MULTIPLEXING

Multiplexing is the process of simultaneously transmitting two or more individual signals over a single communication channel.

Due to multiplexing it is possible to increase the number of communication channels so that more information can be transmitted.

Frequency Division Multiplexing

- Available bandwidth is shared among number of signals.
- Each signal to be transmitted modulates with different carrier. Modulation can be AM, SSB, FM
- Modulated signal then added together to form a composite signal which is transmitted over a single channel.
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← BW → of single channel.

fc1, fc2, fc3, fc4 - Individual carriers.

Application of FDM

1. Telephone Systems
2. AM/FM Broadcasting
3. TV Broadcasting

Time Division Multiplexing

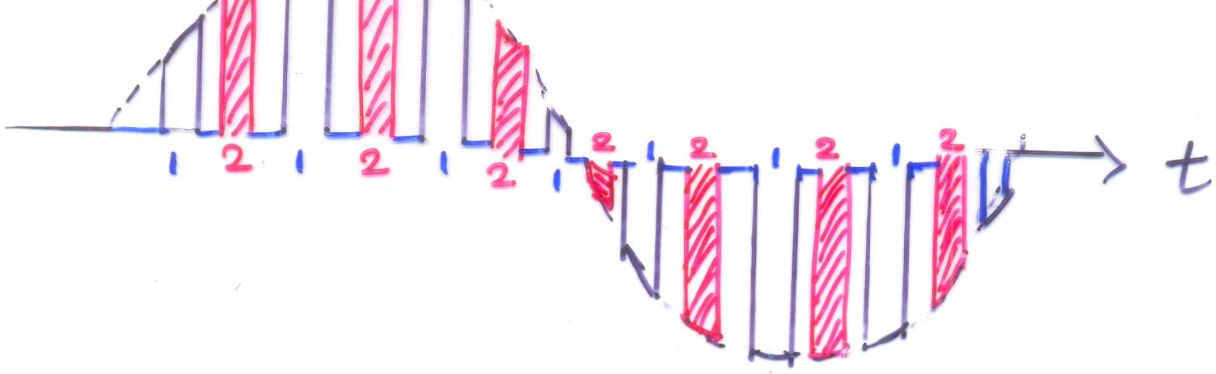
In TDM all signals to be transmitted are not transmitted simultaneously. Instead, they are transmitted one by one.

Thus each signals will be transmitted for a very short time. One frame or cycle is said to be completed when all the signals are transmitted once on the transmission channel.

Signal 1	Signal 2	Signal 3	Signal 4	Signal 1	--------

|← One Frame →| ⟶ time

TDM/PAM



Amplitude Modulation.

defn - The system of modulation in which amplitude of carrier is made proportional to the instantaneous value of modulating signal is called Amplitude Modulation.

Carrier is a high frequency signal.

$$v_c = V_c \sin \omega_c t \rightarrow (1) \quad \text{Carrier signal}$$

$$v_m = V_m \sin \omega_m t \rightarrow (2) \quad \text{Modulating signal}$$

Here phase angles are ignored because in AM phase angle is not changed.

eqn of modulated signal.

$$v = (V_c + V_m \sin \omega_m t) \sin \omega_c t \rightarrow (3)$$

$$= V_c\left(1 + \frac{V_m}{V_c} \sin \omega_m t\right) \sin \omega_c t$$

$$= V_c(1 + m \sin \omega_m t) \sin \omega_c t$$

where $\boxed{m = \frac{V_m}{V_c} = \text{modulation Index}} \rightarrow (4)$

m lies between 0 & 1

Expressed in % called percentage modulation.

$$v = V_c \sin\omega_c t + mV_c \sin\omega_c t \sin\omega_m t$$

$$= V_c \sin\omega_c t + \frac{mV_c}{2}\cos(\omega_c - \omega_m)t - \frac{mV_c}{2}\cos(\omega_c + \omega_m)t \quad \rightarrow (5)$$

(Using $\sin x \sin y = \frac{1}{2}[\cos(x-y) - \cos(x+y)]$)

