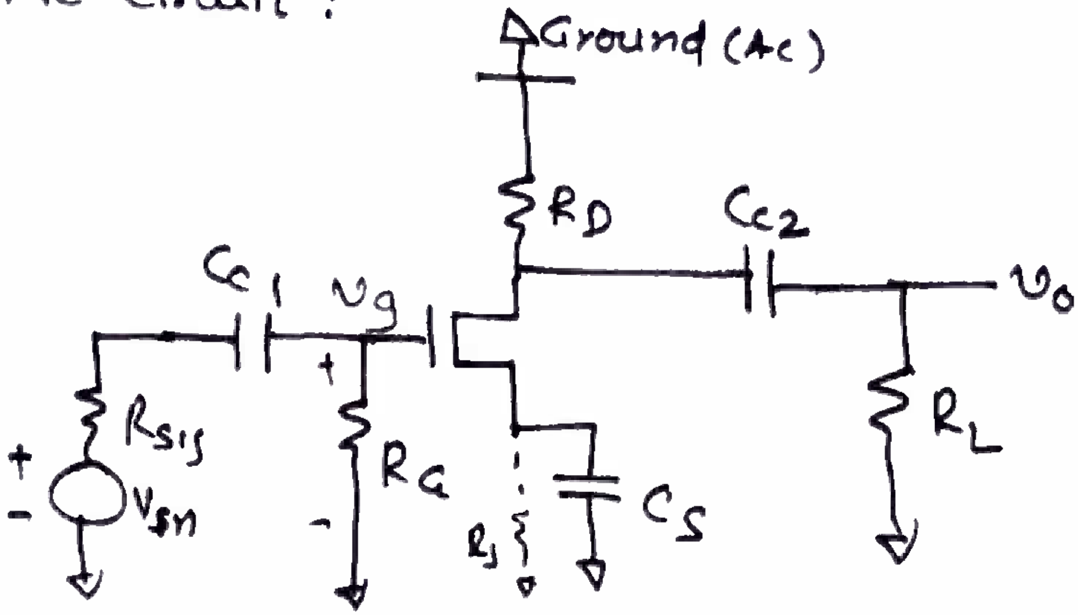
Low frequency Response of CS Amplifier

AC Circuit :

