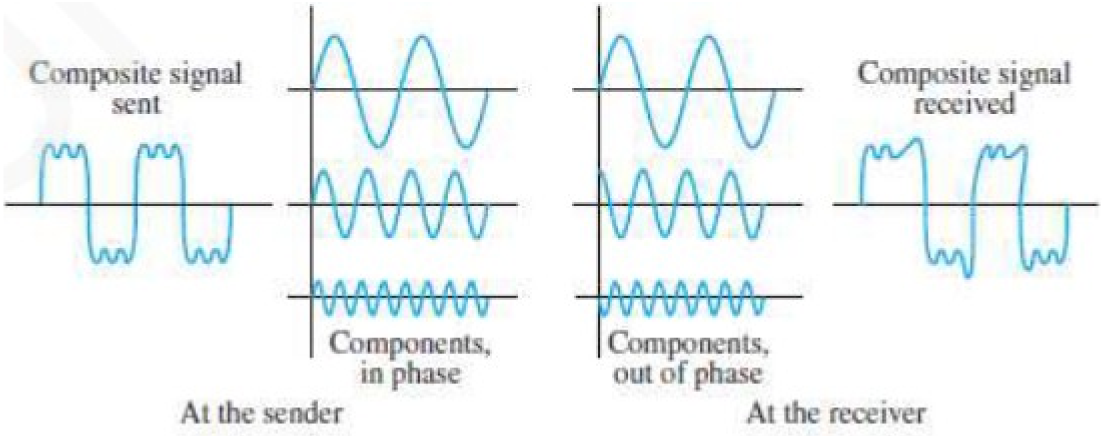
- As signal travels through the medium, its strength decreases as distance increases. This is called attenuation
- As the distance increases, attenuation also increases.
- For example: Voice-data becomes weak over the distance & loses its contents beyond a certain distance.
- To compensate for this loss, amplifiers are used to amplify the signal



Distortion

- Distortion means that the signal changes its form or shape
- Distortion can occur in a composite signal made of different frequencies.
- Different signal-components
  - →have different propagation speed through a medium.
  - →have different delays in arriving at the final destination.
- Differences in delay create a difference in phase if delay is not same as the period-duration.
- Signal-components at the receiver have phases different from what they had at the sender.

- The shape of the composite signal is therefore not the same.



Noise

- Noise is defined as an unwanted data
- In other words, noise is the external energy that corrupts a signal.
- Due to noise, it is difficult to retrieve the original data/information.

Four types of noise:

i) Thermal Noise

- ➢ It is random motion of electrons in wire which creates extra signal not originally sent by transmitter.

ii) Induced Noise

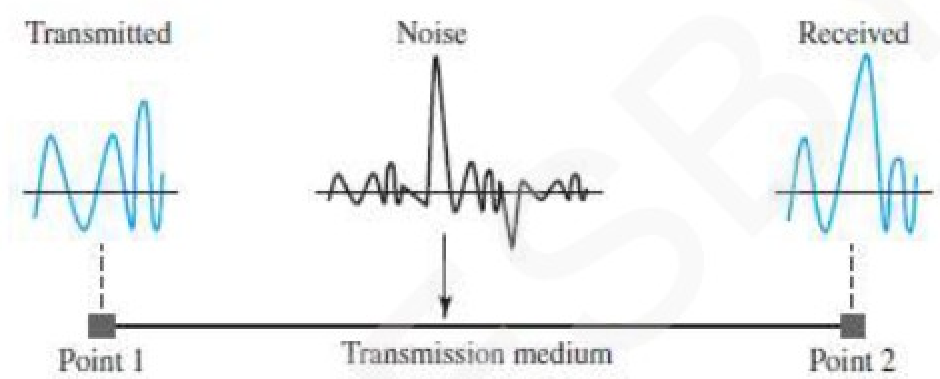
- ➢ Induced noise comes from sources such as motors &appliances.
- ➢ These devices act as a sending-antenna. The transmission-medium acts as the receiving-antenna.

iii) Crosstalk

- ➢ Crosstalk is the effect of one wire on the other.
- ➢ One wire acts as a sending-antenna and the other as the receiving-antenna.

iv) Impulse Noise

- ➢ Impulse Noise is a spike that comes from power-lines, lightning, and so on.
  (spike →a signal with high energy in a very short time)



Noise

Data Rate Limits: Channel Capacity, Nyquist Bit Rate, Shannon Capacity

Channel Capacity

The maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions, is referred to as the channel capacity.

Four basic concepts:

Data rate: The rate, in bits per second (bps), at which data can be communicated

Bandwidth: The bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium, expressed in cycles per second, or Hertz

Noise: The average level of noise over the communications path

Error rate: The rate at which errors occur, where an error is the reception of a1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted.

For digital data, this means that we would like to get as high a data rate as possible at a particular limit of error rate for a given bandwidth. The main constraint on achieving this efficiency is noise.

Two theoretical formulas can be used to calculate the data-rate:

1)Nyquist for a noiseless channel and

2)Shannon for a noisy channel.

<u>Noiseless Channel: Nyquist Bit Rate</u>

For a noiseless channel, the Nyquist bit-rate formula defines the theoretical maximum bit-rate

$$\text{Bitrate} = 2 \times \text{Bandwidth} \times \log_2 L$$

where

bandwidth = bandwidth of the channel

L = number of signal-levels used to represent data

BitRate = bitrate of channel in bps

According to the formula,

- By increasing number of signal-levels, we can increase the bit-rate.
- Although the idea is theoretically correct, practically there is a limit.
- When we increase the number of signal-levels, we impose a burden on the receiver.
- If no.of levels in a signal is 2, the receiver can easily distinguish b/w 0 and 1.
- If no.of levels is 64, the receiver must be very sophisticated to distinguish b/w 64 different levels.
- In other words, increasing the levels of a signal reduces the reliability of the system.

