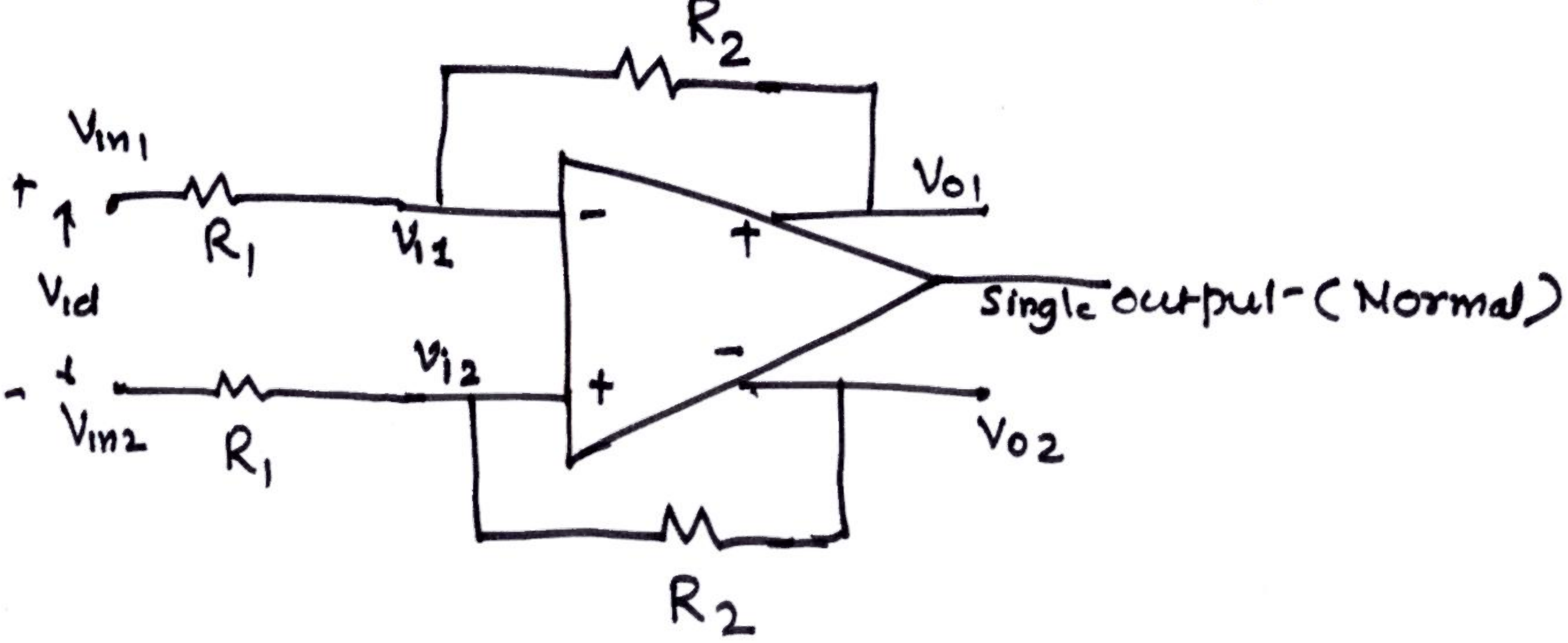
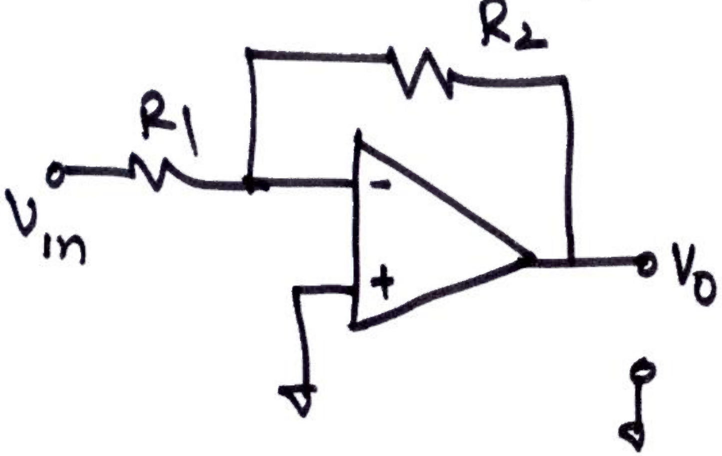
Fully Differential OPAMP

