**Dr. Khalid Subhi Ahmad**

**Department of Electronic Technologies**

**Technical Institute/Mosul**

**Northern Technical University (NTU), Iraq**

**Communication**

# Filters

Electrical filter is a circuit that can be designed to reject unwanted frequencies and pass only those wanted signals.

# passive filters

**1. What are passive filters components**

**Resistors, (R)**

**Capacitors, (C)**

**Inductors (L)**

**2. What are passive filters specifications**

**a- No signal gain**

**b- Output level is less than the input.**

# Active filters

**3. What are active filters components**

**Passive filters components +**

**Diodes,**

**Transistors,**

**Op-amps.**

**4. What are active filters specifications**

**a- Signal gain**

**b- output level is greater than the input.**

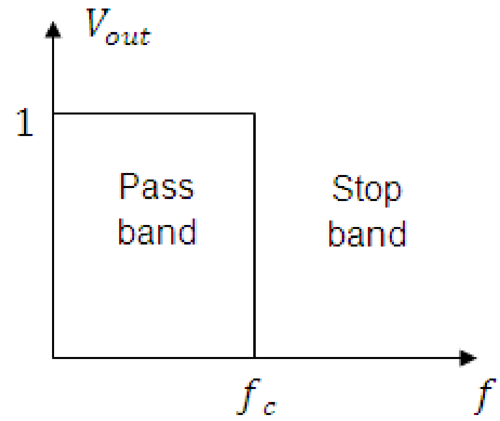
# Filters Types according to their function

**The most commonly used filter designs are:**

1. **Low Pass Filter (LPF)**
2. **High Pass Filter (HPF)**
3. **Band Pass Filter (BPF)**
4. **Band Stop Filter (BSF)**

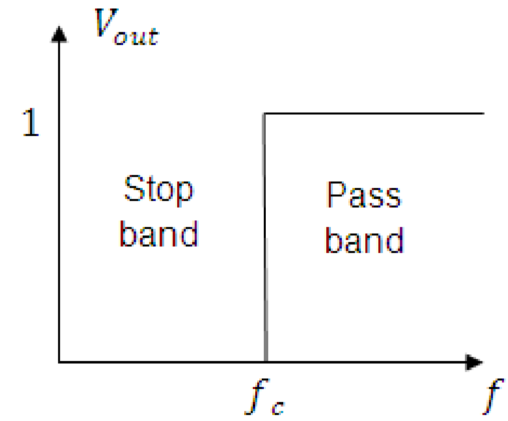
# Ideal Filter Response Curves

**LPF**



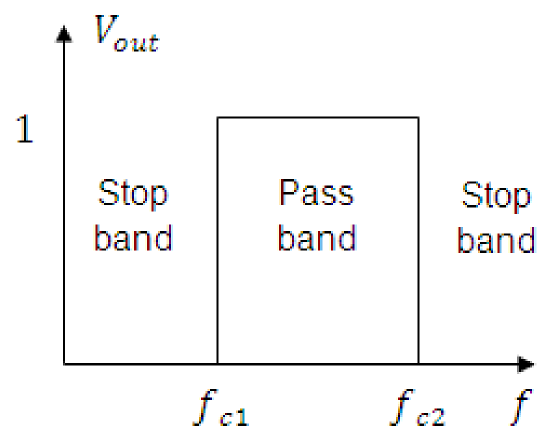

(a) Low-pass filter

**HPF**



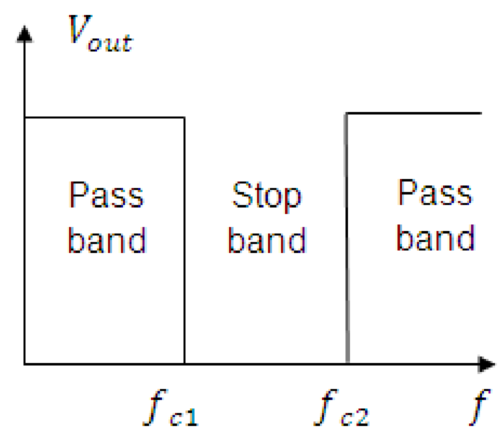

(b) High-pass filter

**BPF**




(c) Band pass filter

**BSF**




(d) Band stop filter

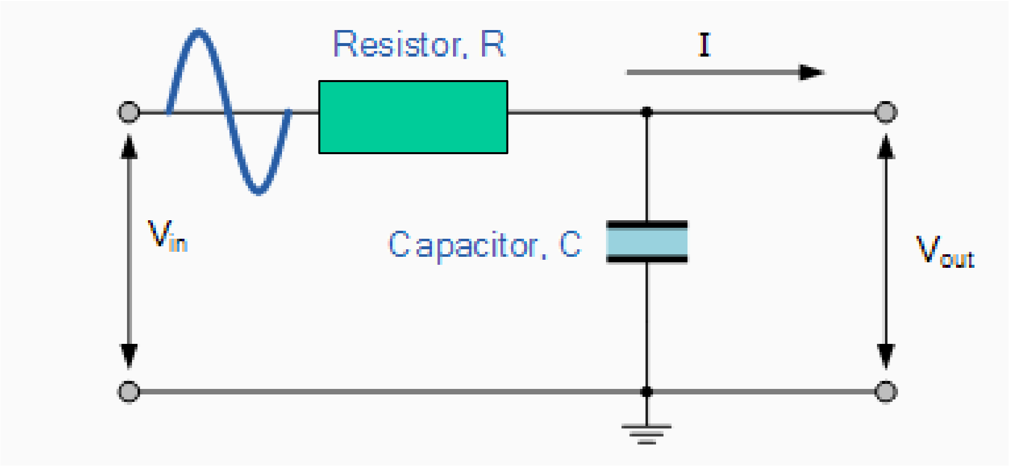
# Typical passive filters applications

**Filters applications:**

1. **amplifiers,**
2. **Oscillators,**
3. **Power supply circuits,**
4. **Speakers systems**

# Filter types

## 1. Low Pass Filter (LPF)



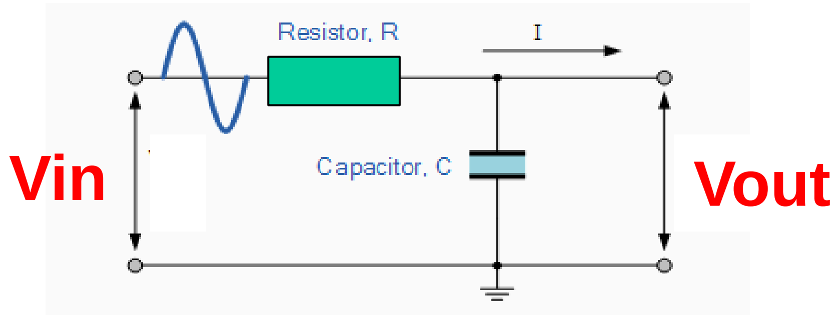

$$X_c = \frac{1}{2\pi f C}$$

Xc depend on f: frequency

$$Z = \sqrt{R^2 + {X_C}^2}$$

$$V_{out} = V_{in} * \frac{X_C}{\sqrt{R^2 + {X_C}^2}} = V_{in} * \frac{X_C}{Z}$$

# Low Pass Filter (LPF)




**Example No1:**

**A Low Pass Filter circuit consisting of a resistor of R = 4.7 kΩ in series with a capacitor of C = 47 nF is connected across a Vin = 10 V sinusoidal supply. Calculate the output voltage (Vout) at a frequency of f = 100 Hz and at a frequency of f = 10 KHz.**

# Low Pass Filter (LPF)

$$X_c = \frac{1}{2\pi f C} = \frac{1}{2\pi * 100 * 47 * 10^{-9}} = 33{,}863\,\Omega$$

nF to Farad

$$V_{out} = V_{in} * \frac{X_C}{\sqrt{R^2 + X_C{}^2}} = 10 * \frac{33{,}863}{\sqrt{4{,}700^2 + 33{,}863^2}} = 9.9\,V$$

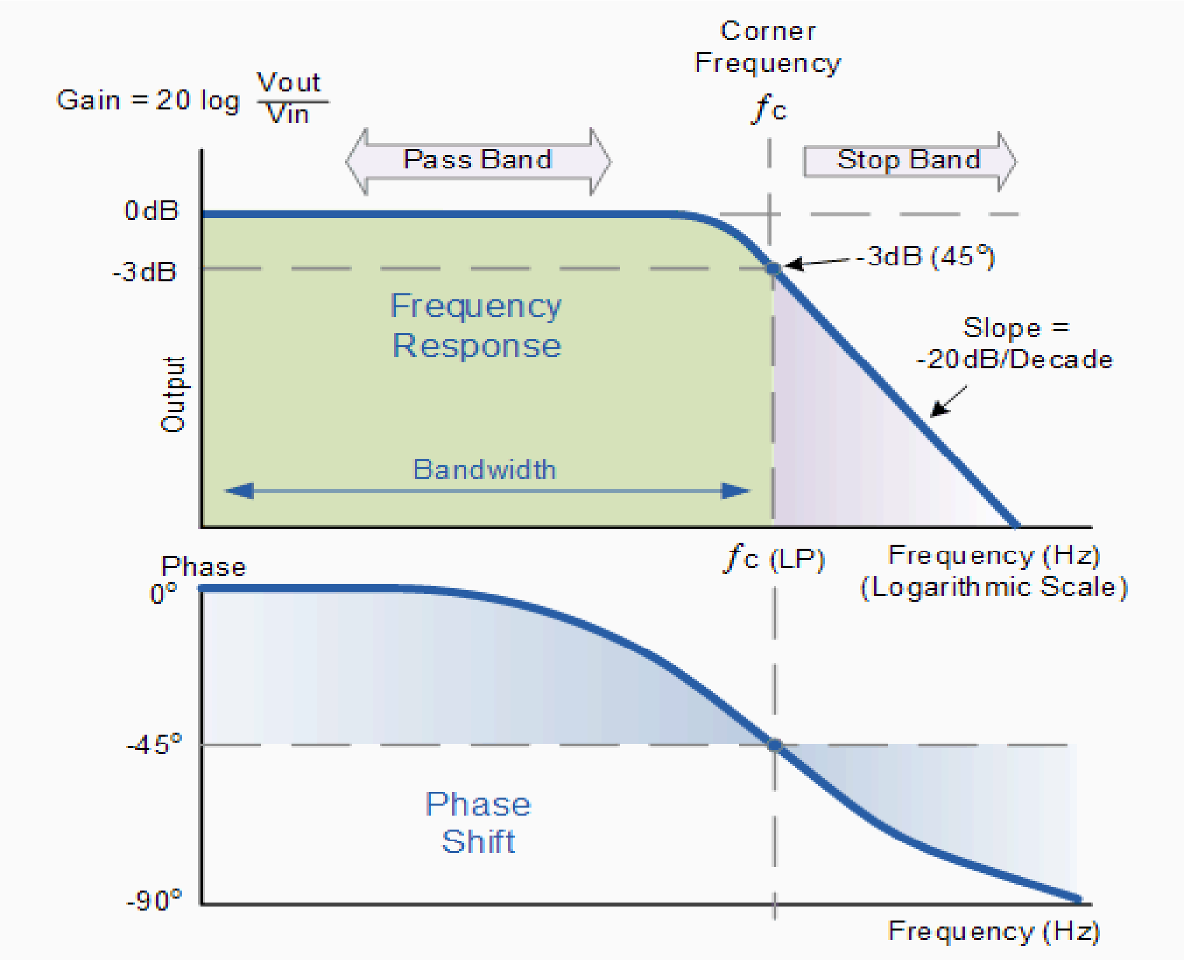
Ω

$$X_c = \frac{1}{2\pi f C} = \frac{1}{2\pi * 10{,}000 * 47 * 10^{-9}} = 338.6\,\Omega$$

Hz

$$V_{out} = V_{in} * \frac{X_C}{\sqrt{R^2 + X_C{}^2}} = 10 * \frac{338.6}{\sqrt{4{,}700^2 + 338.6^2}} = 0.718\,V$$

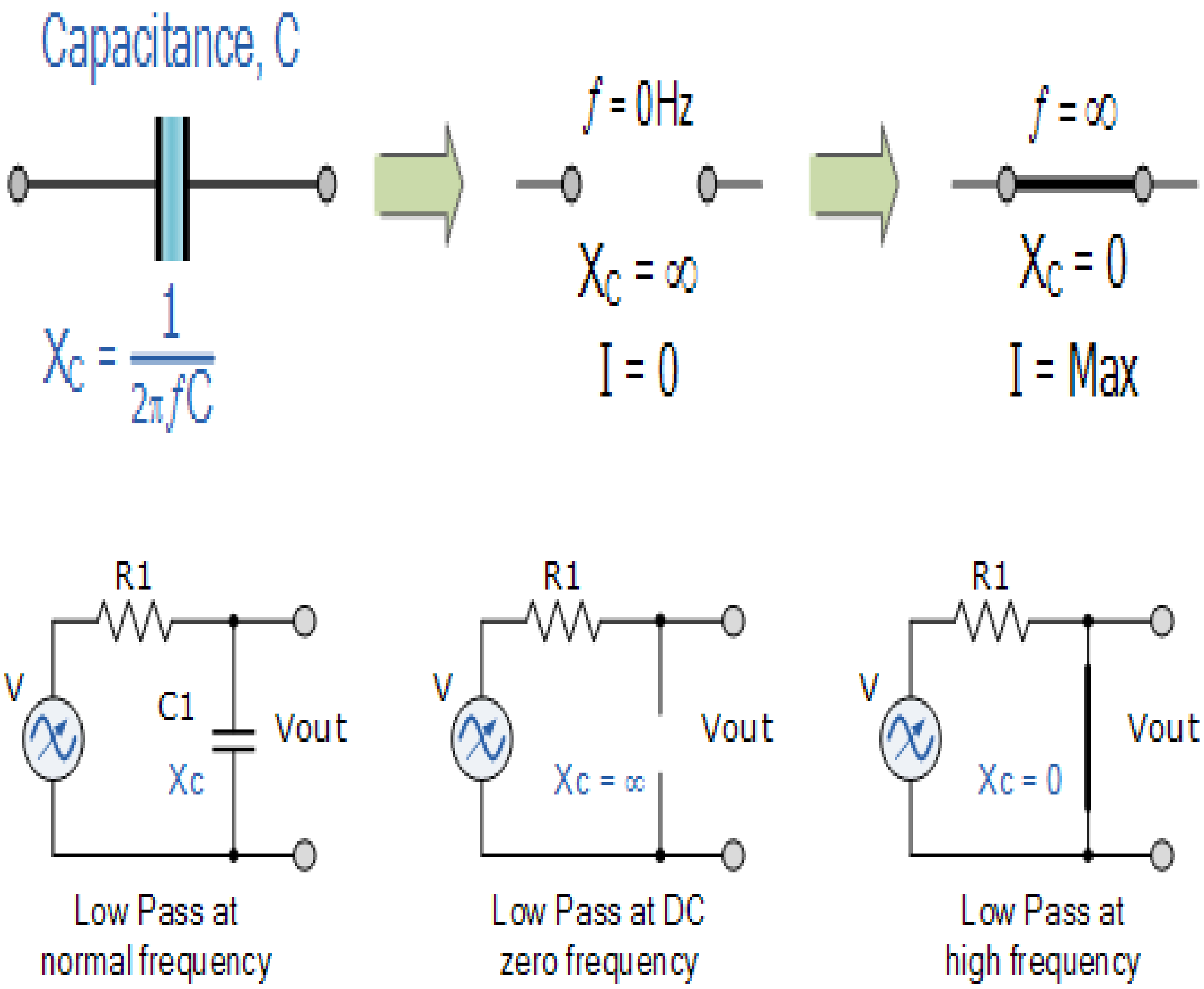
# Frequency Response of LPF




Calculate cutoff frequency: $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi * 4{,}700 * 47 * 10^{-9}} = 720\ Hz$

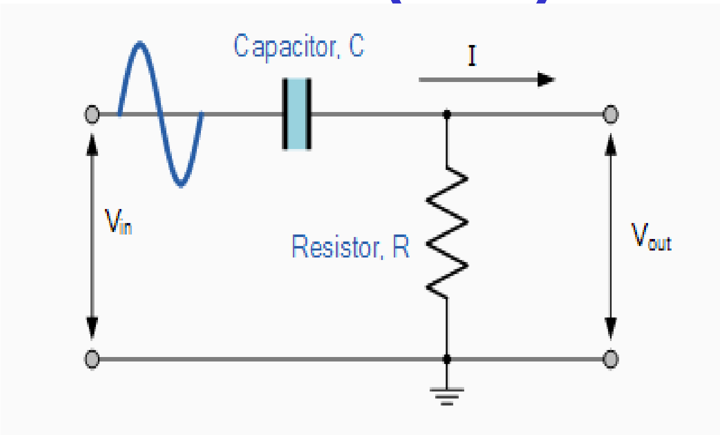
$$\Phi = -\tan^{-1} 2\pi f_c RC = -45°$$

# Low Pass Filter explanation



# Filter types

## 2. High Pass Filter (HPF)




$$f_c = \frac{1}{2\pi RC}$$

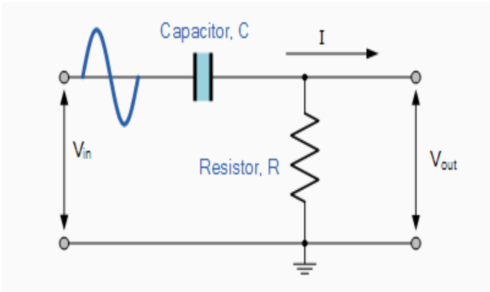
**cut-off or "breakpoint" frequency (fc)**

$$\Phi = \tan^{-1} 2\pi f_c RC$$

$$X_c = \frac{1}{2\pi f C}$$

$$V_{out} = V_{in} * \frac{R}{\sqrt{R^2 + X_C{}^2}}$$

# High Pass Filter (HPF)

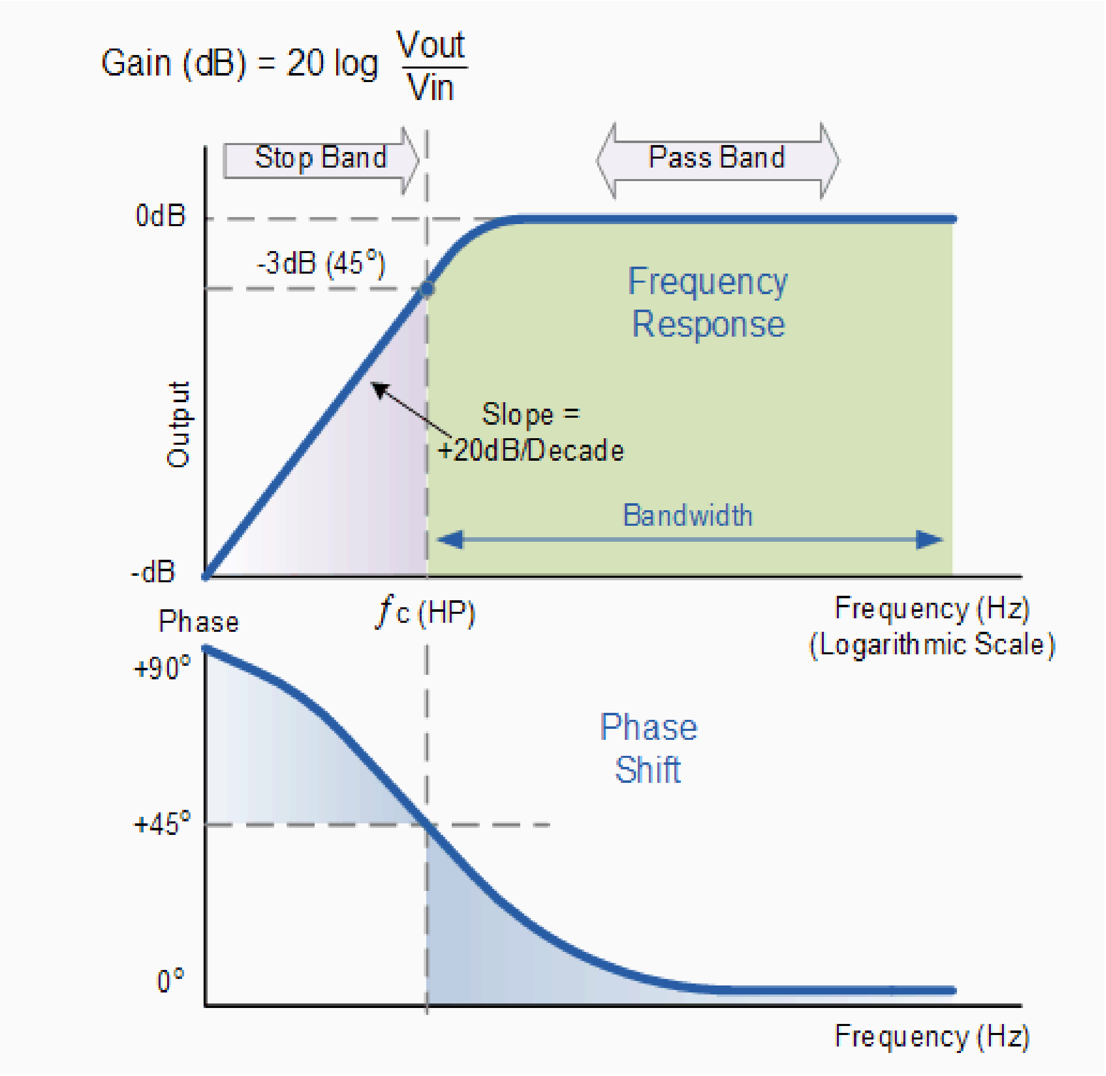



## Example No 2:

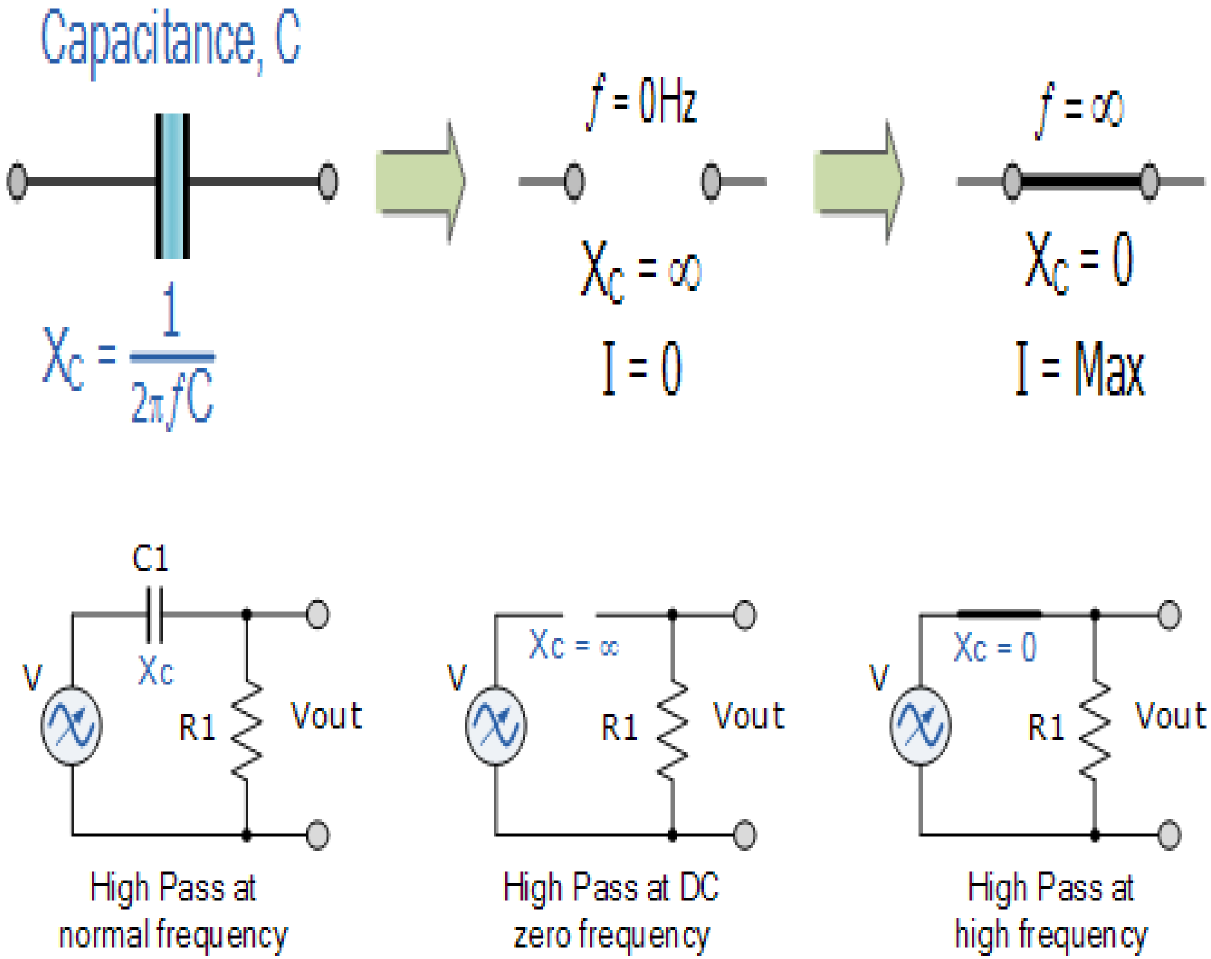
**Calculate the cut-off or "breakpoint" frequency (fc) for a simple high pass filter consisting of an C = 82 pF capacitor connected in series with a R = 240 kW resistor.**

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi * \underset{\Omega}{240 * 10^3} * \underset{\text{pF to Farad}}{82 * 10^{-12}}} = 8\,kHz$$

# Frequency Response of HPF

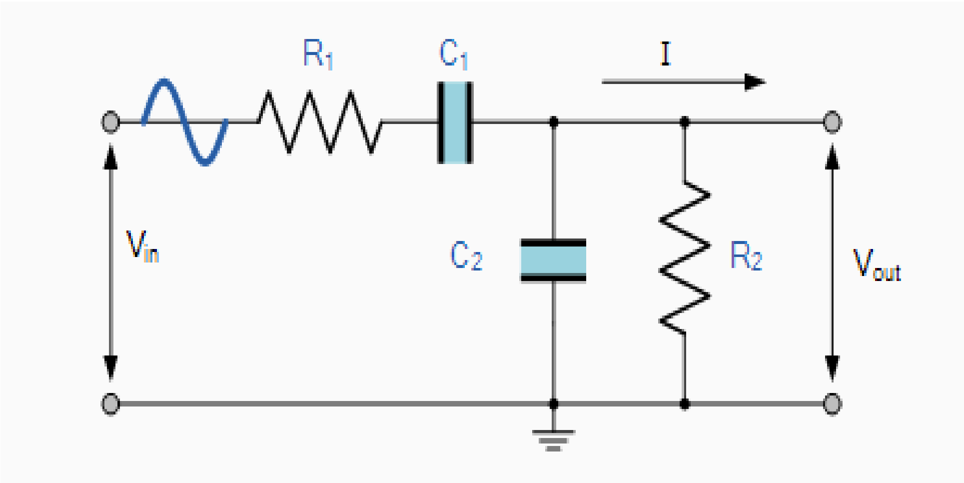


# High Pass Filter explanation



# Filter types

## 3. Band Pass Filter (BPF)



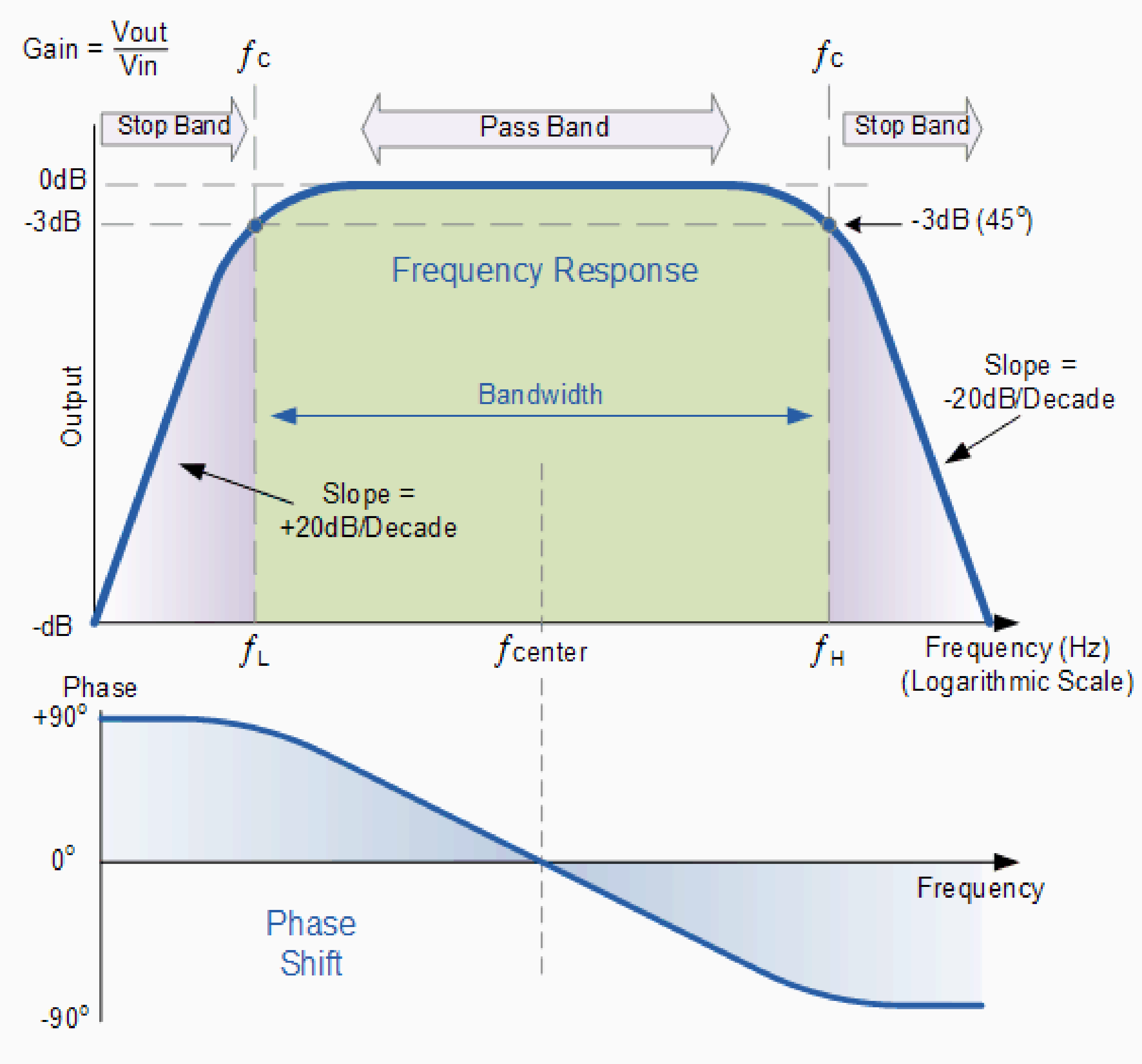

$$BW = f_H - f_L$$

$$f_r^2 = f_H * f_L$$

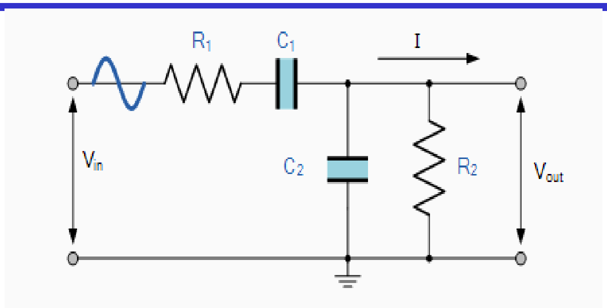
$$f_c = \frac{1}{2\pi RC}$$

# Frequency Response of Wiedband BPF

$$BW = f_H - f_L$$



# Wideband Band Pass Filter (BPF)




$$f_r^2 = f_H * f_L$$

$$f_c = \frac{1}{2\pi RC}$$

**Example No 3:**

**A second-order band pass filter is to be constructed using components that will only allow a range of frequencies to pass above fc1 = 1 kHz and below fc2 = 30 kHz. Assuming that both the resistors have values of R = 10 kW, calculate the values of the two capacitors required. Also calculate the resonant frequency (fr).**

# Wideband Band Pass Filter (BPF)

## 1- High Pass Filter Stage.

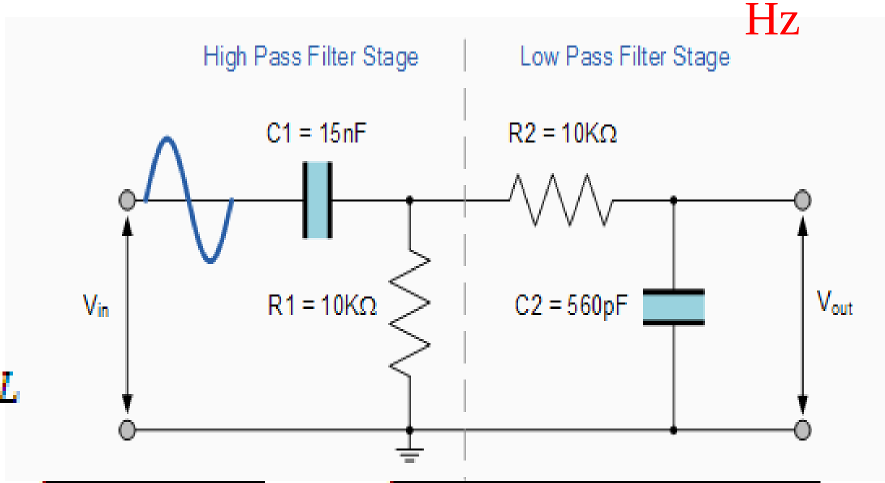
$$C = \frac{1}{2\pi R f_c} = \frac{1}{2\pi * 10{,}000 * 1000} = 15.8\, nF$$

