UNIT 2: MODULATION AND ENCODING

Structures **Page No.**

2.0 INTRODUCTION

Electronic communication has become an analogy for the communication in the present era of electronic gadgets. As a general concept, we can say that transfer of information from one place to another is communication. A significant point about communication is that it involves a sender (transmitter) and a receiver. Only a sender or a receiver can not complete the process of communication. Therefore dual process of "transmitting and receiving" or "coding and decoding" information can be called as communication making it a two way process. In this unit we will discuss about different modulation and encoding techniques. In this unit both analog and digital modulation will be discussed. Further, this unit we will explore how analog signal are converted into digital system and vice-versa.

2.1 OBJECTIVES

After going through this unit, you should be able to:

- Know the concept of modulation
- Understand the different Analog Modulation techniques
- Differentiate between analog and digital modulation
- Know process of analog to digital signal conversion
- Understand the sampling and quantization process
- Know the digital to analog signal conversion process
- Understand the Digital Modulation techniques

2.2 NEED FOR MODULATION

Normal communication signals loose strength as they travel to the large distances. Hence, we often transmit the signals through electromagnetic waves and we use antennas to recover them at a remote point. To send transmitting message signals effectively for long distances, we use Modulation. At the receiver end, after receiving the signal, we need to "move" them back to the original frequency band (baseband) through demodulation. Therefore, we can see the modulation task as "giving wings" to the information message. However, the original information is retrieved at the receiver end.

2.3 MODULATION

Often, the message being communicated is itself a signal, e.g., an audio signal, and to produce a signal that is suitable for transmission through the channel, we effect some transformation on the message signal. Modulation is the Process by which a property or a parameter of a signal is varied in proportion to another signal. The original signal is normally referred as the modulating signal and the high frequency signal, whose properties are changed, is referred as the carrier signal. The resulting signal is finally referred as the modulated signal.

For example in case of the amplitude modulation, the amplitude of the carrier wave is varied in accordance with the amplitude of the message signal, whereas in the angle modulation, phase angle of the carrier is varied with respect to the message signal.

Benefits of Modulation

1. Modulation can shift the frequency spectrum of a message signal into a band which is better suited to the channel. Antennas only efficiently radiate and admit signals, whose wavelength is similar to their physical aperture. Hence, to transmit and receive, say, voice, by radio we need to shift the voice signal to a much higher frequency band.

2. Modulation permits the use of multiplexing. Multiplexing means allowing simultaneous communication by multiple users on the same channel. For instance, the radio frequency spectrum must be shared and modulation allows users to separate themselves into bands.

3. Modulation can provide some control over noise and interference. For example the effect of noise can be controlled to a large extent by frequency modulation.

Modulation can be classified into two categories Analog Modulation and Digital Modulation. Let's see what are these Analog Modulation and Digital Modulation in detail.

Analog Modulation

Analog modulation is the simplest form of the modulation. In analog modulation, the modulation is applied continuously in response to the analog information signal. The process of the analog modulation has been shown in the Figure 1, below. Here the original signal at the baseband frequency has been shifted to the broadband frequency (F_c) .

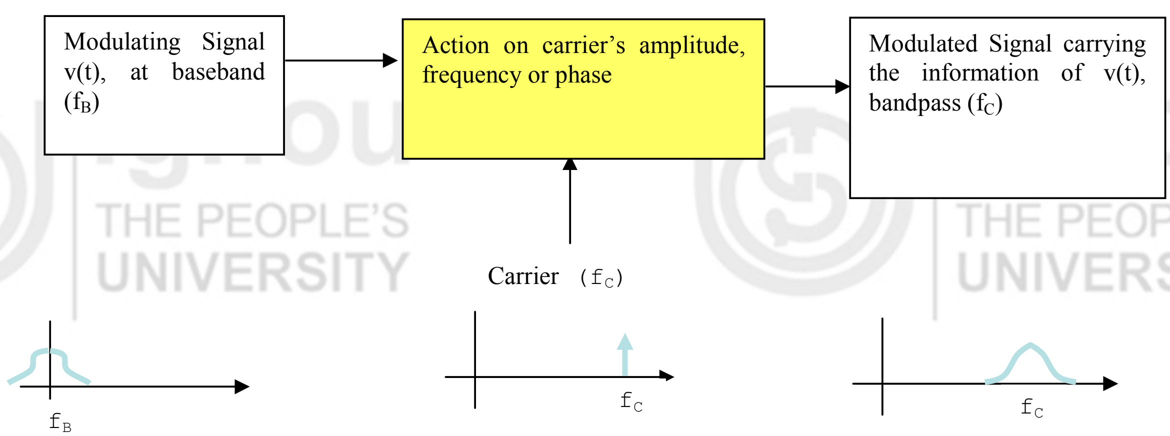

Figure 1: Process of the Analog Modulation

Common analog modulation techniques are:

1. Amplitude Modulation (AM): Here the amplitude of the carrier signal is varied in accordance to the instantaneous amplitude of the modulating signal.