It's generally operated with Balance Input and produces Balance Output

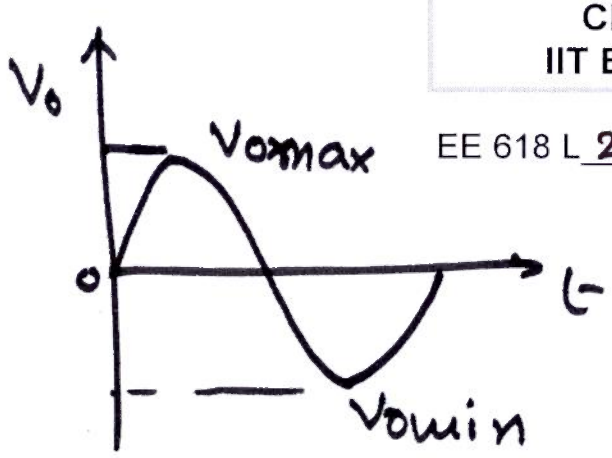


CDEEP
IIT Bombay

For single output OPAMP an Amplifier is



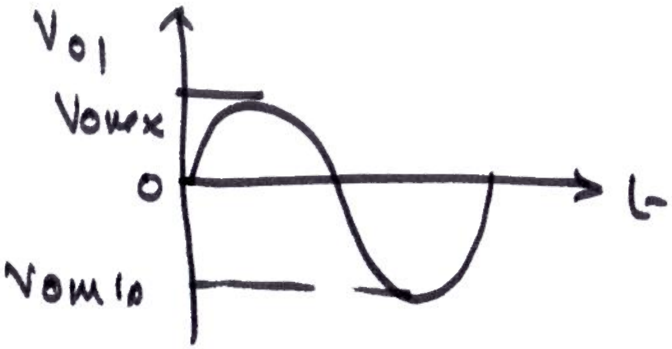
$$V_0 = -\frac{R_2}{R_1} V_{in}$$

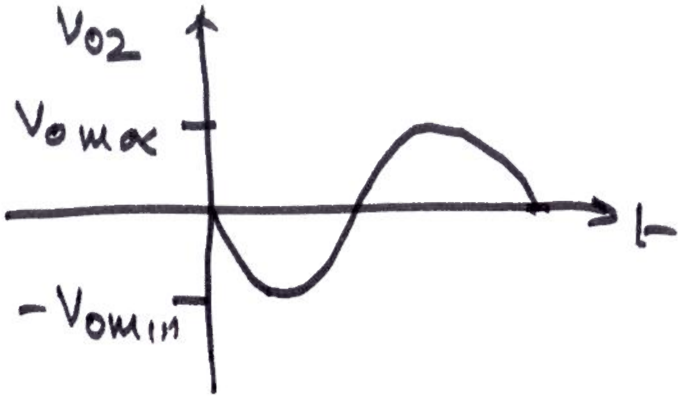


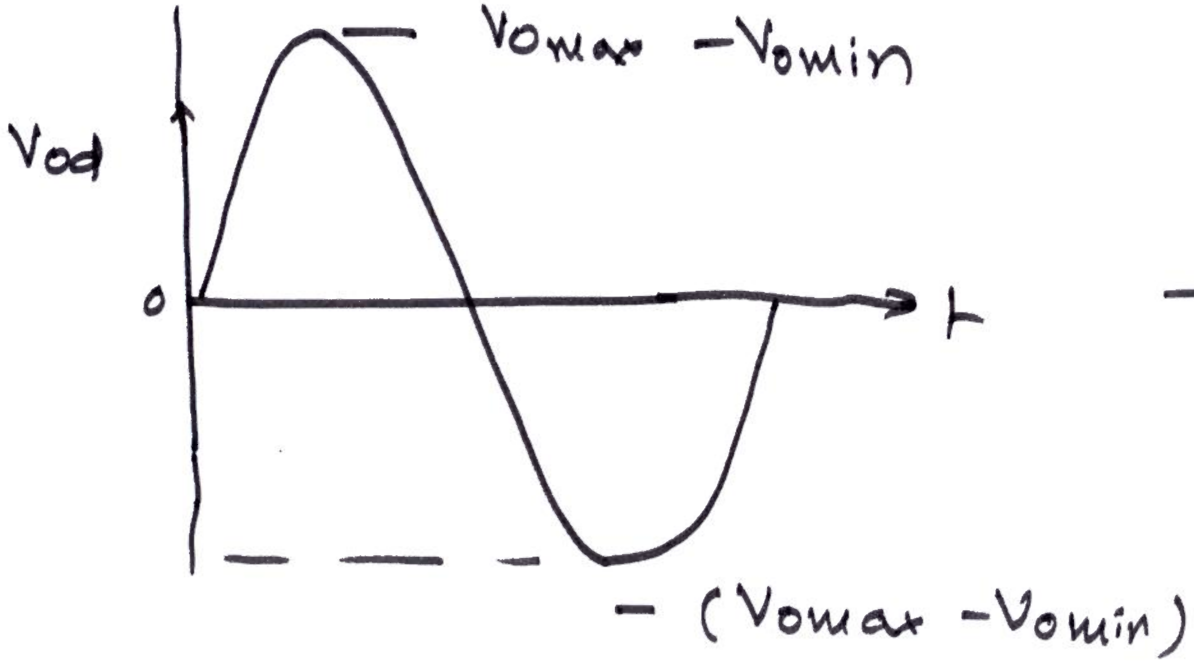
$$V_{ocommon} = \frac{V_{omax} + V_{omin}}{2}$$

i.e. $V_{OCM} = 0$ If $V_{omax} = -V_{omin}$

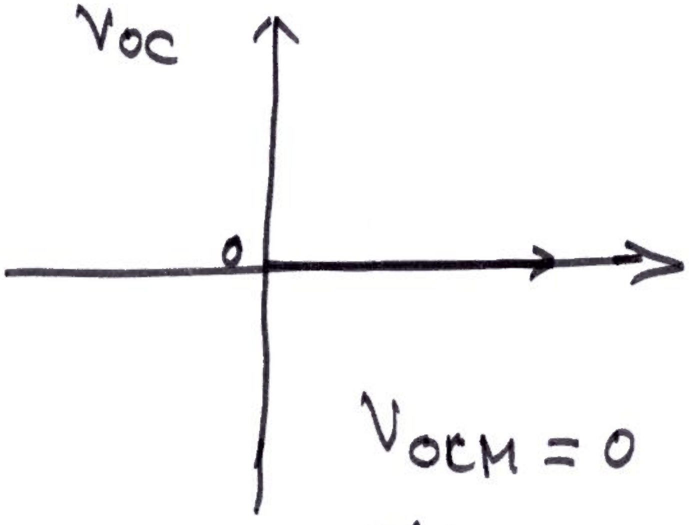
In case of Balanced (Symmetric) Fully Differential system, V_{o1} & V_{o2} look like :







Difference Mode output



$V_{OCM} = 0$

If $V_{omax} = -V_{omin}$

Common Mode output

We may need Amplifier with

① Higher Gain

② Higher SNR (Signal to Noise Ratio)

where $$\text{SNR} = \frac{\text{Max. Signal Output Power } (V_{sig m}^2/2)}{\text{Output Noise Power } (\overline{V_{ON}^2})}$$

where $$\overline{V_{ON}^2} \text{ (Single ended)} = \left(1+\frac{R_2}{R_1}\right)^2 4kTR_1 f_N$$

