Modulation & Demodulation of Signals

By

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Sine Wave & its Characteristics

- Much of the analysis in communication systems involves the use of sinusoidal trigonometric functions.
- *The sine wave is the most fundamental form of a periodic analog signal.*
- When we visualize it as a simple oscillating curve, its change over the course of a cycle is smooth and consistent, a continuous, rolling flow. Figure below shows a sine wave.
- Each cycle consists of a single arc above the time axis followed by a single arc below it.

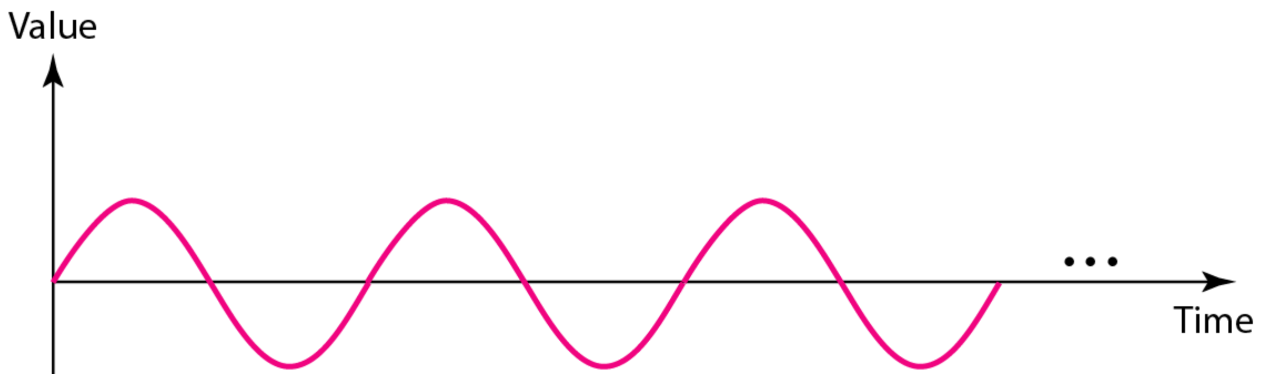


Figure: A sine wave

Sine Wave & its Characteristics

- Sine waves are especially important in information sources
  - because natural phenomena produce sine waves
  - when a microphone picks up an audible tone, the output is a sine
  - electromagnetic radiation can be represented as a sine wave
- We are interested in sine waves that correspond to a signal that oscillates in time.

- A sine wave can be represented by three parameters:
  - the peak amplitude,
  - the frequency, and
  - the phase.

Sine Wave & its Characteristics

Frequency:

- It is the number of oscillations per unit time (usually seconds). In other words, frequency is the rate of change with respect to time.
- A 40-Hz signal has one-half the frequency of an 80-Hz signal; it completes 1 cycle in twice the time of the 80-Hz signal, so each cycle also takes twice as long to change from its lowest to its highest voltage levels.
- Change in a short span of time means high frequency.
- Change over a long span of time means low frequency.
- If a signal does not change at all, its frequency is zero.
- If a signal changes instantaneously, its frequency is infinite.
- Frequency is formally expressed in Hertz (Hz), which is cycle per second.

Sine Wave & its Characteristics

Period:

- Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle.
- Period is formally expressed in seconds.
- Period and frequency are the inverse of each other:

$$f=1/T \qquad \text{and } T=1/f$$

- Figure below shows two signals and their frequencies.

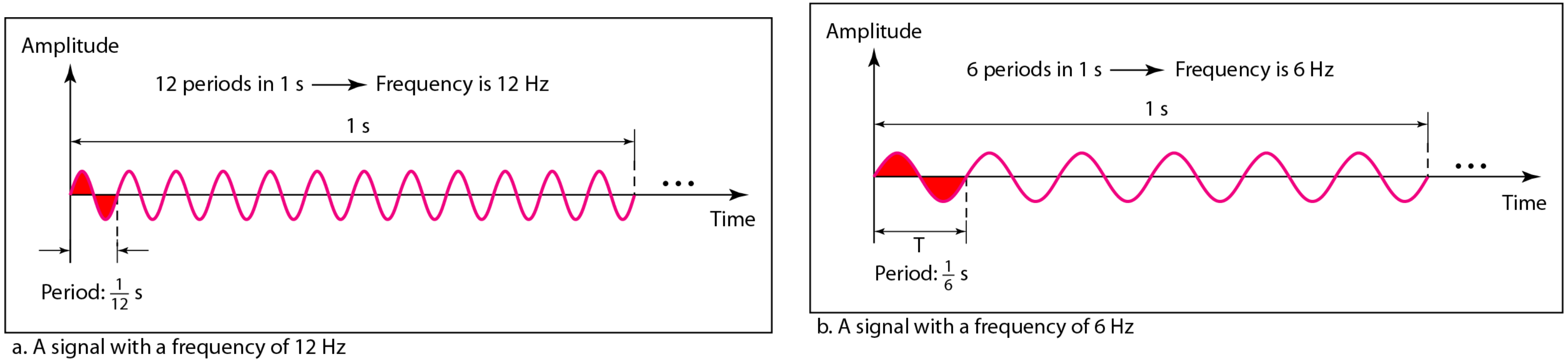
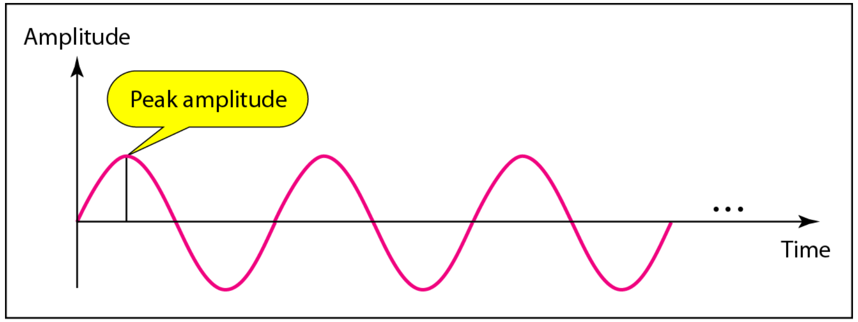


Figure: Two signals with the same amplitude and phase, but different frequencies

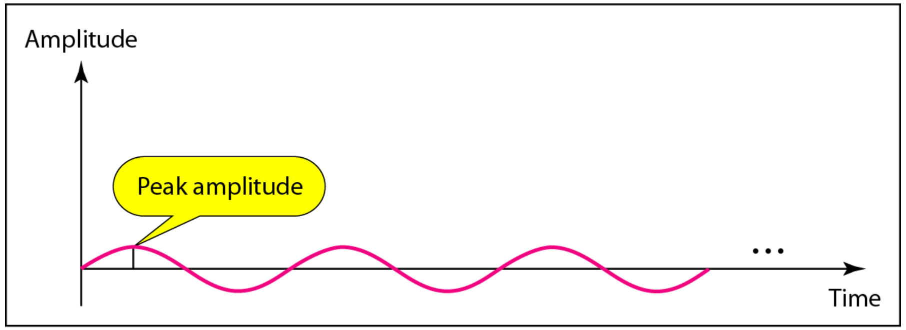
Sine Wave & its Characteristics

Amplitude:

- It refers to the difference between the maximum and minimum signal heights.
- The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries. For electric signals, peak amplitude is normally measured in volts.
- Figure below shows two signals and their peak amplitudes.



a. A signal with high peak amplitude



b. A signal with low peak amplitude

Figure: Two signals with the same amplitude and phase, but different amplitudes

Sine Wave & its Characteristics

Phase:

- Phase describes the position of the waveform relative to time 0. That is, it refers to how far the start of the sine wave is shifted from a reference time.
- Phase describes the amount of that shift. It indicates the status of the first cycle.
- Phase is measured in degrees or radians [360° is 2π rad; 1 degree is 2π /360 rad, and 1 rad is 360/(2π)].
- A phase shift of 360° corresponds to a shift of a complete period; a phase shift of 180° corresponds to a shift of one-half of a period; and a phase shift of 90° corresponds to a shift of one-quarter of a period.
- Figure shows three sine waves with the same amplitude and frequency, but different phases.

Sine Wave & its Characteristics

Phase:

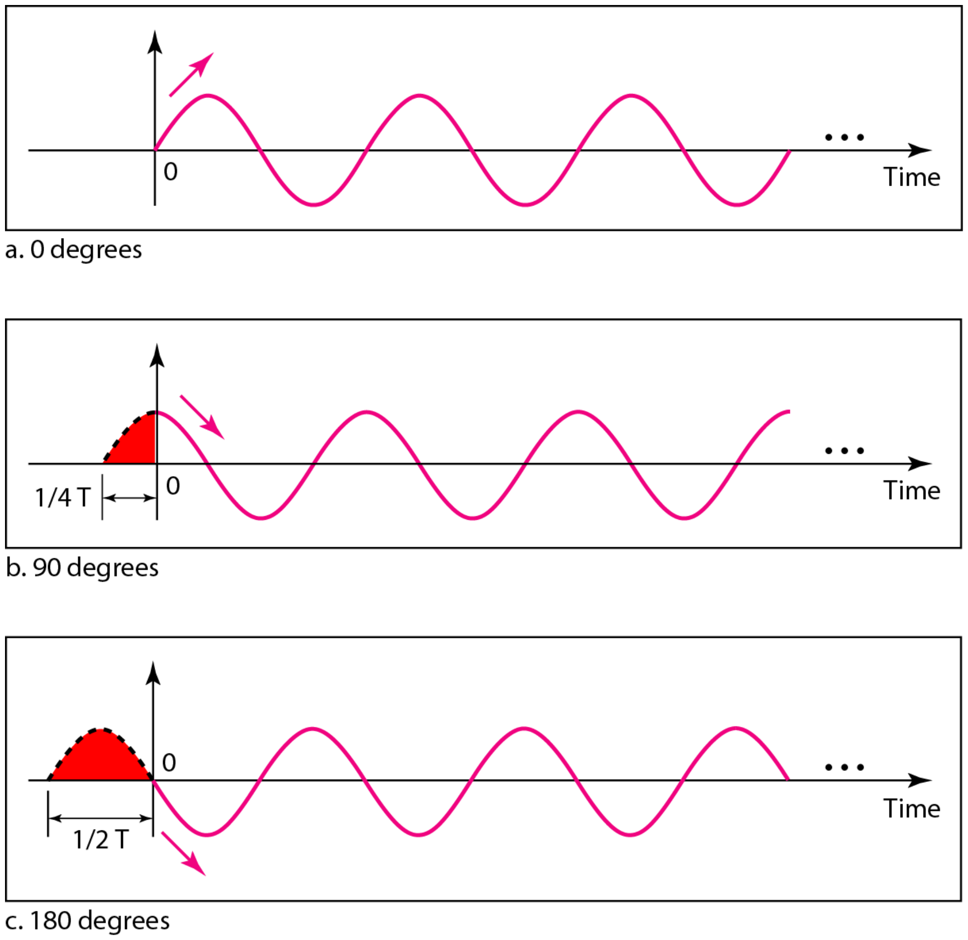


Figure: Three signals with the same amplitude and frequency, but different phases.

Sine Wave & its Characteristics

Phase:

Looking at figure above, we can say that

- A sine wave with a phase of 0° starts at time 0 with a zero amplitude. The amplitude is increasing.
- A sine wave with a phase of 90° starts at time 0 with a peak amplitude. The amplitude is decreasing.
- A sine wave with a phase of 180° starts at time 0 with a zero amplitude. The amplitude is decreasing.

➢ Another way to look at the phase is in terms of shift. We can say that

- A sine wave with a phase of 0° is not shifted.
- A sine wave with a phase of 90° is shifted to the left by 1/4 cycle. However, note that the signal does not really exist before time 0.
- A sine wave with a phase of 180° is shifted to the left by ½ cycle. However, note that the signal does not really exist before time 0.

Sine Wave & its Characteristics

Wavelength:

- Wavelength is another characteristic of a signal traveling through a transmission medium. Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium.
- It is the length of a cycle as a signal propagates across a medium and is determined by the speed with which a signal propagates.
- Figure below shows the wavelength of a signal.

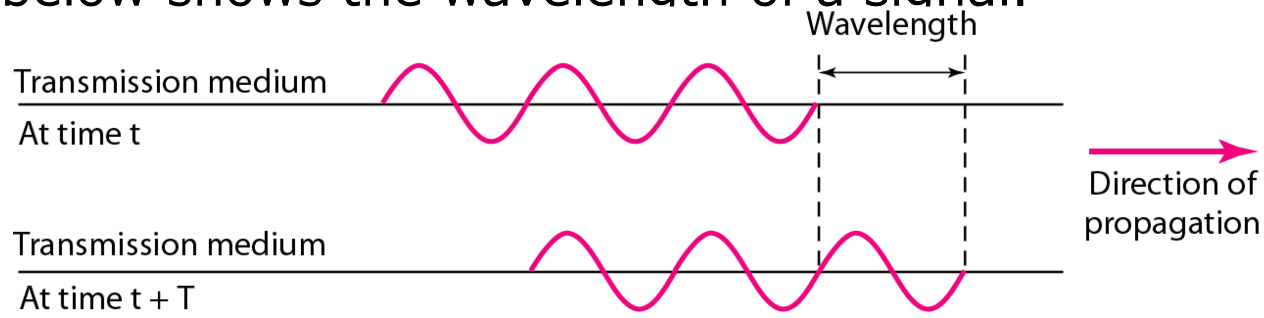


Figure: Wavelength and period

- While the frequency of a signal is independent of the medium, the wavelength depends on both the frequency and the medium.

