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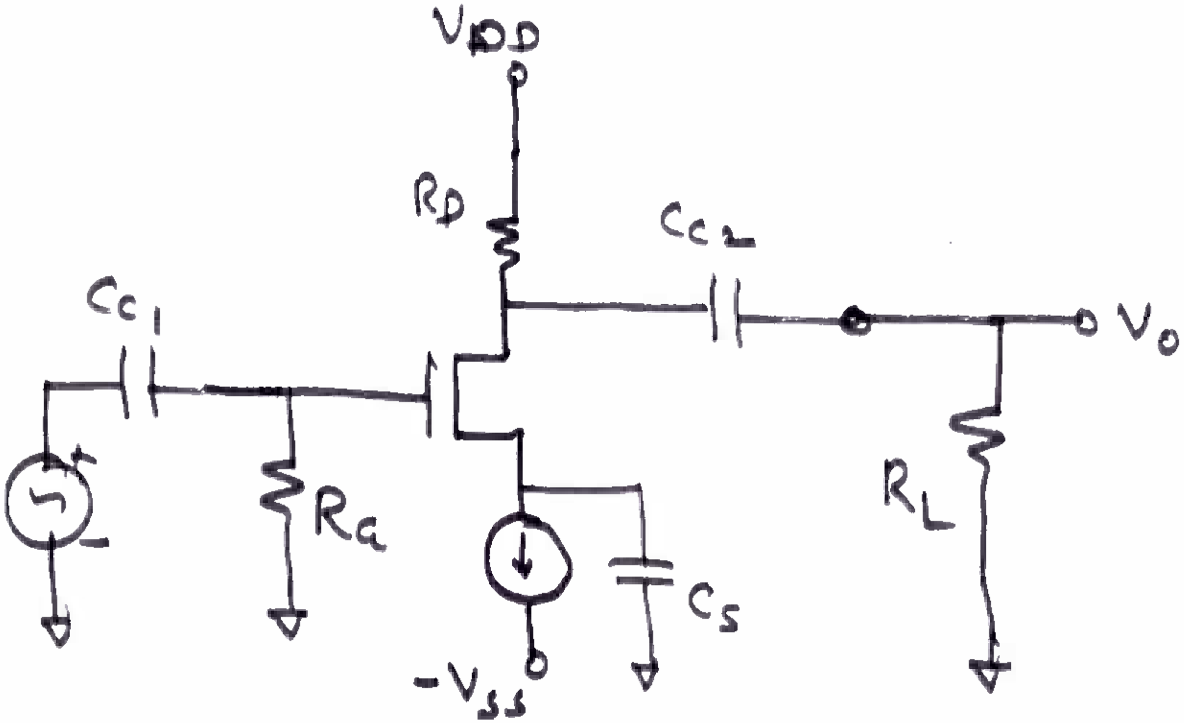
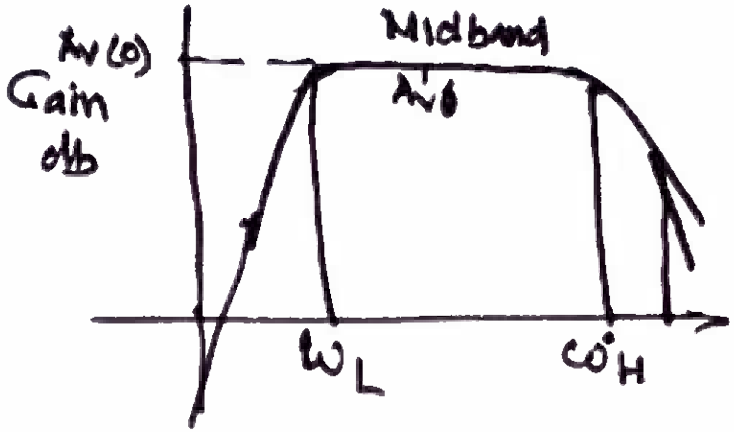
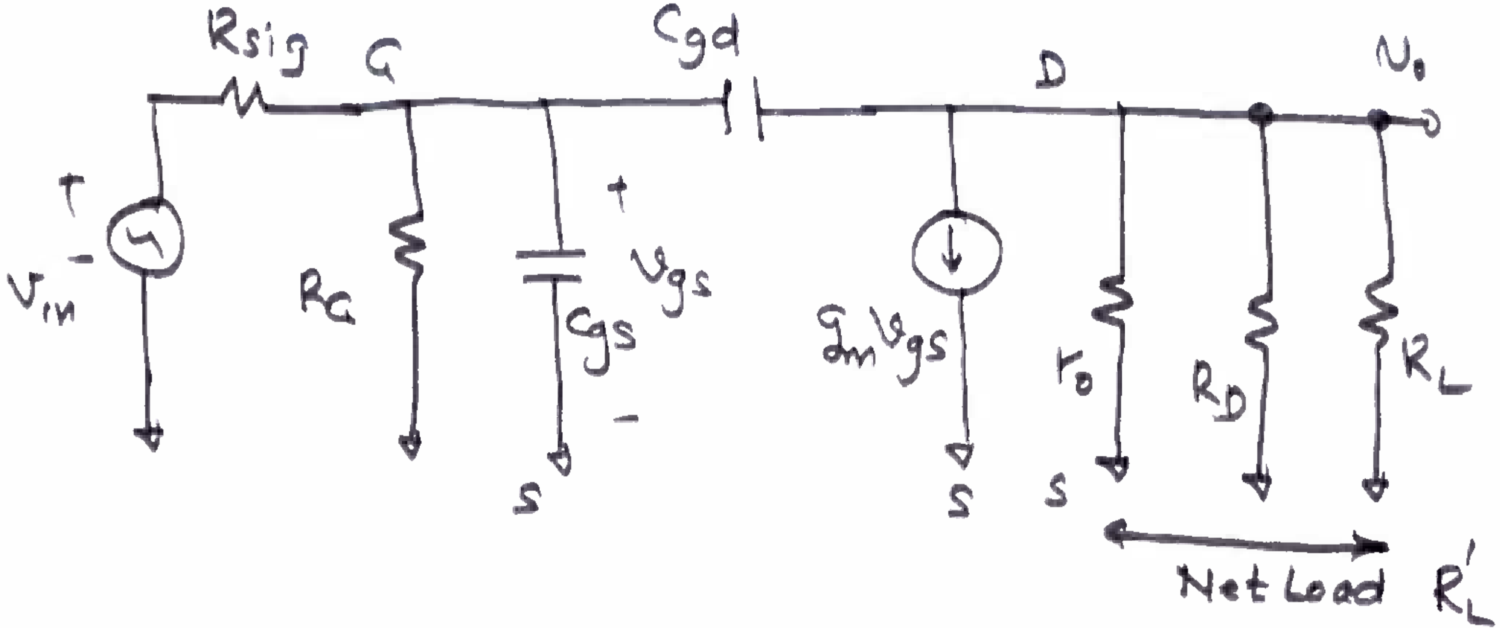
High Frequency Response of a MOS Amplifier (Common Source Type)

