GTU
Electronics Engineering

ELEC 331
Electronic Circuits 2

Fall Semester

Instructor: Assist. Prof. Önder Şuvak

HW 5
Questions and Answers

Updated October 20, 2017 - 13:41

Assigned:

Due:

Answers Out:

Late Due:

Contents

BJT Bias and SCTC **Malik 8.19**

8.19 In Fig. P8.19, $\beta = 200$.

(a) Find I_B so that the transistor is biased at $I_C = 2.5$ mA.

(b) Find the numerical value of r_π.

(c) Write an equation for C so that the low-frequency pole is located at 100 rad/s.

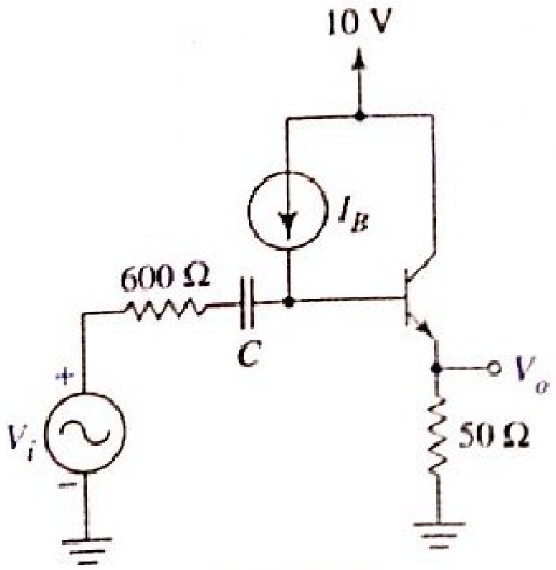


Figure P8.19

Necessary Knowledge and Skills: BJT biasing and small signal equivalent circuit, small signal impedance computations, method of SCTC (short-circuit time constants) for estimating the lower freq. cut off frequency (also interpreted as half-power freq.).

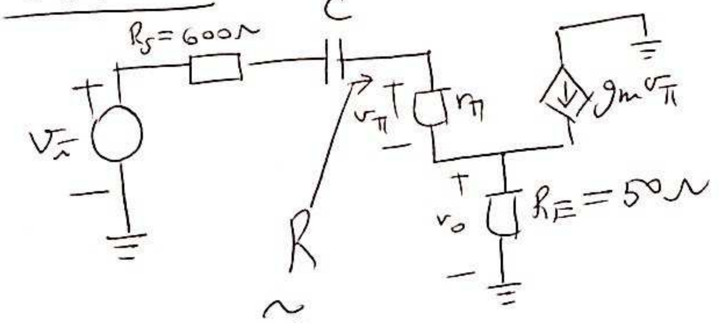
Molik 8.19

$$I_B = \frac{I_C}{\beta} = \frac{2.5mA}{200}$$

$$= 1.25mA \frac{1}{100} = 12.5\mu A$$

$$r_\pi = \frac{\beta}{g_m} = \frac{\beta V_T}{I_C} = \frac{200 \cdot 25mV}{2.5mA} = 2k\Omega$$

ss model



$$\approx (1 + g_m R_E) r_\pi$$

$$\frac{v_o}{v_i} \cong \frac{R}{R_S + R + \frac{1}{Cs}} \frac{R_E}{\frac{1}{g_m} + R_E}$$

$$= \frac{RCs}{(R_S + R)Cs + 1} \frac{R_E}{\frac{1}{g_m} + R_E}$$

$$= \frac{RCs}{1 + \frac{s}{\frac{1}{(R_S+R)C}}} \frac{R_E}{1/g_m + R_E}$$

the pole is at $\Rightarrow \frac{1}{(R_S+R)C}$

1

min val for R

Malik 8-19 cont-

$$g_m = \frac{I_C}{V_T} = \frac{2.5\,mA}{25\,mV} = 100\,mS$$

$$R \cong (1 + g_m R_E) r_\pi \approx \cancel{10\,Mega\Omega >> R_s = 600\Omega}$$

$g_m \to 100\,mS$, $R_E \to 50\Omega$, $r_\pi \to 2k\Omega$

$$= 12k\Omega$$

$$R_s + R = 12.6k\Omega$$

$$\frac{1}{(12.6k\Omega)C} = 100\ rad/s \Rightarrow C = \frac{1}{(12.6k\Omega)(100\ rad/s)}$$

$$= \frac{10^{-5}}{12.6} F$$

$$\approx \frac{\cancel{100}^{\,8}}{\cancel{12.5}} 10^{-2} 10^{-5} F$$

$$= 8 \times 10^{-7} = 0.8\mu F$$

2

BJT Bias and SCTC **Malik 8.20**

8.20 Use short-circuit time constants to estimate the lower half-power frequency for Fig. P8.20; $\beta = 99$, $r_\pi = 100\ \Omega$.

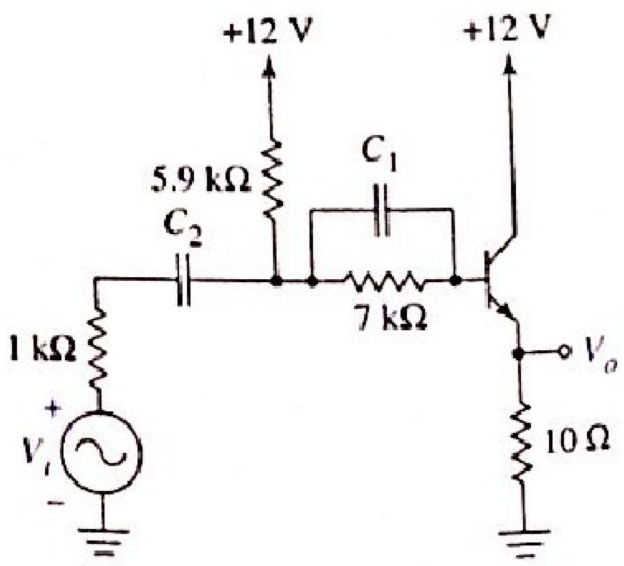


Figure P8.20

Necessary Knowledge and Skills: BJT biasing and small signal equivalent circuit, small signal impedance computations, method of SCTC (short-circuit time constants) for estimating the lower freq. cut off frequency (also interpreted as half-power freq.).

