Noise :-

- Noise may be defined, in electrical terms, as any unwanted introduction of energy tending to interface with the proper reception and reproduction of transmitted signals.
- Many disturbances of an electrical nature produce noise in receivers, modifying the signal in unwanted manner.
- In radio receivers, noise may produce hiss in the loudspeaker o/p.
  In television receivers "snow" or "confetti" (colored snow) becomes superimposed on the picture.
- Noise can limit the range of systems, for a given transmitted power.
  It affects the sensitivity of receivers, by placing a limit on the weakest signals that can be amplified.

Noise in Analog Communication :-

- **Internal Noise**
  - Noise created by any of the active or passive components found in receivers.
    - Shot Noise
    - ** Thermal Noise
    - Flicker Noise
- **External Noise.**
  - → Noise created outside the receiver by external sources which include
    - atmospheric noise
    - extraterrestrial noise
    - Industrial noise

1. Thermal Noise :-

- The noise generated in a resistance or the resistive component is random and is referred to as thermal agitation. It is due to the rapid and random motion of the molecules (atoms & electrons) inside the component itself.

- It is also called White Noise, Gaussian Noise or Johnson Noise

- Noise power transferred by a resistor is directly proportional to its absolute temperature. In addition, this power is also directly proportional to the bandwidth over which noise is measured.

i.e, $P_n \propto T$

$P_n \propto B \Rightarrow P_n \propto TB$

or, $$\boxed{P_n = KTB}$$

P_n = Noise power
T = absolute temp (K)
B = Bandwidth (HZ)
k = Boltzmann constant
$= 1.38 \times 10^{-23}$ J/K.

→ It also follow Gaussian random function with mean zero.

Any Gaussian function PDF (Probability Density function)

$$\boxed{f_X(x) = \frac{1}{\sqrt{2\pi\sigma_x^2}} e^{-\frac{(x-\mu)^2}{2\sigma_x^2}}}$$

[This ~~random~~ Gaussian function comes under Random Variables section of communication] or also in Engineering Mathematics]

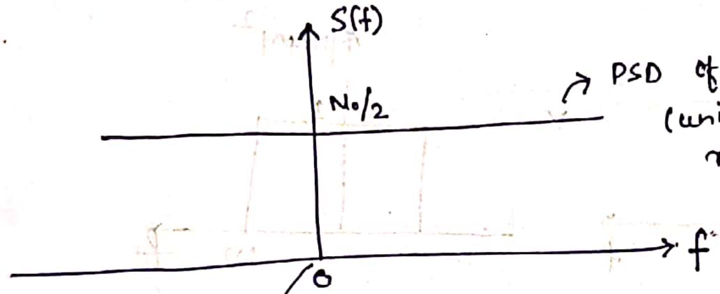
Here, ~~with~~ x = random variable

μ = mean
σ_x = variance of x

Now with mean, $\mu = 0$

$$\boxed{f_x(x) = \frac{1}{\sqrt{2\pi\sigma_x^2}}\, e^{-\frac{x^2}{2\sigma_x^2}}}$$

→ It is also known as white noise because white light contain equal amount of all frequencies within the visible band of electromagnetic radiation; similarly thermal noise has a uniform PSD (power spectral density) over useful range of frequencies.

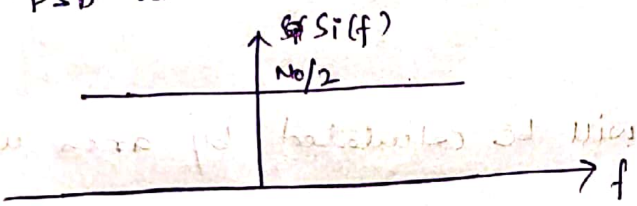


PSD of white Noise (uniform over the range of frequency)

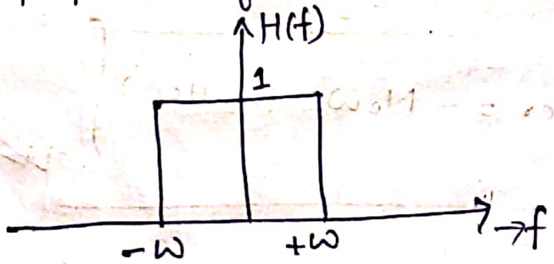
As it is symmetrical about zero, hence its mean is zero.

Now, let's see how o/p PSD or power is calculated.