Example 1

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Example 2

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

Example 3

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula as shown:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L \longrightarrow \log_2 L = 6.625 \longrightarrow L = 2^{6.625} = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

Noisy Channel: Shannon Capacity

- In reality, we cannot have a noiseless channel; the channel is always noisy.
- For a noisy channel, the Shannon capacity formula defines the theoretical maximum bit-rate.

  Capacity=bandwidth X $\log_2 (1 + \text{SNR})$

  where bandwidth = bandwidth of channel in bps.

  SNR = signal-to-noise ratio and

  Capacity= capacity of channel in bps.

- This formula does not consider the no. of levels of signals being transmitted (as done in the Nyquist bit rate).

  This means that no matter how many levels we have, we cannot achieve a data-rate

  higher than the capacity of the channel.
- In other words, the formula defines a characteristic of the channel, not the method of transmission.

Examples

1

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as

$$C = B \log_2 (1 + SNR) = B \log_2(1 + 0) = B \log_2 1 = B \times 0 = 0$$

This means that the capacity of this channel is zero regardless of the bandwidth. In other
words, we cannot receive any data through this channel.

2

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000 Hz (300 to 3300 Hz) assigned for data communications. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$C = B \log_2 (1 + SNR) = 3000 \log_2(1 + 3162) = 3000 \times 11.62 = 34{,}860 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

3.

The signal-to-noise ratio is often given in decibels. Assume that $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10 \log_{10} SNR \longrightarrow SNR = 10^{SNR_{dB}/10} \longrightarrow SNR = 10^{3.6} = 3981$$

$$C = B \log_2(1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

Performance parameters - Bandwidth, Throughput, Delay & Jitter.

One important issue in networking is the performance of the network

1. Bandwidth

It can be used in two different contexts with two different measuring values:

- bandwidth in hertz
- bandwidth in bits per second

Bandwidth in Hertz

Bandwidth in hertz is the range of frequencies contained in a composite signal or the range of frequencies a channel can pass.(eg: bandwidth of a subscriber telephone line is 4 kHz.)

Bandwidth in Bits per Seconds

The term *bandwidth* can also refer to the number of bits per second that a channel, a link, or even a network can transmit.(bandwidth of a Fast Ethernet network (or the links in this network) is a maximum of 100 Mbps)

Examples:

1.

If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth?

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l = 900 - 100 = 800 \text{ Hz}$$

2.

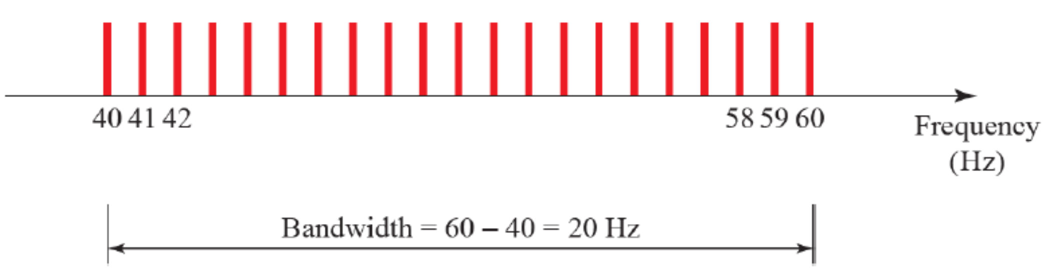
A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l \longrightarrow 20 = 60 - f_l \longrightarrow f_l = 60 - 20 = 40 \text{ Hz}$$

The spectrum contains all integer frequencies. We show this by a series of spikes (see Figure 3.15).



2. Throughput

The throughput is a measure of how fast we can actually send data through a network.

A link may have a bandwidth of *B* bps, but we can only send *T* bps through this link with *T* always less than *B*. In other words, the bandwidth is a potential measurement of a link; the throughput is an actual measurement of how fast we can send data.

For example, we may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps. This means that we cannot send more than 200 kbps through this link.

Example

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

We can calculate the throughput as

$$\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}$$

3. Latency

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.

Latency =propagation time + transmission time + queuing time + processing delay

Propagation Time

Propagation time measures the time required for a bit to travel from the source to the destination. The propagation time is calculated by dividing the distance by the propagation speed.

$$\text{Propagation time} = \frac{\text{Distance}}{\text{Propagation speed}}$$

The propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal.

Example:

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4 × 108 m/s in cable.

Solution

We can calculate the propagation time as

$$\textbf{Propagation time} = (12{,}000 \times 10{,}000) / (2.4 \times 2^8) = 50 \text{ ms}$$

The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

Transmission Time

In data communications we don't send just 1 bit, we send a message. The first bit may take a time equal to the propagation time to reach its destination; the last bit also may take the same amount of time. However, there is a time between the first bit leaving the sender and the last bit arriving at the receiver. The first bit leaves earlier and arrives earlier; the last bit leaves later and arrives later. The time required for transmission of a message depends on the size of the message and the bandwidth of the channel.

$$\text{Transmission time} = \frac{\text{Message size}}{\text{Bandwidth}}$$

Example:

What are the propagation time and the transmission time for a 2.5-KB (kilobyte) message if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 108 m/s.

Solution

We can calculate the propagation and transmission time as

$$\textbf{Propagation time} = (12{,}000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

$$\textbf{Transmission time} = (2500 \times 8) / 10^9 = 0.020 \text{ ms}$$

Note that in this case, because the message is short and the bandwidth is high, the dominant factor is the propagation time, not the transmission time.

Example:

What are the propagation time and the transmission time for a 5-MB (megabyte) message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 108 m/s.