Hz

## 2- Low Pass Filter Stage.

$$C = \frac{1}{2\pi R f_c} = \frac{1}{2\pi * 10{,}000 * 30{,}000} = 510\; pF$$

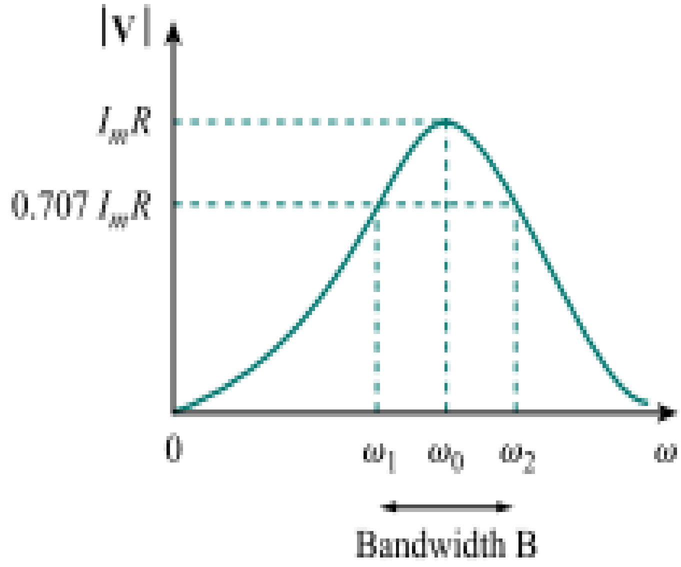
Hz

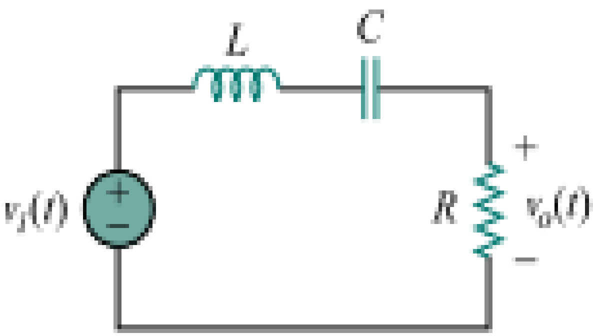


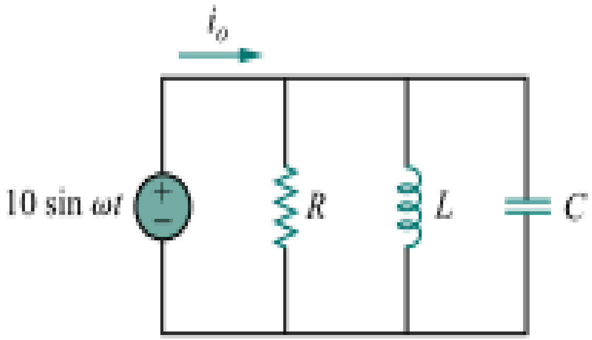

$$f_r^2 = f_H * f_L$$

$$f_r = \sqrt{f_H * f_L} = \sqrt{30{,}000 * 1{,}000} = 5{,}480\; Hz$$

# Narrowband Band Pass Filter (BPF)




**Series RLC BPF**

**Parallel RLC BPF**

# Narrowband Band Pass Filter (BPF)

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{f_{c2} + f_{c1}}{2}$$

$$R_T = \frac{R_o * R_L}{R_o + R_L}$$

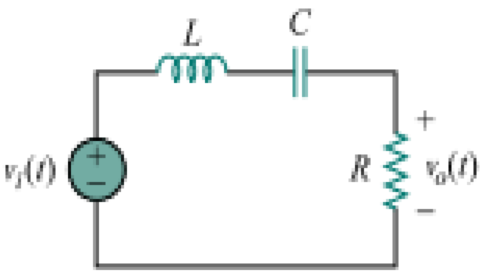
**Input resistance: (Ro)**

**load resistance (RL)**

$$BW = \frac{R_T}{2\pi L} = f_{c2} - f_{c1}$$

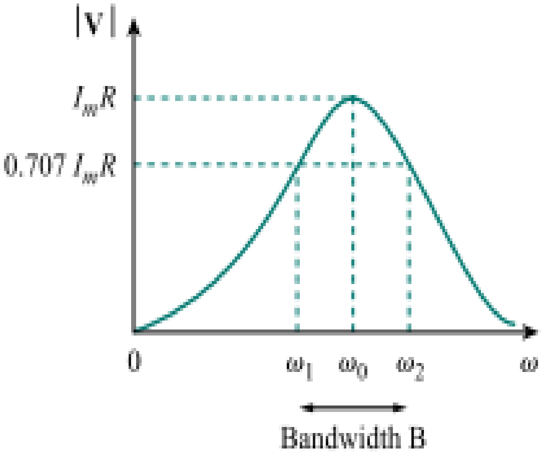
$$Q_s = \frac{f_r}{BW}$$

# Narrowband Band Pass Filter (BPF)




**Example No 4:**

**Design series passive RLC-BPF with: fc1 = 23 kHz, fc2 = 25 kHz, L = 45 mH and RL = 50 ohm. Calculate:**




**1- Resonant frequency (fr)**
**2- Capacitor (C)**
**3- Quality factor (Qs)**
**4- Input resistance (Ro)**

# Narrowband Band Pass Filter (BPF)

$$f_r = \frac{f_{c2}+f_{c1}}{2} = \frac{25\,k+23\,k}{2} = 24\,kHz$$

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{f_{c2}+f_{c1}}{2}$$

$$R_T = \frac{R_o * R_L}{R_o + R_L}$$

$$f_r = \frac{1}{2\pi\sqrt{LC}} \rightarrow C = \frac{1}{(2\pi f_r)^2 L} = 0.977\,nF$$

$$BW = \frac{R_T}{2\pi L} = f_{c2} - f_{c1}$$

$$BW = f_{c2} - f_{c1} = 25\,k - 23\,k = 2\,kHz$$

$$Q_s = \frac{f_r}{BW}$$

$$BW = \frac{f_r}{Q_s} \rightarrow Q_s = \frac{f_r}{BW} = \frac{24\,k}{2\,k} = 12$$

$$BW = \frac{R_T}{2\pi L} = f_{c2} - f_{c1}$$

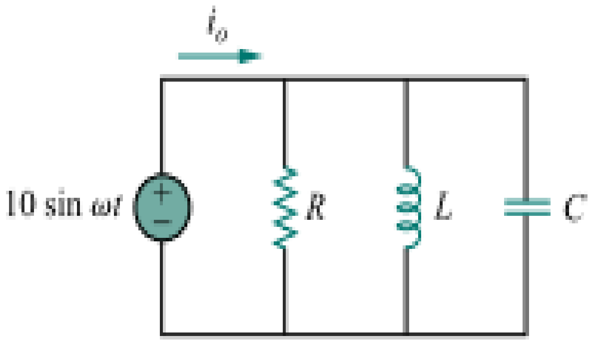
$$Q_s = \frac{2\pi f_r L}{R_T} \rightarrow R_T = \frac{2\pi f_r L}{Q_s} = \frac{2\pi * 24\,k * 45\text{ m}}{12} = 565.5\,\Omega$$

$$R_T = \frac{R_o * R_L}{R_o + R_L} \rightarrow R_o = \frac{R_T * R_L}{R_T - R_L} = \frac{50\,k * 565.5}{50\,k - 565.5} = 571.97\,\Omega$$

# Narrowband Band Pass Filter (BPF)

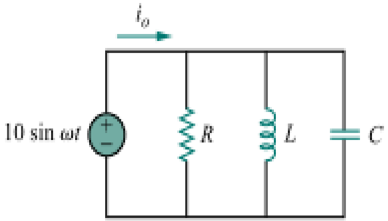
**Example No 5:**

**In parallel passive RLC-BPF if: L = 50 mH, C = 127 nF, Ro = 63 kW and RL = 600 kW.**
**Calculate:**




**1- Resonant frequency (fr)**
**2- Quality factor (Qs)**
**3- Bandwidth (BW)**
**4- Cutoff frequencies (fc1, fc2)**

# Narrowband Band Pass Filter (BPF)




$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{50m * 129n}} = 2\ kHz$$

$$R_T = \frac{R_o * R_L}{R_o + R_L} = \frac{63 * 600}{63 + 600} = 57\ \Omega$$

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{f_{c2} + f_{c1}}{2}$$

$$Q_s = \frac{2\pi f_r L}{R_T} = \frac{2\pi * 2k * 50m}{57} = 11$$

$$R_T = \frac{R_o * R_L}{R_o + R_L}$$

$$BW = \frac{R_T}{2\pi L} = f_{c2} - f_{c1}$$

$$BW = \frac{f_r}{Q_s} = \frac{2k}{11} = 182\ Hz$$

$$Q_s = \frac{f_r}{BW}$$

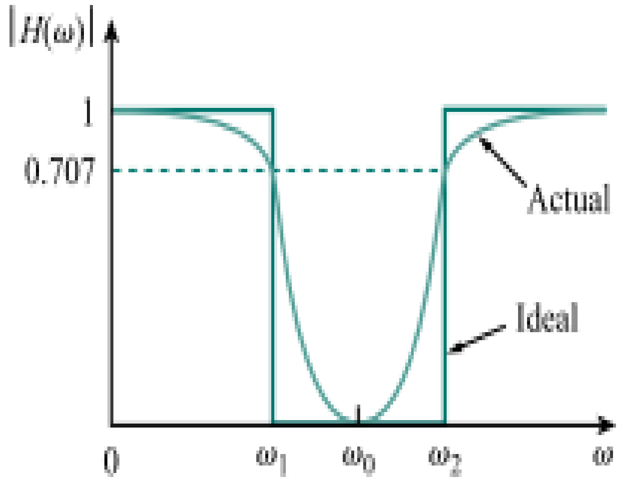
قانون fc1

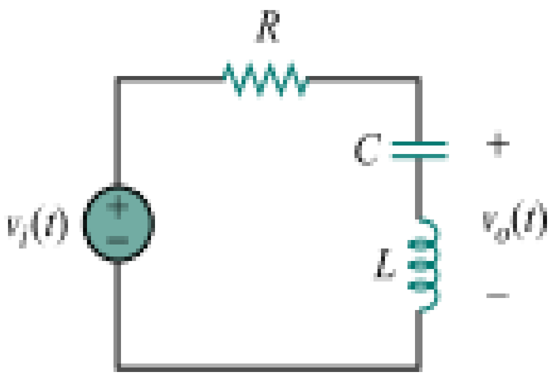
$$f_{c1} = f_r - \frac{BW}{2} = 2\ k - \frac{182}{2} = 1909\ Hz$$

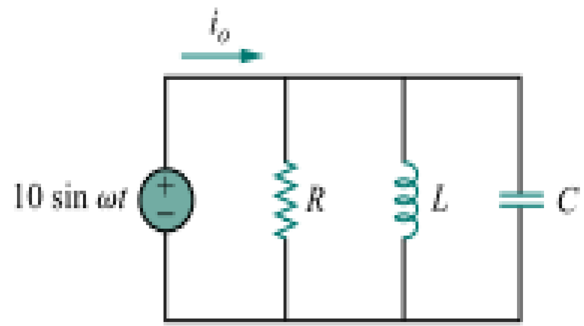
قانون fc2

$$f_{c2} = f_r + \frac{BW}{2} = 2\ k + \frac{182}{2} = 2091\ Hz$$

# Band Stop Filter (BSF)




**Series RLC BSF** **Parallel RLC BSF**

# Narrowband Band Pass Filter (BPF)

## Example No 6:

**In series passive RLC-BSF is to reject a fr = 200 Hz sinusoid while passing other frequencies, calculate the values of L and C. Where RT = 150W and the bandwidth is BW = 100 Hz.**

$$BW = \frac{R_T}{2\pi L} \rightarrow L = \frac{150}{2\pi * 100} = 0.2387\,\mathrm{H}$$

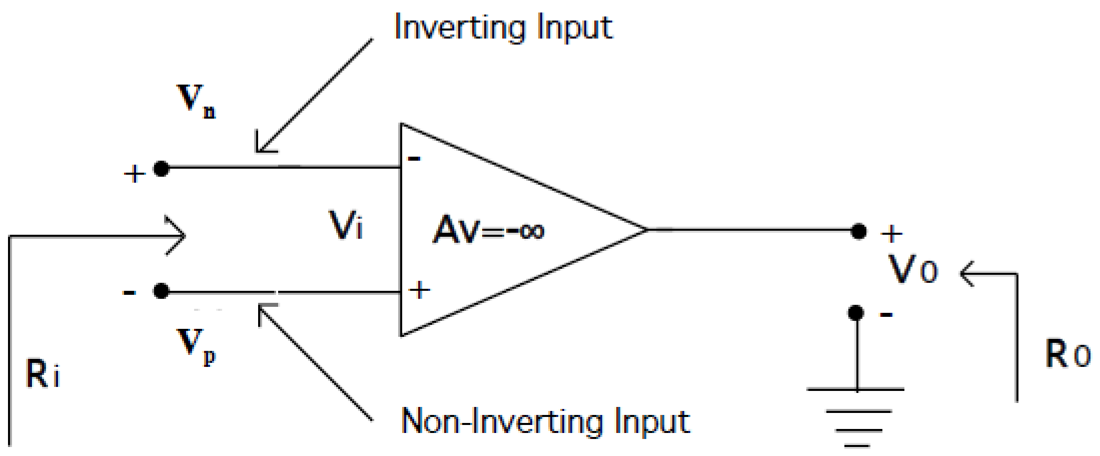
$$f_r = \frac{1}{2\pi\sqrt{LC}} \rightarrow C = \frac{1}{(2\pi f_r)^2 L} = \frac{1}{(2\pi * 200)^2 * 0.2387} = 2.66\,\mu F$$

# Filters

## اسئلة امتحانيه

1. Draw the ideal filters types according to their function, low pass filter (LPF), high pass filter HPF, band pass filter (BPF)and band stop filter (BPF). (page 6)
2. **Example 1, 2, 3, 4, 5, and 6.**

# Active Filters




**Operational amplifier (op-amp) prosperities:**

1. **High input impedance,**
2. **Low output impedance,**
3. **High gain.**
4. **Wide bandwidth (BW)**

# Active filters advantages and disadvantages

## Active filters advantages

1- Reduction in size, weight and cost,
2- Increase circuit reliability,
3- Easy to design,
4- Improve performance,
5- Provide voltage gain,
6- Provide wide frequency range (wide BW),
7- Have excellent isolation capability.

## Active filters disadvantages

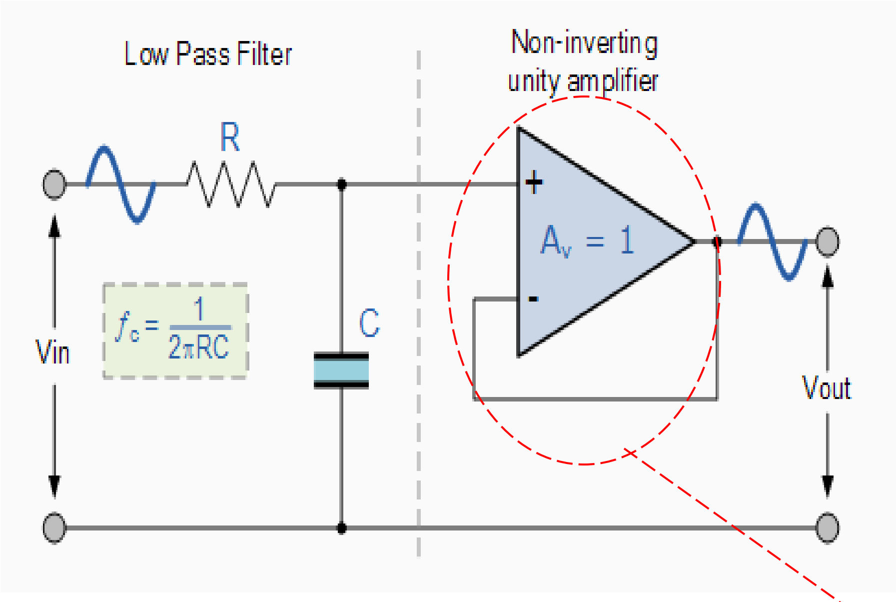
1- Need power supply,
2- Affect by temperature,

# Advantages and disadvantages of active compared to the passive filters

| | Active filters | Passive filters |
|---|---|---|
| 1 | Provide amplification (Output voltage > input voltage) (advantage) | Don’t provide amplification (Output voltage < input voltage) (disadvantage) |
| 2 | Need power supply (disadvantage) | Don’t need power supply (advantage) |

# Filter types

## 1. Low Pass Filter (LPF) without amplification




The main disadvantage of passive filters is that the amplitude of the output signal is less than that of the input signal, the gain is never greater than unity.

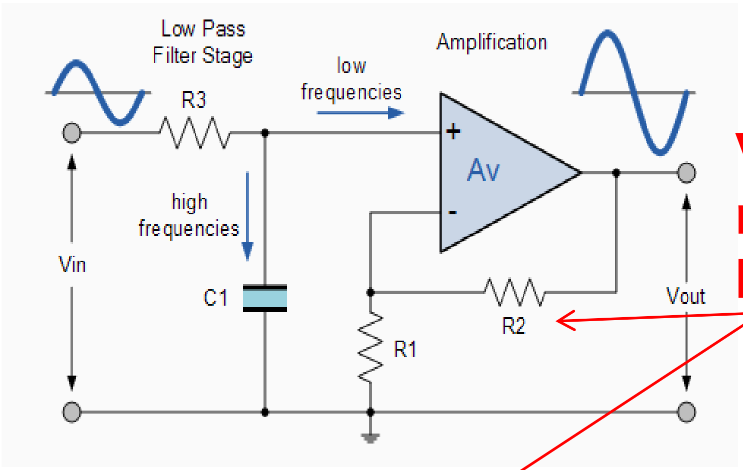
Analog buffer

**Gain is unity:**

$$A_v = +1 \qquad f_c = \frac{1}{2\pi RC}$$

# Filter types

## 1. Low Pass Filter (LPF) with amplification




**Voltage gain determined by the resistor network within its feedback loop.**

**Gain is more than unity:**

$$A_v = 1 + \frac{R_2}{R_1} \qquad f_c = \frac{1}{2\pi RC} \qquad A_v = \frac{V_{out}}{V_{in}}$$

# Low Pass Filter (LPF)

.

.

**Example No 1:**

**Design a non-inverting active low pass filter circuit that has gain $A_v$ = 10 of at low frequencies, a high frequency cut-off frequency of fc = 159 Hz and an input impedance of R = 10 kW.**

# Low Pass Filter (LPF)

**AF = 10 fc = 159 Hz**

$$A_v = 1 + \frac{R_2}{R_1}$$

assume $R_1 = 1\ \mathrm{k\Omega}$

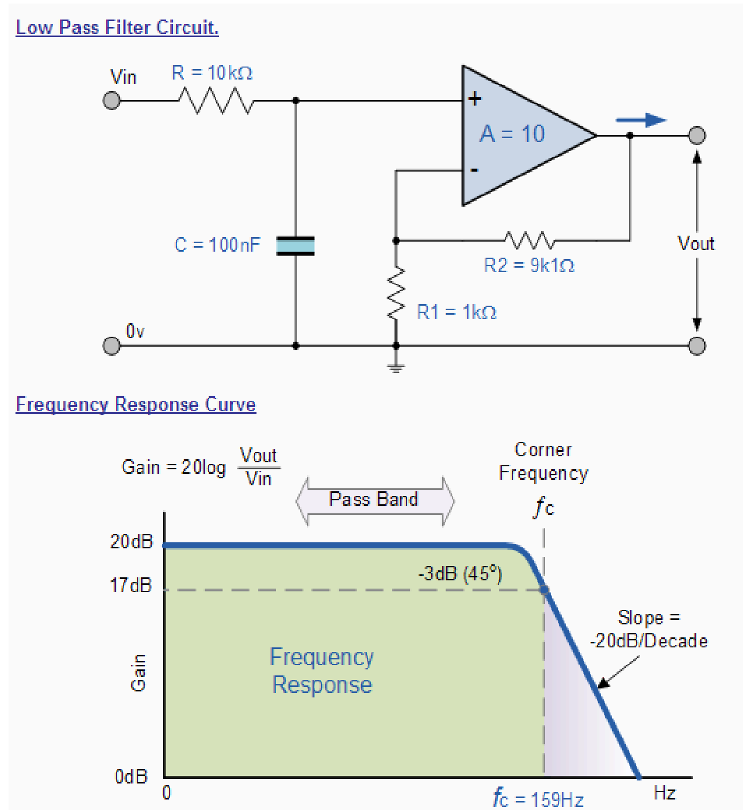
$$10 = 1 + \frac{R_2}{1\,k}$$

$$R_2 = 9\ \mathrm{k\Omega}$$

**R = 10 kΩ**

$$f_c = \frac{1}{2\pi RC}$$

$$C = \frac{1}{2\pi R f_c} = \frac{1}{2\pi * 1000 * 159} = 100\,nF$$




$$A_v = \frac{V_{out}}{V_{in}}$$

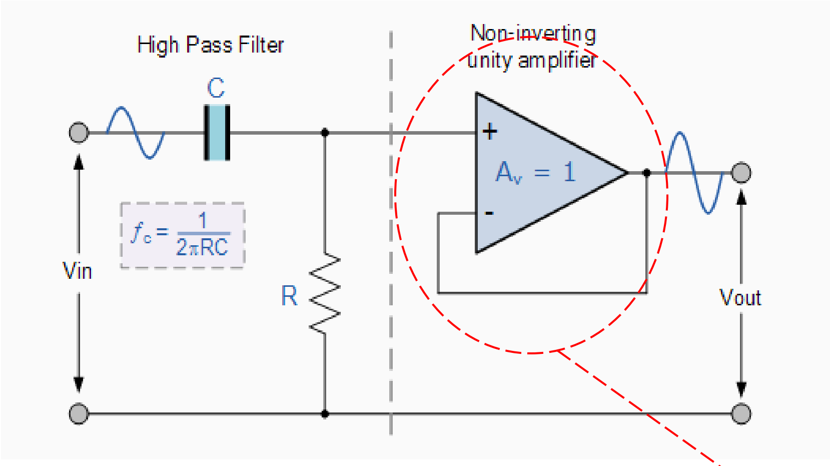
$$A_v = 1 + \frac{R_2}{R_1}$$

$$f_c = \frac{1}{2\pi RC}$$

# Filter types

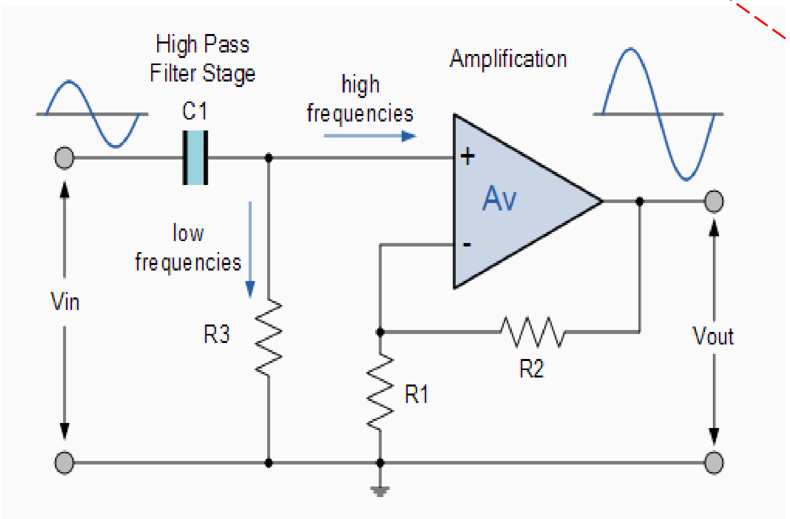
## 2. High Pass Filter (HPF)

**Unity amplification**



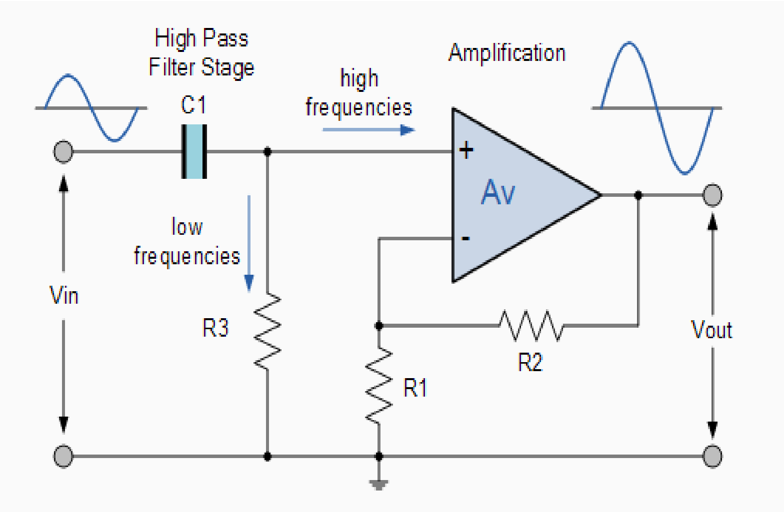

Analog buffer

**with amplification**



# High Pass Filter (HPF)

$$A_v = 1 + \frac{R_2}{R_1}$$

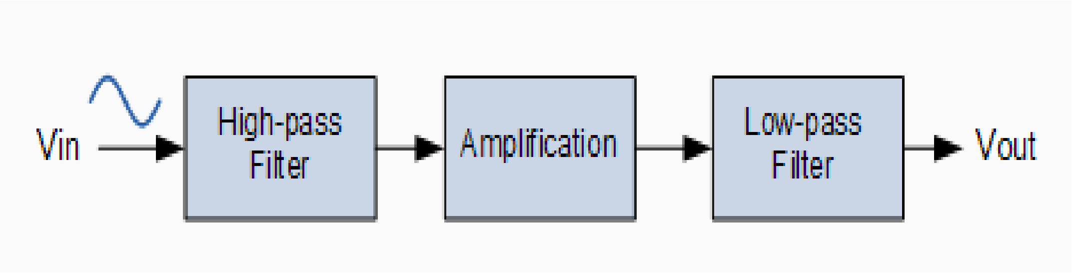


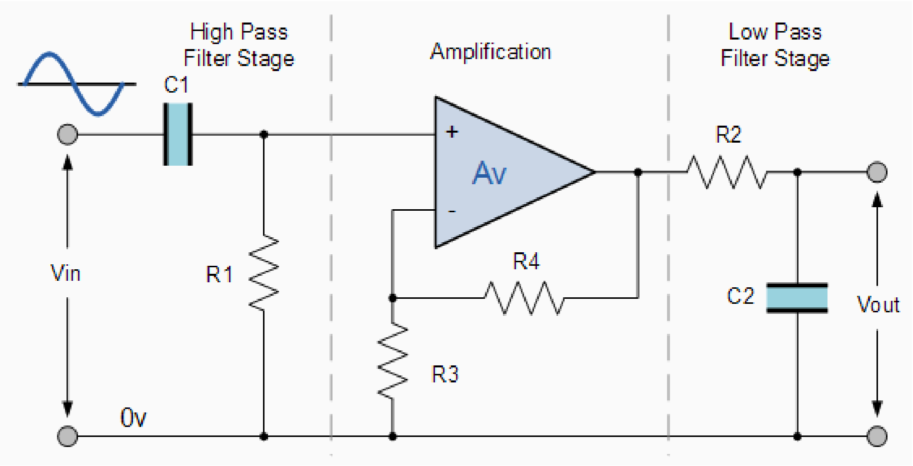

$$f_c = \frac{1}{2\pi RC}$$

$$A_v = \frac{V_{out}}{V_{in}}$$

# Filter types

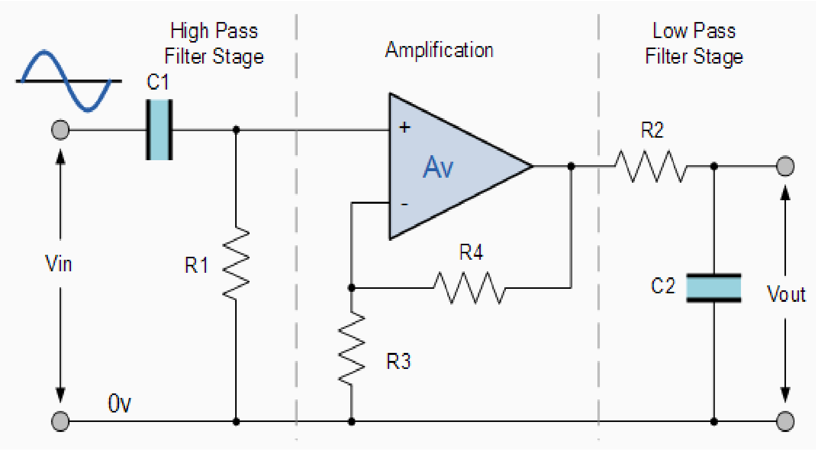
## 3. Band Pass Filter (BPF) or Band Stop Filter (BSF)



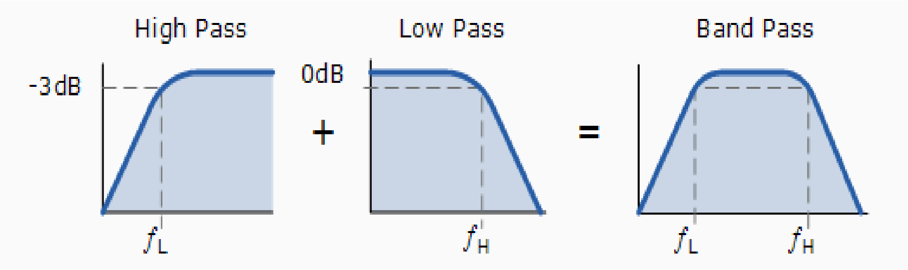



# Band Pass Filter (BPF)

$$A_v = 1 + \frac{R_4}{R_3}$$




$$f_{c1} = \frac{1}{2\pi R_1 C_1}$$




$$f_{c2} = \frac{1}{2\pi R_2 C_2}$$

# Band Pass Filter (BPF)

**Example No 2:**

**Design a non-inverting active band pass filter circuit that has unity gain ( $A_v$ = 1), a low frequency cut-off of fl = 160 Hz and high frequency cut-off of fh = 8 kHz and an output impedance of RL = 1 MΩ.**

# Band Pass Filter (BPF)

$A_v$ **= 1** **fl = 160 Hz** **fh = 8 kHz** **RL = 1 MΩ**

$$A_v = 1 + \frac{R_4}{R_3}$$

$$A_v = 1 = 1 + \frac{R_4}{R_3} \rightarrow R_4 = 0$$

$$f_{c1} = \frac{1}{2\pi R_1 C_1}$$

## 1- Low Pass Filter Stage.

Assume

$$R_2 < R_L \qquad R_2 = 100\ \text{k}\Omega \qquad f_{c2} = 8\ kHz$$

$$f_{c2} = \frac{1}{2\pi R_2 C_2} \rightarrow C_2 = \frac{1}{2\pi R_2 f_{c2}} = \frac{1}{2\pi * 100{,}000 * 8000} = 0.2\ nF$$

$$f_{c2} = \frac{1}{2\pi R_2 C_2}$$

## 2- High Pass Filter Stage.

$$R_1 < R_2 \qquad R_1 = 10\ \text{k}\Omega \quad f_{c1} = 160\ Hz$$

$$f_{c1} = \frac{1}{2\pi R_1 C_1} \rightarrow C_1 = \frac{1}{2\pi R_1 f_{c1}} = \frac{1}{2\pi * 10{,}000 * 160} = 100\ nF$$

# Filters

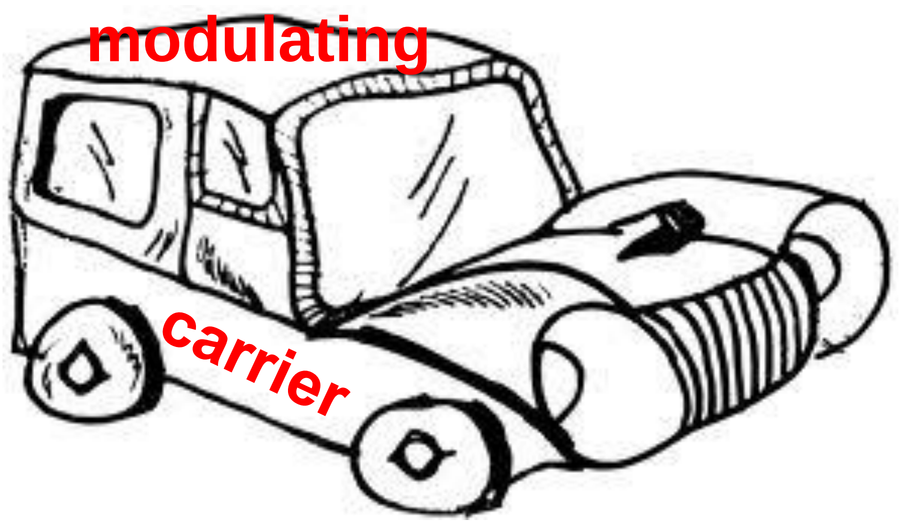
# اسئلة امتحانيه

1. State Operational amplifier (op-amp) prosperities. (pg. 30)
2. State Active filters advantages and disadvantages (pg. 31)
3. Compare between active and passive filters. (pg. 32)
4. Draw Low Pass Filter (LPF) circuit without amplification. (pg. 33)
5. Draw Low Pass Filter (LPF) with amplification. (pg. 34)
6. Example (pg. 35)
7. Draw High Pass Filter (HPF) without amplification. (pg. 37)
8. Draw High Pass Filter (HPF) with amplification. (pg. 37)