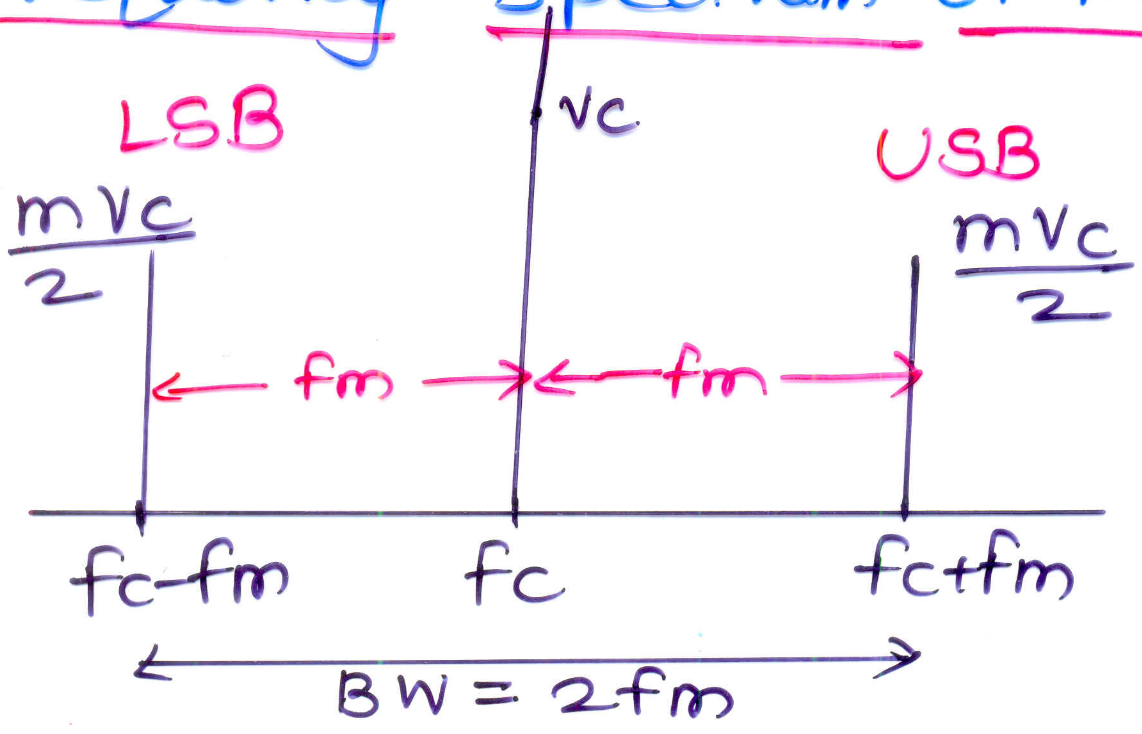
eq^n of AM wave contains 3 terms

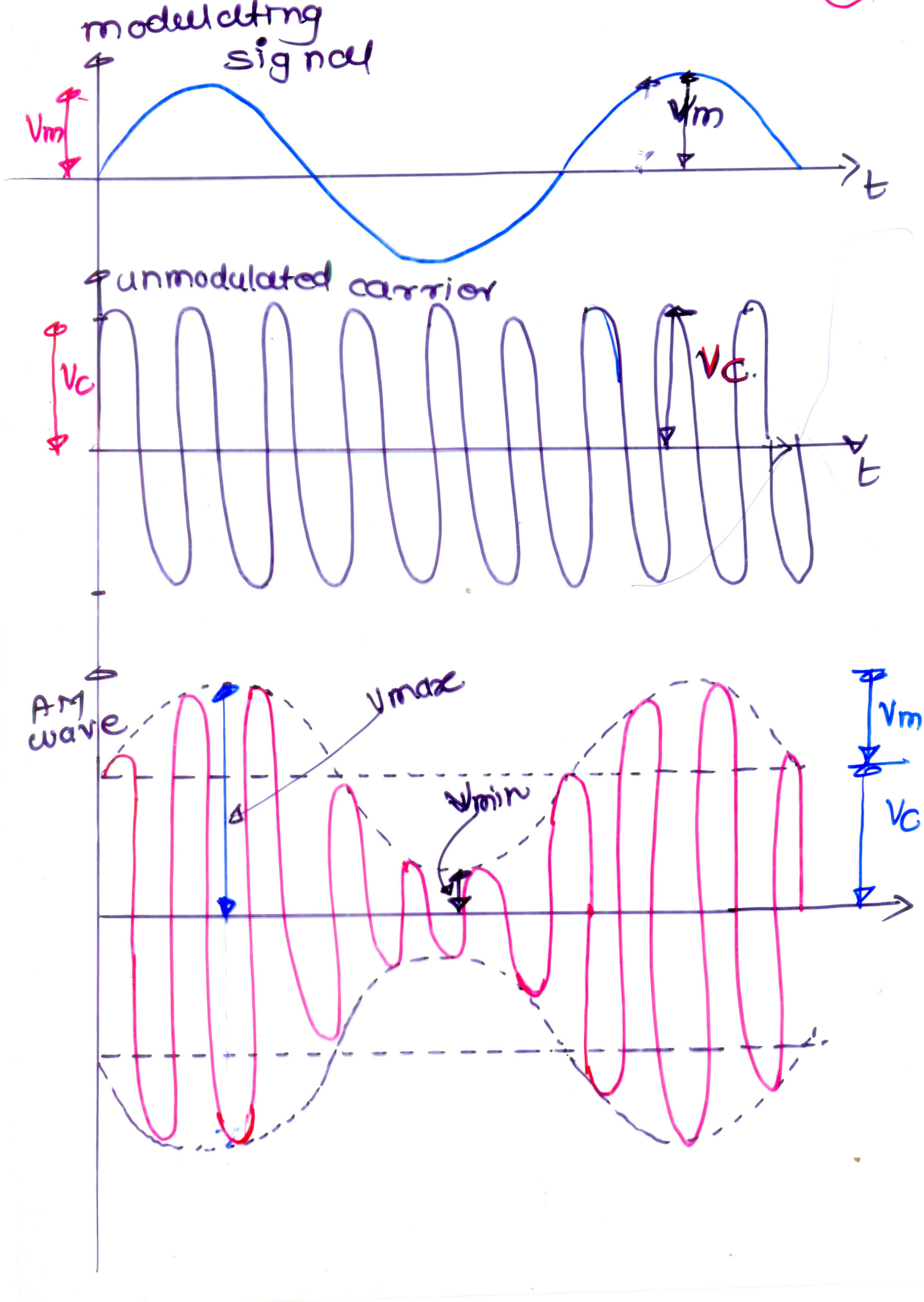
1) First term represents unmodulated carrier

11) Second and third term represents Lower sideband and Upper sideband with frequencies $f_c - f_m$ & $f_c + f_m$ respectively. and amplitude $\frac{mV_c}{2}$

Sideband contains information

Frequency Spectrum of AM.




modulating signal
Vm
Vm
t
unmodulated carrier
Vc
Vc.
t
AM wave
Vmax
Vmin
Vm
Vc

Bandwidth for AM is twice the modulating frequency.

In the modulation by several sine waves simultaneously e.g in AM Broadcasting the B.W is highest modulating freq × 2

