ANALOG COMMUNICATION

Course Code :20EC07

Dr. POORNAIAH BILLA

COURSE EDUCATIONAL OBJECTIVES:

This course provides the knowledge on various analog modulati techniques in both time and frequency domains.

The course will give an idea about generation and demodulation metho of various analog modulation techniques.

It also gives the complete information regarding the transmitter a receiver types and performance evaluation of continuous wa modulation schemes.

COURSE OUTCOMES:

The student will be able to

- CO1: Understand the fundamental concepts of various analog modulation schen with relevant time and frequency domain representations.(Understand – L2)
- CO2 Interpret the generation, detection of continuous wave and pulse ana modulation techniques. (Understand – L2)
- CO3 Apply the concepts of analog modulation and demodulation techniques calculating communication system related parameters.(Apply – L3)
- CO4 Analyze the performance of continuous wave modulation schemes in presence of channel noise.(Analyze – L4)

SKILLS:

- Identify the need for modulation and choice of modulation
- Choose the choice of frequency bands of AM/FM/T.V/Mobile
- Able to analyze the frequency spectrum of various signals
- Ability to determine the quality of demodulated signal
- Select the detector for required modulation
- Identify inherent or interference noise and clasify

Contents

UNIT-IV: **Radio Transmitters:** Classification of Transmitters, AM Transmitter: Low level, high level A Transmitters, FM transmitters: Reactance tube and Armstrong Method.
Radio Receivers: Tuned Radio Frequency receiver and its Limitations, Need for heterodyning, AM Su Heterodyne Receiver, Frequency Changing and Tracking, Concept of Intermediate Frequency, Autom Gain Control: Simple AGC, Delayed AGC, FM receiver.

UNIT-V: **Noise in Analog Communication Systems:** Noise in communication system, Signal to No ratio calculations in AM, DSBSC, SSBSC and FM receivers, Threshold Effect, Pre-Emphasis and Emphasis circuits, Introduction to Carrier to Noise Ratio, Signal to Interference plus Noise Ratio.

Analog Pulse Modulation: Need for Pulse Modulation, Types of Pulse analog Modulation, Pu Amplitude Modulation Generation and Demodulation, Pulse Width Modulation Generation Demodulation, Pulse Position Modulation Generation and Demodulation.

Multiplexing: Frequency Division Multiplexing, Time Division Multiplexing.

TEXT BOOKS:

1. Simon Haykin, “Communication Systems”, John Wiley & Sons, 2nd Edition, 1983.
2. George Kennedy ,Davis, “Electronic Communication Systems”, Tata McGraw Hill Education, 4th edition, 1999

REFERENCE BOOKS:

1. G.K.Mithal, “Radio Engineering”, Khanna Publishers,20th Edition,2000
2. Sanjay Sharma, “Analog Communication Systems”,S.K.Katariya& Sons,2nd Edition, 2007

UNIT 1

NIT-I: **Introduction to Communication System**: Elements of Communication System, Need odulation, Classification of Modulation.

nplitude Modulation: Time and Frequency Domain Representation of AM, Power relations in AM w eneration of AM waves: Square law Modulator, Switching Modulator, and Demodulation of AM w uare law demodulator, Envelope detector.

ouble Side band Suppressed Carrier Modulation: Time and Frequency domain representation, Genera DSBSC: Balanced modulator & Ring Modulator, Coherent Detection of DSBSC wave, Costas Loop.

Signal

gnal: **Signal is a physical quantity, which contains some information and which is a function of on ore variables.**

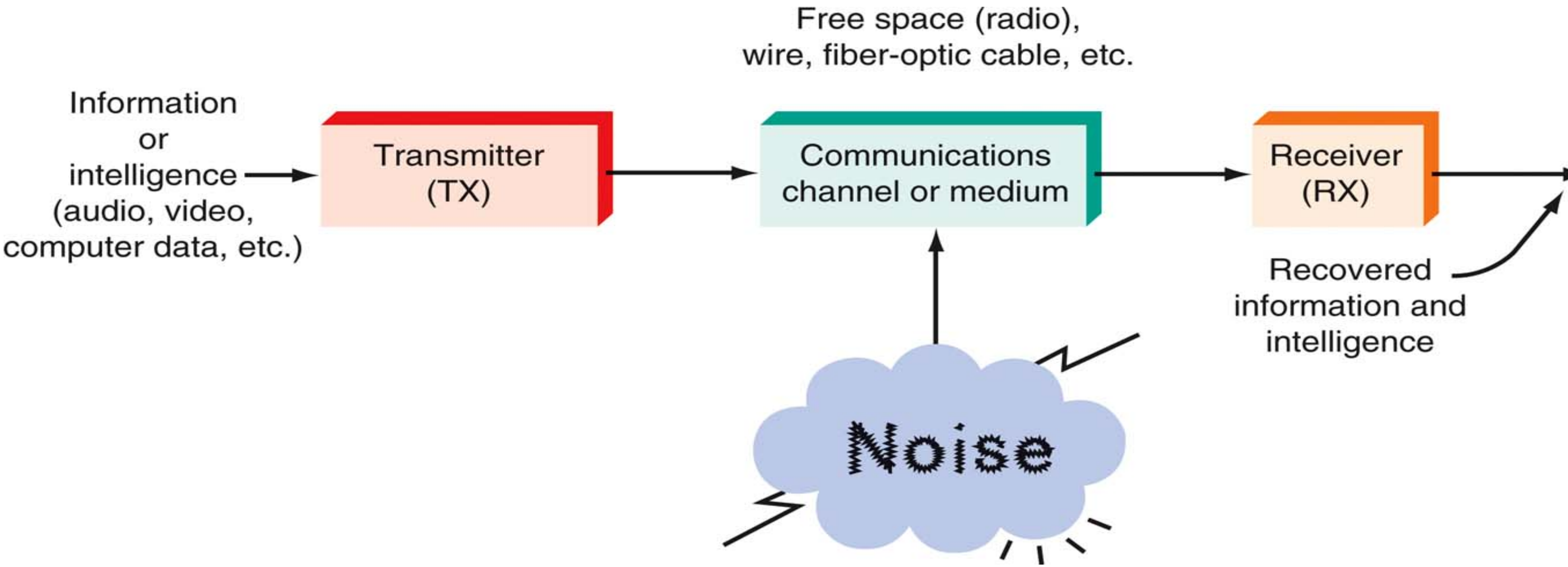
nalog signal: It is defined as the signal having continuous values. They have infinite number of diffe lues. Amplitude of Signal continuously varies with time.

INTRODUCTION

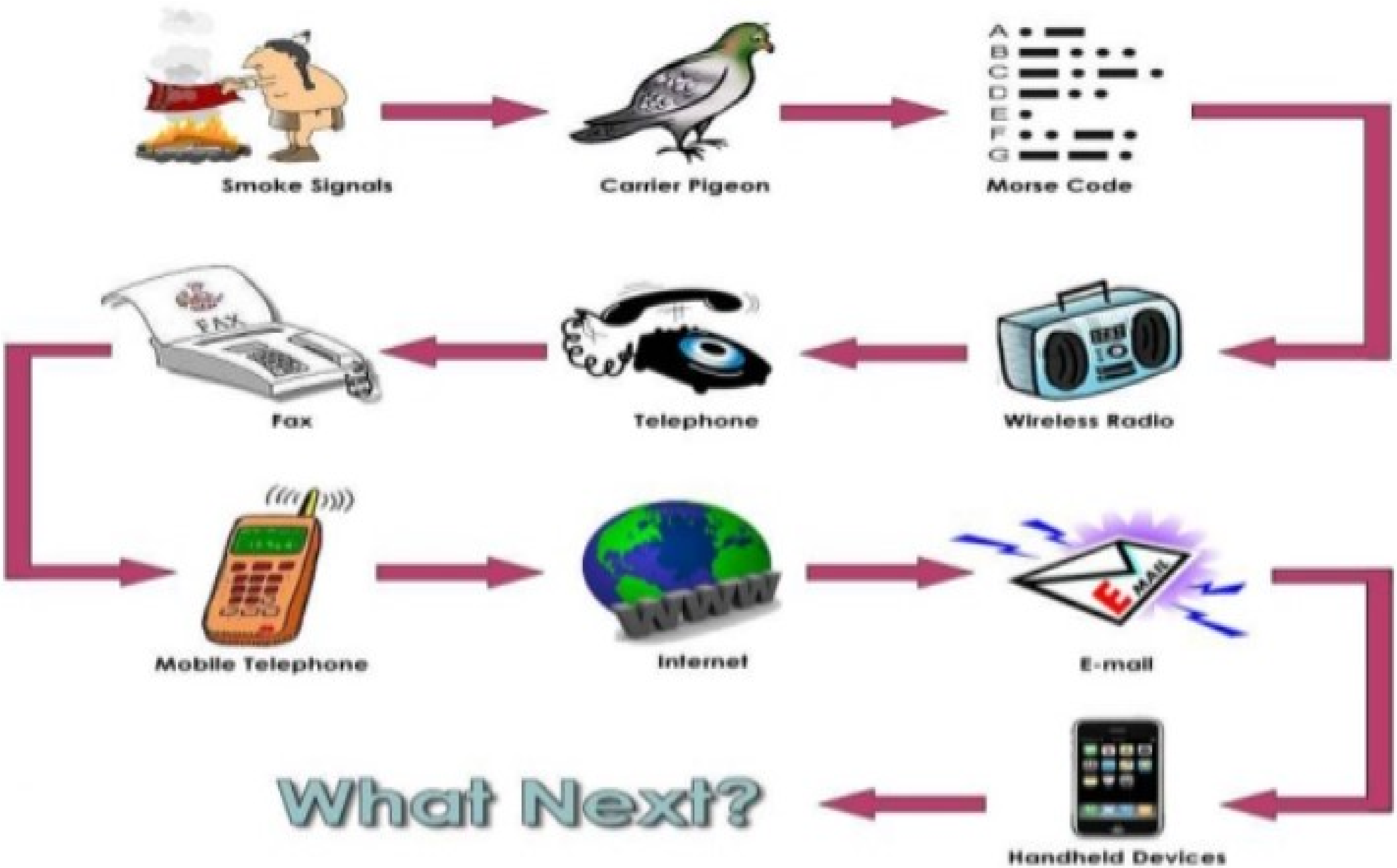
Communication is the transfer of information from one place to another.

This should be done

- *as **efficiently** as possible*
- *with as much **fidelity/reliability** as possible*
- *as **securely** as possible*

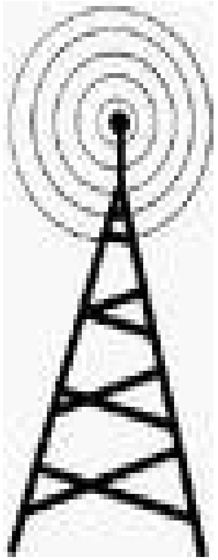


COMMUNICATION TIME LINE

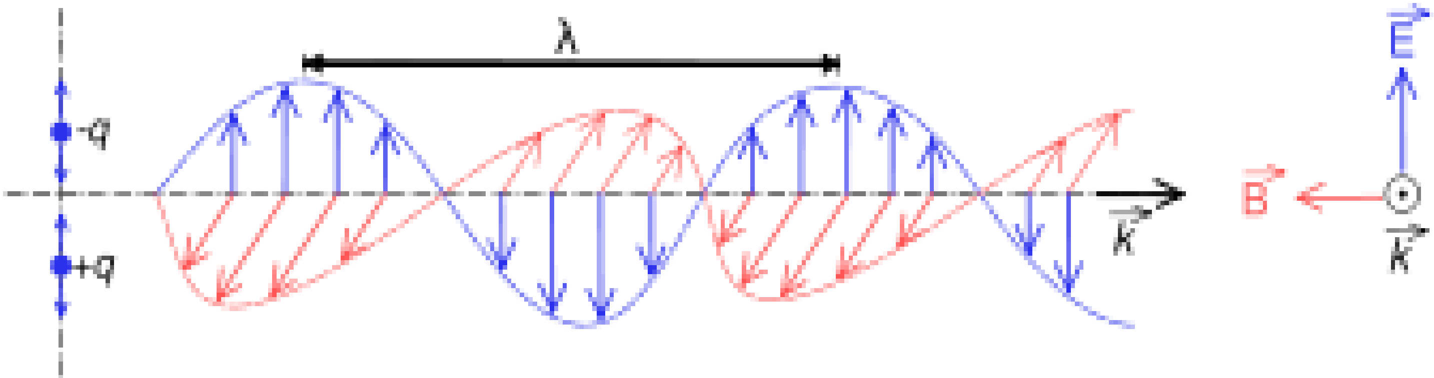


COMMUNICATION

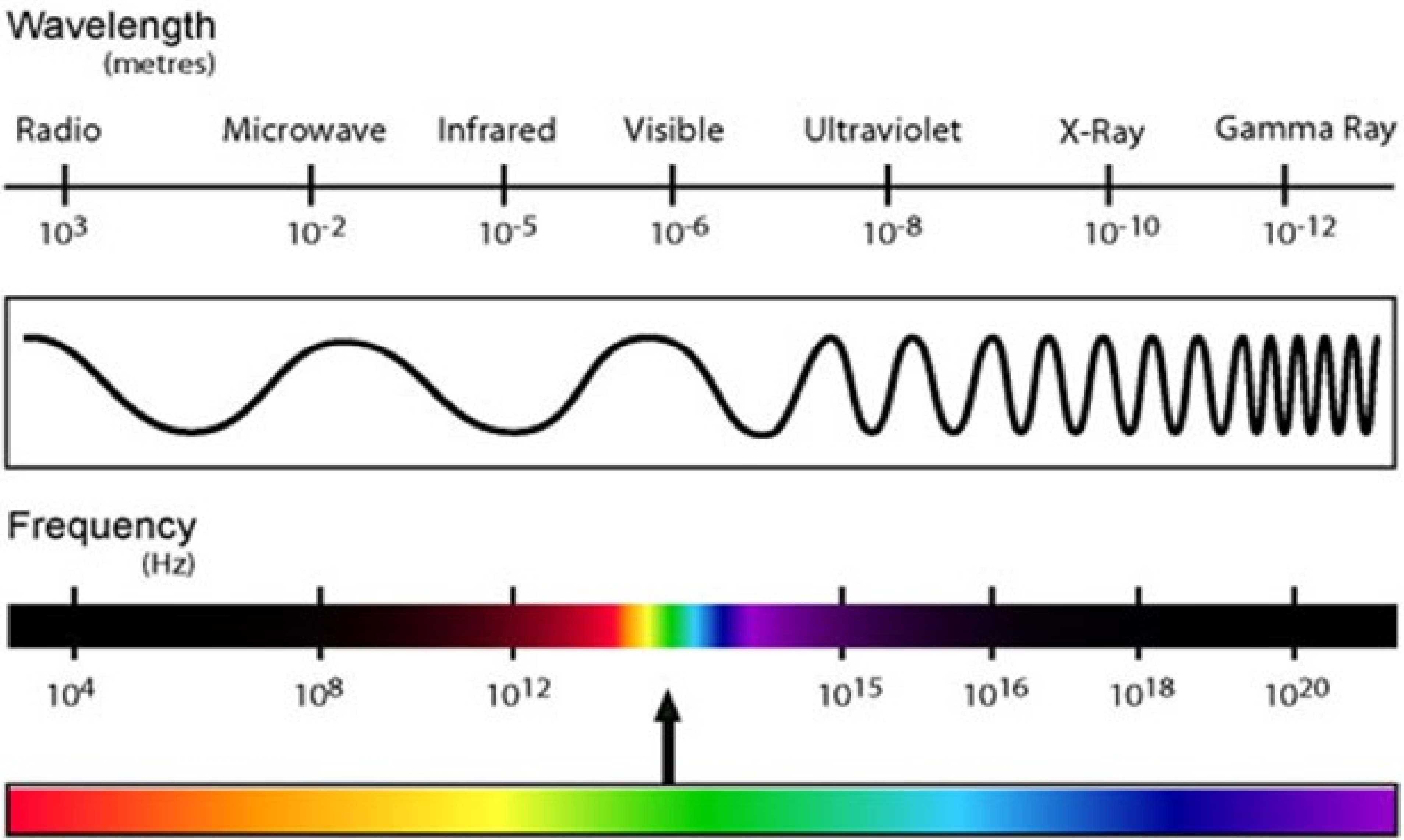
o be transmitted, Information must be transformed to electromagnetic sig



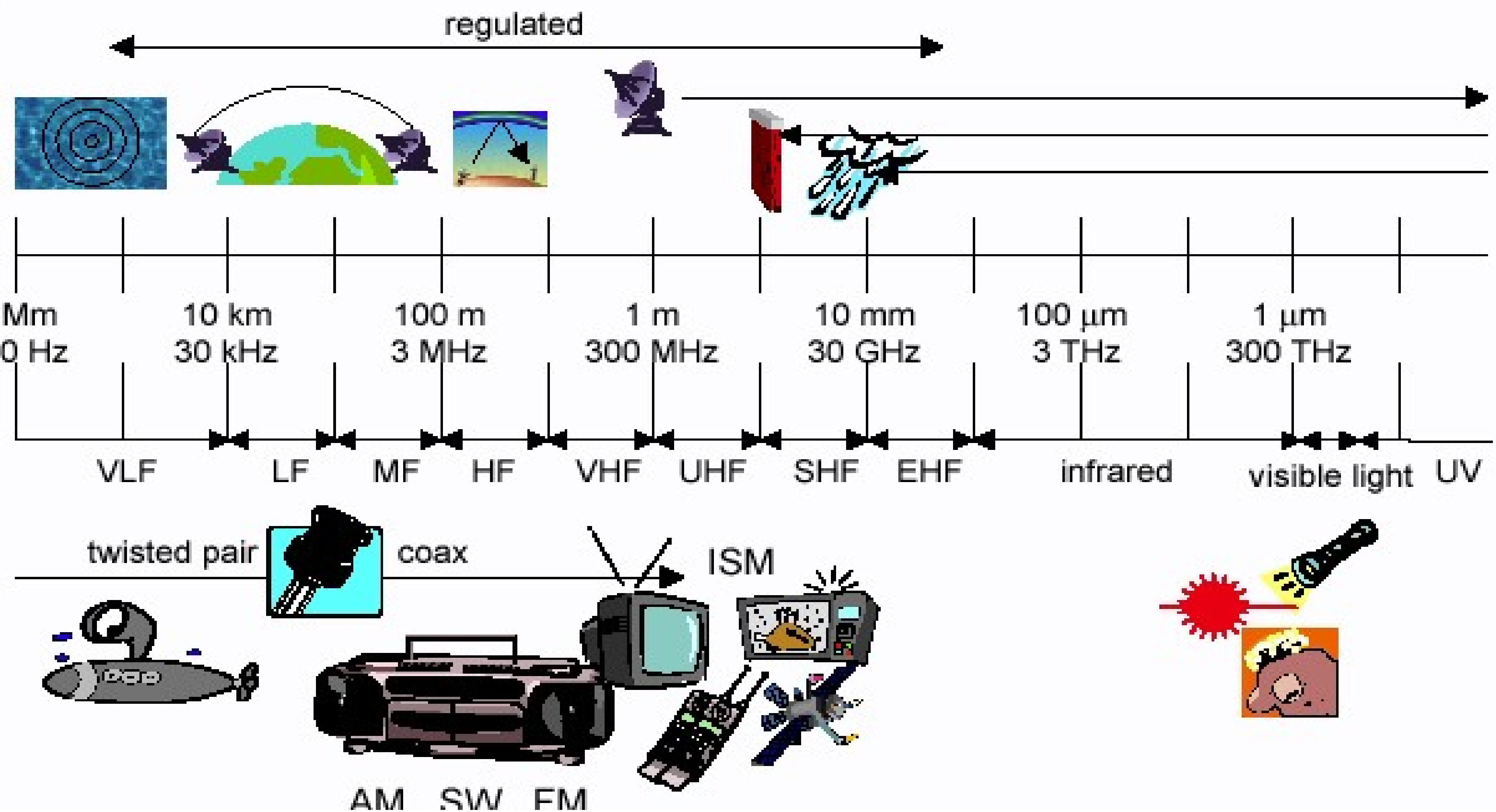
ectromagnetic Waves



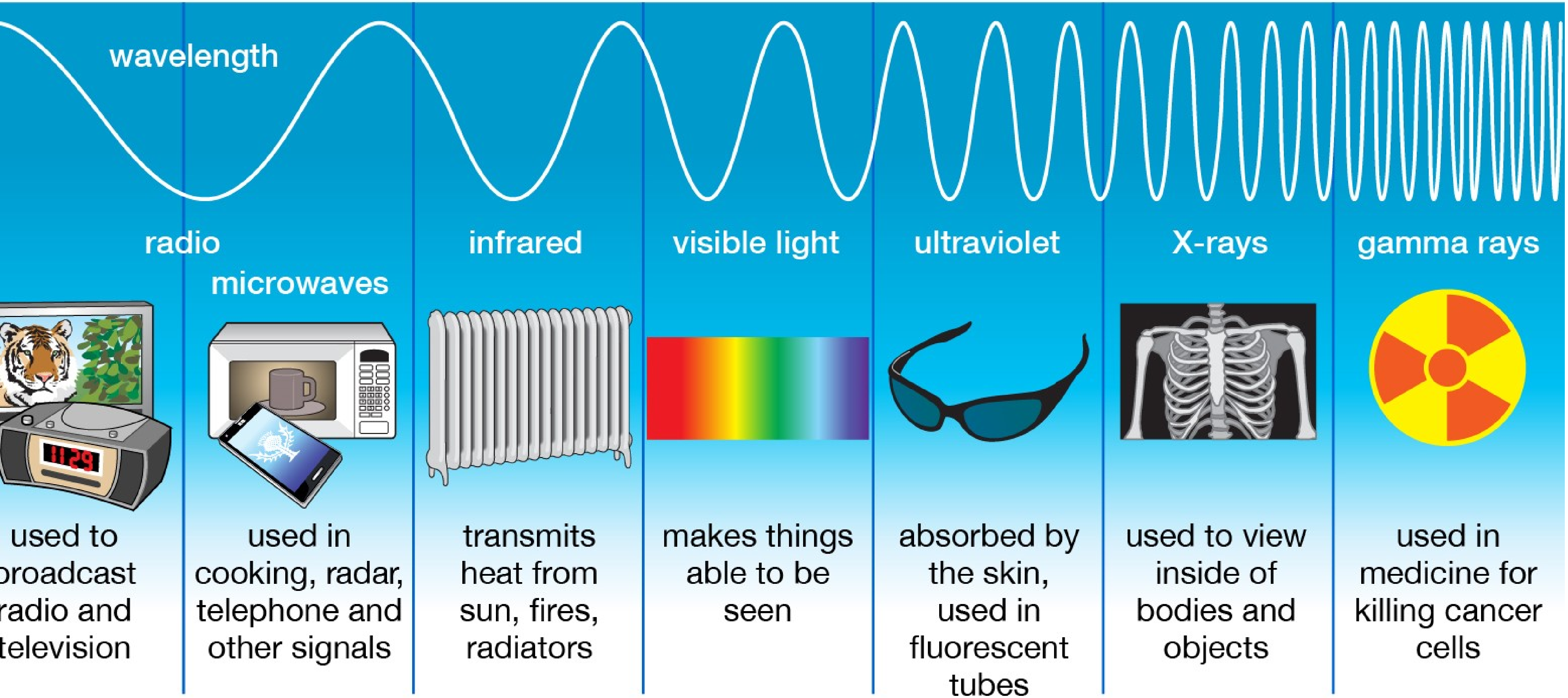
ELECTROMAGNETIC SPECTRUM



ELECTROMAGNETIC SPECTRUM



ypes of Electromagnetic Radiation



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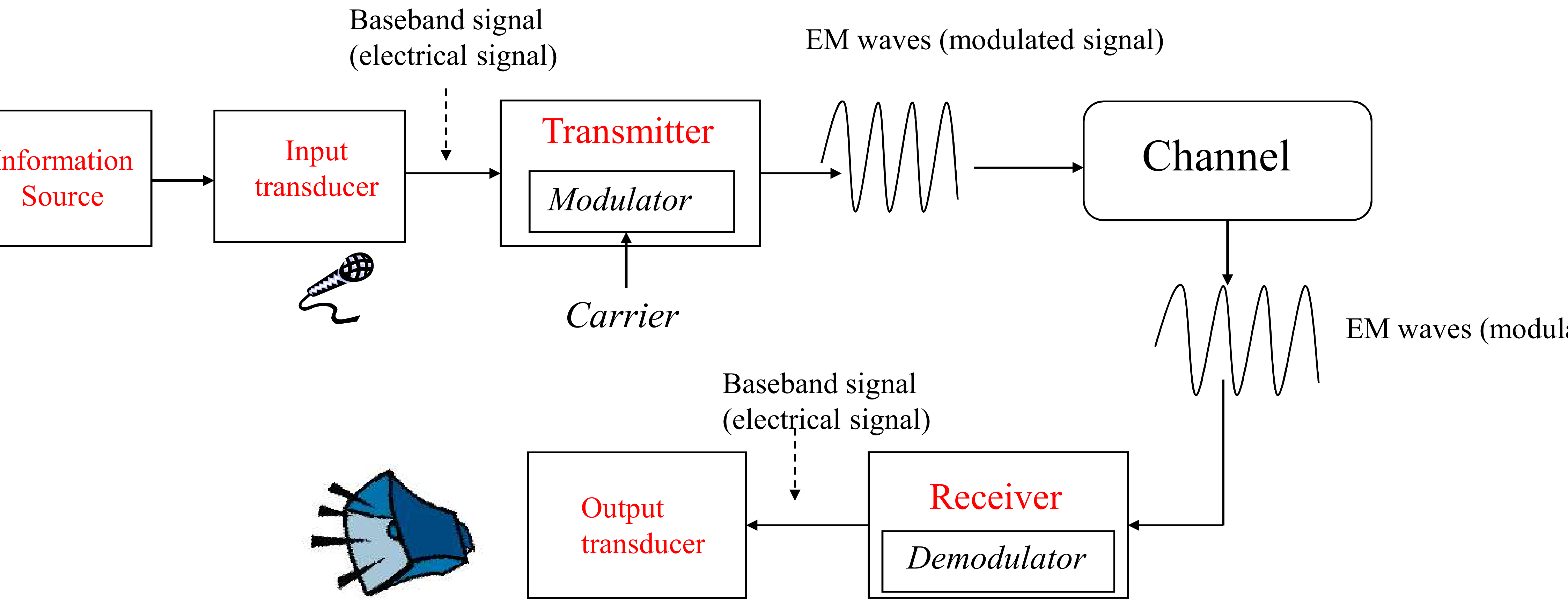
BASIC ANALOG COMMUNICATIONS SYSTEM



