Amplitude and Angle modulation Techniques.

Module 2

Amplitude Modulation and Demodulation

2.1 Basic concepts, need for modulation, waveforms (time domain and frequency domain), modulation index, bandwidth, voltage distribution and power calculations.

2.2 DSBFC: Principles, low-level and high-level transmitters, DSB suppressed carrier, Balanced modulators with diode (Ring modulator and FET) and SSB systems.

2.3 Amplitude demodulation: Diode detector, practical diode detector, Comparison of different AM techniques, Applications of AM and use of VSB in broadcast television.

Transmission techniques

- 1) Baseband transmission
- 2) Modulation Technique/ Bandpass transmission

Baseband Transmission

The electrical equivalent of original information is known as the baseband signal.

The communication system in which the baseband signals are transmitted directly is known as **baseband transmission**.

Baseband transmission is effective only for wire communication.

Example, Telephone network, data communication in computer networks through coaxial cable.

But it is inefficient for wireless or radio communication.

Limitations of Baseband Transmission

1)Baseband signal having small frequency range from 20 Hz to 20 KHz only
(so no large channel accommodation, mixing of signals).

2)Due to small frequency range, baseband signal cannot travel long distance in free space or air.

3)After a travel of short distance signal gets suppressed. So not used for radio communication. i.e. wireless communication.

To make the baseband signal efficient for radio communication modulation technique is used.

Modulation Technique

To overcome the drawbacks of baseband transmission and to transmit baseband signals by radio, modulation techniques must be used.

Baseband signal (Information signal) is a low-frequency signal and cannot travel longer distance. Just like we cannot walk at longer distance.

Definition:

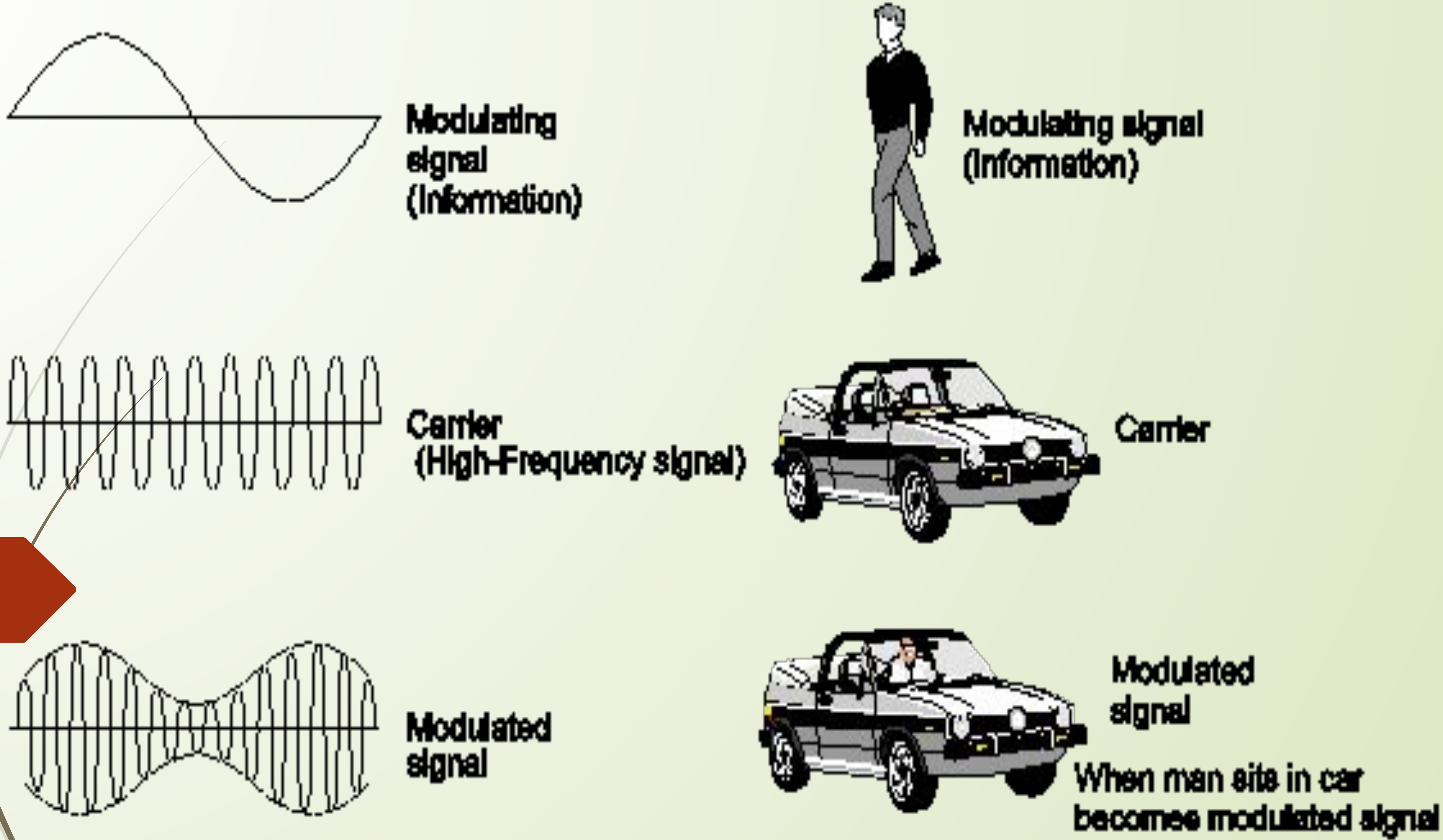
Modulation is the process of superimposing low-frequency information signal on a high-frequency carrier signal

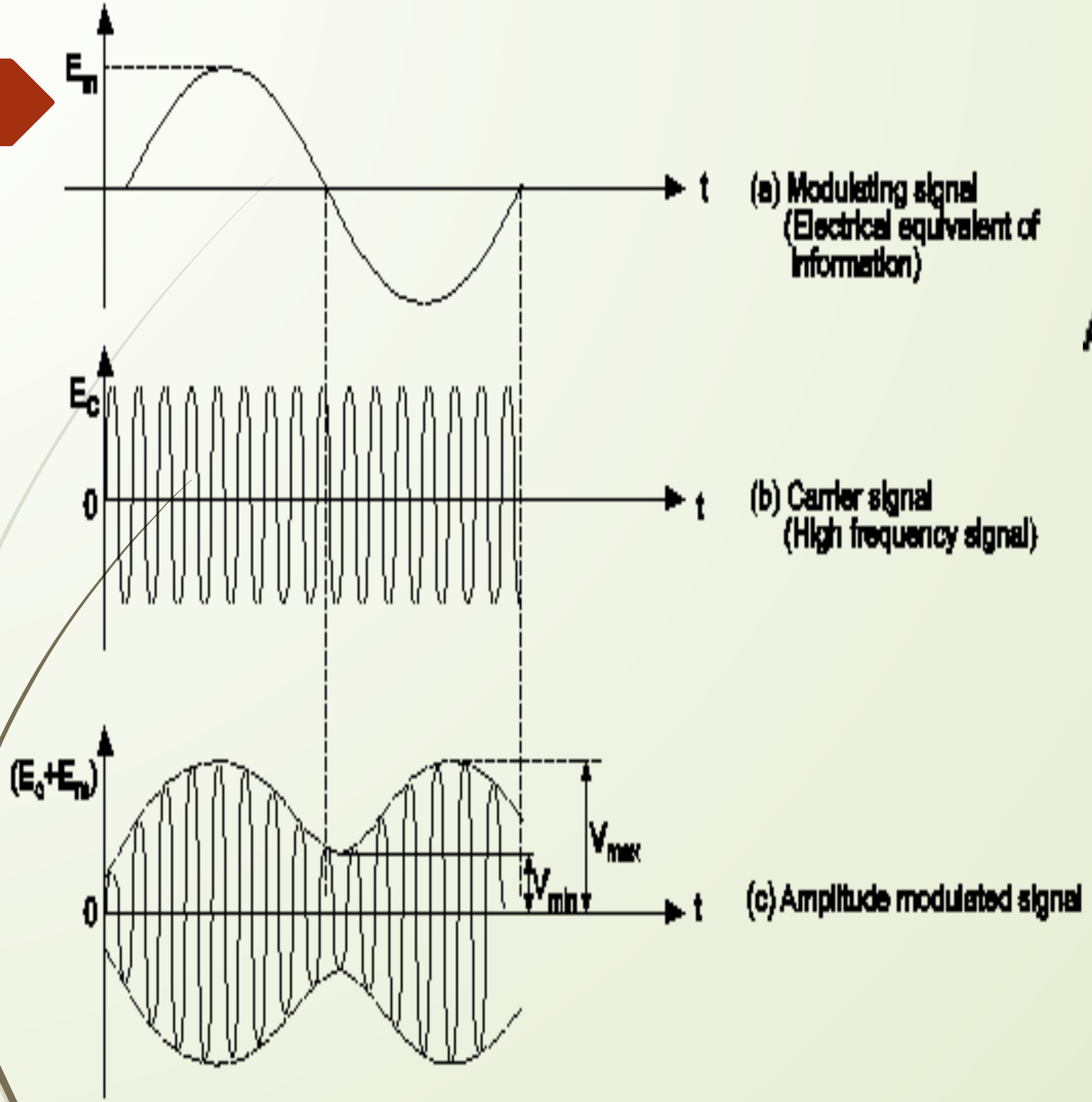
MODULATION

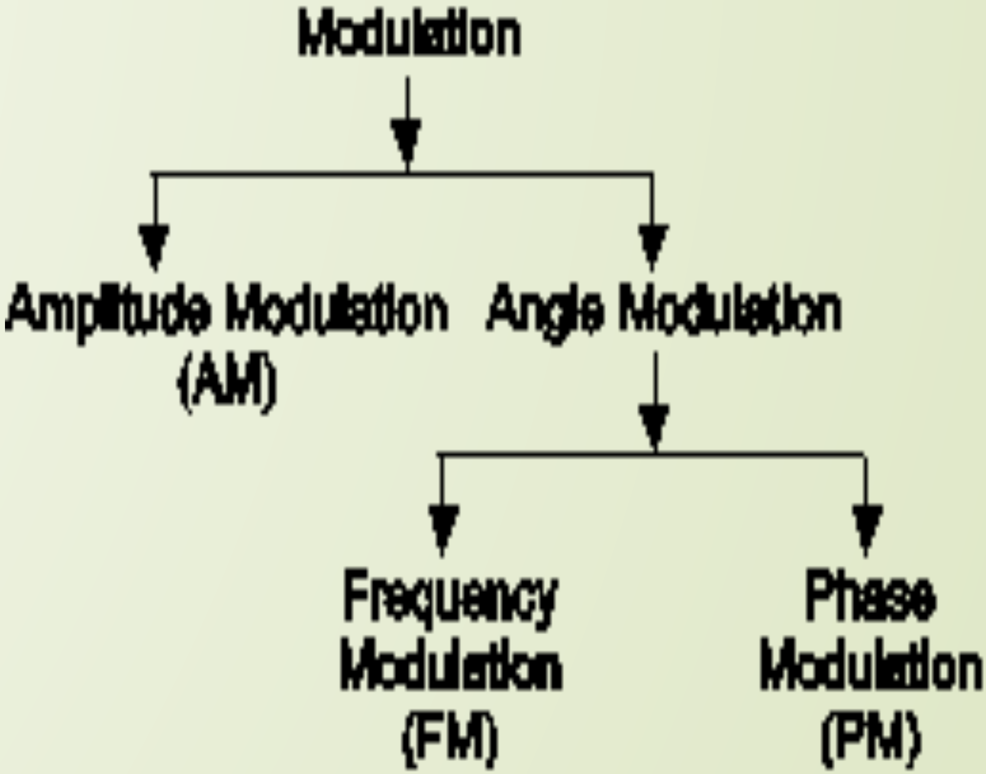
- Defined as

" The process by which some characteristics of a signal called carrier varied in accordance with the instantaneous value of another signal called modulating signal "

- The information bearing signal is called modulating signal
- The signal resulting from process of modulation is known as modulated signal


Modulating signal (Information)
Carrier (High-Frequency signal)
Modulated signal
Modulating signal (Information)
Carrier
Modulated signal
When man sits in car becomes modulated signal


E_m
t
(a) Modulating signal
(Electrical equivalent of
information)
E_c
0
t
(b) Carrier signal
(High frequency signal)
(E_c+E_m)
0
V_{max}
V_{min}
t
(c) Amplitude modulated signal


Modulation
Amplitude Modulation
(AM)
Angle Modulation
Frequency
Modulation
(FM)
Phase
Modulation
(PM)

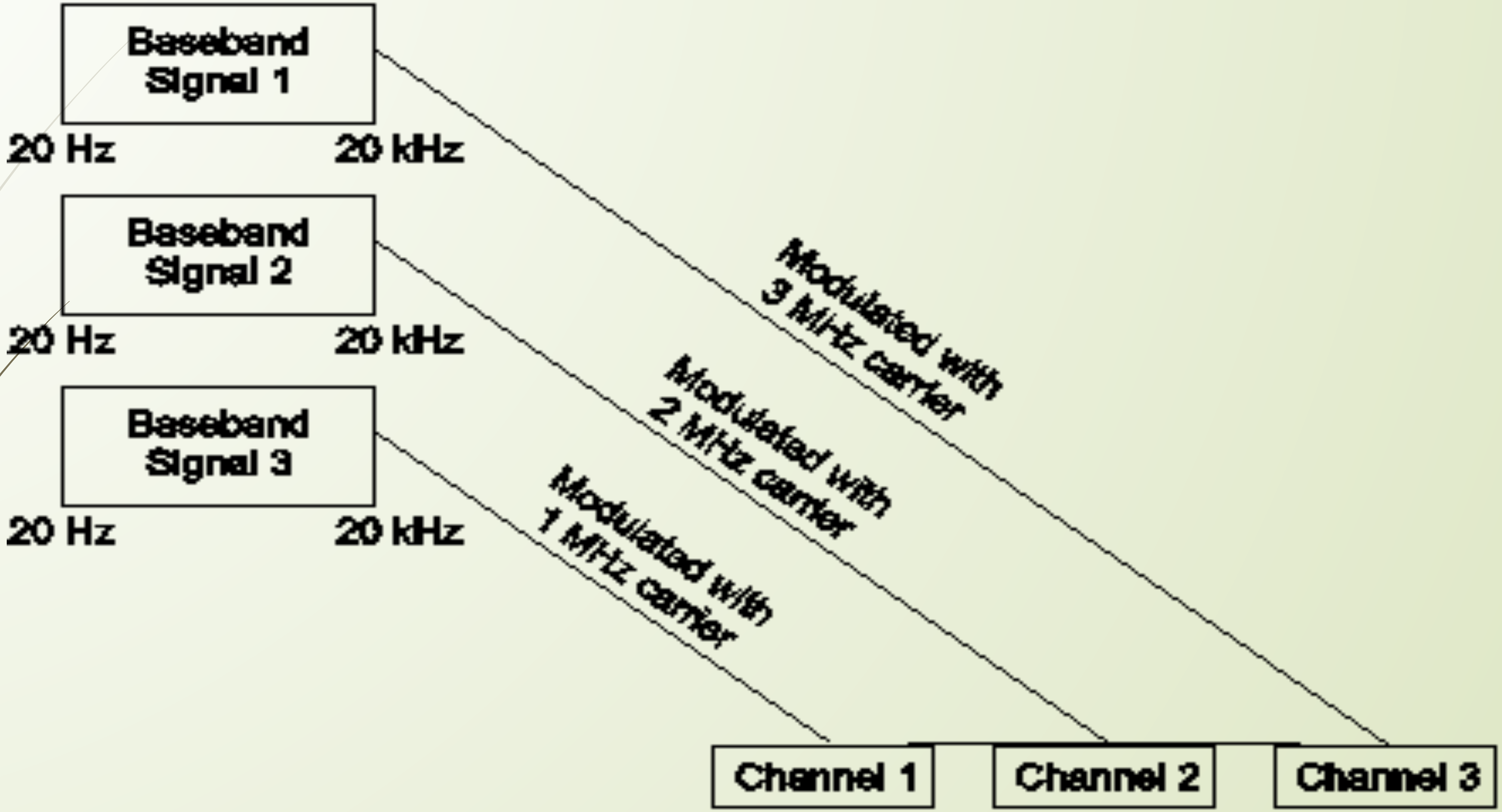
Need of Modulation

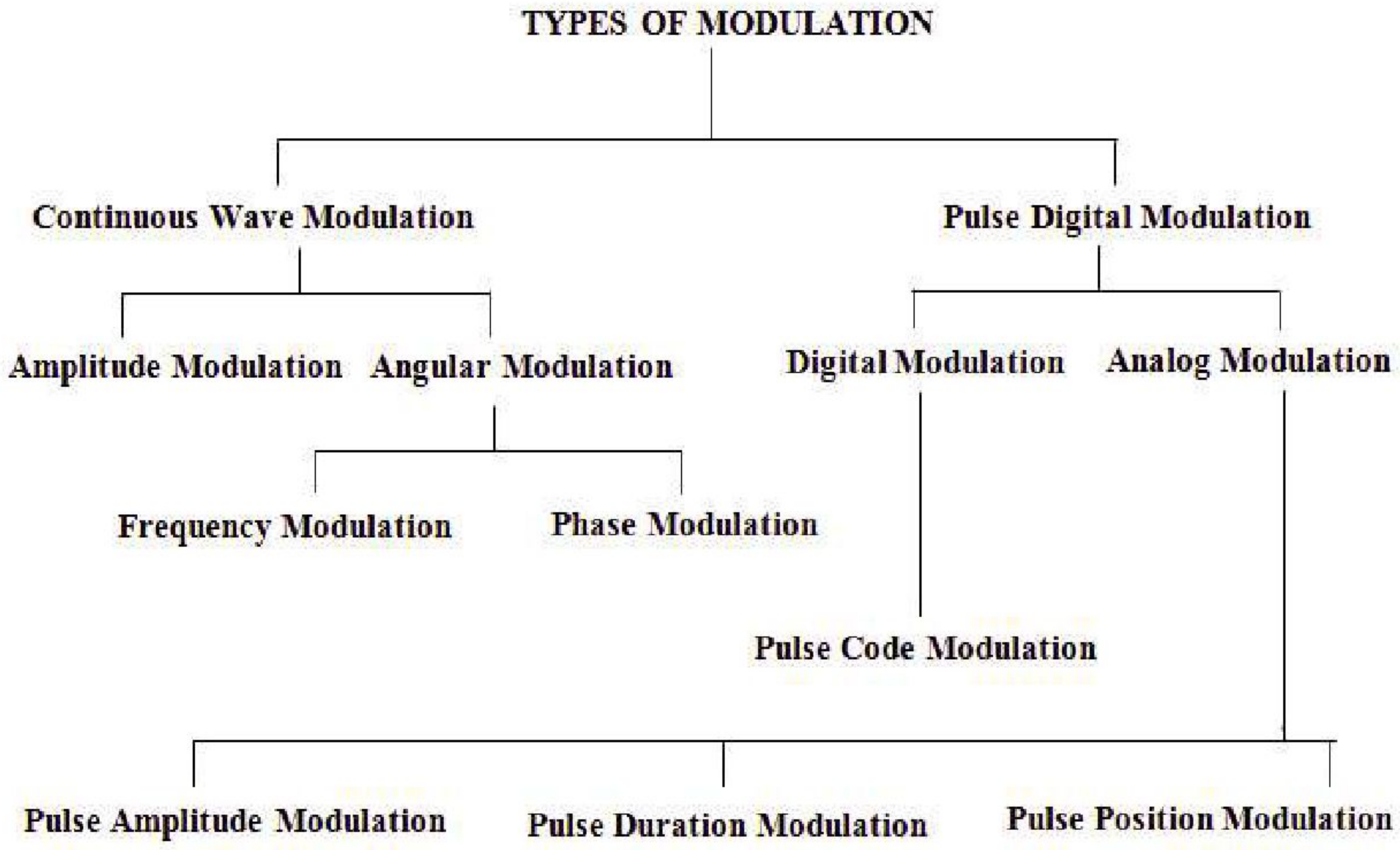
Baseband signal transmission cannot be used for radio communication. To transmit the baseband signal for radio communication, modulation must be used.

Modulation is necessary because of following advantages:

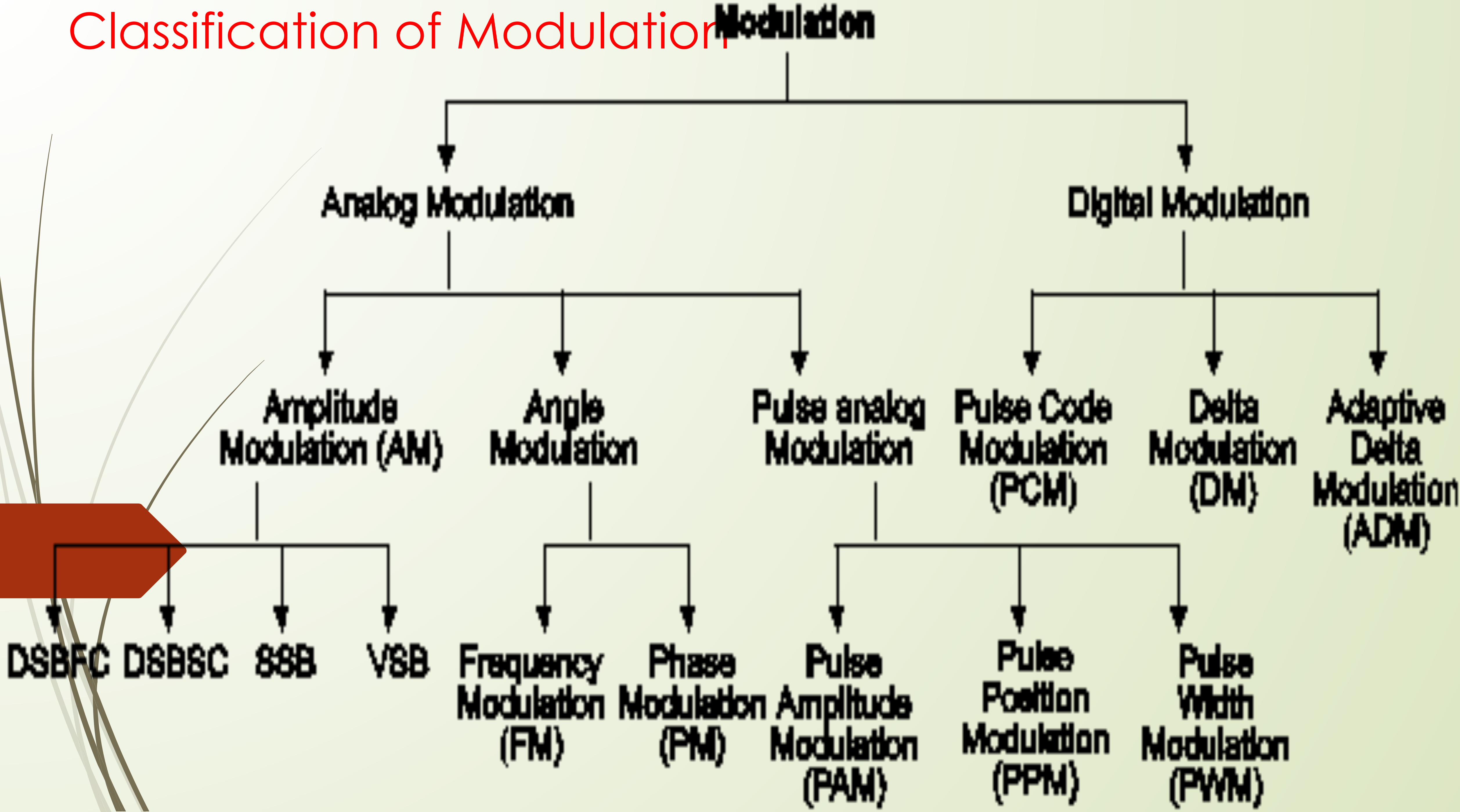
1. Reduction in height of antenna.
2. Avoids mixing of signals.
3. Increase the range of communication.
4. Multiplexing is possible.
5. Improves quality of reception

Avoids Mixing of Signal




TYPES OF MODULATION
Continuous Wave Modulation
Pulse Digital Modulation
Amplitude Modulation
Angular Modulation
Digital Modulation
Analog Modulation
Frequency Modulation
Phase Modulation
Pulse Code Modulation
Pulse Amplitude Modulation
Pulse Duration Modulation
Pulse Position Modulation

Classification of Modulation



Types AM, FM, PM Definition, Waveforms

Sr. No.	Parameter	AM	FM	PM
1.	Definition	Amplitude modulation is a technique of modulation, in which amplitude of carrier varies in accordance with amplitude of modulating signal. Keeping frequency and phase constant.	Frequency modulation is a technique of modulation, in which frequency of carrier varies in accordance with amplitude of modulating signal. Keeping amplitude and phase constant.	Phase modulation is a technique of modulation in which phase of carrier varies in accordance with amplitude of modulating signal. Keeping amplitude and frequency constant.
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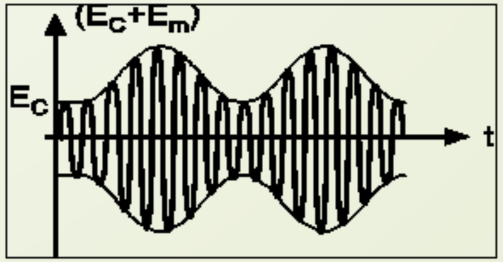
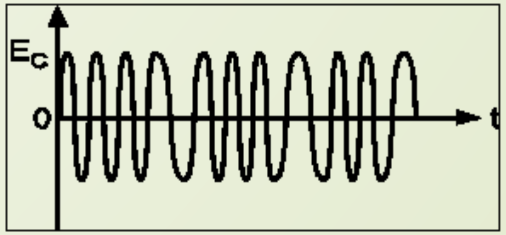
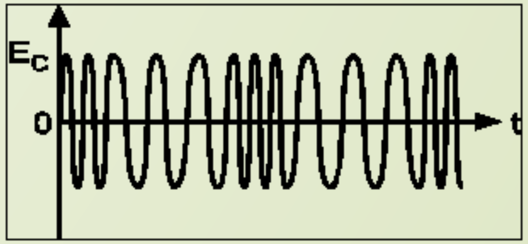
2.	Waveforms	 **Fig. 2.3**	 **Fig. 2.4**	 **Fig. 2.5**

Amplitude Modulation

Definition:

Amplitude modulation, is a technique of modulation in which the instantaneous amplitude of carrier signal varies in accordance with amplitude of modulating signal.

While **frequency** and **phase** of carrier **remains constant**. Nature of Amplitude Modulated waveform shown in Fig. below.

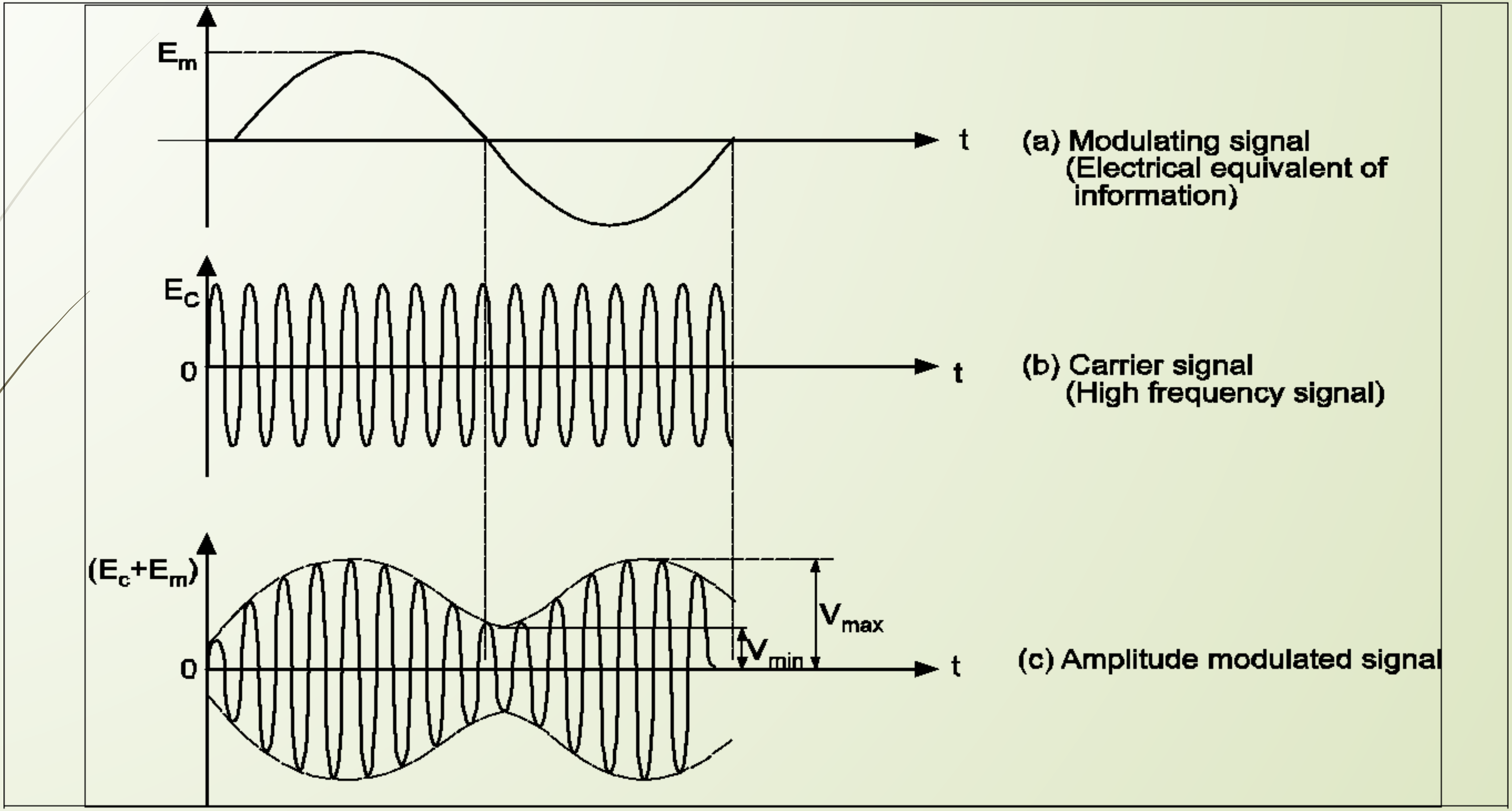
AMPLITUDE MODULATION

"Amplitude Modulation is the process of changing the amplitude of the radio frequency (RF) carrier wave by the amplitude variations of modulating signal"

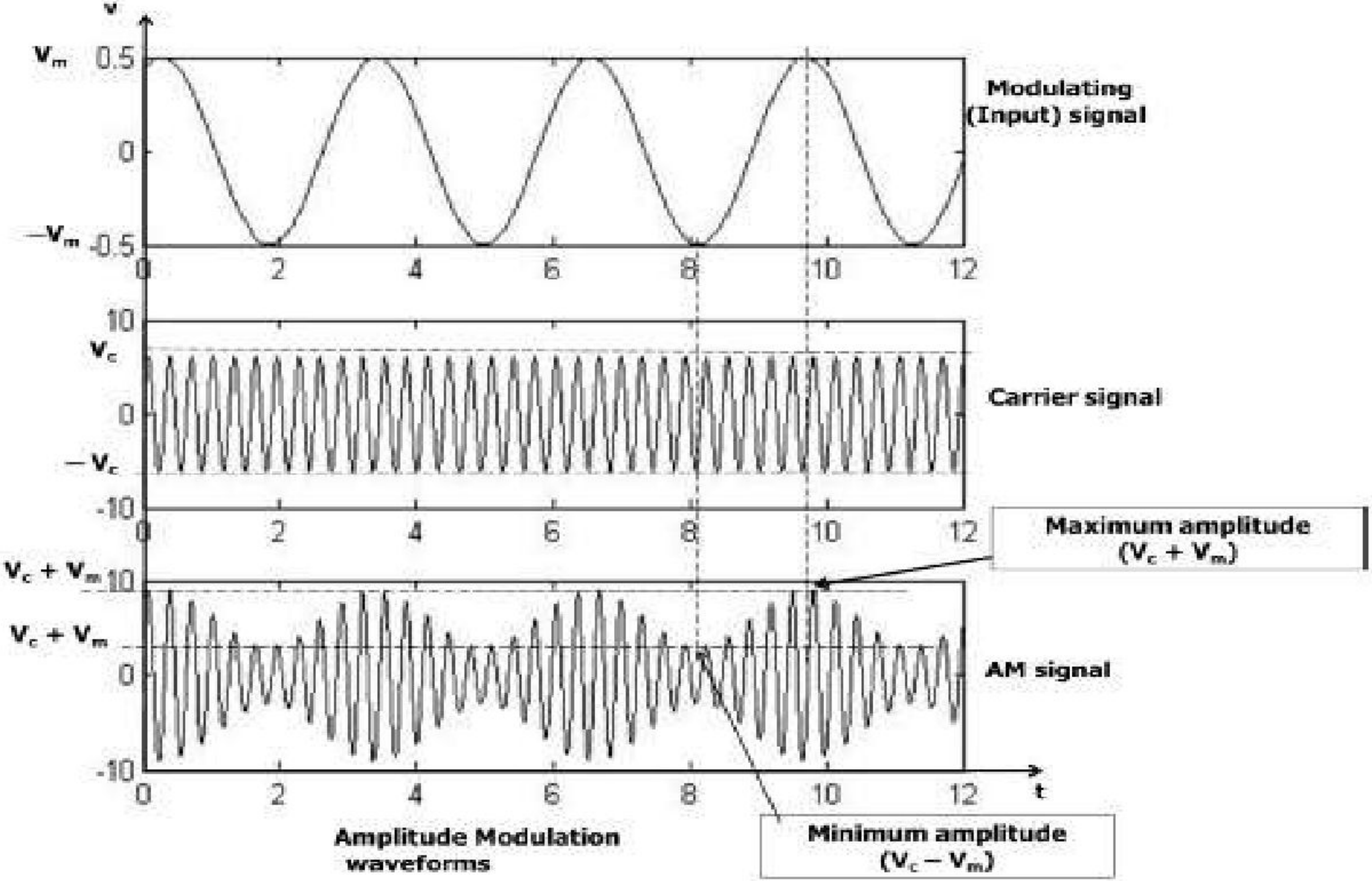
- The **carrier amplitude varied linearly** by the modulating signal which usually consist of a range of a audio frequencies. The frequency of the carrier is not affected

Application of AM	-	Radio broadcasting, TV pictures (video), facsimile transmission
Frequency range for AM		- 535 kHz – 1700 kHz
Bandwidth	-	10 kHz

Continued....



E_m
t
(a) Modulating signal
(Electrical equivalent of information)
E_c
0
t
(b) Carrier signal
(High frequency signal)
(E_c+E_m)
0
V_{max}
V_{min}
t
(c) Amplitude modulated signal


v
Vm
0.5
0
—Vm
-0.5
0
2
4
6
8
10
12
Modulating
(Input) signal
10
Vc
0
— Vc
-10
Carrier signal
Maximum amplitude
(Vc + Vm)
Vc + Vm
Vc + Vm
AM signal
t
Minimum amplitude
(Vc — Vm)
Amplitude Modulation
waveforms

Time domain representation of AM wave

Modulating signal = $e_m = V_m \text{ Sin } w_m t$ --------------------(1)

Carrier signal = $e_c = V_c \text{ Sin } w_c t$ --------------------(2)

Amplitude modulated signal = $e_{AM} = A \text{ Sin } w_c t$ --------------------(3)

Where $A = V_c + e_m$

$= V_c + (V_m \text{ Sin } w_m t)$ --(4)

By putting equation (4) into (3)

$$e_{AM} = A \text{ Sin } w_c t$$
$$e_{AM} = [V_c + (V_m \text{ Sin } w_m t)] \text{ Sin } w_c t$$
$$= V_c \text{ Sin } w_c t \,[1 + (V_m / V_c \text{ Sin } w_m t)]$$

$$e_{AM} = V_c \text{ Sin } w_c t \,[1 + m \text{ Sin } w_m t]$$

where $m = V_m / V_c$ [modulation index]

This is called time domain representation of AM wave

Modulation Index

Definition:

In AM, the modulation index (m) is defined as the ratio of amplitudes of modulating signal to the carrier signal.

$$\text{M.I.} = \frac{\text{Modulating Signal Amplitude}}{\text{Carrier Signal Amplitude}}$$

$$\boxed{m = \frac{E_m}{E_c}} \qquad \ldots (2.4)$$

If modulation index is expressed in percentage, it is called **'percentage modulation'.**

i.e.

$$\boxed{\%m = \frac{E_m}{E_c} \times 100} \qquad \ldots (2.5)$$

Referring to Fig. 2.6, the modulation index is

$$\boxed{m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}}$$

Effect of Modulation Index on Modulated Signal

1. For m < 1,

i.e. $E_m < E_c$

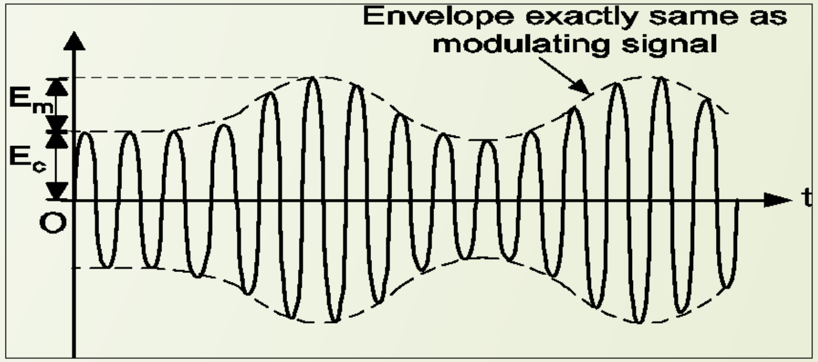


Fig. 2.9 (b) AM Wave for m < 1 (Under Modulation)

2. For m = 1

i.e. $E_m = E_c$. i.e. m = 100%.

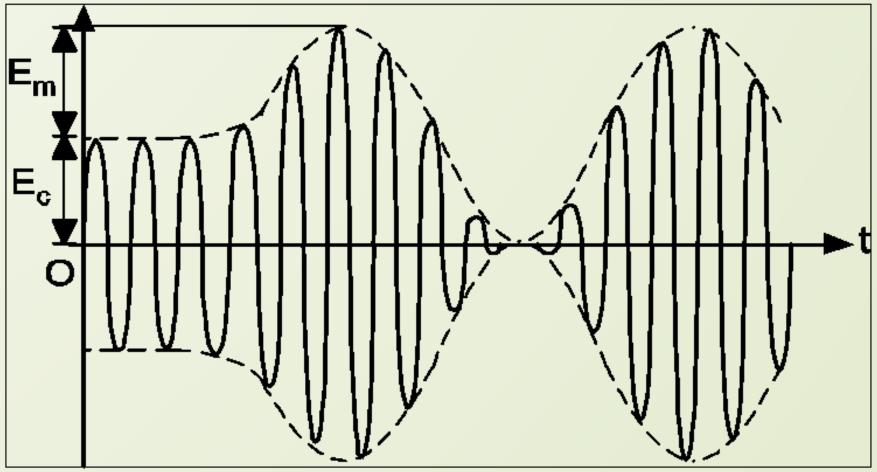


Fig. 2.9 (c) AM Wave for m = 1 (Fully Modulated)

Continued....

3. For m > 1

i.e. $E_m > E_c$

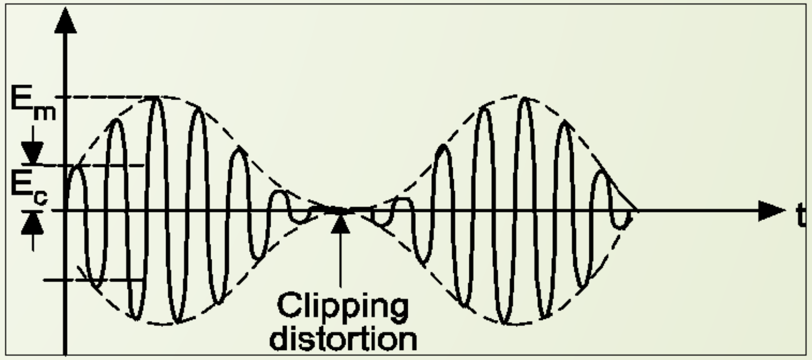


Fig. 2.9 (d) AM Wave at m > 1 (Over Modulation)

For m = 0

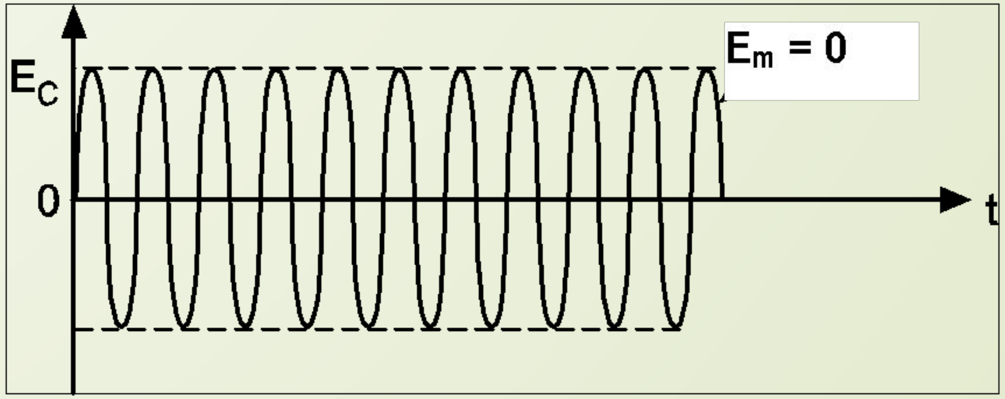
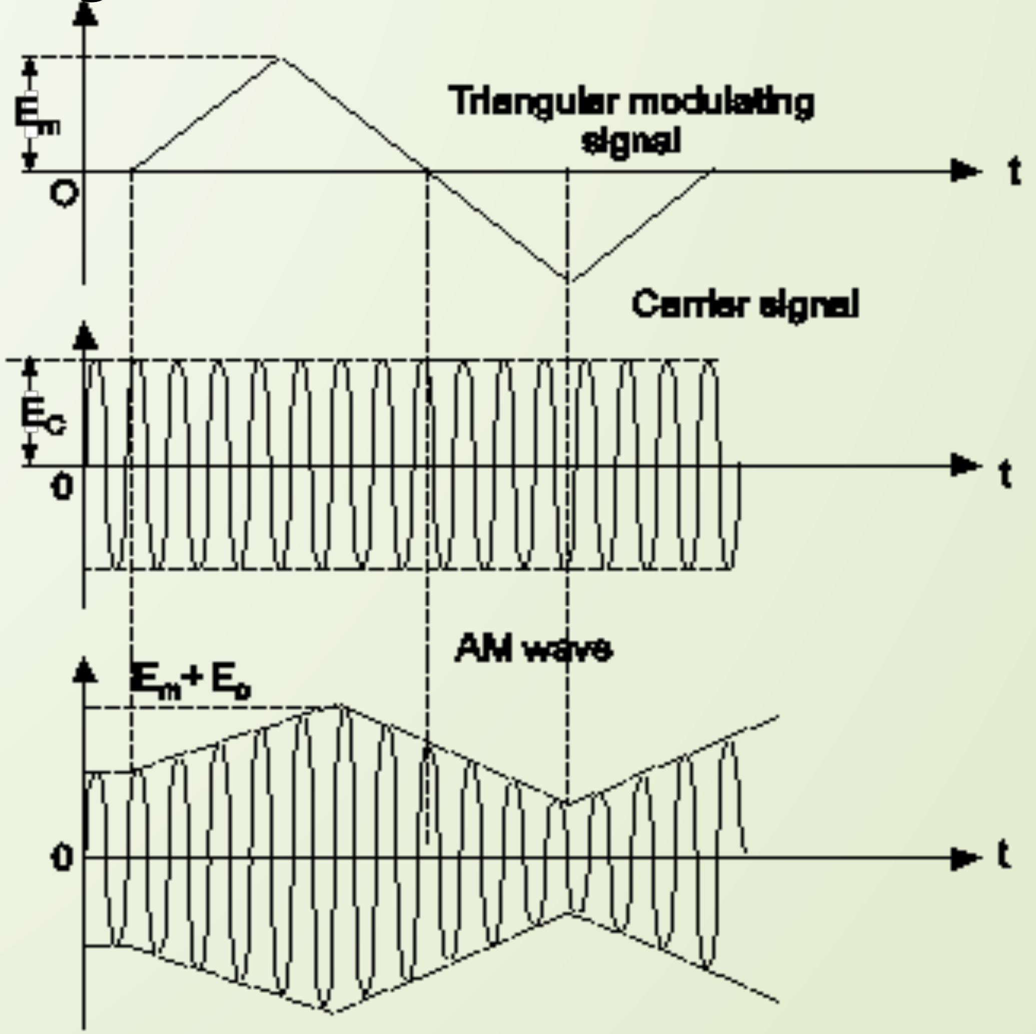


Fig. 2.9 (e) AM Wave at m = 0 (No Modulation Takes Place)

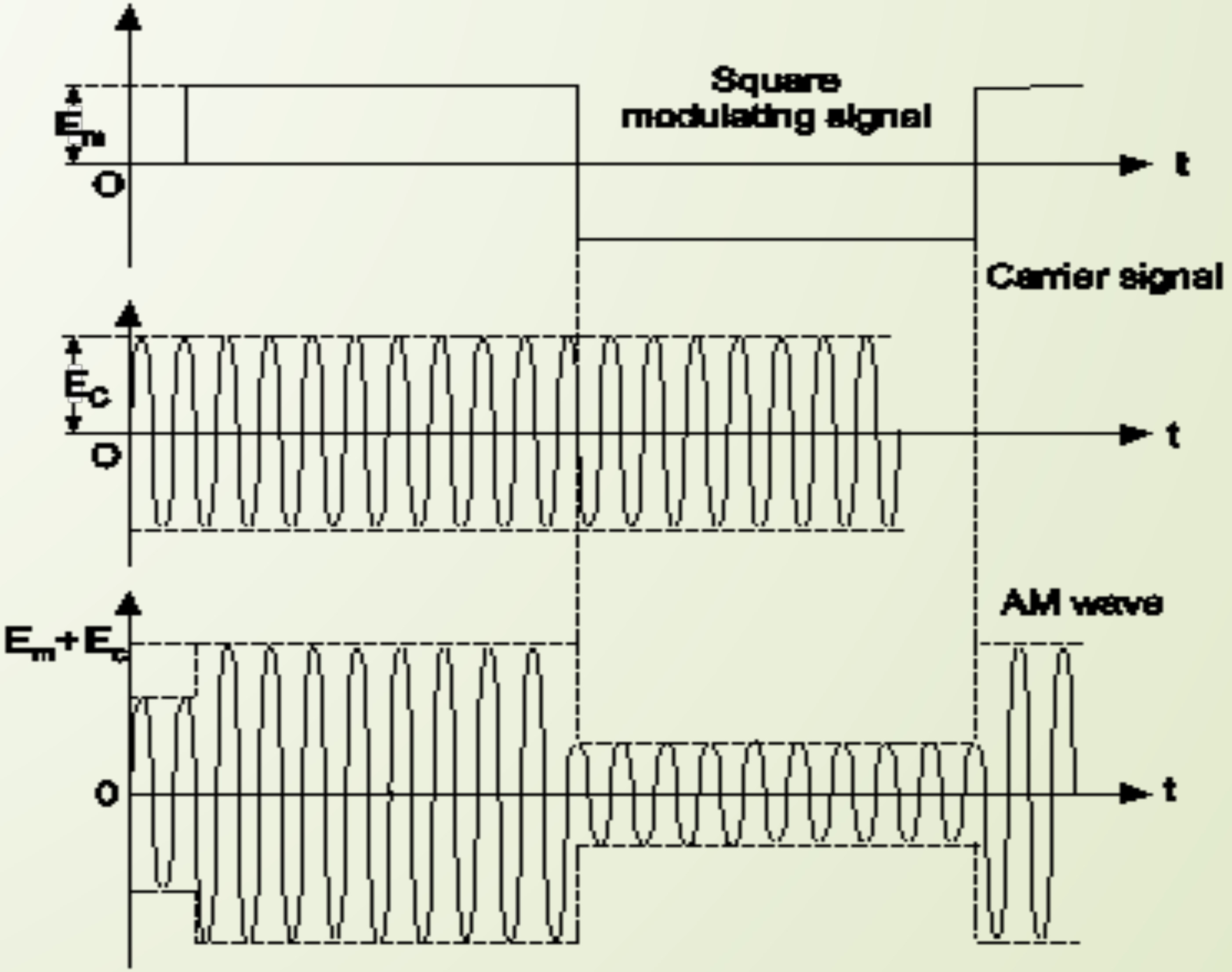
Example

Draw the AM wave for triangular and square wave modulating signal.