2. Angle Modulation: Here the frequency or phase of the carrier signal is varied in accordance with the strength of the modulating signal. Consequently, the Analog Modulation has two forms:

   i) Frequency Modulation (FM): In this case, the frequency of the carrier signal is varied in accordance to the instantaneous frequency of the modulating signal)

   ii) Phase Modulation (PM): In this case, the phase of the carrier signal is varied in accordance to the instantaneous phase of the modulating signal)

2.4 AMPLITUDE MODULATION

Amplitude modulation (AM) is a technique used in electronic communication, most commonly for transmitting information via a high frequency carrier wave. AM works by varying the strength of the transmitted signal in relation to the information being sent. For example, changes in signal strength may be used to specify the sounds to be reproduced by a load speaker, or the light intensity of television pixels. "Undulatory currents" are the initial implementations of the Amplitude modulation. These were the first method to successfully produce quality audio over telephone lines in 1870's. The Figure 2 illustrates the process of modulation, by showing the modulating, carrier and modulated signals. Figure 3, further illustrates the Amplitude modulation process by varying the amplitudes of the modulating (input signal) and plotting the corresponding modulated signal.

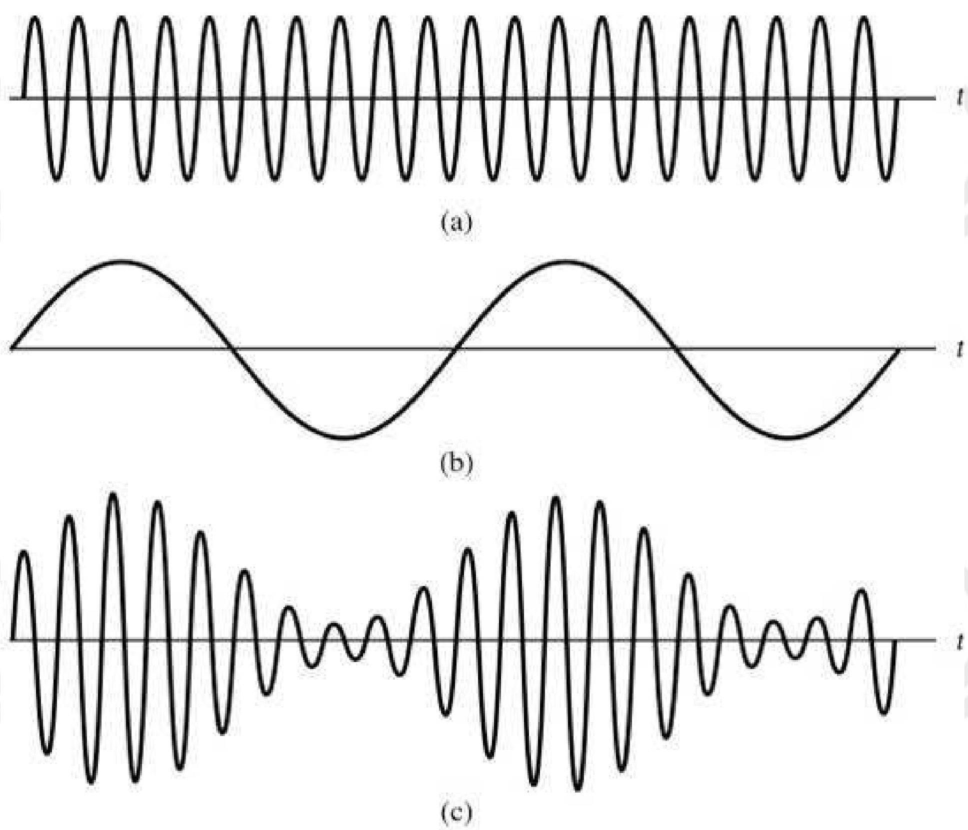

Figure 2: a) Carrier Signal, b) Modulating Signal, c) Modulated Signal

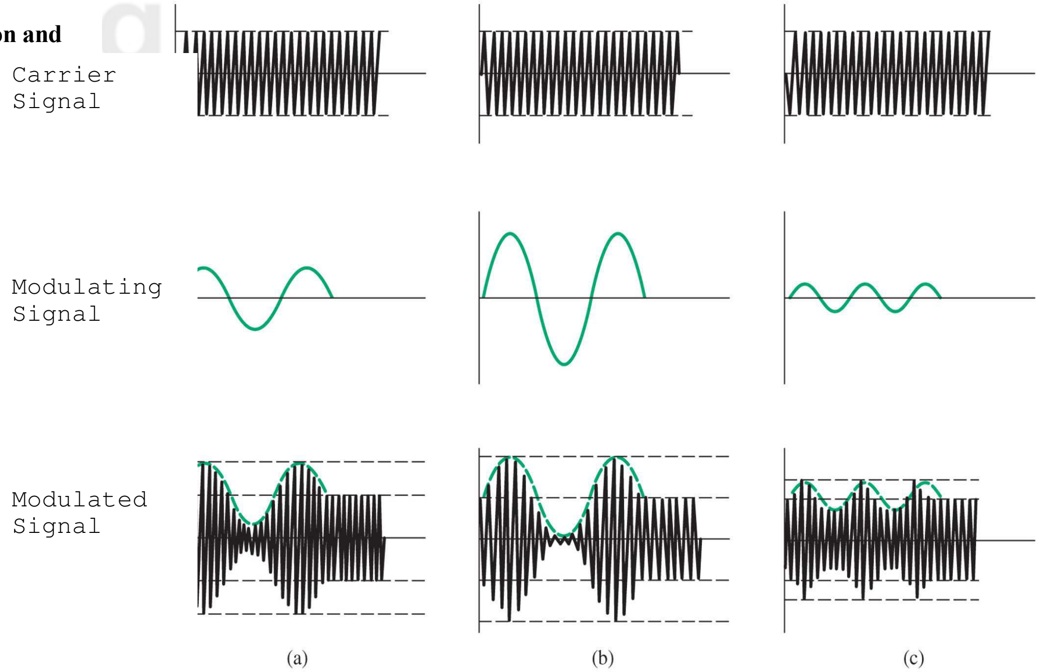

Figure 3: AM Modulation with varying amplitudes of the input signal

Advantages and Disadvantages

Advantages of Amplitude Modulation

1. Coverage area of AM Receiver is wider than FM because atmospheric propagation
2. AM is long distance propagation because of its high power.
3. AM Circuit is the cheapest and least complex,
4. AM can be easily demodulated using a Diode Detector.

Disadvantages of Amplitude Modulation

1. Amplitude modulation is very much sensitive to noise and hence the performance is very weak.
2. Signal of AM is not stronger than FM when it propagates through and obstacle.
3. Only one sideband of AM transmits Information Signal, so it loses power on other sideband and Carrier. Hence the power efficiency of the Amplitude Modulation is very poor.
4. Noise mixes AM Signal in amplitude when it propagates in free space that it makes it difficulty to recover the original signal at receiver in a highly noisy environment.

☞ Check Your Progress 1

1. What is the need for modulation?

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2. What are Analog modulation techniques?

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3. Define amplitude modulation.

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4. What are the limitations of amplitude modulation?