① let i/p PSD at receiver :-



② Frequency spectrum of filter at receiver:-

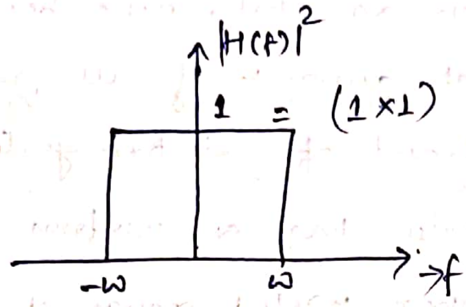


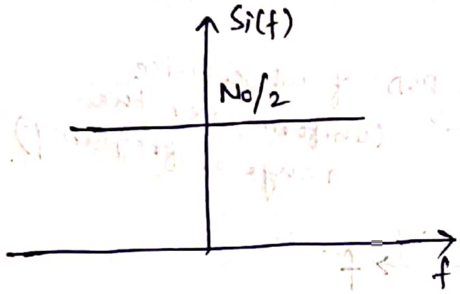
3) Now, PSD at o/p will be:-

$$S_o(f) = S_i(f) \cdot |H(f)|^2$$

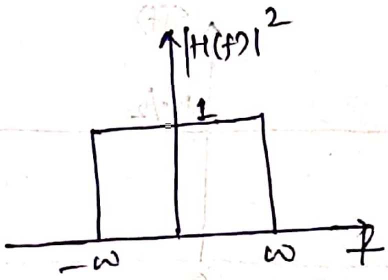
[This comes under Fourier Transform section of Signals & Systems]

$|H(f)|^2 =$

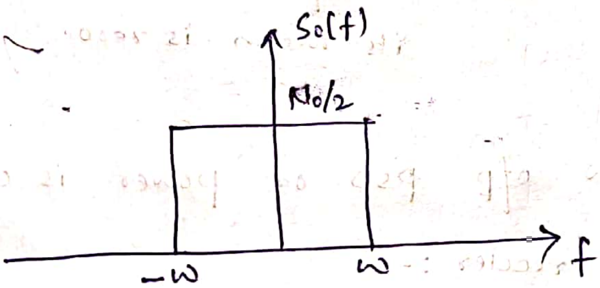




X



$\therefore$ S.



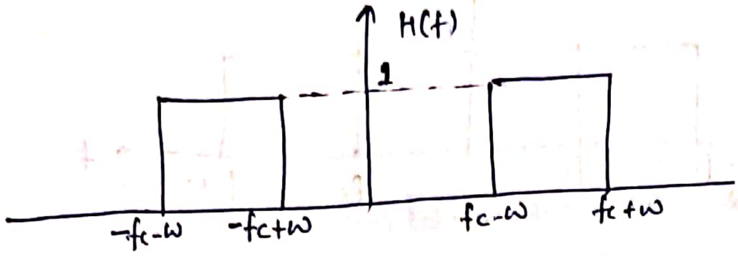
Now, Power will be calculated by area under PSD.

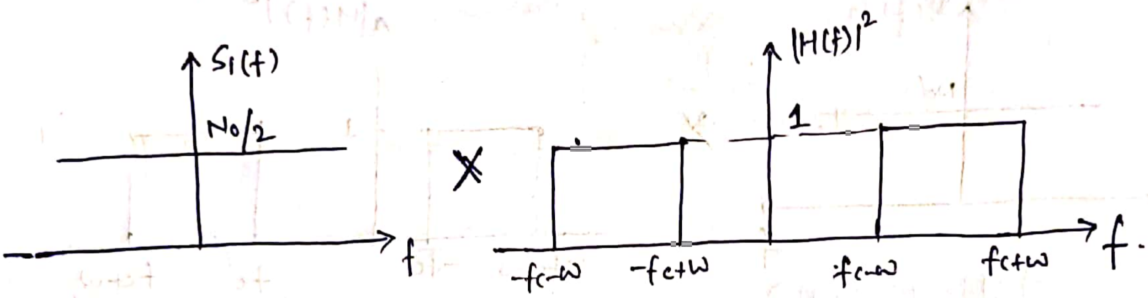
$$\text{Power} = \frac{N_o}{2} \times 2W = N_oW.$$

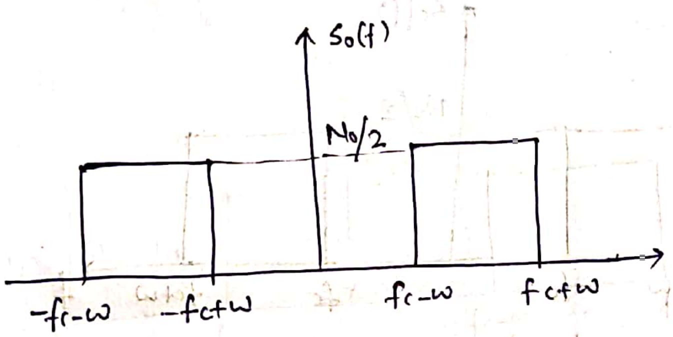
$$\boxed{\text{Power} = N_oW \text{ (watts)}}$$

1. PSD of white Noise affecting AM & DSB signal :-

As BPF(Band pass filter) spectrum is same for both AM & DSB at receiver:- i.e.;







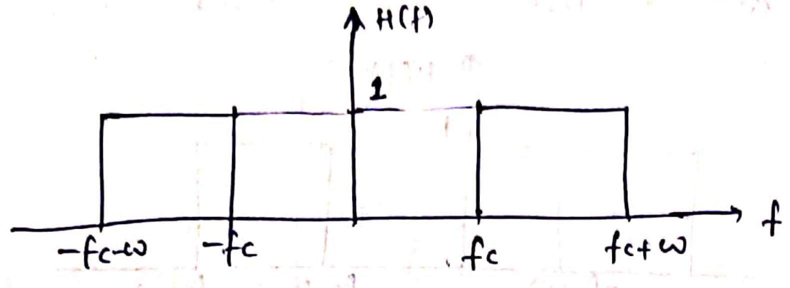
Now, total power of white Noise affecting AM & DSB is:-

