Chapter

Multiplexing

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Abstract

In any communication system that is either digital or analog, we need a communication channel for transmission. This channel can be a wired or a wireless link. It is not practical to allocate individual channels for each user. Therefore a group of signals are combined together and sent over a common channel. For this we use multiplexers. A multiplexer is a device that allows digital information from several sources to be routed onto a single line for transmission to a single destination. A demultiplexer does the reverse operation of multiplexing. It takes digital information from a single line and distributes it to a given number of output lines.

Keywords: frequency division multiplexing, time division multiplexing, code division multiplexing, wave length division multiplexing, orthogonal frequency division multiplexing, amplitude shift keying, frequency shift keying, phase shift keying

1. Introduction

Multiplexing is the process of transmission of information from more than one source into a single signal over a shared medium. We can be able to multiplex analog or digital signal. If analog signals are multiplexed, then this type of multiplexer is called analog multiplexer. If digital signals are multiplexed, then this type of multiplexer is called digital multiplexer. The advantage of multiplexing is that we can transmit a large number of signals to a single medium. This channel can be a physical medium like a coaxial, metallic conductor or a wireless link and will have to handle multiple signals at a time. Thus the cost of transmission can be reduced.

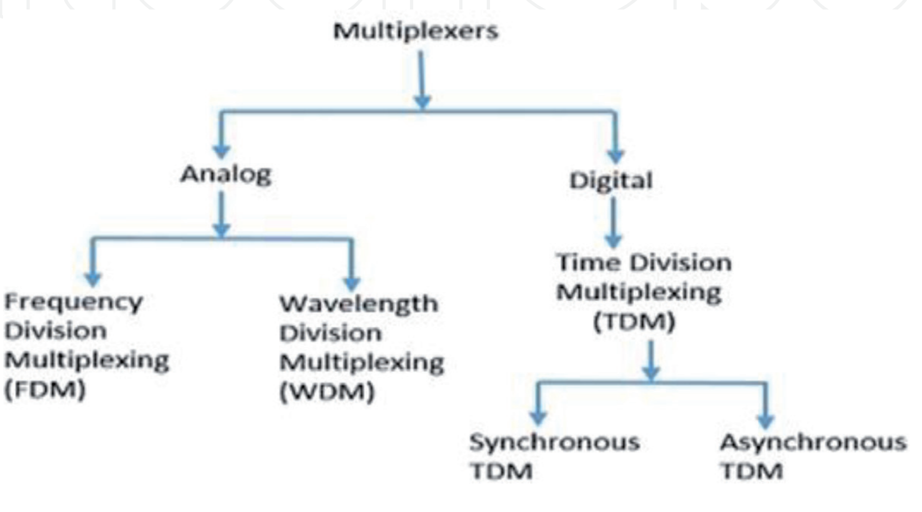

Figure 1.
Classification of multiplexing techniques.

Even though the transmission occurs on the same channel, they do not necessarily occur at the same instant. In general multiplexing is a technique in which several message signals are combined into a composite signal so that these can be transmitted over a common channel. In order to transmit various signals over the same channel, it is essential to keep the signals apart to avoid the interference between them, and then it can be easily separated at the receiving end.

Domains in which multiplexing can be accomplished are time, phase, frequency wavelength, etc. Multiplexing circuits are called multiplexer or MUX.

1.1 Types of multiplexing

Multiplexers are mainly classified as shown in **Figure 1**. Analog multiplexing and digital multiplexing are the major classification.

2. Analog multiplexing

The most commonly used analog multiplexing techniques are frequency division multiplexing (FDM) and wavelength division multiplexing.

2.1 Frequency division multiplexing

Frequency division multiplexing [1–4] is a networking technique which combines many signals into a single one and then transmitted the combined signal through a common communication channel. In the receiver side, the opposite process is carried out which is known as demultiplexing which extracts the individual channel signals. Here the transmitter side performs multiplexing, and the receiver side performs demultiplexing. In FDM the total bandwidth available in a communication medium is divided into a series of nonoverlapping frequency bands. Each of these bands is used to carry a separate signal. In FDM all users use the same common channel at full time. But each of the users is allocated with different frequencies for transmission for avoiding the signal interference. Sometimes there is a possibility of cross talk because all the users use the transmission medium at the same time.

FDM is used for analog signal transmission. It does not need synchronization between the transmitter and receiver. Here a large number of signals can be transmitted simultaneously. It suffers the problem of cross talk, and intermodulation distortion may take place.

FDM is used in amplitude modulation (AM) and FM broadcasting, public telephone networks, and cable TV network systems. The allocation of frequency bands to different users is shown in **Figure 2**.

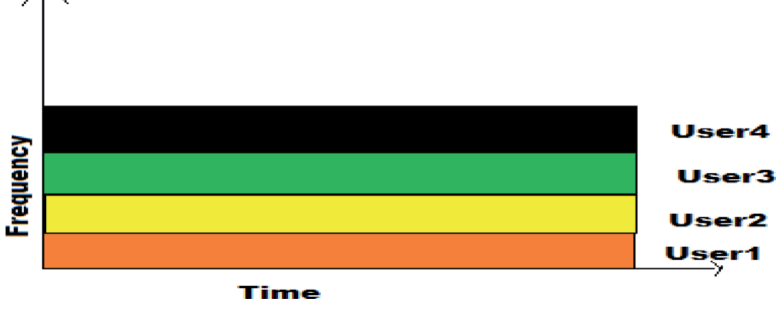

Figure 2.
Allocation of different frequencies to different users in FDM.

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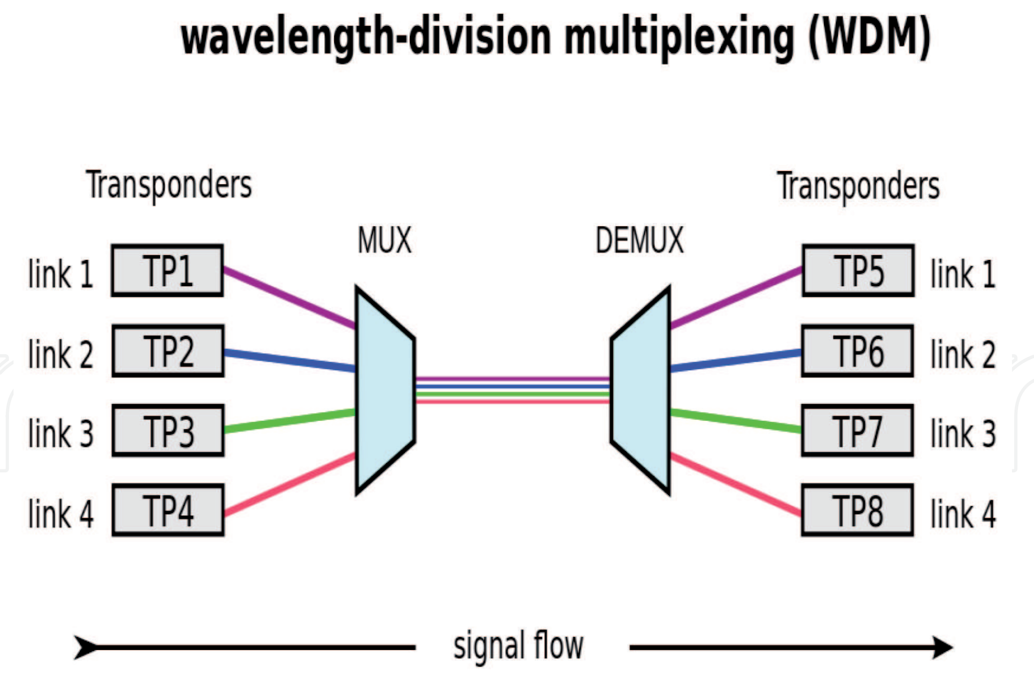


Figure 3.
Representation of WDM multiplexing.