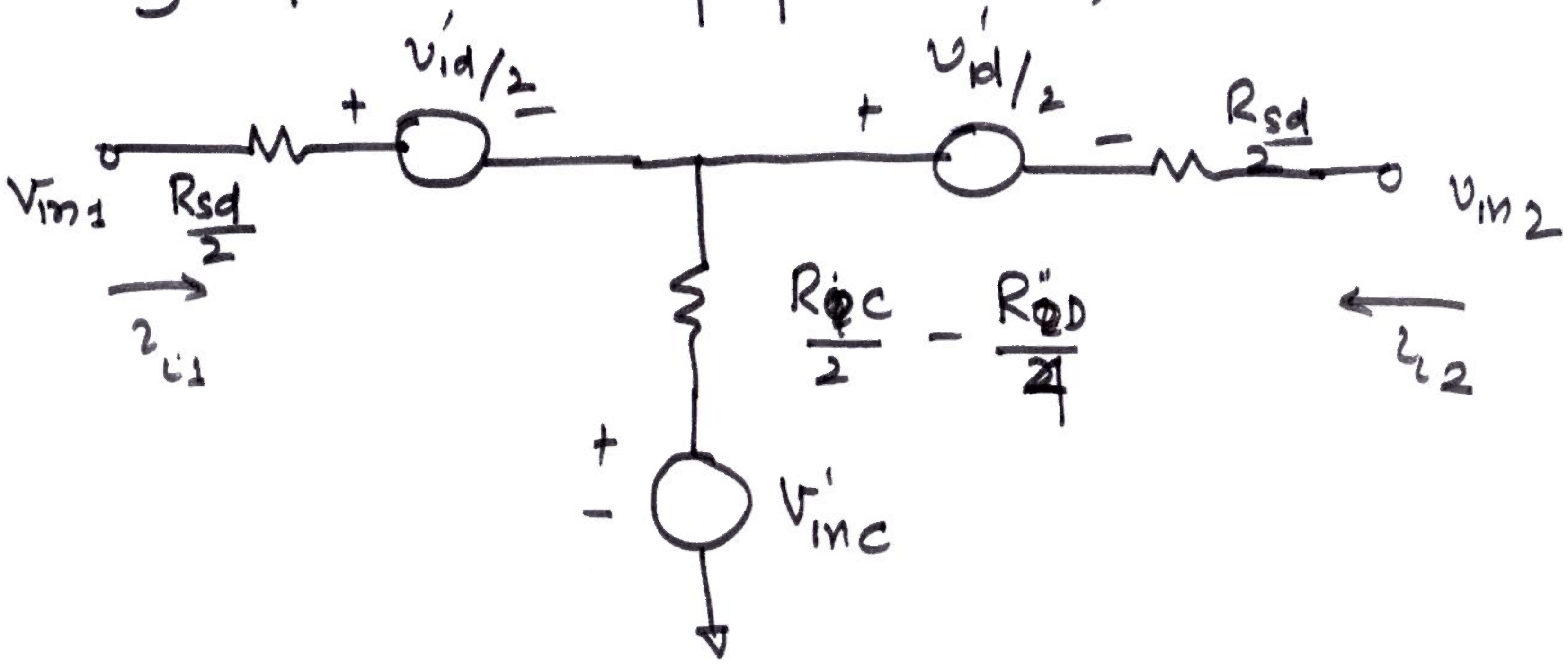
$$\overline{V_{on}^2} \text{ (~~Fully~~ Differential)} = 2\left(1+\frac{R_2}{R_1}\right)^2 4kTR_1 f_N$$

V_{signal} (peak) for Single ended = $V_{omax} - V_{min}$

〃 〃 F. Differential = $2(V_{oxm} - V_{omin})$

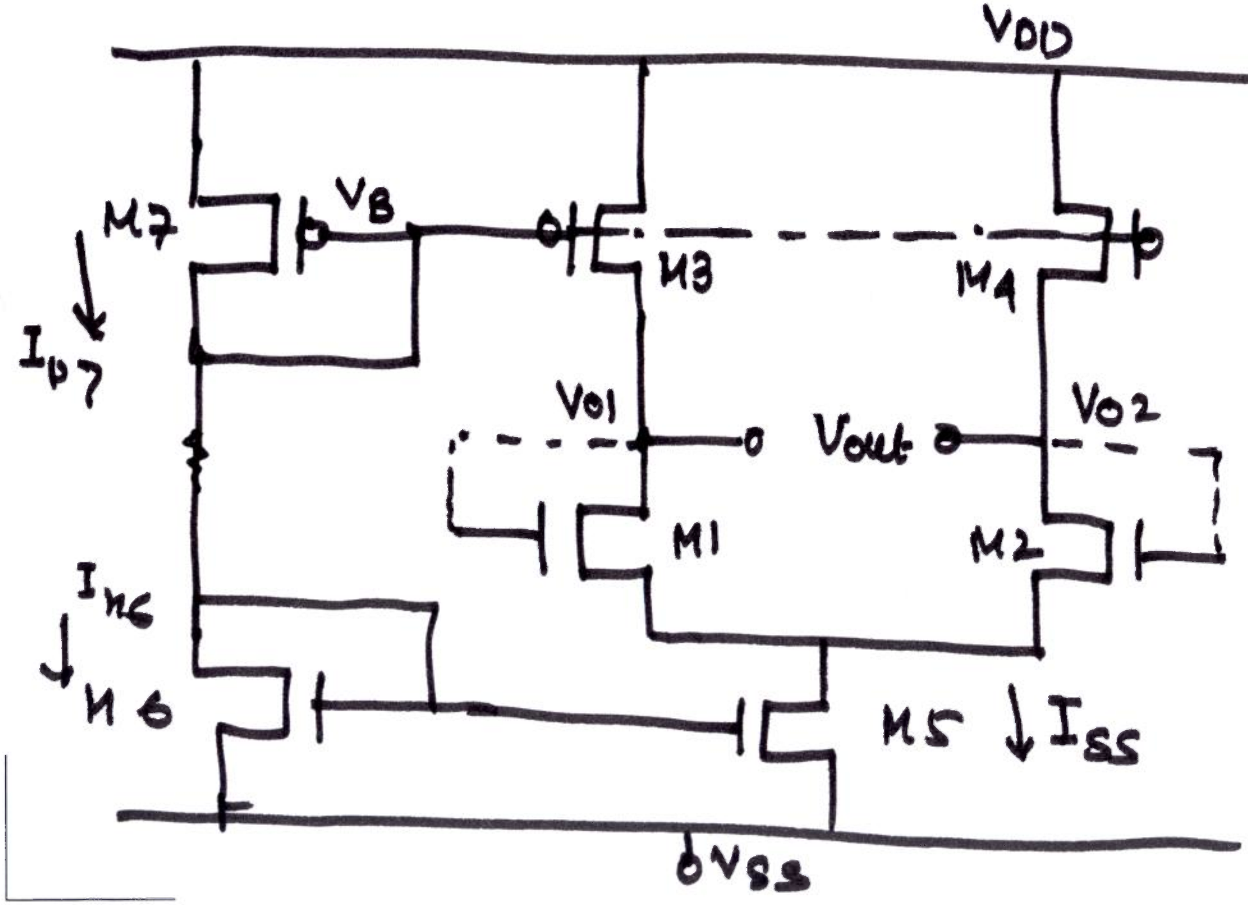
Thus SNR of Fully Differential Amplifier is Twice that of Single output Amplifier.

