Introduction

We live in the world of information. Information needs to be communicated from one entity to another entity. This act of sending and receiving message from one place to another place, successfully, is called communication.

The word successful in the above definition, implies many things like

- Common understanding by the sender and the receiver in interpreting the information
- Quality in communication, which implies no addition, deletion or modification of the actual information

The growing needs of human beings in the field of communication imposed demands on

- Complexity of information
- Speed of transmission

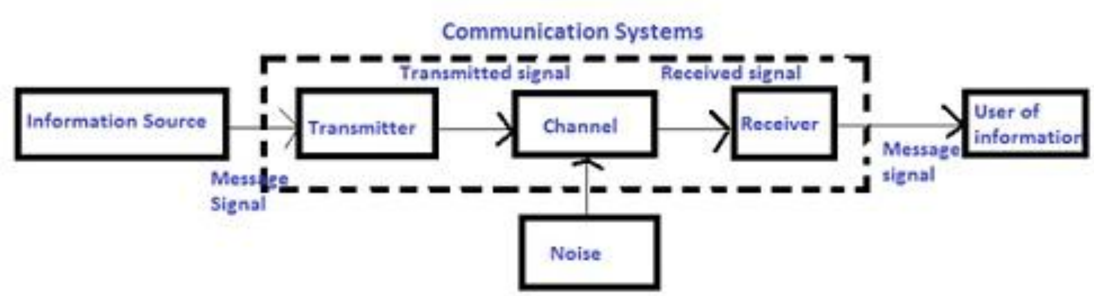
Evolution in communication

The table below shows us how physical messengers who travelled from one place to another changed to the current day situation where information comes to your doorstep anytime with easy access.

Time period	Event	Remarks
When Kings ruled	· Announcement to common people · Peace and war message from one country to another	· Messengers travelled from one place to another · Drum beaters announced Kings decisions
1835	Invention of **Telegraph** by F.B.Morse and Sir Charles Wheatstone	Messengers physically going from one place to another reduced
1876	Invention of Telephone by Alexander Graham Bell and Antonio Meucci	Even now this communication is very useful
1895	Wireless Telegraphy by Jagadis Chandra Bose and G Marconi	Leap in communication history from using wires to wireless
1936	Television broadcast by John Logi Baird	Being used even today
1955	Radio FAX by Alexander Bain	Being used even today
1968	ARPANET by JCR LIcklider	First internet where file transfer from one computer to another computer was possible
1975	Fiber Optics by Bell Laborataries	More economical means of communication
1989-91	World Wide Web by Tim Berners-Lee	Information access made so easy in modern world

Communication System

The general form of communication system is depicted below:



As we see here, the basic elements of communication includes transmitter, Channel and the receiver. The transmitter and the receiver may be located geographically at different places. The Channel connects the transmitter and the receiver.

Information Source – The source produces signal of the information which needs to be communicated.
Signal – Information in electrical form suitable for transmission is called signal.
Transmitter – Converts the source signal into suitable form for transmission through the channel.
Channel – The channel connecting the transmitter and the receiver is a physical medium. The channel can be in the form of wires, cables or wireless.
Noise – When the transmitted signal propagates along the channel, it may get distorted due to channel imperfection.
Thus, noise refers to unwanted signals that tend to disturb the process of communication from the transmitter to the receiver.
Receiver – Due to noise and other factors, the corrupted version of signal arrives at the receiver. The receiver has to reconstruct the signal into recognisable form of the original message for delivering it to the user. The signal at the receiver forms the output.

Modes of communication
Point to point communication – There is a single link between the transmitter and the receiver. Communication takes place between single transmitter and receiver
Example – Telephone


Broadcast mode – There are large number of receivers though information is sent by a single transmitter.
Example – Television and Radio


Communication – Terminology

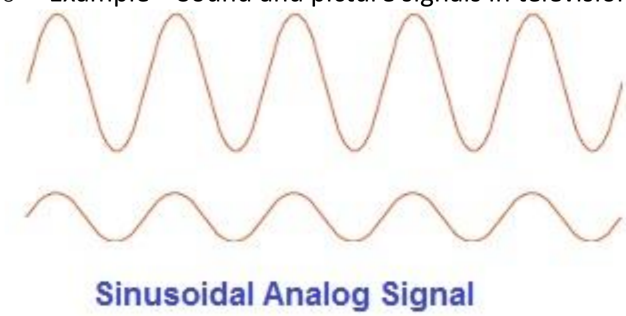
Transducer – Any device which converts energy in one form to another form is called transducer.

Electrical transducer: A device that converts some physical variable like pressure, displacement, force, temperature, into corresponding variations in electrical signal. Hence, the output of this would be an electrical signal.