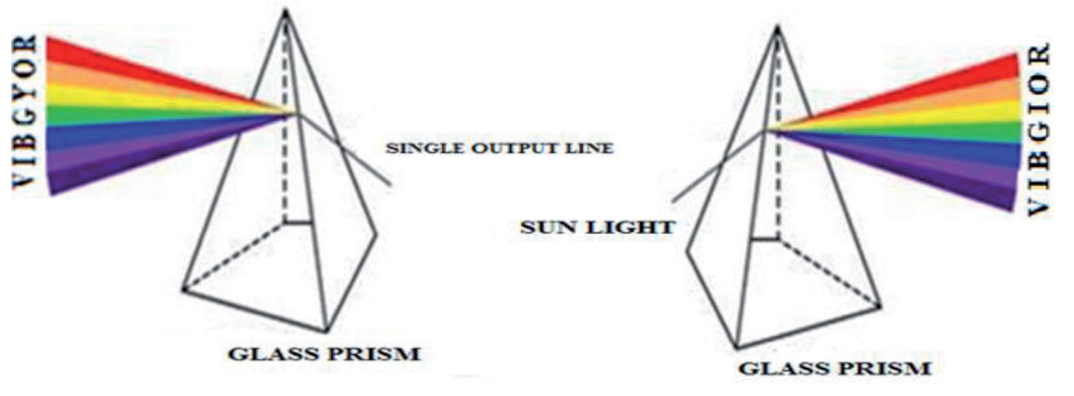


Figure 4.
Refraction of light through prism.

2.2 Wavelength division multiplexing

Fiber-optic communications require a different kind of multiplexer called a wavelength division multiplexer (WAD) [2, 4]. It is an analog multiplexing technique. It is designed for high data rate capability fiber cable. In this technique the bandwidth of the communication channel should be greater than the combined bandwidth of the individual channels. Here signals are converted to light signals; each light which has different wavelengths is transmitted through the same fiber cable. WDM transmission system divides the optical fiber bandwidth into a number of nonoverlapping optical wavelengths; these are referred to as WDM channels. WDM mixes all incoming signals having different wavelengths and are transmitted over a common channel. A demultiplexer does the reverse operation and separates the wavelengths. This multiplexing mechanism provides a much higher available transmission capacity.

Figure 3 shows the representation of WDM system that consists of both multiplexer and demultiplexer.

WDM multiplexing and demultiplexing are similar to the refraction of light through a prism as shown in **Figure 4**.

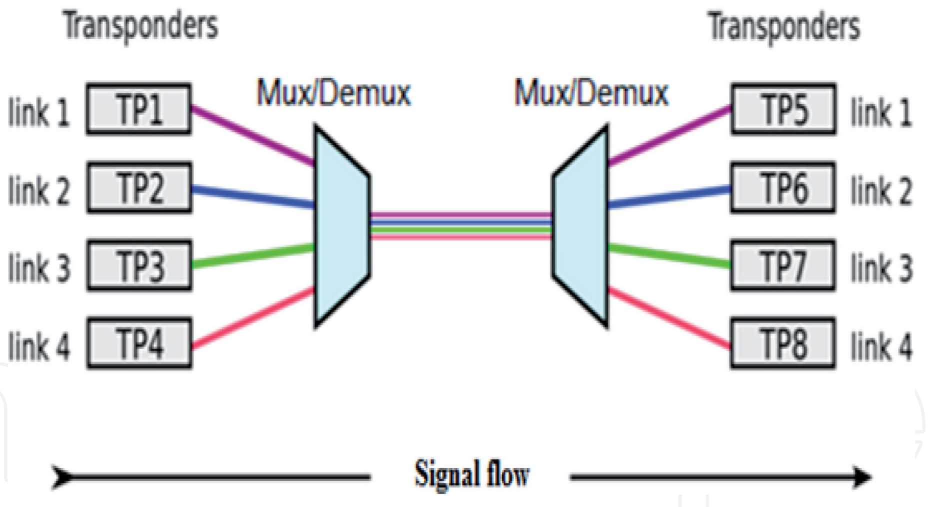


Figure 5.
Bidirectional WDM.

Wavelength division multiplexing is divided into two types, unidirectional WDM and **bi-directional WDM**. In unidirectional WDM, the data is sent only from one side and received on the other side. Multiplexing of the wavelength occurs on the sender side, and demultiplexing of the wavelengths takes place on the receiver side. In bi-directional WDM the data can be sent from both sides which means that both sides can do multiplexing and demultiplexing as shown in **Figure 5**.

2.2.1 Advantages of WDM

- In WDM full-duplex transmission is possible.
- It is easier to reconfigure.
- Optical components are more reliable and provide higher bandwidth.
- Provide high security and faster access to new channel.
- Low cost and easy system expansion.
- Simultaneous transmission of various signals.

2.2.2 Disadvantages of WDM

- Scalability is a concern as optical line termination (OLT); optical line termination has to have transmitter array with one transmitter for each optical network unit (ONU). Adding a new ONU could be a problem unless transmitters were provisioned in advance. Each ONU must have a wavelength-specific laser.
- The cost of the system increases with addition of optical components.
- Inefficiency in BW utilization, difficulty in wavelength tuning, and difficulty in cascaded topology.

2.3 Frequency division multiplexing

FDM [1–4] is based on sharing of the available bandwidth of a communication channel among the signals to be transmitted. It is an analog multiplexing technique that uses a single transmission medium which is divided into several frequency channels. Here the total bandwidth of the channel must be higher than the sum of the individual bandwidth. If the channels are closer to each other, then cross talk may occur; thus, it is necessary to implement channel synchronization. For that purpose some bandwidth is allocated as guard band; these are unused channels placed between the successive transmission channels to avoid cross talk.

For frequency division multiplexing if the input signal is digital, it must be converted to analog before giving it as the input to the modulator.

2.3.1 FDM transmitter block diagram

In FDM signals are generated by sending devices and there are multiple input lines. From the block diagram (**Figure 6**), channel 1 to channel n are taken as the input channels. These signals reach at the input of the corresponding modulator where it receives another signal from a crystal oscillator known as carrier signal, which is a high-frequency high-amplitude signal. The carrier signal is modulated with the input signal. Different modulators use different carrier signals for modulation. It should be noted that the frequency band of one modulator will not make any interference to the frequency band of other modulators.

Each of the modulator produces the corresponding modulated signal at their output. All the output of the modulators will be given to an adder or mixer circuit; from there it is given to another modulator for further shift of total bandwidth. Finally, this higher-frequency signal will be transmitted over the channel.