Sine Wave & its Characteristics

Wavelength:

- Wavelength is a property of any type of signal. In data communications, we often use wavelength to describe the transmission of light in an optical fiber. The wavelength is the distance a simple signal can travel in one period.
- Wavelength can be calculated if one is given the propagation speed (the speed of light) and the period of the signal. However, since period and frequency are related to each other, if we represent wavelength by λ, propagation speed by c (speed of light), and frequency by f, we get

$$\text{Wavelength} = \text{propagation speed} \times \text{period} = \frac{\text{propagation speed}}{\text{frequency}}$$

$$\lambda = \frac{c}{f}$$

- The propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal. For example, in a vacuum, light is propagated with a speed of 3x108 m/s. That speed is lower in air and even lower in cable.
- The wavelength is normally measured in micrometers (microns) instead of meters.
- For example, the wavelength of red light (frequency= 4 x 1014) in air is:

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{4 \times 10^{14}} = 0.75 \times 10^{-6}\ \text{m} = 0.75\ \mu\text{m}$$

Sine Wave & its Characteristics

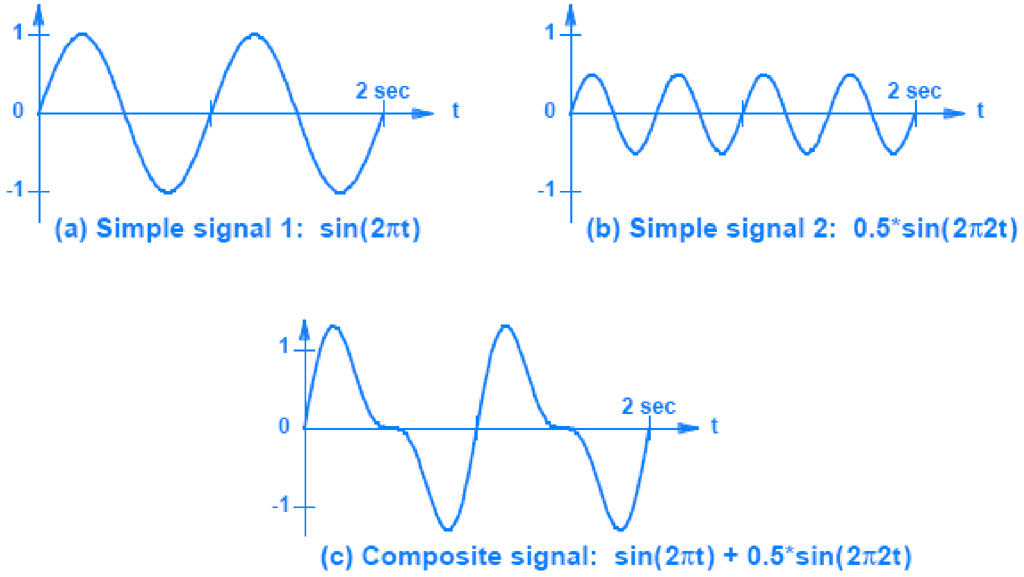
Composite Signals:

- Simple sine waves have many applications in our daily life. For example:
  - We can send a single sine wave to carry electric energy from one place to another. For example, the power company sends a single sine wave with a frequency of 60 Hz to distribute electric energy to houses and businesses.
  - We can use a single sine wave to send an alarm to a security center when a burglar opens a door or window in the house.
- In the first case, the sine wave is carrying energy; in the second, the sine wave is a signal of danger.
- If we had only one single sine wave to convey a conversation over the phone, it would make no sense and carry no information. We would just hear a buzz.
- Therefore, a single-frequency sine wave is not useful in data communications; we need to send a composite signal, a signal made of many simple sine waves.
- According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

Sine Wave & its Characteristics

Composite Signals:

- A composite signal can be periodic or nonperiodic:
  - If it is periodic, it can be decomposed into a series of simple sine waves with discrete frequencies.
  - if the composite signal is nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies.
- The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.
- Figure below illustrates a composite signal formed by adding two simple sine waves.



Sine Wave & its Characteristics

Importance of Composite Signals:

- When we discuss modulation and demodulation, we will understand one of the primary reasons:
  - the signals that result from modulation are usually composite signals.
- A mathematician named Fourier discovered that
  - it is possible to decompose a composite signal into its constituent parts: a set of sine functions, each with a frequency, amplitude, and phase.
- The analysis by Fourier also shows that if the composite signal is periodic, the constituent parts will also be periodic.
- Most systems use composite signals to carry information.
- A composite signal is created at the sending end and the receiver decomposes the signal into the simple components

Sine Wave & its Characteristics

Carrier Wave:

- In telecommunications, a carrier wave, or carrier is a waveform (usually sinusoidal) that is modulated (modified) with an input signal for the purpose of conveying information.
- This carrier wave is usually of much higher frequency than the input signal.
- The purpose of the carrier is usually either to transmit the information through space as an electromagnetic wave (as in radio communication), or to allow several carriers at different frequencies to share a common physical transmission medium by frequency division multiplexing (as is used in, for example, a cable television system).
- Frequency modulation (FM) and amplitude modulation (AM) are commonly used methods to modulate the carrier. The frequency for a given radio or television station is actually the carrier wave's center frequency.

What is Modulation?

- Modulation is a process of mixing a message signal (called modulating signal) with a sinusoid (called carrier signal) to produce a new signal (called modulated signal). This new signal will have certain benefits over an un-modulated signal, especially during transmission.
  - Message signal: The signal that is used in modulating the carrier signal (or sinusoidal signal) is known as the message signal or modulating signal. The message or modulating signal may be either:
    - analog – denoted by m(t)
    - digital – denoted by d(t) – i.e. sequences of 1's and 0's
    - The message signal could also be a multilevel signal, rather than binary.
  - Carrier signal: The sinusoidal signal that is used in the modulation is known as the carrier signal, or simply "the carrier". It is important to notice that a simple sinusoidal carrier contains no information of its own. The carrier could be a 'sine wave' or a 'pulse train'.

What is Modulation?

- In electronics and telecommunications, modulation is the process of varying one or more properties of a high-frequency periodic waveform, called the carrier signal, in proportion to a modulating signal which typically contains information to be transmitted. Therefore, modulation is the technique of superimposing the message signal on the carrier signal.

