HW 3

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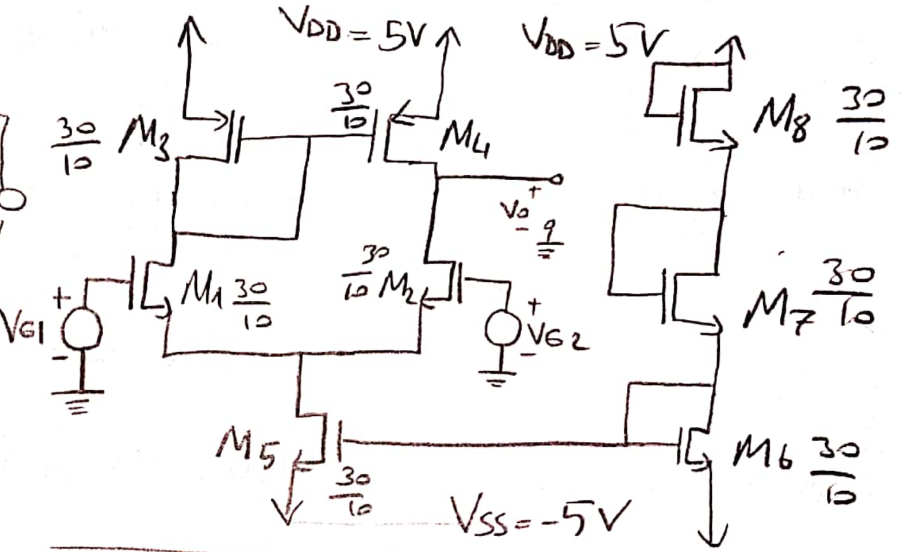
Q1. A CMOS amplifier is shown in fig P9.14
The parameters for the NMOS are $V_t = +2V$, $V_M = -40V$, and $V_{GS} = +4V$ at $I_D = 1mA$: the parameters for the PMOS are $V_t = -3V$, $V_M = 40V$, and $V_{GS} = -6V$ at $I_D = 1mA$. Calculate (a) A_d, A_c and CMRR and (b) R_{id} and R_{ic}



M_6, M_7 ve M_8'in Gate-Drain bağlantısından dolayı

$= V_G = V_D$

$V_{GS} = V_{DS} \rightarrow (M_6, M_7, M_8)$

$V_{DS_8} + V_{DS_7} + V_{DS_6} = V_{DD} - V_{SS}$

$= V_{GS} + V_{GS} + V_{GS} = 5 - (-5)$

$$\boxed{V_{GS_{6,7,8}} = \frac{10}{3} V}$$

Bağlantıdan kaynaklı 3 transistörün satürasyonda olduğu görülüyor.

$$I_D = \frac{1}{2} M_n C_{ox} \frac{W}{L} (V_{GS} - V_t)^2$$

NMOS'lar için verilen değerler

$V_t = 2V$ $\quad V_{GS} = V_{DS} = \frac{10}{3} = 3.33V$

$M_n C_{ox} = 8.5 MA/V^2$

$\frac{W_B}{L} = \frac{30}{10} \rightarrow$ her Mosfet için $\frac{30}{10}$ verilmiş.

$$I_D = \frac{1}{2} \cdot 8.5 \times 10^{-6} \cdot \frac{30}{10} \cdot (3.33 - 2)^2$$

