DAYANANDA SAGAR COLLEGE OF ENGINEERING

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DEPARTMENT OF TELECOMMUNICATION ENGINEERING

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NOTES : MODULE 3

TELECOMMUNICATION SYSTEMS

COURSE CODE: 1 7 T E 6 IETCS

CONTENTS:

1) **MODULATION SCHEMES:**
   a) Analog Modulation: AM, FM and PM - brief review.
   b) Digital Modulation: PCM, ASK, FSK and PSK.
2) **MULTIPLEXING TECHNIQUES:**
   a) Frequency division multiplexing (FDM)
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3) **MULTIPLE ACCESS TECHNIQUES:**
   a) Frequency Division Multiple Access.(FDMA)
   b) Time Division Multiple Access. (TDMA)
   c) Code Division Multiple Access. (CDMA)

3.1 MODULATION SCHEMES

Modulation

It's a process of transmitting information over a medium. It can be defined as the process by which some characteristics/parameter (frequency, amplitude, phase) of high frequency carrier is varied with the low frequency message signal. Modulation occurs at the transmitting end of the system.

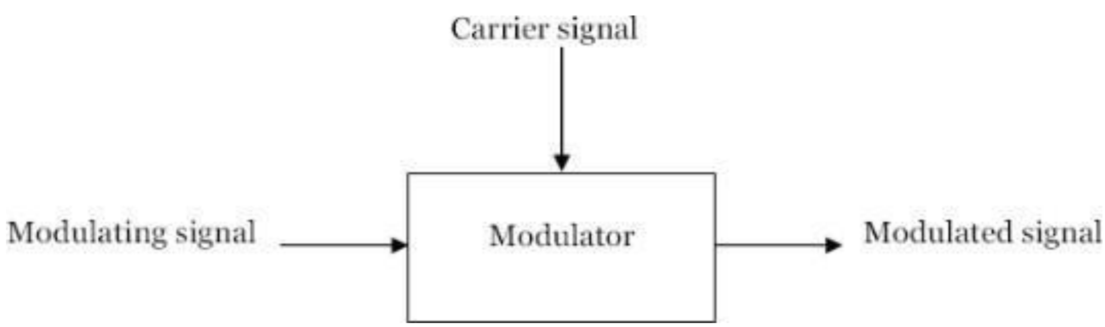


Fig. Block Diagram of a Modulation Process

Fig. Block Diagram of Modulation and Demodulation Process

Demodulation is the reverse process of modulation and converts the modulated carrier back to the original information (that is, extracting the message signal from the carrier).

Need for modulation

The advantages of using modulation technique are given below:

- Reduce the height of the antenna.
- Increase the range of communication.
- Avoids mixing of signals
- Allows multiplexing of signals
- Improves the signal to noiseratio.
- Avoids interference of the bands byproviding guard band
- Improve quality of reception
- Provide possibility for wireless transmission.

1. Practical Antenna length

Theory shows that in order to transmit a wave effectively the length of the transmitting antenna should be approximately equal to the wavelength of the wave.

$$wavelength = \frac{Velocity}{frequency} = \frac{3 \times 10^8}{frequency\ (Hz)}\, metres$$

As the audio frequencies range from 20 Hz to 20Khz, if they are transmitted directly into space, the length of the transmitting antenna required would be extremely large. For example to radiate a frequency of 20 KHz directly into space we would need an antenna length of $3 \times 10^8 / 20 \times 10^3 \approx 15{,}000$ meters. This is too long to be constructed practically. But instead we operate at higher frequencies, say in MHz range, the antenna dimension comes down. The operation at this frequencies is possible only with modulation techniques.

2. Operating Range

The energy of a wave depends upon its frequency. The greater the frequency of the wave, the greater the energy possessed by it. As the audio signal frequencies are small, there fore these cannot be transmitted over large distances if radiated directly into space.

3. Avoids mixing of signals:

The transmission band of 20Hz to 20KHz contains many signals generated from different sources. These signals are translated to different portion of the electromagnetic spectrum called channels, having different band widths, by providing different carrier frequencies. These frequencies are separated at the receiver while receiving.

4. Allows multiplexing of signals

The modulation permits multiplexing of signals, meaning simultaneous transmission of more signals on the same channel. Example MW and SW transmission with frequencies allotted to different bands and transmitted on the same channel

5. Improves the signal to noise ratio

The base band signals which are in the audio frequency range are susceptible to noise. The radio frequencies which are used for modulation are immune to noise. Hence modulating the message signals with the carrier helps in improving the signal to noise ratio.

6. Avoids interference of the bands by providing guard band

Special guard bands are provided between bands to guard the interference of adjacent band signals. This is usually around 25KHz.

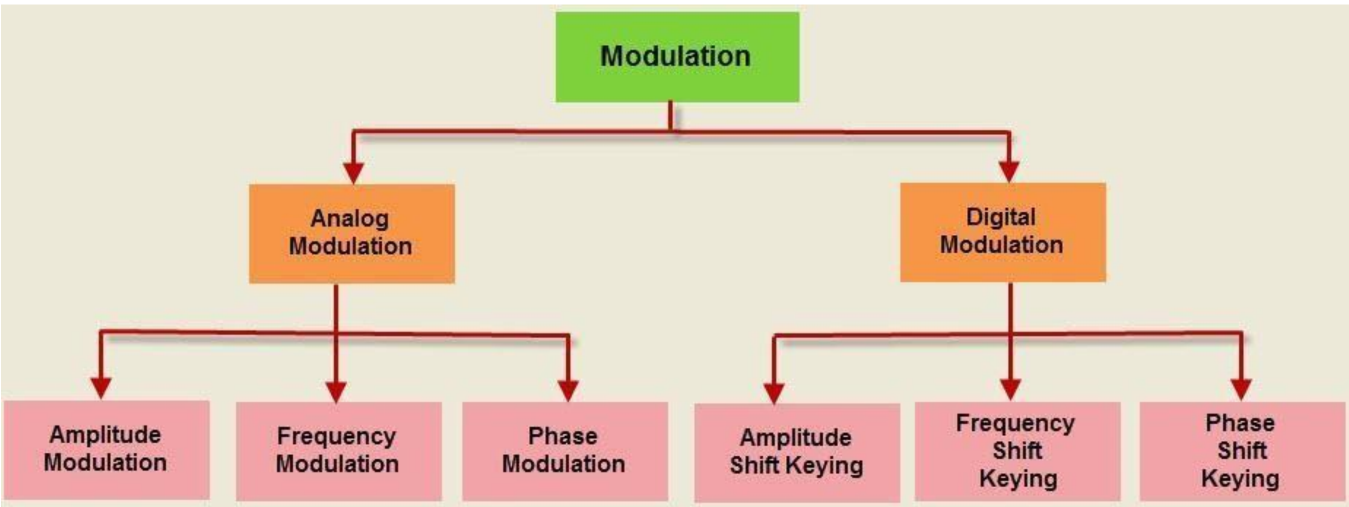
7. Improve quality of reception

Different techniques of transmission like digital modulation improves the quality of reception by reducing the noise in the system.

8. Wireless communication

Radio transmission should be carried out without wires.

Types of modulation



1. ANALOG MODULATION

Analog modulation refers to the process of transferring an **analog** baseband (low frequency) signal, like an audio or TV signal over a higher frequency signal such as a radio frequency band.

There are three ways to **modulate** an RF carrier:

A. Amplitude modulation(AM)

B. Frequency modulation (FM) and

C. Phase modulation(PM)

2. DIGITAL MODULATION

Digital Modulation and is a generic name for modulation techniques that uses discrete (digital) signals to modulate a carrier wave. The three main types of digital modulation are

A. Amplitude Shift Keying (ASK)

B. Frequency Shift Keying (FSK) and

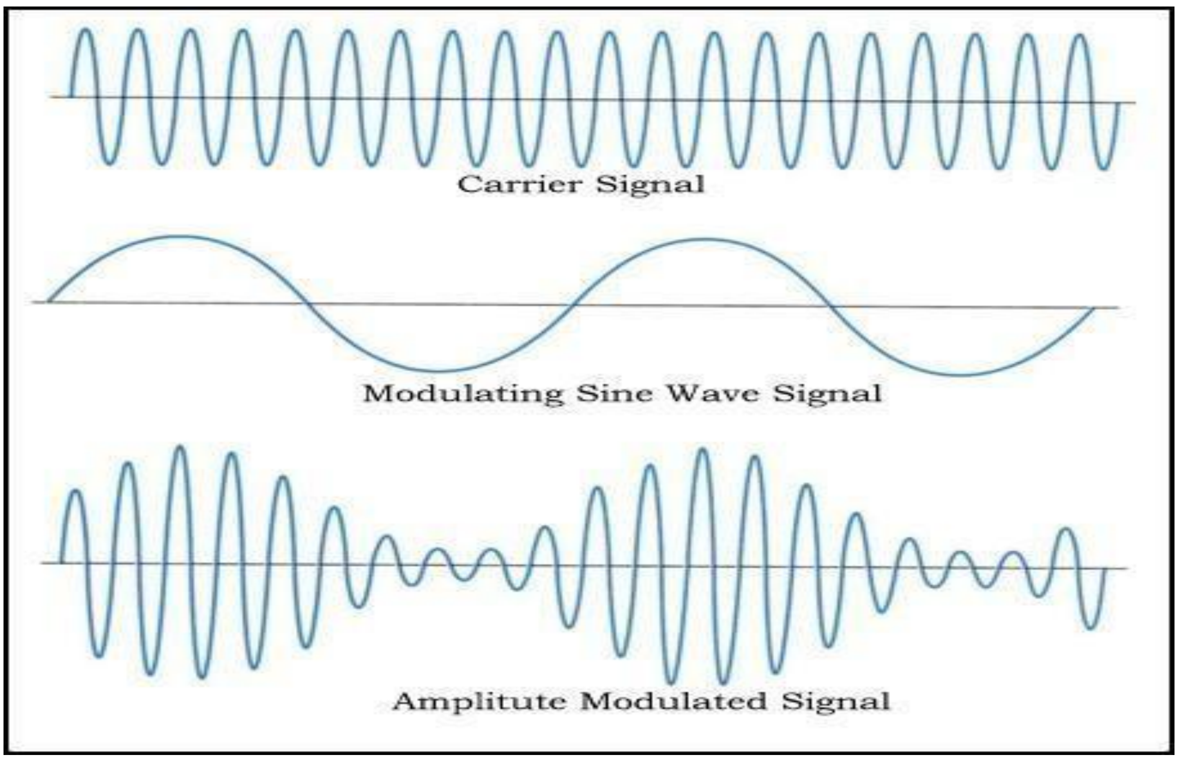
C. Phase Shift Keying (PSK)

