

Module 2

Data Communication Fundamentals

Lesson 5

Analog Data to Analog Signal

Specific Instructional Objective

On completion, the student will be able to:

- Explain the need for Modulation
- Distinguish different modulation techniques
- Identify the key features of Amplitude modulation
- Explain the advantages of SSB and DSBSC transmission
- Explain how the baseband signal can be recovered

2.5.1 Introduction

Although transmission of digital signal is preferred, it is not always feasible to transmit in digital form because it requires channel of high bandwidth having low pass characteristics. On the other hand, an analog transmission requires lower bandwidth having band pass characteristics. The process involved in analog transmission is known as **modulation**, which requires manipulation of one or more of the parameters of the carrier that characterizes the analog signal. Figure 2.5.1 depicts the modulation process to get analog signal.

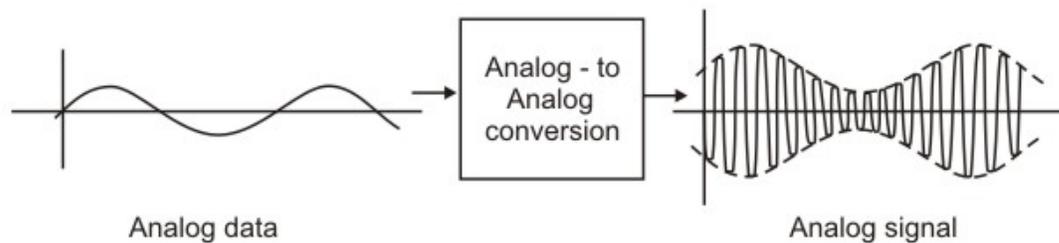


Figure 2.5.1 Translation of analog data to analog signal

Some of the important advantages of modulation are summarized below:

Frequency translation: Modulation translates the signal from one region of frequency domain to another region. This helps to transmit the modulated signal with minimum attenuation through a particular medium.

Practical size of antenna: Modulation translates baseband signal to higher frequency, which can be transmitted through a bandpass channel using an antenna of smaller size. This has made communication practical.

Narrowbanding: As modulation translates a signal from lower frequency domain to higher frequency domain, the ratio between highest to lowest frequency of the modulated signal becomes close to 1.

Multiplexing: Different base band signals originating from different sources can be translated to different frequency ranges. This allows transmission of different signals through the same medium using frequency division multiplexing (FDM) to be discussed in the following lesson.

The modulation technique can be broadly divided into two basic categories; Amplitude modulation and Angle modulation. The Angle modulation can be further divided into two more categories; Frequency and Phase modulations as shown in Fig. 2.5.2. Various modulation techniques are discussed in the following sections.

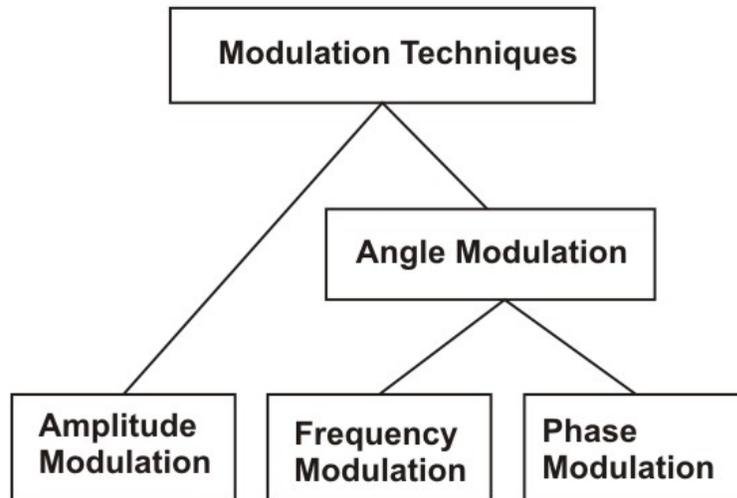


Figure 2.5.2 Categories of modulation techniques

2.5.2 Amplitude Modulation (AM)

This is the simplest form of modulation where the amplitude of the carrier wave is modulated by the analog signal known as the *modulating signal*. A signal to be modulated, a carrier and the modulated signal are shown in Fig. 2.5.3. Let the modulating waveform is given by $e_m(t) = E_m \cos(2\pi f_m t)$ and the carrier signal is given by $e_c(t) = E_c \cos(2\pi f_c t + \Phi_c)$. Then the equation of the modulated signal is given by

$$s(t) = (E_c + E_m \cos 2\pi f_m t) \cos 2\pi f_c t$$

Modulation Index: The modulation index, represented by m , is given by

$$m = (E_{\max} - E_{\min}) / (E_{\max} + E_{\min}) = E_m / E_c,$$

$$\text{where } E_{\max} = E_c + E_m,$$

$$E_{\min} = E_c - E_m, \text{ and } s(t) = E_c (1 + m \cos 2\pi f_m t) \cos 2\pi f_c t,$$

The envelope of the modulated signal is represented by $1+m e_m(t)$ for $m < 1$. The envelope of the modulated signal for different modulation index is shown in Fig. 2.5.4. Loss of information occurs when $m > 1$.