- The three key parameters of a periodic waveform are its amplitude ("volume"), its phase ("timing") and its frequency ("pitch"). Any of these properties can be modified in accordance with a low frequency signal to obtain the modulated signal.

- A device that performs modulation is known as a modulator and a device that performs the inverse operation of modulation is known as a demodulator (sometimes detector or demod). A device that can do both operations is a modem (from "modulator–demodulator").

- Modulation is performed at the transmitter, and the reverse operation (demodulation/detection) is performed at the receiving end.

What is Modulation?

- Let us assume that:

  $m(t)$ = message (or information or modulating) signal

  $c(t)$ = carrier signal

  $s(t)$ = modulated signal (transmitted signal)

- Figure below show the block diagram of a typical modulation system.

- The carrier $c(t)$ is a pure sinusoidal signal generally given as:

  $$c(t) = A_c \cos(2\pi f_c t + \theta_c(t))$$

  where A_c=Amplitude,
  f_c= Frequency, $\theta_c(t)$=Phase

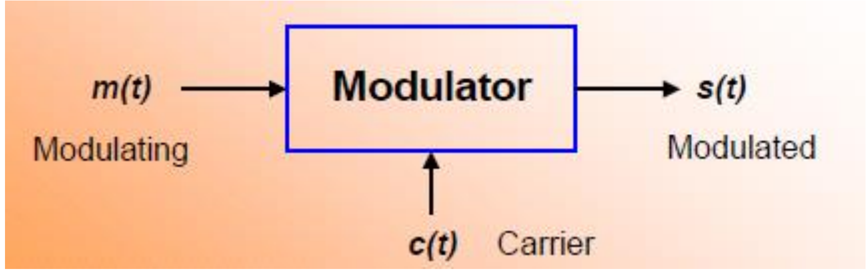


Figure: Typical modulation system

- Examination of $c(t)$ indicate that there are 3 parameters which may be varied:

  1. The amplitude A_c,
  2. The frequency f_c, and
  3. The phase $\theta_c(t)$

- These parameters can be varied in analog or digital form. When varied in digital form, it is referred to as "Shifting & Keying".

What is Demodulation?

- Demodulation is the reverse process of modulation to recover the message signal m(t) or d(t) at the receiver.
- When the modulator and the demodulator are located in the same apparatus, the system is called a MODEM (MOdulator, DEModulator).
- When we do not use modulation, the system is called a "baseband communication" system. At that time, the baseband signal is transmitted directly.

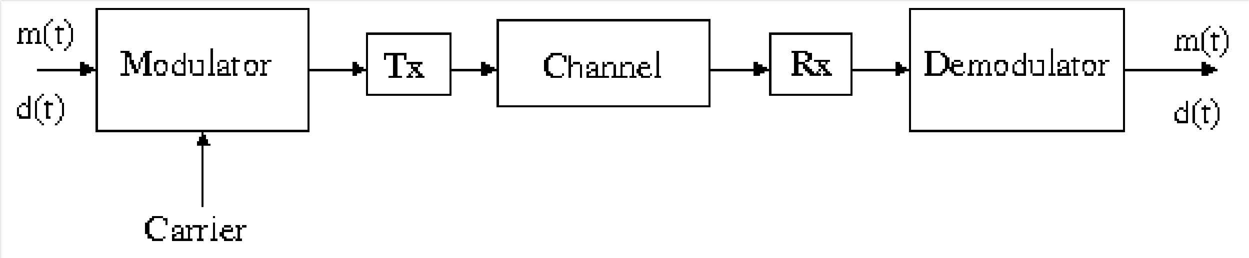


Figure: Typical modulation and demodulation system

Types of Analog Modulation

- Using the message signal m(t) to vary the amplitude (A_c), frequency (f_c), and phase ($\theta_c(t)$) of the carrier signal leads to 3 basic types of analog modulation schemes respectively known as:

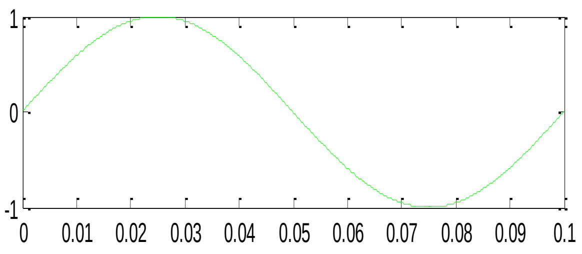
1. Amplitude Modulation:
   - If the analog message signal m(t) controls amplitude A_c of the carrier signal c(t), then the modulation is called amplitude modulation (AM).
2. Frequency Modulation:
   - If the analog message signal m(t) controls the frequency f_c of the carrier signal c(t), then the modulation is called frequency modulation (FM).
3. Phase Modulation:
   - If the analog message signal m(t) controls the phase $\theta_c(t)$ of the carrier signal c(t), then the modulation is called phase modulation (PM).

Types of Digital Modulation

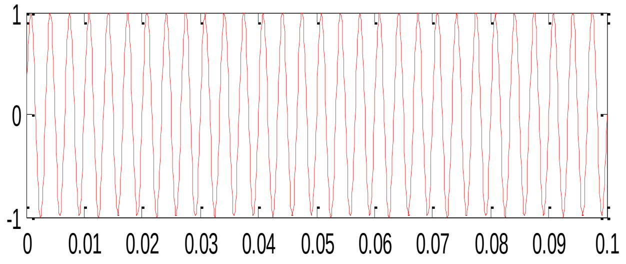
- Considering now a digital message d(t):
  - If the message d(t) controls amplitude – gives amplitude shift keying ASK.
  - If the message d(t) controls frequency – gives frequency shift keying FSK.
  - If the message d(t) controls phase – gives phase shift keying PSK.
- Here d(t) is a binary or 2 level signal representing 1's and 0's.
- The types of modulation produced, i.e. ASK, FSK and PSK are sometimes described as binary or 2 level, e.g. Binary FSK, BFSK, BPSK, etc. or 2 level FSK, 2FSK, 2PSK etc.
- Thus there are 3 main types of digital modulation:
  1. Amplitude shift keying (ASK)
  2. Frequency shift keying (FSK)
  3. Phase shift keying (PSK)

Amplitude Modulation (AM)