BASIC ANALOG COMMUNICATIONS SYSTEM

signed to send the information from a source that generates the message t
stination

ormation Source:

-voice(speech source)
-picture(image source)
-plain text in some particular language, such as English, Japanese, German, French, etc

out Transducer:

-converts the output of a source into an electrical signal that is suitable for transmission

Ex: microphone converts an acoustic speech signal into an electrical signal

BASIC ANALOG COMMUNICATIONS SYSTEM

ransmitter: converts the electrical signal into a form that is suitable for transmission over a channel

in general, the transmitter performs the matching of the messa signal to the channel by the process called modulation,

ex: AM,FM

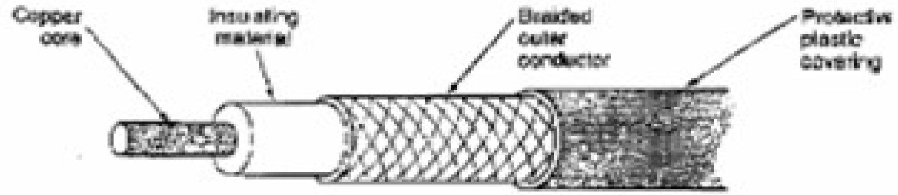
hannel: Physical medium used to send the signal from the transmitter to t receiver

BASIC ANALOG COMMUNICATIONS SYSTEM

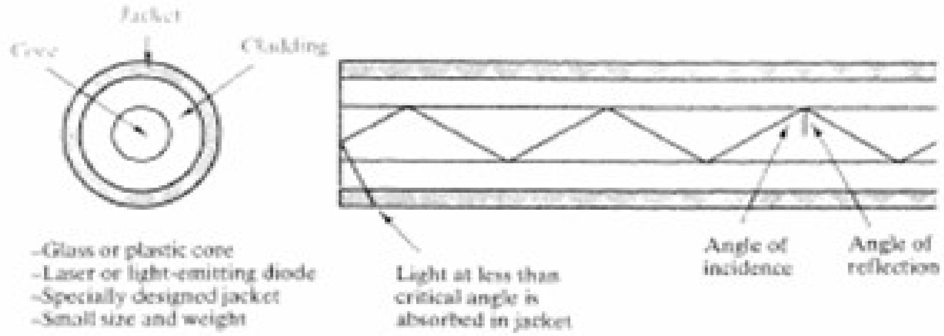
channel

- wireline channel
  - twisted-pair

  - coaxial cable



  - optical fiber



BASIC ANALOG COMMUNICATIONS SYSTEM

vireless channel

- normally atmosphere (free space)
- electromagnetic energy is coupled to the propagation medium by an antenna which serves as the radiator

– underwater acoustic channels

- electromagnetic waves do not propagate over lon distances under water except at extremely low frequencies
- acoustic signals propagate over distances of tens even hundreds of km

BASIC ANALOG COMMUNICATIONS SYSTEM

eceiver:

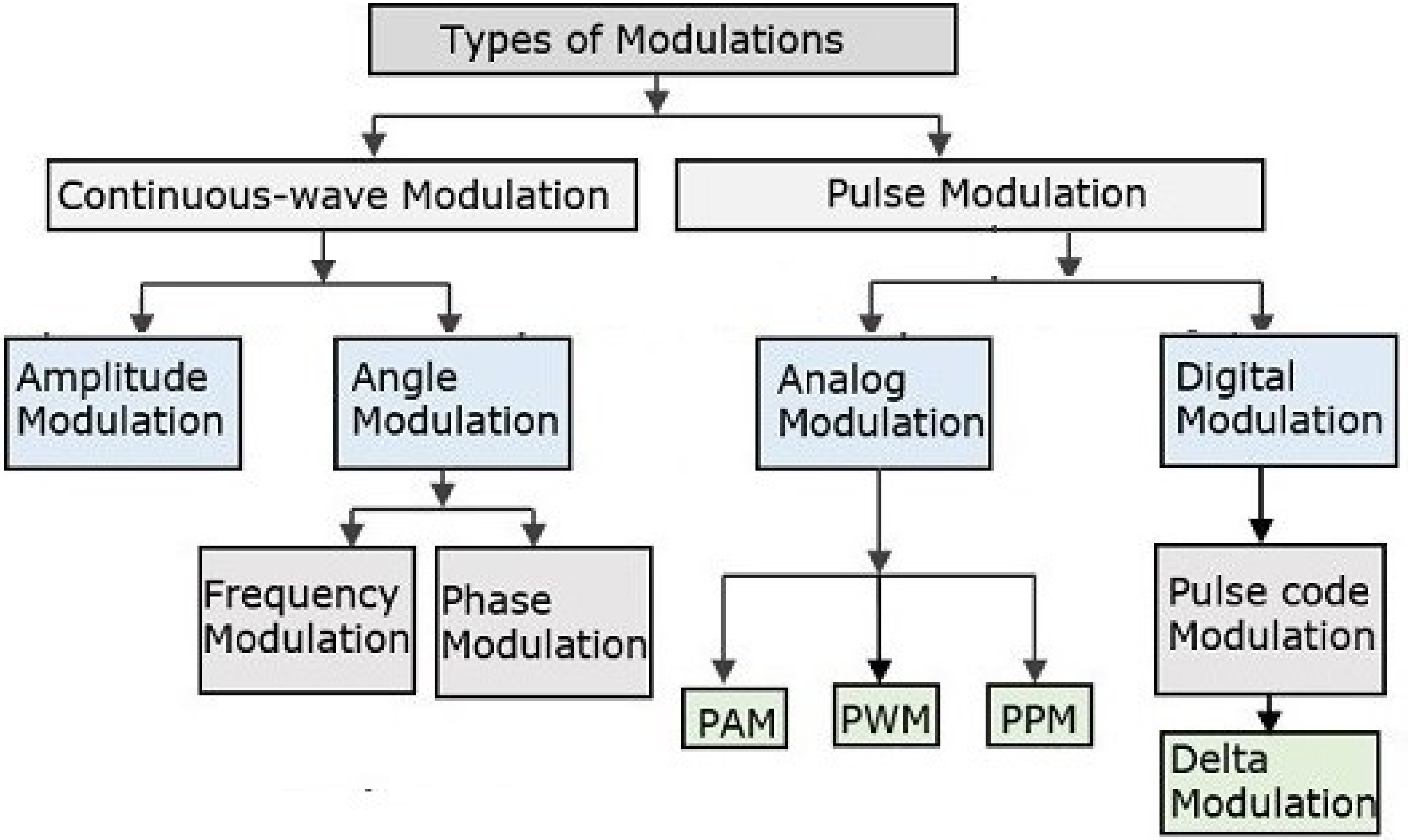
recover the message signal contained in the received signal.
f the message signal is transmitted by the carrier modulation, the receiver erforms carrier demodulation to extract the message signal

Output transducer:

onverts the electrical signals that are received into a form that is suitable fo he use.

Ex: acoustic signals, images,etc

CLASSIFICATION OF MODULATION



TYPES OF ANALOG MODULATION

- Amplitude Modulation (AM)

  Amplitude modulation is the process of *varying the amplitude of a carr*
  wave in proportion to the amplitude of a baseband signal. The frequen
  of the carrier remains constant

- Frequency Modulation (FM)

  Frequency modulation is the process of *varying the frequency of a carr*
  wave in proportion to the amplitude of a baseband signal. The amplitu
  of the carrier remains constant

- Phase Modulation (PM)

  Phase modulation is the process of *varying the phase of a carrier wave*
  proportion to the amplitude of a baseband signal. The amplitude of the
  carrier remains constant

TYPES OF ANALOG MODULATION

Consider the carrier signal below:

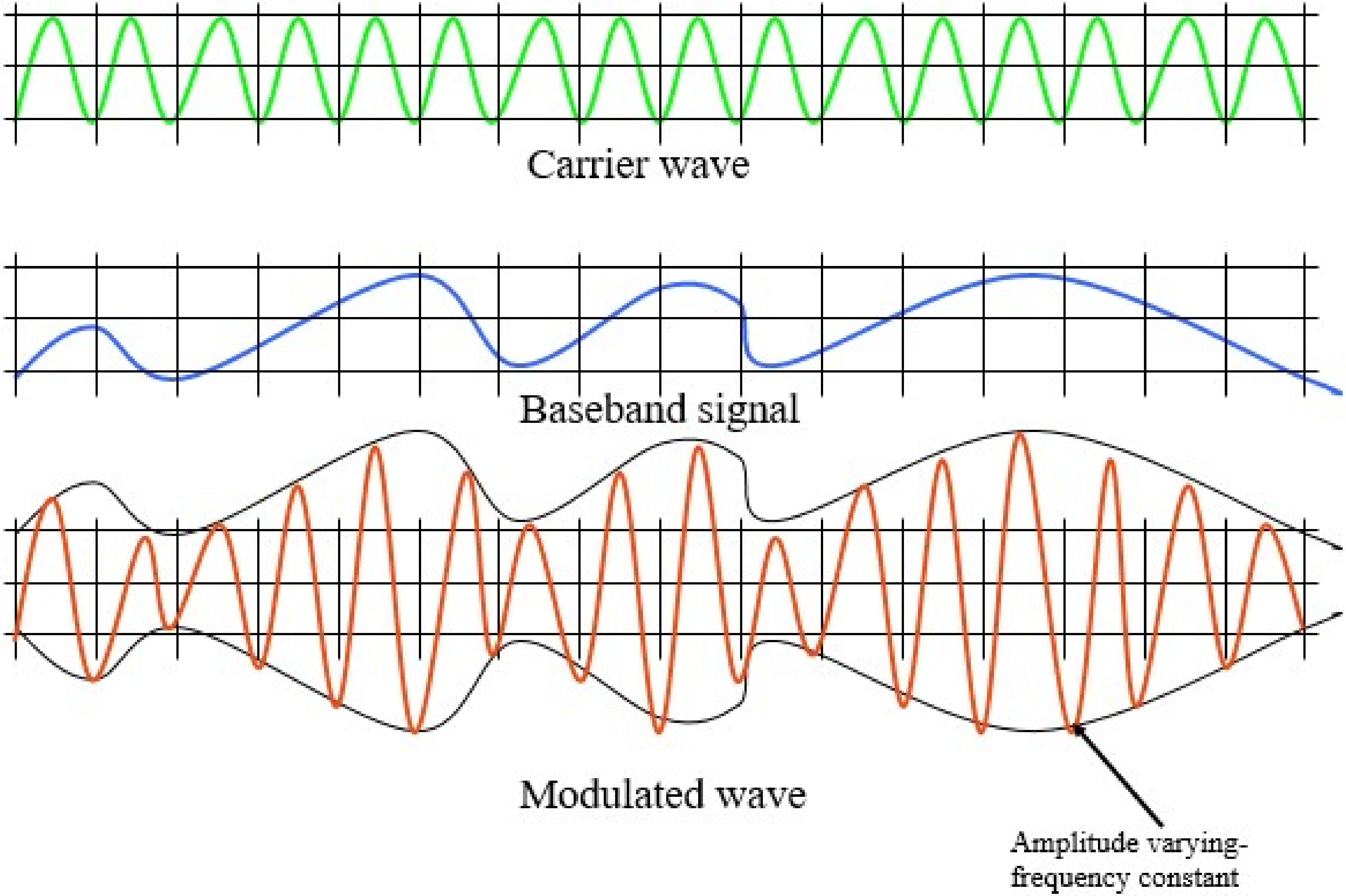
$$C(t) = A_c \cos(2\pi f_c t + \theta)$$

1. Changing of the carrier amplitude A_c produces
   Amplitude Modulation signal (AM)

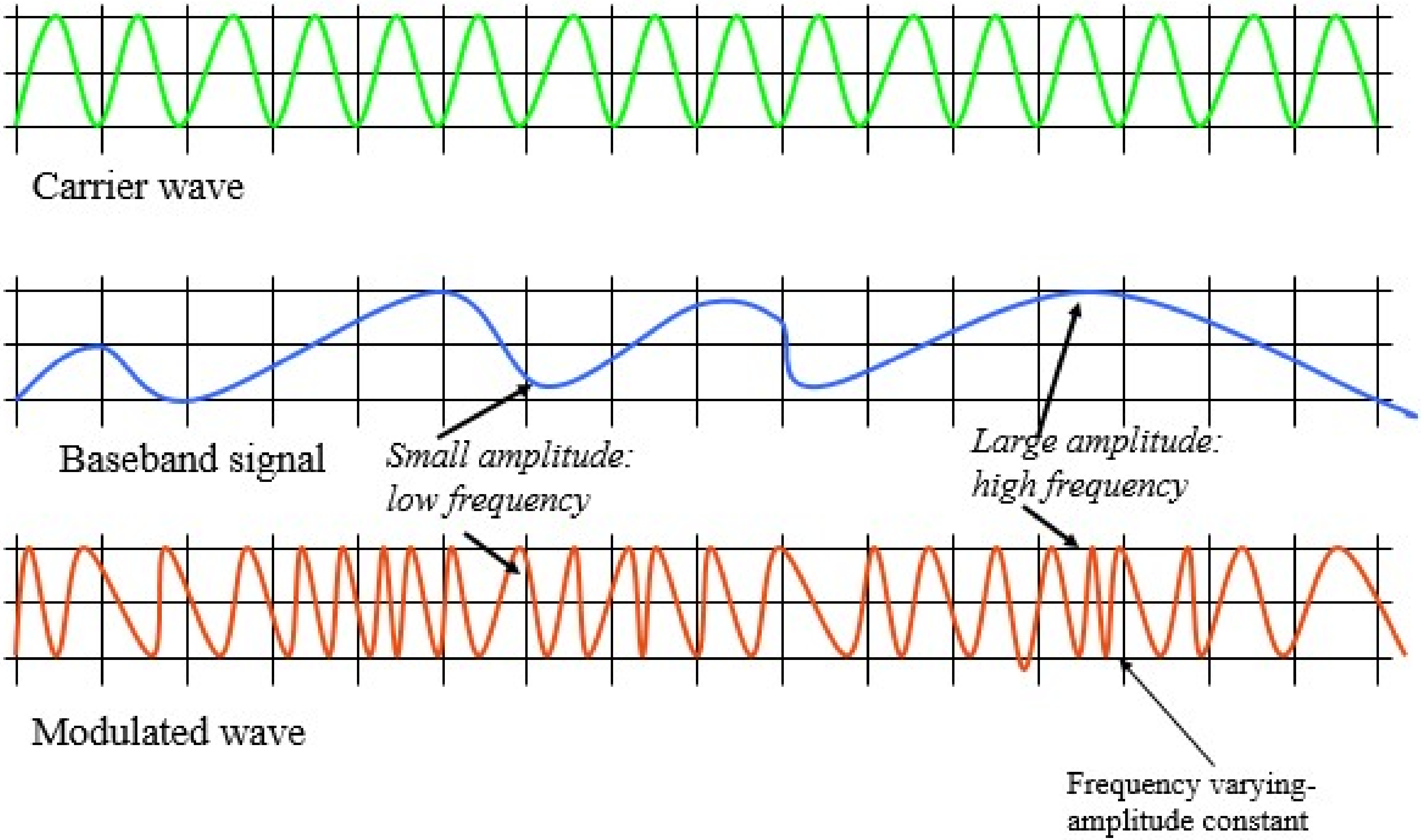
2. Changing of the carrier frequency f_c produces
   Frequency Modulation signal (FM)

3. Changing of the carrier phase θ produces
   Phase Modulation signal (PM)

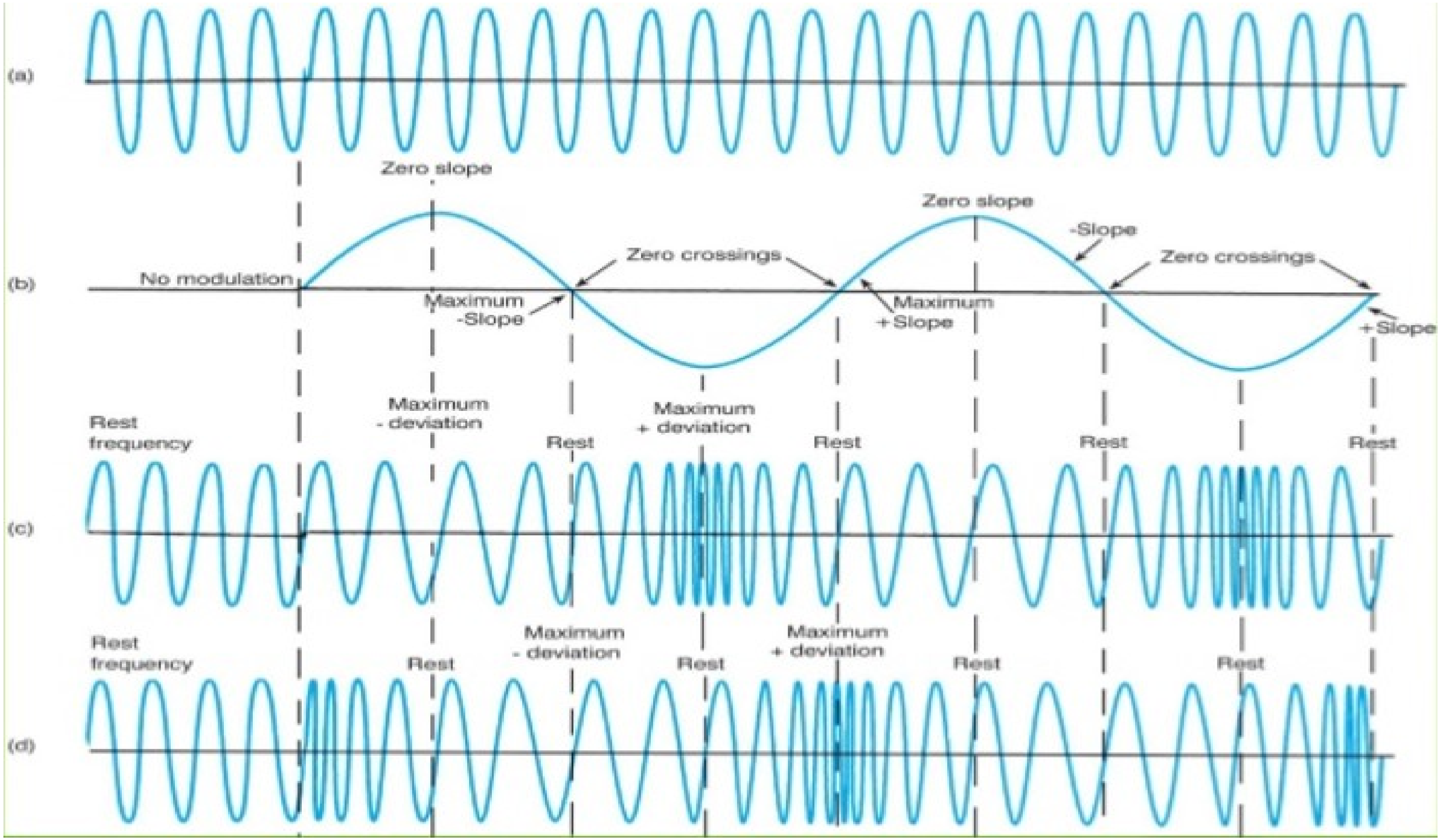
AMPLITUDE MODULATION



FREQUENCY MODULATION



FREQUENCY MODULATION



a) carrier signal b)modulating signal c) FM signal d) PM signal

What is Modulation ?

odulation is the process in which some characteristics of the carrier signal is varied in accordar
th the instantaneous of value of the message signal.

(or)

is the process of mixing of low energy message signal with high energy carrier signal to produ
gh energy modulated signal to carries energy to a long distance

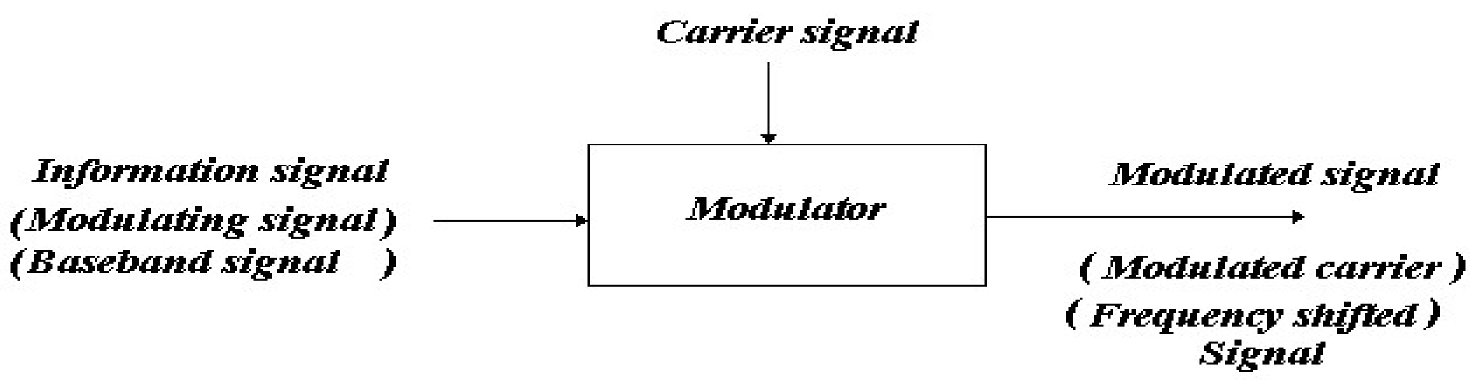


Fig. Process of Modulation

Once this information is received, the low frequency information must be removed fro
the high frequency modulated carrier. This process is known as *" Demodulation".*

Need for Modulation

1. Reduction in the height of antenna
2. Avoids mixing of signals
3. Increases the range of communication
4. Multiplexing is possible
5. Improves quality of reception

Need for Modulation

1. Reduction in the height of antenna

the transmission of radio signals, the antenna height

st be multiple of λ/4 ,where λ is the wavelength .

$$\lambda = c/f$$

ere c : is the velocity of light

f : is the frequency of the signal to be transmitted

The minimum antenna height required to transmit a basebar signal of f= 10 kHz is calculated as follows :

$$Minimum\ antenna\ height = \frac{\lambda}{4} = \frac{c}{4f} = \frac{3 \times 10^8}{4 \times 10 \times 10^3} = 7500\ meters\ i.e. 7.5\ km$$

The antenna of this height is practically impossible to install

Now, let us consider a modulated signal at f = 1 MHz .
Then the minimum antenna height is given by ;

$$Minimum\ antenna\ height = \frac{\lambda}{4} = \frac{c}{4f} = \frac{3 \times 10^8}{4 \times 10 \times 10^6} = 75\ meters$$

This antenna can be easily installed practically .