Moltk
8.20

DC bias

$$I_E = (\beta+1) I_B = 100 I_B$$

$$(100 I_B)(10\,\Omega) + 0.7 + (12.9k) I_B = 12\,V$$

$$(13.9k)\ I_B = 11.3V$$

$$I_B = \frac{11.3\,V}{13.9\,k\Omega}$$

$$I_E = 100 I_B$$

time constant for C_2 (C_1 shorted)

$$\tau_2 = C_2\left[R_S + R_1 // \left[(1+g_m R_E) r_\pi\right]\right]$$

time const. for C_1 (C_2 shorted)

$$\tau_1 = C_1\left[R_2 // \left[R_1 // R_S + (1+g_m R_E) r_\pi\right]\right]$$

$$\left.W_L \cong \frac{1}{\tau_1} + \frac{1}{\tau_2}\right\}$$ method of short cir. time const.

lower half power freq

Note

$R_S = 1K$

$R_E = 10\,\Omega$

$R_1 = 5.9K$

$R_2 = 7K$

$g_m = \frac{\beta}{r_\pi} = \frac{99}{100\,\Omega}$

$= 990\,m\mho$

check

$r_\pi = \frac{\beta V_T}{I_C}$

$= \frac{V_T}{I_B}$

$100\,\Omega = \frac{25mV}{I_B}$

$I_B = 0.25\,mA$

does not check with the above value.

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CS Amplifier Frequency Response **Sedra 4.94**

4.94 In a particular MOSFET amplifier for which the midband voltage gain between gate and drain is –27 V/V, the NMOS transistor has $C_{gs} = 0.3$ pF and $C_{gd} = 0.1$ pF. What input capacitance would you expect? For what range of signal-source resistances can you expect the 3-dB frequency to exceed 10 MHz? Neglect the effect of R_G.

Note: Consider this question as of a common source amplifier configuration.

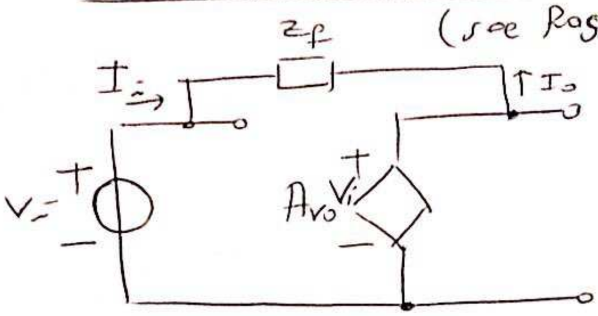
Additional Tasks: Review Miller's theorem, reprove it on paper.

Necessary Knowledge and Skills: Miller's effect in common source configuration, dominant pole determined by the Miller effect, OCTC method for computing the approximate high freq. cut-off, equivalent Thevenin impedance calculations, design for increasing bandwidth.

Sedra 4.94

Review of Miller's theorem

(see Rashid pp 71-72)



Z_f is going to be transformed into two separate impedances. I_i and I_o will each be required to flow into these generated impedances.

$$I_i = \frac{V_i - V_o}{Z_f} = \frac{V_i - A_{vo}V_i}{Z_f}$$

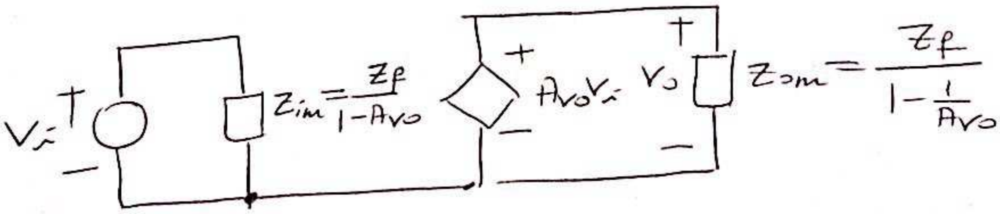
$$= V_i \frac{(1 - A_{vo})}{Z_f}$$

$$\frac{V_i}{I_i} = \frac{Z_f}{1 - A_{vo}}$$

$$I_o = \frac{V_o - V_i}{Z_f} = \frac{V_o - \frac{V_o}{A_{vo}}}{Z_f}$$

$$\frac{V_o}{I_o} = \frac{Z_f}{1 - \frac{1}{A_{vo}}}$$

then we have



(1)

Sedra 4.94 Cont-

For a typical amplifier assume

$A_{vo} < 0$ and $|A_{vo}| > 1$

and let $Z_f = \frac{1}{sC_f}$ (a capacitance)

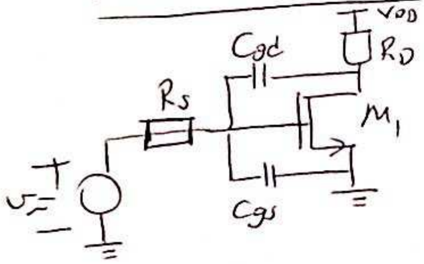
then

$$Z_{in} = \frac{1}{sC_f(1 - A_{vo})} \qquad Z_{out} = \frac{1}{sC_f\left(1 - \frac{1}{A_{vo}}\right)}$$

Corresponds to a capacitance $\Rightarrow C_f(1 - A_{vo})$ (amplified)

Corresponds to $\Rightarrow C_f\left(1 - \frac{1}{A_{vo}}\right)$ (if $|A_{vo}| \gg 1$ then $\simeq C_f$)