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2.5 FREQUENCY MODULATION

Frequency modulation, FM is widely used for a variety of radio communications applications. FM broadcasts on the VHF bands still provide exceptionally high quality audio, and FM is also used for a variety of forms of two way radio communications, and it is especially useful for mobile radio communications, being used in taxis, and many other forms of vehicle. in view of its widespread use, frequency modulation, FM, is an important form of modulation, despite many forms of digital transmission being used these days. Since its first introduction the use of frequency modulation, FM has grown enormously. Now wideband FM is still regarded as a very high quality transmission medium for high quality broadcasting. FM, is also widely used for communications where it is resilient to variations in signal strength.

Frequency Modulation is the technique in which, the frequency of the carrier wave is changed in accordance with the Amplitude of the modulating signal. The process is shown in the Figure 4 below.

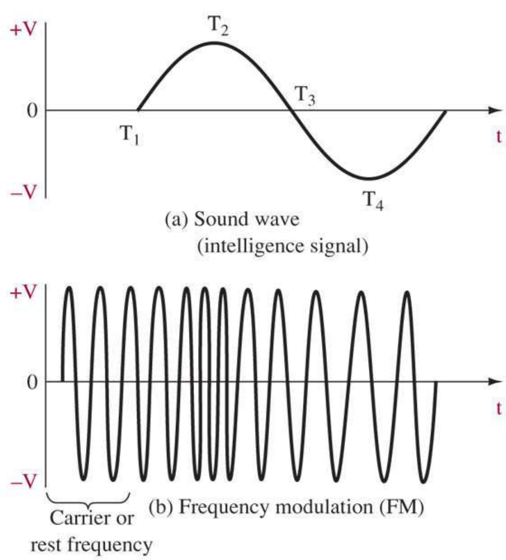

Figure 4: FM representation.

Advantages of Frequency Modulation

There are many advantages of using frequency modulation. These have been widely used for many years, and will remain in use for many years.

- Resilient to noise: One of the main advantages of frequency modulation is that it has been utilised by the broadcasting industry to take care of noise. As most noise is amplitude based, this can be removed by running the signal through a limiter so that only frequency variations appear. This is provided that the signal level is sufficiently high to allow the signal to be limited.

- Resilient to signal strength variations: Signal variations are reduced since noise effect is eliminated. This means that one of the advantages of frequency modulation is that it does not suffer amplitude variations as the signal level varies, and it makes FM ideal for use in mobile applications where signal levels constantly vary. This is provided that the signal level is sufficiently high to allow the signal to be limited.

- Does not require linear amplifiers in the transmitter: As only frequency changes are required to be carried, any amplifiers in the transmitter do not need to be linear.

- Enables greater efficiency than many other modes: The use of non-linear amplifiers, e.g. class C, etc. means that transmitter efficiency levels will be higher - linear amplifiers are inherently inefficient.

Disadvantages of Frequency Modulation

There are a number of dis-advantages to the use of frequency modulation. Some are can be overcome quite easily, but others may mean that another modulation format is more suitable.