We can model the Input side of Fully Differential Amplifier (FDA) as



COMMON MODE FEEDBACK (CMFB)

For fully Differential Amplifier with need of Higher Gains, we use Current Source Loads instead of Diode Connected Loads.



$$\boxed{\begin{aligned} V_{in1} &= V_{o1} \\ V_{in2} &= V_{o2} \end{aligned}}$$

Then:

$$V_{out} = V_{o1} - V_{o2}$$

$$\frac{V_{id}}{2} = \frac{(V_{in1} - V_{in2})}{2}$$

$$V_{ic} = \frac{V_{in1} + V_{in2}}{2}$$

For Diffamp, with M_1 & M_2 identical,

$$I_{DS1} = I_{DS2} = \frac{I_{SS}}{2} \qquad \left(= \frac{I_{DS5}}{2} \right)$$

Since we have connected inputs to outputs

$$\therefore \; V_{CM} = \frac{I_{SS}}{2} \cdot (r_{o3} \| r_{o1}) = \frac{I_{SS}}{2} (r_{o4} \| r_{o2})$$

However if r_{o3} is governed by I_{DS7} (same as r_{o4}) and r_{o1} by I_{DS6} (n-mirror), then issue may come that, in case M_6 & M_7 which are generating n-mirror current I_{SS} and r_{o3} (or r_{o4}) created by M_6, are **not** generating $I_{DS6} = I_{DS7}$

Then we have two cases $I_{DS_{3,4}} > \frac{I_{SS}}{2}$ or $I_{DS_{3,4}} < \frac{I_{SS}}{2}$

Case 1 : If $I_{DS_{3,4}} > \frac{I_{SS}}{2}$

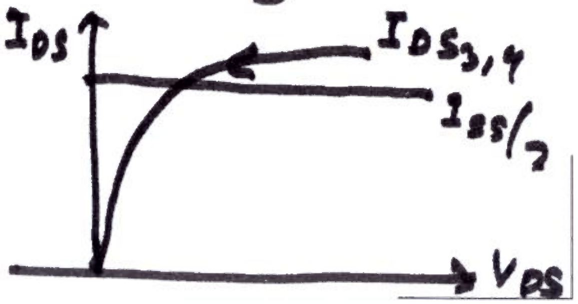
i.e. $I_p = I_{DS_7}$ is larger than $I_n = I_{DS_5} = I_{SS}$

Then $(I_p - I_n)$ current flows in $R_{out_7} || R_{out_6}$ creating a voltage, which may not be Small

For $I_{DS_{3,4}} > \frac{I_{SS}}{2}$, the natural case will be to restore $I_{DS_{3,4}} = \frac{I_{SS}}{2}$

Which means V_{o1} & V_{o2} to be same as normal case, Currents in M_3 & M_4 must reduce. This may bring these transistors Out of Saturation

This may reduce R_{o3}, R_{o4} & hence fall in Gain



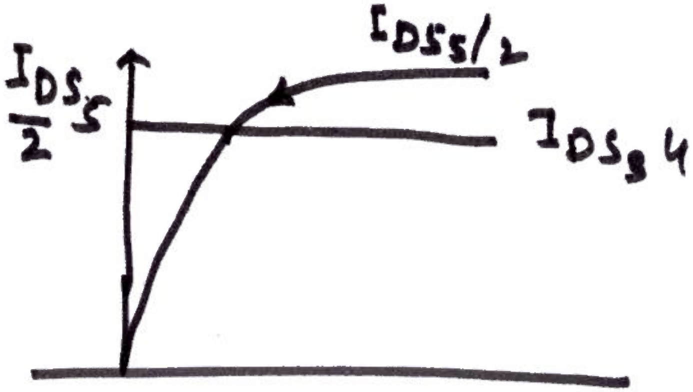
Case II : $I_{DS_{34}} < \frac{I_{SS}}{2}$

Now I_{SS} is supplied by MS.

If $I_{DS_{34}}$ is smaller, then MS must supply smaller current to restore

$$I_{DS_{3,4}} = \frac{I_{SS}}{2}$$

This may bring out MS from Saturation.