Basic CS MOSFET ampli (Bias not shown)



midband voltage gain $\Rightarrow -g_{m1}(R_D // r_{o1}) \simeq -g_{m1} R_D$

OR if R_D is replaced by a current-source with $R_{out} \gg r_{o1}$

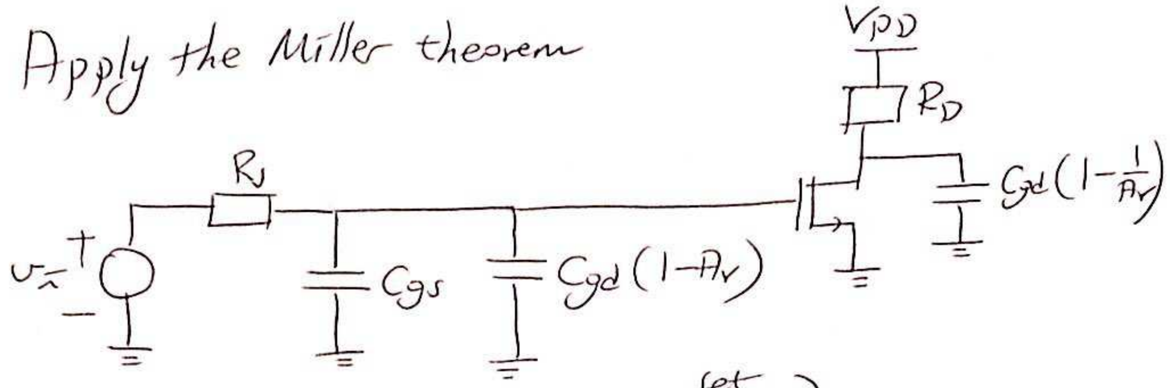
then we have for the gain $\Rightarrow -g_{m1} r_{o1}$

2

Sedra 4.94 cont.

We are given $-g_{m1}R_D$ or $-g_{m1}r_{o1}$ as $A_v = -27$ V/V

Apply the Miller theorem



Apply the method of OCTC ($v_i \overset{set}{=} 0$)

$\Rightarrow$ the capacitance $C_1 = C_{gs} + C_{gd}(1-A_v)$ sees $R_1 = R_s$ ($C_2 = (1-\frac{1}{A_v})C_{gd}$ is open Cir)

time constant $\tau_1 = C_1 R_1 = [C_{gs} + C_{gd}(1-A_v)] R_s$

$\Rightarrow$ the capacitance $C_2 = C_{gd}(1-\frac{1}{A_v})$ sees $R_2 = R_D // r_{o1}$ (could approximate to R_D or r_{o1} depending on the values)

time constant $\tau_2 = C_2 R_2 = \left[C_{gd}\left(1-\frac{1}{A_v}\right)\right]\left[R_D // r_{o1}\right]$

high freq cutoff $\quad w_{3dB} \approx \dfrac{1}{\tau_1 + \tau_2} = \dfrac{1}{C_1R_1 + C_2R_2}$

3

In this question it is expected that

Sedra 4.94 cont.

$\tau_1 >> \tau_2$

then $w_{3dB} \approx \frac{1}{\tau_1}$

Numerical calculations

$$w_{3dB} = 2\pi f_{3dB} = 2\pi(10MHz) < \frac{1}{R_s\left[\underbrace{C_{gs}}_{0.3pF} + \underbrace{C_{gd}}_{0.1pF}(1 - \underbrace{A_v}_{-27V/V})\right]} = \frac{1}{\tau_1}$$

calculate a range for R_s

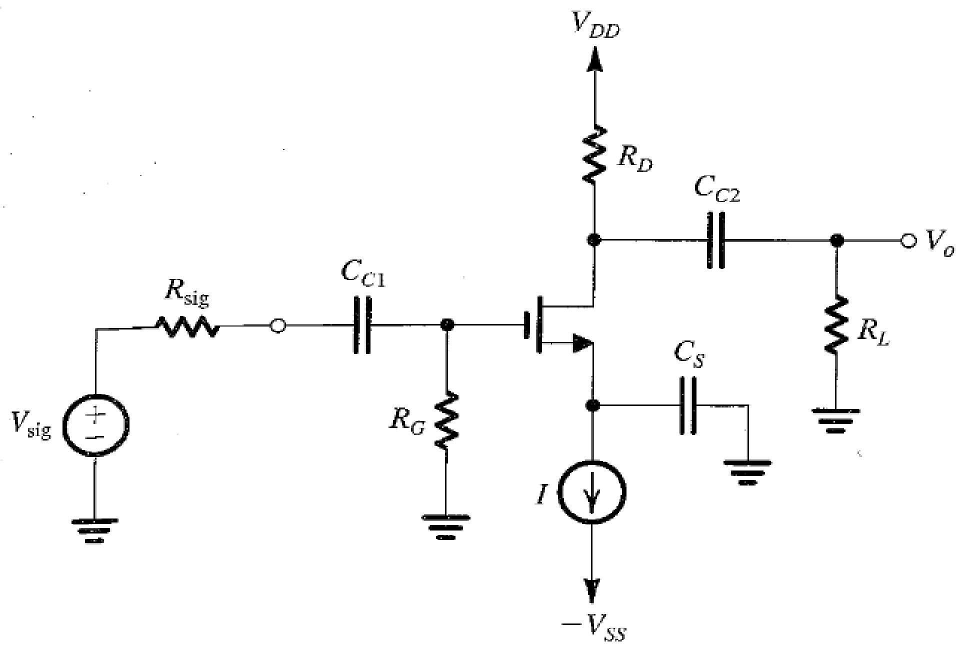
R_s should be smaller than some value

for $w_{3dB} > 2\pi(10MHz)$

4

CS Amplifier OCTC, SCTC and Miller's Effect **Sedra 4.95**

D4.95 In a FET amplifier, such as that in Fig. 4.49(a), the resistance of the source $R_{\text{sig}} = 100\ \text{k}\Omega$, amplifier input resistance (which is due to the biasing network) $R_{\text{in}} = 100\ \text{k}\Omega$, $C_{gs} = 1\ \text{pF}$, $C_{gd} = 0.2\ \text{pF}$, $g_m = 3\ \text{mA/V}$, $r_o = 50\ \text{k}\Omega$, $R_D = 8\ \text{k}\Omega$, and $R_L = 10\ \text{k}\Omega$. Determine the expected 3-dB cutoff frequency f_H and the midband gain. In evaluating ways to double f_H, a designer considers the alternatives of changing either R_{out} or R_{in}. To raise f_H as described, what separate change in each would be required? What midband voltage gain results in each case?



