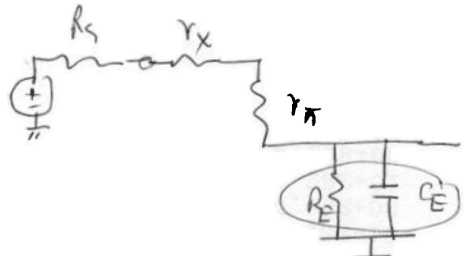
ELEC 312, Ch3, Lecture note pack

3.8.1 (a) very simple series RC circuit

(b)

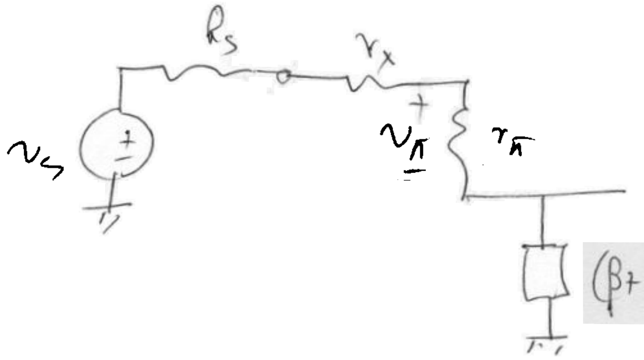


Assume $r_o \to \infty$

R_E ∥ C_E → reflected as $(\beta+1)\,Z$

where $Z = \dfrac{\frac{1}{sC_E}\cdot R_E}{R_E + \frac{1}{sC_E}} = \dfrac{R_E}{1+sC_ER_E}$

So the ac equiv. ckt is



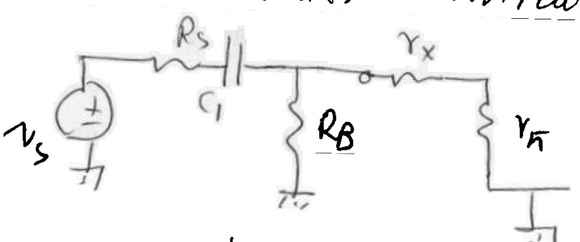
$(\beta+1)\cdot\dfrac{R_E}{1+sC_ER_E}$ Let $\beta+1 = \gamma$

Then $v_\pi = \dfrac{r_\pi}{R_s+r_x+r_\pi+\gamma\dfrac{R_E}{1+sC_ER_E}}\,v_s$

$= v_s\,\dfrac{r_\pi\,(1+sC_ER_E)}{(1+sC_ER_E)(R_s+r_x+r_\pi)+\gamma R_E}$

v_π has a zero at $\omega = 1/C_ER_E$ because of the term $1+sC_ER_E$ in the numerator

3.8.2 Use short circuit time-constant method. The three sub-circuits to consider are:

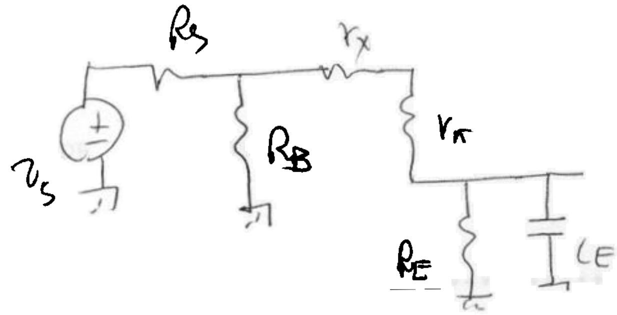


(a)

time constant C_1R_{TH1}

3.8.2

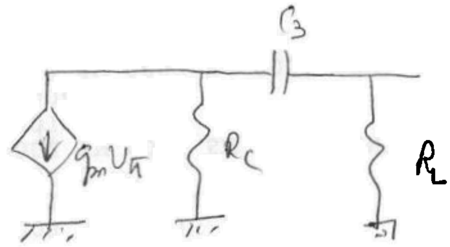
(b)



time constant

$C_E R_{TH2}$

(c)



time constant

$C_3 R_{TH3}$

$C_1 = 1\mu F$; $C_2 = C_E = 25\mu F$ $C_3 = 10\mu F$

3.8.3

(a) $R_{TH}\big|_{C_\pi} = r_\pi \parallel (r_x + R_B \parallel R_S) \rightarrow R_S'$

$R_{TH}\big|_{C_\mu} = R_S' + (1 + g_m R_S')\cdot R_L'$ $\quad R_L' = R_L \parallel R_C$ $\quad r_o \to \infty$ assumed.

OR $R_L' = R_L \parallel R_C \parallel r_o$ if r_o is known.

