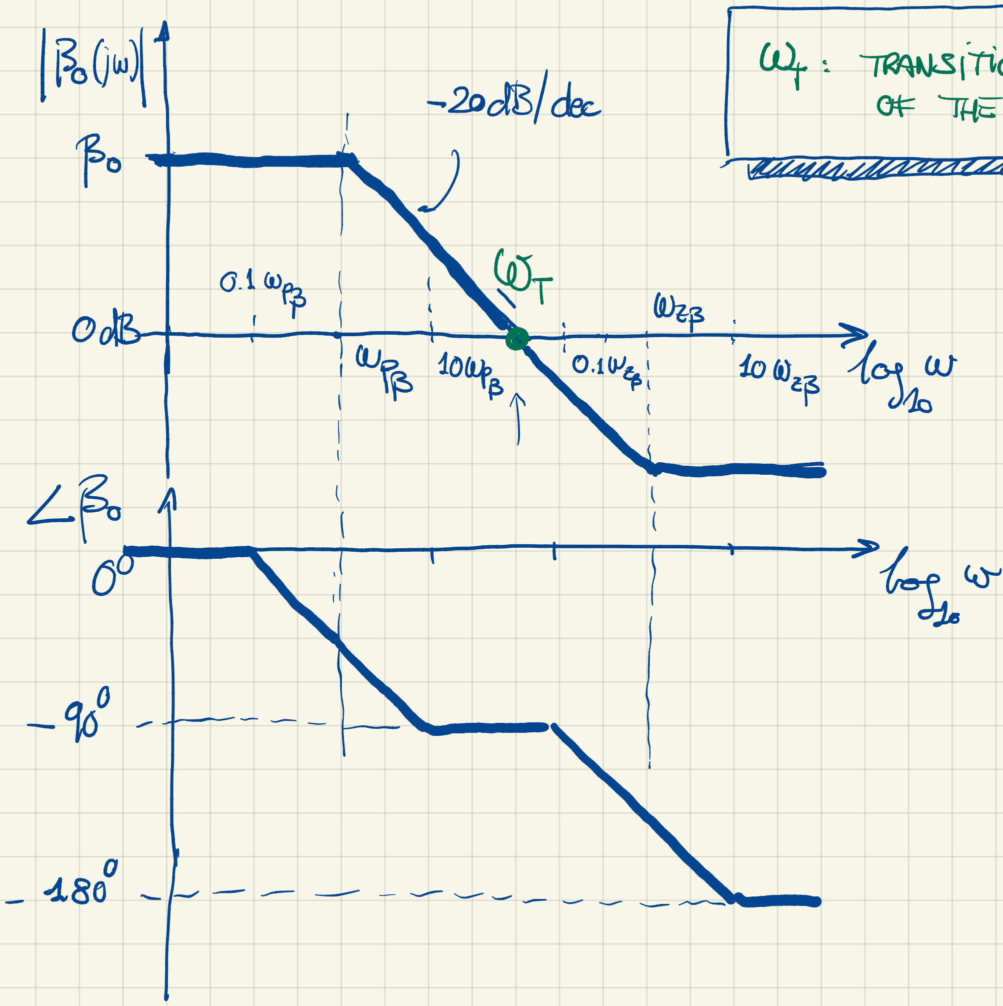
$$\left|\beta_0(\omega_{z\beta})\right| = \beta_0 \cdot \frac{\sqrt{2}}{\sqrt{\cancel{1+}\left(\underbrace{\frac{\omega_{z\beta}}{\omega_{p\beta}}}_{\gg 1}\right)^2}} = \frac{\sqrt{2}}{1+\frac{C_\pi}{C_\mu}} \ll 1$$

ω_T : TRANSITION FREQUENCY OF THE TRANSISTOR



TO FIND ω_T, WE APPROXIMATE $\beta_0(s)$ LIKE:

THE EFFECT OF THE ZERO IS NEGLIGIBLE

$$\beta_0(s) = \frac{\beta_0}{1 + s/\omega_{p\beta}}$$

BECAUSE $\omega_{p\beta} \ll \omega_T \ll \omega_{z\beta}$

ALONG THE $-20\,dB/dec$ ASYMPTOTE, $|\beta(j\omega)|\cdot\omega$ is CONSTANT. THEREFORE