- Requires more complicated demodulator: One of the minor dis-advantages of frequency modulation is that the demodulator is a little more complicated, and hence slightly more expensive than the very simple diode detectors used for AM. Also requiring a tuned circuit adds cost. However this is only an issue for the very low cost broadcast receiver market.

- Some other modes have higher data spectral efficiency: Some phase modulation and quadrature amplitude modulation formats have a higher spectral efficiency for data transmission that frequency shift keying, a form of frequency modulation. As a result, most data transmission system uses the digital transmission techniques such as PSK and QAM.

- Sidebands extend to infinity either side: The sidebands for an FM transmission theoretically extend out to infinity. To limit the bandwidth of the transmission, filters are used, and these introduce some distortion of the signal.

Comparison of FM and AM Transmission

Both the Amplitude and Frequency Modulation have their own advantages and disadvantages. However a comparison of the general performance is shown in the table 1 below:

Table 1: Comparison of AM and FM

S. No.	AM Broadcasting	FM Broadcasting
1.	It requires smaller transmission bandwidth	It requires larger bandwidth.
2.	It can be operated in low, medium and high frequency bands.	It needs to be operted in very high and high frequency bands.
3.	It has wider coverage.	Its range is restricted to 50 km.
4.	The demodulation is simple.	The process of demodulation is complex.
5.	The stereophonic transmission is not possible.	In this, stereophonic transmission is possible.
6.	The system has poor noise performance.	It has an improved noise performance.
7.	The AM signal reception does not have any threshold in the useful range of signal noise ratio (SNR).	The FM signal recepition exhibits a three the useful range of signal noise ratio (SM, SNR value should be higher than the ????

2.6 PHASE MODULATION

Frequency Modulation and the Phase Modulation are the two forms of the angle modulation. The main characteristic of the angle modulation is that the amplitude of the carrier frequency is maintained constant, whereas the frequency or phase is changed. In the phase modulation, the phase of the carrier wave is shifted in accordance with the amplitude of the modulating frequency. Phase modulation is a form of modulation that can be used for radio signals used for a variety of radio communications applications. As it will be seen later that phase modulation and frequency modulation are closely linked together and it is often used in many transmitters and receivers used for a variety of radio communication applications from two way radio communications links, mobile radio communications and even maritime mobile radio communications. Phase modulation is also the basis for many forms of digital modulation based around phase shift keying, PSK which is a form of phase modulation. As various forms of phase shift keying are the favored form of modulation for digital or data transmissions, this makes phase modulation particularly important.

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. This 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 wave.

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. 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. The information regarding sidebands, bandwidth and the like also hold true for phase modulation as they do for frequency modulation, bearing in mind their relationship.

Unlike its more popular counterpart, i.e. frequency modulation (FM), PM is not very widely used for radio transmissions. This is because it tends to require more complex receiving hardware and there can be ambiguity problems in determining whether, for example, the signal has changed phase by +180° or -180°. PM is used, however, in digital music synthesizers such as the Casio CZ synthesizers, or to implement FM Synthesis in digital synthesizers such as the Yamaha DX7. The Phase modulation signals have been illustrated in the Figure 5 and Figure 6 below.

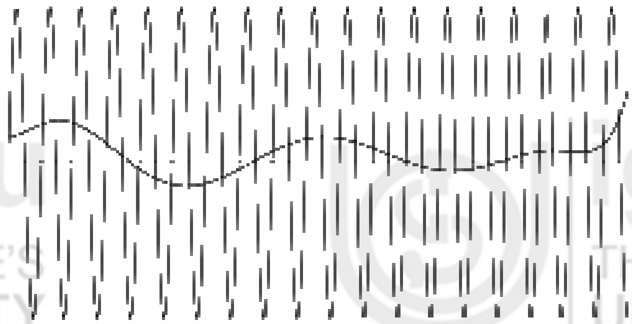

Figure 5: Modulating Signal and the Carrier Wave

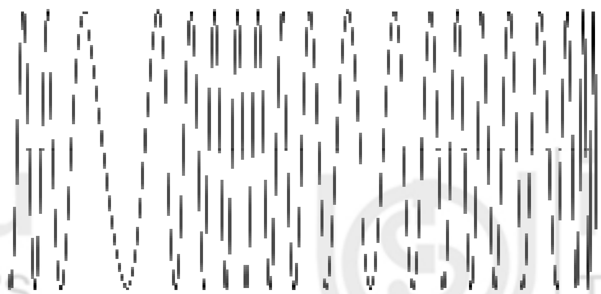

Figure 6: Modulated Wave

☞ Check Your Progress 2

1. Define Frequency Modulation.

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2. What do you know by angle modulation?

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3. What are limitations of AM?