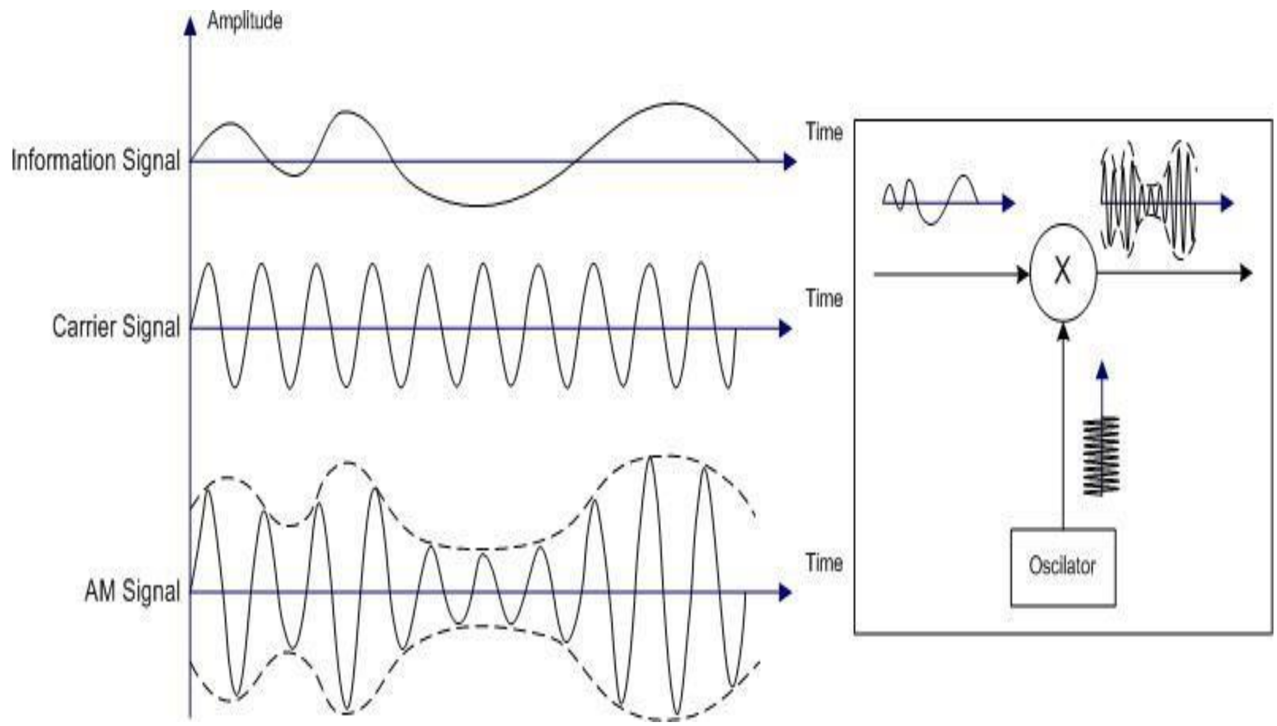
(A). Amplitude modulation(AM)

When the amplitude of high frequency carrier wave is changed in accordance with the intensity of the signal, it is called amplitude modulation. The following points are to be noted in amplitude mod ulation .

1. The amplitude of the carrier wave changes according to the intensity of thesignal.
2. The amplitude variations of the carrier wave is at the signal frequency f_S.
3. The frequency of the amplitude modulated wave remains the same i.e, carrier frequency f_C.

- The carrier signal frequency would be greater than the modulating signal frequency.
- Amplitude modulation is first type of modulation used for transmitting messages for long distances by the mankind.
- The AM radio ranges in between 535 to 1705 kHz which is great. But when compared to frequency modulation, the Amplitude modulation is weak, but still it is used for transmitting messages.
- Bandwidth of amplitude modulation should be twice the frequency of modulating signal or message signal.
- If the modulating signal frequency is 10 kHz then the Amplitude modulation frequency should be around 20 kHz. In AM radio broadcasting, the modulating signal or message signal is 15 kHz. Hence the AM modulated signal which is used for broadcasting should be 30 kHz.





Simplified analysis of standard AM

Consider a carrier wave (sine wave) of frequency f_c and amplitude *A* given by:

$c(t) = A \sin(2 f_c t)$

Let $m(t)$ represent the modulation waveform. For this example we shall take the modulation to be simply a sine wave of a frequency f_m, a much lower frequency (such as an audio frequency) than f_c:

$$m(t) = M\cos(2\pi f_m t + \phi) = Am\cos(2\pi f_m t + \phi).$$

where *m* is the amplitude sensitivity, *M* is the amplitude of modulation. If $m < 1$, $(1 + m(t)/A)$ is always positive for undermodulation. If $m > 1$ then overmodulation occurs and reconstruction of message signal from the transmitted signal would lead in loss of original signal. Amplitude modulation results when the carrier $c(t)$ is multiplied by the positive quantity $(1 + m(t)/A)$:

$$\begin{aligned} y(t) &= \left[1 + \frac{m(t)}{A}\right] c(t) \\ &= [1 + m\cos(2\pi f_m t + \phi)]\, A\sin(2\pi f_c t) \end{aligned}$$

In this simple case *m* is identical to the modulation index, discussed below. With $m = 0.5$ the amplitude modulated signal $y(t)$ thus corresponds to "50% Modulation".

Using trigonometric functions, $y(t)$ can be shown to be the sum of three sine waves:

$$y(t) = A\sin\left(2\pi f_c t\right) + \frac{1}{2}Am\left[\sin\left(2\pi\left[f_c + f_m\right]t + \phi\right) + \sin\left(2\pi\left[f_c - f_m\right]t - \phi\right)\right].$$

Therefore, the modulated signal has three components:

- the carrier wave *c(t)* which is unchanged, and
- two pure sine waves (known as sidebands) with frequencies slightly above and below the carrier frequency f_c.

Modulation Index and Percentage of Modulation

For undistorted AM to occur, the modulating signal voltage *Vm* must be less than the carrier voltage *Vc*. Therefore, the relationship between the amplitude of the modulating signal and the amplitude of the carrier signal is important. This relationship, known as the *modulation index m* (also called the modulating factor or coefficient, or the degree of modulation), is the ratio $\mathbf{m} = \dfrac{\mathbf{V_m}}{\mathbf{V_c}}$

These are the peak values of the signals, and the carrier voltage is the unmodulated value. Multiplying the modulation index by 100 gives the ***percentage of modulation.***

For example, if the carrier voltage is 9 V and the modulating signal voltage is 7.5 V, the modulation factor is 0.8333 and the percentage of modulation is 0.833 X 100 = 83.33.

Percentage of Modulation:

The modulation index can be determined by measuring the actual values of the modulation voltage and the carrier voltage and computing the ratio. However, it is more common to compute the modulation index from measurements taken on the composite modulated wave itself. When the AM signal is displayed on an oscilloscope, the modulation index can be computed from *V*max and *V*min, as shown in Fig. below. The peak value of the modulating signal *Vm* is one- half the difference of the peak and trough values:

$$V_m = \frac{V_{\max} - V_{\min}}{2}$$

As shown in Fig., *V*max is the peak value of the signal during modulation, and *V*min is the lowest value, or trough, of the modulated wave. The *V*max is one-half the peak-to-peak value of the AM signal, or

*V*max (*p*-*p*)/2. Subtracting *V*min from *V*max produces the peak-to-peak value of the modulating signal. One-half of that, of course, is simply the peak value.

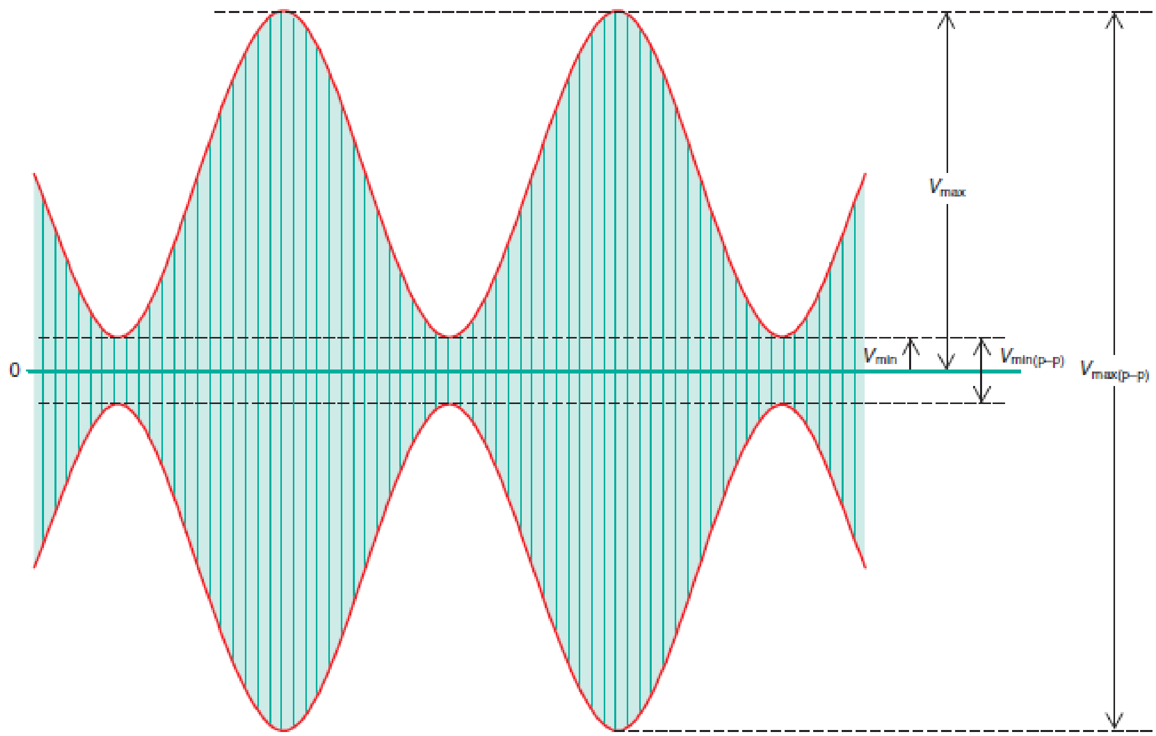
The peak value of the carrier signal *Vc* is the average of the *V*max and *V*min values:

$$V_c = \frac{V_{\max} + V_{\min}}{2}$$

The modulation index is

$$m = \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}}$$

Figure An AM wave showing peaks ($V_{\max}$) and troughs ($V_{\min}$).



Limitations of Amplitude Modulation

1. Noisy Reception- In an AM wave, the signal is in the amplitude variations of the carrier. Practically all the natural and man- made noises consist of electrical amplitude disturbances. As a radio receiver cannot distinguish between amplitude variations that represent noise and those that contain the desired signal. Therefore reception is very noisy.

2. Low efficiency- In AM useful power is in the sidebands as they contain the signal. An AM wave has low sideband power.

For example even if modulation is 100 % i.e, m=1.

$$\frac{P_S}{p_T} = \frac{m^2}{2+m^2} = \frac{1}{2+1} = 0.33$$

$$P_S = 33\% \text{ of } P_T$$

Sideband power is only one-third of the total power of AM wave. Hence efficiency of this type of modulation is low.