Solution

We can calculate the propagation and transmission times as

$$\textbf{Propagation time} = (12{,}000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

$$\textbf{Transmission time} = (5{,}000{,}000 \times 8) / 10^6 = 40 \text{ s}$$

We can calculate the propagation and transmission times as

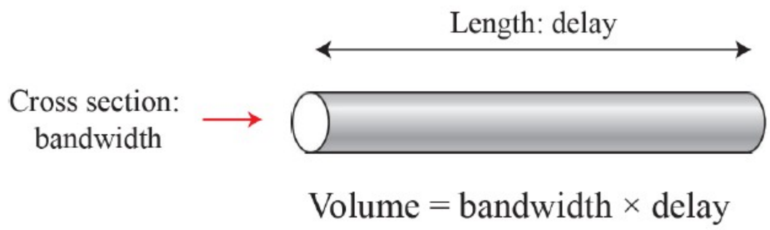
Bandwidth and Delay Product

The **bandwidth-delay** product defines the number of bits that can **fill** the link.

- *Bandwidth and delay are two performance metrics of a link.*

- *What is very important in data communications is the product of the two, the bandwidth-delay product.*

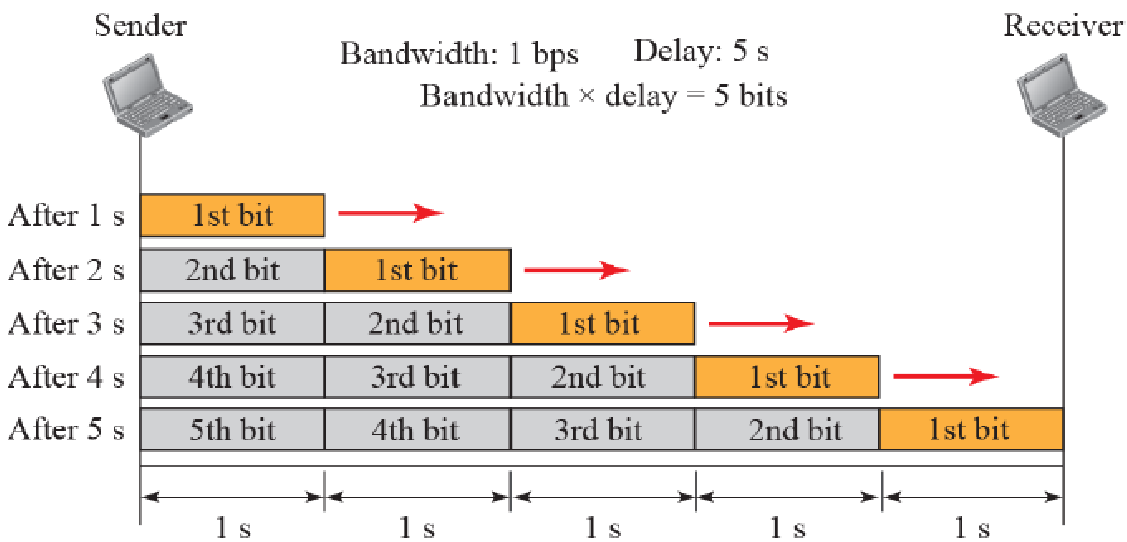
Concept of bandwidth-delay product



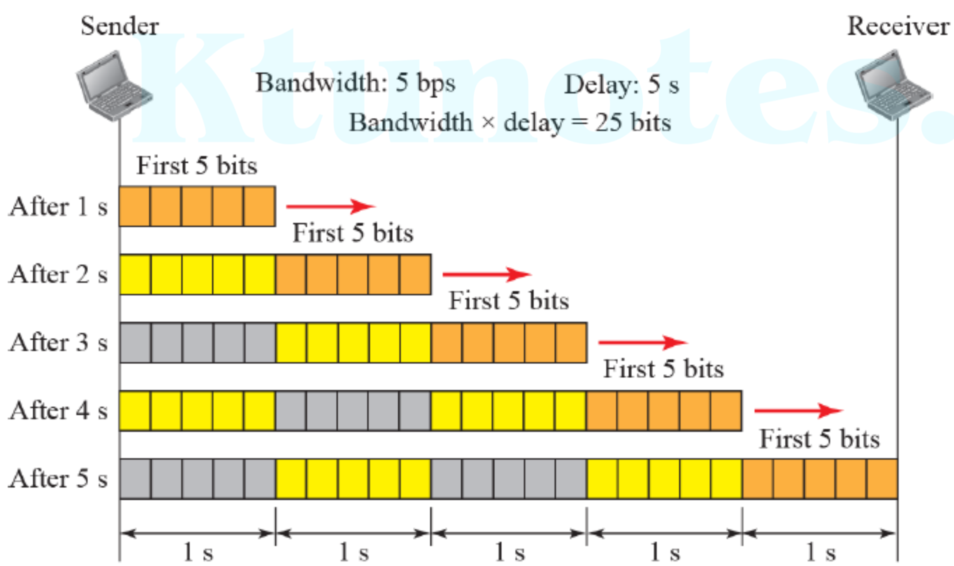
- We can think about the link between two points as a pipe.
- The cross section of the pipe represents the bandwidth, and the length of the pipe represents the delay.
- We can say the volume of the pipe defines the bandwidth-delay product

Example

Filling the links with bits for Case 1



Filling the pipe with bits for Case 2



Queuing Time

The third component in latency is the queuing time, the time needed for each intermediate or end device to hold the message before it can be processed. The queuing time is not a fixed factor; it changes with the load imposed on the network. When there is heavy traffic on the network, the queuing time increases.

An intermediate device, such as a router, queues the arrived messages and processes them one by one. If there are many messages, each message will have to wait.

4. Jitter

Another performance issue that is related to delay is **jitter.** We can roughly say that jitter is a problem if different packets of data encounter different delays and the application using the data at the receiver site is time-sensitive (audio and video data, for example). **If** the delay for the first packet is 20 ms, for the second is 45 ms, and for the third is 40 ms, then the real-time application that uses the packets endures jitter.