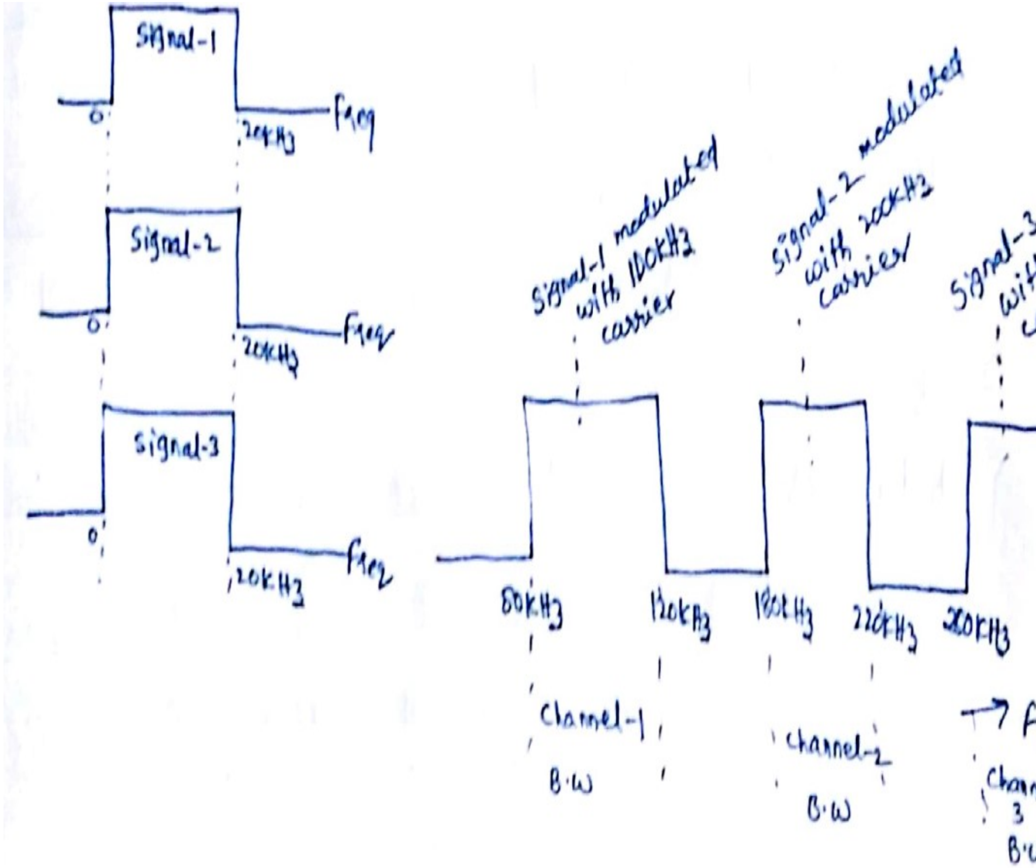
Need for Modulation

2. Avoid Mixing of Signals

hen many transmitters are transmitting
eband information signal simultaneously,
y all get mixed up.

his problem can be resolved by using the
dulation technique.

y using modulation, the baseband sound signals of same
quency range can be shifted to different frequency ranges.
erefore, now each signal has its own frequency range within
total bandwidth.



Need for Modulation

3. Increase the Range of Communication

- The frequency of baseband signal is low, and the low frequency signals can not travel long distance when they are transmitted . They get heavily attenuated .

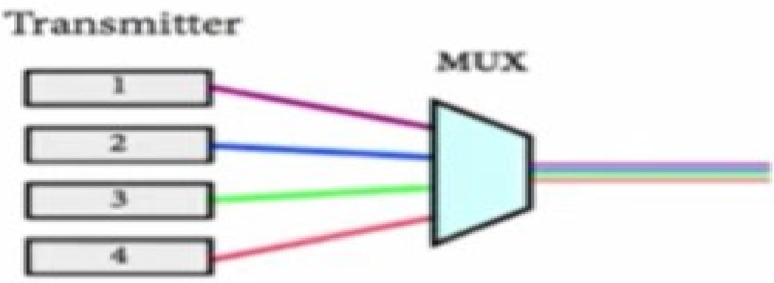
- The attenuation reduces with increase in frequency of the transmitted signal, and they travel longer distance .

- The modulation process increases the frequency of the signal to be transmitted . Therefore, it increases the range of communication.

Need for Modulation

4. Multiplexing is possible

- Multiplexing is a process in which two or more signals can be transmitted over the same communication channel simultaneously.
- This is possible only with modulation.



5. Improves Quality of Reception

- With frequency modulation (FM) and the digital communication techniques such as PCM, the effect of noise is reduced to a great extent . This improves quality of reception .

Noise should minimize if the frequency of the signal increased

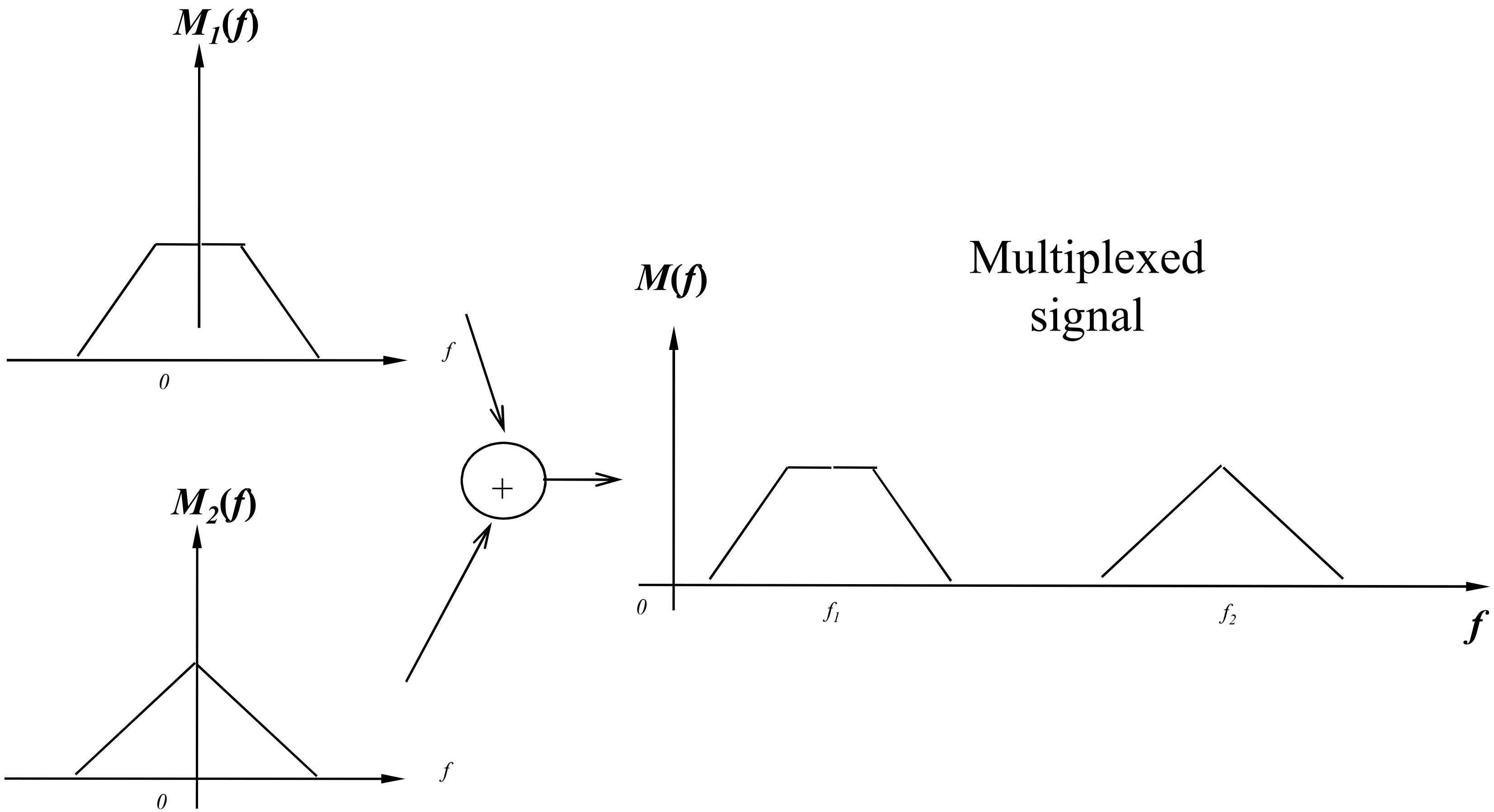
Need for Modulation

5) <u>Allows Adjustments in Bandwidth (BW)</u>:- The B.W of the modulated signal may be made smallar (or) larger than the original signal. $\frac{S}{N}$ ratio at the Rx is the function of signal bandwidth, it can be improved by proper control of the Bandwidth at the modulating stage.

Need of Modulation

1. Multiplexing (To support multiple transmissions via a single channel)

To avoid <u>interference</u>



Need of Modulation

2. Practicality of Antennas

Transmitting very low frequencies require antennas with miles in wavelength

$$\lambda = \frac{C}{F} \qquad C = \text{Velocity of light} = 3X10^{8}\ m/s$$

$$\text{Height of the required} = \frac{\lambda}{4}$$

3.Increase the range of Communication

Information signal cannot travel far. It needs carrier signal of higher frequency for long distance destination.

Amplitude Modulation

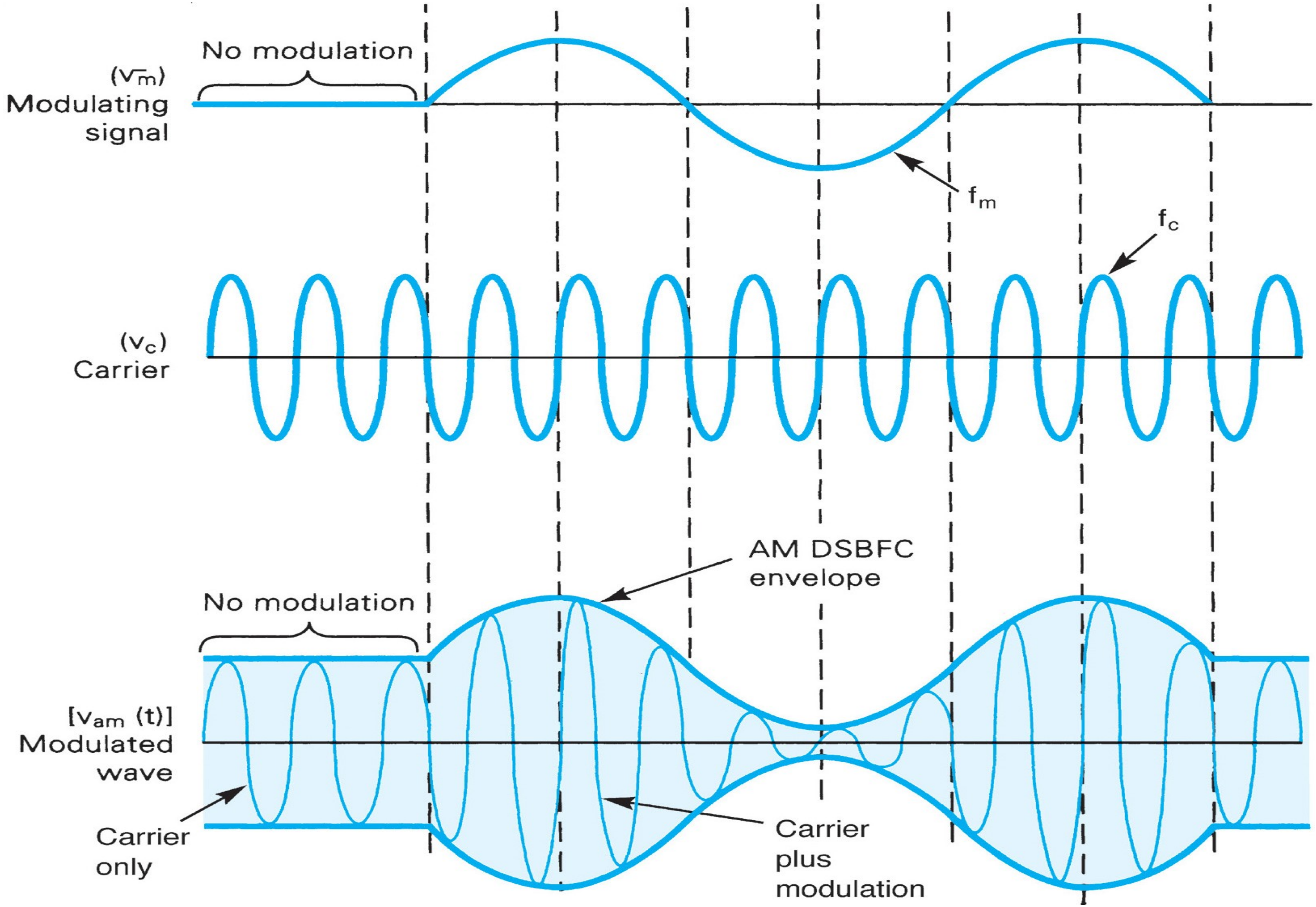
efinition:

- The process of changing the amplitude of a relatively high frequency carrier signal in proportion with the instantaneous value of modulating signal

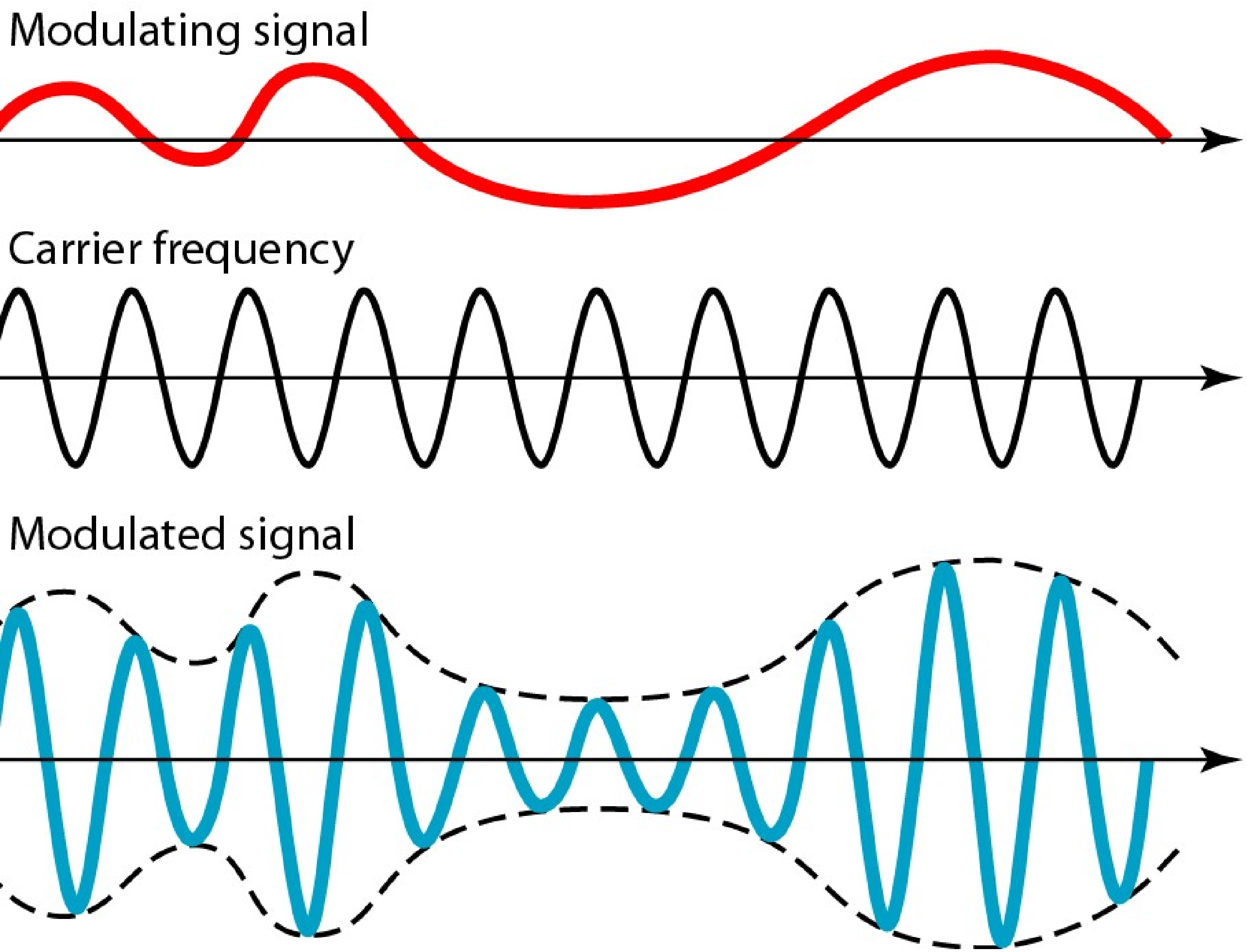
- A process of translating information signal from low band frequency to high band frequency.

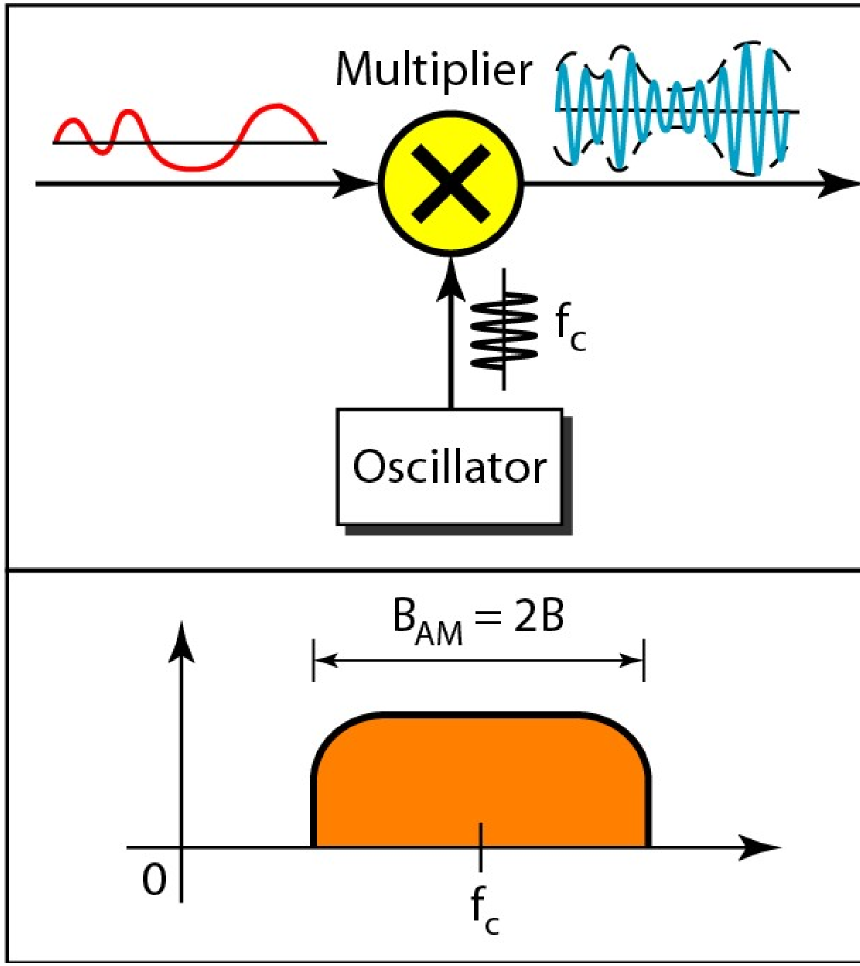
- Amplitude of the carrier signal varies with the information signal.
- The modulated signal consist of carrier signal, upper sideband and lower sideband signals
- The modulated AM signal needs to go through demodulation process to get back the information signal.

Amplitude Modulation



Amplitude Modulation





Mathematical Analysis of AM

1 The carrier signal is

$$C(t) = A_c \cos(\omega_c t) \quad \text{where } \omega_c = 2\pi f_c$$

2 In the same way, a modulating signal (information signal) can also be expressed as

$$m(t) = A_m \cos \omega_m t$$

3 The amplitude-modulated wave can be expressed as

$$s(t) = [A_c + m(t)]\cos(\omega_c t)$$

or $s(t) = A_c[1 + K_a m(t)]\cos(\omega$

Ka is amplitude sensitivity of modulator

$$s(t) = \left[A_c + A_m \cos(\omega_m t)\right]\cos(\omega_c t)$$

S (t) = A_c [1+k_am (t)] cos 2 π

S (t) = Ac [1+ka $A_m$cos 2π f_mt] cos 2π

5 The modulation index.

$$u = \frac{A_m}{A_c}$$

4 By substitution

6 Therefore The full AM signal may be written as

$$s(t) = A_c(1 + u\cos(\omega_m t))\cos(\omega_c t)$$

$$\cos A \cos B = 1/2[\cos(A + B) + \cos(A - B)]$$

$$s(t) = A_c(\cos\omega_c t) + \frac{uA_c}{2}\cos(\omega_c + \omega_m)t + \frac{uA_c}{2}\cos(\omega_c - \omega_m)t$$

- The constant in the first term produces the carrier freq while the sinusoidal component in the first term produces side bands frequencies

$$s(t) = A_c \cos(2\pi f_c t) + [uA_c \cos(2\pi f_m t)][\cos(2\pi f_c t)]$$

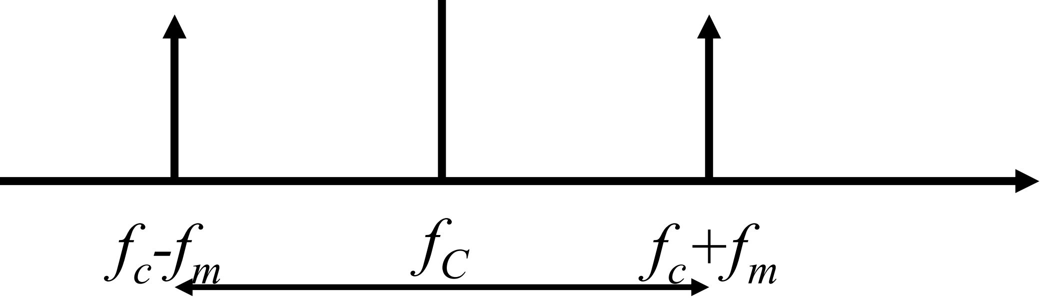
$$= A_c \cos(2\pi f_c t) + \frac{u A_c}{2}\cos[2\pi (f_c + f_m)t]$$

$$+ \frac{uA_c}{2}\cos[2\pi (f_c - f_m)t]$$

Carrier frequency signal (volts)

Upper side frequency signal (volts)

Lower side frequency signal (volts)



ply Fourier Transform to above equation

$$\frac{A_c}{2}[\delta(f - f_c) + \delta(f + f_c)] + \frac{\mu A_C}{4}[\delta(f - f_c - f_m) + \delta(f + f_c + f_m)] + \frac{\mu A_C}{4}[\delta(f - f_c + f_m) + \delta(f + f_c -$$

Frequency domain description of AM signal: The modulated carrier ha two signals at different frequencies is called side frequencies or side bands, occurs in the frequency spectrum directly above and below the carrier frequency.