2.3.2 FDM receiver

The following block diagram (**Figure 7**) shows the concept of demodulation of FDM signal at the receiving side. The antenna receives the multiplexed modulated signal from the transmitter. This signal will be weak at the receiver. Therefore it is necessary to amplify the signal. This is done at the initial stage of the receiver. The amplified signal is then forwarded to the demodulator. The output of the

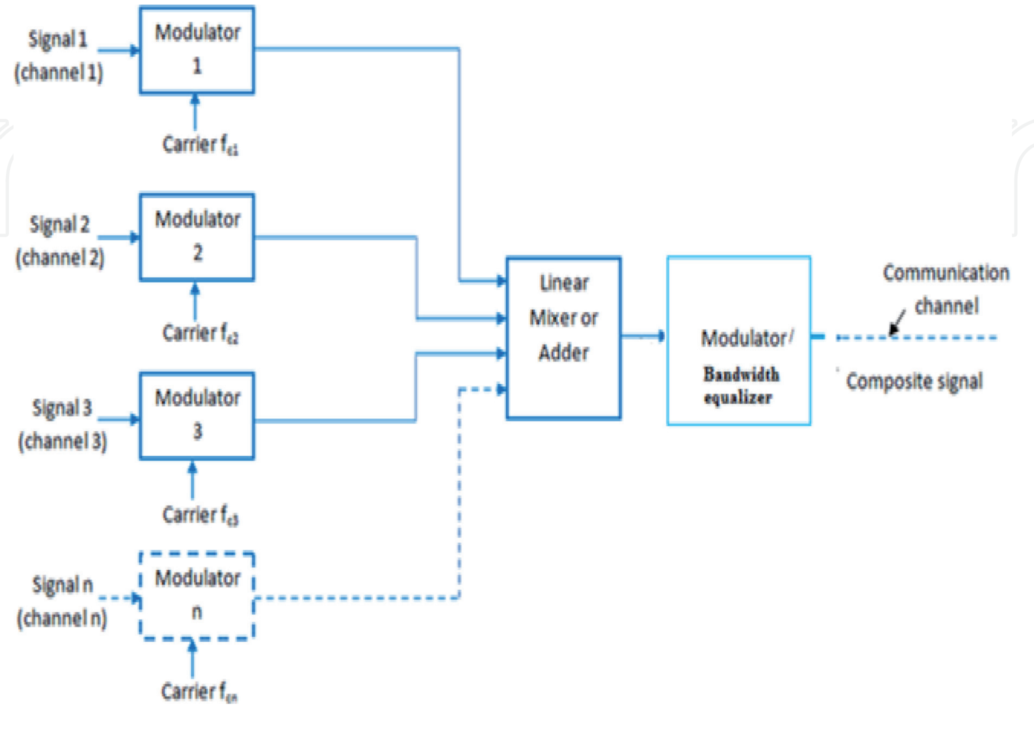


Figure 6.
Block diagram of FDM transmitter.

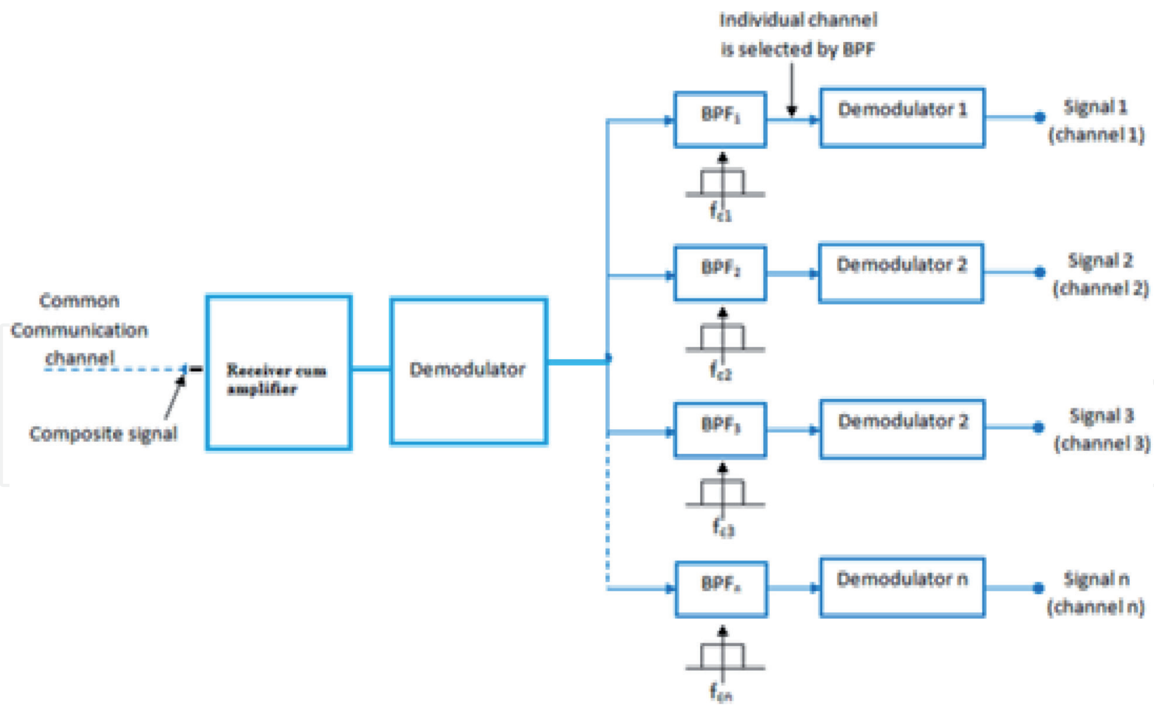


Figure 7.
Block diagram of FDM receiver.

demodulator will be given to the band-pass filters which are well designed with the central frequencies of the carriers as used individually at the transmitting side. Thus the output of each BPF will be the same as that of the originally modulated output of the corresponding modulator.

Then we use the corresponding individual demodulators to recover the original signal.

2.3.3 Advantage of FDM multiplexing

- A large number of signals (channels) can be transmitted simultaneously.
- Demodulation of FDM is easy.
- FDM does not need synchronization between its transmitter and receiver for proper operation.
- Due to slow narrowband fading, only a single channel gets affected.

2.3.4 Disadvantages of FDM

- The communication channel must have a very large bandwidth.
- Intermodulation distortion takes place.
- A large number of modulators and filters are required.
- FDM suffers from the problem of cross talk.
- All the FDM channels get affected due to wideband fading.

2.3.5 Applications of FDM

- FDM is used for FM and AM radio broadcasting.

- FDM is used in television broadcasting.
- First-generation cellular telephone also uses FDM.

2.4 Time division multiplexing

In time division multiplexing (TDM) [1–4], all signals operate with the same frequency at different times, i.e., it is a technique of transmitting several signals over a single communication channel by dividing the time frame into equal slots. Here the signal transmitted can occupy the total bandwidth of the channel, and each signal will be transmitted in its specified time period only. In TDM all signal operates at same frequency at different time slots.

Figure 8 shows the schematic diagram of implementation of TDM system. From this it is clear that a circular ring has been split into eight equal segments and is completely separated from one another. It is also noted that there is a movable arm attached to the inner ring, and it slides over the eight segments over the ring. The eight segments are eight inputs, and the selector moves in clockwise direction from A to H; after completing one revolution, it starts again. The output is taken from the inner ring that contains the signal from only one slot at a time.

The same arrangement is also made at the receiving side. The two inner rings of the transmitting and receiving stations are rotated at the same speed, and they are synchronized. Thus the signal at segment A of the transmitter will reach segment A of the receiver in the period the arm is contacting the segment A. The same is in the case of other segments.

Time division multiplexing is used when data transmission rate of media is greater than the total transmission rate of the sources. Here each signal is allotted to a definite amount of time. These slots are too small so that the transmission appears to be parallel. In TDM all the signals to be transmitted are not transmitted simultaneously. Instead, they are transmitted one by one. When all the signals are transmitted once on the transmission channel, it is said to be one cycle of completion.