Reduction in R_{os} of MS will reduce CMRR as common mode gain will ~~redu~~ Increase

Average of OPAMP outputs is termed of Common-Mode Output

$$V_{CM} = \frac{V_0^+ + V_0^-}{2}$$

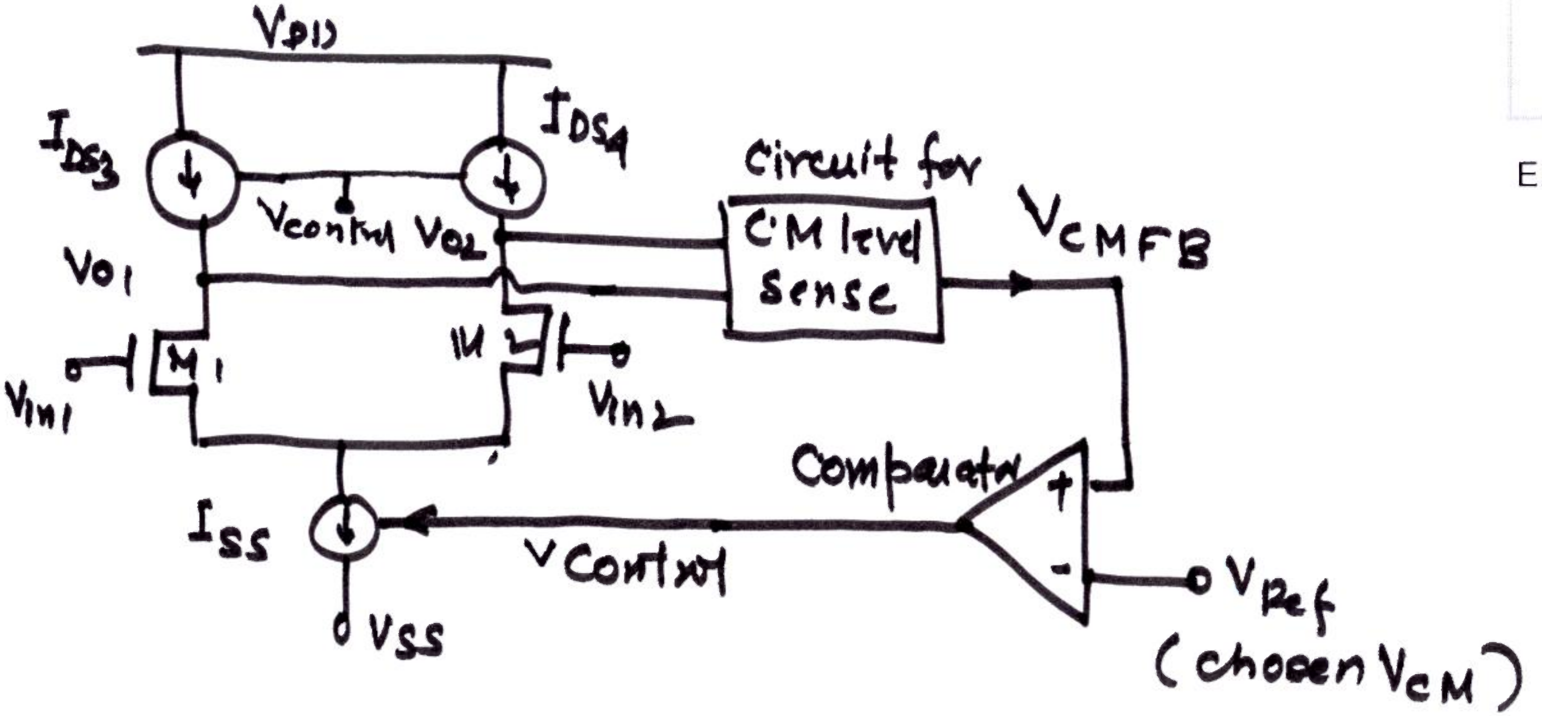
If $\underset{= 2.5V}{V_{DD} = |-V_{SS}|}$ & $V_0^+ \rightarrow V_{DD}$ & $V_0^- \longrightarrow V_{SS}$

Then $V_{CM} = \frac{V_{DD} + V_{SS}}{2} = \frac{2.5 - 2.5}{2} = 0$

But if $V_{DD} = 5$ & $V_{SS} = 0$ $V_{CM} = 2.5\,V$

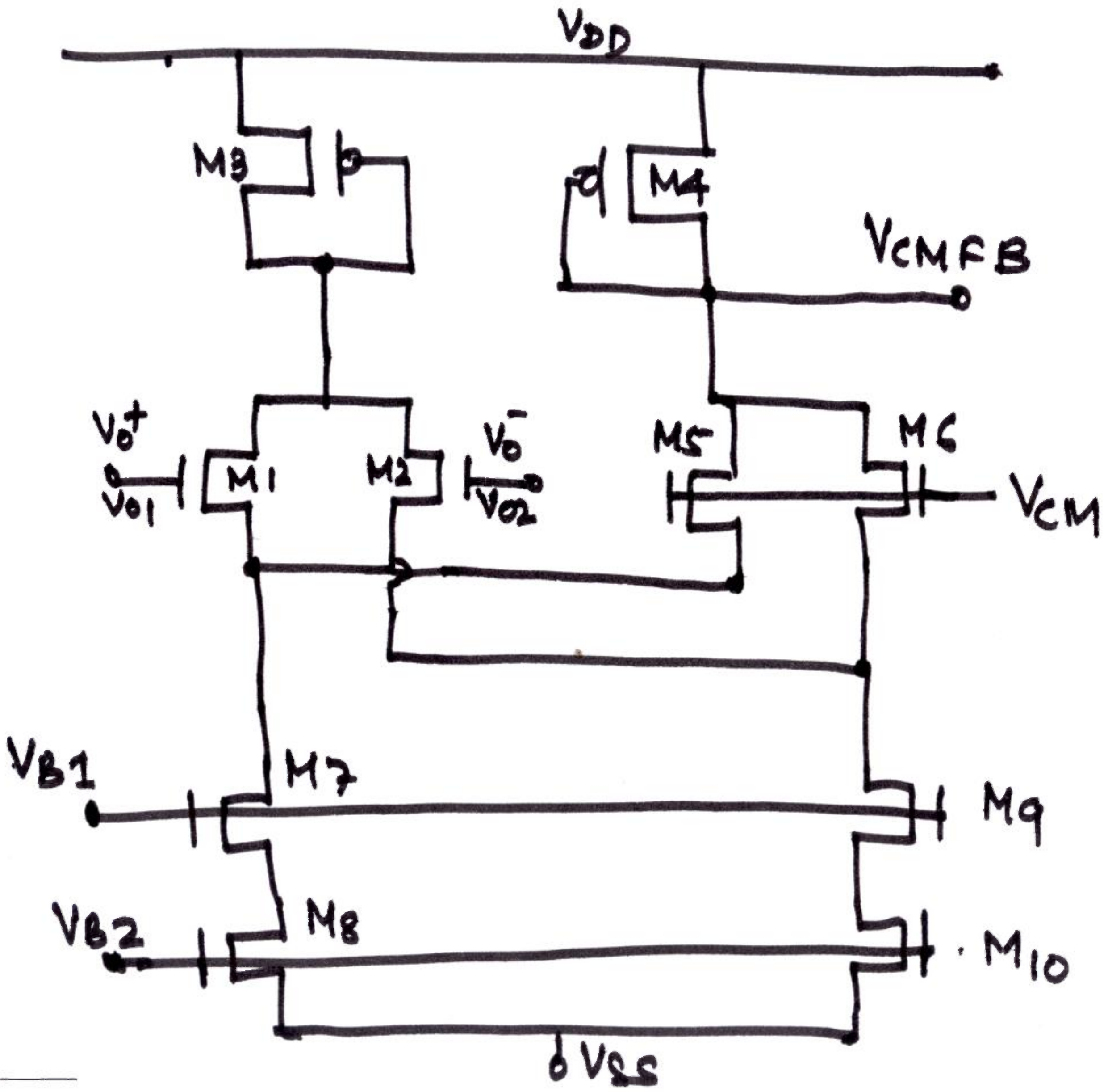
It is necessary that for FD Amplifier to be stable, just Differential Feedback is not good enough but one needs Common Mode Feedback. This allows a fixed value of V_{CM}.