Encoding digital data into digital signal

- **Data** as well as **signals** that represents data can either be digital or analog.
- **Line coding** is the process of converting **digital data to digital signals**.
- By this technique we converts a sequence of bits to a digital signal.
- At the sender side digital data are encoded into a digital signal and at the receiver side the digital data are recreated by decoding the digital signal.

Line coding schemes can be divided into five categories

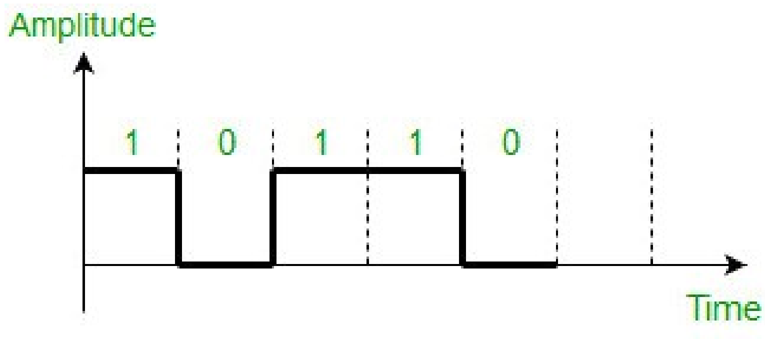
1. Unipolar (eg. NRZ scheme).
2. Polar (eg. NRZ-L, NRZ-I, RZ, and Biphase – Manchester and differential Manchester).
3. Multi level binary (eg: Bipolar AMI and Pseudoternary).

Unipolar scheme

In this scheme, all the signal levels are either above or below the axis.

Non return to zero (NRZ)

- It is unipolar line coding scheme in which positive voltage defines bit 1 and the zero voltage defines bit 0.
- Signal does not return to zero at the middle of the bit thus it is called NRZ. For example: Data = 10110.



- But this scheme uses more power as compared to polar scheme to send one bit per unit line resistance.

Polar schemes

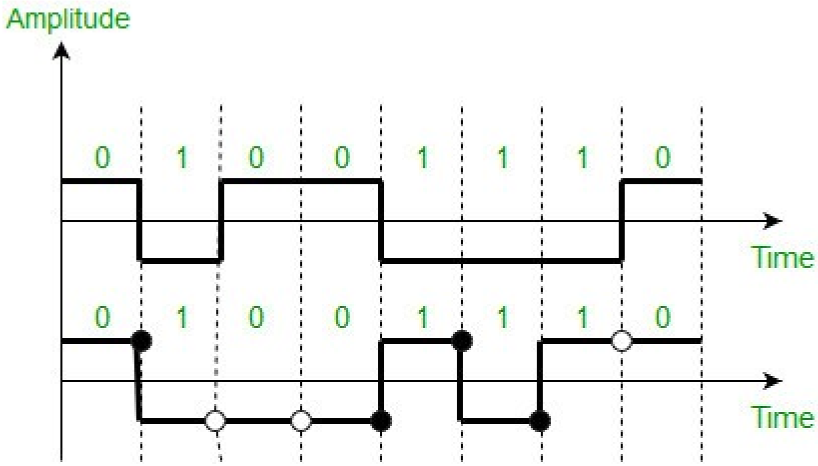
In polar schemes, the voltages are on the both sides of the axis.

NRZ-L and NRZ-I

- These are somewhat similar to unipolar NRZ scheme but here uses two levels of amplitude (voltages).
- For **NRZ-L(NRZ-Level)**, the level of the voltage determines the value of the bit, typically binary 1 maps to logic-level high, and binary 0 maps to logic-level low
- For **NRZ-I(NRZ-Invert)**, two-level signal has a transition at a boundary if the next bit that we are going to transmit is a logical 1, and does not have a transition if the next bit that we are going to transmit is a logical 0.

  Note – For NRZ-I we are assuming in the example that previous signal before starting of data set "01001110" was positive. Therefore, there is no transition at the beginning and first bit "0" in current data set "01001110" is starting from +V.

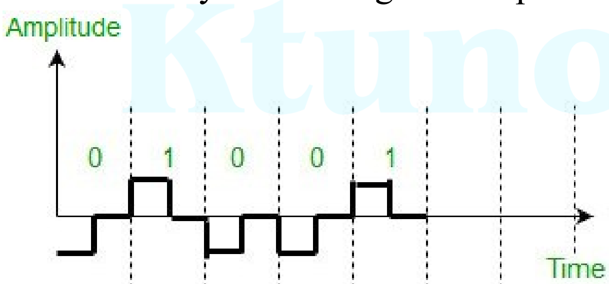
  Example: Data = 01001110.



Return to zero (RZ) –

One solution to NRZ problem is the RZ scheme, which uses three values positive, negative, and zero. In this scheme signal goes to 0 in the middle of each bit.

Note – The logic we are using here to represent data is that for bit 1 half of the signal is represented by +V and half by zero voltage and for bit 0 half of the signal is represented by -V and half by zero voltage. Example: Data = 01001.