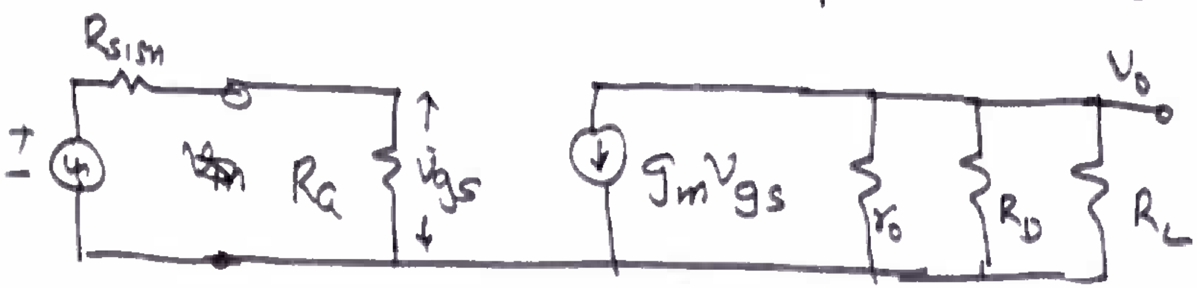




$$\text{Bandwidth} = \omega_H - \omega_L$$



① DC Gain A_{vo} :— All capacitors are omitted appropriately. ($R_G >> R_{sig}$) Normally



$$R_L' = r_o \parallel R_D \parallel R_L$$

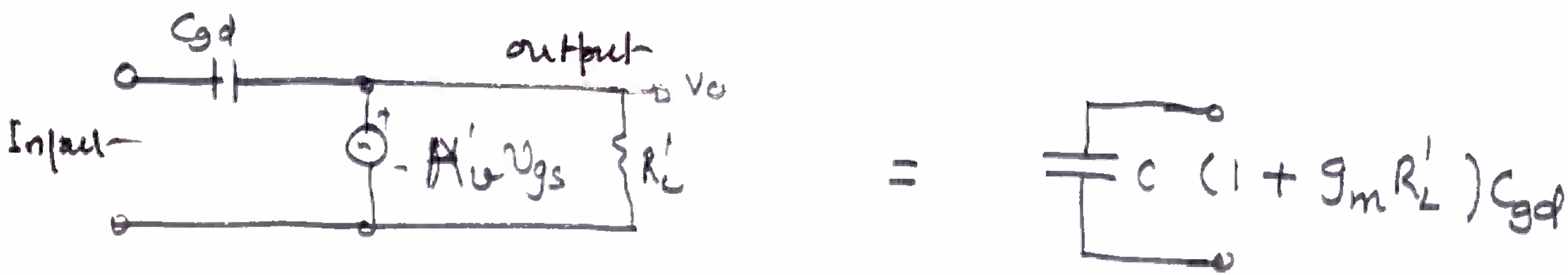
$$A_v'(0) = -\frac{R_G}{R_G + R_s} \cdot g_m R_L'$$

$$v_{gs} = \frac{R_G}{R_G + R_{sig}} \cdot V_{in} \qquad — (1)$$

Then $$v_o = -\, g_m v_{gs} \cdot R_L' \qquad — (2)$$

$$\therefore \frac{v_o}{v_{gs}} = A_{vo}' = -\, g_m R_L' \qquad — (3)$$

Using Miller's theorem between G & D



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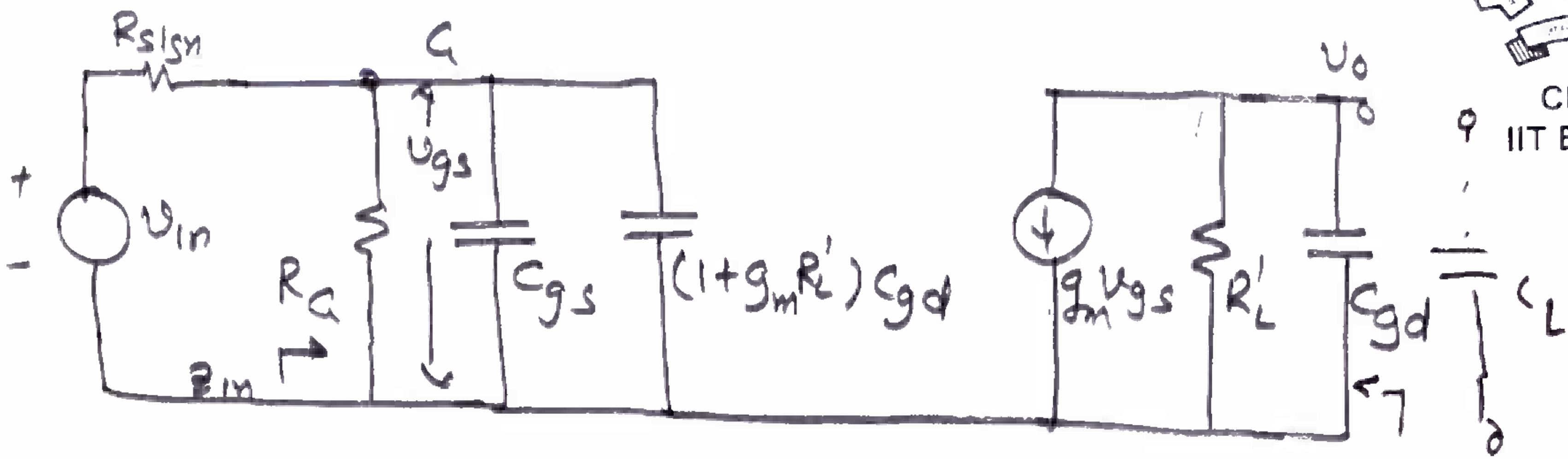
Hence Equivalent Ckt is



