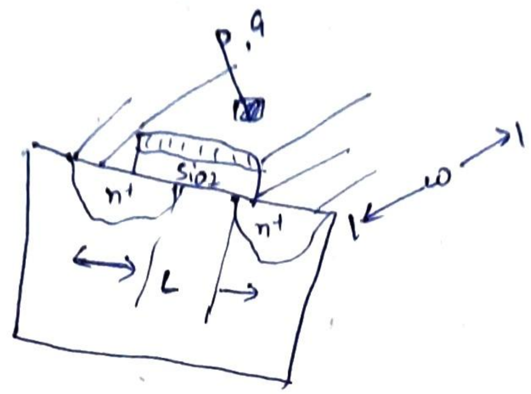
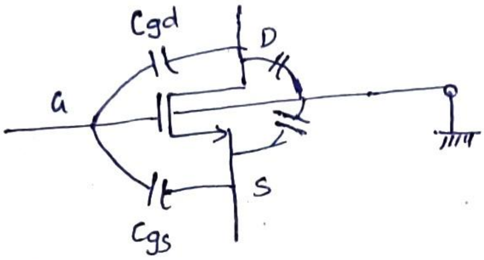
12/9/23

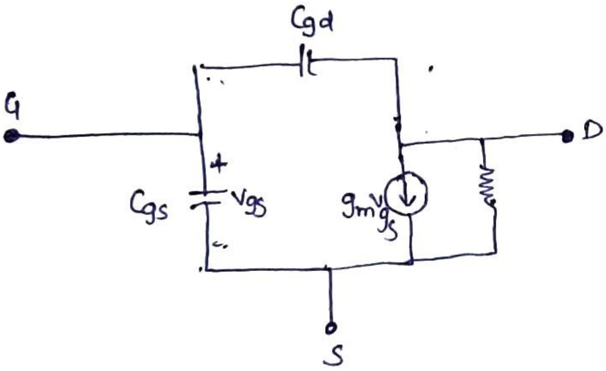
High frequency Analysis



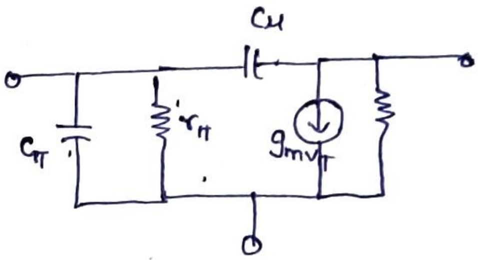
D-S capacitor is not there.

$C = \frac{\epsilon_0 A}{d}$



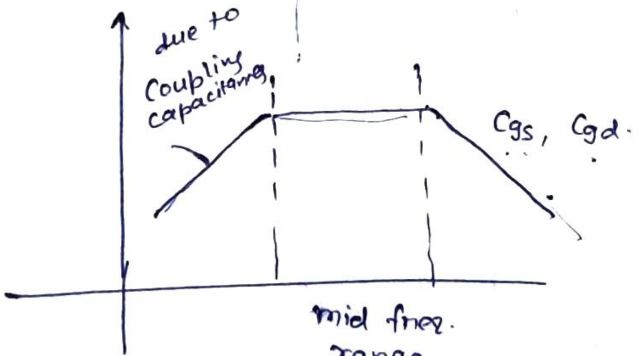


Hybrid - π - high frequency model

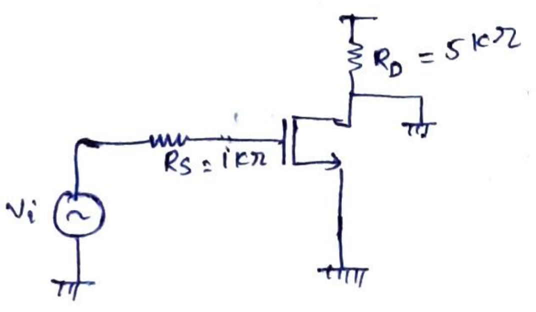


BJT

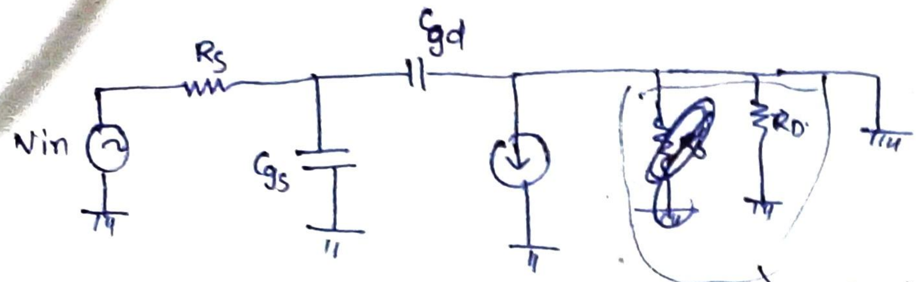
$\frac{1}{j\omega C_{gd}}$



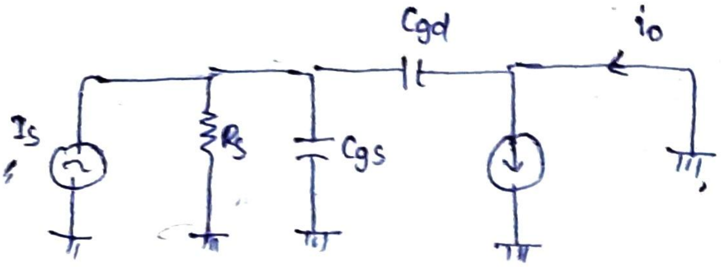
mid freq. range



f_T = unity current gain frequency.



eleminated



$\frac{V_{in}}{R_s}$

$$i_s - \frac{V_{gs}}{R_s} - V_{gs}\cdot sC_{gs} - V_{gs}\cdot sC_{gd} = 0$$

$$i_o = g_m V_{gs} - sC_{gd}V_{gs}$$

$$i_s = V_{gs}\left(\frac{1}{R_s} + sC_{gs} + sC_{gd}\right)$$

$$= \frac{i_o}{(g_m - sC_{gd})}\left(\frac{1}{R_s} + sC_{gs} + sC_{gd}\right)$$

$$\frac{i_o}{i_s} = \frac{(g_m - sC_{gd})R_s}{1 + sR_s(C_{gs} + C_{gd})}$$

$$\left.\frac{i_o}{i_s}\right|_{s=j\omega} = \frac{(g_m - j\omega C_{gd})R_s}{1 + j\omega R_s(C_{gs} + C_{gd})}$$

$$\left|\frac{i_o}{i_s}\right|_{j\omega} = \frac{R_s\sqrt{g_m^2 + \omega^2 C_{gd}^2}}{\sqrt{1 + \omega^2 R_s^2 (C_{gs} + C_{gd})^2}}$$

$$\left|\frac{i_o}{i_s}\right|_{\omega=\omega_T} = 1.$$

$$R_S^2 \left(g_m^2 + \omega_T^2 C_{gd}^2 \right) = 1 + \omega^2 R_S^2 (C_{gs} + C_{gd})^2$$

$$g_m^2 >> \omega^2 C_{gd}^2$$

$$\frac{R_S g_m}{\sqrt{1 + \omega^2 R_S^2 (C_{gs} + C_{gd})^2}} = 1$$

$$g_m^2 R_S^2 = 1 + \omega^2 R_S^2 (C_{gs} + C_{gd})^2$$

$$g_m^2 = \frac{1}{R_S^2} + \omega^2 (C_{gs} + C_{gd})^2 .$$

Generally R_S value is very high as it is connected ~~thorp~~ parallel to current.

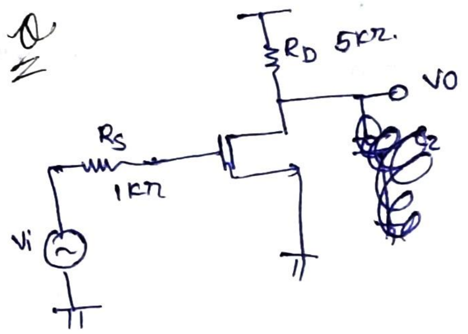
$$\boxed{g_m^2 = \omega_T^2 (C_{gs} + C_{gd})^2}$$

$$\boxed{f_T = \frac{g_m}{2\pi (C_{gs} + C_{gd})}}$$

unity gain current frequency.

output is shorted

Q

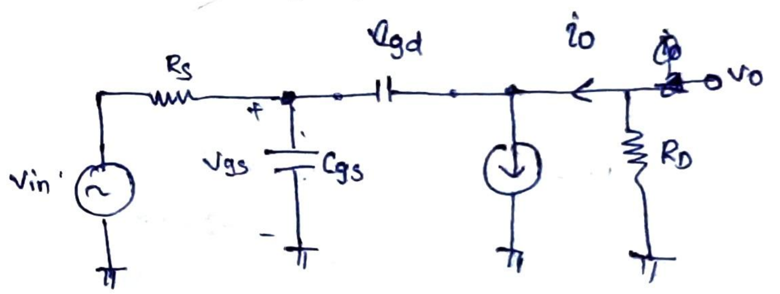


$\mu_n C_{ox} \frac{W}{L} = 100 \, mA/V^2$

$C_{gd} = 0.5 \, pF$

$C_{gs} = 5.15 \, pF$

$I_D = 1mA$.



$i_o = -V_o / R_D$.

$$\frac{V_{in} - V_{gs}}{R_S} = V_{gs} \, s C_{gs} + (V_{gs} - V_o) \, s C_{gd} \quad \text{—— (i)}$$

$$\frac{-V_o}{R_D} - g_m V_{gs} + (V_{gs} - V_o) \, s C_{gd} = 0 \quad \text{—— (ii)}$$

from eq (i) & (ii),

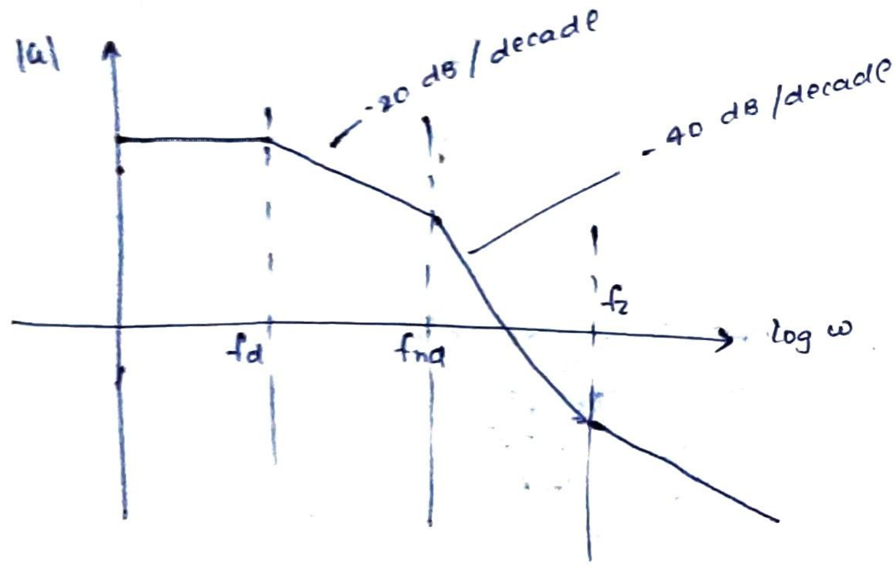
$$\frac{V_o}{V_{in}} = -\frac{(g_m - sC_{gd})R_D}{s^2 R_S R_D C_{gs} C_{gd} + s\{R_S(C_{gs}+C_{gd}) + C_{gd}R_D + g_m R_S R_D C_{gd}\} + 1} \quad \text{——— (i)}$$

$$g_m = \sqrt{2\mu_n C_{ox} W/L \, I_D}$$

$$= \sqrt{2 \times 100 \times 10^{-3} \times 1 \times 10^{-3}}$$

$$= \sqrt{2 \times 10^{-4}}$$

$$= \sqrt{2} \times 10^{-2} = 14.14 \times 10^{-3}$$



f_d = dominant pole

f_{nd} = non-dominant pole.

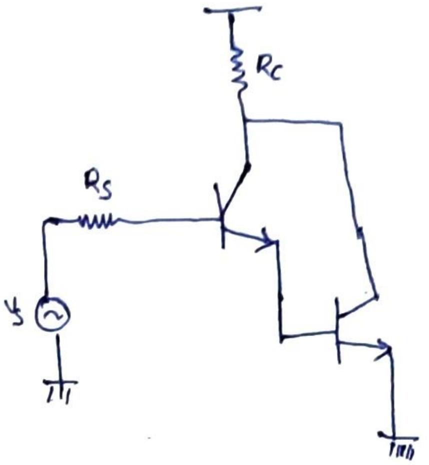
$$R_S R_D C_{gs} C_{gd} = 1 \times 5 \times 10^6 \times 0.5 \times 5.15$$

$$= 12.875 \times 10^{-24+6}$$

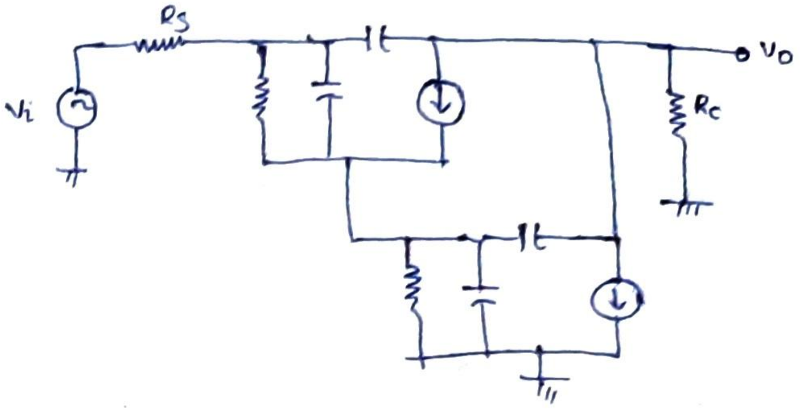
$$= 12.875 \times 10^{-18}$$

$$R_S(C_{gs}+C_{gd}) + C_{gd}R_D + g_m R_S R_D C_{gd}$$

$$= 1 \times 10^3 (5.65) \times 10^{-12} + 0.5 \times 10^{-12} + 14.41 \times 10^{-3} * 5 \times 10^6$$



Impossible to get poles by calculating denominator



dominant pole → using open circuit time constant.

non-dominant pole → using short circuit time constant.

P_1 & P_2 are widely apart.

$$\frac{1}{P_1} >> \frac{1}{P_2}$$

Assumption:-

P_1 - dp

P_2 - ndp.

↳ Denominator of eq (i) = 0

$$\left(\frac{s}{P_1} - 1\right)\left(\frac{s}{P_2} - 1\right) = 0$$

Calculation.

Make,

Ind. Voltage - Short

Ind. current - Open.

During Cgs consideration open circuit Cgd and calculate Resistance across them.

& During Cgd, consideration, open circuit Cgs and calculate equivalent resistance across them.

$$\frac{1}{P_1} = \sum C_i R_i$$

$$\boxed{P_1 = \frac{1}{\sum C_i R_i}}$$

from eq (i)

$$\frac{1}{P_1 P_2} = R_S R_D C_{gs} C_{gd}$$

$$\frac{1}{P_1} + \frac{1}{P_2} = R_S C_{gs} + C_{gd}(R_S + R_D + g_m R_S R_D)$$

$$\frac{1}{P_1} \simeq R_S C_{gs} + C_{gd}(R_S + R_D + g_m R_S R_D).$$

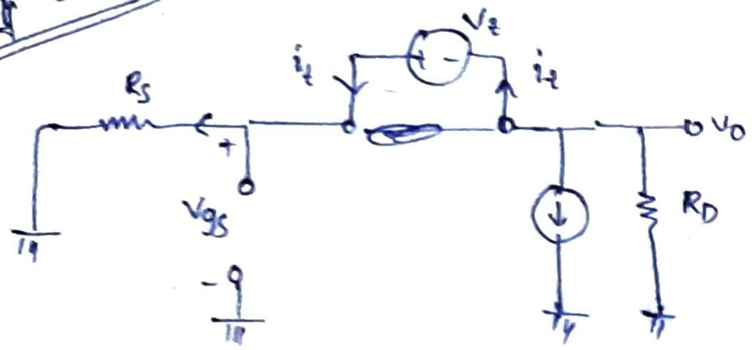
V_t @ C

$$-i_t - g_m i_t R_S - \frac{i_t R_S}{R_D} + \frac{V_t}{R_D} = 0$$

$$-R_D i_t - g_m R_S R_D i_t - i_t (R_S) = -V_t$$

Considering for C_{gd}.

$$\frac{V_t}{i_t} = (R_D + R_S + g_m R_S R_D).$$



$$i_t R_S - V_{gs} = 0$$

$$-i_t - g_m V_{gs} - V_o/R_D = 0$$

$$s^2 + s\frac{\{R_S(C_{gs}+C_{gd}) + C_{gd}R_D + g_m R_S R_D C_{gd}\}}{R_S R_D C_{gs} C_{gd}} + \frac{1}{R_S R_D C_{gs} C_{gd}} = 0.$$

$$(S-P_1)(s-P_2) = 0.$$

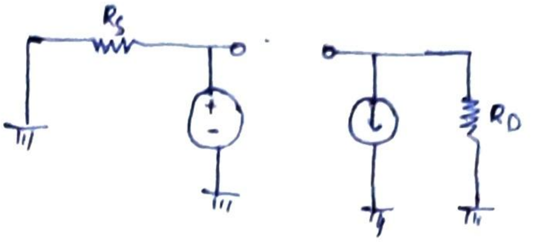
$$P_1 + P_2 = \frac{1}{C_{gd}}\frac{1}{R_D} + \frac{1}{C_{gs}}\left[\frac{1}{R_D} + \frac{1}{R_S} + g_m\right].$$

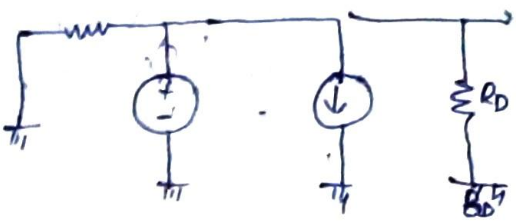
P_2

$$\boxed{p_2 = \Sigma \frac{1}{R_i C_i}}$$

non-dominant pole determination.

In this case, we have to short circuit the other capacitor and determine the equivalent resistance.





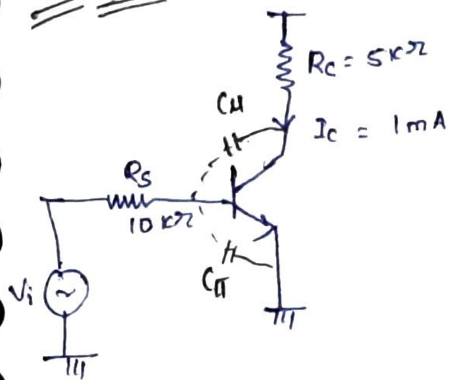
Short ~~circuit~~ Time const.

(for Dominant pole)

Short ckt. T. C.

(for Non-Dominant pole)

Q: BJT.



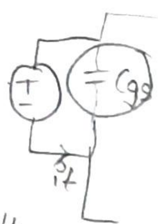
$C_\mu = 0.2$ pF

f_T @ 1mA = 600 MHz

$\beta = 200.$

$g_m = I_C/V_T.$
$= \frac{1mA}{25 mA} = 1/25$

$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)} = \frac{1/25}{2\pi\,(C_\pi + C_\mu)} = 600 \times 10^6.$$



$\frac{V_t}{i_t} = R_q$

R ‖ C

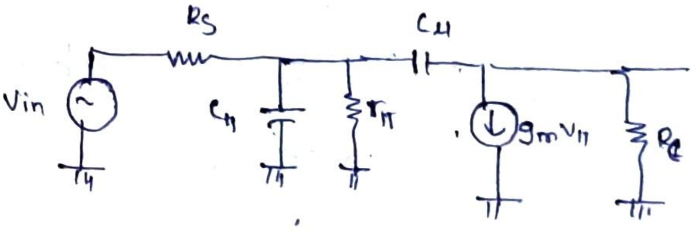
$$(C_\pi + C_\mu) = \frac{1}{50 \times \pi \times 600} \times 10^{-6}$$

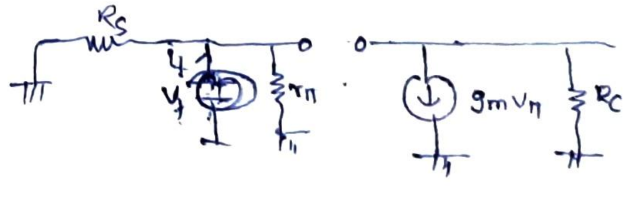
$$= \frac{1}{3\pi} \times 10^{-10}.$$

$$= 1.0471 \times 10^{-10}$$

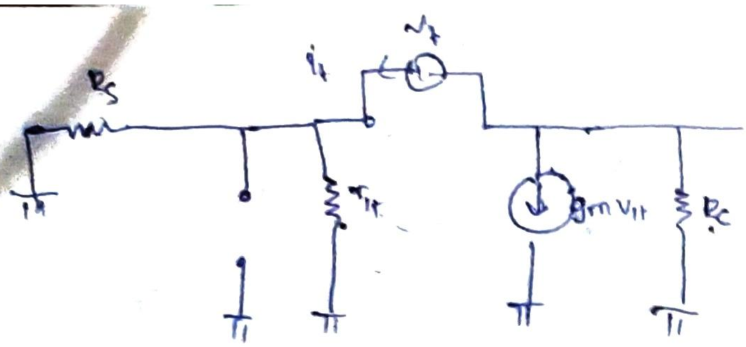
$$= 104.71 \times 10^{-12}$$

C_π = 104.71 − 0.2





$R_\pi = R_S \parallel r_\pi.$



$R_\mu = R_s \parallel r_\pi + R_C + g_m (R_s \parallel r_\pi) \cdot R_C.$

equivalent Resistance across C_μ.

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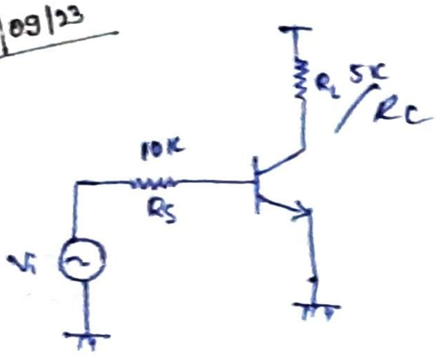
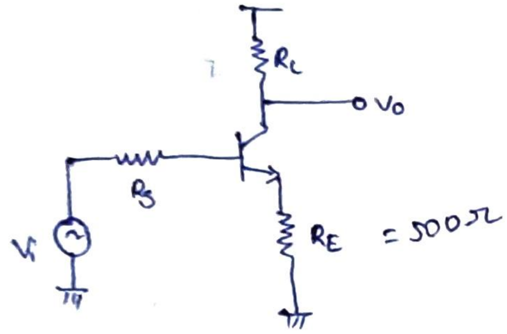
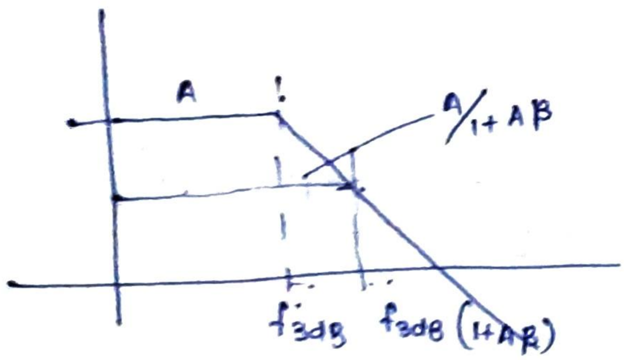


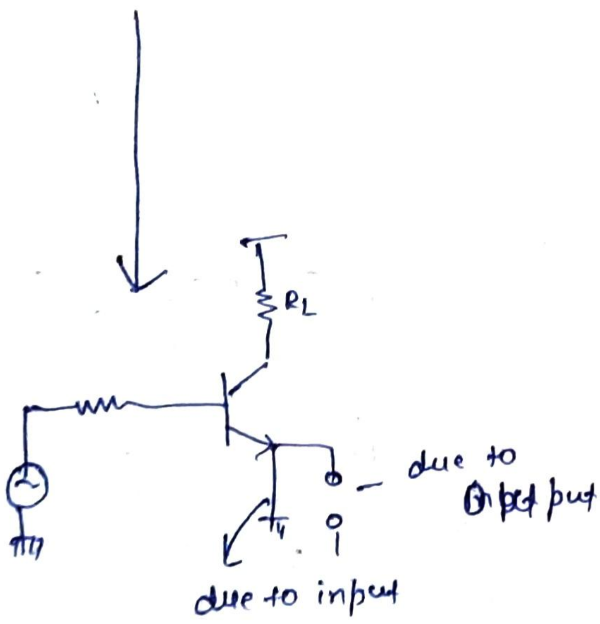
CE without emitter degeneration.