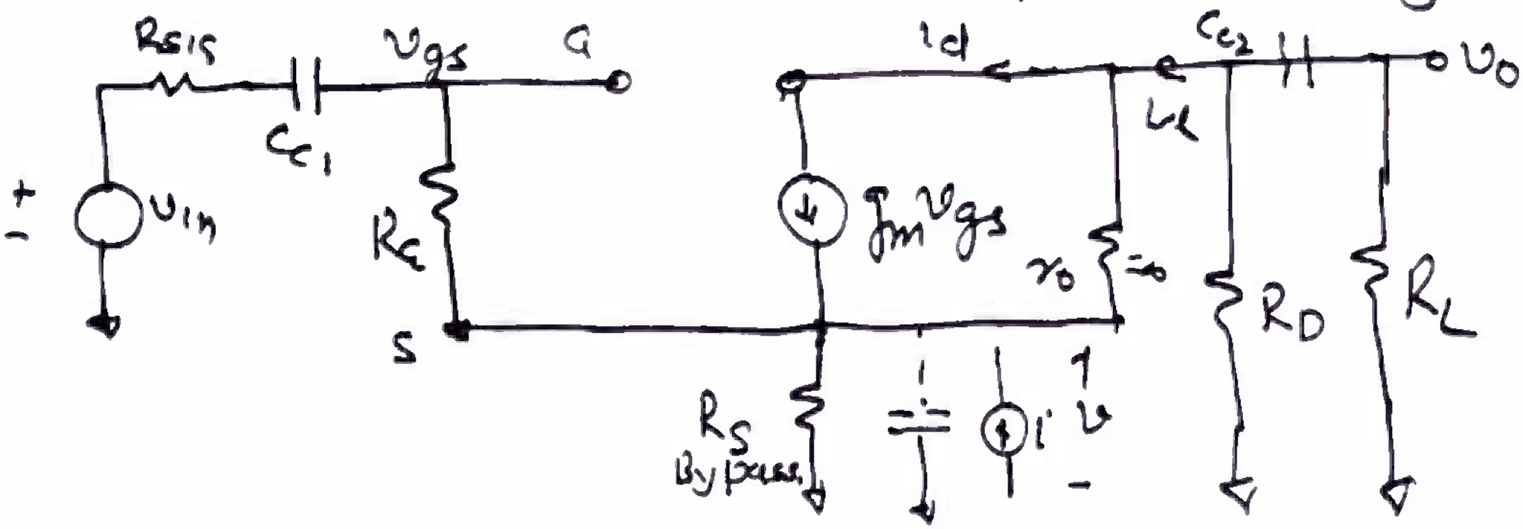


$$v_g = \frac{R_G}{R_G + R_{sig} + \frac{1}{sC_{c1}}} v_{in} = \frac{R_G}{R_G + R_{sig}} \frac{s}{s + \frac{1}{C_{c1}(R_G + R_{sig})}} v_{in}$$

Clearly $\dfrac{v_o}{v_{in}} = R_K \cdot \dfrac{s}{s+\omega_o} = \dfrac{1}{1+\frac{\omega_o}{s}}$

where $R_K = \dfrac{R_G}{R_G+R_{sig}}$, $\omega_o = \dfrac{1}{C_{C1}(R_G+R_{sig})}$

$\therefore$ This transfer function represents a High Pass Filter.



$$\omega_{P1} = \frac{1}{(R_G+R_{sig})C_{C1}}$$

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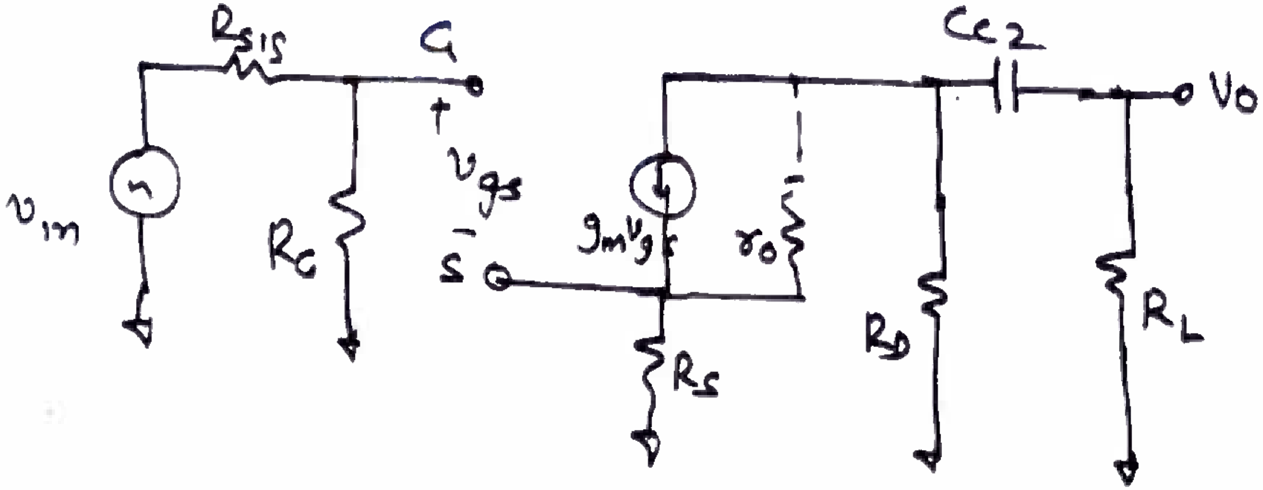
Effect of C_{c2}



Assume

$$g_m v_{gs} > \frac{v_o}{r_o}$$

$$v_{in} = v_{gs} + g_m v_{gs} \cdot R_s = (1 + g_m R_s) v_{gs}$$

For DC Gain

$$|A_{vo}| = \frac{v_o}{v_{in}} = \frac{g_m (R_D \| R_L)}{1 + g_m R_s}$$

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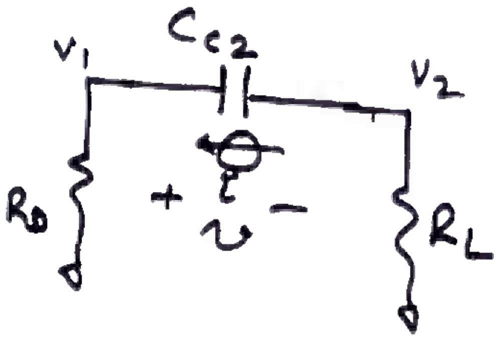
Using zero time constant method