Biphase (Manchester and Differential Manchester)

Manchester encoding

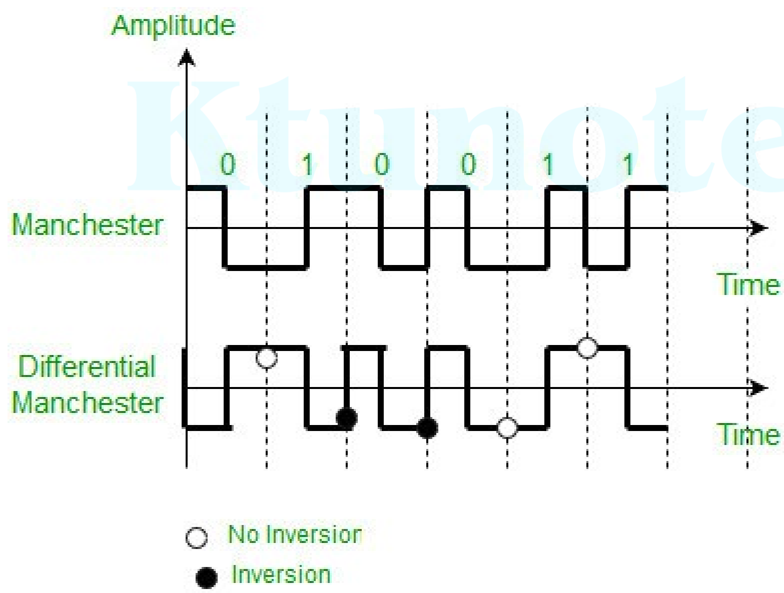
- It is somewhat combination of the RZ (transition at the middle of the bit) and NRZ-L schemes.
- The duration of the bit is divided into two halves.
- The voltage remains at one level during the first half and moves to the other level in the second half.
- The transition at the middle of the bit provides synchronization.

Differential Manchester is somewhat combination of the RZ and NRZ-I schemes.

- There is always a transition at the middle of the bit but the bit values are determined at the beginning of the bit. If the next bit is 0, there is a transition, if the next bit is 1, there is no transition.

Note

1. The logic we are using here to represent data using Manchester is that for bit 1 there is transition form -V to +V volts in the middle of the bit and for bit 0 there is transition from +V to -V volts in the middle of the bit.
2. For differential Manchester we are assuming in the example that previous signal before starting of data set "010011" was positive. Therefore there is transition at the beginning and first bit "0" in current data set "010011" is starting from -V. Example: Data = 010011.

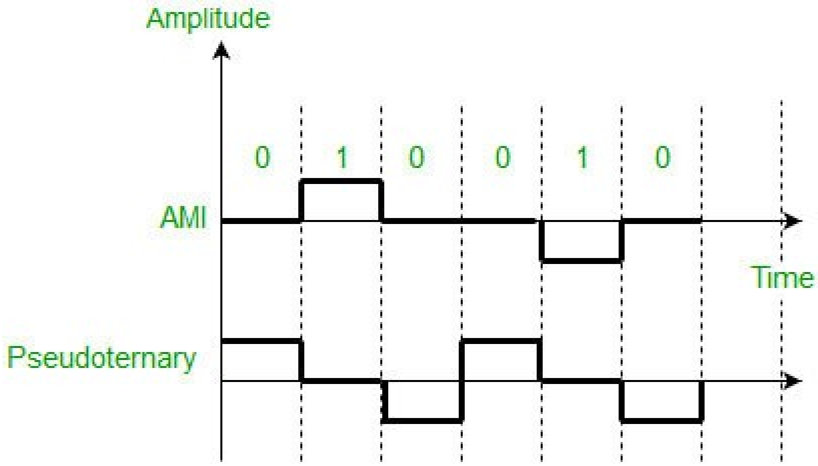


Multilevel binary - Bipolar schemes

In this scheme there are three voltage levels positive, negative, and zero. The voltage level for one data element is at zero, while the voltage level for the other element alternates between positive and negative.

- **Bipolar Alternate Mark Inversion (Bipolar AMI) –** A neutral zero voltage represents binary 0. Binary 1's are represented by alternating positive and negative voltages.

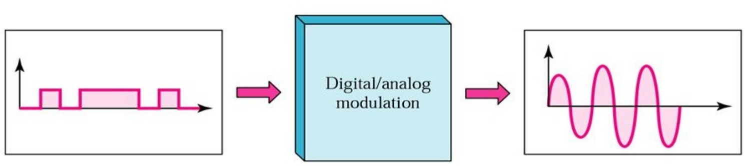
- **Pseudoternary –** Bit 1 is encoded as a zero voltage and the bit 0 is encoded as alternating positive and negative voltages i.e., opposite of AMI scheme. Example: Data = 010010.

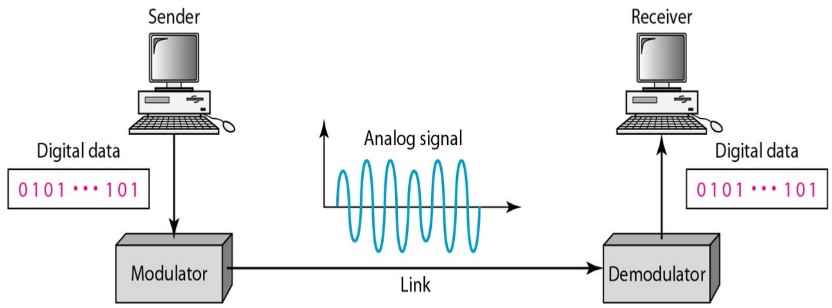


The bipolar scheme is an alternative to NRZ. This scheme has the same signal rate as NRZ, but there is no DC component as one bit is represented by voltage zero and other alternates every time.

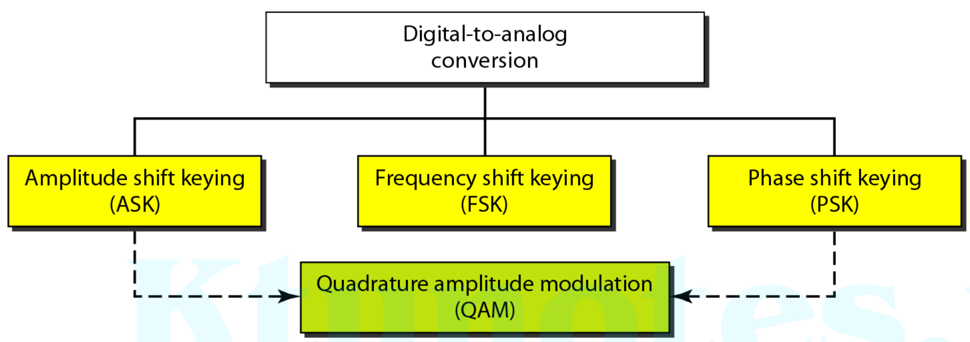
Encoding digital data into analog signals -ASK, FSK, PSK

- Digital-to-analog conversion or modulation
- Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data.