(a)

CS Amplifier OCTC, SCTC and Miller's Effect — Sedra 4.95

Note: This is a common source configuration.

Additional Tasks: Apply the SCTC method for computing the low freq. cut-off, iterate over the AC coupling capacitors, leave results in terms of the parameters used.

Necessary Knowledge and Skills: OCTC methods for computing the high freq cut-off, Thevenin equivalent impedance calculations, small signal equivalent circuits, bandwidth and gain trade-off, gain bandwidth product calculations, Miller's effect.

Sedra 495

Compute low freq cutoff (SCTC method)

$\Rightarrow$ Note that V_{sig} is set to 0, V_{DD} and V_{SS} are set to gnd, I is open cir.

$$\Rightarrow \tau_{l,1} = C_{C1} \underbrace{R_{C_{C1}}}_{R_{sig}+R_G} \quad (C_{C2} \text{ and } C_S \text{ are short cir})$$

$$\Rightarrow \tau_{l,2} = C_{C2} \underbrace{R_{C_2}}_{(R_D // r_o + R_L)} \quad (C_{C1} \text{ and } C_S \text{ are short cir})$$

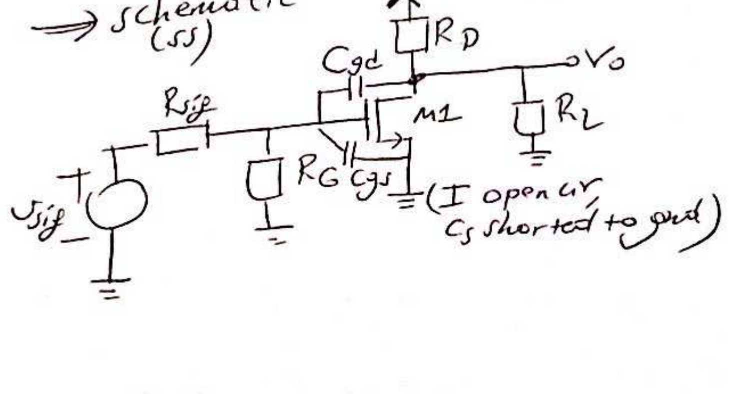
$$\Rightarrow \tau_{l,3} = C_S \underbrace{R_{C_S}}_{1/g_m} \quad (C_{C1} \text{ and } C_{C2} \text{ are short cir})$$

$$\Rightarrow w_L = \sum_{i=1}^{3} \frac{1}{\tau_{l,i}} = \frac{1}{\tau_1} + \frac{1}{\tau_2} + \frac{1}{\tau_3}$$

Compute high freq cutoff (OCTC method)

$\Rightarrow$ C_{C1}, C_{C2} and C_S are effectively short cir

$\Rightarrow$ schematic (ss)



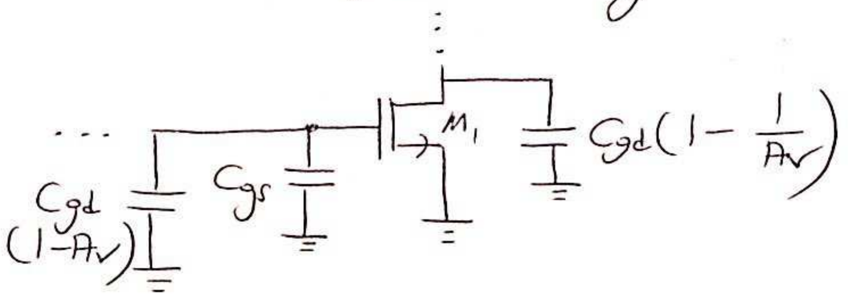
(1)

Sedra 4.95 cont-

⇒ Use Miller's theorem, but compute the midband gain first.

$$A_V = \text{midband voltage gain} = \frac{R_G}{R_{sig}+R_G}(-g_m)\left[R_D /\!/ R_L /\!/ r_o\right] < 0$$

(negative)



(the rest of the schematic not redrawn)

⇒ Compute time constants

$$\tau_{H,1} = \left[C_{gs} + C_{gd}(1-A_v)\right]\left[R_{sig} /\!/ R_G\right]$$

(when $C_{gd}\left(1-\frac{1}{A_v}\right)$ is considered open cir.)

corresponds to this capacitance

$$\tau_{H,2} = \left[C_{gd}\left(1-\frac{1}{A_v}\right)\right]\left[R_D /\!/ R_L /\!/ r_o\right]$$

(when the other cap is considered open cir.)

$$W_H = \frac{1}{\sum_{i=1}^{2} \tau_{H,i}} = \frac{1}{\tau_{H,1}+\tau_{H,2}}$$

if (as usually is the case) $\tau_{H,1} \gg \tau_{H,2}$ ⇒ then $\tau_{H,1}+\tau_{H,2} \approx \tau_{H,1}$

then $W_H \approx \frac{1}{\tau_{H,1}}$

2

CE Amplifier OCTC, SCTC and Miller's Effect **Sedra 5.159**

5.159 Consider the common-emitter amplifier of Fig. P5.159 under the following conditions: $R_{sig} = 5\ \text{k}\Omega$, $R_1 = 33\ \text{k}\Omega$, $R_2 = 22\ \text{k}\Omega$, $R_E = 3.9\ \text{k}\Omega$, $R_C = 4.7\ \text{k}\Omega$, $R_L = 5.6\ \text{k}\Omega$, $V_{CC} = 5$ V. The dc emitter current can be shown to be $I_E \cong 0.3$ mA, at which $\beta_0 = 120$, $r_o = 300\ \text{k}\Omega$, and $r_x = 50\ \Omega$. Find the input resistance R_{in} and the midband gain A_M. If the transistor is specified to have $f_T = 700$ MHz and $C_\mu = 1$ pF, find the upper 3-dB frequency f_H.