Signal Types – Information in electrical form suitable for transmission called signal, is of two types

Analog signal –

- Continuous variations of voltage and current. Hence, single valued functions of time.
- Sine wave is a fundamental analog signal
- Example – Sound and picture signals in television

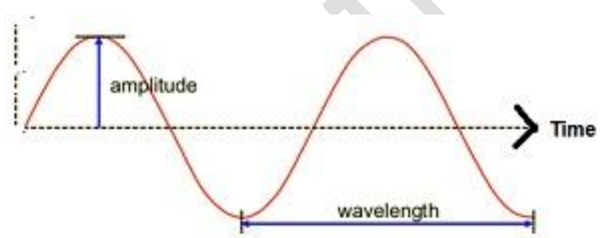


Digital signal –

- Digital step value based
- Binary system where 0 represents low level and 1 represents high level is used
- Universal digital coding methods like BCD – Binary Coded Decimal and ASCII – American Standard Code of Information Interchange is used in common

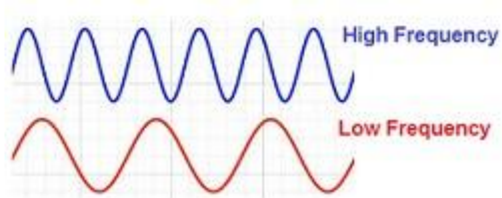
Amplitude –

The maximum extent of vibration or oscillation from the position of equilibrium

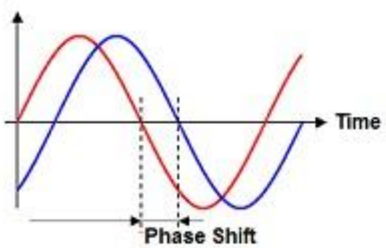


Frequency –

The frequency is the number of waves which pass a fixed place in a given amount of time.

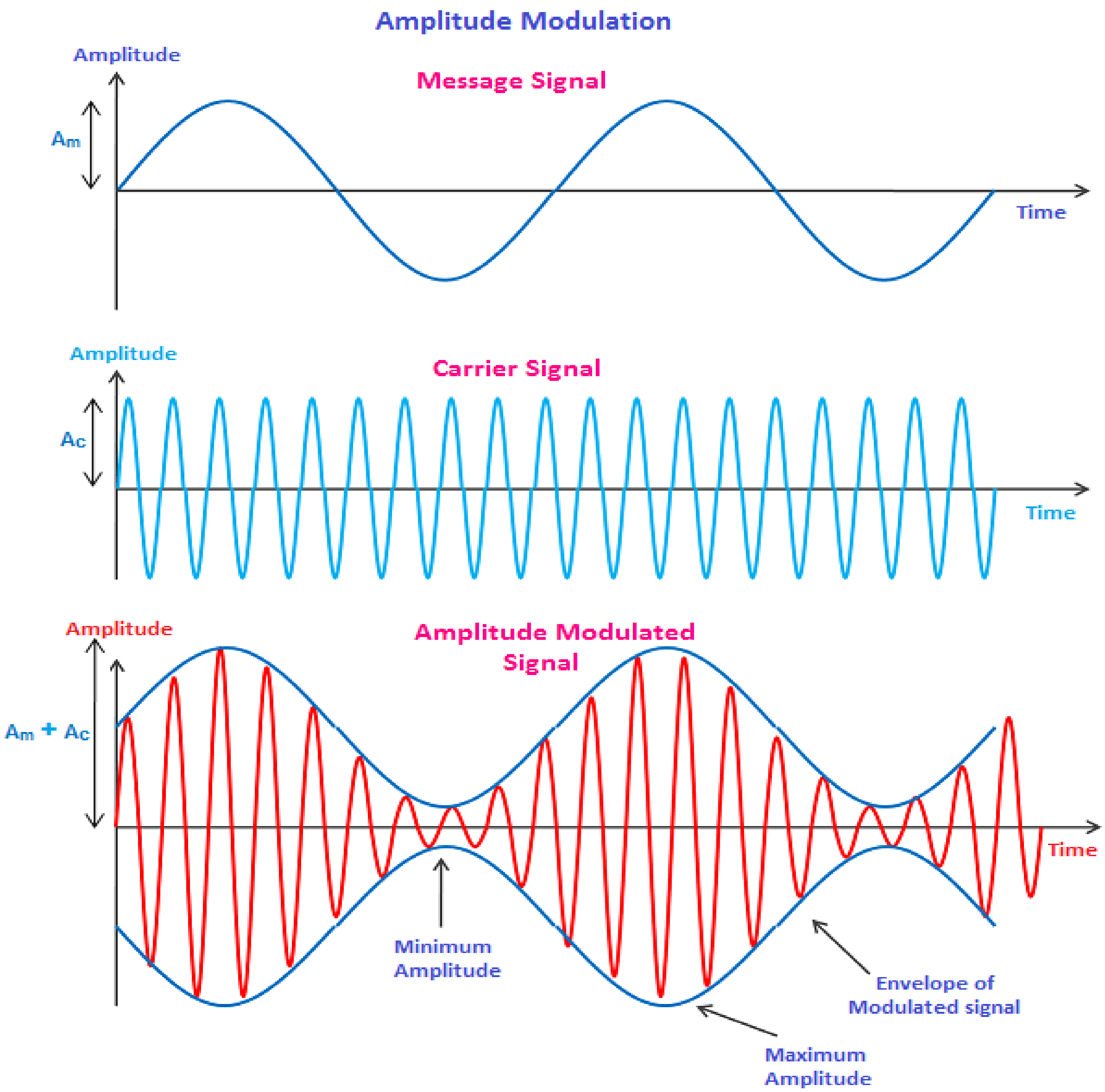


Phase –
The two waves depicted below have a phase difference indicated by the phase shift which is the fraction of the wave cycle which has elapsed relative to the origin.