3. Lack of audio quality- In order to attain high fidelity reception, all audio frequencies upto 15 Khz must be reproduced. This necessitates a bandwidth of 30 KHz since both sidebands must be reproduced (2fs). But AM broadcasting stations are assigned with bandwidth of only 10 KHz to minimize the interference from adjacent broadcasting stations. This means that the highest modulating frequency can be 5 Khz which is hardly sufficient to reproduce the music properly.

(B). Frequency modulation (FM)

In FM, the carrier amplitude remains constant and the carrier frequency is changed by the modulating signal. As the amplitude of the information signal varies, the carrier frequency shifts proportionately. As the modulating signal amplitude increases, the carrier frequency increases. If the amplitude of the modulating signal decreases, the carrier frequency decreases. The reverse relationship can also be implemented. A decreasing modulating signal increases the carrier frequency above its center value, whereas an increasing modulating signal decreases the carrier frequency below its center value. As the modulating signal amplitude varies, the carrier frequency varies above and below its normal center, or *resting*, frequency with no modulation. The amount of change in carrier frequency produced by the modulating signal is known as the ***frequency deviation fd*****.** Maximum frequency deviation occurs at the maximum amplitude of the modulating signal.

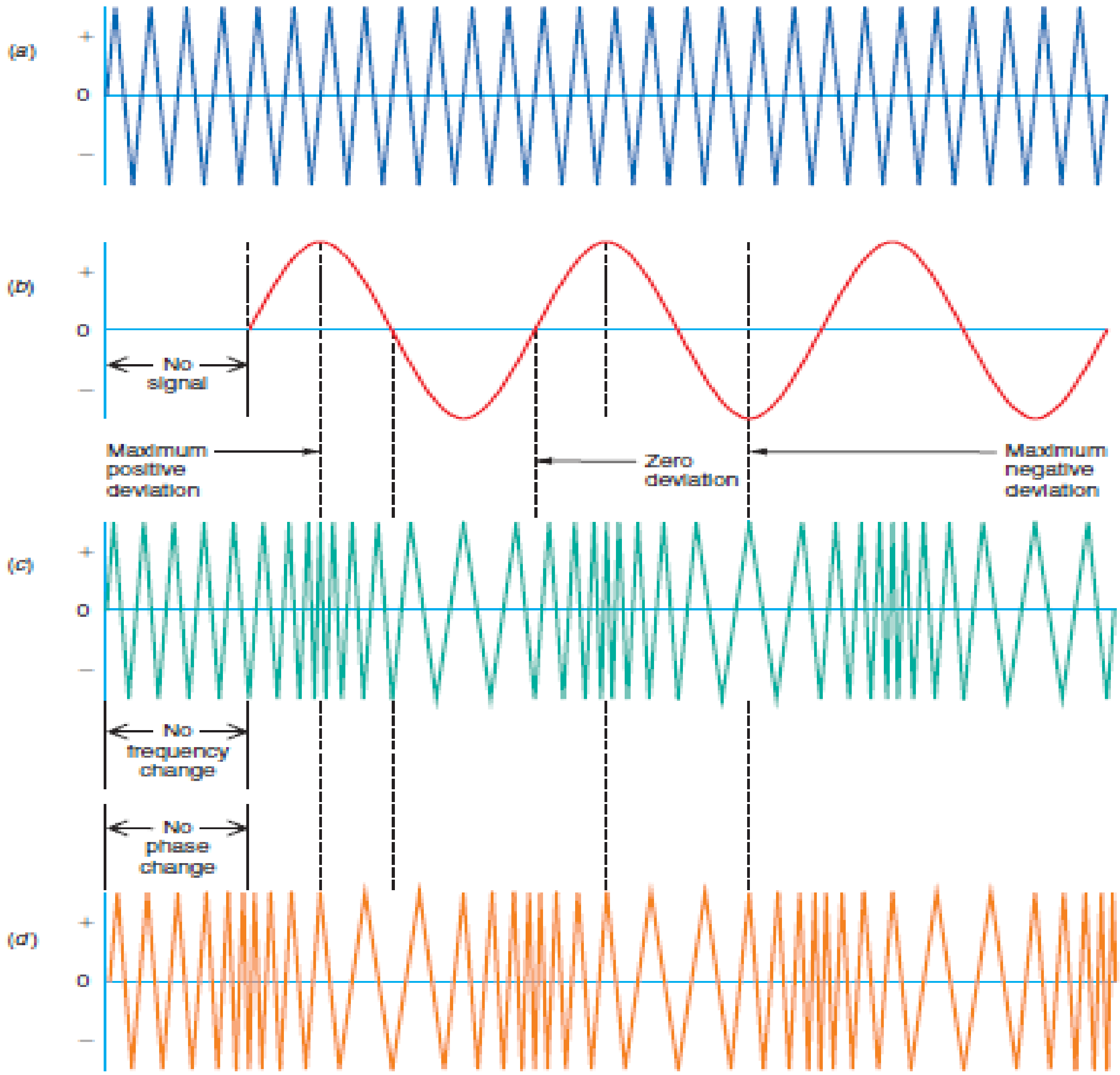
The frequency of the modulating signal determines the frequency deviation rate, or how many times per second the carrier frequency deviates above and below its center frequency. If the modulating signal is a 500-Hz sine wave, the carrier frequency shifts above and below the center frequency 500 times per second.

An FM signal is illustrated in Fig. (*c*). Normally the carrier [Fig. (*a*)] is a sine wave, but it is shown as a triangular wave here to simplify the illustration. With no modulating signal applied, the carrier frequency is a constant-amplitude sine wave at its normal resting frequency.

The modulating information signal [Fig. (*b*)] is a low- frequency sine wave. As the sine wave goes positive, the frequency of the carrier increases proportionately. The highest frequency occurs at the peak amplitude of the modulating signal. As the modulating signal amplitude decreases, the carrier frequency decreases. When the modulating signal is at zero amplitude, the carrier is at its center frequency point.

When the modulating signal goes negative, the carrier frequency decreases. It continues to decrease until the peak of the negative half-cycle of the modulating sine wave is reached. Then as the modulating signal increases toward zero, the carrier frequency again increases. This phenomenon is illustrated in Fig.(*c*), where the carrier sine waves seem to be first compressed and then stretched by the modulating signal.

Figure FM and PM signals. The carrier is drawn as a triangular wave for simplicity, but in practice it is a sine wave. (*a*) Carrier. (*b*) Modulating signal. (*c*) FM signal. (*d*) PM signal.



Advantages of Frequency Modulation:

- Frequency modulation has more noise resistivity when compared to other modulation techniques. That's why they are mainly used in broadcasting and radio communications.

- The frequency modulation is having greater resistance to rapid signal strength variation, which we will use in FM radios even while we are travelling and frequency modulation is also mainly used in mobile communication purposes.
- For transmitting messages in frequency modulation, it does not require special equipments like linear amplifiers or repeaters and transmission levels or higher when compared to other modulation techniques. It does not require any class C or B amplifiers for increasing the efficiency.
- Transmission rate is good for frequency modulation when compared to other modulation that is frequency modulation can transmit around 1200 to 2400 bits per second.
- Frequency modulation has a special effect called capture effect in which high frequency signal will capture the channel and discard the low frequency or weak signals from interference.

Disadvantages of Frequency Modulation:

- In the transmission section, we don’t need any special equipment but in the reception, we need more complicated demodulators for demodulating the carrier signal from message or modulating signal.
- Frequency modulation cannot be used to find out the speed and velocity of a moving object. Static interferences are more when compared to phase modulation. Outside interference is one of the biggest disadvantages in the frequency modulation. There may be mixing because of nearby radio stations, pagers, construction walkie-talkies etc.
- To limit the bandwidth in the frequency modulation, we use some filter which will again introduce some distortions in the signal.
- Transmitters and receiver should be in same channel and one free channel must be there between the systems.
- Spectrum space is limit for the frequency modulation and careful controlling the deviation ration.

Applications of Frequency Modulation (FM):

- Frequency modulation is used in radio’s which is very common in our daily life.
- Frequency modulation is used in audio frequencies to synthesize sound.
- For recording the video signals by VCR systems, frequency modulation is used for intermediate frequencies.
- Used in applications of magnetic tape storage.

Comparison between Amplitude Modulation and Frequency Modulation

Amplitude modulation and frequency modulation are both methods of modifying a carrier signal in order to transmit data. The main difference between amplitude modulation and frequency modulation is that, in amplitude modulation, the amplitude of the carrier wave is modified according to the data whereas, in frequency modulation, the frequency of the carrier wave is modified according to the data.

	AM	FM
Stands for	AM stands for Amplitude Modulation	FM stands for Frequency Modulation
Origin	AM method of audio transmission was first successfully carried out in the mid-1870s.	FM radio was developed in the United states in the 1930s, mainly by Edwin Armstrong.
Modulating differences	In AM, a radio wave known as the "carrier" or "carrier wave" is modulated in amplitude by the signal that is to be transmitted. The frequency and phase remain the same.	In FM, a radio wave known as the "carrier" or "carrier wave" is modulated in frequency by the signal that is to be transmitted. The amplitude and phase remain the same.
Pros and cons	AM has poorer sound quality compared with FM, but is cheaper and can be transmitted over long distances. It has a lower bandwidth so it can have more stations available in any frequency range.	FM is less prone to interference than AM. However, FM signals are impacted by physical barriers. FM has better sound quality due to higher bandwidth.
Frequency Range	AM radio ranges from 535 to 1705 KHz (OR) Up to 1200 bits per second.	FM radio ranges in a higher spectrum from 88 to 108 MHz. (OR) 1200 to 2400 bits per second.
Bandwidth Requirements	Twice the highest modulating frequency. In AM radio broadcasting, the modulating signal has bandwidth of 15kHz, andhence the bandwidth of anamplitude-modulated signal is 30kHz.	Twice the sum of the modulating signal frequency and the frequency deviation. If the frequency deviation is 75kHz and the modulating signal frequency is 15kHz, the bandwidth required is 180kHz.
Zero crossing in modulated signal	Equidistant	Not equidistant
Complexity	Transmitter and receiver are simple but synchronization is needed in case of SSBSC AM carrier.	Transmitter and receiver are more complex as variation of modulating signal has to be converted and detected from corresponding variation in frequencies.(i.e. voltage to frequency and frequency to voltage conversion has to be done).
Noise	AM is more susceptible to noise because noise affects amplitude, which is where information is "stored" in an AM signal.	FM is less susceptible to noise because information in an FM signal is transmitted through varying the frequency, and not the amplitude.