Resistance seen by C_{c2} (short input)



$$\therefore \quad R_{eq} = R_{cc_2} = R_D + R_L$$

as $V_1 = i R_D$ & $V_2 = -i R_L$

$$\therefore -\frac{V_2 - V_1}{i} = \frac{v}{i} = R_{eq.} = R_D + R_L$$

$$\therefore \quad \tau_{cc_2} = R_{cc_2} \cdot C_{c2} \qquad \therefore \quad f_{L_{cc_2}} = \frac{1}{2\pi \left(R_{cc_2} C_{c2}\right)}$$

Similarly $f_{L_{cs}} = \dfrac{g_m / C_s}{2\pi}$ or $\omega_{L_{cs}} = \dfrac{g_m}{C_s}$

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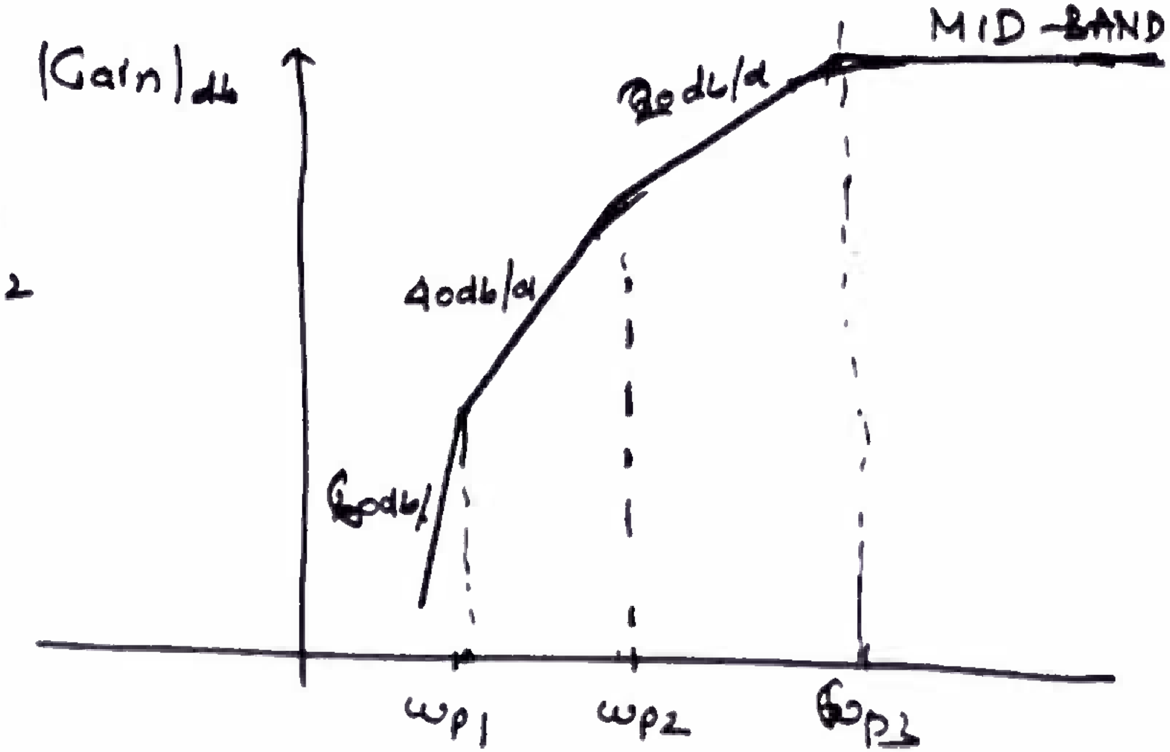
Hence we have Three Poles

$$\omega_{p1_{cc1}} = \frac{1}{(R_a + R_{sig})C_{c1}}$$

$$\omega_{p2_{cs}} = \frac{g_m}{C_s}$$

$$\omega_{p3_{cc2}} = \frac{1}{(R_D + R_L)C_{c2}}$$



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Bandwidth $= f_H - f_L$

1 MHz − 10k Hz

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Zero-Value Time Constant Analysis To Get Dominant Pole of a System

① Evaluate 'Resistance' as seen by a Capacitor after removing (open or short) all other Capacitors.