Solution:

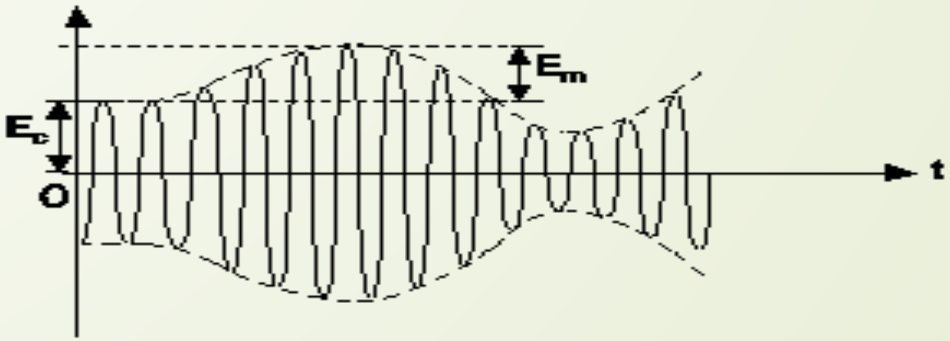


For square wave input.



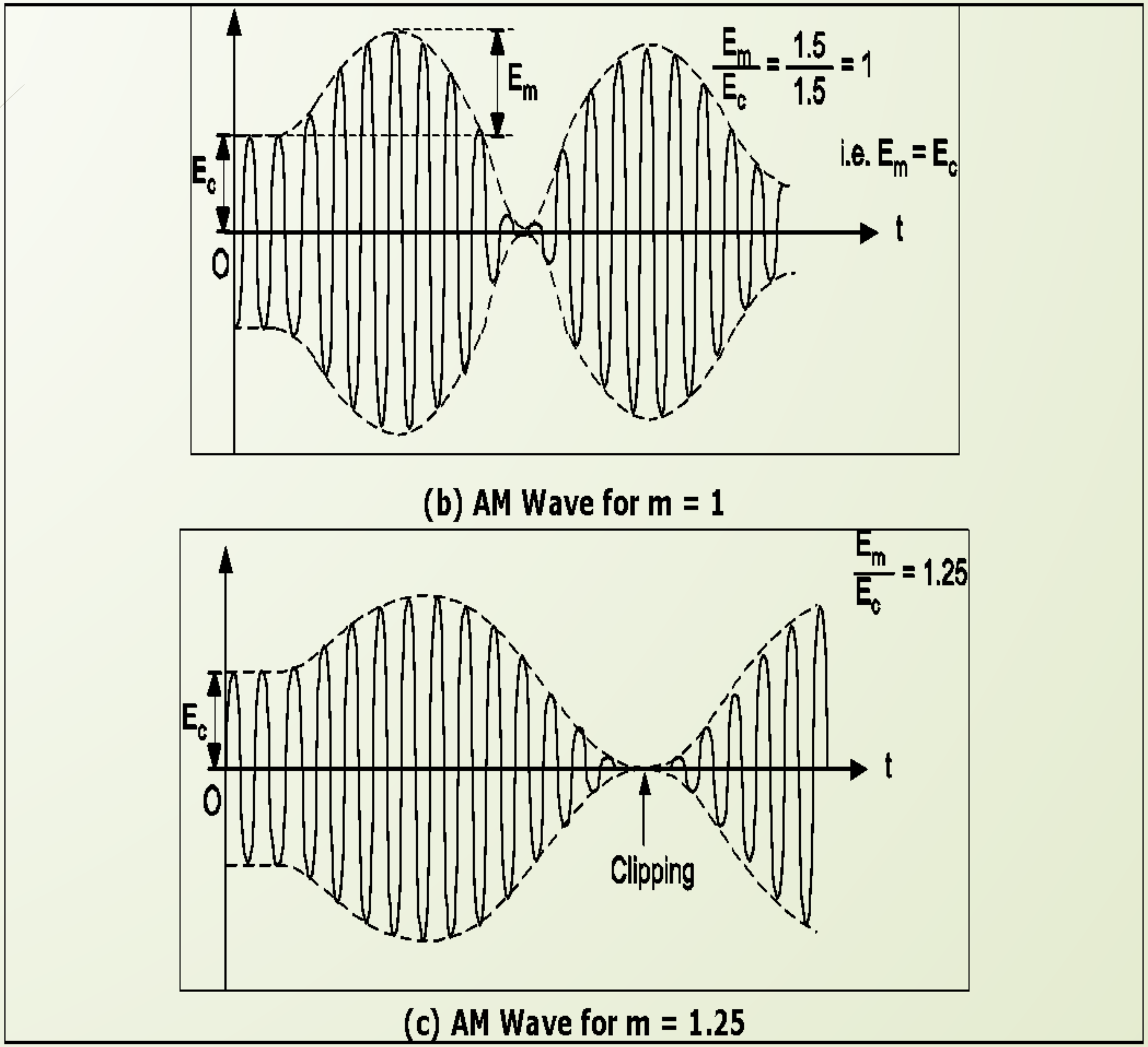
Example 2 Draw the AM waveform for the modulation index m = 0.75, m = 1 and m = 1.25.

Take a graph paper and adjust the value of E_m and E_C in such a way that $\frac{E_m}{E_c} = 0.75$, $\frac{E_m}{E_c} = 1$, $\frac{E_m}{E_c} = 1.25$.



(a) AM wave for m = 0.75

Continued...



$\frac{E_m}{E_c} = \frac{1.5}{1.5} = 1$
i.e. $E_m = E_c$
E_m
E_c
O
t
(b) AM Wave for m = 1
$\frac{E_m}{E_c} = 1.25$
E_c
O
t
Clipping
(c) AM Wave for m = 1.25

Frequency Spectrum

Representation of AM wave in frequency domain is also known as **frequency spectrum of AM wave.**

Definition:

Frequency spectrum is a graph of amplitude versus frequency.

The frequency spectrum of **AM wave tells us about number of sidebands present in AM wave with corresponding amplitudes.**

- Consider equation of AM wave (equation 2.12).

$$e_{AM} = (E_C + E_m \sin \omega_m t) \sin \omega_c t \qquad \text{... (2.12)}$$

$$e_{AM} = E_C \left(1 + \frac{E_m}{E_c} \sin \omega_m t\right) \sin \omega_c t$$

But, $$m = \frac{E_m}{E_c}$$

$\therefore$ $$e_{AM} = E_C(1 + m \sin \omega_m t) \sin \omega_c t \qquad \text{... (2.13)}$$

Simplifying we get,

$$e_{AM} = E_C \sin \omega_c t + mE_C \sin \omega_m t \sin \omega_c t \qquad \text{... (2.14)}$$

There is a trigonometric identity that says that the product of two sin waves is

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

By substituting this identify into equation becomes

$$e_{AM} = \underbrace{E_C \sin \omega_c t}_{\text{Carrier}} + \underbrace{\frac{mE_C}{2} \cos (\omega_c - \omega_m) t}_{\text{LSB}} - \underbrace{\frac{mE_C}{2} \cos (\omega_c + \omega_m) t}_{\text{USB}} \qquad \text{... (2.15)}$$

Features of Frequency spectrum

From equation (2.15) of AM wave, it consists of three terms:

(i) The first term is sine term called unmodulated **carrier signal.**

(ii) The second term is cos term at frequency ($f_c - f_m$) called Lower Side Band (LSB) with amplitude $\frac{mE_C}{2}$. (□ $w_c = 2\pi f_c$ and $w_m = 2\pi f_m$).

(iii) The third term is cos term at frequency ($f_c + f_m$) called **upper sideband (USB)** with amplitude $\frac{mE_C}{2}$.

- **This shows that AM wave, having two sidebands which contains actual information and one carrier.**
- From equation 2.15, plot of frequency spectrum shown in Fig. 2.13 (a).

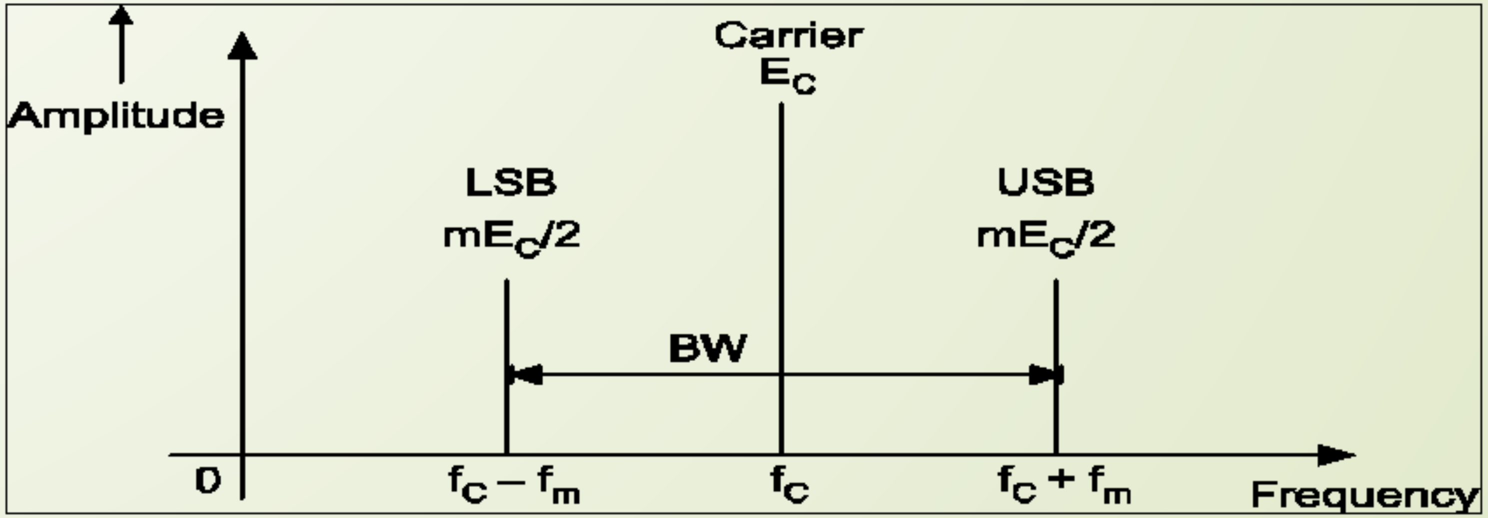


Fig. 2.13 (a): Frequency Spectrum of AM Wave

Bandwidth Requirement

The bandwidth of AM signal is defined as the frequency range from upper sideband to lower sideband frequency in frequency spectrum.

$$BW = f_{USB} - f_{LSB}$$

$$= (f_c + f_m) - (f_c - f_m) \quad \ldots \text{(from Fig. 2.13)}$$

$$= f_c + f_m - f_c + f_m$$

$$= \mathbf{2\,f_m}$$

$\therefore \quad \rightarrow$ BW required for AM signal.

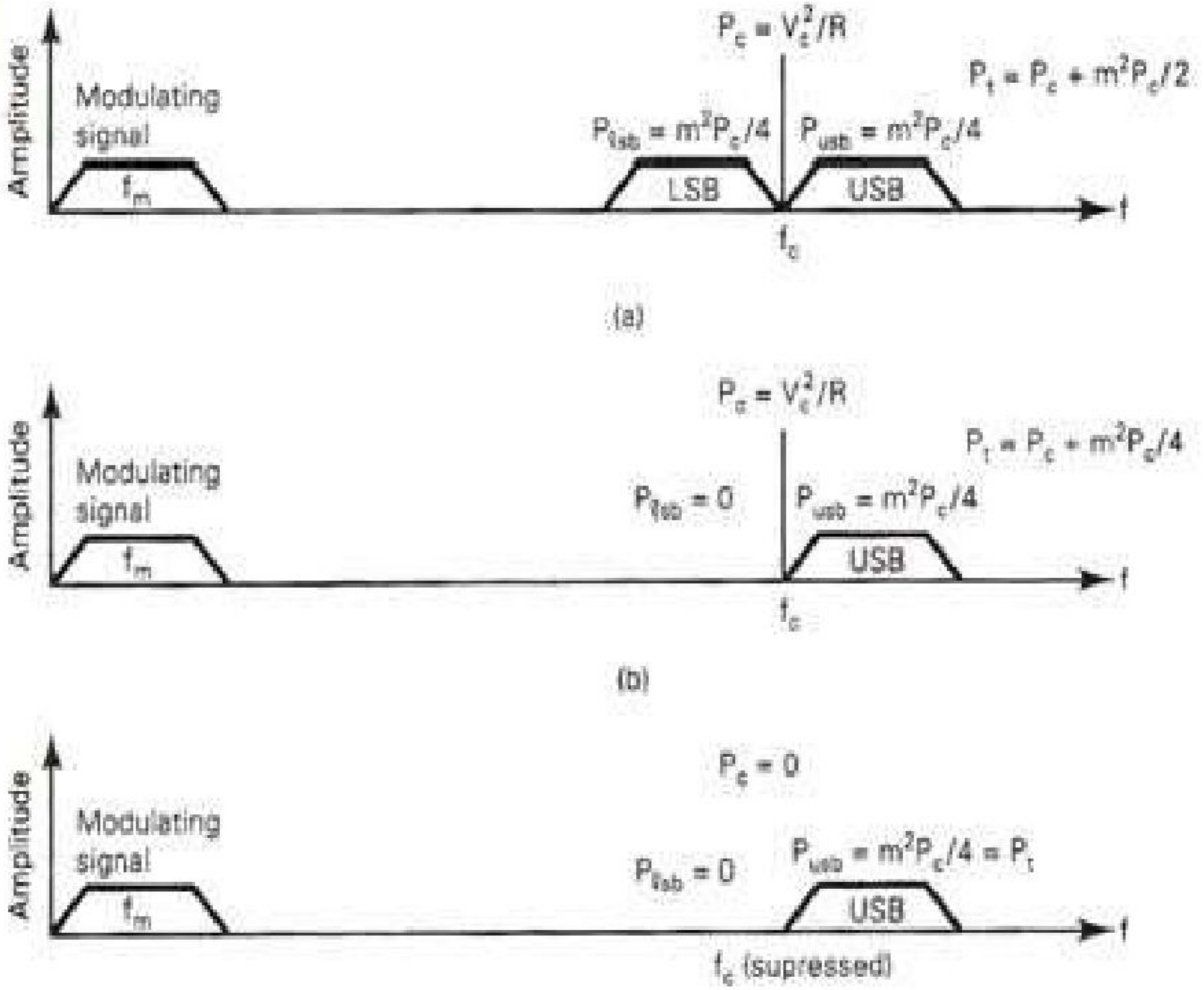
Hence, bandwidth of AM signal is twice the modulating signal frequency.

Types of Amplitude Modulation

- There are several different ways of amplitude modulation:

1. Double-sideband suppressed carrier (DSB-SC) modulation.
2. Amplitude modulation (AM).
3. Single-sideband modulation (SSB).
4. Vestigial-sideband modulation (VSB).

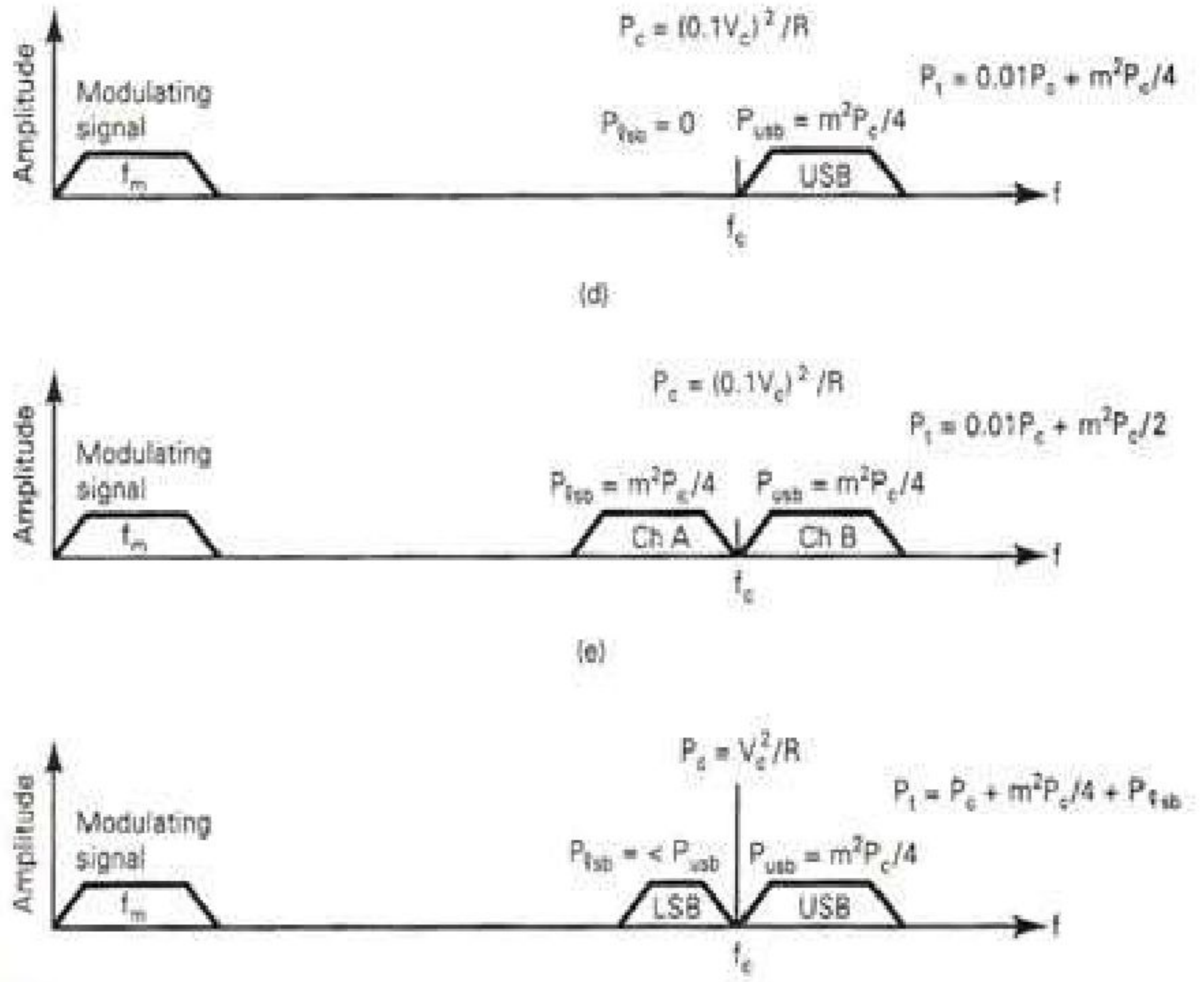
- Each of these schemes has its own distinct advantages, disadvantages, and practical applications.



DSBFC

SSBFC

SSBSC



SSBRC

ISBRC

VSBFC

Power Relations in AM Wave

(i) The Total Power in AM (P_t):

$$P_t = (\text{Carrier Power}) + (\text{Power in USB}) + (\text{Power in LSB})$$

$$P_t = P_c + P_{USB} + P_{LSB} \quad \ldots(2.16)$$

$$\therefore \quad P_t = \frac{E_{carr}^2}{R} + \frac{E_{USB}^2}{R} + \frac{E_{LSB}^2}{R}$$

where, $E_{carr}, E_{USB}, E_{LSB}$ = r.m.s. values of the carrier and side band amplitudes

R = Characteristic resistance of antenna in which total power is dissipated.

(ii) Carrier Power (P_c):

The carrier power is given by,

$$P_c = \frac{E_{carr}^2}{R}$$

$$= \frac{(E_c/\sqrt{2})^2}{R}$$

$$\boxed{P_c = \frac{E_c^2}{2R}} \quad \ldots(2.17)$$

where, E_c = Peak carrier amplitude

(iii) Power in sidebands:

The power in USB and LSB is same as,

$$P_{USB} = P_{LSB} = \frac{E_{SB}^2}{R}$$

From equation (2.15),

$$\text{Peak amplitude of sideband} = \frac{mE_c}{2}$$

$$\therefore \quad P_{USB} = P_{LSB} = \frac{(mE_c/2\sqrt{2})^2}{R}$$

$$= \frac{m^2E_c^2}{8R}$$

$$\therefore \quad P_{USB} = P_{LSB} = \frac{m^2}{4} \times \frac{E_c^2}{2R}$$

From equation (2.17),

$$\frac{E_c^2}{2R} = P_c$$

$$\therefore \quad \boxed{P_{USB} = P_{LSB} = \frac{m^2}{4} P_c}$$

(iv) Total Power in AM:

From equation (2.16),

The total power in AM wave is,

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

$$= P_c + \frac{m^2}{4} P_c + \frac{m^2}{4} P_c$$

$$\therefore \quad \boxed{P_t = \left(1 + \frac{m^2}{2}\right) P_c} \qquad \text{...(2.19)}$$

From this equation, we can say that as value of 'm' increases, total power also increases.

For m = 1, total power will be maximum. (i.e. for unity M.I.)

$$\therefore \quad \boxed{P_t = 1.5\ P_c}$$

AM Power Distribution

Carrier power :

$$P_c = \frac{V_c^2}{2R}$$

Sideband power:

$$P_{SB} = P_{USB} = P_{LSB} = \frac{m_a^2 P_c}{4}$$

$$P_{SB} = P_{USB} + P_{LSB} = \frac{m_a^2 P_c}{2}$$

The total transmitted power in AM is the sum of the carrier power and the power in the sidebands.

$$\begin{aligned} P_{total} &= P_c + P_{USB} + p_{LSB} \\ &= P_c + P_{SB} \\ &= P_c\left(1 + \frac{m_a^2}{2}\right) \end{aligned}$$

%Power saving in DSB-SC

$P_t = (1+m^2/2)\ P_c$

$= 1.5\ P_c$

$P_{USB} = P_{LSB} = 0.25\ P_c$

$P_{SB} = (P_{USB} + P_{LSB}) = 0.5\ P_c$

Percentage Power saving $= (P_t - P_{SB}) / P_t \quad * 100$

$= (1.5 - 0.5)\ P_c / 1.5\ P_c \quad * 100$

$= 66.66\ \%$

SSBSC Power Saving in %

$$P_t = P_c\left(1 + \frac{m^2}{2}\right) = P_c\left(1 + \frac{1^2}{2}\right) = 1.5\ P_c$$

$$P_{SB} = P_c\frac{m^2}{4} = P_c\frac{1^2}{4} = 0.25\ P_c$$

$$\text{Percentage Saving} = \frac{1.5 - 0.25}{1.5} = \frac{1.25}{1.5} = 0.833 = 83.3\%$$

Example 1:

A modulating signal 20 sin $(2\pi \times 10^3 t)$ is used to modulate a carrier signal 40 sin $(2\pi \times 10^4 t)$. Find:

(a) Modulation index

(b) Percentage modulation

(c) Sideband frequencies and their amplitude

(d) Bandwidth of AM wave

(e) Draw the frequency spectrum.

Solution:

Given: Modulating signal,

$$e_m = 20 \sin (2\pi \times 10^3 t) \quad \dots (1)$$

$$e_m = E_m \sin (2\pi f_m t) \quad \dots (2)$$

$\therefore$ Compare equation (1) and (2), we get

$$E_m = 20 \text{ V}$$

$$f_m = 10^3 \text{ Hz} = 1 \text{ kHz}$$

Similarly, carrier signal

$$e_c = 40 \sin (2\pi \times 10^4 t) \quad \dots (3)$$

But, $e_c = E_c \sin (2\pi f_c t) \quad \dots (4)$

Compare equation (3) and (4), we get,

$$E_c = 40 \text{ v}$$

$$f_c = 10^4 \text{Hz} = 100 \text{ kHz}$$

(a) Modulation Index:

$$m = \quad = \quad = 0.5$$

(b) Percentage modulation:

$$\% \text{ modulation} = m \times 100$$

$$= 0.5 \times 100$$

$$= 50\%$$

(c) Sideband frequencies and their amplitude:

$$LSB = F_{LSB} = f_c - f_m$$
$$= 100\ kHz - 1\ kHz$$
$$= 99\ kHz$$

$$USB = F_{USB} = f_c + f_m$$
$$= 100\ k + 1\ kHz$$
$$= 101\ kHz$$

LSB amplitude = USB amplitude

$$= \quad = 0.5 \times$$
$$= 10\ V$$

(d) Bandwidth of AM

$$BW = 2 \times f_m$$
$$= 2 \times 1\ kHz$$

Examples based on equations

1) For an AM, amplitude of modulating signal is 0.5 V and Carrier amplitude is 1V. Find Modulation Index.

2) When the modulation percentage is 75%, an AM transmitter radiates 10KW Power. How much of this is carrier Power?

3) The total Power content of an AM signal is 1000W. Determine the power being transmitted at carrier frequency and at each side band when modulation percentage is 100%.

4) A500W, 100 KHz carrier is modulated to a depth of 60% by modulating frequency of 1KHz. Calculate the total power transmitted. What are the sideband components of AM Wave?

5) A400W, 1MHz carrier is amplitude-modulated with a sinusoidal signal 0f 2500Hz. The depth of modulation is 75%. Calculate the sideband frequencies, bandwidth, and power in sidebands and the total power in modulated wave.

1) A Carrier of 750 W,1MHz is amplitude modulated by sinusoidal signal of 2 KHz to a depth of 50%. Calculate Bandwidth, Power in side band and total power transmitted.

2) A modulating signal $m(t)=10\cos(2\pi\times10^3t)$m(t)=10cos(2π×103t) is amplitude modulated with a carrier signal $c(t)=50\cos(2\pi\times10^5t)$c(t)=50cos(2π×105t). Find the modulation index, the carrier power, and the power required for transmitting AM wave.

3) Calculate the percentage power saving when one side band and carrier is suppressed in an AM signal with modulation index equal to 1.

4) Calculate the percentage power saving when one side band and carrier is suppressed in an AM signal if percentage of modulation is 50%.

5) A Sinusoidal carrier frequency of 1.2MHz is amplitude modulated by a sinusoidal voltage of frequency 20KHz resulting in maximum and minimum modulated carrier amplitude of 110V & 90V respectively.
Calculate

1) A Sinusoidal carrier frequency of 1.2MHz is amplitude modulated by a sinusoidal voltage of frequency 20KHz resulting in maximum and minimum modulated carrier amplitude of 110V & 90V respectively.

   Calculate

   I. frequency of lower and upper side bands

   II. unmodulated carrier amplitude

   III. Modulation index IV. Amplitude of each side band.

2) An audio frequency signal 10 sin($2\pi\times500t$) is used to amplitude modulate a carrier of 50 sin($2\pi\times105t$).

   Calculate

   I. Frequency of side bands

   II. Bandwidth

   III. Modulation index

   IV. Amplitude of each side band.

   V. Transmission efficiency

   VI. Total power delivered to a load of 600Ω.

Current Analysis

- Measuring output voltage may not be very practical
- $P = Vp^2/2R$ is difficult to measure in an antenna!
- However, measuring the current passing through an antenna may be more possible: Total Power is $P_T = I_T^2R$

$$\frac{P_t}{P_c} = \frac{I_t^2 R}{I_c^2 R} = \frac{I_t^2}{I_c^2} = 1 + \frac{m^2}{2}$$

$$\frac{I_t}{I_c} = \sqrt{1 + \frac{m^2}{2}}$$

$$I_t = I_c\sqrt{1 + \frac{m^2}{2}}$$

Note that we can obtain m if we measure currents!

Multiple Input Frequencies

- What if the modulating signal has multiple frequencies?

$$v_{am}(t) = \sin(2\pi f_c t) + \frac{1}{2}\cos[2\pi(f_c - f_{m1})t] - \frac{1}{2}\cos[2\pi(f_c + f_{m1})t]$$
$$+ \frac{1}{2}\cos[2\pi(f_c - f_{m2})t] - \frac{1}{2}\cos[2\pi(f_c + f_{m2})t]$$

- In this case:

$$m_t = \sqrt{m_1^2 + m_2^2 + m_3^2 + m_n^2}$$

- All other power measurements will be the same!

Differentiate between DSBFC , DSBSC,SSBSC and VSB

Parameter of Comparison	DSBFC	DSBSC	SSB	VSB
Carrier Suppression	NA	Fully	Fully	NA
Sideband Suppression	NA	NA	One SB completely	One SB suppressed partially
Bandwidth	$2f_m$	$2f_m$	f_m	f_m < BW > $2f_m$
Transmission efficiency	Minimum	Moderate	Maximum	Moderate
Number of modulating inputs	1	1	1	2
Applications	Radio broadcasting	Radio broadcasting	Point to point mobile communication	TV

Comparison of conventional AM, DSB-SC, SSB and VSB.

- Conventional AM: simple to modulate and to demodulate, but low power efficiency (50% max) and double the bandwidth
- DSB-SC: high power efficiency, more complex to modulate & demodulate, double the bandwidth
- SSB: high power efficiency, the same (message) bandwidth, more difficult to modulate & demodulate.
- VSB: lower power efficiency & larger bandwidth but easier to implement.

Why SSB?

- Shortage of AM and DSB signals is basic information is transmitted TWICE (2X).
  - ☹Once in each sideband
  - ☹Both sideband have identical information
  - ☹No solid reason to transmit both!!
- One sideband may be suppressed, the remaining sideband is SSB signal.
- Bandwidth SSB signal, $BW_{SSB} = f_{m(max)}$

- **DSB-SC and SSB-SC Amplitude Modulation –**
- In AM, information is contained in two side bands and not in carrier. Hence most of the energy is wasted.
- In suppressed carrier system, carrier is not transmitted but only sidebands are transmitted, thus saving lot of transmitter power.

AM Transmitter

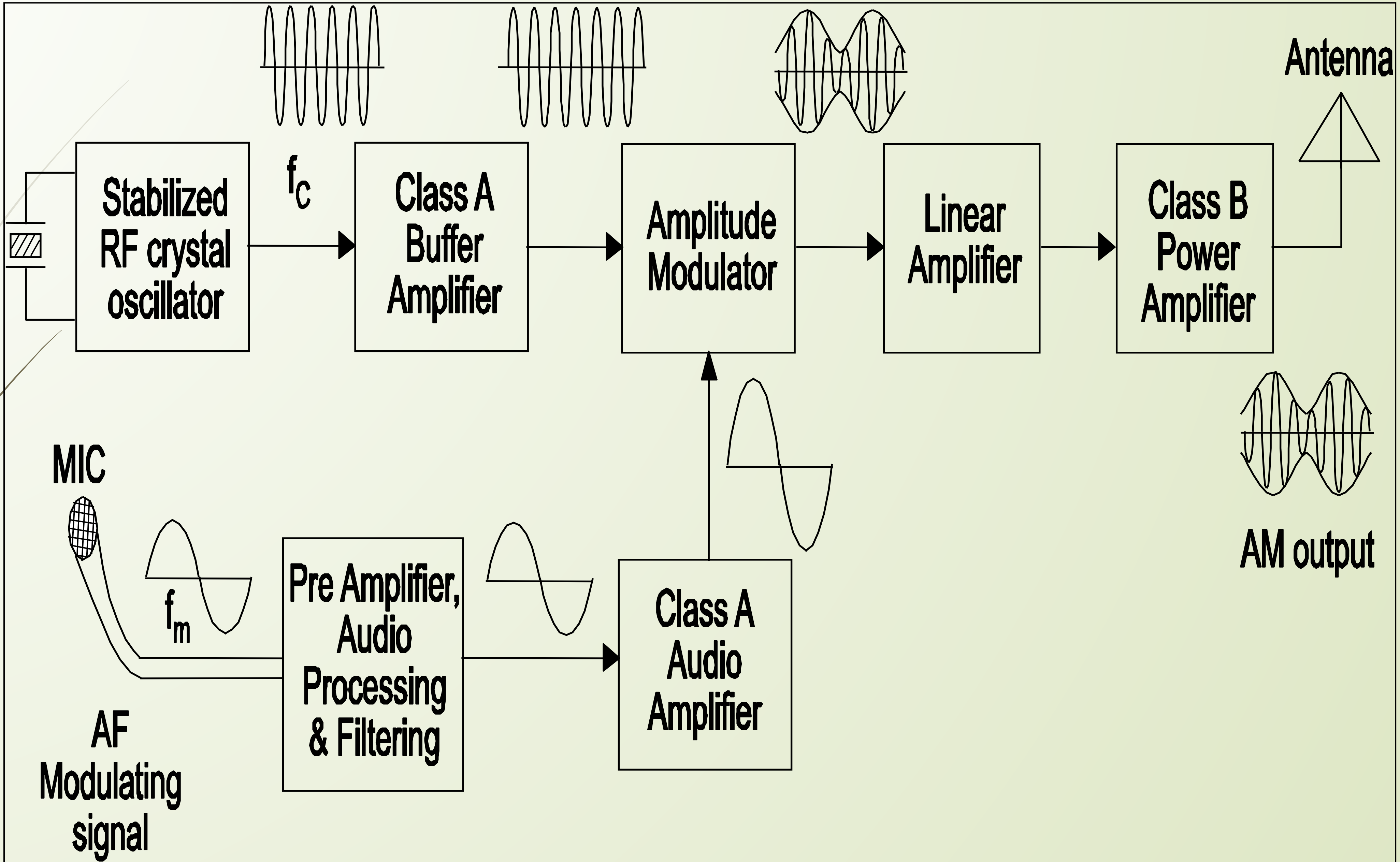
The functions of transmitter are:

1. To convert original information into electrical signal.
2. To amplify the weak signal.
3. To modulate the signal.
4. To increase the power level of modulated signal.
5. To transmit the signal through transmitting antenna.

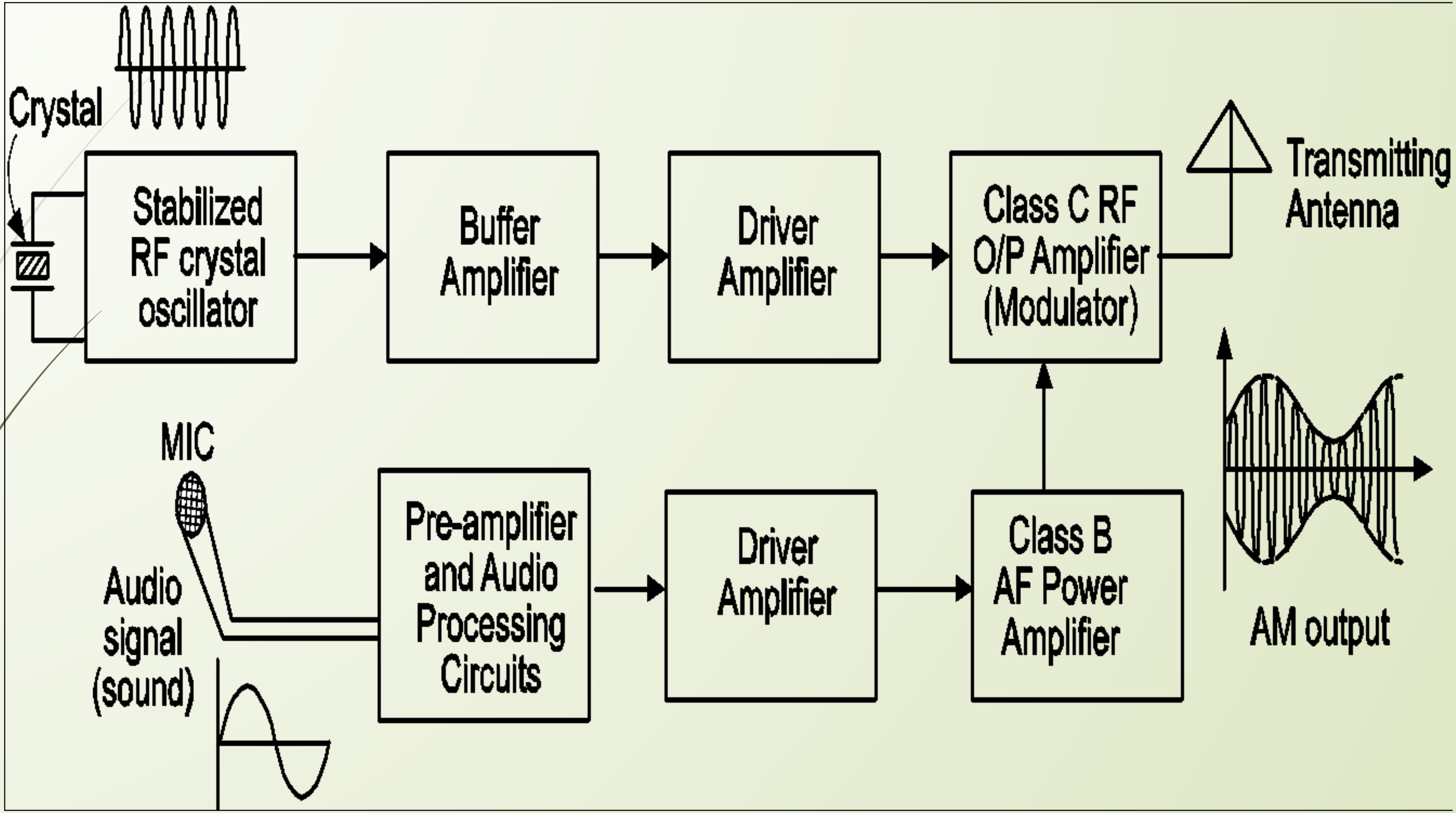
The AM transmitters are of two types:

1. Low level modulated transmitter.
2. High level modulated transmitter.

Low Level Modulated AM Transmitter



High Level Modulated AM Transmitter

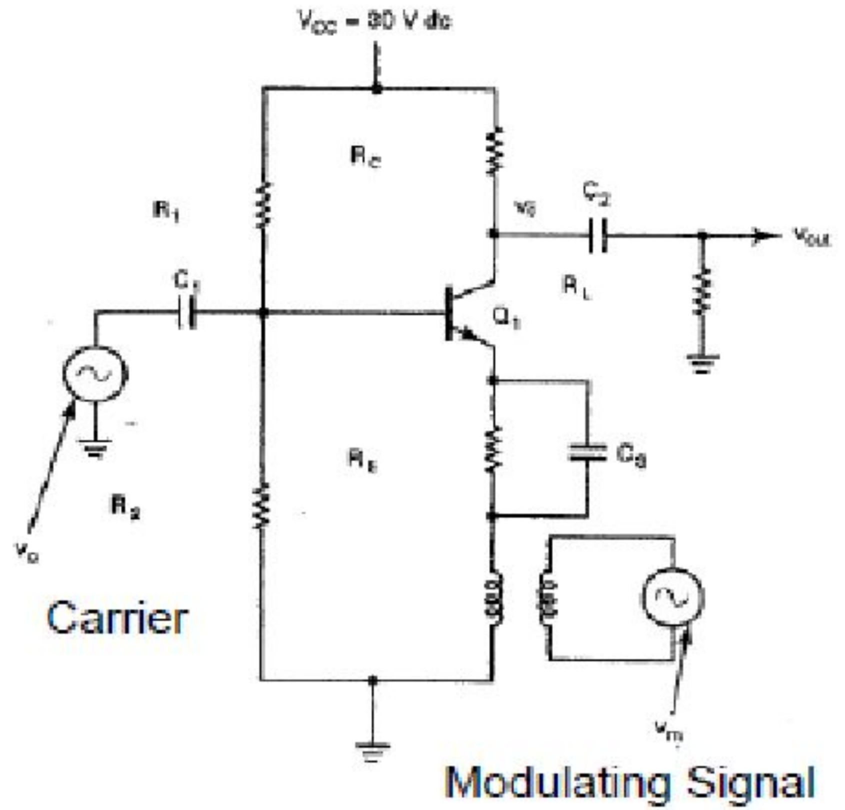


Comparison between High Level and Low Level Modulation

Sr. No.	High Level Modulation	Low Level Modulation
1.	Modulation takes place at high power level.	Modulation takes place at low power level.
2.	Class-C amplifier are used which are highly efficient.	After modulation linear amplifiers (Class A, AB or B) are used.
3.	Very high efficiency.	Low efficiency than high level modulation.
4.	Complex because of very high power.	Easy because of low power.
5.	Used in high power broadcast transmitters.	Used in TV transmitters (IF modulation method). In laboratory equipments, walkie-talkies etc.

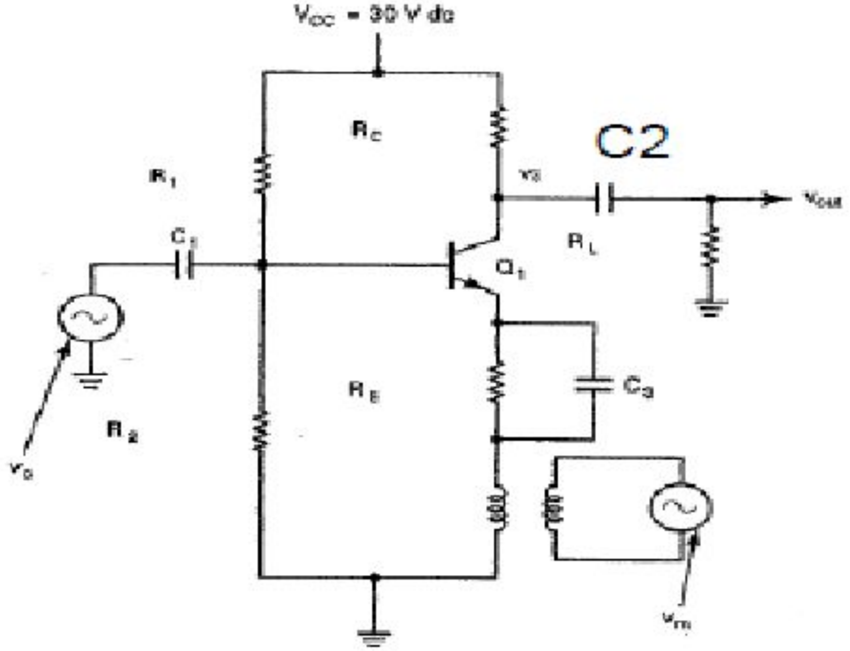
Low-Level AM Modulators

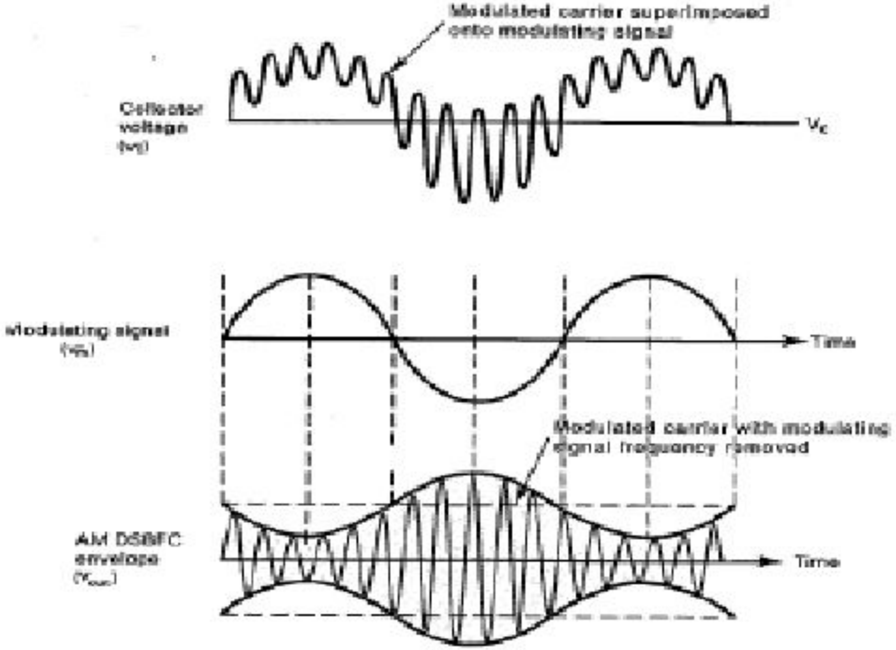
- Requires less modulating signal power to achieve high *m*
- Mainly for low-power applications
- Uses an Emitter Modulator (low power)
  - Incapable of providing high-power
- The amplifier has two inputs: *Vc(t)* and *Vm(t)*
- The amplifier operates in both linear and nonlinear modes



Low-Level AM Modulators – Circuit Operation

- If Vm(t) =0 → amplifier will be in **linear** mode
  - → $A_{out}=V_c\cos(w_c t)$; Vc is voltage gain (unit less)
- If Vm(t) >0 → amplifier will be in **nonlinear** mode
  - → $A_{out}=[V_c + V_m\cos(w_c t)]\cos(w_c t)$
- Vm(t) is isolated using T1
  - The value of Vm(t) results in Q1 to go into cutoff or saturation modes
- C2 is used for coupling
  - Removes modulating frequency from AM waveform



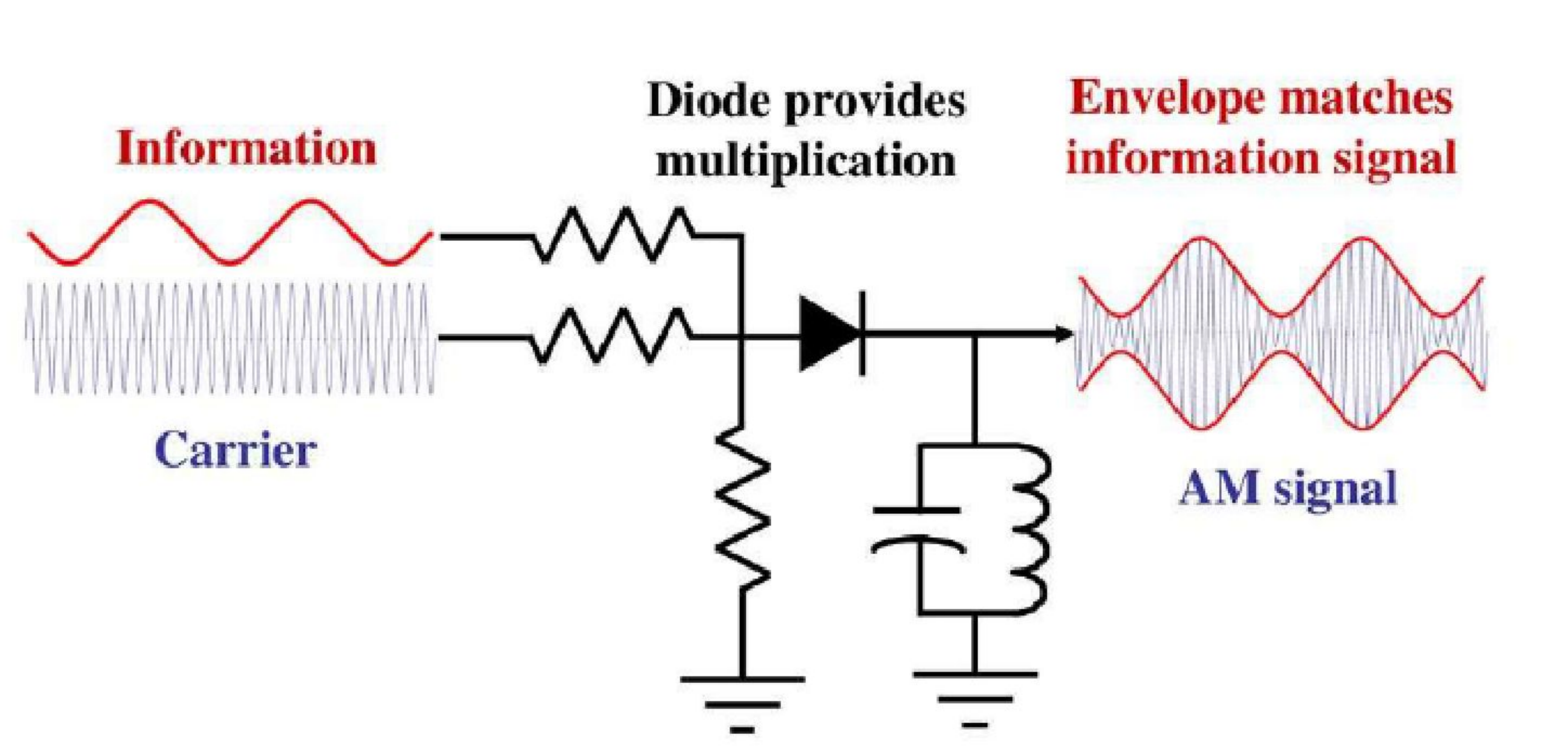


AM modulators

Low-Level AM: Diode Modulator

- **Diode modulation** consists of a resistive mixing network, a diode rectifier, and an *LC* tuned circuit.
- The carrier is applied to one input resistor and the modulating signal to another input resistor.
- This resistive network causes the two signals to be linearly mixed (i.e. algebraically added).
- A diode passes half cycles when forward biased.
- The coil and capacitor repeatedly exchange energy, causing an oscillation or ringing at the resonant frequency.