Signal propagation – Terminology
Attenuation – The loss of strength of the signal while propagating through a medium is known as attenuation.
Amplification – The process of increasing the amplitude of the signal by using an electronic circuit is called amplification. This also increases the strength of the signal. Hence, it compensates the attenuation of the signal.
Range – It is the largest distance between the source and the destination upto which the signal is received with sufficient strength.
Bandwidth – It refers to the frequency range for which the equipment operates.
Modulation – If the information signal is of low frequency, it cannot be transmitted to long distances. Hence, at transmission point, it is super imposed on high frequency wave. This high frequency wave acts as a carrier of information. This is modulation

Sinusoidal wave modulation:
There are 3 types of modulation, namely 1. Amplitude modulation 2.Frequency modulation and 3. Phase modulation
Amplitude modulation –
- The amplitude of the carrier wave is varied in accordance with the information signal



Frequency modulation –

- The frequency of the carrier wave is varied in accordance with the information signal

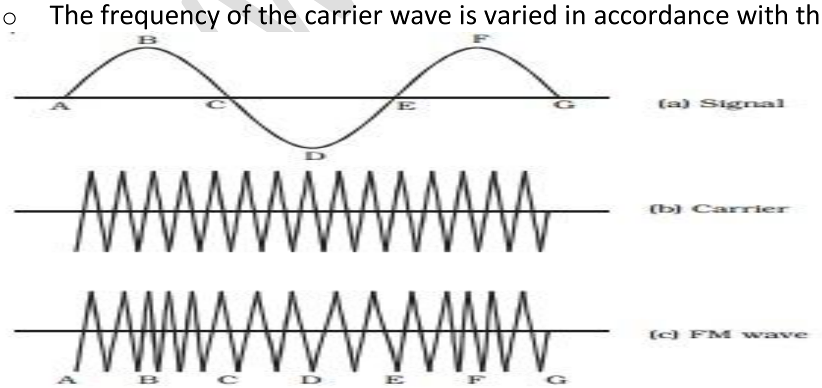
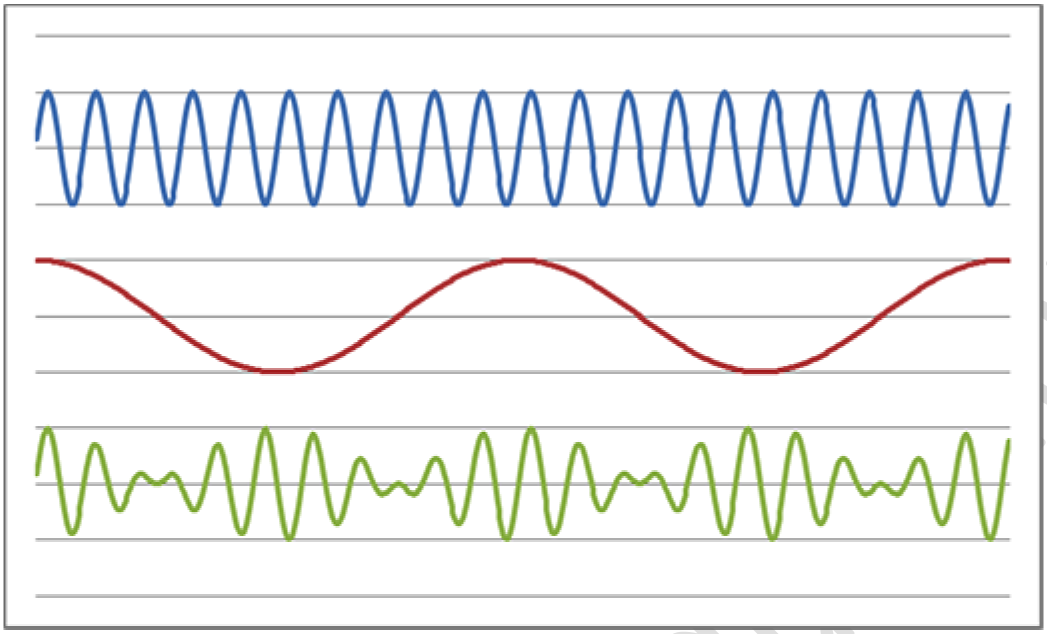