- $f_c \geq 10 f_m$ for Better mod^n

Modulation Index

$$V_m = \frac{V_{max} - V_{min}}{2} \rightarrow (1)$$ (see AM waveform)

$$V_c = V_{max} - V_m$$

$$= V_{max} - \left(\frac{V_{max} - V_{min}}{2}\right)$$

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

$$= \frac{V_{max} + V_{min}}{2} \rightarrow (2)$$

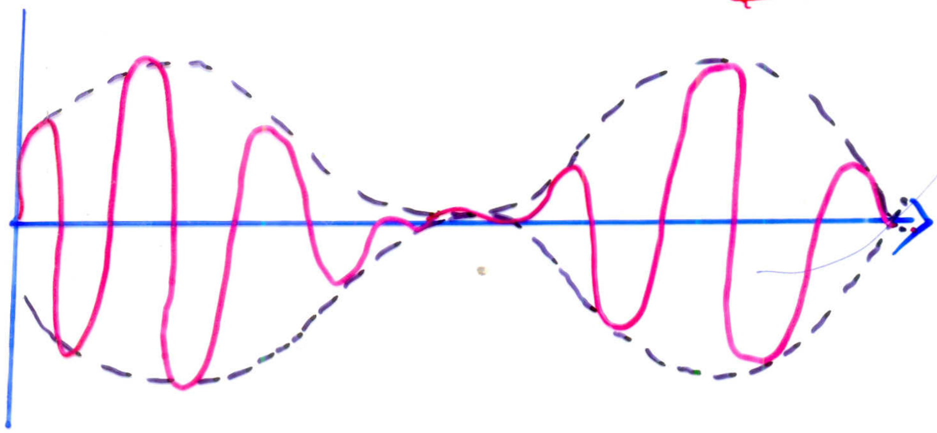
$$m = \frac{V_m}{V_c} = \frac{(V_{max} - V_{min})/2}{(V_{max} + V_{min})/2}$$

$$\boxed{m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}} \rightarrow (3)$$