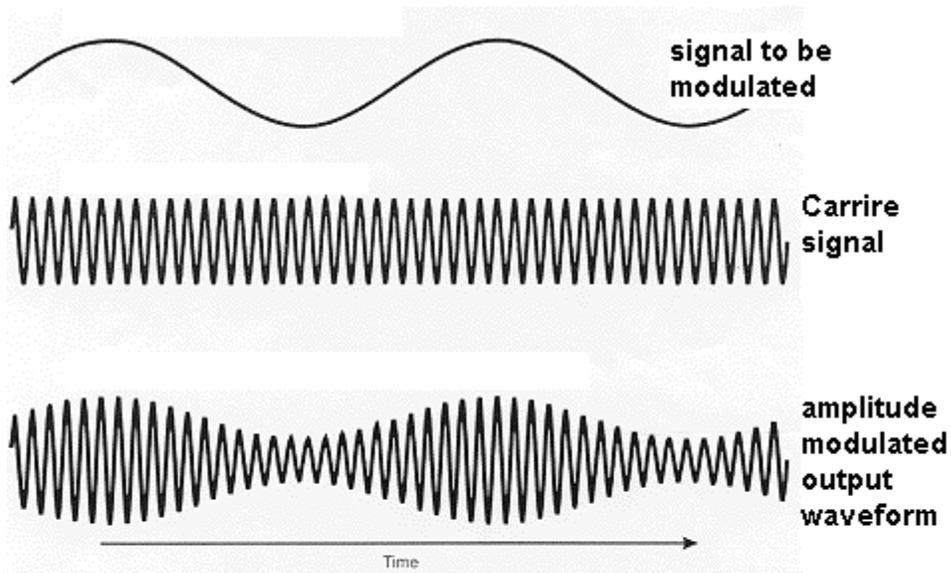


Figure 2.5.3 *Amplitude Modulation*

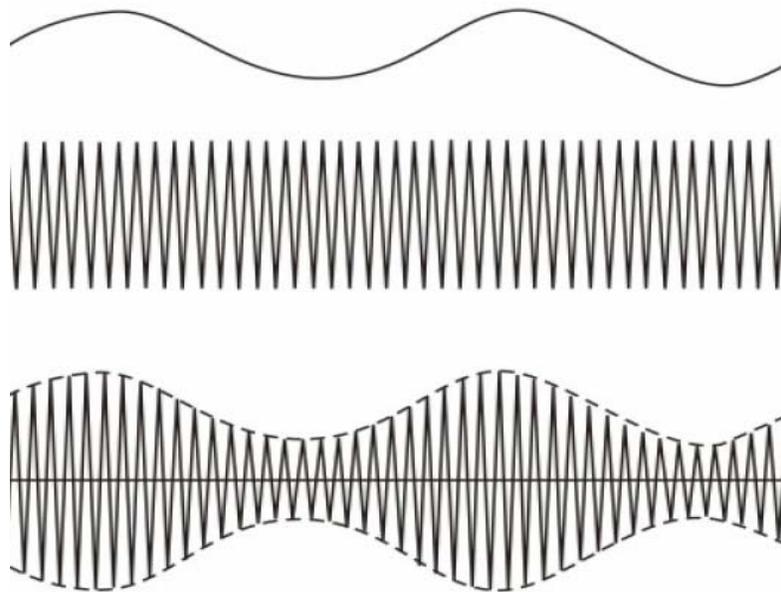


Figure 2.5.4 (a) *Envelope of the signal $1+m e_m(t)$ for $m < 1$*

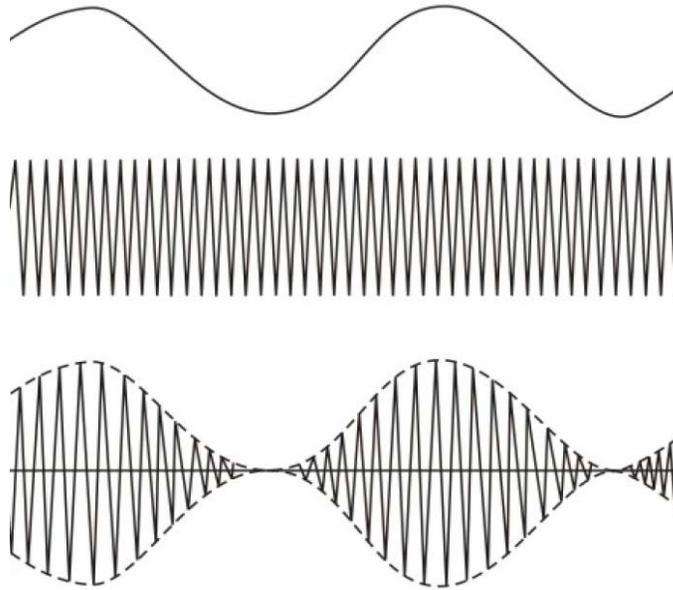


Figure 2.5.4 (b) Envelope of the signal $1+m e_m(t)$ for $m = 1$

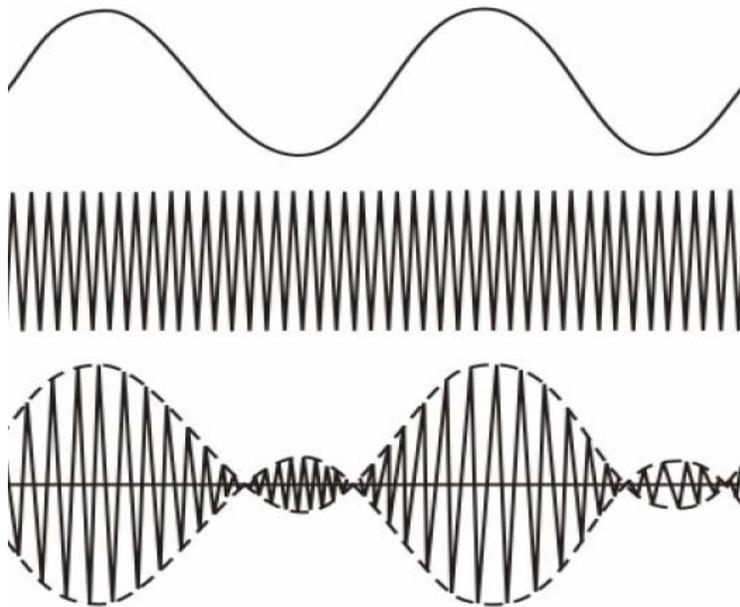


Figure 2.5.4 (c) Envelope of the signal $1+m e_m(t)$ for $m > 1$

Frequency Spectrum: Frequency spectrum of the sinusoidal AM signal can be represented by

$$\begin{aligned}
 s(t) &= E_c [1 + m \cos 2\pi f_m t] \cos 2\pi f_c t \\