Typical Common Mode Feedback works like



We sense V_{O1} and V_{O2} and generate V_{CMFB}. This is compared with set V_{CM} (V_{Ref}) and depending upon $V_{CMFB} >$ or $< V_{CM}$ we increase or decrease bias for Tail Current Source I_{SS}.

A CMFB Circuit using CMOS technology



M7 to M10 are providing Constant Current Sources

① V_o^+ & V_o^- are such that av. value $> V_{CM}$

② V_o^+ & V_o^- are such that their av. value $< V_{CM}$.

D.S

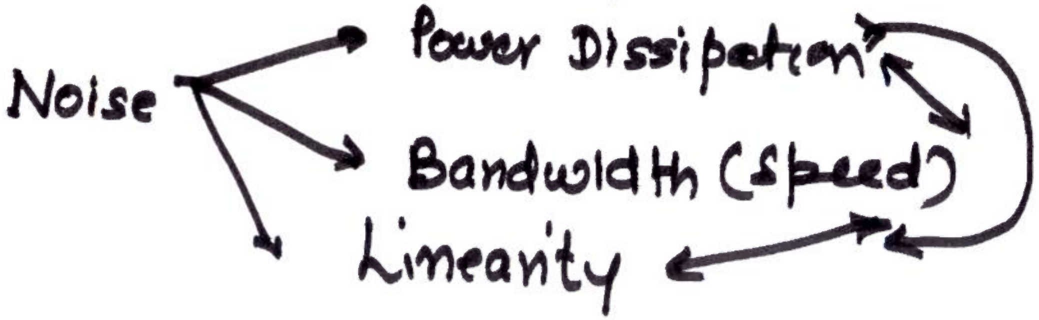
"NOISE"

1. Concept
2. Types of Noise
3. MOS MODELS FOR NOISE
4. Noise evaluation in Circuits.

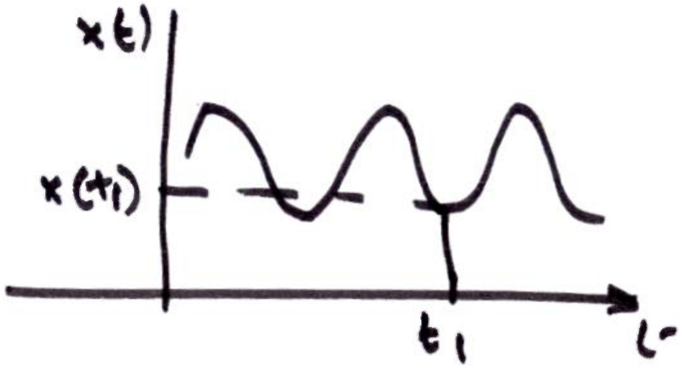
Noise :- Any Unwanted or Undesired Signal couples with Desired Signal is termed as Noise.

"Noise is generated due to a Random Process and limits the Minimum Signal (Desired) level that a Circuit Can process with reasonable but acceptal Quality."

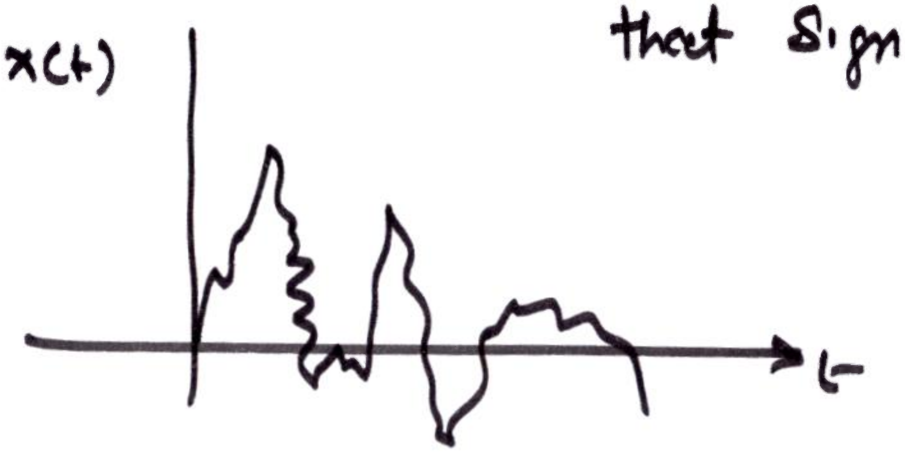
In Analog Circuit the Design Trade-off is between



If we have Signal $x(t)$, which is periodic
Then we can deterministly
say that at $t=t_1$
$x(t) = x(t_1)$



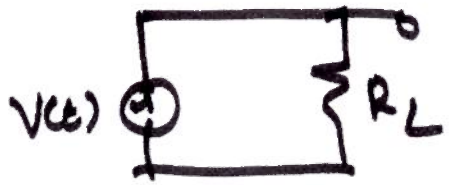
However if the Signal is random in nature
we can predict $x(t_1)$ or $x(t_2)$. We then say
that Signal is 'Noise Signal'.