(C). Phase modulation (PM)

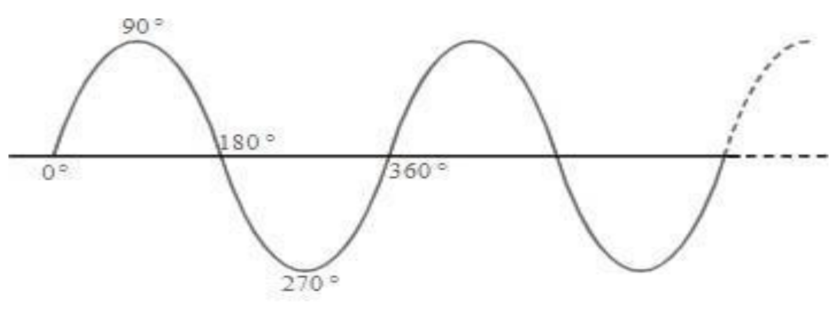
As the name implies, phase modulation, PM uses variations in phase for carrying the modulation.

As phase and frequency are interrelated, this relationship carries forwards into phase modulation where it has many commonalities with frequency modulation. As a result the term angle modulation is often use to describe both.

Phase modulation, PM is sometimes used for analogue transmission, but it has become the basis for modulation schemes used for carrying data. Phase shift keying, PSK is widely used for data communication.

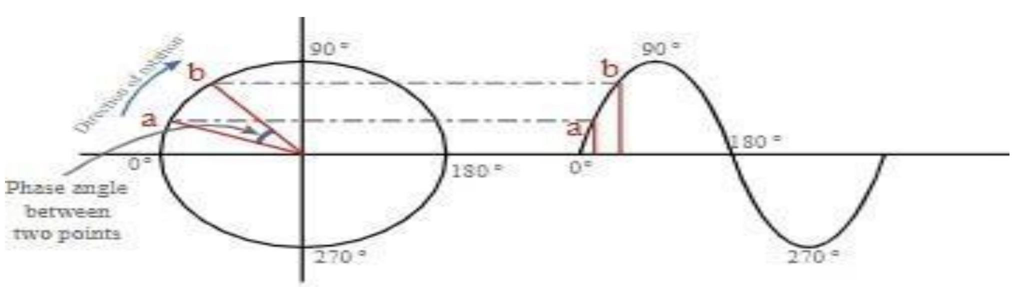
Phase modulation basics

Before looking at phase modulation it is first necessary to look at phase itself. A radio frequency signal consists of an oscillating carrier in the form of a sine wave is the basis of the signal. The instantaneous amplitude follows this curve moving positive and then negative, returning to the start point after one complete cycle - it follows the curve of the sine wave.



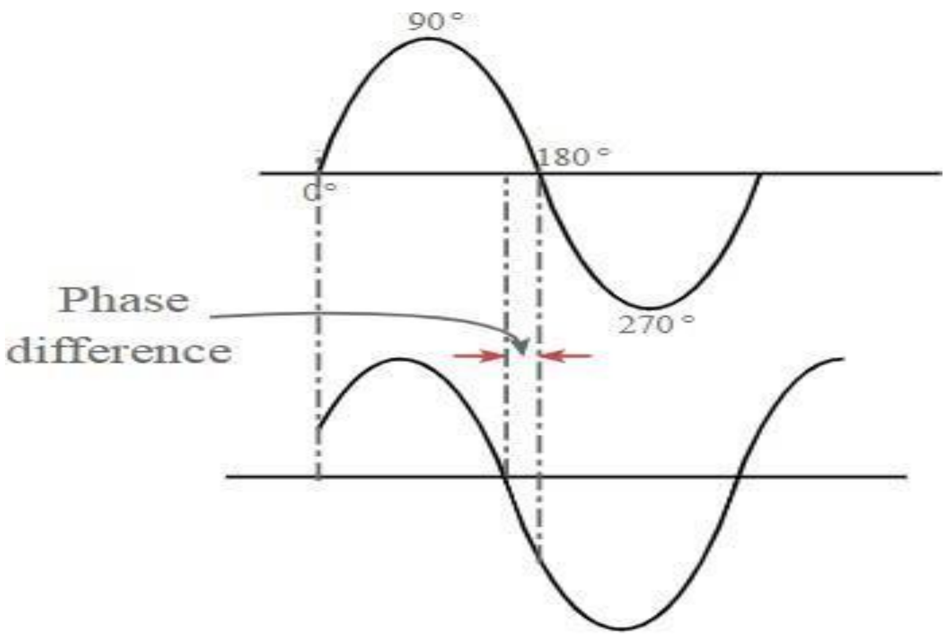
A Sine Wave

The sine wave can also be represented by the movement of a point around a circle, the phase at any given point being the angle between the start point and the point on the waveform as shown.



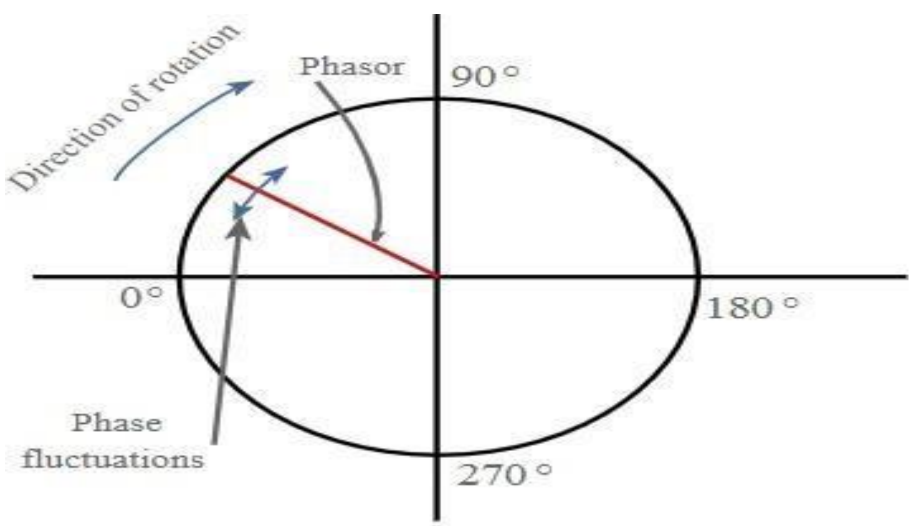
Phase angle of points on a sine wave

Also the phase advances as time progresses so points on the waveform can be said to have a phase difference between them.



Phase difference between signals

Phase modulation works by modulating the phase of the signal, i.e. changing the rate at which the point moves around the circle. This changes the phase of the signal from what it would have been if no modulation was applied. In other words the speed of rotation around the circle is modulated about the mean value.



Phase modulation concept

To achieve this it is necessary to change the frequency of the signal for a short time. In other words when phase modulation is applied to a signal there are frequency changes and vice versa. Phase and frequency are inseparably linked as phase is the integral of frequency.

Frequency modulation can be changed to phase modulation by simply adding a CR network to the modulating signal that integrates the modulating signal. As such the information regarding sidebands, bandwidth and the like also hold true for phase modulation as they do for frequency modulation, bearing in mind theirrelationship.

2. DIGITAL MODULATION

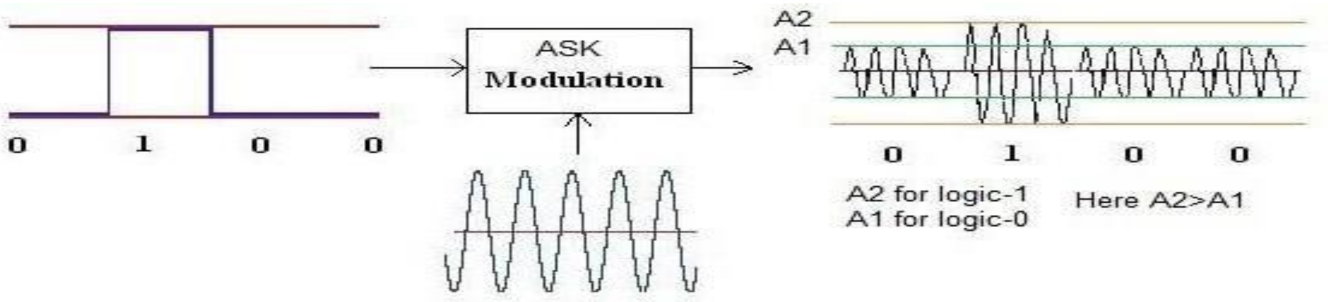
Digital Modulation and is a generic name for modulation techniques that uses discrete (digital) signals to modulate a carrier wave. The three main types of digital modulation are

A. Amplitude Shift Keying (ASK)
B. Frequency Shift Keying (FSK) and
C. Phase Shift Keying (PSK)

All these are digital modulation techniques. Unlike Analog modulation, here input is in digital binary form. The other input is the RF carrier. Input binary data is referred as modulating signal and output is referred as modulated signal.

(A). Amplitude Shift Keying (ASK)

The short form of Amplitude Shift Keying is referred as **ASK**. It is the digital modulation technique. In this technique, amplitude of the RF carrier is varied in accordance with baseband digital input signal. The figure depicts operation of ASK modulation. As shown in the figure, binary 1 will be represented by carrier signal with some amplitude while binary 0 will be represented by carrier of zero amplitude(i.e. no carrier).



ASK modulation can be represented by followingequation:

s(t) = A2* cos (2*π*fc*t) for Binary Logic-1

s(t) = A1* cos(2*π*fc*t) for Binary Logic-0

Here A2>A1

Signalling used is ON-OFF signalling.

Bandwidth requirement for ASK is:

$$\mathbf{BW = 2/Tb = 2*Rb}$$

Often in ASK modulation, binary-1 is represented by carrier with amplitude-A2 and binary-0 is represented by carrier with amplitude-A1. Here A2 is greater in magnitude compare to A1. The form of ASK where in no carrier is transmitted during the transmissio n of logic zero is known as OOK modulation (On Off Keying modulation). This is shown in the figure above.

• In ASK probability of error (Pe) is high and SNR is less.

• It has lowest noise immunity against noise.

• ASK is a bandwidth efficient system but it has lower power efficiency.

ASK Advantages

Following points summarizes ASK advantages:

- It offers high bandwidth efficiency.
- It has simple receiver design.
- ASK modulation can be used to transmit digital data over optical fiber.
- ASK modulation and ASK demodulation processes are comparatively inexpensive.

- Its variant OOK is used at radio frequencies to transmit morse codes.

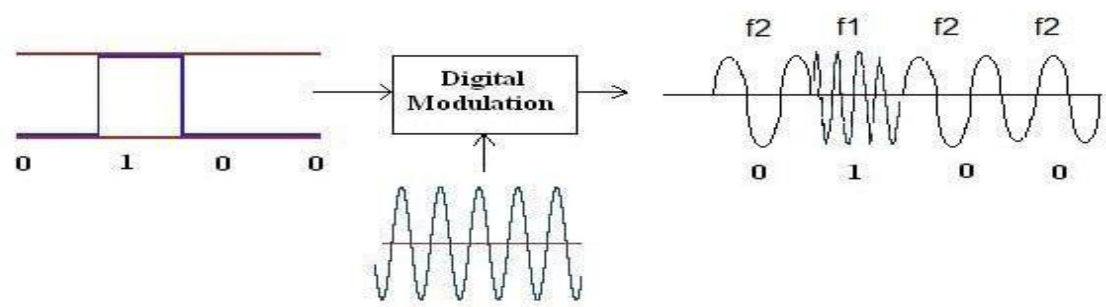
ASK Disadvantages

Following points summarizes ASK disadvantages:

- It offers lower power efficiency.
- ASK modulation is very susceptible to noise interference. This is due to the fact that noise affects the amplitude. Hence another alternative modulation technique such as BPSK which is less susceptible to error than ASK is used.