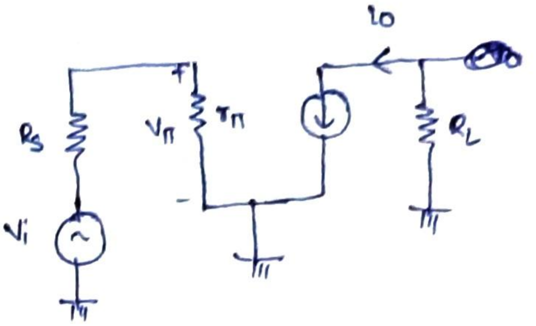


CE stage with emitter degeneration

$g_m = 38\ m\mho$
$r_\pi = 5.22\ K\Omega$
$\beta = 200$







$$i_o = +g_m V_\pi$$
$$= +g_m \times \frac{r_\pi}{r_\pi + R_S} \times V_i$$
$$\frac{i_o}{v_i} = \frac{+g_m r_\pi}{r_\pi + R_S}.$$

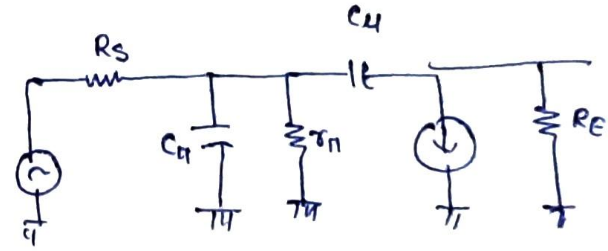
$$f = R_E$$

$$\left.\frac{i_o}{V_i}\right|_{CL} = \frac{+g_m r_\pi}{r_\pi + R_S + g_m r_\pi R_E} = \frac{\frac{+g_m r_\pi}{r_\pi + R_S}}{1 + R_E\left(\frac{+g_m r_\pi}{r_\pi + R_S}\right)}.$$

$$\left.\frac{i_o}{v_i}\right|_{OL} = +\frac{38 \times \cancel{10^{-3}} \times 5.22 \times \cancel{10^{3}}}{15.22 \times 10^3} = \frac{198.36}{15.22}$$
$$= 13.032 \times 10^{-3}.$$

$$\left.\frac{i_o}{v_i}\right|_{CL} = \frac{13.033 \times 10^{-3}}{1 + 13.033 \times \cancel{10^{-3}} \times 0.5 \times \cancel{10^{3}}}$$
$$= \frac{13.033 \times 10^{-3}}{7.515} = 1.734 \times 10^{-3}$$

$1 + A\beta =$
$$1 + 13.033 \times 0.5 = 7.47$$



for Bandwidth determination, we determine only dominant pole $\longrightarrow$ Short circuit,

After short circuit

$$R_\pi = R_S \| r_\pi = 3.43\ k\Omega$$

$$R_\mu = (R_S \| r_\pi) + R_C + g_m (R_S \| r_\pi) R_C$$

$$= 3.43\times10^3 + 5\times10^3 + 38 \times \cancel{10^{-3}} \times 3.43 \times \cancel{10^3} \times 5\times10^3$$

$$= 10^3 (8.43 + 651.7)$$

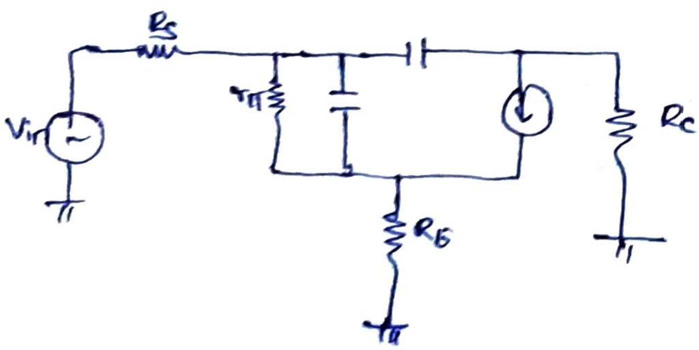
$$= 660\ k\Omega.$$

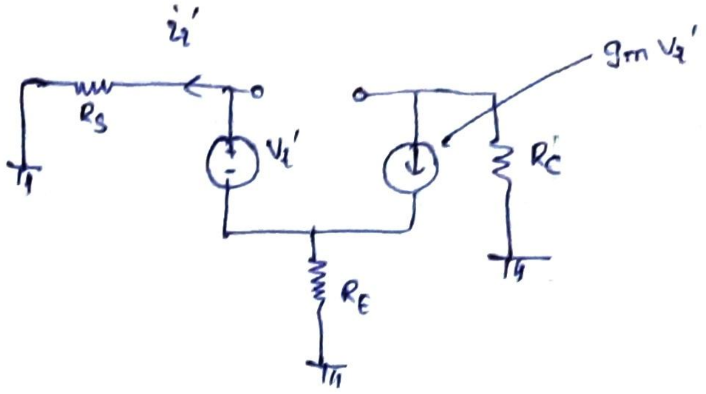
$$\boxed{f_{3dB} = \frac{1}{2\pi (R_\pi C_\pi + R_\mu C_\mu)}}$$

$$= \frac{1}{2\pi (3.43\times10^3 \times 9.8\times10^{-12} + 660\times10^3 \times 10^{-12})}$$

$$= (33.614 + 660) \times 10^{-9}$$

$$= 6.96\ MZ.$$





$$i_t' R_S - v_t' - (g_m v_t' - i_t') R_E = 0$$

$$i_t' (R_S + R_E) = v_t' (1 + g_m R_E)$$

$$\frac{v_t'}{i_t'} = \frac{R_S + R_E}{1 + g_m R_E}$$

$$\frac{v_t'}{i_t'} = \frac{(5 + 0.5) \times 10^3}{1 + 38 \times 0.5}$$

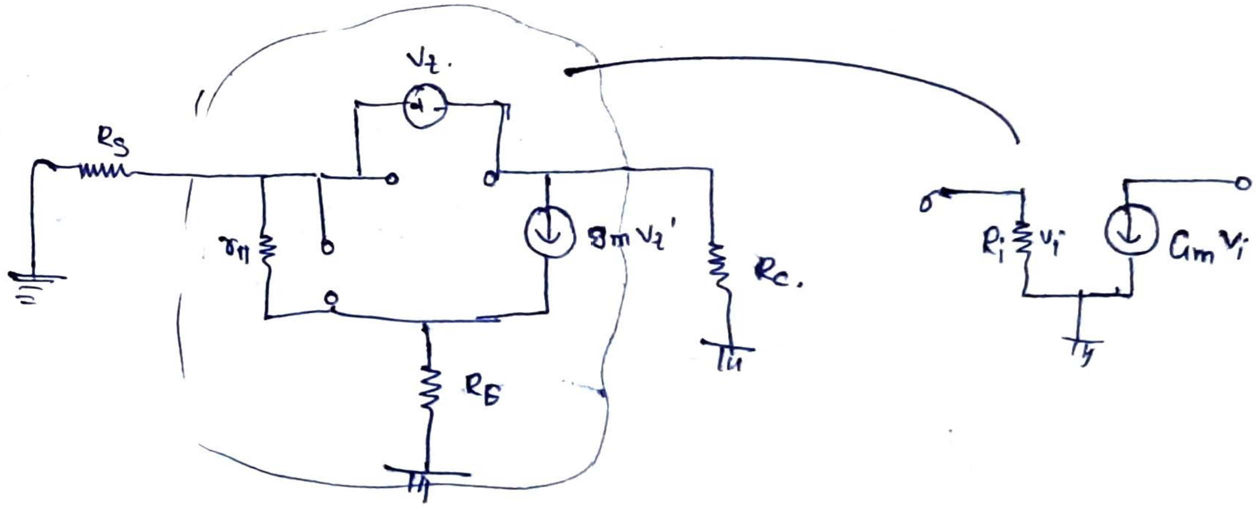
$$= 0.275 \times 10^3$$

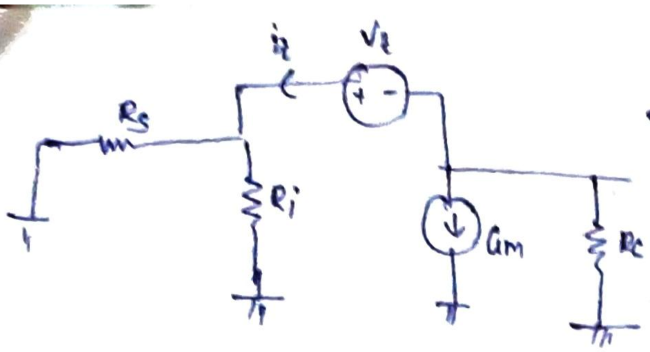
$$= 275$$

$$\frac{v_t}{i_t} = \frac{R_S + R_E}{1 + g_m R_E} \parallel r_\pi$$

$$R_{\pi'} = \frac{r_\pi \times \frac{R_S R_E}{1 + g_m R_E}}{r_\pi + \frac{R_S R_E}{1 + g_m R_E}}$$

$$\frac{v_t}{i_t} = \frac{275 \times 5.22 \times 10^3}{275 +} = \frac{1435.5 \times 10^3}{5495}$$





$$\frac{V_t}{i_t} = (R_S \parallel R_i) + R_C + G_m (R_S \parallel R_i) R_C.$$

$$R_i = r_\pi + (\beta+1) g_m.$$

$$\frac{v_i}{i} = R_i \qquad V_\pi = i\, r_\pi$$

$$V_\pi = \frac{v_i}{R_i} \times r_\pi.$$

$$G_m = \frac{i_o}{v_i} \qquad G_m = \frac{g_m r_\pi}{R_i}$$

$$R_i = r_\pi + (\beta+1) g_m = 105.7\ k\Omega.$$

$$G_m = \frac{g_m r_\pi}{R_i} = 1.88 \times 10^{-3}.$$

$$R_S \parallel R_i = \frac{10 \times 105.7}{115.7} = 9.14\ k\Omega.$$

$$\frac{V_t}{i_t} = 9.14 \times 10^3 + 5 \times 10^3 + 1.88 \times \cancel{10^{-3}} \times 9.14 \times 10^3 \times 5 \times \cancel{10^3}$$

$$= (9.14 + 5 + 85.916) \times 10^3$$

$$= 100.056 \times 10^3.$$

$R_\pi = 480\,\Omega$

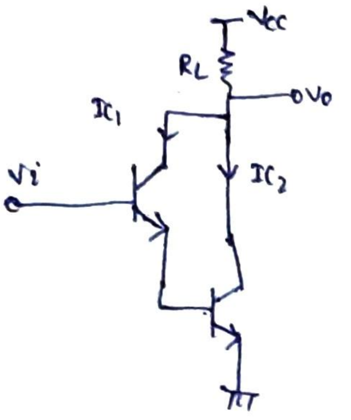
$R_\mu = 100\,K$

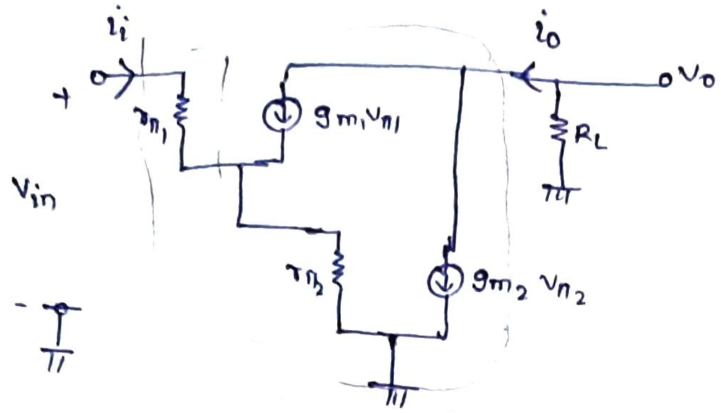
$$f_{3dB} = \frac{1}{2\pi\left(480 \times 9.8 \times 10^{-12} + 10^{5} \times 0.2 \times 10^{-12}\right)}.$$

$$= \frac{10^{12}}{(4704 + 20000) \times 2\pi}$$

$$= 6.44 \times \cancel{10^{6}}\ \text{MHz}.$$

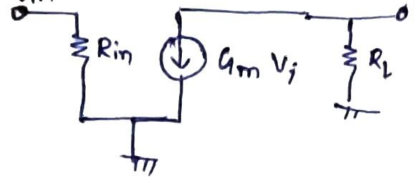
Darlington pair & freq. Analysis





$V_A \to \infty$

$$\boxed{R_{in} = r_{\pi_1} + (\beta_1 + 1)\, r_{\pi_2}.}$$



$$G_m = \frac{i_o}{v_i}$$

$$i_o = g_{m_2} v_{\pi_2} + g_{m_1} v_{\pi_1}$$

$$v_i = v_{\pi_1} + v_{\pi_2}.$$

$$v_{\pi_1} = i_i\, r_{\pi_1} \qquad v_i = i_i\, r_{\pi_1} + v_{\pi_2}$$

$$v_{\pi_2} = v_i - i_i\, r_{\pi_1}$$

$$i_o = g_{m_2}(v_i - i_i r_{\pi_1}) + g_{m_1} i_i r_{\pi_1}$$

$$= g_{m_2} v_i - (g_{m_2} r_{\pi_1} + g_{m_1} r_{\pi_1})\, i_i$$

$$= g_{m_2} v_i - (g_{m_2} r_{\pi_1} + g_{m_1} r_{\pi_1}) \frac{v_i}{R_{in}}$$

$$\frac{i_o}{v_i} = \frac{g_{m_2} R_{in} - g_{m_2} r_{\pi_1} - g_{m_1} r_{\pi_1}}{R_{in}}$$

$$G_m = \frac{g_{m_2}\left(r_{\pi_1} + (g_{m_1} r_{\pi_1} + 1)\, r_{\pi_2}\right) - g_{m_2} r_{\pi_1} - g_{m_1} r_{\pi_1}}{R_{in}.}$$

$$\cancel{g_{m_2} r_{\pi_1}} + g_{m_1} g_{m_2} r_{\pi_1} r_{\pi_2} + g_{m_2} r_{\pi_2} - \cancel{g_{m_2} r_{\pi_1}} - g_{m_1} r_{\pi_1}$$

$$G_m = \frac{g_{m1} g_{m2} r_{\pi1} r_{\pi2} + g_{m2} r_{\pi2} - g_{m1} r_{\pi1}}{R_{in}}$$

$$\boxed{G_m = \frac{\beta_1 \beta_2 + \beta_2 - \beta_1}{R_{in}}}$$

$$\frac{v_0}{v_i} = -G_m R_L = -\frac{(\beta_1 \beta_2 + \beta_2 - \beta_1)}{R_{in}} \times R_L.$$

Q. $I_{C1} = 1mA$ $\quad R_L = 5k\Omega$.

$I_{C2} = 100\mu A$

$\beta_1 = 100 = \beta_2$.

$$R_{in} = r_{\pi1} + (\beta_1 + 1) r_{\pi2}$$

$$\frac{1}{25} + 101 \times 4 \times 10^{-3} = 0.404 + 0.04 = 0.444$$

$$G_m = \frac{100 \times 100 + 100 - 100}{R_{in}} = 24.75$$

$$V_0 = -24.75 \times 5 \times 10^3.$$

$$g_{m1} = \frac{I_C}{V_T} = \frac{1}{25} = 0.04$$

$$r_{\pi2} = \frac{100 \times 10^{-3}}{25 \times 10^{-3}}$$

$$g_{m2} = \frac{100 \times 10^{-6}}{25 \times 10^{-3}}$$

$$r_{\pi1} = \frac{\beta}{g_{m1}} = \frac{100}{1} \times 25 = 25 \times 10^2 = 4 \times 10^{-3}.$$

$$r_{\pi2} = \frac{\beta_2}{g_{m2}} = \frac{100 \times 25}{4} \times 10^3 = 25 \times 10^3.$$

$$R_{in} = 2500 + 101 \times 25 \times 10^3.$$

$$= 2.53 \times 10^6.$$

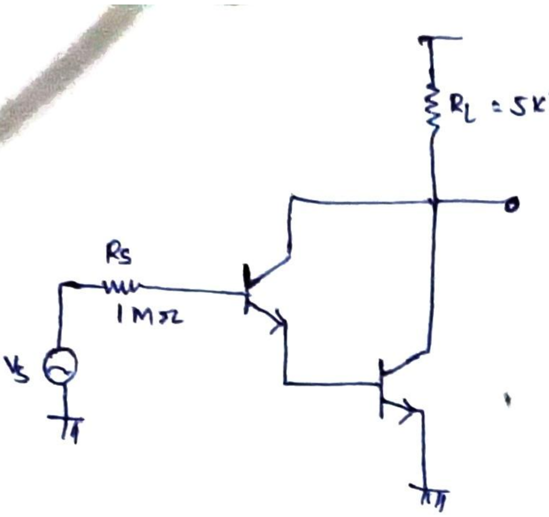
$$\frac{v_0}{v_i} = \sim 3.9m \times 5k \simeq -20 \ V/V.$$

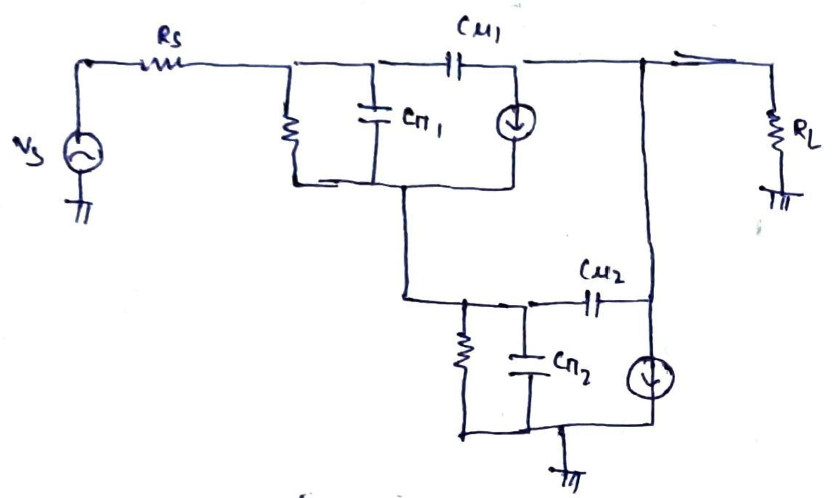
$f_T = 600\ MHz$ @ 1mA

$f_T = 400\ MHz$ @ 100 μA.

$C_\pi = 10\ C_\mu$.

$R_S = 1M\Omega$.





$g_m = I_C / V_T$

$= \frac{1}{25}$

$= 0.04$.

$$f_T = \frac{g_m}{2\pi (C_\pi + C_\mu)} = 600\ MHz.$$

$$C_\pi + C_\mu = \frac{0.04 \times 10^{-6}}{2\pi \times 600} = 0.01047 \times 10^{-4}$$

$$= 1.05\ \mu F.$$

$11\ C_\mu = 1.05\ \mu F$

$C_{\mu_1} = 1.05 = 0.095\ \mu F$.

$C_{\pi_1} = 0.95\ \mu F$.

$$g_{m_2} = \frac{\cancel{100}^{\,4} \times 10^{-3}}{\cancel{25 \times 10^{3}}}$$

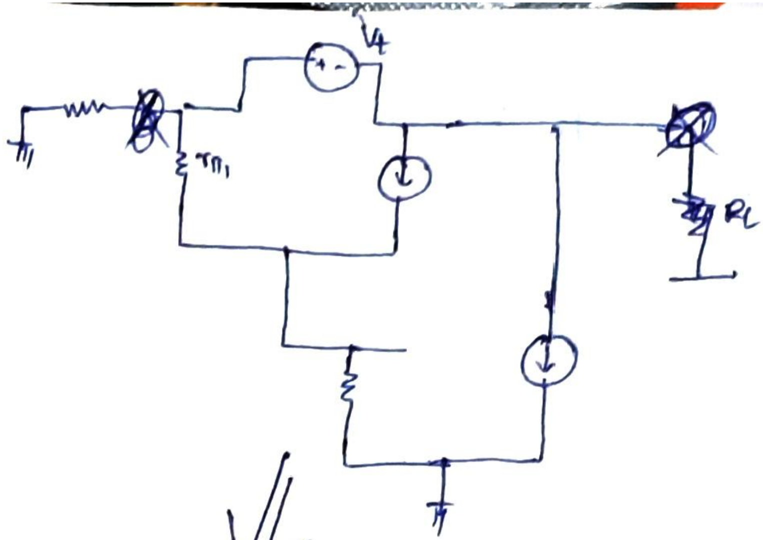
$= 4 \times 10^{-3}$

$$f_{T_2} = \frac{g_{m_2}}{2\pi (C_\pi + C_\mu)} \longrightarrow \frac{4 \times 10^{-3}}{\quad}$$

$$C_{\pi_2} + C_{\mu_2} = \frac{4 \times 10^{-3}}{2\pi \times 400} \times 10^{-6}$$

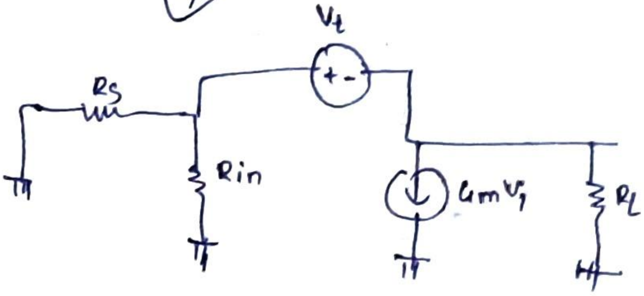
$C_{\pi_2} = 1.4\ pF$

$C_{\mu_2} = 0.14\ pF$.



Rin = 2.57 MΩ

Rs = 1MΩ.



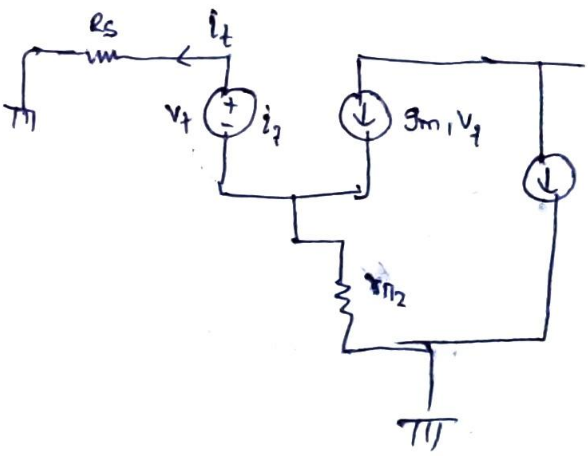
$$\frac{V_t}{i_t} = R_S \| R_{in} + R_L + G_m (R_S \| R_{in}) R_L .$$

$$= \frac{2.57 \times 1}{3.57} + 5\times 10^3 + 3.9 \times \cancel{10^{-3}} \times 0.72 \times 10^6 \times 5 \times \cancel{10^3}$$

$$= 0.72\times 10^6 + 5\times 10^3 + 14.04 \times 10^6$$

$$= 14.76 \times 10^6 + 500$$

$$R_{M_1} = \underline{14.765 \text{ M}\Omega}$$



$$i_t R_S - V_t - (g_{m_1} V_t - i_t) r_{\pi_2} = 0.$$

$$i_t (R_S + r_{\pi_2}) = V_t (1 + g_{m_1} r_{\pi_2})$$

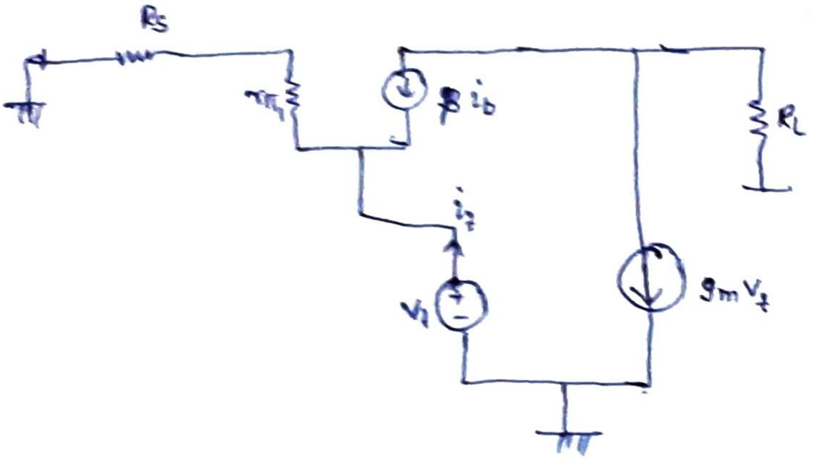
$$\frac{V_t}{i_t} = \frac{(R_S + r_{\pi_2})}{1 + g_{m_1} r_{\pi_2}}.$$

$$R_{\pi_1} = \frac{(R_S + r_{\pi_2})}{1 + g_{m_1} r_{\pi_2}} \| r_{\pi_1} .$$

$$R_{\pi_1} = \frac{10^6 + 25\times10^3}{1 + 0.04\times25\times10^3} \parallel r_{\pi}$$

$$= 1024 \parallel 2500$$

$$= 726.45\ \Omega.$$



$$-i_t = i_b + \beta_1 i_b$$

$$\Rightarrow \quad i_b = \frac{-i_t}{\beta_1+1}$$

$$-i_b R_S - i_b r_{\pi_1} - V_t = 0$$

$$V_t = -i_b\,(R_S + r_{\pi_1})$$

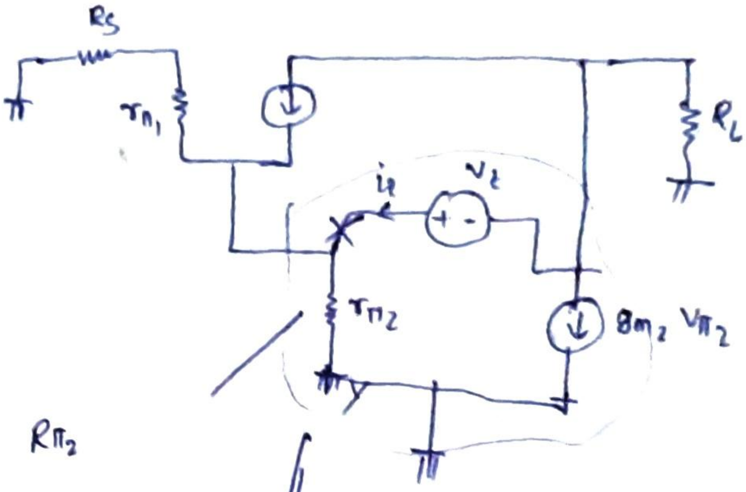
$$V_t = \frac{i_t}{\beta_1+1}\,(R_S + r_{\pi_1})$$

$$R_{\pi_2} = \frac{V_t}{i_t} = \frac{R_S + r_{\pi_1}}{(\beta_1+1)} \parallel r_{\pi_2}.$$

