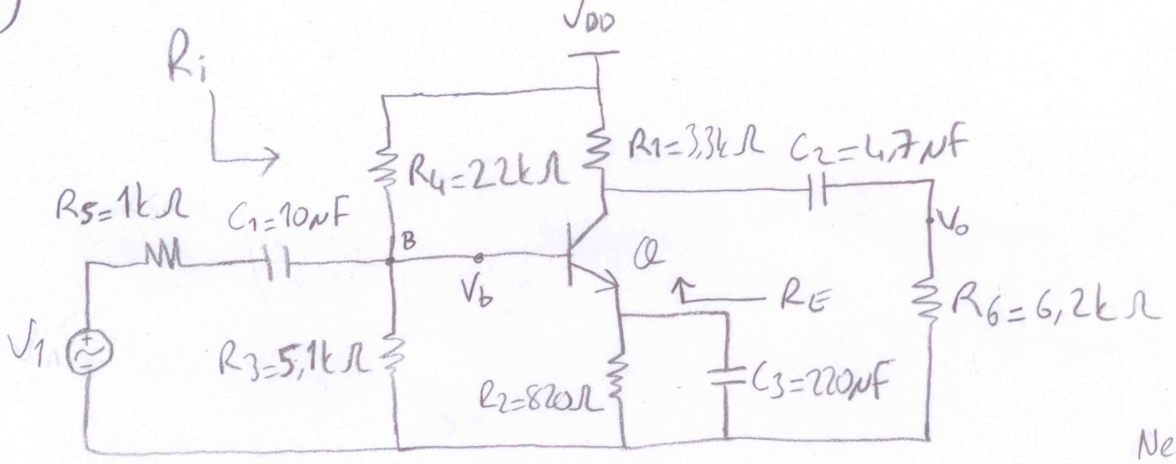
EHB 335E - Problem Solving Session I - Alican Çağlar

(1)



$g_m=0{,}072\,A/V$
$r_\pi=2{,}47k\Omega$
$\beta=178$
$C_\pi=66{,}5pF$
$C_\mu=4pF$
Neglect C_{cs} and r_o.

Draw the frequency response of the circuit.

Solution:

Midband Gain, A_o

$$A_o=\frac{V_b}{V_1}\cdot\frac{V_o}{V_b}=\frac{R_i}{R_i+R_S}\cdot -g_m.R_{out}=-94{,}55 \quad (39{,}5dB)$$

$R_i=R_3//R_4//r_\pi=1{,}55k\Omega$

$R_{out}=R_1//R_6=2{,}15k\Omega$

Due to input coupling capacitor:

$$f_{P1}=\frac{1}{2\pi.C_1(R_5+R_i)}=6{,}25\,Hz$$

Also, it creates zero at DC.

Due to output coupling capacitor:

$$f_{P2}=\frac{1}{2\pi C_2(R_1+R_6)}=3{,}56\,Hz$$

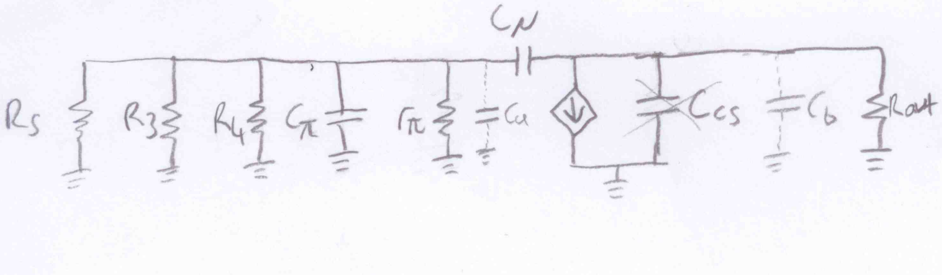
Also, it creates zero at DC.