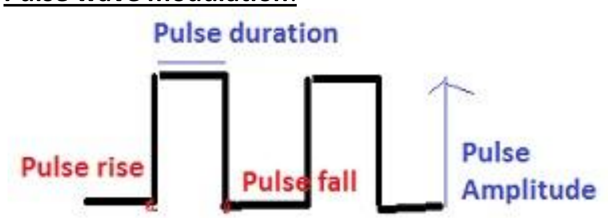
Fig Frequency Modulation

Phase modulation –

- The phase of the carrier wave is varied in accordance with the information signal



Pulse wave modulation:



There are 3 types of pulse wave modulation – namely (a) Pulse amplitude modulation (b) Pulse width modulation (c) Pulse position modulation

Demodulation – The process of retrieval of information from the carrier wave at the receiver is termed as demodulation. This is a reverse of modulation.

Repeater – A repeater is a combination of receiver and a transmitter.

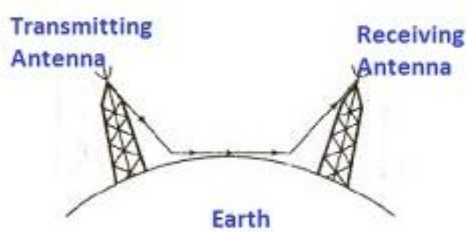
A repeater picks up the signal from the transmitter, amplifies and retransmits it to the receiver. Thus repeaters are used to extend the range of communication system

Example – Communication satellite is a repeater station in space.

Propagation of electromagnetic waves

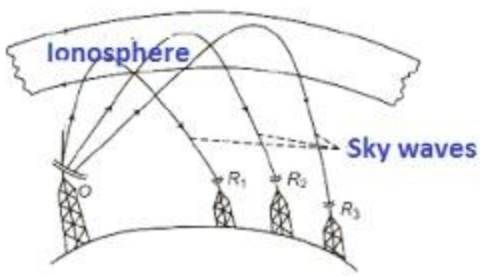
While communication using radio waves, the transmitter antenna radiates electromagnetic waves. These waves travel through the space and reach the receiving antenna at the other end. We have considered below some of the wave propagation methods in brief.

Ground or Surface wave propagation:



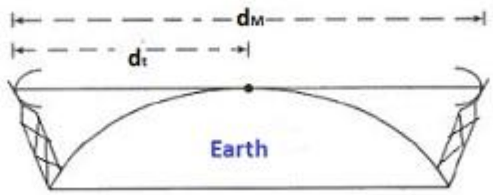
- In this mode of wave propagation, ground has a strong influence on propagation of signal waves from the transmitting antenna to the receiving antenna. The signal wave glides over the surface of the earth
- While propagating on the surface of the earth, the ground wave induces current in the ground. It also bends around the corner of the objects on the earth
- Due to this, the energy of the ground wave is gradually absorbed by the earth and the power of the ground wave decreases
- The power of the ground wave decreases with the increase in the distance from the transmitting station. This phenomenon of loss of power of the ground wave is called attenuation
- The attenuation of ground waves increases very rapidly with the increase in its frequency
- Thus, ground wave communication is not suited for high frequency signal wave and for very long range communication
- To radiate signals with high efficiency, the antennas should have a size comparable to the wavelength of the signal

Sky waves:



- The ionosphere plays a major role in sky wave propagation. We know that the earth's atmosphere is divided into various regions like – Troposphere, Stratosphere, Mesosphere and Ionosphere.
- The ionosphere is also called as thermosphere as temperature increases rapidly here and it is the outermost part of the earth's atmosphere
- Above troposphere, we have various layers like D (part of stratosphere), E (part of stratosphere), F_1 (part of mesosphere), F_2 (part of ionosphere)
- The ionosphere is called so because of the presence of large number of ions or charged particles. Ionisation occurs due to the absorption of the ultraviolet and other high energy radiation coming from the sun, by the air molecues
- The phenomenon of bending of electromagnetic waves in this layer so that they are diverted towards the earth is helpful in skywavepropogation. This is similar to total internal reflection in optics
- The radiowaves of frequency range from 1710 kHz to 40 MHz are propagated in sky wave propagation

Space waves:



- The space waves travel in straight line from the transmitting antenna to the receiving antenna.
- Hence, space waves are used for line of sight communication such as television broadcast, microwave link and satellite communication
- The line of sight communication is limited by (a) the line of sight distance (b) the curvature of the earth
- At some point by the curvature of the earth, the line of sight propagation gets blocked.
- The line of sight distance is the distance between transmitting antenna and receiving antenna at which they can see each other. It is also called range of communication d_M
- The range of space wave communication can be increased by increasing the heights of the transmitting antenna and receiving antenna.
- The maximum line of sight distance (range of communication) d_M between two transmitting anternna of height h_T and the receiving antenna of height h_R above the earth is given by