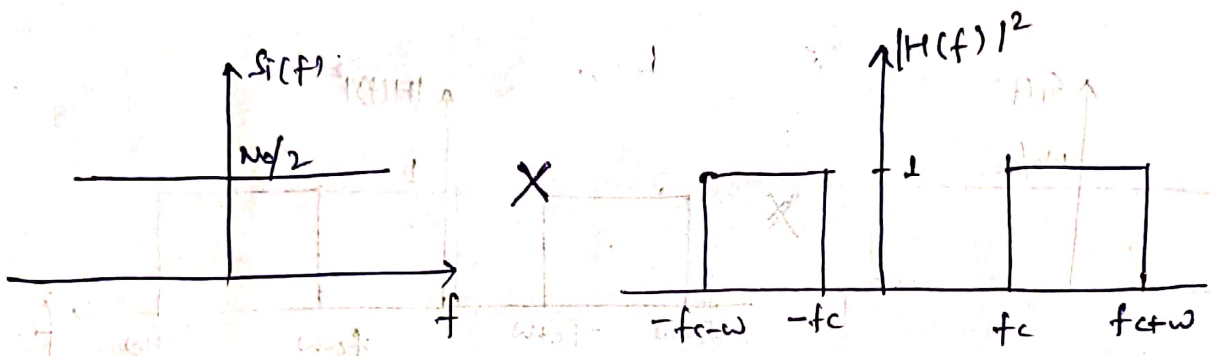
$$P = \frac{N_o}{\cancel{2}} \times \cancel{2}W + \frac{N_o}{\cancel{2}} \times \cancel{2}W$$

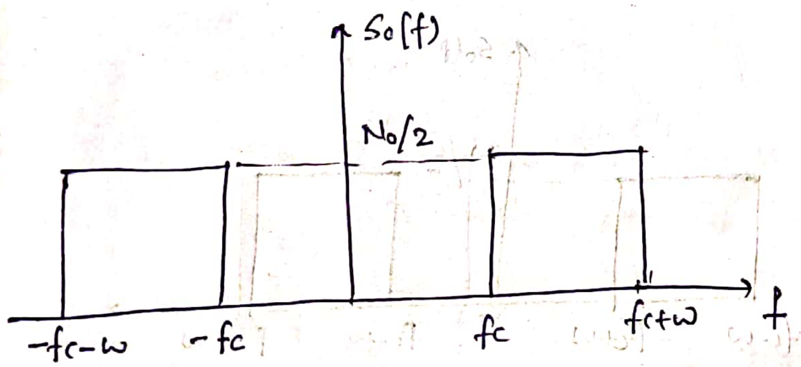
$$\boxed{P_n = 2N_oW} \text{ (watts)}$$

2. PSD of white Noise affecting SSB signal :-

Frequency spectrum of BPF for SSB is :-







Total Power of white Noise affecting SSB signal :-

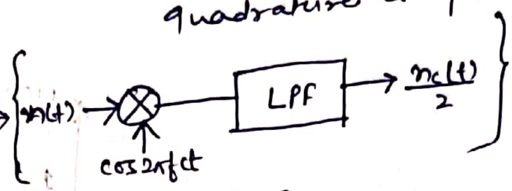
$$P = \frac{N_0}{2} \times W + \frac{N_0}{2} \times W$$

$$\boxed{P = N_0 W} \text{ (watts)}$$

→ when white noise is passed through BPF, the resulting is called as narrow band noise. To see the total effect of white noise on AM, DSB & SSB, the corresponding narrow band noise has to be considered.

$$n(t) \overset{F.T}{\rightleftharpoons} S_0(f)$$

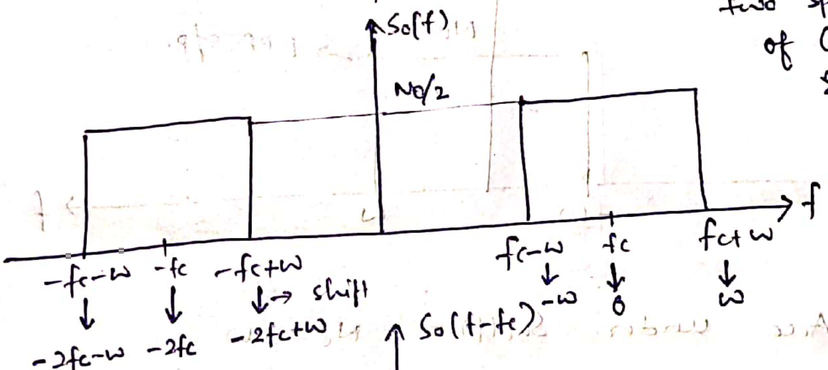
$$n(t) = \underbrace{n_c(t)\cos\omega_c t}_{\text{in-phase component}} + \underbrace{n_q(t)\sin 2\pi f_c t}_{\text{quadrature component}}$$