Diode modulator



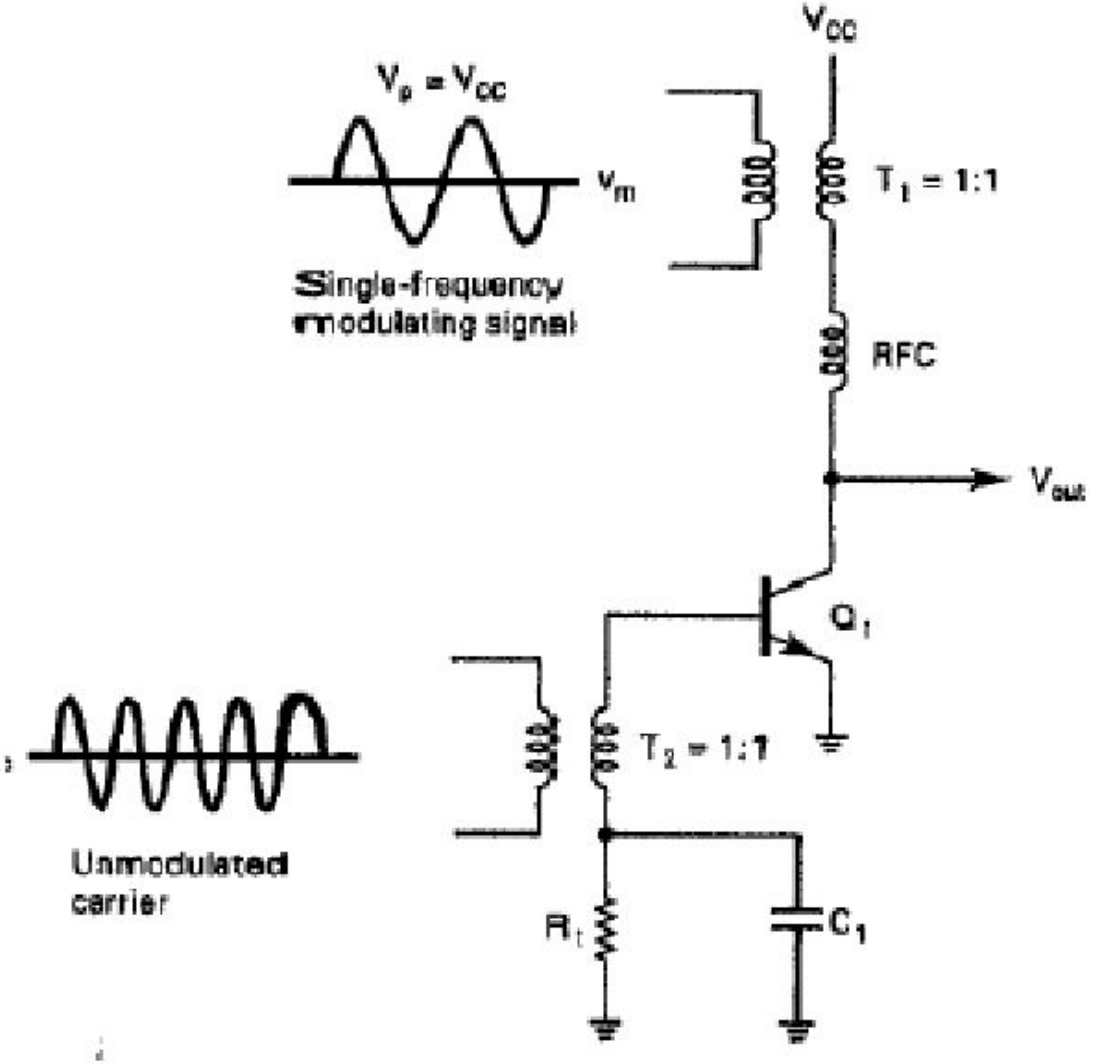
AM modulator

High-Level AM

- In **high-level modulation**, the modulator varies the voltage and power in the final RF amplifier stage of the transmitter.
- The result is high efficiency in the RF amplifier and overall high-quality performance.

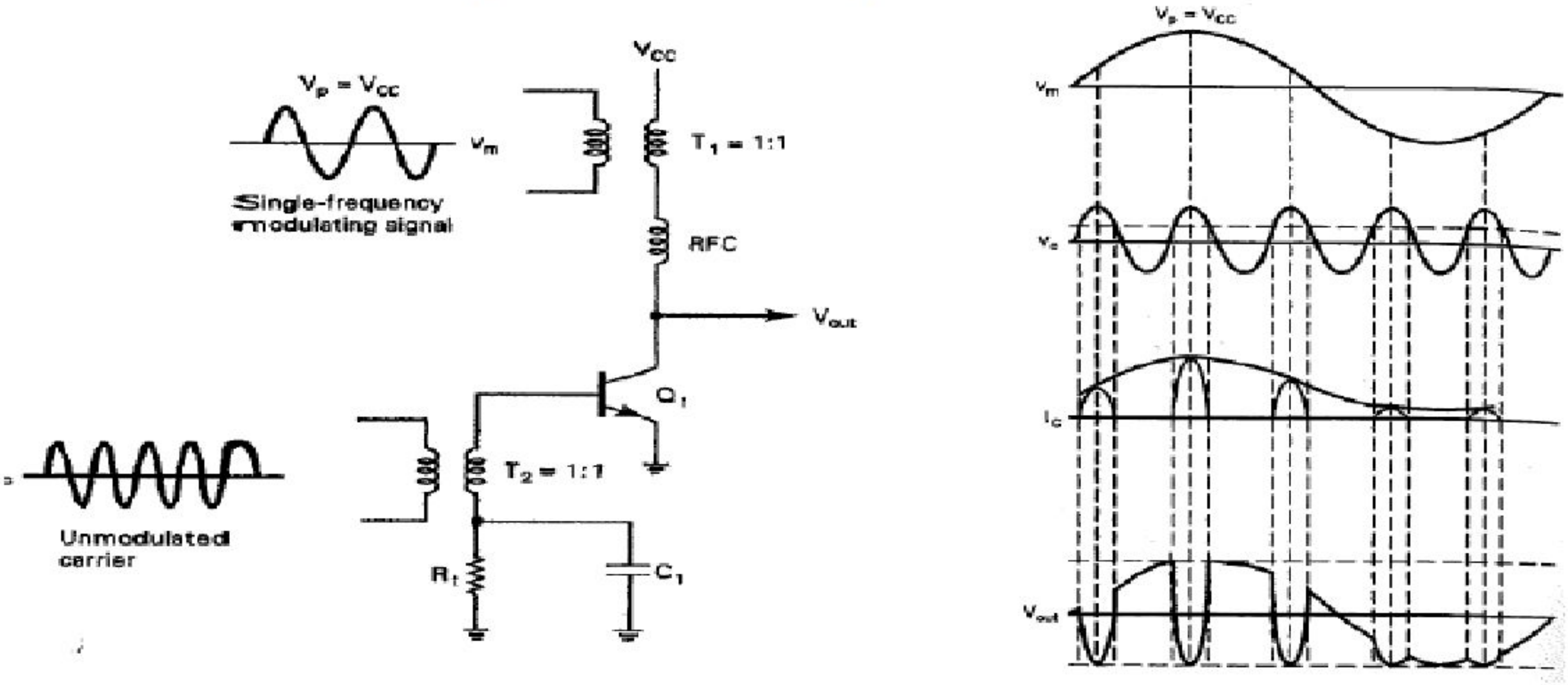
High-Level AM Modulators – Circuit Operation

- Used for high-power transmission
- Uses an Collector Modulator (high power)
  - Nonlinear modulator
- The amplifier has two inputs: *Vc(t)* and *Vm(t)*
- RFC is radio frequency choke – blocks RF



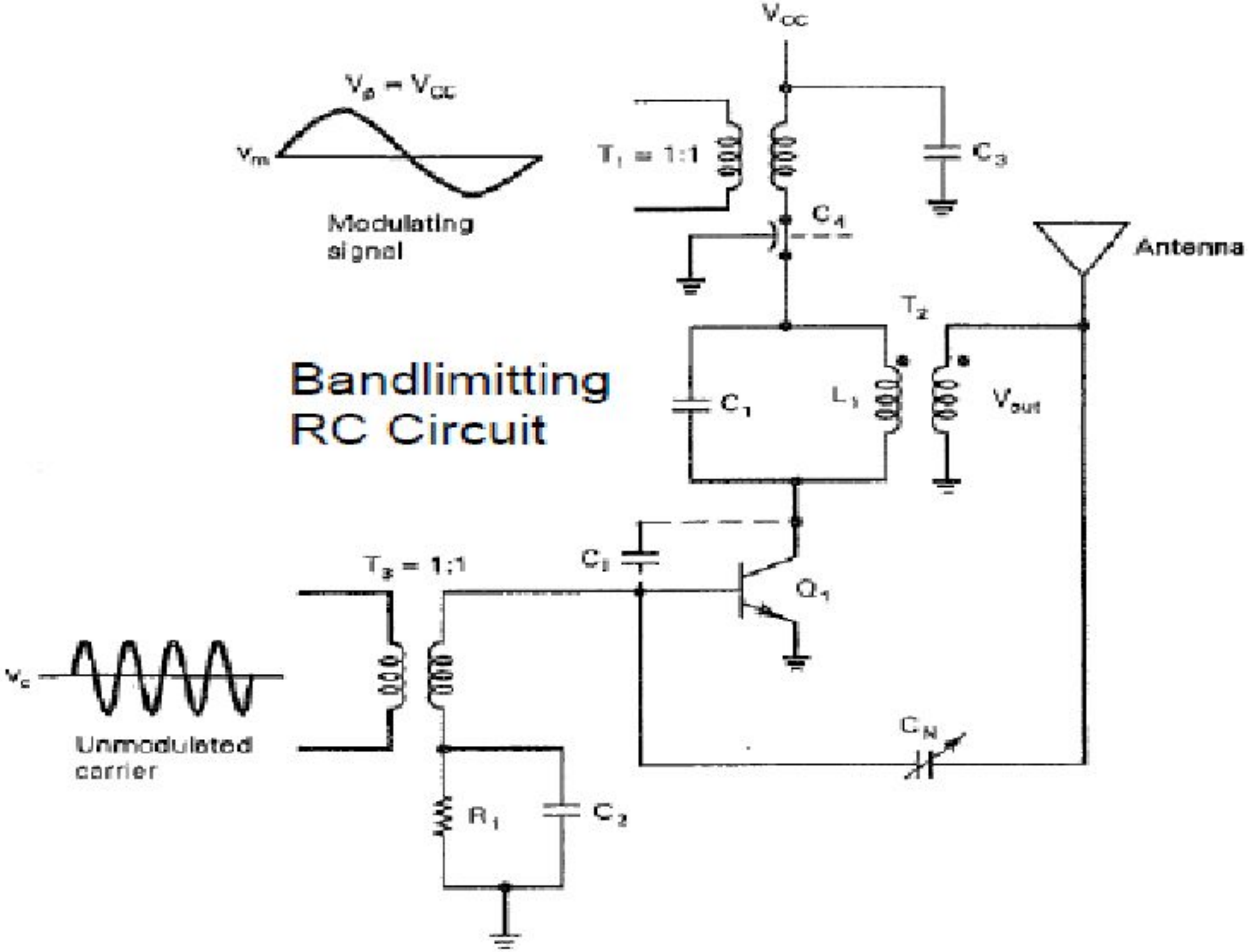
High-Level AM Modulators – Circuit Operation

- General operation:
  - If Base Voltage > 0.7 → Q1 is ON → Ic != 0 → Saturation
  - If Base Voltage < 0.7 → Q1 is OFF → Ic = 0 → Cutoff
  - The Transistor changes between Saturation and Cutoff
- When in nonlinear → high harmonics are generated→ Vout must be bandlimited



High-Level AM Modulators – Circuit Operation

- C_L and L_L tank can be added to act as Bandlimited
  - Only fc + fm and fc – fm can be transmitted



Advantages of AM

1. AM transmitters are not complex.
2. AM receivers are simple and easy to detect.
3. Less expensive.
4. Covers large distance.

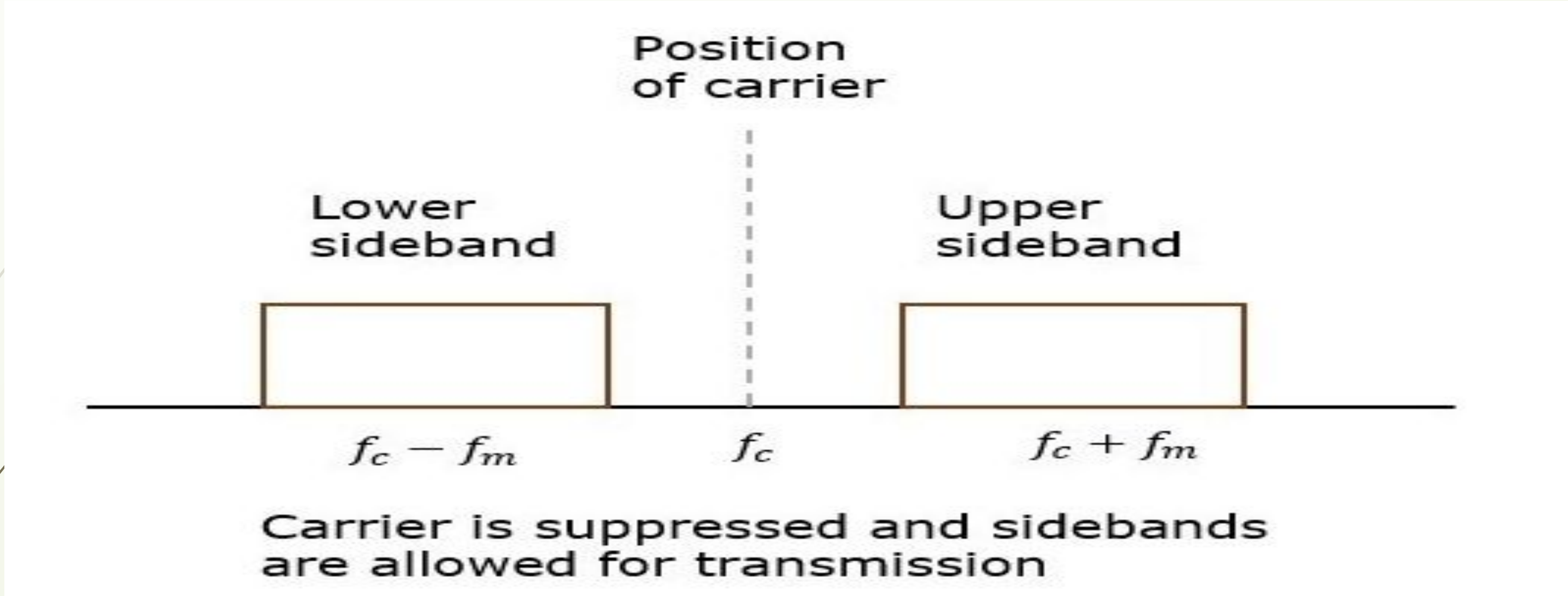
Disadvantages of AM

1. Requires large bandwidth.
2. Requires large power.
3. Gets affected due to noise.

Applications of AM

1. Radio broadcasting.
2. Picture transmission in TV (VSB is used).

DSB-SC



- The simplest method of generating a DSB-SC signal is merely to filter out the carrier portion of a full AM (or DSB-LC) waveform.
- Given carrier reference, modulation and demodulation (detection) can be implemented using product devices or balanced modulators.

Mathematical representation

Let us consider the same mathematical expressions for modulating and carrier signals as we have
considered in the earlier discussion.
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 signals.
$s(t)=m(t)c(t)$

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

$s(t)=A_mA_c2\cos[2\pi(f_c+f_m)t]+A_mA_c2\cos[2\pi(f_c-f_m)t]$

The DSBSC modulated wave has only two frequencies. So, the maximum and minimum frequencies are f_c+f_m and f_c-f_m respectively.
i.e.,
$f_{max}=f_c+f_m$ and $f_{min}=f_c-f_m$

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

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

$\Rightarrow BW = 2f_m$

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.

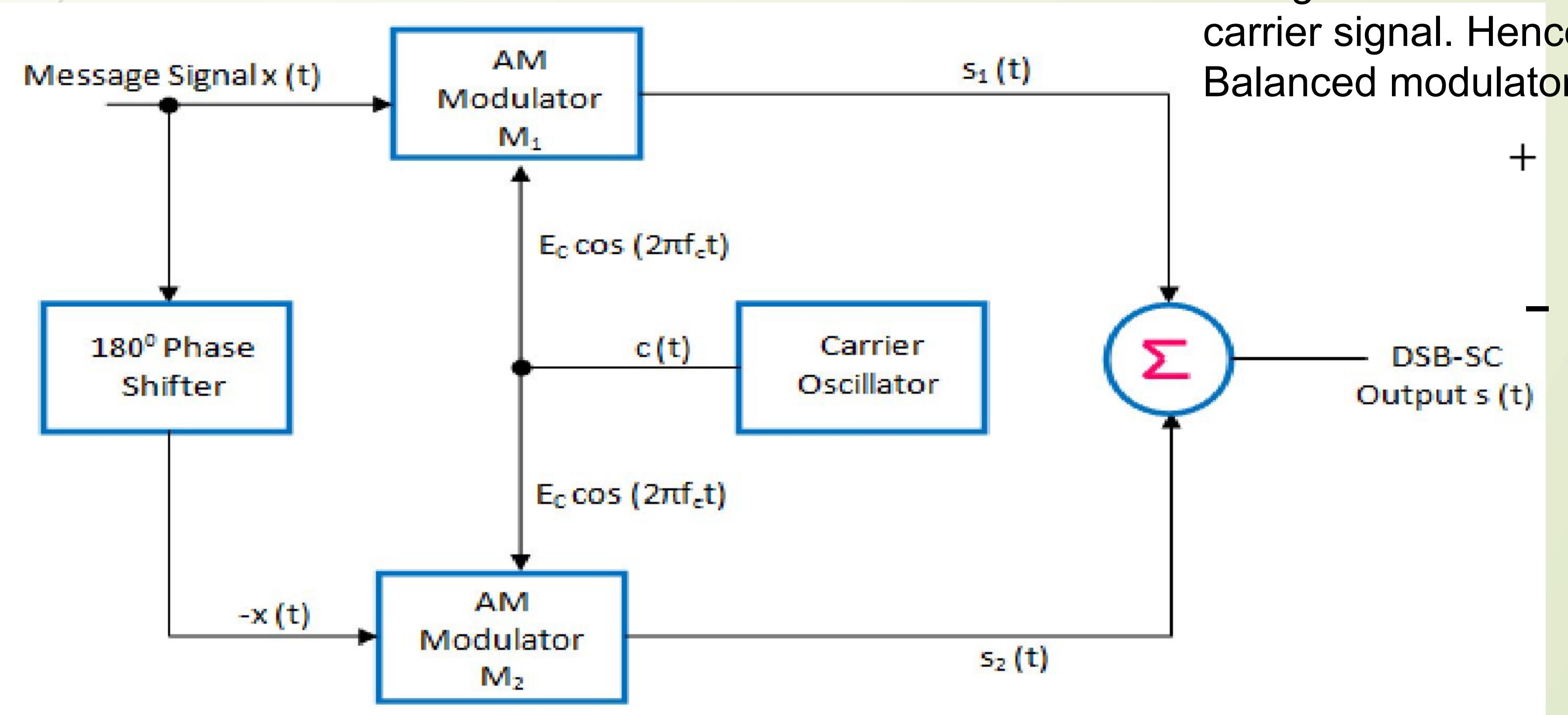
Generation of DSB-SC using Balanced modulator

Two modulators generate DSBSC wave.

- Balanced modulator
- Ring modulator
- FET push-pull balanced 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.



Balanced Modulator

O/P of AM Modulator M1

$S_1(t) = E_c \cos w_c t\,(1 + m \cos w_m t)$

O/P of AM Modulator M2

$S_2(t) = E_c \cos w_c t\,(1 - m \cos w_m t)$

O/P of Adder

$S(t) = S_1(t) + S_2(t)$

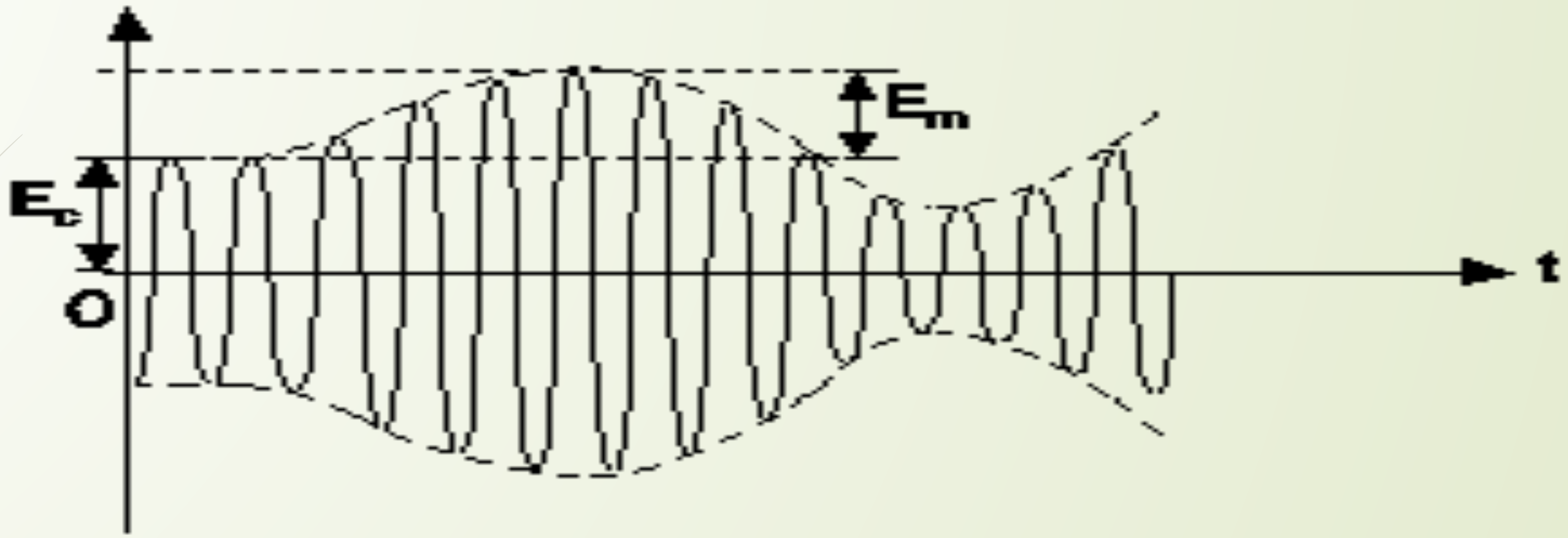
$= Ec \cos w_c t\,(1 + m \cos w_m t) + E_c \cos w_c t\,(1 - m \cos w_m t)$

$= 2m\, E_c \cos w_c t \cos w_m t$ ------------- DSBSC o/p

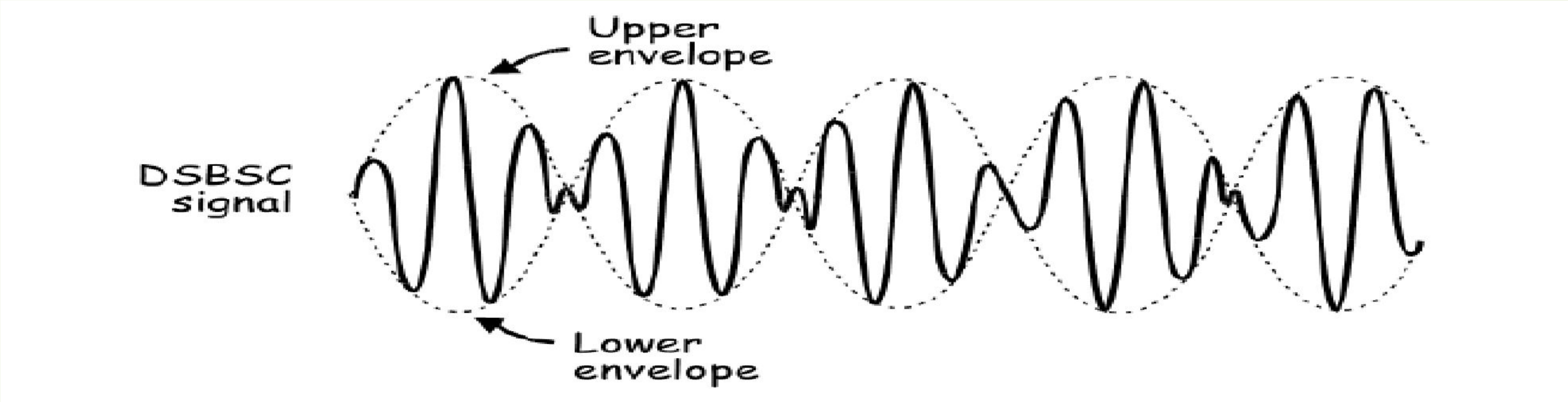
$$s(t) = s_1(t) - s_2(t)$$
$$= 2mA_c \cos(\omega_m t)\cos(\omega_c t)$$

using trigonometric identity

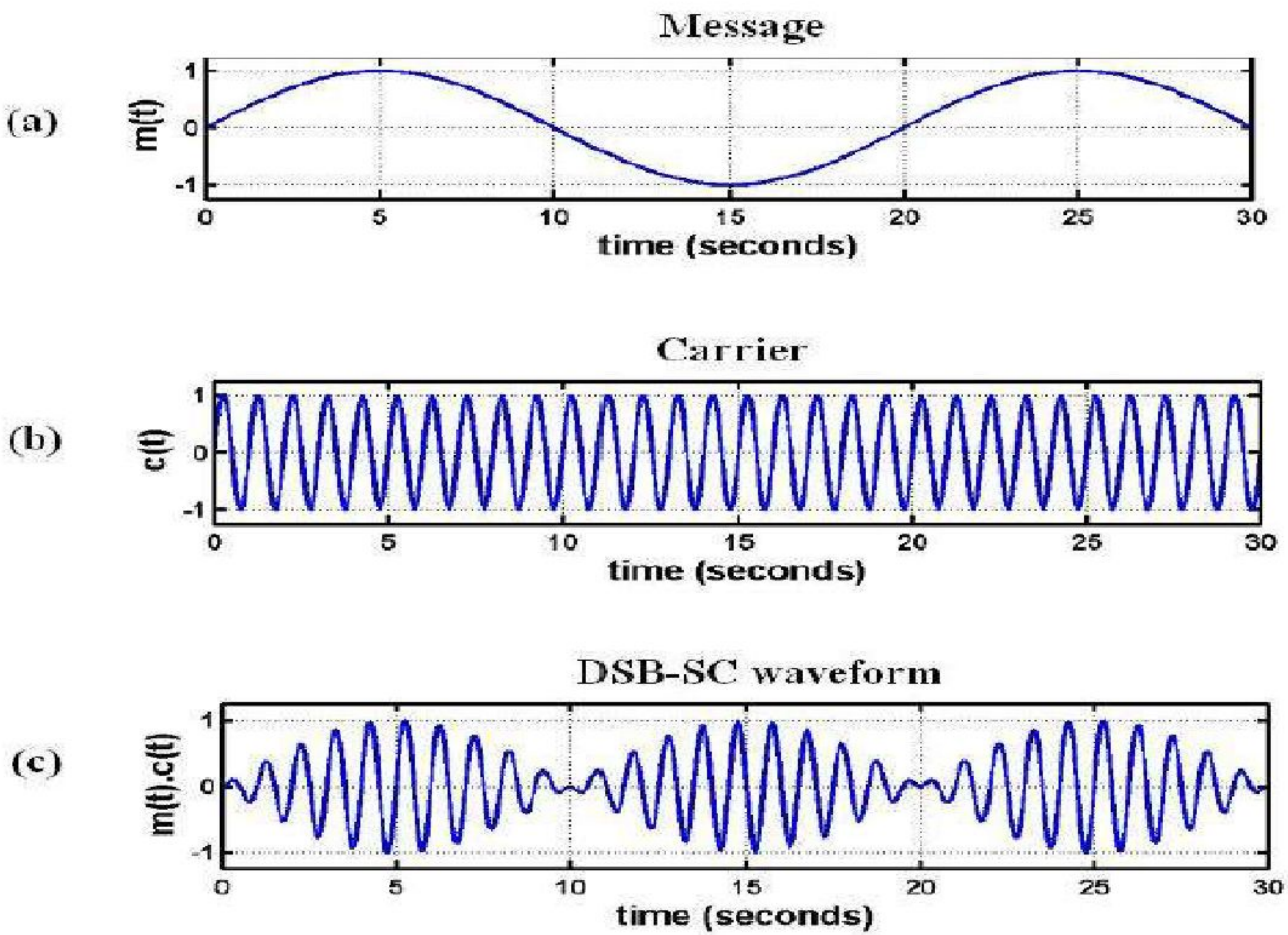
$$\cos x \cdot \cos y = \frac{1}{2}\left[\cos(x-y) + \cos(x+y)\right]$$



E_m
E_c
O
t

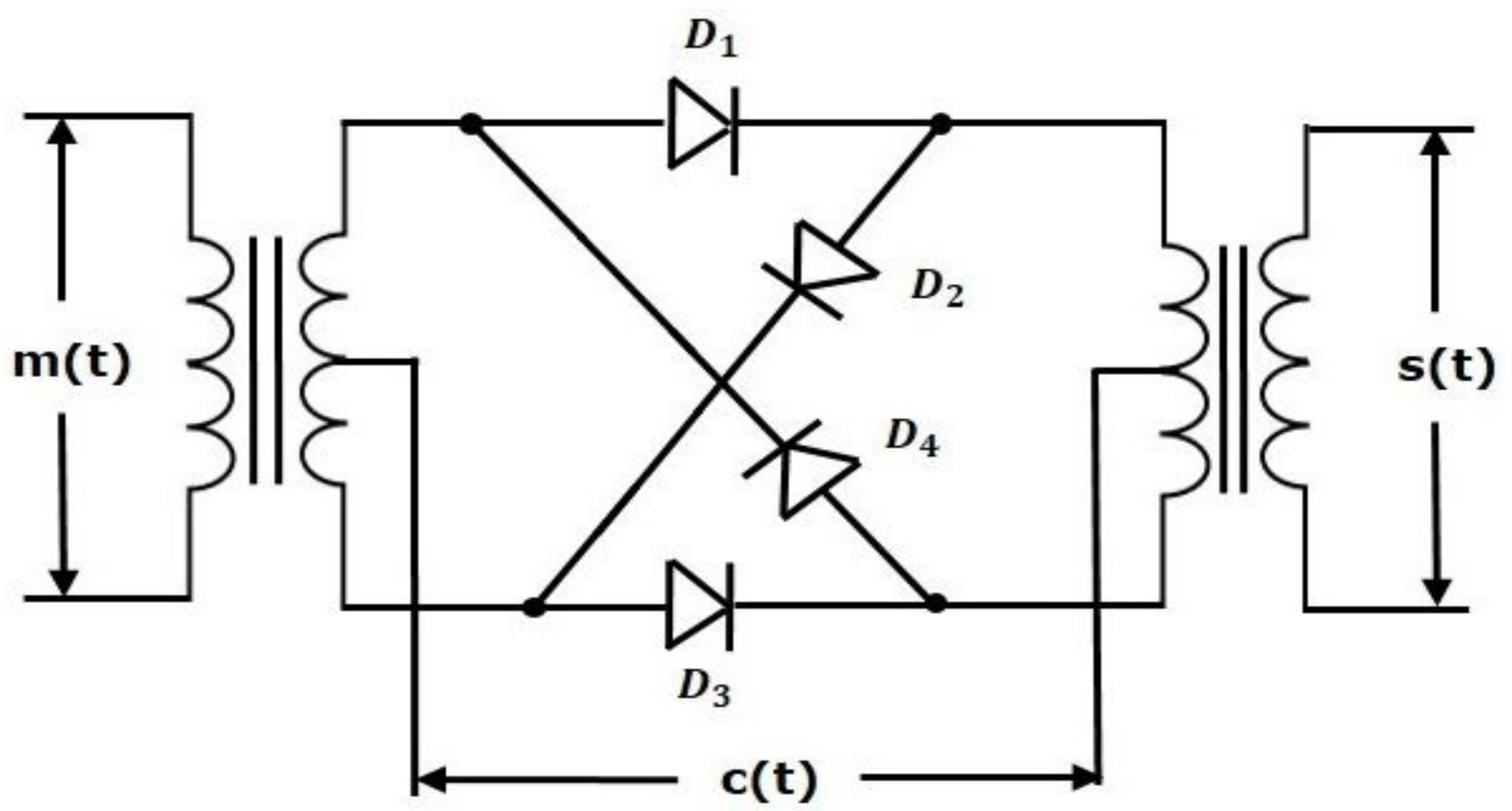


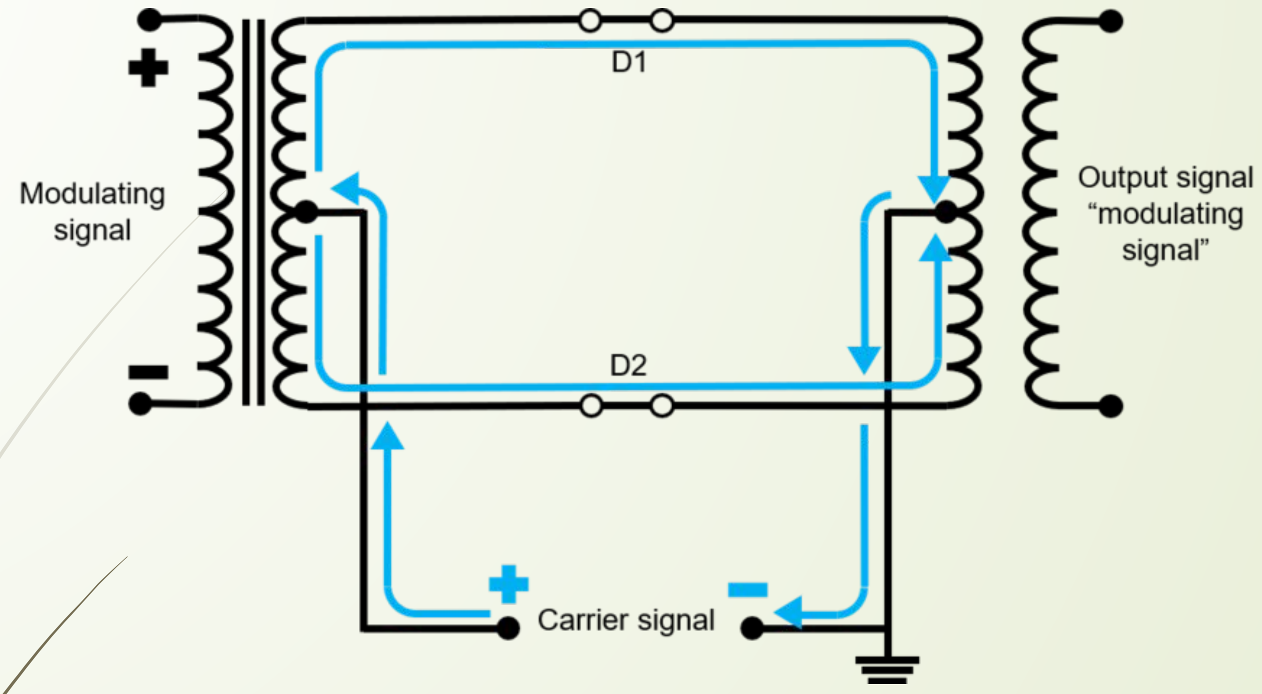
Upper envelope
DSBSC signal
Lower envelope


Message
(a)
m(t)
1
0
-1
0
5
10
15
20
25
30
time (seconds)
Carrier
(b)
c(t)
1
0
-1
0
5
10
15
20
25
30
time (seconds)
DSB-SC waveform
(c)
m(t).c(t)
1
0
-1
0
5
10
15
20
25
30
time (seconds)

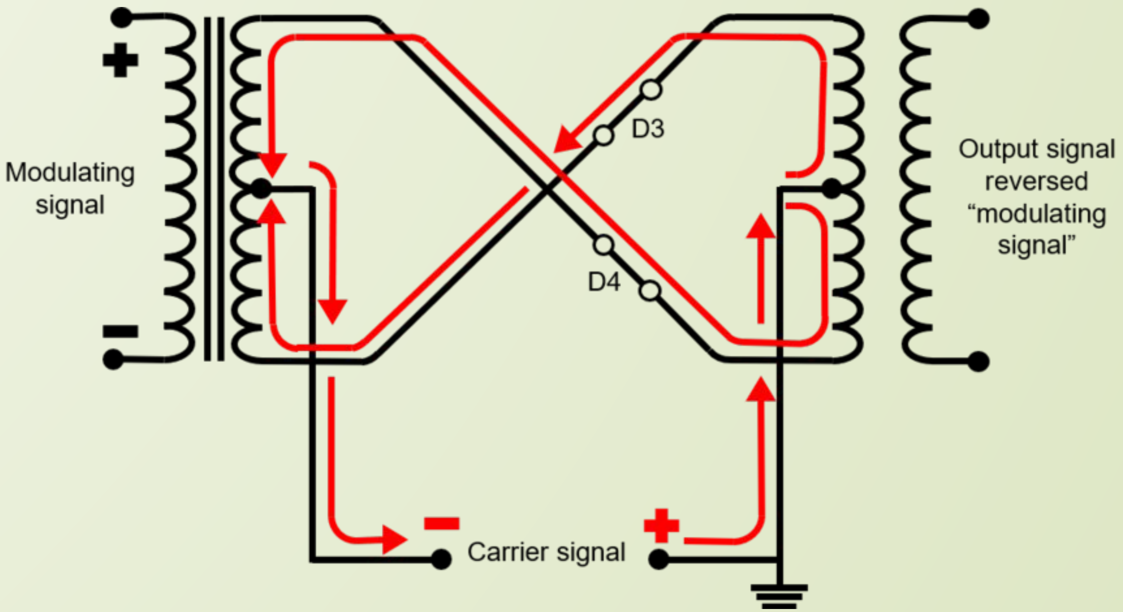
Ring Modulator

Following is the block diagram of the Ring modulator.

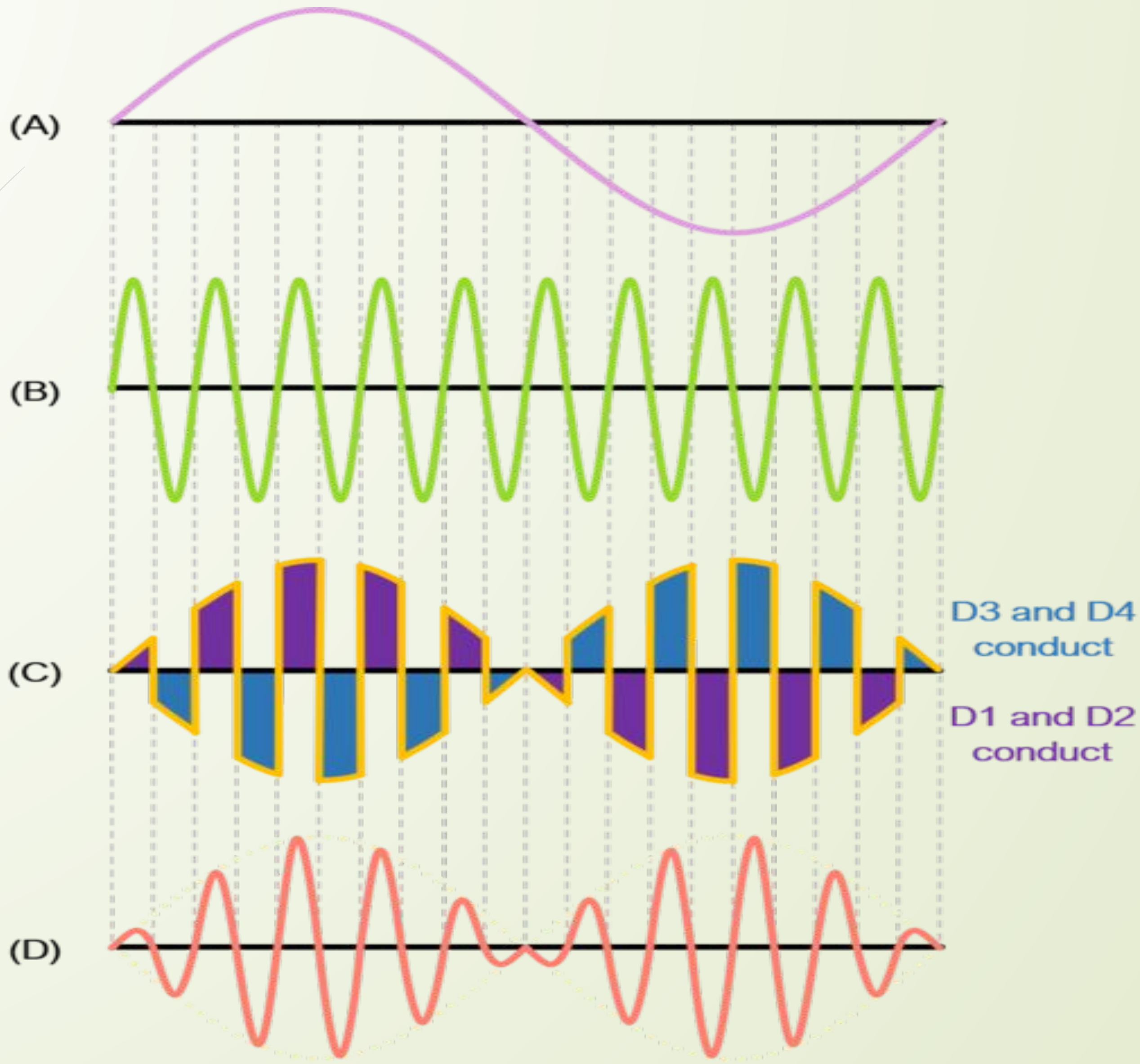




D1
Modulating signal
Output signal "modulating signal"
D2
Carrier signal



D3
Modulating signal
Output signal reversed "modulating signal"
D4
Carrier signal


(A)
(B)
(C)
(D)
D3 and D4 conduct
D1 and D2 conduct

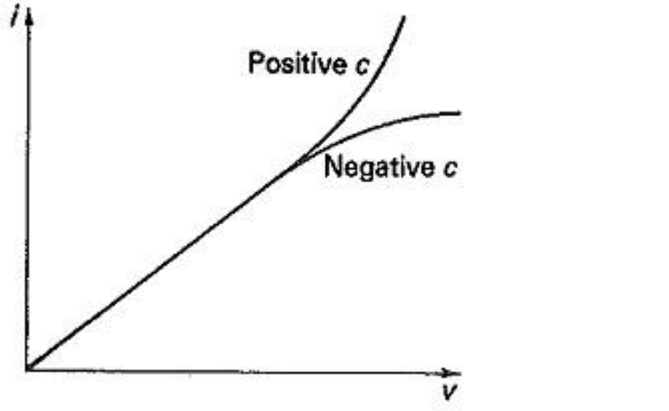


FIGURE 4-2 Nonlinear resistance characteristics.