Techniques



NOTE:

Bit rate, N, is the number of bits per second (bps).

Baud rate is the number of signal elements per second (bauds).

In the analog transmission of digital data, the signal or baud rate is less than or equal to the bit rate.

$$S = N \times 1/r \text{ bauds}$$

Where r is the number of data bits per signal element.

Example:

1. An analog signal carries 4 bits per signal element. If 1000 signal elements are sent per second, find the bit rate.

Solution

In this case, r = 4, S = 1000, and N is unknown. We can find the value of N from

$$\boxed{S = N \times \frac{1}{r} \quad \text{or} \quad N = S \times r = 1000 \times 4 = 4000 \text{ bps}}$$

2. An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How

many data elements are carried by each signal element? How many signal elements do we need?

Solution

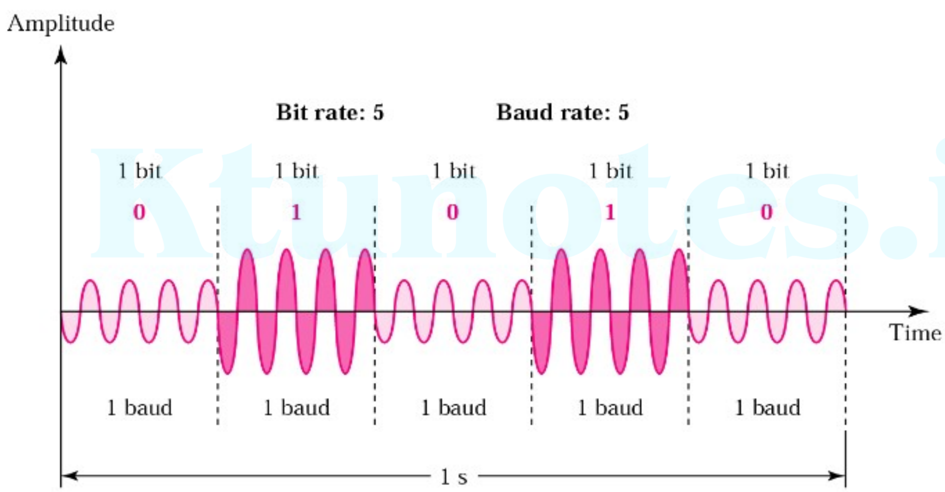
In this example, S = 1000, N = 8000, and r and L are unknown. We find first the value of r and then the value of L.

$$S = N \times \frac{1}{r} \rightarrow r = \frac{N}{S} = \frac{8000}{1000} = 8 \text{ bits/baud}$$

$$r = \log_2 L \rightarrow L = 2^r = 2^8 = 256$$

Amplitude Shift Keying (ASK)

- In ASK the strength of the carrier signal is varied to represent binary 1 or 0
- Both frequency and phase remain constant while the amplitude changes
- A bit duration is the period of time that defines one bit
- The peak amplitude is constant and its value depends on the bit(0/1)



OOK(on-off-keying) - A popular ASK technique. In this one of the bit values is represented by no voltage.

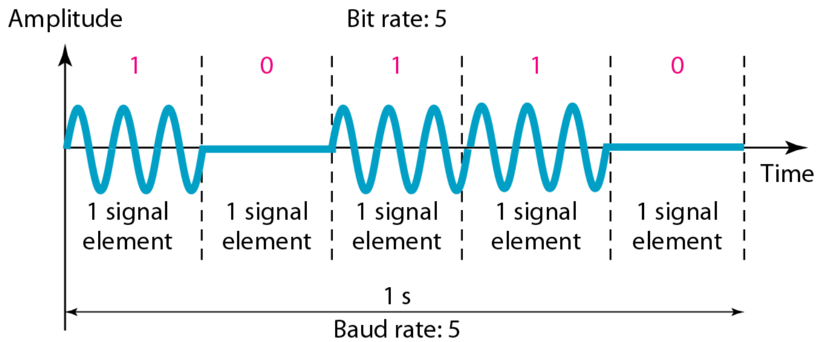
Advantage: Reduction in energy

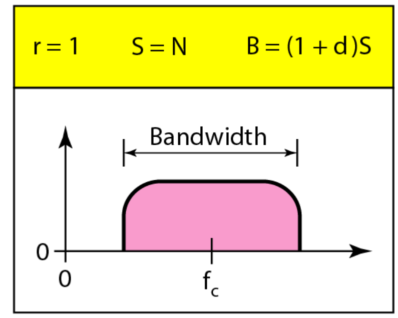
Bandwidth of ASK

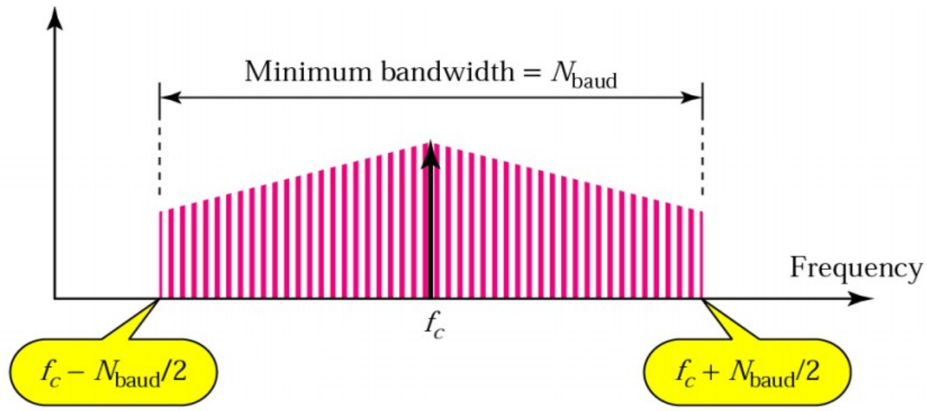
The bandwidth B of ASK is proportional to the signal rate S.