$f_{USB} = f_c + f_m$ $f_{LSB} = f_c - f_m$

AM equation

$$s(t) = A_c(1 + u\cos(\omega_m t))\cos(\omega_c t)$$

$$\cos A \cos B = 1/2[\cos(A + B) + \cos(A - B)]$$

$$s(t) = A_c(\cos\omega_c t) + \frac{uA_c}{2}\cos(\omega_c + \omega_m)t + \frac{uA_c}{2}\cos(\omega_c - \omega_m)t$$

- The constant in the first term produces the carrier freq while the sinusoidal component in the first term produces side bands frequencies

$$s(t) = A_c \cos(2\pi f_c t) + [uA_c \cos(2\pi f_m t)][\cos(2\pi f_c t)]$$

$$= A_c \cos(2\pi f_c t) + \frac{u A_c}{2} \cos[2\pi (f_c + f_m)t]$$

$$+ \frac{uA_c}{2} \cos[2\pi (f_c - f_m)t]$$

Carrier frequency signal (volts)

Upper side frequency signal (volts)

Lower side frequency signal (volts)

Apply Fourier Transform to above equation

$$= \frac{A_C}{2} [\delta(f - f_c) + \delta(f + f_c)] + \frac{\mu A_C}{4} [\delta(f - f_c - f_m) + \delta(f + f_c + f_m)] + \frac{\mu A_C}{4} [\delta(f - f_c + f_m) + \delta(f + f_c$$

We have six frequencies components those are ± fc, ± (fc+fm) , ± (fc-fm)

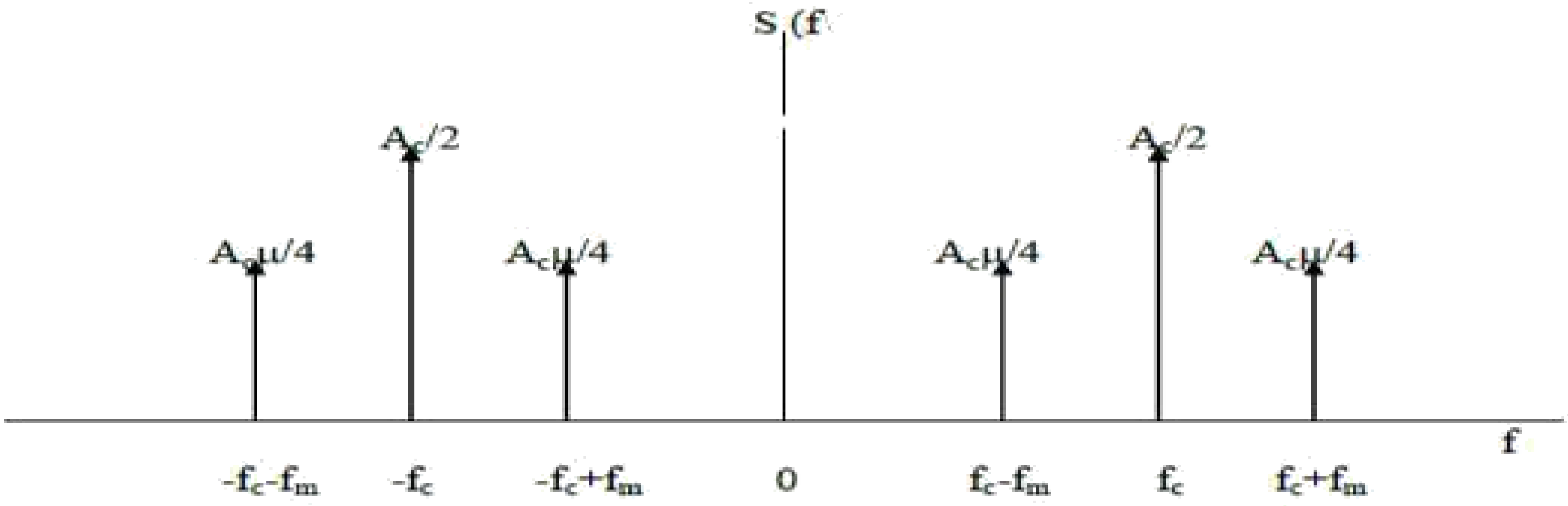
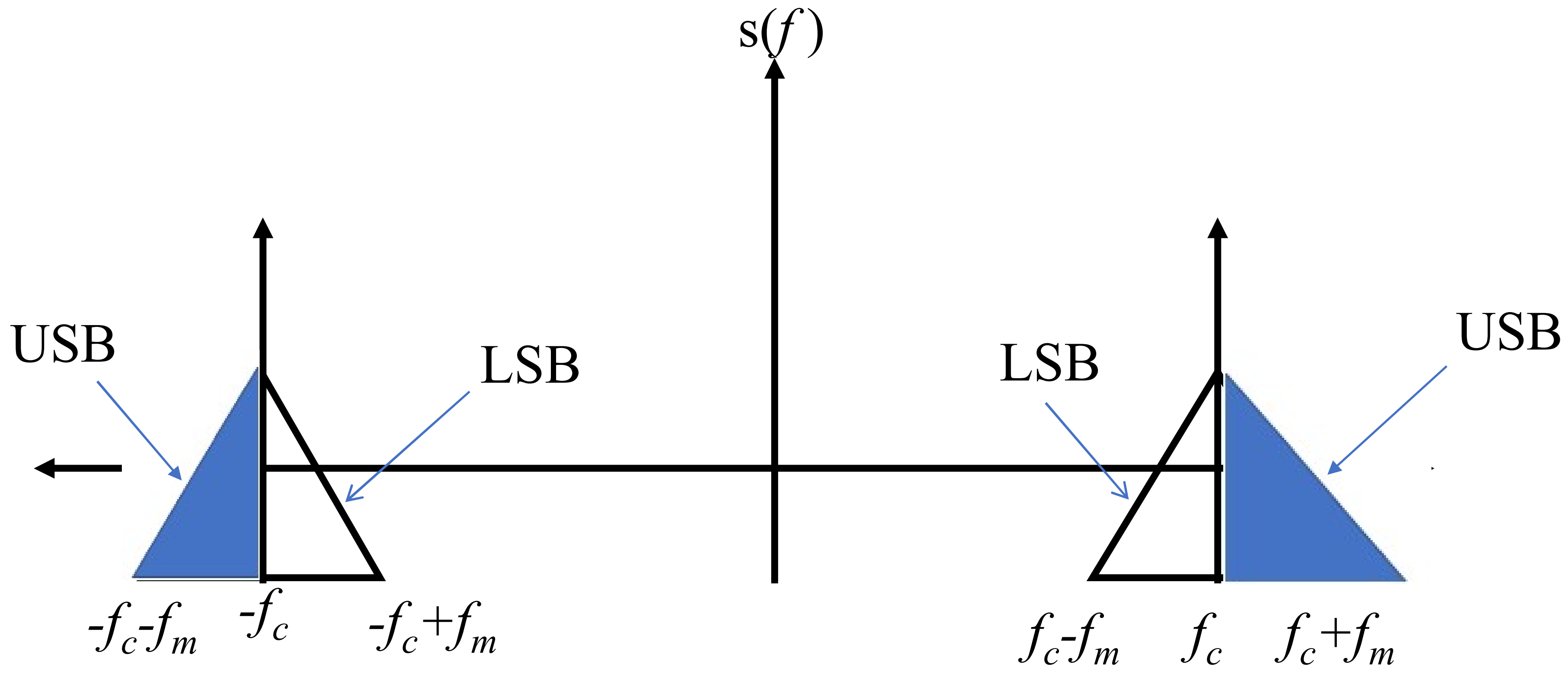


Fig. Spectrum of Single tone AM signal

Left side frequencies are mirror images of right side frequencie

$$= \frac{A_c}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right] + \frac{\mu A_C}{4}\left[\delta(f - f_c - f_m) + \delta(f + f_c + f_m)\right] + \frac{\mu A_C}{4}\left[\delta(f - f_c + f_m) + \delta(f + f_c\right.$$

Spectrum of AM for a complex input signal



Power Calculations in AM

In any electrical circuit, the power dissipated is equal to the voltage square
(rms) divided by the resistance. ($P=V^2/R$). $V=Ac(rms)/\sqrt{2}$

Mathematically power in unmodulated carrier is $$P_c = \frac{(A_c/\sqrt{2})^2}{R} = \frac{A_c^2}{2R}$$

Where ***P_c*** *= carrier power (watts)*

A_c *= peak carrier voltage (volts)*

R *= load resistance i.e antenna (ohms)*

he upper and lower sideband powers will be $$P_{usb} = P_{lsb} = \frac{(uA_c/2)^2}{2R} = \frac{u^2 \ldots}{8 \ldots}$$

Rearranging in terms of P_c, $$P_{usb} = P_{lsb} = \frac{u^2}{4}\left(\frac{A_c^2}{2R}\right) = \frac{u^2}{4} P_c$$

Power Calculations in AM

The total power in an AM wave is $P_t = P_c + P_{usb} + P_{lsb}$

Substituting the sidebands powers in terms of P_C yields

$$P_t = P_c + \frac{u^2}{4} P_c + \frac{u^2}{4} P_c$$
$$= P_c + \frac{u^2}{2} P_c = P_c [1 + \frac{u^2}{2}]$$

Since carrier power in modulated wave is the same as unmodulated wave, obviously power of the carrier is unaffected by modulation process.

Modulation Index or Percentage of Modulation

Modulation index is defined as the ratio of amplitude of message signal to the amplitude of carrier signal.

$$C(t) = A_c \cos(\omega_c t) \quad \text{where } \omega_c = 2\pi f_c$$

$$m(t) = A_m \cos \omega_m t$$

4 By substitution $s(t) = [A_c + m(t)]\cos(\omega_c t)$

$S(t) = A_c [1+k_a m(t)] \cos 2\pi f_c t$

Where ka = $1/A_c$ = Amplitude sensitivity of the modulator.

$S(t) = Ac [1+ka A_m \cos 2\pi f_m t] \cos 2\pi f_c t$

Modulation Index $\mu = K_a A_m = \frac{A_m}{A_C}$

Modulation Index or Percentage of Modulation

et A_{max} and A_{min} be the maximum and minimum amplitudes of the modulated wave.
Ve will get the maximum amplitude of the modulated wave, when $\cos(2\pi f_m t)$is 1.

$$A_{max}= \quad A_c+A_m$$

will get the minimum amplitude of the modulated wave, when $\cos(2\pi f_m t)$ is -1.

$$\Rightarrow A_{min}=A_c-A_m$$

$$A_{max}+A_{min}=A_c+A_m+A_c-A_m=2A_c$$

$$A_{max}-A_{min}=A_c+A_m-(A_c-A_m)=2A_m$$

$$\mu= \; A_m/A_c=\frac{(A_{max}-A_{min})/2}{A_{max}+A_{min})/2}$$

$$\mu= \; A_m/A_c=\frac{(A_{max}-A_{min})}{A_{max}+A_{min})}$$

What is the significance of modulation index ?

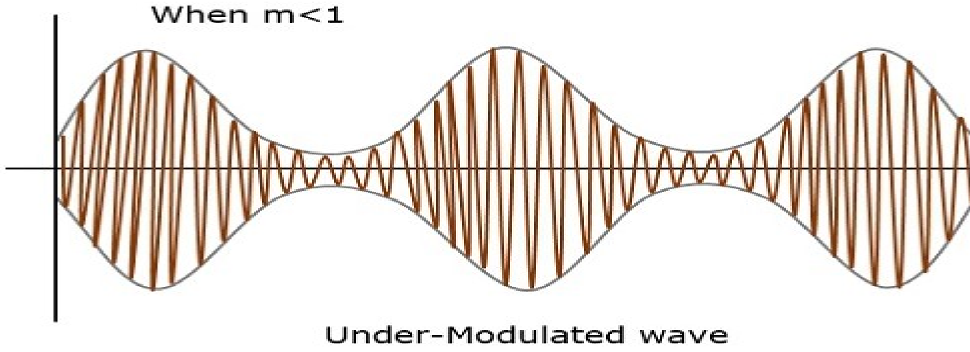
Modulation Index (μ)

- μ is merely defined as a parameter, which determines the amount of modulation a it is dimension less. When it is multiplied by 100 then it is called percentage modulation.
- If **μ <1 then get under modulation**
- If **μ =1 then get perfect modulation**
- If **μ >1 then get over modulation**
- degree of modulation required to establish a desirable AM communication link is **maintain μ <1.0 (μ <100 %).**
- The carrier frequency f_c much greater than highest frequency component W message signal m(t). $f_c \gg$ **W, where** W is message bandwidth
- This is important for successful retrieval of the original transmitted information at receiver end.

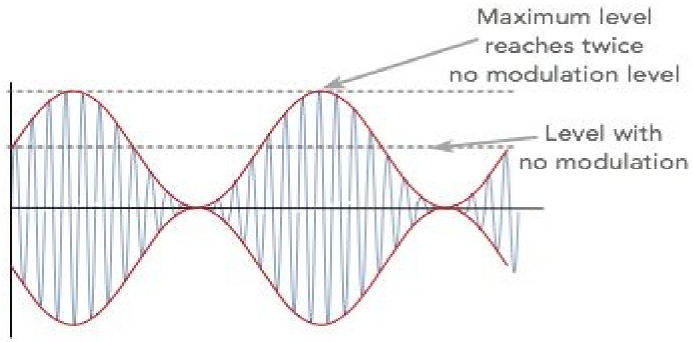
What is the significance of modulation index ?

Iodulation Index (μ)

or instance, if this value is less than 1, i.e., the odulation index is 0.5, then the modulated output would ok like the following figure. It is called as Under-odulation. Such a wave is called as an **under-odulated wave**.

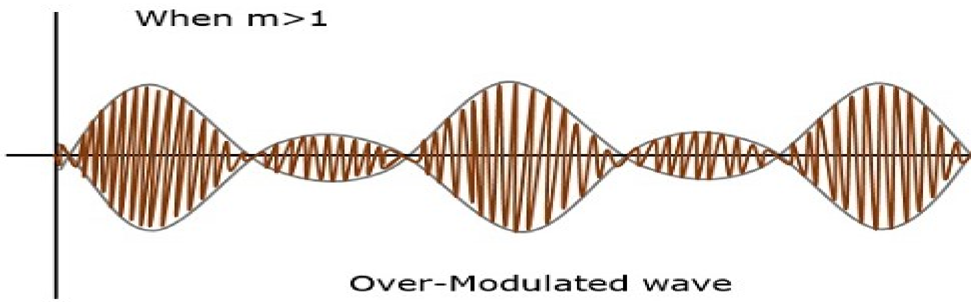


or a perfect modulation, the value of modulation index ould be 1, which means the modulation depth should be 0%.



Perfect Modulation 100%

the value of the modulation index is greater than 1, i.e., 1.5 so, then the wave will be an **over-modulated wave**. It would ok like the following figure.



Band width of an AM signal

$BW = f_{max} - f_{min}$ $\quad$ $BW = f_c + f_m - (f_c - f_m)$ $\quad$ $BW = 2f_m$

roblem 1

modulating signal $m(t)=10\cos(2\pi\times10^3t)$ is amplitude modulated with a carri
gnal $c(t)=50\cos(2\pi\times10^5t)$. Find the modulation index, the carrier power, and the power require
r transmitting AM wave.

$n(t) = 10\cos(2\pi \times 10^3 t)$

$A_m = 10volts$

$n = 10^3 Hz = 1KHz$

$c(t) = 50\cos(2\pi \times 10^5 t)$

$A_c = 50volts$

$f_c = 10^5 Hz = 100KHz$

We know the formula for modulation index as $\mu = \frac{A_m}{A_c}$ $\quad$ $\mu = \frac{10}{50} = 0.2$

Therefore, the value of **modulation index is 0.2** and percentage of modulation is 20%.

The formula for Carrier power, $P_c = \frac{A_c^2}{2R}$

Assume $R = 1\Omega$ and substitute A_c value in the above formula.

$$P_c = \frac{(50)^2}{2(1)} = 1250W$$

We know the formula for **power** required for **transmitting AM** wav

$$\Rightarrow P_t = P_c\left(1 + \frac{\mu^2}{2}\right)$$

$$P_t = 1250\left(1 + \frac{(0.2)^2}{2}\right) = 1275W$$

Band width of an AM signal

roblem 2

he equation of amplitude wave is given by s(t)=20[1+0.8cos(2π×10³t)]cos(4π×10⁵t). Find t arrier power, the total sideband power, and the band width of AM wave.

$= 20\left[1 + 0.8\cos(2\pi \times 10^3 t)\right]\cos(4\pi \times 10^5 t)$

$= 20\left[1 + 0.8\cos(2\pi \times 10^3 t)\right]\cos(2\pi \times 2 \times 10^5 t)$

Amplitude modulated wave is

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

comparing the above two equations, we will get

nplitude of carrier signal as $A_c = 20volts$

odulation index as $\mu = 0.8$

equency of modulating signal as $f_m = 10^3 Hz = 1KHz$

equency of carrier signal as $f_c = 2 \times 10^5 Hz = 200KHz$

Carrier power, P_c is $P_c = \frac{A_c{}^2}{2R}$

Assume $R = 1\Omega$

$$P_c = \frac{(20)^2}{2(1)} = 200W$$

total side band power is $P_{SB} = \frac{P_c \mu^2}{2}$

$$P_{SB} = \frac{200 \times (0.8)^2}{2} = 64W$$

bandwidth of AM wave is $BW = 2f_m$

$$BW = 2(1K) = 2KHz$$

Single tone AM signal

mplitude modulation in which the modulating or baseband signal consists of only ne (single) frequency i.e. modulation is done by a single frequency or tone. This pe of amplitude modulation is known as **single tone amplitude modulation**

$$C(t) = A_c \cos(\omega_c t) \quad \text{where} \quad \omega_c = 2\pi f_c$$

$$m(t) = A_m \cos \omega_m t$$

$$s(t) = \left[A_c + m(t)\right]\cos(\omega_c t)$$

$$S(t) = A_c\,[1+k_a m(t)] \cos 2\pi f_c t$$

Where ka = 1/A_c = Amplitude sensitivity of the modulator.

$$S(t) = Ac\,[1+ka\, A_m \cos 2\pi f_m t] \cos 2\pi f_c t$$

Modulation Index $\mu = K_a A_m = \frac{A_m}{A_C}$

- The constant in the first term produces the carrier freq while the sinusoidal component in the first term produces side bands frequencies

$$s(t) = A_c \cos(2\pi f_c t) + [uA_c \cos(2\pi f_m t)][\cos(2\pi f_c t)]$$

$$= A_c \cos(2\pi f_c t) + \frac{u A_c}{2}\cos[2\pi(f_c + f_m)t]$$

$$+ \frac{uA_c}{2}\cos[2\pi(f_c - f_m)t]$$

Carrier frequency signal (volts)

Upper side frequency signal (volts)

Lower side frequency signal (volts)

ply Fourier Transform to above equation

$$\frac{A_C}{2}[\delta(f - f_c) + \delta(f + f_c)] + \frac{\mu A_C}{4}[\delta(f - f_c - f_m) + \delta(f + f_c + f_m)] + \frac{\mu A_C}{4}[\delta(f - f_c + f_m) + \delta(f + f_c -$$

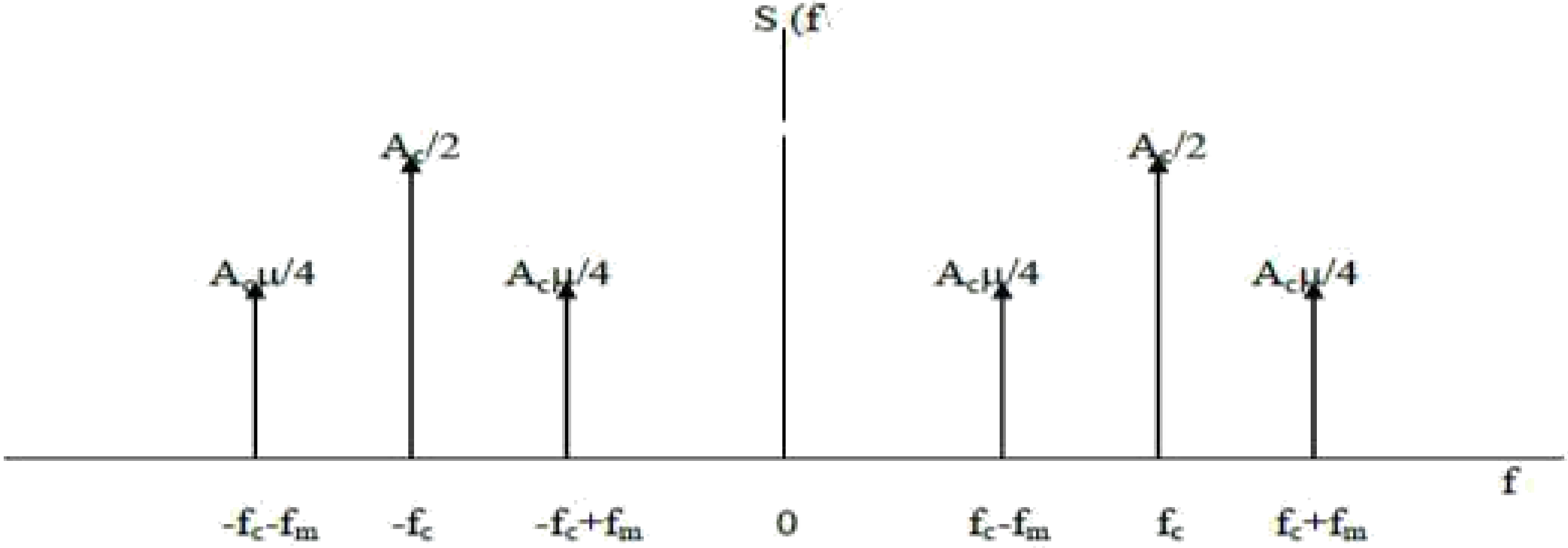


Fig. Spectrum of Single tone AM signal

$$= \frac{A_C}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right] + \frac{\mu A_C}{4}\left[\delta(f - f_c - f_m) + \delta(f + f_c + f_m)\right] + \frac{\mu A_C}{4}\left[\delta(f - f_c + f_m) + \delta(f + f_c\right.$$

Multi tone AM signal

When the message signal contains more than one frequenc
then the corresponding modulation scheme is known as
Multi-Tone Modulation.

- Let us consider the message signal to be

$$m(t) = A_{m1} \, Cos \, 2\pi f_{m1}t + A_{m2} \, Cos \, 2\pi f_{m2}t$$

AM modulated Wave $\quad S(t)= A_C \, [1 + k_a \, m(t)] \cos 2\pi f_C t$

$$S(t)= A_C \, [1 + k_a\{A_{m1} \, Cos \, 2\pi \, f_{m1}t \; + \; A_{m2} \, Cos f_{m2}t \,] \cos 2\pi f_C t$$

$$S(t)= A_C \, [1 + \mu_1 Cos \, 2\pi \, f_{m1}t \; + \; \mu_2 \, Cos f_{m2}t \,] \cos 2\pi f_C t$$

$$(t)= A_C \cos 2\pi f_C t + A_C \mu_1 Cos \, 2\pi \, f_{m1}t \cos 2\pi f_C t + A_C \mu_2 \, Cos f_{m2}t \cos 2\pi$$

$= A_C \cos 2\pi f_C t$

$\frac{\ \ }{}\ Cos\ \ 2\pi(f_C\ - f_{m1})t + \frac{A_C\mu_1}{2}\cos 2\pi(f_C\ + f_{m1})\ t\ +\ \frac{A_C\mu_2}{2} Cos\ \ 2\pi(f_C\ - f_{m2})t + \frac{A_C\mu_2}{2}\cos 2\pi(f_C\ + f_{m2})$

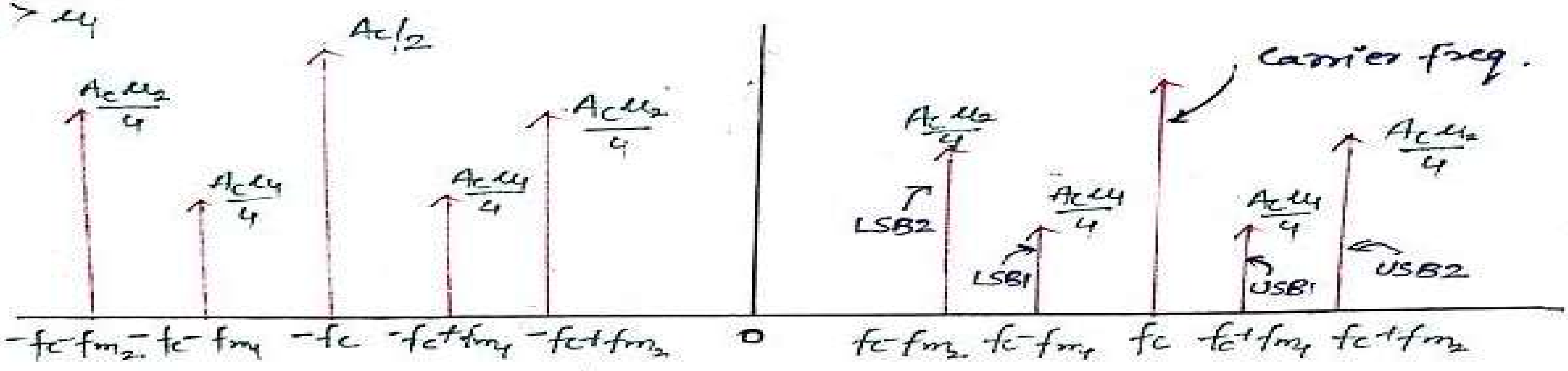
SPECTRUM OF AM SIGNAL (MULTITONE)

$$S_{AM}(t) = A_C \cos 2\pi f_c t + \frac{A_c\mu_1}{2}.\cos 2\pi(f_c - f_{m_1})t + \frac{A_c\mu_1}{2}.\cos 2\pi(f_c + f_{m_1})t$$

$$+ \frac{A_c\mu_2}{2}.\cos 2\pi(f_c - f_{m_2})t + \frac{A_c\mu_2}{2}.\cos 2\pi(f_c + f_{m_2})t$$

Let $f_{m_2} > f_{m_1}$

$\mu_2 > \mu_1$



MODULATION EFFICIENCY (MULTITONE AM)

$$P_t = P_c \left(1 + \frac{\mu_1^2 + \mu_2^2}{2} \right)$$ Assume $\mu_1^2 + \mu_2^2 = \mu_t^2$

$$P_t = P_c \left(1 + \frac{\mu_t^2}{2} \right) = P_c + P_{SB}$$

Hence, Sideband power $(P_{SB}) = \frac{P_c \cdot \mu_t^2}{2}$

Therefore, Modulation Efficiency $= \frac{P_{SB}}{P_t}$

$$\eta = \frac{P_c \cdot \mu_t^2/2}{P_c \left(1 + \mu_t^2/2 \right)} = \frac{\mu_t^2}{2 + \mu_t^2} \times 100\%$$