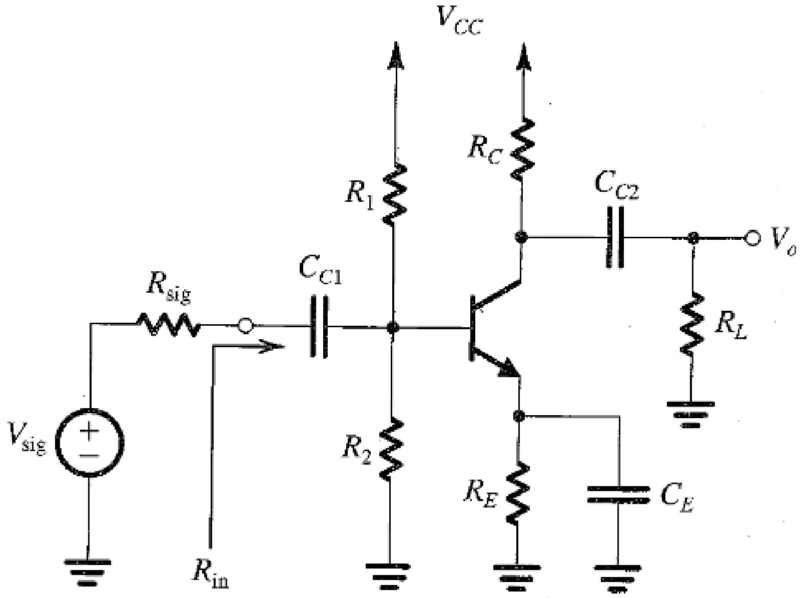


FIGURE P5.159

Notes: This is a common emitter configuration.

Additional Tasks: Apply the SCTC method for computing the low freq. cut-off, iterate over the AC coupling capacitors, leave results in terms of the parameters used.

Necessary Knowledge and Skills: OCTC methods for computing the high freq cut-off, Thevenin equivalent impedance calculations, small signal equivalent circuits, bandwidth and gain trade-off, gain bandwidth product calculations, Miller's effect.

Tasks in this question

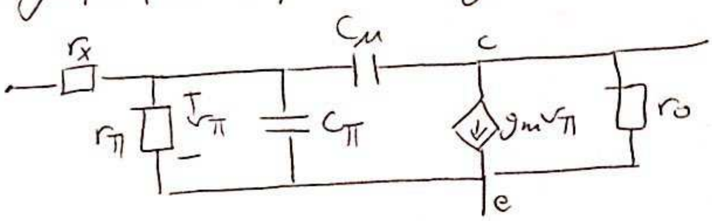
Sedra
5.159

$\Rightarrow$ Use the SCTC method to compute an approximate value for the low freq cut-off w_L. Leave the result in terms of the parameters.

$\Rightarrow$ Compute the midband gain A_m

$\Rightarrow$ Use the OCTC method to compute an approximate value for the high freq cut-off w_H. The result in terms of the parameters.

$\Rightarrow$ The high freq model for BJT is given as (naturally small signal)



Compute the missing values for the parameters.

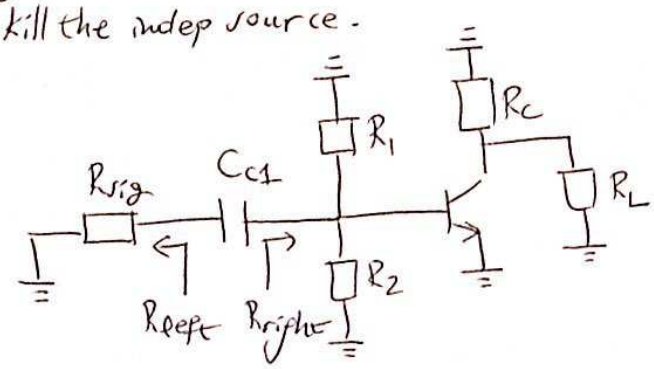
$\Rightarrow$ Compute w_L, w_H, A_m (midband gain) and R_{in} plugging in the values for the parameters.

1

SCTC for ω_L

Sedra 5.159

$\Rightarrow$ given C_{C1} compute $R_{C_{C1}}$, short the other caps, kill the indep source.



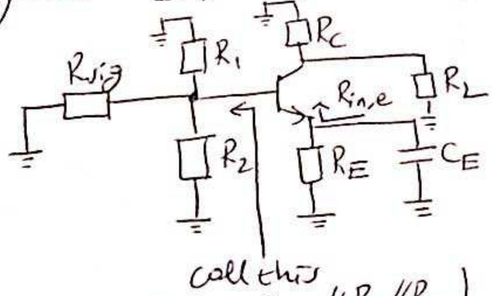
$R_{C_{C1}} = R_{left} + R_{right}$

$R_{left} = R_{sig}$ (easy)

$R_{right} = R_1 // R_2 // r_\pi$ (easy)

time constant $\tau_{C1} = C_{C1} R_{C1}$

$\Rightarrow$ given C_E, compute R_{C_E}, short other caps, kill indep src.



$\left(R_B = R_{sig} // R_1 // R_2 \right)$

$$R_{in,e} = \frac{r_\pi + R_B}{1+\beta}$$

(see derivations elsewhere, done many times)

$\Downarrow$

Then $R_{C_E} = R_{in,e} // R_E$

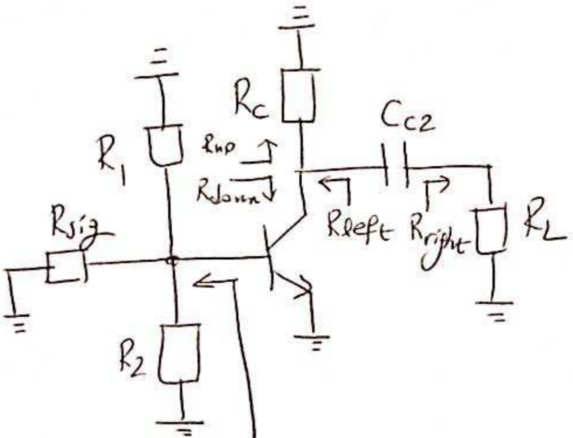
time constant $\tau_{C_E} = C_E R_{C_E}$

2

SCTC for W_L (continued)

Sedra
5-159

$\Rightarrow$ given C_{C2}, compute R_{C2}, kill indep src, short other caps.