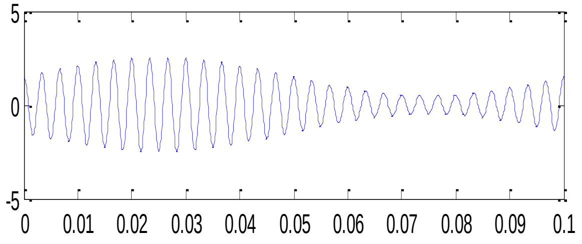
- In amplitude modulation, the amplitude of the carrier signal is controlled or varied (modulated) in proportion to the modulating or message signal while the frequency and phase are kept constant.
- Here, the frequency of the carrier signal is usually much greater than the highest frequency of the input message signal.
- Amplitude of modulated signal is proportional to the message signal.
    - Pitfall\issue of AM: channel noise can corrupt the amplitude easily.
- Figure below shows the amplitude modulation technique.



m(t):
The modulating signal



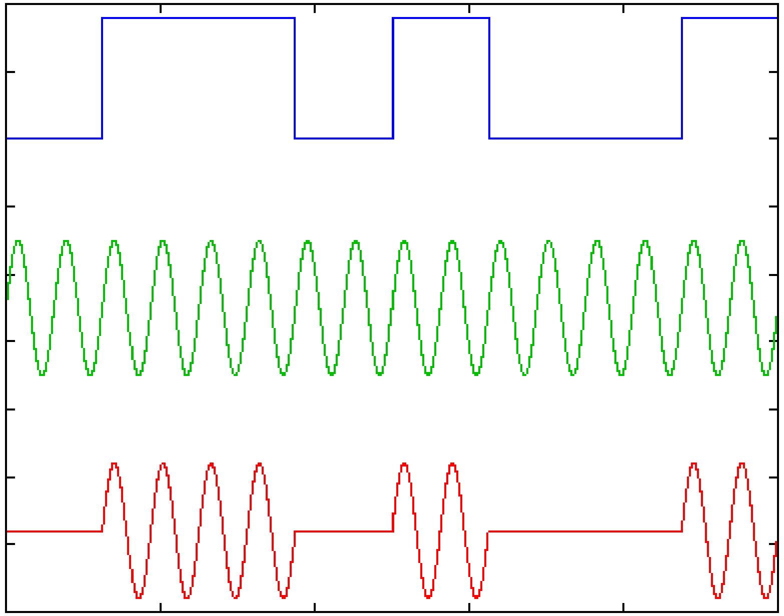
c(t):
The carrier signal



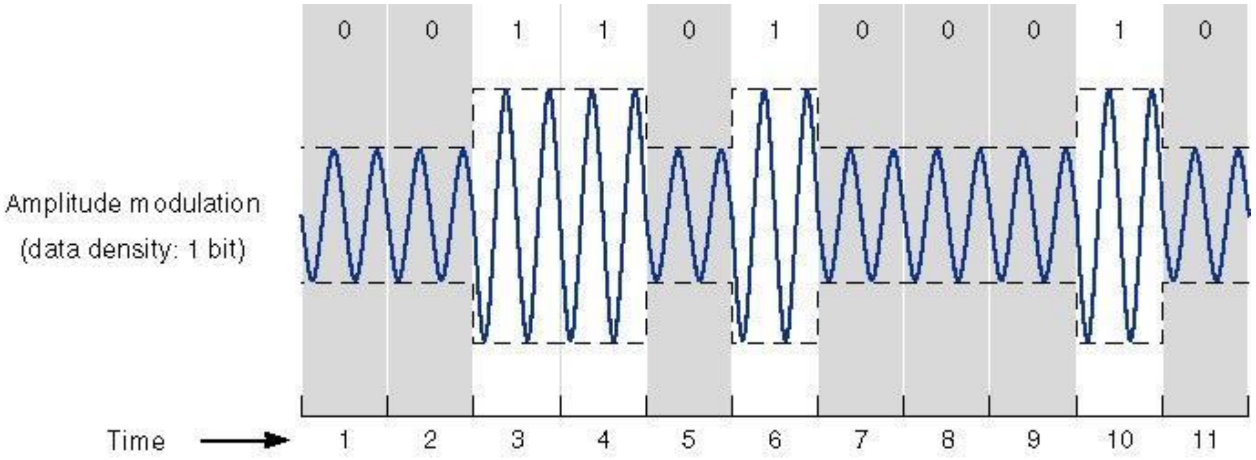
s(t):
AM signal/modulated signal: s(t)

Amplitude Modulation (AM)

- In amplitude modulation, a large amplitude sine wave represents a 1 and zero amplitude represents a 0, as shown in the figure.



- In the figure below, one amplitude represents a 0, another amplitude represents a 1.



Amplitude Modulation (AM)

Time-domain Representation of the Waves

Let the modulating signal be,

$$m(t) = A_m \cos(2\pi f_m t)$$

and the carrier signal be,

$$c(t) = A_c \cos(2\pi f_c t)$$

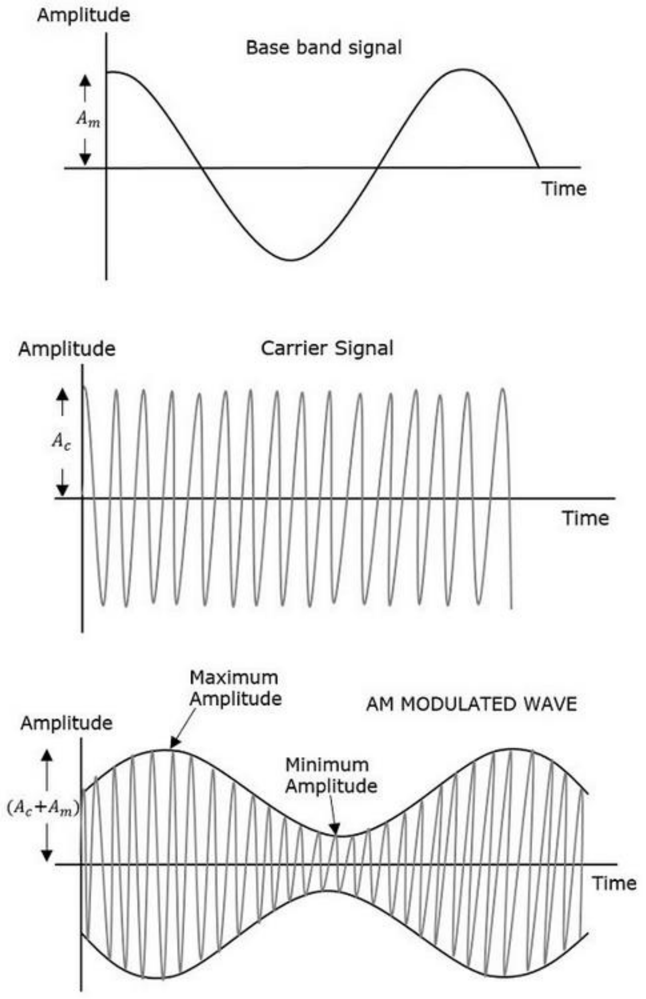
Where,

A_m and A_c are the amplitude of the modulating signal and the carrier signal respectively.

f_m and f_c are the frequency of the modulating signal and the carrier signal respectively.