 &= E_c \cos 2\pi f_c t + m E_c \cos 2\pi f_m t \cos 2\pi f_c t \\
 &= E_c \cos 2\pi f_c t + m/2 E_c \cos 2\pi(f_c - f_m)t + m/2 E_c \cos 2\pi(f_c + f_m)t
 \end{aligned}$$

It may be noted that there are three frequency components; Carrier wave of amplitude E_c , Lower sideband of amplitude $m/2 E_c$ and Higher sideband of amplitude $m/2 E_c$, as shown in Fig.2.5.5.

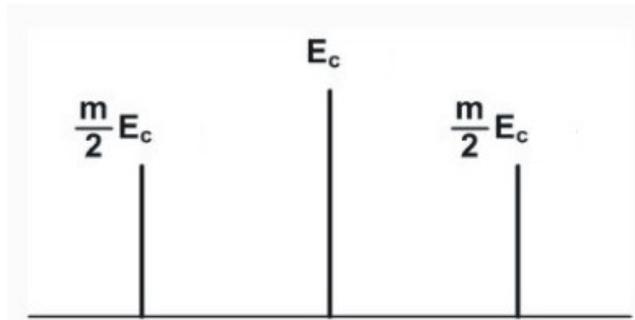


Figure 2.5.5 Spectrum of a modulated signal

Example: A carrier of 1 MHz with peak value of 10V is modulated by a 5 KHz sine wave amplitude 6V. Determine the modulation index and frequency spectrum.

