GTU
Electronics Engineering

ELEC 331
Electronic Circuits 2

Fall Semester

Instructor: Assist. Prof. Önder Şuvak

HW 6
Questions and Answers

Updated October 20, 2017 - 13:43

Assigned:

Due:

Answers Out:

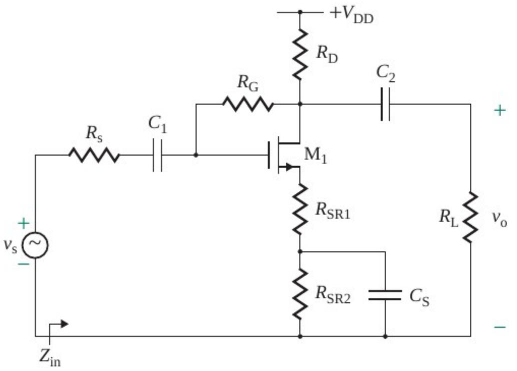
Late Due:

Contents

MOS Amplifier Frequency Response **Rashid 7.67**

7.67 Design a common-source NMOS amplifier as shown in Fig. P7.67 to give a passband gain of $20 \leq |A_{PB}| \leq 30$, $Z_{in(mid)} \geq 100\ \text{k}\Omega$, a low 3-dB frequency of $f_L \leq 10$ kHz, and a high 3-dB frequency of $f_H = 200$ kHz.

FIGURE P7.67



Notes: Carry out only the analysis part of this question and provide the answers in terms of the parameters.

Additional Tasks: Study voltage-shunt feedback and current-series feedback.

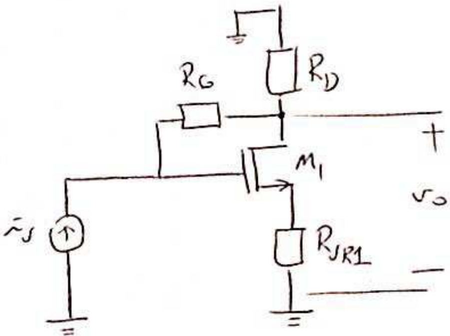
Necessary Knowledge and Skills: Trans-conductance amplifier analysis, trans-resistance amplifier analysis, voltage-shunt feedback, feedback network analysis, effect of feedback on frequency response, MOS small signal model, SCTC, OCTC, Miller effect.

Rashid 7.67

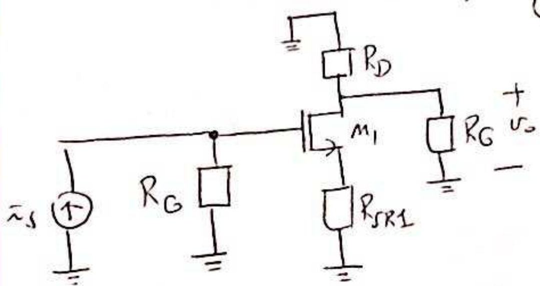
Note: Solving this question via feedback concepts. Alternative one can solve it through applying directly the usual techniques.

→ W_L, W_H and midband gain are to be computed.

Analyzed the following circuit in a separate document: (see that document for the results in this soln, whose derivations have been omitted)

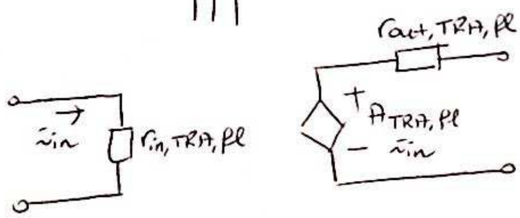


The TRA, fl (feedback loaded TransResistance Amplifier) corresponding to the above circuit is:



⇒ Note that in this circuit the idealized feedback network is not shown. (*)

||| TRA, fl model



$$r_{in,TRA,fl} = R_G$$ (**)

$$r_{out,TRA,fl} = R_G // r_{out,TRA}$$

$$= R_G // R_D // r_{out,TCA}$$

$$= R_G // R_D // [r_{o1}(1+g_{m1}R_{SR1})]$$

$$A_{TRA,fl} = \frac{-g_m R_G}{1+g_m R_s}\left[R_G // R_D // [r_{o1}(1+g_{m1}R_{SR1})]\right]$$

(see the ~~st~~ stated document for derivations)

1

Rashid
7.67
cont-

Refer to (*)

$$\frac{v_{d1}}{v_{g1}} = \frac{-g_{m1}}{1+g_{m1}R_{SR1}}\left[R_D // R_G // \left[r_{o1}\left(1+g_{m1}R_{SR1}\right)\right]\right] \quad (1)$$

This will play a role in the computation of the Miller cap at g1.

if $R_{SR1} \gg \frac{1}{g_{m1}}$, we will, for convenience, not account for C_{gs} in the comput. for w_H.