$$\therefore \quad Z_{in} = \left(R_G \parallel \frac{1}{C_{eq}j\omega}\right) \quad \text{where } C_{eq} = C_{gs} + (1+g_mR_L')C_{gd}$$

$$\therefore \quad v_{gs} = \frac{Z_{in}}{Z_{in} + R_{sign}} \cdot v_{in}$$

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$$Z_o = \left(R_L' \parallel \frac{1}{C_{gd}s}\right)$$

$$\frac{1}{Z_o} = \frac{1}{R_L'} + C_{gd}s$$

$$\therefore \quad Z_o = \frac{R_L'}{1 + R_L' C_{gd} \cdot S}$$

&

$$Z_{in} = \frac{R_G}{1 + R_G C_{eq} \cdot S}$$

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$$A_v(s) = \frac{A'_{vo}(0)}{(1+R'_L C_{gd} \cdot s)\left[1 + \frac{R_{sig}}{R_G} + R_{sig} \cdot C_{eq} \cdot s\right]}$$

$$= \frac{A_{vo}(0)}{R'_L C_{gd}\left(s + \frac{1}{R'_L C_{gd}}\right) R_{sig} C_{eq}\left[s + \frac{\left(1+\frac{R_{sig}}{R_G}\right)}{R_{sig} C_{eq}}\right]}$$

$$= \frac{A'_{vo}(0)}{R'_L R_{sig} \cdot C_{gd} C_{eq}} \cdot \frac{1}{\left(s + \frac{1}{R'_L C_{gd}}\right)\left(s + \frac{1}{R'_{in} C_{eq}}\right)}$$

$$R'_{in} = R_G \| R_{sig}$$

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We define $\omega_0 = \dfrac{1}{R'_{in} C_{eq}}$

$$\omega_1 = \frac{1}{R'_L C_{gd}}$$

$$A_V(0) = \frac{A'_V(0)}{R_{sig} \cdot R'_L \, C_{gd} \cdot C_{eL}} \cdot \frac{1}{(s+\omega_0)(s+\omega_1)}$$

$$= \left[A'_V(0)\,\omega_0\omega_1\right] \frac{1}{(s+\omega_0)(s+\omega_1)}$$

$\omega = \omega_0$

$$= A_{V\,midband} = A_V(0) \cdot \frac{1}{\left(\frac{s}{\omega_0}+1\right)\left(\frac{s}{\omega_1}+1\right)}$$

$j\omega + 1 = 0$

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$$\therefore \; v_o = - g_m z_o \cdot v_{gs}$$

$$= - \frac{g_m R_L'}{1 + R_L' C_{gd} s} \cdot \frac{R_G / (1 + R_G C_{eq} s)}{\dfrac{R_G}{1 + R_G C_{eq} s} + R_{sign}} \cdot v_{in}$$

$$\therefore \; A_v(s) = \frac{v_o(s)}{v_{in}(s)} = - \frac{g_m R_L'}{1 + R_L' C_{gd} \cdot s} \cdot \frac{R_G}{R_G + R_{sig} (1 + R_G C_{eq} s)}$$

$\underline{A_v(0)}$

$A_v'(0)$

$$= - \frac{A_v'(0) \cdot R_G}{(1 + R_L' C_{gd} s) \left[R_G + R_{sig} (1 + R_G C_{eq} \cdot s) \right]}$$

We observe from values of Components

where $\omega_{p1} << \omega_{p2}$

$$\omega_{p1} = \frac{1}{R_{sig}(1+g_m R_L')C_{gd} + R_{sig}C_{gs} + R_L'(C_{gd}+C_{db})}$$

Then we call ω_{p1} as Dominant Pole.

Zero's Presence:

$$\omega_z = \frac{g_m}{C_{gd}} \simeq \frac{10^{-3}}{10^{-12}}$$

10^{+9}

$$\left(\frac{j\omega_z}{\omega} + 1 \right)$$

$$f_z \simeq \frac{1}{2\pi} \times 10^9 = 1.5 \times 10^8$$

$\sqrt{4+1}$

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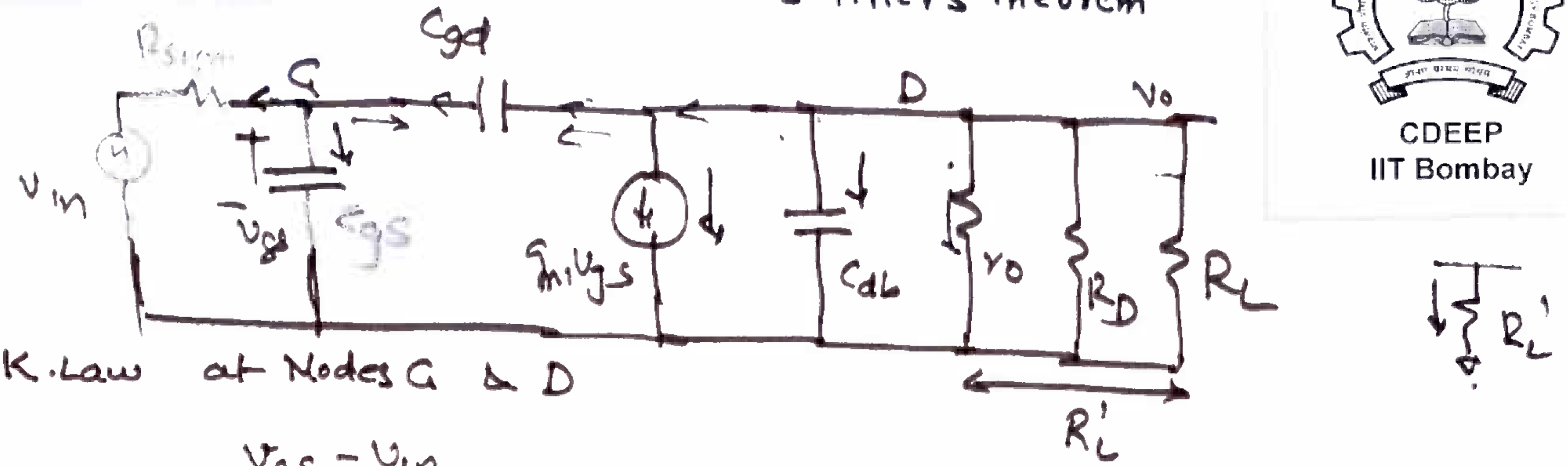
Full Circuit Analysis without use of Miller's Theorem**



K. Law at Nodes G & D

$$\frac{v_{gs} - v_{in}}{R_{sign}} + v_{gs} \cdot C_{gs} \cdot s + (v_{gs} - v_o) C_{gd} \cdot s \quad — (1)$$

$$(v_o - v_{gs}) C_{gd} \cdot s + g_m v_{gs} + v_o \left(\frac{1}{R_L'} + C_{dL} \cdot s \right) \quad — (ii)$$

** Miller Theorem's use earlier, we lost track of 'Zero'.

From equ. (ii)

$$v_{gs} = -\frac{v_o\left(C_{gd}\cdot s + \frac{1}{R_L'} + C_{db}\cdot s\right)}{g_m - C_{gd}\cdot s}$$

substituting this in (i)

$$\frac{-V_o}{g_m - C_{gd}\cdot s}\cdot\left[\frac{1}{R_{sig}} + (C_{gs}+C_{gd})\cdot s\right]\left[(C_{gd}+C_{db})s\right]$$

$$-V_o C_{gd}\cdot s = \frac{V_{in}}{R_{sig}}.$$

$$\therefore \quad \frac{v_o(s)}{v_{in}(s)} = A_v(s) = \frac{(C_{gd}\cdot s - g_m)R_L'}{R_{si}R_L' \Sigma\, s^2 + \left[R_{sig}(1+g_m R_L')C_{gd} + R_{sig}C_{gs} + R_L'(C_{gd}+C_{db})\right]\cdot s + 1}$$

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where $\xi = C_{gd} C_{gs} + C_{gs} C_{db} + C_{gd} C_{db}$

Looking at Denomenator

$$D = \left(\frac{s}{\omega_{p1}} + 1\right)\left(\frac{s}{\omega_{p2}} + 1\right)$$

$$= \frac{s^2}{\omega_{p1}\,\omega_{p2}} + \left(\frac{1}{\omega_{p1}} + \frac{1}{\omega_{p2}}\right)s + 1$$

$$\frac{1}{as^2 + bs + c} \cong k\,\frac{1}{(s+\omega_1)(s+\omega_2)}$$

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Thus apart from Two Poles, the circuit has a Zero at

$$\boxed{S_z = \frac{g_m}{C_{gd}}}$$

The Two poles, include 'Dominant Pole' which we found out using ① Dominant Pole approximation and ② Use of Miller's Theorem

The complete Nodal Analysis, thus is more Accurate as It does not do any 'Assumption'.