(B). Frequency Shift Keying (FSK)

The short form of Frequency Shift Keying is referred as FSK. It is also digital modulation technique. In this technique, frequency of the RF carrier is varied in accodance with baseband digital input. The figure depicts the FSK modulation. As shown, binary 1 and 0 is represented by two different carrier frequencies. Figure depicts that binary 1 is represented by high frequency 'f1' and binary 0 is represented by low frequency 'f2'.



Binary FSK can be represented byfollowing equation:

s(t) = A* cos (2*π*f1*t) for Binary 1

s(t) = A* cos (2*π*f2*t) for Binary 0

In FSK modulation, NRZ signalling method is used.

Bandwidth requirement in case of FSK is:

BW = 2*Rb + (f1-f2)

• In case of FSK, Pe is less and SNR is high.

• This technique is widely employed in modem design and development.

• It has increased immunity to noise but requires larger bandwidth compare to other modulation types.

Benefits or advantages of FSK

Following are the benefits or advantages of FSK:

- It has lower probability of error (Pe).
- It provides high SNR (Signal to Noise Ratio).
- It has higher immunity to noise due to constant envelope. Hence it is robust against variation in attenuation through channel.
- FSK transmitter and FSK receiver implementations are simple for low data rate application.

Drawbacks or disadvantages of FSK

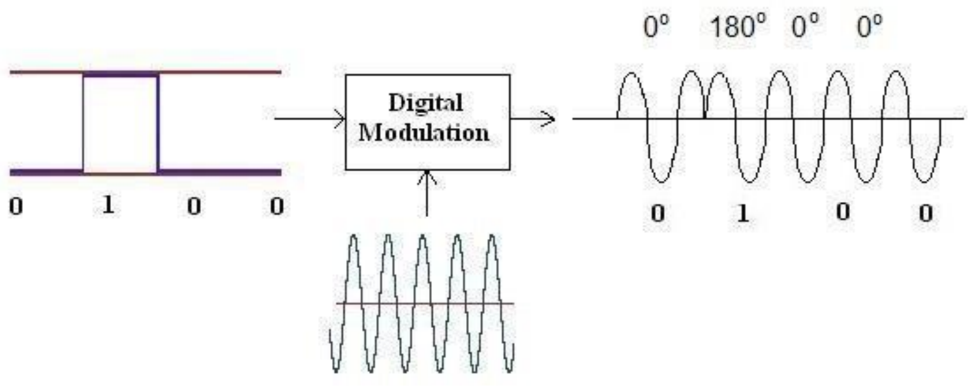
Following are the disadvantages of FSK:

- It uses larger bandwidth compare to other modulation techniques such as ASK and PSK. Hence it is not bandwidth efficient.
- The BER (Bit Error Rate) performance in AWGN channel is worse compare to PSK modulation.

In order to overcome drawbacks of BFSK, multiple FSK modulation techniques with more than two frequencies have been developed. In MFSK (Multiple FSK), more than one bits are represented by each signal elements.

(C). Phase Shift Keying (PSK)

The short form of Phase Shift Keying is referred as PSK. It is digital modulation technique where in phase of the RF carrier is changed based on digital input. Figure depicts Binary Phase Shift Keying modulation type of PSK. As shown in the figure, Binary 1 is represented by 180 degree phase of the carrier and binary 0 is represented by 0 degree phase of the RF carrier.



Binary PSK can be represented by following equation :

If s(t) = A*cos(2*π*fc*t) for Binary 1 than

s(t) = A*cos(2*π*fc*t + π) for Binary 0

In PSK modulation, NRZ signalling is used. Bandwidth requirement for PSK is:

$$\boxed{BW = 2 * Rb = 2 * \text{Bit rate}}$$

- In case of PSK probability of error is less. SNR is high.
- It is a power efficient system but it has lower bandwidth efficiency.
- PSK modulation is widely used in wireless transmission.
- The variants of basic PSK and ASK modulations are QAM, 16-QAM, 64-QAM and so on.

Benefits or advantages of PSK

Following are the benefits or advantages of PSK:

- It carries data over RF signal more efficiently compare to other modulation types. Hence it is more power efficient modulation technique compare to ASK and FSK.
- It is less susceptible to errors compare to ASK modulation and occupies same bandwidth as ASK.
- Higher data rate of transmission can be achieved using high level of PSK modulations such as QPSK (represents 2 bits per constellation), 16-QAM (represents 4 bits per constellation) etc.

Drawbacks or disadvantages of PSK

Following are the disadvantages of PSK:

- It has lower bandwidth efficiency.
- The binary data is decoded by estimation of phase states of the signal. These detection and recovery algorithms are very complex.
- Multi- level PSK modulation schemes (QPSK, 16QAM etc.) are more sensitive to phase variations.
- It is also one form of FSK and hence it also offers lower bandwidth efficiency compare to ASK modulation type.
-

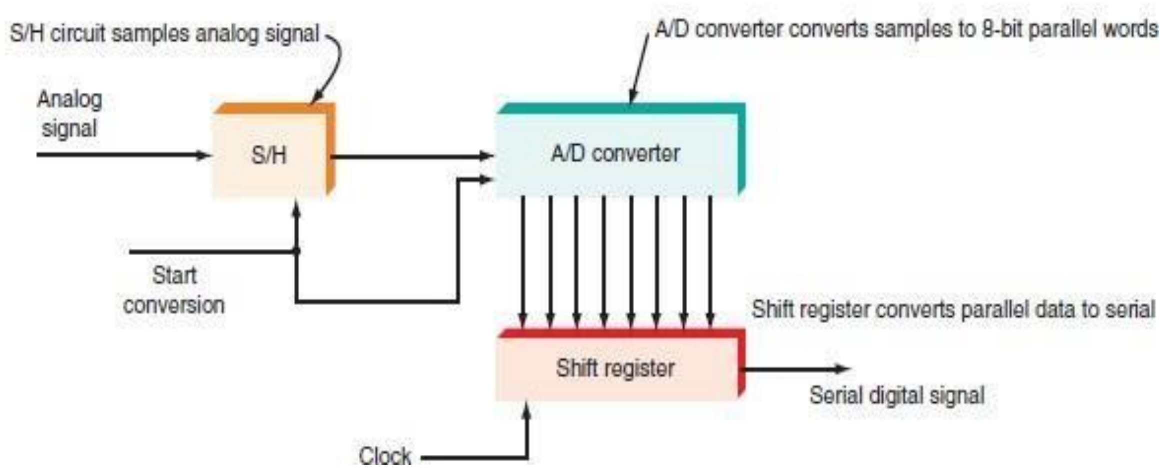
Pulse Modulation

- *Pulse modulation* is the process of changing a binary pulse signal to represent the information to be transmitted. The primary benefits of transmitting information by binary techniques arise from the great noise tolerance and the ability to regenerate the degraded signal.
- There are four basic forms of pulse modulation:
  Pulse-amplitude modulation (PAM),
  Pulse-width modulation (PWM),
  Pulse-position modulation (PPM), and
  Pulse-code modulation (PCM).

Pulse-code modulation (PCM)

The most widely used technique for digitizing information signals for electronic data transmission is pulse-code modulation (PCM). PCM signals are serial digital data. There are two ways to generate them. The more common is to use an S/H circuit and traditional A/D converter to sample and convert the analog signal to a sequence of binary words, convert the parallel binary words to serial form, and transmit the data serially, 1 bit at a time. The second way is to use the delta modulator described

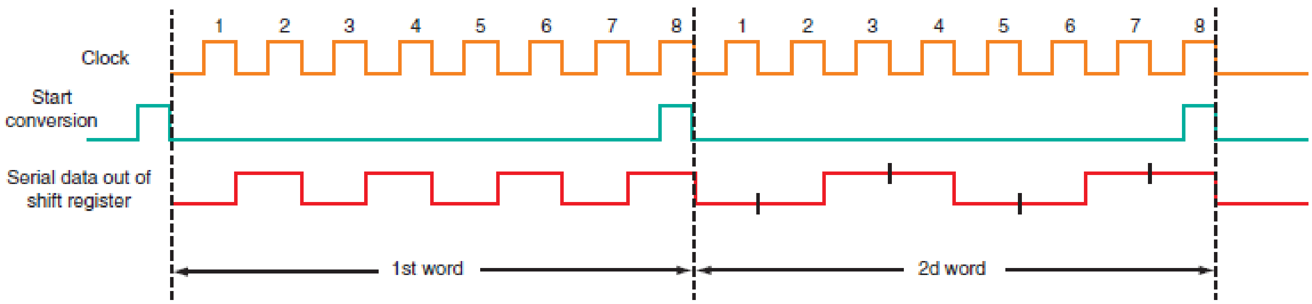
Figure Basic PCM system.



Traditional PCM. In traditional PCM, the analog signal is sampled and converted to a sequence of parallel binary words by an A/D converter. The parallel binary output word is converted to a serial signal by a shift register (see Fig. below). Each time a sample is taken, an 8-bit word is generated by the A/D converter. This word must be transmitted serially before another sample is taken and another binary word is generated. The clock and start conversion signals are synchronized so that the resulting output signal is a continuous train of binarywords.

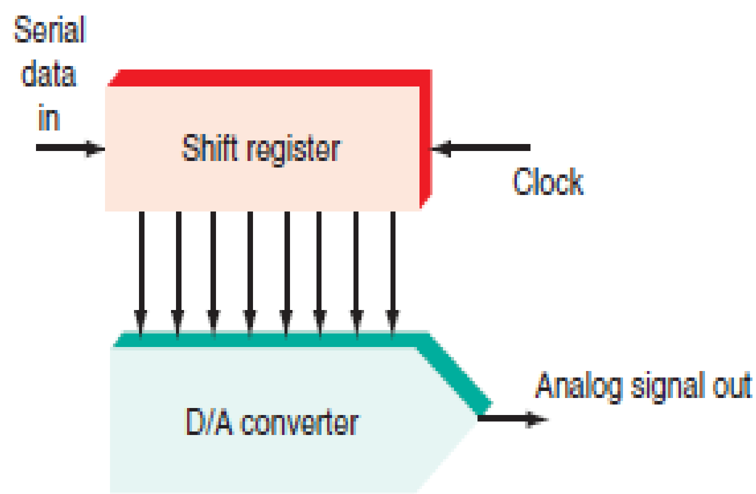
Fig. below shows the timing signals. The start conversion signal triggers the S/H to hold the sampled value and starts the A/D converter. Once the conversion is complete, the parallel word from the A/D converter is transferred to the shift register. The clock pulses start shifting the data out 1 bit at a time. When one 8-bit word has been transmitted, another conversion is initiated and the next word is transmitted. In Fig. 7-30, the first word sent is 01010101; the second word is 00110011.