In a nonlinear resistance, the current is still to a certain extent proportional to the applied voltage, but no longer directly as before. If the curve of current versus voltage is plotted, as in Figure 4-2, it is found that there is now some curvature in it. The previous linear relation seems to apply up to a certain point, after which current increases more (or less) rapidly with voltage. Whether the increase is more or less rapid depends on whether the device begins to saturate, or else some sort of avalanche current multiplication takes place. Current now becomes proportional not only to voltage but also to the square, cube and higher powers of voltage. This nonlinear relation is most conveniently expressed as

$$i = a + bv + cv^2 + dv^3 + \text{higher powers} \tag{4-3}$$

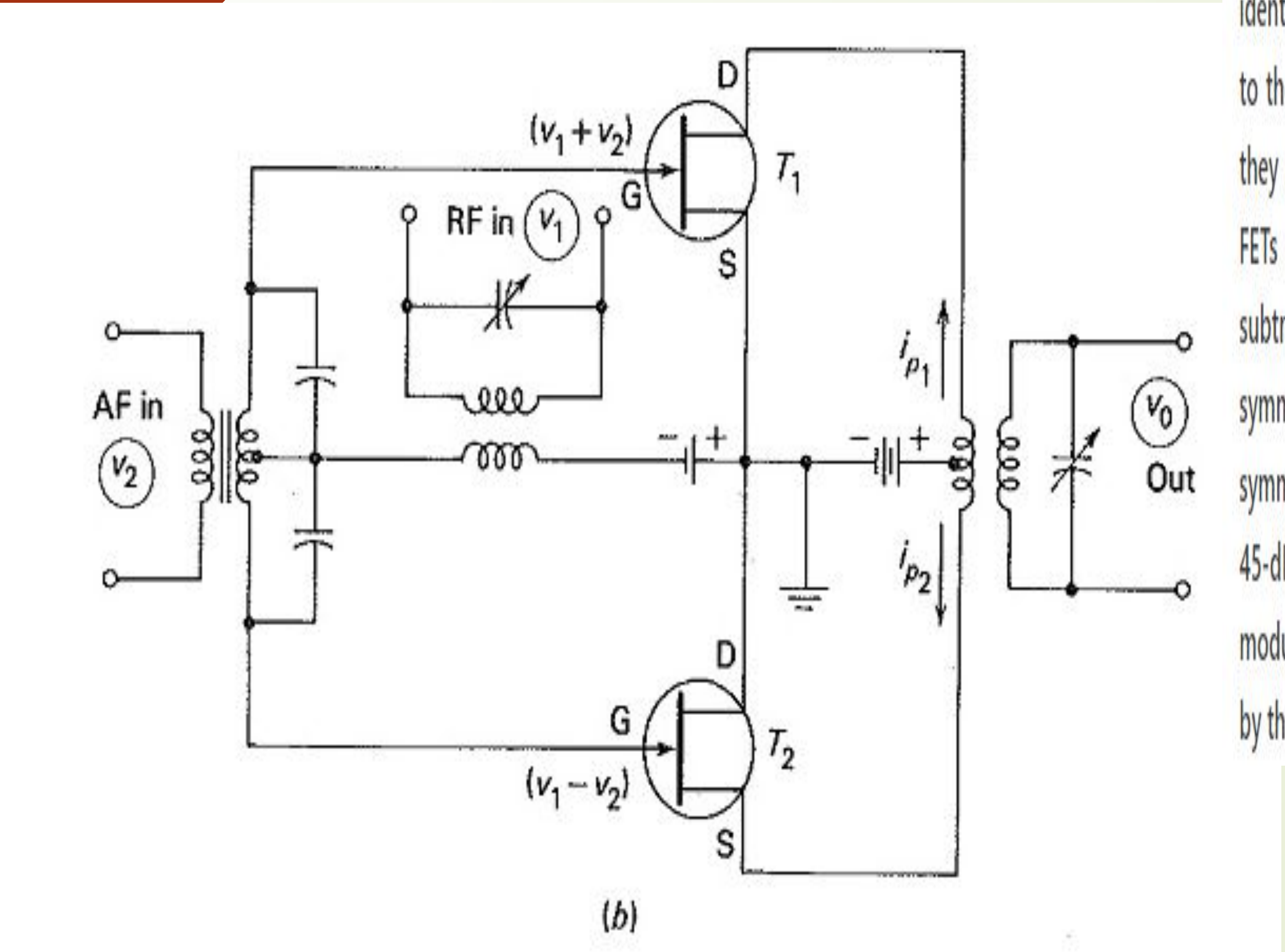
The reason that the initial portion of the graph is linear is simply that the coefficient c is much smaller than b. A typical numerical equation might, well be something like $i = 5 + 15v + 0.2v^2$, in which case curvature is insignificant until v equals at least 3. Therefore, c in practical nonlinear resistances is much greater than d, which is in turn larger than the constants preceding the higher-power terms. Only the square term is large enough to be taken into consideration for most applications, so that we are left with

$$i = a + bv + cv^2 \tag{4-4}$$

where a and b have the meanings previously given, and c is the coefficient of nonlinearity.

Since Equation (4-4) is generally adequate in relating the output current to the input voltage of a nonlinear resistance, it may now be applied to the gate-voltage-drain-current characteristic of a FET. If two voltages are applied simultaneously to the gate, then

FET Balanced Modulator



The modulation voltage v_2 is fed in push-pull, and the carrier voltage v_1 in parallel, to a pair of identical diodes or class A (transistor or FET) amplifiers. In the FET circuit, the carrier voltage is thus applied to the two gates in phase; whereas the modulating voltage appears 180° out of phase at the gates, since they are at the opposite ends of a center-tapped transformer. The modulated output currents of the two FETs are combined in the center-tapped primary of the push-pull output transformer. They therefore subtract, as indicated by the direction of the arrows in Figure 4-3b. If this system is made completely symmetrical, the carrier frequency will be completely canceled. No system can of course be perfectly symmetrical in practice, so that the carrier will be heavily suppressed rather than completely removed (a 45-dB Define Suppression of Carrier is normally regarded as acceptable). The output of the balanced modulator contains the two sidebands and some of the miscellaneous components which are taken care of by the tuning of the output transformers secondary winding. The final output consists only of sidebands.

As indicated, the input voltage will be $v_1 + v_2$ at the gate of T_1 (Figure 4-3b) and $v_1 - v_2$ at the gate of T_2. If perfect symmetry is assumed (it should be understood that the two devices used in the balanced modulator, whether diodes or transistors, must be matched), the proportionality constants will be the same for both FETs and may be called a, b, and c as before. The two drain, currents, calculated as in the preceding section, will be

$$\begin{aligned} i_{d_1} &= a + b(v_1 + v_2) + c(v_1 + v_2)^2 \\ &= a + bv_1 + bv_2 + cv_1^2 + cv_2^2 + 2cv_1v_2. \end{aligned} \tag{4-9}$$

$$\begin{aligned} i_{d_2} &= a + b(v_1 - v_2) + c(v_1 - v_2)^2 \\ &= a + bv_1 - bv_2 + cv_1^2 + cv_2^2 - 2cv_1c_2 \end{aligned} \tag{4-10}$$

As previously indicated, the primary current is given by the difference between the individual drain currents. Thus

$$i_1 = i_{d_1} - i_{d_2} = 2bv_2 + 4cv_1v_2 \tag{4-11}$$

when Equation (4-10) is subtracted from (4-9).

We may now represent the carrier voltage v_1 by $v_c \sin \omega_c t$ and the modulating voltage v_2 by $V_m \sin \omega_m t$. Substituting these into Equation (4-11) gives

$$\begin{aligned} i_1 &= 2bV_m \sin \omega_m t + 4cV_mV_c \sin \omega_c t \sin \omega_m t \\ &= 2bV_m \sin \omega_m t + 4cV_mV_c ½[\cos (\omega_c - \omega_m)t - \cos (\omega_c + \omega_m)t] \end{aligned} \tag{4-12}$$

The output voltage v_0 is proportional to this primary current. Let the constant of proportionality be α. Then

$$v_0 = \alpha i_1$$

$$= 2\alpha b V_m \sin \omega_m t + 2\alpha c V_m V_c[\cos (\omega_c - \omega_m)t - \cos (\omega_c + \omega_m)t]$$

Simplifying, we let $P = 2\alpha b V_m$ and $Q = 2\alpha c V_m V_c$. Then

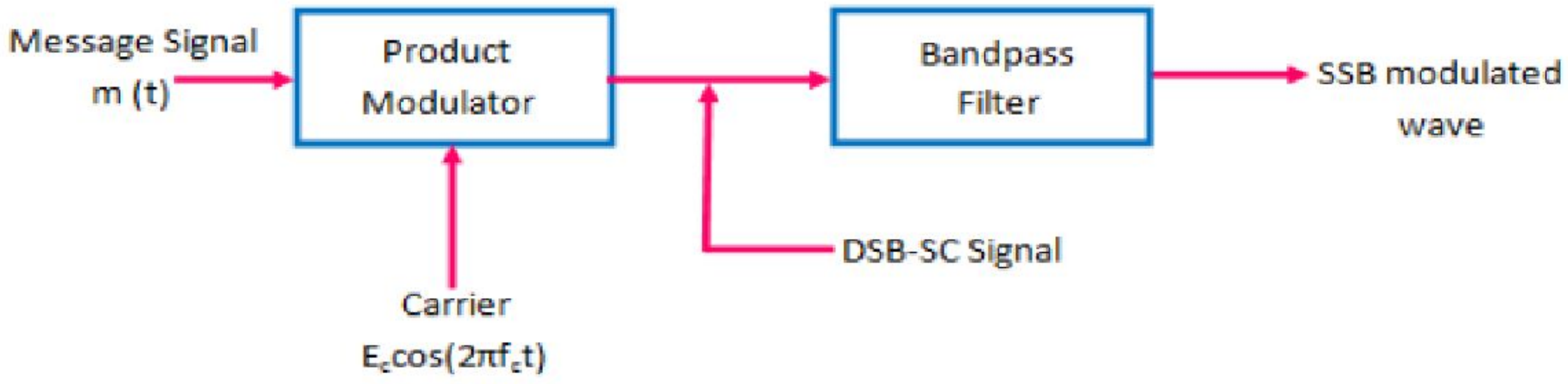
$$v_O = \underbrace{P \sin \omega_m t}_{\text{Modulation frequency}} + \underbrace{Q \cos(\omega_c - \omega_m)t}_{\text{Lower sideband}} - \underbrace{Q \cos (\omega_c + \omega_m)t}_{\text{Upper sideband}} \qquad \textbf{(4-13)}$$

Equation (4-13) shows that (under ideally symmetrical conditions) the Define Suppression of Carrier has been canceled out, leaving only the two sidebands and the modulating frequencies.

Single-SideBand (SSB) Modulation

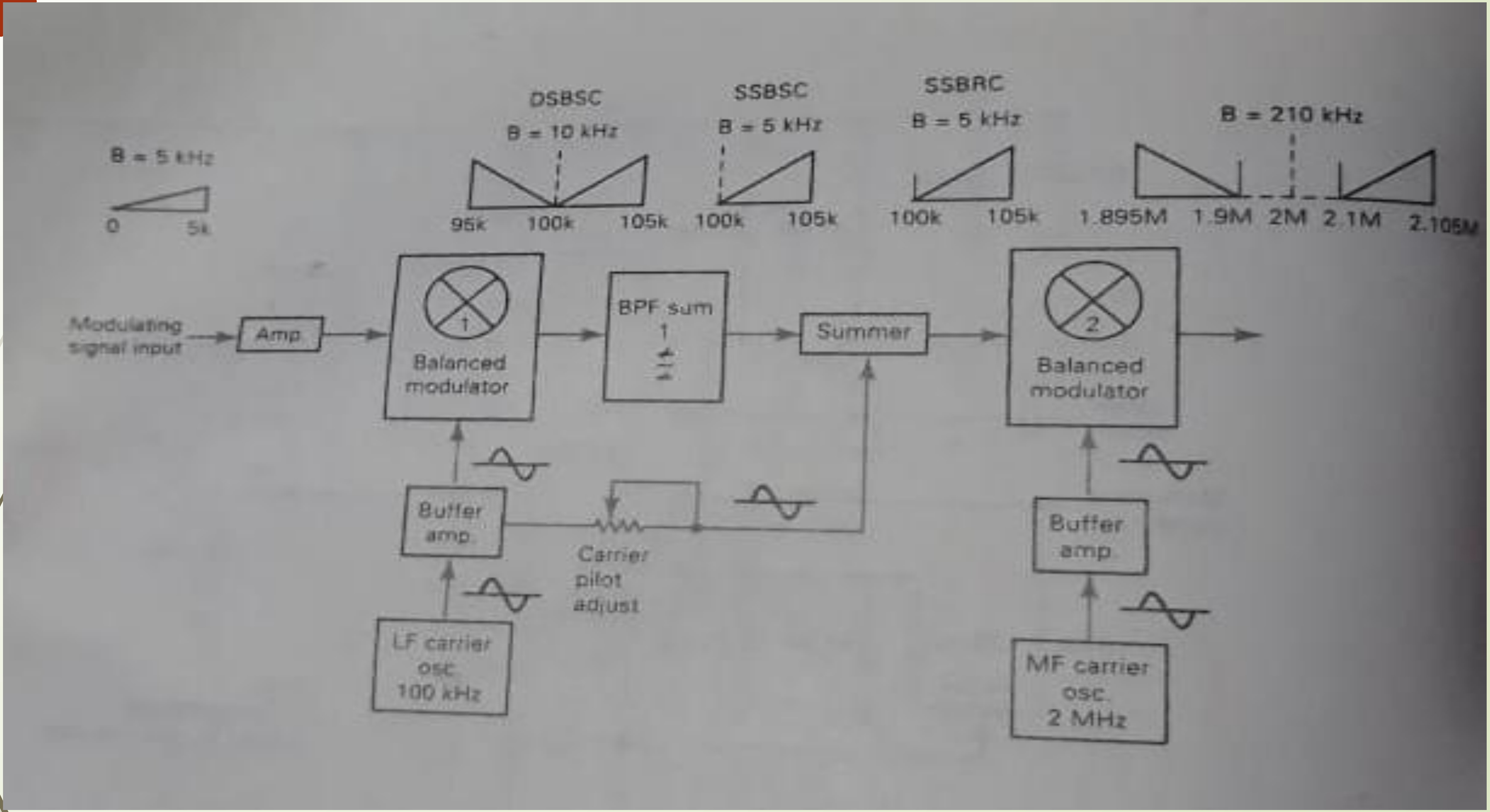
- Standard AM and DSB-SC Modulation are wasteful of bandwidth because they both require a transmission bandwidth equal to twice message the message bandwidth.
- This means that insofar as the transmission of information is concerned, only one sideband is necessary, and no information is lost.
- Thus the channel needs to provide only the same bandwidth as the message signal, a conclusion that is intuitively satisfying.
- When only one sideband is transmitted, the modulation is referred to as single-sideband modulation

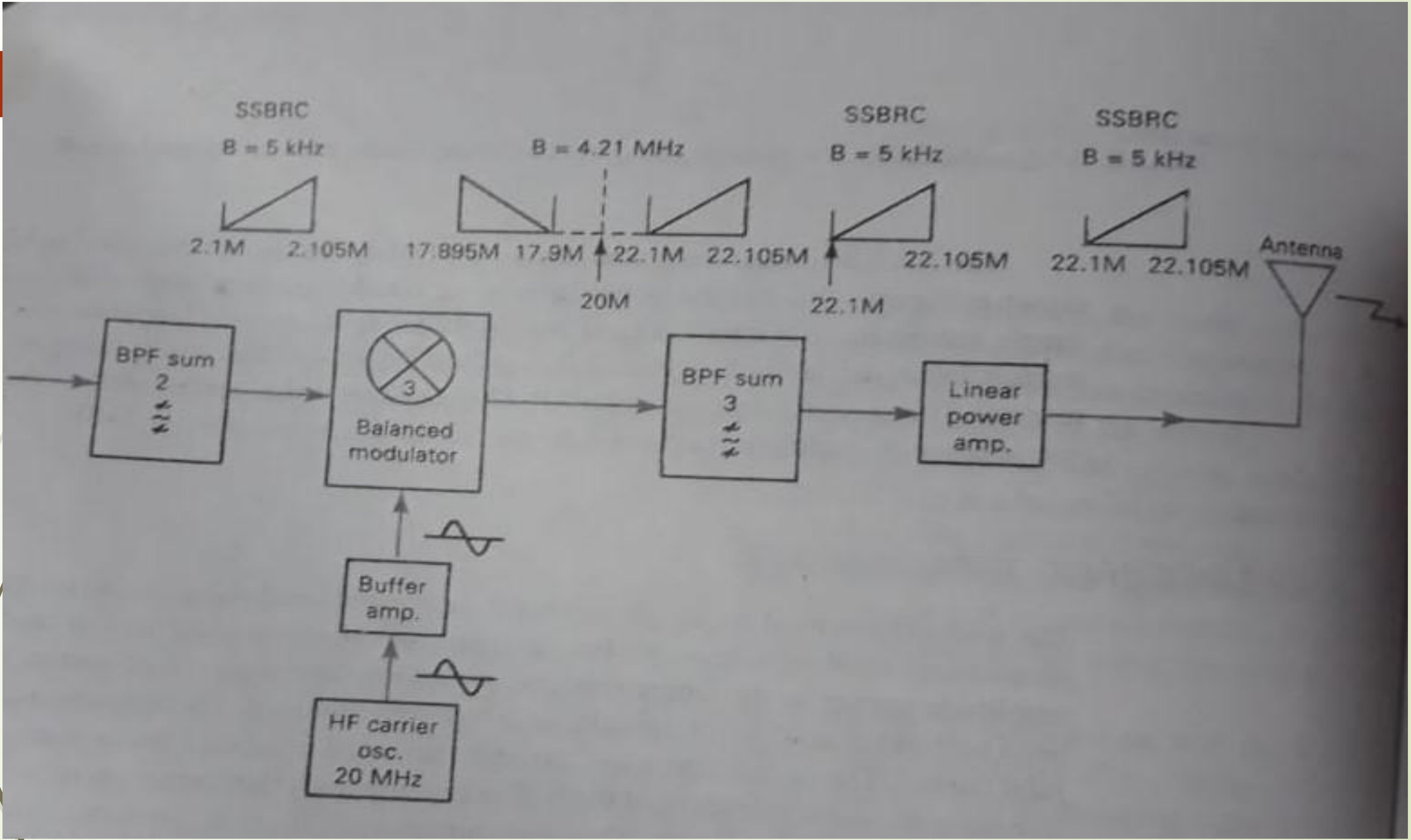
SSBSC Generation - 1) Filter method
2) Phase shift method
3) Weaver's method

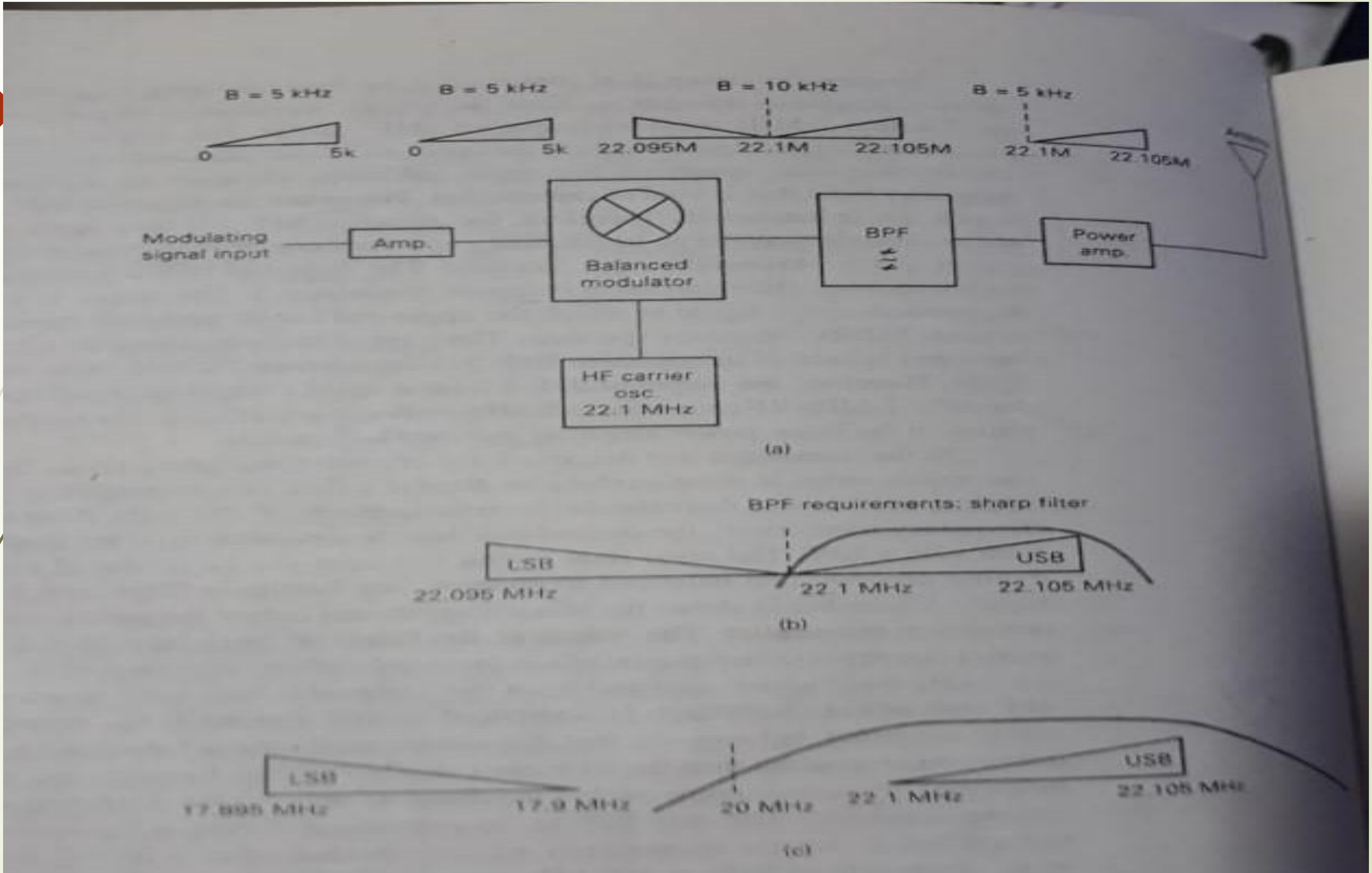


Filter method

Filter method

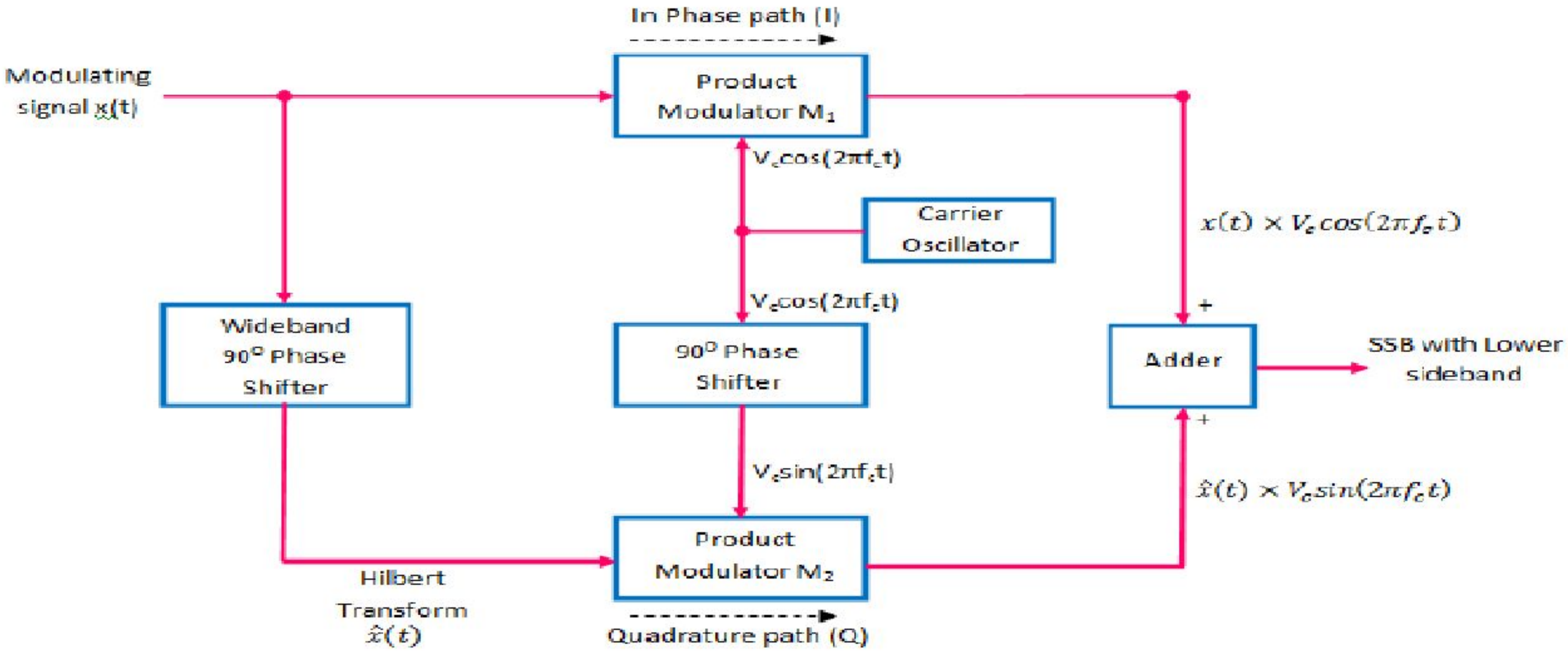



SSBRC
B = 5 kHz
2.1M
2.105M
B = 4.21 MHz
17.895M
17.9M
20M
22.1M
22.105M
SSBRC
B = 5 kHz
22.1M
22.105M
SSBRC
B = 5 kHz
22.1M
22.105M
Antenna
BPF sum 2
Balanced modulator
BPF sum 3
Linear power amp.
Buffer amp.
HF carrier osc. 20 MHz



B = 5 kHz
0
5k
B = 5 kHz
0
5k
B = 10 kHz
22.095M
22.1M
22.105M
B = 5 kHz
22.1M
22.105M
Modulating signal input
Amp.
Balanced modulator
BPF
Power amp.
HF carrier osc. 22.1 MHz
(a)
BPF requirements: sharp filter
LSB
USB
22.095 MHz
22.1 MHz
22.105 MHz
(b)
LSB
USB
17.895 MHz
17.9 MHz
20 MHz
22.1 MHz
22.105 MHz
(c)

SSBSC Generation



Phase shift method

SSB-SC Generation (Phase Shift Method)

$X(t) = V_m \cos(2\pi f_m t)$

$\hat{X}(t) = V_m \sin(2\pi f_m t)$

O/P of Adder

$= X(t) V_c \cos(2\pi f_c t) + \hat{X}(t) V_c \sin(2\pi f_c t)$

Putting $X(t)$

$= V_m \cos(2\pi f_m t) [V_c \cos(2\pi f_c t)] + (-V_m \sin(2\pi f_m t))[V_c \sin(2\pi f_c t)]$

$= V_m V_c (\cos(f_c - f_m) 2\pi t$ --------------------------- o/p is only LSB

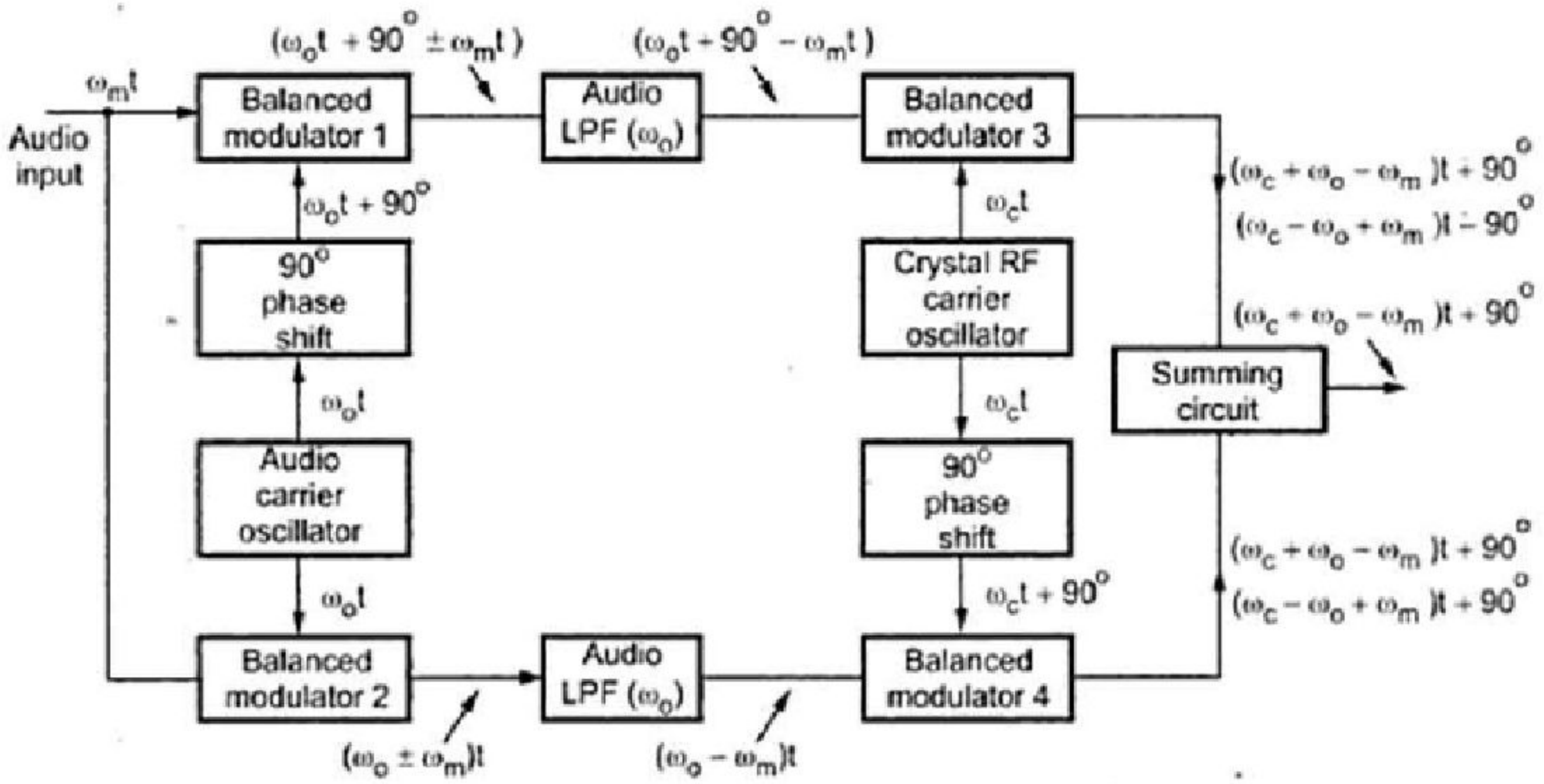
For USB o/p

O/P of Adder must be

$= X(t) V_c \cos(2\pi f_c t) - \hat{X}(t) V_c \sin(2\pi f_c t)$

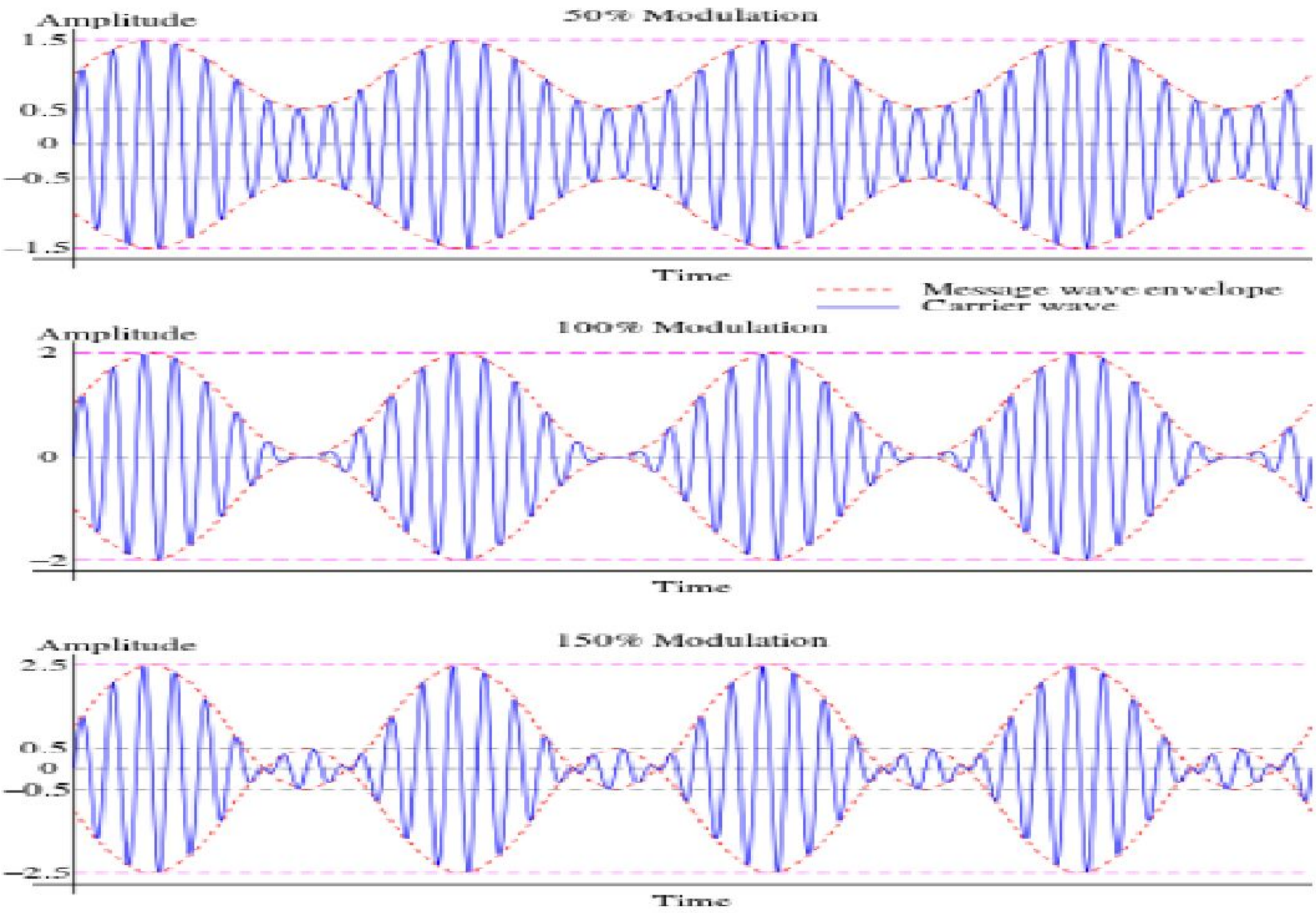
SUPPRESSION OF UNWANTED SIDEBAND TO GENERATE SSB-SC

Weavers method



COMPARISON BETWEEN SSB SUPRESSION METHODS

Sr. No.	Parameter	Filter Method	Phase shift method	Third method
1.	Method used	Filter is used to remove unwanted sideband.	Phase-shifting techniques is used to remove unwanted sideband.	Similar to phase-shift method, but carrier signal is phase shifted by 90°.
2.	90° phase shift	Not required	Requires complex phase shift network	Phase shift network is simple RC circuit
3.	Possible frequency range of SSB	Not possible to generate SSB at any frequency.	Possible to generate SSB at any frequency.	Possible to generate SSB at any frequency.
4.	Need for up-conversion	Required	Not required	Not required
5.	Complexity	Less	Medium	High
6.	Design aspects	Q of tuned circuit, Filter type, it size, weight and upper frequency limit.	Design of 90° phase shifter for entire modulating frequency range. Symmetry of balanced modulators.	Symmetry of balanced modulators.
7.	Bulkyness	Yes	No	No
8.	Switching ability	Not possible with existing circuit. Extra filter and switching network is necessary	Easily possible	Easily possible. But extra crystal is required

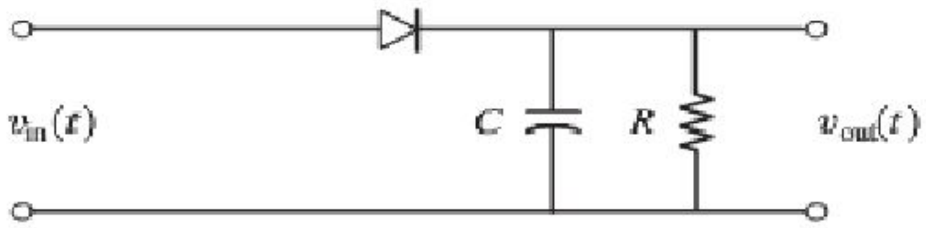


50% Modulation
Amplitude
1.5
0.5
0
−0.5
−1.5
Time
Message wave envelope
Carrier wave
100% Modulation
Amplitude
2
0
−2
Time
150% Modulation
Amplitude
2.5
0.5
0
−0.5
−2.5
Time

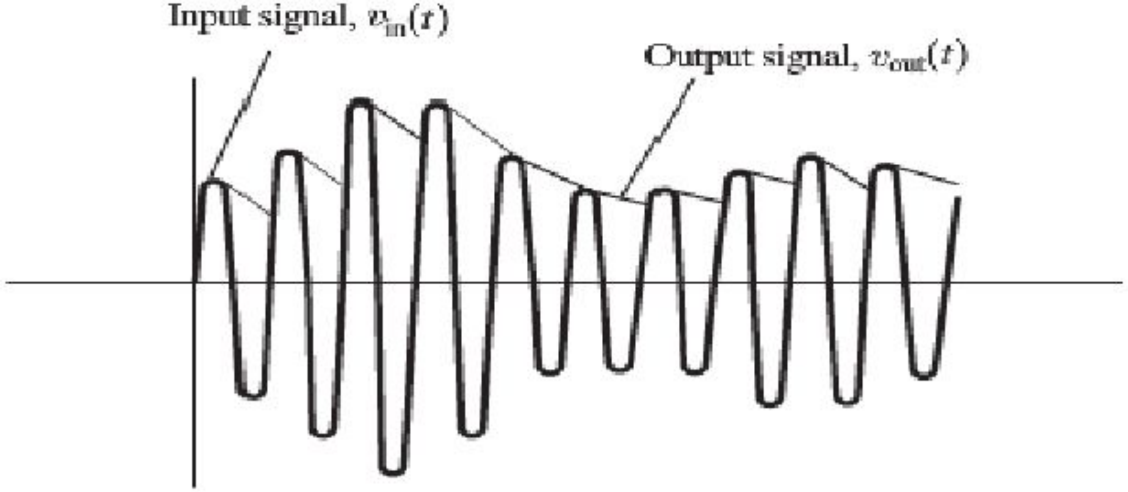
AM Demodulators: Envelope Detector

- Considered as **non-coherent** demodulators
- The diode acts as a **nonlinear** mixer
- Other **names**
  - Diode Detector
  - Peak Detector (Positive)
  - Envelope Detector
- Basic operation: Assume fc = 300 KHz and fm = 2KHz
  - Then there will be frequencies 298, 300, 302 KHz
  - The detector will detect many different frequencies
  - AM frequencies + AM harmonics + SUM of AM frequencies + DIFF of AM frequencies
  - The RC LPF is set to pass only DIFF frequencies

$$B \ll \frac{1}{2\pi RC} \ll f_c$$



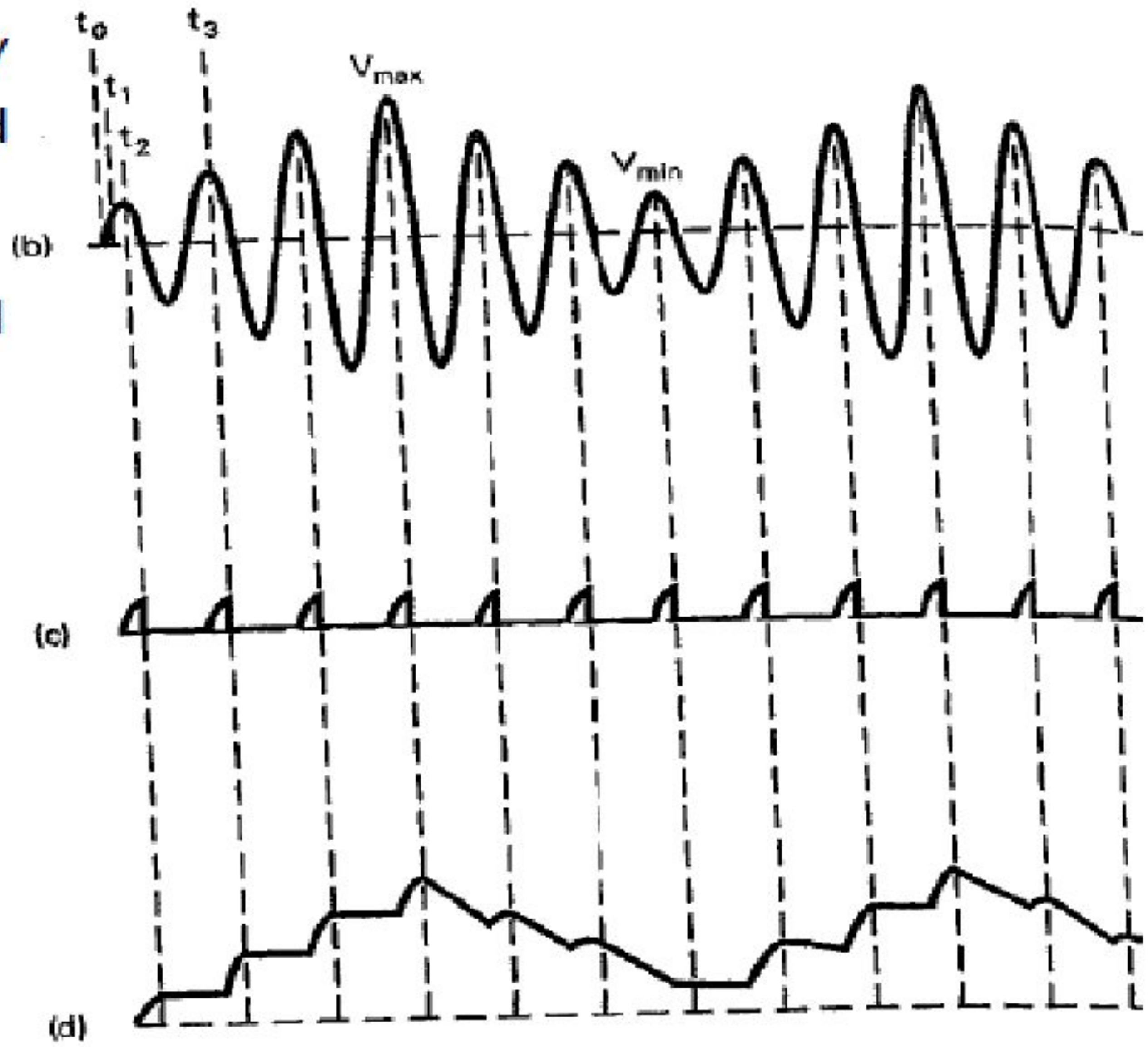
(a) A Diode Envelope Detector



(b) Waveforms Associated with the Diode Envelope Detector

Envelope Detector – Basic Operation

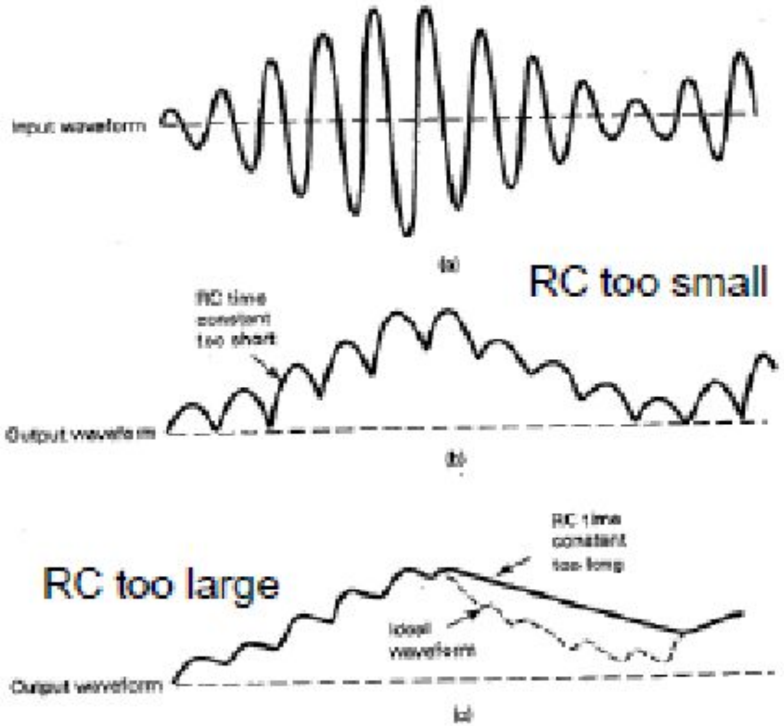
- The diode has $V_{barrier} = V_b = 0.3V$
- When $V_{in} < V_b$ → Reverse Biased → DIODE is OFF
  - → $i_d = 0$ → $V_{cap} = 0$
- When $V_{in} > V_b$ → Forward Biased → DIODE is ON
  - → $i_d > 0$ → $V_{cap} = V_{in} - 0.3$



Envelope Detector – Distortion

- What should be the value of RC?
  - If too low then discharges too fast
  - If too high the envelope will be distorted
  - The highest modulating signal:

$$f_{m(\max)} = \frac{\sqrt{(1/m^2)-1}}{2\pi RC}$$



  - Note that in most cases m=0.70 or 70 percent of modulation →

$$f_{m(\max)} = \frac{1}{2\pi RC}$$

$$B \ll \frac{1}{2\pi RC} \ll f_c$$

AM receivers

Requirements of a Receiver

- It should be cost-effective.
- It should receive the corresponding modulated waves.
- The receiver should be able to tune and amplify the desired station.
- It should have an ability to reject the unwanted stations.
- Demodulation has to be done to all the station signals, irrespective of the carrier signal frequency.