Answer: The modulation index $m = 6/10 = 0.6$. The side frequencies are $(1000 - 5) = 995$ KHz and $(1000 + 5) = 1005$ KHz having amplitude of $0.6 \times 10/2 = 3V$, as shown in Fig. 2.5.6.

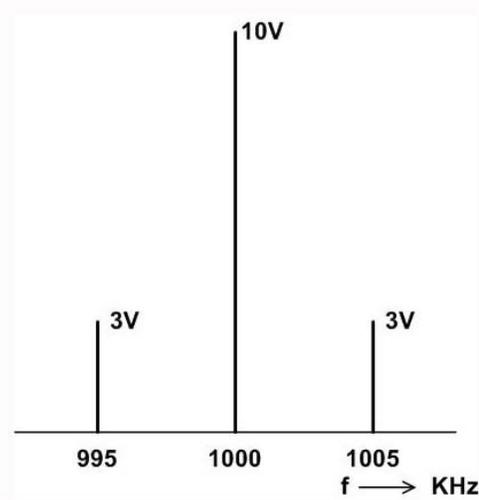


Figure 2.5.6 Spectrum of the modulated signal of the above example

Modulation using Audio signal: Let the bandwidth of the modulating signal is an audio signal with bandwidth equal to B_m . Then the bandwidth of the modulated signal is $2 B_m$, as shown in Fig. 2.5.7.

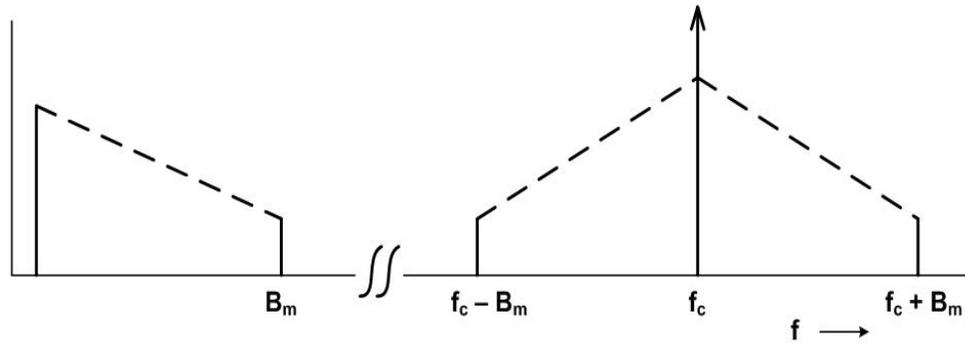


Figure 2.5.7 Bandwidth of an audio signal

Power: Average power developed across a resistor R for the carrier signal is $P_C = E_C^2/2R$. For each of the sideband frequencies the power is $P_{SF} = (mE_C / 2)^2 / 2R = P_C m^2/4$. So, the total power required for transmission is $= P_C (1 + 2(m^2/4)) = P_C (1 + m^2/2)$. To minimize power for transmission, there are two other alternatives:

- Double-Sideband with Suppressed Carrier (DSBSC) Modulation
- Single Side Band (SSB) Modulation

Double-Sideband with Suppressed Carrier (DSBSC) Modulation, as shown in Fig. 2.5.8, utilizes the transmitted power more efficiently than DSB AM. On the other hand, Single Side Band (SSB) Modulation not only conserves energy, it also reduces bandwidth as shown in Fig. 2.5.9. It may be noted that one of the two side bands needs to be transmitted.