$d_M = (2Rh_T)^{1/2} + (2Rh_R)^{1/2}$

Problem – A transmitting antenna at the top of a tower has a height of 32m and the height of the receiving antenna is 50m. What is the maximum distance between them for satisfactory communication in LOS mode? Given radius of earth = $6.4 * 10^6$ m

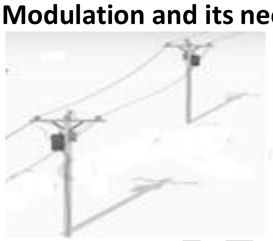
Solution –Given $h_T = 32$m ,$h_r = 50$m, R = $6.4 * 10^6$ m

$d_M = (2Rh_T)^{1/2} + (2Rh_R)^{1/2}$

$= (2 * 6.4 * 10^6 * 32)^{1/2} + (2 * 6.4 * 10^6 * 50)^{1/2}$

= 45.5 Km

Modulation and its necessity



Any message signal, in general, is not a single frequency sinusoidal. But it spreads over a range of frequencies called the signal bandwidth.

Suppose we wish to transmit an electronic signal, in the audio frequency range, say 20 Hz to 20kHz range, over a long distance we need to consider factors like

- Size of the antenna
- Effective power radiated by the antenna
- Avoiding mixing of signals from different transmitters

Size of antenna:

- Antenna is needed for both transmission and reception

- Antenna should have a size comparable to the wavelength of the signal, atleast$\lambda/4$ where λ is the wavelength of the signal
- In the above audio frequency range, if we consider frequency υ = 15,000 Hz. Then $\lambda = c / \upsilon = 3 * 10^8 / 15{,}000 = 20{,}000$ m
- Hence, antenna length = $\lambda/4$ = 20,000 / 4 = 5000 m.
- It is practically impossible to design an antenna of height 5000m
- So the transmission frequency should be raised in such a way that the length of the antenna is within 100m which is feasible for practical purpose
- This shows that there is a need for converting low frequency signal to high frequency before transmission

Effective power radiated by the antenna:
- Effective power rated by the antenna = $P = E/t$
- Also, $E = h\upsilon = hc/\lambda$
- Hence, $P = E/t = hc/\lambda * c/\lambda$
- Studies reveal that if l is the linear length of the antenna, then P is proporational to $(l/\lambda)^2$
- Hence, for good transmission, high power and hence small wavelength and high frequency waves are required
- High frequency waves becomes inevitable in this case also

Avoiding mixing of signals from different transmitters:
- When many transmitters are transmitting baseband information signals simultaneously, they all gets mixed up
- There is no way to distinguish between them
- Possible solution is communication at high frequencies and allotting a band of frequencies for each transmitter so that there is no mixing
- This is what is being dene for different radio and TV broadcast stations

Hence, we understand the necessity of modulation.

Problem - Find the minimum length of the antenna required to transmit a radio signal of frequency 10 MHz.
Solution - We know that $\lambda = c / \upsilon = 3 * 10^8 / 10 * 10^6 = 30$ m
Minimum length of the antenna = $\lambda / 4 = 30 / 4 = 7.5$ m

Band width

Bandwidth is also defined as the amount of data that can be transmitted in a fixed amount of time

Signals – Bandwidth:
- The message signal can be voice, music, picture or computer data
- Each of the above have different frequency ranges
- The speech signals frequency range from 300Hz to 3100Hz. Hence, bandwidth = 3100 -300 = 2800 Hz
- Any music requires bandwidth of 20kHz because of high frequencies produced by musical instruments
- Video signals for transmission of picture requires 4.2 MHz of bandwidth

- The Television signal which contains both voice and picture is usually allocated a bandwidth of 6MHz bandwidth for transmission

Transmission Medium – Bandwidth:

- Different types of transmission media offers different bandwidth
- Coaxial cables, widely used wire medium offers bandwidth of approximately 750 MHz
- Communication through free space using radio waves offers wide range from hundreds of kHz to few GHz
- Optical fibres are used in the frequency range of 1THz to 1000 THz (THz – Tera Hertz; 1THz = 10^{12}Hz)
- As mentioned earlier, to avoid mixing of signals, allotting a band of frequencies to a specific transmitter is in practise
- The International Telecommunication Union administers this frequency allocation
- Services like FM Broadcast, Television, Cellular Mobile Radio and Satellite communication operate under fixed frequency bands

Let us now consider amplitude modulation in detail.