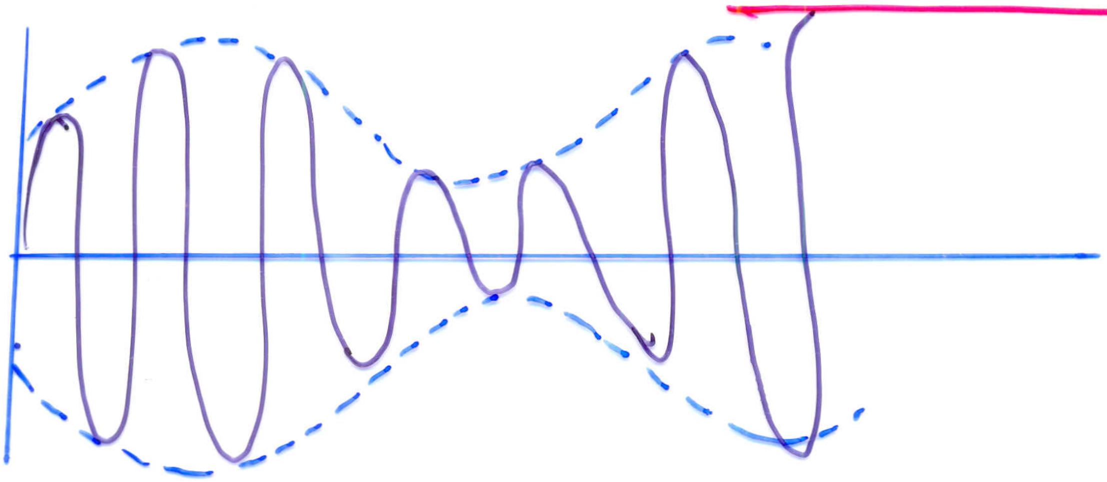
Eq^n 3 is used to calculate modulation Index, when AM w/f is seen on CRO ie when modulating signal & carrier signal is not known.