Synchronization between the multiplexer and demultiplexer is a major issue in TDM. If the multiplexer and the demultiplexer are not properly synchronized, a bit belonging to one channel may be received by another channel. Therefore, one or more synchronization bits are generally added to the beginning of each frame. These bits, called framing bits, allow the demultiplexer to synchronize with the incoming

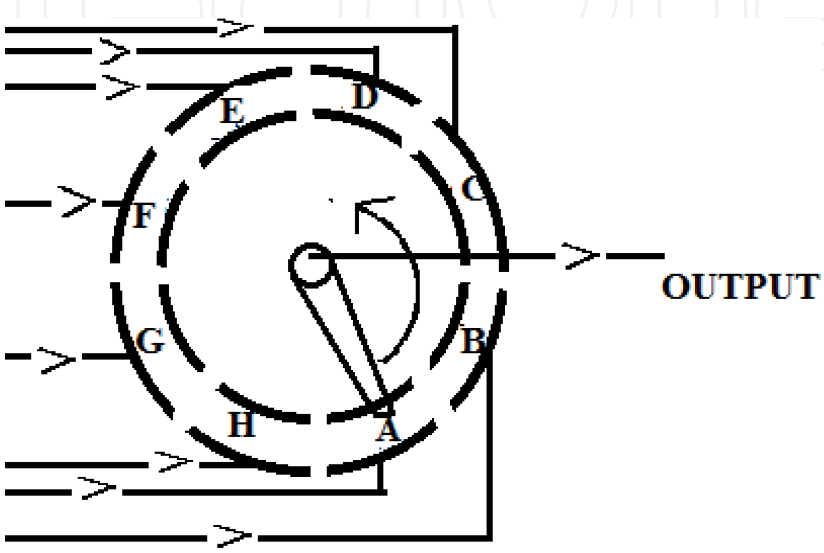


Figure 8.
Schematic diagram of TDM operation.

stream so that it can separate the time slots accurately. Normally, this synchronization information consists of 1 bit per frame, alternating between 0 and 1.

There are two types of TDM multiplexing, synchronous TDM and asynchronous or statistical TDM or intelligent TDM.

2.4.1 Synchronous time division multiplexing

In synchronous TDM the slots are arranged in a round robin manner, i.e., if there are n sources, then a single frame consists of n time slots, and each time slot is dedicated to exactly one source for carrying data from the corresponding input. Each source places its data to the link only when the corresponding slot arrives. In synchronous TDM, if a device does not have data to send, then its time slots remain empty. The transmission of data with synchronous TDM is shown in **Figure 9**.

2.4.1.1 Disadvantages

- The channel capacity cannot be fully utilized when some source do not want to send the data.
- The capacity of the transmission link must be higher than the total capacity of input lines.
- It is very complex to implement.

2.4.2 Asynchronous time division multiplexing

In synchronous TDM if a particular terminal has no data to transmit at a particular time period, the corresponding slot in a frame is wasted or an empty slot will be transmitted. Asynchronous TDM or statistical TDM is used to overcome this difficulty. It dynamically allocates the time slots on the demand to separate input channels, thus saving the channel capacity. Here the time slots are flexible, and the total capacity of input lines can be greater than the link capacity of the channel. In synchronous TDM if there are n input lines, there must be n time slots, but in asynchronous TDM if we have n input lines, then the frame may contain less than n slots. Here the number of slots in a frame is based on a statistical analysis of the number of input lines. The transmission of data with asynchronous TDM is shown in **Figure 10**.

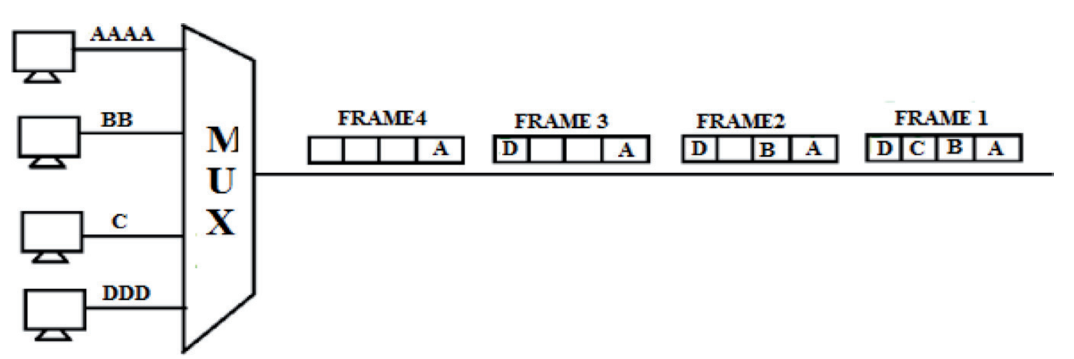


Figure 9.
Synchronous TDM transmission representation.

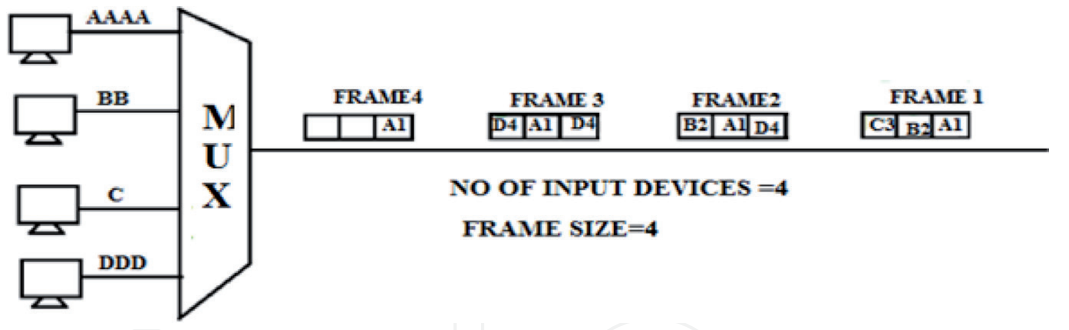


Figure 10.
Data transmission with asynchronous TDM.

2.4.2.1 Disadvantages

- Frames have different sizes.
- An output slot in synchronous TDM is totally occupied by data, in statistical TDM; a slot needs to carry data as well as the address of the destination.
- It requires buffer, and address information is needed as there is no separate slots assigned for each user.

2.5 Code division multiplexing

Code division multiplexing (CDM) [3] is a form of multiplexing in which the transmitter encodes the signal by using a unique chip code which is generated by a pseudorandom sequence generator. It uses spread-spectrum communication, and a narrowband signal is spread over a large band of frequency; it allows multiple signals from multiple users to share a common communication channel. CDM involves the modulation of data with this spreading code in the transmitter side.

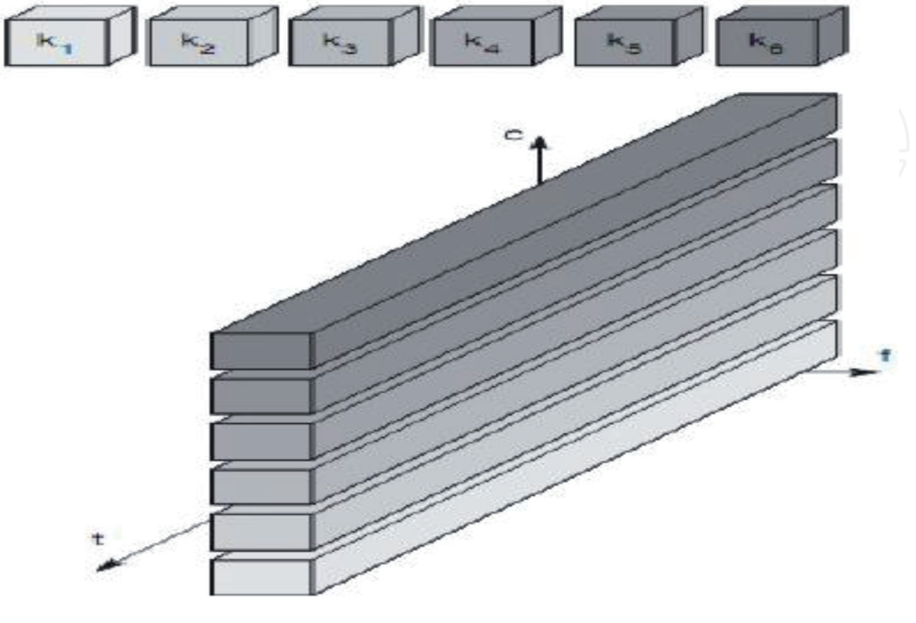


Figure 11.
Code division multiplexing (CDM).