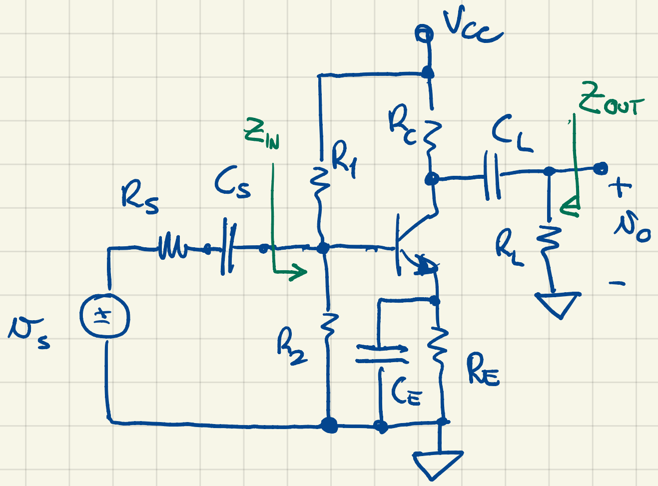
$$\beta_0 \cdot \omega_{p\beta} = 1 \cdot \omega_T \implies \omega_T = \frac{\beta_0}{r_\pi (C_\pi + C_\mu)} = \frac{g_m}{C_\pi + C_\mu} \cong \frac{g_m}{C_\pi} = \frac{1}{\tau_F}$$

FOR THE MOSFET $\omega_T = \frac{g_m}{C_{gs}}$ EXACTLY SYMMETRICAL

ω_T MOSFET $\ll$ ω_T BJT FOR SIMILAR VOLTAGE/CURRENT RATINGS.

◊ HF ANALYSIS OF THE CE AMPLIFIER

11/10/2022



C_S, C_L, C_E ARE RESPONSIBLE FOR THE LOW FREQUENCY RESPONSE OF THE AMPLIFIER.

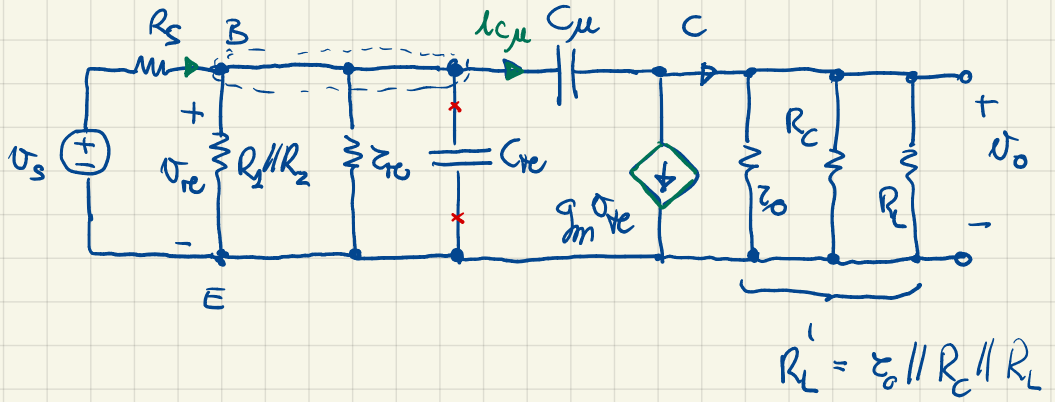
IN GENERAL $\omega_L = f(C_S, C_E, C_L)$

$\Downarrow$

THEY HAVE NO EFFECT AT HF, AS THEY APPEAR TO BE LIKE SHORT CIRCUITS

LET'S DRAW THE SMALL SIGNAL EQUIVALENT CIRCUIT AT HF. WE ASSUME THE SMALL SIGNAL MODEL PARAMETERS ARE KNOWN FROM BIAS POINT ANALYSIS

REVISE !!



$C_{\pi e} \in [20\,pF \div 100\,pF]$

$C_\mu \in [1 \div 5\,pF]$

LET'S FIND $A_v^{HF}(s) \triangleq \dfrac{V_o(s)}{V_s(s)} = \dfrac{v_o}{v_s}$

→ BRUTE FORCE APPROACH

$$\begin{cases} v_o = R_L' \left[sC_\mu (v_{\pi e} - v_o) - g_m v_{\pi e} \right] & (1) \\ v_{\pi e} = \dfrac{r_{\pi} // R_1 // R_2}{1 + s\, C_{\pi e}\, r_{\pi e} // R_1 // R_2} \cdot \left[\dfrac{v_s - v_{\pi e}}{R_s} - sC_\mu (v_{\pi e} - v_o) \right] & (2) \end{cases}$$

PROCEDURE: FROM (1) WE CAN FIND $v_{\pi e} = f(v_o)$. REPLACING $v_{\pi e}$ IN (2) WE CAN ELIMINATE IT AND SOLVE FOR v_o.