Modulation Index

case 1, $m = 1$ ie $V_m = V_c$
then it is called 100% modulation

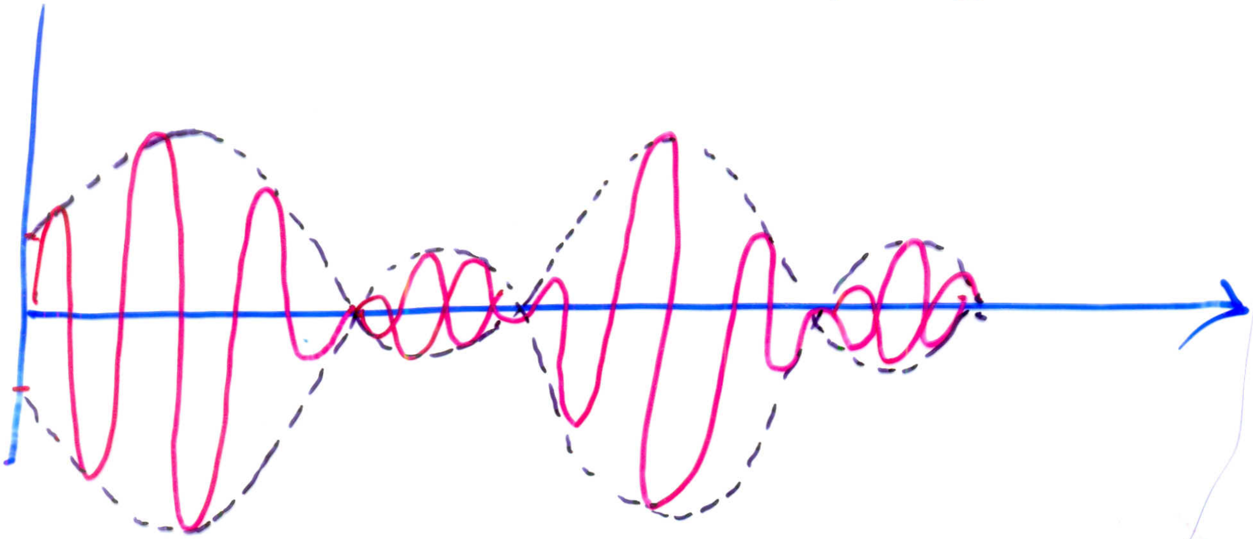


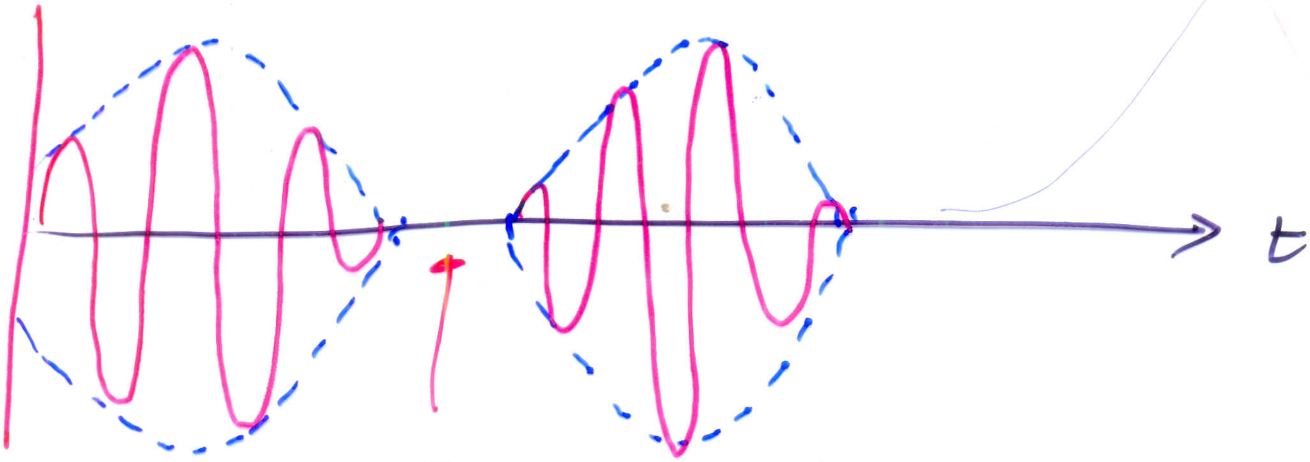
case 2, $m < 1$ ie $V_m < V_c$
then it is called Undermodulation



Overmodulation

When $m > 1$ ie $V_m > V_c$





Information is lost

Power Relation in AM wave

$$P_T = P_{carrier} + P_{USB} + P_{LSB} \rightarrow (1)$$

$$P_T = \frac{V^2_{carrier}}{R} + \frac{V^2_{LSB}}{R} + \frac{V^2_{USB}}{R} \rightarrow (2)$$

Where all voltages are r.m.s voltages & R is the resistance (Antenna Resistance) in which power is dissipated

$$P_C = \frac{V^2_{carrier}}{R} = \frac{(V_C/\sqrt{2})^2}{R} = \frac{V_C^2}{2R} \rightarrow (3)$$

$$\boxed{P_C = \frac{V_C^2}{2R}} \rightarrow (3)$$

$$P_{LSB} = P_{USB} = \left(\frac{m V_C}{2\sqrt{2}}\right)^2 / R$$

$$= \frac{m^2 V_C^2}{8R} = \frac{m^2}{4} \times \frac{V_C^2}{2R} \rightarrow (4)$$

$$\boxed{P_{LSB} = P_{USB} = \frac{m^2}{4} P_C} \rightarrow (5)$$

put eq^n 3 + 5 in eq^n 1

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

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

$$\boxed{P_T = P_c\left(1+\frac{m^2}{2}\right)} \rightarrow 9$$

when $m = 1$

$$P_T = 1.5\,P_c$$

Transmission efficiency of AM

$$P_T = P_c + P_{USB} + P_{LSB} \rightarrow 1$$

In AM spectrum we get three freq component

- Carrier does not contain any information
- Two side bands carry same information

when $m = 1$

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

$$P_T = \frac{3}{2}P_c$$

$$\boxed{P_c = 2/3\,P_T} \rightarrow 2$$

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

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

$$\boxed{P_{SB} = \frac{P_C}{2}} \rightarrow (3)$$

$$\% \eta_{AM} = \frac{P_{SB}}{P_T} \times 100$$

$$= \frac{P_C/2}{\frac{3}{2}P_C} \times 100$$

$$\boxed{\eta_{AM} = 33.33\ \%}$$

Actually Both the sideband contain useful information but they are mirror images of each other (carry same information) so only one sideband power is useful.