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2.7 DIGITAL COMMUNICATION

Digital communication is the process of communication in which, the signals are transferred in the form of discrete formats rather than the continuous analog forms. Digital communication is very common in the present day communication systems and the signals are normally transmitted in binary formats. It is always easy to process the digital information as compared to the analog signals, because of their discrete nature and hence they have become more popular in the electronic communication. However, the voice based communication is Analog in nature, the signals needs to be converted into the digital formats to process in through the digital communication systems. The opposite process happens, while reconstructing the voice signal at the receiver end. A device called Modem (Modulator + demodulator) in the process. A modem (modulator-demodulator) is a device that modulates an analog carrier signal to encode digital information, and also demodulates such a carrier signal to decode the transmitted information. The goal is to produce a signal that can be transmitted easily and decoded to reproduce the original digital data. The basic process is depicted in the Figure 7 below.

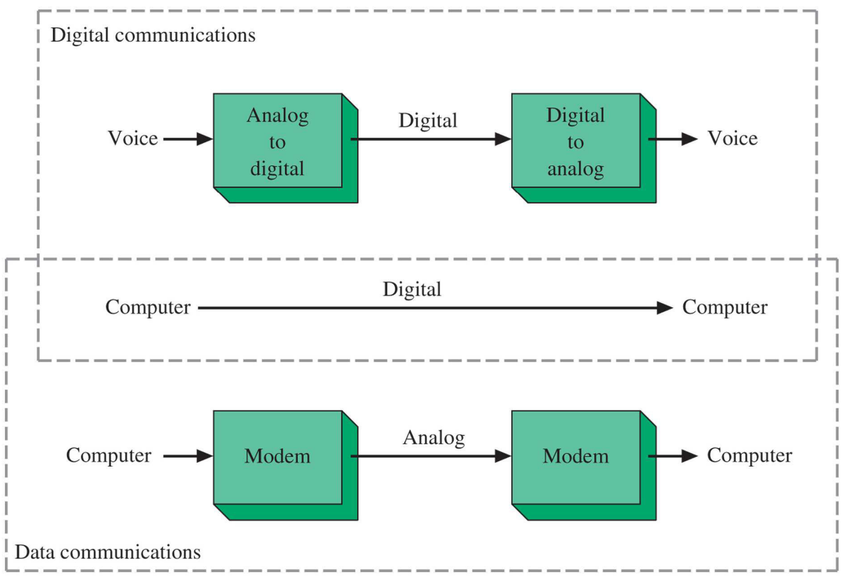


Figure 7: Digital Communication System

Advantages of Digital Communication

1. Reliable communication
2. Less sensitivity to changes in environmental conditions (temperature, etc.)
3. Easy multiplexing
4. Easy signaling
5. Voice and data integration
6. Easy processing like encryption and compression

7. Easy system performance monitoring
8. Quality of Service monitoring
9. Better Signal to Noise Ratio
10. Easy Regeneration of signals

Disadvantages

1. Increased bandwidth requirement for the communication channels.
2. Need for precision timings (Bit, character, frame synchronization needed)
3. Need for the Analog to Digital and Digital to Analog conversions
4. Higher complexity of the system design

Sampling

Digital communication uses the discrete signals; hence the natural analog signals needs to be converted to the discrete signals, in order to process them digitally. For this, purpose a technique known as sampling is employed. In electronic signals, sampling is the reduction of a continuous signal to a discrete signal. A sample refers to a value or set of values at a point in time and/or space. The process is illustrated in the Figure 8 below.

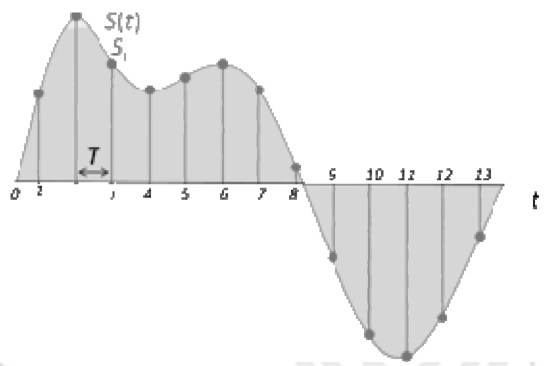


Figure 8: Sampling from the Analog Signals

Sampling is the first step towards the digitization. However, in order to codify these samples, the flat top sampling is most widely used. The block diagram of the natural and flat top sampling has been shown in the Figure 9 below.