Miller cap

$$C_{gd1,g1} = C_{gd1}\left(1 - \left(\frac{v_{d1}}{v_{g1}}\right)\right) \quad (2)$$

see (1)

$$R_{C_{gd1,g1}} = R_G \quad (3)$$

$$\tau_{C_{gd1,g1}} = R_{C_{gd1,g1}} C_{gd1,g1} \quad (4)$$

$$w_H \cong \frac{1}{\tau_{C_{gd1,g1}}} \quad (5)$$

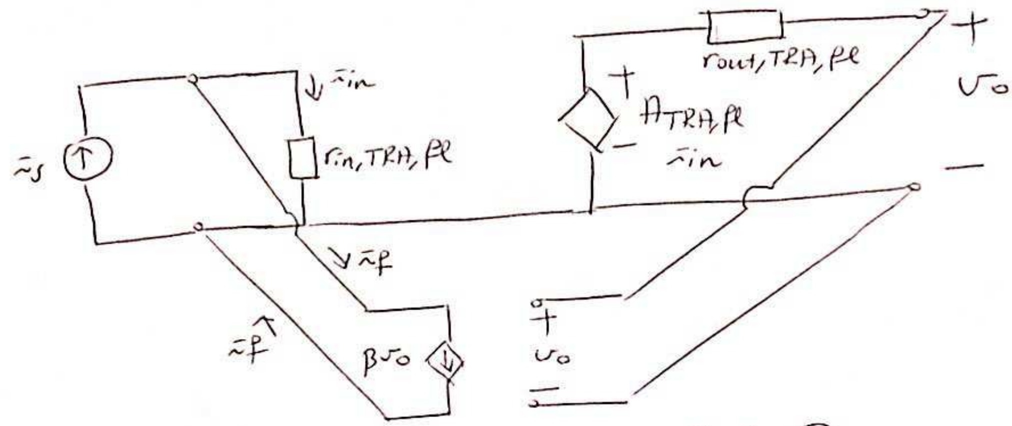
2

Rashid
7.67 cont-

$\beta = -\frac{1}{R_G}$ for the feedback network (6)

see the other document for the derivation

We now have the following network:
(the feedback amplifier)



(***)

Note that $A_{TRA,fl} < 0$, $\beta < 0$

but the loop gain $A_{TRA,fl}\,\beta > 0$

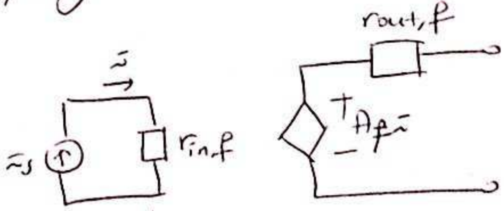
so that the improvement factor $(1 + A_{TRA,fl}\,\beta) > 1$

See (**) and (***), and including what we know of negative feedback theory:

(****)
$$A_f = \frac{A_{TRA,fl}}{1+\beta A_{TRA,fl}}$$

$$r_{in,f} = \frac{r_{in,TRA,fl}}{1+\beta A_{TRA,fl}}$$

$$r_{out,f} = \frac{r_{out,TRA,fl}}{1+\beta A_{TRA,fl}}$$

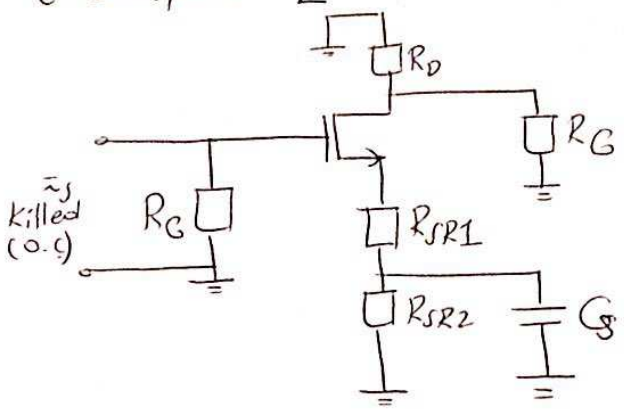


with $w_{H,f} = \underbrace{w_H}_{\text{given as in (5)}}(1 + A_{TRA,fl}\,\beta)$

3

Recall the relevant portion of the orig. circuit to compute w_L:

Rashid 7.67 cont.



$$R_{C_S} \text{ for } C_S \Rightarrow \left(\tau_{C_S} = R_{C_S} C_S\right) \quad (7)$$

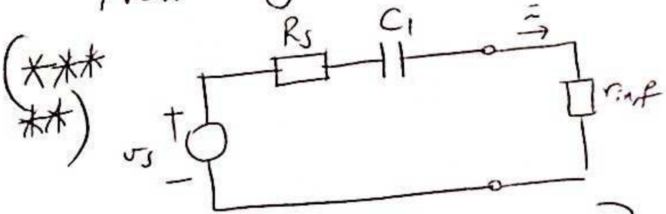
$$R_{C_S} \cong R_{SR2} // \left(R_{SR1} + \frac{1}{g_{m1}}\right) \quad (8)$$