$$\therefore \eta_{AM} = \frac{P_{LSB}\,(\text{or } P_{USB})}{P_T} \times 100$$

$$= \frac{P_C/4}{\frac{3}{2}P_C} = 16.67\%$$

Transmission efficiency

$$\eta = \frac{P_{LSB} + P_{USB}}{P_t}$$

$$= \frac{P_c \frac{m^2}{4} + P_c \frac{m^2}{4}}{P_c\left(1 + \frac{m^2}{2}\right)}$$

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

$$\eta = \frac{m^2}{2 + m^2}$$

$$\boxed{\% \eta = \frac{m^2}{2 + m^2} \times 100 \ \%}$$

Justify AM is wastage of Power and Bandwidth.

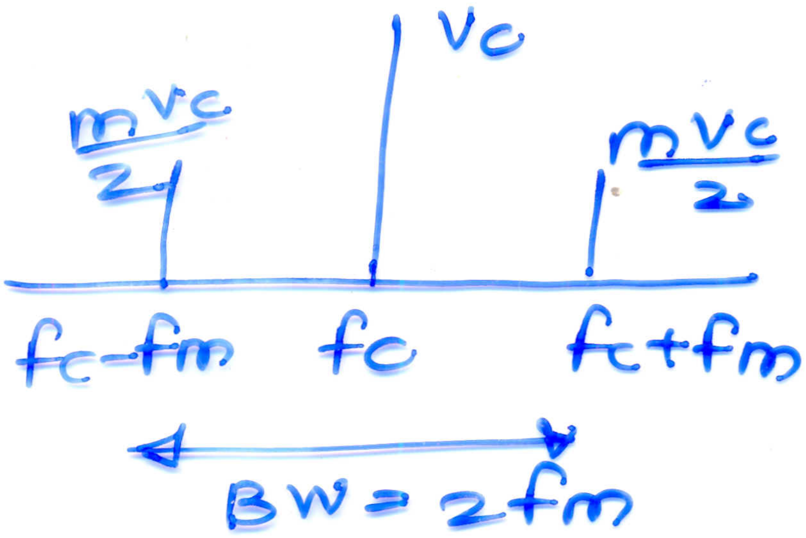
$$v = V_c \sin\omega_c t + \frac{mV_c}{2}\cos(\omega_c-\omega_m)t - \frac{mV_c}{2}\cos(\omega_c+\omega_m)t$$

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

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

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

spectrum of AM



- AM signal contains unmodulated carrier which does not contain any information
- Two sideband contain same information
- when $m=1$, $P_c = \frac{2}{3}P_T$ carrier contain $\frac{2}{3}$ of total

power and does not contain any information.

- $\frac{1}{3}$ of total power is present in two sidebands. Actually only one sideband power is of use as both contain same information

so $\frac{1}{6}$ of total power is useful.

Hence we can say that AM is a wastage of Power.

* BW of AM is $f_c + f_m - (f_c - f_m)$ i e $2f_m$.

Since Both sideband carries same information. Only one sideband is sufficient. Hence for one sideband BW will be f_m.

So we can say that AM is a wastage Bandwidth.

Current Calculations -

Let I_c be unmodulated current
I_t is total or modulated current
of AM Tx^r both being r.m.s values

If R is the resistance in which
these current flow

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

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

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

Modulation By Several Sine Waves

Let V_1, V_2, V_3 --- be the simultaneous modulating signal's voltages. Then total modulating voltage V_t will be equal to

$$V_t = \sqrt{V_1^2 + V_2^2 + V_3^2 + \cdots} \rightarrow (1)$$

Dividing Both sides by V_c we get

$$\frac{V_t}{V_c} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 + \cdots}{V_c}} \rightarrow (2)$$

$$= \sqrt{\frac{V_1^2}{V_c^2} + \frac{V_2^2}{V_c^2} + \frac{V_3^2}{V_c^2} + \cdots}$$