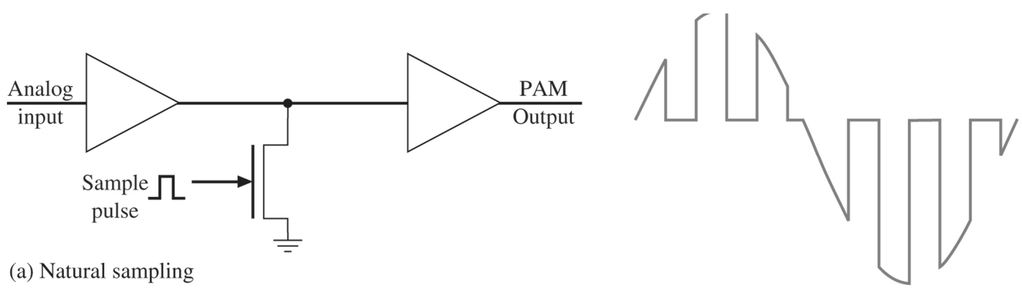
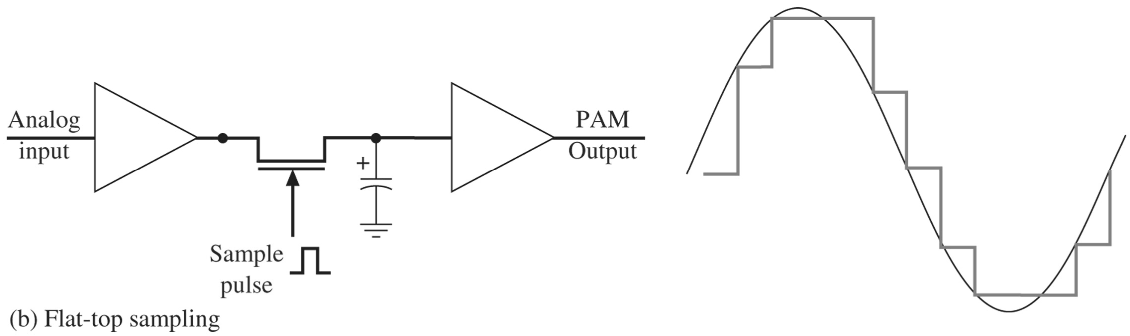


Figure 9: a) Natural sampling



(b) Flat-top sampling

Figure 9: b) flat-top sampling

Once we get the samples, these samples are then quantized as per the voltage levels and finally converted to the binary codes to process them digitally. This process along with corresponding voltage levels and binary codes are shown in the Figure 9 b above.

Analog to Digital Conversion

An analog-to-digital converter (ADC, A/D) is a device that converts the input continuous physical quantity to a digital number that represents the quantity's amplitude. Instead of doing a single conversion, an ADC often performs the conversions ("samples" the input) periodically. The result is a sequence of digital values that have converted a continuous-time and continuous-amplitude analog signal to a discrete-time and discrete-amplitude digital signals. The most commonly employed A/D converter is the Ramp based circuit. It uses a comparator to compare the voltage levels

Digital to Analog Conversion

Digital to analog converter is the electronic circuit, which takes digital input and converts this into an analog waveform. A common use of digital-to-analog converters is generation of audio signals from digital information in music players. Digital video signals are converted to analog in television and cell phones to display colors and shades

2.8 DIGITAL MODULATION TECHNIQUES

There are three major classes of digital modulation techniques used for transmission of digital data:

- Amplitude Shift Keying
- Frequency Shift Keying(FSK)
- Phase-shift keying (PSK)

All of these processes convey the data by changing some aspect of a carrier wave, in response to a data signal.

2.9 AMPLITUDE SHIFT KEYING (ASK)

Amplitude-shift keying (ASK) is a form of modulation that represents digital data as variations in the amplitude of a carrier wave.

Any digital modulation scheme uses a finite number of distinct signals to represent digital data. ASK uses a finite number of amplitudes, each assigned a unique pattern of binary. Usually, each amplitude encodes an equal number of bits. Each pattern of bits forms the symbol that is represented by the particular amplitude. The demodulator, which is designed specifically for the symbol-set used by the modulator, determines the amplitude of the received signal and maps it back to the symbol it represents, thus recovering the original data. Frequency and Phase of the carrier are kept constant.

Like Amplitude Modulation, ASK is also linear and sensitive to atmospheric noise, distortions, propagation conditions on different routes in PSTN (Public Switched Telephone Network) etc. Both ASK modulation and demodulation processes are relatively inexpensive. The ASK technique is also commonly used to transmit digital data over optical fiber. For LED transmitters, binary 1 is represented by a short pulse of light and binary 0 by the absence of light. Laser transmitters normally have a fixed "bias" current that causes the device to emit a low light level. This low level represents binary 0, while a higher-amplitude light wave represents binary 1. The simplest and most common form of ASK operates as a switch, using the presence of a carrier wave to indicate a binary one and its absence to indicate a binary zero. This type of modulation is called on-off keying, and is used at radio frequencies to transmit Morse code.

More sophisticated encoding schemes have been developed which represent data in groups using additional amplitude levels. For instance, a four-level encoding scheme can represent two bits with each shift in amplitude; an eight-level scheme can represent three bits; and so on. These forms of amplitude-shift keying require a high signal-to-noise ratio for their recovery, as by their nature much of the signal is transmitted at reduced power.

2.10 FREQUENCY SHIFT KEYING

Frequency-shift keying (FSK) is a frequency modulation scheme in which digital information is transmitted through discrete frequency changes of a carrier wave. The simplest FSK is a binary FSK (BFSK). BFSK uses a pair of discrete frequencies to transmit binary (0s and 1s) information. With this scheme, the "1" is called the mark frequency and the "0" is called the space frequency.

FSK Transmitter

The block diagram of the FSK modulator is shown below in Figure 10. The modulating signal and the carrier frequency are fed to the frequency modulator circuitry and correspondingly the output is transmitted in the form of a signal with varied frequency.