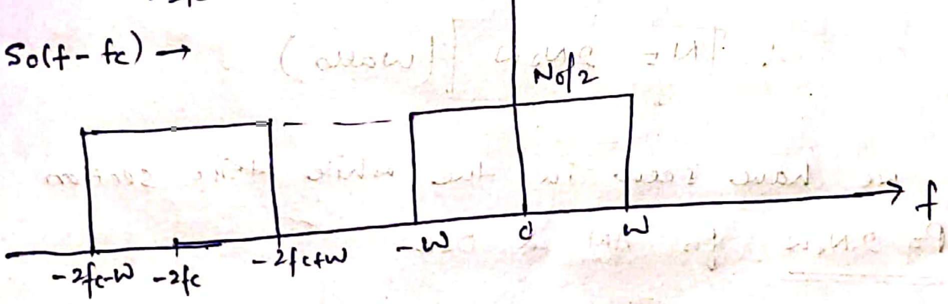
1. Effect of $n(t)$ and $n_q(t)$ on AM & DSB:-

$$n(t) \rightleftharpoons S_0(f)$$

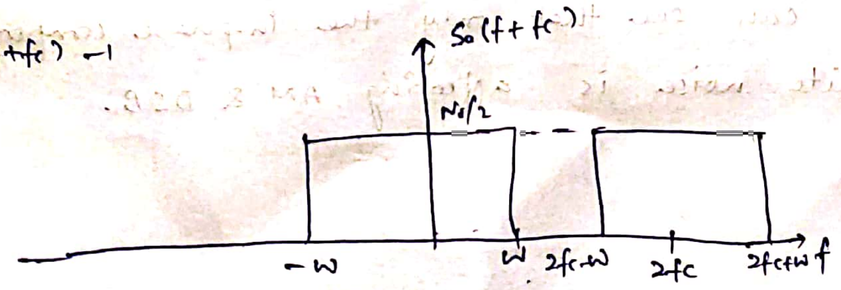
on multiplying by $\cos 2\pi f_c t$ (in-phase) → $\dfrac{S_0(f-f_c)+S_0(f+f_c)}{2}$ → two spectrums of $(f-f_c)$ & $(f+f_c)$



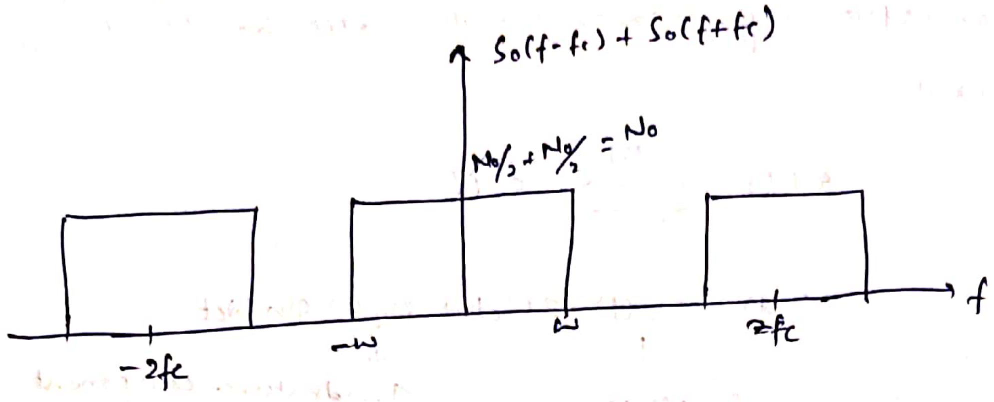
① $S_0(f-f_c)$ →

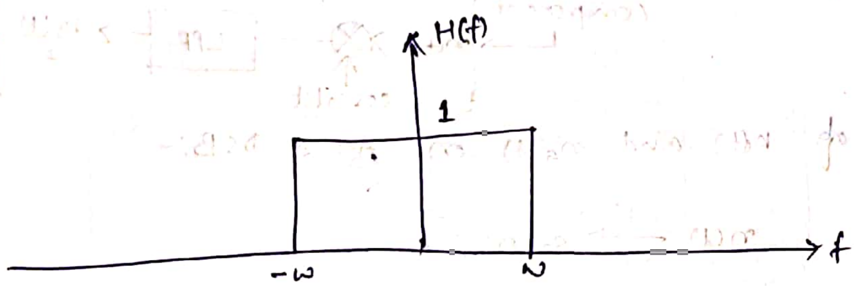


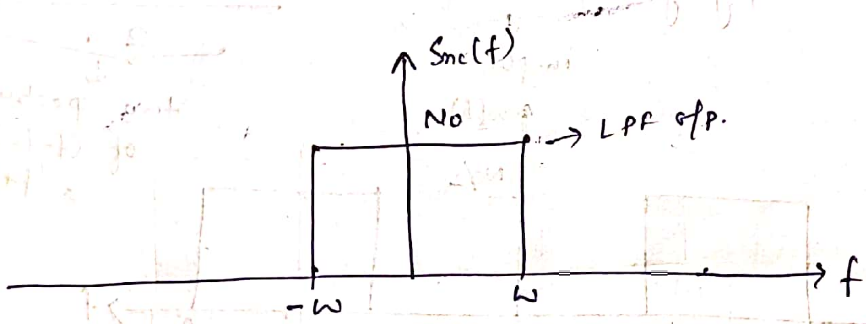
Hly ② $S_0(f+f_c)$ →



∴ PSD of $n_c(t)$ is







$N =$ Area under $S_{nc}(f) = N_o \times 2w$

∴ $\boxed{N = 2N_o w}$ (watts)

initially, we have seen in the white Noise section

$P = 2N_o w$ for AM & DSB.