_ "LAZY" APPROACH : USE OCTC METHOD

#1 : LET'S FIND THE MID-BAND GAIN A_v^{MB} CONSIDERING C_π AND C_μ OPEN

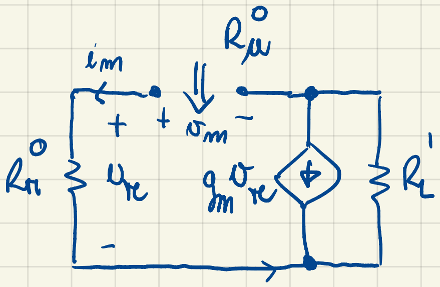
$$A_v^{MB} = -\alpha_{in}\, g_m R_L' \qquad \text{WITH } \alpha_{in} = \frac{r_\pi /\!/ R_1 /\!/ R_2}{R_s + r_\pi /\!/ R_1 /\!/ R_2}$$

WE CAN ALSO WRITE α_{in} AS $\alpha_{in} = \dfrac{R_\pi^0}{R_s}$

LET'S CALCULATE a_1 AND a_2

$$R_\pi^0 = R_s /\!/ r_\pi /\!/ R_1 /\!/ R_2 \qquad \in [10^2 - 10^3 \Omega]$$

$$R_\mu^0 = R_L' + R_\pi^0 (1 + g_m R_L') = R_\pi^0 + R_L' (1 + g_m R_\pi^0) \qquad \in [10^5 - 10^6 \Omega]$$



$$v_m = R_\pi^0 i_m + R_L' (i_m + g_m R_\pi^0 i_m)$$

$$R_\mu^0 \triangleq \frac{v_m}{i_m} = R_\pi^0 + R_L'(1 + g_m R_\pi^0)$$

$$= R_L' + R_\pi^0 \underbrace{(1 + g_m R_L')}_{1 - A_{v_{MAX}}^{MB}}$$

MILLER MULTIPLIER

$$a_1 = \overset{10^{-8}}{C_\pi \cdot R_\pi^0} + \overset{10^{-7}}{C_\mu \cdot R_\mu^0} \propto 10^{-7}$$

$$a_2 = C_\pi C_\mu R_\pi^0 R_\mu^\pi = C_\pi C_\mu R_\mu^0 R_\pi^\mu$$

USING THE FIRST, BY INSPECTION

$$a_2 = C_\pi C_\mu R_\pi^0 R_L' \quad 10^{-22} \cdot 10^3 \cdot \underbrace{10^4}_{R_L'} = 10^{-15}$$

$R_L' \in [10^3 \div 10^4]$

VERIFICATION OF DOMINANT POLE ASSUMPTION

$$\frac{a_1^2}{a_2} \gg 1 \qquad \frac{10^{-14}}{10^{-15}} = 10$$

WITH SENSIBLE VALUES OF R_L' IT IS NORMALLY POSSIBLE TO VERIFY THE DOMINANT POLE ASSUMPTION!

ASSUMING THE ERROR TO BE SMALL IN ANY CASE

$$\omega_H \cong \frac{1}{a_1}$$

SO FAR WE HAVE FOUND THAT

$$A_v^{HF}(s) = A_v^{MB} \cdot \frac{\left(1 - s\frac{C_\mu}{g_m}\right)}{1 + a_1 s + a_2 s^2} \qquad \begin{array}{ll} m = ? & N(s) \text{ IS UNKNOWN} \\ n = 2 & a_1, a_2 \ \underline{\text{KNOWN}} \end{array}$$

CIRCUIT INSPECTION AT $s \to +\infty$ SHOWS THAT $v \to \emptyset$ TRACKING v_π SO, IT GOES TO ZERO AS $1/sC_\pi$

THIS MEANS $m = 1$! $\Rightarrow$ THERE IS <u>ONE</u> ZERO AT THE NUMERATOR.