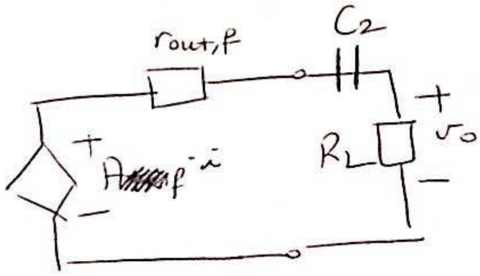
if $r_{o1} \gg R_D // R_G$

$$w_L \cong \frac{1}{\tau_{C_S}} \Rightarrow \underset{\text{with feedback}}{w_{L,f}} = \frac{w_L}{1+\beta A_{TRA,fl}} \quad (9)$$

Now analyze the whole circuit:

(*****)





Should now compute $\frac{v_o}{v_s}$, $w_{L,cir}$, $w_{H,cir}$

$$w_{H,cir} = w_{H,f} = w_H\left(1+\beta A_{TRA,fl}\right) \quad (10)$$

(4)

Rashid
7.67 cont.

$$\frac{v_o}{v_s} = ?$$

$$i = \frac{v_s}{R_s + r_{in,f}}$$

$$v_o = A_f \cdot i \frac{R_L}{R_L + r_{out,f}}$$

$$v_o = A_f \frac{v_s}{R_s + r_{in,f}} \frac{R_L}{R_L + r_{out,f}}$$

$$\frac{v_o}{v_s} = \frac{A_f}{R_s + r_{in,f}} \frac{R_L}{R_L + r_{out,f}} \quad (11)$$

see (****)

Refer to (*****).

We have new time constants to compute:

- R_{C1} for C_1 $(\tau_{C1} = R_{C1} \cdot C_1)$

$$R_{C1} = R_s + r_{in,f}$$

- R_{C2} for C_2 $(\tau_{C2} = R_{C2} \cdot C_2)$

$$R_{C2} = r_{out,f} + R_L$$

see (9). Using SCTC again we have:

$$W_{L,cr} = \frac{1}{\tau_{Cs}(1 + \beta A_{TRA,fe})} + \frac{1}{\tau_{C1}} + \frac{1}{\tau_{C2}}$$

(5)

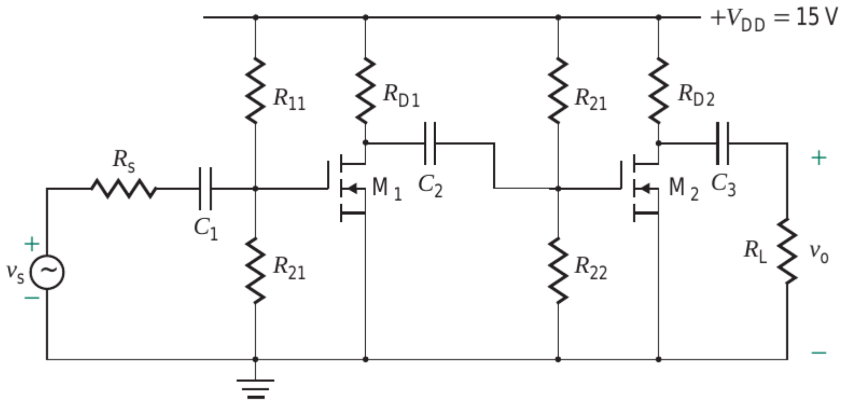
Cascaded MOS Amplifier – SCTC and OCTC **Rashid 7.71**

7.71 A two-stage amplifier is shown in Fig. P7.71. The parameters are $R_s = 1\ \text{k}\Omega$, $R_{11} = 500\ \text{k}\Omega$, $R_{21} = 500\ \text{k}\Omega$, $R_{D1} = 10\ \text{k}\Omega$, $R_{12} = 500\ \text{k}\Omega$, $R_{22} = 500\ \text{k}\Omega$, $R_{D2} = 15\ \text{k}\Omega$, $R_L = 10\ \text{k}\Omega$, $g_{m1} = 20\ \text{mA/V}$, $g_{m2} = 50\ \text{mA/V}$,

P

$C_1 = 1\ \mu\text{F}$, $C_2 = 1\ \mu\text{F}$, $C_3 = 10\ \mu\text{F}$, $C_{gd1} = C_{gd2} = 2\ \text{pF}$, and $C_{gs1} = C_{gs2} = 5\ \text{pF}$. Calculate the low 3-dB frequency f_L and the high cutoff frequency f_H.

FIGURE P7.71



Notes: None.

Additional Tasks: None.

Necessary Knowledge and Skills: MOS small signal model, amplifier voltage gain computations, SCTC, OCTC, Miller's effect.

Quick answers for the analysis

Rashid 7-71

⇒ SCTC

- R_{C1} for $C_1 \Rightarrow (\tau_{C1} = R_{C1} C_1)$

$$R_{C1} = R_s + R_{11} // R_{21}$$

- R_{C2} for $C_2 \Rightarrow (\tau_{C2} = R_{C2} C_2)$

$$R_{C2} = R_{D1} // r_{o1} + R_{21} // R_{22}$$

- R_{C3} for $C_3 \Rightarrow (\tau_{C3} = R_{C3} C_3)$

$$R_{C3} = R_L + R_{D2} // r_{o2}$$

Then

$$w_L \cong \frac{1}{\tau_{C1}} + \frac{1}{\tau_{C2}} + \frac{1}{\tau_{C3}}$$

⇒ Midband gain

$$A_m = \frac{v_{g1}}{v_s} \frac{v_{d1}}{v_{g1}} \frac{v_{d2}}{v_{g2}}$$

⇒ Note that $v_{d1} = v_{g2}$

$$\frac{v_{g1}}{v_s} = \frac{R_{11} // R_{21}}{R_{11} // R_{21} + R_s} \qquad \frac{v_{d1}}{v_{g1}} = -g_{m1}(R_{D1} // R_{21} // R_{22} // r_{o1}) \qquad \frac{v_{d2}}{v_{g2}} = -g_{m2}(R_{D2} // R_L // r_{o2})$$