'Correlated Noise' ?!

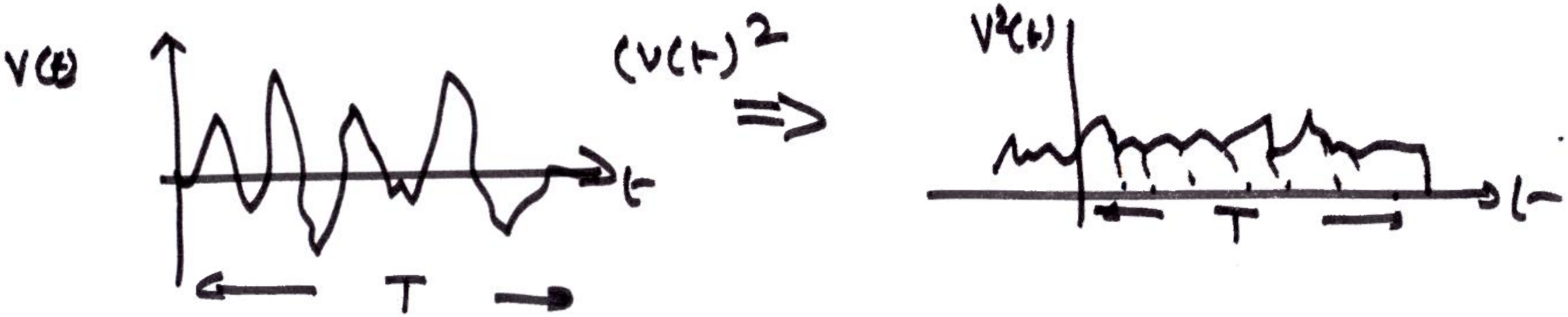
It is interesting that most noise sources show constant average power over a period. i.e.

$$P_{av} = \underset{T\to\infty}{\text{Lt}} \frac{1}{T} \int_{-T/2}^{+T/2} \frac{v^2(t)}{R_L}\, dt$$



$$P = \frac{v^2(t)}{R_L}$$

That is averaging is done for long period of time.

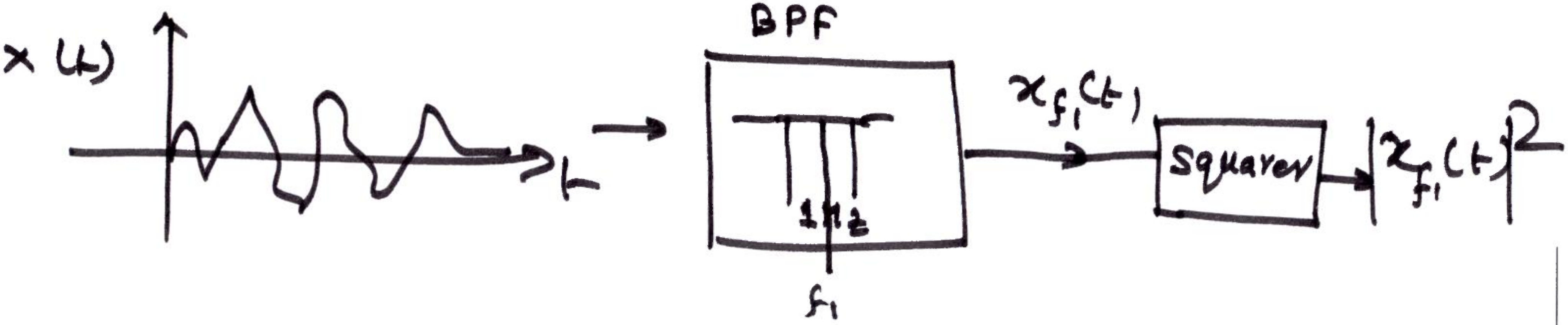


$\sqrt{P_{av}}$ = Voltage which is called Noise (rms) Voltage) / Load.

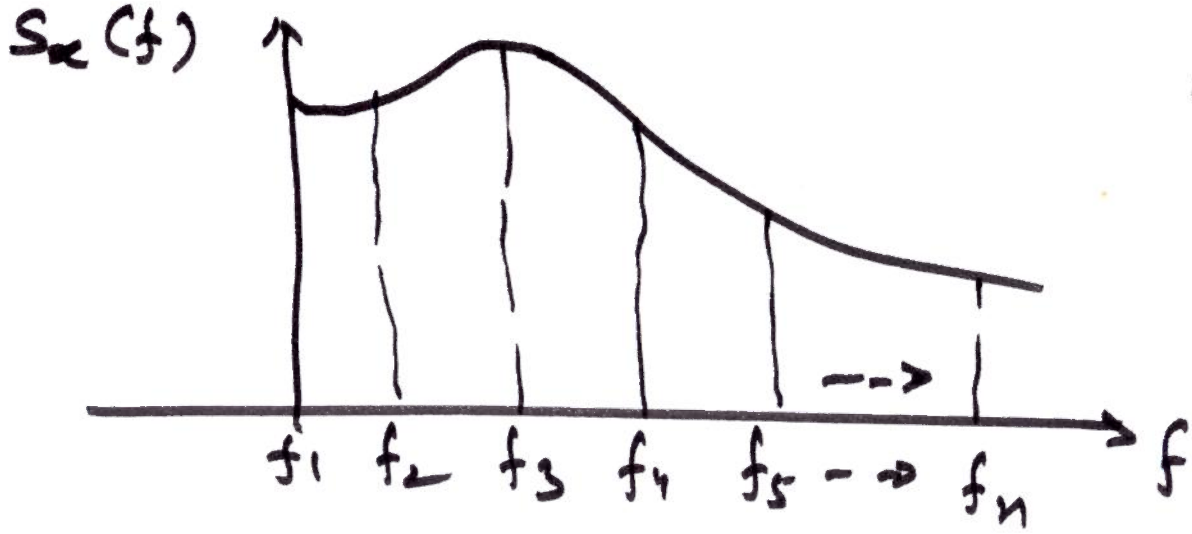
Concept of Noise Spectrum

If Noise av. power is defined in frequency domain, we get Noise Spectrum, which is called Power Spectral Density (PSD).