So, we can see that only the In-phase component of white noise is affecting AM & DSB.

left as an assignment for students.

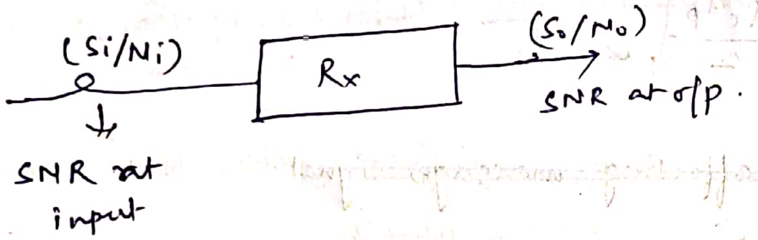
Similary, for PSD of $n_c(t)$ affecting SSB comes as:-

Noise Power, $\boxed{N = N_0 B}$ which is same as calculated earlier.

So, in SSB also, the affect of quadrature component of white noise is NULL, only in-phase component affects SSB.

Figure of Merit :-

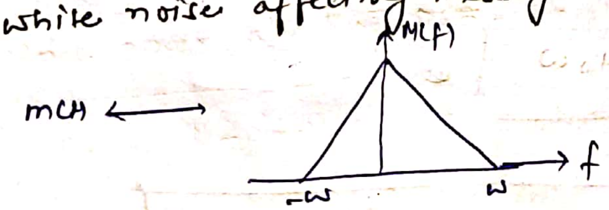
$$FOM = \frac{[S_0/N_0]}{[S_i/N_i]}$$

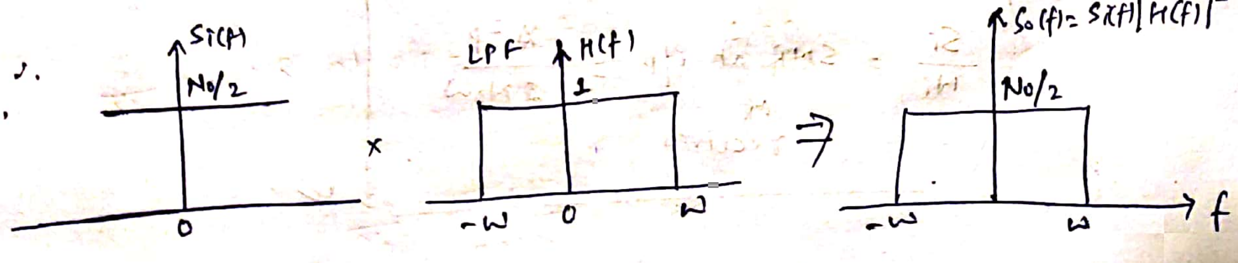


if FOM > 1 ⇒ Receiver is very efficient in decreasing the effect of noise

FOM < 1 ⇒ Receiver is adding some amount of noise and it is efficient for reducing the noise effect.

PSD of white noise affecting message signal:-





→ Total white noise power affecting message signal

$$N = \frac{N_0}{2} \times 2W$$

$$\therefore \boxed{N = N_0 W} \text{ (Watts)}$$

1. FOM of DSB Receiver :-

$S_{DSB}(t) = A_c m(t) \cos 2\pi f_c t$

Power of signal, $S_i = \frac{A_c^2 m^2(t)}{2R}$

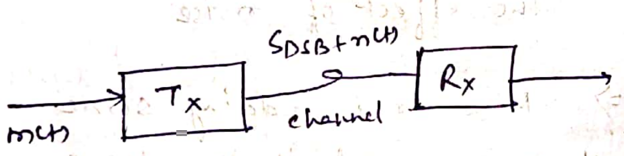
as $m(t)$ is changing, hence it gives the instantaneous power.

Let, $m^2(t)$ = instantaneous power of $m(t) = P$.

$$\therefore \boxed{S_i = \frac{A_c^2 P}{2}}$$

Now, ~~white noise affecting message signal~~.