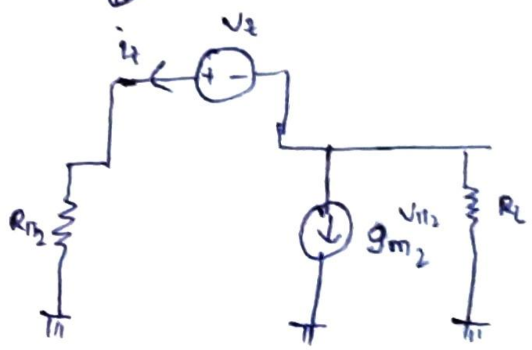
$$= \frac{10^6 + 2500}{(101)} \parallel 25\times10^3.$$

$$99{\cdot}25.74$$

$$= 7.1\ \text{k}\Omega.$$



R_{π_2}

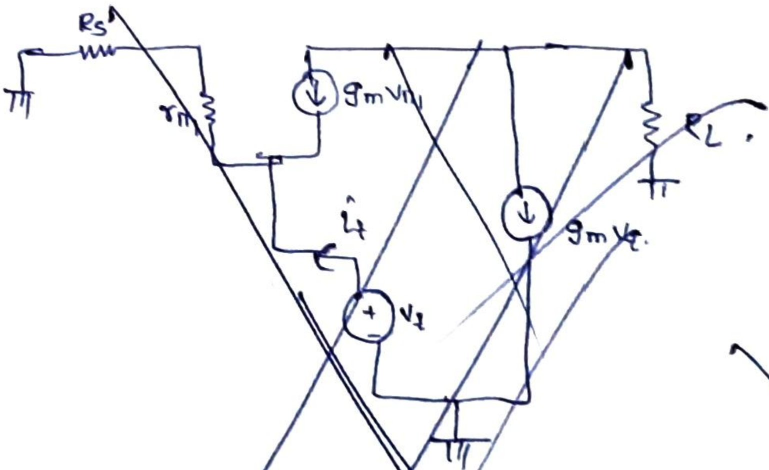


$$R_{i_2} = \frac{v_t}{i_t} = R_{\pi_2} + R_L + g_{m_2} R_{\pi_2} \times R_L .$$

$$= 25\times10^3 + 5\times10^3 + 4\times\cancel{10^{3}} \times 25\times\cancel{10^{3}} \times 5\times10^3$$

$$30\times10^3 + 105\times10^3$$

$$= 135\ k\Omega .$$



$$-i_t = \cancel{i_b} + \beta_1 i_b$$

$$i_b = \frac{-i_t}{\beta_1 + 1}$$

$$-i_b R_S - i_b r_{\pi_1} - v_t = 0$$

$$v_t = -i_b (R_S + r_{\pi_1})$$

$$v_t = \ .$$

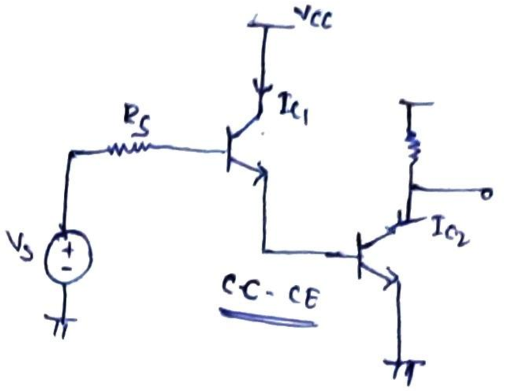
$$f_{3\text{-}dB} = \frac{1}{2\pi \left(C_{\pi_1} R_{\pi_1} + C_{\pi_2} R_{\pi_2} + C_{\mu_1} R_{\mu_1} + C_{\mu_2} R_{\mu_2} \right)}$$

$C_{\pi_1} = 9.2\ pF$ $\qquad$ $R_{\pi_1} = 726.45\ \Omega$

$C_{\mu_1} = 0.92\ pF$ $\qquad$ $R_{\pi_2} = 7.1\ k\Omega.$

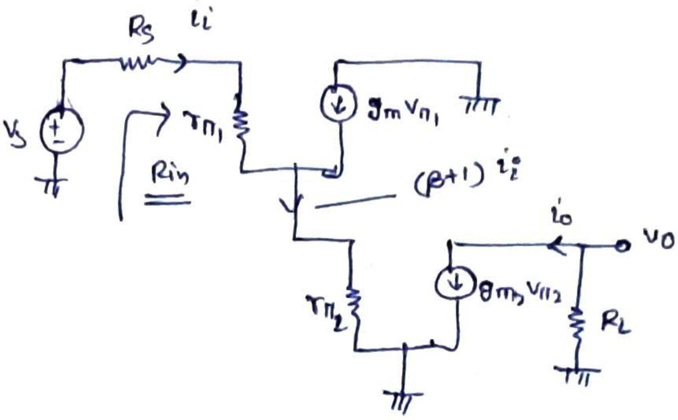
$C_{\pi_2} = 1.4\ pF$ $\qquad$ $R_{\mu_1} = 14.765\ M\Omega.$

$C_{\mu_2} = 0.14\ pF$



$I_{C_1} = 1mA$

$I_{C_2} = 100\ \mu A$



$R_{in} = r_{\pi_1} + (\beta_1+1)\, r_{\pi_2}$

$$i_o = g_{m_2} v_{\pi_2}$$

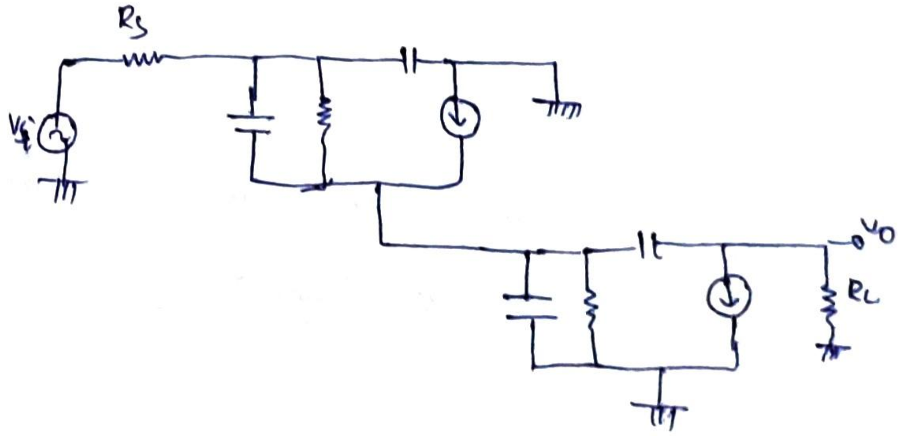
$$= g_{m_2}\ i_i\ (\beta+1)\, r_{\pi_2}$$

$$i_o = g_{m_2}\,(\beta+1)\, r_{\pi_2} \times \frac{v_i}{R_{in}}$$

$$\frac{i_o}{v_i} = G_m = \frac{\beta_2\,(\beta_1+1)}{R_{in}} = \frac{100 \times 101}{2.53 \times 10^6}$$

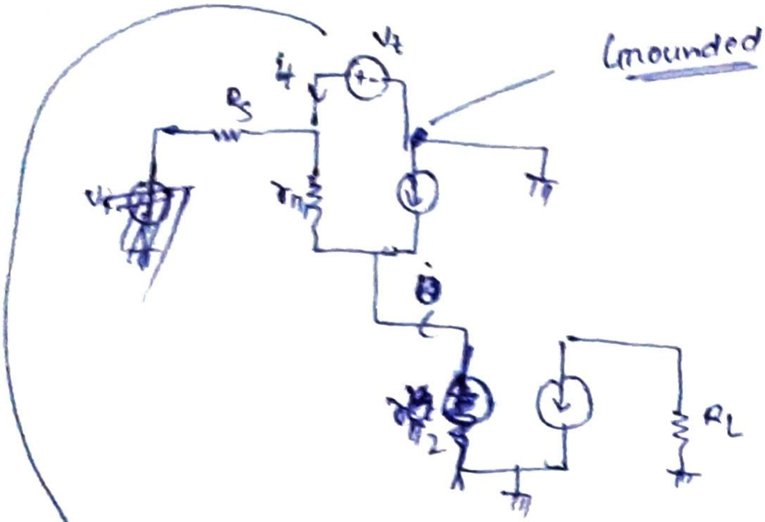
$$= 3992.09 \times 10^{-6}$$

$$= 3.99 \times 10^{-3}$$



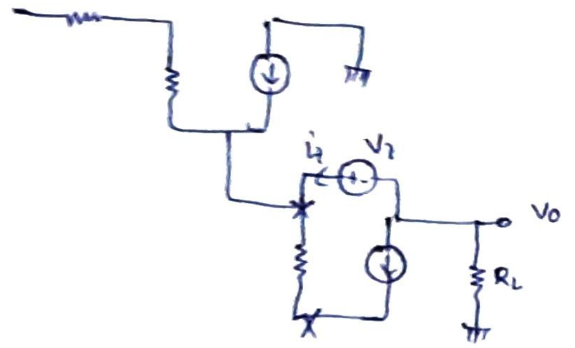
$R_{\pi_1} = 0.71\,k\Omega$ → circuit resembles same as earlier discussed.

Grounded



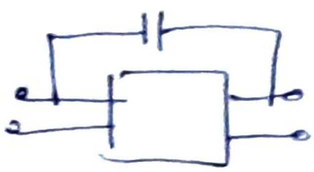
Equivalent resistance will be R_{in}.

$R_{\mu_1} = R_{in} = 2.5\,M\Omega$.



$R_{\mu_2} = 152\,k\Omega$.

$R_{\pi_2} = 7\,k\Omega$.



Miller capacitance C_{μ_1} present in darlington pair

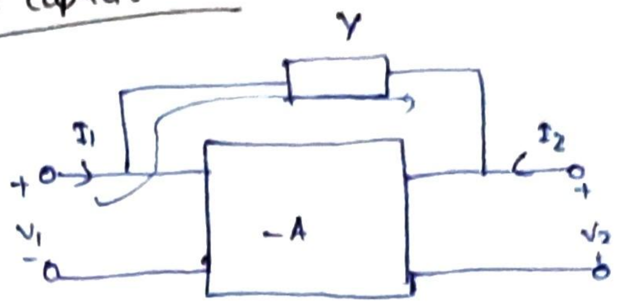
Slow in nature.

If we remove it, we can achieve higher Bandwidth.

In 2nd circuit

R_{μ_2} → lower than earlier (darlington pair).

Miller capacitance



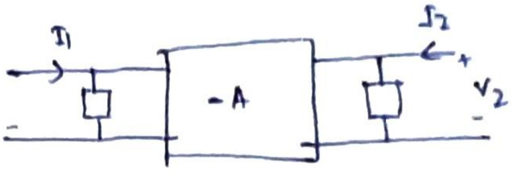
$$\frac{V_2}{V_1} = -A$$

$$V_1 - \frac{I}{Y} - V_2 = 0$$

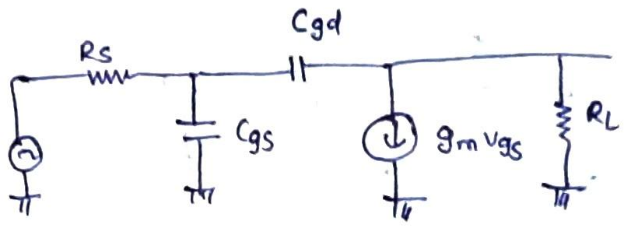
$$V_1 - \frac{I}{Y} + AV_1 = 0$$

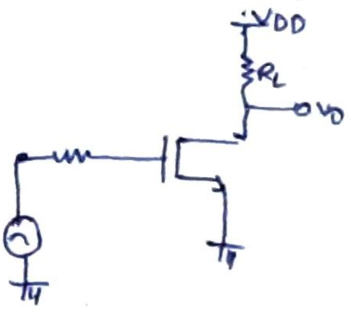
$$V_1(1+A) = I/Y$$

$$Y(1+A) = \frac{I}{V_1}$$

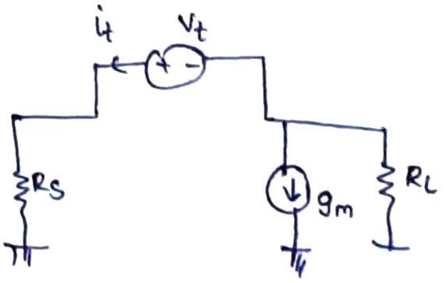


$$\boxed{Y' = Y(1+A)}$$





$$V_o = -g_m R_L$$



$$\frac{V_t}{i_t} = R_s + R_L + g_m R_s R_L$$

$$= R_s(1+g_m R_L) + R_L$$

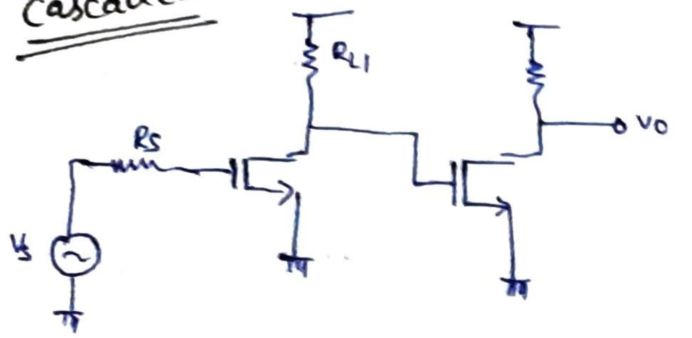
$$f_{3dB} = \frac{1}{2\pi\{C_{gd}(R_s(1+g_m R_L)+R_L) + C_{gs}R_s}$$

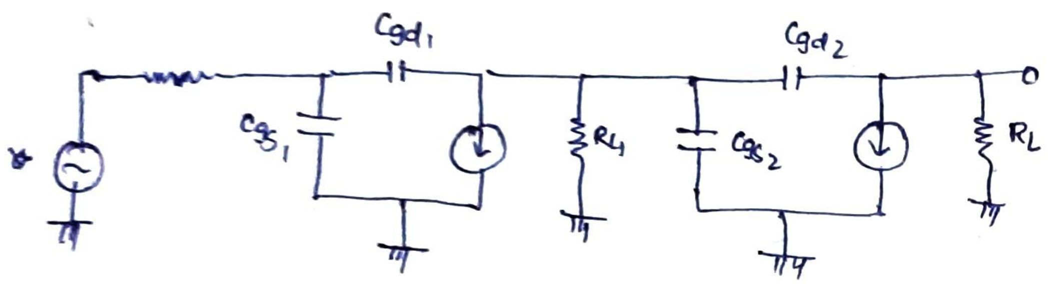
$$= \frac{1}{2\pi\{\underbrace{C_{gd}(1+g_m R_L)R_s} + C_{gd}R_L + C_{gs}R_s)}$$

Miller capacitance

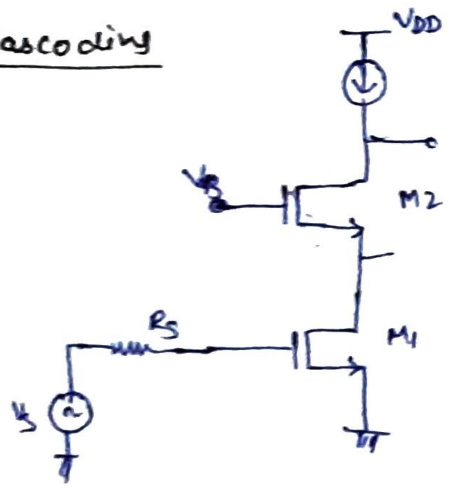
Miller capacitance $\rightarrow$ $C_{gd}(1+g_m R_L)$

Cascaded





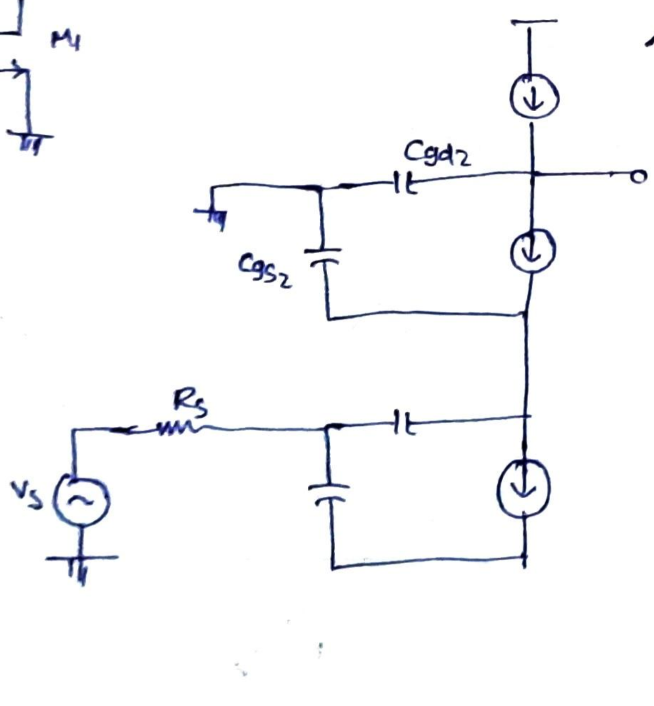
Cascoding

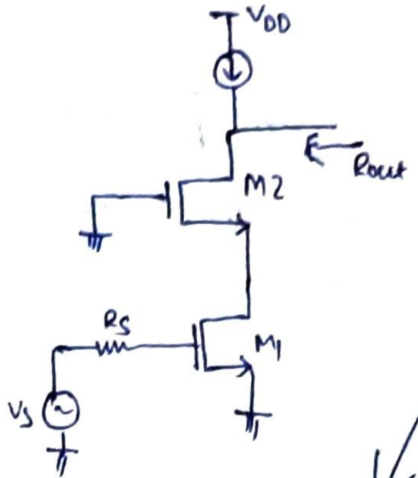


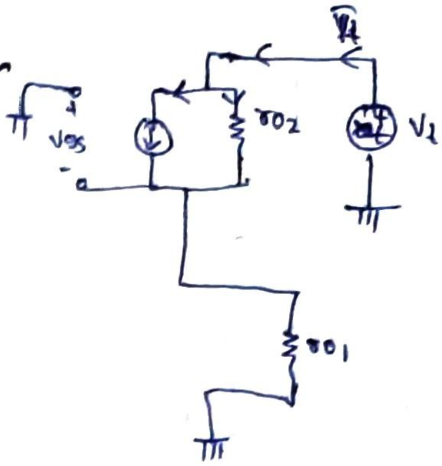
No miller capacitance b/w i/p & o/p

⇓

Bandwidth will be Improved/Increase







Only gate is connected to ground not source.

$$v_{gs2} = -i_t r_{o1}$$

$$-v_{gs_2} - i_t r_{o1} = 0 \quad (1)$$

$$i_t - g_{m_2} v_{gs_2} - \frac{(V_t - i_t r_{o1})}{r_{o2}} = 0 \quad (2)$$

$$i_t + g_{m_2} i_t r_{o1} - \frac{V_t}{r_{o2}} + i_t \frac{r_{o1}}{r_{o2}} = 0$$

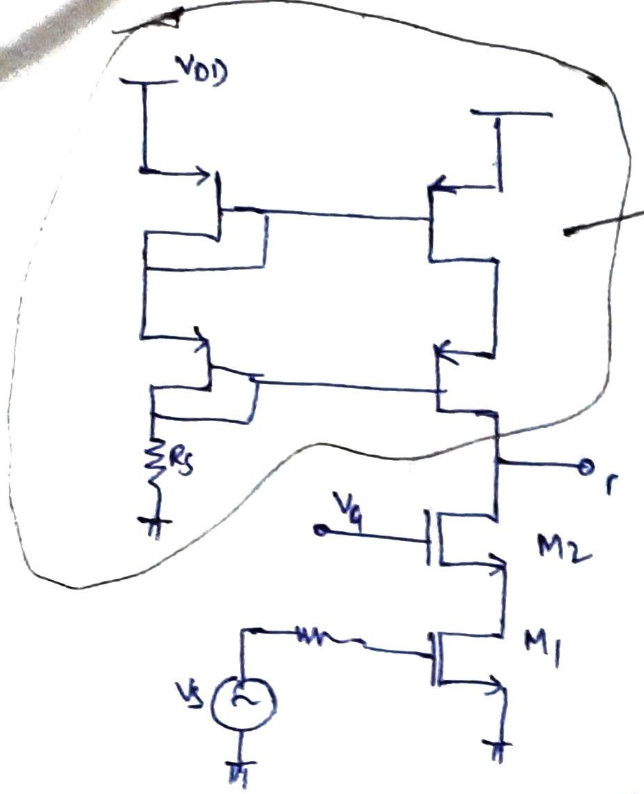
$$\frac{V_t}{r_{o2}} = i_t \left(1 + g_{m_2} r_{o1} + \frac{r_{o1}}{r_{o2}} \right)$$

$$\frac{V_t}{i_t} = r_{o2} \left(1 + g_{m_2} r_{o1} + \frac{r_{o1}}{r_{o2}} \right)$$

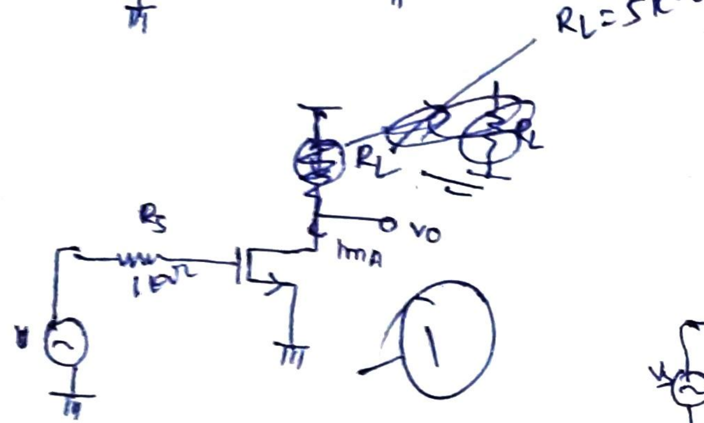
$$\frac{V_t}{i_t} = r_{o2} + g_{m_2} r_{o1} r_{o2} + r_{o1}$$

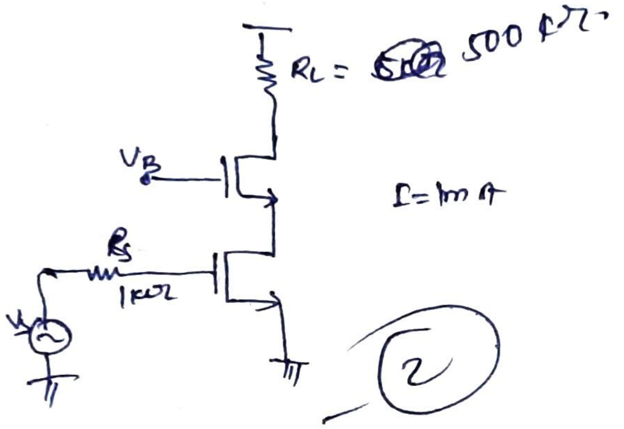
$$\frac{V_t}{i_t} \cong (g_{m_2} r_{o2})\, r_{o1}$$

To preseve gain we must have R_L of the order $(g_{m_2} r_{o2})\, r_{o1}$



design to perserve the gain of cascoding circuit.





$\frac{W}{L} = 100$

$\mu_n C_{ox} = 60 \mu A/V^2$

$C_{gs} = 100 fF$

$C_{gd} = 20 pF$

$(g_{m_2} r_{o_2}) r_{o_1}$

$r_{o_1} = r_{o_2} = 10 k\Omega$

$g_{m_2} = \sqrt{2 \mu_n C_{ox} \frac{W}{L} \times I}$

$= \sqrt{2 \times 60 \times 10^{-6} \times 100 \times 10^{-3}}$

$= \sqrt{12 \times 10^{-6}}$

$= 3.46 \times 10^{-3}$.