9. **Draw Band Pass Filter (BPF) circuit and draw its frequency response. (pg. 40)**
10. **draw LPF frequency response. (pg. 36)**
11. **Example No 2. (PG. 41)**

# MODULATION

**MODULATION is the process of varying properties of a carrier signal with a modulating signal which typically contains information.**



# MODULATION

**A device that performs modulation is known as a modulator and a device that performs the inverse operation of modulation is known as a demodulator (sometimes detector).**

# Frequency bands and their uses

| | | | |
|---|---|---|---|
| Medium frequency | MF | 300–3000 kHz<br>1 km – 100 m | AM (medium-wave) broadcasts, amateur radio, avalanche beacons |
| High frequency | HF | 3–30 MHz<br>100 m – 10 m | Shortwave broadcasts, citizens' band radio, amateur radio and over-the-horizon aviation communications, RFID, Over-the-horizon radar, Automatic link establishment (ALE) / Near Vertical Incidence Sky-wave (NVIS) radio communications, Marine and mobile radio telephony |
| Very high frequency | VHF | 30–300 MHz<br>10 m – 1 m | FM, television broadcasts and line-of-sight ground-to-aircraft and aircraft-to-aircraft communications. Land Mobile and Maritime Mobile communications, amateur radio, weather radio |
| Ultra high frequency | UHF | 300–3000 MHz<br>1 m – 100 mm | Television broadcasts, microwave ovens, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, Zig-Bee, GPS and two-way radios such as Land Mobile, FRS and GMRS radios, amateur radio |
| Super high frequency | SHF | 3–30 GHz<br>100 mm – 10 mm | Radio astronomy, microwave devices/communications, wireless LAN, most modern radars, communications satellites, satellite television broadcasting, DBS, amateur |

# Frequency bands and their uses

| | | | |
|---|---|---|---|
| Extremely high frequency | EHF | 30–300 GHz<br>10 mm – 1 mm | Radio astronomy, high-frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimeter wave scanner |
| Terahertz or Tremendously high frequency | THz or THF | 300–3,000 GHz<br>1 mm – 100 μm | Terahertz imaging – a potential replacement for X-rays in some medical applications, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, sub-mm remote sensing, amateur radio |

# Why we need modulation?

1. Reduce antenna size.
2. To increase radiated power from antenna.
3. Mixing signals from different transmitters.
4. Modulation to reduce noise and interference

# Transmission antenna length

**L = λ /10 (Antenna length)**

**λ= C/f (C=3*$10^8$ m/sec)**

**<u>Example No 1:</u>**

**Calculate the antenna length L for f=20 kHz and f=100 MHz .**

**<u>Solution</u>**

$$\lambda = \frac{C}{f} = \frac{3 * 10^8}{20 * 10^3} = 15\ Km$$

$$L = \frac{\lambda}{10} = \frac{15\ Km}{10} = 1.5\ Km!!!!!!!$$

$$\lambda = \frac{C}{f} = \frac{3 * 10^8}{100 * 10^6} = 3\ m$$

$$L = \frac{\lambda}{10} = \frac{3\ m}{10} = 30\ cm$$

# Carrier signal and audio signal

Amplitude (AM)

Phase (PM)

$$v_c(t) = V_c \sin(2\pi f_c t + \Phi)$$

Carrier Signal

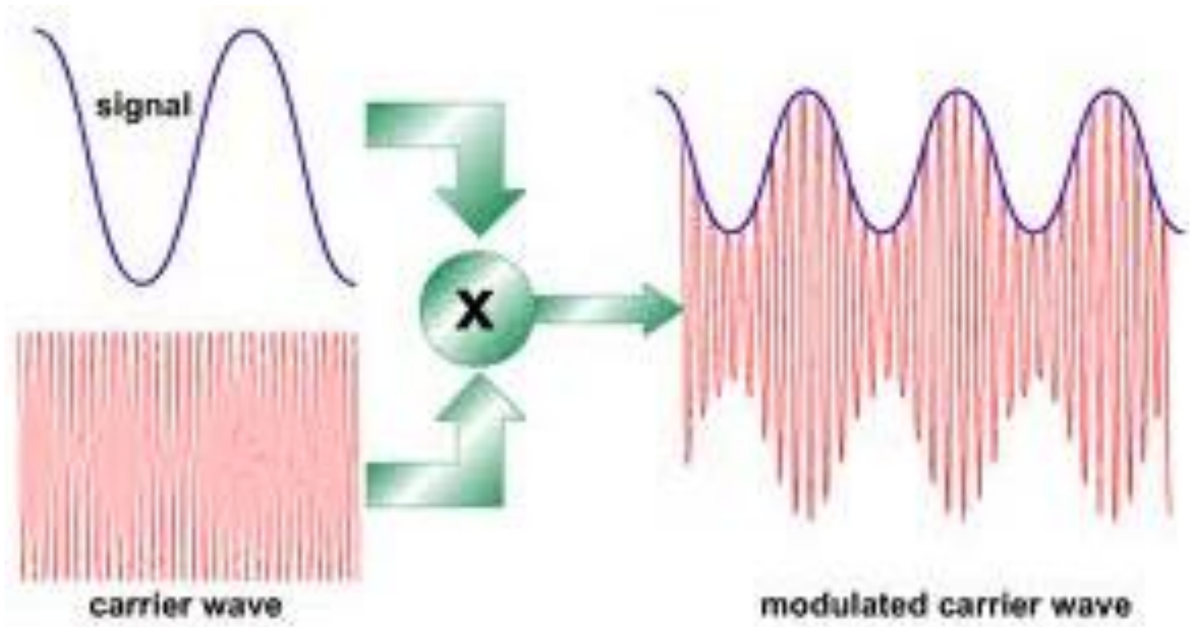
Frequency (FM)

audio signal

$$v_m(t) = V_m \sin(2\pi f_m t)$$

# Amplitude Modulation (AM)

$$v_m(t) = V_m \sin(2\pi f_m t)$$




$$v_c(t) = V_c \sin(2\pi f_c t)$$

**Modulating signal + Carrier signal = modulated signal**

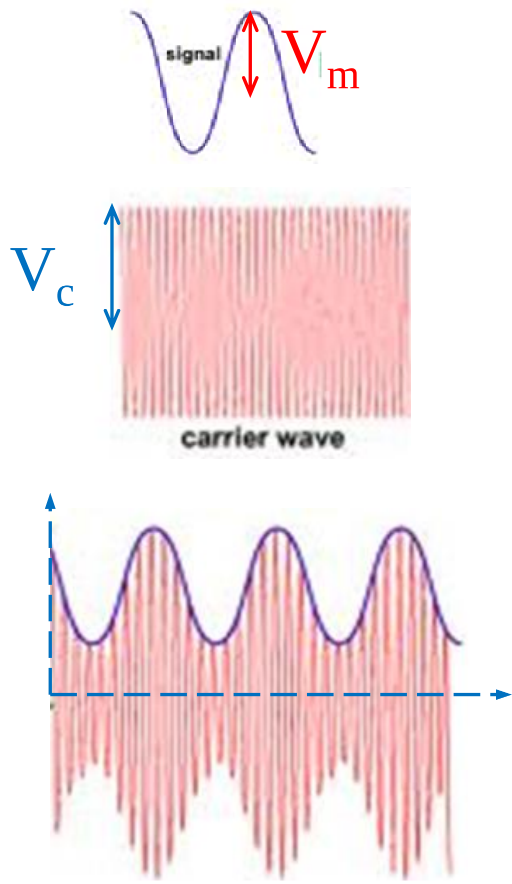
# Amplitude Modulation (AM)

**m: Modulation Index (percentage of modulation or modulation depth)**

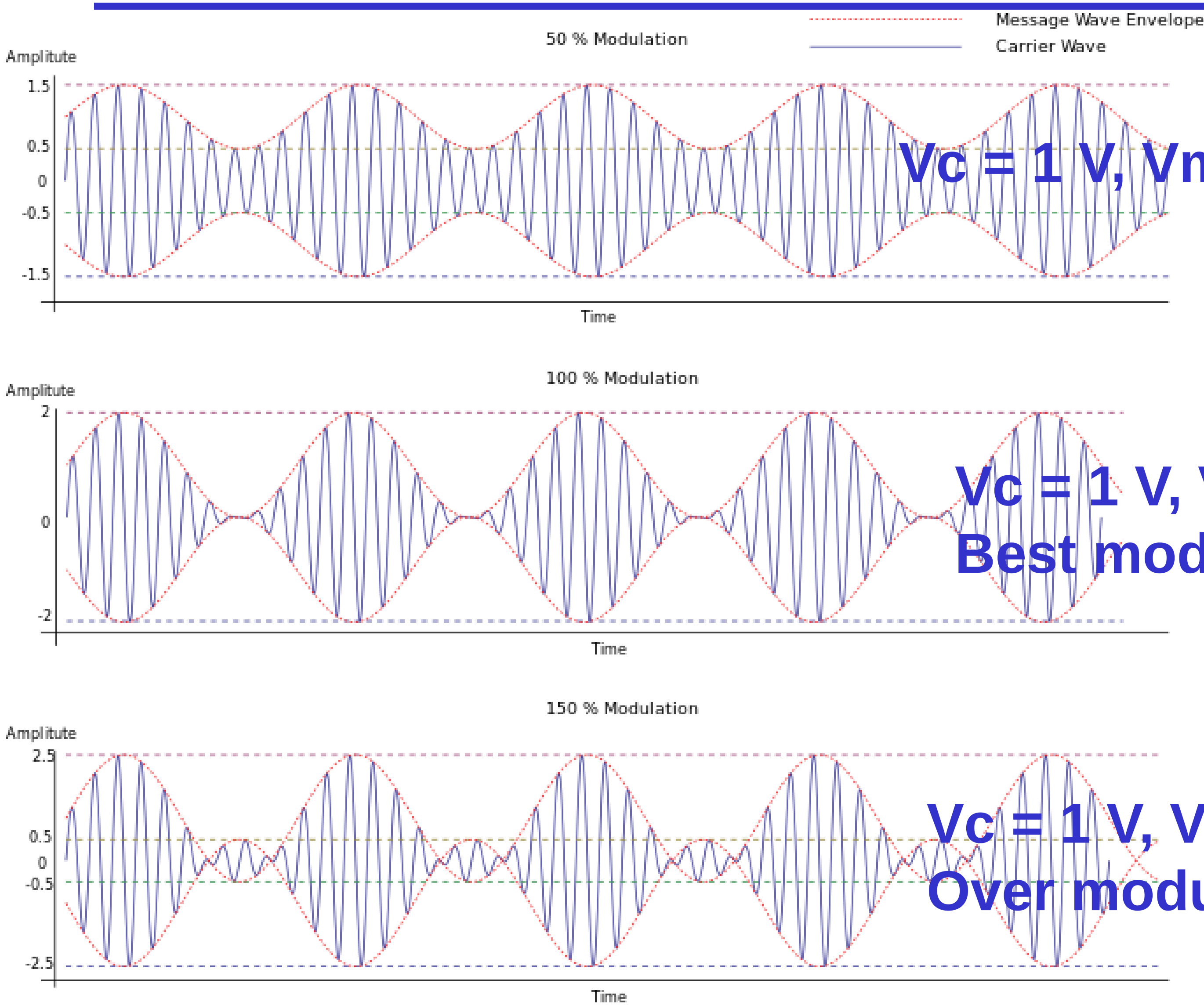
$$m = \frac{V_m}{V_c} \qquad (0 < m < 1 \text{ and } V_m < V_c)$$

**For example: Vc = 9 V, Vm = 7.5 V,**
**m = 7.5 / 9 = 0.83**
**m% = m * 100 = 83 %**

**If Vc = 9 V, Vm = 9 V,**
**m = 9 / 9 = 1**
**m% = m * 100 = 100 % (best modulation)**



# Amplitude Modulation (AM)




**Vc = 1 V, Vm = 0.5 V**

**Vc = 1 V, Vm = 1 V**
**Best modulation**

**Vc = 1 V, Vm = 1.5 V**
**Over modulation**

# Amplitude Modulation (AM) Equation

$$v_m(t) = V_m \sin(2\pi f_m t)$$ **audio signal**

$$v_c(t) = V_c \sin(2\pi f_c t)$$ **carrier signal**

$$m = \frac{V_m}{V_c}$$

$$v_{AM}(t) = (V_c + V_m \sin(2\pi f_m t)) \sin(2\pi f_c t) \qquad (1)$$

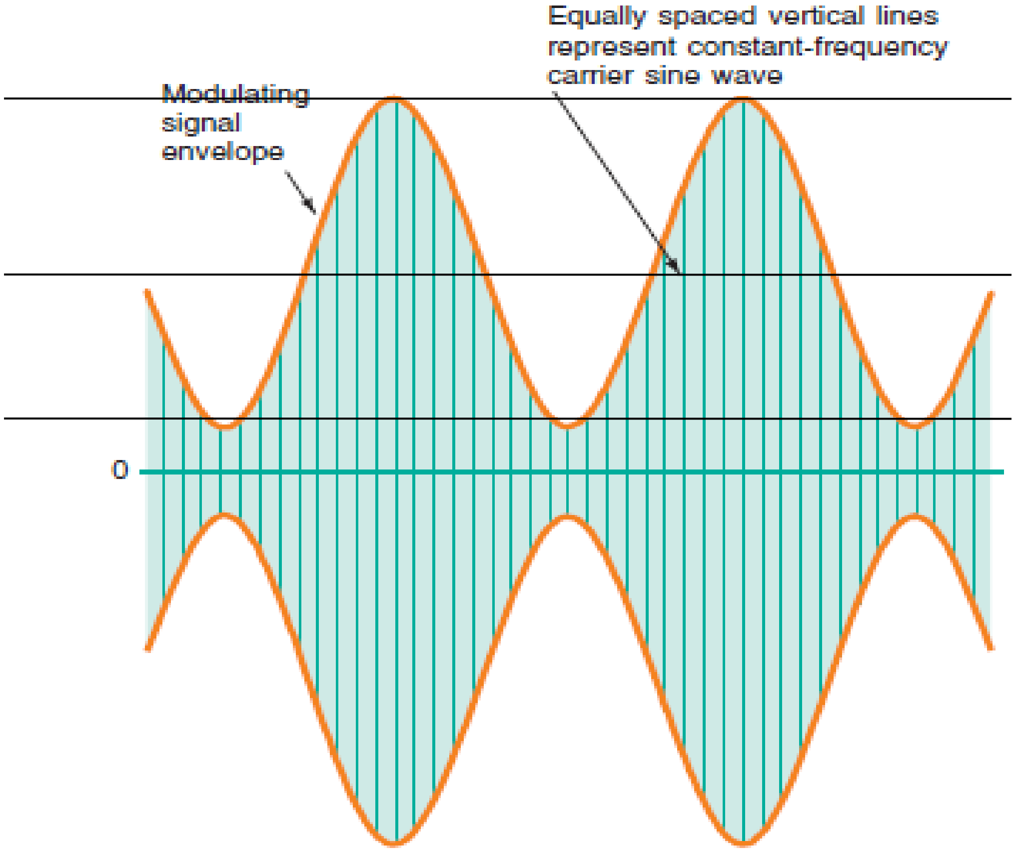
$$v_{AM}(t) = V_c \sin(2\pi f_c t) + V_m \sin(2\pi f_m t) \sin(2\pi f_c t) \qquad (2)$$

$$v_{AM}(t) = V_c \left(1 + \frac{V_m}{V_c} \sin(2\pi f_m t)\right) \sin(2\pi f_c t) \qquad (3)$$

$$v_{AM}(t) = V_c \sin(2\pi f_c t) + \frac{V_m}{2} \cos 2\pi(f_c - f_m)t - \frac{V_m}{2} \cos 2\pi(f_c + f_m)t$$

(4)

# Time-domain AM signal




**Vmax(peak) =Vc+Vm**

**Vc**

**Vmin(peak) =Vc-Vm**

# Amplitude Modulation (AM)

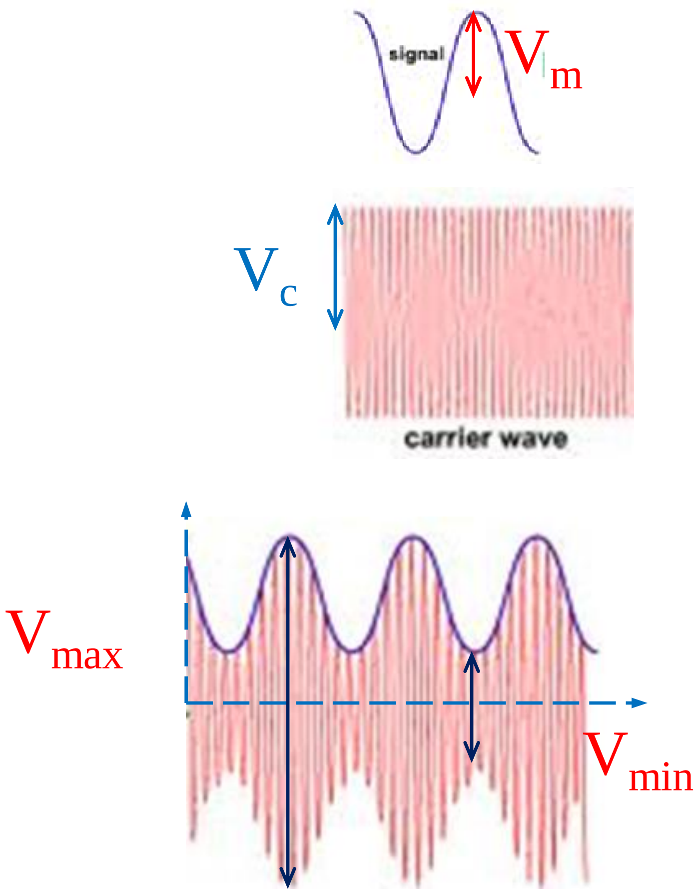
$$m = \frac{V_m}{V_c}$$

$$V_m = \frac{V_{max} - V_{min}}{2}$$

$$V_c = \frac{V_{max} + V_{min}}{2}$$

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

**Note: Vmax and Vmin are peak to peak**



# Amplitude Modulation (AM)

**Example No 2:**

**Suppose that on an AM signal, the Vmax(p-p) value read from the the oscilloscope screen is 5.9 divisions and Vmin(p-p) is 1.2 divisions.**

A. **What is the modulation index?**
B. **Calculate Vc and Vm if the vertical scale is 2V per division.**

# Amplitude Modulation (AM)

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} = \frac{5.9 - 1.2}{5.9 + 1.2} = 0.662$$

$$V_c = \frac{V_{max} + V_{min}}{2} = \frac{5.9 + 1.2}{2} = 3.55 \text{ divisions}$$

$$V_c = 3.55 * 2\,V = 7.1\,V$$

$$V_m = \frac{V_{max} - V_{min}}{2} = \frac{5.9 - 1.2}{2} = 2.35 \text{ divisions}$$

$$V_m = 2.35 * 2\,V = 4.7\,V$$

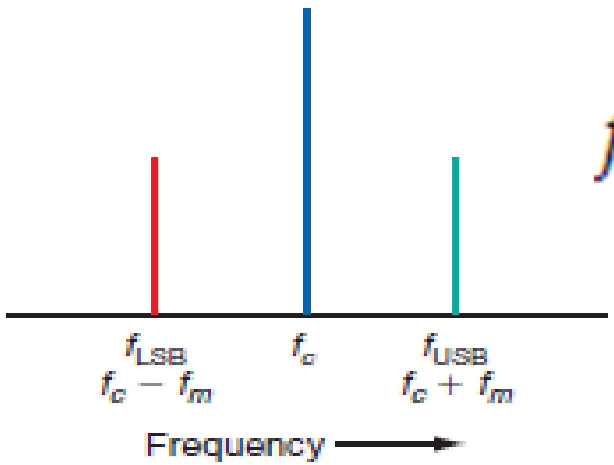
$$m = \frac{V_m}{V_c} = \frac{4.7}{7.1} = 0.662$$

# frequency-domain of an AM signal

## AM-equation

$$v_{AM}(t) = V_c \sin(2\pi f_c t) + \frac{V_m}{2}\cos 2\pi(f_c - f_m)t - \frac{V_m}{2}\cos 2\pi(f_c + f_m)t$$

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




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

frequency-domain of an AM signal

# Amplitude Modulation (AM)

## Example No 3:

AM broadcast station transmit modulating frequencies up to $f_m = 5$ kHz. If the AM station is transmitting on a frequency of $f_c = 980$ kHz, compute the maximum and minimum upper $f_{USB}$ and lower $f_{LSB}$ sidebands and the total bandwidth BW occupied by the AM station.

# Amplitude Modulation (AM)

or

## Solution:

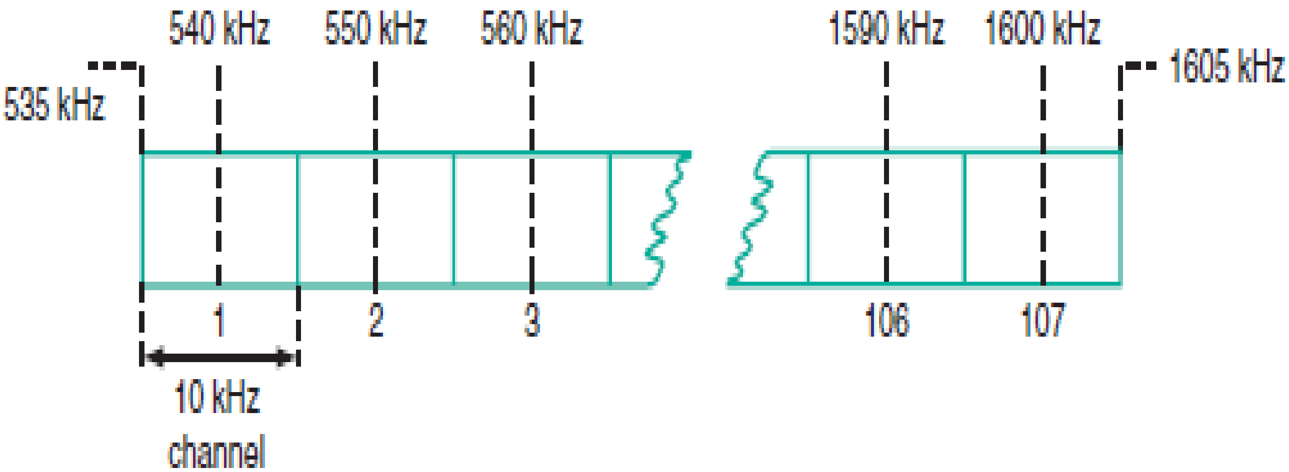
$$f_{USB} = f_c + f_m = 980\,k + 5\,k = 985\,kHz$$

$$f_{LSB} = f_c - f_m = 980\,k - 5\,k = 975\,kHz$$

$$BW = f_{USB} - f_{LSB} = 985\,k - 975\,k = 10\,kHz$$

$$BW = 2f_m = 2 * 5\,k = 10\,kHz$$

# Amplitude Modulation (AM)




**Example of frequency spectrum of AM broadcast band**

**Spectrum from 540 kHz to 1600 kHz**
**Channels = 107**
**BW = 10 kHz**

# Amplitude Modulation (AM)

# Amplitude Modulation (AM)

**Example No 4:**

**Calculate the peak value and frequency for the signals below:**

$\omega = 2\pi f$

$$v(t) = V\sin(2\pi f t) = 4\sin(2\pi * 500t)$$

$V = 4$

$$\omega = 2\pi * 500 \rightarrow f = \frac{2\pi * 500}{2\pi} = 500\ Hz$$

$$v(t) = V\sin(2\pi f t) = 8\sin(4\pi * 500t)$$

$V = 8$

$$w = 4\pi * 500 \rightarrow f = \frac{4\pi * 500}{2\pi} = 1{,}000\ Hz$$

$$v(t) = V\sin(2\pi f t) = 10\sin(\pi * 1000t)$$

$V = 10$

$$w = \pi * 1000 \rightarrow f = \frac{\pi * 1000}{2\pi} = 500\ Hz$$

$$v(t) = V\sin(2\pi f t) = 12\sin(6\pi * 1000t)$$

$V = 12$

$$w = 6\pi * 1000 \rightarrow f = \frac{6\pi * 1000}{2\pi} = 3{,}000\ Hz$$

# Amplitude Modulation (AM)

**Example No 5:**

**For an equation:**

$$v_{AM}(t) = 3\,[\,1 + 0.7\,sin(2\pi * 2{,}000t)\,]\,sin(2\pi * 40{,}000t)$$

1. **Calculate the frequency and amplitude of carrier and information $V_m$, $V_c$, $f_m$ and $f_c$.**
2. **Calculate the frequency and amplitude of side bands $V_{USB}$, $V_{LSB}$, $f_{USB}$ and $f_{LSB}$.**
3. **Draw the frequency spectrum,**
4. **Sketch the AM signal in time-domain,**
5. **Estimate the bandwidth BW.**

# Amplitude Modulation (AM)

$$v_{AM}(t) = 3\,[\,1 + 0.7\,sin(2\pi * 2{,}000t)\,]\,sin(2\pi * 40{,}000t)$$

$$V_{AM}(t) = V_c[1 + m\,sin(2\pi f_m t)]sin(2\pi f_c t)$$

قانون

$$V_c = 3\,V, m = 0.7 \Rightarrow V_m = V_c * m = 2.1\,V$$

$$m = \frac{V_m}{V_c}$$

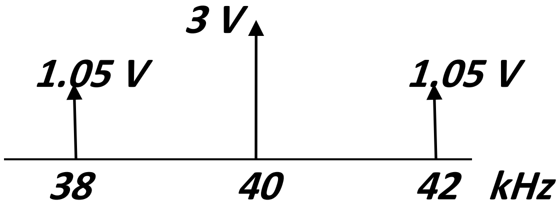
$$f_m = \frac{2\pi * 2{,}000}{2\pi} = 2\,kHz \qquad f_c = \frac{2\pi * 40{,}000}{2\pi} = 40\,kHz$$

$$V_{USB} = V_{LSB} = \frac{V_m}{2} = \frac{2.1}{2} = 1.05\,V$$

اذهب الى المحاضرة السابقة

$$f_{USB} = f_c + f_m = 40 + 2 = 42\ kHz \quad f_{LSB} = f_c - f_m = 40 - 2 = 38\,kHz$$

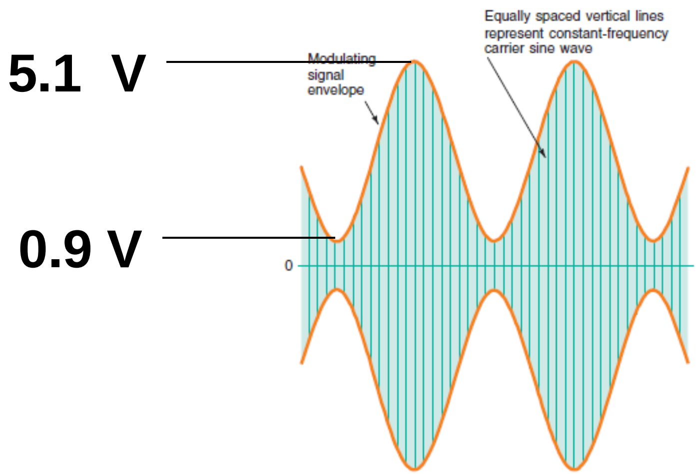
frequency domain:



## Time domain:

$$V_{max} = V_c + V_m = 3 + 2.1 = 5.1\ V$$

$$V_{max} = V_c - V_m = 3 - 2.1 = 0.9\ V$$




$$BW = 2f_m = 2 * 2\ k = 4\ kHz$$

# Amplitude Modulation (AM)

**Example No 6:**

**A modulated AM signal is expressed as:**

$$v_{AM}(t) = 50\, sin(2\pi * 10^7 t) + 30\, sin(2\pi * 10^7 t)\, sin(2\pi * 10^4 t)$$

1. **Calculate m, $f_{USB}$, $f_{LSB}$ and BW.**
2. **Sketch the frequency-domain spectrum of an AM signal.**

# Amplitude Modulation (AM)

**m, $f_{USB}$, $f_{LSB}$ and BW ?**

$$v_{AM}(t) = 50\,sin(2\pi * 10^7 t) + 30\,sin(2\pi * 10^7 t)\,sin(2\pi * 10^4 t)$$

$$v_{AM}(t) = V_c sin(2\pi f_c t) + V_m\,sin(2\pi f_m t)\,sin(2\pi f_c t)$$

قانون

$$m = \frac{V_m}{V_c} = \frac{30}{50} = 0.6$$

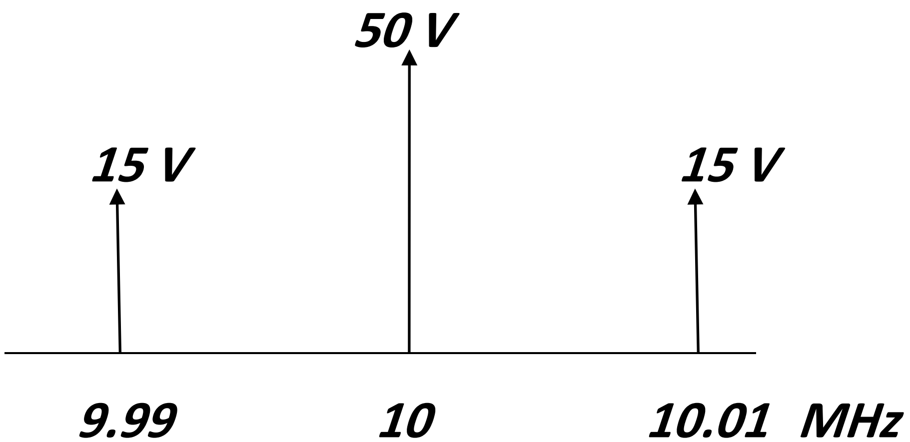
$$f_c = \frac{2\pi * 10^7}{2\pi} = 10\,MHz \qquad f_m = \frac{2\pi * 10^4}{2\pi} = 10\,kHz$$

$$f_{USB} = f_c + f_m = 10{,}000 + 10 = 10{,}010\,kHz$$

$$f_{LSB} = f_c - f_m = 10{,}000 - 10 = 9{,}99\,kHz$$

$$BW = 2 f_m = 2 * 10\,k = 20\,kHz$$

# Amplitude Modulation (AM)

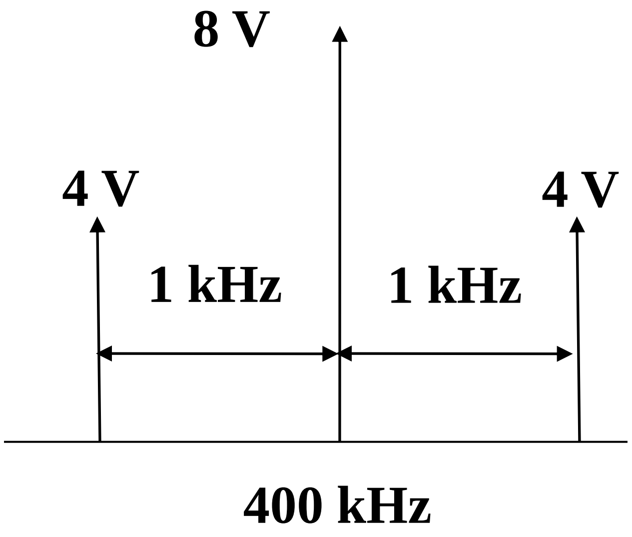



**frequency-domain spectrum of an AM signal.**

# Amplitude Modulation (AM)

**<u>Example No 7:</u>**

**For the following spectrum, write the AM equation?**



# Amplitude Modulation (AM)

$$V_c = 8\,V, \qquad \frac{V_m}{2} = 4 \Rightarrow V_m = 8, \qquad m = \frac{V_m}{V_c} = 1$$

$$f_c = 400\;kHz$$

$$f_m = 1\;kHz$$

$$V_{AM}(t) = V_c[1 + m\,sin(2\pi f_m t)]sin(2\pi f_c t)$$

$$V_{AM}(t) = 8\,[1 + \;sin(2\pi * 1000\;t)]sin(2\pi * 400{,}000\;t)$$

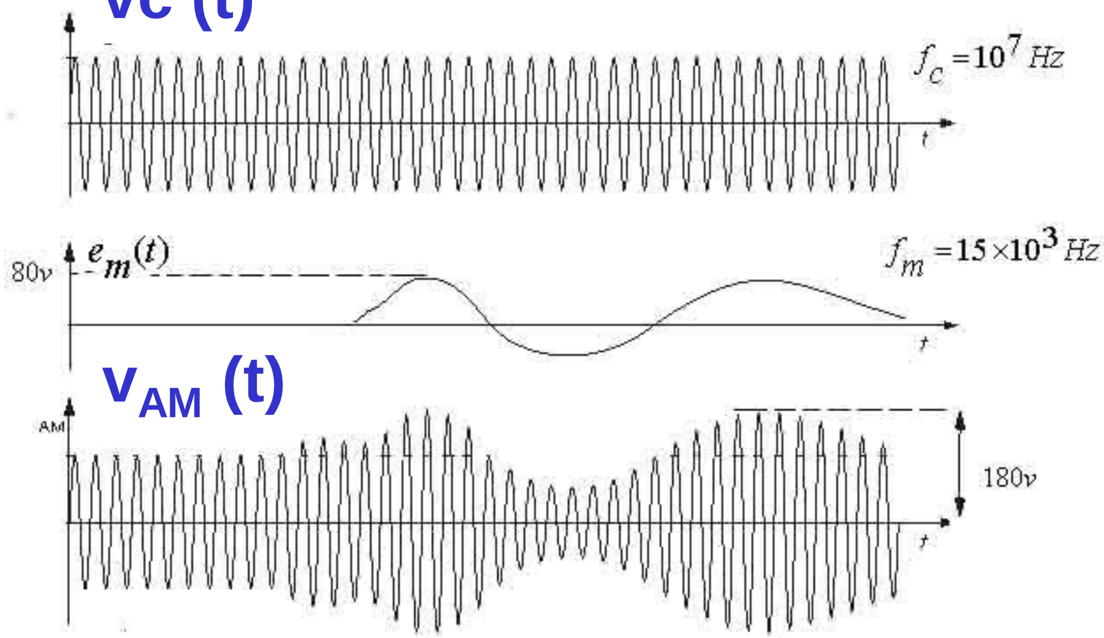
**Example No 8:** **Homework**

**Write the expression of vc (t) , vm (t) , $v_{AM}$ (t) of the following signals.**

**Then calculate:**

1. **M, $f_{USB}$ , $f_{LSB}$, BW**
2. **Draw frequency specter AM signal.**

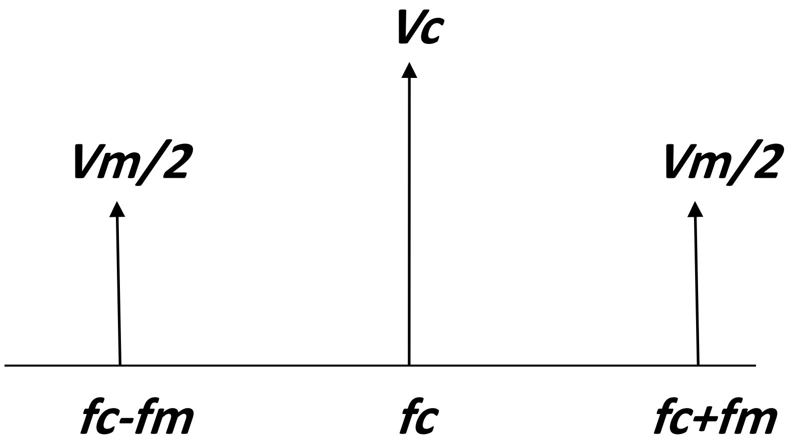
vc (t)