Then, the equation of Amplitude Modulated wave will be

$$s(t) = [A_c + A_m \cos(2\pi f_m t)] \cos(2\pi f_c t) \qquad \text{(Equation 1)}$$



Amplitude Modulation (AM)

Modulation Index

A carrier wave, after being modulated, if the modulated level is calculated, then such an attempt is called as **Modulation Index** or **Modulation Depth**. It states the level of modulation that a carrier wave undergoes.

Rearrange the Equation 1 as below.

$$s(t) = A_c\left[1 + \left(\frac{A_m}{A_c}\right)\cos(2\pi f_m t)\right]\cos(2\pi f_c t)$$

$$\Rightarrow s\,(t) = A_c\,[1 + \mu\cos(2\pi f_m t)]\cos(2\pi f_c t) \qquad \text{(Equation 2)}$$

Where, μ is Modulation index and it is equal to the ratio of A_m and A_c. Mathematically, we can write it as

$$\mu = \frac{A_m}{A_c} \qquad \text{(Equation 3)}$$

Hence, we can calculate the value of modulation index by using the above formula, when the amplitudes of the message and carrier signals are known.

$$\Rightarrow \mu = \frac{A_{\max} - A_{\min}}{A_{\max} + A_{\min}}$$

Amplitude Modulation (AM)

Bandwidth of AM Wave

Bandwidth (BW) is the difference between the highest and lowest frequencies of the signal. Mathematically, we can write it as

$$BW = f_{max} - f_{min}$$

Consider the following equation of amplitude modulated wave.

$$s(t) = A_c\left[1 + \mu\cos(2\pi f_m t)\right]\cos(2\pi f_c t)$$

$$\Rightarrow s(t) = A_c\cos(2\pi f_c t) + A_c\mu\cos(2\pi f_c t)\cos(2\pi f_m t)$$

$$\Rightarrow s(t) = A_c\cos(2\pi f_c t) + \frac{A_c\mu}{2}\cos[2\pi(f_c + f_m)t] + \frac{A_c\mu}{2}\cos[2\pi(f_c - f_m)t]$$

$$\cos A\cos B = \frac{1}{2}[\cos(A+B) + \cos(A-B)]$$

Hence, the amplitude modulated wave has three frequencies. Those are carrier frequency f_c, upper sideband frequency $f_c + f_m$ and lower sideband frequency $f_c - f_m$

Here,

$$f_{max} = f_c + f_m \quad \text{and} \quad f_{min} = f_c - f_m$$

Substitute, f_{max} and f_{min} values in bandwidth formula.

$$BW = f_c + f_m - (f_c - f_m)$$

$$\Rightarrow BW = 2f_m$$

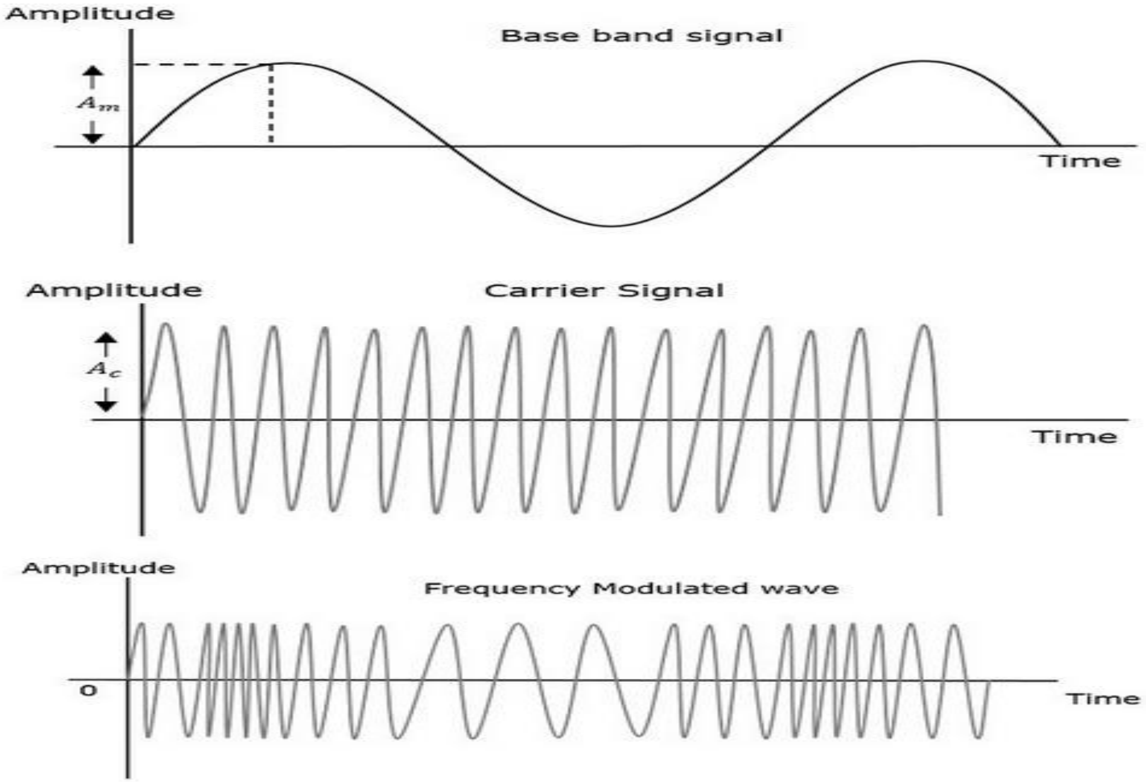
Thus, it can be said that the bandwidth required for amplitude modulated wave is twice the frequency of the modulating signal.

Usage of Amplitude Modulation

- Amplitude is susceptible to interference
    - This technique in not normally used in modems
- A variation of this technique is used in AM radio transmission
    - Analog-to-analog modulation takes place

Frequency Modulation (FM)

- In frequency modulation, the frequency of the carrier signal is controlled or varied in proportion to the modulating or message signal while the amplitude and phase are kept constant.
- Here, the transmitter sends different frequencies for a 1 than for a 0. This technique is also called FSK - frequency shift keying.
- The frequency of the modulated wave increases, when the amplitude of the message signal increases. Similarly, the frequency of the modulated wave decreases, when the amplitude of the modulating signal decreases. Note that, the frequency of the modulated wave remains constant and it is equal to the frequency of the carrier signal, when the amplitude of the modulating signal is zero.