Due to emitter bypass capacitor:

$$f_z=\frac{1}{2\pi.C_3R_2}=0{,}88\,Hz \qquad f_{P3}=\frac{1}{2\pi C_3R_k}=40{,}3\,Hz$$

$R_k=R_E//R_2=17{,}9\Omega$, $R_E=\frac{R_S//R_3//R_4}{\beta+1}+r_e=18{,}33\Omega$

High frequency small signal equivalent circuit:



Miller Approximation

$A_1=\frac{V_o}{V_b}=-g_m.R_{out}=-155$

$C_a=C_\mu(1-A_1)=620pF$

$C_b=C_\mu\left(1-\frac{1}{A_1}\right)=4{,}02pF$

(1) Continue

$$f_{Hi} = \frac{1}{2\pi (C_a + C_\pi) R_a}$$

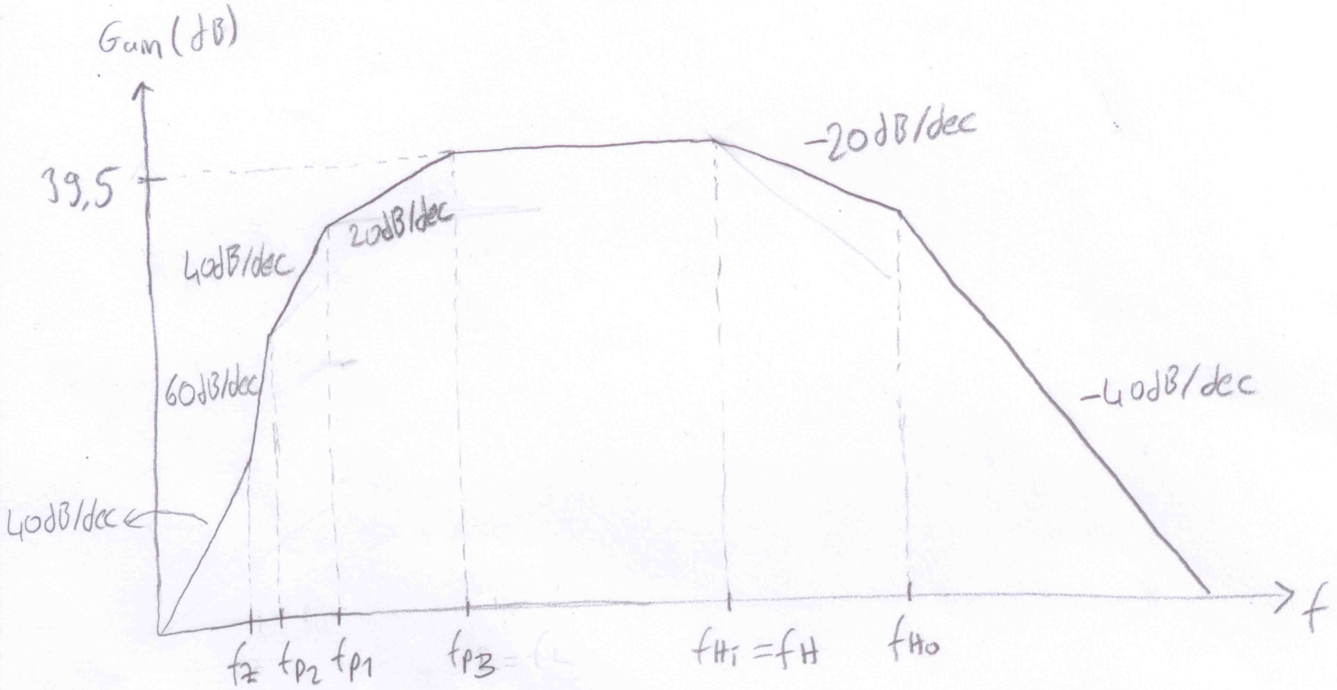
$$= 382\ kHz$$

R_a is the resistance seen from node B:

$R_a = R_3 // R_4 // R_5 // r_\pi = 607\ \Omega$

$$f_{Ho} = \frac{1}{2\pi . C_b . R_{out}} = 18{,}4\ MHz$$

$$A_v = A_0 . \frac{s+w_z}{s+w_{p3}} . \frac{s}{s+w_{p1}} . \frac{s}{s+w_{p2}} . \frac{w_{Hi}}{s+w_{Hi}} . \frac{w_{Ho}}{s+w_{Ho}}$$