Frequency Response of the CE Amplifier

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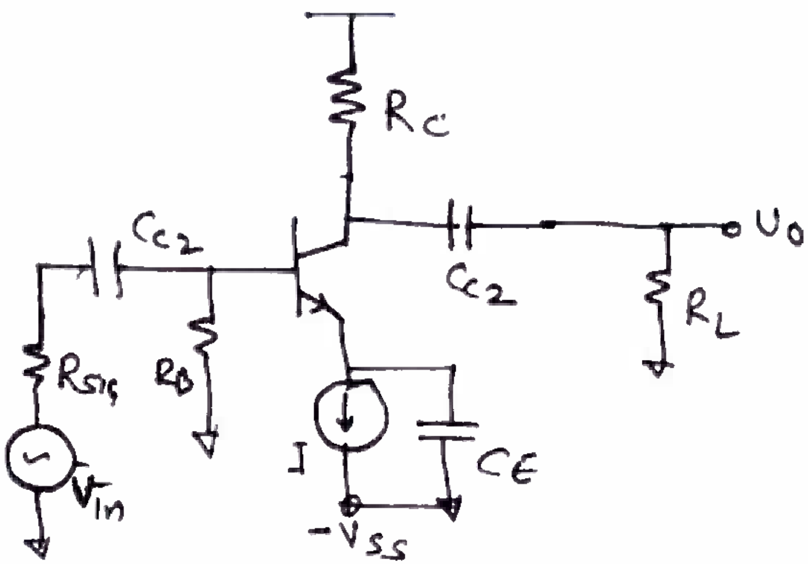
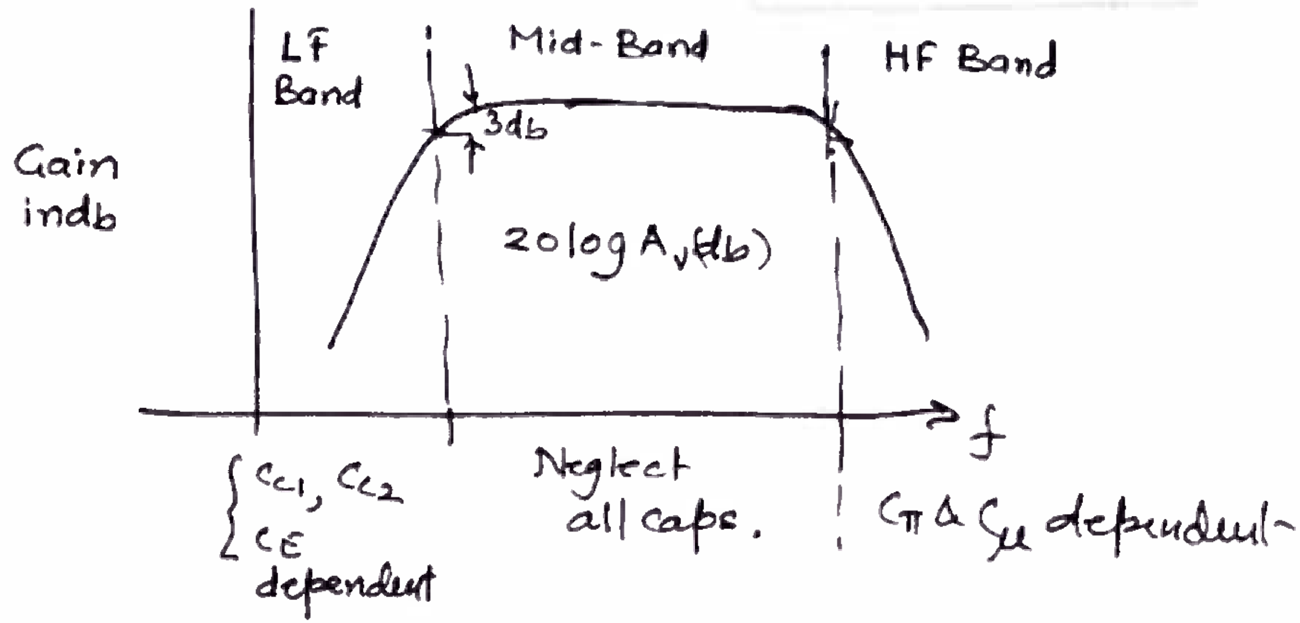
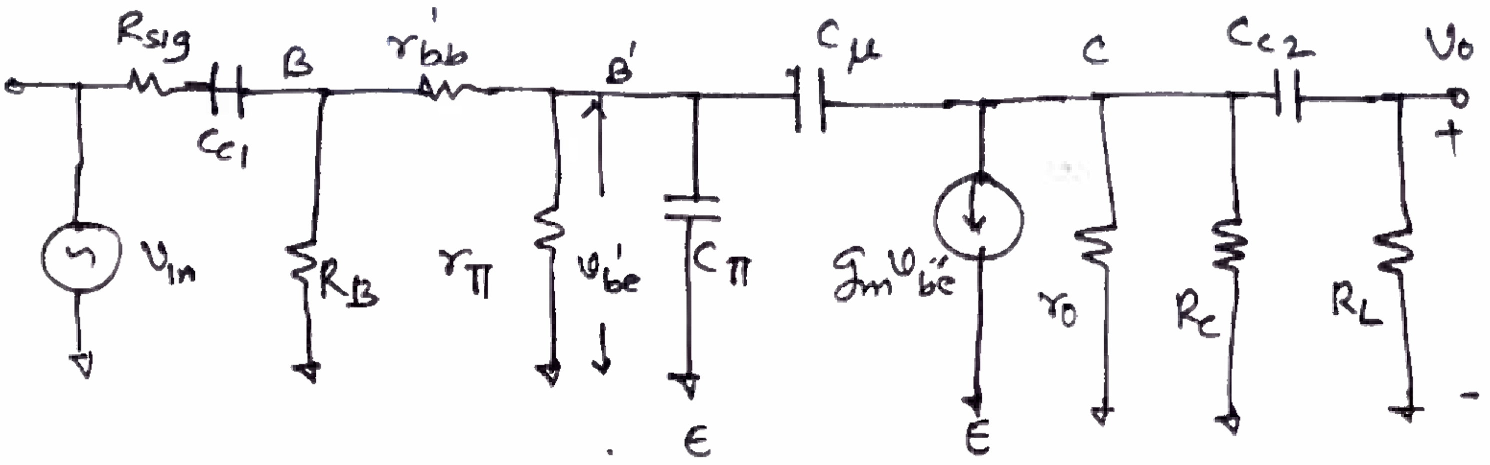
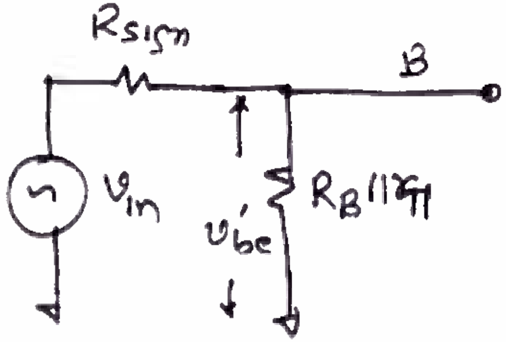


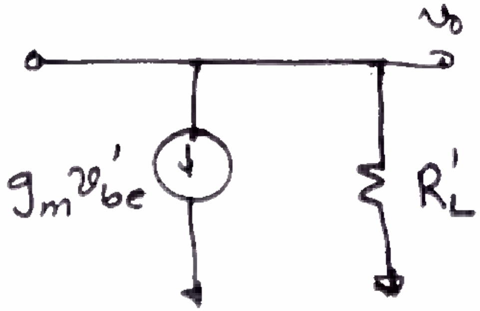


Eq. Ckt is :



① DC Gain : Neglect all capacitors appropriately.
Neglect $r_{bb'}$ as we assume $i_b = 0$ (V. small.)