B = (1+d)S

“d” is due to modulation and filtering, lies between 0 and 1.







Example:

1. Find the minimum bandwidth for an ASK signal transmitting at 2000 bps. The transmission mode is half-duplex.

Solution : In ASK the baud rate and bit rate are the same. The baud rate is therefore 2000. An ASK signal requires a minimum bandwidth equal to its baud rate. Therefore, the minimum bandwidth is 2000 Hz.

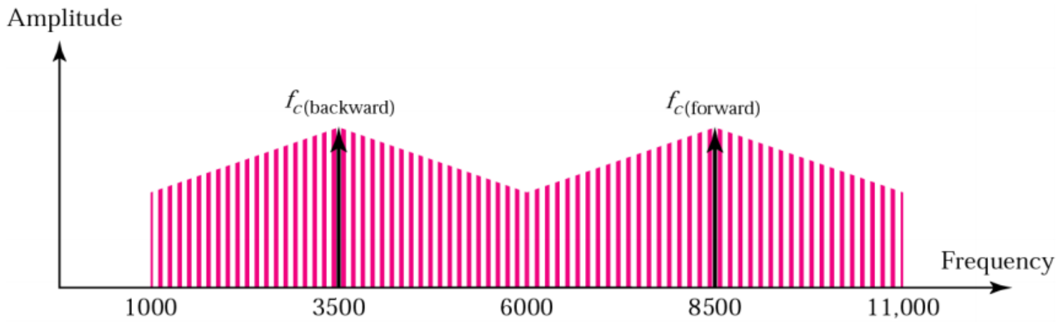
2. Given a bandwidth of 5000 Hz for an ASK signal, what are the baud rate and bit rate?

Solution: In ASK the baud rate is the same as the bandwidth, which means the baud rate is 5000. But because the baud rate and the bit rate are also the same for ASK, the bit rate is 5000 bps.

3. Given a bandwidth of 10,000 Hz (1000 to 11,000 Hz), draw the full-duplex ASK diagram of the system. Find the carriers and the bandwidths in each direction. Assume there is no gap between the bands in the two directions.

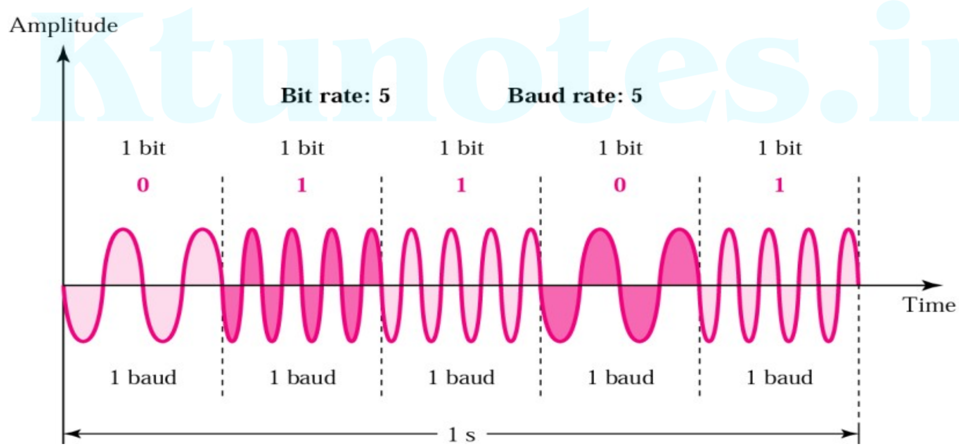
Solution: For full-duplex ASK, the bandwidth for each direction is BW = 10000 / 2 = 5000 Hz The carrier frequencies can be chosen at the middle of each band (see Fig. 5.5).

fc (forward) = 1000 + 5000/2 = 3500 Hz fc (backward) = 11000 – 5000/2 = 8500 Hz



Frequency Shift Keying

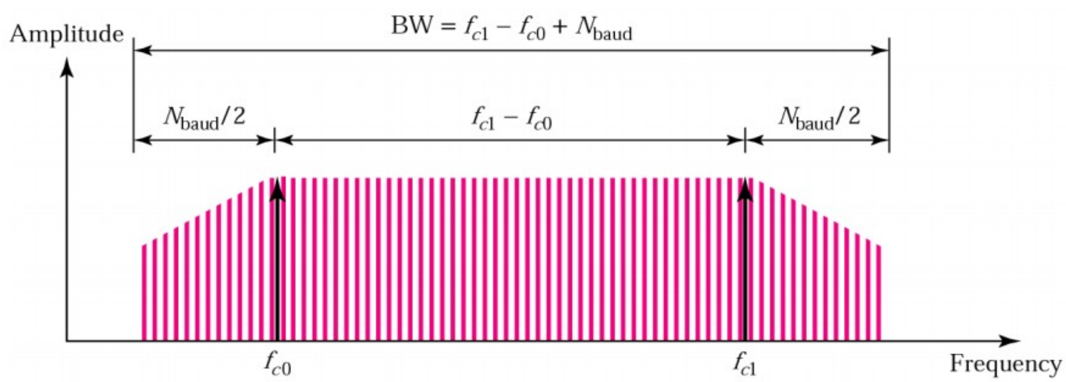
- Frequency of carrier signal is varied to represent binary 1 0r 0
- Frequency of the signal during each bit duration is constant and its value depends on the bit (1/0)
- Both peak amplitude and phase remains constant
- FSK avoids most of the noise problems of ASK
- Limiting factors of FSK are the physical capabilities of the carrier.