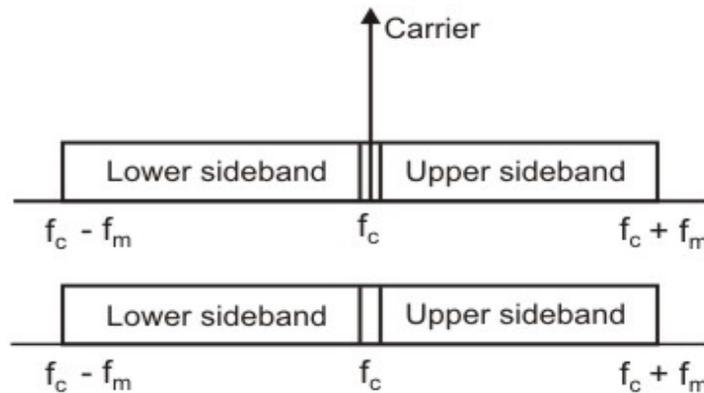


Figure 2.5.8 Double-Sideband with Suppressed Carrier (DSBSC) Modulation

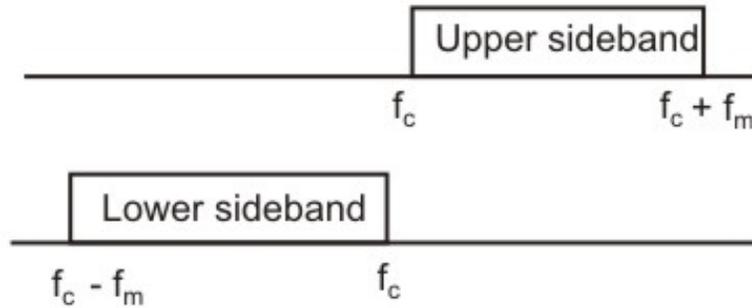


Figure 2.5.9 Single Sideband (SSB) Modulation

Recovery of the Base band Signal

At the receiving end the signal is being demodulated to get the original data. Let a base band signal $m(t)$ is translated out by multiplication with the carrier signal $\cos W_c t$ to get $m(t) \cos W_c t$, the modulated signal. By multiplying second time with the carrier we get $(m(t) \cos W_c t) \cos W_c t$

$$= m(t) \cos^2 W_c t = m(t) (1/2 + 1/2 \cos 2W_c t)$$

$$= m(t)/2 + 1/2 m(t) \cos 2W_c t$$

It may be noted that

- The base band signal reappears along with two spectral components of frequencies $2f_c - f_m$ to $2f_c + f_m$
- The spectral components $2f_c - f_m$ to $2f_c + f_m$ can be easily removed by a low-pass filter. This process is known Synchronous detection

The synchronous detection approach has the disadvantage that the carrier signal used in the second multiplication has to be precisely synchronous. A very simple circuit, as shown in Fig. 2.5.10, can accomplish the recovery of the base and signal using envelope detection.

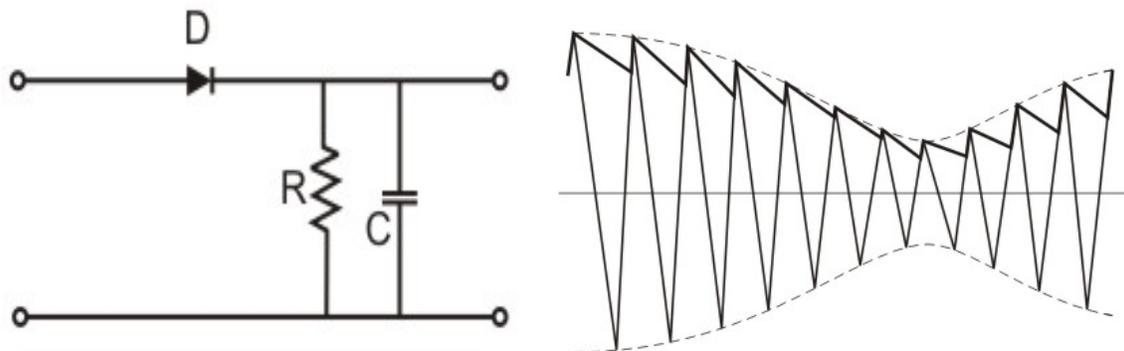


Figure 2.5.10 Recovery of the baseband signal using envelope detection

Another approach is to use Superhetrodyne approach. In this approach the modulated signal received at the receiving end is greatly attenuated and mixed with noise. There may be other channels adjacent to it. The signal has to be amplified before detection and the noises are to be removed by suitable filtering. Superhetrodyne approach, as shown in Fig. 2.5.11, is commonly used because it provides many advantages.

- It is used to improve adjacent channel selection
- To provide necessary gain
- To provide better S/N ratio

This is the commonly used technique of the popular AM receivers, as shown in Fig. 2.5.11. The received AM signal is amplified with the help of a RF amplifier. Then a mixer stage translates the signal to an intermediate frequency (IF) by mixing the RF signal with a local oscillator (shown in B). The IF signal is amplified (shown in C) and then a detector stage is used to get back the base band audio signal (shown in C). The audio signal can be amplified before allying it to a speaker.