Amplitude modulation

1. As we know, in amplitude modulation, the amplitude of the carrier wave is varied in accordance with the amplitude of the information signal or modulating signal.
2. For sinusoidal modulating wave,

$m(t) = A_m \sin\omega_m t$ --------------------------------(1)

- A_m – Amplitude of modulating signal
- ω_m- $2\pi\upsilon_m$ – Angular frequency of modulating signal

3. For carrier wave,

$C_m(t) = A_c \sin\omega_c t$ --------------------------------(2)

- A_c – Amplitude of carrier wave
- ω_m- $2\pi\upsilon_c$– Angular frequency of carrier wave

4. For carrier wave, the amplitude is changed by adding the amplitude of the modulating signal which is A_c $_{plus}$ $A_m \sin\omega_m t$

$C_m(t) = (A_c + A_m \sin\omega_m t) \sin \omega_c t$ --------------------------------(3)

5. Multiply and Divide equation (3) RHS by A_c

$C_m(t) = A_c (A_c/A_c + A_m/A_c \sin \omega_m t) \sin \omega_c t$ ---------------------------(4)

Replace $A_m / A_c = \mu$

μ is called Amplitude modulation index and is always less than or equal to 1 to avoid distortion.

$C_m(t) = A_c \sin \omega_c t + \mu A_c \sin \omega_c t \sin \omega_m t$ ---------------------------(5)

6. We know that sin A sin B = ½ [cos (A-B) – cos (A + B)]

Hence, $\sin \omega_c t \sin \omega_m t = [\cos (\omega_c-\omega_m)t - \cos(\omega_c+\omega_m)t]$

$C_m(t) = A_c \sin \omega_c t + \mu A_c/2[\cos (\omega_c-\omega_m)t - \cos(\omega_c+\omega_m)t]$

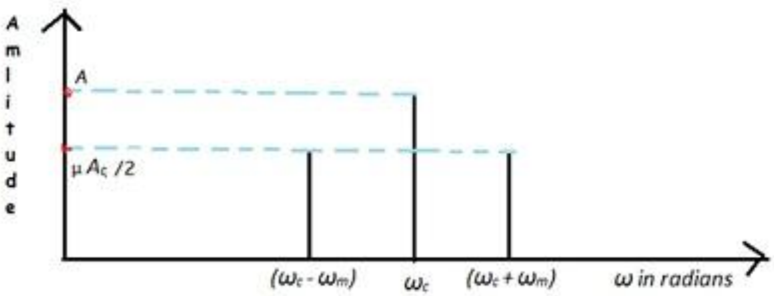
$C_m(t) = A_c \sin \omega_c t + \mu A_c/2\cos (\omega_c-\omega_m)t - \mu A_c/2\cos(\omega_c+\omega_m)t$--------(6)

7. Equation (6) shows that the amplitude modulated signal consists of
   1. Carrier wave of frequency ω_c
   2. Sinusoidal wave of frequency $(\omega_c-\omega_m)$
   3. Sinusoidal wave of frequency $(\omega_c+\omega_m)$
8. The two additional waves are called side bands. The frequency of these bands are called side band frequencies
   1. Frequency of lower side band = $(\omega_c-\omega_m)$

2. Frequency of upper side band = $(\omega_c+\omega_m)$

9. The band width of the AM wave is Frequency of lower side band minus Frequency of upper side band $(\omega_c+\omega_m) - (\omega_c-\omega_m) = 2\omega_m$ *(Twice the frequency of modulating signal)*

10. Graphical representation



Problem – The frequencies of two side bands in an AM wave are 640 kHz and 660 kHz respectively. Find the frequencies of carrier and modulating signal. What is the bandwidth required for amplitude modulation ?**(CBSE 2017 Set 1)**

Solution - Given $(\omega_c+\omega_m) = 660$ kHz ; $(\omega_c-\omega_m) = 640$ kHz

- $(\omega_c+\omega_m) - (\omega_c-\omega_m) = 2\omega_m = 660 - 640 = 20$ kHz

Hence, frequency of modulating signal $\omega_m = 10$ kHz

- *Now,* $(\omega_c+\omega_m) = 660$ kHz, $(\omega_c+10) = 660$ kHz, *Hence, frequency of carrier wave* $\omega_c = 660 - 10 = 650$ kHz
- *The band width of the AM wave is Frequency of lower side band minus Frequency of upper side band* $(\omega_c+\omega_m) - (\omega_c-\omega_m) = 2\omega_m$

Hence, $2\omega_m = 20$ kHz

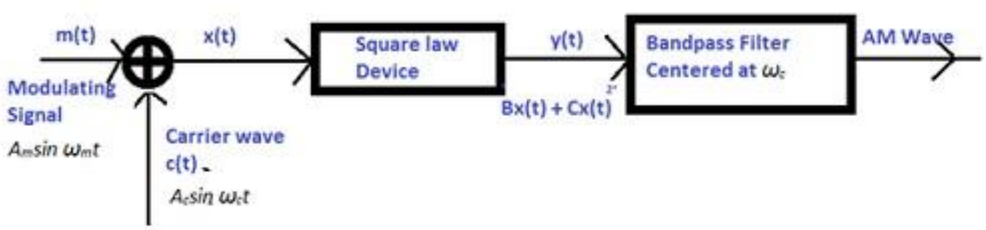
Problem – An audio signal of amplitude 0.1 V is used in amplitude modulation of a carrier wave of amplitude 0.2 V. Calculate the modulation index.