Band width of an AM signal

andwidth of AM Wave

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

$$s(t) = A_c \cos(2\pi f_c t) + [uA_c \cos(2\pi f_m t)][\cos(2\pi$$

$$= A_c \cos(2\pi f_c t) - \frac{u A_c}{2}\cos[2\pi(f_c + f_m$$

$$+ \frac{uA_c}{2}\cos[2\pi(f_c - f_m)t]$$

$BW=f_{max}-f_{min}$ $BW=f_c+f_m-(f_c-f_m)=2f_m$

$$) = A_c(1 + u\cos(\omega_m t))\cos(\omega_c t)$$

$$= A_c(\cos\omega_c t) + \frac{uA_c}{2}\cos(\omega_c + \omega_m)t + \frac{uA_c}{2}\cos(\omega_c - \omega_m)t$$

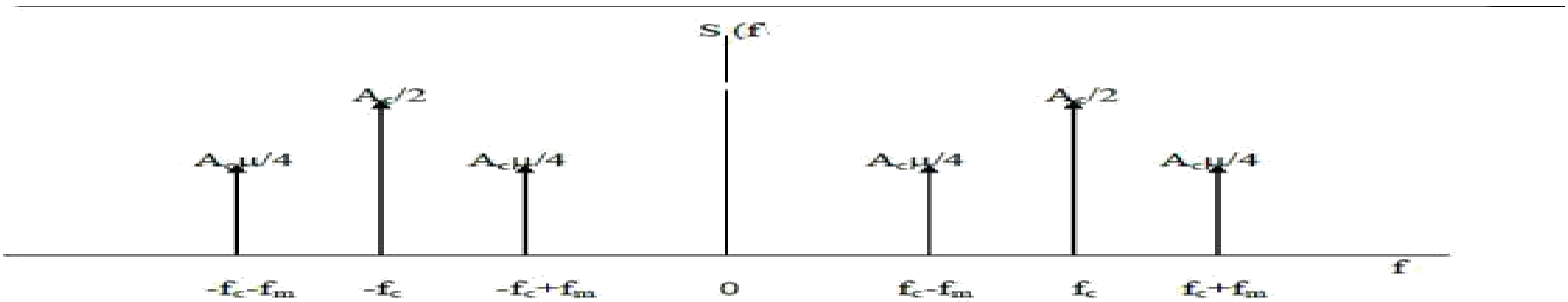


Fig. Spectrum of Single tone AM signal

Frequency Spectrum of an AM signal

requency spectrum of AM waveform contains three parts:

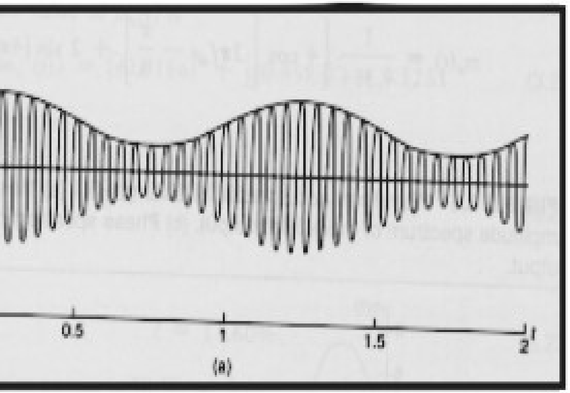
1. A component at the carrier frequency f_c
2. An upper side band (USB),whose highest frequency component is at f_c+f_m
3. A lower side band (LSB), whose highest frequency component is at f_c-f_m

The bandwidth of the modulated waveform is twice *the information signal bandwidt*

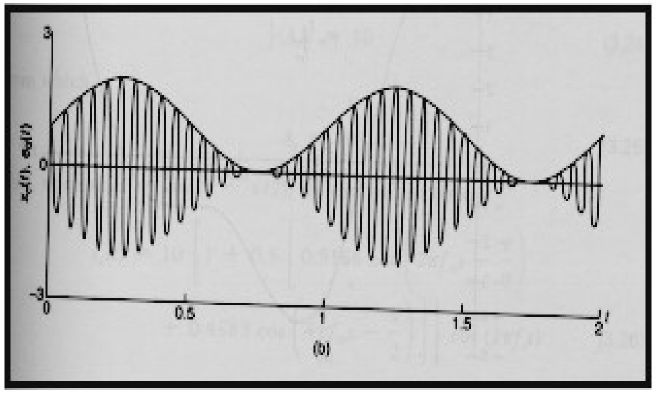
cause of the two side bands in the frequency spectrum its often called Double Sideb
th Full Carrier.(DSB-FC)

e information in the message signal is duplicated in the **LSB** and **USB** and the **ca**
nveys **no** information.

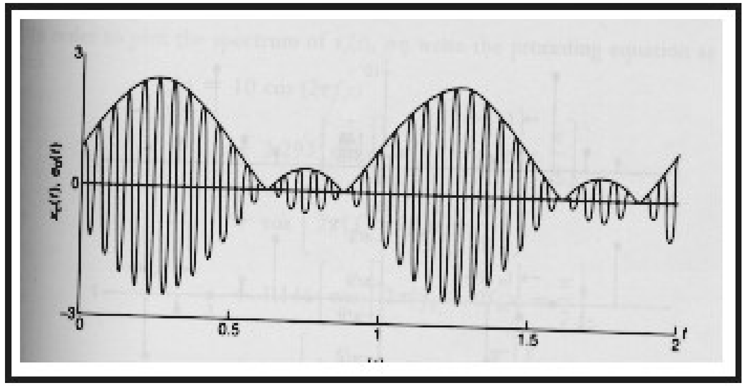
AM Types



$\mu = 0.5$



$\mu = 1.0$



$\mu = 1.5$

- If the amplitude of the modulating signal is higher than the carrier amplitude, which in turn implies the modulation index. This will cause severe distortion to the modulated signal.

Bandwidth(BW)

- The BW of an AM DSBFC wave is equal to the difference between t highest upper side frequency and lowest lower side frequency:

$$BW = [f_c + f_{m(max)}] - [f_c - f_{m(max)}]$$
$$= 2f_{m(max)}$$

- For efficiency transmission the carrier and sidebands must be high enou to be propagated thru earth's atmosphere.

Calculate the power efficiency of AM signals

Power efficiency :The ratio of power in sidebands to total power,

$$\frac{sidebands\ power}{total\ power} = \frac{u^2/2}{1+u^2/2} = \frac{u^2}{2+u^2}$$

In terms of **power efficiency**, for $\mu = 1$ modulation, only 33% power efficiency is achieved which tells us that only one-third of the transmitted power carries the useful information.

Frequency Spectrum of an AM signal

e frequency spectrum of AM waveform contains three parts:

A component at the carrier frequency f_c

An upper side band (USB), whose highest frequency component is at f_c+f_m

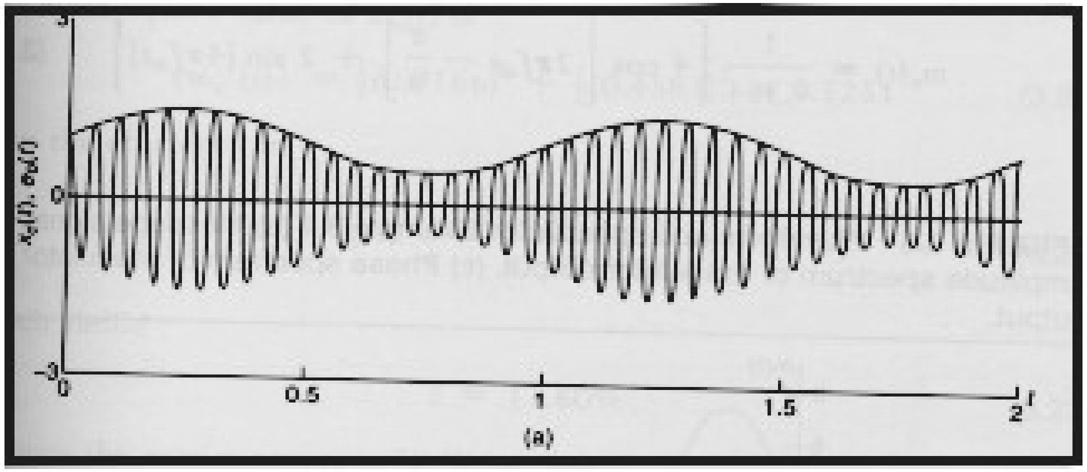
A lower side band (LSB), whose highest frequency component is at f_c-f_m

e bandwidth of the modulated waveform is twice *the information signal bandwidth.*

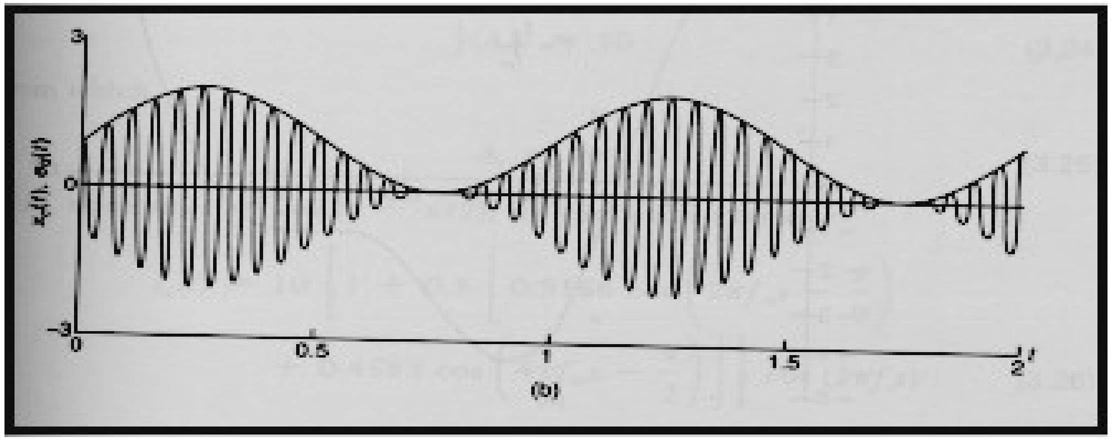
Because of the two side bands in the frequency spectrum its often called Double Sideba with Large Carrier.(DSB-LC)

The information in the base band (information) signal is duplicated in the **LSB** and **US** and the **carrier** conveys **no** information.

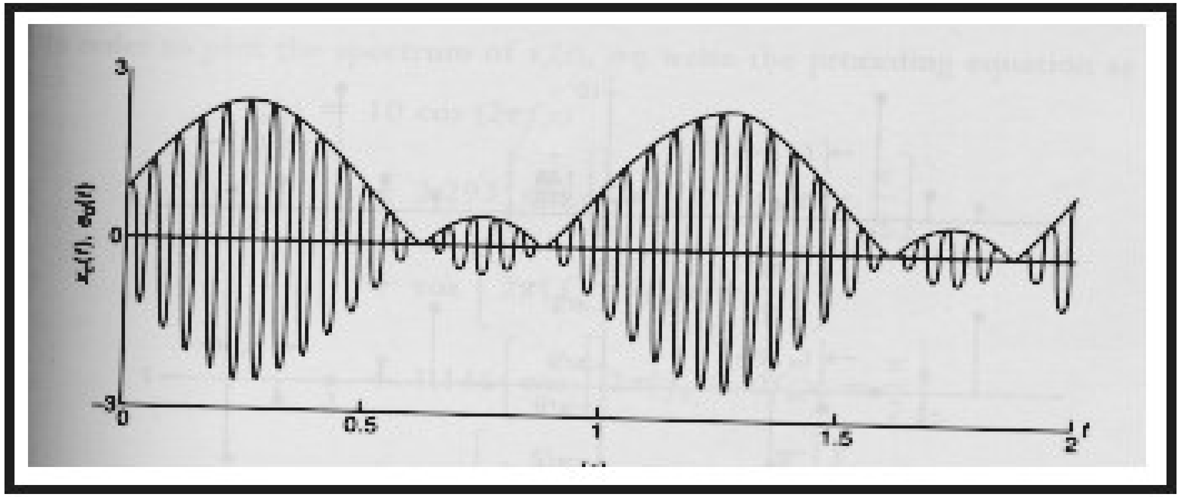
Modulation carrier and envelope detector outputs for various values of the modulation index



$\mu = 0.5$



$\mu = 1.0$



$\mu = 1.5$

If the amplitude of the modulating signal is higher than the carrie amplitude, which in turn implies the modulation index. This will cause severe distortion to the modulated signal.

Basic Principles of Amplitude Modulation

M in the Frequency Domain

- The product of the carrier and modulating signal can be generated by applying bot signals to a nonlinear component such as a diode.

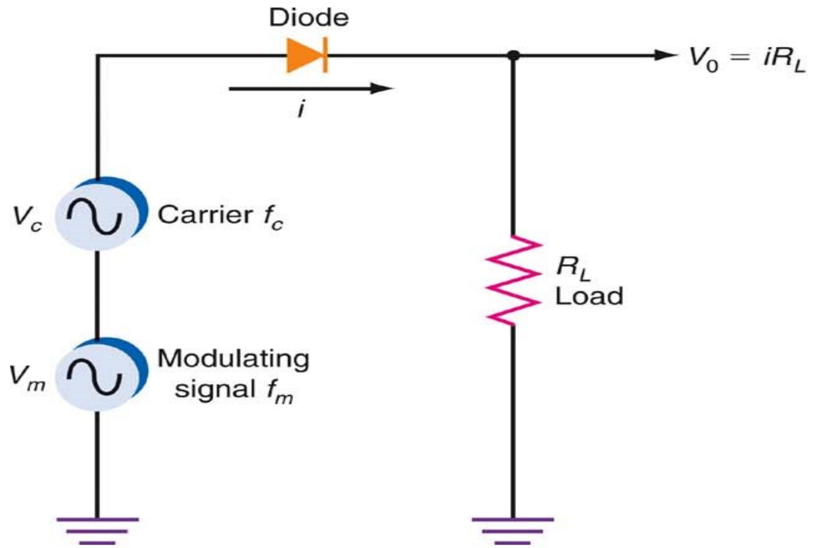
- A **square-law function** is one that varies in proportion to the square of the inpu signals. A diode gives a good approximation of a square-law response. Bipolar ar field-effect transistors (FETs) can also be biased to give a square-law response.

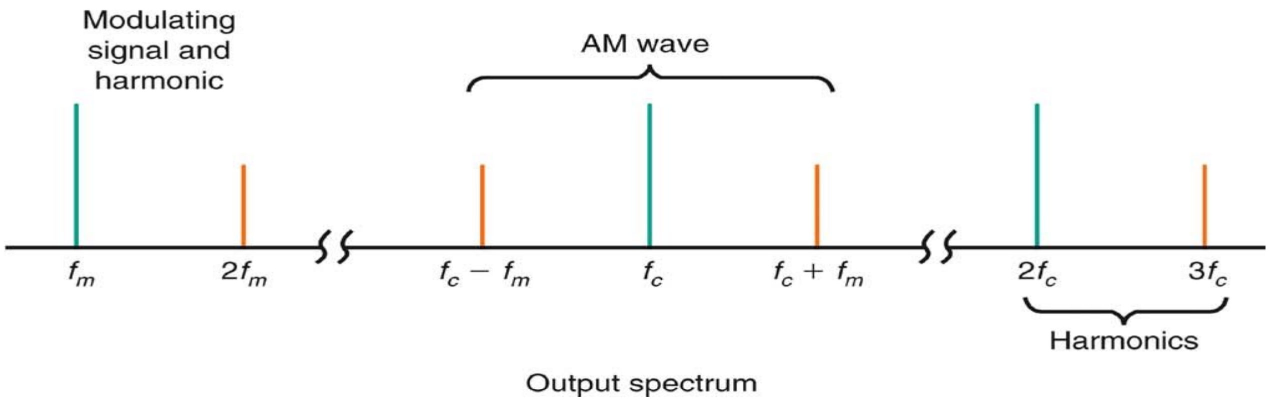
- Diodes and transistors whose function is not a pure square-law function produc third-, fourth-, and higher-order harmonics, which are sometimes referred to a **intermodulation products.**

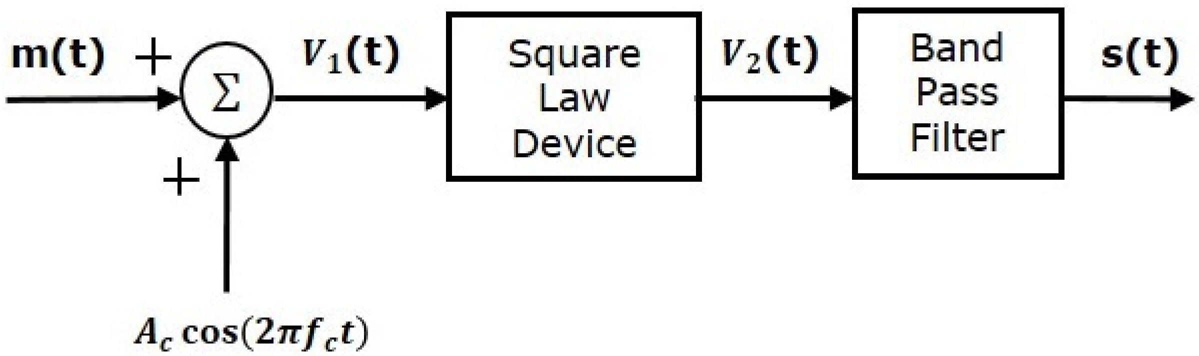
- Intermodulation products are easy to filter out.

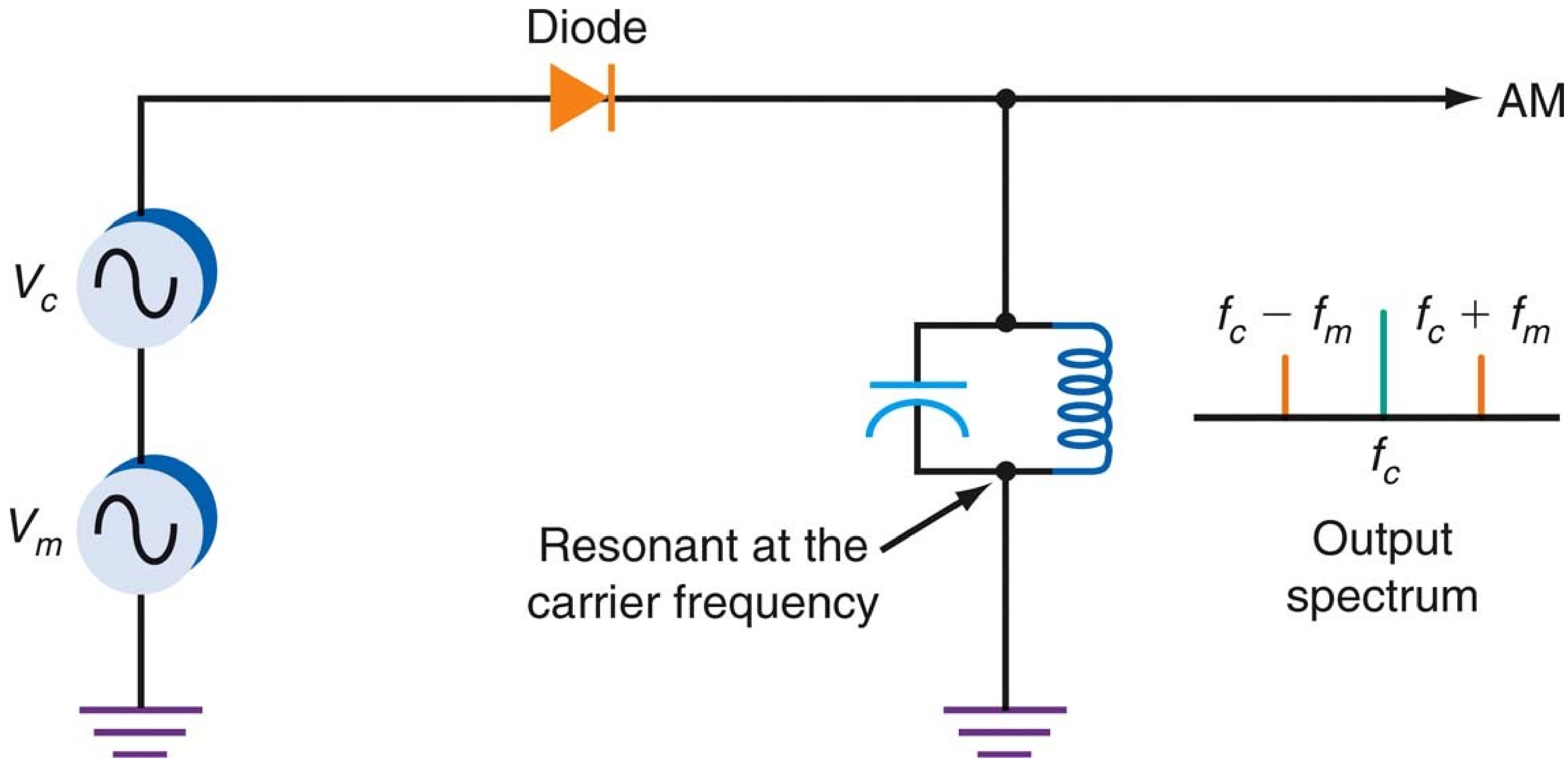
- Tuned circuits filter out the modulating signal and carrier harmonics, leaving on carrier and sidebands.

A square-law modulator circuit for producing AM.









The tuned circuit filters out the modulating signal and carrier harmonics, leavir
only the carrier and sidebands.

quare Law Modulator:

$$C(t) = A_c \cos(\omega_c t) \quad \text{where } \omega_c = 2\pi f_c$$

$$m(t) = A_m \cos \omega_m t$$

ese two signals are applied as inputs to the summer (adder) block. This summer block produces output, which is the addition of the modulating and the carrier signal.
athematically, we can write it as

$$V_1 t = m(t) + A_c \mathrm{Cos}(2\pi f_c t)$$

s signal $V_1 t$ is applied as an input to a nonlinear device like diode. The aracteristics of the diode are closely related to square law.

$$V_2 t = k_1 V_1(t) + k_2 V_1^2(t)$$

Where, k_1 and k_2 are constants.

bstitute $V_1(t)$ in Equation 1

$$V_2(t)= k_1 [m(t)+A_c\cos(2\pi f_c t)] + k_2 [m(t)+A_c \cos(2\pi f_c t)]^2$$

$$V_2(t)= k_1 m(t)+k_1 A_c\cos(2\pi f_c t)+k_2 m^2(t)+ k_2 A_c^2 \cos^2(2\pi f_c t)+2k_2 m(t)A_c\cos(2\pi f_c t)$$

$$V_2(t)=k_1 m(t)+k_2 m^2(t)+k_2 A_c^2\cos^2(2\pi f_c t)+ k_1 A_c[1+(2k_2 / k_1)m(t)] \cos(2\pi f_c t)$$

e last term of the above equation represents the desired AM wave and the first ee terms of the above equation are unwanted. So, with the help of band pass er, we can pass only AM wave and eliminate the first three terms.

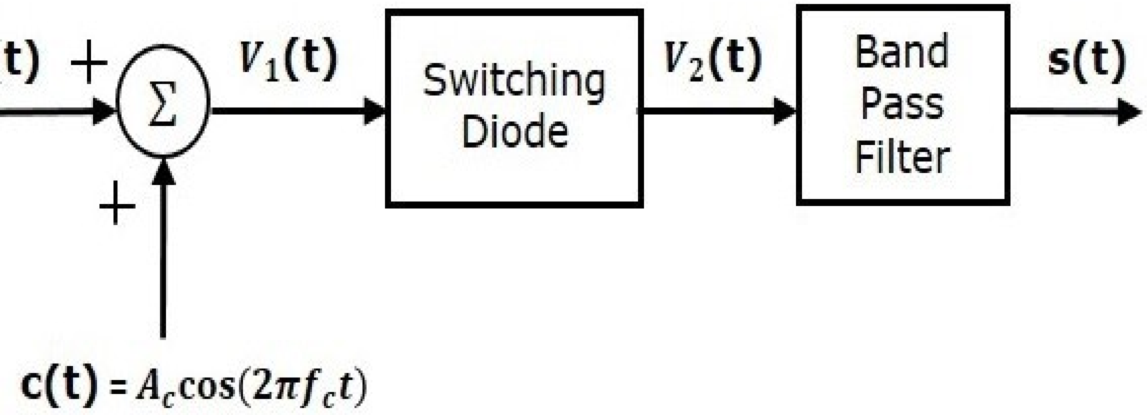
Therefore, the output of square law modulator is

$$s(t)=k_1 A_c[1+(2k_2 / k1)\, m(t)] \cos(2\pi f_c t)$$

Amplitude Sensitivity (K_a)= $2k_2$ / k

The standard equation of AM wave is $s(t)=A_c[1+k_a m(t)]\cos(2\pi f_c t)$

Switching modulator circuit for producing AM.



Switching modulator is similar to the sq
law modulator. The only difference is tha
the square law modulator, the diode
operated in a non-linear mode, whereas, in
switching modulator, the diode has to ope
as an ideal switch.

Let the modulating and carrier signals be denoted as m(t) and c(t)=$A_c$cos ($2\pi f_c t$) respectively.