$$\frac{1}{R_L'} = \frac{1}{r_o} + \frac{1}{R_C} + \frac{1}{R_L}$$

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$$v_o = -g_m R_L' v_{be}'$$

$$v_{be}' = \frac{R_{B\pi}}{R_{sgn} + R_{B\pi}} v_{in}$$

where $R_{B\pi} = R_B \parallel r_\pi$

$$\therefore \quad v_o = -g_m R_L' \cdot \frac{R_{B\pi}}{R_{B\pi} + R_{sig}} \cdot v_{in}$$

$$\therefore \quad A_v(0) = \frac{v_o}{v_{in}} = -\frac{R_{B\pi}}{R_{B\pi} + R_{sig}} \cdot g_m R_L'$$

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HF response

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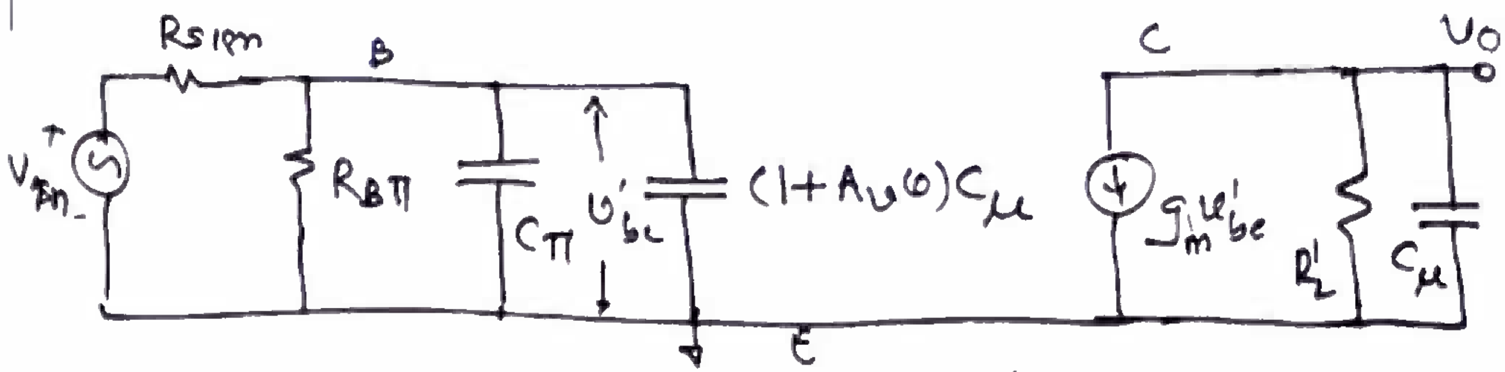
We have values of C_{c_1} & C_{c_2} high enough to give $\frac{1}{j\omega C_{c_1}}$ & $\frac{1}{j\omega C_{c_2}}$ at high frequencies

=> Short ckt.

Similarly Bypass Capacitor C_E too is high & at High Frequ. its impendance $= 0$

Infact the values of C_{c_1}, C_{c_2} & C_E are normally v. high so that they provide 'short' ckt from Midband to HF.

Using Miller's theorem for C_μ, we have equivalent ckt of the BJT Amplifier as



$$\text{Load Imp.} = R_L' \,\|\, \frac{1}{C_\mu s} = \frac{R_L'}{1 + R_L' C_\mu s}$$

Further $$v_{be}' = \frac{\left(R_{B\pi} \,\|\, \frac{1}{C_{\pi\mu} s}\right)}{\left(R_{B\pi} \,\|\, \frac{1}{C_{\pi\mu} s}\right) + R_{sign}} \cdot v_{in}$$ where $$C_{\pi\mu} \triangleq C_\pi + C_\mu(1 + A_v(0))$$

$$\therefore \quad v_o = -\frac{g_m R_L'}{1 + R_L' C_\mu s} v_{be}'$$

$R_{B\pi} \parallel \frac{1}{C_{\pi\mu}}$

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or $$v_o = -\frac{g_m R_L'}{1 + R_L' C_\mu s} \frac{\left(\frac{R_{B\pi}}{1 + R_{B\pi} C_{\pi\mu} s}\right)}{R_{sig.} + \frac{R_{B\pi}}{(1 + R_{B\pi} C_{\pi\mu} s)}} v_{in}$$

or $$\frac{v_o}{v_{in}} = A_v(s) = -\frac{g_m R_L'}{1 + R_L' C_\mu s} \cdot \frac{R_{B\pi}}{R_{B\pi} + R_{sig} + R_{sig} R_{B\pi} C_{\pi\mu} s}$$

$$A_v(s) = \frac{-\; g_m R_L'}{1 + \frac{R_s}{R_{B\pi}} + \left[R_s C_{\pi\mu} + \left(1 + \frac{R_s}{R_{B\pi}}\right) R_L' C_\mu \right] s + R_s R_L' C_\mu C_{\pi\mu} s^2}$$

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Slide No: 20 There are Two Poles

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$$\omega_2 = \frac{1}{R_L' C_\mu} \quad \text{(output Pole)}$$

& $$\omega_1' = \frac{1}{\frac{1}{R_S C_{\pi\mu}}\left(1+\frac{R_S}{R_{B\pi}}\right)}$$

or $$\omega_1 = \frac{(1+R_S/R_{B\pi})}{R_S C_{\pi\mu}} \simeq \frac{1}{R_S' C_{\pi\mu}}.$$

$$= \frac{1}{R_S'\left[C_\pi + \{1+A_v(0)\}C_\mu\right]} \qquad R_S' = \frac{R_S}{R_S \| R_{B\pi}}$$