$R_{C_{C2}} = R_{left} + R_{right}$

$R_{right} = R_L$

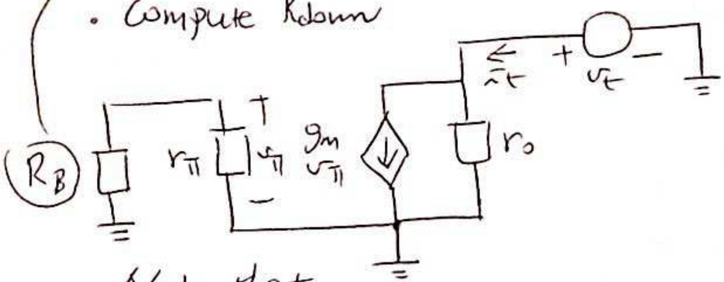
$R_{up} = R_C$

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

$R_{down} = ?$

call this
$R_B = R_1 // R_2 // R_{sig}$

• compute R_{down}



$\frac{v_t}{i_t} = R_{down}$
$= r_o$

Note that there is no current over $r_\pi \Rightarrow v_\pi = 0 \Rightarrow g_m v_\pi$ open cir.

• time constant $\tau_{C_{C2}} = C_{C2} R_{C2}$

SCTC formula $\Rightarrow$ $W_L = \frac{1}{\tau_{C1}} + \frac{1}{\tau_{C2}} + \frac{1}{\tau_{CE}}$ (all have been computed above)

3

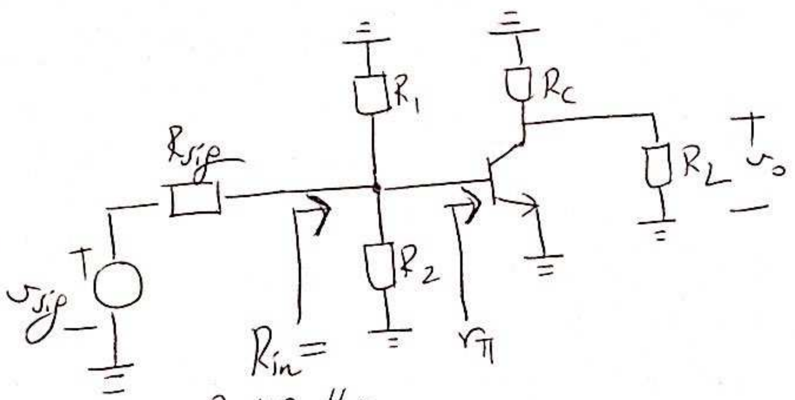
Sedra 5.159

R_{in} (in midband computation)

$\Rightarrow$ large valued C_{C1}, C_{C2}, C_E caps are all short cir in small signal in midband.

$\Rightarrow$ internal caps (BJT caps) are open cir in midband.

$\Rightarrow$ Draw schematic and compute R_{in}



$R_{in} = R_1 // R_2 // r_\pi$

A_M (in midband)

$\Rightarrow$ coupling caps and C_E short cir in s.s.

$\Rightarrow$ internal caps open cir.

$$\frac{v_o}{v_{sig}} = A_M = \underbrace{\frac{R_{in}}{R_{in}+R_{sig}}}_{\frac{v_b}{v_{sig}}} \underbrace{(-g_m)}_{\frac{i_{out}}{v_{sig}} \text{ (transcond. of BJT)}} \underbrace{\left[R_C // r_o // R_L\right]}_{\text{load } \frac{v_{out}}{i_{out}}}$$

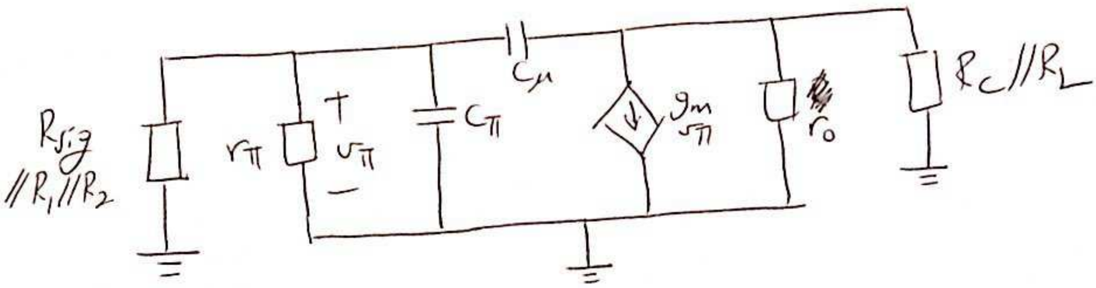
Note that R_{in} is computed above.

 4

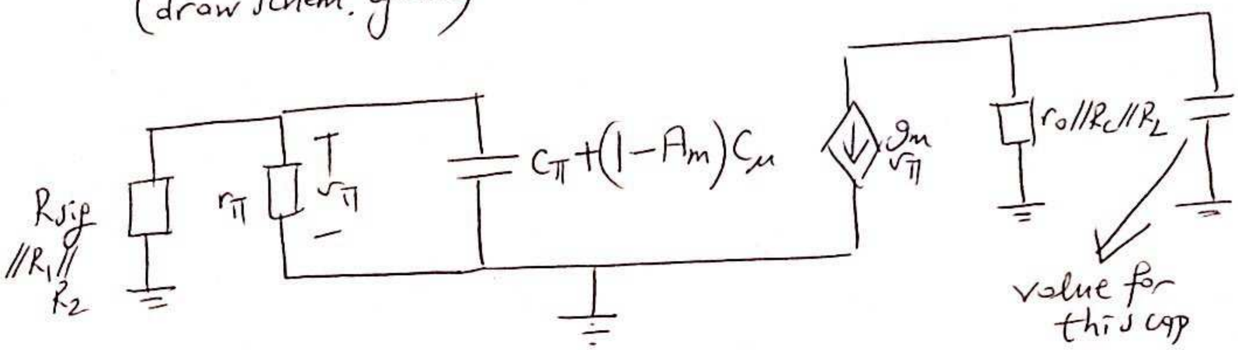
OCTC method for computing ω_H

Sedra 5.159

⇒ Draw schematic (kill indep. src, coupling caps are short cir)