# Amplitude Modulation Types

## 1- Double Side Band / Full Carrier (DSB/FC)

$$v_{AM}(t) = V_c \sin(2\pi f_c t) + \frac{V_m}{2}\cos 2\pi(f_c - f_m)t - \frac{V_m}{2}\cos 2\pi(f_c + f_m)t$$

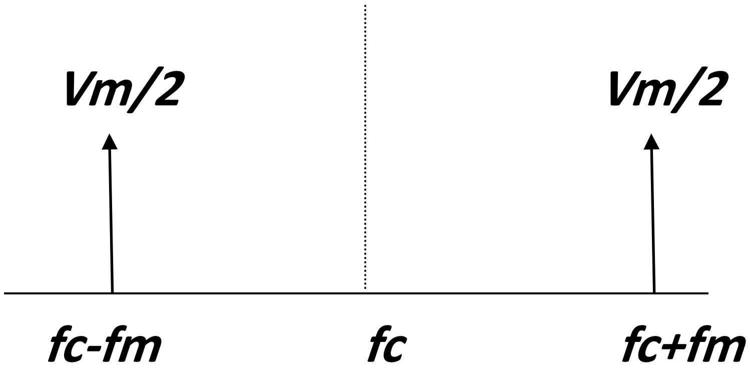



$$BW = 2f_m$$

# Amplitude Modulation Types

## 2- Double Side Band / Suppressed Carrier (DSB/SC)

$$v_{AM}(t) = \frac{V_m}{2}\cos 2\pi(f_c - f_m)t - \frac{V_m}{2}\cos 2\pi(f_c + f_m)\,t$$

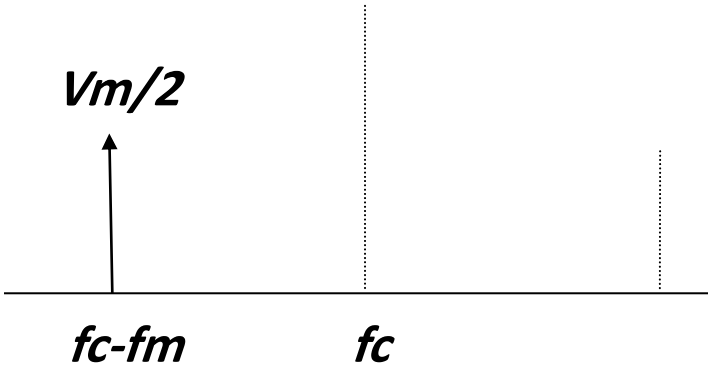



$$BW = 2f_m$$

# Amplitude Modulation Types

## 3- Single Side Band / Suppressed Carrier (SSB/SC)

$$v_{AM(LSB)}(t) = \frac{V_m}{2}\cos 2\pi(f_c - f_m)t \qquad v_{AM(USB)}(t) = \frac{V_m}{2}\cos 2\pi(f_c + f_m)\,t$$




$$BW = f_m$$

# Amplitude Modulation Types

## Advantages of DSB and SSB:

1. Save power
2. Save bandwidth

/SC

## Disadvantages of DSB and SSB:

1. Difficult detection
2. Receiver must produce very stable carrier signal.

## Applications of SSB

For military applications. (why?)

## Applications of DSB

1. FM and TV broadcasting

# Amplitude Modulation (AM)

# AM Power

$$v_{AM}(t) = V_c \sin(2\pi f_c t) + \frac{V_m}{2}\cos 2\pi(f_c - f_m)t - \frac{V_m}{2}\cos 2\pi(f_c + f_m)t$$

$$P_T = P_C + P_{LSB} + P_{USB}$$

$P_{USB}$ **: power in upper side band**

$P_{LSB}$ **: power in lower side band**

$P_C$ **: power in carrier signal**

$$P_{USB} = P_{LSB} = \frac{m^2}{4} P_C$$

$$P_{SB}(both) = \frac{m^2}{2} P_C$$

$$P_T = P_C\left(1 + \frac{m^2}{2}\right)$$

**Total power in AM-DSB-FC**

# Amplitude Modulation **Power**

## Example No 7:

**An AM transmitter has a carrier power of $P_c$ = 30 W. The percentage of modulation is m = 85%. Calculate:**

**(a) The total power $P_T$.**

**(b) The power in one sideband.**

# AM Power

## Solution:

**(a) The total power PT.**

$$P_T = P_C\left(1+\frac{m^2}{2}\right) = 30\left(1+\frac{0.85^2}{2}\right) = 40.8\,W$$

**(b) The power in one sideband PSB(one).**

$$P_{USB} = P_{LSB} = \frac{m^2}{4}P_C \quad =5.41\text{ W}$$

# AM Power

## 1- Double Side Band-Full Carrier (DSB/FC)

$$P_T = P_C + P_{LSB} + P_{USB}$$

$$P_T = P_C\left(1 + \frac{m^2}{2}\right)$$

## 2- Double Side Band / Suppressed Carrier (DSB/SC)

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

$$P_T = P_C\frac{m^2}{2}$$

## 3- Single Side Band / Suppressed Carrier (SSB/SC)

$$P_T = P_C\frac{m^2}{4}$$

# Amplitude Modulation-power

## Example No 10:

**Transmitter radiate with ($P_c = 9$ kW) with unmodulated carrier signal. While the AM-signal transmitted power is ($P_T = 10.125$ kW) when the carrier is sinusoidally modulated. Calculate the modulation depth (m).**

# Amplitude Modulation-power

## Solution:

$$P_T = P_C\left(1 + \frac{m^2}{2}\right)$$

$$10.125\,K = 9\,K\left(1 + \frac{m^2}{2}\right)$$

$$m = 0.5$$

# Amplitude Modulation-power

## Example No 11:

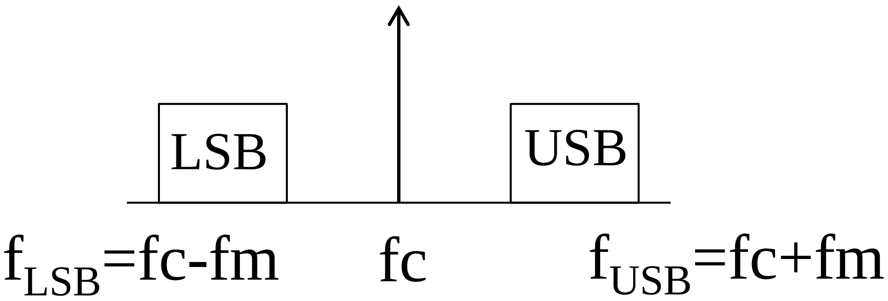
**The output power of an AM transmitter is PT = 24 kW and the output power of the carrier is (PC= 16KW). Find the output power when m = 60 % if one side band is suppressed.**

$$P_T = P_C\left(1+\frac{m^2}{4}\right) = 16\,k * \left(1+\frac{0.6^2}{4}\right) = 17.44\,kW$$

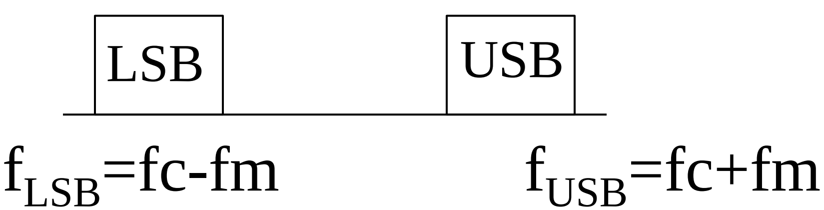
# Amplitude Modulation (AM)

# AM signal spectrum

**1- DSB/FC: double side band full carrier**

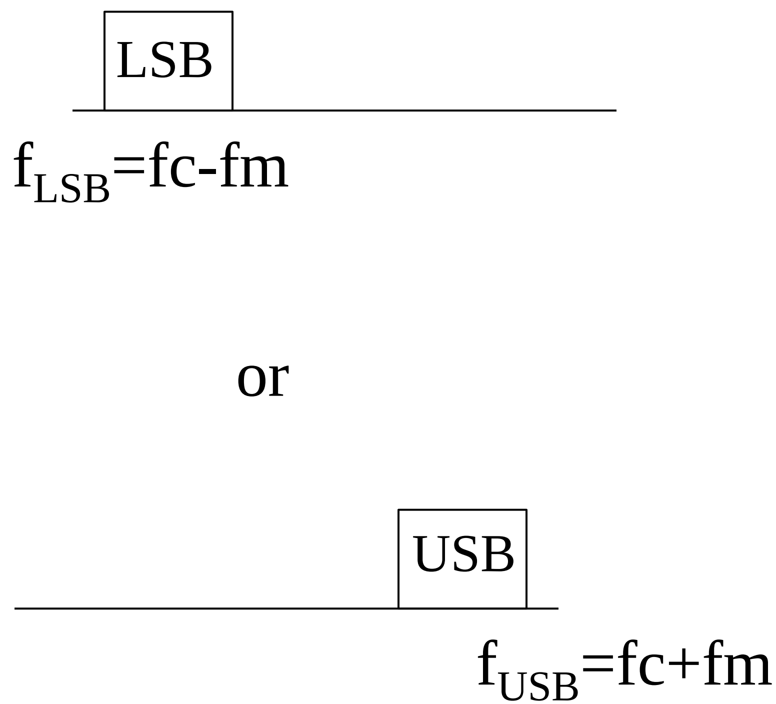



**2- DSB/SC: double side band suppressed carrier**




$f_{USB}$: frequency upper side band
$f_{LSB}$: frequency lower side band

**3- SSB/SC: single side band suppressed carrier**



**Advantages and disadvantages of DSB/SC**

1.Save power (no carrier) (adv.)
2.Receiver must produce very stable carrier signal(dis.)
3.High cost (dis.)

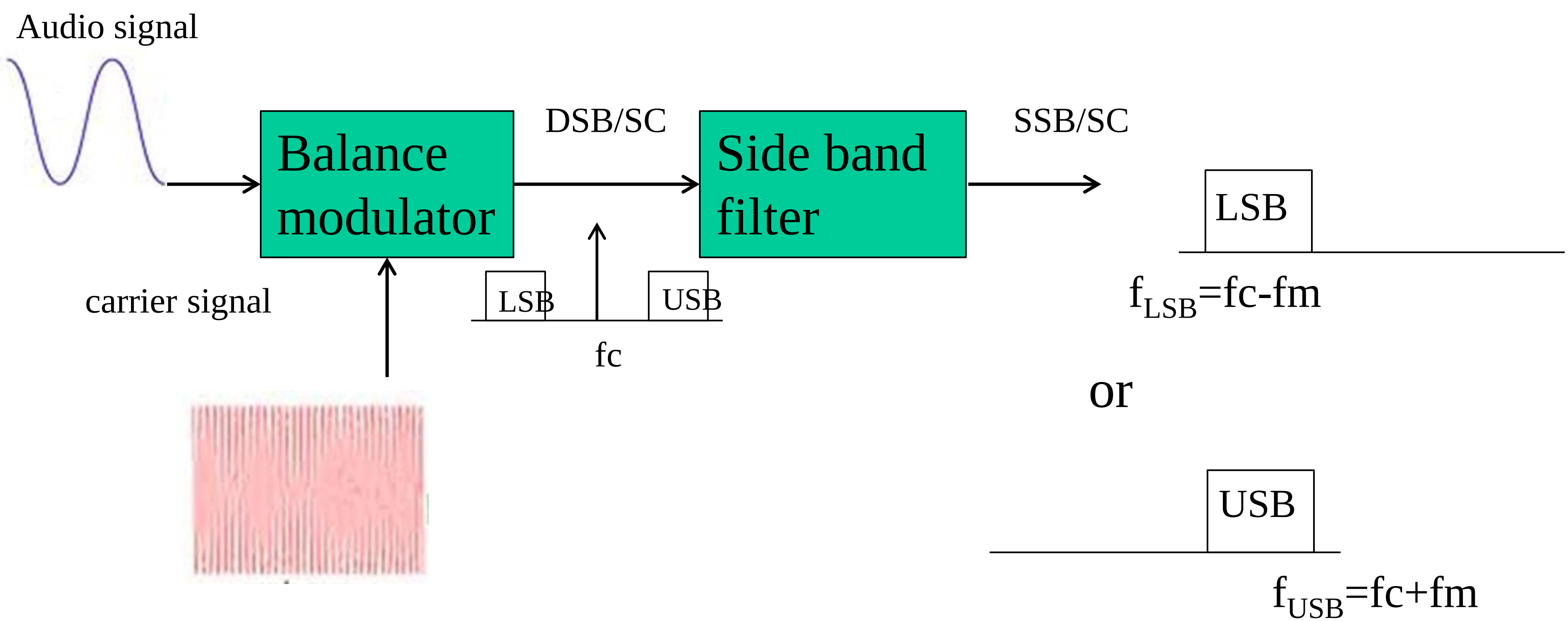
**Advantages and disadvantages of SSB/SC**

1.Save power (no carrier) (adv.)
2. Save bandwidth (BW) (adv.)
3.Noise reduction (adv.)
4.Receiver must produce very stable carrier signal(dis.)
5.Difficult detection (dis.)

# Generation of SSB/SC

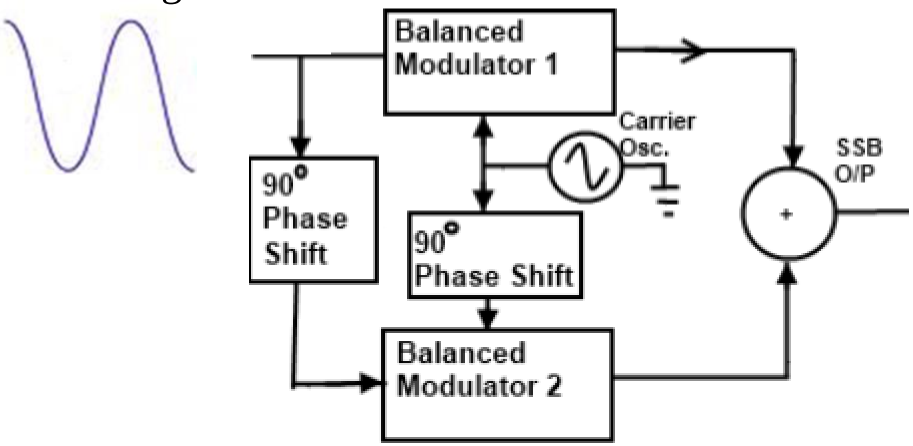
There are two methods used to generate SSB/SC

## 1. Filter method



# 2. Phase shift method

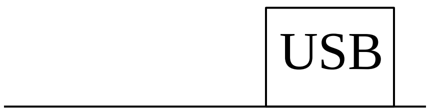
Audio signal




SSB/SC method

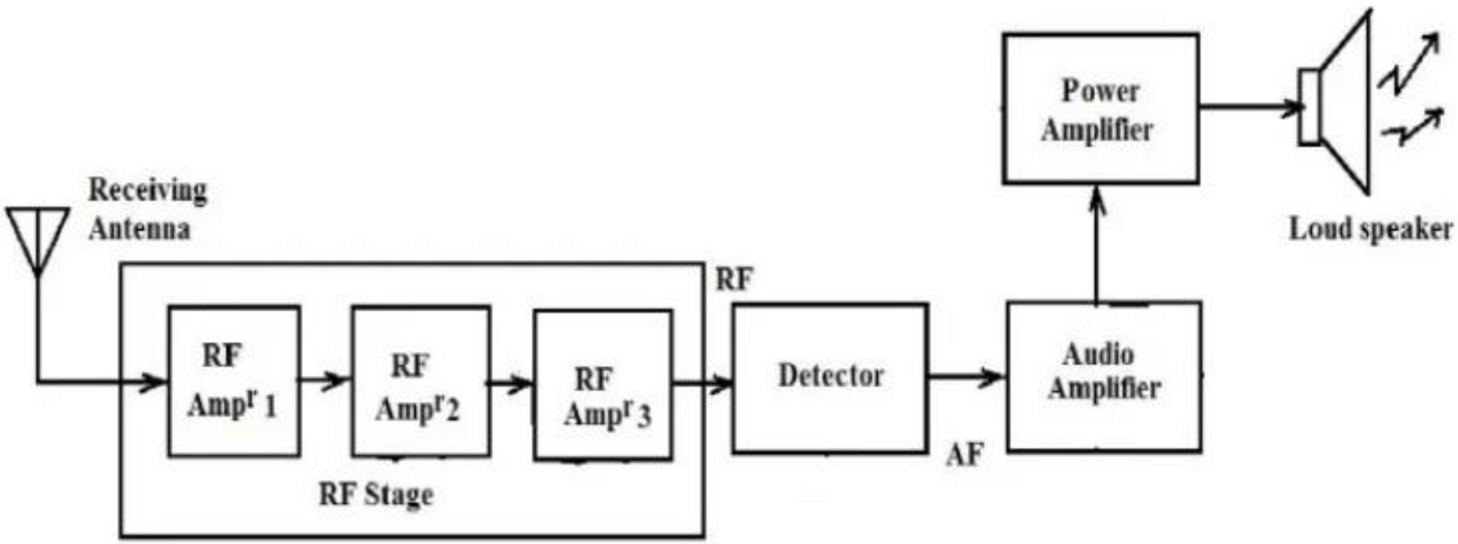

$f_{LSB}$=fc-fm

or




$f_{USB}$=fc+fm

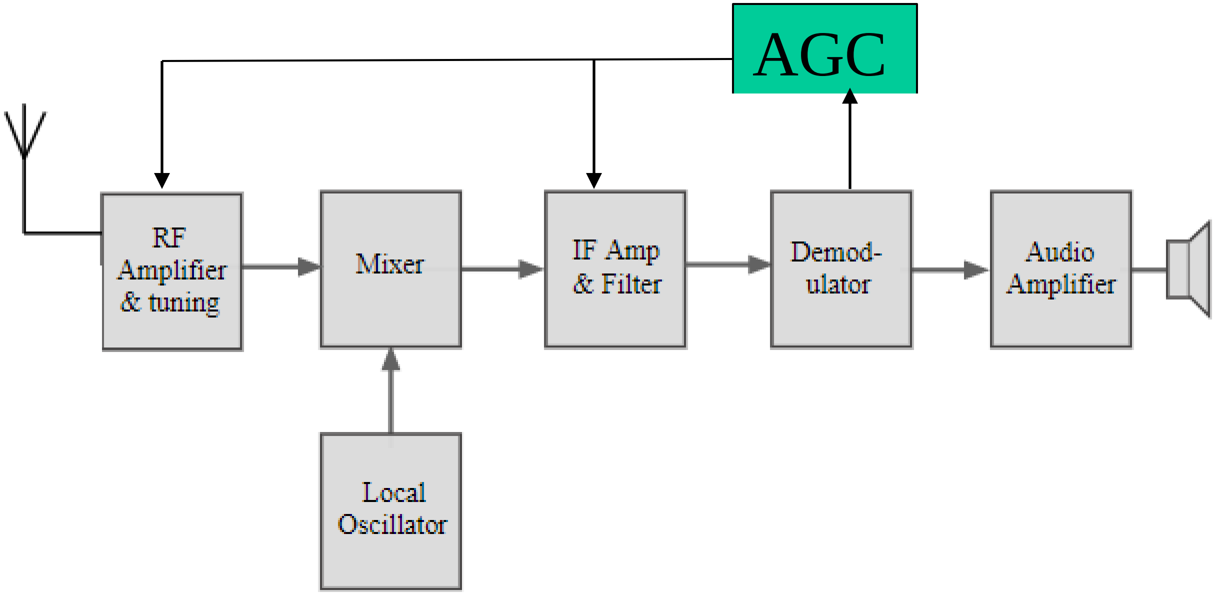
# Tuned radio frequency receiver (TRF receiver)




Disadvantages of TRF receiver

1. The selectivity is not constant
2. The amplification is not constant

# Super Heterodyne Receiver with AGC




**RF: radio frequency**
**AF: audio frequency**
**IF: intermediate frequency**

# Super Heterodyne Receiver

Mixer circuit with two RF inputs (one from channel and the other from local oscillator producing an output equal to the sum and the difference of RF inputs.

# AM Receivers

**Advantages of super- heterodyne receivers over TRF receiver:**

1. Improve selectivity
2. Higher gain
3. Improve stability
4. Uniform BW
5. Easy to detect.

# AM Receivers

## AGC: Automatic gain control

**AGC provides:**

1. **Keeping receiver output constant for different stations.**
2. **Prevent IF amplifier from over modulation.**

# AM Receivers

## Basic functions of receivers

1. **Reception** small signal induced in the antenna by RF wave.
2. **Selection** select only one signal from the induced signals in the antenna.
3. **Detection** getting original signal from the received signal
4. **Amplification** amplifying the detected signal.
5. **Reproduction** re-changing the electric signal to sound signal.

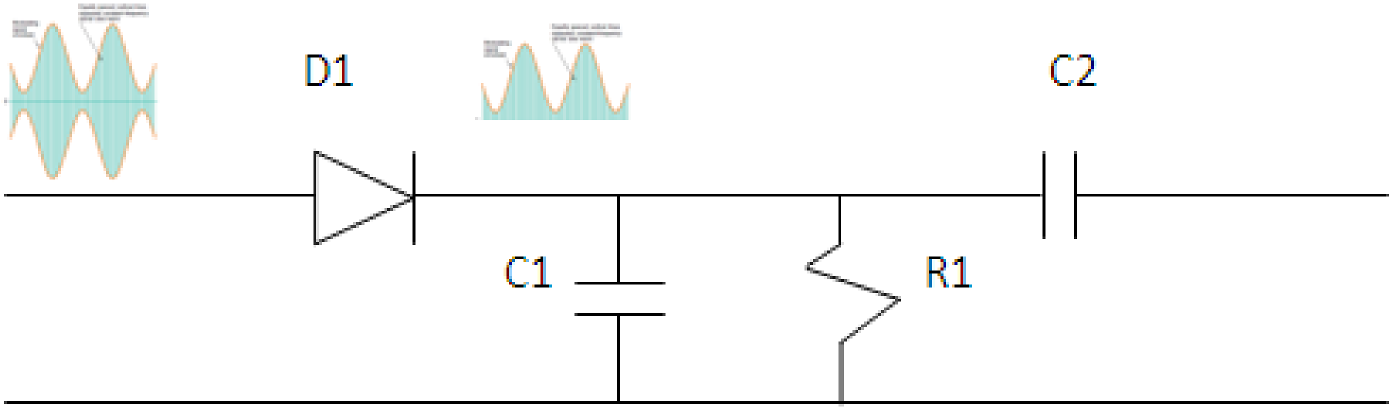
# AM Receivers

## Receivers quality measured by:

1. **Sensitivity:** **ability to receive weak signal.**
2. **Selectivity:** **ability to select wanted signal**
3. **Stability:** **ability to remain tuned to the selected frequency over long time.**

# AM Demodulation (Detection)

## Envelope Detector: for detection AM- DSB/FC



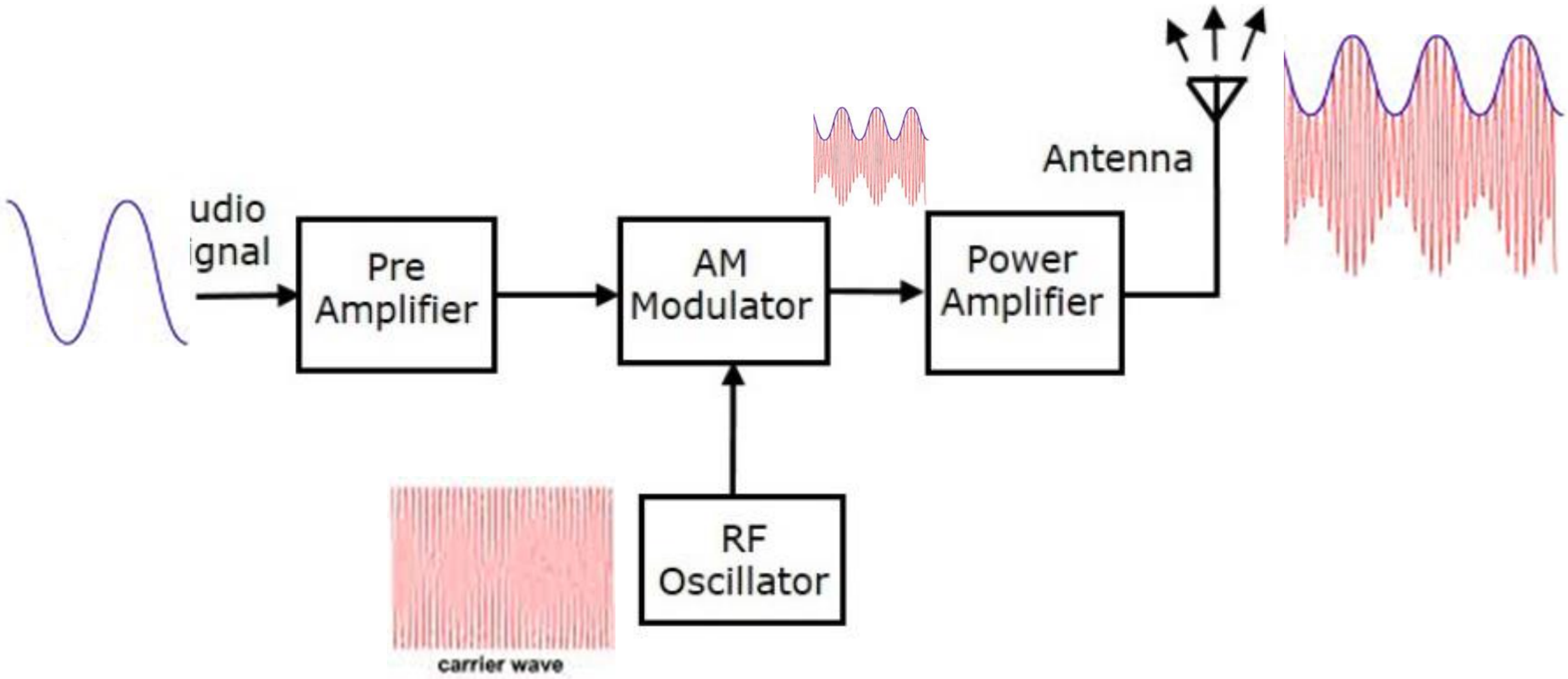

Circuit diagram of AM envelope detector.

1- Diode $D_1$ to clip one-half of an AM wave.

2- $R_1C_1$ is LPF to reject the high frequency carrier.

3- $C_2$ to block the DC component.

# AM transmitter



# Amplitude Modulation (AM)

# ANGLE MODULATION

**There are 2 types of angle; modulation;**

**1. Frequency Modulation  (FM).**

**2. Phase  Modulation  (PM).**

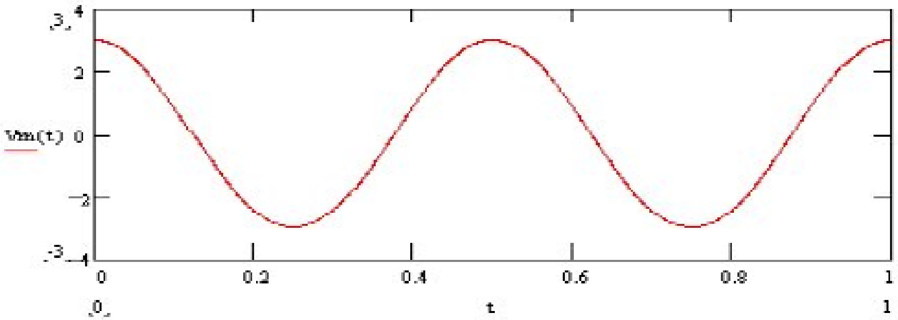
# ANGLE MODULATION

**Angle modulation applications:**

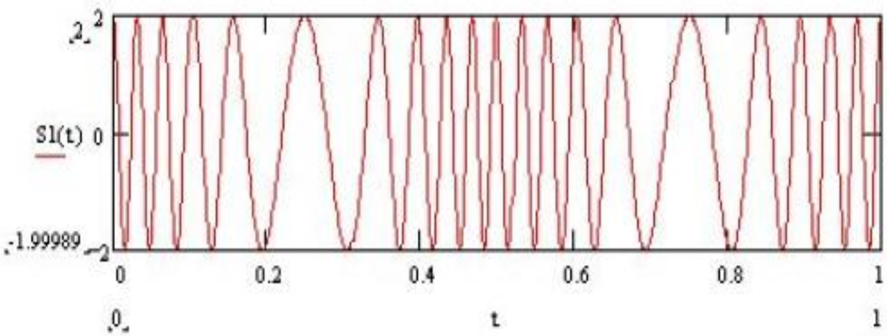
1. **Radio broadcasting,**
2. **TV sound transmission,**
3. **cellular radio,**
4. **Satellite communication.**

# Frequency MODULATION (FM)

**Is the process of varying the frequency of carrier by amplitude of modulating signal (audio or information signal)**



Baseband Signal



Frequency Modulated Wave

# FM equation

$$e_{FM}(t) = A_c Sin\ (2\pi f_c t - m_f Cos\ (2\pi f_m t))$$

$m_f$:index modulation (**β)**

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

$f_m$: modulating frequency

$\Delta f_c$ : frequency deviation

Frequency deviation is the range of varying in carrier frequency due to modulating frequency (audio signal)

deviation in FM=

$f_c \pm \Delta f_c$

## Example (1):

**Find the carrier, modulating signal frequencies (fc, fm), modulation index (β= $m_f$), and maximum frequency deviation ($\Delta f_c$) of an FM signal represented by:**

$$e_{FM}(t) = 12Sin\,(6 * 10^8 t - 5\,Cos\,(125\,t)$$

# FREQUENCY MODULATION (FM)

## Solution:

$$e_{FM}(t) = V_c Sin\,(2\pi f_c t - m_f Cos\,(2\pi f_m t))$$

$$e_{FM}(t) = 12Sin\,(6 * 10^8 t - 5\,Cos\,(125\,t))$$

$V_c = 12$ $\quad$ $m_f$=5 $\quad$ $\beta = 5$

$$f_c = \frac{6 * 10^8}{2\pi} = 95.5\,MHz$$

$$f_m = \frac{1250}{2\pi} = 199\,Hz$$

This mean that deviation

$$\Delta f_c = f_c \pm 995$$

$$\Delta f_c = m_f * f_m = 5 * 199 = 995\,Hz$$

# FREQUENCY MODULATION (FM)

## Example (2):

In FM system, when the audio frequency is ($f_m$ = 500 Hz), and the maximum frequency deviation is ( $\Delta f_c$ = 4.8 kHz).

Calculate the modulation index ($m_f$)?