Here $R_S = 100\,\Omega$, $R_B = 1\,k\Omega$

$r_x = 50\,\Omega$; $r_\pi = \dfrac{\beta}{g_m} = \dfrac{h_{fe}}{g_m} = 99 \times \dfrac{25mV}{1mA} = 2475\,\Omega$

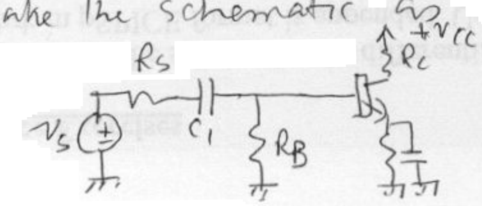
$r_o = \dfrac{V_A}{I_C} = \dfrac{50V}{1mA} = 50K\,\Omega$

So calculate now

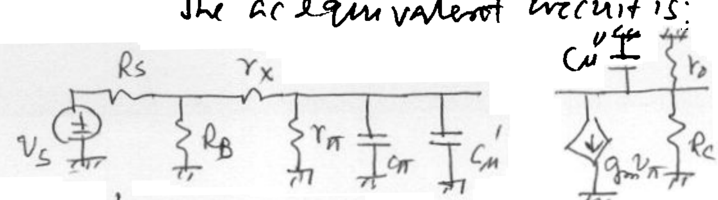
(b) $\omega_H \approx \dfrac{1}{\tau_\pi + \tau_\mu}$ where $\tau_\pi = R_{TH}\big|_{C_\pi} \times C_\pi$

$\tau_\mu = R_{TH}\big|_{C_\mu} \times C_\mu$

(c) Take the schematic as



The ac equivalent circuit is:



$C_\mu' = (1 + g_m R_C)\, C_\mu$, $C_\mu'' = (1 + \frac{1}{g_m R_C})\, C_\mu$

3.8.3 (contd.) (d) pole freq. due to $C_\pi + C_\mu'$ $\rightarrow \dfrac{1}{(C_\pi + C_\mu') \cdot R_x}$

$$R_x = r_\pi \parallel (r_x + R_s \parallel R_B)$$

pole freq. due to C_μ'' $\rightarrow \dfrac{1}{C_\mu''(r_o \parallel R_C)}$

(e) $\omega_H \approx \dfrac{1}{\tau_1 + \tau_2}$, $\tau_1 = (C_\pi + C_\mu')R_x$

$\tau_2 = C_\mu'' \cdot (r_o \parallel R_C)$

(f) The full transfer function is (p14) of ch 3 notes

$$T(s) = -\frac{(g_m - sC_\mu)\,g_s'}{s^2 C_\pi C_\mu + s\left[(g_\pi + g_s')C_\mu + (g_o + g_L)(C_\pi + C_\mu) + g_m C_\mu\right] + (g_s' + g_\pi)(g_o + g_L)}$$

$$= -\frac{N(s)}{D(s)}$$

Solve for $D(s) = 0$ The roots are the pole frequencies (with positive signs)

(g) Dominant pole $\omega_{DP} = \dfrac{(g_s' + g_\pi)(g_o + g_L)}{(g_\pi + g_s')C_\mu + (g_o + g_L)(C_\pi + C_\mu) + g_m C_\mu}$

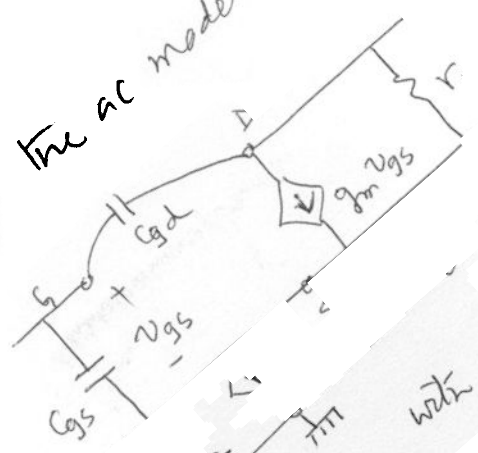
(h) Results in f) and (g)

(i) Simple work

3.8.4 - routine procedure as in 3.8.3 above Use relevant expressions (formula?)

3.8.15

For each MOS the ac model circuit



with $g_i = \frac{1}{r_i}$ for all i

is formulated as

NAM

$+ s(C_{gs1} + C_{gs2} + C_{gd2})$

$g_{o1} + g_{d2}$

$-sC_{gd2}$

$g_{o2} +$

$\begin{pmatrix} v_{①} \\ \end{pmatrix} = \begin{pmatrix} i_i - g_{m1} v_{gs1} \\ i_o - g_{m2} v_{gs2} \end{pmatrix}$

& $v_{gs1} = v_{①}$

ie $v_{①} = v_{②}$

$v_{gs1} = v_{gs2}$

sC_{gd2}

$\begin{pmatrix} i_i \\ i_o \end{pmatrix}$

(ie close the loop)