Figure Timing signals for PCM.



At the receiving end of the system, the serial data is shifted into a shift register (see Fig. below). The clock signal is derived from the data to ensure exact synchronization with the transmitted data. Once one 8-bit word is in the register, the D/A converter converts it to a proportional analog output. Thus the analog signal is reconstructed one sample at a time as each binary word representing a sample is converted to the corresponding analog value. The D/A converter output is a stepped approximation of the original signal. This signal may be passed through a low-pass filter to smooth out the steps.

Figure PCM to analog translation at the receiver.



3.2 MULTIPLEXING TECHNIQUES

Introduction:

- A communication channel, or link, between **two points** is established whenever a cable is connected or a radio transmitter and receiver are set up between the twopoints.
- When there is only one link, only one function— whether it involves **signal transmission or control operations**—can be performed **at a time**.
- For **two-way communication**, a **half duplex** process is set up: Both ends of the communication link can send and receive **but not at the same time**.
- Transmitting **two or more signals simultaneously** can be accomplished by running **multiple cables** or **setting up one transmitter/receiver pair** for each channel.
- But this is an **expensive** approach.
- A **single cable or radio link** can handle **multiple signals** simultaneously by using a technique known as **multiplexing.**
- Multiplexing **permits hundreds or even thousands** of signals to be combined and transmitted over a **single medium.**
- **Advantages** : 1. simultaneous communication more practical and economically feasible,
  2. conserve spectrum space, and
  3. allowed new, sophisticated applications to be implemented.

Multiplexing Principles:

- ***Multiplexing*** is the process of simultaneously transmitting two or more individual signals over a single communication channel, cable or wireless.
- It increases the number of communication channels so that more information can be transmitted.
- Often in communication it is necessary or desirable to transmit more than one voice or data signal simultaneously.
- An application may require multiple signals, or cost savings can be gained by using a single communication channel to send multiple information signals.
- **Four applications** that would be prohibitively expensive or impossible without multiplexing are **telephone systems, telemetry, satellites, and modern radio and TV broadcasting.**
- The **greatest use** of multiplexing is in the **telephone system**, where millions of calls are multiplexed on cables, long-distance fiber-optic lines, satellites, and wireless paths.

- Multiplexing increases the telephone carrier’s ability to handle more calls while **minimizing system costs and spectrum usage**.
- Multiplexing is accomplished by an electronic circuit known as a *multiplexer*.
- A simple multiplexer is illustrated in Fig. below.

Figure Concept of multiplexing.

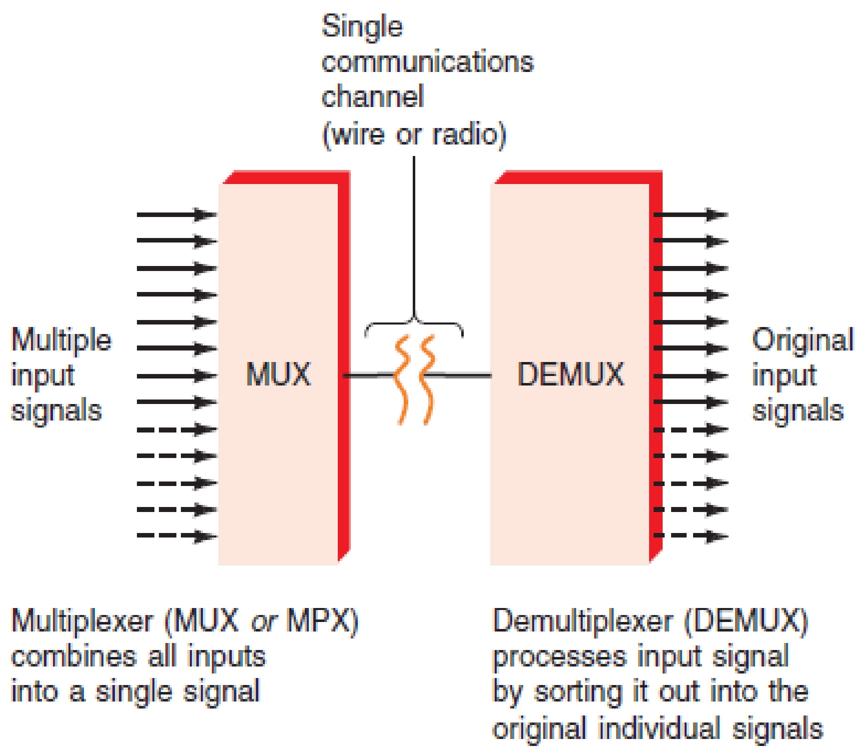


Fig : Concept of Multiplexing

- Multiple input signals are combined by the multiplexer into a single composite signal that is transmitted over the communication medium.
- Alternatively, multiplexed signals can modulate a carrier before transmission.
- At the other end of the communication link, a demultiplexer is used to process the composite signal to recover the individual signals.

<u>Types of Multiplexing techniques:</u>

The two most common types of multiplexing are:

i. **Frequency-division multiplexing (FDM) and**
ii. **Time-division multiplexing (TDM).**

Two variations of these basic methods are

1) Frequency-division multiple access (FDMA) and
2) Time-division multiple access (TDMA).

- In general, FDM systems are used for analog information and TDM systems are used for digital information.
- TDM techniques are also found in many analog applications because the processes of A/D and D/A conversion.
- The primary difference between these techniques is:
  - In FDM, individual signals to be transmitted are assigned a different frequency within a common bandwidth.
  - In TDM, the multiple signals are transmitted in different time slots on a single channel.

Another form of multiple access is known as *code-division multiple access (CDMA)*.
It is widely used in cell phone systems to allow many cell phone subscribers to use a common bandwidth at the same time. This system uses special codes assigned to each user that can be identified. CDMA uses a technique called spread spectrum to make this type of multiplexing possible.

NOTE:

SPATIAL MULTIPLEXING

- Spatial multiplexing is the term used to describe **the transmission of multiple wireless signals on a common frequency** in such a way that **they do not interfere with one another**.
- One way of doing this is to use low-power transmissions so that the signals do not interfere with one another.
- When very low power is used, the signals do not travel very far. The transmission distance is a function of the power level, frequency, and antenna height.
- Spatial multiplexing is sometimes referred to as frequency reuse.
- This technique is widely
- used in satellite and cellular telephone systems.

i. Frequency - Division Multiplexing

- In *frequency-division multiplexing (FDM),* multiple signals share the bandwidth of a common communication channel.
- All channels have specific bandwidths, and some are relatively wide.
- e.g., A coaxial cable has a bandwidth of about 1 GHz. The bandwidths of radio channels vary, and are usually determined by FCC regulations and the type of radio service involved.
- Regardless of the type of channel, a wide bandwidth can be shared for the purpose of transmitting many signals at the same time.

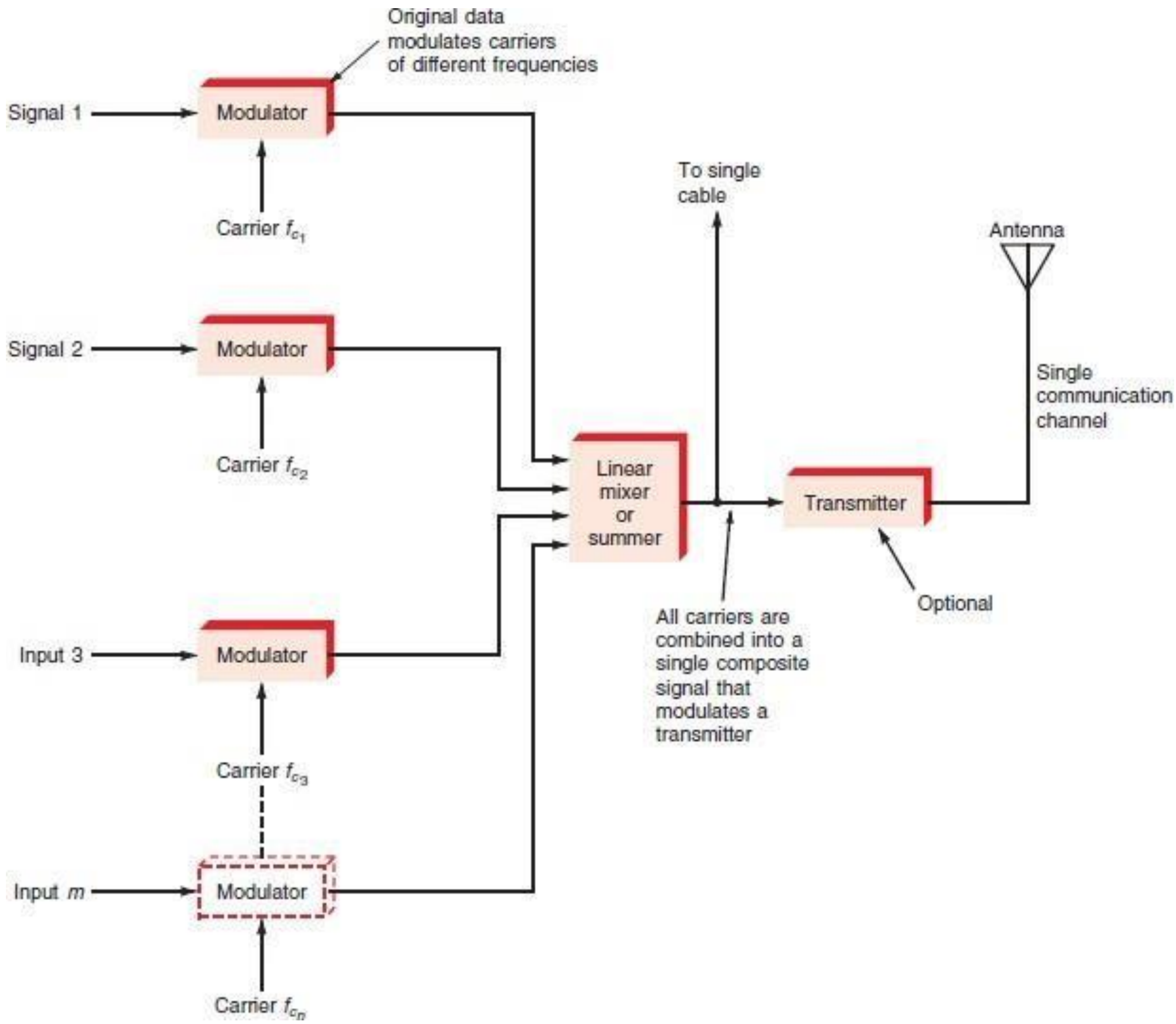


Fig : The transmitting end of an FDM system

(a).<u>Transmitter-Multiplexers</u>

- Fig. above shows a general block diagram of an FDM system. Each signal to be transmitted feeds a modulator circuit. The carrier for each modulator (*fc*) is on a different frequency.
- The carrier frequencies are usually equally spaced from one another over a specific frequency range. These carriers are referred to as *subcarriers*.
- Each input signal is given a portion of the bandwidth. The resulting spectrum is illustrated in the below Fig. below.
- Any of the standard kinds of modulation can be used, including AM, SSB, FM, PM, or any of the various digital modulation methods.
- The FDM process divides up the bandwidth of the single channel into smaller, equally spaced channels, each capable of carrying information in sidebands.