A radio receiver consists of the following:

- A Radio Frequency (RF) section
- An RF-to-IF converter (mixer)
- An Intermediate Frequency (IF) section
- Demodulator
- Audio amplifier

Classification of Radio Receivers:

Depending upon application

- AM Receivers - receive broadcast of speech or music from AM transmitters which operate on long wave, medium wave or short wave bands.
- FM Receivers – receive broadcast programs from FM transmitters which operate in VHF or UHF bands.
- Communication Receivers - used for reception of telegraph and short wave telephone signals.
- Television Receivers - used to receive television broadcast in VHF or UHF bands.
- Radar Receivers – used to receive radio detection and ranging signals.

Depending upon fundamental aspects

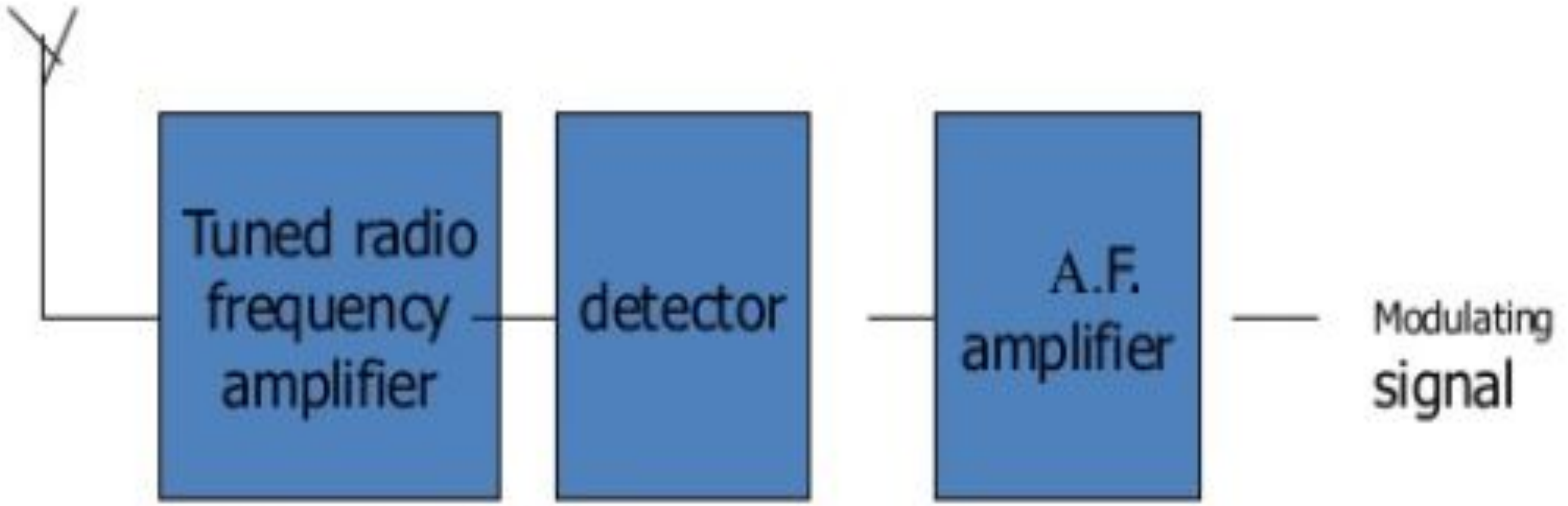
- Tuned Radio Frequency (TRF)Receivers
- Super-heterodyne Receivers

TRF

Tuned Radio Frequency (TRF) Receiver:

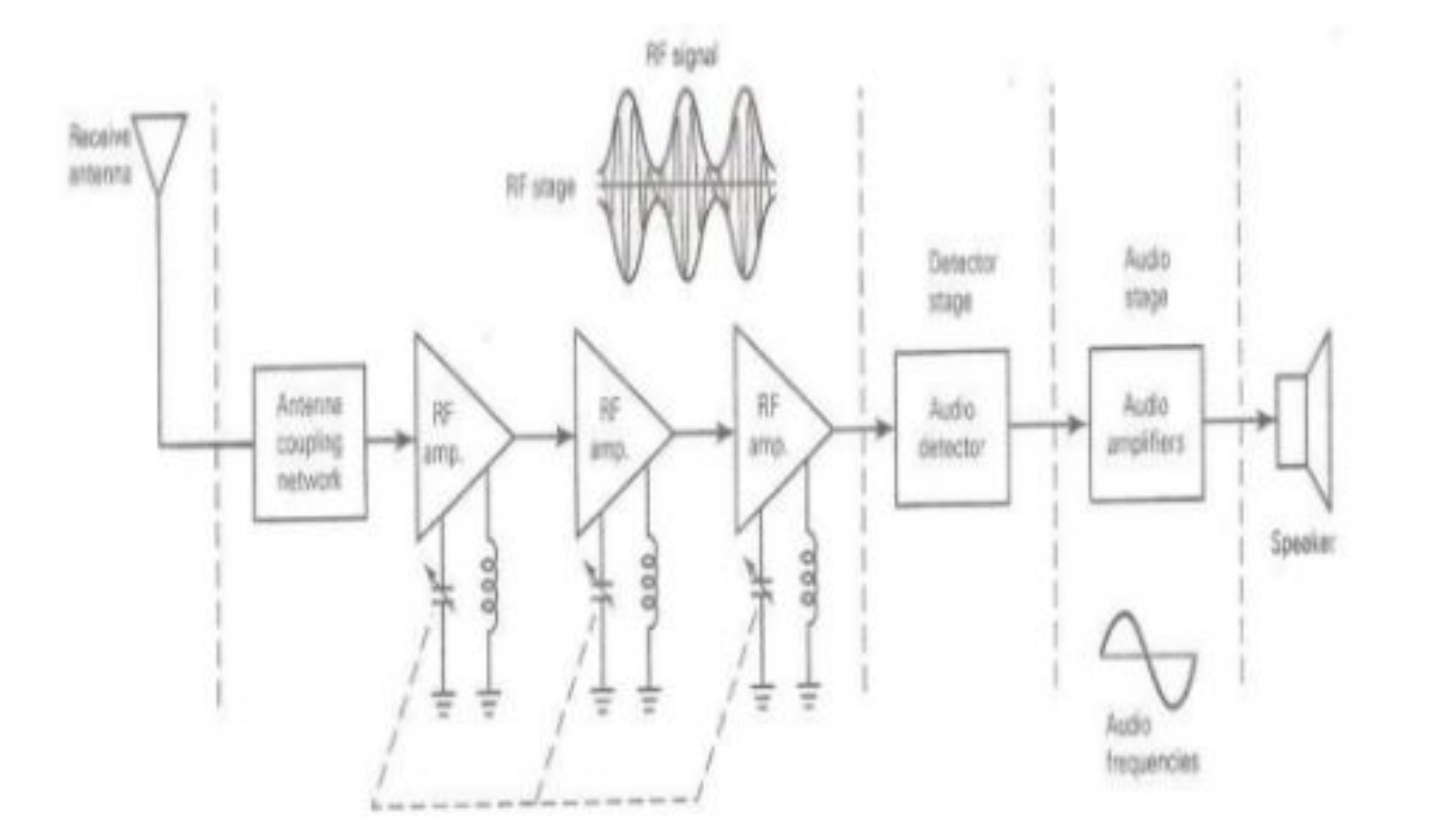
- Composed of RF amplifiers and detectors.
- No frequency conversion
- It is not often used.
- Difficult to design tunable RF stages.
- Difficult to obtain high gain RF amplifiers

TRF (Tuned Radio frequency) RECEIVER:



- TRF receiver includes an
  - RF stage
  - a detector stage
  - and an audio stage .
- Two or three RF amplifiers are required to filter and amplify the received signal to a level sufficient to drive the detector stage.

TRF Receiver



TRF Receiver

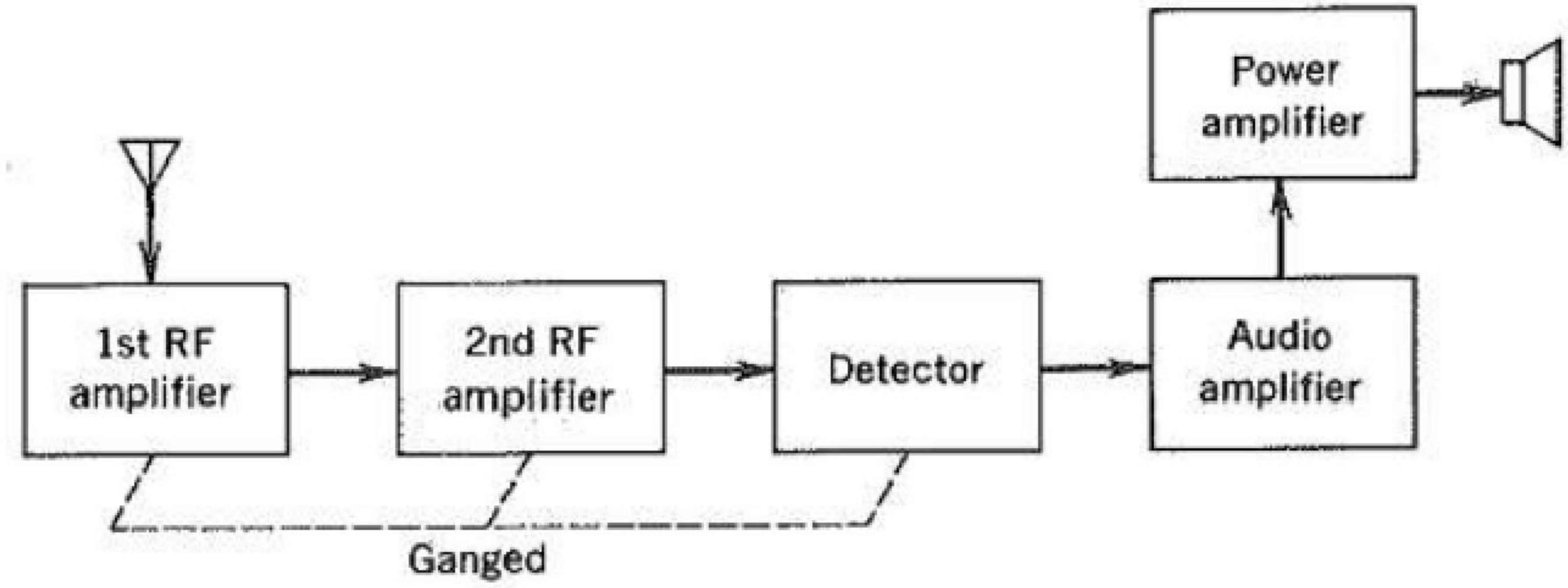


FIGURE 6-1 The TRF receiver.

- RF section (Receiver front end)
  - used to detect the signal
  - bandlimit the received RF signal
  - and amplifying the received RF signal.
- AM detector
  - Demodulates the AM wave and converts it to the original information signal.
- Audio section
  - Used to amplify the recovered signal

Advantages of TRF:

- TRF receivers are simple to design and allow the broadcast frequency 535 KHz to 1640 KHz.
- High senstivity.

Disadvantages of TRF:

Disadvantages of TRF:

- At the higher frequency, it produces difficulty in design.
- It has poor audio quality.
- Drawbacks
  - Instability
  - Variation in BW
  - Poor Selectivity
- <u>INSTABILITY</u>
  - Due to high frequency, multi stage amplifiers are susceptible to breaking into oscillation.

- As gain of RF amplifier is very high ,a small feedback from output to input with correct phase can lead to oscillations.
- Correct phase means a positive feedback and it takes place due through stray capacitances
- As reactance of stray capacitances decreases at higher frequencies resulting in increased feedback.
- Forcing the device to work as an oscillator instead of an amplifier.

- <u>VARIATION IN BANDWIDTH</u>
  - ➢ The bandwidth is inconsistent and varies with the center frequency when tuned over a wide range of input frequencies.
  - ➢ As frequency increases, the bandwidth (f/Q) increases. Thus, the selectivity of the input filter changes over any appreciable range of input frequencies.
- <u>POOR SELECTIVITY</u>
  - The gains are not uniform over a very wide frequency range.
  - Due to higher frequencies ability to select desired signal is affected.

Due to these drawbacks TRF are rarely used.

Merits

- TRF receivers are simple to design.
- TRF has high sensitivity.
- ability to drive the speaker to an acceptable level (to amplify)

Demerits

- It allow the broadcast frequency 535 KHz to 1640 KHz. But at the higher frequency, it produces difficulty in design.
- Problem of instability.
- It has poor audio quality.

Super heterodyne receiver

- ***Heterodyne*** *– to mix two frequencies together in a nonlinear device or to transmit one frequency to another using nonlinear mixing.*
- Also known as ***frequency conversion*** , high frequency down converted to low frequency.(IF)
- A super heterodyne receiver converts all incoming radio frequency (RF) signals to a lower frequency known as an intermediate frequency (IF).

DRAWBACKS OVERCOMED:

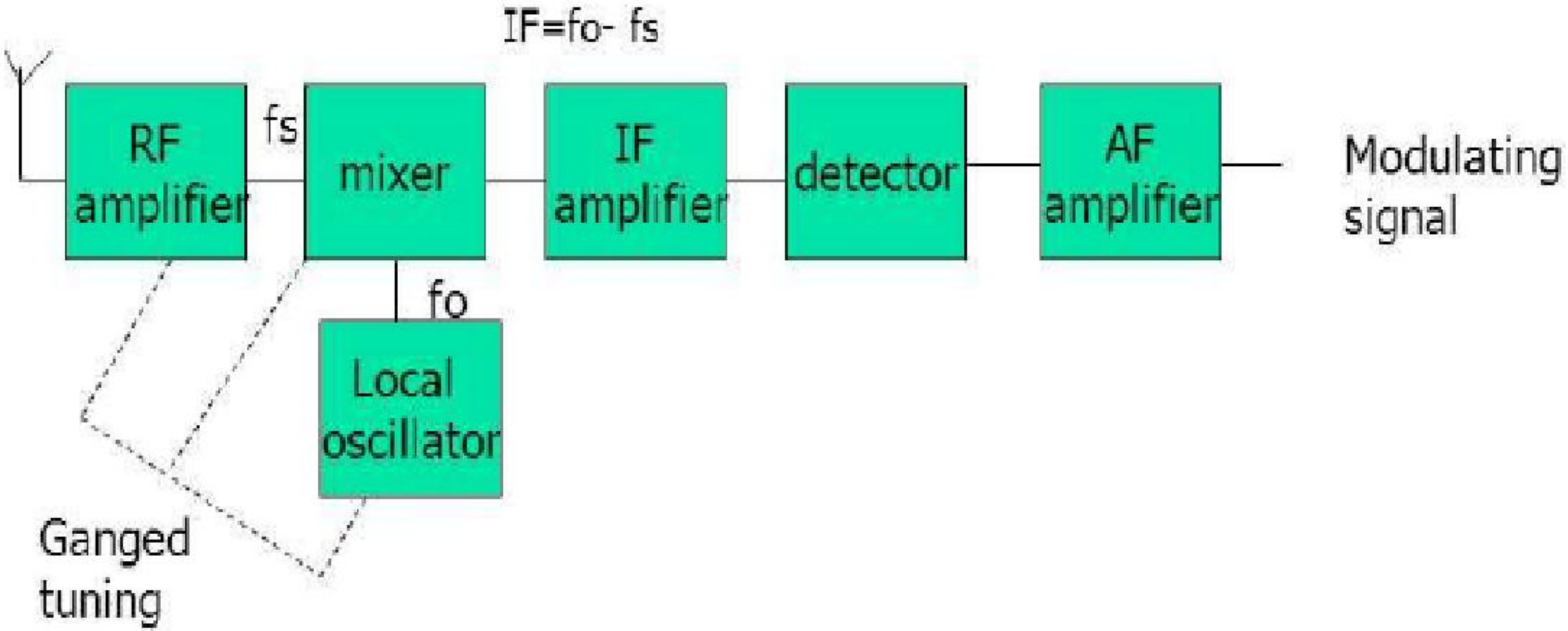
Stability – as high frequency is down converted to IF the reactance of stray capacitances will not decrease as it was at higher frequencies resulting in increased feedback.

No variation in BW- as IF range is 438 to 465 KHz (in case of AM receivers) mostly 455KHz ,appropriate for Q limit (120).

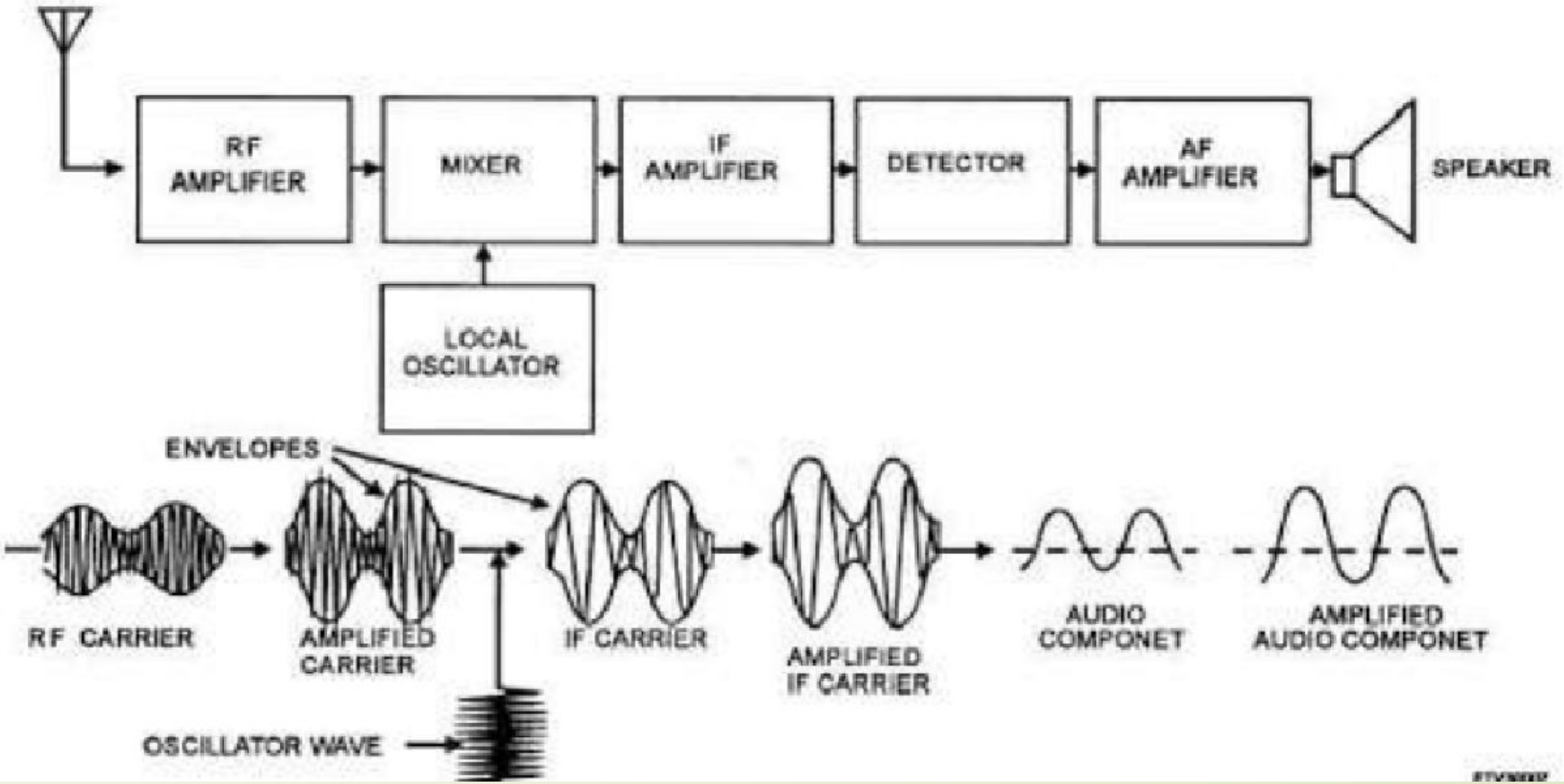
Better selectivity- as no adjacent channels are picked due to variation in BW.

Super Heterodyne Receiver

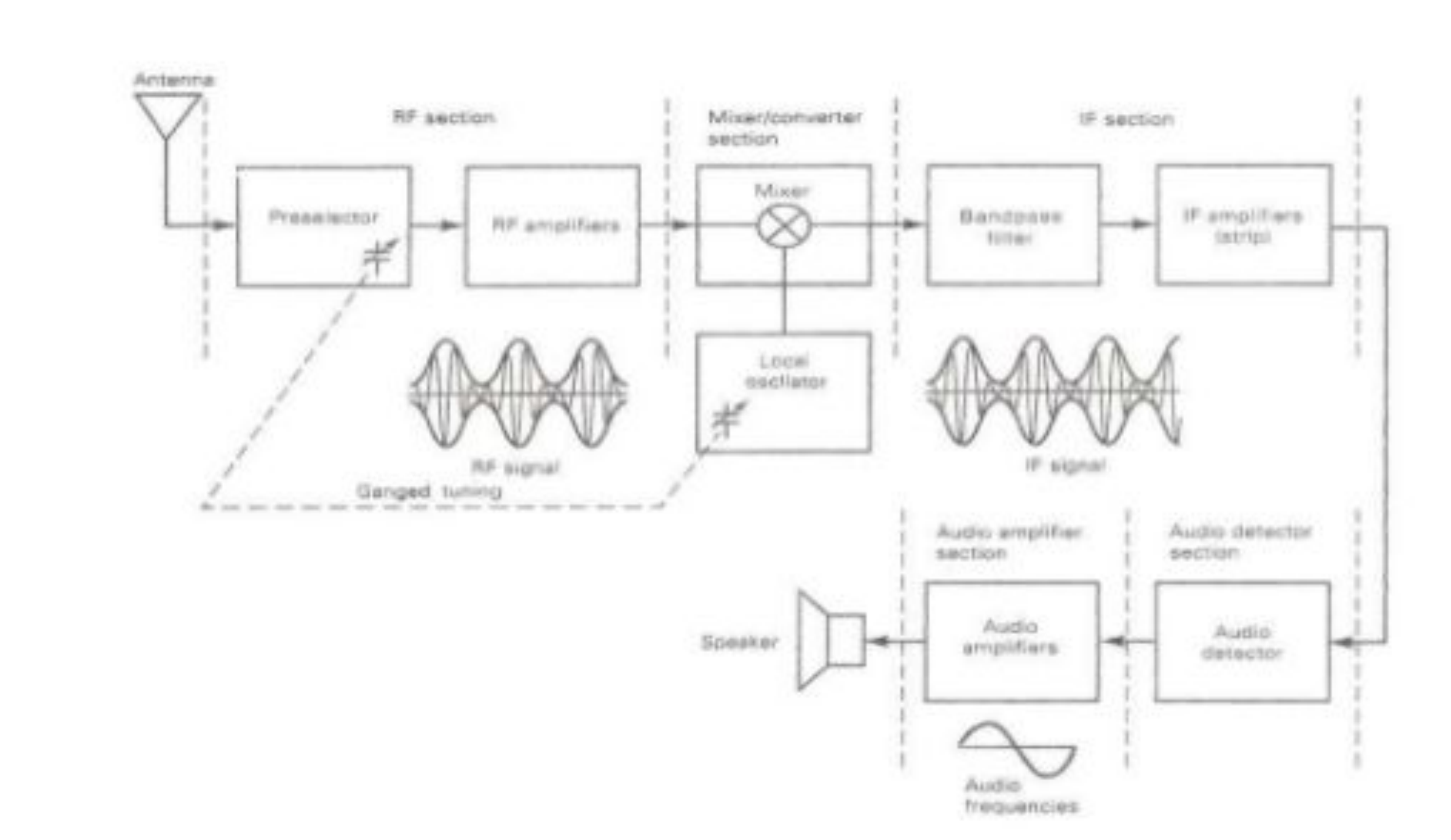
- The shortcomings of the TRF receiver are overcome by the invention of the super heterodyne receiver.
- A super heterodyne receiver converts all incoming radio frequency (RF) signals to a lower frequency known as an intermediate frequency (IF).



Superhetrodyne Receiver



Super heterodyne receiver

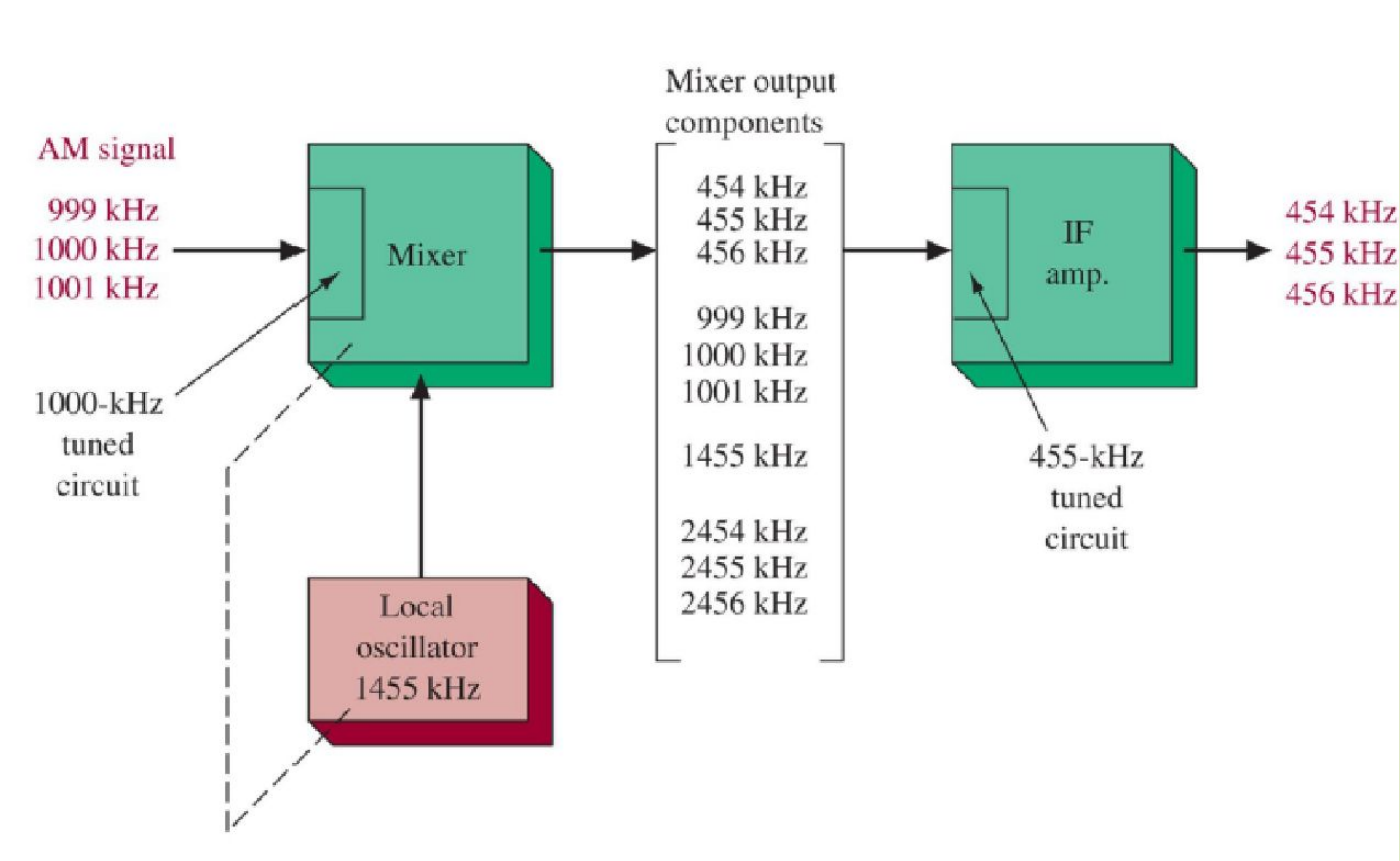


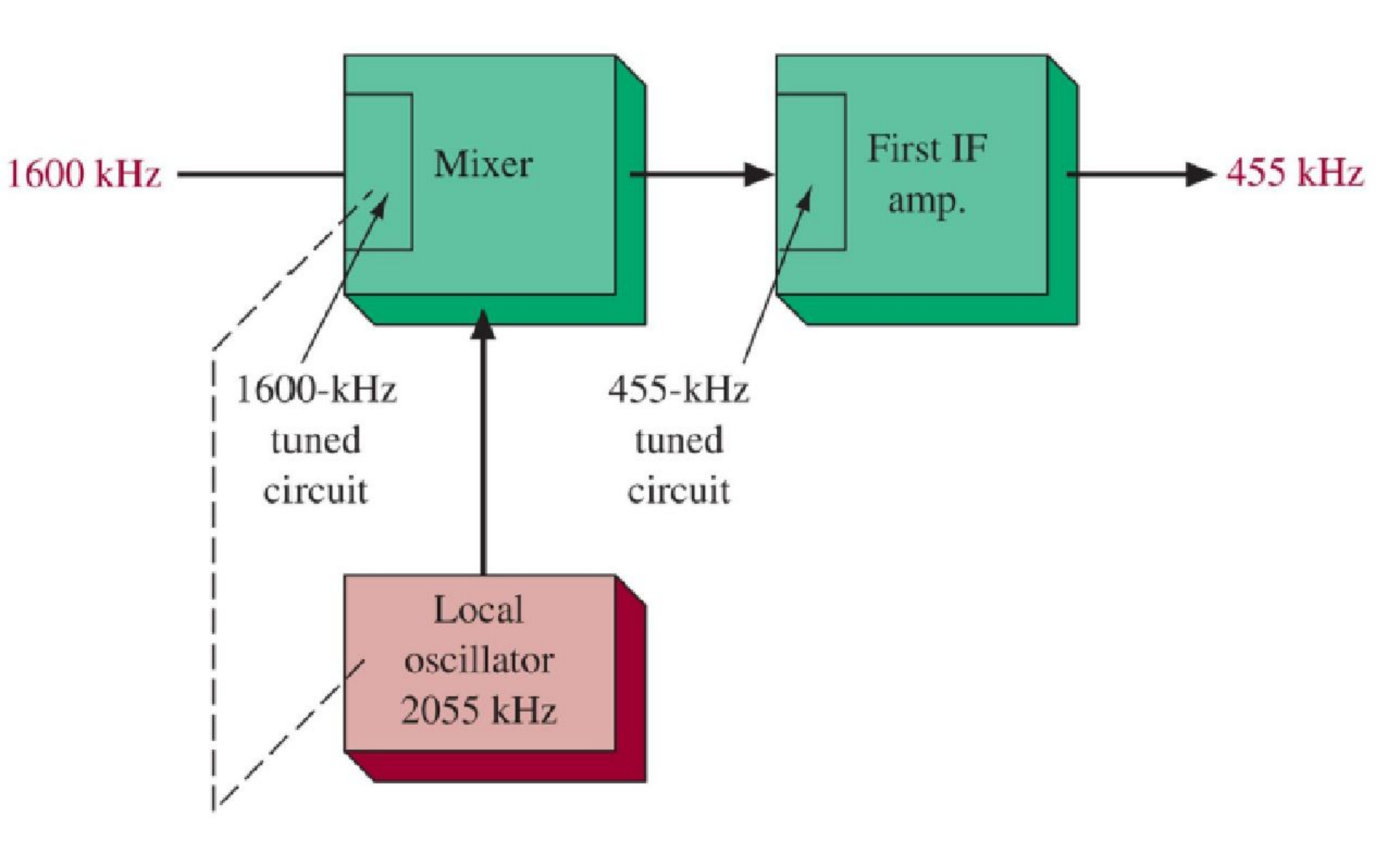
RF section

- Consists of a pre-selector and an amplifier
- Pre-selector is a broad-tuned bandpass filter with an adjustable center frequency used to reject unwanted radio frequency and to reduce the noise bandwidth.
- RF amplifier determines the sensitivity of the receiver and a predominant factor in determining the noise figure for the receiver.

- **Mixer/converter section**
  - Consists of a radio-frequency oscillator and a mixer.
  - Choice of oscillator depends on the stability and accuracy desired.
  - Mixer is a nonlinear device to convert radio frequency to intermediate frequencies (i.e. heterodyning process).

- The Mixer, being a nonlinear device, produces the following components:
  - Frequencies at all original inputs: f_{LO}, f_c , $f_c + f_i$, $f_c - f_i$,
  - Sum and difference components of all original inputs: $f_{LO} \pm f_c$, $f_{LO} \pm (f_c + f_i)$, $f_{LO} \pm (f_c - f_i)$
  - Harmonics of all above frequencies
  - A DC component
- The IF Amplifier is tuned to only accept components around 455 KHz: $f_{LO} - f_c$, $f_{LO} - (f_c + f_i)$ $f_{LO} - (f_c - f_i)$
- The IF Amplifier output is a replica of original AM signal, except that carrier frequency is now 455 KHz


AM signal
999 kHz
1000 kHz
1001 kHz
1000-kHz tuned circuit
Mixer
Local oscillator 1455 kHz
Mixer output components
454 kHz
455 kHz
456 kHz
999 kHz
1000 kHz
1001 kHz
1455 kHz
2454 kHz
2455 kHz
2456 kHz
IF amp.
455-kHz tuned circuit
454 kHz
455 kHz
456 kHz


1600 kHz
Mixer
First IF
amp.
455 kHz
1600-kHz
tuned
circuit
455-kHz
tuned
circuit
Local
oscillator
2055 kHz

The shape of the envelope, the bandwidth and the original information contained in the envelope remains unchanged although the carrier and sideband frequencies are translated from RF to IF

- **IF section**
  - Consists of a series of IF amplifiers and bandpassfilters to achieve most of the receiver gain and selectivity.
  - The IF is always lower than the RF because it is easier and less expensive to construct high-gain, stable amplifiers for low frequency signals.
  - IF amplifiers are also less likely to oscillate than their RF counterparts.

Detector section

To convert the IF signals back to the original source information (demodulation).

Can be as simple as a single diode or as complex as a PLL or balanced demodulator.

Audio amplifier section

Comprises several cascaded audio amplifiers and one or more speakers

AGC (Automatic Gain Control)

- Adjust the IF amplifier gain according to signal level(to the average amplitude signal almost constant).
- AGC is a system by means of which the overall gain of radio receiver is varied automatically with the variations in the strength of received signals, to maintain the output constant.
- AGC circuit is used to adjust and stabilize the frequency of local oscillator.

Types of AGC –

- No AGC
- Simple AGC
- Delayed AGC
- FREQUENCY CONVERSION in the mixer stage is identical to the frequency conversion in the modulator except that in the receiver, the frequencies are down-converted rather that up-converted.
  - In the mixer, RF signals are combined with the local oscillator frequency
  - The local oscillator is designed such that its frequency of oscillation is always above or below the desired RF carrier by an amount equal to the IF center frequency.
  - Therefore the difference of RF and oscillator frequency is always equal to the IF frequency
  - The adjustment for the center frequency of the pre-selector and the local oscillator frequency are gang-tune (the two adjustments are tied together so that single adjustment will change the center frequency of the pre-selector and at the same time change the local oscillator)

- when local oscillator frequency is tuned above the RF – *high side injection*

when local oscillator frequency is tuned below the RF – *low side injection*

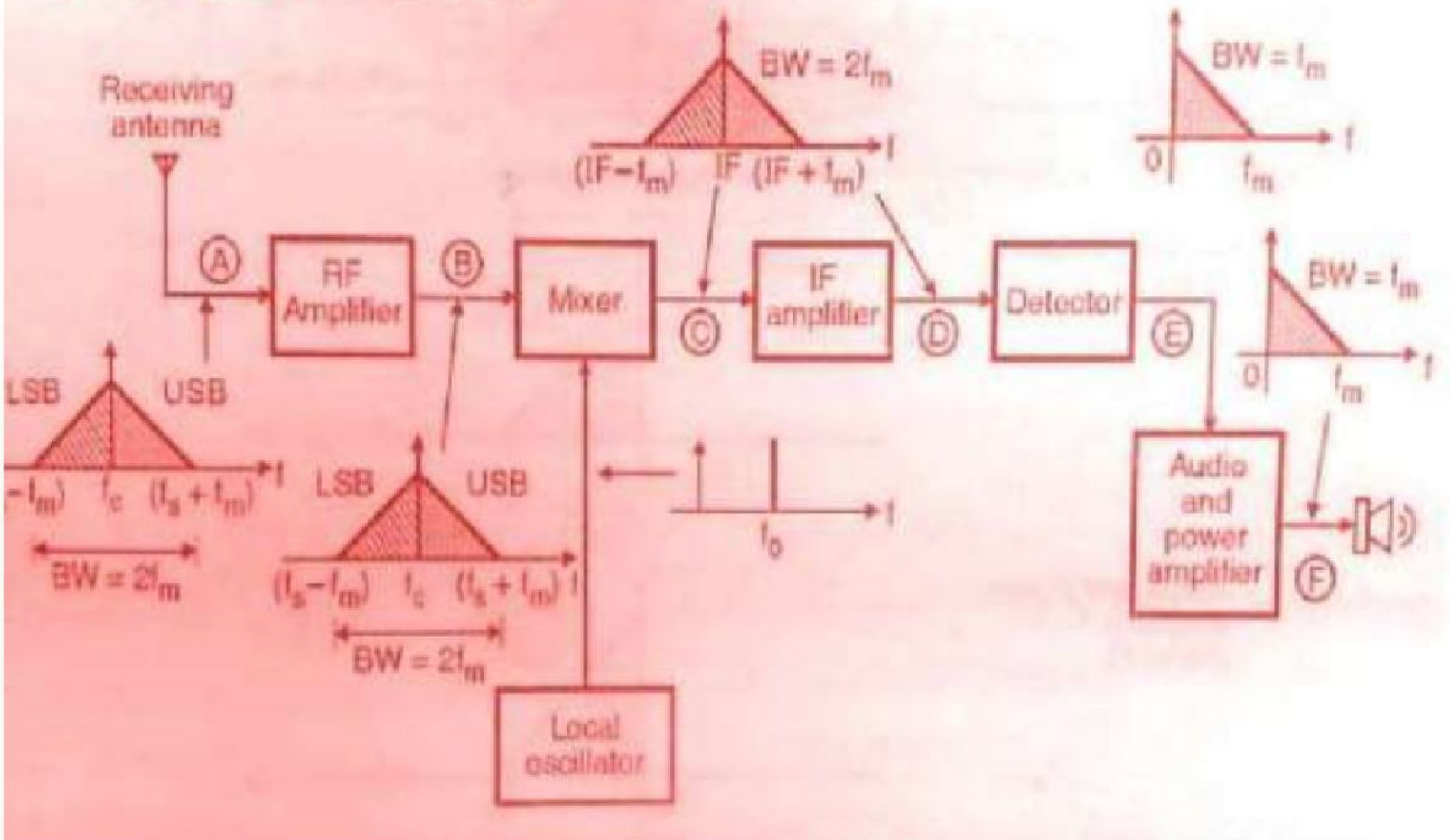
- Mathematically expressed :

$$f_{lo} = f_{RF} + f_{IF}$$ High side injection

$$f_{lo} = f_{RF} - f_{IF}$$ Low side injection

SHRR with center freq.& B.W of each block

receiver as shown in Fig. 6.2.4(a).



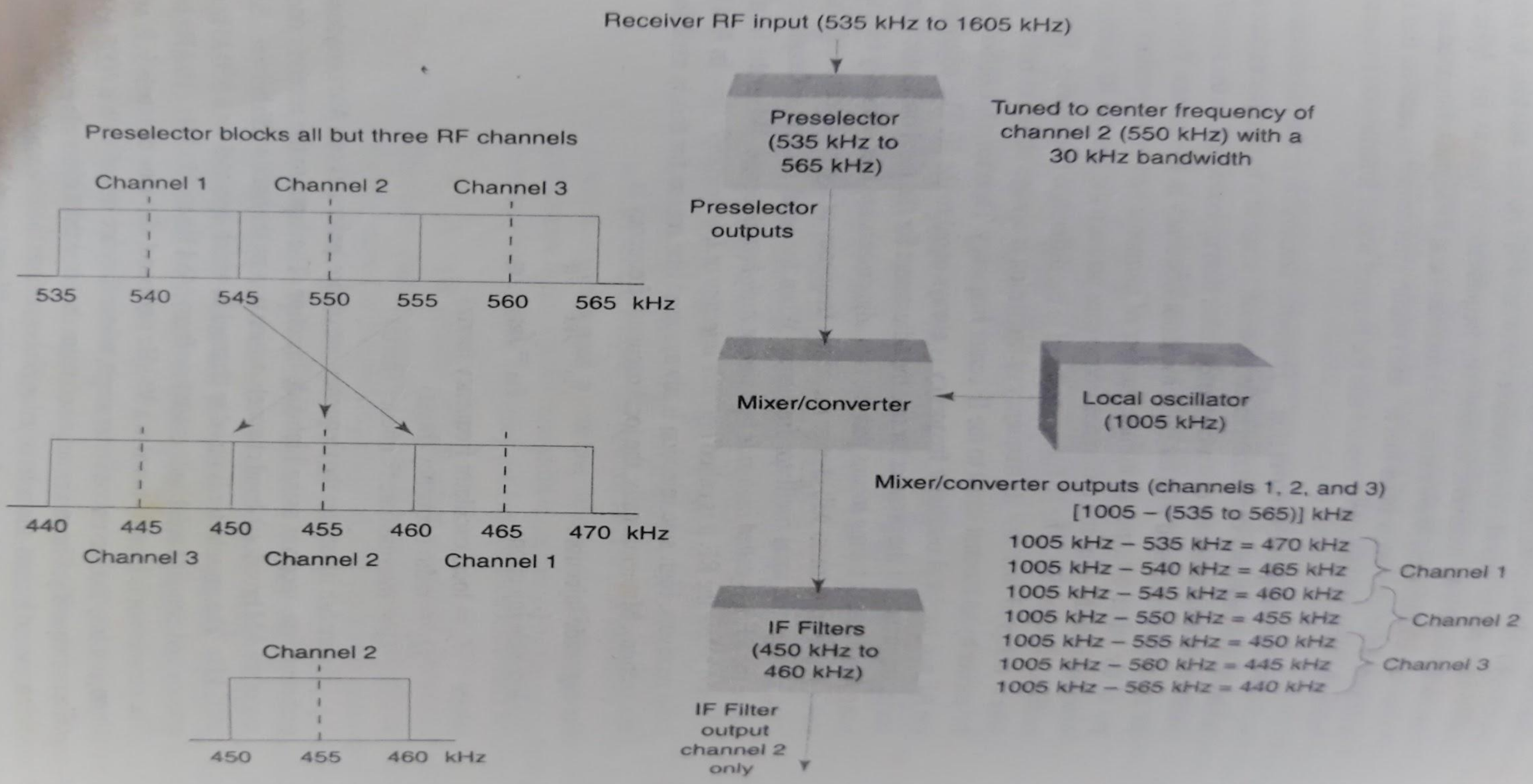


FIGURE 5-5 Superheterodyne receiver RF-to-IF conversion

Advantages of SHRR

- No variation in bandwidth. It remains constant over the entire frequency range.
- High selectivity & sensitivity
- High adjacent channel rejection

COMPARISON

TRF Receiver	Super hetrodyne Receiver
• No frequency conversion	• Frequency conversion
• No IF frequency	• Downconvert RF signal to lower IF frequency
• Instability , variation in BW and poor selectivity due to high frequencies	• No instability, variation in BW and poor selectivity as IF introduced.
• Difficult to design tunable RF stages.	• Main amplifixcation takes place at IF
• Rarely used	• Mostly used

Characteristics of AM Radio Receiver

The performance of radio receiver is determined by its characteristics/ parameters.

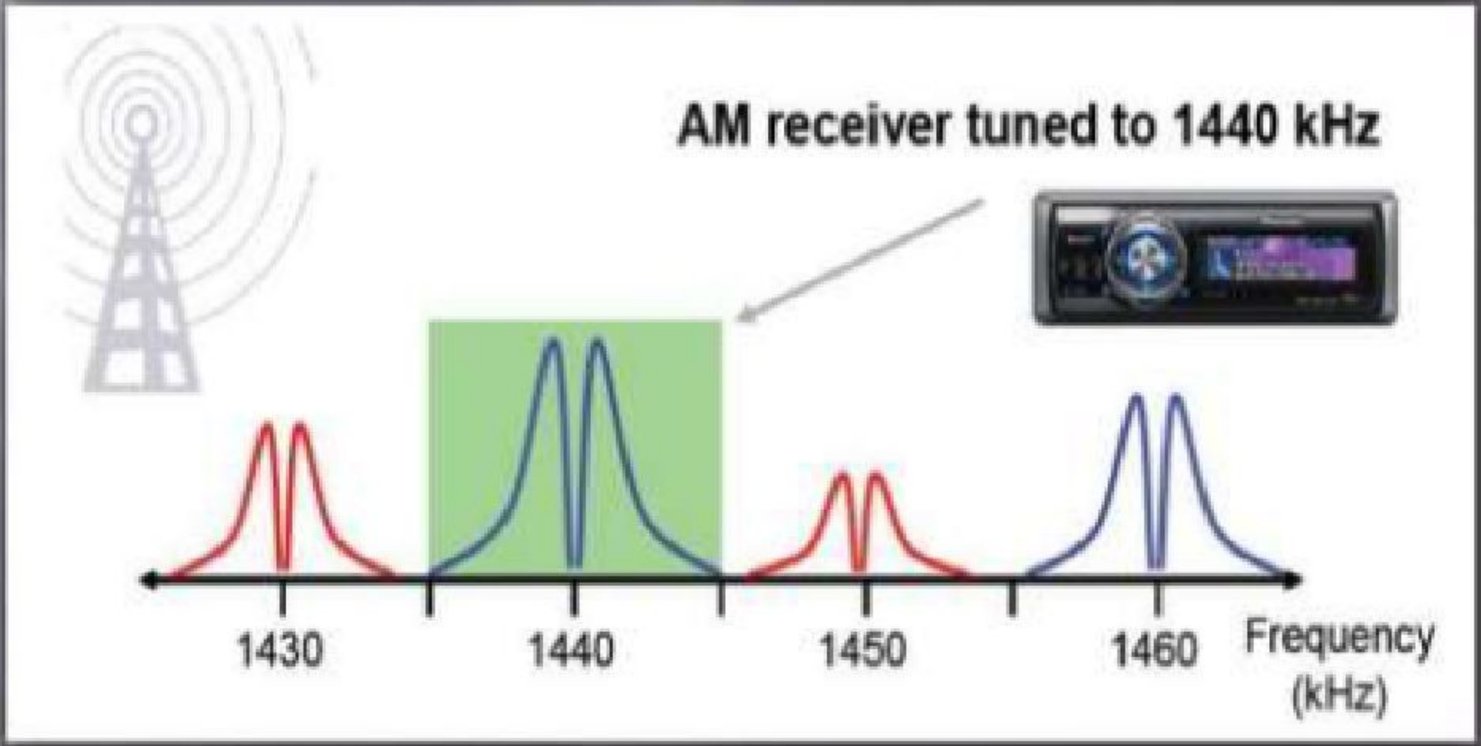
- These are of three types.