The receiver also wants to know the same code used at the transmitter side in order to decode the signal at the receiving side. Here different random sequences correspond to different communication channels from different stations. To separate other channels, CDM assigns each channel with its own code. The main advantage of CDM is protection from interference and tapping because only the sender and the receiver know the spreading code (**Figure 11**).

CDM is widely used in second-generation and third-generation wireless communication network.

2.5.1 Advantage of CDM

- The CDM does not require any synchronization.
- In CDM more number of users can share the same bandwidth.
- It is scalable.
- It is well-matched with other cellular technologies.
- Interference is reduced because different code words are allocated to each user.
- Efficient utilization of fixed frequency spectrum.

2.5.2 Disadvantages

- The system is more complicated.
- As the number of users increases, the overall quality of services decreases.
- More complex system and primarily it is used in wireless transmission.

2.6 Orthogonal frequency division multiplexing

Orthogonal frequency division multiplexing (OFDM) [4, 5] is a multiplexing technique used in broadband communication system. It is a multicarrier modulation scheme. Now it is used in 4G broadband communication system and next-generation systems. OFDM is popular in broadband wireless systems due to its resistance to multipath fading. OFDM has high data rate capability with reasonable computational complexity. OFDM divides a broadband channel into multiple parallel narrowband subchannels, and each channel carries a low data rate stream of signals. Finally these signals are summing and then transmit as a high data rate stream. In an OFDM transmitter, the input signal bits are mapped into a bank of quadrature amplitude modulator which encodes these into complex symbols. This is fed to an inverse fast Fourier transform (IFFT) to ensure the orthogonality of the subchannels. This output is converted into parallel to serial, modulated into a carrier wave, and then transmitted into the air. At the receiver the reverse process is performed for recovering the original signal. The advantages of OFDM are that its low computational complexity because OFDM may be viewed as a many slowly modulated narrowband signals rather than a rapidly modulated wideband signal.

2.6.1 OFDM transmitter

The block diagram depicting the OFDM transmitter is shown in **Figure 12**. For OFDM transmitter, a serial stream of binary digits is considered as the input. The input is converted into N parallel streams using inverse multiplexing. The transformation of N parallel streams into the state-space mechanism is performed by means of modulation techniques like quadrature amplitude modulation (QAM) and phase shift keying (PSK).

A digital modulation system for data communication by varying or modulating the phase of the reference signal or the carrier wave signal is known as PSK. A finite number of phases is involved in PSK with each phase having a distinctive pattern of binary digits. An integration of trouble-free AM and simple phase modulation is called QAM in which the large amount of data is transmitted over the same bandwidth due to the synergistic effect of simple amplitude modulation and phase modulation. Hence, QAM increases the efficiency of data transmission for radio communication systems (**Figure 13**).

2.6.2 Block diagram of OFDM transmitter

To provide a set of complex time-domain samples, IFFT is calculated for each set of symbols. Later, the time-domain samples are quadrature mixed to passband in the normal way. By the use of digital-to-analog converters (DACs), the real and imaginary components are primarily converted to the analog domain. Such analog signal helps to modulate corresponding cosine and sine waves at the carrier frequency. Finally, those signals are summed up to provide the transmission signal.

2.6.3 OFDM receiver

At the OFDM receiver's side, the reverse process of transmitter side is performed. The block diagram representing the OFDM receiver is shown in **Figure 14**. The transmitter-generated signal is further transmitted over the channel for receiving. The receiver receives the baseband OFDM signals, and then it passes through a low-pass filter to remove the unwanted signals. The baseband signals are then sampled and digitized using ADCs, and a forward FFT is used to convert back to the frequency domain.

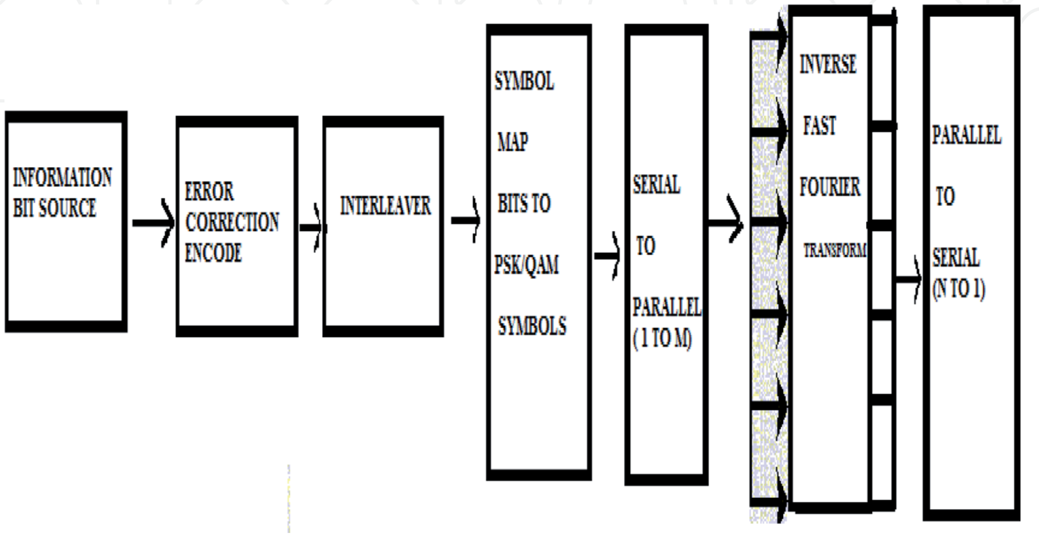


Figure 12.
OFDM transmitter.

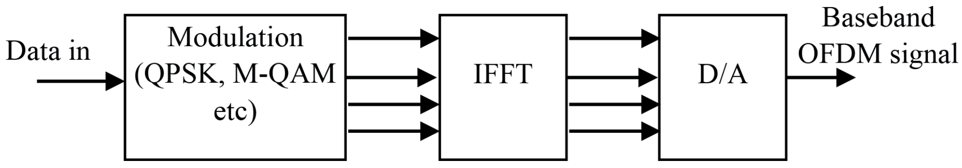


Figure 13.
OFDM transmitter simple block diagram.

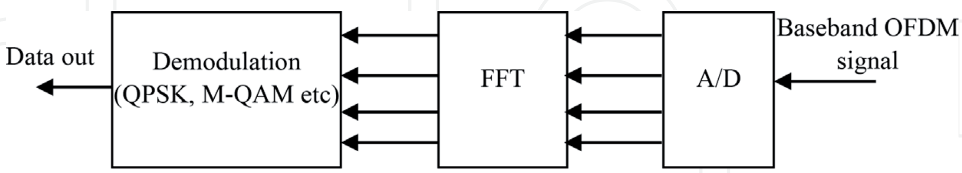


Figure 14.
OFDM simple block diagram of OFDM receiver.

By means of an appropriate symbol detector, the frequency domain signals are converted to N parallel streams, and each stream is converted to a binary stream. A sequential stream combining all binary stream acts as an estimate of the original binary stream at the transmitter side.