Frequency Modulation (FM)

Mathematical Representation

The equation for instantaneous frequency f_i in FM modulation is

$$f_i = f_c + k_f m(t)$$

Where,

f_c is the carrier frequency

k_t is the frequency sensitivity

$m(t)$ is the message signal

We know the relationship between angular frequency ω_i and angle $\theta_i(t)$ as

$$\omega_i = \frac{d\theta_i(t)}{dt}$$

$$\Rightarrow 2\pi f_i = \frac{d\theta_i(t)}{dt}$$

$$\Rightarrow \theta_i(t) = 2\pi \int f_i dt$$

Frequency Modulation (FM)

Substitute, f_i value in the above equation.

$$\theta_i(t) = 2\pi \int (f_c + k_f m(t))\, dt$$

$$\Rightarrow \theta_i(t) = 2\pi f_c t + 2\pi k_f \int m(t)\, dt$$

Substitute, $\theta_i(t)$ value in the standard equation of angle modulated wave.

$$s(t) = A_c \cos\left(2\pi f_c t + 2\pi k_f \int m(t)\, dt\right)$$

This is the **equation of FM wave**.

If the modulating signal is $m(t) = A_m \cos(2\pi f_m t)$, then the equation of FM wave will be

$$s(t) = A_c \cos(2\pi f_c t + \beta \sin(2\pi f_m t))$$

Where,

β = ***modulation index*** $= \frac{\Delta f}{f_m} = \frac{k_f A_m}{f_m}$

The difference between FM modulated frequency (instantaneous frequency) and normal carrier frequency is termed as **Frequency Deviation**. It is denoted by Δf , which is equal to the product of k_f and A_m .

Frequency Modulation (FM)

FM can be divided into Narrowband FM and Wideband FM based on the values of modulation index β

Narrowband FM:

- This frequency modulation has a small bandwidth when compared to wideband FM.
- The modulation index β is small, i.e., less than 1.
- Its spectrum consists of the carrier, the upper sideband and the lower sideband.
- This is used in mobile communications such as police wireless, ambulances, taxicabs, etc.

Wideband FM features:

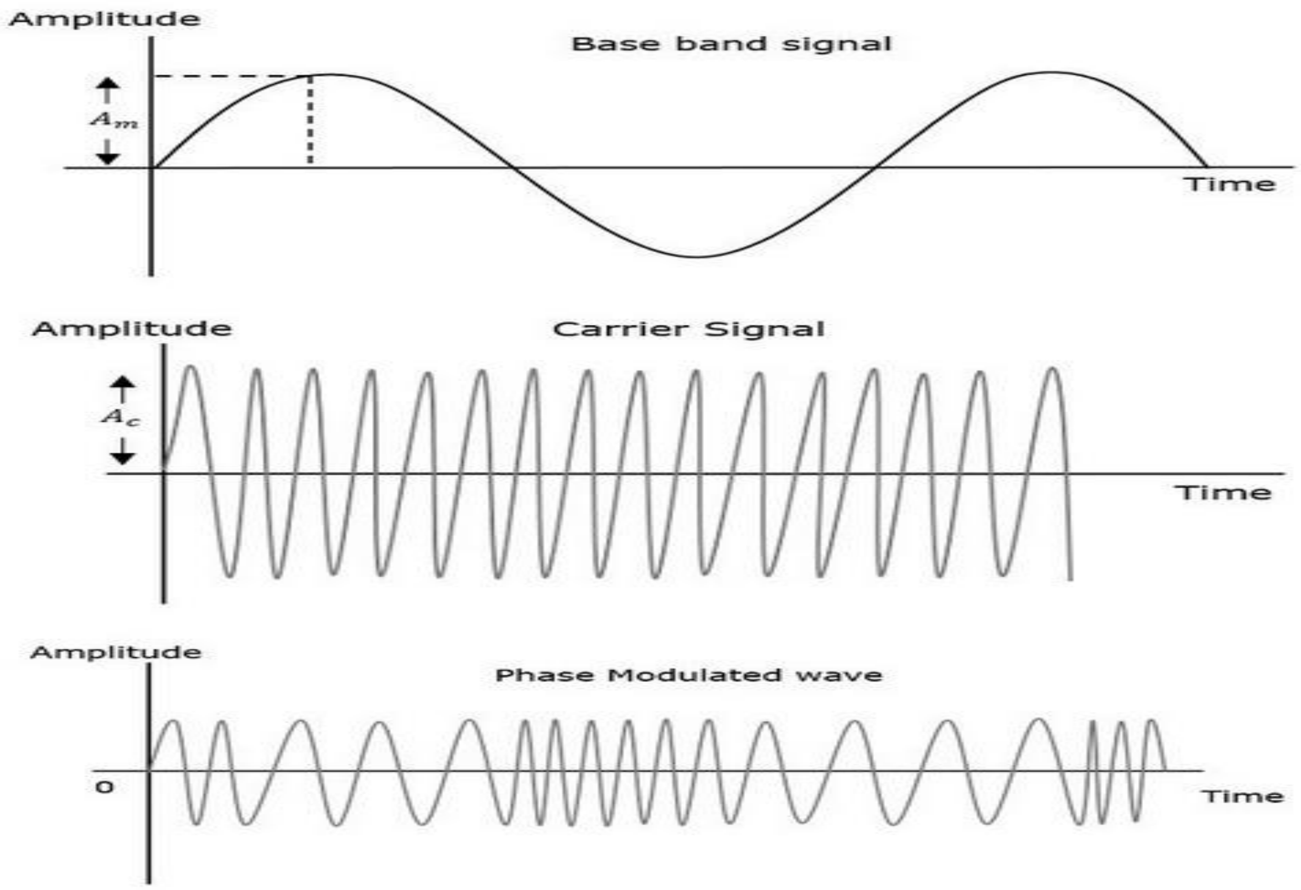
- This frequency modulation has infinite bandwidth.
- The modulation index β is large, i.e., higher than 1.
- Its spectrum consists of a carrier and infinite number of sidebands, which are located around it.
- This is used in entertainment, broadcasting applications such as FM radio, TV, etc.

Usage of Frequency Modulation

- Variations in frequency are easy to detect
  - They are less susceptible to interference
- FM and variations of this technique are used in modems
- Easy to implement full duplex transmission under FM
- A variation of the FM technique described here is used in FM radio transmission

Phase Modulation (PM)

- It is a type of modulation where the phase of the carrier signal is modulated (changed) in proportion to the message signal while the amplitude and frequency are kept constant.
- The phase of the modulated wave has got infinite points, where the phase shift in a wave can take place. The instantaneous amplitude of the modulating signal changes the phase of the carrier signal. When the amplitude is positive, the phase changes in one direction and if the amplitude is negative, the phase changes in the opposite direction.