⇒ OCTC ⇒ C_{gd1} and C_{gd2} will have timeconstants that are large enough to dominate the others

$C_{gd1,g1}$ ⇒ Miller cap at $g1$

$$C_{gd1,g1} = C_{gd1}\left(1 - \frac{v_{d1}}{v_{g1}}\right) = C_{gd1}\left(1 + g_{m1}(R_{D1} // R_{21} // R_{22} // r_{o1})\right)$$

$C_{gd2,g2}$ ⇒ Miller cap at $g2$

$$C_{gd2,g2} = C_{gd2}\left(1 - \frac{v_{d2}}{v_{g2}}\right) = C_{gd2}\left(1 + g_{m2}(R_{D2} // R_L // r_{o2})\right)$$

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Rashid
7.71
contin-

$$R_{C_{gd1,g1}} = R_s // R_{11} // R_{21}$$

$$R_{C_{gd2,g2}} = R_{21} // R_{22} // R_{D1} // r_{o1}$$

$$\tau_{C_{gd1,g1}} = R_{C_{gd1,g1}} C_{gd1,g1}$$

$$\tau_{C_{gd1,g2}} = R_{C_{gd2,g2}} C_{gd2,g2}$$

$$W_H \cong \frac{1}{\tau_{C_{gd1,g1}} + \tau_{C_{gd2,g2}}}$$

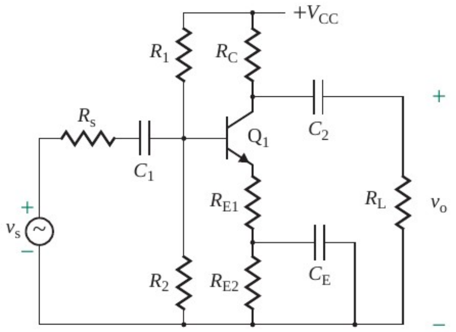
2

CE Amplifier Frequency Response — Rashid 8.54

For Probs. 8.54–8.59 involving BJT amplifiers, use transistors whose parameters are $\beta_f = 100$, $C_{je} = 8$ pF at $V_{BE} = 0.5$ V, $C_\mu = 4$ pF at $V_{CB} = 5$ V, $C_{cs} = 4$ pF at $V_{CS} = 8$ V, $\beta_f = 100$, $V_{je} = V_{jc} = V_{js} = 0.8$ V, and $h_{oe} = 1/r_o = 5\ \mu\mho$ at $V_{CE} = 10$ V. The transition frequency is $f_T = 300$ MHz at $V_{CE} = 20$ V, $I_C = 10$ mA. The substrate is connected to the ground. Assume $I_C = 5$ mA (unless specified), $V_{CC} = 15$ V, $V_{BE} = 0.7$ V, $R_s = 1$ kΩ, and $R_L = 10$ kΩ. Use PSpice/SPICE to check your design by plotting the frequency response and give an approximate cost estimate.

8.54 D P Design a CE amplifier as shown in Fig. P8.54 to give a passband gain of $40 \le |A_{PB}| \le 50$, a low 3-dB frequency of $f_L \le 1$ kHz, and a high 3-dB frequency of $f_H = 50$ kHz.

FIGURE P8.54



Notes: Analyze the circuit to compute its high and low frequency response. State your answers in terms of the parameters.

Additional Tasks: None.

Necessary Knowledge and Skills: BJT small signal model, Miller effects, OCTC, SCTC.

Quick answers for the analysis

Rashid
8.54

⟹ Midband gain

$$A_M = \frac{v_o}{v_s}$$

$$\cong \frac{R_1 // R_2 // R_{in,b1}}{R_1 // R_2 // R_{in,b1} + R_s} \left[\frac{-g_{m1}}{1+g_{m1} R_{E1}}\right] \left[\left(R_C // R_L\right) // \left[r_{o1}\left(1+g_{m1} R_{E1}\right)\right]\right]$$

where $R_{in,b1} \cong r_{\pi 1}\left[1+g_{m1} R_{E1}\right]$ (*)

⟹ SCTC ⟹ $\omega_L \cong \frac{1}{\tau_{C1}} + \frac{1}{\tau_{C2}} + \frac{1}{\tau_{CE}}$

- R_{C1} for C_1 $\left(\tau_{C1} = R_{C1} \cdot C_1\right)$

$R_{C1} \cong R_s + R_1 // R_2 // R_{in,b1}$

where $R_{in,b1}$ is as above in (*)