N_i = noise affecting $m(t)$ and $c(t)$ and channel Noise

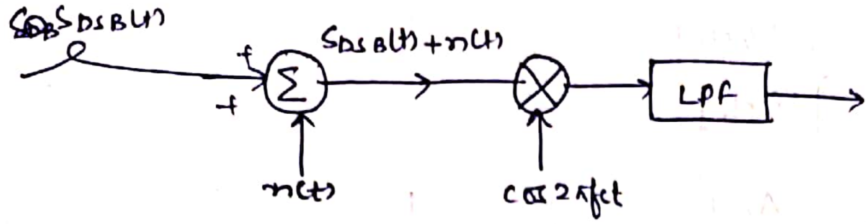


But, in specifying N_i, noise affecting msg signal is only taken in consideration as standards given.

$$\therefore \boxed{N_i = N_0 W}$$

$$\boxed{\frac{S_i}{N_i} = \text{SNR at i/p of receiver} = \frac{A_c^2 P}{2 N_0 W}}$$

At receiver:-



While considering Receiver (R_x) section, only demodulators are considered.

$$(MUL)\,o/p = [S_{DSB}(t) + n(t)]\cos 2\pi f_c t$$

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

$$= A_c\, m(t)\cos^2 2\pi f_c t + n_c(t)\cos^2 2\pi f_c t + n_q(t)\sin 2\pi f_c t\cos 2\pi f_c t.$$

$$= \frac{A_c\, m(t)}{2}(1+\cos 4\pi f_c t) + \frac{n_c(t)}{2}(1+\cos 4\pi f_c t) + n_q(t)\,\cancel{\sin 4\pi f_c t}\,\sin 4\pi f_c t$$

LPF will only allow:-

$$(LPF)\,o/p = \underbrace{\frac{A_c\, m(t)}{2}}_{\text{signal}} + \underbrace{\frac{n_c(t)}{2}}_{\text{noise}}$$

$$S_o = \text{signal power} = \frac{A_c^2\, m^2(t)}{4} = \frac{A_c^2 P}{4}$$

$$N_o = \text{Noise power} = \frac{n_c^2(t)}{4} = \frac{2N_oW}{4_2} = \frac{N_oW}{2}$$

$n_c^2(t)$ = Noise power affecting DSB = $2N_oW$ [already calculated while PSD of $n(t)$ affecting DSB]

$\therefore$

$$\frac{S_o}{N_o} = \text{SNR at } o/p = \frac{A_c^2 P \times 2}{4 \times N_oW} = \frac{A_c^2 P}{2N_oW}$$

$$\therefore \boxed{\frac{S_o}{N_o} = \frac{A_c^2 P}{2N_oW}}$$

So, $\text{FOM} = \dfrac{[S_o/N_o]}{[S_i/N_i]}$

$$= \frac{\cancel{A_c^2 P}}{2\cancel{N_oW}} \times \frac{2\cancel{N_oW}}{\cancel{A_c^2 P}} = 1$$

$$\therefore \boxed{\text{FoM} = 1} \quad \text{(for DSB receiver).}$$

2. FOM of SSB Receiver :-

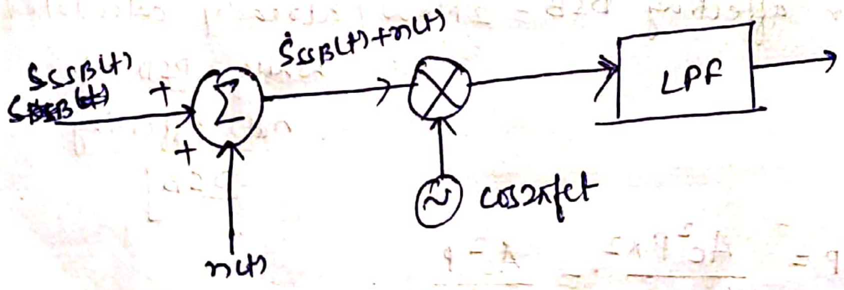
$$S_{SSB}(t) = \frac{A_c}{2} m(t)\cos 2\pi f_c t + \frac{A_c}{2}\hat{m}(t)\sin 2\pi f_c t$$

$$S_i = \cancel{\frac{A_c^2 P}{4}} \quad \frac{A_c^2 m^2(t)}{8} + \frac{A_c^2 m^2(t)}{8} \quad \cancel{\frac{A_c^2 m^2(t)}{4}}$$

$$\boxed{S_i = \frac{A_c^2 P}{4}}$$

$$\boxed{N_i = N_oW}$$

$$\therefore \boxed{\frac{S_i}{N_i} = \frac{A_c^2 P}{4N_oW}}$$



$$(MUL)\ o/p = \{S_{SSB}(t) + n(t)\}\cos 2\pi f_c t$$

$$= \frac{A_c m(t)}{2}\cos^2 2\pi f_c t + \frac{A_c \hat{m}(t)}{2}\sin 2\pi f_c t \cos 2\pi f_c t + n(t)\cos 2\pi f_c t$$

$$= \frac{A_c m(t)}{4}[1+\cos 4\pi f_c t] + \frac{A_c \hat{m}(t)}{2} \times \frac{\sin 4\pi f_c t}{2} + \frac{n_c(t)}{2}[1+\cos 4\pi f_c t]$$

$$+ \frac{n_q(t)}{2} \times \sin 4\pi f_c t$$

Now; $(LPF)\ o/p = \underbrace{\frac{A_c m(t)}{4}}_{\text{signal}} + \underbrace{\frac{n_c(t)}{2}}_{\text{Noise}}$

$$S_o = \frac{A_c^2 m^2(t)}{16} = \frac{A_c^2 P}{16}$$

$$N_o = \frac{n_c^2(t)}{4} = \frac{N_o W}{4}$$

$n_c^2(t)$ = Noise power affecting SSB = $N_o W$

$$\therefore \boxed{\frac{S_o}{N_o} = \frac{A_c^2 P}{4 N_o W}}$$

$\therefore$ Now, $\boxed{FOM = 1}$ [for SSB Receiver]