Frequency Modulation (FM)

Mathematical Representation

The equation for instantaneous phase ϕ_i in phase modulation is

$$\phi_i = k_p m(t)$$

Where,

- k_p is the phase sensitivity
- $m(t)$ is the message signal

The standard equation of angle modulated wave is

$$s(t) = A_c \cos(2\pi f_c t + \phi_i)$$

Frequency Modulation (FM)

Substitute, ϕ_i value in the above equation.

$$s(t) = A_c \cos(2\pi f_c t + k_p m(t))$$

This is the **equation of PM wave**.

If the modulating signal, $m(t) = A_m \cos(2\pi f_m t)$, then the equation of PM wave will be

$$s(t) = A_c \cos(2\pi f_c t + \beta \cos(2\pi f_m t))$$

Where,

- β = *modulation index* = $\Delta\phi = k_p A_m$
- $\Delta\phi$ is phase deviation

Usage of Phase Modulation

- Phase modulation is used in wireless technology.
- Phase modulation is also used in signal transmission system in army. It helps to transmit video signal along with the audio signal.
- Thus phase modulation is used in communication system by army by making the use of special receiver devices which can receive and demodulate both audio and video signal simultaneously.

Solved Problems

Problem 1: A sinusoidal modulating waveform of amplitude 5 V and a frequency of 2 KHz is applied to FM generator, which has a frequency sensitivity of 40 Hz/volt. Calculate the frequency deviation, modulation index, and bandwidth.

Solution:Given,Amplitude of modulating signal, Am=5V
Frequency of modulating signal, fm=2KHz
Frequency sensitivity, kf=40Hz/volt

We know the formula for Frequency deviation as

$\Delta f = kf\ Am$

$\Delta f = 40 \times 5 = 200Hz$

Therefore, frequency deviation, Δf is 200Hz

The formula for modulation index is

$B = \Delta f / fm$

$B = 200/2000 = 0.1$

Here, the value of modulation index, β is 0.1, which is less than one. Hence, it is Narrow Band FM.

The formula for Bandwidth of Narrow Band FM is the same as that of AM wave.

$BW=2fm$

$BW=2 \times 2K=4KHz$

Therefore, the bandwidth of Narrow Band FM wave is 4KHz.

Solved Problems

Problem 2

An FM wave is given by $s(t) = 20\cos\left(8\pi \times 10^6 t + 9\sin\left(2\pi \times 10^3 t\right)\right)$. Calculate the frequency deviation, bandwidth,

Solution

Given, the equation of an FM wave as

$$s(t) = 20\cos\left(8\pi \times 10^6 t + 9\sin\left(2\pi \times 10^3 t\right)\right)$$

We know the standard equation of an FM wave as

$$s(t) = A_c \cos(2\pi f_c t + \beta \sin(2\pi f_m t))$$

We will get the following values by comparing the above two equations.

Amplitude of the carrier signal, $A_c = 20V$

Frequency of the carrier signal, $f_c = 4 \times 10^6 Hz = 4MHz$

Frequency of the message signal, $f_m = 1 \times 10^3 Hz = 1KHz$

Modulation index, $\beta = 9$

Here, the value of modulation index is greater than one. Hence, it is **Wide Band FM**.

Solved Problems

We know the formula for modulation index as

$$\beta = \frac{\Delta f}{f_m}$$

Rearrange the above equation as follows.

$$\Delta = \beta f_m$$

Substitute β and f_m values in the above equation.

$$\Delta = 9 \times 1K = 9KHz$$

Therefore, **frequency deviation**, Δf is $9KHz$.

The formula for Bandwidth of Wide Band FM wave is

$$BW = 2\left(\beta + 1\right) f_m$$

Substitute β and f_m values in the above formula.

$$BW = 2\left(9 + 1\right) 1K = 20KHz$$

Therefore, the **bandwidth** of Wide Band FM wave is $20KHz$

Need for Modulation

- There are two principal motivating reasons for modulation:

  1. Matching the transmission characteristics of the medium, and considerations of power and antenna size, which impact portability.

  2. The desire to multiplex, or share, a communication medium among many concurrently active users.

- Some message signals are not always suitable for direct transmission, but the modulated signal may be more suitable.

  - A communication channel only operates at a certain frequency range. Modulation translates a signal from its baseband to the operating range of the channel. In telecommunications, modulation is used for conveying a message signal (for example a digital bit stream or an analog audio signal) inside another signal (called carrier signal) that can be physically transmitted.

Need for Modulation

- An important reason to modulate a signal is to allow the use of a smaller antenna.
  - Physical channel is usually not well suited to the transmission of baseband (low frequency) signal, because an efficient projection of baseband signal requires a huge antenna of dimension comparable with the wavelength of the signal, typically a quarter wavelengths in the case of a tower antenna.
  - Since the wavelength of the (electromagnetic) wave is inversely proportional to the frequency, the higher the frequency, the smaller the antenna. For example, the wavelength of a 1 GHz electromagnetic wave in free space is 30 cm, whereas a 1 kHz electromagnetic wave is one million times larger, 300 km, which would make for an impractically huge antenna and transmitter power to transmit signals of that frequency!
  - Modulation shifts the baseband signal up to a much higher frequency, which has much smaller wavelengths and allows the use of a much smaller antenna.

Need for Modulation

- In order to match the baseband signal to the physical and regulatory specifications of a transmission channel, one typically has to go through a modulation process.
    - Even if we could arrange for direct transmission of the baseband signal (after digital-to-analog conversion), there would be issues related to the required transmitter power, the attenuation caused by the atmosphere at this frequency, interference between this transmission and everyone else’s, and so on. Regulatory organizations such as the U.S. Federal Communications Commission (FCC), and equivalent bodies in other countries, impose constraints on transmissions, which further restrict what sort of signal can be applied to a physical channel.

Need for Modulation

- By modulating different signals to different frequency bands, they can be transmitted simultaneously over the same channel.
  - Analog and digital modulation facilitate frequency division multiplexing (FDM), where several low pass information signals are transferred simultaneously over the same shared physical medium, using separate passband channels (several different carrier frequencies).

Aim of Analog & Digital Modulation

- The aim of digital modulation (In digital modulation, an analog carrier signal is modulated by a discrete signal) is to transfer a digital bit stream over an analog bandpass channel, for example over the public switched telephone network (where a bandpass filter limits the frequency range to between 300 and 3400 Hz), or over a limited radio frequency band.
- The aim of analog modulation is to transfer an analog baseband (or lowpass) signal, for example an audio signal or TV signal, over an analog bandpass channel at a different frequency, for example over a limited radio frequency band or a cable TV network channel.

Thank You