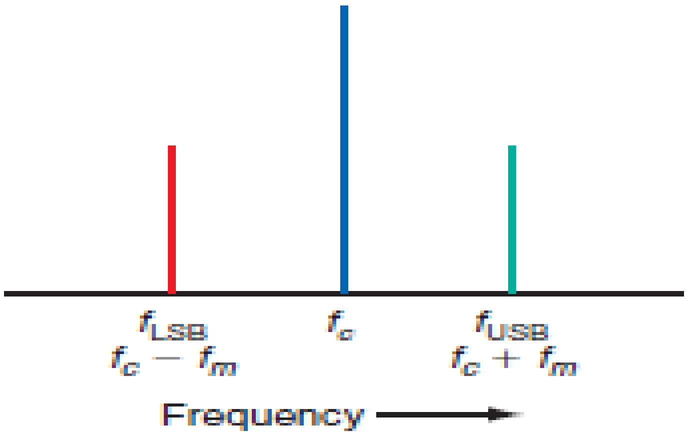
$$m_f = \frac{\Delta f_c}{f_m} = \frac{4.8\ k}{0.5\ k} = 9.6$$ بدون وحده

# Amplitude Modulation (AM)

## FM specter types

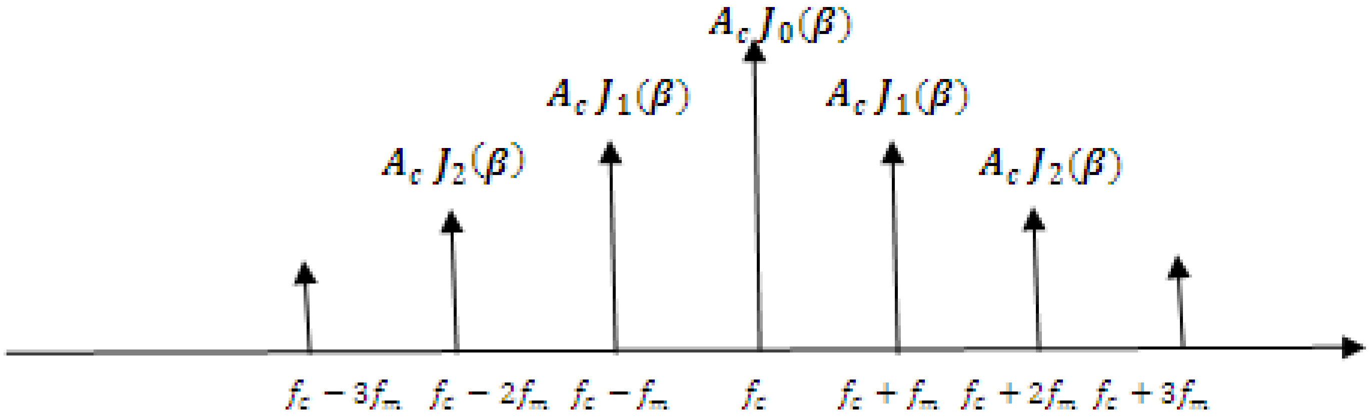
Based on the value of $m_f$ there are two types of bandwidth (BW)

**1- Narrow band FM (NBFM)** if $m_f \ll 1$




$$BW_{NBFM} = BW_{AM} = 2f_m$$

## 2- Wide band FM (WBFM) if $m_f > 1$




$$BW_{WBFM} = 2(\Delta f_c + f_m)$$

# FREQUENCY MODULATION (FM)

$J_n(\beta)$ **is nth order Bessel function of the first kind.**

| Mf | J0 | J1 | J2 | J3 | J4 | J5 | J6 | J7 | J8 | J9 | J10 | J11 | J12 | J13 | J14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.000 | 1.00 | | | | | | | | | | | | | | |
| 0.250 | 0.98 | 0.12 | 0.01 | | | | | | | | | | | | |
| 0.500 | 0.94 | 0.24 | 0.03 | | | | | | | | | | | | |
| 1.000 | 0.77 | 0.44 | 0.11 | 0.02 | | | | | | | | | | | |
| 1.500 | 0.51 | 0.56 | 0.23 | 0.06 | 0.01 | | | | | | | | | | |
| 2.000 | 0.22 | 0.58 | 0.35 | 0.13 | 0.03 | 0.01 | | | | | | | | | |
| 2.405 | 0.00 | 0.52 | 0.43 | 0.20 | 0.06 | 0.02 | | | | | | | | | |
| 3.000 | -0.26 | 0.34 | 0.49 | 0.31 | 0.13 | 0.04 | 0.01 | | | | | | | | |
| 4.000 | -0.40 | -0.07 | 0.36 | 0.43 | 0.28 | 0.13 | 0.05 | 0.02 | | | | | | | |
| 5.000 | -0.18 | -0.33 | 0.05 | 0.36 | 0.39 | 0.26 | 0.13 | 0.05 | 0.02 | 0.01 | | | | | |
| 7.000 | 0.30 | 0.00 | -0.30 | -0.17 | 0.16 | 0.35 | 0..34 | 0.23 | 0.13 | 0.06 | 0.02 | 0.01 | | | |
| 10.00 | -0.25 | 0.04 | 0.25 | 0.06 | -0.22 | -0.23 | -0.01 | 0.22 | 0.32 | 0.29 | 0.21 | 0.12 | 0.06 | 0.03 | 0.01 |

**Example (3):**

**FM broadcast transmitter has a index modulation of ($m_f$ = 5) and the frequency of the modulating audio is ($f_m$ = 15 kHz). Determine occupied Bandwidth (BW)?**

# FREQUENCY MODULATION (FM)

## Solution:

$m_f$=5 $\quad\quad m_{f>1}$

$$BW_{WBFM} = 2(\,\Delta f_c + f_m)$$

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

$\Delta f_c = m_f * f_m$=5*15=75 KHz

$BW_{WBFM} = 2(75 + 15)$=180 KHz

# FREQUENCY MODULATION (FM)

**Example (4): A carrier signal ($f_c$ = 100 MHz) is modulated using FM by a sine wave such that the frequency deviation of ($\Delta f_c$ = 50 kHz). Determine the bandwidth (BW) of FM-signal for**

**(a) $f_m$= fm = 500 kHz (b) $f_m$= fm = 10 kHz**

**(a)**

$$m_f = \frac{\Delta f_c}{f_m} = \frac{50\,k}{500\,k} = 0.1, \qquad m_f < 1$$

$$BW_{NBFM} = 2f_m = 2 * 500\,k = 1000 \text{ KHz}$$

**(b)**

$$m_f = \frac{\Delta f_c}{f_m} = 50/10 = 5 \qquad m_f > 1$$

$$BW_{WBFM} = 2(\Delta f_c + f_m)$$

$$BW_{WBFM} = 2(50 + 10) = 120 \text{ KHz}$$

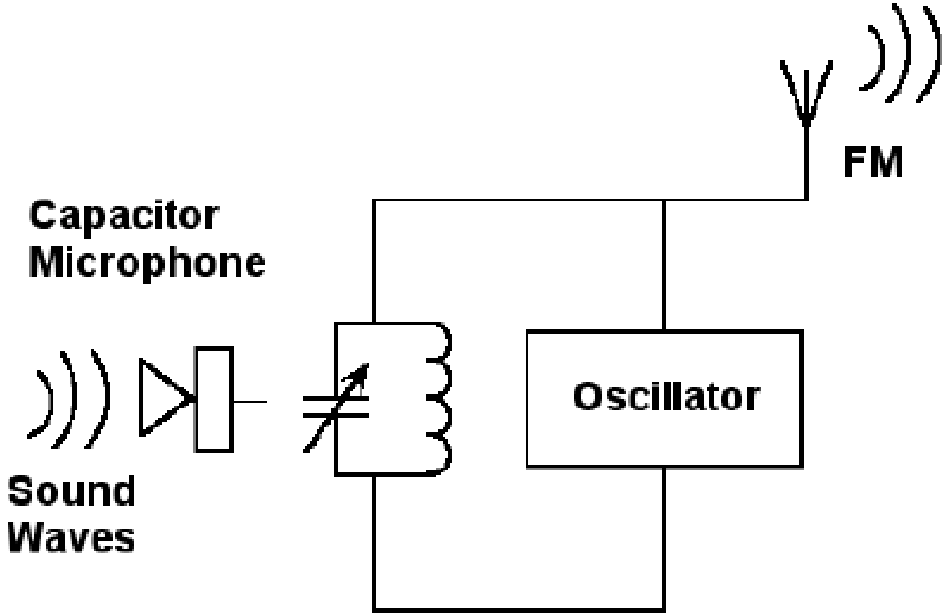
# FREQUENCY MODULATION (FM)

# FM GENERATION

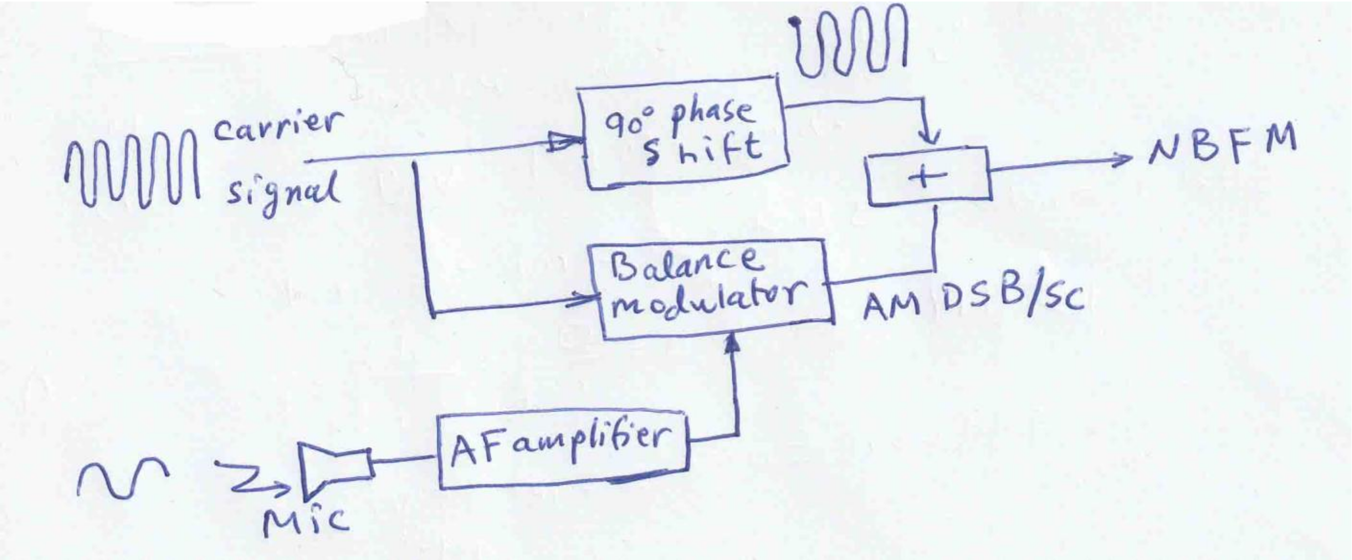
**There are two methods for generating FM-signal**

1. **Direct method**
2. **Indirect method (Armstrong method)**

## 1. Direct method

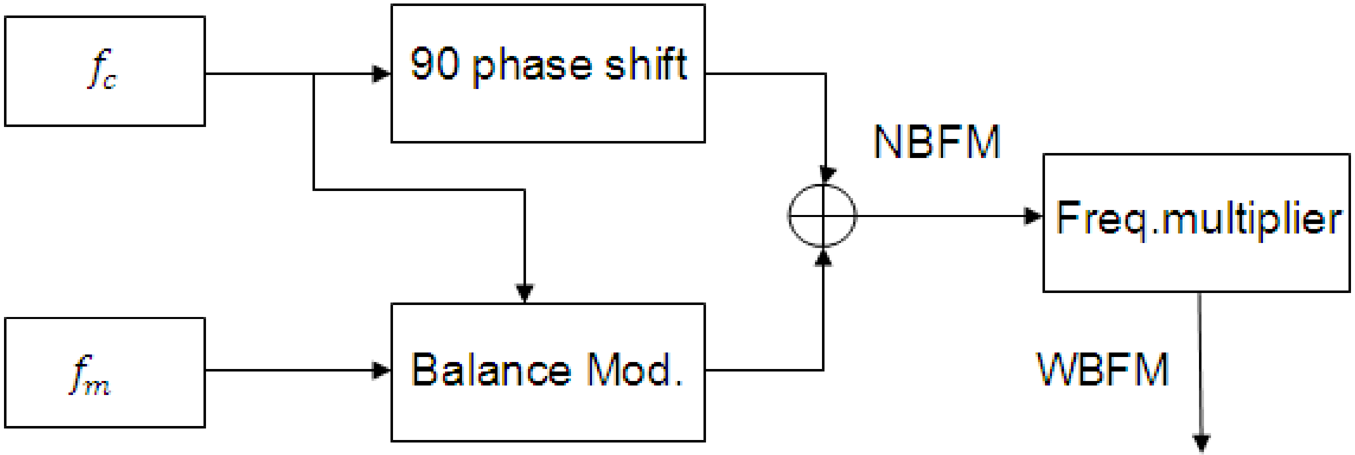


# 2. Indirect method (Armstrong method)

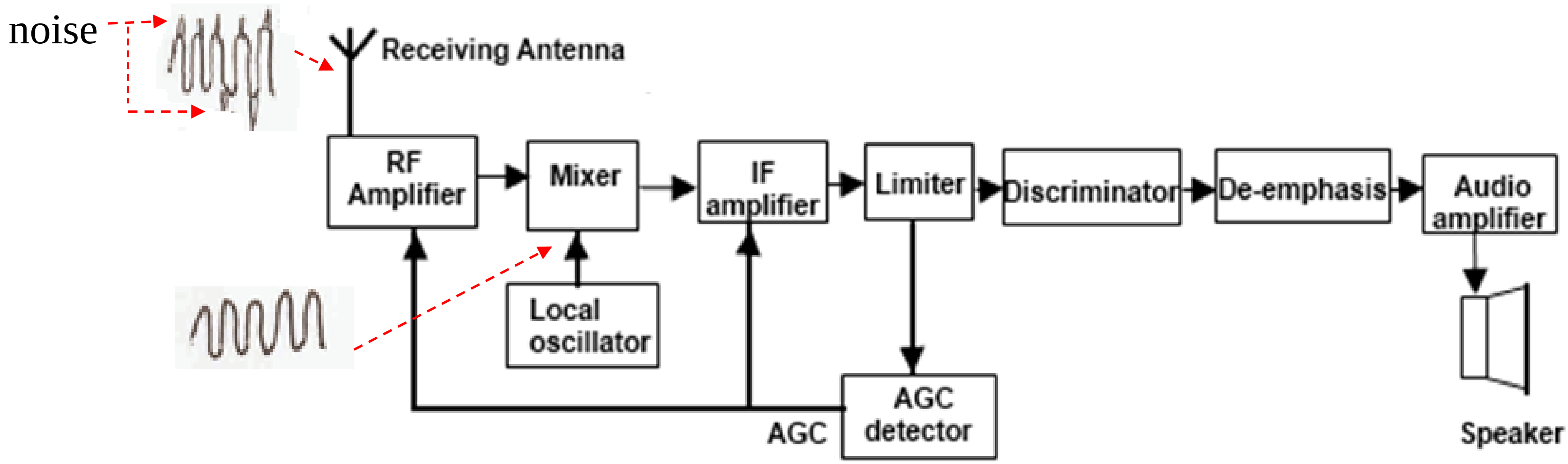



**ملاحظه:**

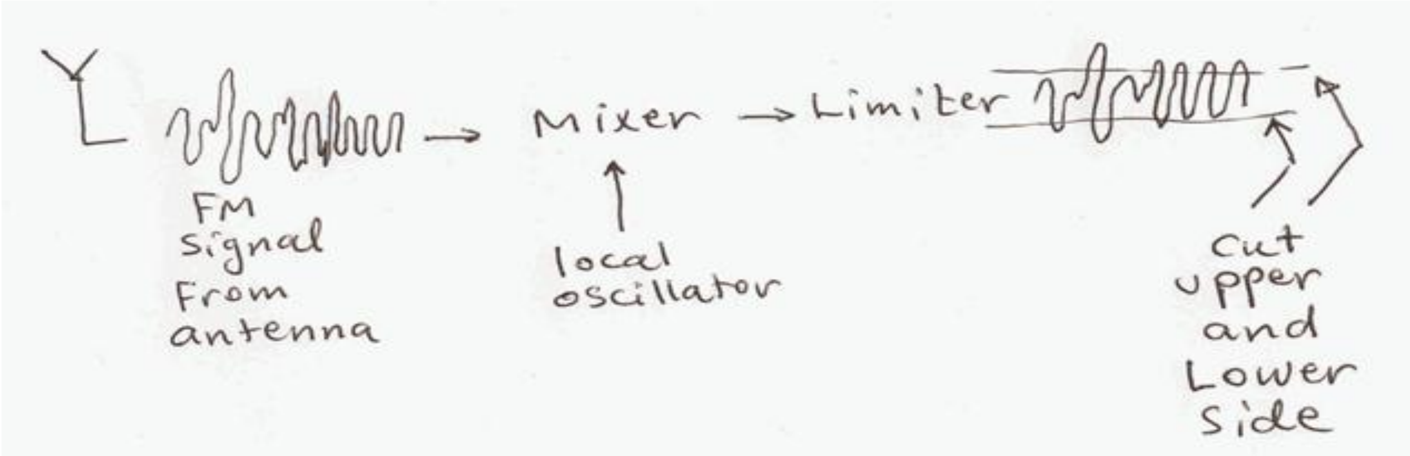
رسم واحد فقط مطلوب



# FM Receiver




**Limiter** it is double ended clipping circuit use to eliminate AM-noise in FM system by flat topping the upper and lower peaks of FM-signal.



# FM - Discriminator

Why need discriminator?

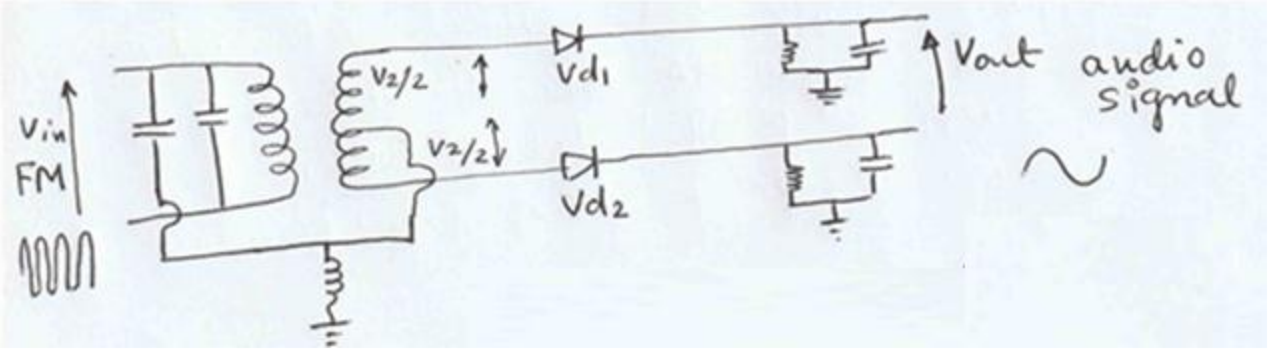
It used to obtain modulating signal (audio) from FM-signal, where change in frequency converted to amplitude change.

Types of discriminator:

**1.** Foster-seeley discriminator

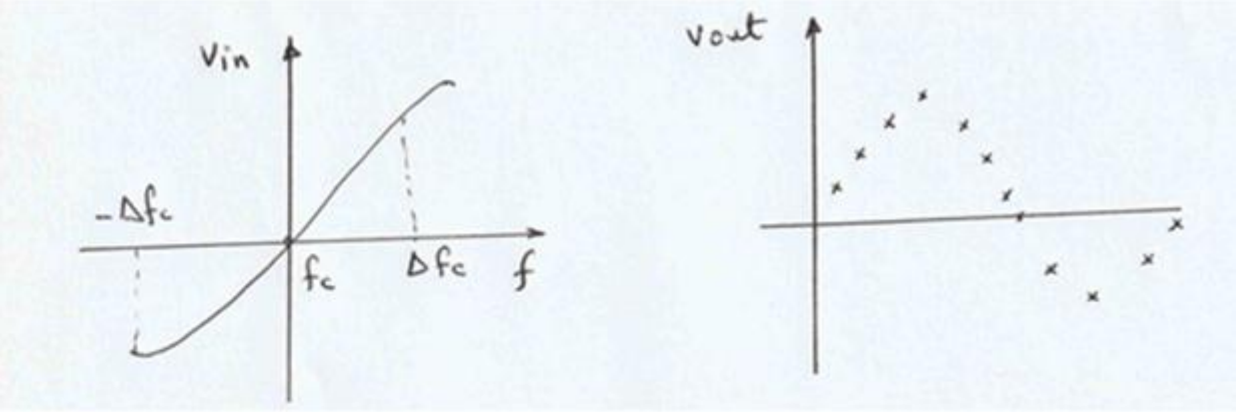
**2.** Ratio detector

# Foster-Seeley discriminator

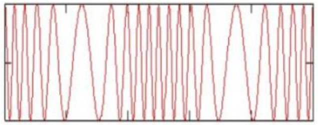


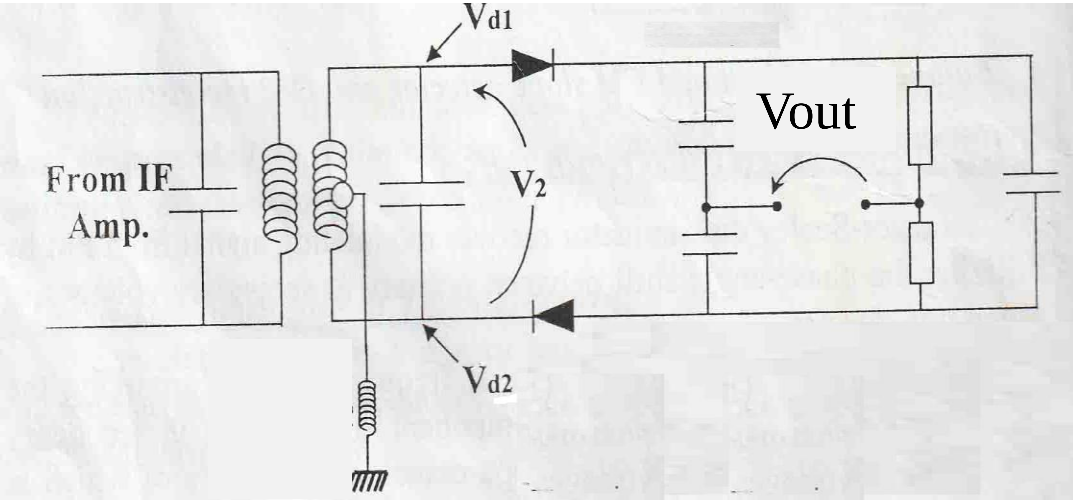

When input signal has the following values:

1. f = fc  Vd1=Vd2  Vout = 0V
2. f < fc  Vd1 < Vd2  Vout = negative value
3. f > fc  Vd1 > Vd2  Vout = positive value



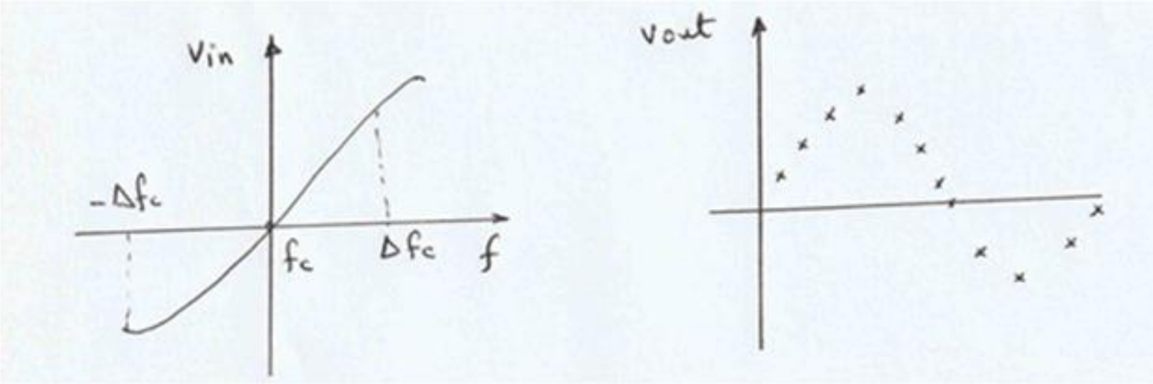
# 2. Ratio detector






When input signal has the following values:

1. f = fc    Vd1=Vd2    Vout = 0V
2. f < fc    Vd1 < Vd2    Vout = negative value
3. f > fc    Vd1 > Vd2    Vout = positive value



# De-emphasis

- **De-emphasis is employed in the receiver to restore the modulated audio back to its original power distribution.**

# AM and FM comparison

## AM

1. Carrier amplitude change
2. Narrow band (adv.)
3. Low S/N signal to noise ratio. (dis.)
4. Low cost. (adv.)
5. Much interference (dis.)
6. Wide radiation range. (adv.)
7. Can not reject noise. (dis.)
8. Easy to detect. (adv.)
9. Depend on (m) index modulation.

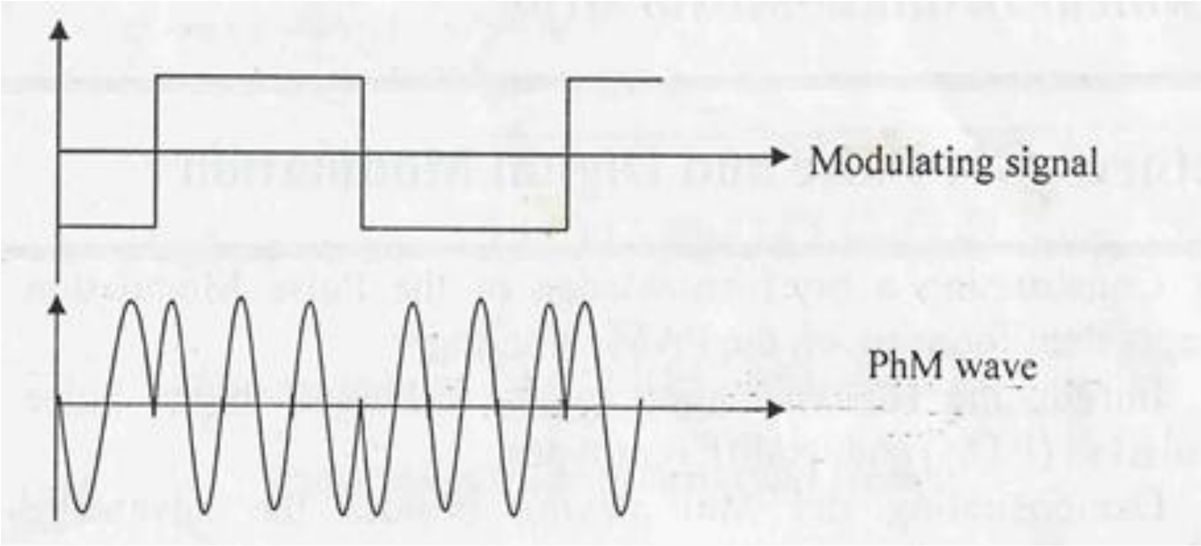
## FM

1. Carrier frequency change
2. Wide band (dis.)
3. High S/N signal to noise ratio. (adv.)
4. High cost. (dis.)
5. Less interference (adv.)
6. Less radiation range. (dis.)
7. Can reject noise (limiter). (adv.)
8. Hard to detect. (dis.)
9. Don’t depend on (mf) index modulation.

(adv.)= advantage
(dis.)= disadvantage

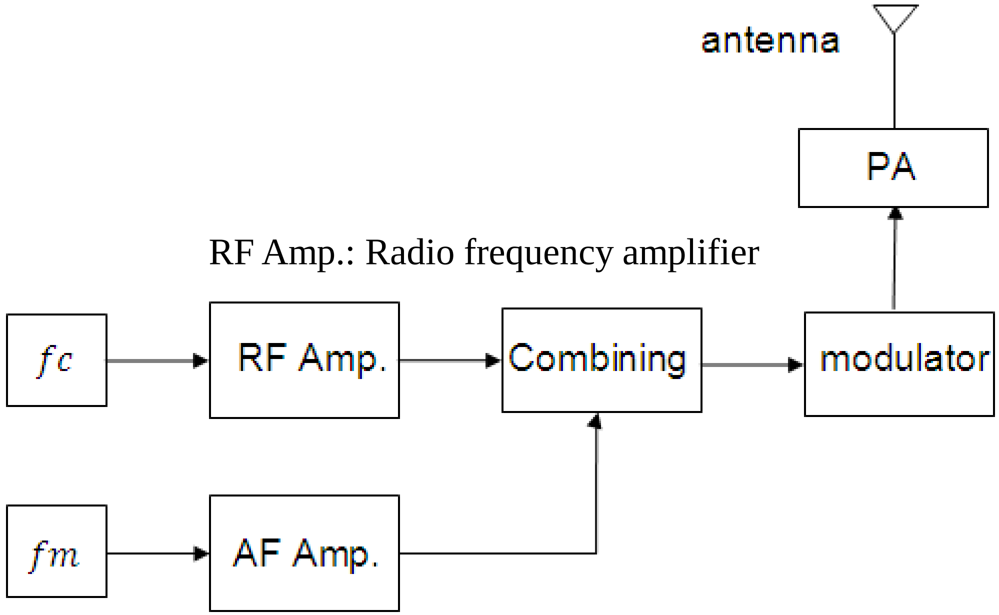
# PHASE MODULATION (Ph. M)

PH. M: Regulating the phase of a high frequency signal (carrier) by amplitude of the modulating signal (audio signal).



# PHASE MODULATION (Ph.M)

**1) Block diagram of** Ph M transmitter

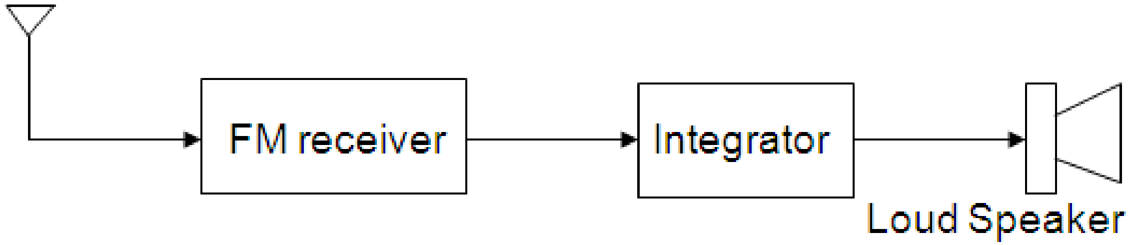



PA: Power amplifier

RF Amp.: Radio frequency amplifier

AF Amp.: Audio frequency amplifier

2) **Block diagram of** Ph M receiver




Why integrator?

Integrator is LPF to reduce the wide BW of FM-signal then its easy to amplify the signal.

# FREQUENCY MODULATION (FM)

# (FM) Questions

**ملاحظه:** جميع الاسئله الرياضيه مطلوبه

**Q1: Give the meaning of the following symbols:**

FM, Ph. M, $m_f$, $\Delta f_c$, NBFM, WBFM, BW.