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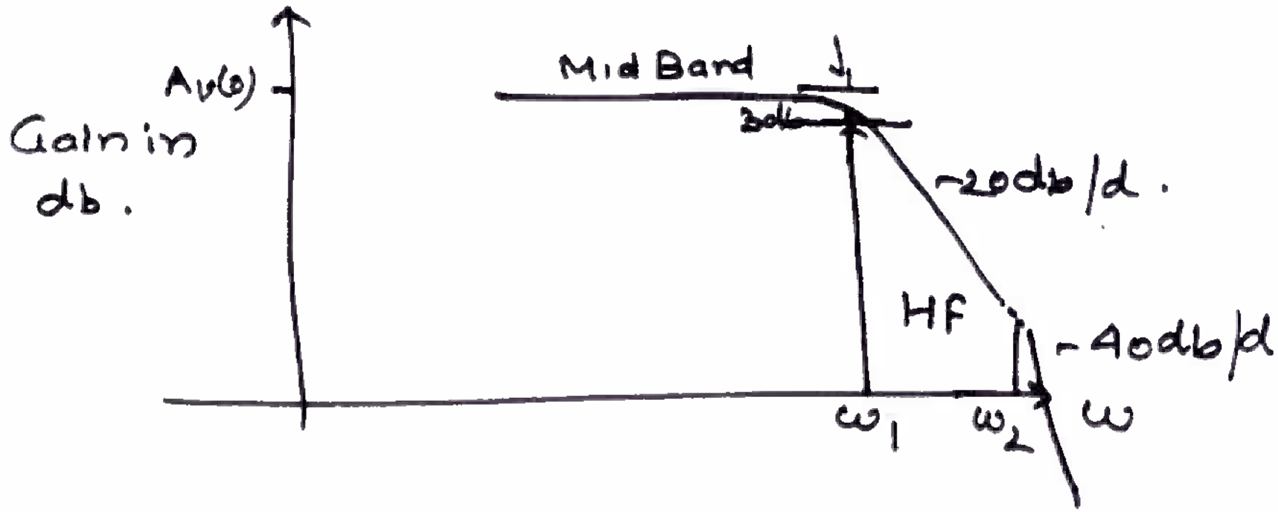
As $A_v(0) >> 1$

$\omega_2 >> \omega_1$

$\therefore$ ω_1 is Dominant Pole



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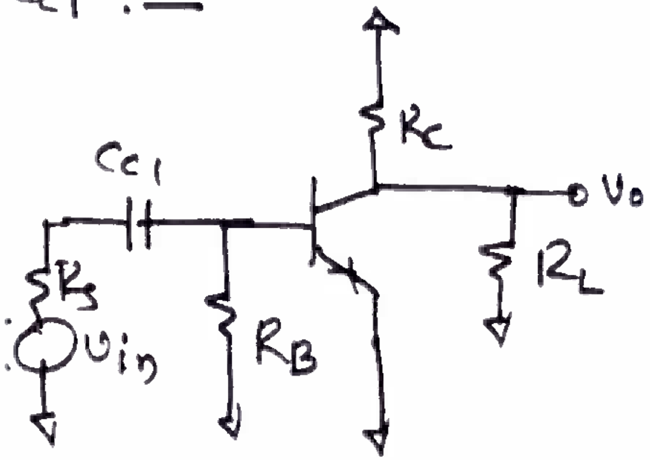
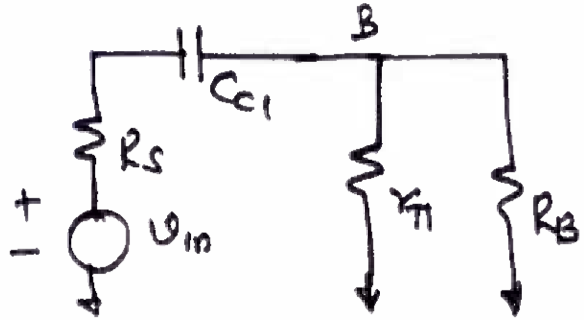
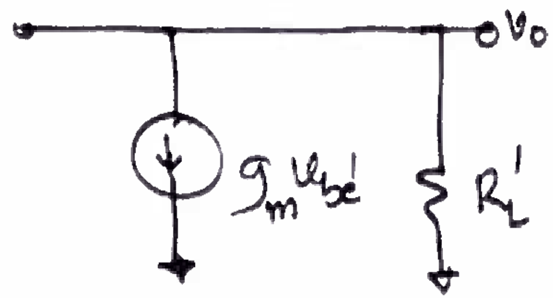
Low Frequency Response

Due to C_{c_1}, C_{c_2} and C_E. We use superposion Theorem.

C_{c_1} :—







∴ Pole is on the Input Side & is

$$\omega_{p1} = 2\pi f_{p1} = \frac{1}{C_{c_1}\left[R_{B\pi} + R_s\right]}$$

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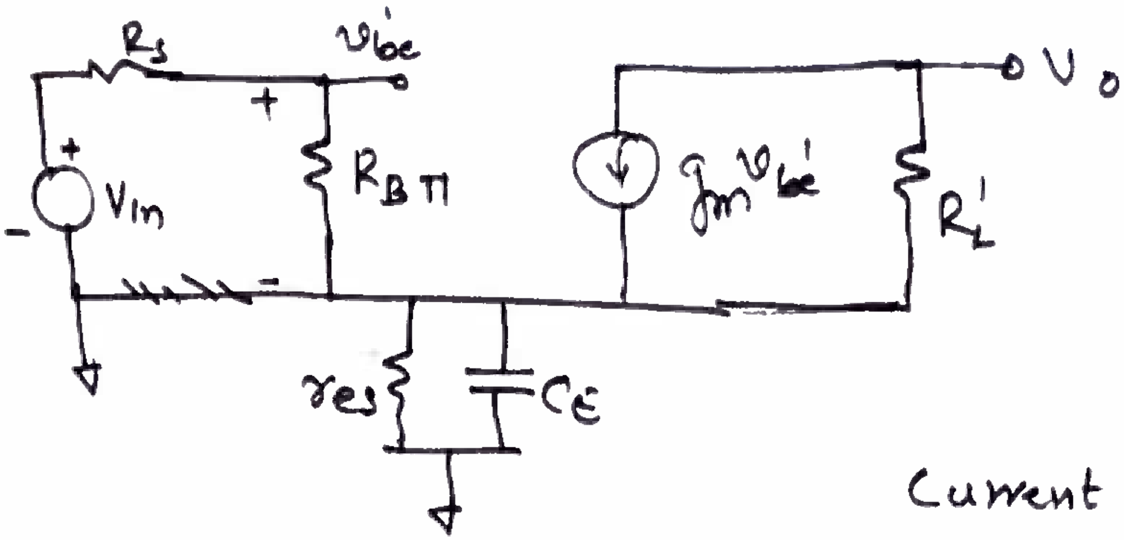
C_E :—