- R_{CE} for C_E $\left(\tau_{CE} = R_{CE} C_E\right)$

$$R_{CE} \cong R_{E2} // \left[R_{E1} + \frac{r_{\pi 1} + R_s // R_1 // R_2}{1+\beta_1}\right]$$

- R_{C2} for C_2 $\left(\tau_{C2} = R_{C2} C_2\right)$

$R_{C2} = R_L + R_C // R_{in,c1}$

where $R_{in,c1} \cong r_{o1}\left(1+g_{m1} R_{E1}\right)$

assuming $R_s \ll R_1 // R_2$
and $R_s \ll r_\pi$

1

Rashid
8.54
Cont'n

$\Rightarrow$ OCTC

account for only C_μ (Miller-effect component at b1)

$$C_{\mu,b1} = C_\mu \left[1 + \frac{g_{m1}}{1+g_{m1}R_{E1}} \left(R_C // R_L // \left[r_{o1}(1+g_{m1}R_{E1}) \right] \right) \right]$$

$$R_{C_{\mu,b1}} \cong R_1 // R_2 // R_S // \underbrace{R_{in,b1}}_{\text{as in } (*)}$$

$$\longrightarrow \; w_H \cong \frac{1}{R_{C_{\mu,b1}} C_{\mu,b1}}$$

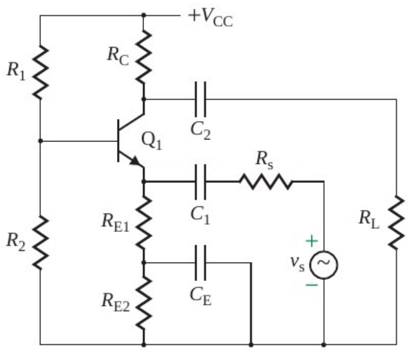
 2

CB Amplifier Frequency Response **Rashid 8.55**

For Probs. 8.54–8.59 involving BJT amplifiers, use transistors whose parameters are $\beta_f = 100$, $C_{je} = 8$ pF at $V_{BE} = 0.5$ V, $C_\mu = 4$ pF at $V_{CB} = 5$ V, $C_{cs} = 4$ pF at $V_{CS} = 8$ V, $\beta_f = 100$, $V_{je} = V_{jc} = V_{js} = 0.8$ V, and $h_{oe} = 1/r_o = 5$ μ℧ at $V_{CE} = 10$ V. The transition frequency is $f_T = 300$ MHz at $V_{CE} = 20$ V, $I_C = 10$ mA. The substrate is connected to the ground. Assume $I_C = 5$ mA (unless specified), $V_{CC} = 15$ V, $V_{BE} = 0.7$ V, $R_s = 1$ kΩ, and $R_L = 10$ kΩ. Use PSpice/SPICE to check your design by plotting the frequency response and give an approximate cost estimate.

8.55 Design a CB amplifier as shown in Fig. P8.55 to give a passband gain of $20 \le |A_{PB}| \le 30$, a low 3-dB frequency of $f_L \le 1$ kHz, and a high 3-dB frequency of $f_H = 100$ kHz. Assume $R_s = 15$ kΩ and $R_L = 10$ kΩ.

FIGURE P8.55



Notes: Analyze the circuit to compute its high and low frequency response. State your answers in terms of the parameters.

Additional Tasks: None.

Necessary Knowledge and Skills: BJT small signal model, Miller effects, OCTC, SCTC.

Quick answers for the analysis of freq response

Rashid 8.55

I am assuming that B (base of the BJT) is gnd-ed ~~that~~ via a large cap. C_B.

$\Rightarrow$ SCTC method (all cap except the chosen one are short cir)

- R_{C_E} corresponding to C_E to be computed $\Rightarrow \tau_{C_E} = R_{C_E} C_E$

$$R_{C_E} \cong R_{E_2} /\!/ \left[R_{E1} + R_S /\!/ \frac{1}{g_{m1}}\right]$$

- R_{C1} corresponding to C_1 to be computed $\Rightarrow \tau_{C1} = R_{C1} C_1$

$$R_{C_1} \cong R_S + R_{E1} /\!/ \frac{1}{g_{m1}}$$

- R_{C2} corresponding to C_2 to be computed $\Rightarrow \tau_{C_2} = R_{C_2} C_2$

$$R_{C_2} \cong R_L + R_C /\!/ \left[r_{o1}\left(1 + g_{m1} R_{E1}\right)\right]$$

- R_{C_B} corresponding to C_B to be computed $\Rightarrow \tau_{C_B} = R_{C_B} C_B$

$$R_{C_B} \cong R_1 /\!/ R_2 /\!/ \left[r_{\pi 1}\left(1 + g_{m1} R_{E1}\right)\right]$$

$$\rightarrow \quad W_L \cong \frac{1}{\tau_{C_E}} + \frac{1}{\tau_{C_1}} + \frac{1}{\tau_{C_2}} + \frac{1}{\tau_{C_B}}$$

1

Rashid
8.55
cont.