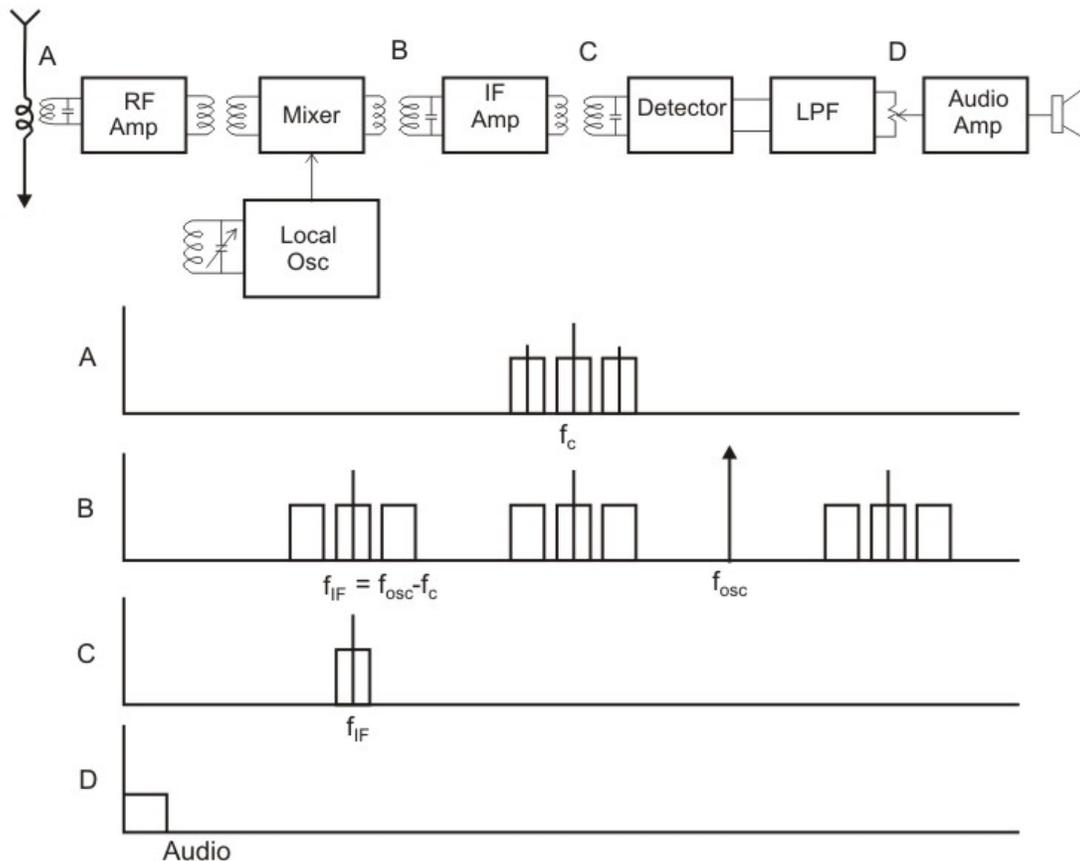


Figure 2.7.11 Operation of a superheterodyne AM radio receiver

2.5.3 Angle Modulation

Angle modulation is shown in Fig. 2.5.12. It may be noted that the amplitude of the modulated signal is constant. *Frequency Modulation* (FM) and *Phase Modulation* (PM) are the special cases of Angle modulation. For Phase Modulation, the phase is proportional to the modulating signal, whereas for frequency modulation, the derivative of the phase is proportional to the modulating signal.

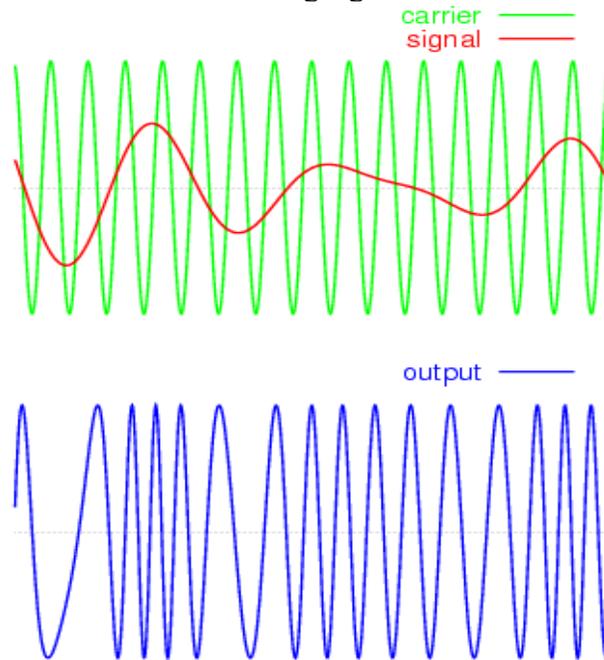


Figure 2.5.12 Angle modulation

2.5.3.1 Frequency modulation

In case of frequency modulation, the modulating signal $e_m(t)$ is used to vary the carrier frequency. The change in frequency is proportional to the modulating voltage $ke_m(t)$, where k is a constant known as frequency deviation constant, expressed in Hz/V. The instantaneous frequency of the modulated signal can be represented by $f_i(t) = f_c + ke_m(t)$, where f_c is the carrier frequency.