$(g_{m_2} r_{o_2}) r_{o_1} = 3.46 \times 10^{-3} \times 10 \times 10 \times 10^{6}$

346×10^{3}

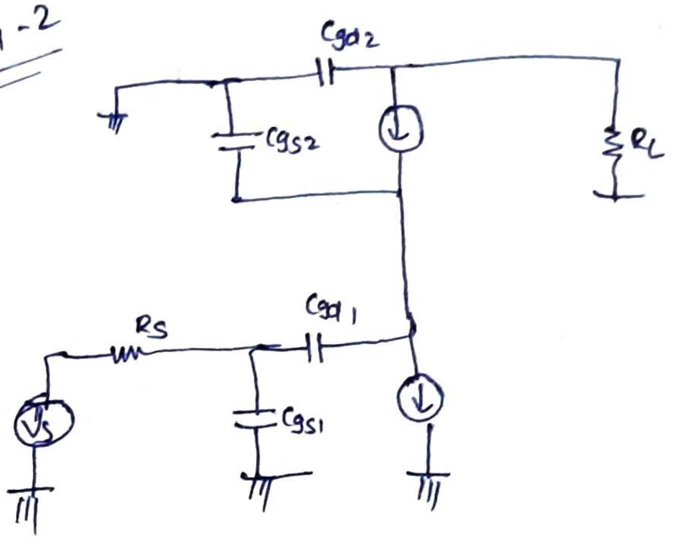
$346 k\Omega$.

$$f_{3dB} = \frac{1}{2\pi \{ C_{gs} R_{gs} + C_{gd} R_{gd} \}}$$

for circuit ① .

$$f_{3dB} = \frac{1}{2\pi \{ C_{gs} R_S + C_{gd} (R_S + R_L + g_m R_S R_L) \}}$$

for circuit -2



$$= \frac{1}{2\pi \left(100\times10^{-15} \times 10^{3} + 20\times10^{-15} \left(1+5+ 3.46\times10^{-3} \times 1\times5 \times 10^{3} \right) \right)}$$

$$6 + 3.46 \times 5$$

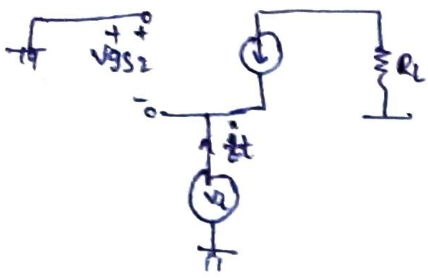
$$23.3 \times 10^{3}$$

$$= \frac{1}{2\pi \left(10^{-10} + 466 \times 10^{-12} \right)}$$

$$= \frac{1}{2\pi \times 5.66} \times 10^{10}$$

$$= 0.2775 \times 10^{10}$$

$$= 2.78 \times 10^{9}$$



$$i_t = -g_{m2} v_{gs2}$$

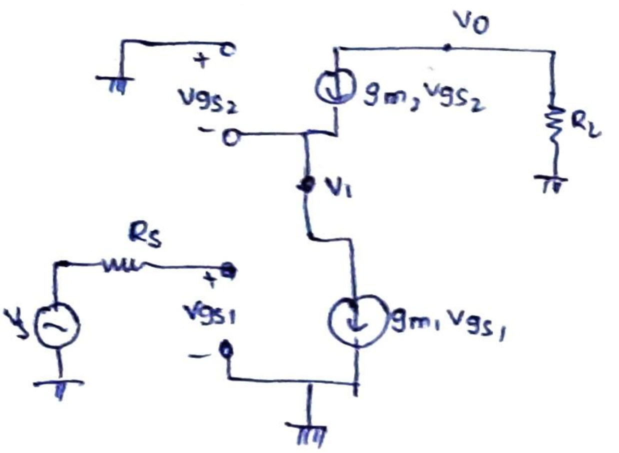
$$-v_{gs} - v_t = 0$$

$$\frac{v_t}{i_t} = 1/g_{m2}$$

$$v_1 = -g_{m1} v_s \times \frac{1}{g_{m2}}$$

$$\frac{v_1}{v_s} = -\frac{g_{m1}}{g_{m2}} = -1$$

Gain of cascoding amplifier.



$$v_{gs2} = -v_1$$

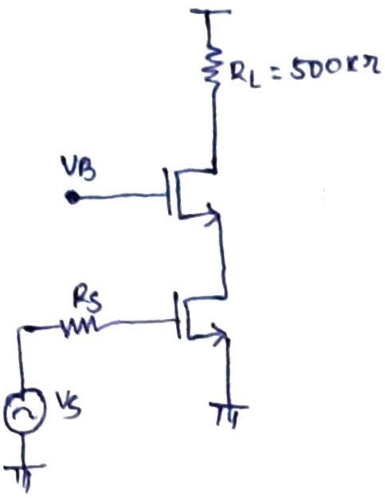
$$v_o = -R_L g_{m2} v_{gs2}$$

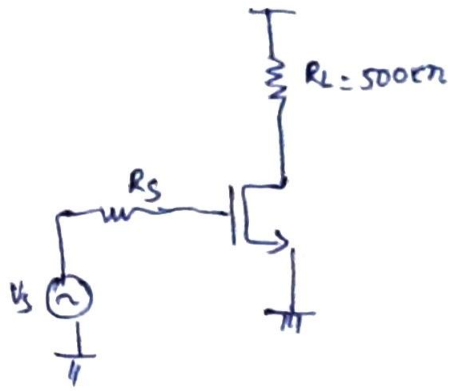
$$v_o = -R_L g_{m2} \times (-v_1)$$

$$\frac{v_o}{v_1} = R_L g_{m2}.$$

$$\boxed{\frac{v_o}{v_s} = \frac{v_1}{v_s} \times \frac{v_o}{v_1} = -1 \times g_{m2} R_L = -g_{m2} R_L}$$

Both cascoding and CS gain are $(-g_{m2} R_L)$





$$f_{3\text{-}dB} = \frac{1}{2\pi\left\{C_{gs} R_s + C_{gd}\left(R_s + R_L + g_m R_s R_L\right)\right\}}.$$

$$= \frac{1}{2\pi\left[100\times10^{-15}\times10^{3} + 20\times10^{-15}\times10^{3}\left\{1+500+3.46\times10^{3}\times1\times500\right\}\right]}$$

$$= \frac{1}{2\pi\left[10^{-10} + 2\times10^{-11}\left[2231\right]\right]}.$$

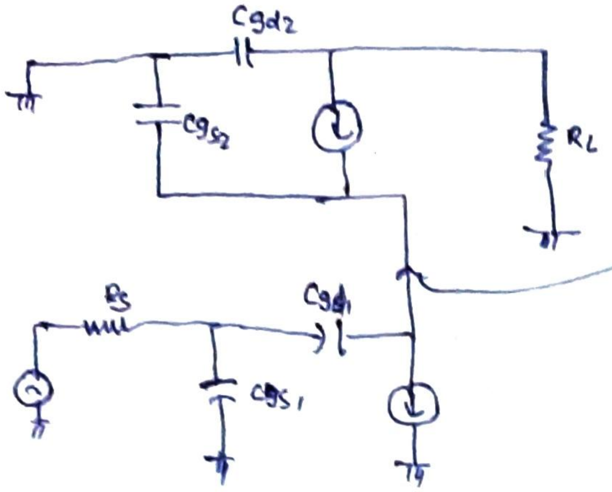
$$= \frac{10^{10}}{2\pi\left[1 + 0.2\times2231\right]}.$$

$$= \frac{10^{10}}{2\pi\times447.2}.$$

$$= 0.0003512 \times 10^{10}$$

$$= 3.512\times10^{6}.$$

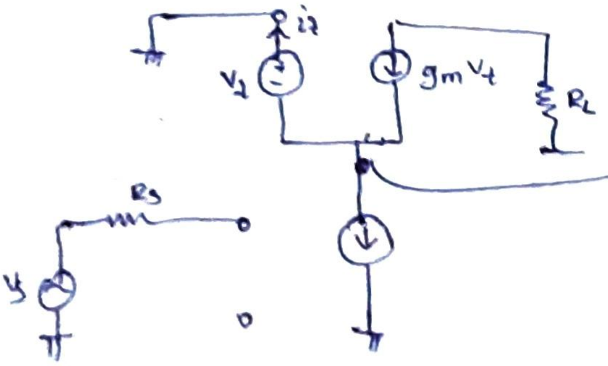
$$= 3.5\,MHz.$$



Resistance across this

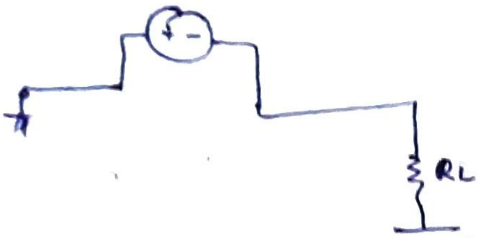
$R_{gs_1} = R_s$

$R_{gd_1} = R_s + \frac{1}{g_{m_2}} + g_{m_1} R_s \times \frac{1}{g_{m_2}}$



$v_t / i_t = \frac{1}{g_{m_2}}$

$R_{gs_2} = \frac{1}{g_{m_2}}$



$R_{gd_2} = R_L$

$$f_{3dB} = \frac{1}{2\pi \left\{ C_{gs_1} R_s + C_{gd_1} R_{gd_1} + C_{gs_2} \times \frac{1}{g_{m_2}} + C_{gd_2} R_L \right\}}.$$

$$= \frac{1}{2\pi \left\{ C_{gs_1} \left\{ R_s + \frac{1}{g_{m_2}} \right\} + C_{gd_1} \left\{ 2R_s + \frac{1}{g_{m_2}} + R_L \right\} \right\}}.$$

$$= \frac{1}{2\pi \left\{ 100\times10^{-15}\left(10^3 + \frac{10^3}{3.46}\right) + 20\times10^{-15}\left\{2\times10^3 + \frac{10^3}{3.46} + 500\times10^3\right\}\right.}$$

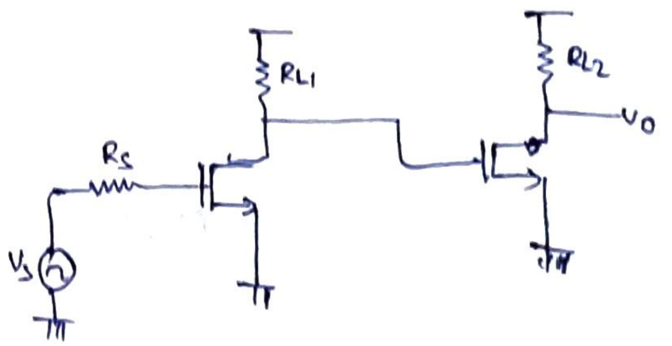
$$10^{-10} \times 1.289 \quad + \quad \underbrace{2\times10^{-11}\underbrace{\left[2 + \tfrac{1}{3.46} + 500\right]}_{502.289}}_{1004.578\times10^{-11}}$$

$$= \frac{10^{10}}{2\pi\left\{1.289 + 100.4578\right]}$$

$$= \frac{10^{10}}{2\pi \times 101.7466}$$

$$= 15.6\,MHz.$$

↳ Cascoding design with more component is faster than simple CS Amplifier having same gain.



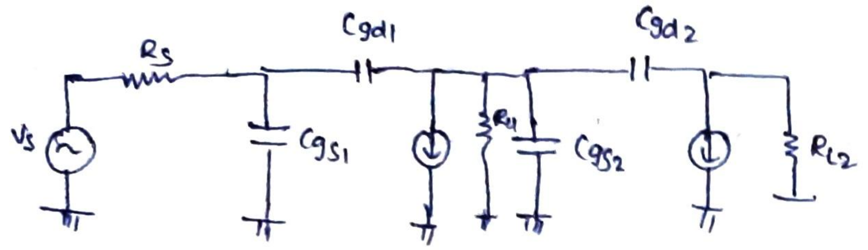
$$\frac{V_o}{V_s} = (g_{m1} \times R_{L1})(g_{m2}\times R_{L2})$$

$$= 3.46m\,(1\quad)\;3.46\,(\quad)$$

↳ 120

$R_{L1} = R_{L2} = 12k\Omega$

to match the gain of above discussed amplifier.



1KΩ

$R_{gs} = R_s$

$R_{gd1} = R_s + R_{L1} + g_{m} R_s R_{L1}$

$R_{gs_2} = R_{L1}$

$R_{gd_2} = R_{L1} + R_{L2} + g_{m_2} R_{L1} R_{L2}$

$R_{gd_1} = 10^3 + 12 \times 10^3 + 3.46 \times \cancel{10^{-3}} \times 1 \times 12 \times 10^3 \times \cancel{10^3}$

$= 54.52\ k\Omega$

$R_{gs_2} = 12k\Omega$

$R_{gd_2} = 24\ k + 3.46 \cancel{\times 10^{-3}} \times 144 \times 10^3$

$= 522.24\ k\Omega.$

$$f_{3dB} = \frac{1}{2\pi \{ C_{gs} \times 1K + C_{gd_1} \times 54.52k + C_{gs_2} \times 12K + C_{gd_2} \times 522.24.}$$

$$= \frac{1}{2\pi \left[100 \times 10^{-15} \times 13 \times 10^3 + 20 \times 10^{-15} \times 10^3 \times 596.76 \right\}.}$$

$$= \frac{1}{2\pi \times \{ 13 \times 10^{-10} + 115.352 \times 10^{-20}}$$

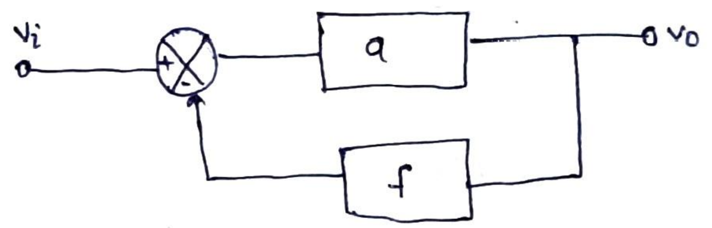
$$= \frac{10^{10}}{2 \times 3.14 \times 128.352}$$

$f_{3dB} = 1.3\ MHz.$

for 0 Miller capacitor	for 1 Miller capacitor	for - 2 miller capacitance
f_{3dB} 15.6 MHZ	$f_{3dB} =$ 3.56 MHz	$f_{3dB} = 1.3$ MHZ

5/10/23

Stability of (-ve) feedback amplifier



$$\frac{V_o}{V_i} = \frac{a}{1+af}$$ C.L gain

af → loop gain

a → O.L. gain

$$= \frac{a(j\omega)}{1+a(j\omega)f}.$$

$$\frac{V_o}{V_i} = \frac{a(j\omega)}{1+|a(j\omega)| \angle a(j\omega) f}.$$

$$T(j\omega) = a(j\omega)f$$

i) if $|T(j\omega)| = 1$

$\angle T(j\omega) = 180°$

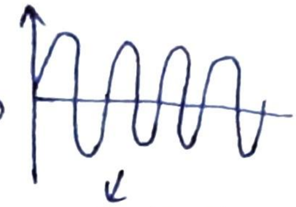
→ V_o becomes oscillatory.

(ii) if $|T(j\omega)| > 1$

$\angle T(j\omega) = 180°$

$\rightarrow$ $V_0 \rightarrow$ unstable.

no input $\rightarrow$

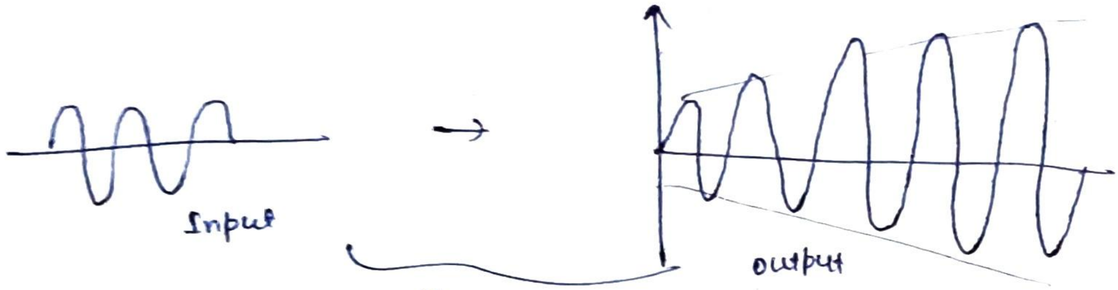


Oscillating output

$\Downarrow$

unstable condn.

In pratical, amplitude & parameter doesn't vary with time due to pratical nature of ckt.



(iii) if $|T(j\omega)| < 1$

and $\angle T(j\omega) = 180°$ $\Big\}$ $\rightarrow$ Stable.

These three conditions are Barkhausen's criteria

2 pole amplifier

$$a(s) = \frac{a_0}{(s+p_1)(s+p_2)}$$

$$= \frac{a_0'}{(1+s/p_1)(1+s/p_2)}$$

All poles are widely apart

$p_2 >> p_1$

$\Downarrow$

$p_2 > 10p_1$

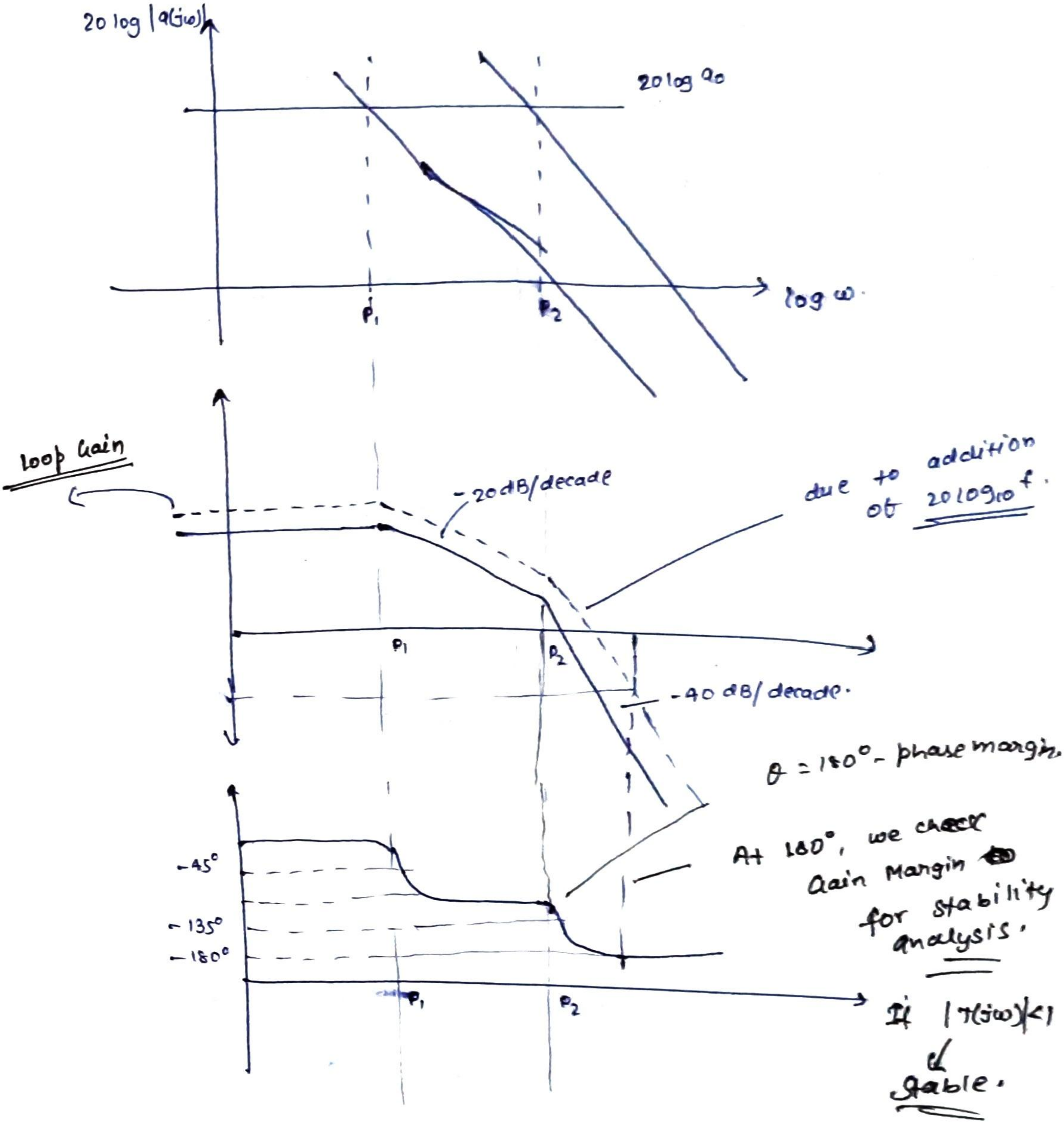
$\Downarrow$

p_1 & p_2 are widely apart.

$$|a(j\omega)| = \frac{a_0'}{\sqrt{1+\left(\frac{\omega}{p_1}\right)^2}\sqrt{1+\left(\frac{\omega}{p_2}\right)^2}}$$

$$|a(j\omega)|_{dB} = 20\log\left(\frac{a_0'}{\sqrt{1+(\omega/p_1)^2}\left(\sqrt{1+\left(\frac{\omega}{p_2}\right)^2}\right)}\right).$$

$$20\log|a(j\omega)| = 20\log a_0 - 20\log\sqrt{1+\left(\frac{\omega}{P_1}\right)^2} - 20\log\sqrt{1+\left(\frac{\omega}{P_2}\right)^2}.$$



At ~~[illegible]~~, Loop Gain = 1,

If phase margin < 180°, → Stable

Greater than 180° → Unstable.

phase = 180°

↳ check GM for Stability.

Q. An amplifier with low freq. fwd gain 40k V/V

-ve real poles are 2kHz, 200kHz, 4MHz. It is

connected in feedback with β - constant.

Close loop gain of the circuit = 400.

Find out the phase margin?

Soln:

$$a(j\omega)f = \frac{a_0 \beta}{\left(1+\frac{j\omega}{P_1}\right)\left(1+\frac{j\omega}{P_2}\right)\left(1+\frac{j\omega}{P_3}\right)}$$

$$= \frac{a_0 \beta}{\left(1+\frac{jf}{P_1}\right)\left(1+\frac{jf}{P_2}\right)\left(1+\frac{jf}{P_3}\right)}$$

$$= \frac{40k \ \beta}{\left(1+\frac{jf}{2k}\right)\left(1+\frac{jf}{200k}\right)\left(1+\frac{jf}{4M}\right)}$$

$$\frac{a_0}{1+a_0\beta} = 400$$

$$\frac{\cancel{4}0\times10^3}{1+40k\,\beta} = \cancel{4}00$$

$$100 = 1 + 40\times10^3\times\beta$$

$$\beta = \frac{99}{40}\times10^{-3}$$

$$= 2.475\times10^{-3}$$

$a_0 \beta = 2.495 \times 10^{-3} \times 40 \times 10^{3}$

$= 99.$

$$a(j\omega)\beta = \frac{100}{\left(1+\frac{jf}{2k}\right)\left(1+\frac{jf}{200k}\right)\left(1+\frac{jf}{4M}\right)}.$$

$|a(j\omega)\beta| = 1$

$$\frac{100}{\sqrt{1+\left(\frac{f_c}{2k}\right)^2}\sqrt{1+\left(\frac{f_c}{200k}\right)^2}\sqrt{1+\left(\frac{f_c}{4M}\right)^2}} = 1$$

at $f = 2K$

$\frac{100}{\sqrt{2}} > 1$

$f_{p_1} < f_c < f_{p_2}.$

at $f = 200k.$

$\frac{100}{100 \times \sqrt{2} \times 1} = 1/\sqrt{2} < 1$

$f_{p_1} < f_c < f_{p_3}$ $\longrightarrow$ p_3 terms can be ignored.