$$\boxed{m_t = \sqrt{m_1^2 + m_2^2 + m_3^2 + \cdots}} \rightarrow (3)$$

m_t = Total modulation Index

m_1, m_2, m_3 ---- modulation Index due to V_1, V_2, V_3 ---- respectively

Eqn of AM wave

total modulating signal can be written as

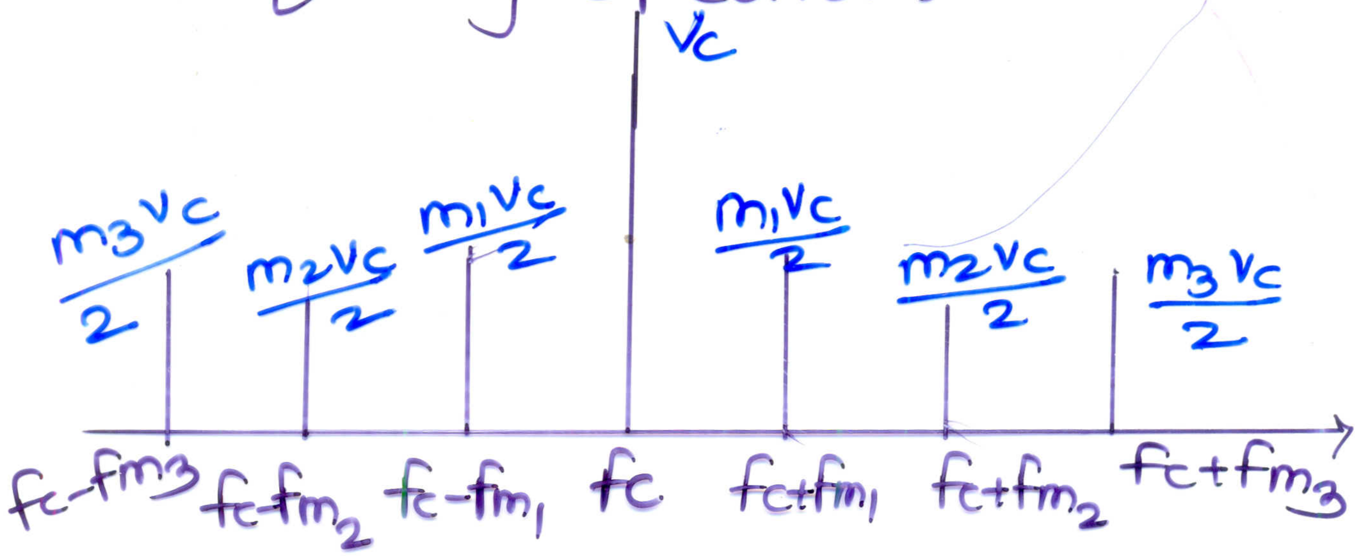
$$e_m = V_1 \sin\omega_{m1}t + V_2 \sin\omega_{m2}t + V_3 \sin\omega_m t + \cdots \rightarrow (4)$$

$$v = e_{AM} = (V_c + V_1 \sin\omega_{m1}t + V_2 \sin\omega_{m2}t + V_3 \sin\omega_{m3}t + \cdots) \sin\omega_c t \rightarrow (5)$$

$$v = e_{AM} = V_c(1 + m_1 \sin\omega_{m_1}t + m_2 \sin\omega_{m_2}t + m_3 \sin\omega_{m_3}t + \cdots)\sin\omega_c t \rightarrow (6)$$

$$= V_c \sin\omega_c t + \frac{m_1 V_c}{2}\cos(\omega_c - \omega_{m_1})t - \frac{m_1 V_c}{2}\cos(\omega_c + \omega_{m_1})t + \frac{m_2 V_c}{2}\cos(\omega_c - \omega_{m_2})t - \frac{m_2 V_c}{2}\cos(\omega_c + \omega_{m_2})t + \cdots \rightarrow (7)$$

Frequency spectrum



$$P_{SBT} = P_{SB1} + P_{SB2} + P_{SB3} + \cdots \quad (8)$$

$$\frac{P_c m_t^2}{2} = \frac{P_c m_1^2}{2} + \frac{P_c m_2^2}{2} + \frac{P_c m_3^2}{2} + \cdots \rightarrow (9)$$

$$m_t^2 = m_1^2 + m_2^2 + m_3^2 + \cdots \rightarrow (10)$$

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

We get same result as eq^n (3)