These two signals are applied as inputs to the summer (adder) block. Summer block produces a
output, which is the addition of modulating and carrier signals. Mathematically, we can write it as

$$V_1 t = m(t) + A_c \text{Cos}(2\pi f_c t)$$

s signal $V_1(t)$ is applied as an input of diode. Assume, the magnitude of the modulating al is very small when compared to the amplitude of carrier signal Ac. So, the diode's and OFF action is controlled by carrier signal c(t). This means, the diode will be vard biased when $c(t)>0$ and it will be reverse biased when $c(t)<0$.

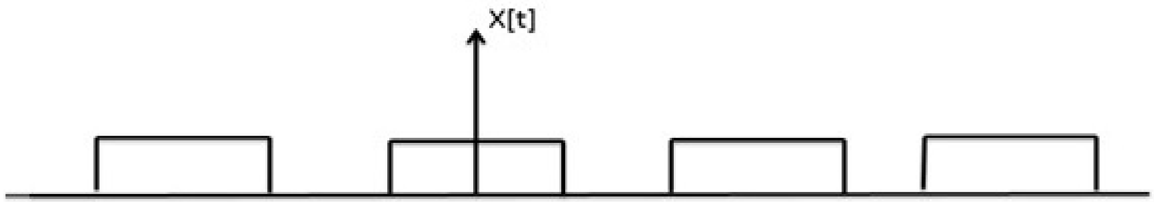
Therefore, the output of the diode is

$$V_2(t) = \begin{cases} V_1(t) & \text{if } c(t) > 0 \\ 0 & \text{if } c(t) < 0 \end{cases}$$

e can approximate this as

$$V_2(t)=V_1(t)\,x(t)$$

here, x(t) is a periodic pulse train with time period $T=1\,/\,f_c$



he Fourier series representation of this periodic pulse train is

$$x(t) = \frac{1}{2} + \frac{2}{\pi}\sum_{n=1}^{\infty} \frac{(-1)^{n}-1}{2n-1} \cos(2\pi(2n-1)fct)$$

$$x(t) = \frac{1}{2} + \frac{2}{\pi} \cos(2\pi f_c t) - \frac{2}{3\pi} \cos(6\pi f_c t) + \cdots$$

Substitute, $V_1(t)$ and $x(t)$ values in Equation 2.

$$V_2(t) = [m(t) + A_C \cos(2\pi f_c t)][\frac{1}{2} + \frac{2}{\pi} \cos(2\pi f_c t) - \frac{2}{3\pi} \cos(6\pi f_c t) + \cdots]$$

$$(t) = \frac{m(t)}{2} + \frac{A_c}{2} \cos(2\pi f_c t) + \frac{2m(t)}{\pi}\cos(2\pi f_c t) + \frac{2A_c}{\pi} \cos^2(2\pi f_c t) - \frac{2m(t)}{3\pi} \cos(6\pi f_c t) - \frac{2A_c}{3\pi}\cos(2\pi f_c t)\cos(6\pi f_c t) + \cdots$$

$$(t) = \frac{m(t)}{2} + \frac{A_c}{2}\left(1 + \left(\frac{4}{\pi A_c}\right) m(t)\right) \cos(2\pi f_c t) + \frac{2A_c}{\pi} \cos^2(2\pi f_c t) - \frac{2m(t)}{3\pi} \cos(6\pi f_c t) - \frac{2A_c}{3\pi}\cos(2\pi f_c t)\cos(6\pi f_c t) + \text{-------}$$

e 1st term of the above equation represents the desired AM wave and the remaining term unwanted terms. Thus, with the help of band pass filter, we can pass only AM wave an minate the remaining terms.

efore, the output of switching modulator is

$$s(t) = \frac{A_c}{2}\left(1 + \left(\frac{4}{\pi A_c}\right) m(t)\right) \cos(2\pi f_c t)$$

We know the standard equation of AM wave is

$$s(t) = A_c[1 + k_a m(t)] \cos(2\pi f_c t)$$

Where, k_a is the amplitude sensitivity.

By comparing the output of the switching modulator with the standard equation of AM wave, we will get the scaling factor as 0.5 and amplitude sensitivity k_a as $4 / \pi A_c$.

AM Demodulators

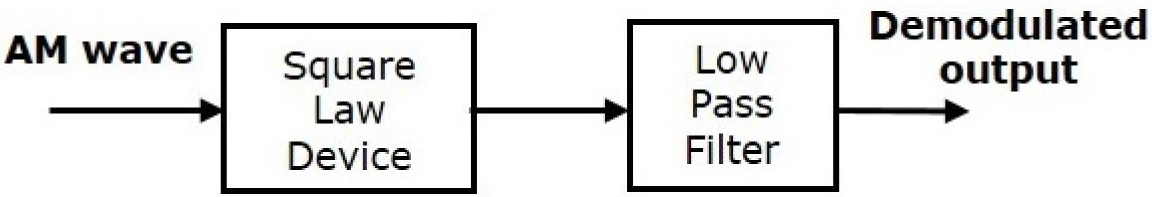
e process of extracting an original message signal from the modulated wave is known **detection** or **demodulation**. The circuit, which demodulates the modulated wave is known as e **demodulator**. The following demodulators (detectors) are used for demodulating AM wave.

Square Law Demodulator

Envelope Detector

Square Law Demodulator

uare law demodulator is used to demodulate low level AM wave. Following is e block diagram of the **square law demodulator**



s demodulator contains a square law device and low pass filter. The AM wave V_1 (t) is applied as nput to this demodulator.

The standard form of AM wave is

$$V_1 t = m(t) + A_c \, Cos(2\pi f_c t)$$

$$V_1(t) = Ac[1 + k_a m(t)] \cos(2\pi f_c t)$$

We know that the mathematical relationship between the input and the output of square law device is

$$V_2(t) = k_1 V_1(t) + k_2 V_1^2(t) \text{ -----------(1)}$$

Where,

$V_1(t)$ is the input of the square law device, which is nothing but the AM wave

$V_2(t)$ is the output of the square law device, k_1 and k_2 are constants.

ostitute $V_1(t)$ in Equation 1

$$V_2(t) = k_1(A_c[1+k_a m(t)] \cos(2\pi f_c t)) + k_2(A_c[1+k_a m(t)] \cos(2\pi fct))^2$$

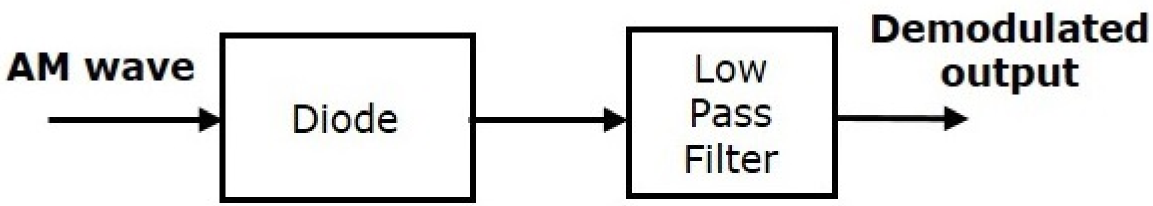
$$V_2(t) = k_1 A_c \cos(2\pi f_c t) + k_1 A_c k_a m(t) \cos(2\pi f_c t) + k_2 A_c^2 [1 + K_a^2 m^2(t) + 2k_a m(t)]((1 + \cos(4\pi fct)) / 2)$$

$= k_1 A_c \cos(2\pi f_c t) + k_1 A_c k_a m(t) \cos(2\pi fct) + K_2 A_C^2 / 2 + (K_2 A_c^2/2) \cos(4\pi f_c t) + (k_2 A_c^2 k_a^2 m^2(t)) / 2 + ((k_2 A_c^2 k_a^2 m^2(t) / 2)$
$\pi fct) + k_2 A_c^2 k_a m(t) + k_2 A_c^2 k_a m(t) \cos(4\pi f_c t)$

he above equation, the term $k_2 A_c^2 k_a m(t)$ is the scaled version of the message signal. It can be extracted by passing ve signal through a low pass filter and the DC component $(k_2 Ac^2 / 2)$ can be eliminated with the help of a coup acitor.

nvelope Detector

Envelope detector is used to detect (demodulate) high level AM wave. Following is the block diagram of the envelope detector.



his envelope detector consists of a diode and low pass filter. Here, the diode is the main detecting element. Hence, ne envelope detector is also called as the **diode detector**. The low pass filter contains a parallel combination of the esistor and the capacitor.

AM wave s(t) is applied as an input to this detector.

/e know the standard form of AM wave is

The standard form of AM wave is

$$V_1 t = m(t) + A_c \cos(2\pi f_c t)$$

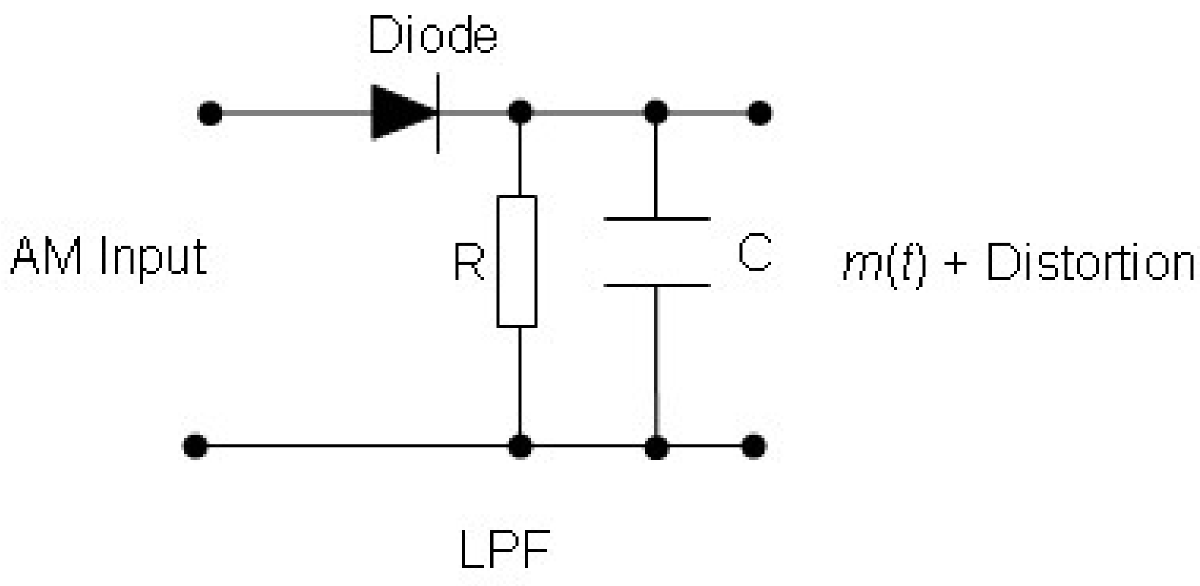
$$V_1(t) = Ac[1 + k_a m(t)] \cos(2\pi f_c t)$$

the positive half cycle of AM wave, the diode conducts and the capacitor charges to the peak value of I wave. When the value of AM wave is less than this value, the diode will be reverse biased. Thus, the pacitor will discharge through resistor **R** till the next positive half cycle of AM wave. When the value of I wave is greater than the capacitor voltage, the diode conducts and the process will be repeated.

should select the component values in such a way that the capacitor charges very quickly and charges very slowly. As a result, we will get the capacitor voltage waveform same as that of the envelope AM wave, which is almost similar to the modulating signal.

Envelope or Non-Coherent Detection

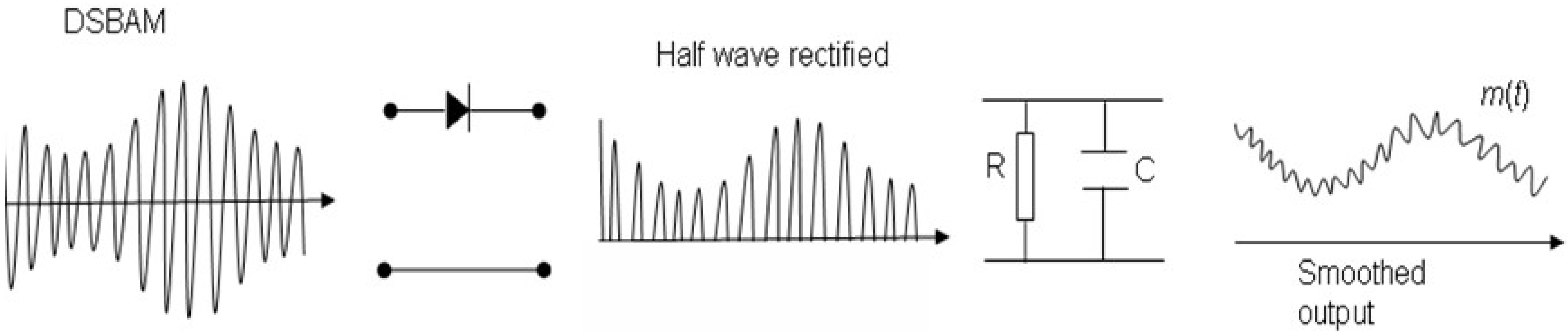
An envelope detector for AM is shown below:



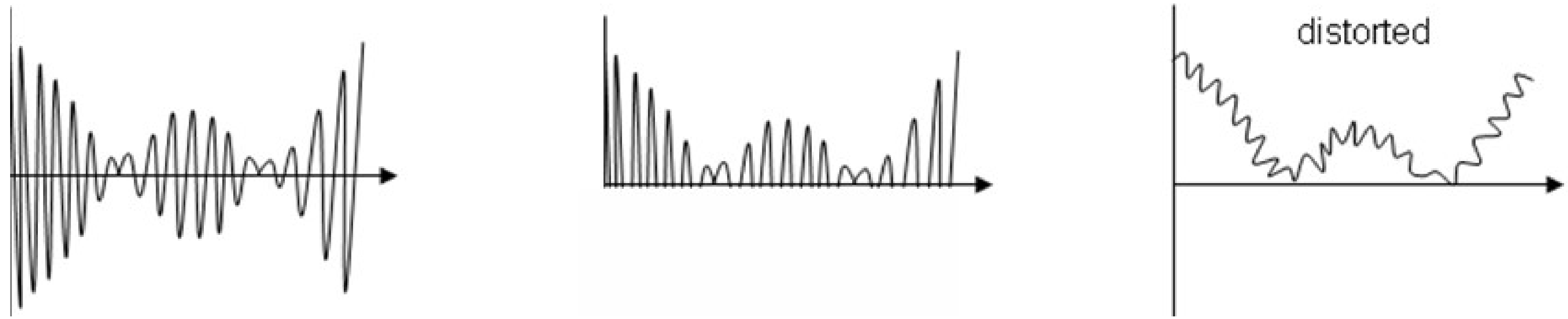
his is obviously simple, low cost. But the AM input <u>must be</u> DSBAM with μ<< 1.

Large Signal Operation

r large signal inputs, (≈ Volts) the diode is switched *i.e.* forward biased ≡ ON, reverse ased ≡ OFF, and acts as a half wave rectifier. The 'RC' combination acts as a 'smoothing rcuit' and the output is $m(t)$ plus 'distortion'.



he modulation depth is > 1, the distortion below occurs



Applications

roadcasting of both audio and video signals.

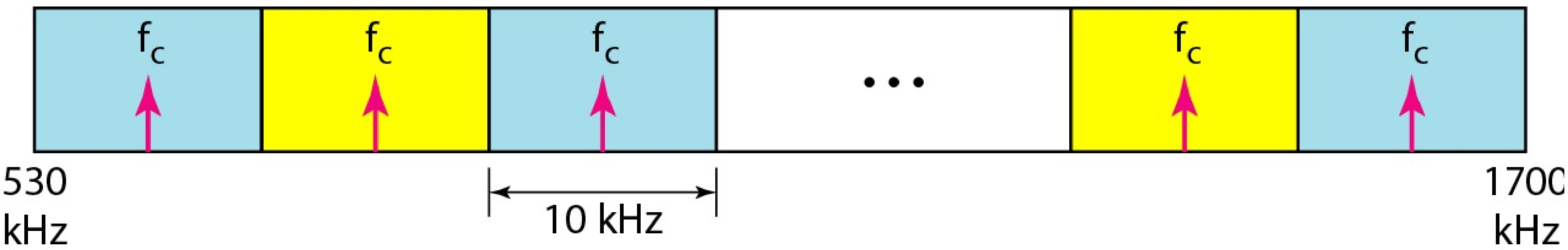
Iobile radio communications, such as cell phone.

adio broadcasting, TV pictures (video), facsimile ransmission

requency range for AM - 535 kHz – 1700 kHz

andwidth-10 kHz

Figure *AM band allocation*



Advantages/disadvantages

dvantages:

here are several advantages of amplitude modulation, and some of these reasons have meant that it is still in widespread use today:

- It is **simple** to implement
- it can be demodulated using a circuit consisting of **very few components**
- AM receivers are **very cheap** as no specialized components are needed.

isadvantages:

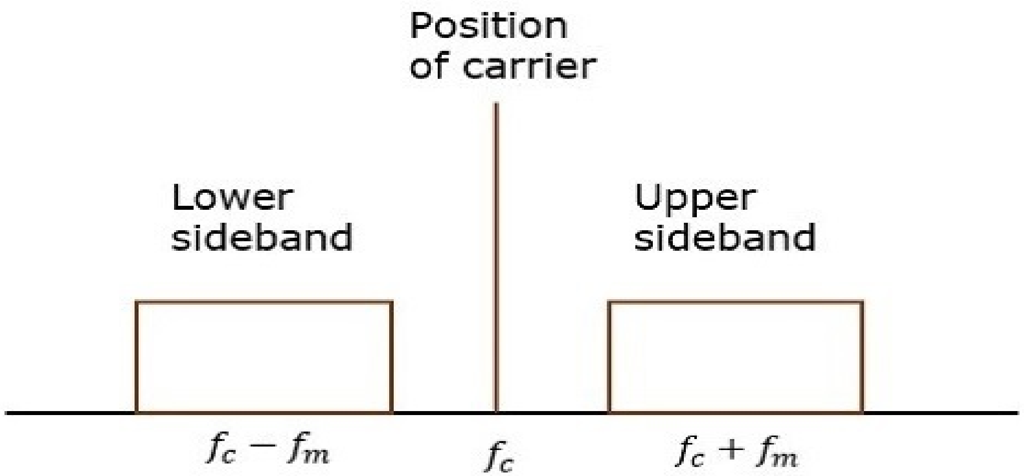
- It is not **efficient in terms of its power usage**
- It is not **efficient in terms of its use of bandwidth**, requiring a bandwidth equal to twic that of the highest audio frequency
- It is prone **to high levels of noise** because most noise is amplitude based and obviously AM detectors are sensitive to it.

THANK YOU

DSBSC Modulation

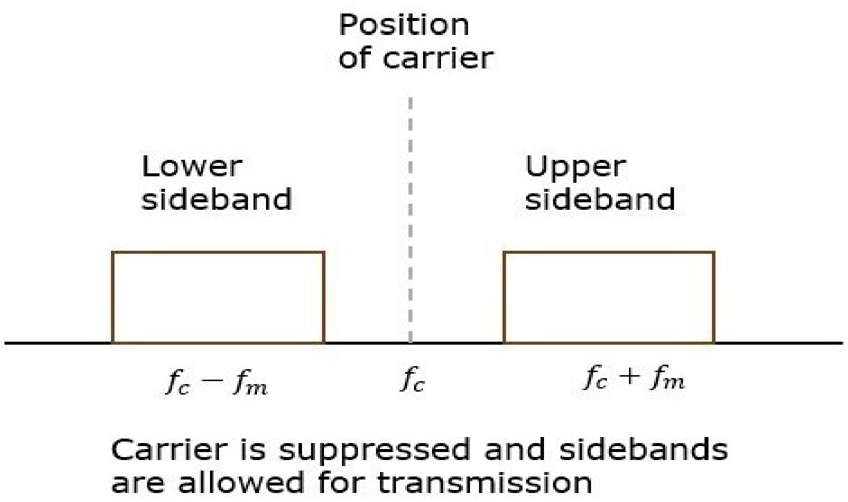
In the process of Amplitude Modulation, the modulated wave consists of the carrier wave and tw sidebands. The modulated wave has the information only in the sidebands. **Sideband** is nothing but band of frequencies, containing power, which are the lower and higher frequencies of the carrie frequency. In DSBSC. In AM, modulation efficiency is less because of high carrier power. To improv modulation efficiency the carrier is suppressed only sidebands are to be transmitted.

The transmission of a signal, which contains a carrier along with two sidebands can be terme as **Double Sideband Full Carrier** system or simply **DSBFC**. It is plotted as shown in the following figure



However, such a transmission is inefficient. Because, two-thirds of the power is being wasted in the carrier, which carries no information.

If the carrier is suppressed and only two side bands are transmitted and the saved power is distribut
to the two sidebands, then such a process is called as **Double Sideband Suppressed Carrier** system
simply **DSBSC**. It is plotted as shown in the following figure.



DSBSC Modulation

Mathematical Expressions

Let us consider the same mathematical expressions for modulating and carrier signals as we have considered i
the earlier chapters.
i.e., Modulating signal

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

Carrier signal

$$C\,(t)=A_c\cos(2\pi f_c t)$$

Mathematically, we can represent the **equation of DSBSC wave** as the product of modulating and carrier signa

$$s(t)=m(t)\,c(t)$$

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

DSBSC Modulation

Time domain representation of DSBSC Wave:

Modulating signal

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

Carrier signal

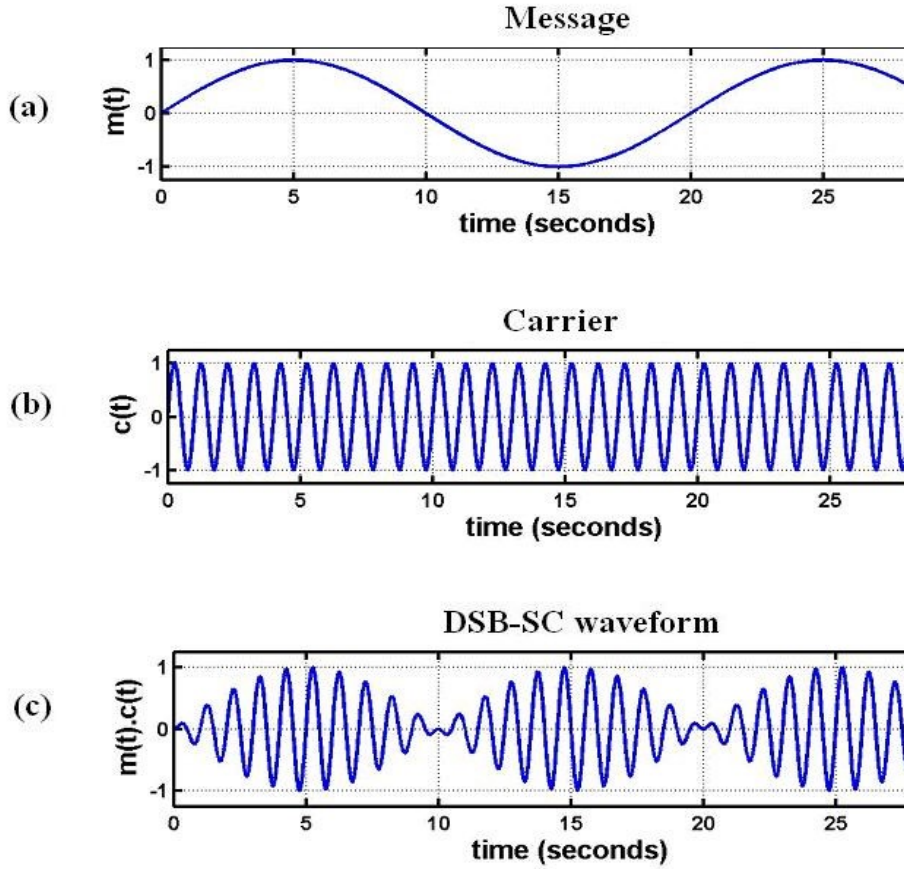
$$C(t)=A_c\cos(2\pi f_c t)$$

Mathematically, we can represent the **equation of DSBSC wave** as the product of modulating and carrier signals

$$s(t)=m(t)\,c(t)$$

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

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



In DSBSC modulated Wave underg
phase reversal when the message si
crossing zero

DSBSC Modulation

Frequency domain representation of DSBSC Wave:

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

Carrier signal $C(t)=A_c\cos(2\pi f_c t)$

Mathematically, we can represent the **equation of DSBSC wave** as the product of modulating and carrier signa

$$s(t)=m(t)\,c(t)$$

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

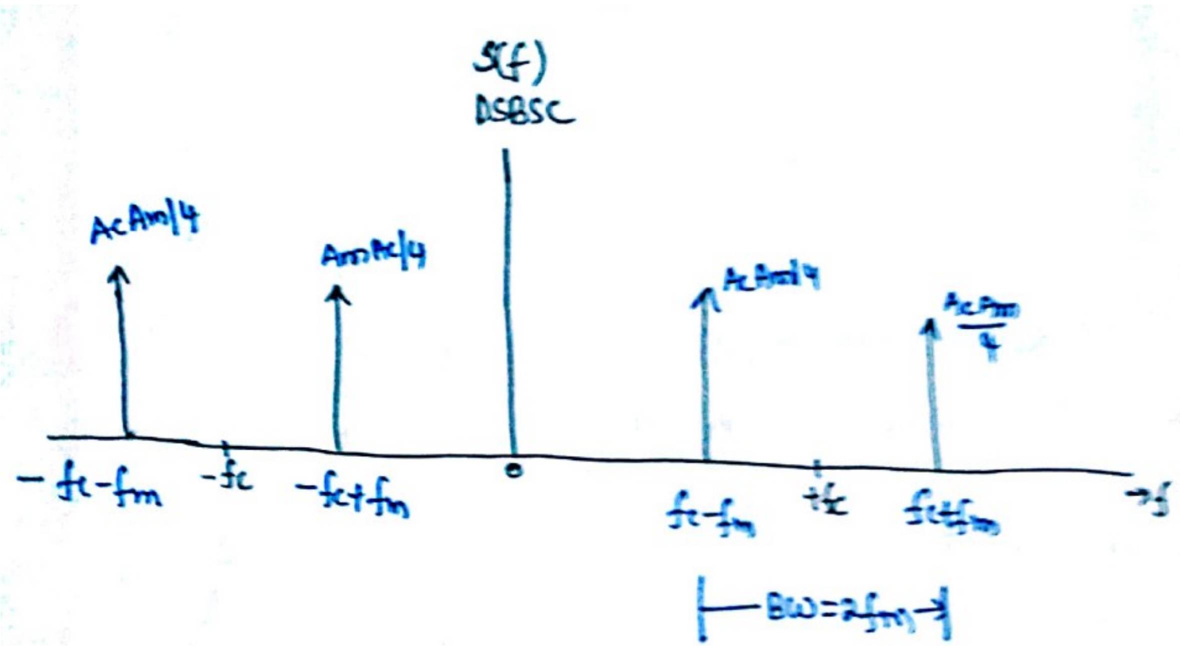
$$s(t)=\frac{A_m A_c}{2}\cos\left[2\pi(f_c+f_m)t\right]+\frac{A_m A_c}{2}\cos\left[2\pi(f_c-f_m)t\right]$$

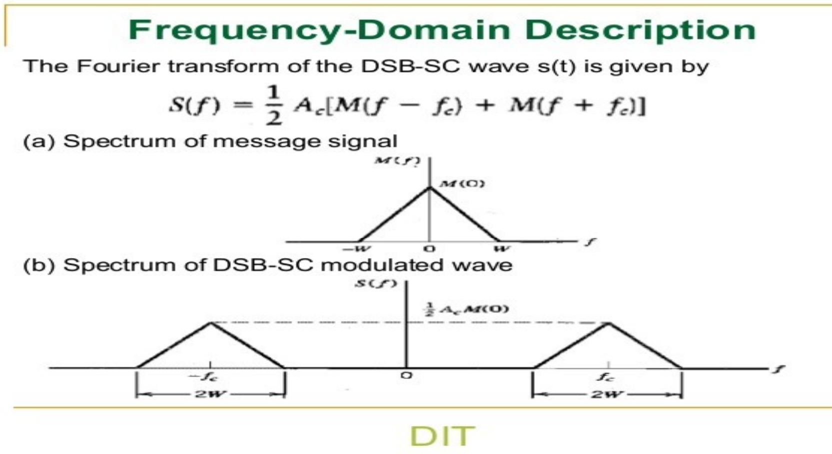
Apply Fourier Transform to the above equation

$$S(f)=\frac{A_m A_c}{4}[\delta(f+f_c+f_m)+\delta(f-f_c-f_m)+\delta(f+f_c-f_m)+\delta(f-f_c+f_m)$$

DSBSC Modulation

Frequency domain representation of DSBSC Wave:





DSBSC Modulation

Bandwidth of DSBSC Wave

We know the formula for bandwidth (BW) is

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

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

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

$$BW = 2f_m$$

Thus, the bandwidth of DSBSC wave is same as that of AM wave and it is equal to twice the frequency of the modulating signal.

DSBSC Modulation

Power Calculations of DSBSC Wave:

Consider the following equation of DSBSC modulated wave.

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

Power of DSBSC wave is equal to the sum of powers of upper sideband and lower sideband frequency compone

$$P_t = P_{USB} + P_{LSB}$$

$$Power\ (P) = \frac{V_{rms}^2}{R} = \frac{(V_m/\sqrt{2})^2}{R}$$

$$P_{USB} = \frac{(A_m A_C / 2\sqrt{2})^2}{R} = \frac{(A_m)^2 (A_C)^2}{8R}$$

DSBSC Modulation

$$P_{USB} = P_{LSB} = \frac{A_m^2 A_c^2}{8R}$$

$$P_t = P_{USB} + P_{LSB} = \frac{A_m^2 A_c^2}{8R} + \frac{A_m^2 A_c^2}{8R} = \frac{A_m^2 A_c^2}{4R}$$

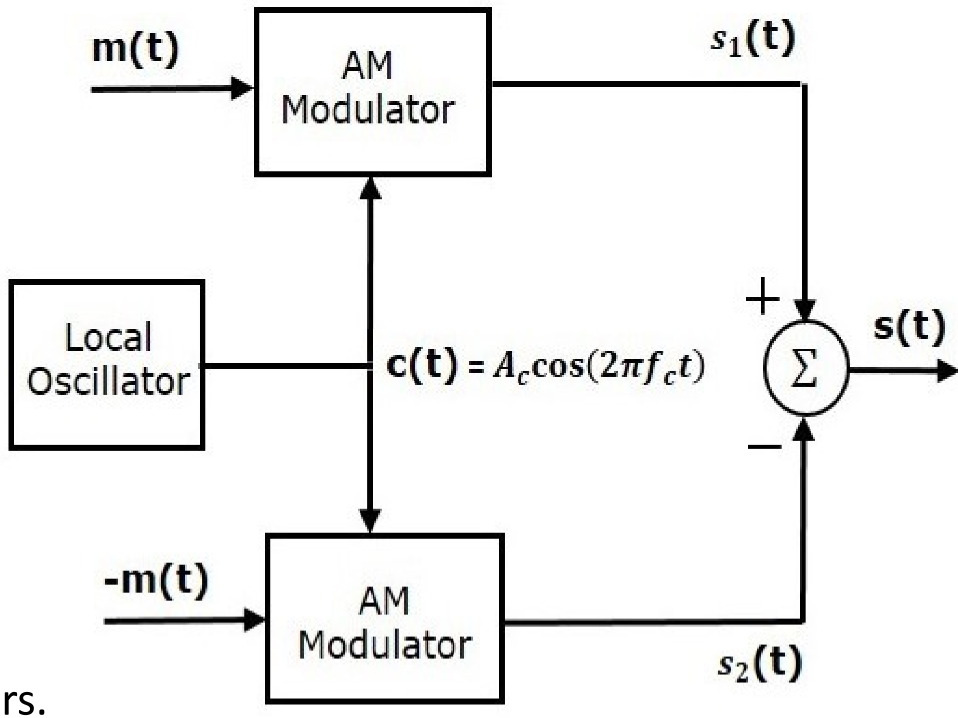
Therefore, the power required for transmitting DSBSC wave is equal to the power of both sidebands.

DSBSC Modulators

DSBSC modulators, which generate DSBSC wave. The following two modulators generate DSBSC wave. DSBSC modulators are also called as **product modulators** as they produce the output, which is the product of two input signals.

- Balanced modulator
- Ring modulator

Balanced Modulator:



Balanced modulator consists of two identical AM modulators. These two modulators are arranged in a balanced configuration in order to suppress the carrier signal. Hence, it is called as Balanced modulator.

The same carrier signal $c(t)=A_c\cos(2\pi f_c t)$ is applied as one of the inputs to these two AM modulators.

The modulating signal m(t) is applied as another input to the upper AM modulator.

Whereas, the modulating signal m(t) with opposite polarity, i.e., −m(t) is applied as another input to the lower AM modu

DSBSC Modulation

Output of the upper AM modulator is $s(t) = A_c[1 + k_a m(t)]\cos(2\pi f_c t)$

Output of the lower AM modulator is $s(t) = A_c[1 - k_a m(t)]\cos(2\pi f_c t)$

We get the DSBSC wave s(t) by subtracting $s_0(t)$ from $s_1(t)$. The summer block is used to per this operation. $s_1(t)$ with positive sign and $s_2(t)$ with negative sign are applied as inputs to sum block. Thus, the summer block produces an output s(t) which is the difference of $s_1(t)$and $s_2(t)$

$$s(t)=A_c[1+k_a m(t)]\cos(2\pi f_c t) - A_c[1-k_a m(t)]\cos(2\pi f_c t)$$

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

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

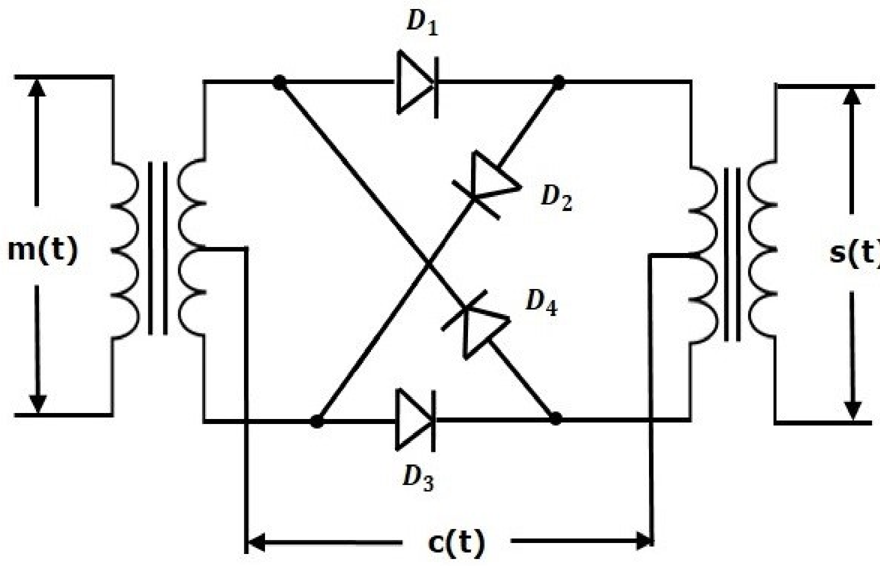
We know the standard equation of DSBSC wave is $s(t)=A_c m(t)\cos(2\pi f_c t)$

By comparing the output of summer block with the standard equation of DSBSC wave, we w get the scaling factor as $2k_a$

DSBSC Modulation

Ring Modulator:

The four diodes D1,D2,D3 and D4 are connected in the ring structure. Hence, this modulator is called as the **ring modulator**. Two center tapped transformers are used in this diagram. The message signal m(t) is applied to the input transformer. Whereas, the carrier signals c(t) is applied between the two center tapped transformers.



For positive half cycle of the carrier signal, the diodes D1 and D3 are switched ON, for negative ha cycle D2, D4 are conducted. .

We will get DSBSC wave s(t), which is just the product of the carrier signal c(t) and t message signal m(t) i.e.,

$$s(t) = \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^n - 1}{2n-1}\cos[2\pi(2n-1)f_c t]\, m(t)$$

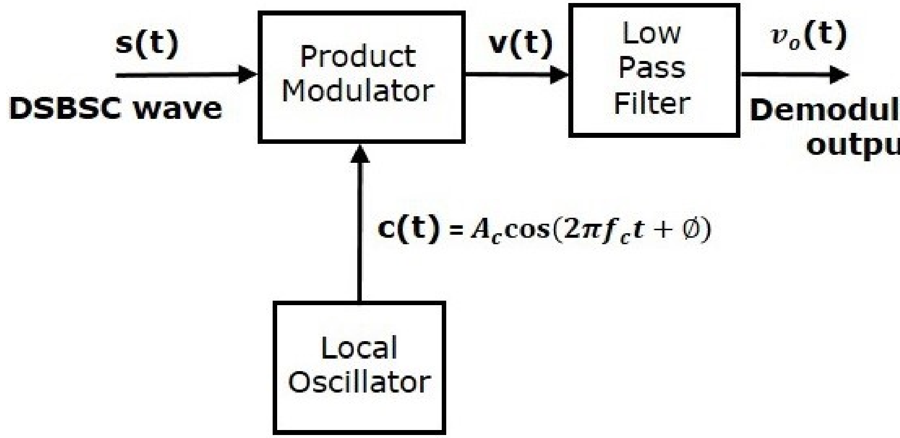
The above equation represents DSBSC wave, which is obtained at the output transformer of the ring modulator.

DSBSC Demodulation

The process of extracting an original message signal from DSBSC wave is known as detection o demodulation of DSBSC. The following demodulators (detectors) are used for demodulating DSBS wave.

- **Coherent Detector**
- **Costas Loop**

Coherent Detector :



The same carrier signal (which is used for generating DSBSC signal i.e. Frequency and phase must be same if not same will get phase and frequency error) is used to detect the message signal. Hence, this process of detection is called as **coherent** or **synchronous detection**. Following is the block diagram of the coherent detector.

In this process, the message signal can be extracted from DSBSC wave by multiplying it with a carrie having the same frequency and the phase of the carrier used in DSBSC modulation. The resulting sign is then passed through a Low Pass Filter. Output of this filter is the desired message signal.

DSBSC Demodulation

Let the DSBSC wave be

$$s(t)=A_c\cos(2\pi f_c t) \text{ x } m(t)$$

The output of the local oscillator is

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

Where, ϕ is the phase difference between the local oscillator signal and the carrier signa
which is used for DSBSC modulation.

From the figure, we can write the output of product modulator as

$$v(t)=s(t)c(t)$$

Substitute, s(t) and c(t) values in the above equation.

$$v(t)= A_c\cos(2\pi f_c t)\, m(t)\, A_c\cos(2\pi f_c t+\varphi)$$

$$= A_c^2\cos(2\pi f_c t)\cos(2\pi f_c t+\varphi)m(t)$$

$$= (A_c^2/2)\,[\cos(4\pi f_c t+\varphi)+\cos\varphi]m(t)$$

DSBSC Demodulation

$$v(t)= (A_c^2/2) \cos\varphi\ m(t) + (A_c^2/2) \cos(4\pi f_c t+\varphi)\ m(t)$$

In the above equation, the first term is the scaled version of the message signal. It can be extracte by passing the above signal through a low pass filter.

Therefore, the output of low pass filter is

$$V_0\ (t)= (A_c^2/2\ )\cos \varphi \times m(t)$$

The demodulated signal amplitude will be maximum, when $\phi=0^0$. That's why the local oscillat signal and the carrier signal should be in phase, i.e., there should not be any differen between these two signals.

The demodulated signal amplitude will be zero, when $\phi= \pm 90^0$. This effect is calle as **quadrature null effect**.

DSBSC Demodulation

Effect of Phase Error on the Demodulated Output

Let us consider the expression for the output of coherent detector is given by :

$$V_0 (t)= (A_c^2/2)\cos \varphi \times m(t)$$

The demodulated signal amplitude will be maximum, when $\phi=0^0$. That's why the local oscilla signal and the carrier signal should be in phase, i.e., there should not be any phase differe between these two signals.

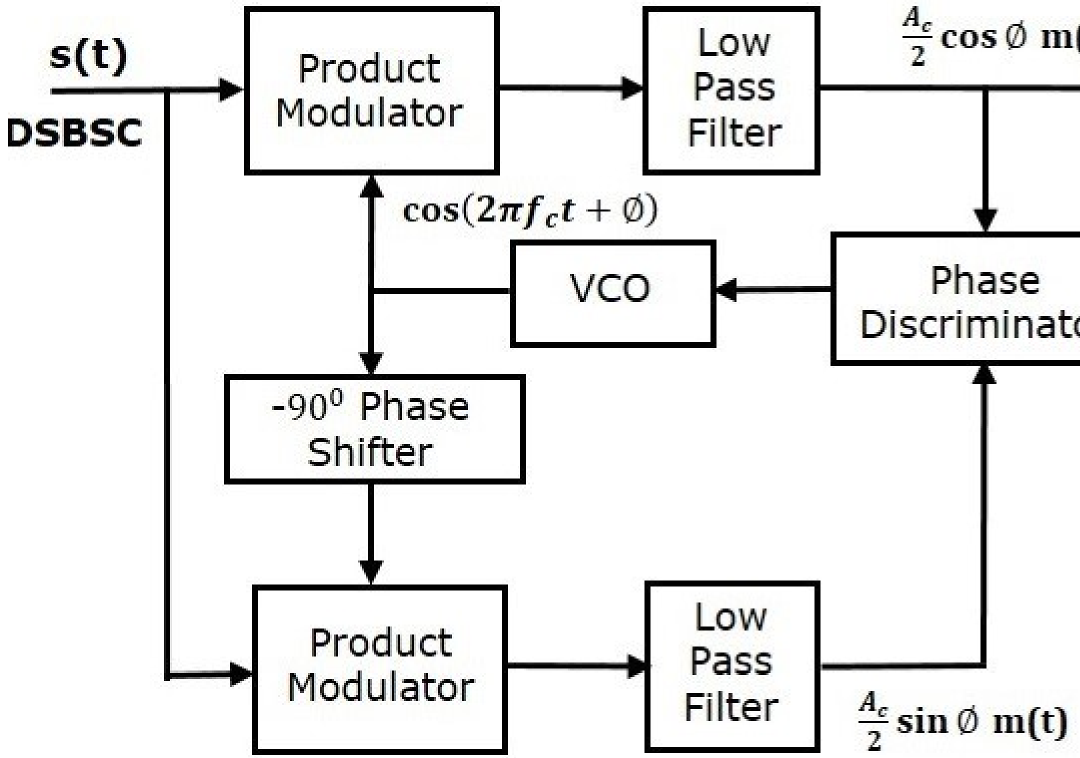
The demodulated signal amplitude will be zero, when $\phi= \pm 90^0$. This effect is ca as **quadrature null effect**.

In this above expression, φ represents the phase error and the amplitude of the demodulate output is maximum and equal to $(1/2) A_c^2$ when $\varphi = 0^o$ and the amplitude is zero when φ = 9

Costas Loop:

Costas loop is used to make both the carrier signal (used for DSBSC modulation) and the locally generated signal in phase. Following is the block diagram of Costas loop.

Costas loop consists of two product modulators with common input s(t), which is DSBSC wave. The other input for both product modulators is taken from **Voltage Controlled Oscillator** (VCO) with -90^0 phase shift to one of the product modulator as shown in figure.



We know that the equation of DSBSC wave is

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

Let the output of VCO be

$$c_1(t)=\cos(2\pi f_c t+\phi)$$

This output of VCO is applied as the carrier input of the upper product modulator.

DSBSC Demodulation

Hence, the output of the upper product modulator is

$$v_1(t) = s(t)c_1(t)$$

Substitute, s(t) and $c_1(t)$ values in the above equation.

$$v_1(t)=A_c\cos(2\pi f_c t)\, m(t)\cos(2\pi f_c t+\varphi)$$

$\cos A \cos B = 1/2[\cos(A+B) + \cos(A-$

After simplifying, we will get $v_1(t)$as

$$v_1(t)=(A_c/2)\cos\varphi\, m(t)+(A_c/2)\cos(4\pi fct+\varphi)m(t)$$

This signal is applied as an input of the upper low pass filter. The output of this low pass filter is

$$v_{01}(t)=(A_c/2)\cos\varphi\, m(t)$$

Therefore, the output of this low pass filter is the scaled version of the modulating signal.

DSBSC Demodulation

The output of -90^0 phase shifter is

$$c_2(t) = \cos(2\pi f_c t + \phi - 90^0) = \sin(2\pi fct + \phi)$$

This signal is applied as the carrier input of the lower product modulator.

The output of the lower product modulator is

$$v_2(t) = s(t)c_2(t)$$

Substitute, s(t) and $c_2(t)$ values in the above equation.

$$v_2(t) = A_c\cos(2\pi f_c t)\, m(t)\, \sin(2\pi f_c t + \phi)$$

$2 \sin A \cos B = \sin(A + B) + \sin(A - B$

After simplifying, we will get $v_2(t)$ as

$$v_2(t) = (A_c / 2)\sin\phi\, m(t) + (A_c/2)\sin(4\pi f_c t + \phi)m(t)$$

This signal is applied as an input of the lower low pass filter. The output of this low pass filter is

$$v_{02}(t) = (A_c / 2)\, \sin\phi\, m(t)$$

DSBSC Demodulation

The output of this lower Low pass filter has -90^0 phase difference with the output of the upper low p
filter.

The outputs of these two low pass filters are applied as inputs of the phase discriminator. Based on t
phase difference between these two signals, the phase discriminator produces a DC control signal.

This signal is applied as an input of VCO to correct the phase error in VCO output. Therefore, the carri
signal (used for DSBSC modulation) and the locally generated signal (VCO output) are in phase.

DSBSC modulation

Applications of DSB-SC modulation

- During the transmission of binary data, DSB-SC system is used in phase shift keying methods.
- In order to transmit 2 channel stereo signals, DSB signals are used in Television and FM broadcasting.

DSBSC

Advantages of DSB-SC modulation

It provides 100% modulation efficiency.

Due to suppression of carrier, it consumes less power.

It provides a larger bandwidth.

Disadvantages of DSB-SC modulation

It involves a complex detection process.

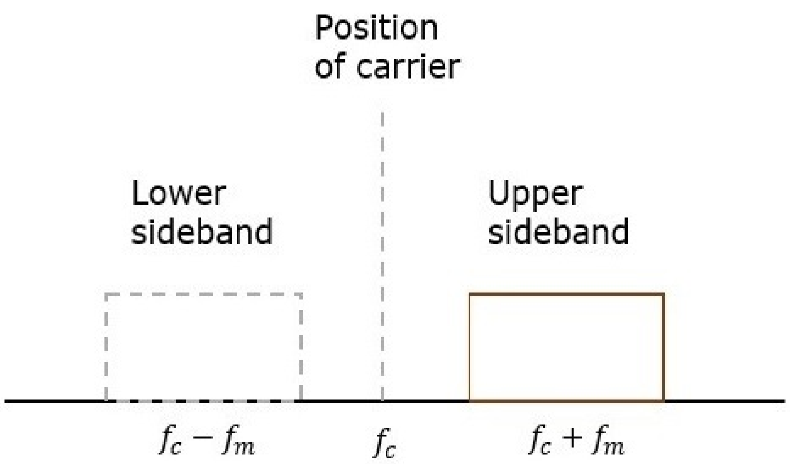
Using this technique it is sometimes difficult to recover the signal at the receiver.

It is an expensive technique when it comes to demodulation of the signal.

SSBSC Modulation

n the previous chapters, we have discussed DSBSC modulation and demodulation. The DSBSC modulated signal has two sidebands. Since, the two sidebands carry the same information, there is no need to transmit both sidebands. We can eliminate one sideband.

The process of suppressing one of the sidebands along with the carrier and transmitting a single sideband is called as **Single Sideband Suppressed Carrier** system or simply **SSBSC**. It is plotted as shown in the following figure.



Carrier and a sideband are suppressed and a single sideband is allowed for transmission

In the above figure, the carrier and the lower sideband are suppressed. Hence, the upper sideband is used for transmission. Similarly, we can suppress the carrier and the upper sideband while transmitting the lower sideband.

This SSBSC system, which transmits a single sideband has high power, as the power allotted for both the carrier and the other sideband is utilized in transmitting this Single Sideband.

SSBSC Modulation

Mathematical Expressions

Let us consider the same mathematical expressions for the modulating and the carrier signals as we have considered in the earlier chapters.

i.e., Modulating signal

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

Carrier signal

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

Mathematically, we can represent the equation of SSBSC wave as

$$s(t) = (A_m A_c / 2)\cos[2\pi(f_c+f_m)t]$$ for the upper sideband

or

$$s(t)=(A_m A_c/2)\cos[2\pi(f_c-f_m)t]$$ for the lower sideband

SSBSC Modulation

Bandwidth of SSBSC Wave

We know that the DSBSC modulated wave contains two sidebands and its bandwidth is $2f_m$. Since SSBSC modulated wave contains only one sideband, its bandwidth is half of the bandwidth of DSB modulated wave.

i.e., ***Bandwidth of SSBSC modulated wave*** $=2f_m / 2=f_m$

Therefore, the bandwidth of SSBSC modulated wave is f_m and it is equal to the frequency of modulating signal.

SSBSC Modulation

Power Calculations of SSBSC Wave:

Consider the following equation of SSBSC modulated wave.

$$s(t) = (A_m A_c / 2)\cos[2\pi(f_c + f_m)t]$$ for the upper sideband

or

$$s(t) = (A_m A_c / 2)\cos[2\pi(f_c - f_m)t]$$ for the lower sideband

Power of SSBSC wave is equal to the power of any one sideband frequency components.

$$P_t = P_{USB} = P_{LSB}$$

$$Power\ (P) = \frac{V_{rms}^2}{R} = \frac{(V_m/\sqrt{2})^2}{R}$$

$$P_{USB} = \frac{(A_m A_C / 2\sqrt{2})^2}{R} = \frac{(A_m)^2 (A_C)^2}{8R}$$

SSBSC Modulation

$$P_{USB} = P_{LSB} = \frac{A_m^2 A_c^2}{8R}$$

$$P_t = P_{USB} = P_{LSB} = \frac{A_m^2 A_c^2}{8R}$$

Applications

- For power saving requirements and low bandwidth requirements.
- In land, air, and maritime mobile communications.
- In point-to-point communications.
- In radio communications.
- In television, telemetry, and radar communications.
- In military communications, such as amateur radio, etc.