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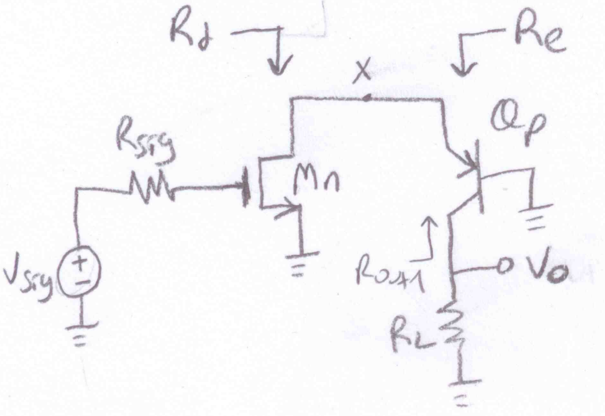


$R_{sig} = 10k\Omega$

$R_L = 100k\Omega$

For Mn	For Qp
$I_D = 0{,}25\,mA$	$\beta = 200$
$k = 1{,}28\,mA/V^2$	$V_A = 50V$
$f_T = 400\,MHz$	$C_\mu = C_S = 0{,}25pF$
$\lambda = 1/(15V)$	$I_C = 0{,}25\,mA$
$C_{gd} = C_{db} = 25\,fF$	$f_T = 400\,MHz$

a) Find the low-frequency gain.

b) Estimate upper corner frequency for the folded-cascade circuit using open circuit time constant method.

Solution:

a) Mn: $g_{mn} = \sqrt{2kI_D} = \sqrt{2.1{,}28.0{,}25} = 0{,}8\,mA/V$ $\qquad r_{on} = \dfrac{1}{\lambda I_D} = \dfrac{15V}{0{,}25mA} = 60k\Omega$

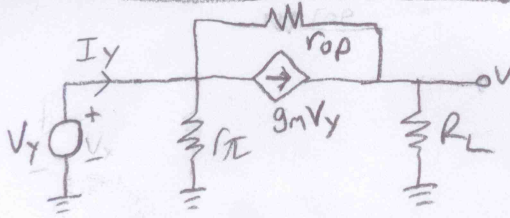
$$C_{gs} = \frac{g_{mn}}{2\pi f_T} - C_{gd} = \frac{0{,}8.10^{-3}}{2\pi.4.10^8} - 25.10^{-15} = 293fF$$

Qp: $g_{mp} = \dfrac{I_C}{V_T} = \dfrac{0{,}25\,mA}{25\,mV} = \dfrac{1}{104\Omega}$ $\qquad r_\pi = \dfrac{\beta}{g_{mp}} = 200.104 = 20{,}8\,k\Omega$

$r_{op} = \dfrac{V_A}{I_C} = \dfrac{50V}{25mA} = 200k\Omega$ $\qquad r_{ep} = \dfrac{r_\pi}{\beta+1} = \dfrac{20{,}8k}{201} = 103{,}5\,\Omega$

$$C_\pi = \frac{g_{mp}}{2\pi f_T} - C_\mu = \frac{1}{104.2\pi.4.10^8} - 0{,}25.10^{-12} = 3{,}58\,pF$$

Equivalent resistance seen looking down to emitter, Re



$$\left(I_Y - g_m V_Y - \frac{V_Y}{r_\pi}\right) r_{op} + \left(I_Y - \frac{V_Y}{r_\pi}\right).R_L = V_Y$$

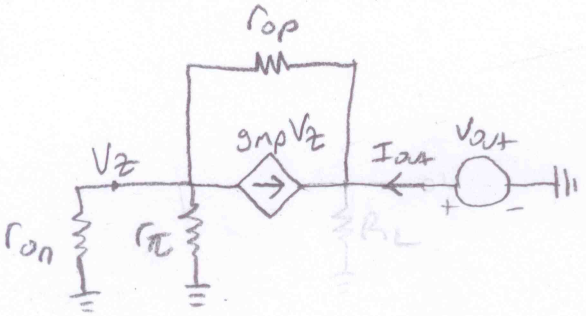
$$R_e = \frac{V_Y}{I_Y} = \frac{r_{op} + R_L}{1 + \frac{r_{op}+R_L}{r_\pi} + g_m.r_{op}} \cong 155\,\Omega$$