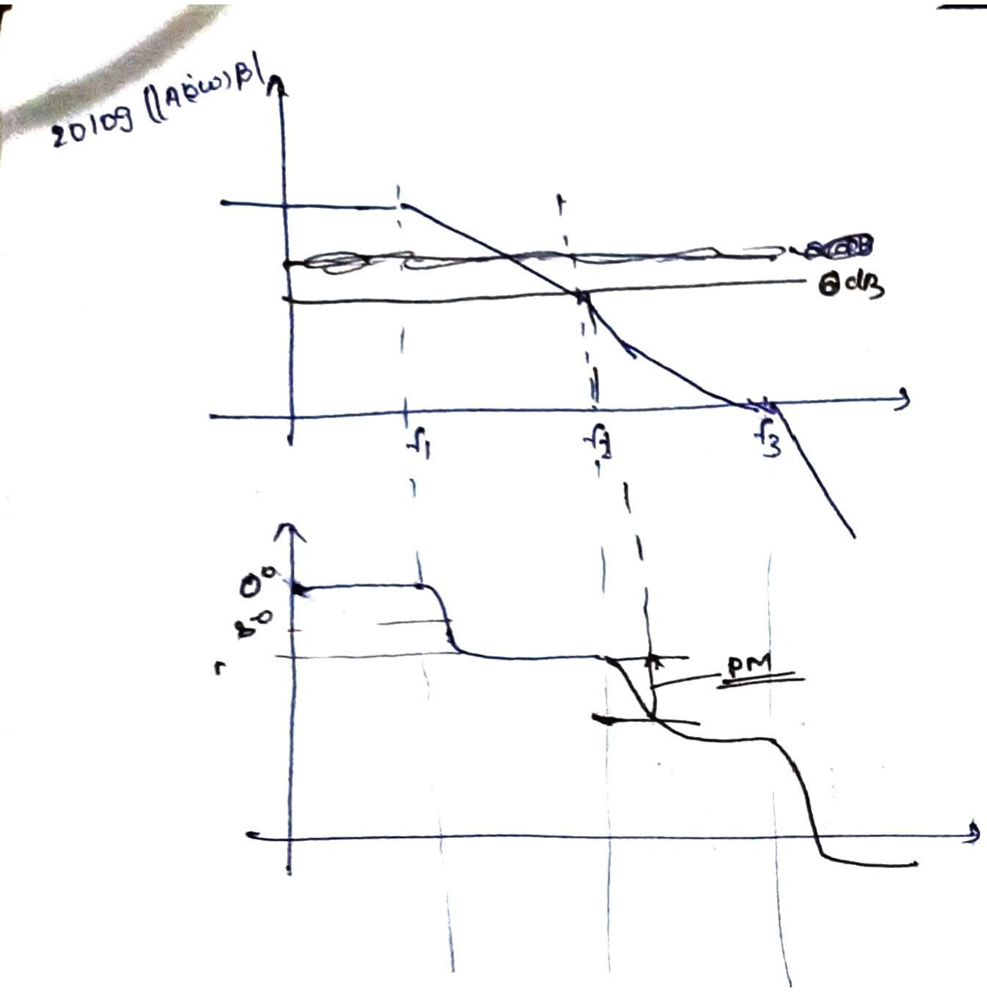
$$100^2 = \left(1+\frac{f_c^2}{(2k)^2}\right)\left(1+\frac{f_c^2}{(200k)^2}\right)$$

$f_c = 157.230 \times 10^3$

$$\Rightarrow \frac{f_c^4}{(2k)^2(200k)^2} + f_c^2\underbrace{\left(\frac{1}{(2k)^2}+\frac{1}{(200k)^2}\right)}_{2.5 \times 10^{-7}} - 100^2 = 0.$$

$$\frac{x^2}{a\,b} + x \times \left(\frac{1}{a} + 1/b\right) - 100^2 = 0.$$

$$x = \frac{-\left(\frac{1}{a}+1/b\right) \pm \sqrt{\left(\frac{1}{a}+\frac{1}{b}\right)^2 - 4 \cdot 10^4 \cdot 1/ab}}{2\, 1/ab}.$$



$f_1 = 2\,kHz$
$f_2 = 200\,kHz$
$f_3 = 4\,MHz$.

$f_c = 157\,kHz$

$$\angle A(j\omega)\beta = -\tan^{-1}\frac{f_c}{f_1} - \tan^{-1}\frac{f_c}{f_2} - \tan^{-1}\frac{f_c}{f_3}.$$

$$= -89.27^\circ - 38.13 - 2.25$$

$$= -129.65^\circ$$

$$PM = 180^\circ - 129.65^\circ$$
$$= 50.35^\circ$$

for General circuit PM should be $(50-60)^\circ$

open loop gain = 40K
closed loop gain = 400
↓.
100

$$\frac{A_0}{1+A_0\beta} = 100$$

$$100 = \frac{40\times10^3}{1+40\times10^3\times\beta}$$

$$40\times10^3\times\beta = 400-1$$

$$\beta = \frac{399}{40\times}\times10^{-3}$$

$$= 9.975\times10^{-3}.$$

$$\beta \simeq 0.01$$

$$|A(j\omega)\beta|_{f=f_1} = \frac{A_0\ \beta}{\sqrt{\left(1+\left(\frac{f}{f_1}\right)^2\right.}\sqrt{1+\left(\frac{f}{f_2}\right)^2}\sqrt{1+\left(\frac{f}{f_3}\right)^2}}$$

At $f=f_1$

$$\theta = \frac{40\times10^3\times10^{-2}}{\sqrt{2}\times\underbrace{\sqrt{1+(0.01)^2}}_{\simeq 1}\underbrace{\sqrt{1+\left(\frac{\cancel{2}\times10^3}{\cancel{4}_2\times10^6}\right)}}_{\simeq 1}}$$

$$= \frac{400}{\sqrt{2}} = 200\sqrt{2}.$$

At $f=f_2$

$$|A(j\omega)\beta|^{\theta} = \frac{A_0\ \beta}{\frac{f_2}{f_1}\times\sqrt{2}\times\sqrt{1+\frac{\cancel{200}\times\cancel{10^3}}{\cancel{4}_2\times10^3}}}$$

$0.0\cancel{101}(0.05)^2$

$$= \frac{40\times10^3\times\cancel{10^{3}}\ 10^{-2}}{\frac{\cancel{2}}{\cancel{200}\ \cancel{100}\ 100}\times\sqrt{2}}$$

$$= \underline{\underline{2\sqrt{2}.}}$$

At $f = f_3$,

$$|A_o(j\omega)\beta| = \frac{A_o\ \beta}{f_3/f_1 \times \dfrac{f_3}{f_2} \times \sqrt{2}}.$$

$$= \frac{\cancel{40}^{\cancel{20}\ 10} \times \cancel{10^5} \times 10^{-2}}{\dfrac{\cancel{4} \times \cancel{10^6}}{7 \times \cancel{10^3}} \times \dfrac{4 \times 10^6}{\cancel{200}_{100} \times \cancel{10^5}} \times \sqrt{2}}$$

$$= \frac{1000 \times 10^{-2}}{\sqrt{2}} = \frac{100}{\sqrt{2}}.$$

$$= \frac{1}{100\sqrt{2}}.$$

$f_2 < f_c < f_3$ & also $f_c \ll f_3$.

$f_2 \gg f_1$ $f_c \gg f_1$.

at $\underline{\underline{f = f_c}}$

$$|A_o(j\omega)\beta| = \frac{A_o\ \beta}{\sqrt{1 + \left(\frac{f_c}{f_1}\right)^2}\sqrt{1 + \left(\frac{f_c}{f_2}\right)^2}\sqrt{1 + \left(\frac{f_c}{f_3}\right)^2}}$$

$$\simeq \frac{A_o\ \beta}{\frac{f_c}{f_1}\sqrt{1 + \left(\frac{f_c}{f_2}\right)^2}} > 1.$$

$$A_o\beta = \frac{f_c}{f_1}\sqrt{1 + \left(\frac{f_c}{f_2}\right)^2}$$

$$(A_0\beta)^2 = \left(\frac{f_c}{f_1}\right)^2 + \left(\frac{f_c}{f_1}\right)^2\left(\frac{f_c}{f_2}\right)^2$$

$$\frac{x^4}{f_1^2 f_2^2} + \frac{x^2}{f_1^2} - A_0^2\beta^2 = 0$$

$$x^4 + f_2^2 x^2 - f_1^2 f_2^2 (A_0\beta)^2 = 0$$

$$x^4 + 4\times10^{10} x^2 - 4\times4\times10^{16} \quad 16\times10^{8} * 10^{-4}$$

$$256 * 10^{20}.$$

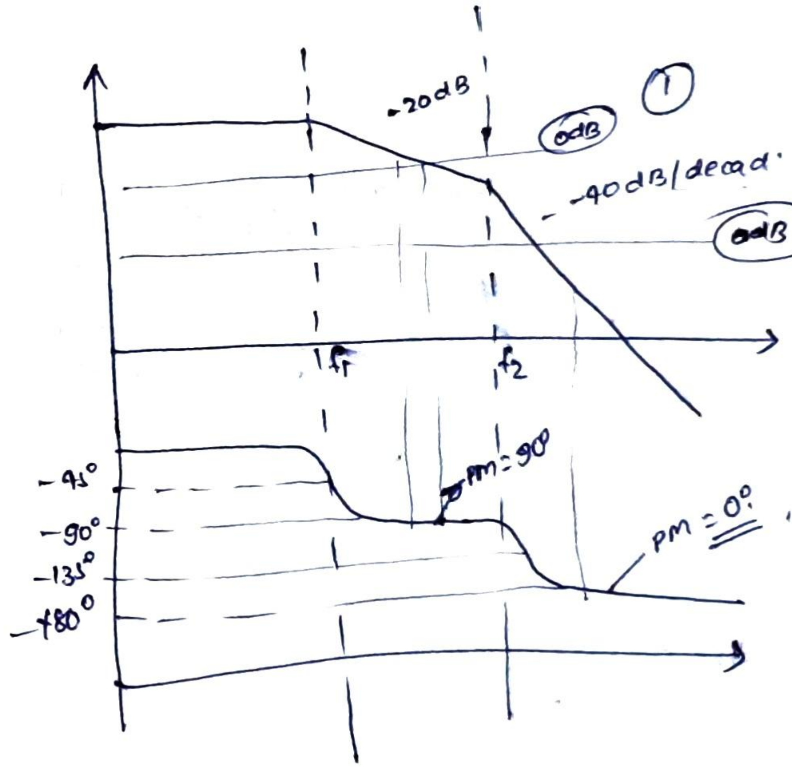
$f_1 = 2K$
$f_2 = 200K$

$f_c = 380\ \text{kHz}$

$PM = 180^\circ - |\angle A(j\omega)\beta|$

$\angle A(j\omega)\beta = -157^\circ$

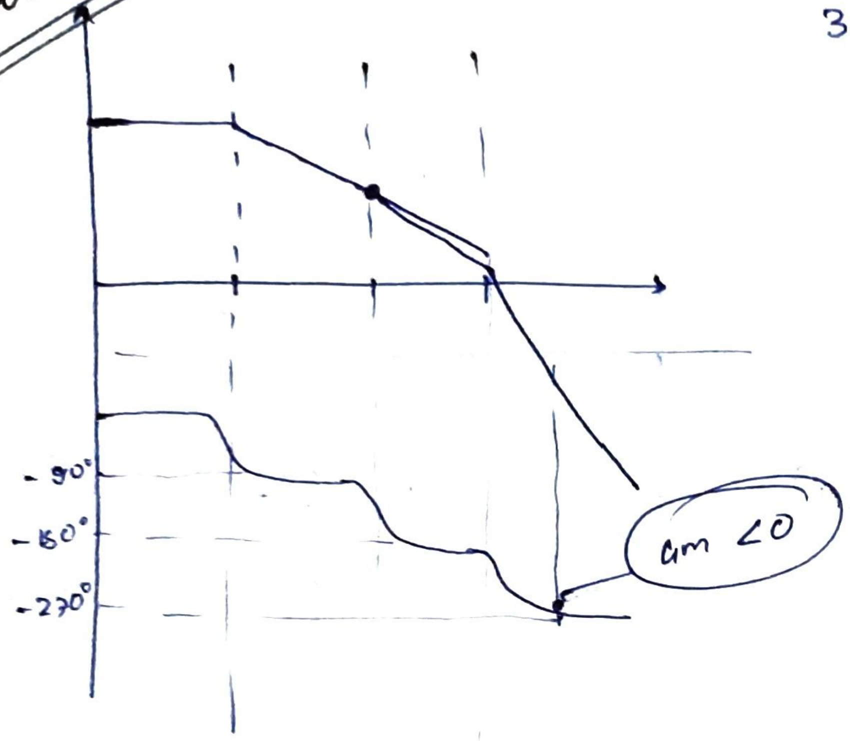
$PM = 180^\circ - 157^\circ.$



for any two pole system,
It can't be unstable but it may be very close to unstability.

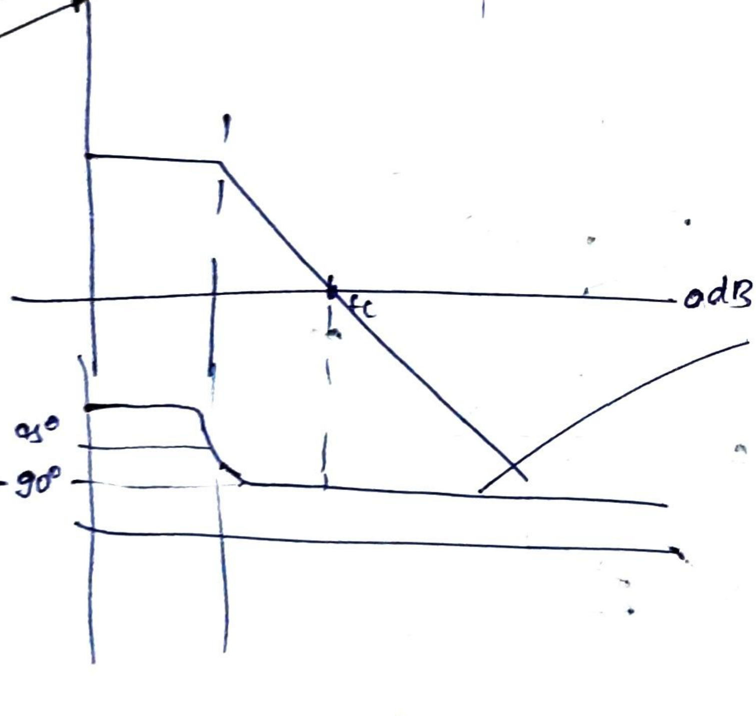
3-pole

3- pole



So, for 3-pole system
It become
unstable

single pole



for single pole system
GM always will
be 90°
and stable.

$$A_0(j\omega)\beta = \frac{A_0 B}{\left(1+j\frac{f}{f_1}\right)\left(1+j\frac{f}{f_2}\right)}$$

$f_2 >> f_1$

domin

$$A_0(j\omega)\beta = \frac{A_0\beta}{\left(1+j\frac{f}{f_1}\right)}$$

$$|A_0(j\omega)\beta| = \frac{A_0\beta}{\sqrt{1+\left(\frac{f}{f_1}\right)^2}}$$

$$|A_0(j\omega_c)\beta| = \frac{A_0\beta}{\sqrt{1+\left(\frac{f_c}{f_1}\right)^2}}$$

as $f_c >> f_1$

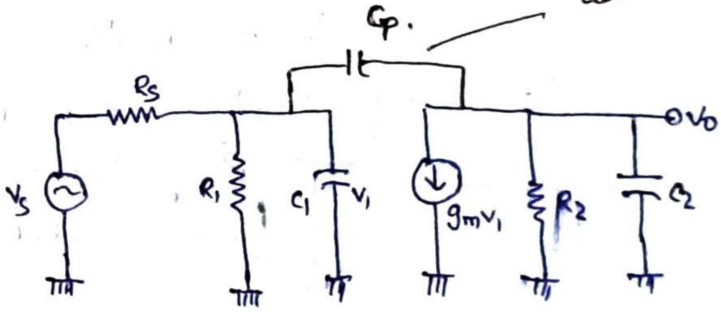
$$|A_0(j\omega_c)\beta| = \frac{A_0\beta}{f_c/f_1} \approx 1.$$

only for single-pole System

$$\boxed{\underbrace{A_0\beta}_{\text{Gain}}\ \underbrace{f_1}_{\text{Bandwidth}} = \underbrace{1.\ f_c.}_{\text{constant}}}$$

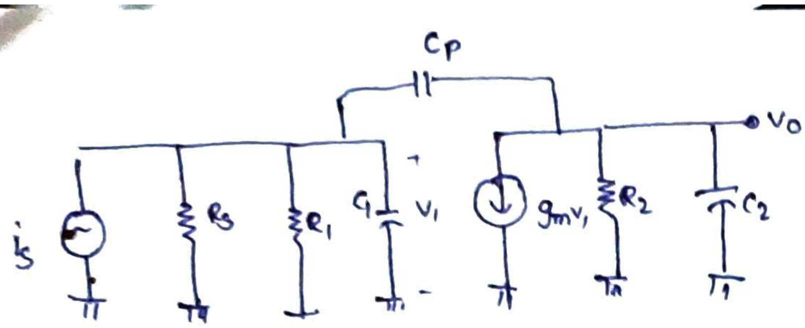
Theory of pole Splitting

C_p. addition of miller capacitance.



$$f_d = \frac{1}{2\pi\{C_1\, R_1 \| R_s + C_2 R_2\}}$$

$$f_{nd} = \frac{1}{2\pi}\left\{\frac{1}{C_1\, R_1 \| R_s} + \frac{1}{C_2 R_2}\right\}.$$



$R_1' = R_1 \parallel R_S$

$$\frac{V_o(s)}{i_s(s)} = \frac{(C_p s - g_m) R_2}{s^2 R_2 R_1' \left(C_1 C_2 + C_p(C_1 + C_2)\right) + s\left\{R_1'(C_p + C_1) + R_2 (C_p + C_2) + g_m R_2 R_1' C_p\right\} + 1}$$

$$\frac{V_o}{i_s} = \frac{(C_p s - g_m) R_2}{\left(1 + \frac{s}{P_d}\right)\left(1 + \frac{s}{P_{nd}}\right)}$$

$f_d \ll f_{nd}$, after pole splitting.

$$= \frac{(C_p s - g_m) R_2}{\frac{s^2}{P_d P_{nd}} + s\left[\frac{1}{P_d} + \frac{1}{P_{nd}}\right] + 1}$$

$$1/P_d + 1/P_{nd} \approx 1/P_d$$

$$= R_1'(C_p + C_1) + R_2(C_p + C_2) + g_m R_2 R_1' C_p$$

$$g_m R_2 R_1' C_p \gg R_1'(C_p + C_1) + R_2(C_p + C_2)$$

$$\frac{1}{P_d} = g_m R_2 R_1' C_p.$$

Considering dominant pole analysis,

~~then~~ open

$$R_{C_1} = R_s \parallel R_1 = R_1'$$

$$R_{C_S} = R_1' + R_2 + g_m R_1' R_2$$

$$R_{C_2} = R_2$$

$$f_d = \frac{1}{2\pi\left\{C_1 \times R_1' + C_2 R_2 + C_p\left\{R_1' + R_2 + g_m R_1' R_2\right\}\right\}}.$$

$$f_d \approx \frac{1}{2\pi\, g_m R_1' R_2 C_p}.$$

In this we can't determine non-dominant pole we have to go through exact Solution method.

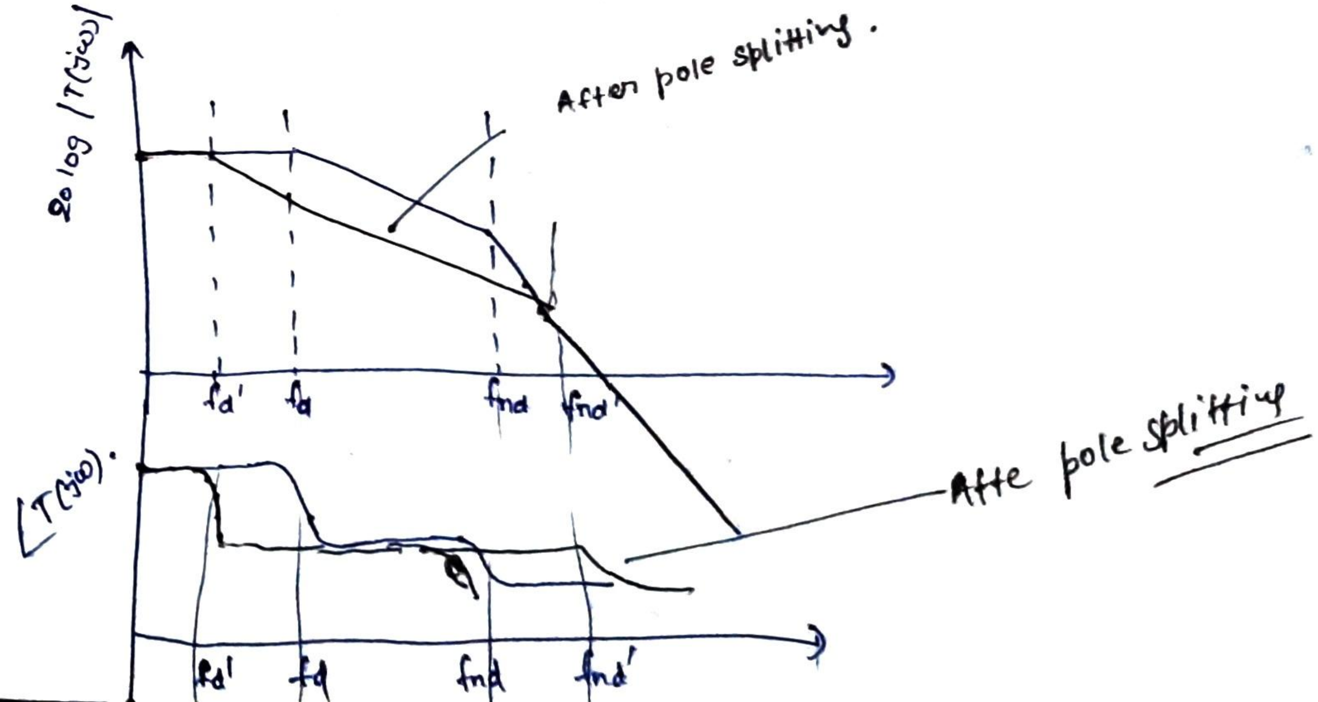
$$\frac{1}{P_d P_{nd}} = R_2 R_1' \left\{ C_1 C_2 + C_p (C_1 + C_2) \right\}.$$

$$\boxed{1/P_d = g_m R_2 R_1' C_p.}$$

$$\Rightarrow \frac{g_m R_2 R_1' C_p}{P_{nd}} = R_2 R_1' \left\{ C_1 C_2 + C_p (C_1 + C_2) \right\}.$$

$$\boxed{P_{nd} = \frac{g_m C_p}{C_1 C_2 + C_p (C_1 + C_2)}.}$$

$$\boxed{f_{nd}' = \frac{g_m C_p}{2\pi \left\{ C_1 C_2 + C_p (C_1 + C_2) \right\}}.}$$

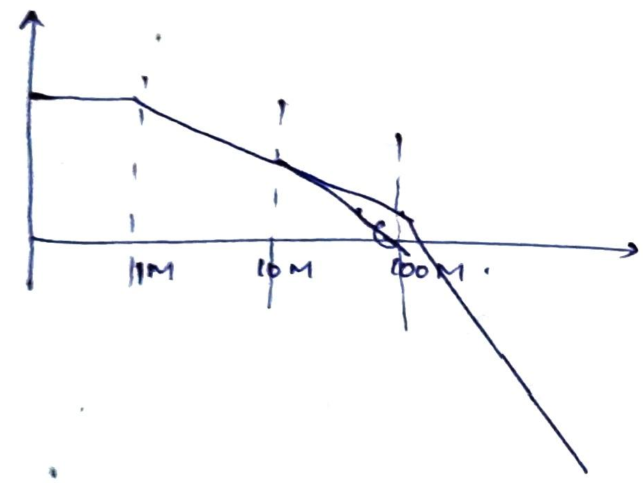


Q. Consider the following transfer fn

$$T(jf) = \frac{5\times10^5}{\left(1+\frac{jf}{1M}\right)\left(1+\frac{jf}{10M}\right)\left(1+\frac{jf}{100M}\right)}$$

Insert a dominant pole in the T.F so that the PM becomes 45^0.

Sol^n:- Step 1 Calculate PM for $T(jf)$.



$$|T(jf)| = 1$$

$$\frac{5\times10^5}{\sqrt{1+\left(\frac{fc}{1M}\right)^2}\cdot\sqrt{1+\left(\frac{fc}{10M}\right)^2}\sqrt{1+\left(\frac{fc}{100M}\right)^2}} = 1$$

first determine where fc lies;

At $fc = f_1$

$$|T(jf)| = 5/\sqrt{2}\times10^5$$

At $fc = 10M$

$$|T(jf)| = \frac{5\times10^5}{\frac{10}{2}\times\sqrt{2}} = \frac{5}{2\sqrt{2}}\times10^5$$

At $fc = 100M$

$$|T(j\omega)| = \frac{5\times10^5}{\sqrt{2}\times}$$

$f_c > 100M.$

from the phase plot we can say,

GM is -ve $\Rightarrow$ Unstable.

$\Downarrow$

Inserting dominant pole.

$$T(j\omega) = \frac{5 \times 10^5}{\left(1 + \frac{jf}{f_d}\right)\left(1 + \frac{jf}{1M}\right)\left(1 + \frac{jf}{10M}\right)\left(1 + \frac{jf}{100M}\right)}$$

$\Downarrow$

so to get $PM = 45^\circ$, 0dB line cross over should occur at 135°.