$$g_m v_{be}' \Rightarrow g_m v_\pi = \frac{r_\pi}{R_{B\pi}}$$

$$= g_m \cdot i_b \cdot R_{B\pi}$$

$$= \beta i_b \frac{R_{B\pi}}{r_\pi}$$

Current through $(C_E \| r_{es})$

$$= i_b + \beta i_b = (\beta+1) i_b$$

Solving, Second Pole will be

$$\omega_{p2} = \frac{1}{C_E \left[r_{es} + \frac{R_{B\pi}}{\beta+1} \right]} = \frac{\beta+1}{R_{B\pi} C_E} \quad (r_{es} \text{ Small})$$

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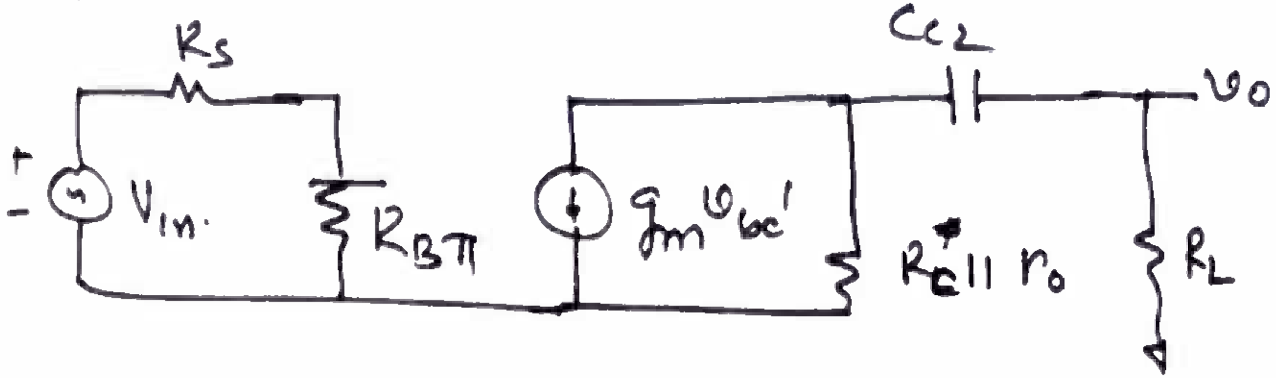
Effect due to C_{c2}



∴ output pole $\omega_{p3} = \dfrac{1}{C_{c2}\left(R_c \| r_o + R_L\right)}$

It is observed that for Typical BJT Parameters & Values of Bias & Load networks,

$\omega_{p2} > \omega_{p3} > \omega_{p1}$ $\qquad$ $\omega_{p2} > \omega_{p1} > \omega_{p3}$

∴ C_E dominates the f_L value's estimation

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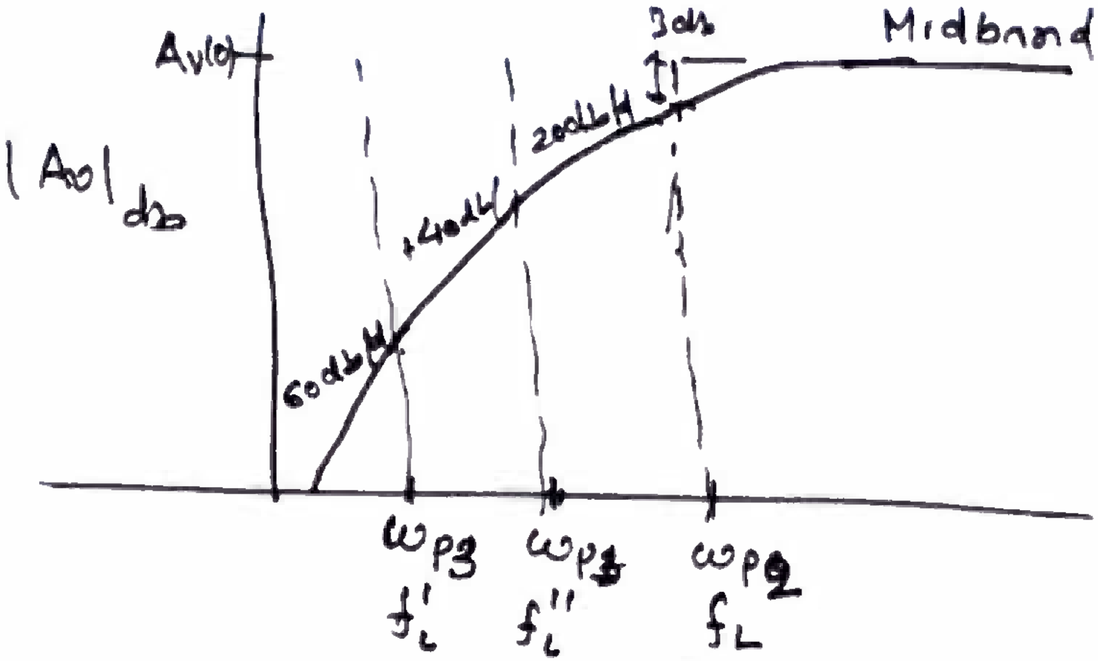

LF response

Clearly ω_{p3} is of relevence for evaluating Bandwidth

$$\text{Bandwidth} = \underline{\underline{\omega_1 - \omega_{p3}}} = f_H - f_L$$