**Q2: Fill in blanks:**

- FM : Is the process of varying the -------- by -------- of modulating signal (audio or information signal). (page 3)
- Frequency deviation is the range of varying in -------- due to -------------.
  (page 4)
  There are two methods for generating FM-signal ----------- and --------------- (page 14)
- Limiter it is -------- circuit use to -------- AM-noise in FM system by flat topping the upper and ------- peaks of FM-signal. (page 16)

# (FM) Questions

- Discriminator used to obtain ------ from FM-signal, where change in frequency converted to ------ change. (page 17)
- There are two types of discriminator ----------- and --------------. (page 17)
- PH. M: Regulating the ------- of a high frequency signal (carrier) by ------- of the ---------------. (page 22)
- Both de-emphasis & limiting circuits are included in ---------receivers to reduce the noise.
- The bandwidth of NBFM is equal to the BW of -------------. (page 8)
- The modulation index of NBFM is ---------- than unity.
- The modulation index of WBFM is ---------- than unity.
- The bandwidth of WBFM is equal -------------. (page 9)
- There are two methods for generating FM-signal ---------------- and ------------ .(page 14)

# (FM) Questions

**Q3: State the comparison between AM and FM?** (page 21)

**Q4: State the FM advantages?** (page 21)

**Q5: State the FM disadvantages?** (page 21)

**Q6: State the AM advantages?** (page 21)

**Q7: State the AM disadvantages?** (page 21)

Note:

# (FM) Questions

**Q8: Draw**

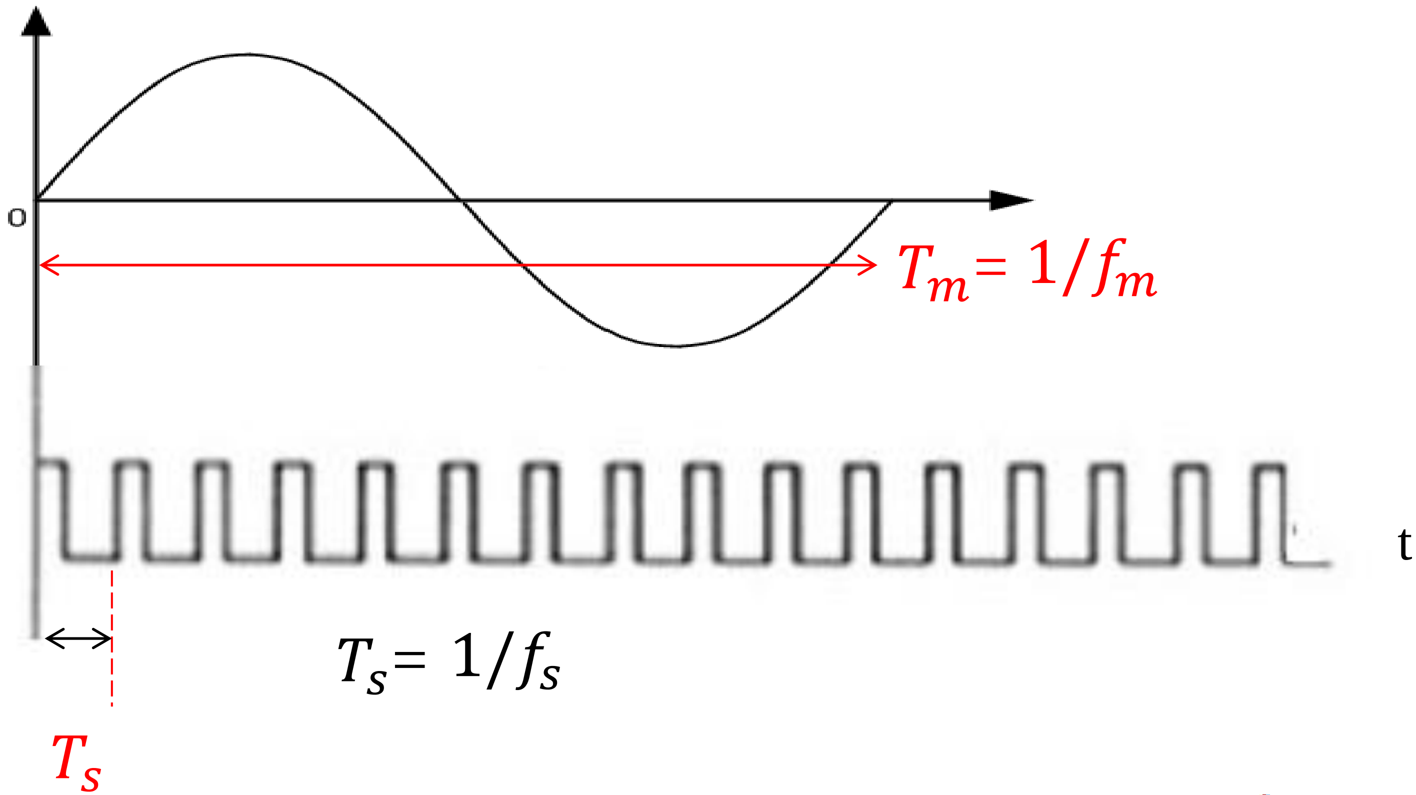
1. NBFM bandwidth?  (page 8)
2. WBFM bandwidth?  (page 9)
3. Direct method FM generation? (page 14)
4. Indirect method (Armstrong method) FM generation? (page 15)
5. FM Receiver? (page 16)
6. Foster-Seeley discriminator? (page 18)
7. Ratio detector**?** (page 19)
8. Ph. M transmitter? (page 23)
9. Ph. M receiver? (page 24)

**Q8: Explain and draw the operation of**

1. Foster-Seeley discriminator? (page 18)
2. Ratio detector**?** (page 19)

# PULSE MODULATION (PM)

## PM use a digital carrier signal

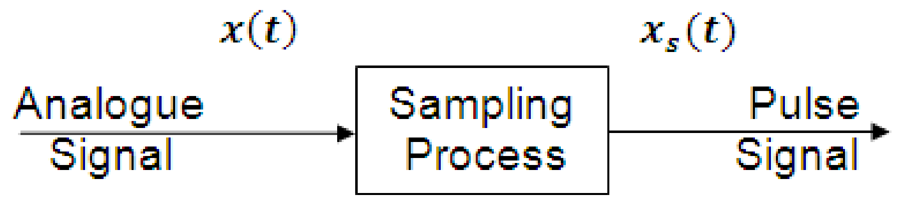



**Nyquist rate** $f_s = \dfrac{1}{T_s} = 2f_m \qquad T_s \le \dfrac{1}{2f_m}$

# PULSE MODULATION

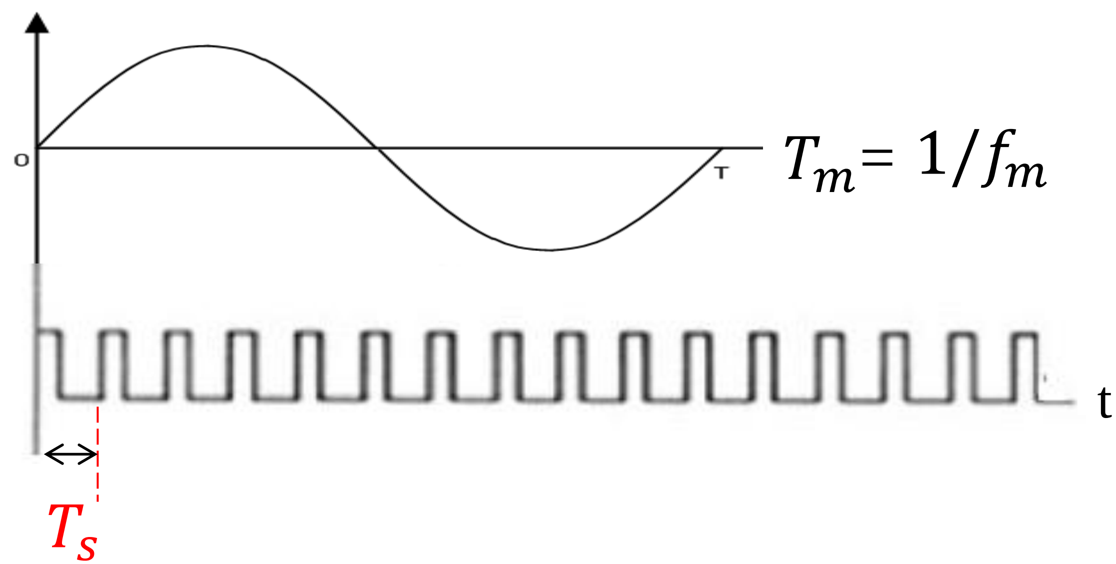
## Sampling theorem:

$$T_s \le \frac{1}{2\ f_m}$$




## Nyquist rate

$$f_s = \frac{1}{T_s} = 2 f_m$$



# PULSE MODULATION (PM)

**Example: calculate** $Nyquist\ rate\ (f_s)$ for audio signal $f_m$ = 4 KHz ?

**Nyquist rate** $f_s = \frac{1}{T_s} = 2f_m$ $\quad T_s \le \frac{1}{2\ f_m}$

**$f_m$ = 4 kHz**

**$f_s$ = 2 $f_m$ = 2 * 4 k = 8,000 sample/sec**

# PULSE MODULATION (PM)

## Advantages of PM

1. Low cost
2. Lower power use
3. Low noise
4. High capacity

# PM types

1. **Pulse amplitude modulation (PAM)**
2. **Pulse width modulation (PWM)**
3. **Pulse position modulation (PPM)**

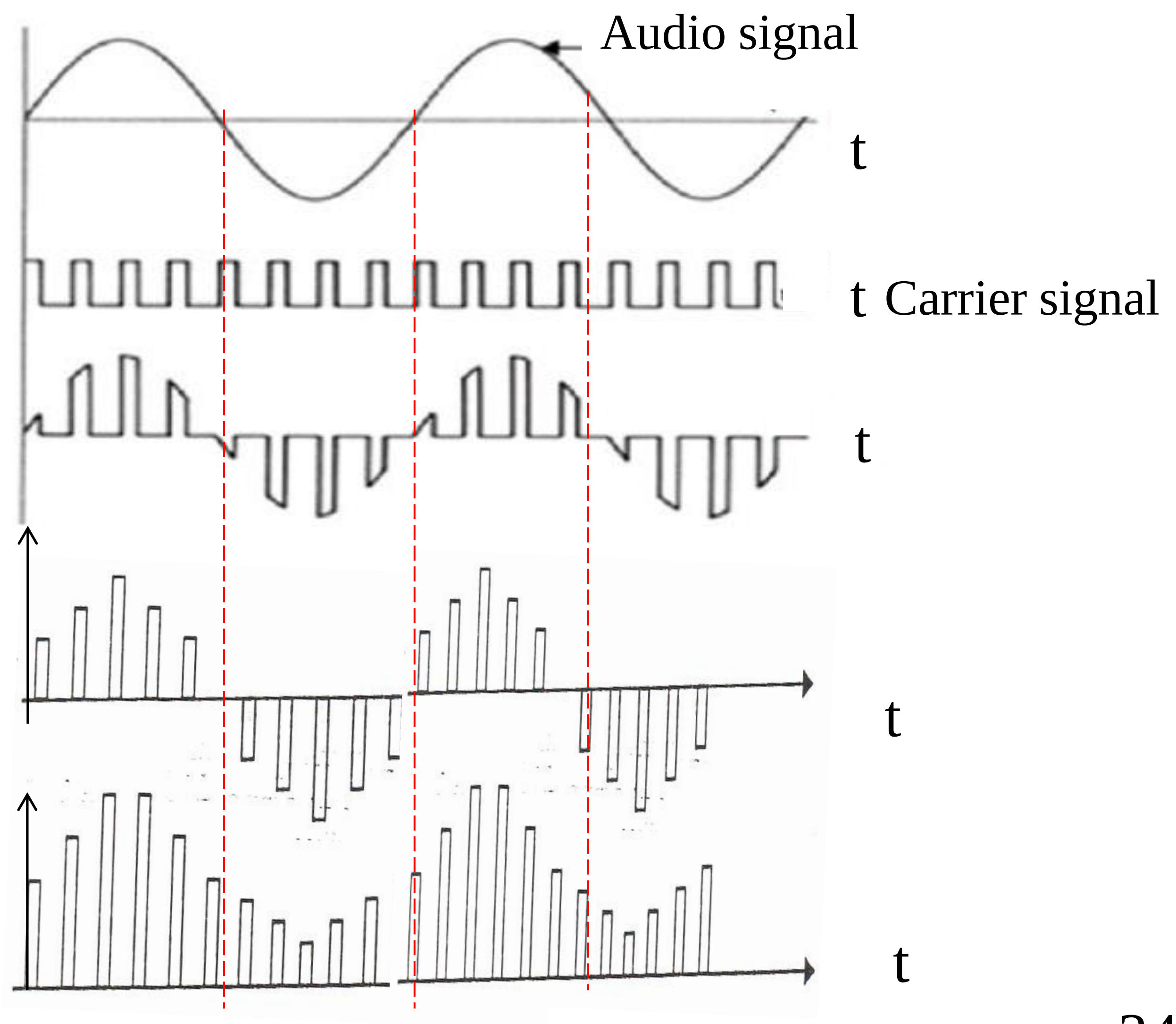
# Pulse amplitude modulation (PAM) types

**PAM types ?**

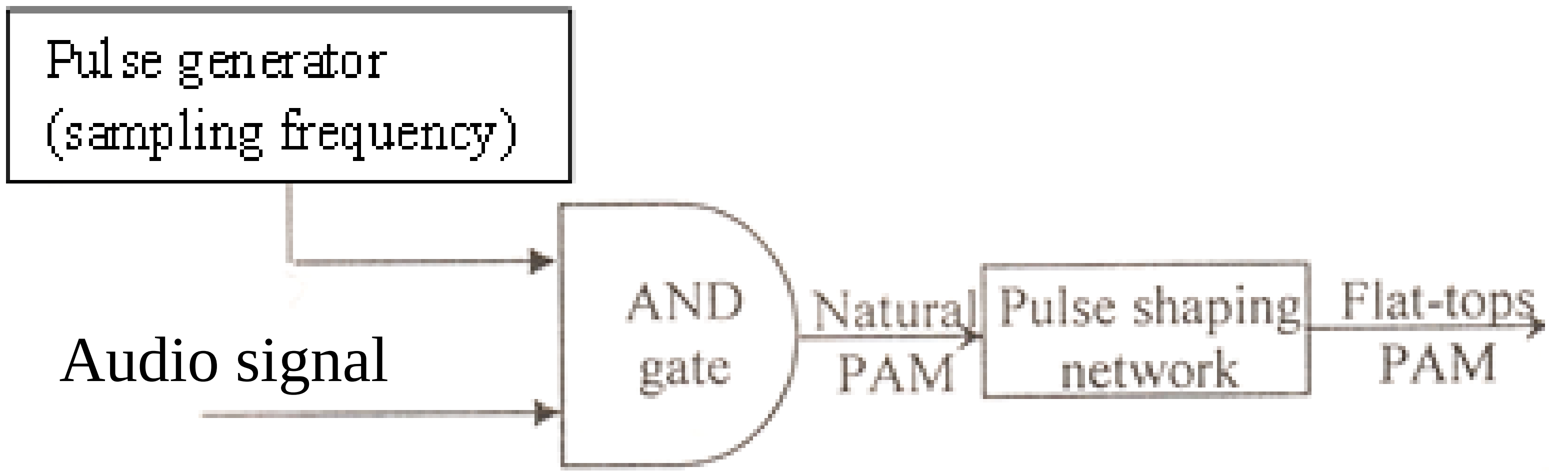
1. Natural PAM

2. Flat-top-PAM double polarity

3. Flat-top-PAM single polarity



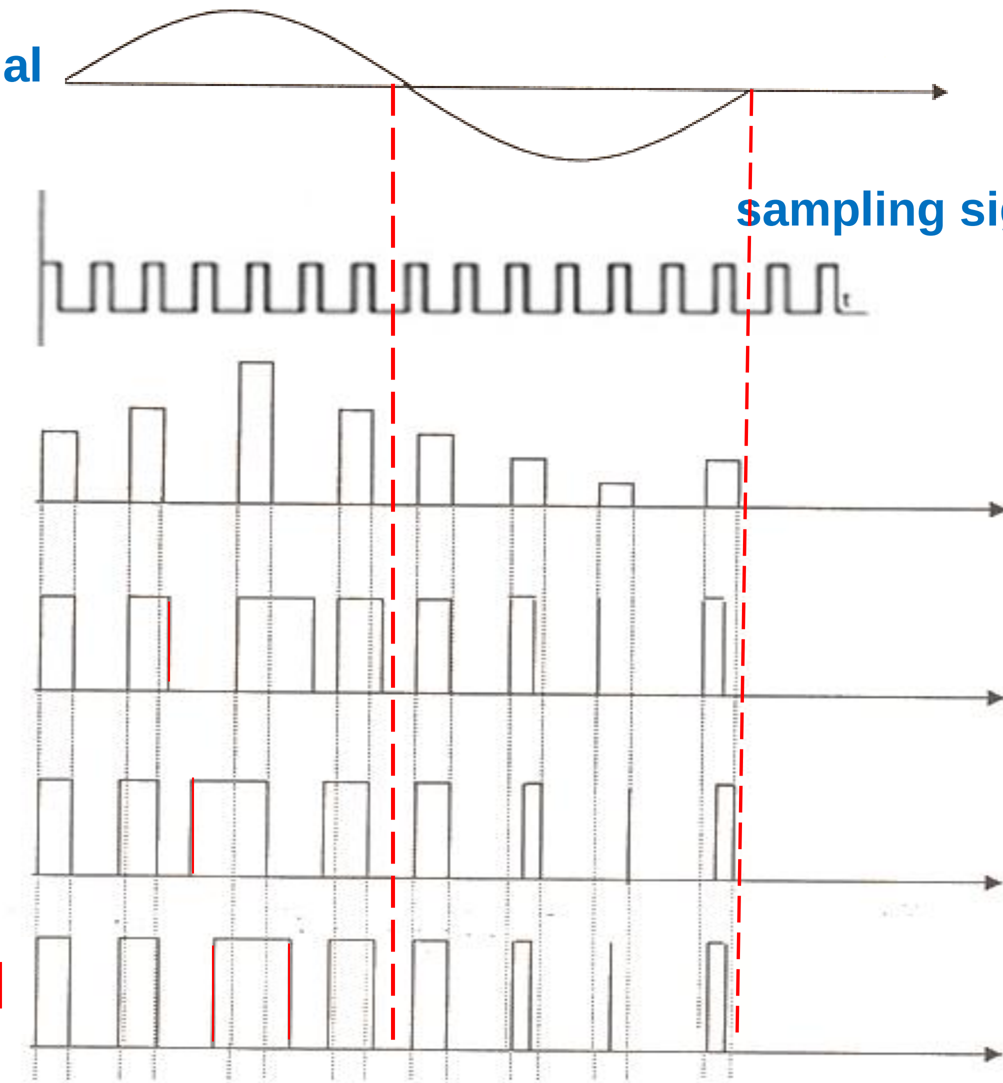
# PAM generation




PAM generation principle

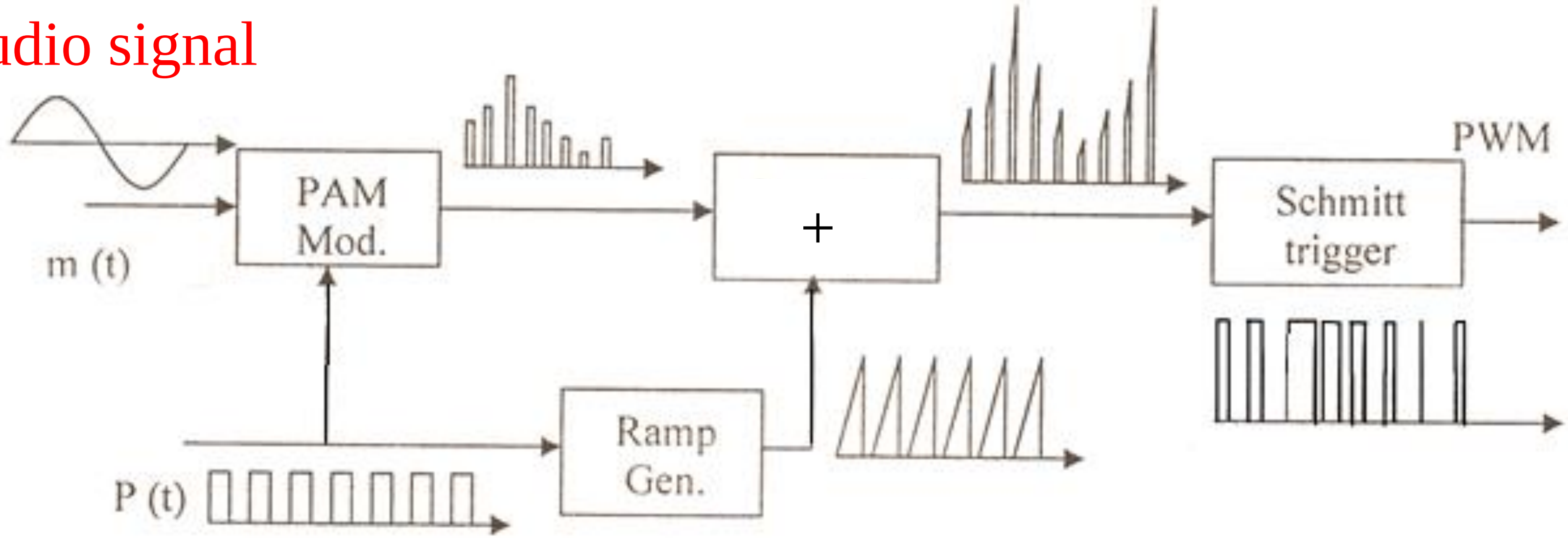
# Pulse width modulation (PWM) types

PWM types?
1. PWM lag-edge
2. PWM lead-edge
3. PWM symmetrical



# PWM Transmitter

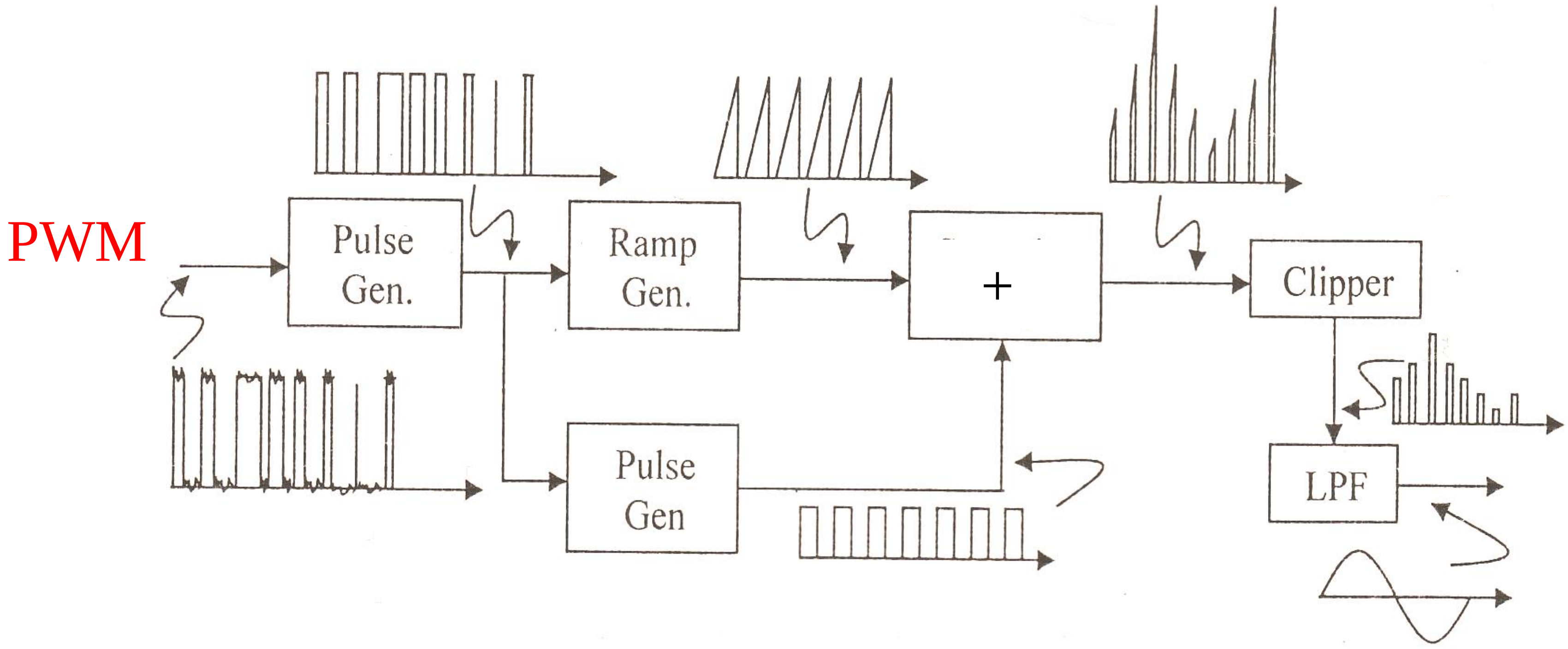
Audio signal




sampling signal

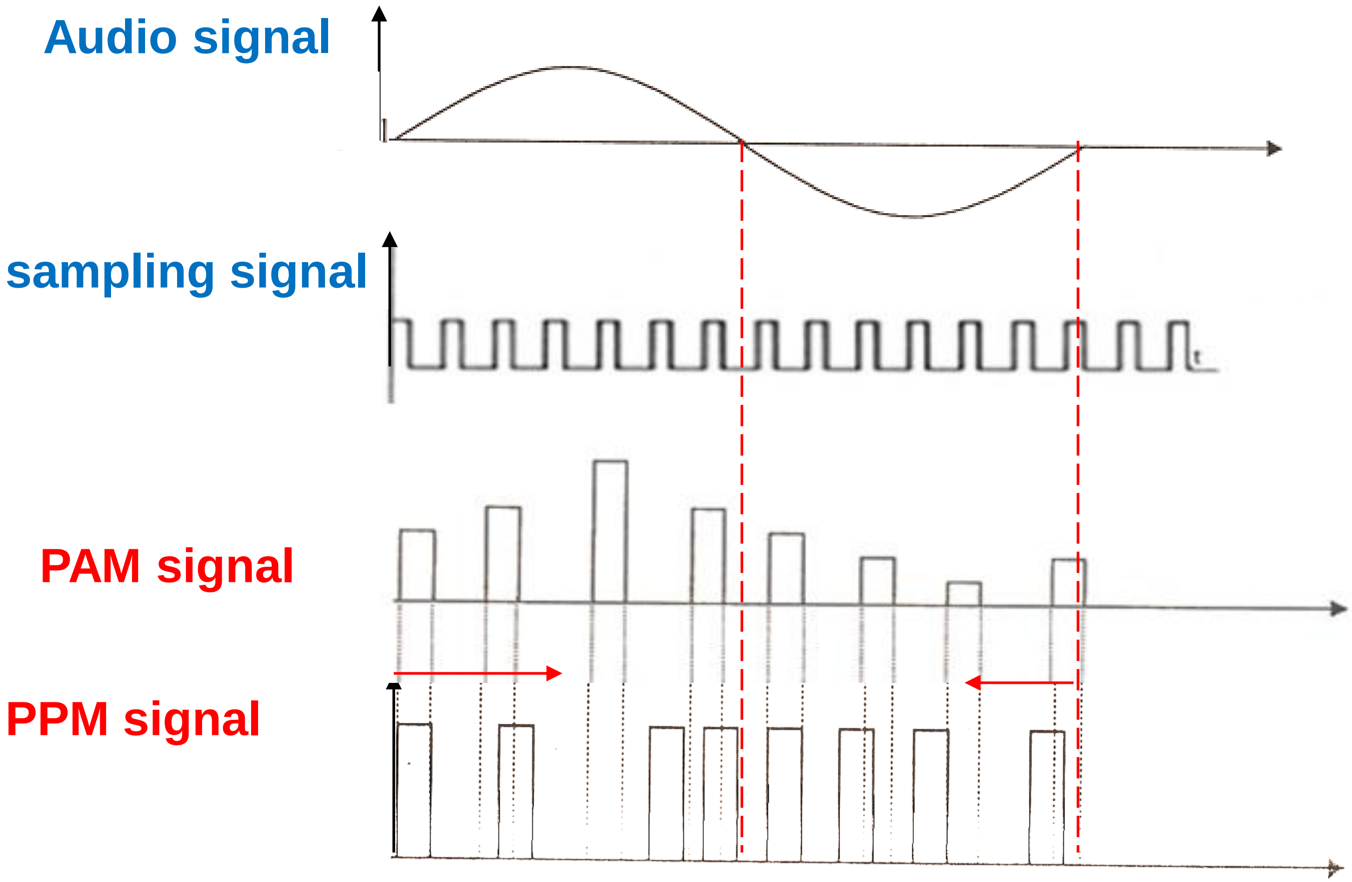
**Block diagram of PWM transmitter**

# PWM Receiver




**Block diagram of PWM receiver**

# Pulse Position modulation (PPM)



# Comparison between PAM, PWM, PPM

| PAM | PWM | PPM |
|---|---|---|
| • Amplitude of pulse carrier change with audio signal. | • Width of pulse carrier change with audio signal. | • Position of pulse carrier change with audio signal. |
| • High noise | • Low noise | • Low noise |
| • Similar to AM | • Similar to FM | • Similar to Ph.M |

# Amplitude Modulation (AM)

# PULSE CODE MODULATION (PCM)

PM suffer from distortion and noise for this it used as intermediate steps in generation of pulse code modulation (PCM)

PCM process is done in three steps

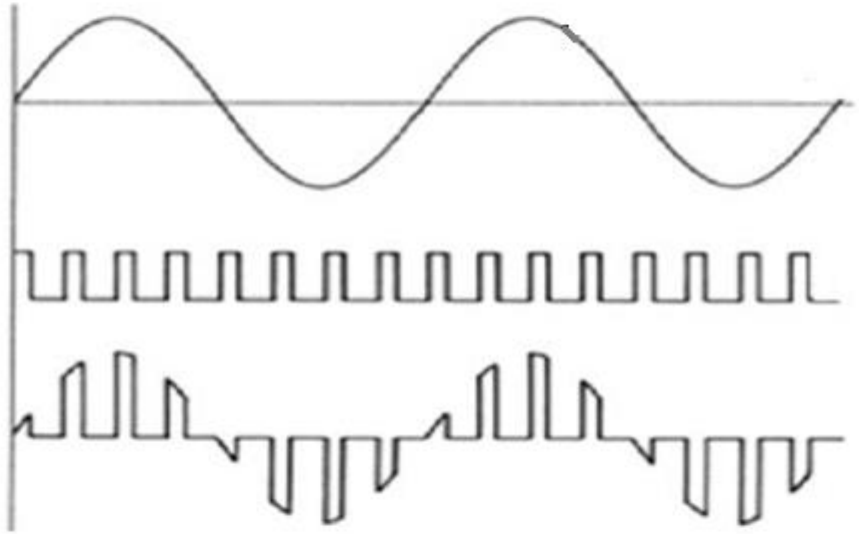
1- Sampling

2- Quantization

3- Coding

# Sampling

1- sampling



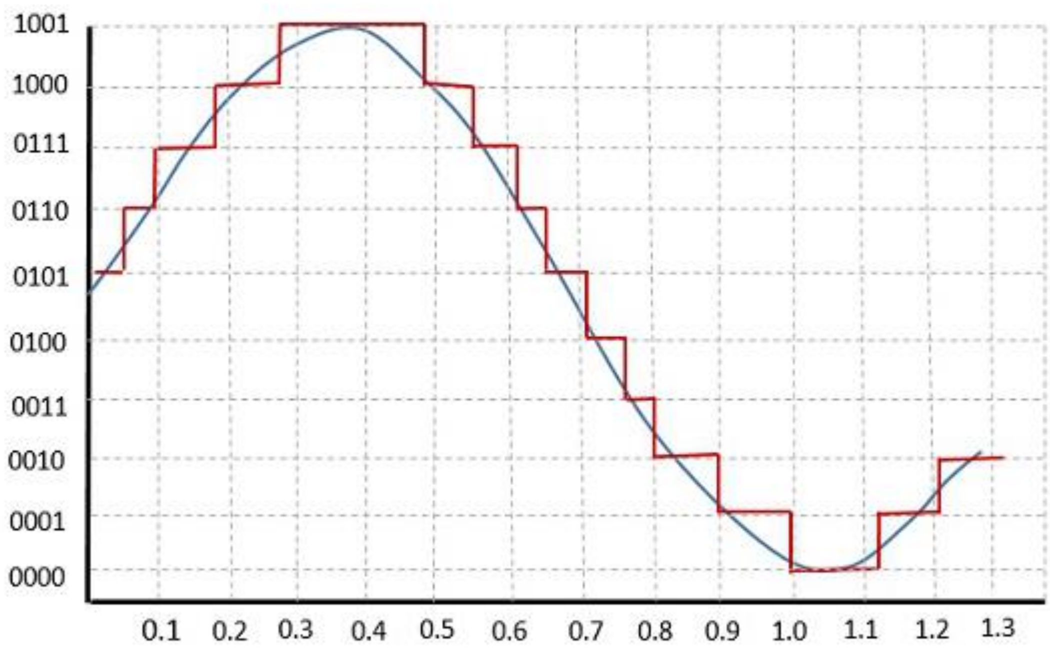
Audio signal

Sampling frequency

PAM

# Quantization

2- Quantization means quantizing samples to levels and then to binary sequences.




$$\boxed{2^P = q}$$

$p$ : maximum number of pulses.

$q$ : number of quantized level.

# Quantization

**Example:** Calculate the number of quantized level ($q$) in pulse code modulation system (PCM), if the maximum number of pulses ($p = 3$)?

$q$ = ? (number of quantized level)

$$\boxed{2^P = q}$$

$$2^3 = 8$$

$$q = 8$$

| | |
|---|---|
| 000 | 0 |
| 001 | 1 |
| 010 | 2 |
| 011 | 3 |
| 100 | 4 |
| 101 | 5 |
| 110 | 6 |
| 111 | 7 |

# Quantization

**Example:** Calculate the number of quantized level ($q$) in pulse code modulation system (PCM), if the maximum number of pulses ($p = 4$) ?

$$\boxed{2^P = q}$$

$$2^4 = 16$$

$$q = 16$$

| | |
|---|---|
| 0 | 0000 |
| 1 | 0001 |
| 2 | 0010 |
| 3 | 0011 |
| 4 | 0100 |
| 5 | 0101 |
| 6 | 0110 |
| 7 | 0111 |
| 8 | 1000 |
| 9 | 1001 |
| 10 | 1010 |
| 11 | 1011 |
| 12 | 1100 |
| 13 | 1101 |
| 14 | 1110 |
| 15 | 1111 |

# Quantization

Usually the number of quantized level ($q=128$) is chosen for speech signal.

**Example:** Calculate the number of quantized level ($q$) in pulse code modulation system (PCM), if the maximum number of pulses ($p = 7$)?

$q$ = ? (number of quantized level)

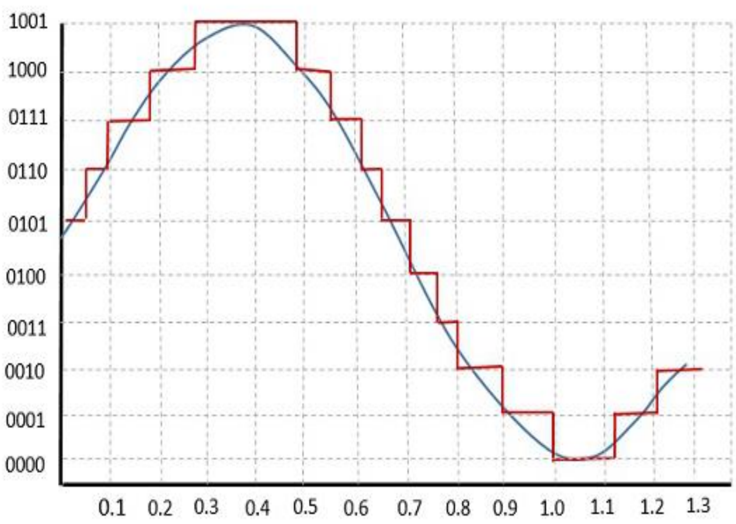
$$\boxed{2^P = q}$$

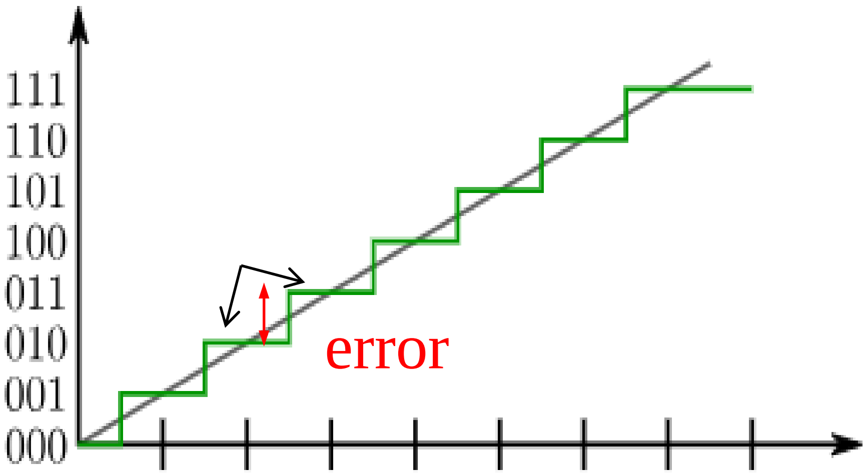
$$2^7 = 128$$

$$q = 128$$

# Quantization noise

<u>Quantization noise</u> The difference between the analog signal levels and quantized signal level.