Characteristics of Radio Receiver

- Sensitivity
- Selectivity
- Fidelity

Selectivity

- Selectivity of radio receiver is its ability to accept a given band of frequencies & reject unwanted signals.



Sensitivity

- Ability to amplify weak signals.
- Minimum RF signal level that can be detected at the input to the receiver and still produce a usable demodulated information signal.
- Broadcast receivers/ radio receivers should have reasonably high sensitivity so that it may have good response to the desired signal
- But should not have excessively high sensitivity otherwise it will pick up all undesired noise signals.
- It is function of receiver gain and measures in decibels.

- ✓ Sensitivity of a receiver is expressed in microvolts of the received signal.
- ✓ Typical sensitivity for commercial broadcast-band AM receiver is 50 μV.

Sensitivity of the receiver depends on :

- ✓ Noise power present at the input to the receiver
- ✓ Receiver noise figure
- ✓ Bandwidth improvement factor of the receiver

The best way to improve the sensitivity is to reduce the noise level.

Fidelity= Is A Measure Of The Ability Of A Communications System To Produce At The Output Of The Receiver, An Exact Replica Of The Original Source Information

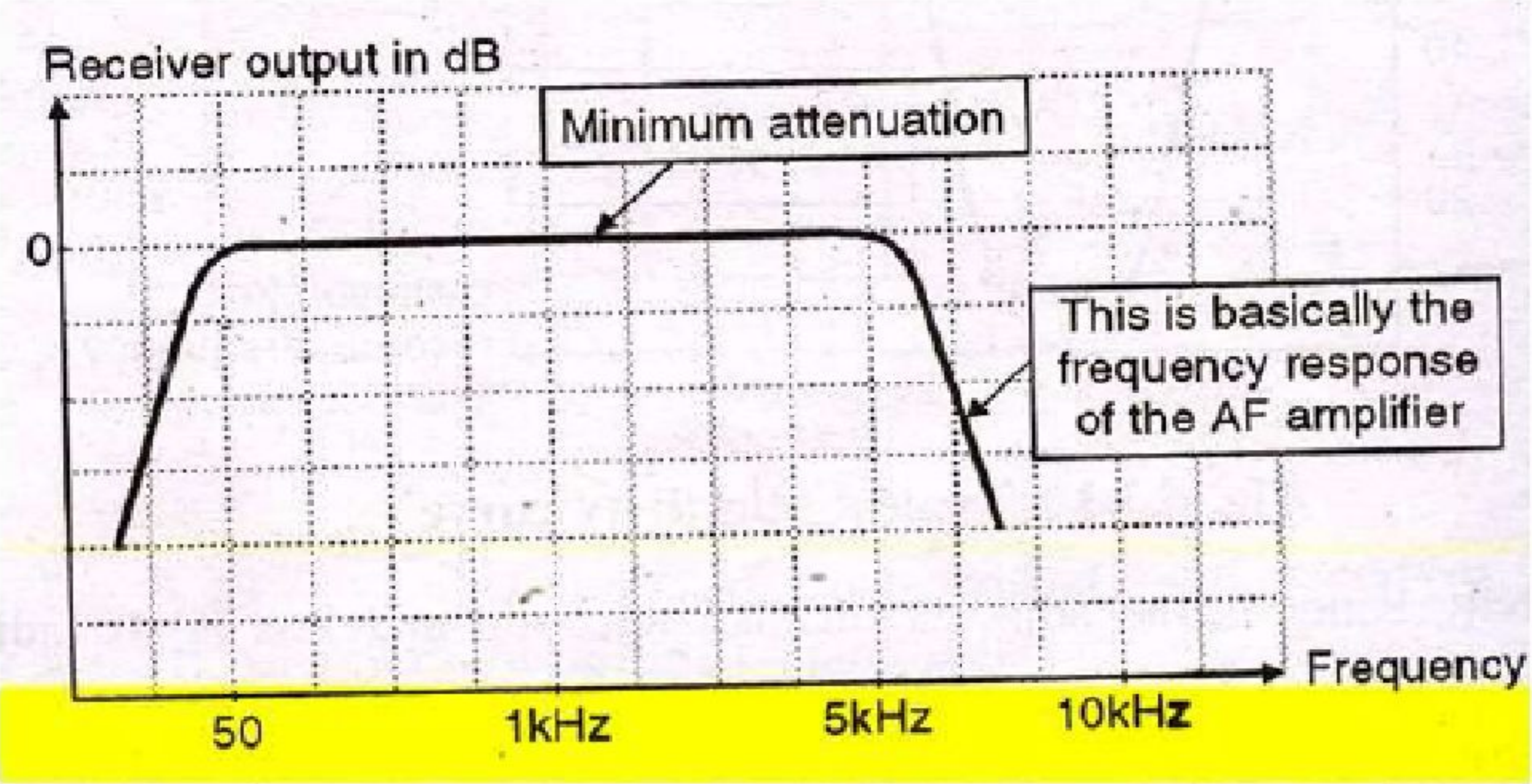


Fig. 5.3.4 : Fidelity curve

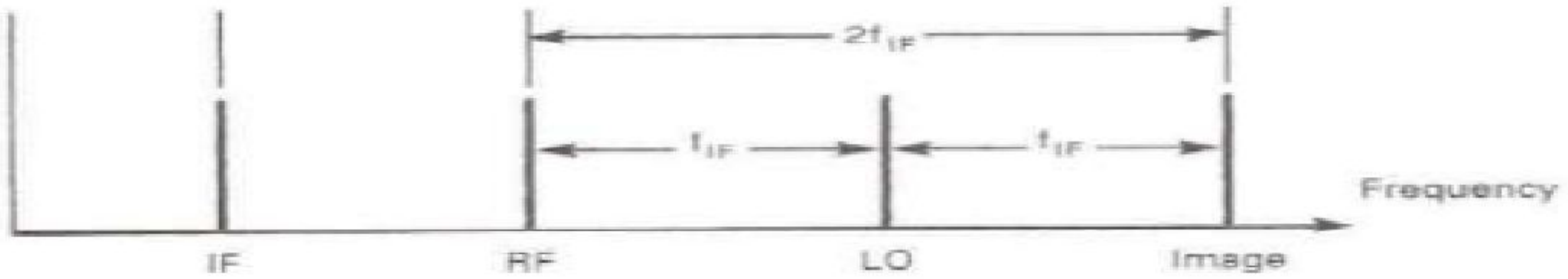
IMAGE FREQUENCY:

- In radio reception using heterodyning in the tuning process, an undesired input frequency that is capable of producing the same intermediate frequency (IF) that the desired input frequency produces.
- Image frequency – *any frequency other than the selected radio frequency carrier that will produce a cross-product frequency that is equal to the intermediate frequency if allowed to enter a receiver and mix with the local oscillator.*
- It is given by signal frequency plus twice the intermediate frequency

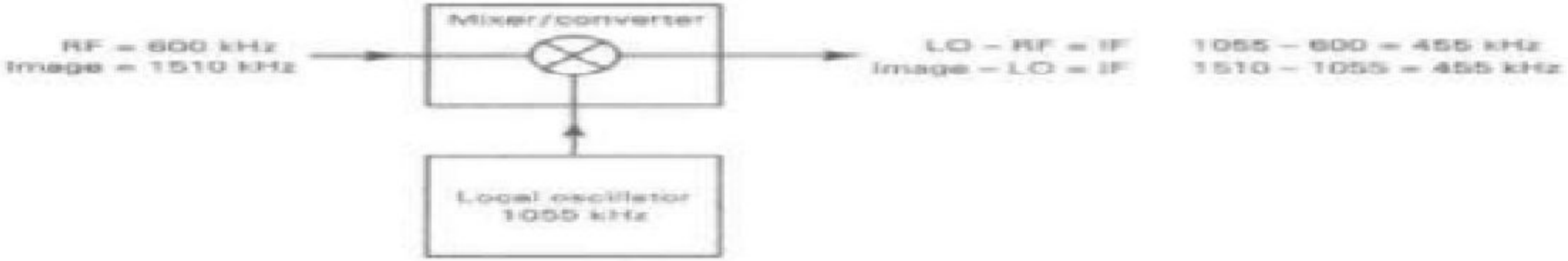
$f_{si} = f_s + 2f_i$

- It is equivalent to a second radio frequency that will produce an IF that will interfere with the IF from the desired radio frequency.
    - if the selected RF carrier and its image frequency enter a receiver at a same time, they both mix with the local oscillator frequency and produce different frequencies that are equal to the IF.
    - Consequently, two different stations are received and demodulated simultaneously
    - The higher the IF, the farther away the image frequency is from the desired radio frequency. Therefore, for better image frequency rejection, a high IF is preferred.

However, the higher the IF, it is more difficult to build a stable amplifier with high gain. i.e. there is a trade-off when selecting the IF for a radio receiver (image frequency rejection vs IF gain andstability.



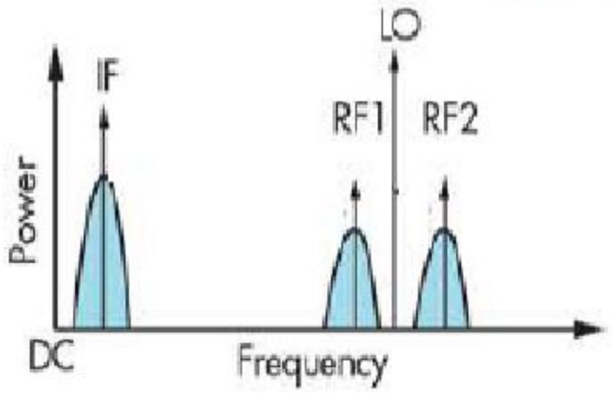
- Once an image frequency has down-converted to IF, it cannot be removed. In order to reject the image frequency, it has to be blocked prior to the mixer stage. i.e. the bandwidth of the pre-selector must be sufficiently narrow to prevent image frequency from entering the receiver.



CHOICE OF IF:

- Very high IF will result in poor selectivity and poor adjacent channel rejection
- A high value of IF will result in tracking difficulties
- At low values of IF image frequency rejection is poor. Also the selectivity will be too sharp that cut off the sidebands

RF1 -- Desired
RF2 -- Image



IF = LO - RF1 (Desired)
IF = RF2 - LO (Image)

Image Frequency rejection Ratio

$$IFRR = \alpha = \frac{Gain at signal freq}{Gain at image freq} = \sqrt{1+Q^2\rho^2}$$

Where Q= Loaded Q of the tuned ckt.

$$\rho = \frac{fsi}{fs} - \frac{fs}{fsi}$$

If two tuned ckts are there then

$$IFRR = \alpha 1 * \alpha 2$$

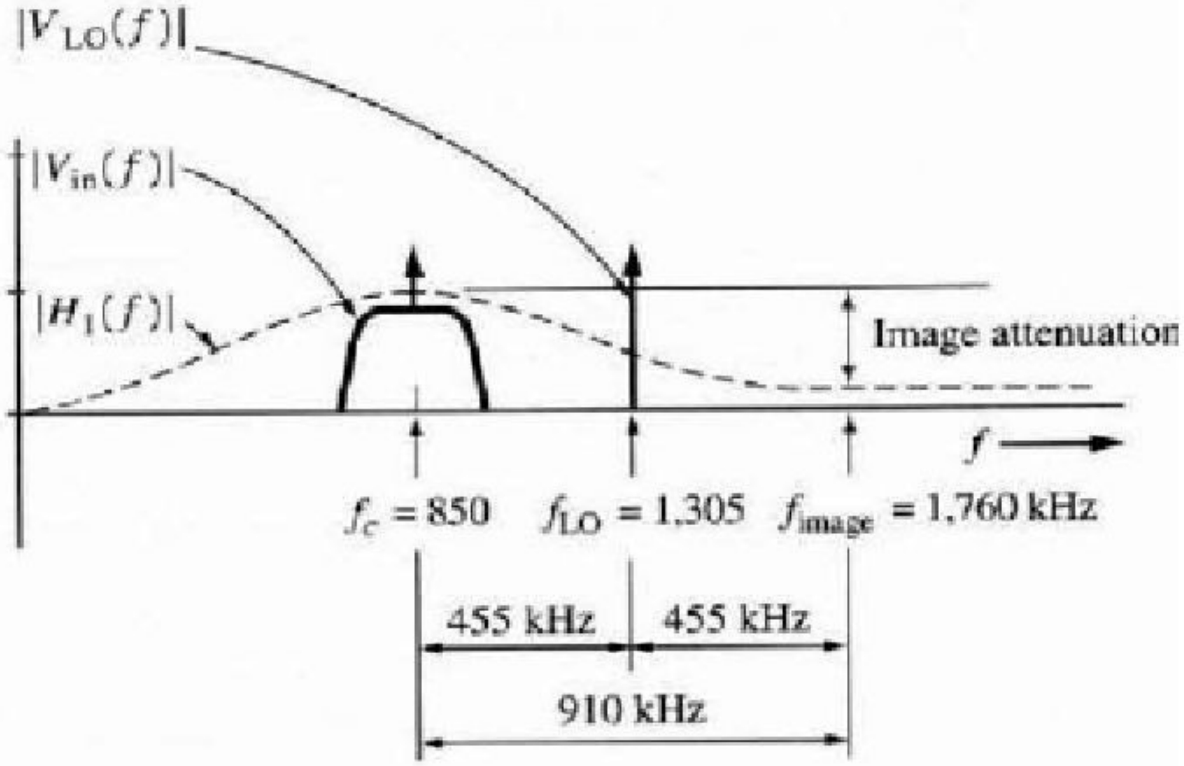
Superheterodyne Receiver Frequencies

- Incoming RF signal: $f_c = 850 \text{ kHz}$ IF signal: $f_{IF} = 455 \text{ kHz}$
- Up-side conversion: $f_{LO} = f_c + f_{IF} = 1305 \text{ kHz}$
- Image frequency: $f_{image} = f_{LO} + f_{IF} = f_c + 2f_{IF} = 1760 \text{ kHz}$

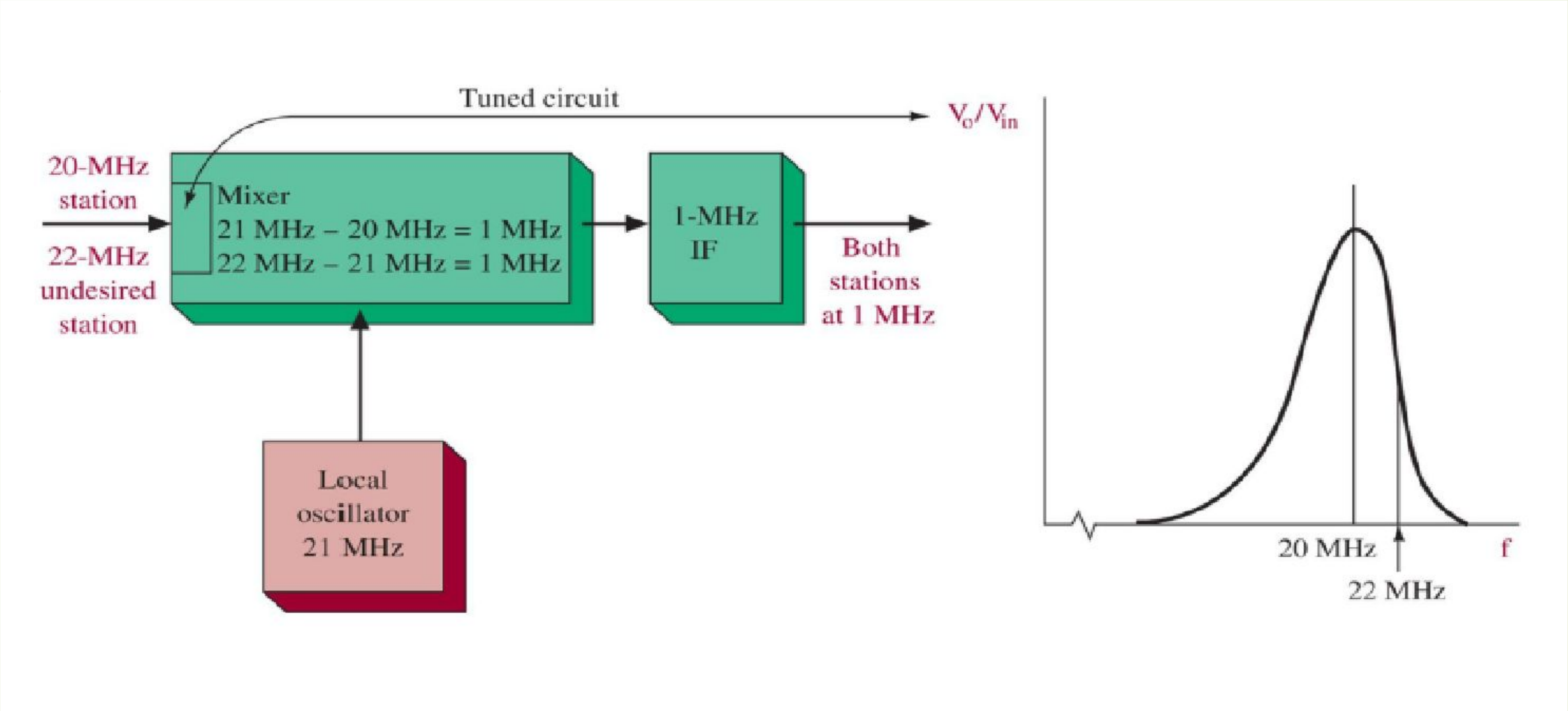
Note: image rejection is due to RF amplifier only!

IF must be high enough to reject the image response.

On the other hand, IF must be low enough to provide large gain and adjacent channel rejection.



Double spotting



Given Data:

Quality factor, Q = 150

Intermediate frequency, f_{IF} = 455 kHz

Signal frequency, f_s =1400 kHz

To find :

Image signal frequency, f_{si} = ?

Rejection ratio, α = ?

Solution:

Image frequency f_{si} is given by:

$$f_{si} = f_s + 2f_{IF}$$
$$= 1400 + 2(455)$$
$$f_{si} = 2310kHz$$

Image frequency rejection ratio (α) is given by:

$$\alpha = \sqrt{(1 + Q^2\rho^2)}$$
$$\rho = f_{\frac{si}{f_s}} - \frac{f_s}{f_{si}}$$
$$= \frac{2310}{1400} - \frac{1400}{2310} = 1.043$$
$$\alpha = \sqrt{(1 + (150^2 \times 1.043^2))} = 156.453$$

α in dB is given as:

α in dB=20 log α

α = 20 log156.452 = **43.887 dB**

Thus the image frequency is 2310 kHz and its rejection ratio is 43.887

Image Frequency Rejection Ratio

- Is defined as the ratio of voltage gain at the input frequency to which the receiver is tuned to gain the image frequency.
- Numerical measure of the preselector ability to reject the image frequency.

The Image Rejection, IR, $\alpha = \sqrt{1 + Q^2 \rho^2}$

where The rejection ratio $\rho = \frac{f_{im}}{f_{RF}} - \frac{f_{RF}}{f_{im}} = \frac{fsi}{fs} - \frac{fs}{fi}$

$Q =$ Quality factor of tuned circuit

$= \frac{X_L}{R} = f/B$ where $B = bandwidth$

$IR(dB) = 20 \log \alpha$

Example 3.2

Determine the image frequency for a standard broadcast band receiver using 455-kHz IF and tuned to station at 620 kHz.

The first is determine the frequency of the LO

The LO frequency minus the desired station's frequency of 620 kHz should equal the IF of 455 KHz

Hence,

$$fLO - 620\text{ kHz} = 455\text{ kHz}$$
$$fLO = 620\text{ KHz} + 455\text{ kHz}$$
$$fLO = 1075\text{ kHz}$$

Now determine what other frequency, when mixed with 1075 kHz, yields an output component at 455 kHz

$$X - 1075\text{ kHz} = 455\text{ kHz}$$
$$X = 1075\text{ kHz} + 455\text{ kHz}$$
$$X = 1530\text{ kHz}$$

Thus, 1530 is the <u>image frequency</u> in this situation. To solve the problem associated with image frequency, sometimes a technique known as double conversion is employed.

Advantages/disadvantages

Advantages of Amplitude Modulation, AM

There 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.

Disadvantages of amplitude modulation

Amplitude modulation is a very basic form of modulation, and although its simplicity is one of its major advantages, other more sophisticated systems provide a number of advantages. Accordingly it is worth looking at some of the disadvantages of amplitude modulation.

- 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 twice 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.

Types of Modulation

Amplitude Modulation

$$V \cdot \sin(\omega * t + \Phi)$$

Phase Modulation

$$V \cdot \sin(\omega * t + \Phi)$$

Frequency Modulation

$$V \cdot \sin(\omega * t + \Phi)$$

With very few exceptions, phase modulation is used for digital information

Advantages over AM:

- Freedom from interference: all natural and external noise consist of amplitude variations, thus receiver usually cannot distinguish between amplitude of noise or desired signal. AM is noisy than FM.
- Operate in very high frequency band (VHF): 88MHz-108MHz
- Can transmit musical programs with higher degree of fidelity.

Angle Modulation

Angle Modulation

Frequency Modulation

Phase Modulation

What is Angle Modulation?

$$v_c(t) = V \cdot \sin(2 \cdot \pi \cdot f_c \cdot t + \text{phase})$$

Amplitude

Frequency

Phase

$$\text{Phase} = \Phi$$

$$\text{Frequency} = \frac{\Delta\Phi}{\Delta t}$$

Angle modulation is a variation of one of these two parameters.

Understanding Angle Modulation

Frequency Modulation

Phase Modulation

Angle modulation, either PM or FM, varies the frequency or phase of the carrier wave. Because of the practicalities of implementation, FM is predominant; analog PM is only used in rare cases.

$$V \cdot \sin(\omega * t + \Phi)$$

Vary one of these parameters

Angle Modulation – Basic Concepts

- Phase modulation (PM) & Freq modulation (FM) are special cases of angle modulated signaling.
- Complex envelope is $g(t)=A_c e^{j\theta(t)}$
  - Real envelope $R(t) = |g(t)| = A_c = constant$
  - Phase $\theta(t)$ is linear function of modulating signal $m(t)$
    - $g(t)$ being a nonlinear function of modulation
- Angle modulated signal $s(t) = A_c \cos[\underbrace{\omega_c t + \theta(t)}_{\Phi_i(t)}]$

Definitions:

- $\theta(t)$ is the instantaneous phase deviation (excess phase) - radian
- $\theta'(t)$ is the instantaneous frequency deviation – radian/sec
- $\Phi_i(t)=\omega_c t + \theta(t)$ is the instantaneous phase (exact) - radian
- $f_i(t)=(1/2p)d\Phi_i(t)/dt = d(\omega_c t + \theta(t))/dt$
  - This is the instantaneous frequency (exact) – radian/sec

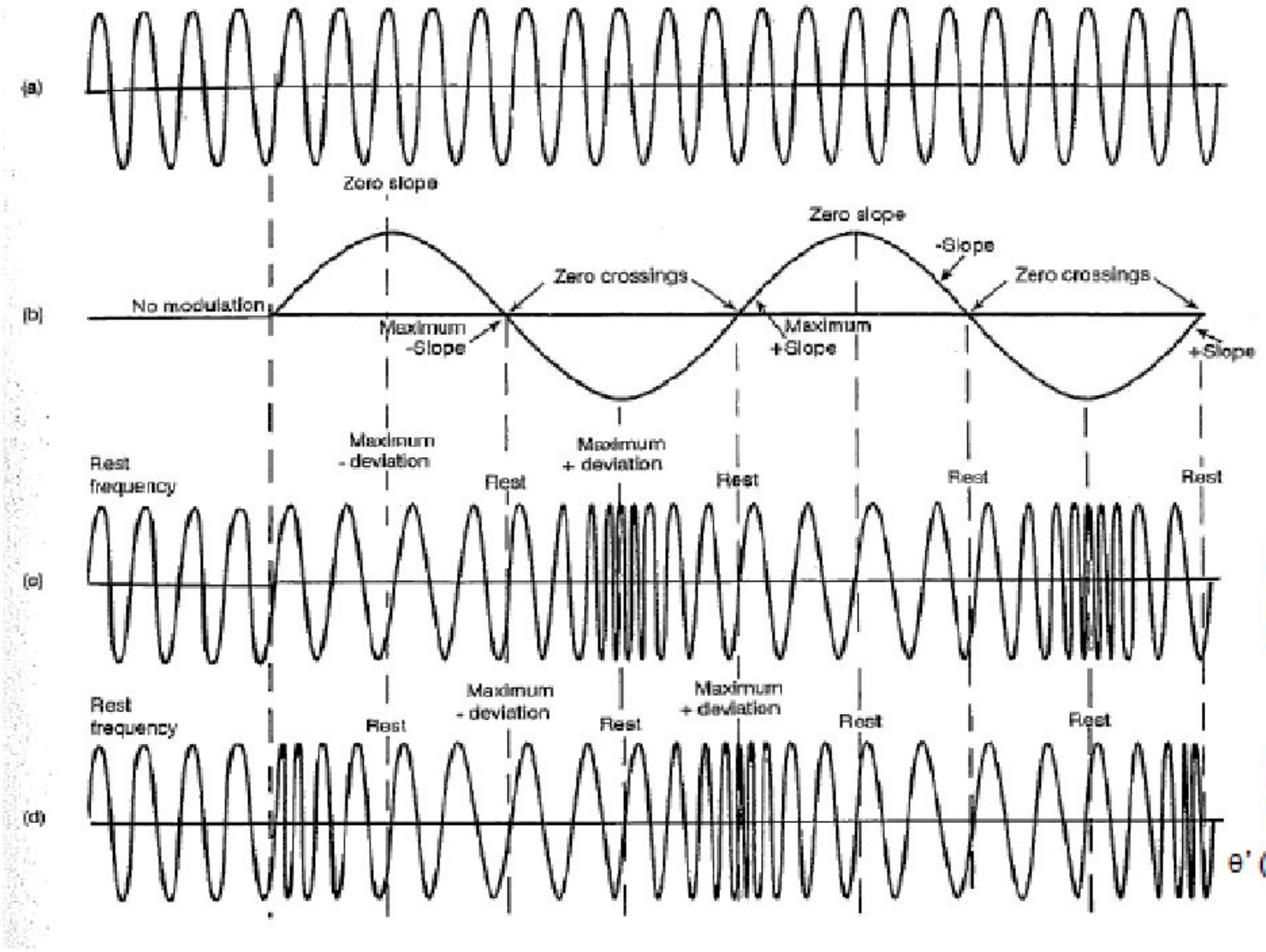
$$f_i(t) = \frac{\omega_i(t)}{2\pi} = \frac{1}{2\pi}\left[\frac{d\Psi(t)}{dt}\right] = f_c + \frac{1}{2\pi}\left[\frac{d\theta(t)}{dt}\right] \qquad \phi_i(t) = 2\pi\int_{-\infty}^{t} f_i(\alpha)d\alpha$$

Angle Modulation Representation

- Angle modulated signal $s(t) = A_c \cos[\omega_c t + \theta(t)]$
- For PM, $\theta(t) = D_p m(t)$ $=K\, m(t)$
  - $D_p =$ Constant called Phase deviation sensitivity (rad/V)
- For FM, $\theta(t) = D_f \int_{-\infty}^{t} m(\sigma) d\sigma$ $=K_1 m(t)$
  - $D_f =$ Constant called Freq. deviation sensitivity in ((rad/sec)/V) or $Df/2\pi$ = Hz/V

In PM: θ(t) is proportional to m(t) → θ(t) = Dp . m(t) →θ' (t) = Dp . d [m(t)] / dt → Max. Instant. Frequency Deviation at Zero Crossing! In FM: θ' (t) is proportional to m(t) → θ' (t) = Df . m(t) → Max. Instant. Frequency Deviation at max[m(t)]

Frequency VS Phase Modulation



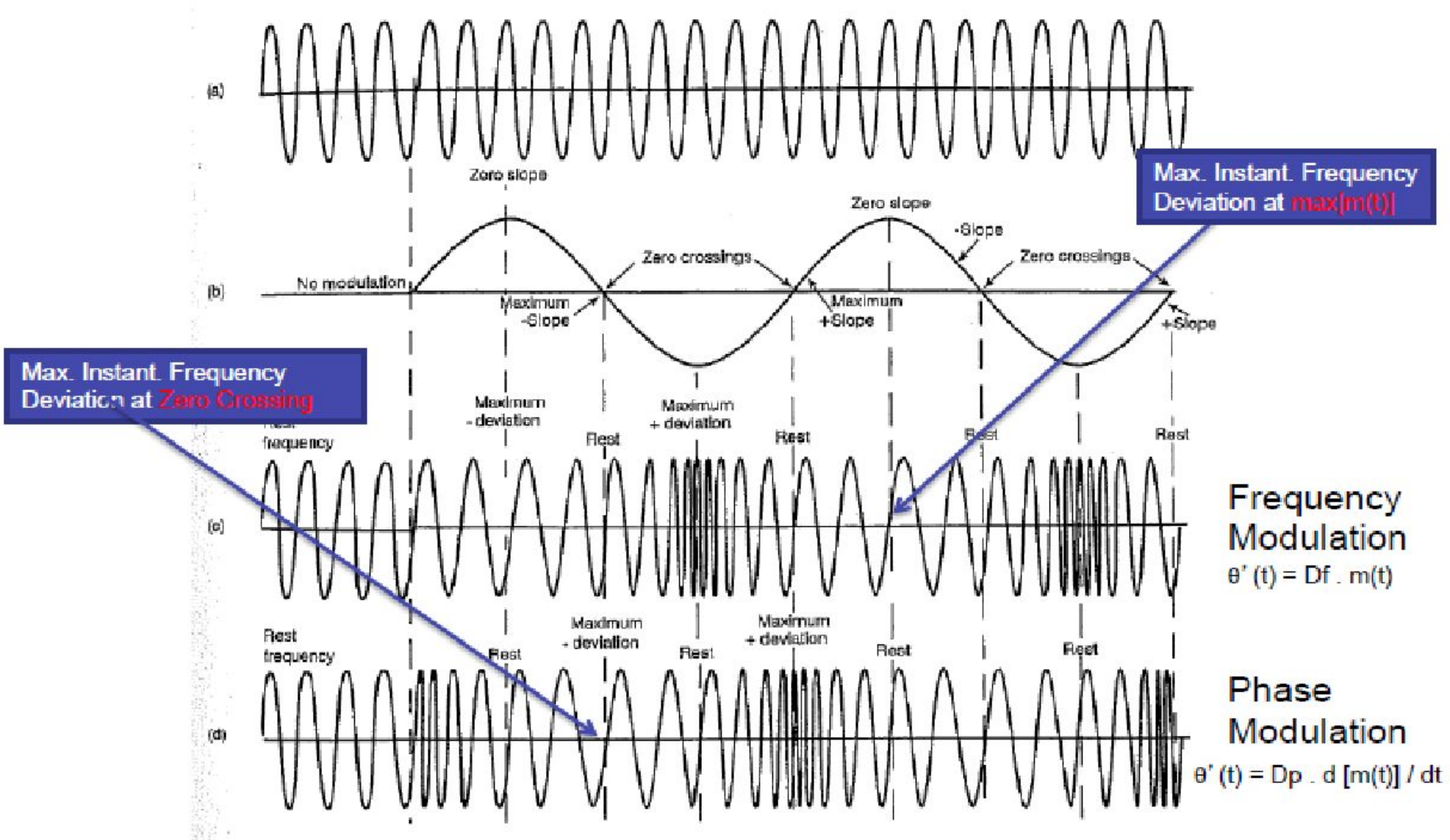
Frequency Modulation

$\theta'(t) = Df \cdot m(t)$

Phase Modulation

$\theta'(t) = Dp \cdot d[m(t)] / dt$

Frequency VS Phase Modulation

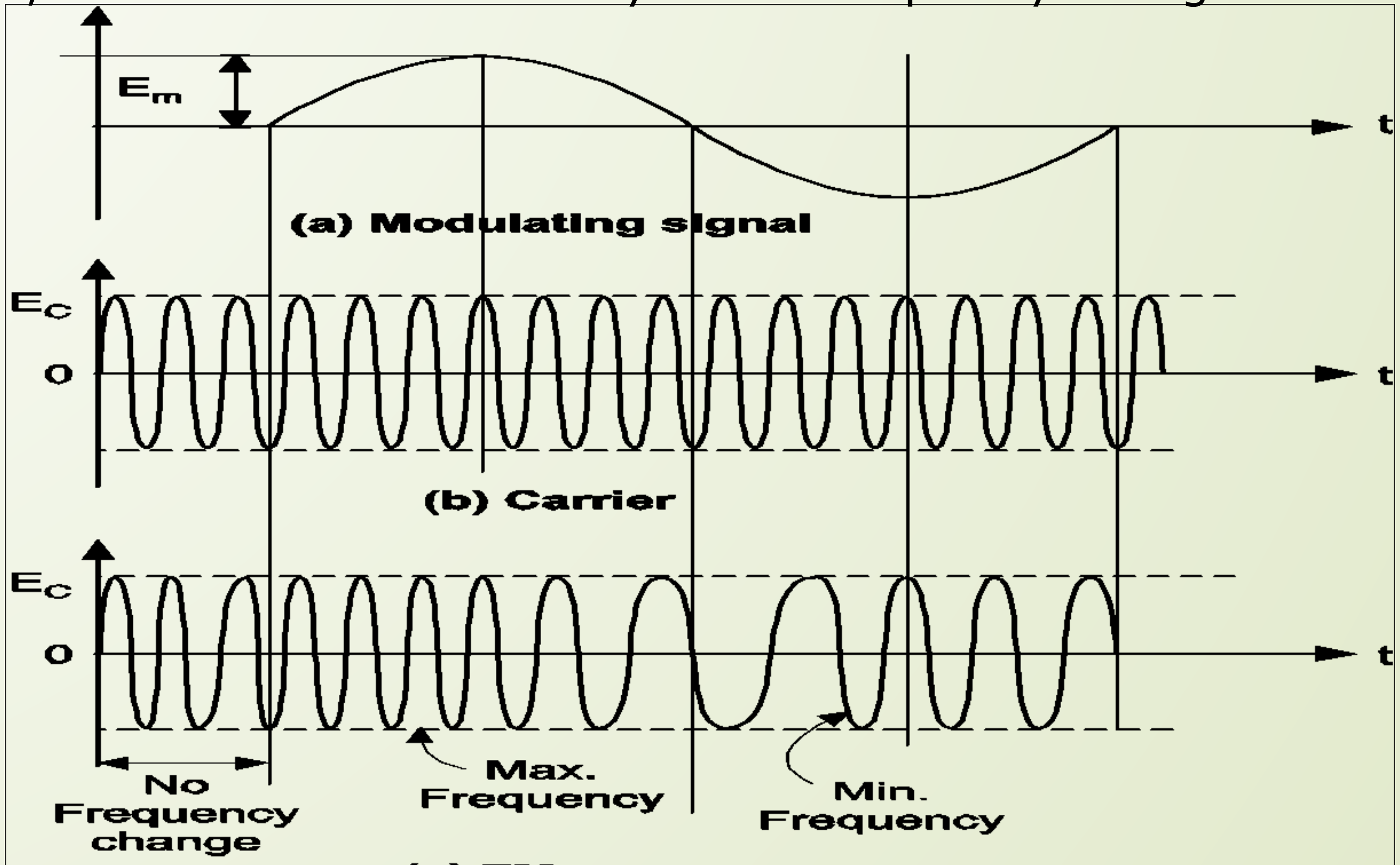


Frequency Modulation

Definition of FM:

Frequency modulation is a technique of modulation in which the frequency of carrier is varied in accordance with the amplitude of modulating signal.

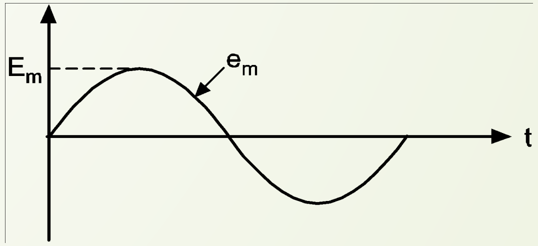
- In FM, amplitude and phase remains constant.
- Thus, the information is conveyed via. frequency changes



(c) FM wave (variation in frequency, amplitude and phase remains constant)

Mathematical Representation of FM

(i) Modulating Signal:



It may be represented as,

$$e_m = E_m \cos \omega_m t \qquad \ldots(1)$$

Here cos term taken for simplicity

where,

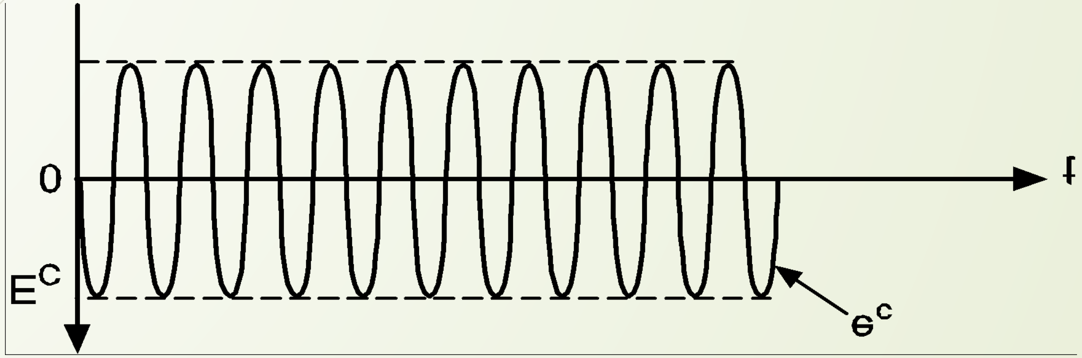
e_m = **Instantaneous amplitude**

ω_m = **Angular velocity**

= $2\pi f_m$

f_m = **Modulating frequency**

(ii) Carrier Signal:



Carrier may be represented as,

$$e_c = E_c \sin(\omega_{ct} + \varphi) \qquad \text{-----(2)}$$

where,

e_c = Instantaneous amplitude

ω_c = Angular velocity

= $2\pi f_c$

f_c = Carrier frequency

φ = Phase angle

(iii) FM Wave:

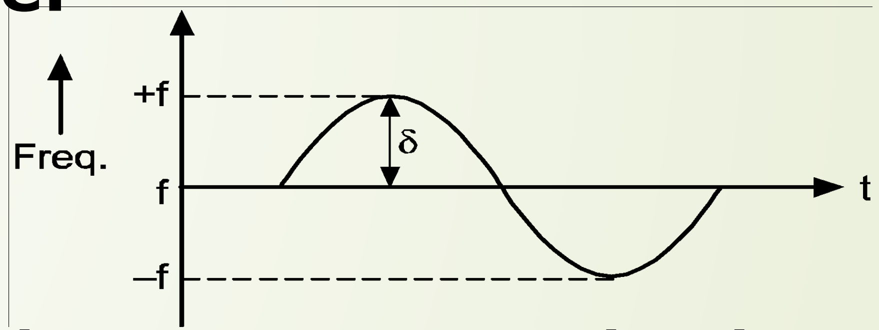


Fig. Frequency Vs. Time in FM

FM is nothing but a deviation of frequency.

it is seen that instantaneous frequency 'f' of the FM wave is given by,

$$\mathbf{f = f_c (1 + K E_m \cos \omega_m t)} \ldots (3)$$

where,

f_c = Unmodulated carrier frequency

K = Proportionality constant

$E_m \cos \omega_m t$ = Instantaneous modulating signal

(Cosine term preferred for simplicity otherwise we can use sine term also)

- The maximum deviation for this particular signal will occur, when

$\cos \omega_m t = \pm 1$ i.e. maximum.

∴ Equation (2.26) becomes,

$$\mathbf{f = f_c (1 \pm K E_m) \ldots (4)}$$

$$\therefore \quad \mathbf{f = f_c \pm K E_m f_c \ldots (5)}$$

So that maximum deviation δ will be given by,

$$\boldsymbol{\delta = K E_m f_c} \quad \dots (6)$$

The instantaneous amplitude of FM signal is given by,

$$e_{FM} = A \sin [f(\omega_c, \omega_m)]$$

$$= A \sin \theta \quad \dots (7)$$

where,

$f(\omega_c, \omega_m)$ = Some function of carrier and modulating frequencies

Let us write equation 3, in terms of ω as,

$$\boldsymbol{\omega = \omega_c (1 + K E_m \cos \omega_m t)}$$

To find θ, ω must be integrated with respect to time.

Thus,

$$\theta = \omega \, dt$$

$$= \omega_c (1 + K E_m \cos \omega_m t) \, dt$$

$$\theta = \omega_c (1 + K E_m \cos \omega_m t) \, dt$$

$$= \omega_c \left(t + KE_m \frac{\sin \omega_m t}{\omega_m}\right)$$

$$= \omega_c t + KE_m \omega_c \frac{\sin \omega_m t}{\omega_m}$$

$$= \omega_c t + KE_m f_c \frac{\sin \omega_m t}{f_m}$$

$$= \omega_c t + \frac{\delta}{f_m} \sin\omega_m t \quad [\because \quad \delta = K E_m f_c]$$

$\therefore$

Substitute value of θ in equation (7)

Thus,

$$e_{FM} = A \sin\left(\omega_c t + \frac{\delta}{f_m} \sin\omega_m t\right) \text{---(8)}$$

$$e_{FM} = A \sin\left(\omega_c t + m_f \sin\omega_m t\right) \text{---(9)}$$

This is the equation of FM.

- Therefore:

$$\Delta f = K_1 V_m ;$$

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

- K_l – deviation sensitivities Hz/V

Modulation Index

Definition:

Modulation Index is defined as the ratio of frequency deviation (δ) to the modulating frequency (f_m).

$$\text{M.I.} = \frac{\text{Frequency Deviation}}{\text{Modulating Frequency}}$$

$$mf = \frac{\delta}{fm}$$

In FM M.I.>1

Modulation Index of FM decides –

(i) Bandwidth of the FM wave.

(ii) Number of sidebands in FM wave.