⇒ Make use of Miller's thm (draw schem. gain)



Note that $(1-A_m) \gg 1$

and $1 < 1 - \frac{1}{A_m} < 2$

(A_M computed above as midband gain)

⇒ call $C_1 = C_\pi + (1-A_m) C_\mu$

$C_2 = C_\mu \left(1 - \frac{1}{A_m}\right)$

⇒ open cir C_2, compute R_{C1} corresponding to C_1

$R_{C1} = R_{sig} // R_1 // R_2 // r_\pi$ and $\tau_{C1} = R_{C1} C_1$

⇒ open cir C_1, compute R_{C2} corresponding to C_2

Note that no current over $r_\pi \Rightarrow v_\pi = 0 \Rightarrow g_m v_\pi$ open cir

$R_{C2} = r_o // R_C // R_L$ and $\tau_{C2} = R_{C2} C_2$

5

OCTC for w_H computation

Sedra 5.159

⇒ Apply the OCTC formula.

$$W_H = \frac{1}{\tau_{c1} + \tau_{c2}}$$

Both computed above

Numerical values

⇒ Left as an exercise but note the following:

- $g_m = \frac{I_C}{V_T} = \underbrace{\frac{\beta}{\beta+1}}_{\text{very close to } 1 \text{ since } \beta=120} I_E \frac{1}{\underbrace{V_T}_{25mV}}$

- r_x can be neglected in the calculations, it is very small compared to $R_{sig} // R_1 // R_2$.

- f_T : transition frequency (see Rashid pg. 504-506)

$$\underbrace{f_T}_{\text{given}} = \frac{\overbrace{g_m}^{\text{computed as above}}}{2\pi(\underbrace{C_\pi}_{\text{compute from this eqn.}} + \underbrace{C_\mu}_{\text{given}})}$$

6

BJT Differential Amplifier High-Freq. Response **Sedra 7.82**

7.82 A BJT differential amplifier operating with a 1-mA current source uses transistors for which $\beta = 100$, $f_T = 600$ MHz, $C_\mu = 0.5$ pF, and $r_x = 100\ \Omega$. Each of the collector resistances is 10 kΩ, and r_o is very large. The amplifier is fed in a symmetrical fashion with a source resistance of 10 kΩ in series with each of the two input terminals.

(a) Sketch the differential half-circuit and its high-frequency equivalent circuit.
(b) Determine the low-frequency value of the overall differential gain.
(c) Use Miller's theorem to determine the input capacitance and hence estimate the 3-dB frequency f_H and the gain–bandwidth product.

Notes: None.

Additional Tasks: None.

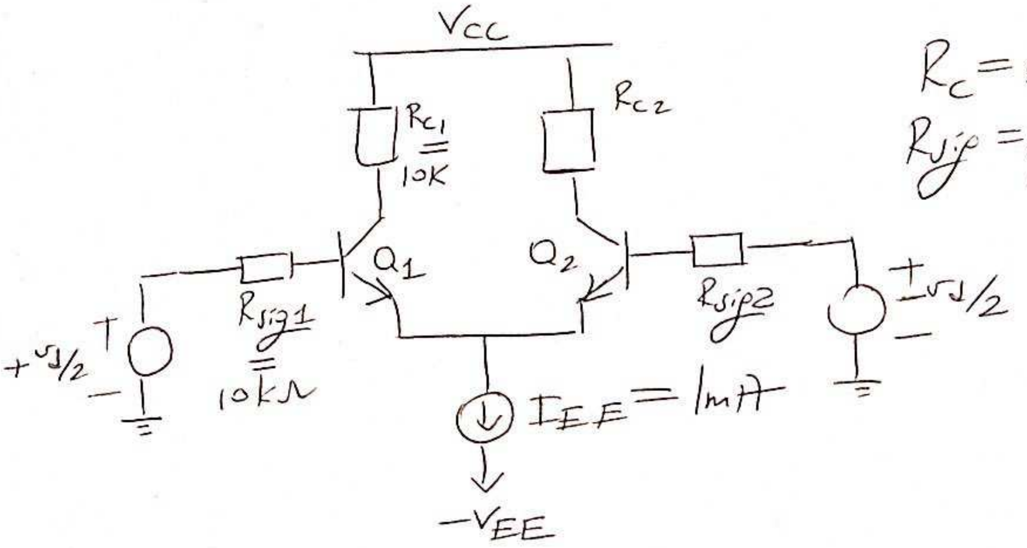
Necessary Knowledge and Skills: Differential amplifier, half circuit in differential mode, no emitter degeneration, small signal equivalent of BJT, differential voltage midband gain calculation, OCTC, Miller's effect, dominant pole approximation, gain bandwidth product.