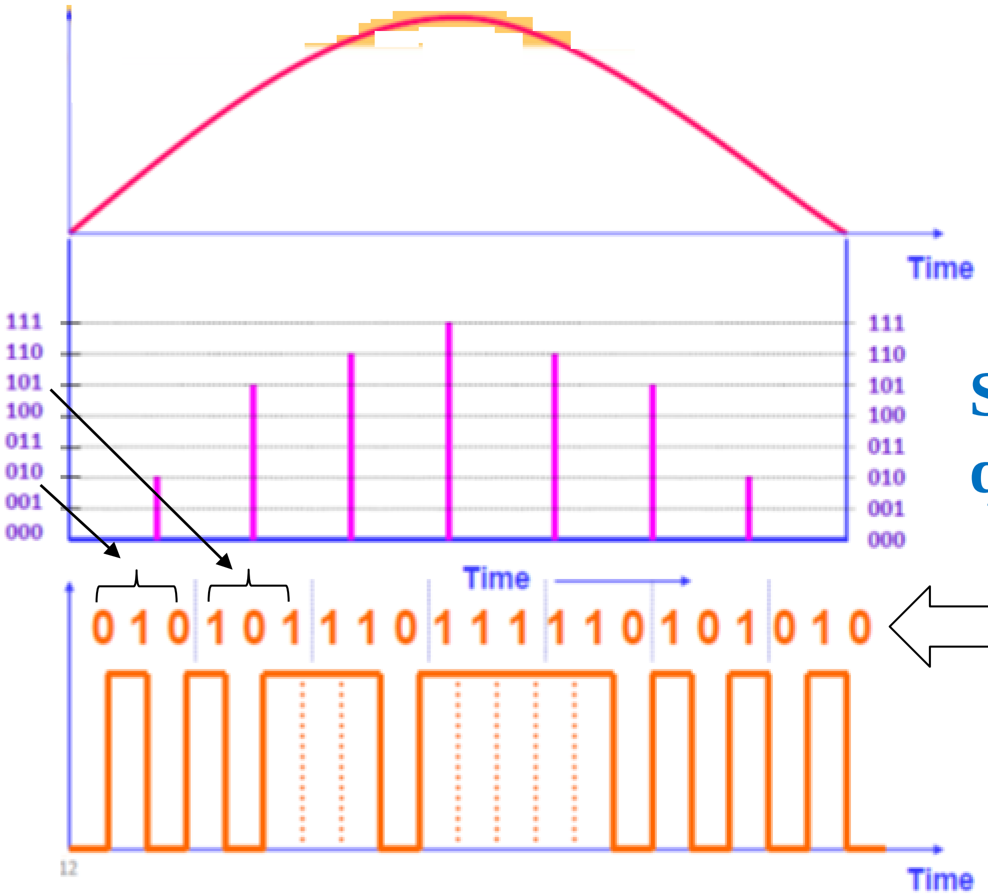



Increasing the quantization levels will reduce error (quantization noise)

# Coding

3- Coding means convert the quantitating level to binary number.

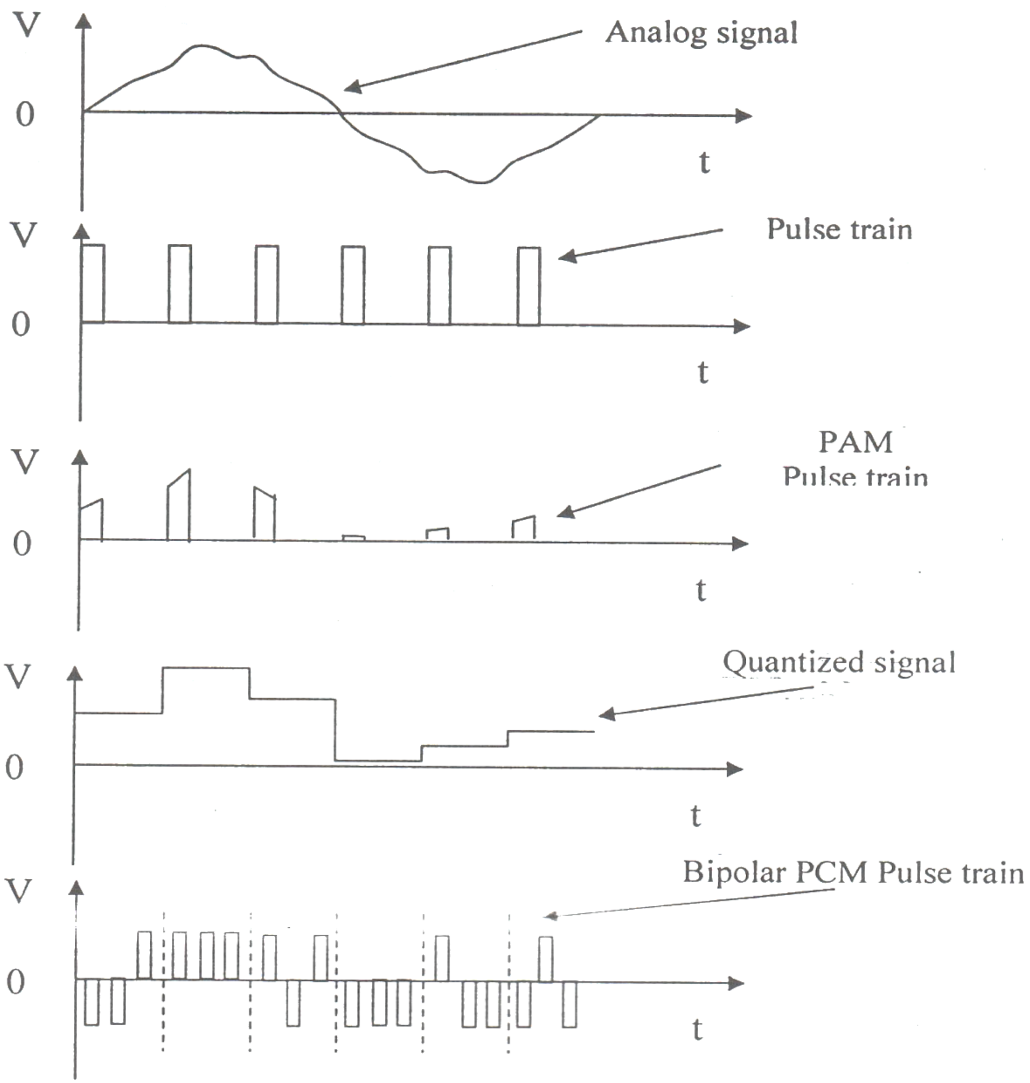



Analog signal

**Sampling and quantization**

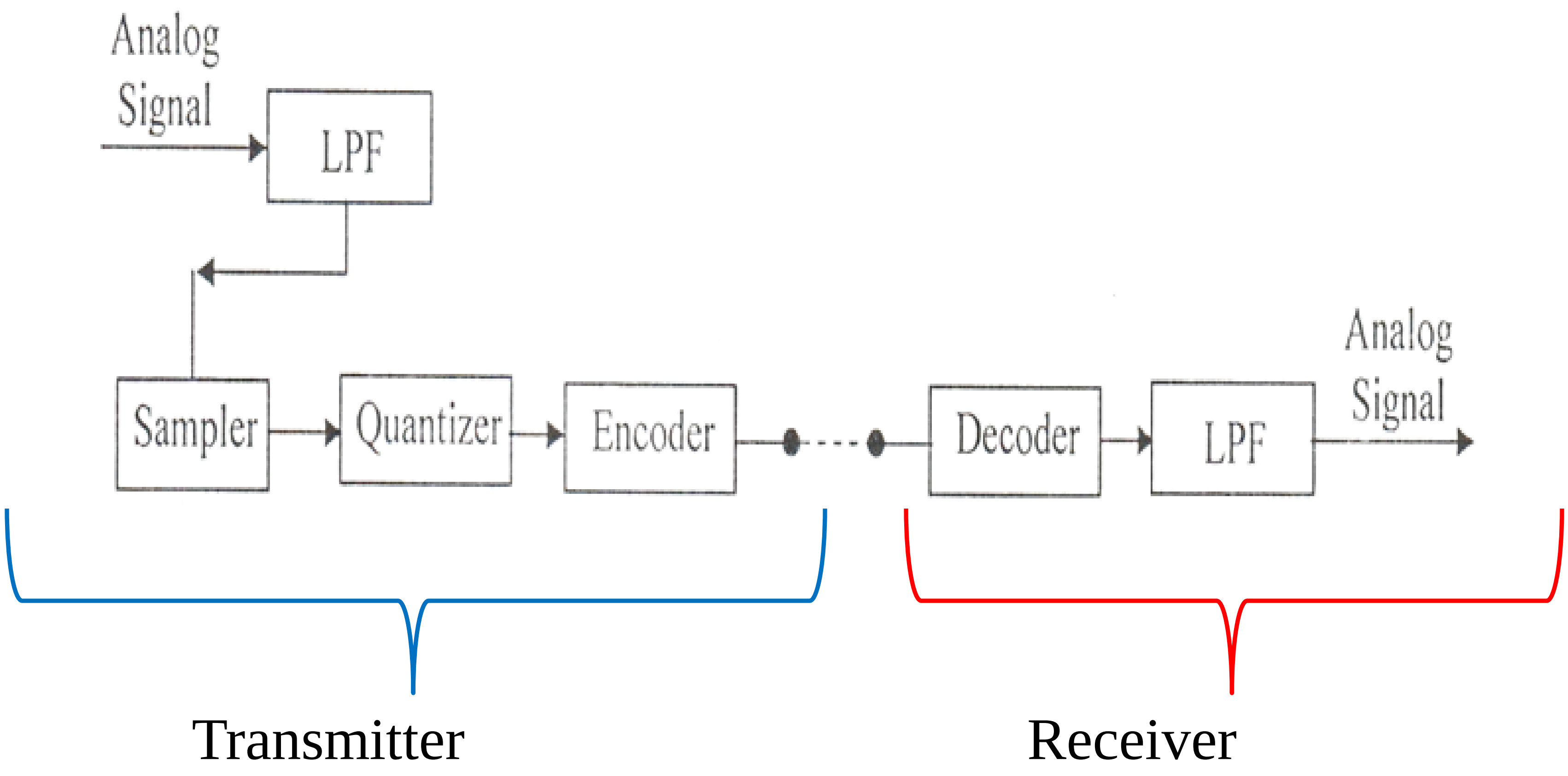
**Coding (binary numbers)**

# PULSE CODE MODULATION (PCM)



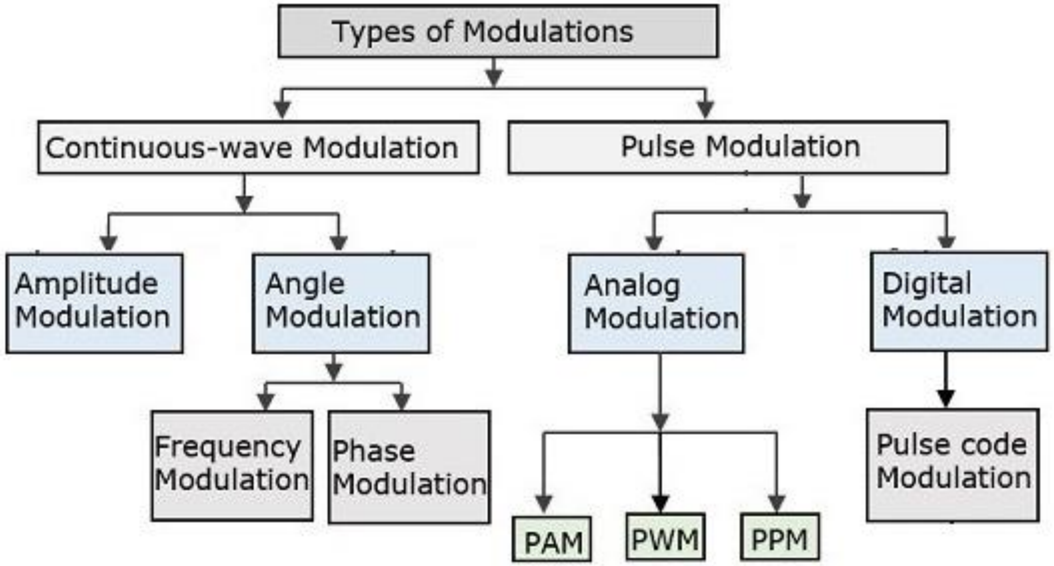

Signals of PCM system

# PCM system




**Block diagram of PCM system**

# Types of Modulation



# Amplitude Modulation (AM)

# (Pulse Modulation) Questions

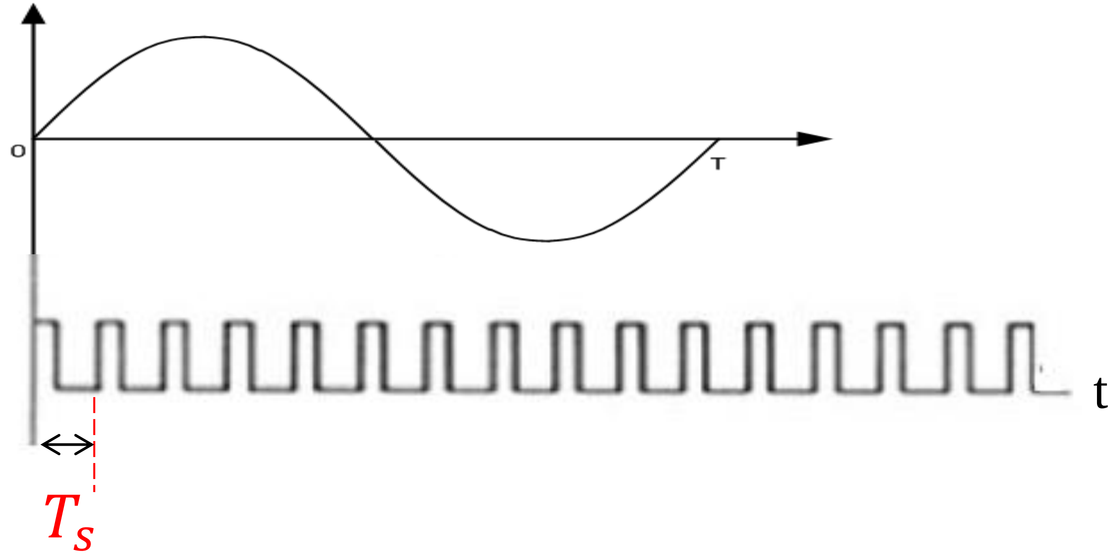
ملاحظه: جميع الاسئله الرياضيه مطلوبه

**Q1**: Explain sampling theorem?

## Nyquist rate

$$f_s = \frac{1}{T_s} = 2f_m$$

$$T_s \le \frac{1}{2\ f_m}$$



**Q2**: **Calculate** $Nyquist\ rate\ (f_s)$ for audio signal $f_m$= 5 KHz ?

**fm = 5 kHz**
**fs = 2 fm = 2 * 5 k = 10,000 sample/sec**

**Q3:** What are the pulse modulation types?

1- Pulse Amplitude Modulation (PAM)
2- Pulse Width Modulation (PWM)
3- Pulse Position Modulation (PPM)

**Q4: State the advantages of PM?**

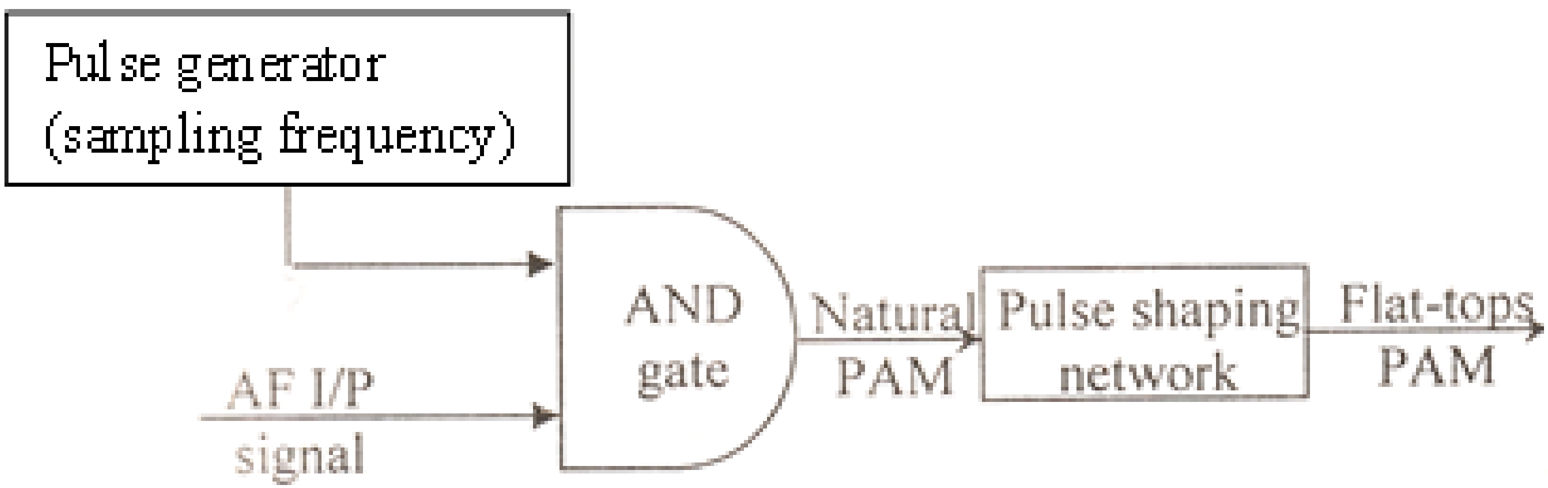
1- Low cost
2- Lower power use
3- Low noise
4- High capacity

**Q5:** **Draw PAM types?** (page 34)

**Q6: State PAM types?** (page 34)

1. Natural PAM
2. Flat-top-PAM double polarity
3. Flat-top-PAM single polarity

**Q7:** Plot the block diagram of PAM system (transmitter).



**Q8:** **Draw PWM types?** (page 36)

**Q9:** **State PWM types?** (page 36)

**PWM types?**

1. **PWM lag-edge**
2. **PWM lead-edge**
3. **PWM symmetrical**

**Q10:** **Plot block diagram of PWM transmitter.**(page 37)

**Q11:** **Plot block diagram of PWM receiver.** (page 38)

**Q12:** **plot Pulse position modulation signal.** (page 39)

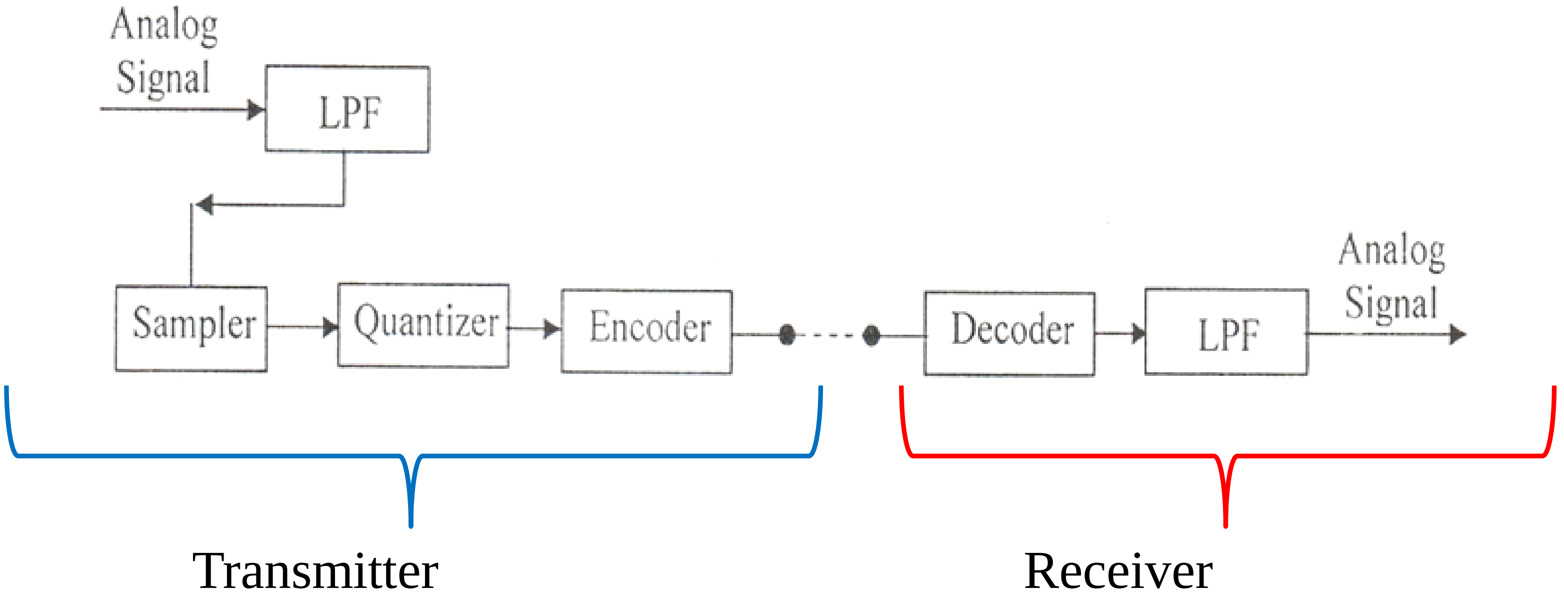
**Q13:** **Compare between PAM, PWM, and PPM**

**Q14:** State the steps for generating PCM.

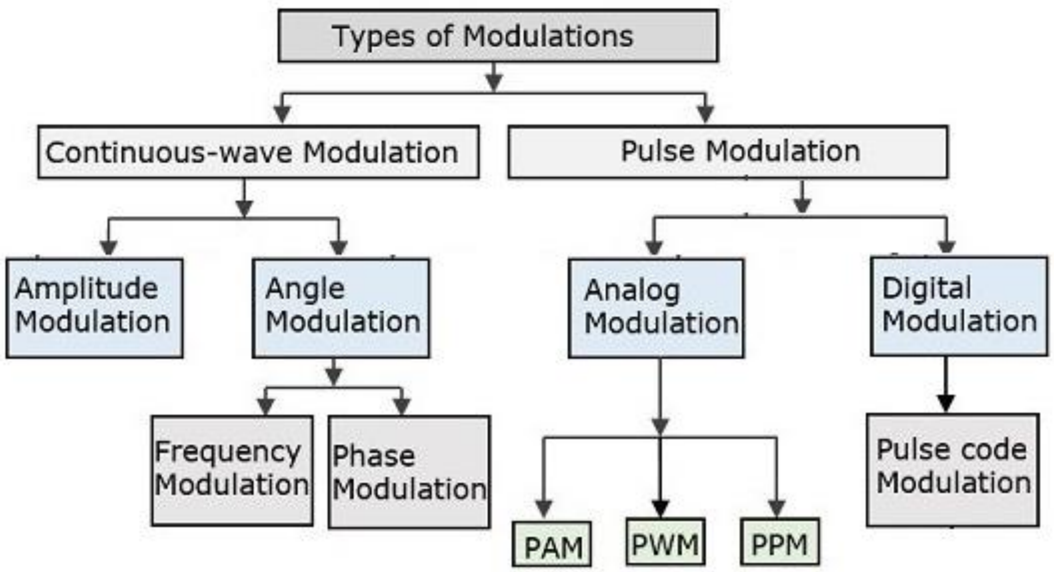
1- Sampling
2- Quantization
3- Coding

**Q15**: Plot PCM signals.

**Q16**: Plot Block diagram of PCM system. (transmitter and receiver) **(page 50)**



**Q17**: State the types of modulation.



**Q18: Give the meaning of the following symbols: PM, PAM, PWM, PPM, PCM.**

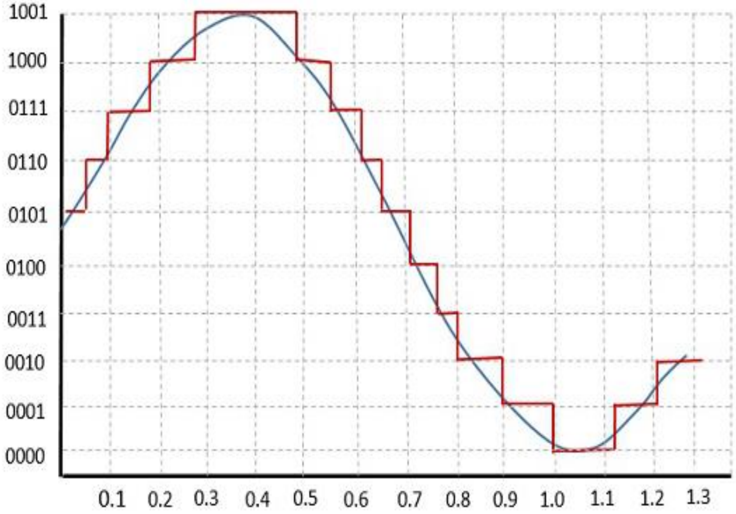
**Q19:** Fill in blanks:

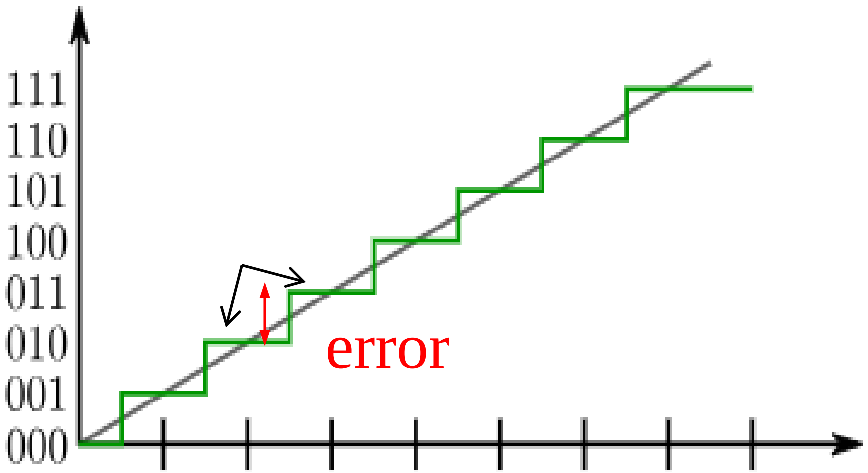
1. PCM process is done in three steps sampling, quantization and coding.
2. Quantization noise is the difference between the analog signal levels and quantized signal level.
3. Coding means convert the quantitating level to binary number.

$$f_s = \frac{1}{T_s} = 2 f_m$$

4. Nyquist rate equal -------------------------.

## Q20: Explain quantization noise.




Increasing the quantization levels will reduce error (quantization noise). The number of quantized level ($q=128$) is chosen for speech signal.

$$\boxed{2^P = q}$$

$q$ : number of quantized level

$p$ : maximum number of pulses

# MULTIPLEXING

**In order to use the same cable for sending multi channels multiplexing have been used.**

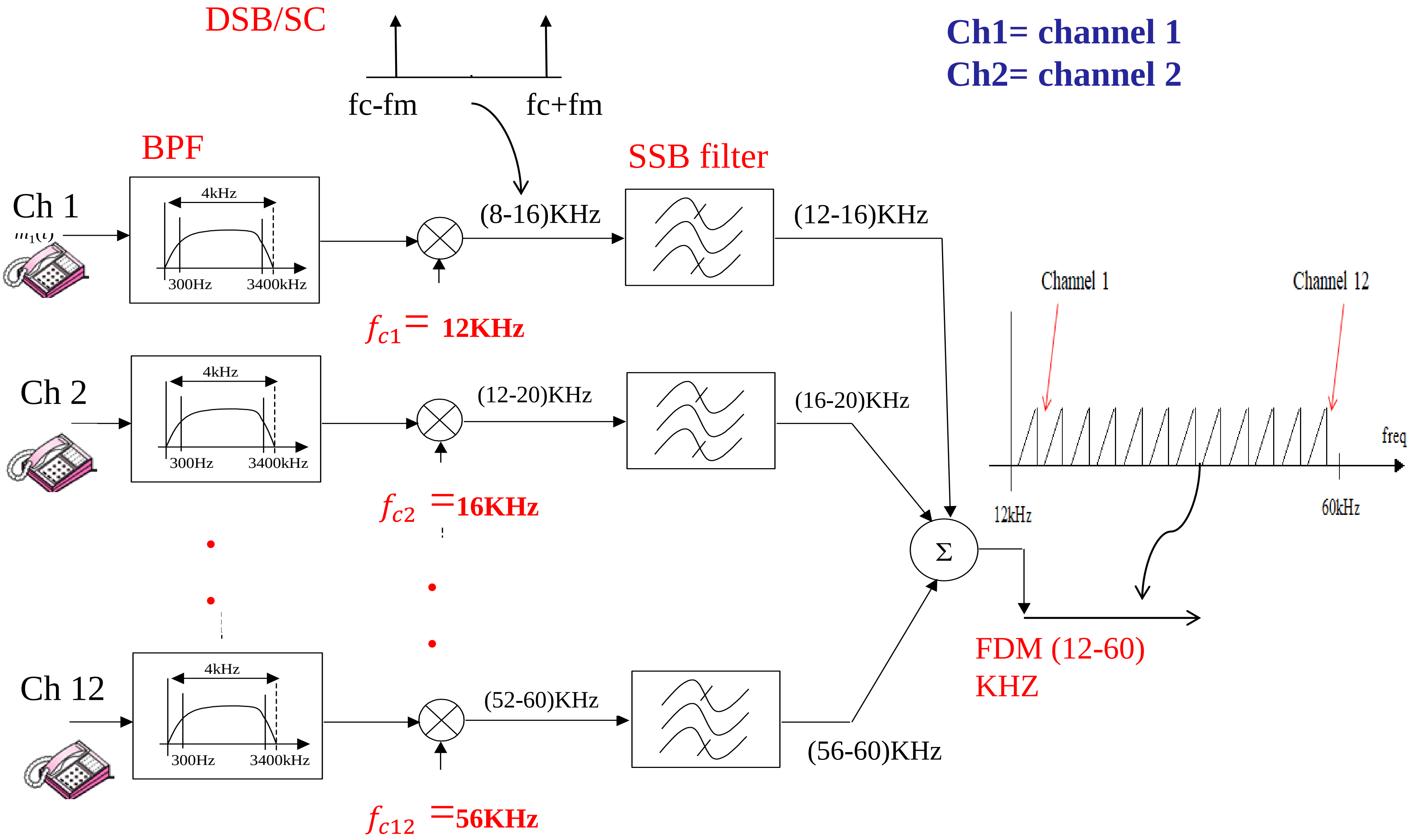
**MULTIPLEXING is sending of a number of separate signals over the same cable, simultaneously without interference.**

**There are two basic forms of Multiplexing**

1. **Frequency division multiplexing (FDM)**
2. **Time division multiplexing (TDM)**