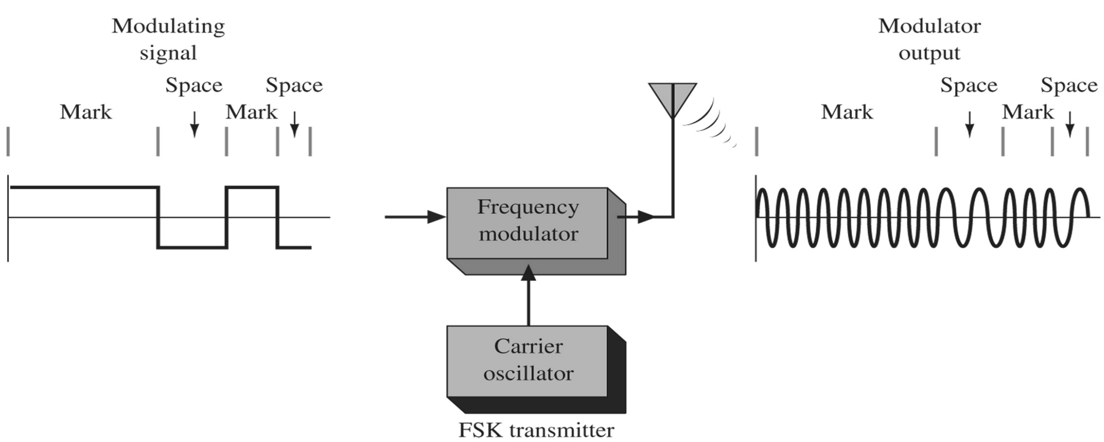


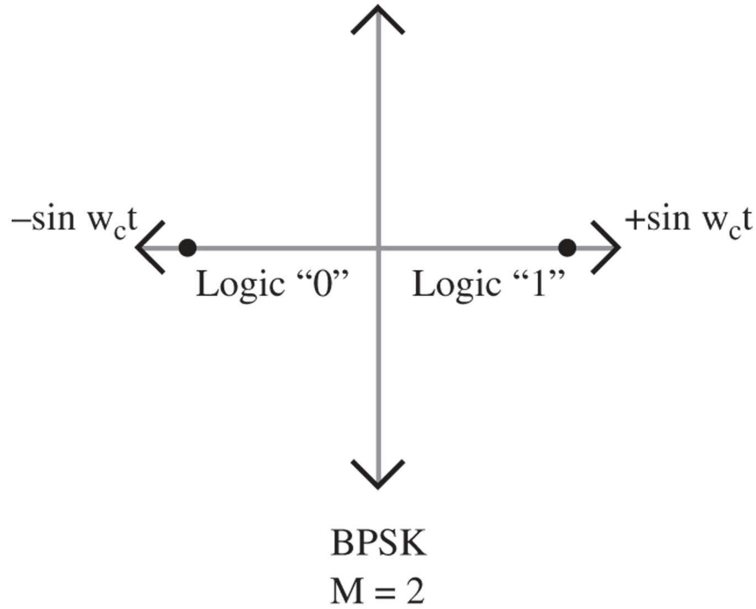
Figure 10: FSK Modulator

2.11 PHASE SHIFT KEYING

Phase-shift keying (PSK) is a digital modulation scheme that communicates the data by changing, or modulating, the phase of the carrier wave. Any digital modulation scheme uses a finite number of distinct signals to represent digital data. PSK uses a finite number of phases, each assigned a unique pattern in the form of a binary code. Each pattern of bits forms the symbol that is represented by the particular phase. On the other hand, the demodulator is designed specifically for the symbol-set used by the modulator. It determines the phase of the received signal and maps it back to the symbol it represents, thus recovering the original data. This requires the receiver to be able to compare the phase of the received signal to a reference signal. Another simple way of operation is that instead of operating with respect to a constant reference wave, the broadcast can operate with respect to itself. Changes in phase of a single broadcast waveform can be considered the significant items. In this system, the demodulator determines the changes in the phase of the received signal rather than the phase (relative to a reference carrier wave) itself. Since this scheme depends on the difference between successive phases, it is termed differential phase-shift keying (DPSK). DPSK can be significantly simpler to implement than ordinary PSK since there is no need for the demodulator to have a copy of the reference signal to determine the exact phase of the received signal.

Like any form of shift keying, there are defined states or points that are used for signaling the data bits. The basic form of binary phase shift keying is known as Binary Phase Shift Keying (BPSK) or it is occasionally called Phase Reversal Keying (PRK). A digital signal alternating between +1 and -1 (or 1 and 0) will create phase reversals, i.e. 180 degree phase shifts as the data shifts state. This has been illustrated in the Figure 11 below.