$R_d = r_{on} \Rightarrow R_X = R_d // R_e \cong 155\,\Omega$

$$\frac{V_X}{V_{sig}} = -g_{mn}.R_X = -0{,}124$$

② Continue

Output Resistance, R_{out}



$$I_{out} \cdot r_{on} // r_\pi + (I_{out} + g_{mp} V_z) r_{op} = V_{out}$$

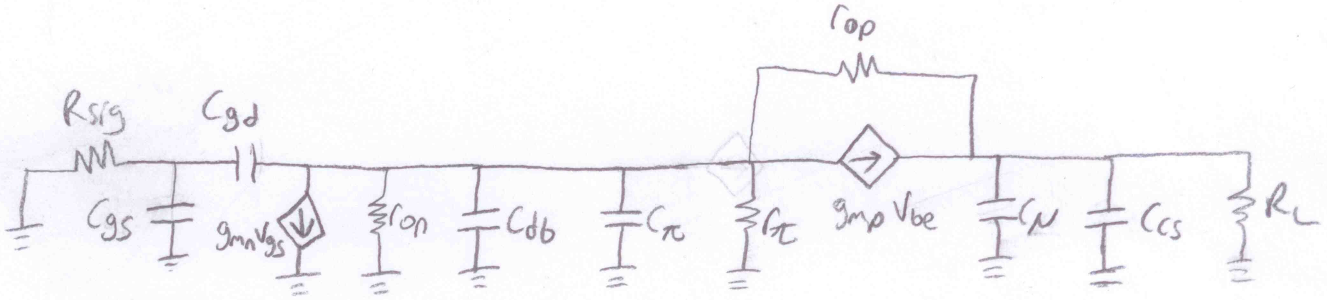
$$V_z = I_{out} \cdot r_{on} // r_\pi$$

$$\frac{V_{out}}{I_{out}} = R_{out1} = r_{on} // r_\pi + r_{op} + g_{mp} \cdot r_{on} // r_\pi \cdot r_{op}$$

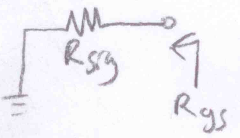
$$R_{out} = R_L // R_{out1} \qquad \frac{V_{out}}{V_x} = \frac{R_{out}}{R_e} = 643$$

$$A_o = \frac{V_x}{V_{sig}} \cdot \frac{V_{out}}{V_x} = -79{,}7$$

b)

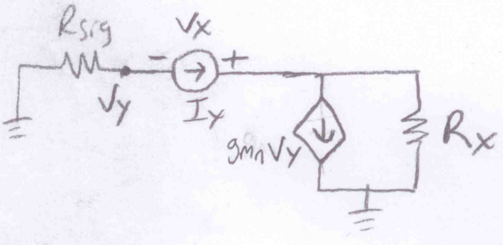


$\tau_{gs} \Rightarrow$



$$\tau_{gs} = R_{sig} \cdot C_{gs} = 2{,}93 \text{ ms}$$

$\tau_{gd} \Rightarrow$



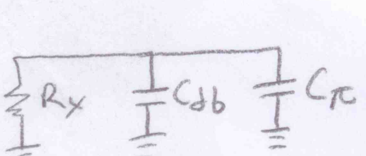
$$V_y = -R_{sig} \cdot I_x$$

$$(I_x - g_m V_y) R_x = V_x + V_y$$

$$\frac{V_x}{I_x} = R_{gd} = R_{sig} + R_x + g_{mn} R_x R_{sig}$$

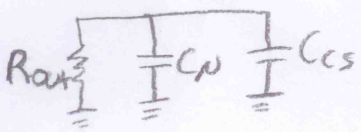
$$\tau_{gd} = R_{gd} \cdot C_{gd} = 0{,}285 \text{ ms}$$