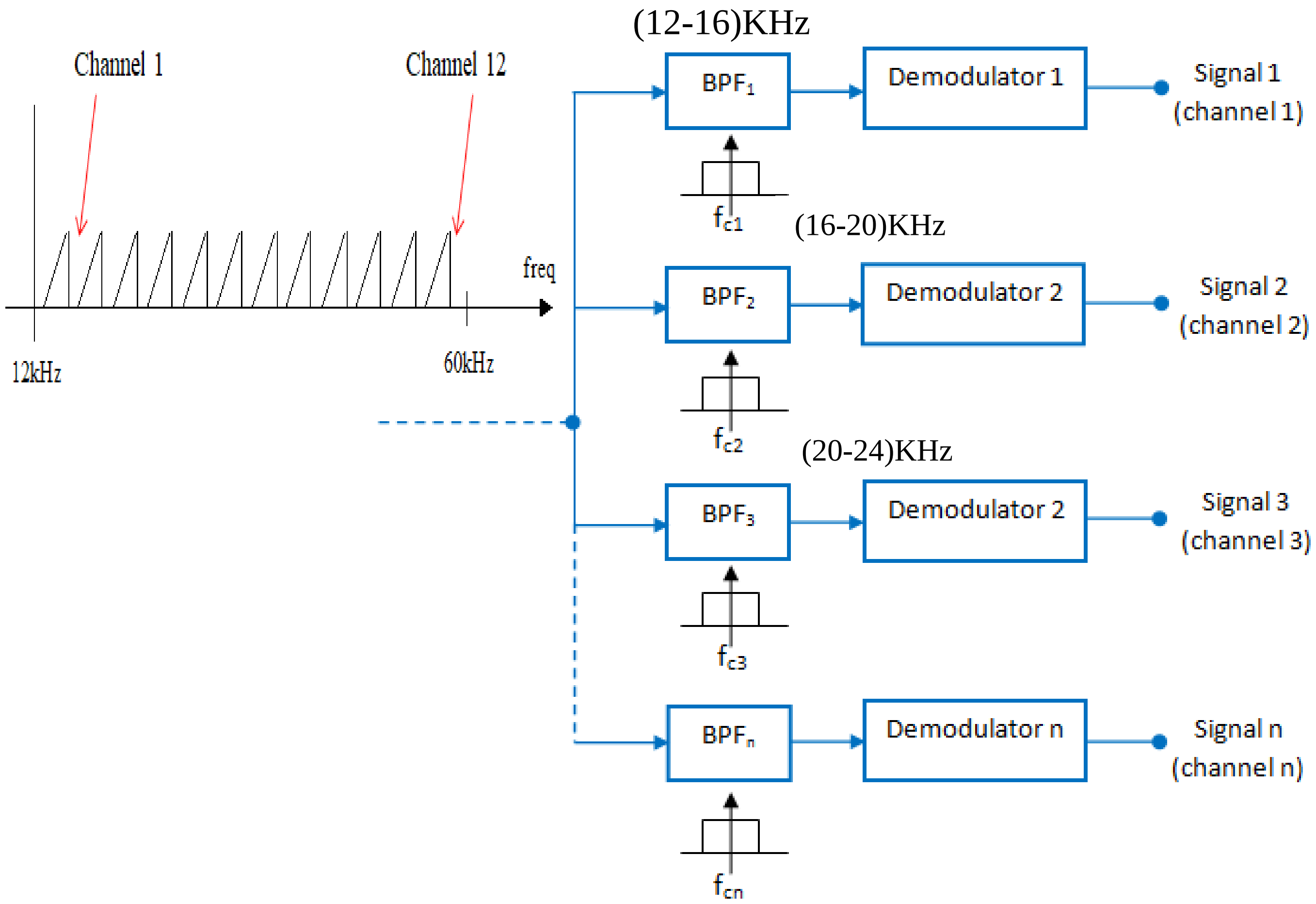
**FDM is the process of combining many signals to different frequency groups so that they can all transmitted at the same time.**

# FDM Transmitter




Block diagram of FDM transmitter

# FDM Receiver




Block diagram of FDM receiver

# FDM advantages and disadvantages

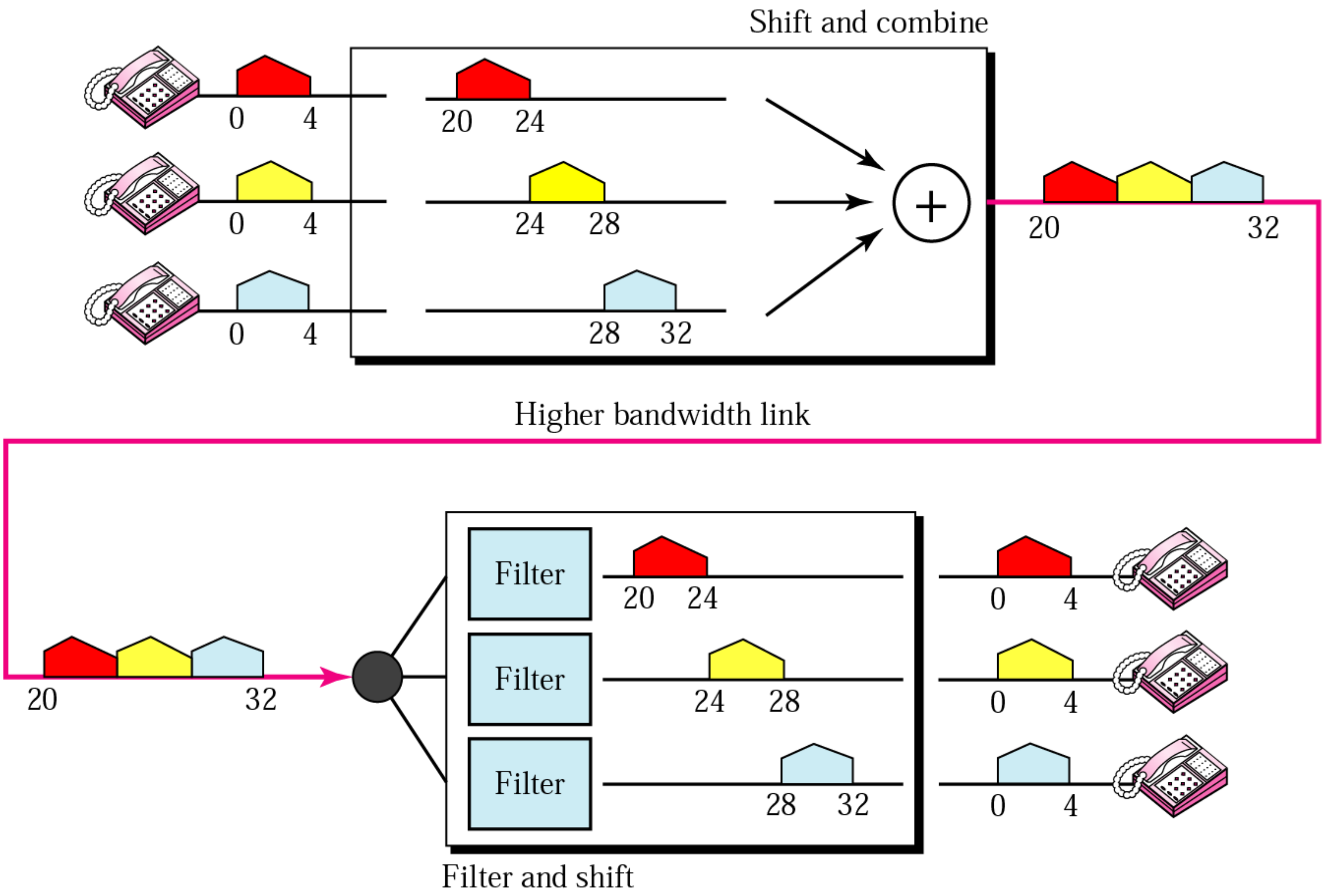
**FDM Advantages:**

1. Works for analog signals.

**Disadvantages:**

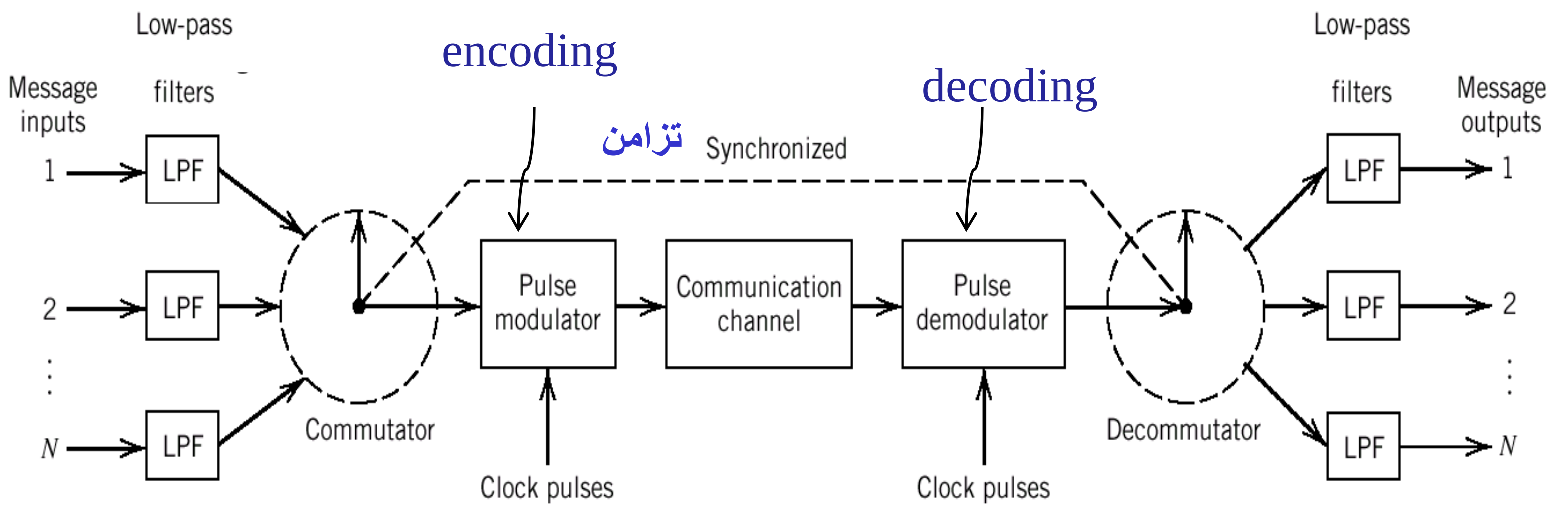
1. Large bandwidth (BW)
2. Spaces between channels

# DIGITAL PULSE MODULATION

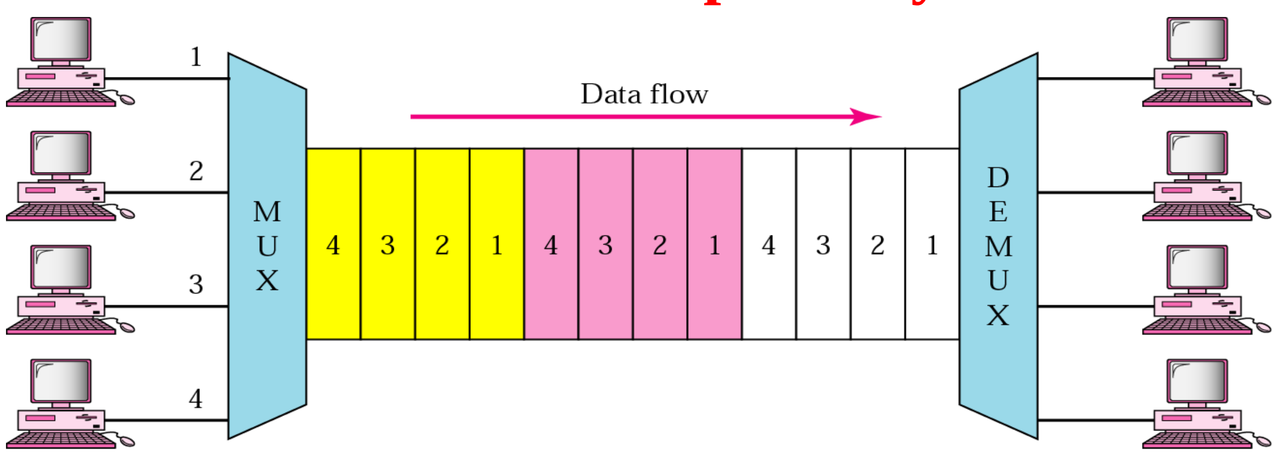


# Time division multiplexing (TDM)

TDM used for PCM system

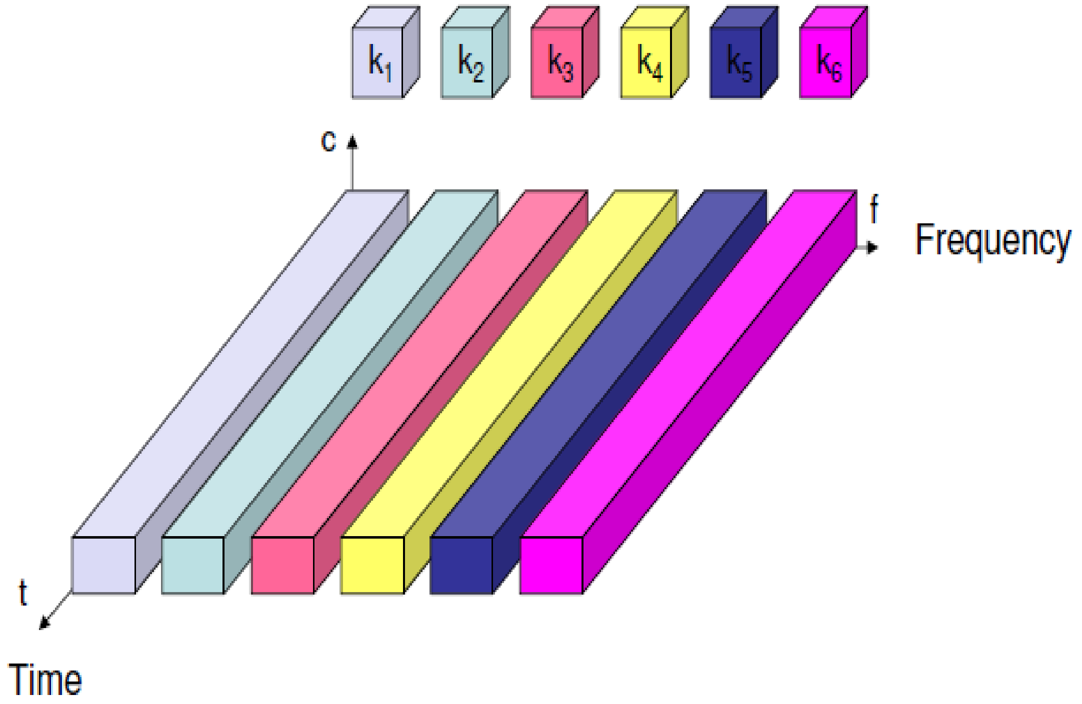



## TDM/PCM telephone system



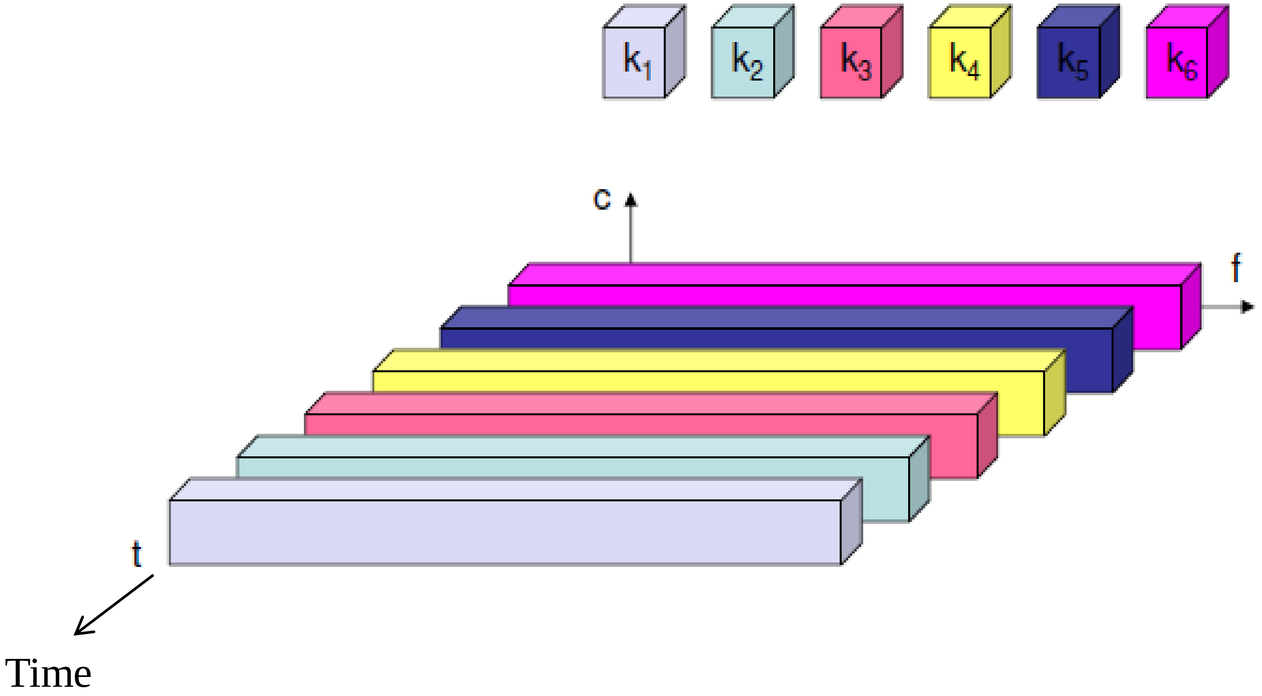
# DIGITAL PULSE MODULATION

## Frequency division multiplexing



# DIGITAL PULSE MODULATION

## Time division multiplexing



# DIGITAL PULSE MODULATION

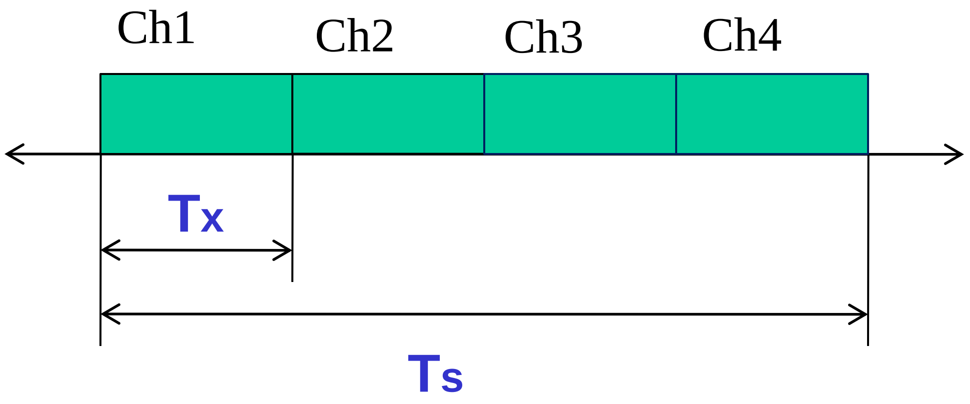
## PAM/TDM equations:

$$f_s \geq 2 * f_m \qquad f_s = 2 * f_m$$

$$T_s = \frac{1}{f_s}$$

$$T_x = \frac{T_s}{M}$$

$$\mathrm{BW} = \frac{1}{2T_x}$$




M: number of channels

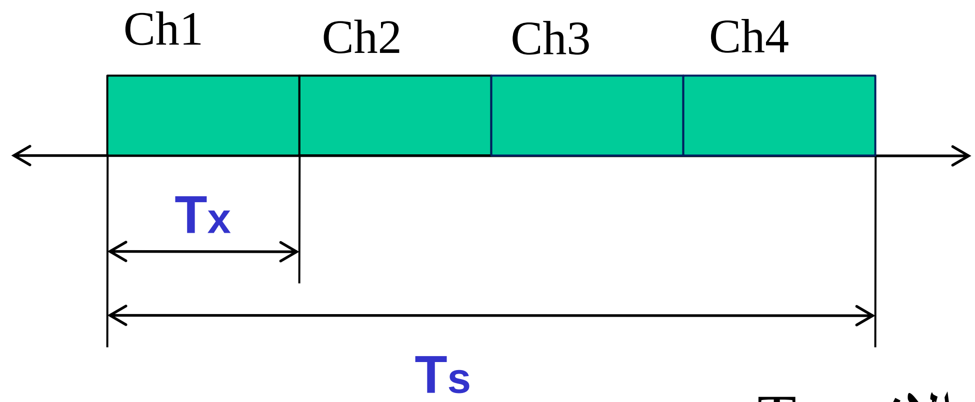
# DIGITAL PULSE MODULATION

**Example (1):**

**Ten analogue telephone channels, the bandwidth of each channel is $f_m = 3.2$ kHz, if the channels are modulated by PAM/TDM at sampling frequency $f_s = 8$ kHz. Calculate the time period $T_x$ and the bandwidth (BW) required to transmit the output signal from the multiplexer.**

# DIGITAL PULSE MODULATION

## Solution:




$$T_s = \frac{1}{f_s} = \frac{1}{8k} = \frac{1}{8000\ Hz} = 0.000125\ \text{sec} = \mathbf{125\mu sec}$$

Ts: الزمن الازم لأرسال 10 مكالمات كما في السؤال

$$T_x = \frac{T_s}{M} = \frac{0.000125}{10} = 0.0000125\ \text{sec}$$

Tx: الزمن الازم لأرسال مكالمة واحدة

$$BW = 2f_m = \frac{1}{2T_x} =$$

$$BW = \frac{1}{2T_x} = \frac{1}{2 * 0.0000125} = \frac{1}{0.000025} = 40000\ \text{Hz} = 40\ \text{KHz}$$

# Advantages and disadvantages of PCM

1. High S/N ratio (adv.)
2. Suitable for long distance (adv.)
3. Large BW (dis.)
4. Expensive system (dis.)
5. Complicated system (dis.)
6. Uneconomical for short distance (dis.)

# DIGITAL PULSE MODULATION

أسئلة مهمة

Q1. Fill in blanks

a. **MULTIPLEXING** is sending of a number of separate signals over the same cable, simultaneously without interference.

b. b. **FDM** is the process of combining many signals to different frequency groups so that they can all transmitted at the same time.

c. There are two basic forms of Multiplexing Frequency division multiplexing (FDM) and Time division multiplexing (TDM.

(page-61)

d. The disadvantages of FDM are large bandwidth (BW) and spaces between channels

(page-63)

e: The PCM advantages are high S/N ratio and suitable for long distance. (page-71)

f: The PCM disadvantages are large BW , expensive system, complicated system and uneconomical for short distance . (page-71)

g: FDM used for analog signals and TDM used for PCM system.

**FDM: Frequency division multiplexing**

**TDM: Time division multiplexing**

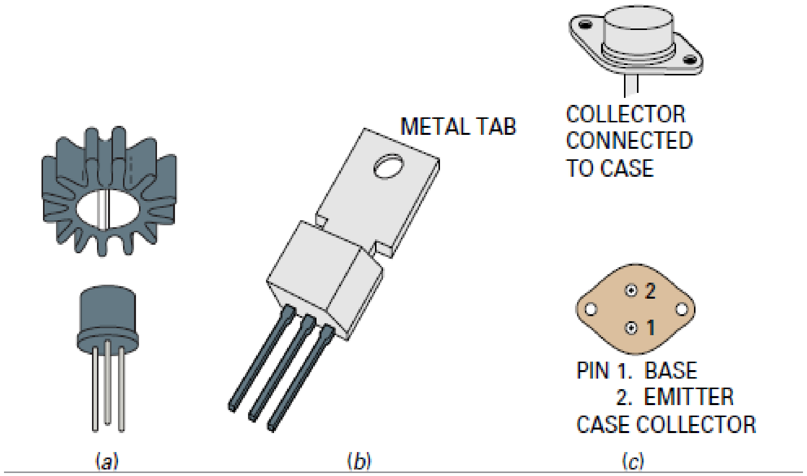
Q2: Plot the block diagram of FDM transmitter. (page-61)

Q3: Plot the block diagram of FDM receiver. (page-62)

Q4: Plot the block diagram of TDM/PCM telephone system. (page-65)

Q5: Example (1): (page-69-70).

# Power Amplifiers (PA)



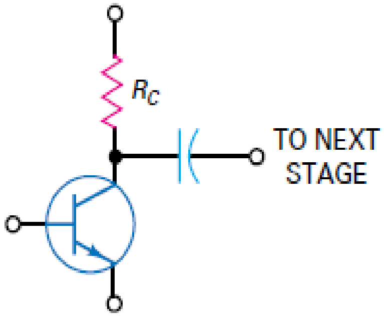

**PA can be used in Stereo amplifier speakers, Radio, Television.**

**Typically load power values range from 300 W (for antennas at transmitter) to 8 W (for audio speakers at receiver).**

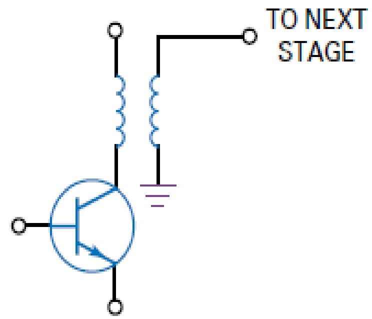
**Power transistors have a power rating of more than 1 W.**

# Types of Coupling

## A. AC coupling




(a)

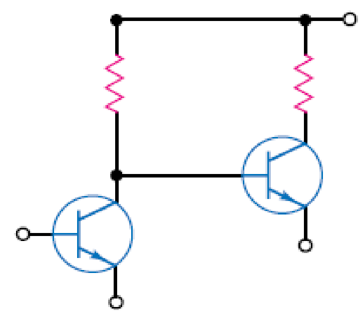



(b)

### 1. Capacitor coupling

### 2. Transformer coupling

## B. Direct coupling



(c)

# Ranges of Frequency

Amplifier types stating their frequency range.

1) Audio amplifier (AF) refers to an amplifier that operates in the range of 20 Hz to 20 kHz.

2) Radio frequency (RF) amplifier is one that amplifies frequencies above 20 kHz up to 300 GHz.

Example: the RF amplifiers in AM radios amplify frequencies between 535 kHz and 1605 kHz, and the RF amplifiers in FM radios amplify frequencies between 88 MHz and 108 MHz.

# Ranges of Frequency

**Amplifiers are also classified as narrowband or wideband.**

1) **A narrowband amplifier works over a small frequency range like 450 kHz to 460 kHz.**
2) **A wideband amplifier operates over a large frequency range like 0 Hz to 1MHz.**

**Narrowband amplifiers are usually tuned RF amplifiers, which mean that their AC load is a high-Q resonant tank tuned to a radio station or television channel.**

**Wideband amplifiers are usually un-tuned; that is, their AC load is resistive.**

# Classes of Operation

**1) Class-A operation**

**Collector current flows for 360 of the AC cycle, the maximum efficiency is 25 %.**

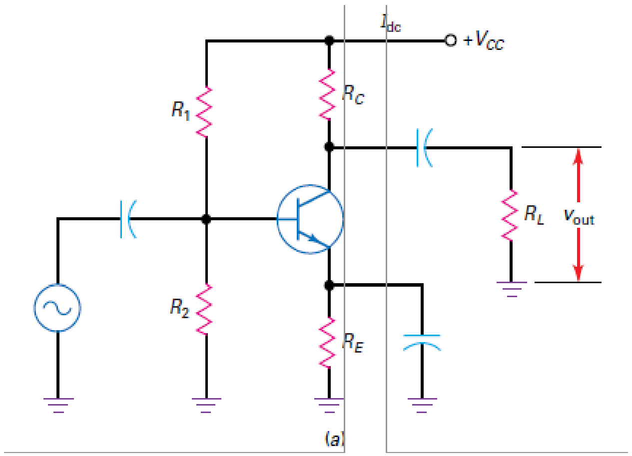
**2) Class-B operation**

**Collector current flows only for 180 of the AC cycle, the maximum efficiency is 78.5 %.**

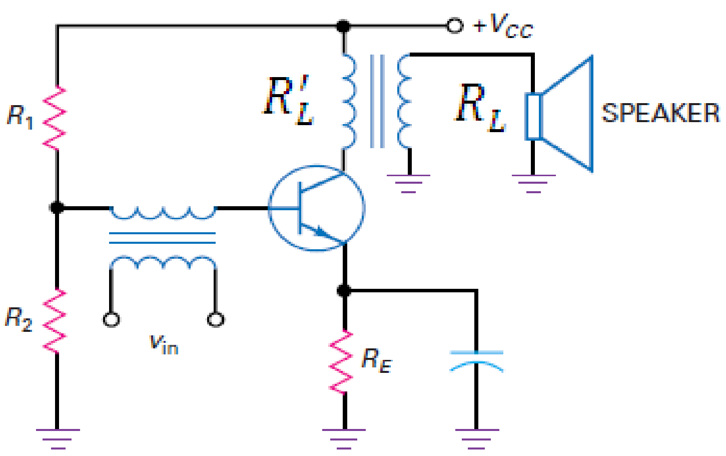
**3) Class-C operation**

**Collector current flows for less than 180 of the AC cycle, the maximum efficiency is 99 %.**

# Class-A operation




Capacitive coupling class-A amplifier.




$$\boxed{\frac{R'_L}{R_L} = \left(\frac{N_1}{N_2}\right)^2}$$

Transformer coupling class-A amplifier.

# Class-A operation

**Example No 1:**

**What resistance would an RL = 8 W speaker appear to the collector as, if the transformer's turns ratio is 15 : 1?**

**Solution:**

$$\frac{R_L'}{R_L} = \left(\frac{N_1}{N_2}\right)^2 \rightarrow \frac{R_L'}{8} = \left(\frac{15}{1}\right)^2 \rightarrow R_L' = 1.8\ \text{k}\Omega$$

# Class-A operation

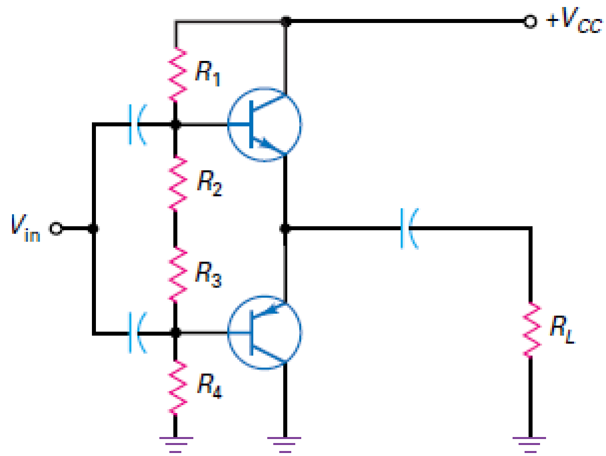
**Example No 2:**

**What transformer turns ratio is required to match RL = 16 W speaker load so that the effective load resistance seen at the primary is RL’ = 10 kW ?**

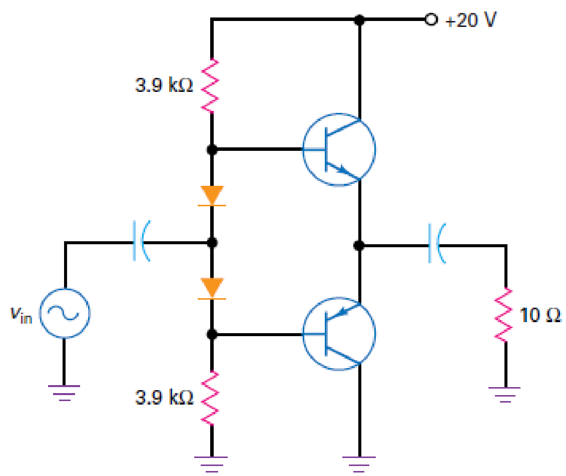
**Solution:**

$$\frac{R_L'}{R_L} = \left(\frac{N_1}{N_2}\right)^2 \rightarrow \frac{10{,}000}{16} = \left(\frac{N_1}{N_2}\right)^2 \rightarrow \frac{N_1}{N_2} = \frac{25}{1}$$

# Class-B operation




Class-B push-pull voltage-divider biasing circuit.



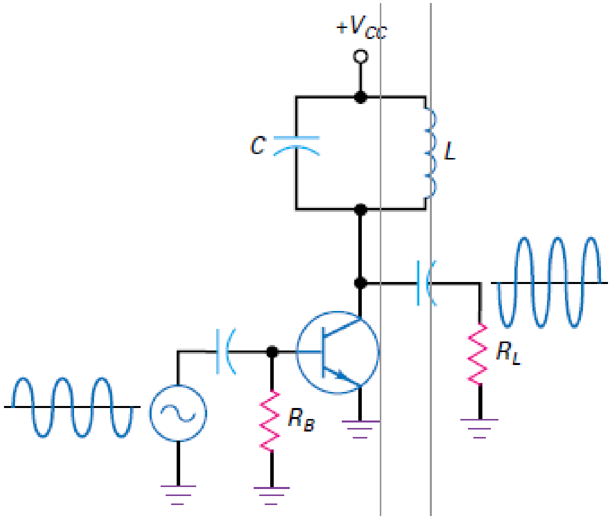

Class-B push-pull diode biasing circuit.

# Advantages of class-B amplifier

1) Since there is no bias, each transistor is at cutoff when there is no input signal, an advantage because there is no current drain when the signal is zero.

2) Another advantage is improved efficiency where there is an input signal. The maximum efficiency of a class-B push-pull amplifier is 78.5 %, so a class-B push-pull power amplifier is more commonly used for an output stage than a class-A power amplifier.

# Class-C operation




**Class-C circuit.**

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$BW = \frac{R_s}{2\pi L}$$

$$Q_s = \frac{f_r}{BW}$$

# Class-C operation

**Example No 3:**

**Calculate the resonant frequency (fr), bandwidth (BW) and quality factor (Qs) for class-C amplifier, where L = 2 mH, and C = 470 mF and Rs = 10 W**

# Class-C operation

## Solution:

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{2 * 10^{-6} * 470 * 10^{-6}}} = 5.19\ MHz$$

$$BW = \frac{R_s}{2\pi L} = \frac{10}{2\pi * 2 * 10^{-6}} = 0.796\ MHz$$

$$Q_s = \frac{f_r}{BW} = \frac{5.19\ M}{0.796\ M} = 6.52$$

# High Power Amplifiers (HPA)

HPA are used in an earth station for mobile and satellite communication systems.

HPA can be classified into two categories;

1) traveling wave tube amplifier (TWTA),
2) solid state power amplifier (SSPA).

The TWTA is used in fixed satellite services and has high gain about 45 dB, while the SSPA is used in mobile communication stations.

# HPA advantages and disadvantages

**TWTA advantages**

1- High amplification
2- Efficient.

**TWTA disadvantages**

1- Has nonlinear characteristics
2- Short life (25,000-100,000 hrs)
3- High cost

**SSPA disadvantages**

1- Low amplification
2- Less efficient.

**SSPA advantages**

1- Has linear characteristics
2- Long life (ten times better)
3- Less cost

# Power Amplifiers