Since G_1 G_2

$g_{o1} + g_{m1}$

$v_{②} = i_i$

$v_{①}$

i_o

To calculate the node at

$[g_{o1} +$ sC_{gd2}

g_{o1}

$\frac{i_o}{i_i}$

the matrix ... v_1 ... $=0$

3.8.5 Expanding the matrix equation with $v_{(2)} = 0$

$$[g_{o1} + g_{m1} + s(C_{gs1} + C_{gs2} + C_{gd2})]\, v_{(1)} = i_i$$

$$[g_{m2} - sC_{gd2}]\, v_{(1)} = i_o$$

So

$$\frac{i_o}{i_i} = \frac{g_{m2} - sC_{gd2}}{g_{o1} + g_{m1} + s(C_{gs1} + C_{gs2} + C_{gd2})}$$

It has a zero at $\omega = g_{m2}/C_{gd2}$ on RHS of s-plane

and a pole at $\omega = \dfrac{g_{o1} + g_{m1}}{C_{gs1} + C_{gs2} + C_{gd2}}$ on LHS of s-plane

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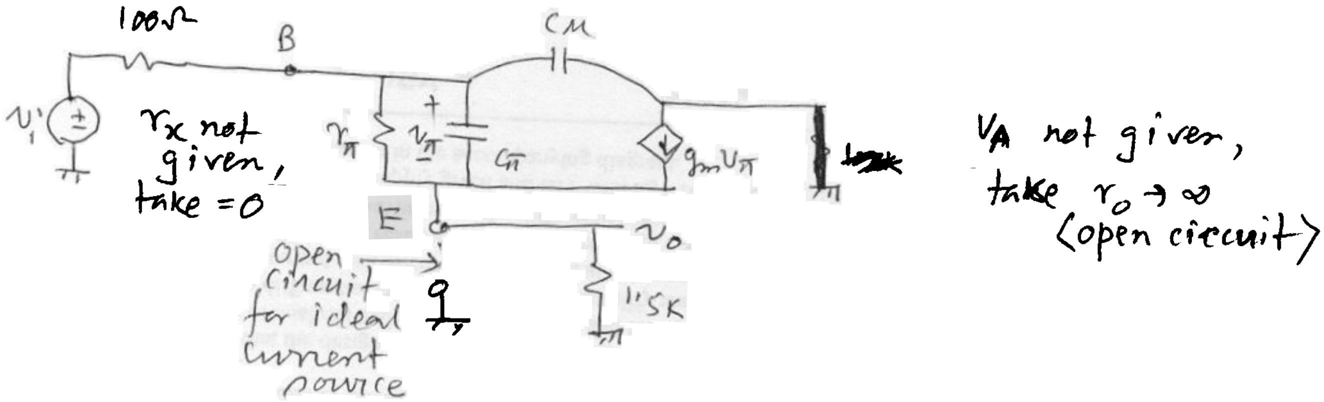
3.8.6 Remembering that the transition frequency $\omega_T = \dfrac{g_m}{C_\mu + C_\pi}$, for this BJT

$C_\pi = \dfrac{g_m}{\omega_T} - C_\mu$, where $g_m \simeq \dfrac{I_E}{V_T} = \dfrac{5\,mA}{25\,mV} = 0.2\,\mho$

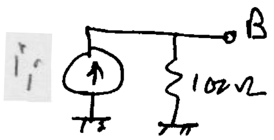
$\omega_T = 2\pi f_T = 2\pi \times 600 \times 10^6$

$C_\pi = \dfrac{.2}{2\pi \times 600 \times 10^6} - .5 \times 10^{-12} = 52.55\ pF$

Now the ac equivalent circuit is:



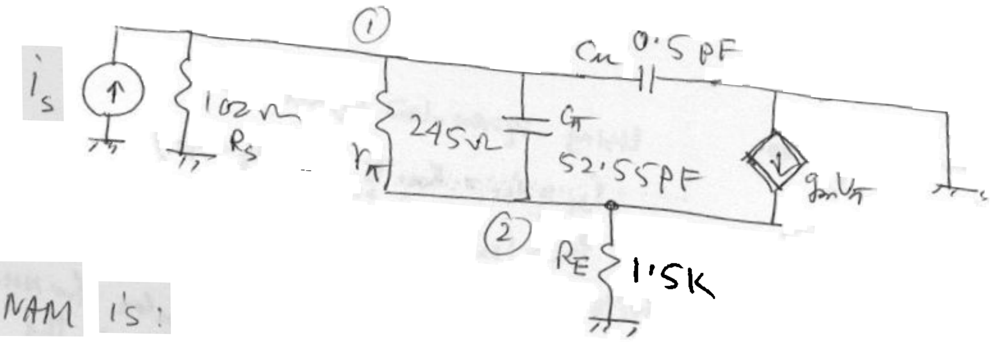
v_i in series with 100Ω can be transformed to



with $i_i = \dfrac{v_i}{100}$

3.8.6 (contd.)