⇒ Midband gain (all coupling or bypass caps are shorted)

$$A_M = \frac{v_o}{v_s}$$

$$\cong \frac{R_{E1} // \frac{1}{g_{m1}}}{R_{E1} // \frac{1}{g_{m1}} + R_s} g_{m1} (R_C // R_L)$$

⇒ There is no Miller-effect, C_π and C_μ have one node gnd-ed if we assume C_B is between B and gnd.

⇒ OCTC method (all cap except the chosen one are open cir.) / But big coupling cap are already short cir.)

· R_{C_μ} for C_μ $(\tau_{C_\mu} = R_{C_\mu} C_\mu)$

$$R_{C_\mu} \cong R_C // R_L // [r_{o1}(1 + g_{m1} R_{E1})]$$

· R_{C_π} for C_π $(\tau_{C_\pi} = R_{C_\pi} C_\pi)$

$$R_{C_\pi} \cong R_{E1} // R_s // \frac{1}{g_{m1}}$$

$$\rightarrow W_H \cong \frac{1}{\tau_{C_\mu} + \tau_{C_\pi}}$$

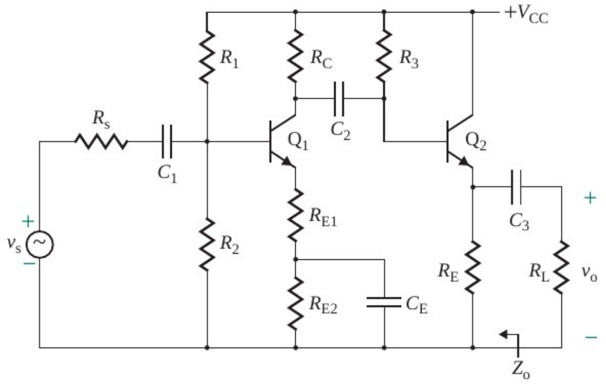
2

Cascaded Amplifier Frequency Response — Rashid 8.58

For Probs. 8.54–8.59 involving BJT amplifiers, use transistors whose parameters are $\beta_f = 100$, $C_{je} = 8$ pF at $V_{BE} = 0.5$ V, $C_\mu = 4$ pF at $V_{CB} = 5$ V, $C_{cs} = 4$ pF at $V_{CS} = 8$ V, $\beta_f = 100$, $V_{je} = V_{jc} = V_{js} = 0.8$ V, and $h_{oe} = 1/r_o = 5$ μ℧ at $V_{CE} = 10$ V. The transition frequency is $f_T = 300$ MHz at $V_{CE} = 20$ V, $I_C = 10$ mA. The substrate is connected to the ground. Assume $I_C = 5$ mA (unless specified), $V_{CC} = 15$ V, $V_{BE} = 0.7$ V, $R_s = 1$ kΩ, and $R_L = 10$ kΩ. Use PSpice/SPICE to check your design by plotting the frequency response and give an approximate cost estimate.

8.58 D P Design a CE-CC amplifier as shown in Fig. P8.58 to give a passband gain of $20 \le |A_{PB}| \le 30$, $Z_{i1(mid)} \le 100\ \Omega$, a low 3-dB frequency of $f_L \le 1$ kHz, and a high 3-dB frequency of $f_H = 100$ kHz.

FIGURE P8.58



Notes: Analyze the circuit to compute its high and low frequency response. State your answers in terms of the parameters.

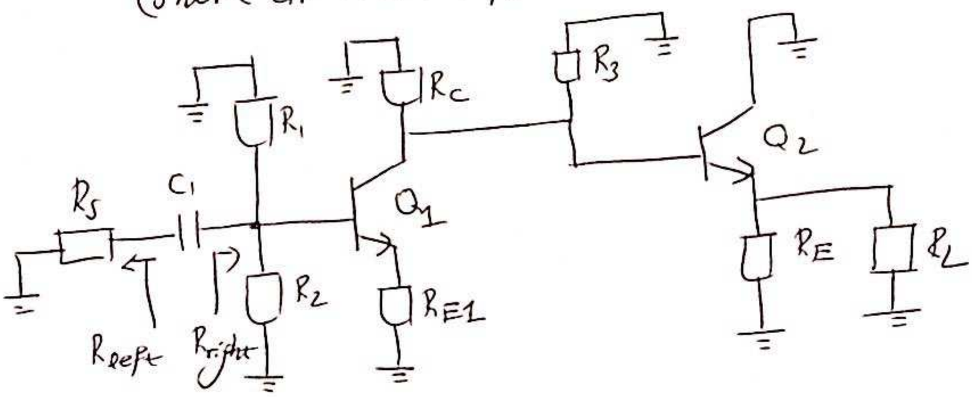
Additional Tasks: None.

Necessary Knowledge and Skills: BJT small signal model, Miller effects, OCTC, SCTC.

Rashid 8.58

SCTC for computing w_L (low-freq cutoff)

$\Rightarrow$ Compute R_{C1} corresponding to C_1 (short cir other cap, kill indep sources in s.s.)