Sedra 7-82

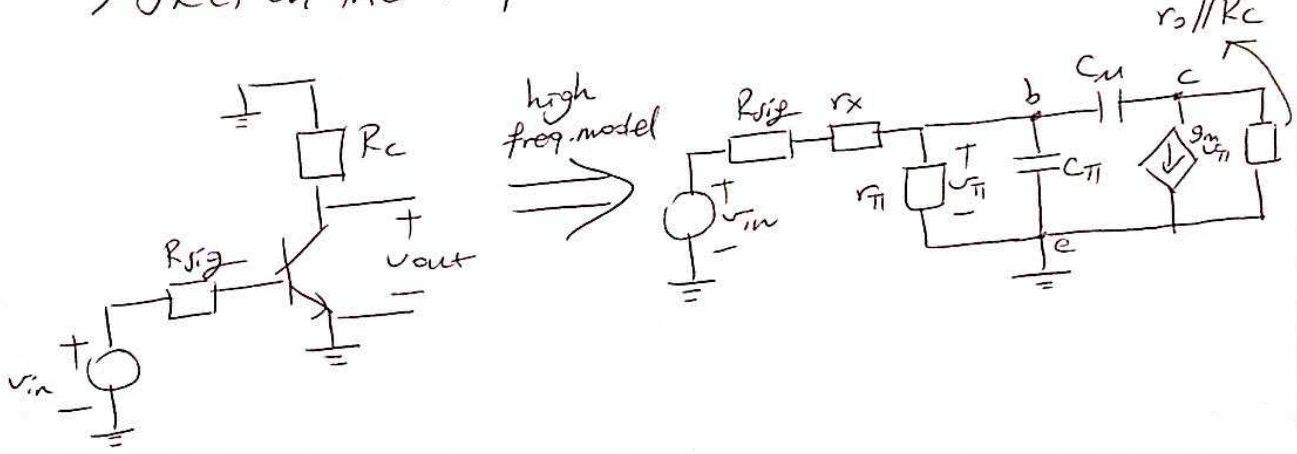
⇒ Sketch the full schematic

$R_C = R_{C1} = R_{C2}$

$R_{sig} = R_{sig1} = R_{sig2}$



⇒ Sketch the half circuit.



⇒ Since $r_o \to +\infty$ (as given), we have $R_C // r_o = R_C$

⇒ midband gain of the common emitter stage

$\left(A = \frac{v_c}{v_b} = -g_m R_C\right)$

⇒ Overall midband gain $A_M = \underbrace{\frac{r_\pi}{r_\pi + R_{sig} + r_x}}_{\frac{v_b}{v_{in}}} \underbrace{(-g_m R_D)}_{\frac{v_c}{v_b}}$

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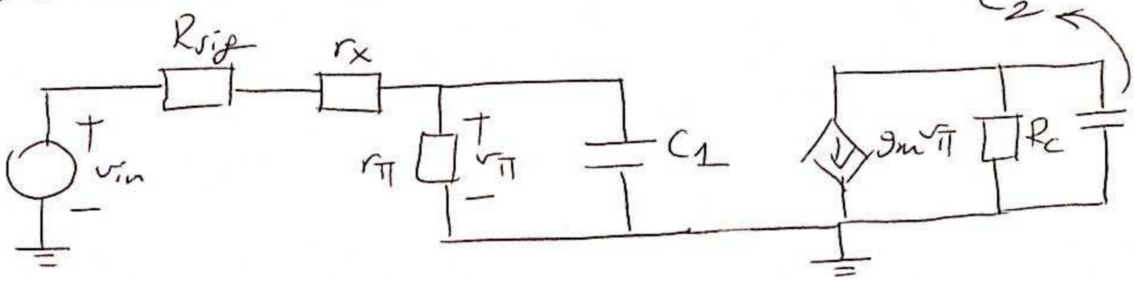
⟹ Miller's thm and OCTC will be applied now to compute w_H or f_H.

→ Miller's thm applied



$$C_1 = C_\pi + C_\mu \underbrace{(1 - A)}_{(1 + g_m R_c)}$$

$$C_2 = C_\mu \left(1 - \frac{1}{A}\right)$$

$$= C_\mu \left(1 + \frac{1}{g_m R_c}\right)$$

→ Apply OCTC (kill indep. src)

- C_2 open cir, compute R_{c1} corresponding to C_1

$$R_{c1} = r_\pi // (R_{sig} + r_x)$$

$$\tau_{c1} = R_{c1} C_1$$

- C_1 open cir, compute R_{c2} corresponding to C_2

$$R_{c2} = R_c \quad (\text{no current through } r_\pi \Rightarrow v_\pi = 0)$$

$$\tau_{c2} = R_{c2} C_2$$

- $w_H = \dfrac{1}{\tau_{c1} + \tau_{c2}}$ ⟶ But in this config $\tau_{c1} \gg \tau_{c2}$ therefore $w_H \cong \dfrac{1}{\tau_{c1}}$

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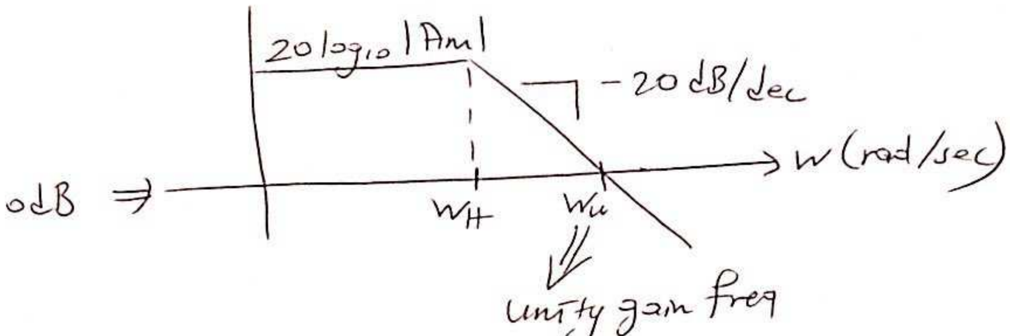
Gain – Bandwidth product Sedra 7-82

$$GBW = |A_M| \cdot \frac{w_H}{2\pi}$$

$$= |A_M| \cdot f_H$$

$$\cong \left| \frac{r_\pi}{r_\pi + r_x + R_{sig}} (-g_m R_C) \right| \frac{1}{2\pi \tau_{C1}}$$

where τ_{C1} is given as above.



Note that $|A_M| w_H = 1 \cdot w_u$

therefore $\frac{GBW}{2\pi} = \frac{w_u}{2\pi} = f_u$ (unity gain freq in Hz)

⇒ Numerical values comput. ⇒ exercise

Note the following:

$I_{C1} = I_{C2} \cong \frac{I_{EE}}{2} = 0.5mA$

$g_m = \frac{I_C}{V_T} = \frac{0.5mA}{25mV}$

$f_T = \frac{g_m}{2\pi(C_\mu + C_\pi)}$

g_m → computed; f_T → given; C_μ → given; C_π → compute

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