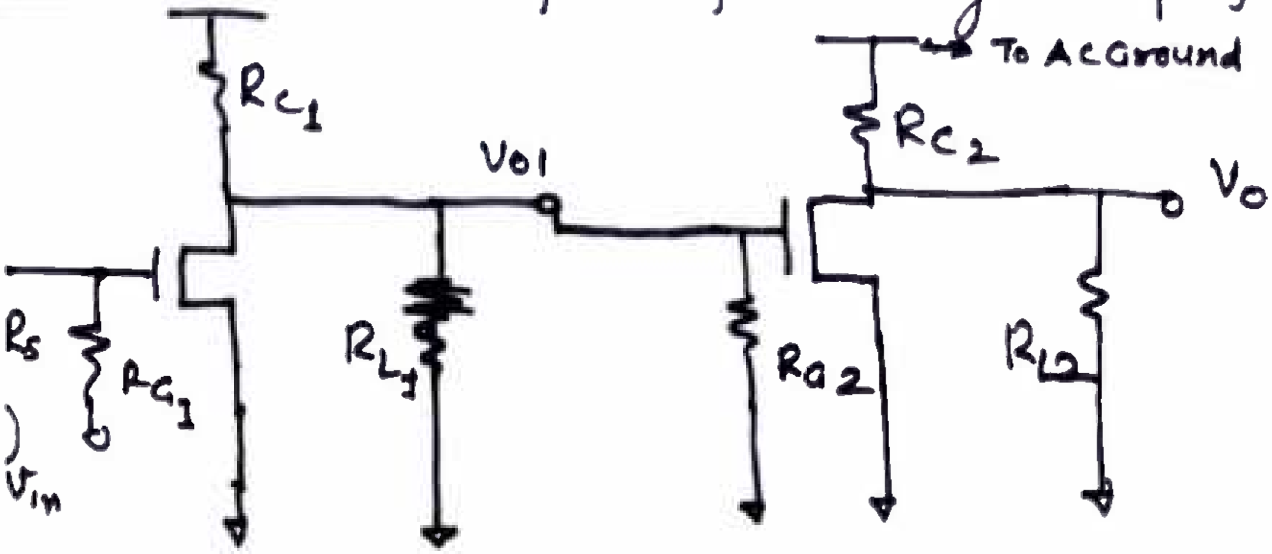
② Then the associated Time-Constant $= R_{seen} \cdot C_{W1}$

③ Evaluate similar to ① all other resistances seen by Capacitances and evaluate respective Time-Constants.

④ Then get net Time constant $\tau = \Sigma \tau_i$

⑤ Then the Pole frequency $\omega_p = \frac{1}{\tau}$ is the Dominant Pole.

Example of 2-Stage Amplifier (CE Type)