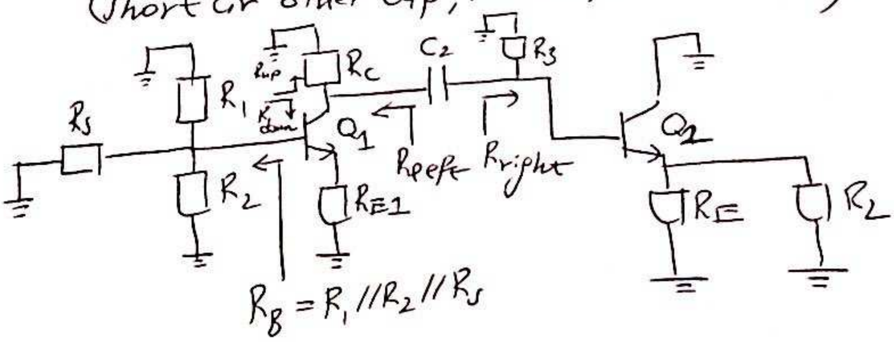
$$R_{C1} = R_{left} + R_{right}$$

$$R_{left} = R_s$$

$$R_{right} \cong R_1 // R_2 // \left[\left(1+g_{m1} R_{E1}\right) r_{\pi 1} \right]$$

$$\tau_{C1} = R_{C1} C_1$$

$\Rightarrow$ Compute R_{C_2} corresponding to C_2 (short cir other cap, Kill indep sources in ss)



(1)

SCTC continued $\Rightarrow R_{C2} = R_{left} + R_{right}$

Razavi 8.58

$$R_{right} = R_3 \,//\, \left[\left(1 + g_{m2}\left(R_E // R_L\right)\right) r_{\pi 2} \right]$$

$$R_{left} = R_{up} \,//\, R_{down}$$

$$R_{up} = R_C$$

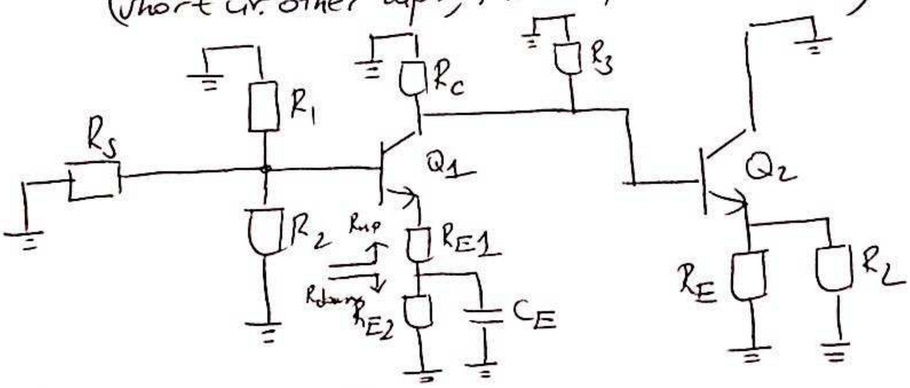
$$R_{down} = r_{o1}\left[1 + \frac{g_{m1} R_{E1} r_{\pi 1}}{R_{E1} + r_{\pi 1} + R_B} \right] + R_{E1} // \left(r_{\pi 1} + R_B\right)$$

(see the derivation elsewhere, in a separate document)

R_B defined on the prev page.

$$\tau_{C2} = R_{C2} C_2$$

$\Rightarrow$ compute R_{CE} corresponding to C_E
(short cir. other cap., kill indep. sources in c.s.)



$$R_{CE} = R_{up} \,//\, R_{down}$$

$$R_{down} = R_{E2}$$

$$R_{up} = R_{E1} + \frac{r_{\pi 1} + R_1 // R_2 // R_S}{1 + \beta_1}$$

(see related derivations)

$$\tau_{CE} = R_{CE} C_E$$

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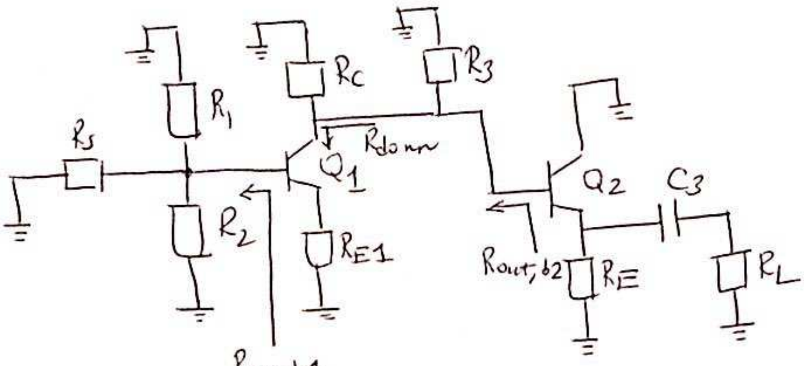
2

SCTC continued

Rashid
8.58

$\Rightarrow$ Compute R_{C3} corresponding to C_3:
(short other cap, kill indep sources in SS.)



$$R_{C3} = R_L + R_E // \left[\frac{r_{\pi 2} + R_{out,b2}}{1+\beta_2} \right]$$

$$R_{out,b2} = R_3 // R_C // R_{down}$$

$$R_{down} = r_{o1}\left[1 + \frac{g_{m1} R_{E1} r_{\pi 1}}{R_{E1} + r_{\pi 1} + R_{out,b1}}\right] + R_{E1} // (r_{\pi 1} + R_{out,b1})$$