2.6.4 Significance of the OFDM system

- OFDM is computationally efficient to deploy the modulation and demodulation techniques through IFFT and FFT, respectively.
- OFDM signal is robust and more tolerant in multipath propagation environment to delay spread.
- OFDM is more resistant to frequency selective fading than single carrier transmission systems.
- OFDM system gives good protection against co-channel interference and impulsive parasitic noise.
- OFDM system uses pilot subcarriers to prevent the frequency and phase shift errors.

OFDM system has also certain limitations rather than the abovementioned potential capabilities. High peak-to-average power ratios (PAPR) of transmitted signal are the major drawback of the OFDM signal. OFDM is very sensitive to carrier frequency offset and hence becomes difficult to synchronize during sharing of subcarriers different transmitters.

3. Digital multiplexer

Digital multiplexer [6–8] or data selector is a logic circuit that has several input lines and a single output line. It also consists of data selector switch which is used to select the inputs and permit the data into the device to output.

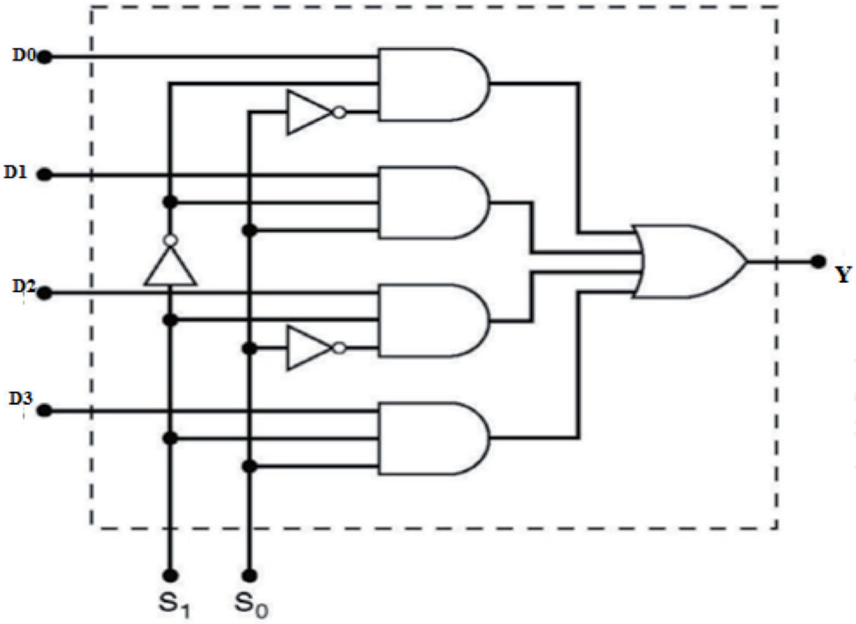
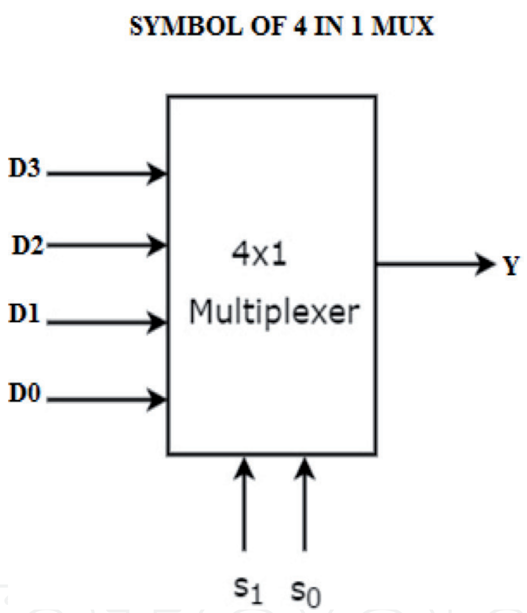


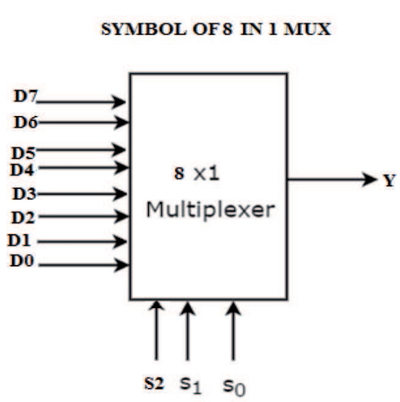
Figure 15.
Circuit diagram of four-in-one multiplexer.



SELECTOR SWITCH

S1	S0	INPUT SELECTED
0	0	**D0**
0	1	**D1**
1	0	**D3**
1	1	**D4**

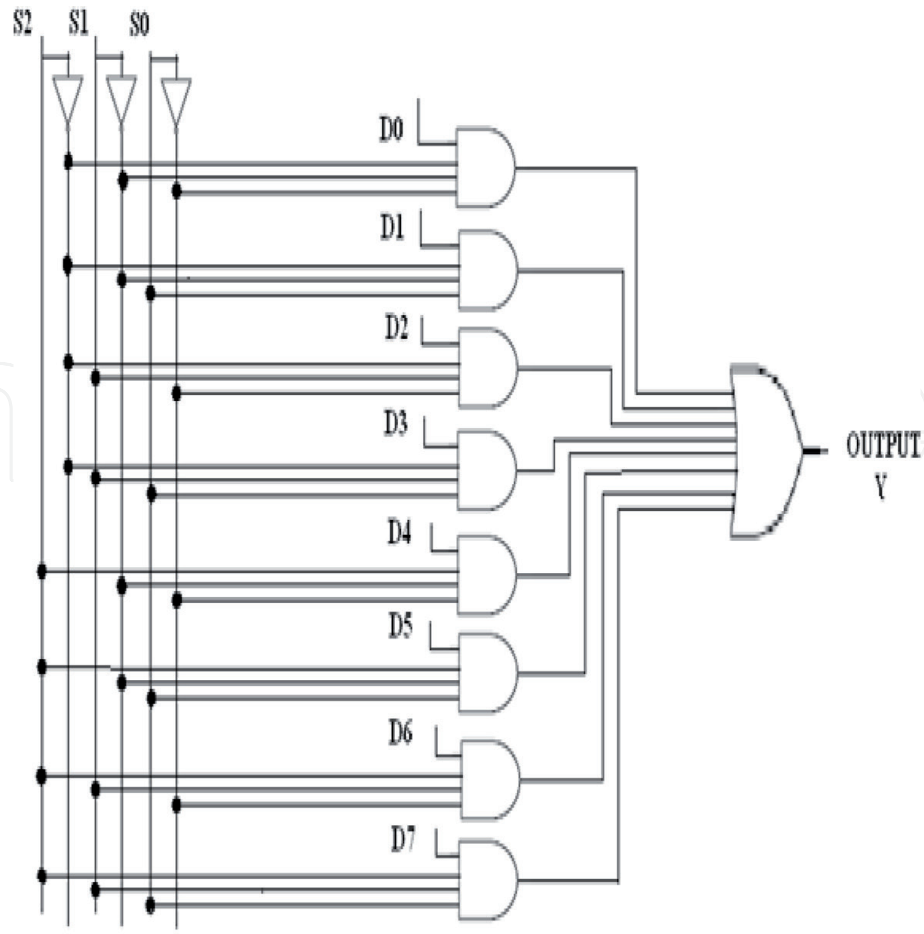
Figure 16.
Circuit symbol and selector switch pattern of four-in-one multiplexer.