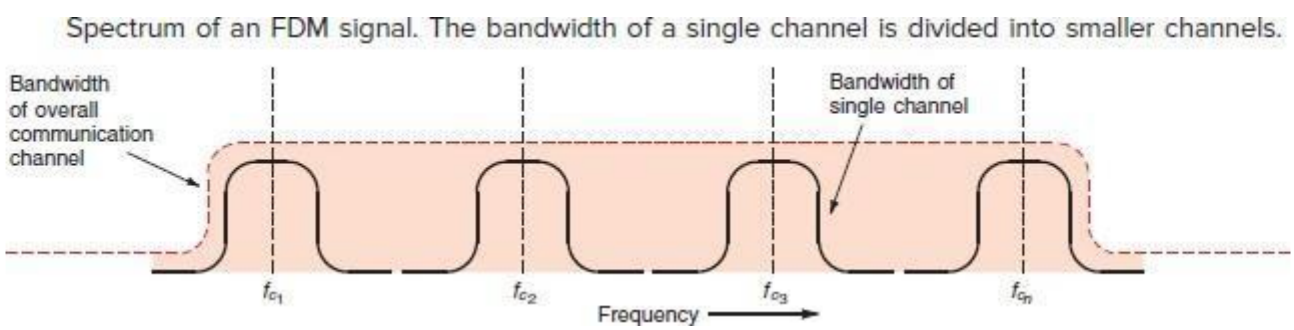


Fig: Spectrum of an FDM Signal.

Figure The receiving end of an FDM system.

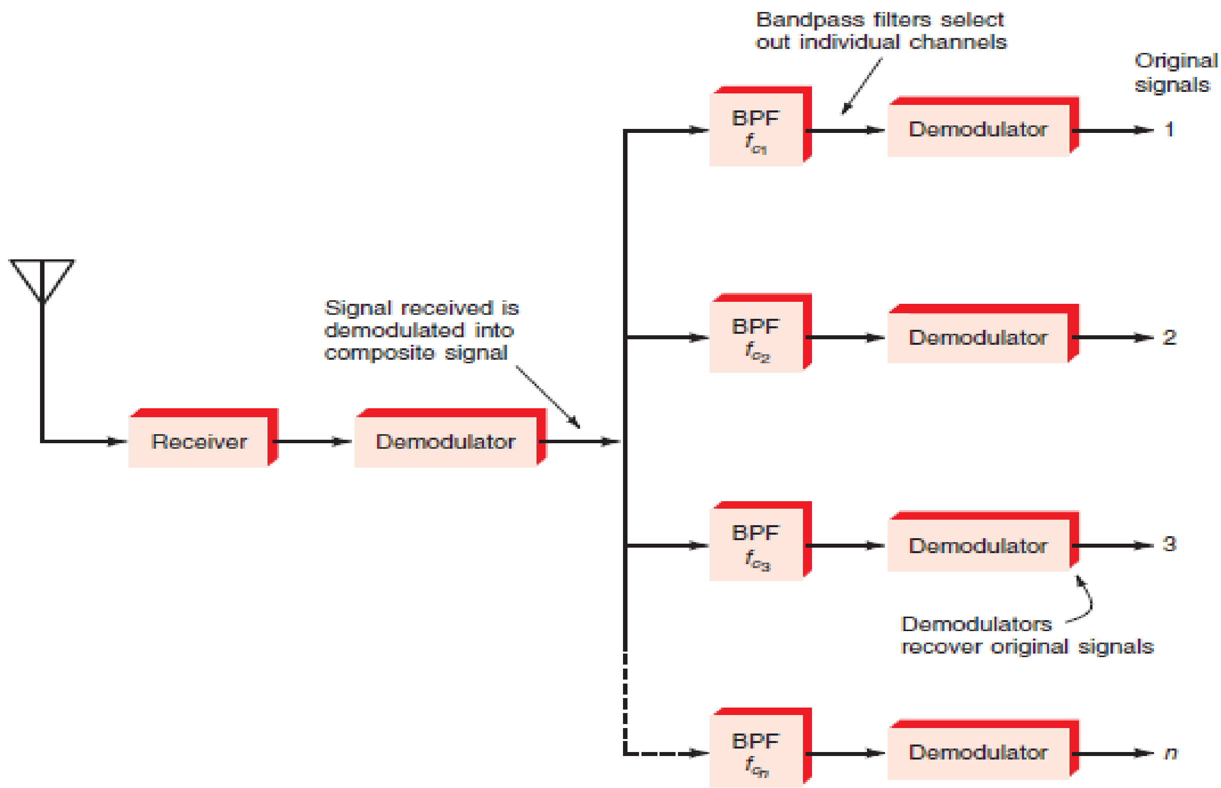


Fig : The Receiving end of an FDM

- The modulator outputs containing the sideband information are added algebraically in a linear mixer; no modulation or generation of sidebands takes place.
- The resulting output signal is a composite of all the modulated subcarriers. This signal can be used to modulate a radio transmitter or can itself be transmitted over the single communication channel. Alternatively, the composite signal can become one input to another multiplexed system.

(b). Receiver - Demultiplexers

- The receiving portion of an FDM system is shown in Fig. above.
- A receiver picks up the signal and demodulates it, recovering the composite signal.
- This is sent to a group of bandpass filters, each centered on one of the carrier frequencies.
- Each filter passes only its channel and rejects all others.
- A channel demodulator then recovers each original input signal.

ii. Time-Division Multiplexing

- In FDM, multiple signals are transmitted over a single channel, each signal being allocated a portion of the spectrum within thatbandwidth.
- In *time-division multiplexing (TDM),* each signal occupies the entire bandwidth of the channel. However, each signal is transmitted for only a brieftime.
- In other words, multiple signals take turns transmitting over the single channel, as in Fig. .

Figure The basic TDM concept.

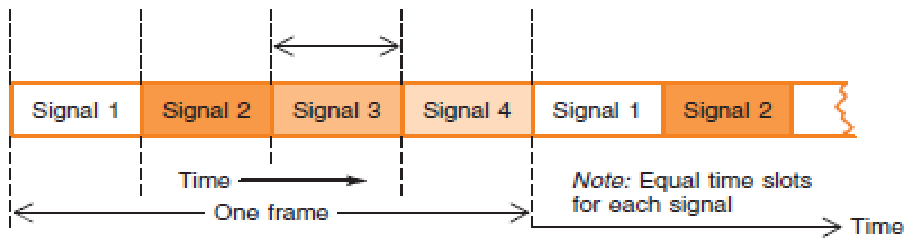


Fig: Basic TDM Concept

- Here, each of the four signals being transmitted over a single channel is allowed to use the channel for a fixed time, one after another. Once all four have been transmitted, the cycle repeats. One binary word from each source creates a frame. The frames are then repeated over and over again.
- TDM can be used with both digitaland analog signals.
- For example, if the data consists of sequential bytes, 1 byte of data from each source can be transmitted during the time interval assigned to a particular channel.
- Each of the time slots shown in Fig. above might contain a byte from each of four sources.
- One channel would transmit 8 bits and then halt, while the next channel transmitted 8 bits. The third channel would then transmit its data word, and so on. The cyc le would repeat itself at a high rate of speed.
- The transmission of digital data by TDM is straightforward in that the incremental digital data is already broken up into chunks, which can easily be assigned to different time slots.
- TDM can also be used to transmit continuous analog signals, whether they are voice, video, or telemetry-derived.

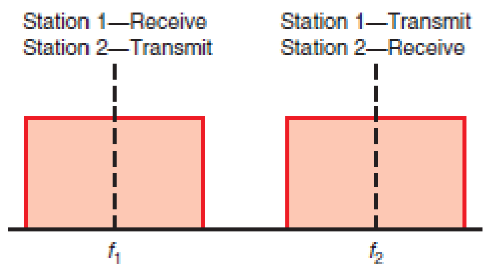
DUPLEXING

- Duplexing is the method by which two-way communications are handled.
- **Half duplexing** means that the two stations communicating take turns transmitting and receiving. Examples: Mobile, marine, and aircraft radios use half duplexing.
- **Full duplexing** means that the two stations can send and receive simultaneously.
- Full duplex is certainly preferred, as in phone calls. But not all systems require a simultaneous send/receive capability.
- There are two ways to provide duplexing—
  (1) Frequency-Division Duplexing (FDD) and
  (2) Time-Division Duplexing (TDD).

Frequency-Division Duplexing (FDD)

- The simplest and perhaps best way to provide full duplex is to use FDD, which utilizes two separate channels, one for send and another for receive. Fig. below shows the concept.

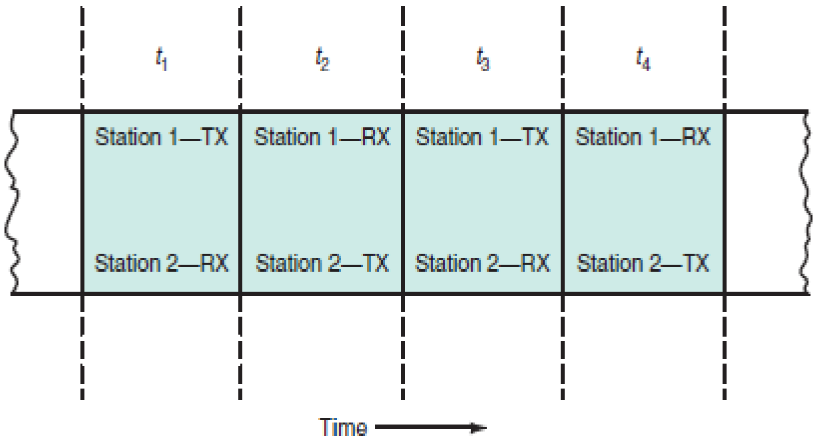
Figure Frequency-division duplexing (FDD).



- The communicating parties are called station 1 and station 2. Station 1 uses the channel around $f1$ for receiving only and the channel around $f2$ for transmitting. Station 2 uses $f1$ for transmitting and $f2$ for receiving.
- By spacing the two channels far enough apart, the transmitter will not interfere with the receiver. Selective filters keep the signals separated.
- The big disadvantage of this method is the extra spectrum space required. Spectrum space is scarce and expensive.
- Most cell phone systems use this method because it is the easiest to implement and the most reliable.

Time-Division Duplexing (TDD)

Figure Time-division duplexing (TDD).