(See related derivations in separate documents)

$$\tau_{C3} = R_{C3} C_3$$

$$W_L \cong \frac{1}{\tau_{C1}} + \frac{1}{\tau_{C2}} + \frac{1}{\tau_{C3}} + \frac{1}{\tau_{CE}}$$

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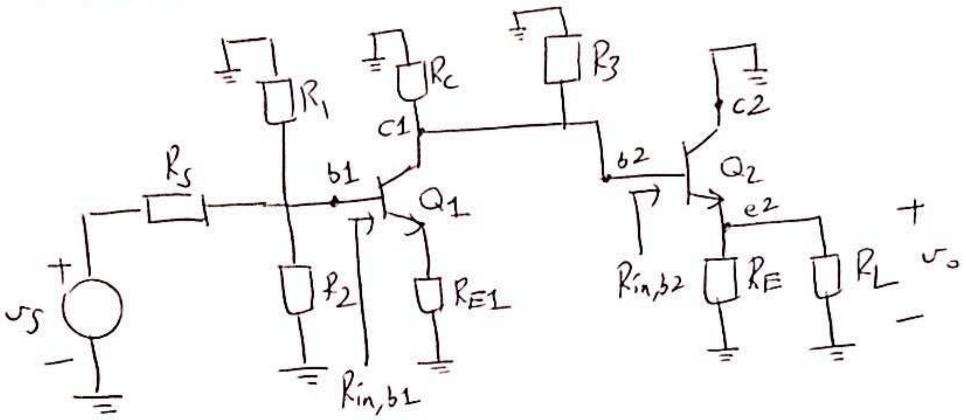
⟹ High freq ω_H approx will follow

→ voltage Gain computations

→ Miller's effects accounted for

→ OCTC applied

Gain computations



$$\frac{v_o}{v_s} = \frac{v_{b1}}{v_s}\,\frac{v_{c1}}{v_{b1}}\,\frac{v_{e2}}{v_{c1}}$$

$$\frac{v_{b1}}{v_s} = \frac{R_{in,b1} /\!/ R_1 /\!/ R_2}{R_{in,b1} /\!/ R_1 /\!/ R_2 + R_S}$$

$$\frac{v_{c1}}{v_{b1}} \cong \left[-\frac{g_{m1}}{1+g_{m1}R_{E1}}\right]\left[R_C /\!/ R_3 /\!/ R_{in,b2}\right]$$

$$\frac{v_{e2}}{v_{b2}} \cong \frac{R_E /\!/ R_L}{R_E /\!/ R_L + \frac{1}{g_{m2}}}$$

Note that, above

$R_{in,b1} \cong r_{\pi 1}(1+g_{m1}R_{E1})$

$R_{in,b2} \cong r_{\pi 2}(+g_{m2}(R_E /\!/ R_L))$

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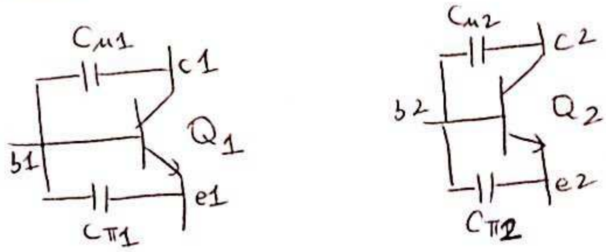
Miller's effects



$C_{\mu 1}$: Miller's effect applies.
Converted to grounded cap. at b1

$$C_{\mu 1, b1} = \left(1 - \frac{v_{c1}}{v_{b1}}\right) C_{\mu 1}$$

Also converted to

$$C_{\mu 1, c1} = \left(1 - \frac{v_{b1}}{v_{c1}}\right) C_{\mu 1} \Longleftarrow$$ small cap, do not account for this one

$C_{\pi 1}$: Provided that $R_{E1} \gg \frac{1}{g_{m1}}$ ($\frac{v_{e1}}{v_{b1}}$ will be very close to 1)
Miller's effect renders this capacitor ineffective
(see related lecture notes)

$C_{\pi 2}$: the same conclusion as for $C_{\pi 1}$
provided that $R_E // R_L \gg \frac{1}{g_{m2}}$ ($\frac{v_{e2}}{v_{b2}}$ will be very close to 1)

$C_{\mu 2}$: one node is grounded $\Rightarrow$ no Miller effect

$$C_{\mu 2, b2} = C_{\mu 2} \Longleftarrow$$ small cap, do not account for this

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OCTC

⟹ There is only one time constant that is big enough to dominate the others.

$$W_H \cong \frac{1}{\tau_{C_{\mu 1},b1}} = \frac{1}{R_{C_{\mu 1},b1} C_{\mu 1,b1}}$$

$R_{C_{\mu 1},b1}$ needs to be computed

$$R_{C_{\mu 1},b1} = R_S // R_1 // R_2 // R_{in,b1}$$

where $R_{in,b1} \cong r_{\pi 1}(1 + g_{m1} R_{E1})$

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