For sinusoidal modulation

$$e_m(t) = E_m \cos 2\pi f_m t \quad \text{and} \quad f_i(t) = f_c + k e_m(t) \\ = f_c + k E_m \cos 2\pi f_m t = f_c + \Delta f \cos 2\pi f_m t$$

Therefore,

$$s(t) = E_c \cos \theta(t) \\ = E_c \cos (2\pi f_c t + 2\pi \Delta f \int_0^t \cos 2\pi f_m t \, dt) \\ = E_c \cos (2\pi f_c t + (\Delta f/f_m) \sin 2\pi f_m t)$$

The modulation index, denoted by β , is given by $\beta = (\Delta f / f_m)$
 or $s(t) = E_c \cos (2\pi f_c t + \beta \sin 2\pi f_m t)$

Bandwidth: The modulated signal will contain frequency components $f_c + f_m, f_c + 2f_m,$
 and so on. It can be best approximated based on Carson's Rule, when β is small.

$$B_T = 2(\beta + 1)B_m,$$

$$\text{where } \beta = \Delta f / B = n_f A_m / 2\pi B$$

$$\text{Or } B_T = 2\Delta f + 2B.$$

$$\text{Peak deviation} = \Delta f = (1/2\pi) n_f A_m \text{ Hz,}$$

where A_m is the maximum value of $m(t)$

It may be noted that FM requires greater bandwidth than AM. In Fig. 2.5.13 the bandwidth is shown to be 10 times that of the base band signal.

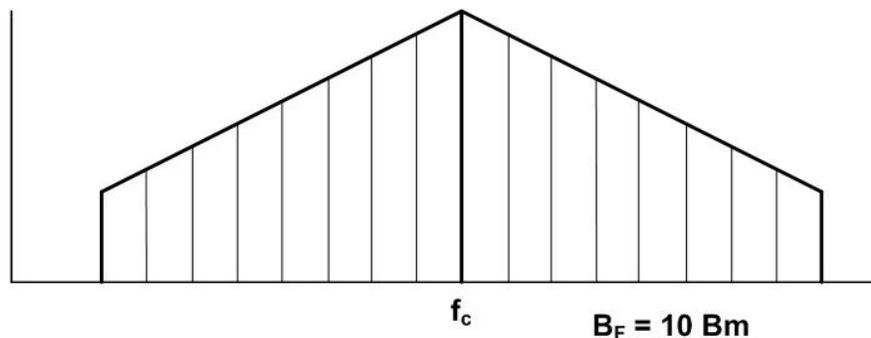


Figure 2.5.13 Bandwidth of a frequency modulated signal

Power: As the amplitude remains constant, total average power is equal to that of the unmodulated carrier power. So, the power = $A_c^2/2$. Although A_m increases the bandwidth, it does not affect power. Therefore, the transmission power for FM is less compared to AM at the expense of higher bandwidth.

2.5.3.2 Phase modulation

In case of phase modulation the modulated signal can be represented by

$$s(t) = A_c \cos[w_c t + \Phi(t)]$$

The angle $(w_c t + \Phi(t))$ undergoes a modulation around the angle $\theta = w_c t$. The signal is therefore an angular-velocity modulated signal. When the phase is directly proportional to the modulating signal, i.e, $\Phi(t) = n_p m(t)$, we call it phase modulation, where n_p is the

phase modulation index. The instantaneous frequency of a phase modulated signal is given by

$$s(t) = E_c \cos (W_c t + k' m(t)), \text{ where } k' \text{ is a constant}$$

Relationship between FM and PM

The relationship between the two types of angle modulated signal depicted in Fig. 2.5.14. Let $m(t)$ be derived as an integral of the modulated signal $e_m(t)$, so that $m(t) = k'' \int e(t)$, Then with $k = k'k''$, we get $s(t) = E_c \cos (W_c t + k \int e(t))$. The instantaneous angular frequency of $s(t)$ is $2\pi f_i(t) = d/dt [2\pi f_c t + k \int e(t)]$

$$\text{or } f_i(t) = f_c + (1/2\pi)k e(t)]$$

The waveform is therefore modulated in frequency

In summary, these two together are referred to as angle modulation and modulated signals have similar characteristics. In this process, since the frequency or phase of the carrier wave is being modulated by the signal and the modulation lies near the base band, the external noise or electromagnetic interference cannot affect much the modulated signal at the receiving end. Analog data to Analog signal modulation techniques at a glance are shown in Fig. 2.5.15.