Deviation Ratio

The modulation index corresponding to maximum deviation and maximum modulating frequency is called deviation ratio.

$$\text{Deviation Ratio} = \frac{\text{Maximum Deviation}}{\text{Maximum modulating Frequency}}$$

$$= \frac{\delta max}{fmax}$$

In FM broadcasting the maximum value of deviation is limited to **75 kHz.** The maximum modulating frequency is also limited to **15 kHz.**

Percentage M.I. of FM

The percentage modulation is defined as the ratio of the actual frequency deviation produced by the modulating signal to the maximum allowable frequency deviation.

$$\% \text{ M.I} = \frac{\text{Actual deviation}}{\text{Maximum allowable deviation}}$$

$\therefore$

Example 1 (FM)

- Determine the peak frequency deviation (Δf) and modulation index (m) for an FM modulator with a deviation sensitivity K_1 = 5 kHz/V and a modulating signal,

$$v_m(t) = 2\cos(2\pi 2000t)$$

Summary

	FM	PM
Modulated wave	$m(t) = V_c \cos\left[\omega_c t + \frac{K_1 V_m}{f_m}\sin(\omega_m t)\right]$	$m(t) = V_c \cos[\omega_c t + K V_m \cos(\omega_m t)]$
or	$m(t) = V_c \cos[\omega_c t + m \sin(\omega_m t)]$	$m(t) = V_c \cos[\omega_c t + m \cos(\omega_m t)]$
or	$m(t) = V_c \cos\left[\omega_c t + \frac{\Delta f}{f_m}\sin(\omega_m t)\right]$	$m(t) = V_c \cos[\omega_c t + \Delta\theta \cos(\omega_m t)]$
Deviation sensitivity	K_1 (Hz/V) =Df	K (rad/V) =Dp
Deviation	$\Delta f = K_1 V_m$ (Hz)	$\Delta\theta = K V_m$ (rad)
Modulation index	$m = \frac{K_1 V_m}{f_m}$ (unitless)	$m = K V_m$ (rad)
or	$m = \frac{\Delta f}{f_m}$ (unitless)	$m = \Delta\theta$ (rad)
Modulating signal	$v_m(t) = V_m \sin(\omega_m t)$	$v_m(t) = V_m \cos(\omega_m t)$
Modulating frequency	$\omega_m = 2\pi f_m$ rad/s	$\omega_m = 2\pi f_m$ rad/s
or	$\omega_m/2\pi = f_m$ (Hz)	$\omega_m/2\pi = f_m$ (Hz)
Carrier signal	$V_c \cos(\omega_c t)$	$V_c \cos(\omega_c t)$
Carrier frequency	$\omega_c = 2\pi f_c$ (rad/s)	$\omega_c = 2\pi f_c$ (rad/s)
or	$\omega_c/2\pi = f_c$ (Hz)	$\omega_c/2\pi = f_c$ (Hz)

Note K = D = Sensitivity; Vm = max [m(t)]=max [Vm(t)] = Modulating Signal
m modulation index; ΔF=Δf;

Bessel Function for Angle Modulation

- In general the modulated signal (s(t)) is

$$V_c \cos[\omega_c t + m \cos(\omega_m t)]$$

$$\cos(\alpha + m \cos \beta) = \sum_{n=-\infty}^{\infty} J_n(m) \cos\left(\alpha + n\beta + \frac{n\pi}{2}\right)$$

$$S(t) = V_c \sum_{n=-\infty}^{\infty} J_n(m) \cos\left(\omega_c t + n\omega_m t + \frac{n\pi}{2}\right)$$

- The Bessel Function:

$$J_n(m) = \left(\frac{m}{2}\right)^n \left[\frac{1}{n} - \frac{(m/2)^2}{1!(n+1)!} + \frac{(m/2)^4}{2!(n+2)!} - \frac{(m/2)^6}{3!(n+1)!} + \cdots\right]$$

where $! =$ factorial $(1 \times 2 \times 3 \times 4$, etc.)
$n = J$ or number of the side frequency
$m =$ modulation index

Bessel Function for Angle Modulation

$$S(t) = V_c\Big\{J_0(m)\cos\omega_c t + J_1(m)\cos\left[(\omega_c+\omega_m)t+\frac{\pi}{2}\right]$$

$$-J_1(m)\cos\left[(\omega_c-\omega_m)t-\frac{\pi}{2}\right]+J_2(m)\cos[\omega_c+2\omega_m t]$$

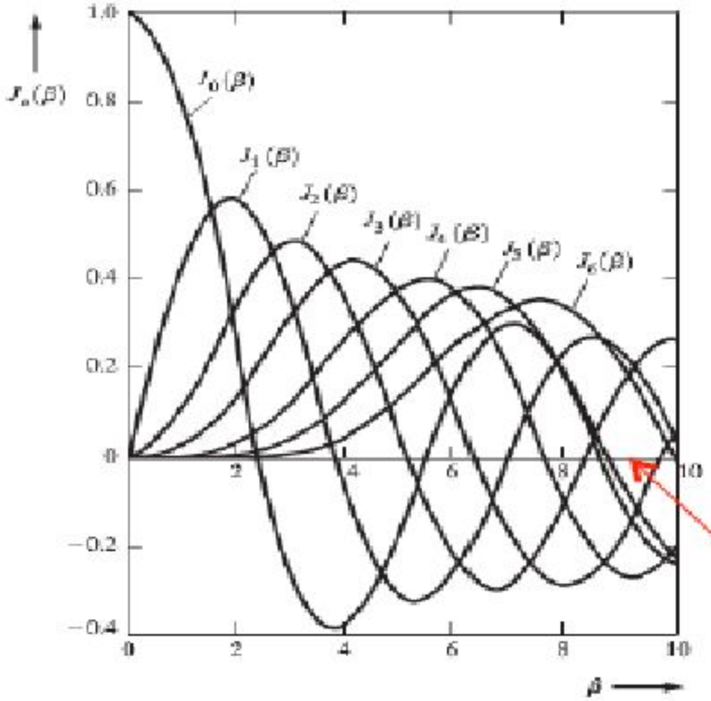
$$+J_2(m)\cos[\omega-2\omega_m t]+\cdots J_n(m)\cdots\Big\}$$

S(t) = angle-modulated wave
m = modulation index
V_c = peak amplitude of the unmodulated carrier
$J_0(m)$ = carrier component
$J_1(m)$ = first set of side frequencies displaced from the carrier by ω_m
$J_2(m)$ = second set of side frequencies displaced from the carrier by $2\omega_m$
$J_n(m)$ = nth set of side frequencies displaced from the carrier by $n\omega_m$

Bessel Function

TABLE 5–2 FOUR-PLACE VALUES OF THE BESSEL FUNCTIONS $J_n(\beta)$

n \ β:	0.5	1	2	3	4	5	6	7	8	9	10
0	0.9385	0.7652	0.2239	−0.2601	−0.3971	−0.1776	0.1506	0.3001	0.1717	−0.09033	−0.2459
1	0.2423	0.4401	0.5767	0.3391	−0.06604	−0.3276	−0.2767	−0.004683	0.2346	0.2453	0.04347
2	0.03060	0.1149	0.3528	0.4861	0.3641	0.04657	−0.2429	−0.3014	−0.1130	0.1448	0.2546
3	0.002564	0.01956	0.1289	0.3091	0.4302	0.3648	0.1148	−0.1676	−0.2911	−0.1809	0.05838
4		0.002477	0.03400	0.1320	0.2811	0.3912	0.3576	0.1578	−0.1054	−0.2655	−0.2196
5			0.007040	0.04303	0.1321	0.2611	0.3621	0.3479	0.1858	−0.05504	−0.2341
6			0.001202	0.01139	0.04909	0.1310	0.2458	0.3392	0.3376	0.2043	−0.01446
7				0.002547	0.01518	0.05338	0.1296	0.2336	0.3206	0.3275	0.2167
8					029	0.01841	0.05653	0.1280	0.2235	0.3051	0.3179
9						0.005520	0.02117	0.05892	0.1263	0.2149	0.2919
10						0.001468	0.006964	0.02354	0.06077	0.1247	0.2075
11							0.002048	0.008335	0.02560	0.06222	0.1231
12								0.002656	0.009624	0.02739	0.06337
13									0.003275	0.01083	0.02897
14									0.001019	0.003895	0.01196
15										0.001286	0.004508
16											0.001567



Carson's Rule: shown that 98% of the total power is contained in the bandwidth (sometimes we use 99% rule)

Zero crossing points;
Used to determine the modulation index

Carrier Distribution Charts:

Table 2.2: Carrier Side Band Distribution Chart for different Modulation

Modulatio n Index m	Carrier J_0	Side Frequencies											
		1st J_1	2nd J_2	3rd J_3	4th J_4	5th J_5	6th J_6	7th J_7	8th J_8	9th J_9	10th J_{10}	11th J_{11}	12th J_{12}
0.25	0.98	0.12	0.01										
0.5	0.94	0.24	0.03	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01
1	0.77	0.44	0.11	0.06	0.03	0.04	0.05	0.05	0.03	0.01	0.02	0.03	0.02
1.5	0.51	0.56	0.23	0.13	0.06	0.13	0.13	0.09	0.06	0.02	0.06	0.05	
2	0.22	0.58	0.35	0.2	0.13	0.26	0.19	0.13	0.13	0.02	0.1		
2.4	0	0.52	0.43	0.31	0.28	0.32	0.25	0.23	0.22	0.13			
3	−0.26	0.34	0.49	0.43	0.39	0.36	0.34	0.32	0.28	0.18			
4	−0.4	−0.07	0.36	0.36	0.4	0.35	0.34	0.34					
5	−0.18	−0.33	0.05	0.26	0.36	0.19	0.34						
5.5	0	−0.34	−0.12	0.11	0.16	0.03							
6	0.15	−0.28	−0.24	−0.17	−0.1								
7	0.3	0	−0.3	−0.29	0.03								
8	0.17	0.23	−0.11	−0.24									
8.65	0	0.27	0.06										

Frequency Spectrum of FM

Frequency spectrum is a graph of amplitude versus frequency. The frequency spectrum of FM wave tells us about number of sideband present in the FM wave and their amplitudes.

The expression for FM wave is not simple. It is complex because it is sine of sine function.

Only solution is to use **'Bessels Function'.**

Equation (2.32) may be expanded as,

$$\begin{aligned} e_{FM} = \; & \{A\, J_0\,(m_f) \sin \omega_c t \\ & + J_1\,(m_f)\,[\sin(\omega_c + \omega_m)\,t - \sin(\omega_c - \omega_m)\,t] \\ & + J_1\,(m_f)\,[\sin(\omega_c + 2\omega_m)\,t + \sin(\omega_c - 2\omega_m)\,t] \\ & + J_3\,(m_f)\,[\sin(\omega_c + 3\omega_m)\,t - \sin(\omega_c - 3\omega_m)\,t] \\ & + J_4\,(m_f)\,[\sin(\omega_c + 4\omega_m)\,t + \sin(\omega_c - 4\omega_m)\,t] \\ & + \ldots\ldots\} \ldots \; (2.33) \end{aligned}$$

From this equation it is seen that the FM wave consists of:

(i) Carrier (First term in equation).

(ii) Infinite number of sidebands (All terms except first term are sidebands).

The amplitudes of carrier and sidebands depend on 'J' coefficient.

$$\omega_c = 2\pi f_c, \qquad \omega_m = 2\pi f_m$$

So in place of ω_c and ω_m, we can use f_c and f_m.

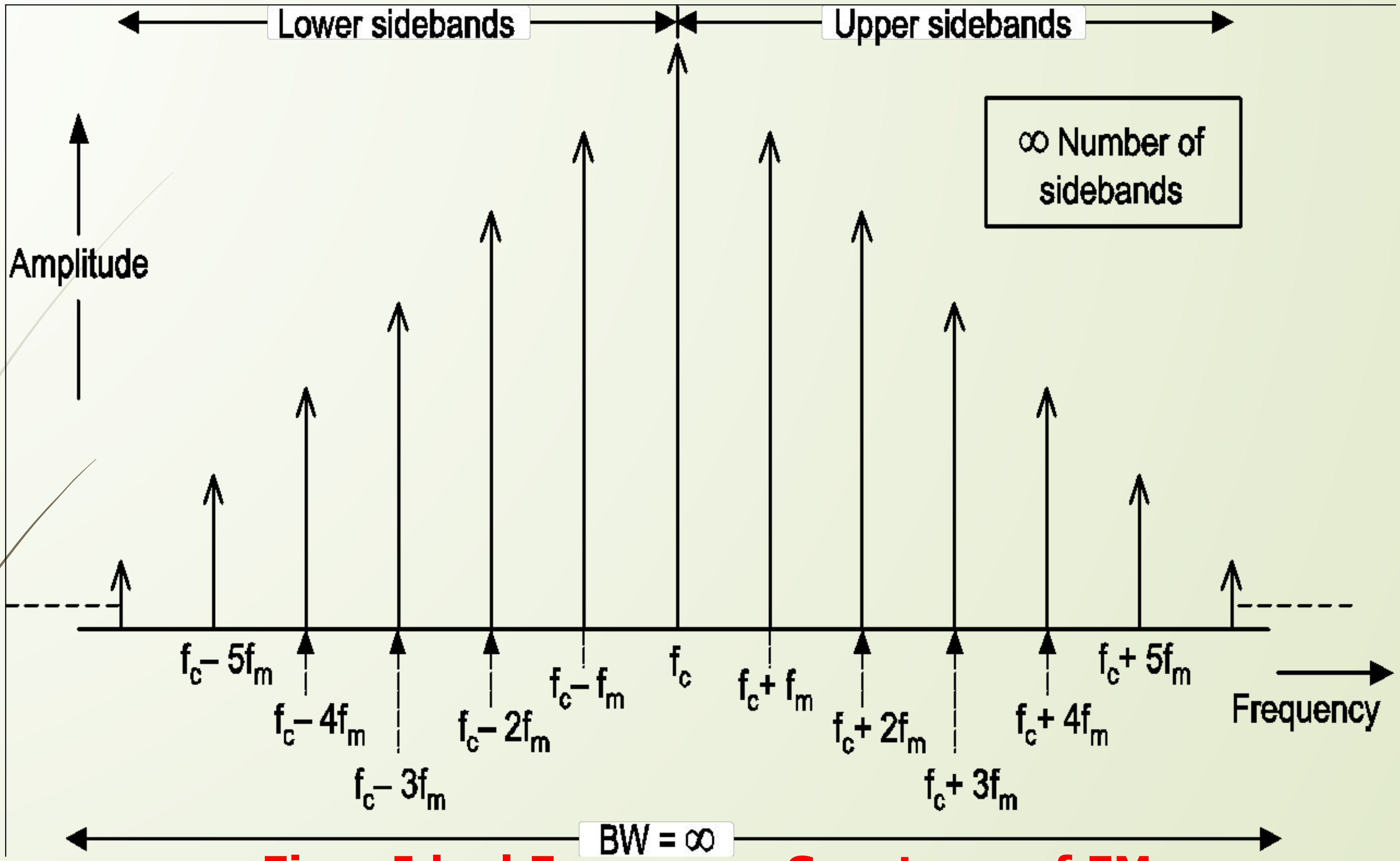


Fig. : Ideal Frequency Spectrum of FM

Bandwidth of FM

From frequency spectrum of FM wave shown in Fig. 2.26, we can say that the bandwidth of FM wave is infinite.

But practically, it is calculated based on how many sidebands have significant amplitudes.

(i) The Simple Method to calculate the bandwidth is –

BW=2fmx Number of significant sidebands --(1)

With increase in modulation index, the number of significant sidebands increases. So that bandwidth also increases.

(ii)The second method to calculate bandwidth is by **Carson's rule.**

Carson's rule states that, the bandwidth of FM wave is twice the sum of deviation and highest modulating frequency.

$$BW=2(\boldsymbol{\delta} + \mathbf{fmmax}) \quad \ldots(2)$$

Highest order side band = To be found from table 2.1 after the calculation of modulation Index m where, m = **δ/fm**

e.g. If m= 20KHZ/5KHZ

From table, for modulation index 4, highest order side band is 7^{th}.

Therefore, the bandwidth is

$$\begin{aligned} B.W. &= 2\, f_m \times \text{Highest order side band} \\ &= 2 \times 5 \text{ kHz} \times 7 \\ &= 70 \text{ kHz} \end{aligned}$$

Carrier Distribution Charts:

Table 2.2: Carrier Side Band Distribution Chart for different Modulation

Modulation Index m	Carrier J_0	Side Frequencies											
		1st J_1	2nd J_2	3rd J_3	4th J_4	5th J_5	6th J_6	7th J_7	8th J_8	9th J_9	10th J_{10}	11th J_{11}	12th J_{12}
0.25	0.98	0.12	0.01										
0.5	0.94	0.24	0.03	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01
1	0.77	0.44	0.11	0.06	0.03	0.04	0.05	0.05	0.03	0.01	0.02	0.03	0.02
1.5	0.51	0.56	0.23	0.13	0.06	0.13	0.13	0.09	0.06	0.02	0.06	0.05	
2	0.22	0.58	0.35	0.2	0.13	0.26	0.19	0.13	0.13	0.02	0.1		
2.4	0	0.52	0.43	0.31	0.28	0.32	0.25	0.23	0.22	0.13			
3	−0.26	0.34	0.49	0.43	0.39	0.36	0.34	0.32	0.28	0.18			
4	−0.4	−0.07	0.36	0.36	0.4	0.35	0.34	0.34					
5	−0.18	−0.33	0.05	0.26	0.36	0.19	0.34						
5.5	0	−0.34	−0.12	0.11	0.16	0.03							
6	0.15	−0.28	−0.24	−0.17	−0.1								
7	0.3	0	−0.3	−0.29	0.03								
8	0.17	0.23	−0.11	−0.24									
8.65	0	0.27	0.06										

Example (A)

- Assume FM modulation with modulation index of 1
- m(t) =$V_m$sin(2.pi.1000t) and Vc(t)= =10sin(2.pi.500.10^3t)
- Find the following:
  - Number of sets of significant side frequencies (G(f))
  - Amplitude of freq. components
  - Draw the frequency component

$$G(f) = A_c \sum_{n=-\infty}^{n=\infty} J_n(\beta)\delta(f - nf_m)$$

n \ β:	0.5	1
0	0.9385	0.7652
1	0.2423	0.4401
2	0.03060	0.1149
3	0.002564	0.01956
4		0.002477
5		

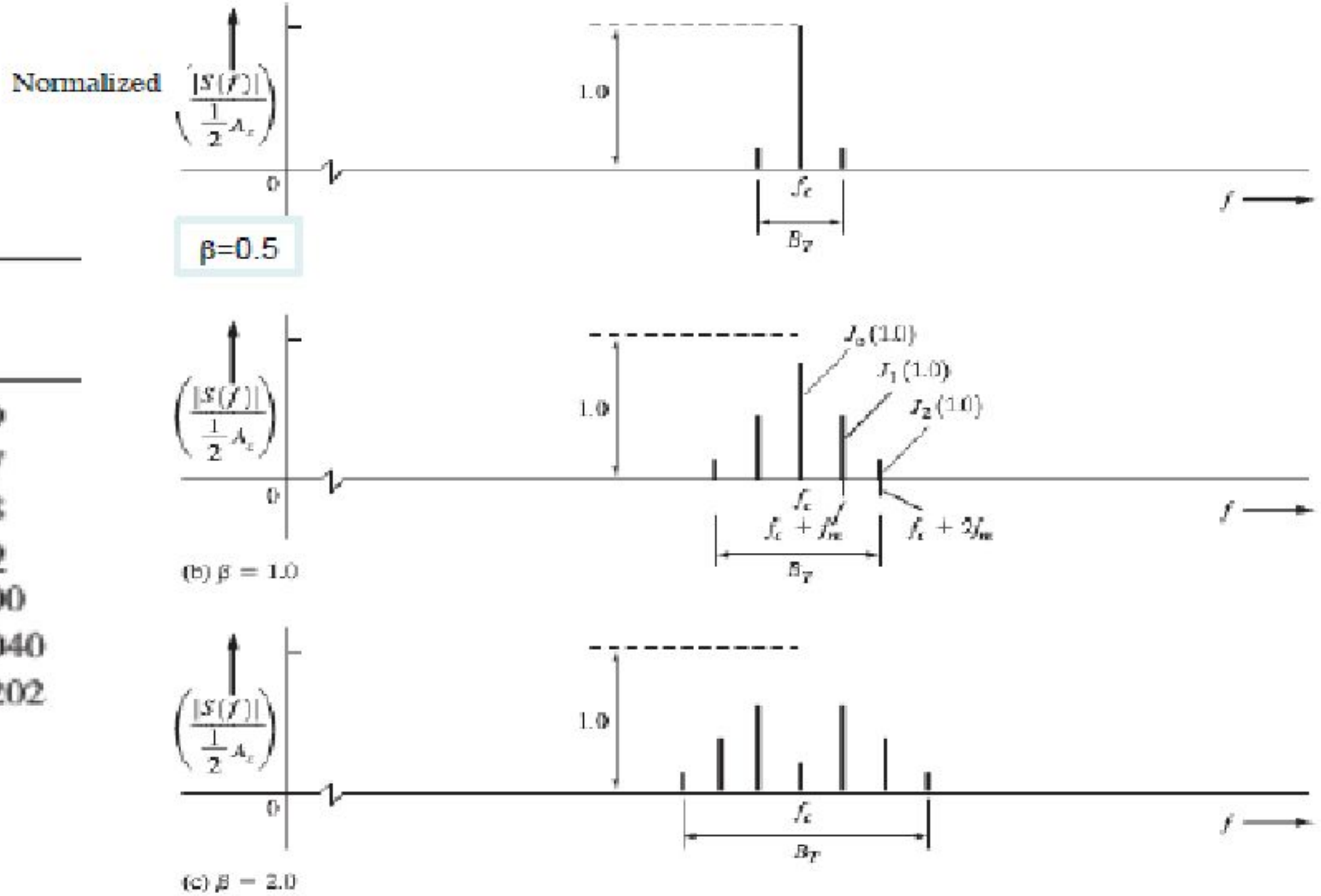
Example (B)

- Plot the spectrum from the modulated FM signal for β=0.5, 1, 2

$$S(f) = \frac{1}{2}[G(f - f_c) + G^*(-f - f_c)],$$

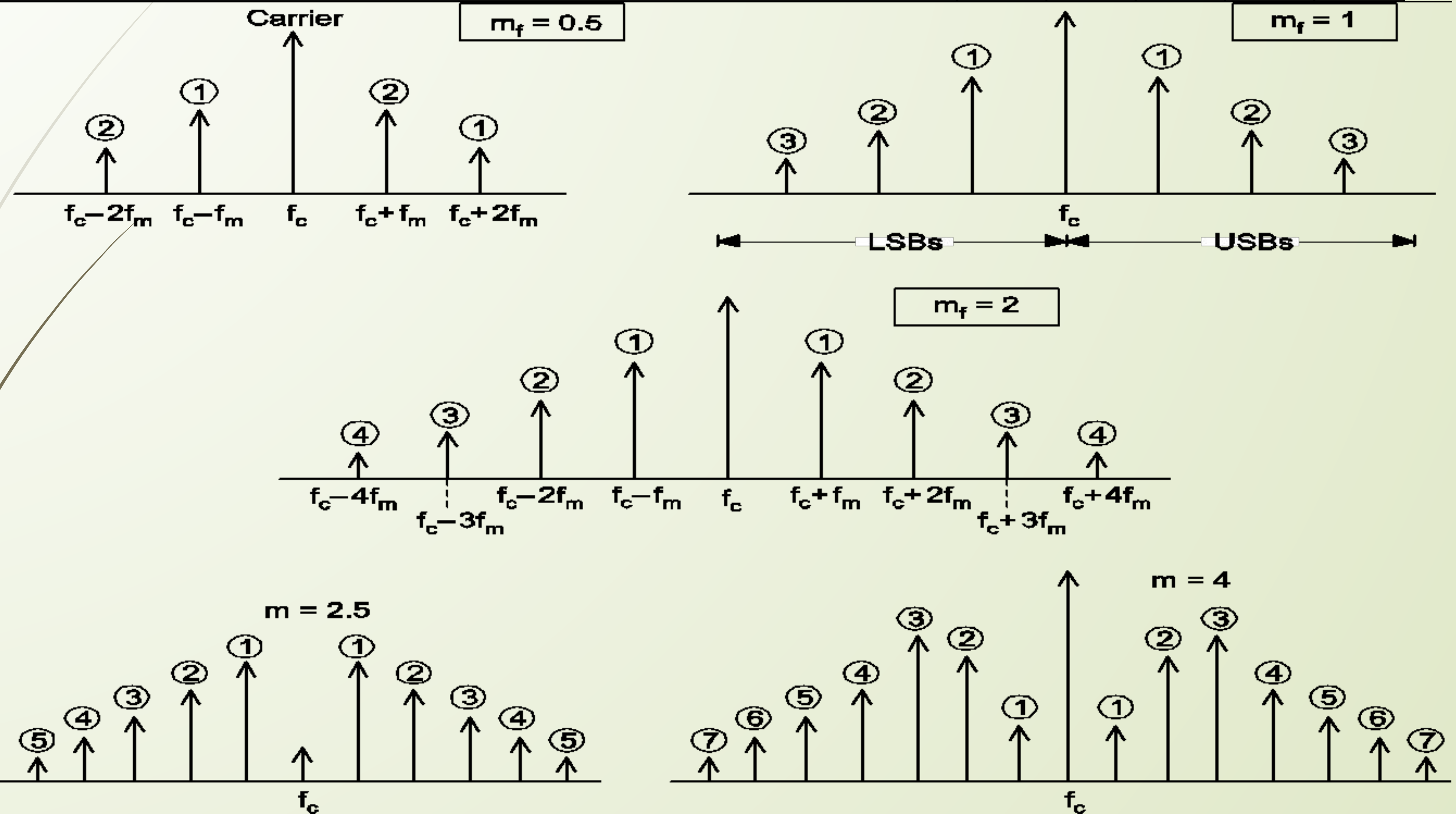
$$G(f) = A_c \sum_{n=-\infty}^{n=\infty} J_n(\beta)\delta(f - nf_m)$$

n \ β:	0.5	1	2
0	0.9385	0.7652	0.2239
1	0.2423	0.4401	0.5767
2	0.03060	0.1149	0.3528
3	0.002564	0.01956	0.1289
4		0.002477	0.03400
5			0.007040
6			0.001202
7			



Effect of Modulation Index on Sidebands

Modulation index	0.5	1	2	2.5	4
Number of significant sideband on either side of carrier	2	3	4	5	7



Types of Frequency Modulation

FM (Frequency Modulation)

Narrowband FM (NBFM) [When modulation index is small]

Wideband FM (WBFM) [When modulation index is large]

Comparison between Narrowband and Wideband FM

Sr. No.	Parameter	NBFM	WBFM
1.	Modulation index	Less than or slightly greater than 1	Greater than 1
2.	Maximum deviation	5 kHz	75 kHz
3.	Range of modulating frequency	20 Hz to 3 kHz	20 Hz to 15 kHz
4.	Maximum modulation index	Slightly greater than 1	5 to 2500
5.	Bandwidth	Small approximately same as that of AM BW = $2f_m$	Large about 15 times greater than that of NBFM. BW = $2(\delta+fmmax)$
6.	Applications	FM mobile communication like police wireless, ambulance, short range ship to shore communication etc.	Entertainment broadcasting (can be used for high quality music transmission)

Representation of FM

FM can be represented by two ways:

1. Time domain.
2. Frequency domain.

1. FM in Time Domain

Time domain representation means continuous variation of voltage with respect to time as shown in Fig.

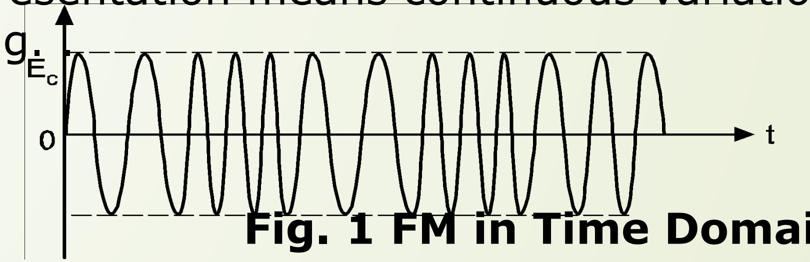


Fig. 1 FM in Time Domain

2. FM in Frequency Domain

- Frequency domain is also known as **frequency spectrum.**
- FM in frequency domain means graph or plot of amplitude versus frequency as shown in Fig. 2.29.

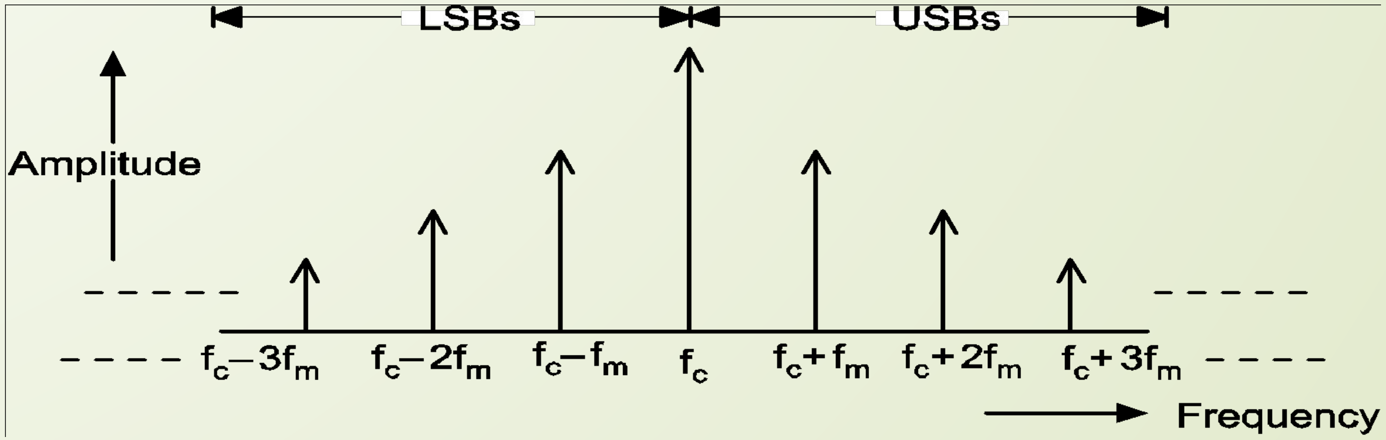


Fig. 2: FM in Frequency Domain

FM Noise triangle

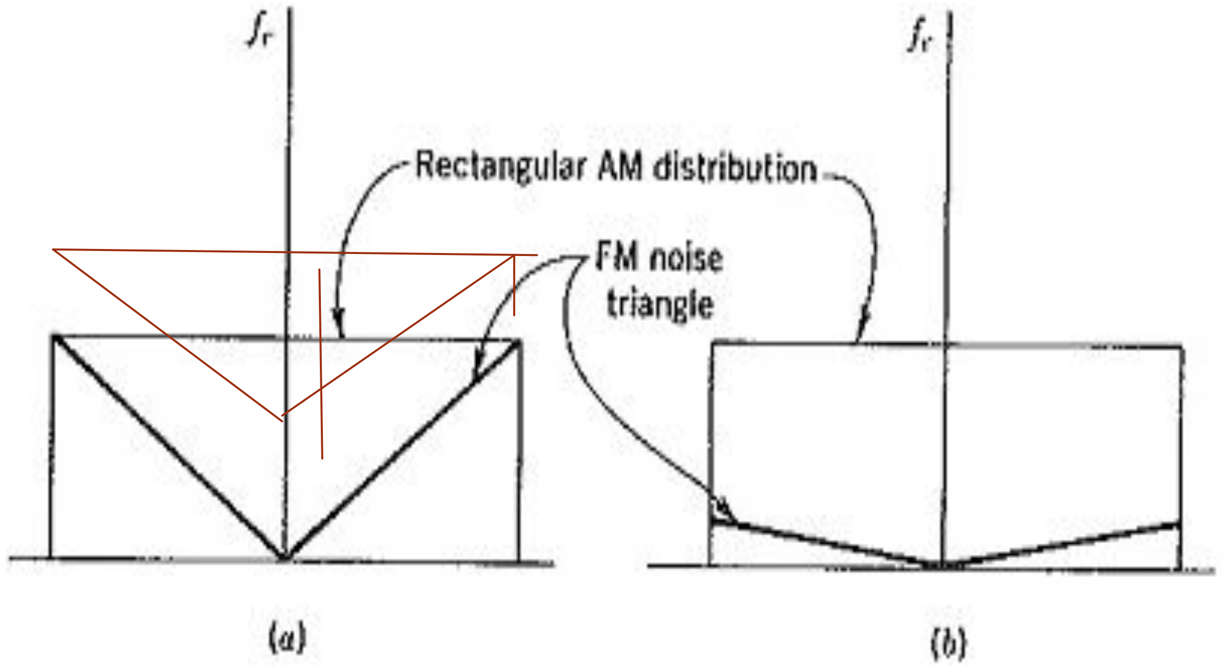


FIGURE 5-6 Noise sideband distribution (noise triangle). (*a*) $m_f = 1$ at the maximum frequency; (*b*) $m_f = 5$ at the maximum frequency.

Pre-emphasis and De-emphasis

- Pre and de-emphasis circuits are used only in frequency modulation.
  - Pre-emphasis is used **at transmitter** and de-emphasis **at receiver**.

1. Pre-emphasis

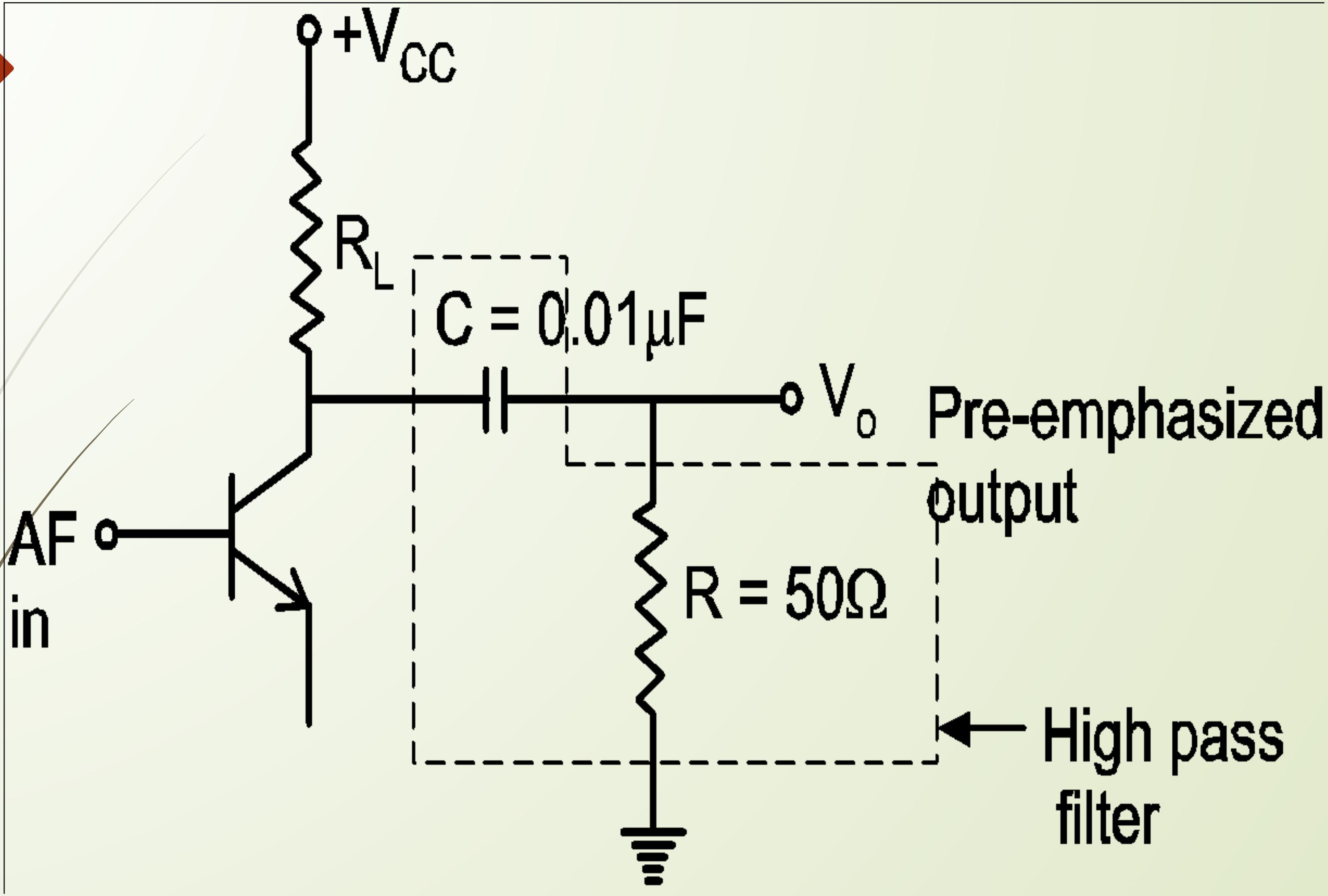
- In FM, the noise has a greater effect on the higher modulating frequencies.
- This effect can be reduced by increasing the value of modulation index (m_f), for higher modulating frequencies.
- This can be done by increasing the deviation 'δ' and 'δ' can be increased by increasing the amplitude of modulating signal at higher frequencies.

Definition:

The artificial boosting of higher audio modulating frequencies in accordance with prearranged response curve is called pre-emphasis.

- Pre-emphasis circuit is a high pass filter as shown in Fig. 1

Fig. 1: Pre-emphasis Circuit



As shown in Fig. 1, AF is passed through a high-pass filter, before applying to FM modulator.

- As modulating frequency (f_m) increases, capacitive reactance decreases and modulating voltage goes on increasing. $f_m \propto$ Voltage of modulating signal applied to FM modulat Boosting is done according to pre-arranged curve as shown in Fig. 2.

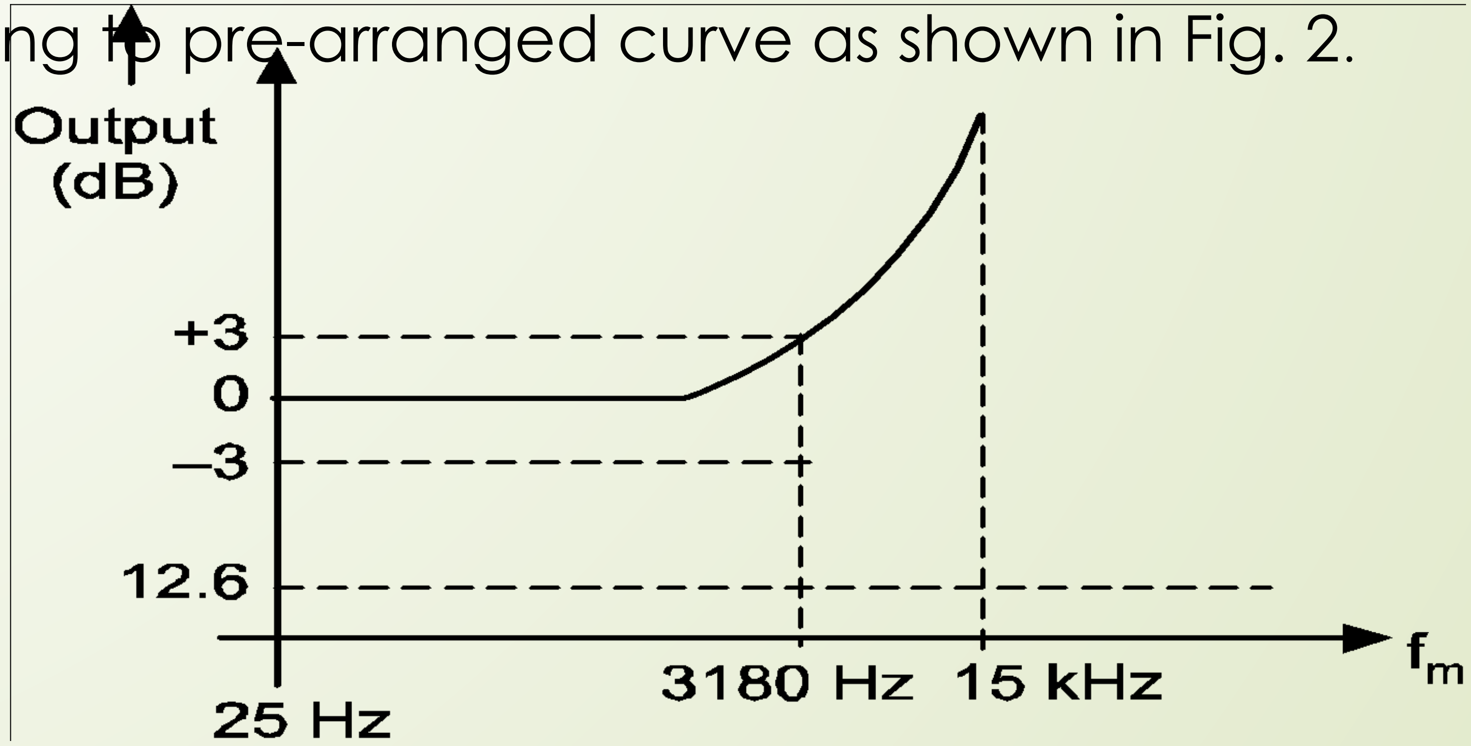


Fig. 2: P re-emphasis Curve

- The time constant of pre-emphasis is at 50 μs in all CCIR standards.
- In systems employing American FM and TV standards, networks having time constant of 75 μsec are used.
- **The pre-emphasis is used at FM transmitter** as shown in Fig. 3.

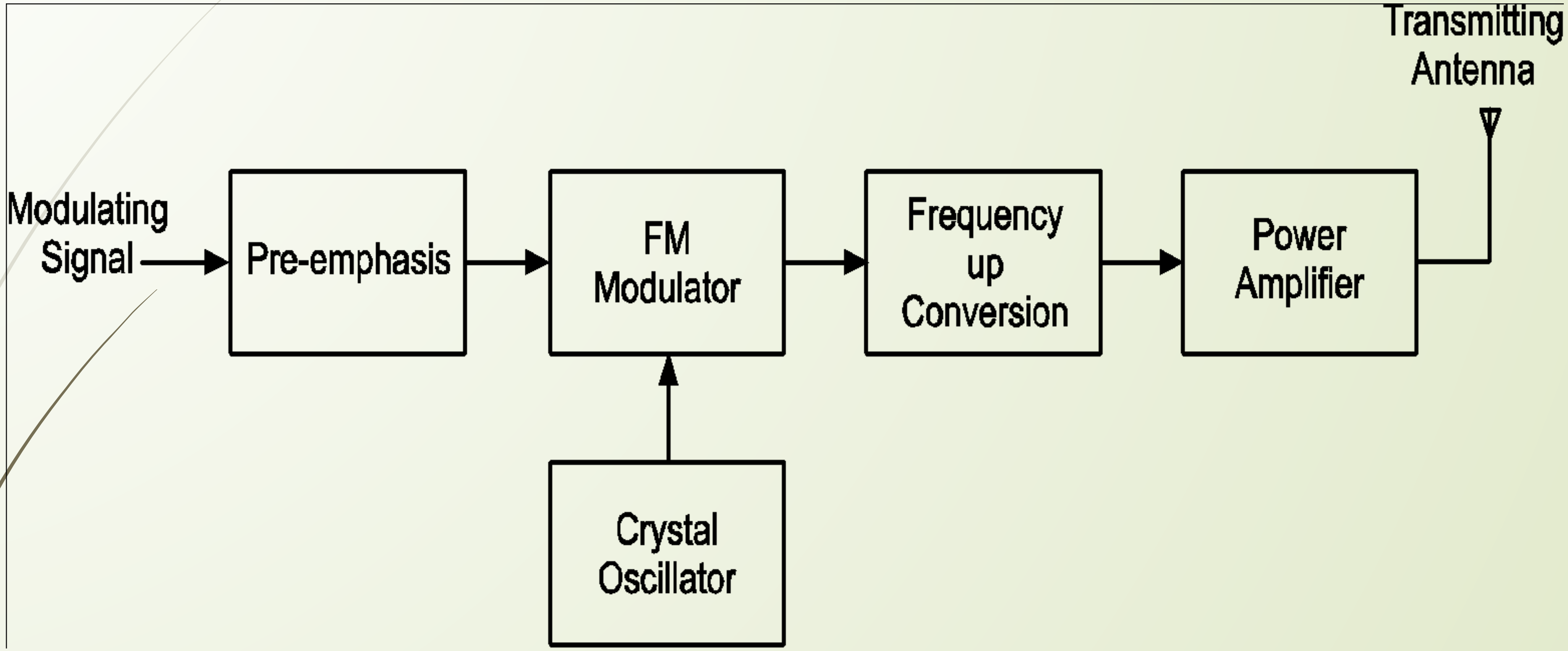


Fig. 3: FM Transmitter with Pre-emphasis

De-emphasis

- De-emphasis circuit is **used at FM receiver**.

Definition:

The artificial boosting of higher modulating frequencies in the process of pre-emphasis is nullified at receiver by process called de-emphasis.

- De-emphasis circuit is a low pass filter shown in Fig. 4.

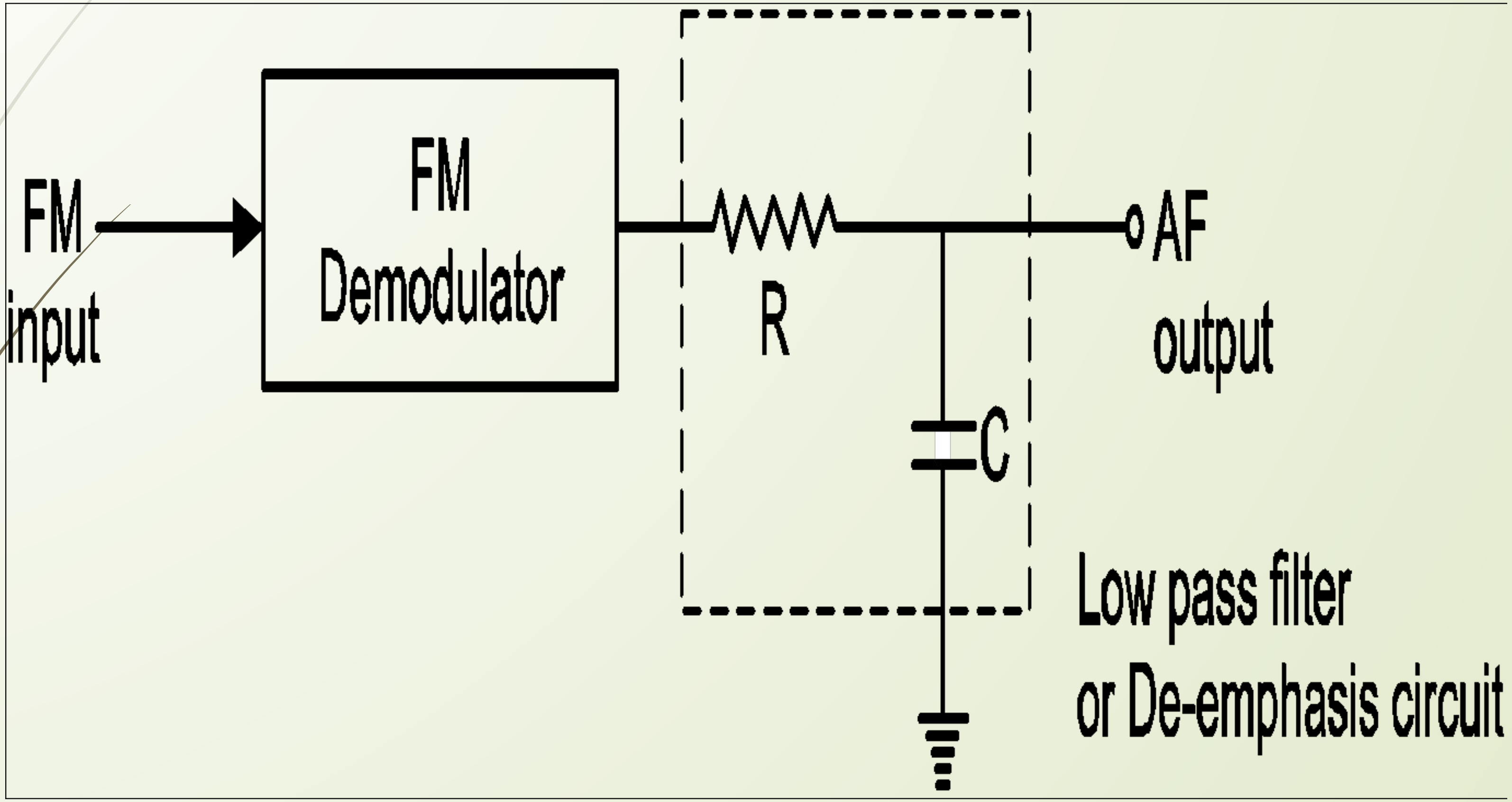
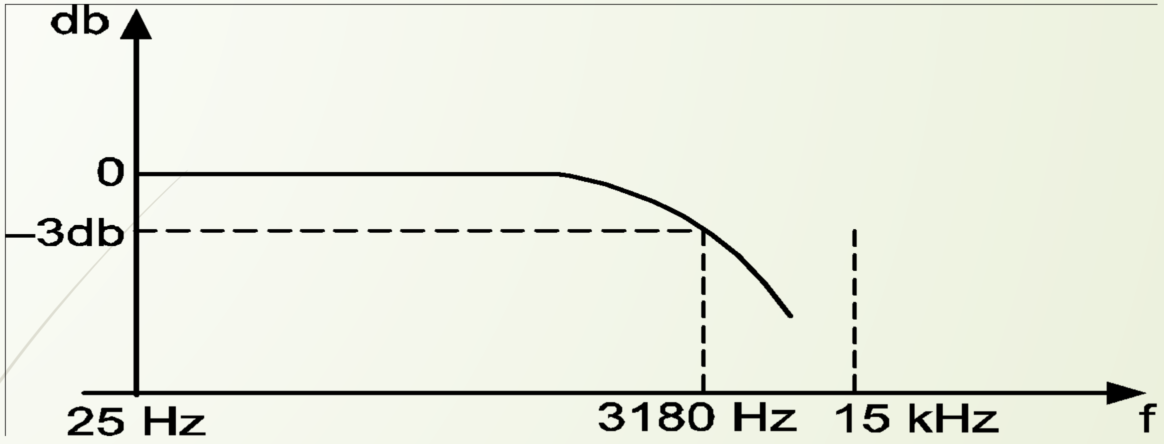


Fig. 4: De-emphasis Circuit

Fig. 5: De-emphasis Curve



As shown in Fig.5, de-modulated FM is applied to the de-emphasis circuit (low pass filter) where with increase in f_m, capacitive reactance X_c decreases. So that output of de-emphasis circuit also reduces • Fig. 5 shows the de-emphasis curve corresponding to a time constant 50 μs. A 50 μs de-emphasis corresponds to a frequency response curve that is 3 dB down at frequency given by,

$$f = 1/\ 2\pi RC$$

$$= 1/\ 2\pi \times 50 \times 1000$$

$$= 3180 \text{ Hz}$$

The de-emphasis circuit is used after the FM demodulator at the FM receiver shown in Fig. 6.