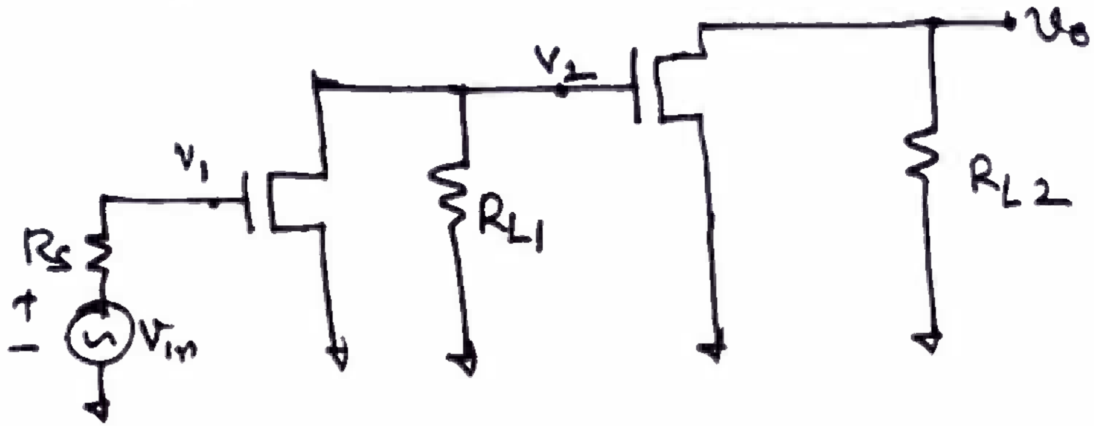


AC Diagram

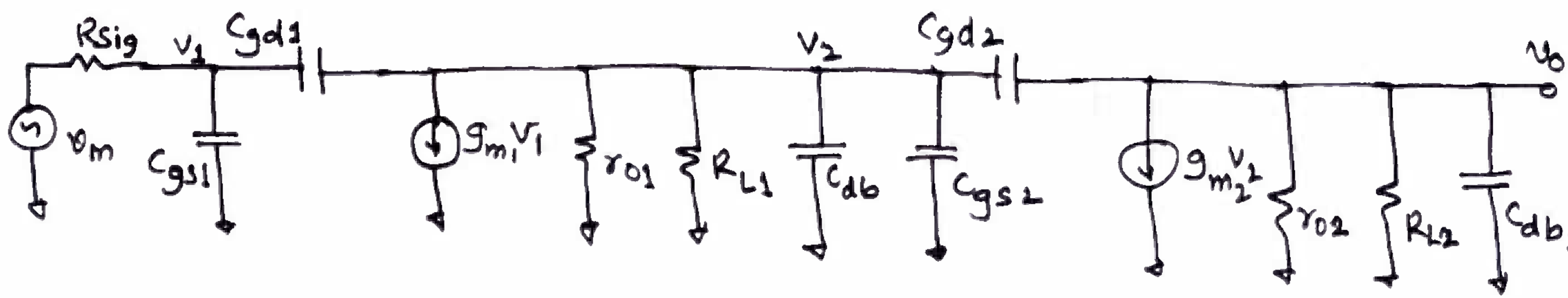
We wish to know Dominant Pole of this System

Zero-Value Time Constant Analysis

Ex. Multistage Cascode Amplifier (AC Circuit)



Equivalent Circuit



Approx. Method to estimate presence of a Dominant Pole

If there are no Dominant Zeros, then

$\omega_{-3db} = p_1$ Dominant pole

and $p_1 < p_2 < p_3$ . . . . We observe that Gain T.F is

$$A_v(s) = \frac{N(s)}{D(s)} = \frac{A_{vo}}{\left(1-\frac{s}{p_1}\right)\left(1-\frac{s}{p_2}\right)\left(1-\frac{s}{p_3}\right)\cdots\left(1-\frac{s}{p_n}\right)}$$

Typical T F

$$= \frac{a_0 + a_1 s + a_2 s^2 + \cdots a_n s^n}{1 + b_1 s + b_2 s^2 - - b_n s^n}$$

$s\left(\frac{1}{p_1} + \cancel{\frac{1}{p_2}}\right)$ $\therefore$ $b_1 = \sum_{i=1}^{N}\left(-\frac{1}{p_i}\right) = \left|\frac{1}{p_1}\right|$