3. <u>FOM of AM receiver using Envelope Detector:-</u>

$$S_{AM}(t) = A_c\{1 + k_a m(t)\}\cos 2\pi f_c t$$

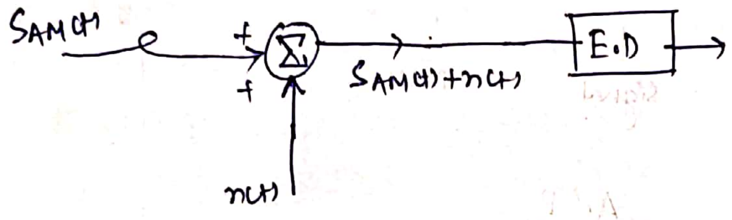
$$= A_c \cos 2\pi f_c t + A_c k_a m(t)\cos 2\pi f_c t$$

$$= \frac{A_c^2}{2} + \frac{A_c^2 k_a^2 m^2(t)}{2} = \frac{A_c^2}{2} + \frac{A_c^2}{2}k_a^2 P.$$

$$\boxed{S_i = \frac{A_c^2}{2}(1+K_a^2 P)} \quad W$$

$$\boxed{N_i = N_0 W}$$

$$\therefore \boxed{\frac{S_i}{N_i} = \frac{A_c^2(1+K_a^2 P)}{2 N_0 W}} \quad W$$



$$(E.D)\ i/p = S_{AM}(t) + n(t)$$

$$= A_c \cos 2\pi f_c t + A_c k_a m(t) \cos 2\pi f_c t + n_I(t) \cos 2\pi f_c t + n_Q(t) \sin 2\pi f_c t$$

$$= \underbrace{\{A_c + A_c k_a m(t) + n_I(t)\}}_{A} \cos 2\pi f_c t + \underbrace{n_Q(t)}_{B} \sin 2\pi f_c t$$

So, $(E.D)\ o/p = \sqrt{A^2 + B^2}$

$$= \sqrt{\{A_c + A_c k_a m(t) + n_I(t)\}^2 + \{n_Q(t)\}^2}$$

$\{n_Q(t)\}^2 \to 0$

As we know quadrature component has no effect (or NULL) on AM signal.

$$\therefore (E.D)\ o/p = A_c + A_c K_a m(t) + n_I(t)$$

A_c → DC component is blocked.

$A_c K_a m(t)$ → Signal

$n_I(t)$ → Noise

$$S_o = A_c^2 K_a^2 \overline{m^2(t)} = A_c^2 K_a^2 P$$

$$N_o = \text{Power}\{n_c(t)\} = 2N_o W$$

$$\boxed{\frac{S_o}{N_o} = \frac{A_c^2 K_a^2 P}{2N_o W}}$$

$$FOM = \frac{\cancel{A_c^2} K_a^2 P}{\cancel{2N_o W}} \times \frac{\cancel{2N_o W}}{\cancel{A_c^2}(1+K_a^2 P)} = \frac{K_a^2 P}{1+K_a^2 P}$$

Now, ~~for~~ $P = \text{power}\{m(t)\}$

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

then, $P = \frac{A_m^2}{2}$

$$FOM = \frac{K_a^2 \times \frac{A_m^2}{2}}{1 + K_a^2 \times \frac{A_m^2}{2}} = \frac{\frac{\mu^2}{2}}{1+\frac{\mu^2}{2}} \quad [\mu = K_a A_m]$$

$$\therefore \boxed{FOM = \frac{\mu^2}{2+\mu^2}}$$

i.e. $\mu \uparrow \Rightarrow FOM \uparrow$

$$(FOM)_{max} = \frac{1}{2+1} = \frac{1}{3} \quad [\mu = 1]$$

i.e,

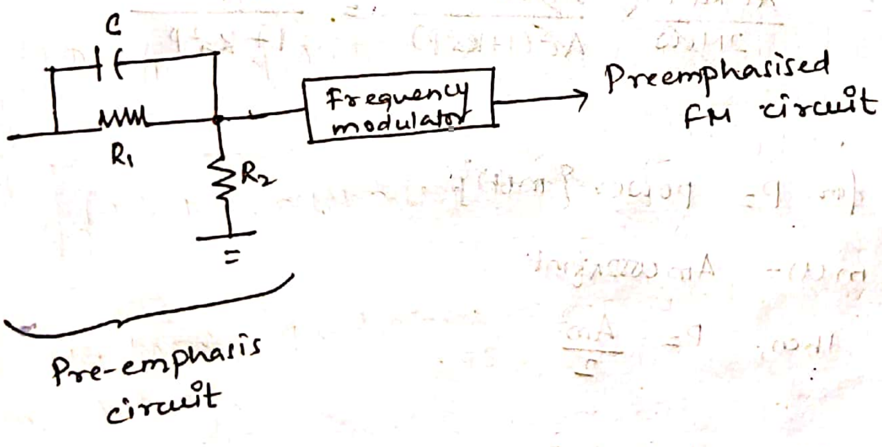
$$\frac{S_o}{N_o} = \frac{1}{3}\frac{S_i}{N_i}$$

Hence, noise performance of envelope detector is not good as compared to synchronous detector.