$\tau_x \Rightarrow$



$$\tau_x = R_x \cdot (C_{db} + C_\pi) = 0{,}559 \text{ ms}$$

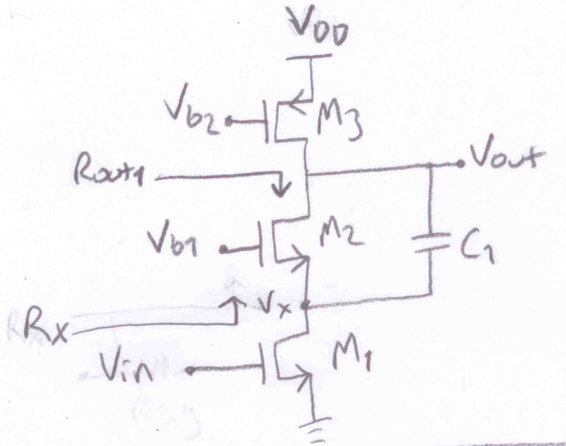
$\tau_o \Rightarrow$



$$\tau_o = R_{out}(C_\mu + C_{cs}) = 49{,}8 \text{ ms}$$

$$f_{-3dB} = \frac{1/2\pi}{\tau_{gs} + \tau_{gd} + \tau_x + \tau_o} = 3 \text{ MHz}$$

3



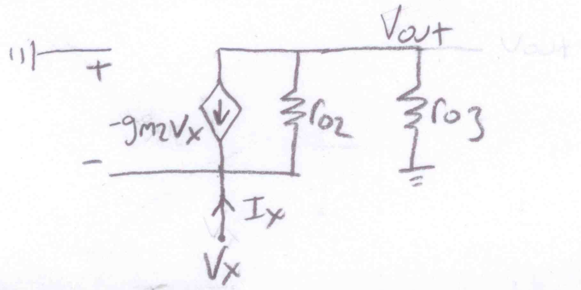
Assume internal capacitance of transistors are negligible compared to C_1.

$\lambda > 0$

Find poles of the circuit by Miller's approximation.

Solution:

Applying Miller's approximation



$$-(I_x - g_{m2}V_x)r_{o2} + V_x = V_{out}$$

$$I_x = \frac{V_{out}}{r_{o3}} \qquad A_2 = \frac{V_{out}}{V_x} = \frac{g_{m2}r_{o2}r_{o3} + r_{o3}}{r_{o3} + r_{o2}}$$

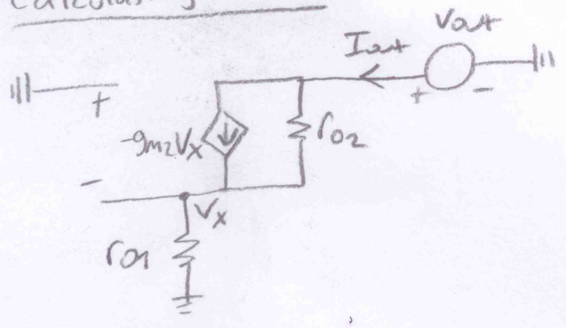
$$C_x = C_1.(1 - A_2) \qquad C_{out} = C_1.\left(1 - \frac{1}{A_2}\right)$$

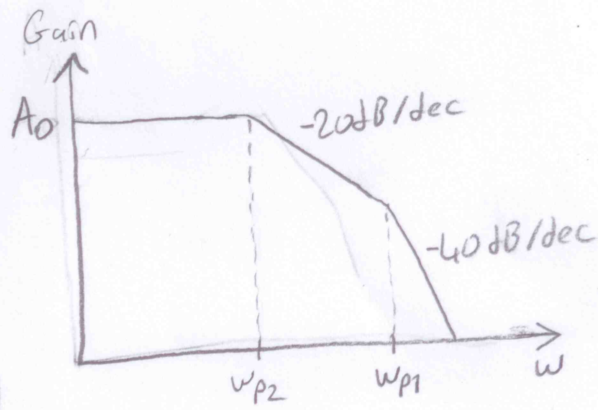
Calculating R_x

$$(I_x - g_{m2}V_x)r_{o2} + I_x r_{o3} = V_x \quad \Rightarrow \quad R_x = \frac{r_{o2} + r_{o3}}{1 + g_{m2}r_{o2}}$$

$$w_{p1} = \frac{1}{C_x(R_x \,//\, r_{o1})}$$

Calculating Rout1





$$V_x = I_{out}.r_{o1}$$

$$r_{o2}.I_{out} + g_{m2}V_x.r_{o2} + I_{out}r_{o1} = V_{out}$$

$$R_{out1} = \frac{V_{out}}{I_{out}} = g_{m2}r_{o1}r_{o2} + r_{o1} + r_{o2}$$

$$R_{out} = R_{out1} \,//\, r_{o3} \quad \Rightarrow \quad w_{p2} = \frac{1}{C_{out}.R_{out}}$$