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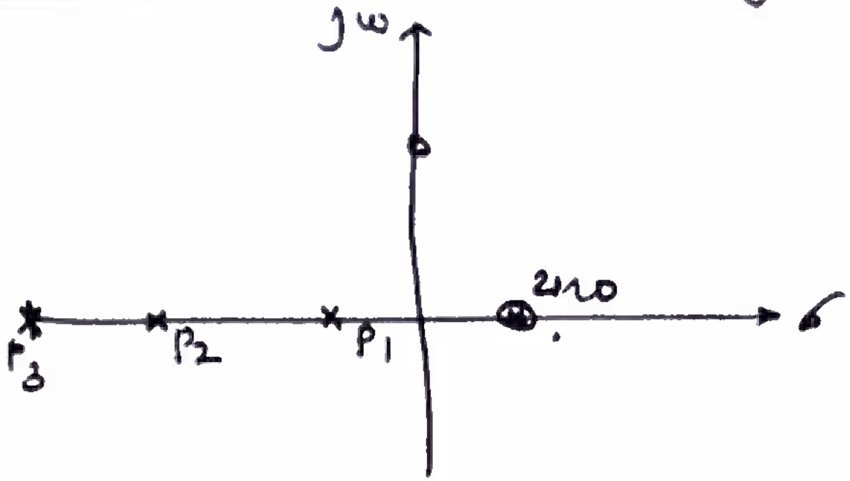
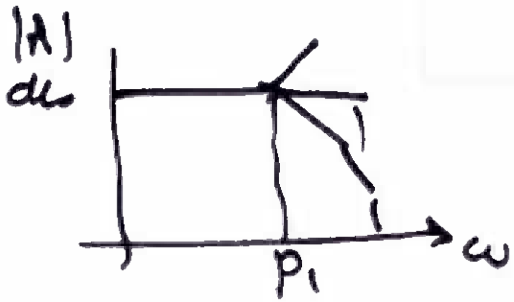
$s = \sigma + j\omega$ (s-plane)





$$|A(j\omega)| = \frac{A_{vo}}{\sqrt{1 + \left(\frac{\omega}{p_1}\right)^2}}$$

$\therefore$ Bode Plot is correct as long as $\omega \le |p_1|$

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In zero-Value time constant analysis every capacitor sees some equivalent Resistance, & then $\tau = R_{eq} \cdot C$

We evaluate R_{eq} for each capacitor and get $\tau_1 = R_{eq1} C_1$, $\tau_2 = R_{eq2} C_2$ - -, $\tau_n = R_{eqn} C_n$

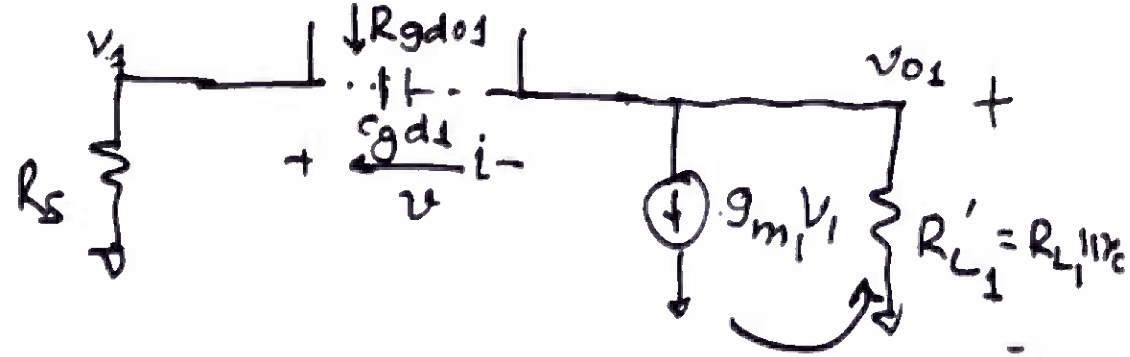
Then net $\tau = \Sigma \tau_i$ & then the Dominant Pole p_1

$$p_1 = \frac{1}{\tau}$$

For our circuit we evaluate R_{eq} seen by C_{gd1}, - - - C_{db2}

(i) $R_{gdo1} = R_{eq}$ seen by C_{gd1}

Here $R_{gdo1} = \frac{v}{i}$



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$$i \cdot R_s = V_1 \quad \text{— (i)}$$

$$(-i - g_{m_1} V_1) R'_{L_1} = V_{01} \quad \text{— (ii)}$$

&

$$R_{gd01} = \frac{V_1 - V_{01}}{i} \quad \text{— (iii)}$$

from (ii)

$$-(i + g_{m_1} i R_s) R'_{L_1} = V_{01}$$

$$\therefore \quad -\frac{V_{01}}{i} = (1 + g_m R_s) R'_{L_1} \quad \text{— (iv)}$$

$$+\frac{V_1}{i} = R_s \quad \text{— (v)}$$

$$\therefore \quad \frac{V_1 - V_{01}}{i} = R_s + (1 + g_{m_1} R_s) R'_{L_1}$$

$$\therefore \quad \boxed{R_{gd01} = R_s + R'_{L_1} + g_{m_1} R_s R'_{L_1}}$$

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Similarly R_{gdo2} is seen by C_{gd2} & is given by $R_{gdo2} = R'_{L1} + R'_{L2} + g_{m2} R'_{L1} R'_{L2}$