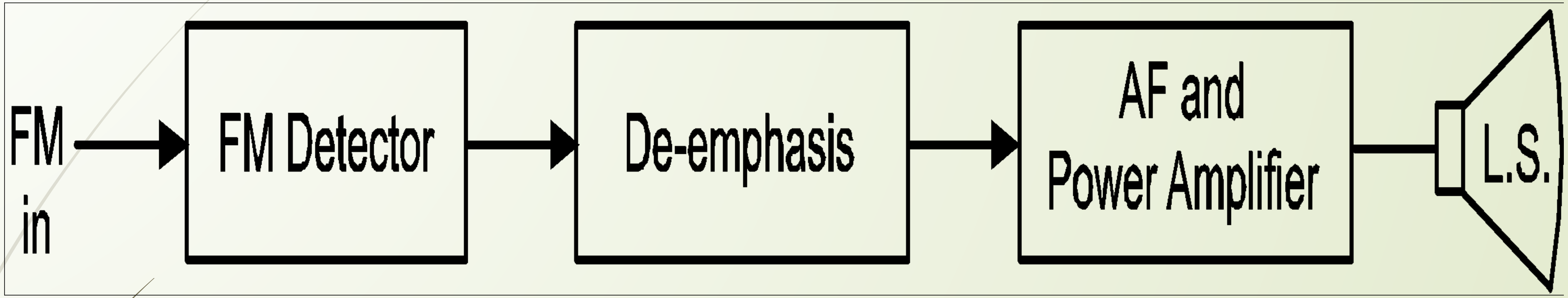
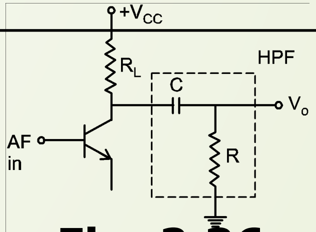
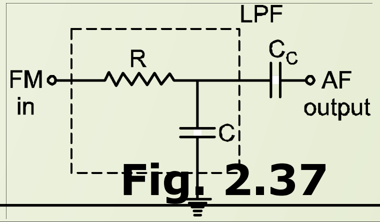
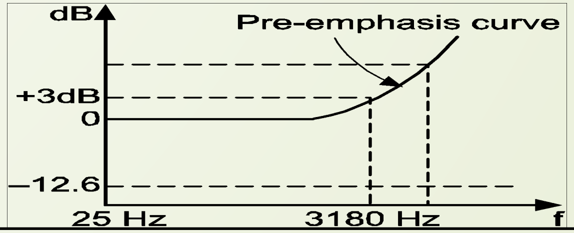
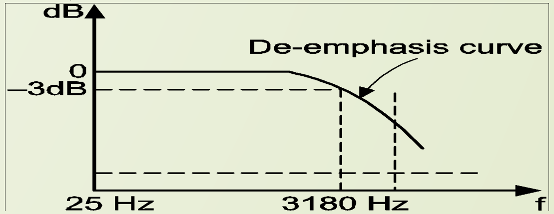
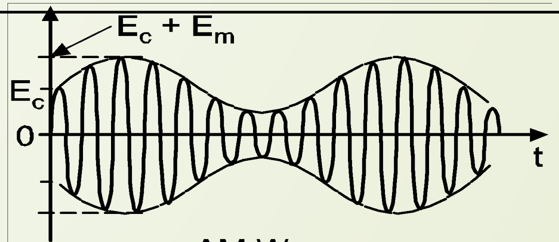
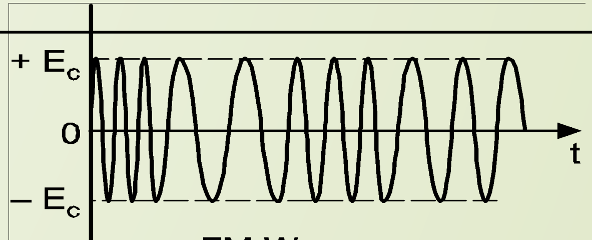


Fig. 6: De-emphasis Circuit in FM Receiver

Comparison between Pre-emphasis and De-emphasis

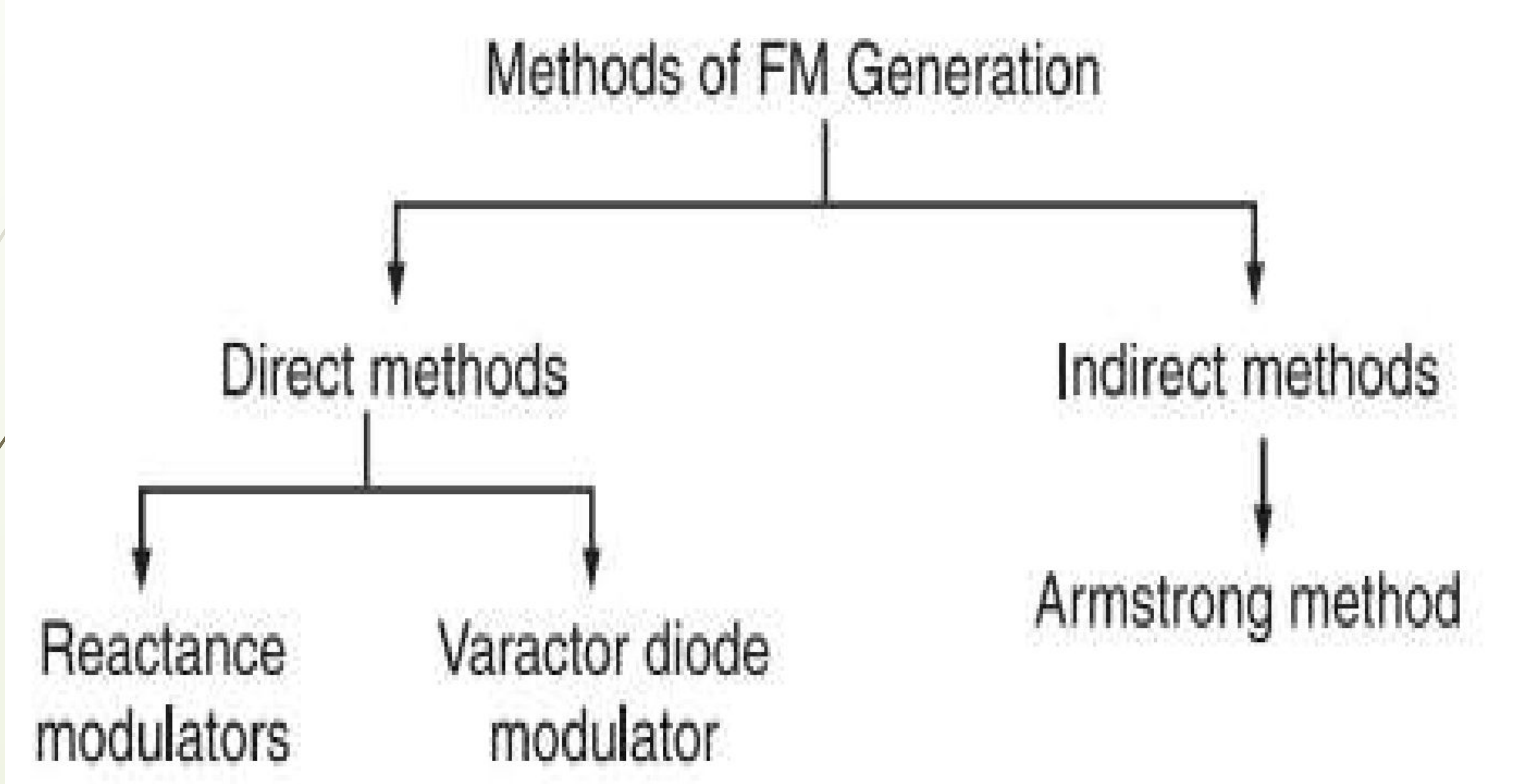
Parameter	Pre-emphasis	De-emphasis
1. Circuit used	High pass filter.	Low pass filter.
2. Circuit diagram	 **Fig. 2.36**	 **Fig. 2.37**
3. Response curve		
4. Time constant	T = RC = 50 μs	T = RC = 50 μs
5. Definition	Boosting of higher frequencies	Removal of higher frequencies
6. Used at	FM transmitter	FM receiver.

Comparison between AM and FM

Parameter	AM	FM
1. Definition	Amplitude of carrier is varied in accordance with amplitude of modulating signal keeping frequency and phase constant.	Frequency of carrier is varied in accordance with the amplitude of modulating signal keeping amplitude and phase constant.
2. Constant parameters	Frequency and phase.	Amplitude and phase.
3. Modulated signal	 AM Wave	 FM Wave
4. Modulation Index	m=Em/Ec	m = δ/ fm
5. Number of sidebands	Only two	Infinite and depends on m_f.
6. Bandwidth	$BW = 2f_m$	$BW = 2 (\delta + f_{m\ (max)})$
7. Application	MW, SW band broadcasting, video transmission in TV.	Broadcasting FM, audio transmission in TV.

FM Generation

There are two methods for generation of FM wave.



- TWO types of FM Modulators –
- 1. Indirect FM – Modulation is obtained by phase modulation of the carrier.
  An instantaneous phase of the carrier is directly proportional to the amplitude of the modulating signal.
- 2. Direct FM- The frequency of carrier is varied directly by modulating signal.
  An instantaneous frequency variation is directly proportional to the amplitude of the modulating signal.

Varactor Diode Modulator

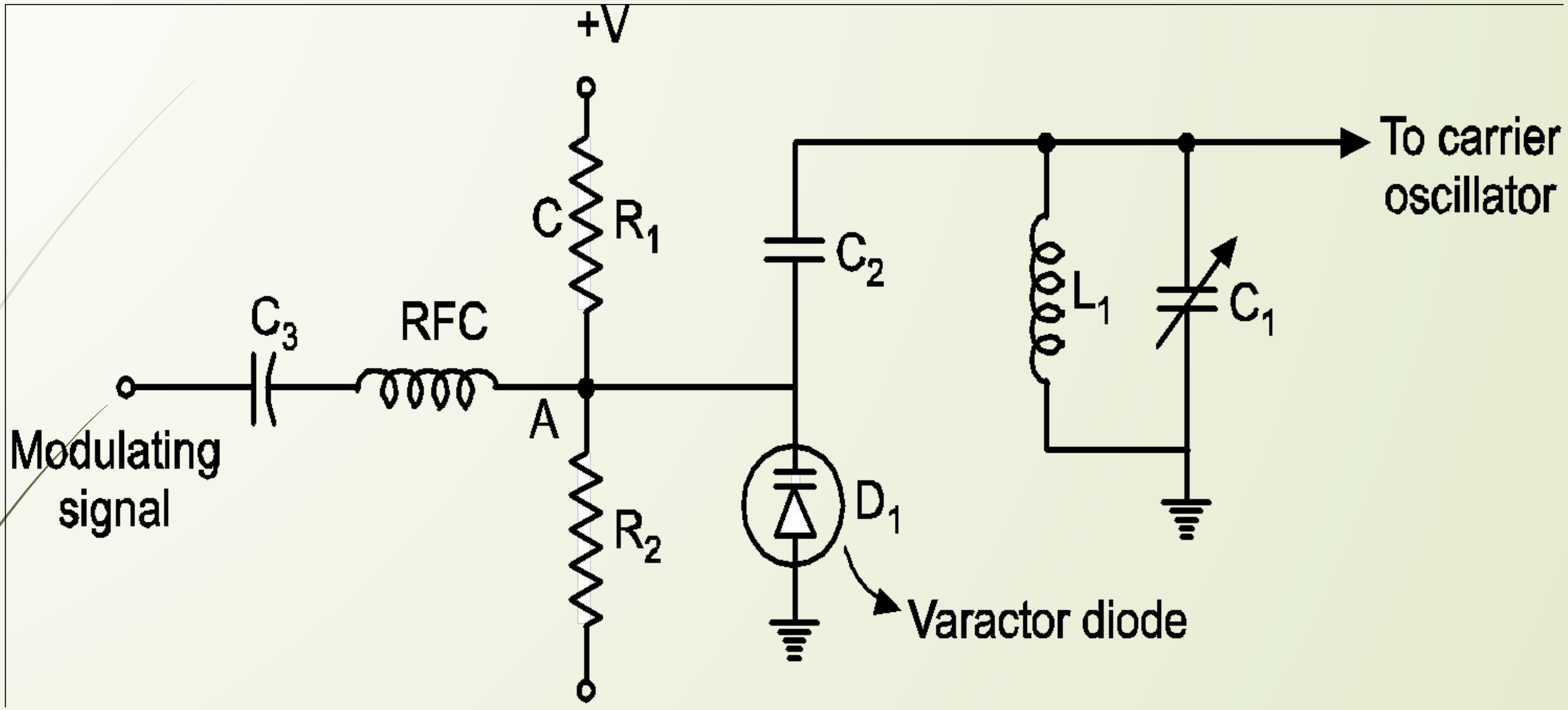


Fig. : Varactor Diode Frequency Modulator

Varactor diode FM Modulator

A varactor diode is a semiconductor diode whose junction capacitance varies linearly with the applied bias and The varactor diode must be reverse biased.

Working Operation

The varactor diode is reverse biased by the negative dc source $-V_b$.

The modulating AF voltage appears in series with the negative supply voltage. Hence, the voltage applied across the varactor diode varies in proportion with the modulating voltage.

This will vary the junction capacitance of the varactor diode.

The varactor diode appears in parallel with the oscillator tuned circuit.

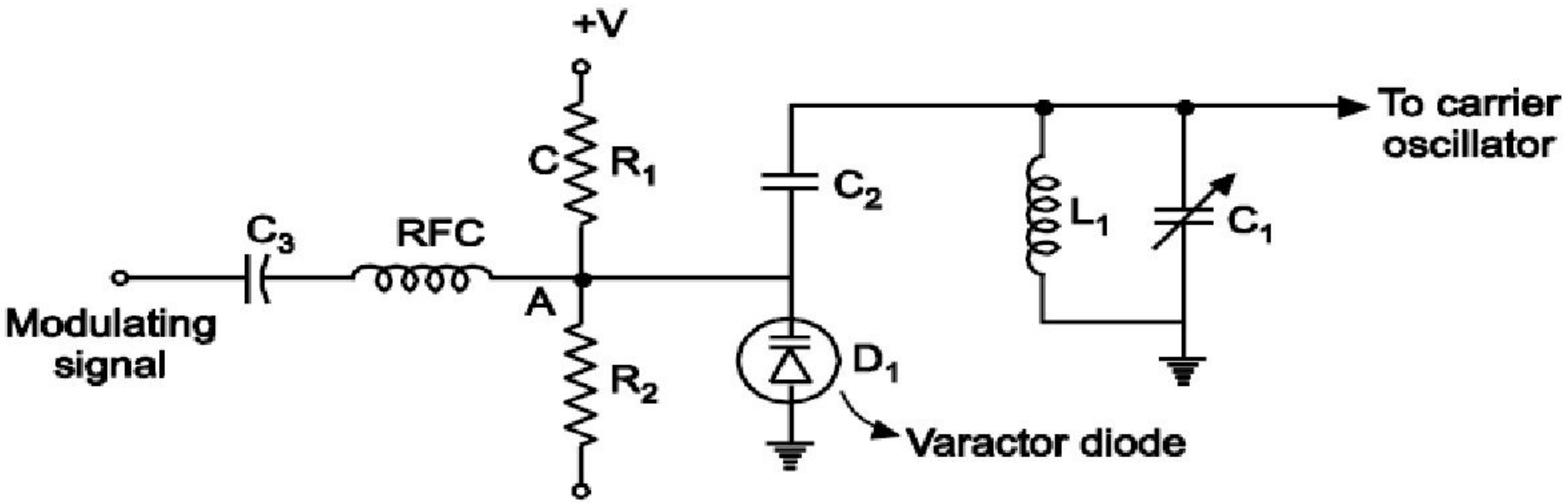
Hence the oscillator frequency will change with change in varactor diode capacitance and FM wave is produced.

The RFC will connect the dc and modulating signal to the varactor diode but it offers a very high impedance at high oscillator frequency. Therefore, the oscillator circuit is isolated from the dc bias and modulating signal.

Limitations of Direct Method of FM Generation

1.In this method, it is very difficult to get high order stability in carrier frequency because in this method the basic oscillator is not a stable oscillator, as it is controlled by the modulating signal.

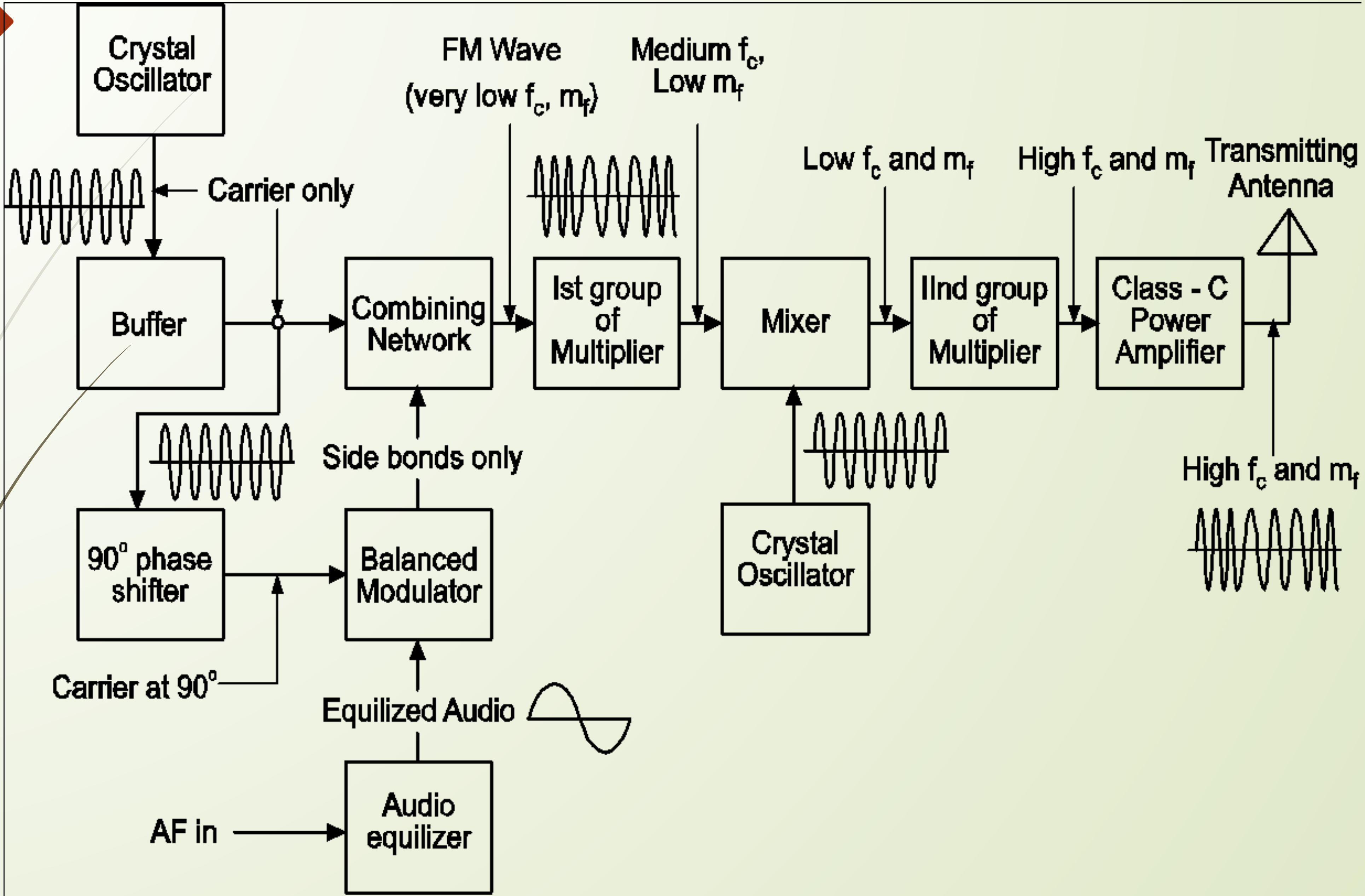
2.Generally in this method we get distorted FM, due to non-linearity of the varactor diode.

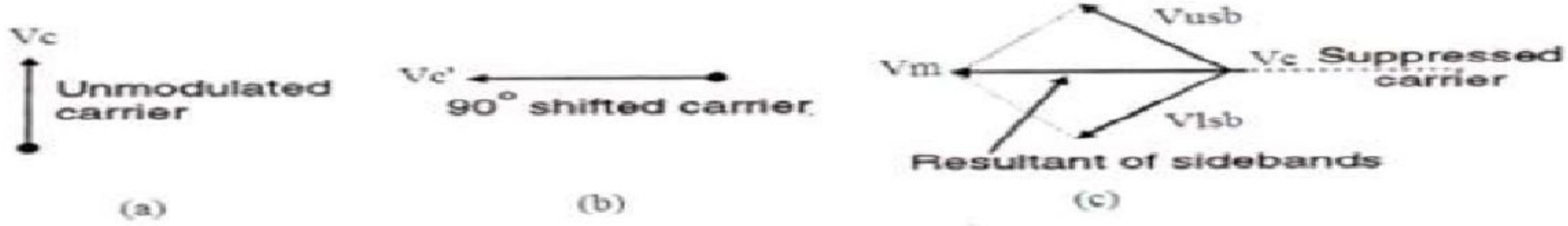


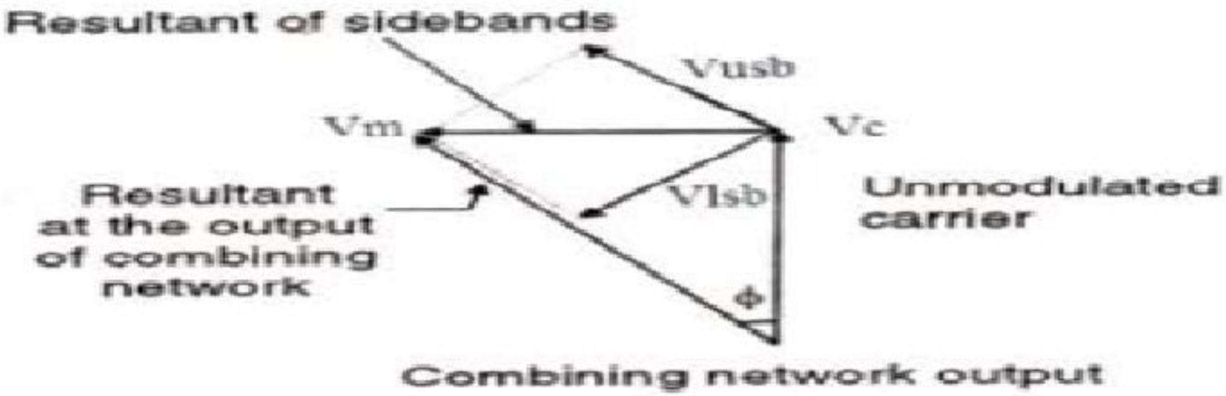
Indirect method

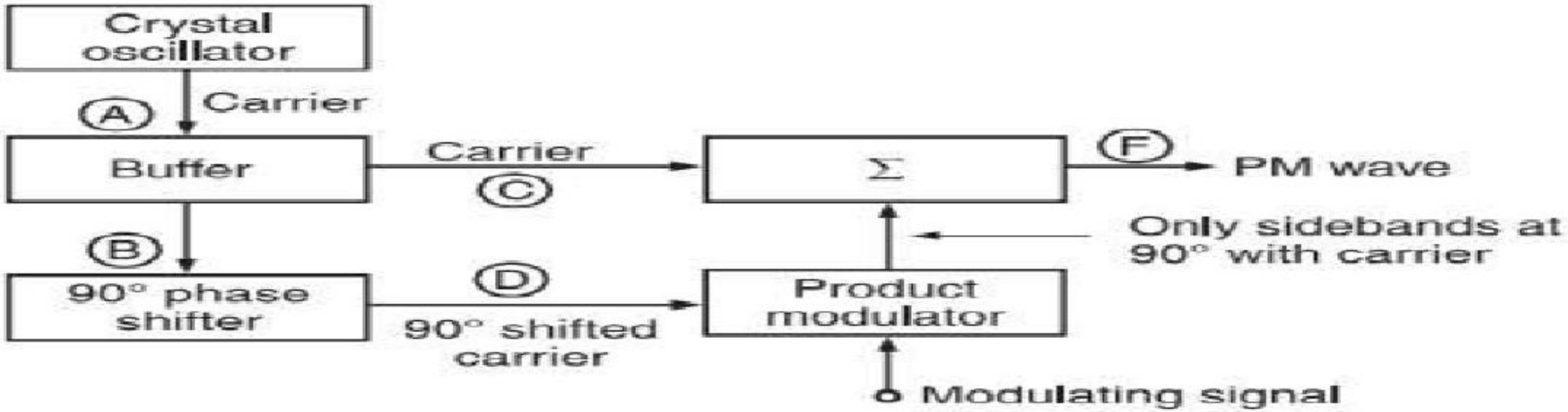
- This method of FM generation is also known as Armstrong method of FM generation.
- In this method the FM is obtained through phase modulation.
- In this method crystal oscillator is used for frequency stability.

FM Transmitter (Armstrong Method)




Vc
Unmodulated carrier
Vc'
90° shifted carrier
Vusb
Vm
Vc
Suppressed carrier
Vlsb
Resultant of sidebands
(a)
(b)
(c)


Resultant of sidebands
Vusb
Vm
Vc
Resultant at the output of combining network
Vlsb
Unmodulated carrier
ϕ
Combining network output


Crystal oscillator
Carrier
A
Buffer
Carrier
C
Σ
F
PM wave
B
Only sidebands at 90° with carrier
90° phase shifter
D
90° shifted carrier
Product modulator
Modulating signal

Advantages / Disadvantages / Applications of FM

Advantages of FM

1. Transmitted power remains constant.
2. FM receivers are immune to noise.
3. Good capture effect.
4. No mixing of signals.

Disadvantages of FM

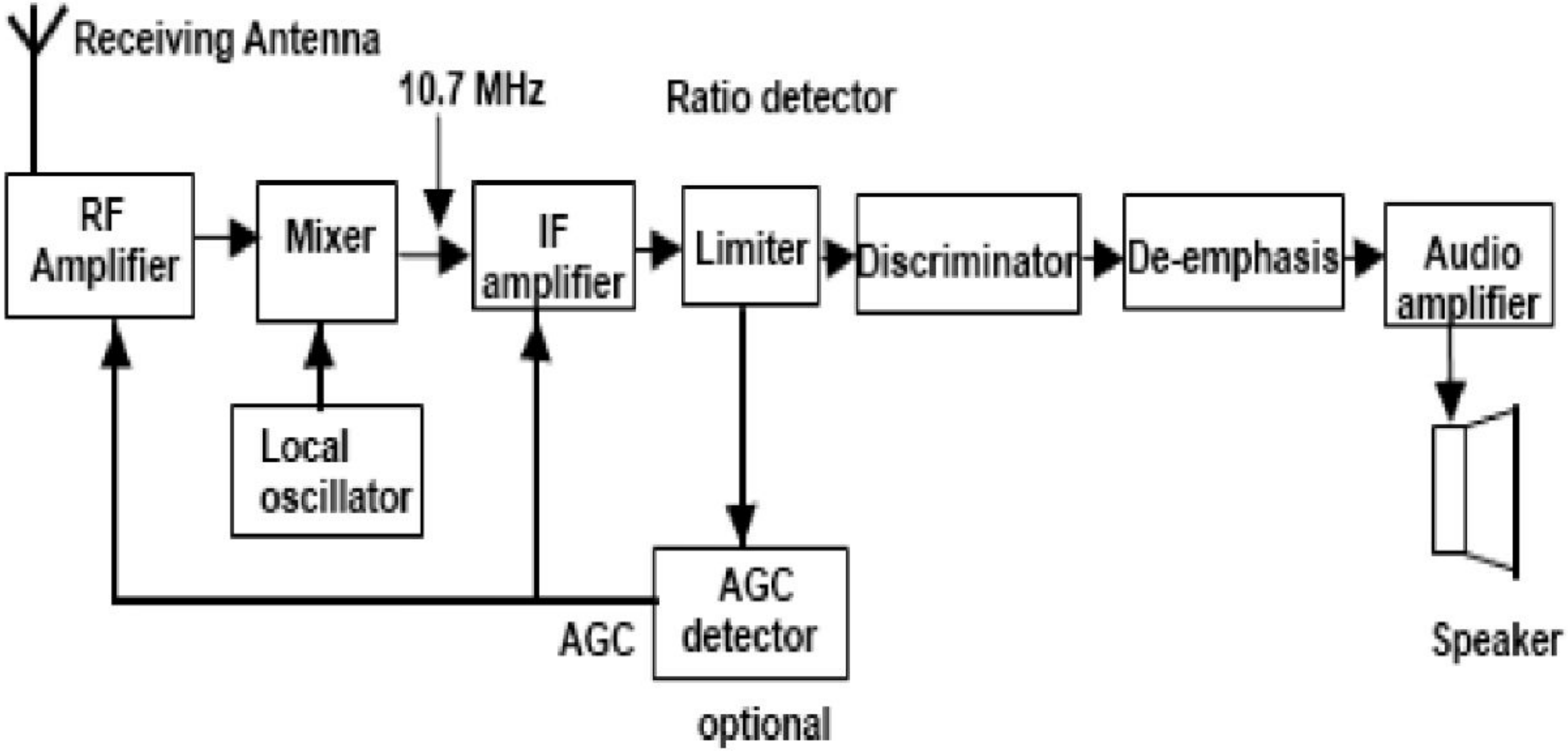
The greatest disadvantages of FM are:

1. It uses too much spectrum space.
2. The bandwidth is wider.
3. The modulation index can be kept low to minimize the bandwidth used.
4. But reduction in M.I. reduces the noise immunity.
5. Used only at very high frequencies.

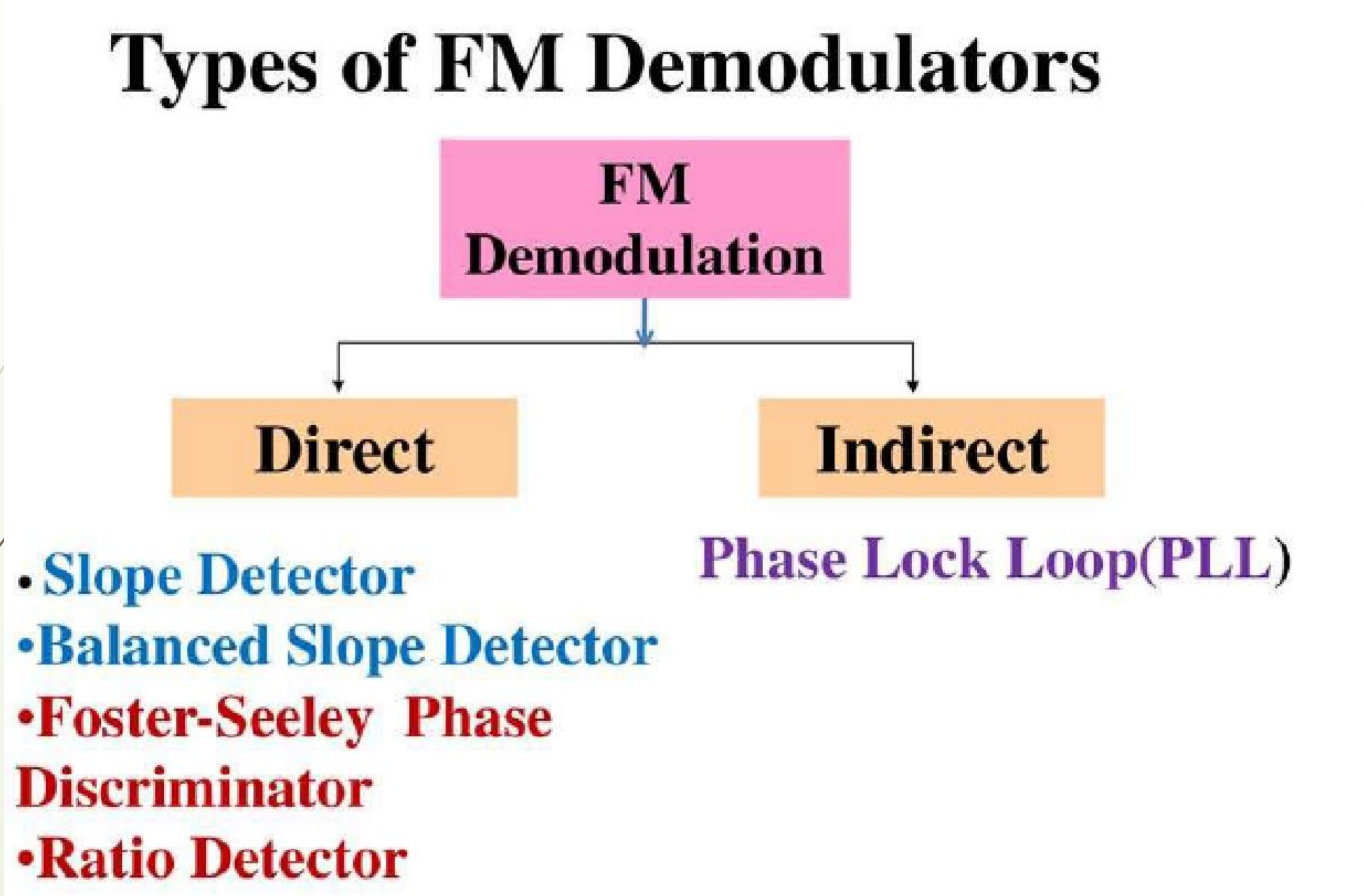
Applications of FM

1. FM radio broadcasting.
2. Sound transmission in TV.
3. Police wireless.

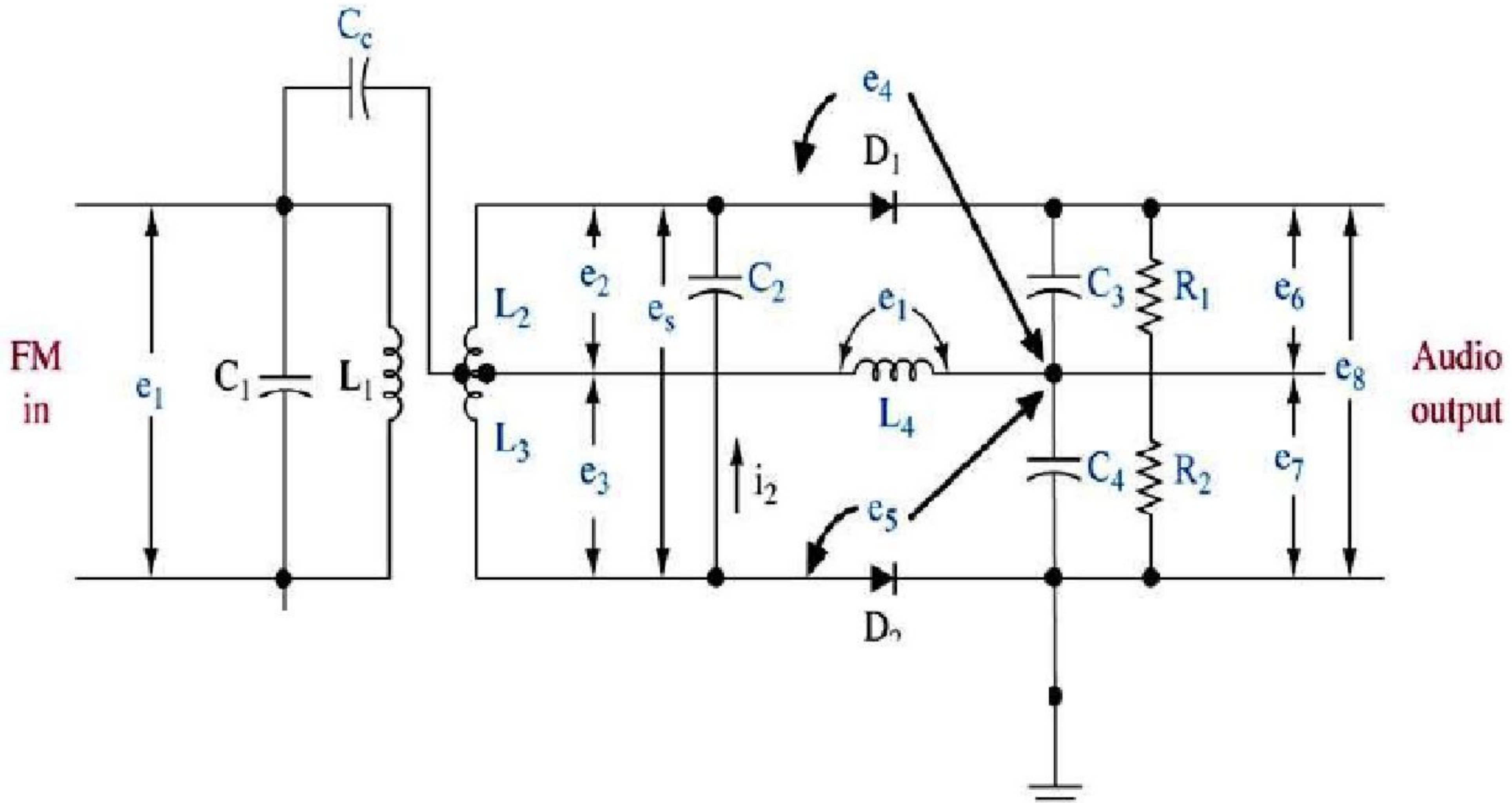
FM Receiver



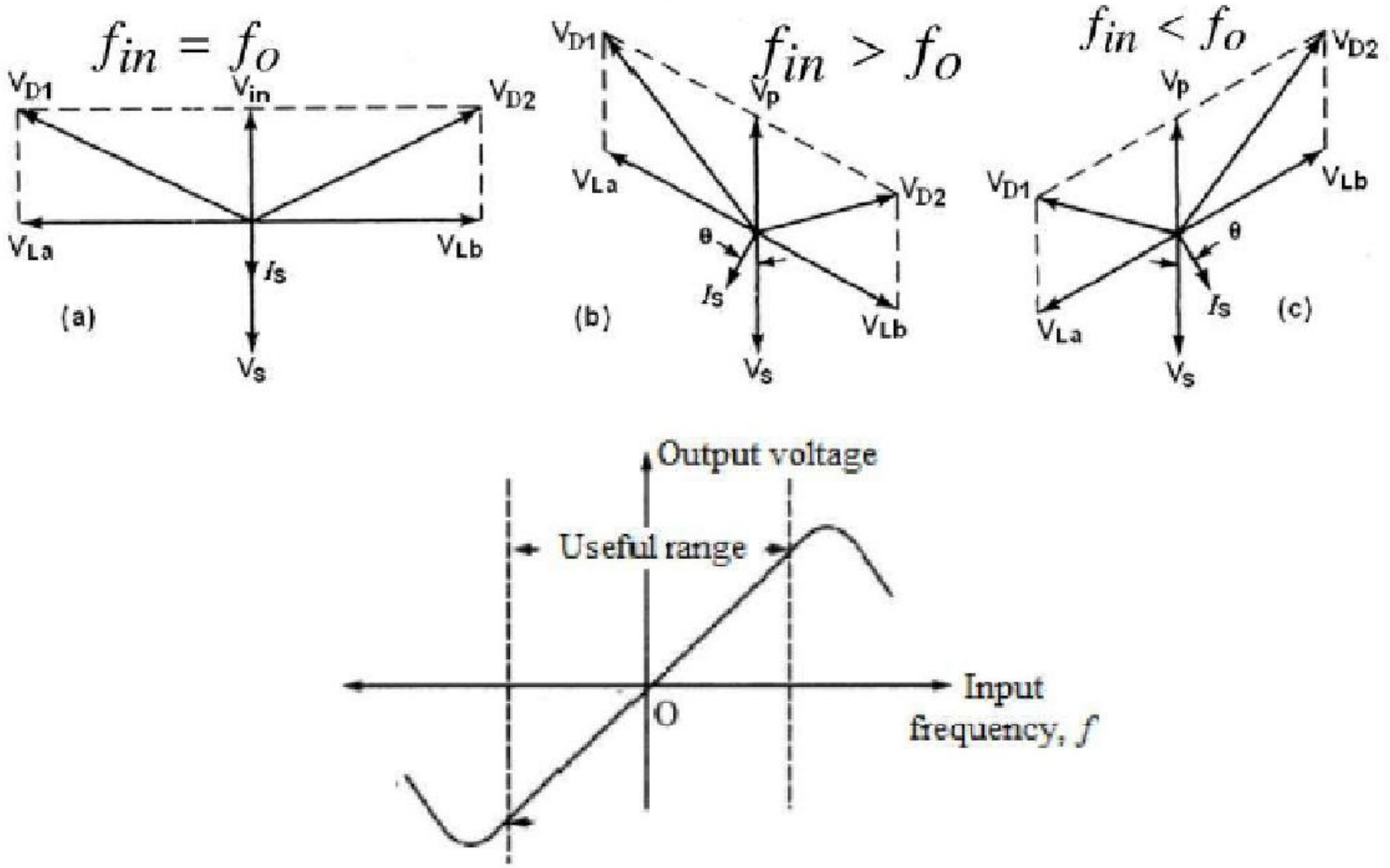
Receiving Antenna
10.7 MHz
Ratio detector
RF Amplifier
Mixer
IF amplifier
Limiter
Discriminator
De-emphasis
Audio amplifier
Local oscillator
AGC
AGC detector
optional
Speaker


Types of FM Demodulators
FM Demodulation
Direct
Indirect
• Slope Detector
•Balanced Slope Detector
•Foster-Seeley Phase Discriminator
•Ratio Detector
Phase Lock Loop(PLL)

FOSTER-SEELEY DISCRIMINATOR



Foster-Seeley Discriminator



Foster-Seeley…

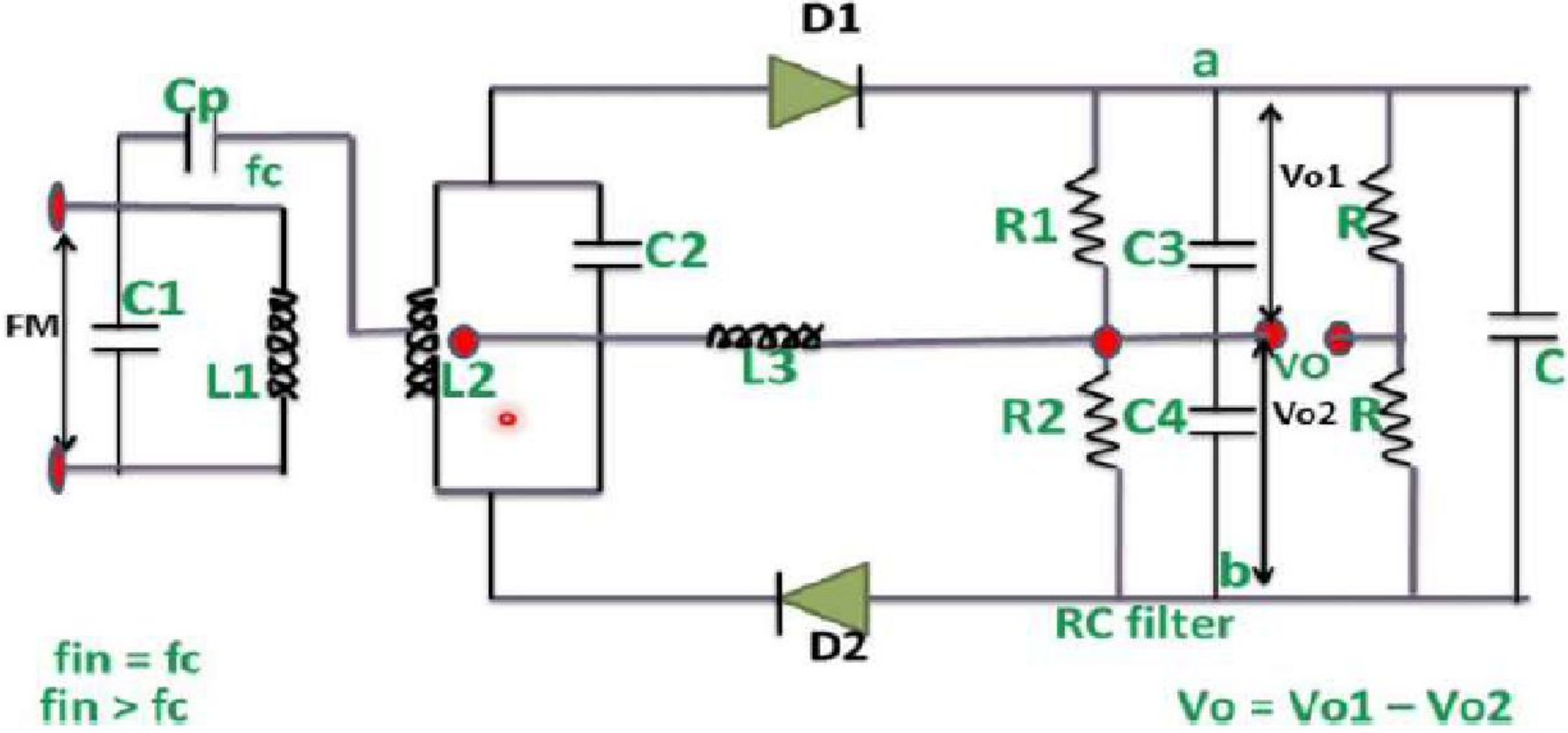
***Advantages*:**

- Tuning procedure is simpler than balanced slope detector, because it contains only two tuned circuits and both are tuned to the same frequency .
- Better linearity, because the operation of the circuit is dependent more on the primary to secondary phase relationship which is very much linear.

***Limitations*:**

It does not provide amplitude limiting. So in the presence of noise or any other spurious amplitude variations, the demodulator output respond to them and produce errors.

Ratio detector



Ratio Detector

Similar to the Foster-Seeley discriminator .

(i) The direction of diode is reversed.

(ii) A large capacitance C_s is included in the circuit.

(iii) The output is taken different locations.

Advantages:

- Easy to align.
- Good linearity due to linear phase relationship between primary and secondary.
- Amplitude limiting is provided inherently. Hence additional limiter is not required.

Performance Comparison of FM Demodulators

S.No.	Parameter of Comparison	Balanced Slope detector	Foster-Seeley (Phase) discriminator	Ratio Detector
(i)	Alignment/tuning	Critical as three circuits are to be tuned at different frequencies	Not Critical	Not Critical
(ii)	Output characteristics depends on	Primary and secondary frequency relationship	Primary and secondary phase relation.	Primary and secondary phase relation.
(iii)	Linearity of output characteristics	Poor	Very good	Good
(iv)	Amplitude limiting	Not providing inherently	Not Provided inherently	Provided by the ratio detector.
(v)	Amplifications	Not used in practice	FM radio, satellite station receiver etc.	TV receiver sound section , narrow band FM receivers.