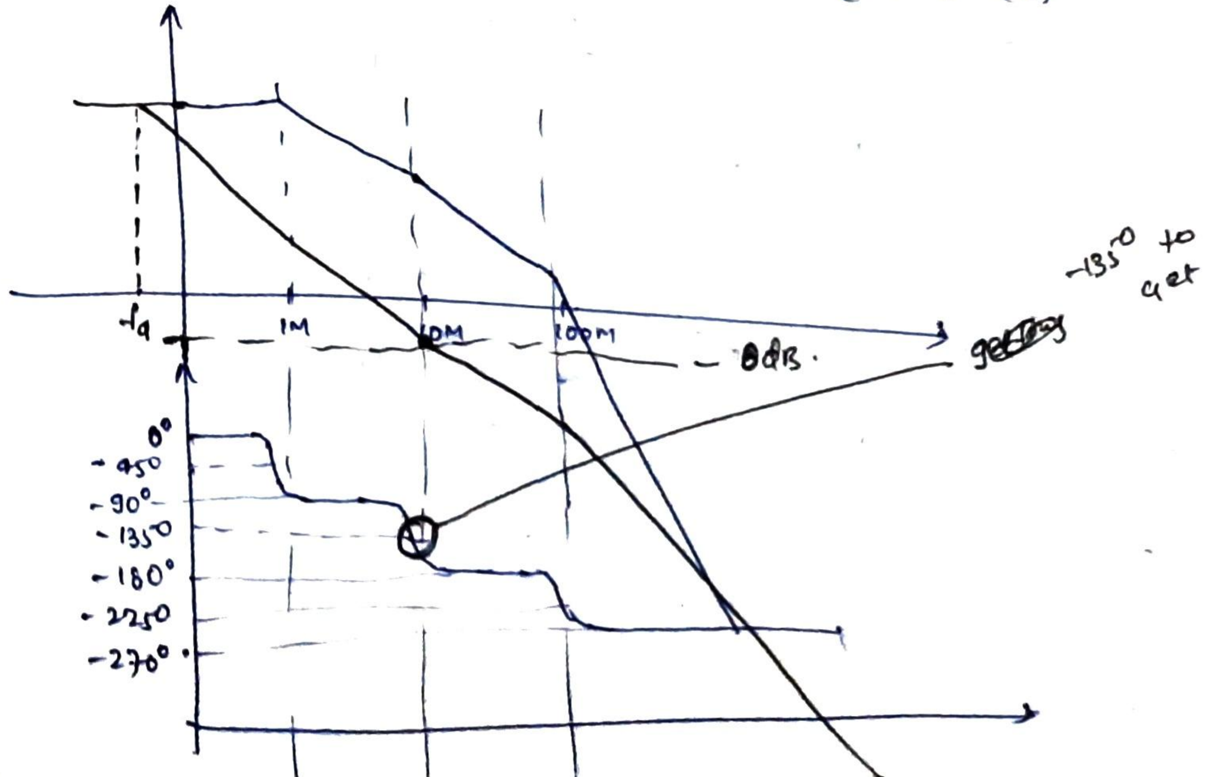
$\Downarrow$

from the phase Graph at $f = f_2$ it lies on 135°

Hence,

at $f = f_2$,

$$|T(jf_2)| = 1 \Rightarrow \frac{5 \times 10^5}{\sqrt{1 + \left(\frac{f}{f_d}\right)^2}\sqrt{1 + \left(\frac{f}{f_2}\right)^2} \times 1 \times 1} = 1$$



$$(5\times10^5)^2 = \left\{1+\left(\frac{f_2}{f_d}\right)^2\right\} \times 2 \times 1$$

$$\frac{25\times10^{10}}{2} = 1+\left(\frac{f_2}{f_d}\right)^2$$

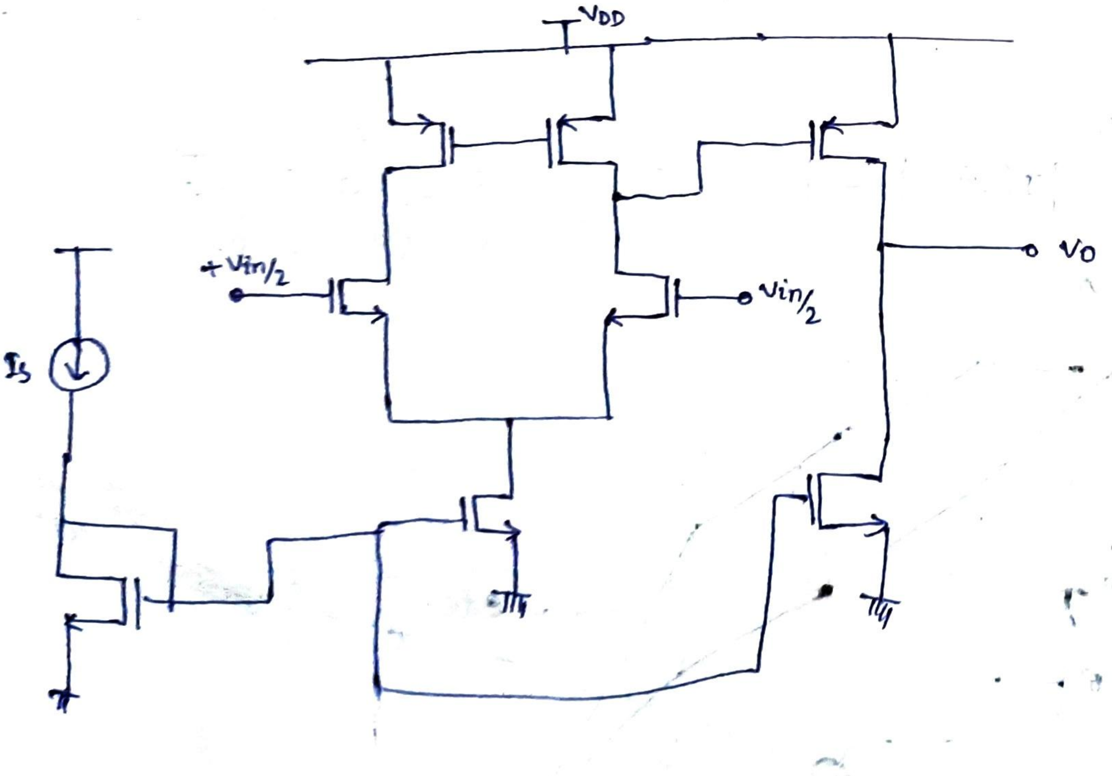
$$\left(\frac{f_2}{f_d}\right)^2 = \frac{25\times10^{10}}{2}$$

$$\frac{\cancel{10}^{\,2}\times10^{\cancel{6}\,10}}{f_d} = \frac{\cancel{5}\times\cancel{10^5}}{\sqrt{2}}$$

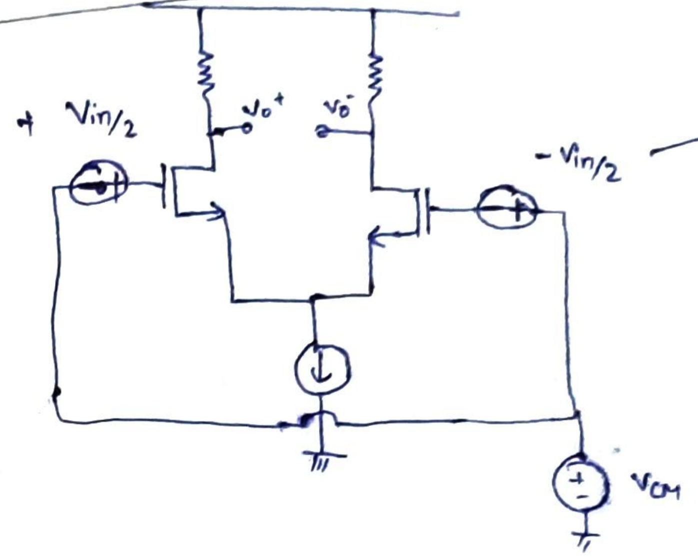
$$f_d = 20\sqrt{2} = \underline{28.28\ Hz}$$

~~1~~2/10/23

Two Stage CMOS op-amp

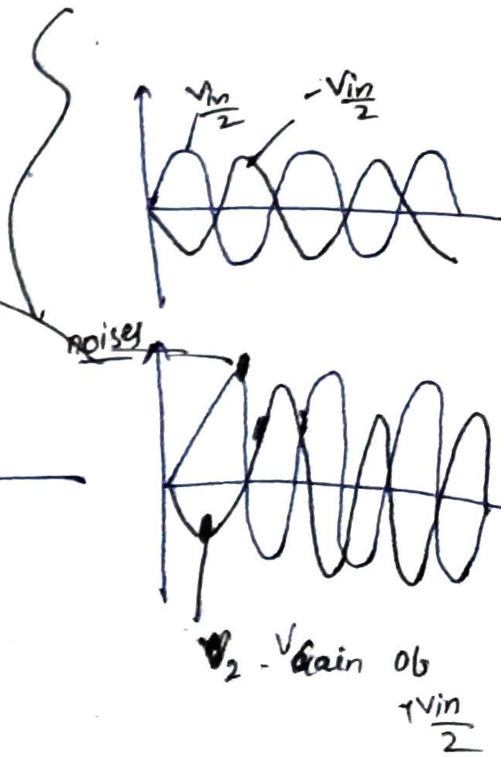


Differential Amplifier

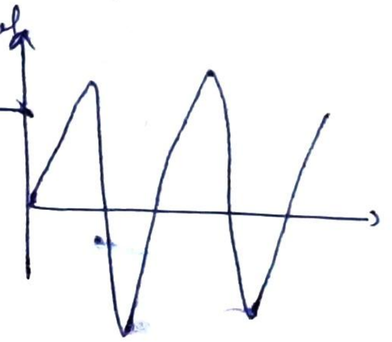


time varying signal.

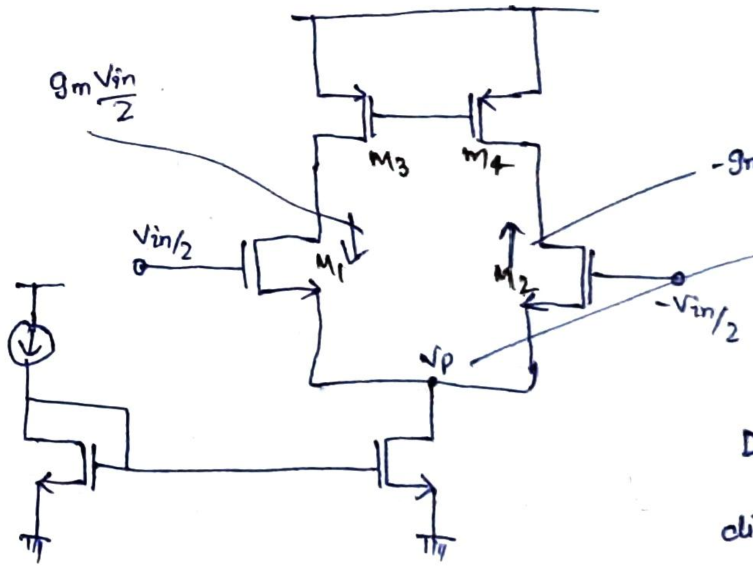
for Symmetric Circuit



reduce noise ⇐ differential output



Differential Mode Output



virtual ground for small signal analysis

Differential transconductance.

differential gain = A_d

Common mode gain = A_c.

Common mode Rejection Ratio (CMRR)

$$= 20 \log \frac{A_d}{A_c}$$

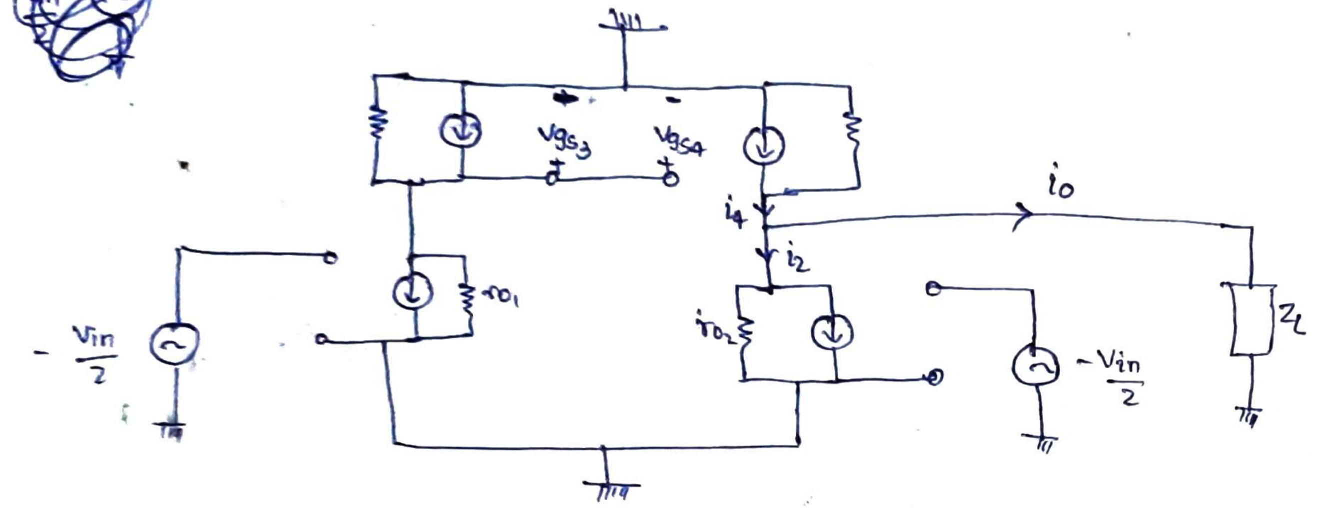
for

$A_d \to \infty$

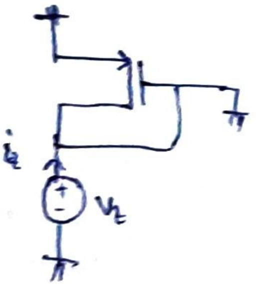
$A_c \to 0$

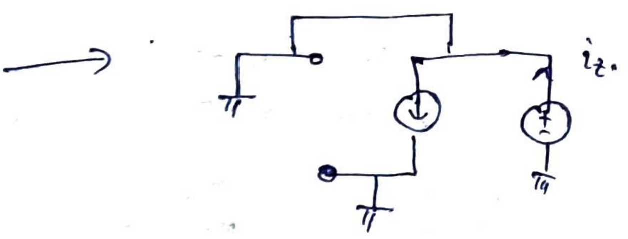
$A_d = G_m R_{out}$.

r_{o1} & r_{o2} very high.



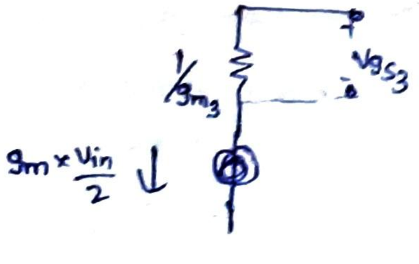
$$V_{in} = \frac{V_{in}}{2} - \left(-\frac{V_{in}}{2}\right) \qquad G_m = \frac{i_o}{V_{in}}$$





$$\frac{V_t}{i_t} = 1/g_{m3},$$

In the above M3, can be replaced as $1/g_{m3}$ as a resistor



$$V_{gs3} = -g_{m1} \frac{V_{in}}{2} \times \frac{1}{g_{m3}}.$$

$i_4 = -g_{m4} V_{gs4}$

as $V_{gs_3} = V_{gs4}$.

$i_4 = g_{m_1} g_{m4} \frac{V_{in}}{2} \frac{1}{g_{m3}}$.

$$\left.\begin{array}{l} g_{m_3} = g_{m4} \\ g_{m_1} = g_{m_2} \end{array}\right\} \text{ Symmetric.}$$

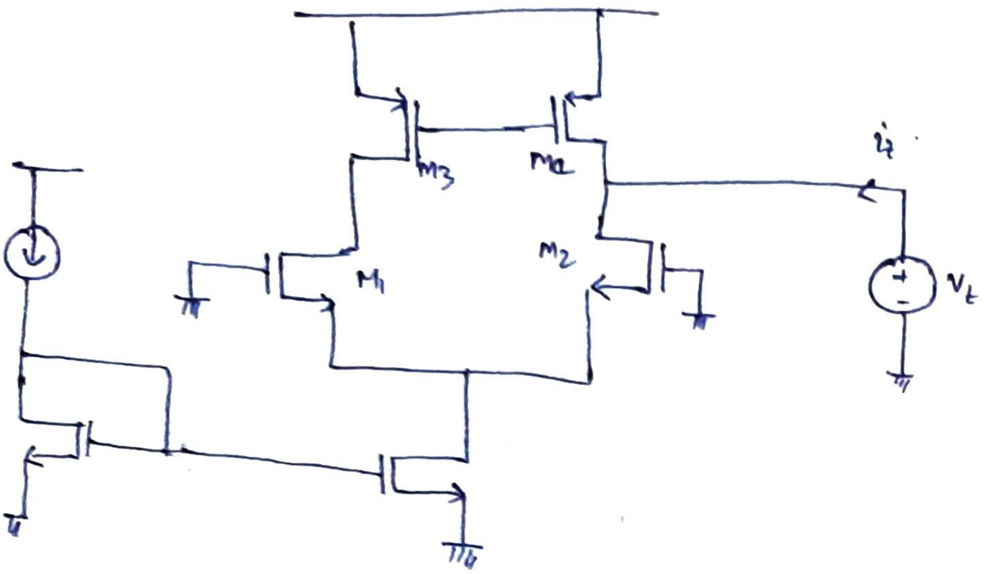
$i_4 = g_{m_1} \frac{V_{in}}{2}$

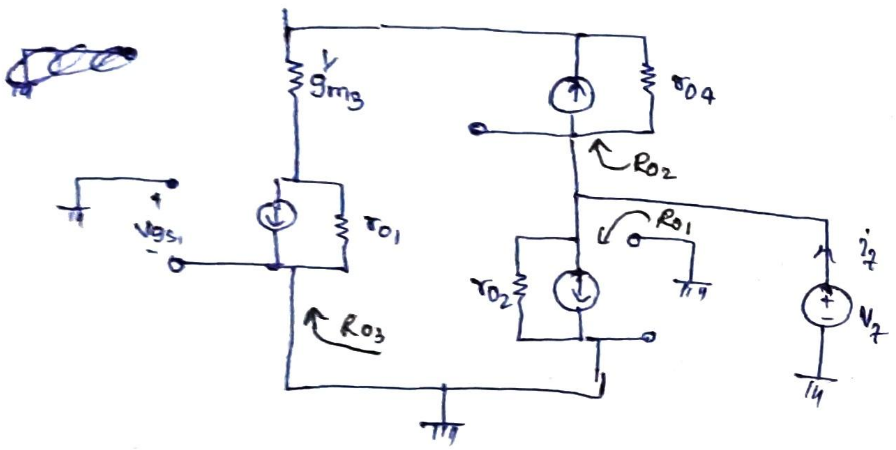
$i_2 = -g_{m_2} \frac{V_{in}}{2}$

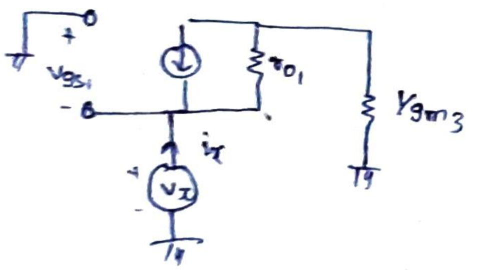
$$\begin{aligned} i_o &= i_4 - i_2 \\ &= g_{m_1} \frac{V_{in}}{2} - \left(-g_{m_2} \frac{V_{in}}{2}\right) \\ &= g_{m_1} \frac{V_{in}}{2} + g_{m_2} \frac{V_{in}}{2} \end{aligned}$$

$$\boxed{i_o = g_{m_1} V_{in} \text{ or } g_{m_2} V_{in}} \quad [\because g_{m_1} = g_{m_2}].$$

equivalent transconductance $\boxed{G_M = g_{m_1} \text{ or } g_{m_2}}$







$$-V_{gs_1} - V_x = 0$$

$$V_x = -V_{gs_1}$$

Q. Consider the following T(s)

$$T(jf) = \frac{\beta \times 1000}{\left(1 + j\frac{f}{1K}\right)\left(1 + j\frac{f}{50K}\right)\left(1 + j\frac{f}{1M}\right)}$$

Find the value of β that will yield a PM of 45°.

means 0dB lies at $f = f_2$

$$t_a \; e = e \; \tan\left(\frac{f}{1K}\right) e$$

At $f = f_2$

$$|T(jf)|\Big|_{f=f_2} = 1$$

$$\frac{\beta \times 1000}{\sqrt{1 + \left(\frac{50K}{K}\right)^2} \; \sqrt{2} \times \cancel{\sqrt{1 + \left(\frac{1K}{1M}\right)^2}}^{\,0}} = 1$$

$$\{\beta \times 10^3\}^2 = \sqrt{2 \times \{1 + (50)^2\}}.$$

$$= \sqrt{2 \times (50)^2}$$

$$= \sqrt{2} \times 50.$$

$$\beta = \frac{\sqrt{2} \times 50}{10^3}.$$

$$= \frac{\sqrt{2} \times \cancel{50}}{\cancel{1000}\,20} = 0.070.$$

Q. An amplifier has a low freq. forward gain of 20dB

Transfer fn of the amplifier has poles

$f_1 = 200kHz$, $f_2 = 2MHz$, $f_3 = 25MHz$.

Calculate the dominant pole magnitude required to give unity gain compensation of 45°.

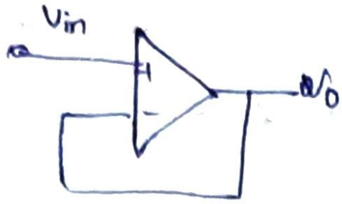
$\beta = 1$

Soln:-

$$A(j\omega) = \frac{A_0}{\left(1 + j\frac{f}{f_1}\right)\left(1 + j\frac{f}{f_2}\right)\left(1 + j\frac{f}{f_3}\right)}$$

$20 \log A_0 = 20$

$A_0 = 10.$



unity gain

$$A'(jf) = \frac{10}{\left(1+\frac{jf}{f_d}\right)\left(1+j\frac{f}{200k}\right)\left(1+j\frac{f}{2M}\right)\left(1+j\frac{f}{25M}\right)}$$

$$|A(jf)| = \frac{10}{\sqrt{1+\left(\frac{f}{200k}\right)^2}\sqrt{1+\left(\frac{f}{2M}\right)^2}\sqrt{1+\left(\frac{f}{25M}\right)^2}}$$

$\underline{f_c}$

At $f = f_c = \boxed{1}$

At $f = f_1$

f_c

$$|A| = \frac{10}{\sqrt{2} \times \frac{200\times 10^3}{2\times 10^6}} = 5\sqrt{2}. \geq 0$$

$1 + (0.1)^2.$

At $f = f_2$

$$|A| = \frac{\cancel{10}}{\cancel{\frac{2M\,10^6}{200\times10^5}} \times \sqrt{2}} = 1/\sqrt{2}.$$

~~At f = f3~~

$$\boxed{f_1 < f_c < f_2.}$$

At $f = f_3$

$$\frac{10}{\frac{25\times 10^6}{2\times 10^5} \times \frac{25\times 10^6}{2\times 10^6} \times \sqrt{2}}$$

$$\frac{10}{625 \times 5 \times}$$

$$\frac{10}{\sqrt{1+\left(\frac{f}{200k}\right)^2}\sqrt{1+\left(\frac{f_c}{2M}\right)^2}} = 1.$$

$$100 = \left(1+\left(\frac{f_c}{200k}\right)^2\right)\left(1+\left(\frac{f_c}{2M}\right)^2\right)$$

$$100 = 1 + \frac{f_c^4}{f_1^2 f_2^2} + \left(\frac{1}{f_1^2} + \frac{1}{f_2^2}\right) f_c^2$$

$$\frac{f_c^4}{f_1^2 f_2^2} + \left(\frac{1}{f_1^2} + \frac{1}{f_2^2}\right) f_c^2 - \underline{\underline{99}} = 0$$

$$f_1^2 f_2^2 = 4 \times 10^{10} \times 4 \times 10^{12}$$
$$= 16 \times 10^{22}$$

$$\left.\begin{aligned} 1/f_1^2 &= 2.5 \times 10^{-11} \\ 1/f_2^2 &= 2.5 \times 10^{-13}. \end{aligned}\right\} \quad 2.525 \times 10^{-11}$$

$f_c = 1.6\,\text{MHz}.$

$$\angle = -\tan^{-1}\left(\frac{f_c}{f_1}\right) - \tan^{-1}\left(\frac{f_c}{f_2}\right) - \tan^{-1}\left(\frac{f_c}{f_3}\right)$$

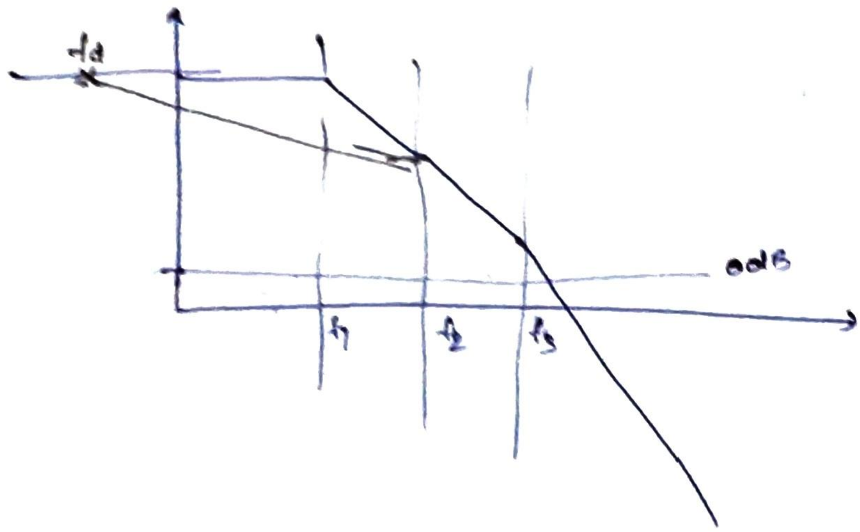
$$= -\tan^{-1}\left(\frac{1.6 \times 10^6}{2 \times 10^5}\right) - \tan^{-1}\left(\frac{1.6 \times 10^6}{2 \times 10^6}\right) - \tan^{-1}\left(\frac{1.6 \times 10^6}{25 \times 10^6}\right)$$

$$-\tan^{-1}(8) - \tan^{-1}(0.8) - \tan^{-1}(0.064).$$

$$= -125.196.$$

$$PM = 180 - 125.196 = 54.8 = 55^\circ$$

When forward gain (5000).