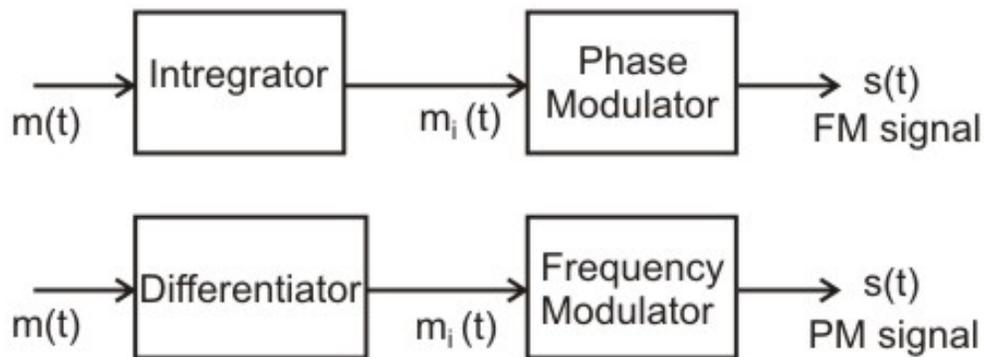


Figure 2.5.14 Difference between frequency and phase modulation

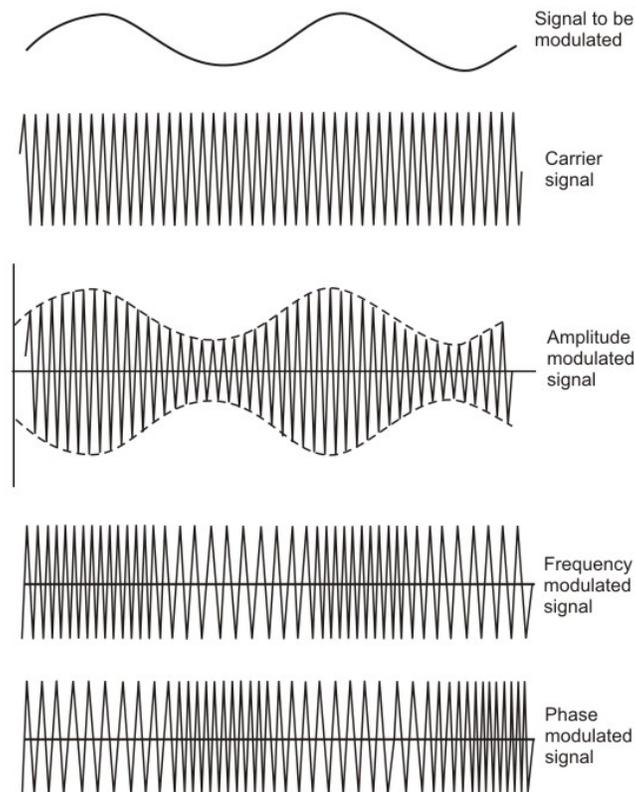


Figure 2.5.15. Analog data to Analog signal modulation techniques at a glance

Review Questions

Q1. Why analog-to-analog modulation technique is required?

Ans: Analog-to-analog modulation is required to achieve the following goals:

- Use of higher frequency for efficient transmission through a media
- Possibility of sending more than one signal through a media simultaneously through FDM (Frequency Division Multiplexing) technique.
- Use of smaller antenna size

Q2. What are the possible analog-to-analog modulation techniques?

Ans: Three possible analog-to-analog modulation techniques are:

- Amplitude modulation
- Frequency modulation
- Phase modulation

Q3. Compare the bandwidth requirement of the three analog-to-analog modulation techniques?

Ans: The bandwidth requirement of the three analog-to-analog modulation techniques can be given as follows:

Amplitude Modulation: $2B$

Frequency Modulation: $2(1 + n_f \cdot A_m / 2 \cdot \pi \cdot B) \cdot B$

Phase Modulation: $2(1 + n_p \cdot A_m) \cdot B$

where, B – Bandwidth of the analog signal

n_f – Frequency modulation index

n_p – Phase modulation index

A_m – Amplitude of the modulating frequency

Q4. Between AM and FM, which one gives better noise immunity?

Ans: FM is more immune to noise than AM, since the power of transmission is independent of the modulation index.