Bandwidth of FSK

If the difference between the two frequencies (fc_1 and fc_2) is $2\Delta f$, then the required BW B will be:

$$B = (1+d)xS + 2\Delta f$$



Example

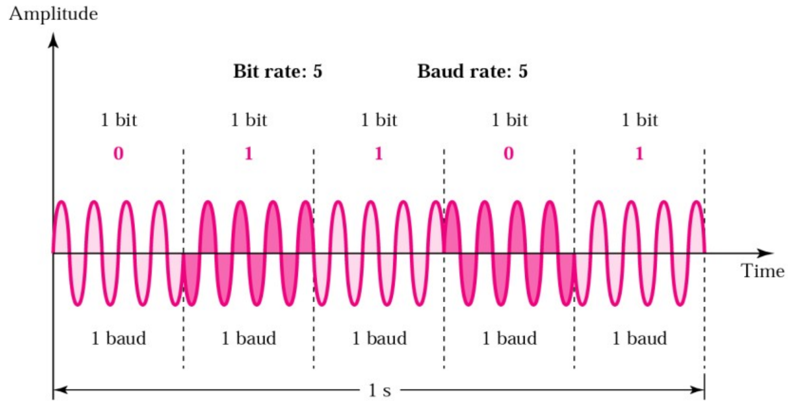
1. Find the minimum bandwidth for an FSK signal transmitting at 2000 bps. Transmission is in half-duplex mode, and the carriers are separated by 3000 Hz. Solution: For FSK BW = baud rate + fc1 − fc0 BW = bit rate + fc1 − fc0 = 2000 + 3000 = 5000 Hz
2. Find the maximum bit rates for an FSK signal if the bandwidth of the medium is 12,000 Hz and the difference between the two carriers is 2000 Hz. Transmission is in full-duplex mode.

Solution:

Because the transmission is full duplex, only 6000 Hz is allocated for each direction. BW = baud rate + fc1 − fc0 Baud rate = BW − (fc1 − fc0) = 6000 − 2000 = 4000 But because the baud rate is the same as the bit rate, the bit rate is 4000 bps.

Phase Shift Keying

- phase of carrier signal is varied to represent binary 1 0r 0
- maximum bit rate in PSK is greater than ASK
- PSK is much more robust than ASK as it is not that vulnerable to noise, which changes amplitude of the signal.



PSK constellation

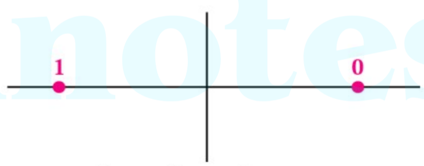
A constellation diagram helps us to define the amplitude and phase of a signal when we are using two carriers, one in quadrature of the other.

The X-axis represents the in-phase carrier and the Y-axis represents quadrature carrier.

2-PSK –Uses two variations of asignal to represent two bits

Bit	Phase
0	0
1	180

Bits

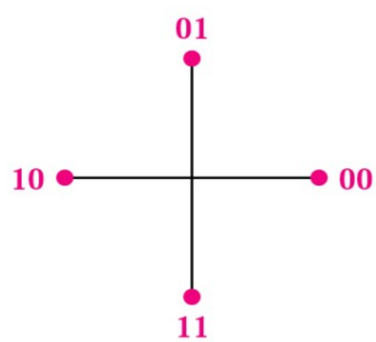


Constellation diagram

4-PSK – uses four variations of a signal, each phase shift represents two bits

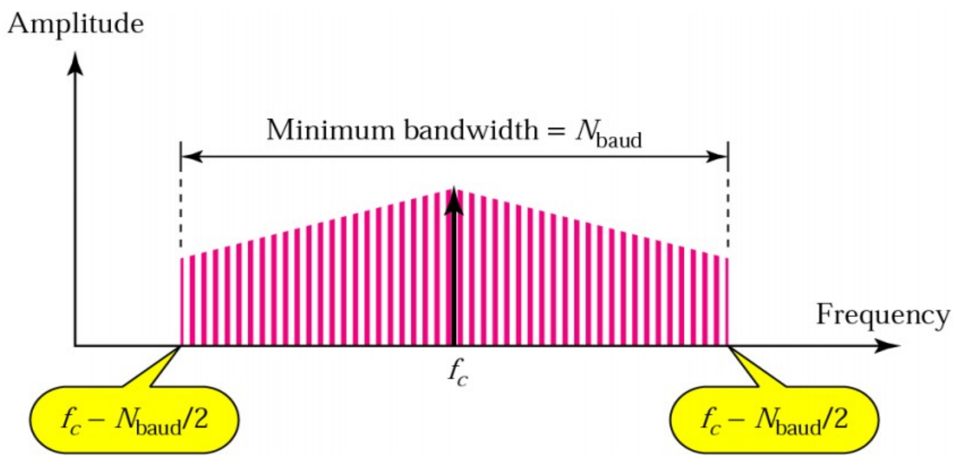
Dibit	Phase
00	0
01	90
10	180
11	270

Dibit
(2 bits)



Constellation diagram

Relationship between baud rate and bandwidth in PSK



Example:

1. Find the bandwidth for a 4-PSK signal transmitting at 2000 bps. Transmission is in half-duplex mode.

Solution:

For PSK the baud rate is the same as the bandwidth, which means the baud rate is 5000. But in 8-PSK the bit rate is 3 times the baud rate, so the bit rate is 15,000 bps.

2. Given a bandwidth of 5000 Hz for an 8-PSK signal, what are the baud rate and bit rate?

Solution : For PSK the baud rate is the same as the bandwidth, which means the baud rate is 5000. But in 8-PSK the bit rate is 3 times the baud rate, so the bit rate is 15,000 bps.

QAM

Quadrature amplitude modulation is a combination of ASK and PSK.