$$A'(jf) = \frac{5000}{(1+j\,f/f_d)\left(1+j\frac{f}{200K}\right)\left(1+j\frac{f}{2M}\right)\left(1+j\frac{f}{25M}\right)}.$$

dominant pole insertion

At $f = f_2$, (200K)

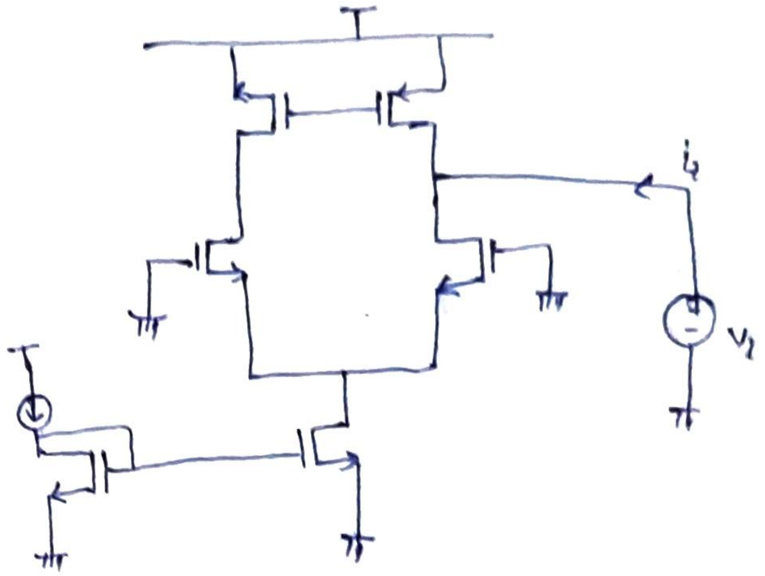
$$|A'(jf)| = 1 = \frac{5000}{\sqrt{1+\left(\frac{200K}{f_d}\right)^2}\ \sqrt{1+1}\ \sqrt{1+\left(\frac{200K}{2M}\right)^2}\ \sqrt{1+\left(\frac{200K}{25M}\right)^2}}$$

$$(5000)^2 = 1+\left(\frac{2\times 10^5}{f_d}\right)^2 \times 2 \times \frac{\cancel{200K}}{\cancel{2M}\ 10} \times 1$$

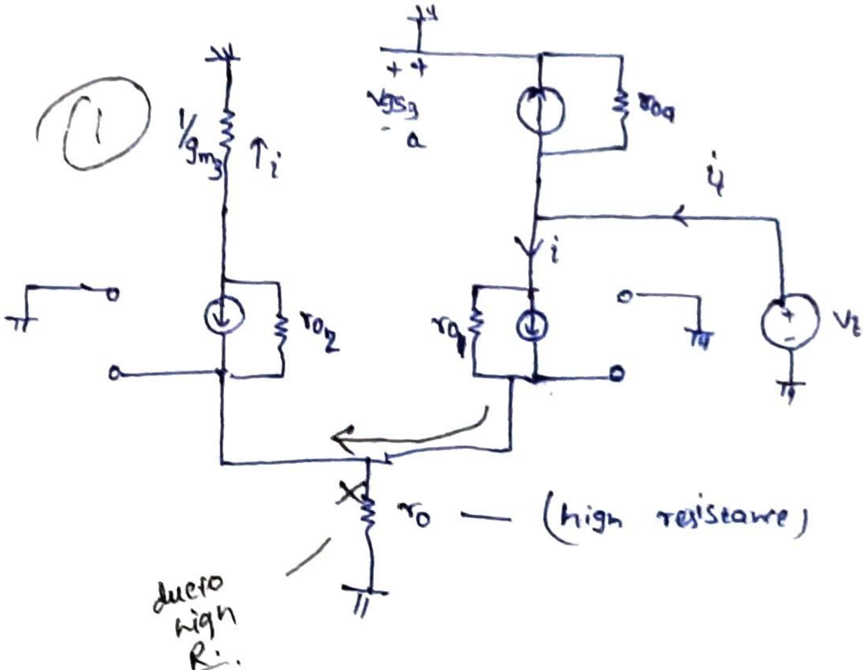
$$\frac{25\times 10^6 \times 10}{2} = \frac{4\times 10^{10}}{f_d^2}.$$

$$f_d^2 = \frac{8\times 10^{3}}{25\times \cancel{10^7}}$$

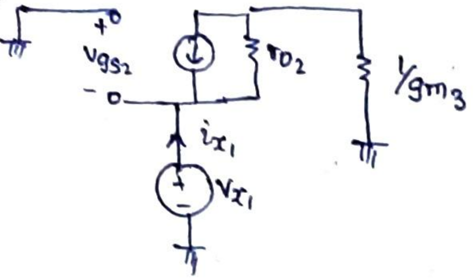
Output Resistance of the current mirror loaded Diff. Amplifier



1



2



$$V_{gs_2} + V_{x_1} = 0$$

$$i_{x_1} + g_{m_2} V_{gs_2} + \frac{V_{x_1} - i_{x_1} 1/g_{m_3}}{r_{o_2}} = 0$$

$$i_{x_1} - g_{m_2} V_{x_1} + \frac{V_{x_1} - \frac{i_{x_1}}{g_{m_3}}}{r_{o_2}} = 0.$$

$$i_{x_1}\left(1 - \frac{1}{g_{m_3} r_{o_2}}\right) = \left(-\frac{1}{r_{o_2}} + g_{m_2}\right) V_{x_1}$$

$$\frac{V_{x1}}{I_{x1}} = \frac{\dfrac{g_{m3} r_{o2} - 1}{g_{m3} \cancel{r_{o2}}}}{\dfrac{(g_{m2} r_{o2} - 1)}{\cancel{r_{o2}}}}$$

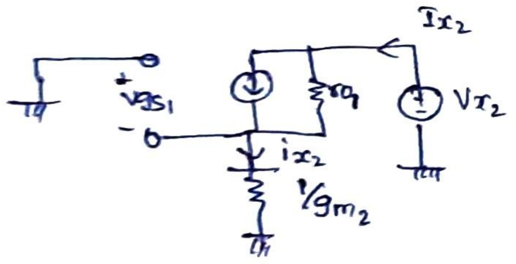
$$\frac{V_{x1}}{I_{x1}} = \frac{g_{m3} r_{o2} - 1}{g_{m3}(g_{m2} r_{o2} - 1)}$$

$$= \frac{g_{m3} r_{o2} \left(1 - 1/g_{m2} r_{o2}\right)}{g_{m3} g_{m2} r_{o2} \left(1 - 1/g_{m3} r_{o2}\right)}$$

$g_m r_o \gg 1.$

$$\frac{V_{x1}}{I_{x1}} \approx \frac{1}{g_{m2}}$$

3



$$V_{gs1} + i_{x2} \times 1/g_{m2} = 0$$

$\cancel{i_{x2} = g_{m1} V_{gs1}}$

$$i_{x2} - g_{m1} V_{gs1} - \frac{\left(V_{x2} - i_{x2} \times 1/g_{m2}\right)}{r_{o1}} = 0$$

$$i_{x2} + g_{m1} \times i_{x2}\, 1/g_{m2} - \frac{V_{x2}}{r_{o1}} + i_{x2} \frac{1}{g_{m2} r_{o1}} = 0$$

$$i_{x2}\left(1 + \frac{g_{m1}}{g_{m2}} + \frac{1}{g_{m2} r_{o1}}\right) = \frac{V_{x2}}{r_{o1}}$$

$$\frac{V_{x_2}}{I_{x_2}} = r_{o1}\left(1 + \frac{g_{m1}}{g_{m2}} + \frac{1}{g_{m2} r_{o1}}\right)$$

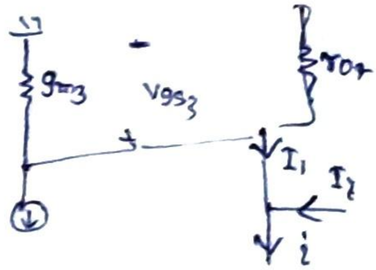
$g_{m1} = g_{m2}$ & $g_{m2} r_{o1} >> 1$.

$$\frac{V_{x_2}}{I_{x_2}} = 2 r_{o1}$$

considering M_4.

$$i_t = -g_{m4} V_{gs_3} - \frac{V_t}{r_{o4}}.$$

$$V_{gs_3} = i \times 1/g_{m3}$$



$$i_1 = -g_{m4} \times i \times 1/g_{m3} - \frac{V_t}{r_{o4}}$$

$g_{m3} = g_{m4}$.

$$i_1 = -i - \frac{V_t}{r_{o4}}.$$

$$i_t + i_1 - i = 0.$$

$$i_t = i - i_1$$

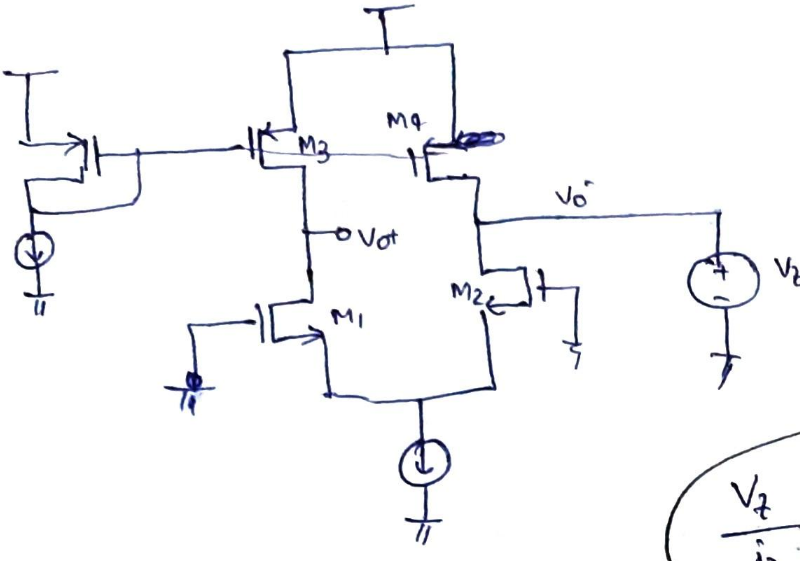
$$= \frac{V_t}{2r_{o1}} + i + \frac{V_t}{r_{o4}}$$

$$= \frac{V_t}{2r_{o1}} + \frac{V_t}{2r_{o1}} + \frac{V_t}{r_{o4}}.$$

$$i_t = \frac{V_t}{r_{o1}} + \frac{V_t}{r_{o4}}.$$

$$\boxed{R_{out} = r_{o1} \parallel r_{o4}.}$$

output resistance.



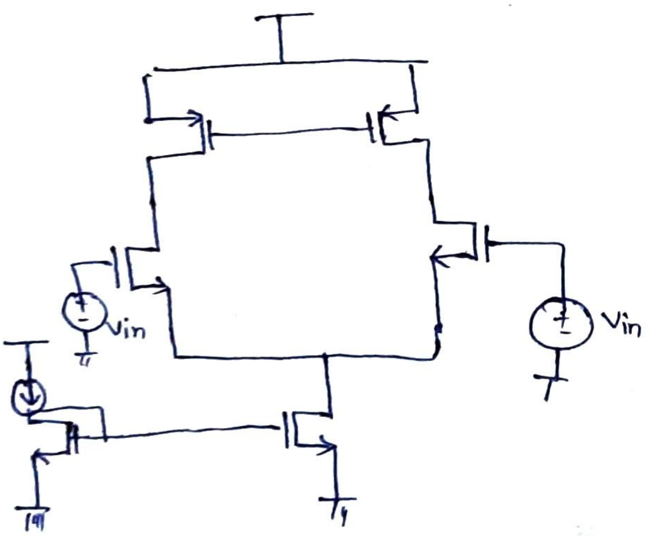
$$\frac{V_t}{i_t} = r_{o2} \parallel r_{o4}$$

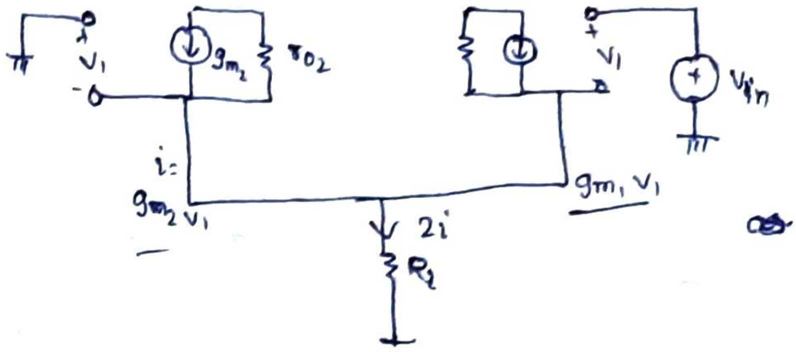
$$\boxed{\text{differential gain} = \text{transconductance} \times \text{output resistance}}$$

$$\approx g_{m1} \left(r_{o1} \parallel r_{o4} \right)$$

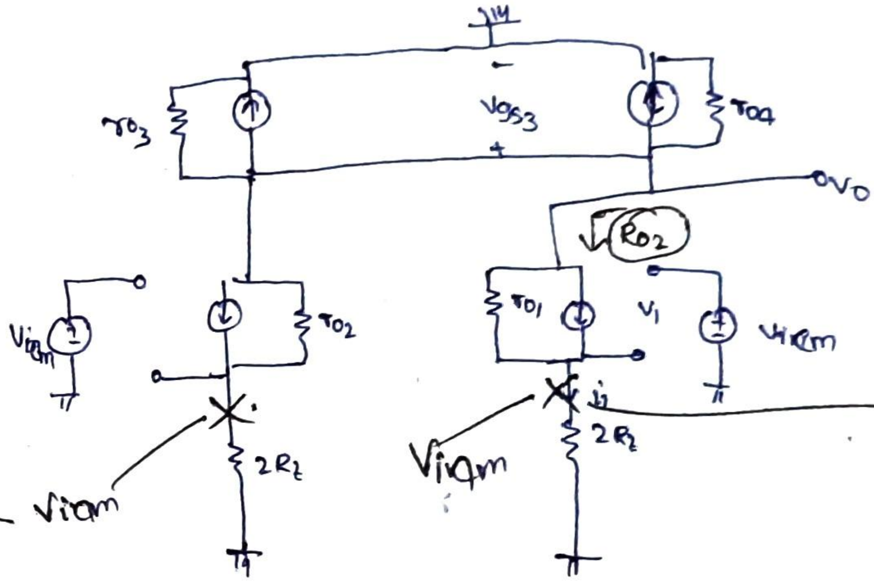
$$= g_{m1} \times \left(r_{o1} \parallel r_{o4} \right)$$

Common mode gain of CM loaded diff. Amplifier





as $g_{m_1} = g_{m_2}$ then $2i$ will flow through R_t.

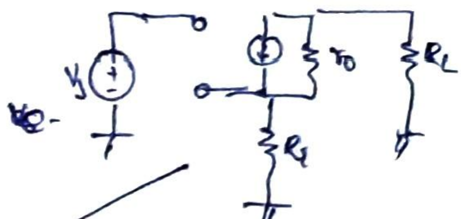


As gain = 1.

As gain = 1

As R_t is very high,

For M2.



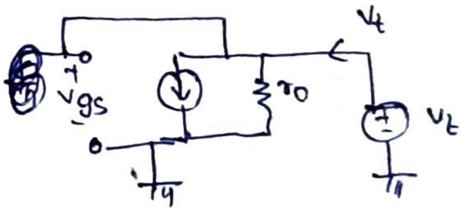
$$V_o = g_{m_2} V_{gs} R_t.$$

$$V_s = V_{gs}(1 + g_m R_t).$$

$$\frac{V_o}{V_s} = \frac{g_m R_t}{1 + g_m R_t} \approx 1$$

R_t is very high.

$$i_1 = \frac{V_{icm}}{2R_t}.$$



$$\frac{V_{gs}}{r_o} + g_m V_{gs} = i_t$$

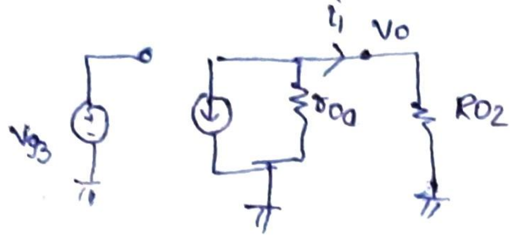
$$\frac{V_t}{r_o} + g_m V_t = i_t$$

$$\frac{V_t}{i_t} = \frac{r_o}{1 + g_m r_o}.$$

Resistance of M3 $\dfrac{1}{g_{m_3}} \parallel r_o$

$$V_{g3} = \underbrace{-i_1}_{\text{Current flowing}} \times \underbrace{\left(\frac{1}{g_{m3}} \parallel r_{o3}\right)}_{\text{Req.}}$$

$$V_{g3} = -i_1 \times 1/g_{m3}.$$



$$V_o = -\left(g_{m4} V_{g3} + i_1\right) r_{o4}$$

$$V_o = -\left\{-g_{m4} \times i_1 \times \left(\frac{1}{g_{m3}} \parallel r_{o3}\right) + i_1\right) r_{o4}$$

$$= -\left\{-g_{m4} \times \frac{\frac{1}{g_{m3}} \times r_{o3}}{1/g_{m3} + r_{o3}} + 1\right] i_1 r_{o4}.$$

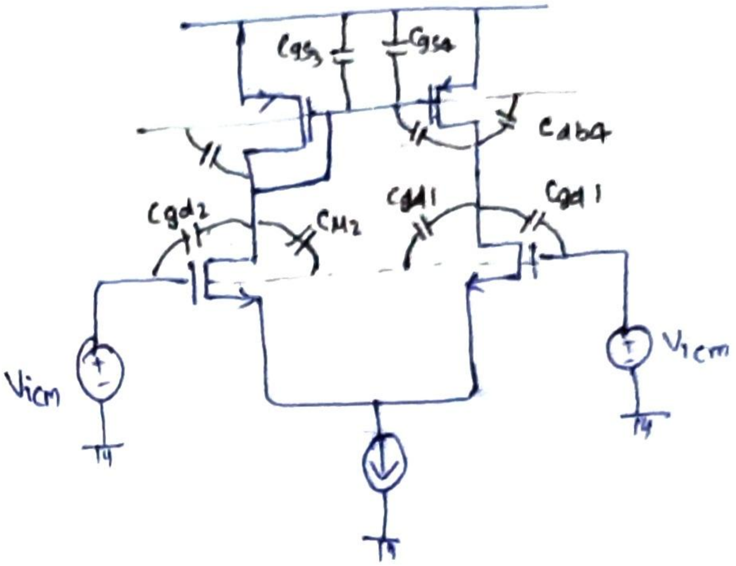
$$= \left\{\frac{r_{o3}}{1/g_{m3} + r_{o3}} - 1\right\} i_1 r_{o4}.$$

$$= -\frac{r_{o4}}{g_{m3} r_{o3} + 1} \times \frac{V_{icm}}{2R_T}$$

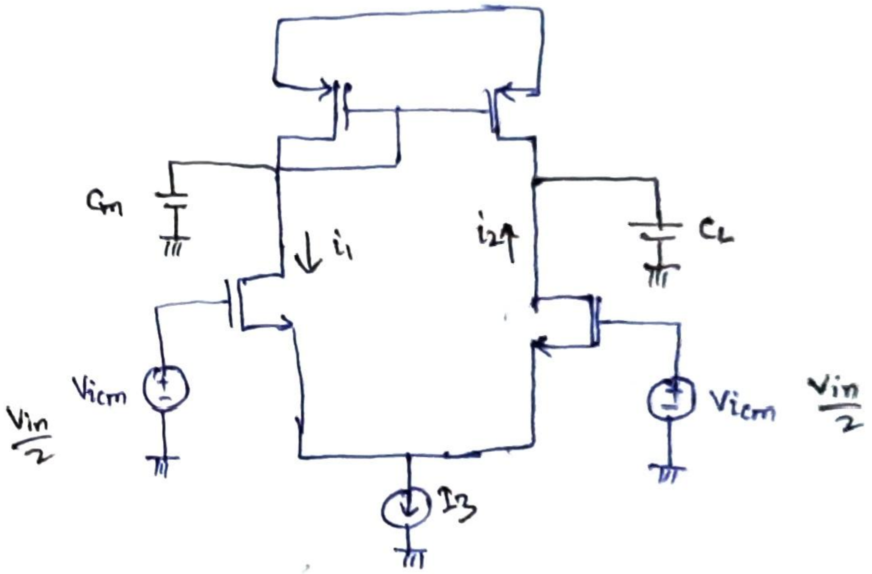
$$= -\frac{r_{o4}}{g_{m3} r_{o3}} \times \frac{V_{icm}}{2R_T}$$

$$\boxed{\frac{V_o}{V_{icm}} = -\frac{1}{2 g_{m3} R_T}.}$$

$$\boxed{A_{\text{common mode}} = -\frac{1}{2 g_{m3} R_T}}$$



For n-type
p-type substrate
is bulk.

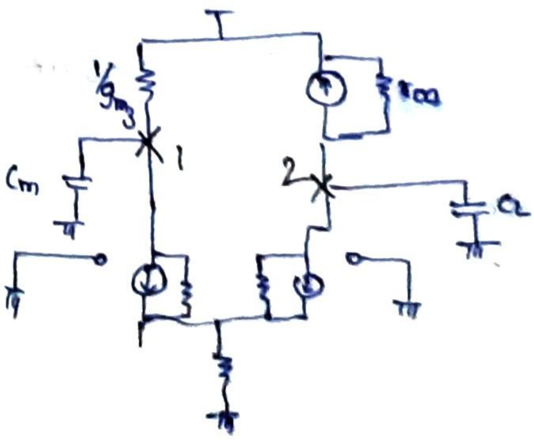


C_{db} - Drain to Bulk capacitance.

$$\boxed{C_m = C_{db3} + C_{gs3} + C_{gs4} + C_{gd2} + C_{db2}}$$

$$\boxed{C_L = C_{db4} + C_{gd1} + C_{db1} + C_{gd4}}$$

open circuit time constant



At, 1,

$$R_m = \frac{1}{g_{m3}} \parallel r_{o1}$$

$$R_L = r_{o2} \parallel r_{o4}$$

open circuit time constant.