TO LOCATE THE ZERO, WE TAKE COLLECTOR CURRENT INTO ACCOUNT.

$$i_c = sC_\mu(v_\pi - v_o) - g_m v_\pi \overset{!}{=} \emptyset \quad \forall v_s$$

THE CONDITION IMPLIES $v_o \equiv 0$ AND THEREFORE THE EQUATION BECOMES

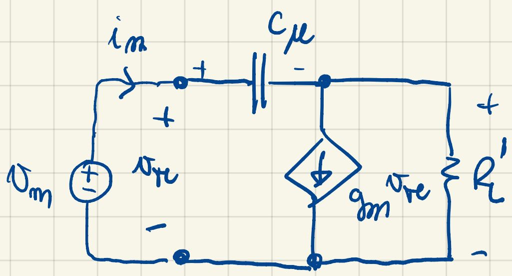
$$sC_\mu \cancel{v_\pi} - g_m \cancel{v_\pi} = \emptyset \quad \Rightarrow \text{ WE HAVE A RHP ZERO}$$

AT $s = \frac{g_m}{C_\mu}$ $\Rightarrow$ $N(s) = 1 - s\frac{C_\mu}{g_m}$ VERY HIGH FREQUENCY ZERO! $\gg \omega_T$

$\emptyset$ LET'S STUDY THE INPUT IMPEDANCE OF THE AMPLIFIER, $Z_{IN}(s)$

$$Z_{IN}(s) = r_\pi // R_1 // R_2 // \frac{1}{sC_\pi} // Z_x(s)$$ TO FIND $Z_x(s)$:

$$Z_x(s) = \frac{v_m}{i_m}$$



$$i_m\left(R_L' + \frac{1}{sC_\mu}\right) = v_m(1 + g_m R_L')$$

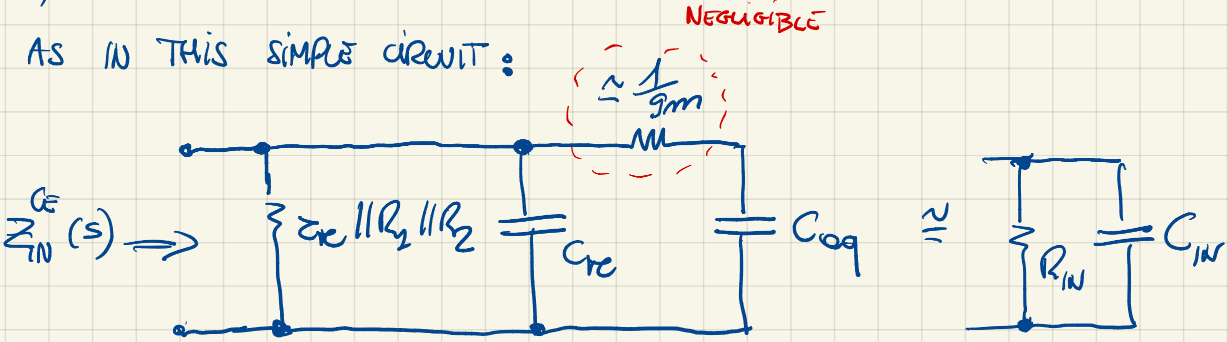
$$i_m \cdot \frac{1}{sC_\mu} + R_L'(i_m - g_m v_m) = v_m$$

$$Z_x(s) = \frac{1 + sC_\mu R_L'}{(1 + g_m R_L')\, sC_\mu}$$

$$Z_x(s) = \underbrace{\frac{1}{sC_\mu(1+g_m R_L')}}_{C_{eq}} + \frac{\cancel{sC_\mu} R_L'}{\cancel{sC_\mu}(1+g_m R_L')} = \frac{1}{sC_{eq}} + \underbrace{R_L' \,\|\, \frac{1}{g_m}}_{\simeq \frac{1}{g_m}}$$

AS A RESULT, WE FOUND THAT

$Z_{IN}(s)$ IS AS IN THIS SIMPLE CIRCUIT:



$R_{IN} = r_\pi \,\|\, R_1 \,\|\, R_2$

CE INPUT RESISTANCE

$$C_{IN} \simeq C_\pi + C_\mu \underbrace{(1 + g_m R_L')}_{\text{MILLER MULTIPLIER}} \longleftarrow \text{MILLER EFFECT}$$

CONCLUSION: THE CE INPUT IMPEDANCE HAS A STRONG CAPACITIVE COMPONENT THAT IS DOMINATED BY C_μ, THROUGH MILLER EFFECT