The problem with phase shift keying is that the receiver cannot know the exact phase of the transmitted signal to determine whether it is in a mark or space condition. This would not be possible even if the transmitter and receiver clocks were accurately linked because the path length would determine the exact phase of the received signal. To overcome this problem PSK systems use a differential method for encoding the data onto the carrier. This is accomplished, for example, by making a change in phase equal to a one, and no phase change equal to a zero. Further improvements can be made upon this basic system and a number of other types of phase shift keying have been developed. One simple improvement can be made by making a change in phase by 90 degrees in one direction for a one, and 90 degrees the other way for a zero. This retains the 180 degree phase reversal between one and zero states, but gives a distinct change for a zero. In a basic system not using this process it may be possible to loose synchronization if a long series of zeros are sent. This is because the phase will not change state for this occurrence. There are many variations on the basic idea of phase shift keying. Each one has its own advantages and disadvantages enabling system designers to choose the one most applicable for any given circumstances. Other common forms include QPSK (Quadrature phase shift keying) where four phase states are used, each at 90 degrees to the other, 8-PSK where there are eight states used and so forth. For an example the output of a BPSK modulator circuit for a 1010101 input is shown in figure 11.



A BPSK signal

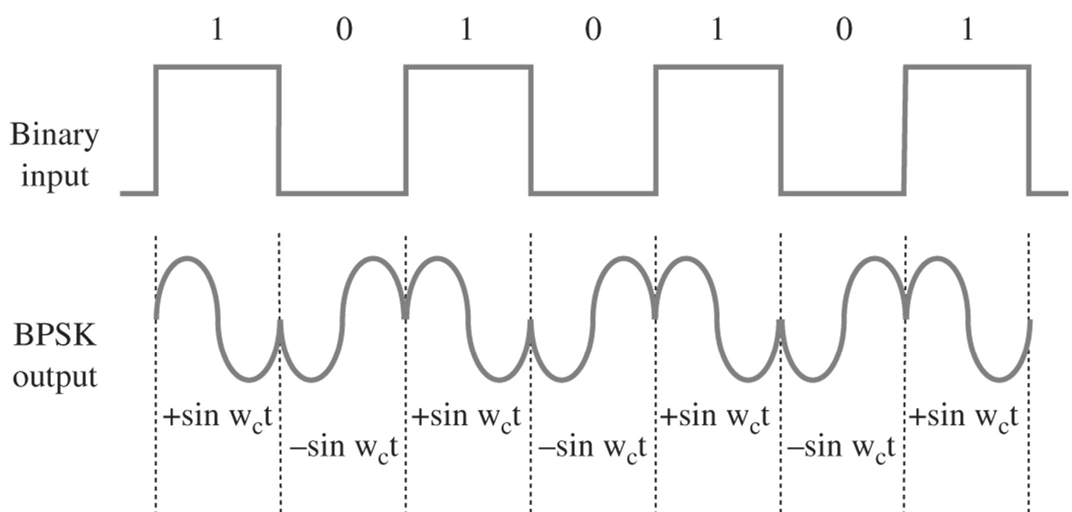


Figure 11: The output of a BPSK modulator circuit for a 1010101 input.

☞ Check Your Progress 3

1. What are the different digital modulation techniques?

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2. How many different phase states are used in BPSK and QPSK?

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3. Why digital modulation is better than the Analog Modulation?

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2.12 SUMMARY

After completing this unit we are sure that you have understood the term modulation. Why modulation is need in out communication systems. In this unit we have studied about different modulation techniques both analog and digital modulation type. We have also discussed different techniques for converting the analog signals into digital system and vice-versa.

2.13 REFERENCES/FURTHER READING

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2.14 SOLUTIONS/ANSWERS

☞ **Check Your Progress 1**

1. To send transmitting message signals effectively for long distances, we use Modulation.

2. The Analog modulation techniques are:
   a) Amplitude modulation
   b) Angle modulation
      i) Frequency modulation
      ii) Phase modulation.

3. This is defined as the modulation, in which amplitude of carrier is changed in accordance to the amplitude of the modulating signal.

4. The amplitude modulation suffers from the following limitations

i) The useful power is contained in the sidebands and even at 100% modulation the and contain only 33% of the total power and hence the modulation efficiency is poor.

ii) Due to poor efficiency, the transmitters employing amplitude modulation have very poor range.

iii) The reception in this modulation is noisy. The radio receiver picks up all the surrounding noise along with the signal.

☞ Check Your Progress 2

1. Frequency Modulation is the technique in which, the frequency of the carrier wave is changed in accordance with the Amplitude of the modulating signal.

2. It is possible to convey or transmit information by varying its frequency as well as angle of phase. These are known as frequency and phase modulations respectively and both collectively are known as "Angle Modulation". The frequency and phase modulation systems have similar characteristics with minor differences.

   Briefing we can say angle modulations of two types:

   i) Frequency modulation

   ii) Phase modulation

3. Limitations of AM:

   i) Power of carrier and of one side band is useless.

   ii) The AM reception is noisy.

   iii) The BW is much less.

   iv) Only two S.Bs are available.

☞ Check Your Progress 3

1. There are three major classes of digital modulation techniques used for transmission of digitally represented data:

   - Amplitude Shift Keying
   - Frequency Shift Keying(FSK)
   - Phase-shift keying (PSK)

2. BPSK uses two different phase states and each one differs by 180^o , whereas the QPSK uses four different phases and each one differs by 90^o.

3. i) It is easy to process the digital information.

   ii) Digital systems are less prone to noise.

   iii) Digital signals can be easily re-transmitted.