Solution –

We know that $A_m / A_c = \mu$, given $A_m = 0.1$ V , $A_c = 0.2$ V

$\mu = 0.1 / 0.2 = 0.5$

Production of amplitude modulated wave



We know that modulating signal is represented by

$m(t) = A_m \sin\omega_m t$ --------------------------------(1)

- A_m – *Amplitude of modulating signal*
- ω_m- $2\pi\upsilon_m$ – *Angular frequency of modulating signal*

Similarly, carrier wave is represented by

$C_m(t) = A_c \sin\omega_c t$ --------------------------------(2)

- A_c – *Amplitude of carrier wave*
- ω_m- $2\pi\upsilon_c$– *Angular frequency of carrier wave*

Modulating signal is added to the carrier wave, Hence, the representation is

$x(t) = A_m \sin\omega_m t + A_c \sin\omega_c t$

4. The above signal is passed to a square law device (non-linear device)

$y(t) = B\, x(t) + c\, [x(t)]^2$

B,C – Arbitrary constants

Substitute for x(t) in y(t) and use formula $(A + B)^2 = A^2 + B^2 + 2AB$

$y(t) = B[A_m \sin\omega_m t + A_c \sin\omega_c t] + c[A_m \sin\omega_m t + A_c \sin\omega_c t]^2$

$= B[A_m \sin\omega_m t + A_c \sin\omega_c t] + c[A_m^2 \sin^2\omega_m t + A_c^2 \sin^2\omega_c t$

$+ 2 A_m A_c \sin\omega_m t \sin\omega_c t]$

We know $\sin A \sin B = ½ [\cos(A-B) – \cos(A+B)]$

Hence,

$\sin\omega_c t \sin\omega_m t = ½ [\cos(\omega_c – \omega_m)t – \cos(\omega_c + \omega_m)t]$

Also, $\sin^2 A = (1 - \cos 2A)/2$

Hence,

$\sin^2\omega_c t = (1 – \cos 2\omega_c t) / 2$

$\sin^2\omega_m t = (1 – \cos 2\omega_m t) / 2$

Therefore y(t) can be re-written as

$Y(t) = B[A_m \sin\omega_m t + A_c \sin\omega_c t] + cA_m^2/ 2(1 – \cos 2\omega_m t)$

$+ cA_c^2/ 2(1 – \cos 2\omega_c t)$

$+ 2 A_m A_c (c/2)[\cos(\omega_c – \omega_m)t – \cos(\omega_c + \omega_m)t]]$

$Y(t) = BA_m \sin\omega_m t + BA_c \sin\omega_c t + c/2[A_m^2 + A_c^2]$

$– cA_m^2/2 \cos 2\omega_m t – c A_c^2/2 \cos 2\omega_c t$

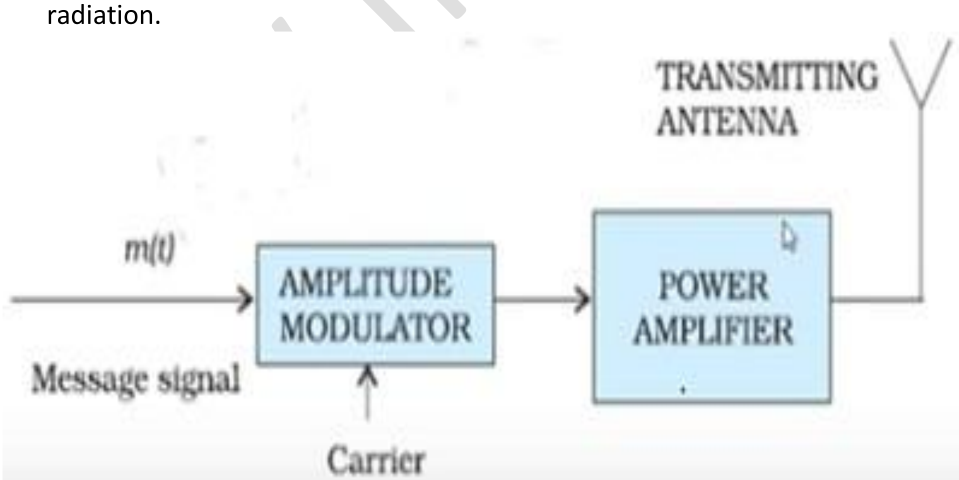
$+ cA_m A_c \cos(\omega_c – \omega_m)t – c A_m A_c \cos(\omega_c + \omega_m)t$

In the above equation, there is a d.c. term $½ c [A_m^2 + A_c^2]$ and sinusoidal waves of frequency ω_c, ω_m, $2\omega_m$, $(\omega_c – \omega_m)$ and $(\omega_c + \omega_m)$

The signal is passed through band pass filter centered at ω_c

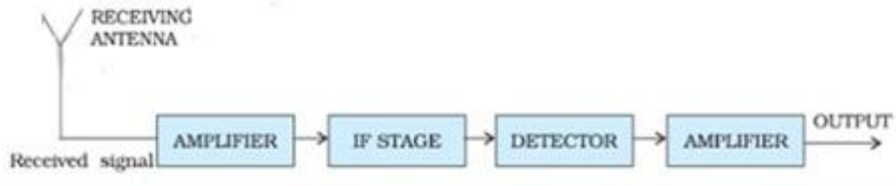
This rejects the low and high frequencies. In the above case, the filter rejects d.c, ω_c, ω_m, $2\omega_m$, $(\omega_c – \omega_m)$. The frequencies ω_c, $(\omega_c – \omega_m)$ and $(\omega_c + \omega_m)$ are passed. This is amplitude modulated wave.