- Time-division duplexing (TDD) means that signals are transmitted simultaneously on a single channel by interleaving them in different time slots. For example, alternating time slots are devoted to transmitting and receiving. This is illustrated inFig.
- During time slot *t*1, station 1 is transmitting (TX) while station 2 is receiving (RX). Then during time slot *t*2, station 1 is receiving while station 2 is transmitting.
- Each time slot may contain one data word, such as 1 byte from an A/D converter or a D/A converter.
- The primary benefit of TDD is that only one channel is needed. It saves spectrum space and cost. On the other hand, the TDD method is harder to implement.

3.3 MULTIPLE ACCESS TECHNIQUES

Multiple Access:

Multiple access refers to how the subscribers are allocated to the assigned frequency spectrum. Access methods are the ways in which many users share a limited amount of spectrum. These are similar to multiplexing methods.

The techniques include frequency reuse, frequency-division multiple access (FDMA), time-division multiple access (TDMA), code-division multiple access (CDMA), and spatial-division multiple access (SDMA).

Frequency Reuse:

- ❖ In frequency reuse, individual frequency bands are shared by multiple base stations and users. This is possible by ensuring that one subscriber or base station does not interfere with any others.
- ❖ This is achieved by controlling such factors as transmission power, base station spacing, and antenna height and radiation patterns.
- ❖ With low-power and lower-height antennas, the range of a signal is restricted to only a mile or so.
- ❖ (Refer Fig.) in any given city, the same frequencies are used over and over simply by keeping cell site base stations isolated from one another.

Figure Horizontal antenna radiation pattern of a common cell site showing 120° sectors that permit frequency reuse.

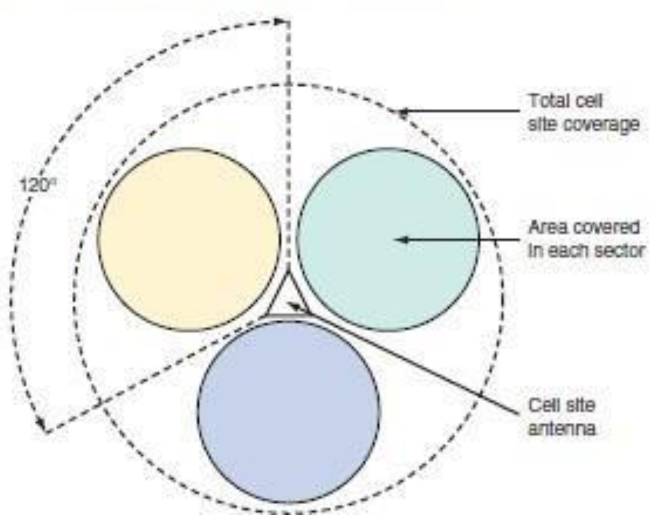


Fig : Antenna radiation pattern

Frequency-Division Multiple Access:

FDMA:

It stands for Frequency division multiple access.

- The entire allocated radio spectrum is divided into many slices of the frequency bands and each band or channel is allocated to user. The channel allocation can be done on a demand basis to the users to request service.
- When a call is processed, no other user can share the same channel.
- Users are assigned a pair of frequencies, one for forward channel and other for reverse channel.

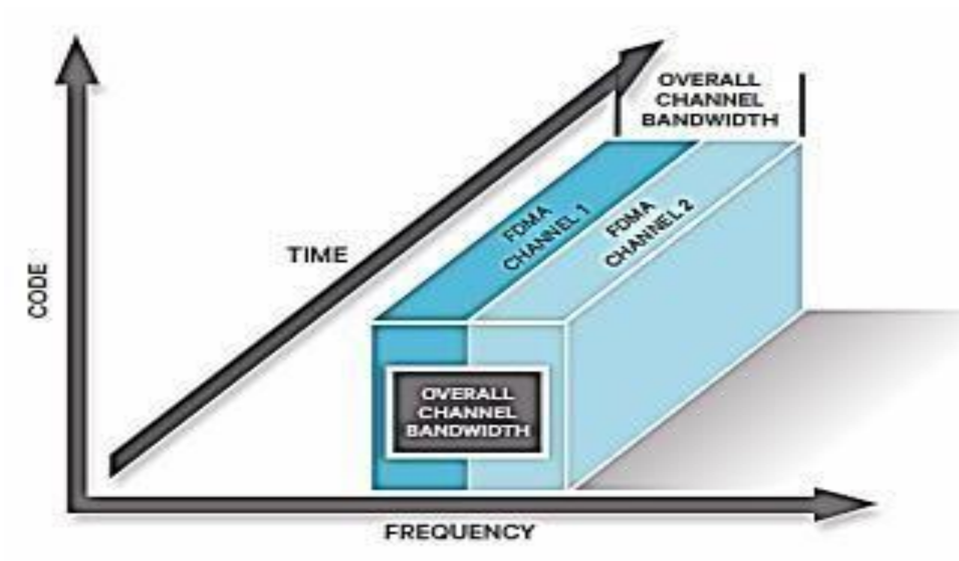


Fig: FDMA

Features:

- No synchronization necessary
- Complexity of system islow
- All stations can operate continuously 24 hours without having to wait for their turn to come.
- Hard handover is done.

Time Division Multiple Access TDMA:

It stands for time division multiple access.

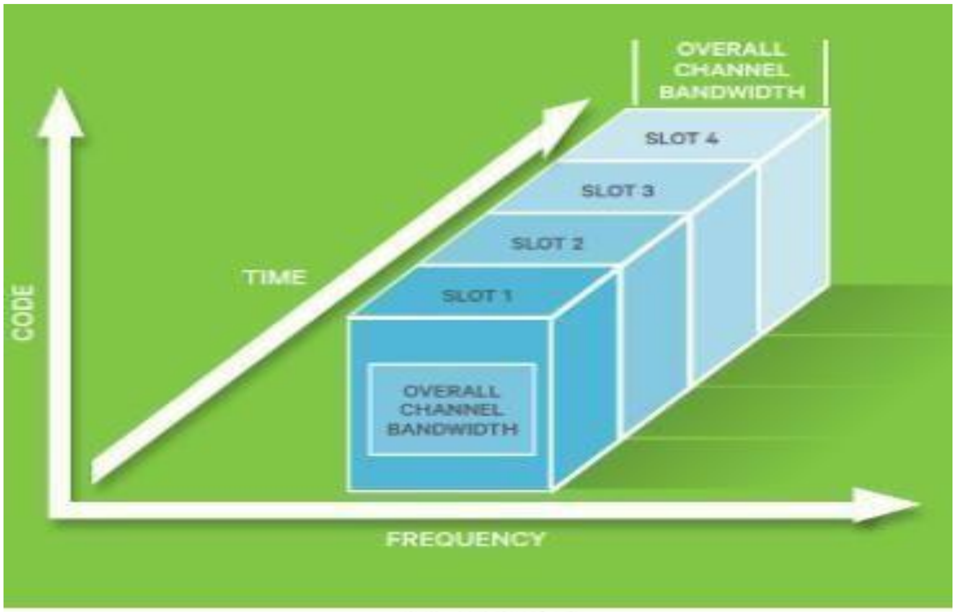


Fig: TDMA

- It uses time instead of frequency. Different users share same time slots of the complete time available.
- Each user is allocated a time slot in which user can access the channel.
- Transmission of data is in "burst and buffer" method. The transmission from different users is interfaced into repeating frame structure.

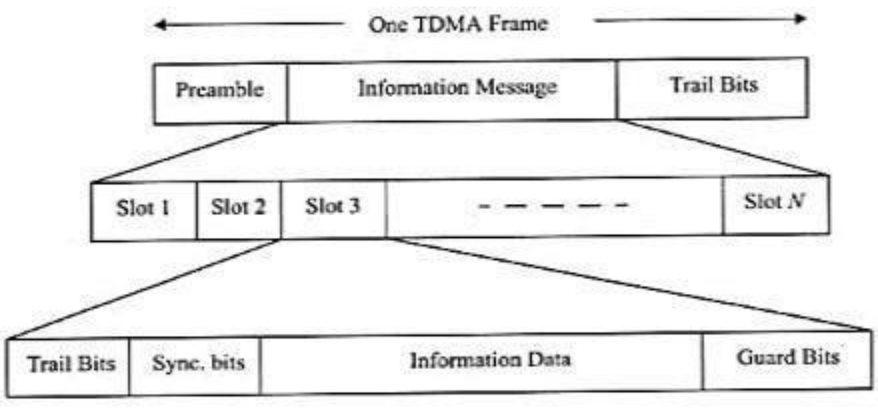


Fig: TDMA frame structure

A frame consists of a no of slots. Each frame consists of preamble, an information message and trail bits. Half of the time slots are used for forward link channels and remaining for reverse link channe ls.

Guard bits are used to provide synchronization of different receivers between different time slots and frames.

- Guard time needs to be minimized
- Transmission rates are high.
- Handoff process is simple.

Code Division Multiple Access **CDMA:**

It stands for Code division multiple access.

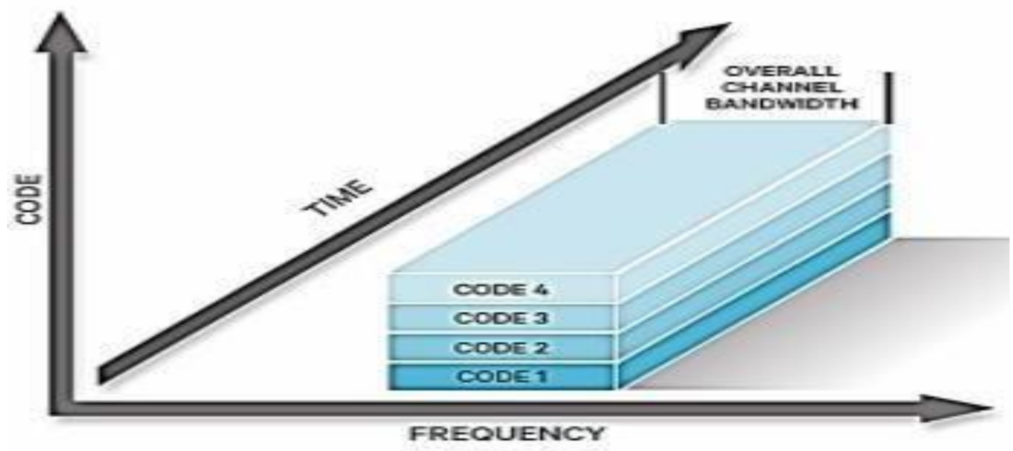


Fig: CDMA

- Users share the same carrier frequency(fc). The narrow band message signal is also multiplexed with a spreading signal of larger bandwidth. This spreading signal is pseudo noise code sequence and it has higher chip rate than rate of message.
- The main advantage is reduced level of interference. As each user is allocated an individual pseudo random codeword that is orthogonal to the codewords of the other users that the receiver end receives, tunes to receive the intended signal of the user.
- Same channel is used by several users, there may be a problem of near-far-effect. To reduce this power control is implemented at the base station.

Features:

- Self- jamming is a problem
- Soft handoff is done
- Multipath fading can be reduced as signal is spread over a large spectrum.