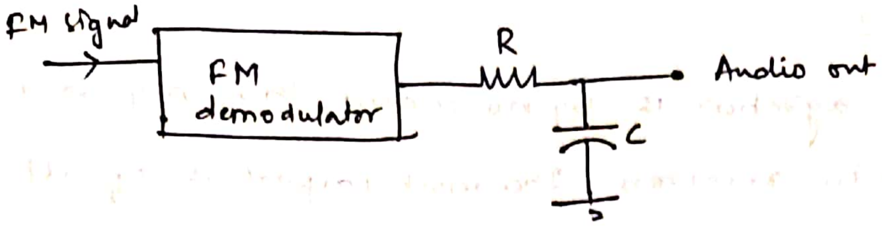
FM Receiver :-

- To improve the SNR of FM Receiver, we use the pre-emphasis and de-emphasis circuit in the transmitter and receiver respectively.

- **Pre-emphasis:-**
The noise suppression ability of FM decreases with the increase in the frequencies. Thus increasing the relative strength or amplitude of high frequency component of the message signal before modulation is termed as Pre-emphasis.



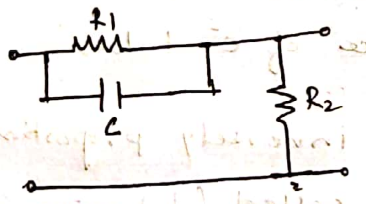
- **De-emphasis:-**
In the de-emphasis, by reducing the amplitude level of the received high frequency signal by the same amount as the increase in the pre-emphasis is termed as de-emphasis.



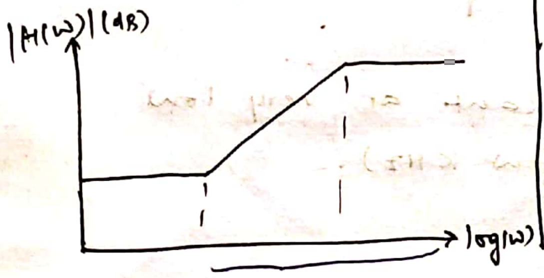
- The pre-emphasis process is done at the transmitter side, while the de-emphasis process is done at the receiver side.
- Due to pre-emphasis and de-emphasis, the S/N ratio at the o/p of the reciever is improved.
- Pre-emphasis circuit is a high pass filter (RC circuit) or differentiator which allows high frequencies to pass and amplified., whereas de-emphasis circuit is a low pass filter or integrator which allows low frequencies.

Transmitter

Pre-emphasis filter



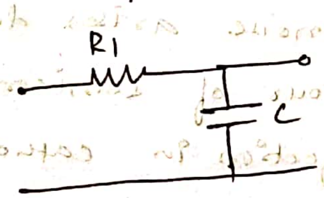
$$H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{1 + j\omega R_1 C}{1 + j\omega (R_1/R_2) C}$$



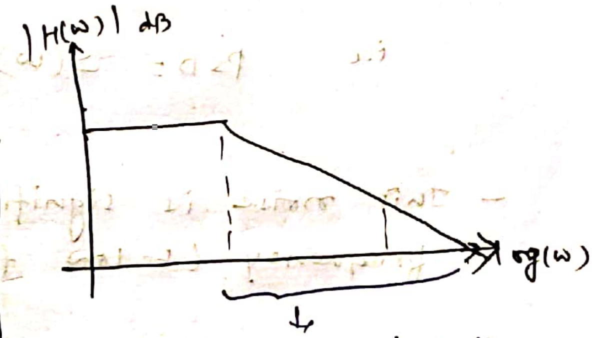
Increasing strength at higher freq.

Receiver

De-emphasis filter



$$H(\omega) = \frac{1}{1 + j\omega R_1 C}$$



decreasing strength at higher frequency.

Shot Noise :-

- Thermal agitation is by no means the only source of noise in receivers. The most important of all the other sources is the shot effect; which leads to shot noise in all amplifying devices and virtually all active devices.

- It is caused by the random variations in the arrival of e's (or holes) at the o/p electrode of an amplifying device. and appears as a randomly varying noise current superimposed on the o/p.

- "Shot Noise" is Gaussian- distributed with zero mean.

- It increases with the biasing current in a reverse biased junction and will be proportional to I_0. This noise is negligible in FETs.

Flicker Noise :-

- The noise arises due to imperfect surface behaviour of semiconductor devices and due to imperfection in cathode surface of e^- tubes.

- The PSD of this noise is inversely proportional to frequency, so that it is called $\left(\frac{1}{f}\right)$ noise.

i.e $\quad PSD = S(\omega) \propto \frac{1}{f}$

- This noise is significant at very low frequency (below few KHz).