DATA SELECTOR

S2	S1	S0	INPUT SELECTED
0	0	0	D0
0	0	1	D1
0	1	0	D2
0	1	1	D3
1	0	0	D4
1	0	1	D5
1	1	0	D6
1	1	1	D7

Figure 17.
Logic symbol and switching pattern of eight-in-one multiplexer.



$$Y = E.[\overline{S2}\,\overline{S1}\,\overline{S0}\,D0 + \overline{S2}\,\overline{S1}\,S0\,D1 + \overline{S2}\,S1\,\overline{S0}\,D2 + \overline{S2}\,S1\,S0\,D3 + S2\,\overline{S1}\,\overline{S0}\,D4 + S2\,\overline{S1}\,S0\,D5 + S2\,S1\,\overline{S0}\,D6 + S2\,S1\,S0\,D7]$$

Figure 18.
Logic diagram of eight-in-one multiplexer.

3.1 Four-in-one multiplexer

The logic symbol and circuit for a four-input multiplexer are shown in **Figure 15**.

Here D0, D1, D2, and D3 are data input lines. S0 and S1 are data selector or logic switches. When S0 = S1 = 0, then the two inputs of the first AND gate become actively high because the selectors S0 and S1 are inverted using NOT gate and given to this gate. Thus the data from D0 line is outputted through this AND gate. At that time the other gates are in 0 output position. Similarly when S0 = 1 and S1 = 0, then the two inputs of the AND gate 2 become actively high; thus, data from D1 is transmitted through gate 2 as output, and all other gates are in 0 output position. In this manner D2 and D3 are inputted to consecutive switch positions. Here an OR gate is used to combine these four output lines as a single output (**Figure 16**).

3.2 Eight-in-one multiplexer

The logic symbol and data selector of eight-in-one multiplexer is shown in **Figure 17**.

If input is 2, then one data selector switch is needed; if input is 4, then two selector switches are needed; if input is 8, then three selector switches are needed; if input is 16, then four selector switches are needed; and so on.

In an eight-in-one multiplexer (**Figure 18**), eight data input lines such as D0, D1, D2, D3, D4, D5, D6, and D7, data selector S0, S1, and S2. In this circuit these inputs are fed to eight AND gates, and the outputs of the AND gates are combined by using an OR gate.

3.2.1 Working

When the three selector switches are actively low, then the three inputs of the first AND gate become actively high because the selector outputs are NOTed and given to the first AND gate. Thus the data from D0 line is outputted through the first AND gate, and all other AND gates are in 0 output position. When S0 = 1, S1 = 0, and S2 = 0, then the three input terminals of the second AND gate become actively high, and D1 is outputted through this gate. At that time all other gates are in 0 output position. In that manner D2, D3, D4, D5, D6, and D7 data are outputted in the next consecutive switch positions.

Important TTL multiplexer IC's are as follows:

74,157—2 input data selector/MUX.

74,151—8 input data selector/MUX.

74,150—16 input data selector/MUX.

3.2.2 Application of MUX

- Seven-segment display unit
- Function generators
- Digital counters
- Parallel-to-serial conversion

4. Demultiplexers

Demultiplexer [6] is a logic circuit that performs the reverse multiplexer function. Demultiplexer receives signal from a single line (serial input) and transmits these information into multiple output lines and parallel output lines (**Figure 19**).

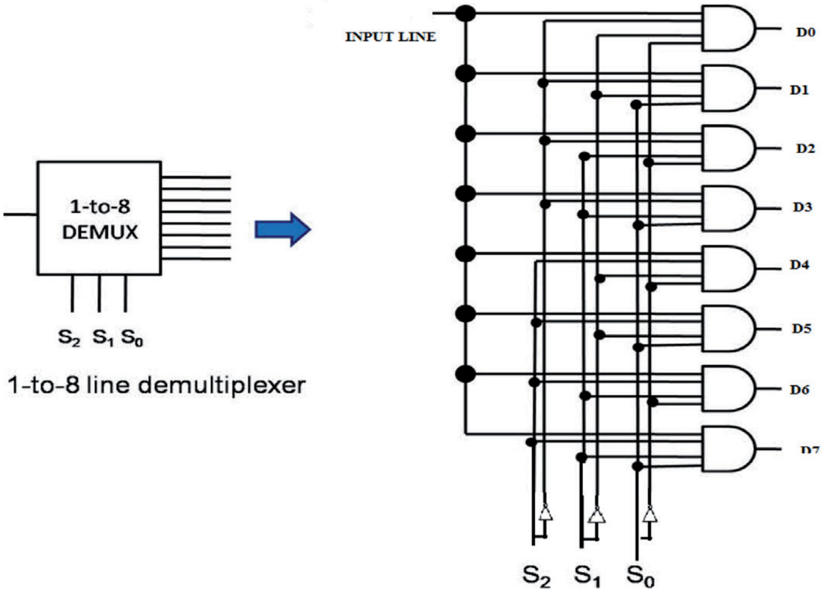


Figure 19.
Circuit diagram of one-to-eight demultiplexer.

5. Major digital modulation schemes

In analog communication we use different modulation schemes like amplitude modulation, frequency modulation, phase modulation, etc. [9]. In digital communication we use the following schemes:

- Amplitude shift keying (ASK)
- Frequency shift keying (FSK)
- Phase shift keying (PSK)

5.1 Amplitude shift keying

The principle of amplitude shift keying is that the amplitude of the carrier wave is modulated in accordance with the digital message signal, i.e., ASK signal represents the binary data in the form of variations in the amplitude of the carrier signal. When an ON condition of digital pulse exists, then carrier will be switched ON, and when an OFF condition encounters, the carrier will be switched OFF. The time period for which the carrier is present or absent depends on the time interval for which the unipolar pulses are present.

Here the amplitude of carrier signal is varied to represent binary 1 and binary 0 data inputs, while the frequency and phase of the carrier signal remain constant. Voltage levels are left to designers of the modulation system (**Figure 20**).

5.1.1 ASK advantages and disadvantages

The major advantage of ASK includes high bandwidth efficiency and simplicity in its design. In ASK the modulation and demodulation processes are comparatively inexpensive.

Its disadvantages include lower power efficiency, and it is very susceptible to noise interference.

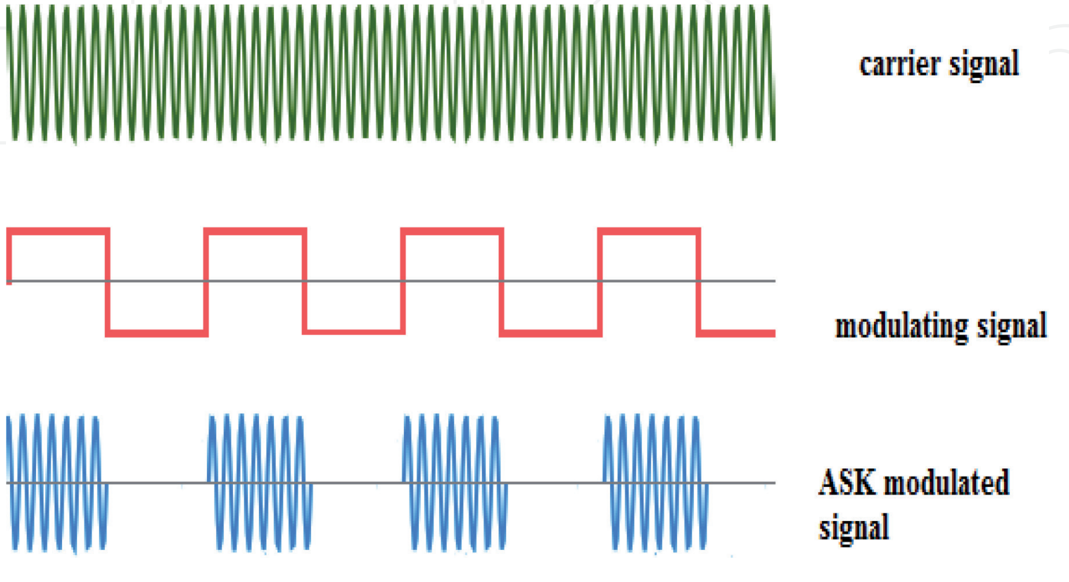


Figure 20.
Amplitude shift keying.