R_{gso1} = R_{eq} seen by C_{gs1}

$\therefore R_{gso1} = R_S$

similarly

$R_{gso2} = R'_{L1}$ — seen by C_{gs2}

& $R_{dbo1} = R'_{L1}$ — " " C_{db1}

$R_{dbo2} = R'_{L2}$ — " " C_{db2}

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Then time constants are

$$\tau_{gs1} = R_{gso1} \cdot C_{gs1}$$

$$\tau_{gs2} = R_{gso2} \cdot C_{gs2}$$

$$\tau_{gd1} = R_{gdo1} \cdot C_{gd1} = (R_s + R'_{L1} + g_{m1} R'_{L1} R_s)\, C_{gd1}$$

$$\tau_{gd2} = R_{gdo2} \cdot C_{gd2} = (R'_{L1} + R'_{L2} + g_{m2} R'_{L2} R'_{L1})\, C_{gd2}$$

$$\tau_{db1} = R_{db1} \cdot C_{db1} = R'_{L1}\, C_{db1}$$

$$\tau_{db2} = R_{db2}\, C_{db2} = R'_{L2}\, C_{db2}$$

Then $\tau = \sum_{i=1}^{6} \tau_i = \tau_{gs1} + \tau_{gs2} + \tau_{gd1} + \tau_{gd2} + \tau_{db1} + \tau_{db2}$

Then the Dominant Pole $= \dfrac{1}{\tau} = \omega_{-3db}$

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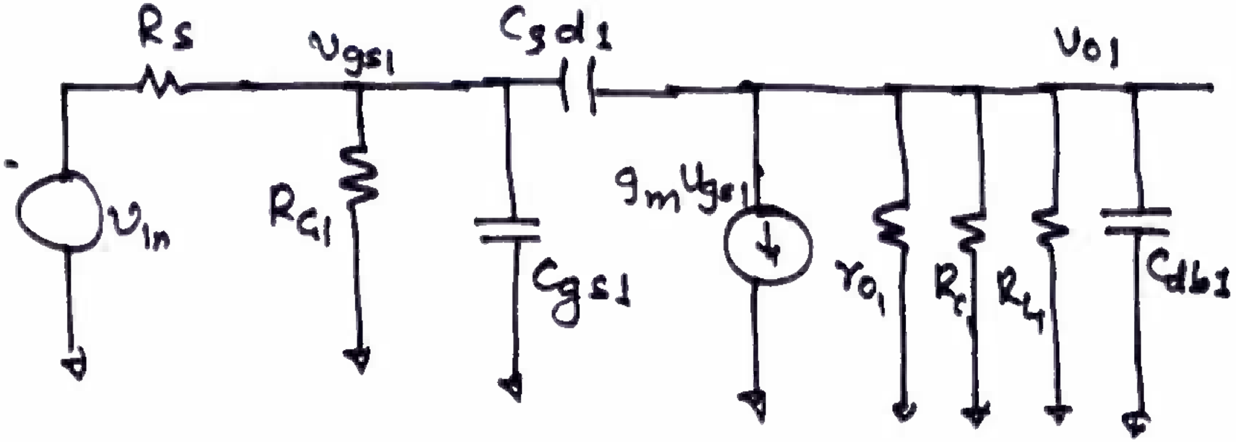
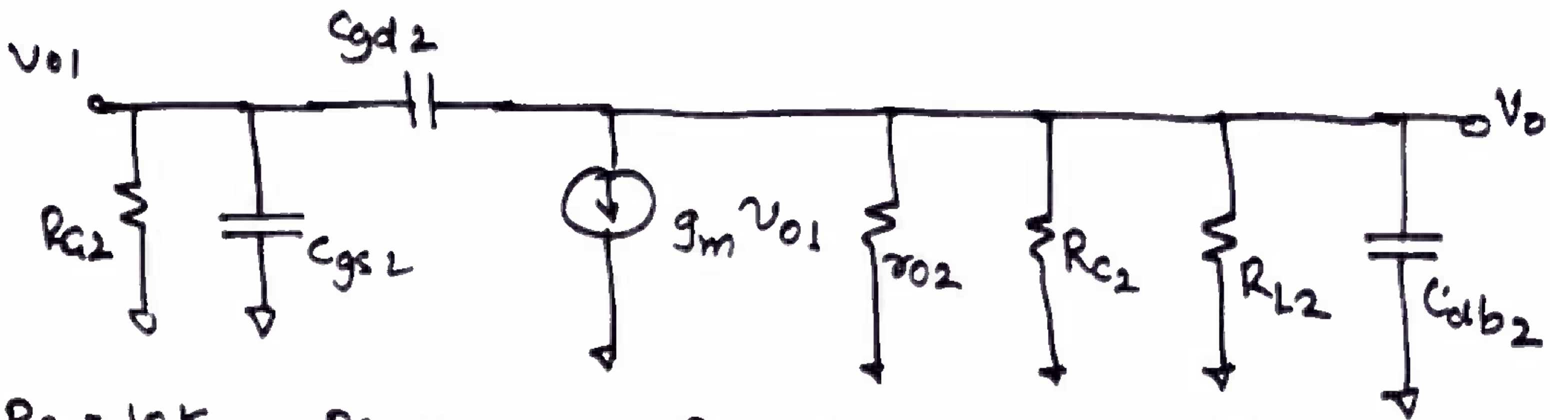
Equivalent Ckt