PSD is defined as $S_x(f)$ of a noise waveform $x(t)$. Av. Power here is carried by $x(t)$ in bandwidth of 1 Hz, around centre frequency f.



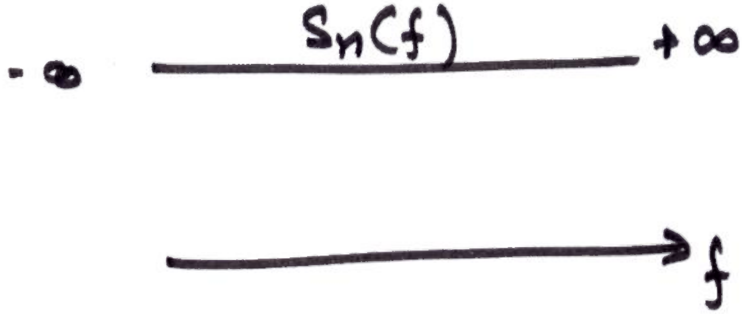
Then we can evaluate Power spectral Density $S_x(f)$ if we obtain PSD at various values of $f \Rightarrow f_1, f_2 -- f_n$



$S_x(f)$ is expressed as V^2/Hz

$\therefore \sqrt{S_x(f)}$ has units of $V/\sqrt{Hz}$

White Noise has spectrum



Generally we limit the spectrum frequency to large values.

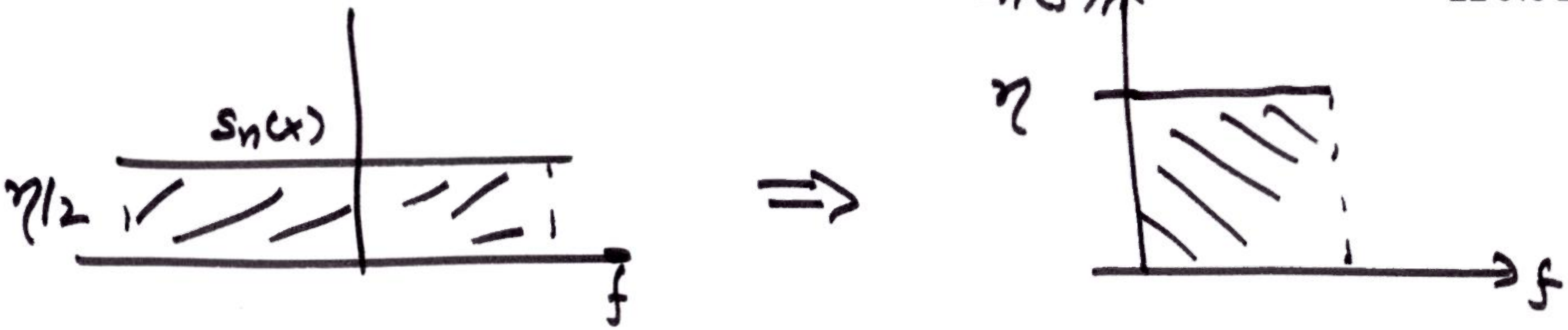
Response of PSD input to a system with Transferfn $H(f)$.

$$S_F(f) = S_x(f) \cdot |H(f)|^2$$

where $H(f) = H(s = 2\pi j f)$

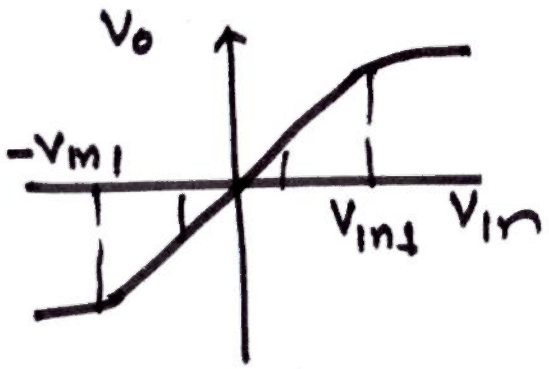
If White noise spectrum is inputted to Transferfn

Two sided Symmetric spectral function can be transformed to Single sides sp.f^n by doubling the magnitude



Distinction between Device Noise, Distortion and Interference due to signals.

1. Distortion: If the output signal waveform departs from expected waveform which should have occured due to Input signal operated on a Transfer function. Example:



Amplifier response

For V_{in} between $-V_{in1}$ to V_{in1}

$$V_o = \text{Gain} \cdot V_{in} \quad \text{where Gain} = \frac{dV_o}{dV_{in}}$$

However beyond $V_{in} > V_{in1}$ or $< -V_{in1}$ $\frac{dV_o}{dV_{in}}$ keeps changing. This is due to nonlinear behavior of the system. The Output will then have Non-linear Distortion.

Thus Distortion occures due to

1. Nonlinearities in the Transfer Function of Active Devices
2. Distortion due Passive components like cable or by Inhomogeneities In the Propagation Path.

2. Interference :

In a spectrum, nearby Signal frequency interferes in the interest band

Eg Intermodulation in a RF receiver Input leads to Interference.

3. Noise :

Electronic components produce combination of Three Noise spectra

i $S_n(f) = \text{Const.}$ White Noise

ii $S_n(f) \propto \frac{1}{f}$ 1/f Noise

iii $S_n(f) \propto \frac{1}{f^2}$ Popcorn Noise

However we have another class of Noise which are categorised as Thermal Noise types. Overall we have number of Noises :—

ⓐ Shot Noise (b) Johnson Noise (Most commonly called Thermal Noise)

Third type of Noise is called G-R noise and finally we have noise called kT/C noise.