Short circuit

$$R_m = \frac{1}{g_{m3}} \parallel r_{o1}$$

$$R_L = r_{o2} \parallel r_{o4}$$

$$f_d = \frac{1}{2\pi \sum RC} \qquad f_{nd} = \frac{1}{2\pi} \sum \frac{1}{RC}$$

$$\boxed{f_d = \frac{1}{2\pi \left\{ C_m \left[\frac{1}{g_{m3}} \parallel r_{o1} \right) + C_L \left(r_{o2} \parallel r_{o4} \right) \right\}}}$$

$$\boxed{f_{nd} = \frac{1}{2\pi} \left\{ \frac{1}{C_m \left\{ \frac{1}{g_{m3}} \parallel r_{o1} \right)} + \frac{1}{C_L \left\{ r_{o2} \parallel r_{o4} \right\}} \right\}.}$$

non-dominant

Q. $k_n' = 60\ \mu A/V^2$

$k_p' = 30\ \mu A/V^2$ $\qquad \lambda_n = \lambda_p = 0.02V$

$\left(\frac{W}{L}\right)_n = 10 \qquad \left(\frac{W}{L}\right)_p = 20 \qquad I_3 = 200\ \mu A.$

$C_L = 400\ fF$

$C_m = 100\ fF.$

Opencct

$$R_m = \frac{1}{g_{m3}} \parallel r_{o1}$$

$$g_{m1} = \frac{I_C}{V_T} = \frac{100}{25} = 4 \times 10^{-3}$$

$$g_{m2} = 4 \times 10^{-3}.$$

$$r_{o1} = \frac{1}{\lambda I_D} = \frac{1}{10^{-2}} = 100.$$

$$g_{m3} = \sqrt{2 I_D \, \mu_p C_{ox} \times \frac{W}{L}}$$

$$= \sqrt{2 \times 100 \times 10^{-6} \times 30 \times 10^{-6} \times \frac{W}{L}}$$

$$= \sqrt{6 \times 10^{-9} \times 20}$$

$$= \sqrt{12} \times 10^{-4}$$

$$= 34.64 \text{ m}\mho$$

$$f_d = \frac{1}{2\pi (r_{o2} \parallel r_{o4}) C_L}$$

$$f_{nd} = \frac{1}{2\pi} \sum \frac{1}{RC}$$

$$= \frac{1}{2\pi} \sum \frac{1}{C_m \, 1/g_{m3}}$$

From the same circuit

$$V_o = i_o \times \frac{1}{C_L s} \parallel (r_{o2} \parallel r_{o4})$$ Equivalent resistance at V_o.

$$i_o = i_4 + i_2$$

$$V_{g3} = -i_1 \times \left(\frac{1}{g_{m3}} \parallel \frac{1}{C_m s} \right)$$

$$V_{g3} = -g_{m1} \frac{V_{in}}{2} \left(\frac{1}{g_{m3}} \parallel \frac{1}{C_m s} \right]$$

$$i_1 = g_{m1} \frac{V_{in}}{2}.$$

$$i_4 = -g_{m4} \times V_{g3}$$

$$= g_{m4} \times g_{m1} \times \frac{V_{in}}{2}\left(\frac{1}{g_{m3}} \parallel \frac{1}{C_m S}\right)$$

$$i_o = i_4 + i_2$$

$$= g_{m4}\, g_{m1}\, \frac{V_{in}}{2}\left(\frac{1}{g_{m3}} \parallel \frac{1}{C_m S}\right) + g_{m2}\frac{V_{in}}{2}$$

$$i_o = \frac{V_{in}}{2}\left\{ g_{m1}\, g_{m4}\left(\frac{1}{g_{m3}} \parallel \frac{1}{C_m S}\right) + g_{m2}\right\}$$

$$g_{m1} = g_{m2}$$
$$g_{m3} = g_{m4}.$$

$$V_o = \frac{V_{in}}{2}\left\{ g_{m1}\, g_{m4}\left(\frac{1}{g_{m3}} \parallel \frac{1}{C_m S}\right) + g_{m2}\right\}.\left\{\frac{1}{C_L S} \parallel R_o\right)$$

$$g_{m1} \times \cancel{g_{m4}} \times \frac{\frac{1}{\cancel{g_{m3}}} \times \frac{1}{C_m S}}{1/g_{m3} + \frac{1}{C_m S}} + g_{m2} \qquad \frac{\frac{1}{C_L S} \times R_o}{R_o + 1/C_L S}$$

$$\frac{g_{m1}}{C_m S}\left\{\frac{g_{m3}\, C_m S}{g_{m3} + C_m S} + g_{m2}\right\}. \qquad \frac{R_o}{C_L S R_o + 1}$$

zeros

$$\boxed{V_o = \frac{V_{in}}{2}\, g_{m1}\left(\frac{C_m S + 2g_{m3}}{C_m S + g_{m3}}\right) * \frac{R_o}{1 + R_o C_L S}}$$

poles where $R_o = r_{o2} \parallel r_{o4}$.

μ -	10^{-6}
n -	10^{-9}
p -	10^{-12}
f =	10^{-15}
atto =	10^{-18}

$$f_d = \frac{1}{2\pi\,(r_{o2} \| r_{o4}) \times C_L}$$

$$= \frac{1}{2\pi \times 500 \times 10^3 \times 400} \times 10^{15}$$

$$= \frac{1}{4\pi} \times 10^7$$

$$= 6.78539 \times 10^7 \quad \} \quad 796\ \text{KHz}.$$

~~785~~.

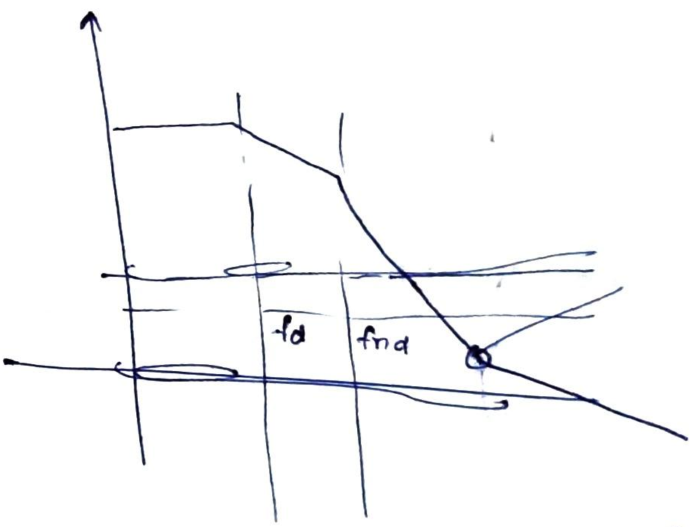
$$f_{nd} = \frac{1}{2\pi} \left\{ \frac{1}{C_m \times 1/g_{m3}} \right\}$$

$$= \frac{1}{2\pi} \times \frac{1}{100 \times 10^{-15}} \times .346 \times 10^{-6}$$

$$= \frac{.346}{2\pi} \times \cancel{10^{13}} \times \cancel{10^{-6}} \cdot 10^7.$$

$$= .568\ \text{MHz}.$$

Designer choise:- Increase $\frac{W}{L}$ of pmos for making more stable.



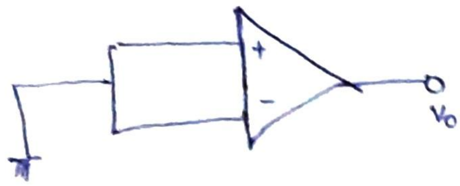
closer ~~this pole~~ zero to fnd
$\Downarrow$
more it will be unstable.

$$f_z = \frac{2g_{m3}}{2\pi C_m}$$
zero

$C_m \uparrow$ — zero $\downarrow$

81/10/23
Missing

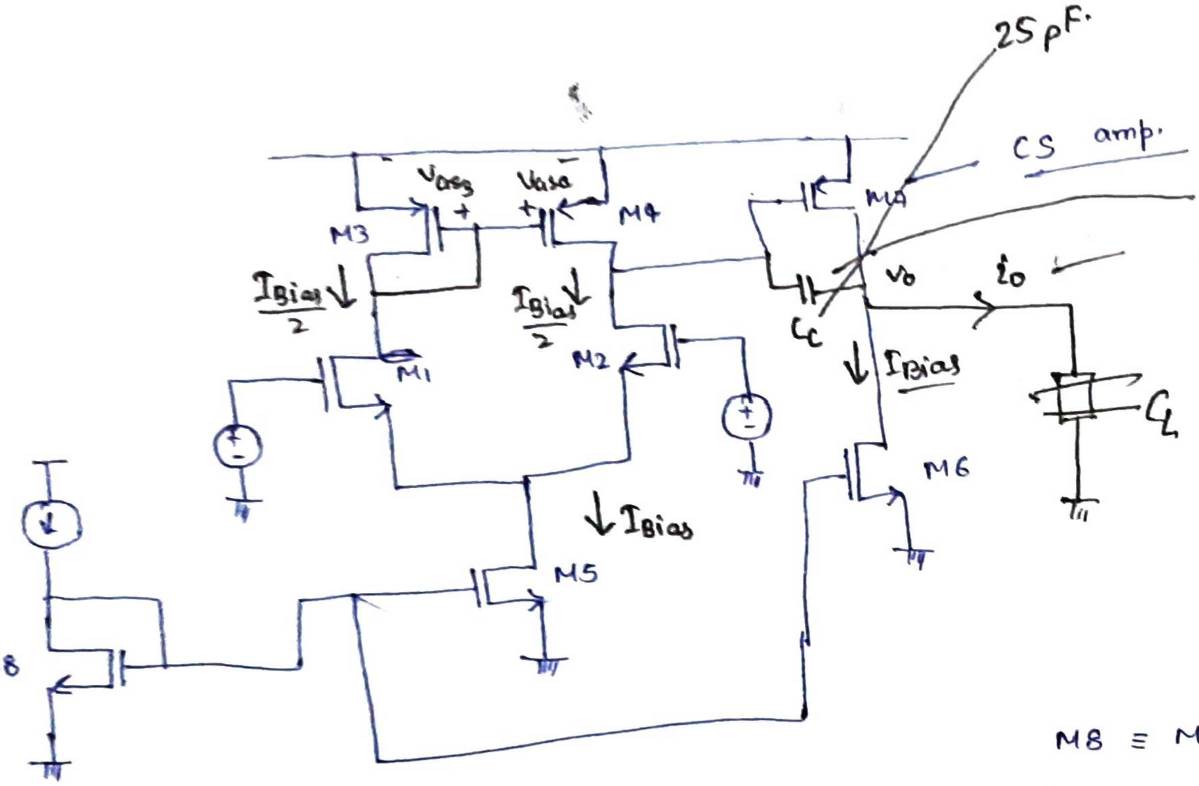
1/11/23



$V_{os} = \frac{V_o}{A_d}$ — differential gain

(Input preferred offset)

If Vos connected to i/p, Vo will become 0.



poles are spread apart to → to make stable

Ideally Io should be zero.

M8 ≡ M5 ≡ M6

2 stage CMOS op-amp.

All the transistor in saturation

$\underbrace{V_{GS_3} = V_{DS_3}}_{\text{Gate and Drain is connected}} = \underbrace{V_{DS_4}}$ due to equal current

All the transistors are in saturation

$\Downarrow$

$$\frac{I_{Bias}}{2} = \frac{1}{2} \mu_p C_{ox} \left(\frac{W}{L}\right)_p (V_{SG} - |V_{tp}|)^2 (1 + \lambda |V_{SD}|_p).$$

$V_{SG_3} = V_{SG_7}$.

$$I_7 = \frac{1}{2} \mu_p C_{ox} \left(\frac{W}{L}\right)_7 (V_{SG_7} - |V_{tp}|)^2$$

$$\frac{I_{Bias}}{2} = \frac{1}{2} \mu_p C_{ox} \left(\frac{W}{L}\right)_4 (V_{SG_4} - |V_{tp}|)^2$$

As $V_{SG_4} = V_{SG_7}$.

$$\frac{I_7}{\frac{I_{Bias}}{2}} = \frac{(W/L)_7}{(W/L)_4}$$

$$2\left(\frac{I_7}{I_{Bias}}\right)\left(\frac{W}{L}\right)_4 = \left(\frac{W}{L}\right)_7.$$

$\underbrace{\text{To ensure } I_0 = 0,}_{\text{zero offset}}$ I_7 should be equal to I_{Bias}.

$$\boxed{\left(\frac{W}{L}\right)_7 = 2 \times \left(\frac{W}{L}\right)_4}$$

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$$ — same for n-mos & p-mos.

$$I_n = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right)_n (V_{GS} - V_{tn})^2$$

$$I_p = \frac{1}{2} \mu_p C_{ox} \left(\frac{W}{L}\right)_p (V_{SG} - |V_{tp}|)^2$$

$$\frac{\mu_n}{\mu_p} \approx 2.5 - 4$$

Given:-

M_1 & $M_2 = \frac{10}{1}$

$M_7 = \frac{50}{1}$

$M_3, M_4 = \frac{25}{1}$

$M_8, M_5, M_6 = \frac{40}{2}$

$\mu_n C_{ox} = 60 \mu A/V^2$

$\mu_p C_{ox} = 30 \mu A/V^2$

$I_{Bias} = 0.6 mA$

$\lambda_n = |\lambda_p| = \frac{1}{9} V^{-1}$

$C_c = 25 pF$

Q. Find the gain of op-amp.

$\underbrace{\text{Gain of first stage}}_{\text{differential}} = -g_{m1} (r_{o1} \parallel r_{o4})$

$$g_{m1} = \sqrt{2 \mu_n C_{ox} \left(\frac{W}{L}\right)_1 \frac{I_{Bias}}{2}}$$

$$= \sqrt{\cancel{2} \times 60 \times 10^{-6} \times \frac{10}{1} \times \frac{0.6}{\cancel{2}} \times 10^{-3}}$$

$$= \sqrt{36 \times 10^{-8}}$$

$$= 6 \times 10^{-4}$$

$$= 60 m℧$$

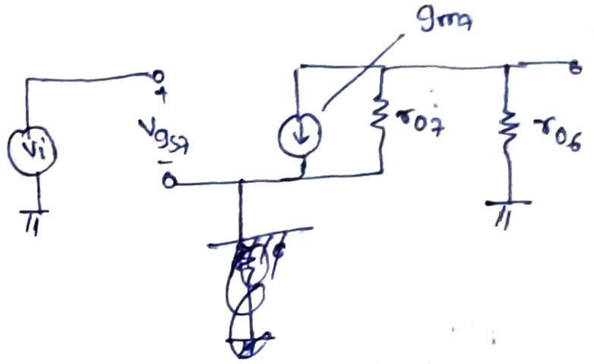
$$r_{o2} = \frac{1}{\lambda_n \times \frac{I_{Bias}}{2}} = \frac{9 \times 2}{0.6 mA} = \frac{\cancel{18}^{3}}{\cancel{6}} \times 10^4$$

$$= 30 K.$$

$r_{o2} = r_{o4} = 30K.$

$$\text{Gain} = -6 \times 10^{-4} \times 15 \times 10^{3}$$

$$= -9 \text{ V/V}.$$



$$\frac{V_o}{V_i} = -g_{m7}\left(r_{o7} \parallel r_{o6}\right)$$

$$g_{m7} = \sqrt{2 \mu_p C_{ox} \left(\frac{W}{L}\right)_7 \times I_{Bias}}$$

$$= \sqrt{2 \times 30 \times 10^{-6} \times \frac{50}{1} \times 6 \times 10^{-4}}$$

$$= \sqrt{18000 \times 10^{-10}}.$$

$$= 134.16 \times 10^{-5}$$

$$= \cancel{1341.6 \times 10^{-6}}.$$

$$1.3416 \times m\mho$$

$$r_{o7} = \frac{1}{\lambda_p I_{Bias}} = \frac{\cancel{6}\,3 \times 10^{4}}{0.\cancel{6}\,2}$$

$$= 1.5 \times 10^{4}$$

$$= 15K.$$

$$\frac{V_o}{V_i} = -1.34\, m\mho \times 7.5K$$

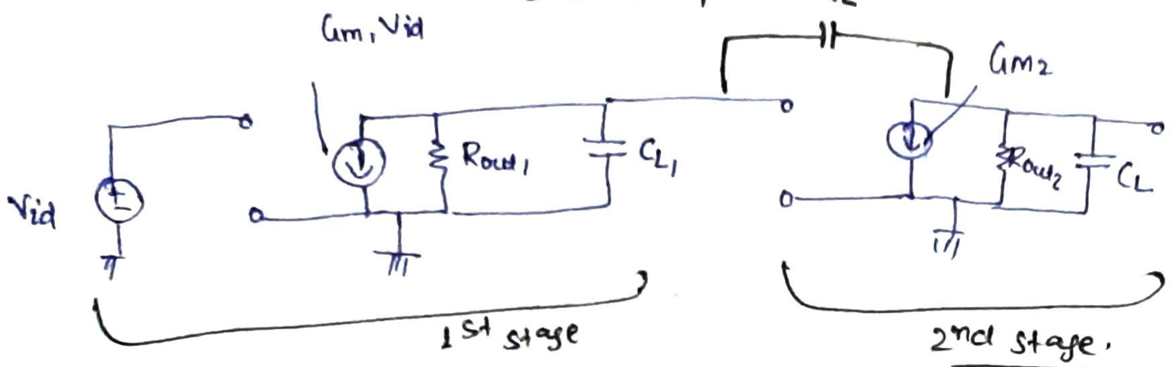
$$= -10 \text{ V/V}$$

$$\text{gain of op-amp} = 90 \text{ V/V}$$

B.W of the op-amp.

$C_m = 0.1\ pF$

$C_L = 0.2\ pF$



$G_{m1} = g_{m1}$

$R_{out1} = r_{o2} \parallel r_{o4}$

$G_{m2} = g_{m7}$

$R_{out2} = r_{o6} \parallel r_{o7}$.

Alreaday calc

$$f_{3dB} = \frac{1}{2\pi \left\{ C_{L1} R_{out1} + C_L \times R_{out2} + C_c \left(R_{out1} + R_{out2} + G_{m2} R_{out1} R_{out2} \right) \right\}}$$

Given:- $C_c >> C_L$ & C_{L1}

$$f_{3dB} \simeq \frac{1}{2\pi C_c \left\{ R_{out1} + R_{out2} + G_{m2} R_{out1} R_{out2} \right\}}.$$

$C_c = 25\ pF$

$R_{out1} = 15K$.

$R_{out2} = 7.5K$.

$$= \frac{1}{2\pi \times 25 \times 10^{-12} \left\{ 15K + 7.K + 1.84m \times 15K \times 7.5K \right)}.$$

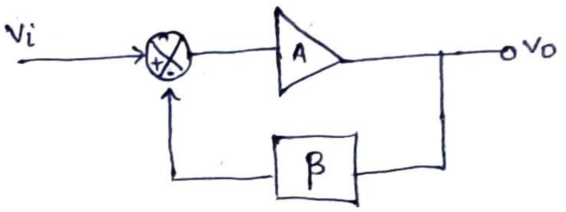
$$= \frac{1}{2\pi \times 25\times 10^{-12} \times 123 \times 10^{3}}$$

$$= 0.0000517577 \times 10^{9}$$

$$f_{3dB} = 5.17577 \times 10^{4}.$$

2/11/23

Oscillators



$$\frac{V_o}{V_i} = \frac{A}{1 + A\beta}$$

Oscillation condition,

$$|A\beta| = 1$$

$$\angle A\beta = 180^\circ$$

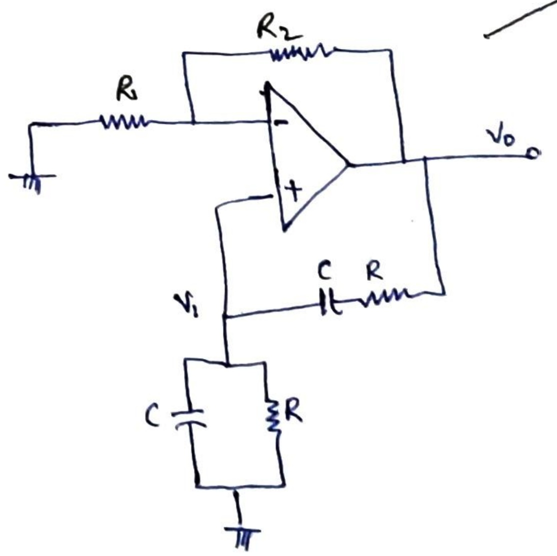
for +ve feedback ckt,

$$\frac{V_o}{V_i} = \frac{A}{1 - A\beta}$$

$$|A\beta| = 1$$

$$\angle A\beta = 0^\circ.$$

wien Bridge Oscillator



$$|A\beta| = 1$$

$$\angle A\beta = 0^\circ$$

feedback network
⇓
passive — frequency dependant
⇓
Simply voltage divider.

$$\frac{V_1}{V_o} = \frac{\left(\frac{1}{cs} \parallel R\right)}{\left(\frac{1}{cs} \parallel R\right) + \left(R + \frac{1}{cs}\right)}$$

$$\frac{0 - V_1}{R_1} = \frac{V_1 - V_o}{R_2}$$

$$V_1\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{V_o}{R_2}$$

$$V_1\left(\frac{R_1+R_2}{R_1 \cancel{R_2}}\right) = \frac{V_o}{\cancel{R_2}}$$

$$\underbrace{\frac{V_o}{V_{in}} = \left(1 + \frac{R_2}{R_1}\right)}_{A}.$$

$$\frac{1}{cs} \parallel R = \frac{\frac{1}{cs} \times R}{\frac{1}{cs} + R} = \frac{R}{1 + sRC}$$

$$\frac{\frac{R}{1+sRC}}{\frac{R}{1+sRC} + \frac{(sRC+1)}{cs}}$$

$$\frac{V_1}{V_o} = \left.\frac{sRC}{sRC + (1+sRC)^2}\right\} \beta$$

$$\text{loop gain} = \overbrace{\frac{V_o}{V_1}}^{A} \times \overbrace{\frac{V_1}{V_o}}^{\beta}$$

$$= \left(1 + \frac{R_2}{R_1}\right) \times \frac{1}{RCs + \frac{1}{RCs} + 3}.$$

$$A\beta(j\omega) = \left(1 + \frac{R_2}{R_1}\right) \times \frac{1}{3 + j\left(\omega RC - \frac{1}{\omega RC}\right)}$$

$$\angle A\beta = -\tan^{-1}\left(\frac{\omega RC - 1/\omega RC}{3}\right) = 0^\circ$$

$$\omega_0 RC = 1/\omega RC$$

$$\omega_0 = \frac{1}{RC}.$$

$$|A\beta|_{\omega = 1/RC} = \frac{\left(1+\frac{R_2}{R_1}\right)}{3} = 1.$$

$$\boxed{R_2 = 2R_1}$$

Q. For the wein Bridge Oscillator the phase shift by op-amp & resistors is -15° at $\omega = 1/RC$. Find the frequency of oscillation.

Soln.

$$\text{Loop phase } (\phi) = -\tan^{-1}\left(\frac{\omega RC - 1/\omega RC}{3}\right)$$

$$\frac{\Delta\phi}{\Delta\omega} = \frac{1}{1+x^2} = \frac{1}{1+\frac{\left(\omega RC - 1/\omega RC\right)^2}{9}}$$

$$x^2 = \frac{\omega^2R^2C^2 + \frac{1}{\omega^2R^2C^2} - 2}{9} + 1$$

$$\frac{\omega^2R^2C^2 + \frac{1}{\omega^2R^2C^2} - 2 + 9}{9}$$

$$\frac{9}{\omega^2R^2C^2 + \frac{1}{\omega^2R^2C^2} + 7} \times \left(RC + \frac{1}{\omega^2}RC\right)$$

$$\frac{\Delta\phi}{\Delta\omega} = -\frac{2}{3} RC$$

$$\Delta\omega = \frac{\pi}{10 \times \frac{2}{3} RC}$$

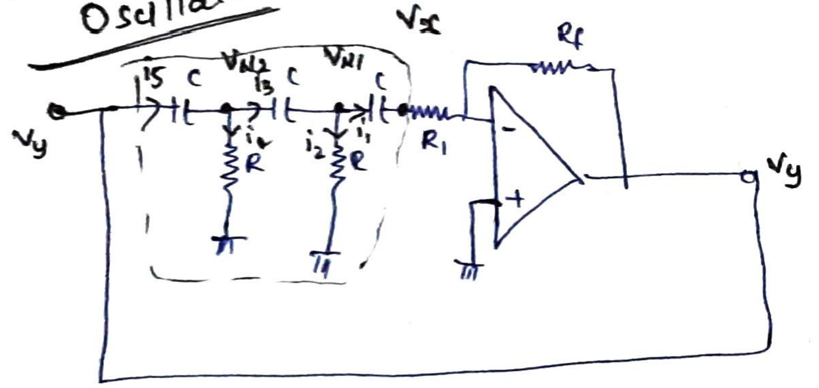
$$\boxed{\omega'_{osc} = \frac{1}{RC} + \Delta\omega.}$$

Phase shift Oscillator

If $A = -ve$

the $\angle A\beta = 180°$.

Phase shift Oscillator



$$A = -\frac{R_f}{R_1}$$

$$\frac{V_y}{V_x} = \frac{-R_f}{R_1}$$

$$i_1 = (V_{N_1} - V_x)\, sC$$

$$i_2 = \frac{V_{N_1}}{R}$$

$$i_3 = i_1 + i_2 = (V_{N_1} - V_x)\, sC + \frac{V_{N_1}}{R}.$$

$$\& \quad i_3 = (V_{N_2} - V_{N_1})\, sC$$

$$(V_{N_2} - V_{N_1})\, sC = (V_{N_1} - V_x)\, sC + \frac{V_{N_1}}{R}$$

$$V_{N_2}\, Cs = V_{N_1}\left(2sC + 1/R\right) - V_x sC$$

$$= V_{N_1}\left(\frac{2sRC + 1}{R}\right) - V_x sC$$

$$i_4 = \frac{V_{N_2}}{R}$$

$$(V_{N_1} - V_x)CS = V_x/R_1$$

$$i_5 = i_3 + i_4$$

$$= \frac{V_{N_2}}{R} + (V_{N_2} - V_{N_1})\, sC$$

$$\& \; i_5 = (V_y - V_{N_2})\, Cs$$

$$(V_y - V_{N_2})\, sC = \frac{V_{N_2}}{R} + (V_{N_2} - V_{N_1})\, sC$$

$$V_y\, sC = V_{N_2}\left(2sC + 1/R\right) - V_{N_1}\, sC$$

$$= V_{N_2}\left(\frac{2sRC + 1}{R}\right) - V_{N_1}\, sC$$

$$V_y\, sC = \left\{V_{N_1}\left(\frac{1 + 2RCs}{RCs}\right) - V_x\right\}\left(\frac{1 + 2RCs}{R}\right) - V_{N_1}\, Cs.$$

$$V_y\, sC = V_{N_1}\left\{\left(\frac{1 + 2RCs}{RCs}\right)\left(\frac{1 + 2RCs}{R}\right) - \frac{1}{Cs}\right\} - V_x\left(\frac{1 + 2RCs}{R}\right)$$

$$= V_{N_1}\left\{\frac{(1 + 2RCs)^2 - R^2}{R^2 Cs}\right\} - V_x\left(\frac{1 + 2RCs}{R}\right)$$

$$= \frac{V_x(1 + RCs)}{RCs}\left(\frac{(1 + 2RCs)^2 - R^2}{R^2 Cs}\right) - V_x\left(\frac{1 + 2RCs}{R}\right).$$