Given $R_s = 10K$, $R_{G1} = 1M\Omega$, $R_{L1} = 10K$, $R_{L2} = 5K$, $R_{G2} = 1M$

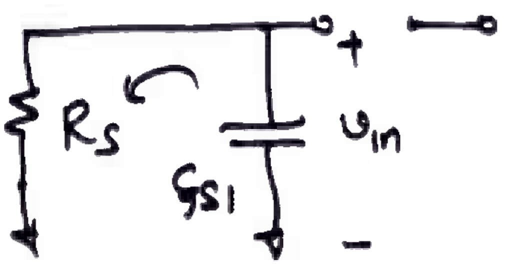
$C_{gs1} = 5pf$, $C_{gs2} = 10pf$, $C_{gd1} = C_{gd2} = 1pf$ $C_{db1} = C_{db2} = 2pf.$

$$r_{o1} = r_{o2} = 5\,M\Omega$$

$$g_{m1} = 3mA/V \quad , \quad g_{m2} = 6mA/V$$

As $R_s << R_{G1}$ we need neglect R_G in evaluations.

① Capacitanc C_{gs1} related R_{gso1} is found as



$R_{gso1} = R_s$ (could be $R_s \| R_{G1}$)

$$\therefore \quad \tau_{ogs1} = R_s C_{gs1}$$

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Then repeating this procedure for all capacitors

$$\tau_{gdo1} = R_{gdo1} \cdot C_{gd1}$$

$$= (R_s + R'_{L1} + g_{m1} R'_{L1} R_s)\, C_{gd1} = 320\,ns.$$

$$\tau_{cgdo2} = R_{cgdo2} C_{gd2} = (R'_{L1} + R'_{L2} + g_{m2} R'_{L2} R'_{L1})\, C_{gd2}$$

$$= 315\,ns.$$

$$\tau_{cgs1} = R_{cgso1} \cdot C_{gs1} = 50\,ns$$

$$\tau_{cgs2} = R_{cgso2} \cdot C_{gs2} = 100\,ns$$

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$$\tau_{db_1} = R_{cdbo1} \cdot C_{db_1} = R'_{L_1} C_{db_1}$$
$$= 20 ns$$

$$\tau_{cdb_2} = R_{cdbo2} \cdot C_{db_2} = R'_{L_2} C_{db_2}$$
$$= 10 ns.$$

$$\therefore \quad \tau = \Sigma \text{ All } \tau = 320 + 315 + 50 + 100 + 20 + 10 \text{ ns}$$
$$= 815 \text{ ns}$$

$$\therefore \quad \omega_p = \text{Dominant Pole} = \frac{1}{815 \text{ ns}} = 1.2 \times 10^6 \text{ rad/s}$$

$$\text{or } f_p \simeq 196 \text{ kHz}$$