5.1.2 Application

- Used in our infrared remote controls
- Used in fiber optical transmitter and receiver

5.2 Frequency shift keying

The principle of frequency shift keying is that the frequency of the carrier wave is modulated in accordance with the digital message signal, i.e., FSK signal represents the binary data in the form of variations in the frequency of the carrier signal. When an ON condition of digital pulse exists, then carrier will be switched to one frequency, and when an OFF condition encounters the carrier, it will be switched to another frequency, i.e., in "frequency shift keying," the frequency of a sinusoidal carrier is shifted between two discrete values (**Figure 21**).

5.2.1 Advantages and disadvantages of FSK

Its advantages include lower probability of error and provide high signal-to-noise ratio. It has higher immunity to noise due to constant envelope. Therefore the probability of error-free reception of data is high. FSK transmitter and FSK receiver implementations are simple for low data rate application.

The disadvantage of FSK includes the usage of larger bandwidth than other modulation techniques such as ASK and PSK. Hence it is not bandwidth efficient and is extensively used in low-speed modems having bit rates below 1200 bits/sec. It is not preferred for the high-speed modems because with increase in speed, the bit rate increases.

5.2.2 Application

Many modems used FSK in telemetry systems.

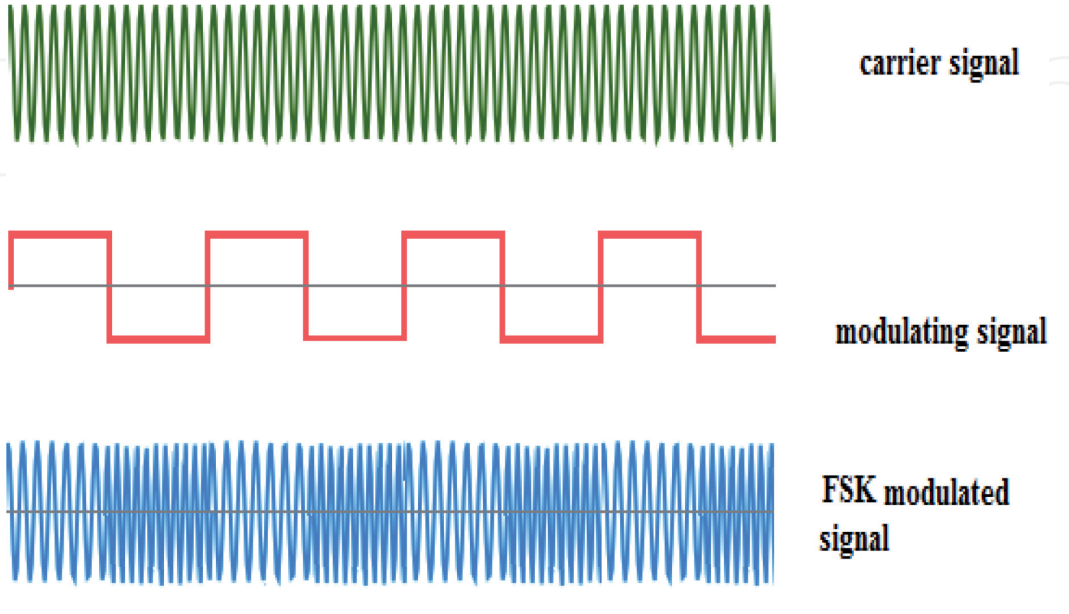


Figure 21.
Frequency shift keying.

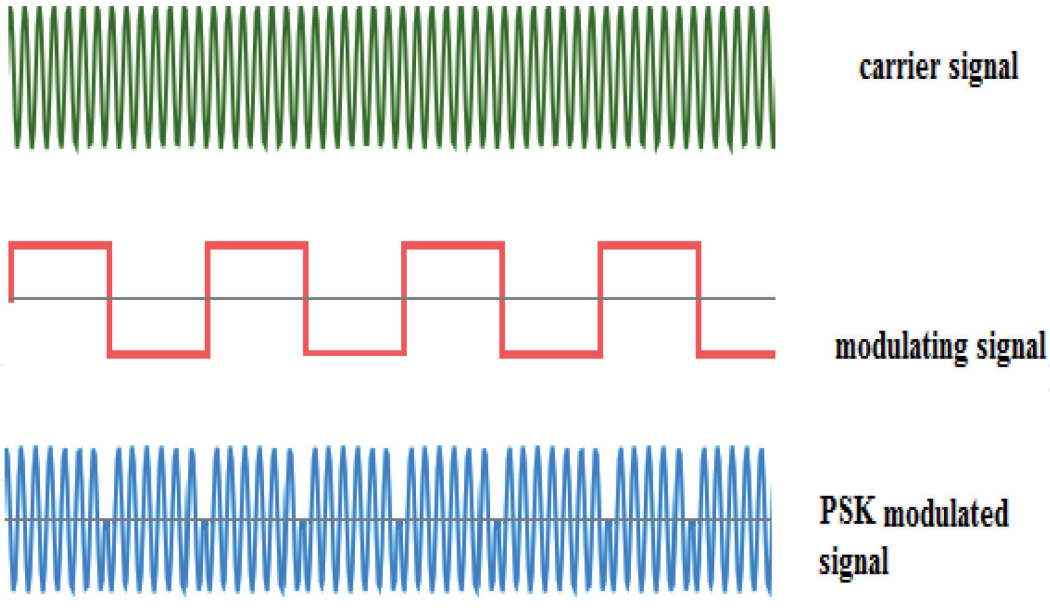


Figure 22.
Phase shift keying.

5.3 Phase shift keying

The principle of phase shift keying is that the phase of the carrier wave is modulated in accordance with the digital message signal, i.e., PSK signal represents the binary data in the form of variations in the phase of the carrier signal. Here the carrier signal changes its phase depending on the nature of the transmitted bit, i.e., 0 or 1. In two levels of PSK, the difference of 180-phase shift is used between binary 1 and binary 0 (**Figure 22**).

5.3.1 Advantages and disadvantages of PSK

It is a more power-efficient modulation technique than the ASK and FSK as it is less susceptible to errors than ASK modulation and occupies the same bandwidth as ASK. The disadvantage of PSK includes lower bandwidth efficiency. The binary data is decoded by estimation of phase states of the signal. These detection and recovery algorithms are very complex. It is also one form of FSK, and hence it also offers lower bandwidth efficiency than ASK modulation type.

5.3.2 Application

1. Used in our ADSL broadband modem

2. Used in satellite communication

3. Used in our mobile phones

6. Summary

This chapter "multiplexing" deals with different multiplexing techniques commonly used in both analog and digital communication systems and their classifications. This chapter contains the detailed description of analog modulation techniques like FDM, WDM, etc. It also describes about OFDM techniques and various digital modulation schemes like TDM and its variants. It also focuses on

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CDM multiplexing techniques and different digital multiplexers and demultiplexers and varies in digital demodulation techniques like ASK, PSK, and FSK with detailed diagrams.

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