Then the AC equiv ckt is:



The NAM is:

$$\begin{bmatrix} g_s+g_\pi+s(C_\pi+C_\mu) & -sC_\pi-g_\pi \\ -g_\pi-sC_\pi & g_\pi+g_E+sC_\pi \end{bmatrix}\begin{bmatrix} v_{①} \\ v_{②} \end{bmatrix}=\begin{bmatrix} i_s \\ g_m v_\pi \end{bmatrix}$$

But $v_\pi = v_{①} - v_{②}$

$$\begin{bmatrix} g_s+g_\pi+s(C_\pi+C_\mu) & -g_\pi-sC_\pi \\ -g_m-g_\pi-sC_\pi & sC_\pi+g_m+g_\pi+g_E \end{bmatrix}\begin{bmatrix} v_{①} \\ v_{②} \end{bmatrix}=\begin{bmatrix} i_s \\ 0 \end{bmatrix}$$

$$v_{②} = \frac{1}{\Delta}\begin{vmatrix} g_s+g_\pi+s(C_\pi+C_\mu) & i_s \\ -g_m-g_\pi-sC_\pi & 0 \end{vmatrix}$$

For ω_H determination $\Delta = \begin{vmatrix} g_s+g_\pi+s(C_\pi+C_\mu) & -g_\pi-sC_\pi \\ -g_m-g_\pi-\cdots & \end{vmatrix}$

contd

So $\Delta = [g_s+g_\pi+s(C_\pi+C_\mu)][g_m+g_\pi+g_E+sC_\pi]$
$\qquad - (g_\pi+sC_\pi)(g_m+g_\pi+sC_\pi)$

$= 0.002 + 0.6629\times10^{-12}s + 0.2627\times10^{-22}s^2$

The dominant pole $\omega_H \approx \dfrac{.002}{.6629\times10^{-12}} = 0.3017\times10^{10}$ rad/sec

3.8.6 (Contd.)

For mid-band gain, we take the NAM as (assume $s \to 0$ now)

$$\begin{bmatrix} g_s+g_\pi & -g_\pi \\ -g_m-g_\pi & g_m+g_\pi+g_E \end{bmatrix} \begin{bmatrix} v_{①} \\ v_{②} \end{bmatrix} = \begin{bmatrix} i_s' \\ 0 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} g_s+g_\pi & -g_\pi \\ -g_m-g_\pi & g_m+g_\pi+g_E \end{vmatrix} = 0.002$$

$$v_{②} = \frac{1}{\Delta} \begin{vmatrix} g_s+g_\pi & i_s' \\ -g_m-g_\pi & 0 \end{vmatrix} = \frac{1}{\Delta} i_s' (g_m+g_\pi)$$

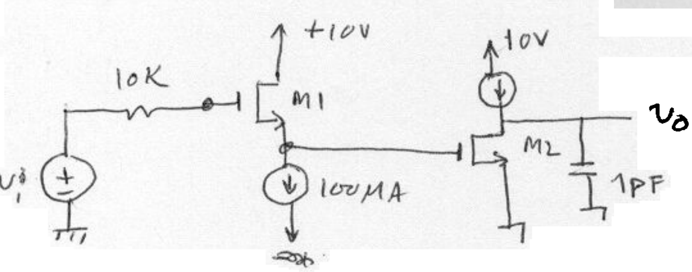
$$= \frac{1}{\Delta} g_s \cdot v_s (g_m+g_\pi)$$

So $$A_m = \frac{v_{②}}{v_s} = \frac{v_o}{v_s} = \frac{1}{\Delta} g_s (g_m+g_\pi) = 0.995$$

Finally, $$A(s) = .995 \frac{.3017 \times 10^{10}}{s + .3017 \times 10^{10}}$$

X

3.8.7



$$I_{DC} = 50 (V_{GS} - V_{TH})^2 \ \mu A$$
$$= 100 \ \mu A \quad \text{for M1}$$
$$(V_{GS} - V_{TH})^2 = 2$$
$$V_{GS} = V_{TH} \pm 1.414 \to 2.414$$
(acceptable)

$$g_m = \frac{\partial I_{DC}}{\partial V_{GS}} = 100 (V_{GS} - V_{TH}) = 100 \times 1.414$$
$(V_{GS} - V_{TH}) = \sqrt{2}$
$$= 141.4 \ \mu \mho$$

Now one can construct the ac equivalent circuit

$$r_o \text{ of M1 \& M2} = \frac{V_A}{I_{DC}} = \frac{20}{.1mA} = 200k\Omega$$