SSBSC Modulation

Advantages:

- Bandwidth or spectrum space occupied is lesser than AM and DSBSC waves.
- Transmission of more number of signals is allowed.
- Power is saved.
- High power signal can be transmitted.
- Less amount of noise is present.
- Signal fading is less likely to occur.

Disadvantages:

- The generation and detection of SSBSC wave is a complex process.
- The quality of the signal gets affected unless the SSB transmitter and receiver have an excellent frequency stability.

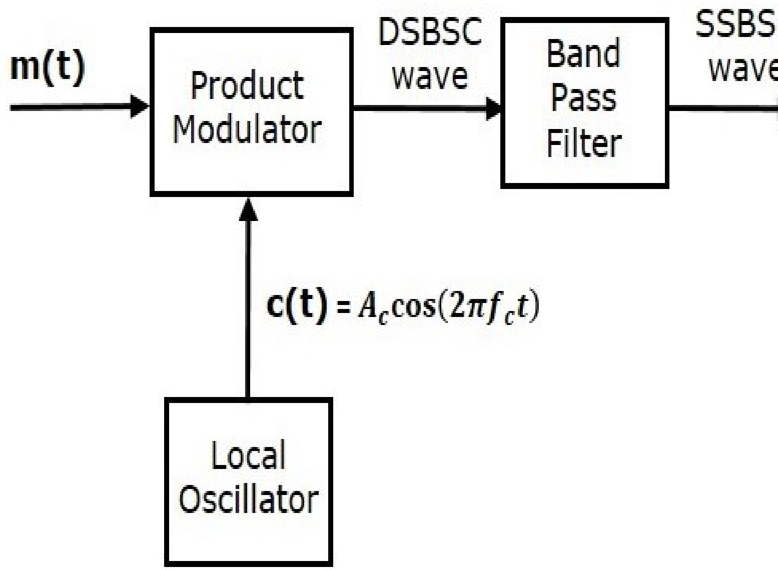
SSBSC Modulation

SSBSC modulators, which generate SSBSC wave. We can generate SSBSC wave using the followi
two methods.

- Frequency discrimination method
- Phase discrimination method

Frequency Discrimination Method:

The following figure shows the block diagram of SSBSC modulator using frequency discrimination method.



In this method, first we will generate DSBSC wave with the help of the product modulator. Then, apply this DSBSC wave as an input of band pass filter. This band pass filter produces an output, which is SSBSC wave.

Select the frequency range of band pass filter as the spectrum of the desired SSBSC wave. This means the band pass filter can be tuned to either upper sideband or lower sideband frequencies to get the respective SSBSC wave having upper sideband or lower sideband.

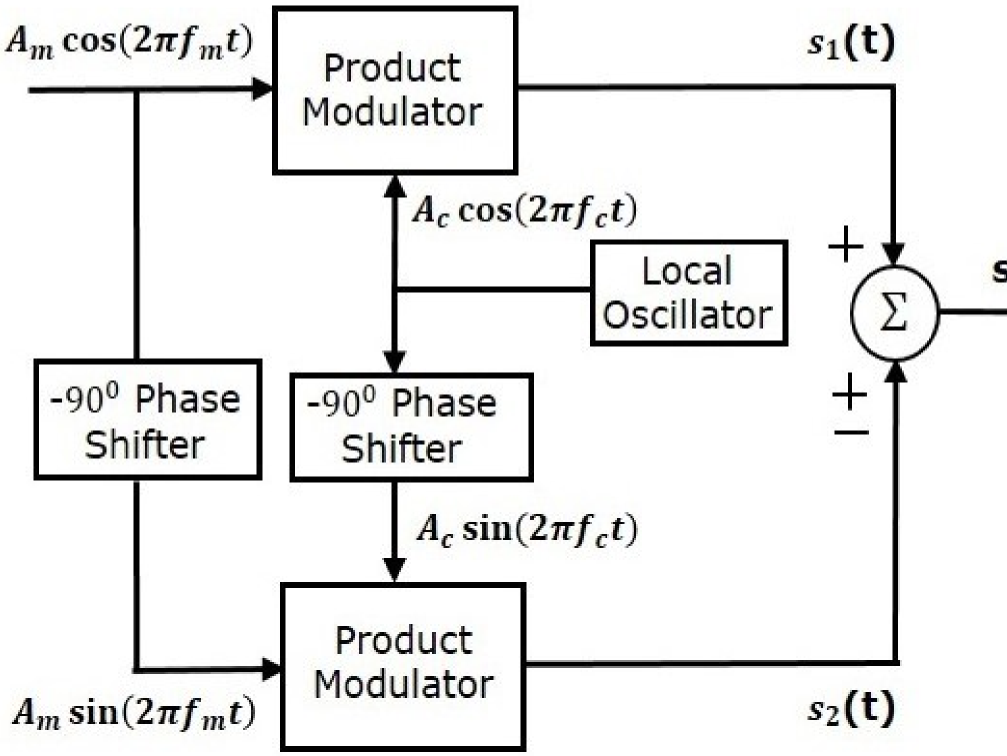
SSBSC Modulation

Phase Discrimination Method:

The following figure shows the block diagram of SSBSC modulator using phase discrimination metho

This block diagram consists of two product modulators, two -90^0 phase shifters, one local oscillator and one summer block. The product modulator produces an output, which is the product of two inputs. The -90^0phase shifter produces an output, which has a phase lag of -90^0 with respect to the input.

The local oscillator is used to generate the carrier signal. Summer block produces an output, which is either the sum of two inputs or the difference of two inputs based on the polarity of inputs.



SSBSC Modulation

The modulating signal $A_m\cos(2\pi f_m t)$ and the carrier signal $A_c\cos(2\pi f_c t)$ are directly applied as inputs to the upper product modulator. So, the upper product modulator produces an output, which is the product of these two inputs.

The output of upper product modulator is

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

$$s_1(t) = \frac{A_m A_c}{2}\cos\left[2\pi(f_c + f_m)t\right] + \frac{A_m A_c}{2}\cos\left[2\pi(f_c - f_m)t\right]$$

The modulating signal $A_m\cos(2\pi f_m t)$ and the carrier signal $A_c\cos(2\pi f_c t)$ are phase shifted by -90^0 befo applying as inputs to the lower product modulator. So, the lower product modulator produces an outp which is the product of these two inputs.

The output of lower product modulator is

$$s_2(t)=A_m A_c \cos(2\pi f_m t-90^0)\cos(2\pi f_c t-90^0)$$

SSBSC Modulation

$$s_2(t)=A_mA_c\sin(2\pi f_mt)\sin(2\pi f_ct)$$

$$s_2(t) = -\frac{A_mA_c}{2}\cos\ [2\pi(f_c + f_m\ )t] + \frac{A_mA_c}{2}\cos\ [2\pi(f_c - \ f_m\ )t]$$

Add s1(t) and s2(t) in order to get the SSBSC modulated wave s(t) having a lower sideband.

$$s(t)=s_1(t) + s_2(t) = A_mA_c\cos[2\pi(f_c-f_m)t]$$

Subtract s2(t) from s1(t) in order to get the SSBSC modulated wave s(t) having a upper sideband.

$$s(t)=s_1(t) - s_2(t) = A_mA_c\cos[2\pi(f_c+f_m)t]$$

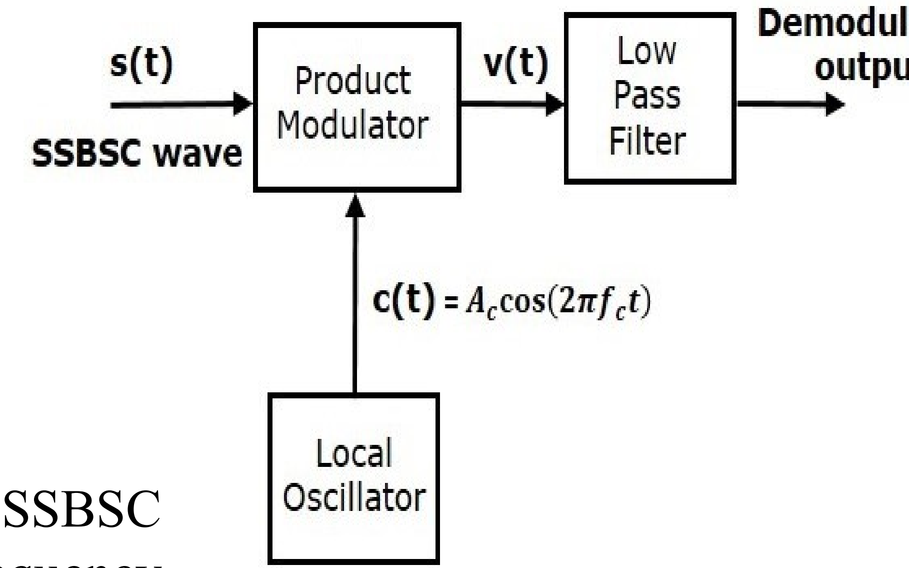
Hence, by properly choosing the polarities of inputs at summer block, we will get SSBSC wave having a upper sideband or a lower sideband.

SSBSC Demodulation

The process of extracting an original message signal from SSBSC wave is known as detection o demodulation of SSBSC. Coherent detector is used for demodulating SSBSC wave.

Coherent Detector:

Here, the same carrier signal (which is used for generating SSBSC wave) is used to detect the message signal. Hence, this process of detection is called as **coherent** or **synchronous detection**. Following is the block diagram of coherent detector.



In this process, the message signal can be extracted from SSBSC wave by multiplying it with a carrier, having the same frequency and the phase of the carrier used in SSBSC modulation. The resulting signal is then passed through a Low Pass Filter. The output of this filter is the desired message signal.

SSBSC Demodulation

Consider the following **SSBSC** wave having a **lower sideband**.

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

The output of the local oscillator is

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

From the figure, we can write the output of product modulator as

$$v(t)=s(t)c(t)$$

Substitute s(t) and c(t)values in the above equation.

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

$$V(t) = \frac{A_m A_c{}^2}{4} \{\cos\left[2\pi(2f_c - f_m)t\right] + \cos(2\pi f_m)t\}$$

SSBSC Demodulation

$$V\,(t) = \frac{A_m A_c{}^2}{4} \cos\,[2\pi(2f_c - f_m)t] + \frac{A_m A_c{}^2}{4} \mathrm{Cos}(2\pi f_m)t$$

In the above equation, the second term is the scaled version of the message signal. It can be extracted by passing the above signal through a low pass filter.

Therefore, the output of low pass filter is

$$V_0\,(t) = \frac{A_m A_c{}^2}{4} \mathrm{Cos}(2\pi f_m t)$$

Here, the scaling factor is $\frac{A_c{}^2}{4}$

We can use the same block diagram for demodulating SSBSC wave having an upper sideband. Consider th following **SSBSC** wave having an **upper sideband**.

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

SSBSC Demodulation

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

We can write the output of the product modulator as $v(t)=s(t)c(t)$

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

$$V(t) = \frac{A_m A_c{}^2}{4} \cos\left[2\pi(2f_c + f_m)t\right] + \frac{A_m A_c{}^2}{4} \operatorname{Cos}(2\pi f_m)t$$

In the above equation, the second term is the scaled version of the message signal. It can be extrac by passing the above signal through a low pass filter.

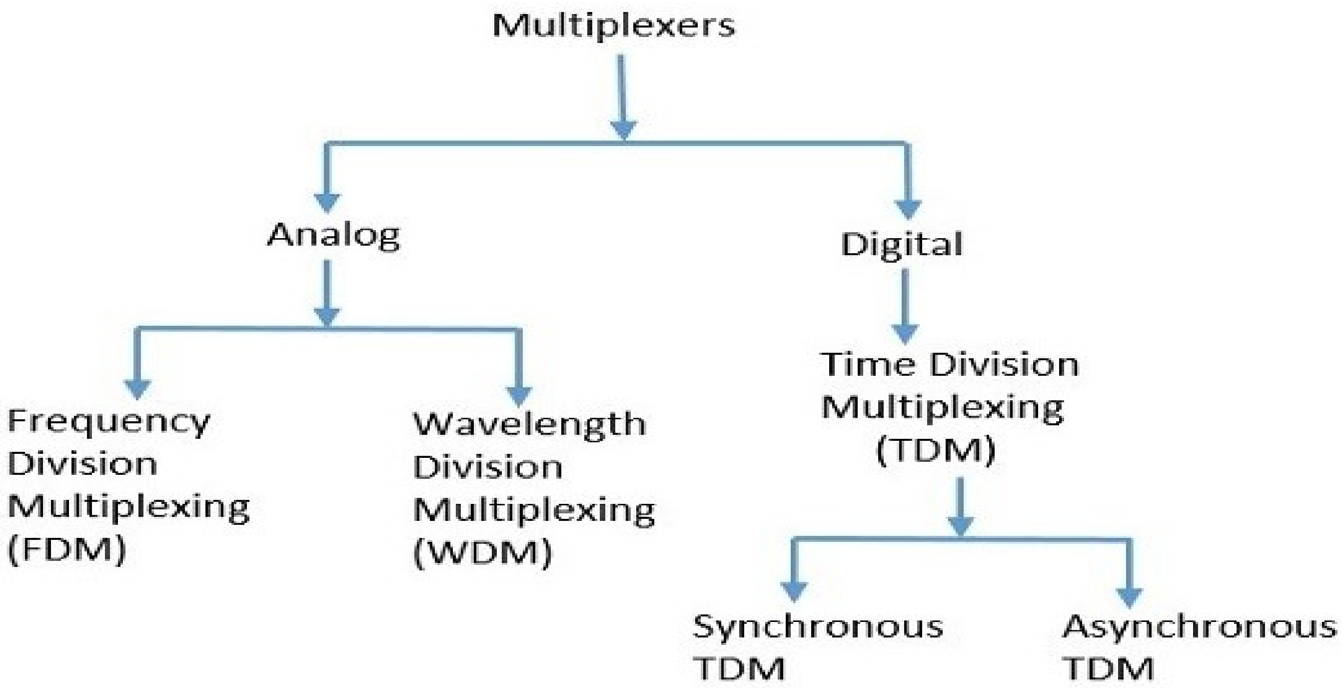
Therefore, the output of low pass filter is $V_0(t) = \frac{A_m A_c{}^2}{4} \operatorname{Cos}(2\pi f_m t)$

Here, the scaling factor is $\frac{A_c{}^2}{4}$

Therefore, we get the same demodulated output in both the cases by using coherent detector.

Multiplexing

Multiplexing is the process of combining multiple signals into one signal, over a shared medium. If the analog signals are multiplexed, then it is called as **analog multiplexing**. Similarly, if the digital signals are multiplexed, then it is called as **digital multiplexing**.



Frequency Division Multiplexing(FDM)

Frequency division multiplexing (FDM) is a technique of multiplexing which means combining more than one signal over a shared medium. In FDM, signals of different frequencies are combined for concurrent transmission.

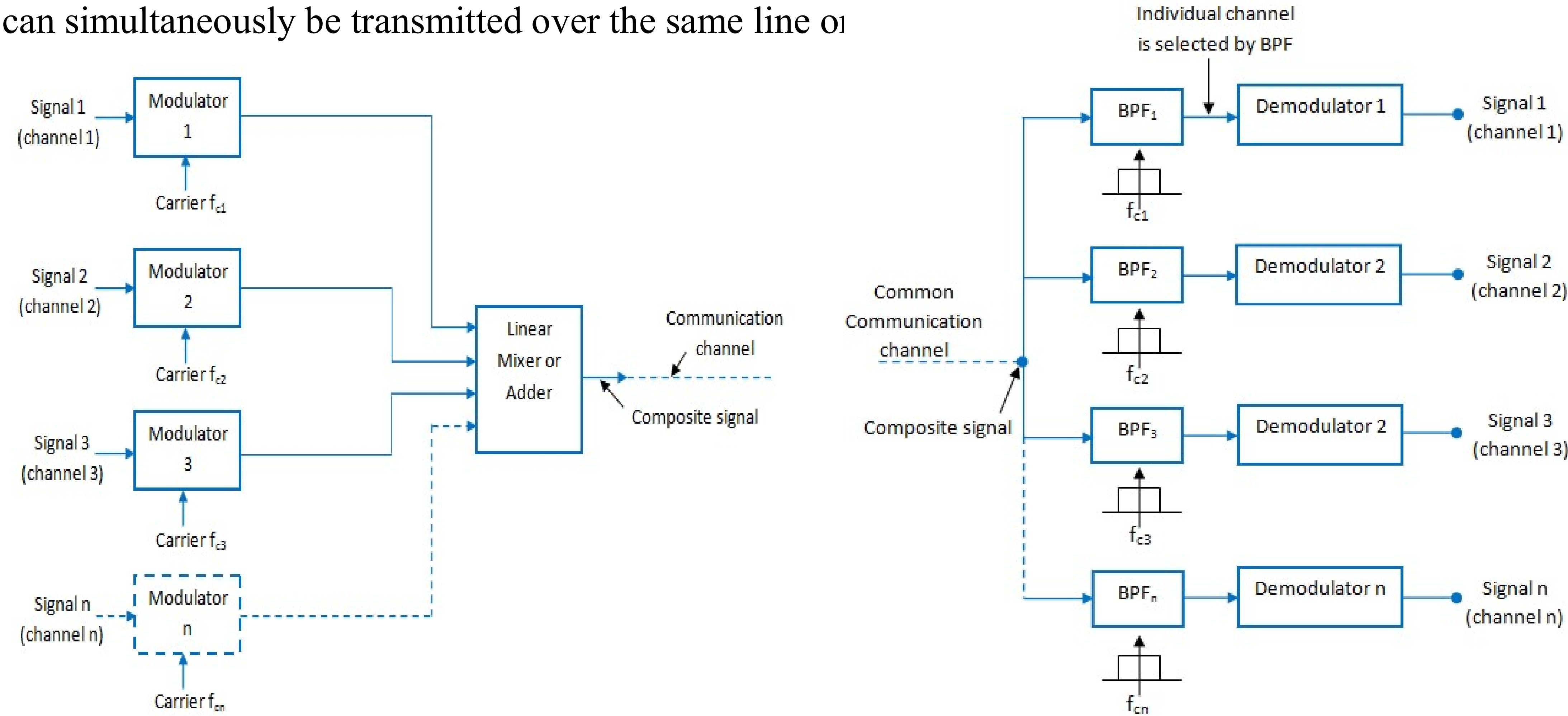
Concept and Process

In FDM, the total bandwidth is divided to a set of frequency bands that do not overlap. Each of these bands is a carrier of a different signal that is generated and modulated by one of the sending devices. The frequency bands are separated from one another by strips of unused frequencies called the guard bands, to prevent overlapping of signals.

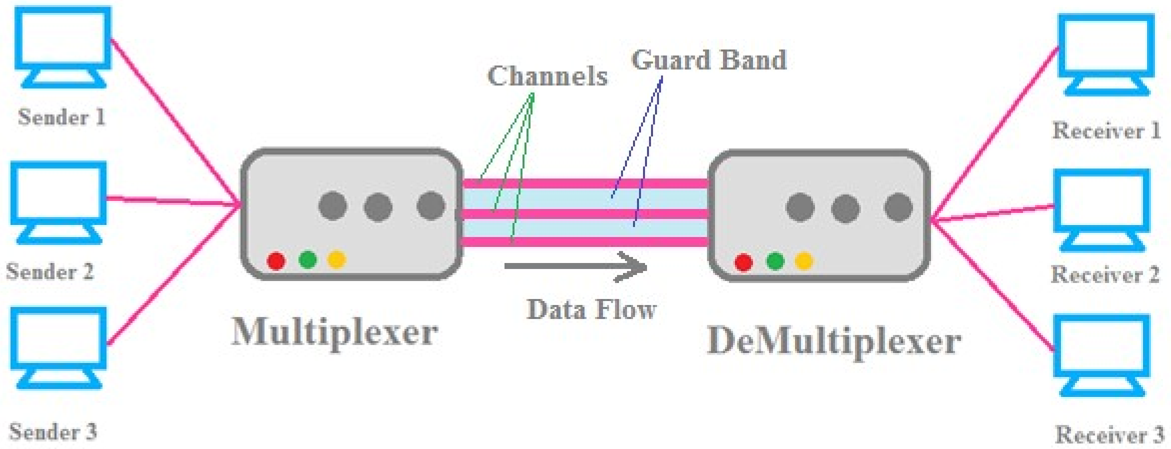
The modulated signals are combined together using a multiplexer (MUX) in the sending end. The combined signal is transmitted over the communication channel, thus allowing multiple independent data streams to be transmitted simultaneously. At the receiving end, the individual signals are extracted from the combined signal by the process of demultiplexing (DEMUX).

Frequency Division Multiplexing(FDM)

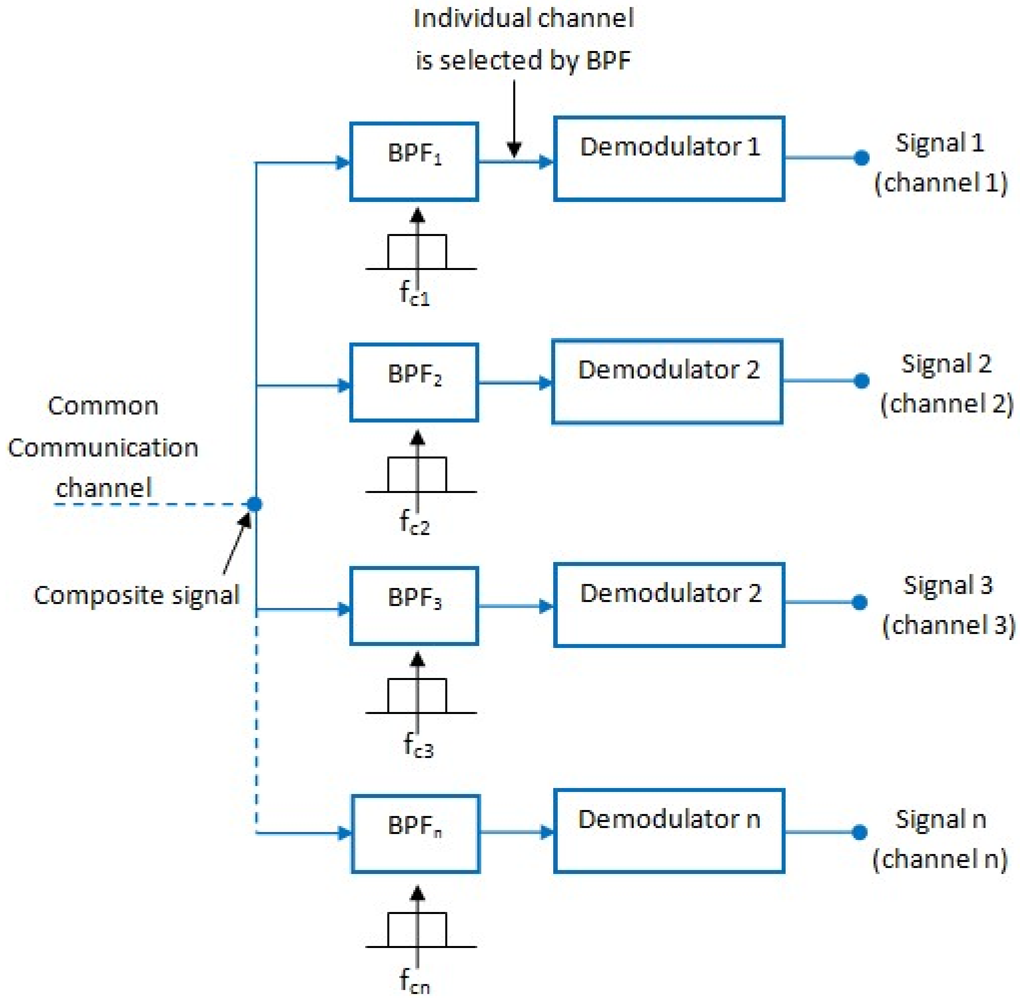
Frequency-Division Multiplexing (FDM) is a signal transmission technology in which multiple signals can simultaneously be transmitted over the same line o



SSBSC Modulation



Frequency Division Multiplexing



Individual channel
is selected by BPF
BPF1
Demodulator 1
Signal 1
(channel 1)
fc1
BPF2
Demodulator 2
Signal 2
(channel 2)
fc2
Common
Communication
channel
Composite signal
BPF3
Demodulator 2
Signal 3
(channel 3)
fc3
BPFn
Demodulator n
Signal n
(channel n)
fcn