This wave cannot be passed as such. It needs to be amplified and then fed to an antenna of appropriate size for radiation.



Detection of amplitude modulated wave

- Detection is the process of recovering the modulating signal from the modulated carrier wave.
- The transmitted message gets attenuated in propagating through the channel



- The receiving antenna receives the signal which is then amplified.

- The carrier frequency is changed to a lower frequency by Intermediate frequency (IF) stage

<u>Detection Process</u>:

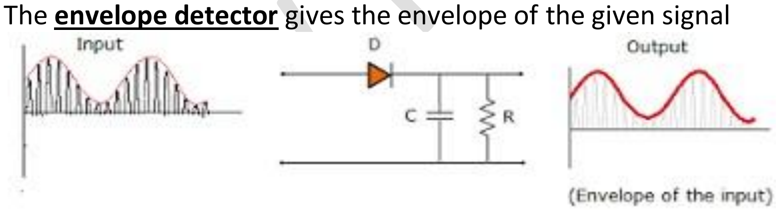
- It is then passed through the detector.

Hence, INPUT – Modulated carrier wave of frequencies ω_c, $(\omega_c+\omega_m)$ and $(\omega_c-\omega_m)$

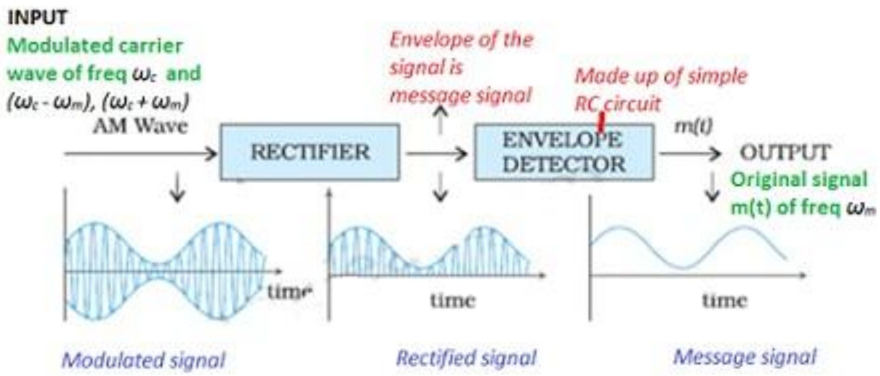
OUTPUT – Original signal m(t) of frequency ω_m

We know that **<u>Rectifier</u>** consists of a simple circuit, which gives the input and output as indicated below:

The **<u>envelope detector</u>** gives the envelope of the given signal



Block Diagram for Detection of Amplitude modulated wave



Problem -Due to economic reasons, only the upper side band of the AM wave is transmitted, but at the receiving station, there is a facility for generating the carrier. Show that if the device is available which can multiply two signals, then it is possible to recover the modulating signal at the receiver station.

Solution - We know that the upper side band of AM wave is $(\omega_c + \omega_m)$

where ω_c is the angular frequency of carrier wave and ω_m is the angular frequency of signal wave respectively

In simple form, the signal received at the receiving station can be given as

$m(t) = A \cos (\omega_c + \omega_m) t$

The carrier wave, at the receiving station, can be represented as

$C(t) = A_c \cos \omega_c t$

Multiplying the above 2 signals,

$m(t) * c(t) = AA_c \cos (\omega_c + \omega_m) t \cos \omega_c t$

We know cos A cos B = ½ [cos (A+B) + cos (A-B)]

Hence,

$\cos(\omega_c + \omega_m) t \cos \omega_c t = ½ [\cos (\omega_c + \omega_m)t + \omega_c t + \cos (\omega_c + \omega_m)t - \omega_c t]$

$m(t) * c(t) = A A_c ½ [\cos (\omega_c + \omega_m)t + \omega_c t + \cos (\omega_c + \omega_m)t - \omega_c t]$

$= A A_c / 2 [\cos(2\omega_c + \omega_m)t + \cos \omega_m t]$

At the receiving station, the above signal gets passed into the bandpass filter. The filter will oppose the signal of frequency $2\omega_c + \omega_m$ and hence, we get the modulating signal $A A_c / 2 \cos \omega_m t$ of frequency ω_m will be received.