$$\boxed{I_D = 22.553 MA}$$

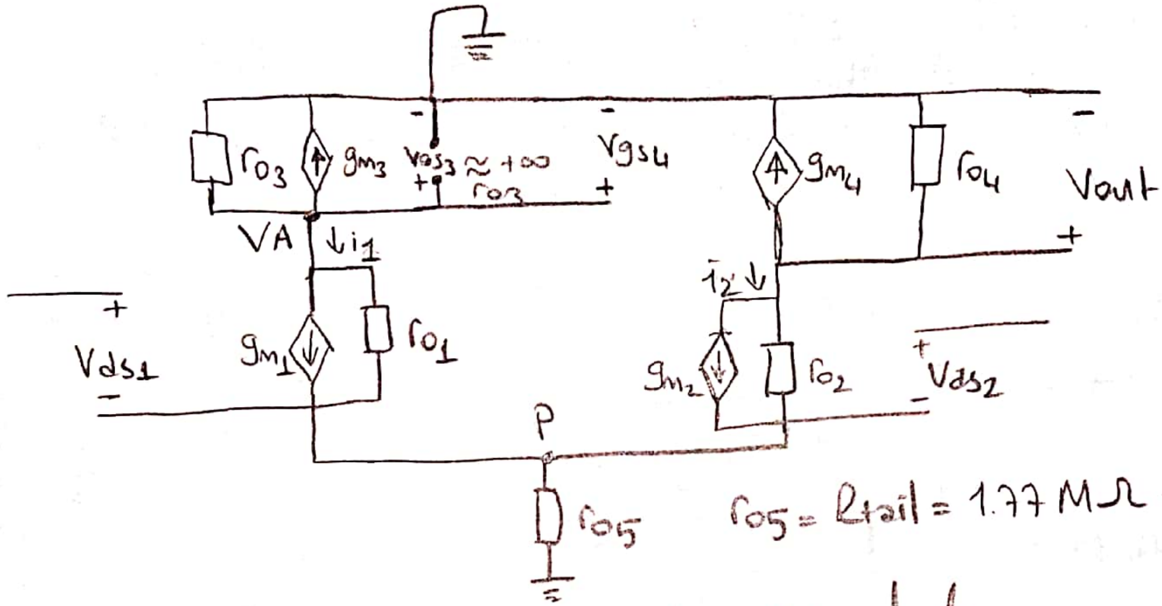
$$\boxed{I_{TAIL} = I_D}$$

$$\boxed{I_{TAIL} = 22.553 MA}$$

$$\boxed{R_{tail} = \frac{V_M}{I_{tail}} = \frac{40V}{22.553 MA} = 1.773 M\Omega}$$

$$\boxed{R_{tail} = 1.773 M\Omega}$$

Differential mode (active loaded single ended differential amp. gibi davranır)
↳ simetriden



$r_{o5} = R_{tail} = 1.77\,M\Omega$ → açık devre kabul edilebilecek kadar büyük.

PMOS'lar ve NMOS'lar eş transistörler olmalı (NMOS'lar kendi aralarında, PMOS'lar kendi aralarında)

$g_{m3} = g_{m4}$, $g_{m1} = g_{m2}$

$r_{o3} = r_{o4}$ $\qquad$ $r_{o1} = r_{o2}$ $\qquad$ $\boxed{V_{gs3} = V_{gs4} = V_A}$ $\qquad$ $\boxed{i_1 + i_2 = 0}$

simetriden gelen eşitlikler yazıldı.

$$\boxed{V_{gs3} = -i_1\left(\frac{1}{g_{m3}} \,//\, r_{o3}\right)} \rightarrow eq.1$$

$$i_2 + g_{m3}V_A + \frac{V_{out}}{r_{o3}} = 0$$

$$g_{m3}V_A + \frac{V_{out}}{r_{o3}} = \underbrace{-i_2}_{i_1} \rightarrow \boxed{g_{m3} \cdot i_1 \cdot \left(\frac{1}{g_{m3}} \,||\, r_{o3}\right) + \frac{V_{out}}{r_{o3}} = i_1}$$

$$i_1 + i_1\, g_{m3}\left(\frac{1}{g_{m3}} \,||\, r_{o3}\right) = \frac{V_{out}}{r_{o3}} \rightarrow i_1\left(1 + g_{m3} \cdot \left(\frac{1}{g_{m3}} \,||\, r_{o3}\right)\right) = \frac{V_{out}}{r_3}$$

$$\boxed{i_1 = \frac{V_{out}}{r_3 \cdot \left(1 + g_{m3}\left(\frac{1}{g_{m3}} \,||\, r_{o3}\right)\right)}} \rightarrow eq.2$$

Gevrim

$$-V_2 + (i_1 - g_{m1} \cdot V_{ds1}) r_{o1} - (i_2 - g_{m1} \cdot V_{ds2}) r_{o2} + V_{out} = 0$$

$i_1 = -i_2$

$$\rightarrow -V_2 + (2 i_1 r_{o1}) - g_{m1} r_{o1} (V_{ds1} - V_{ds2}) + V_{out} = 0$$

eq.1 ve eq.2 (V_2 ve i_1) yerlerine yazılırsa

$$= -\left(-i_1 \cdot \left(\frac{1}{g_{m3}} \| r_{o3}\right)\right) + (2 i_1 r_{o1}) - g_{m1} r_{o1} (V_{ds1} - V_{ds2}) + V_{out} = 0$$

$$= \frac{V_{out} \cdot (1/g_{m3} \| r_{o3})}{r_3 * (1 + g_{m3} \underbrace{(\frac{1}{g_{m3}} \| r_{o3})}_{\frac{1}{g_{m3}}})} + \frac{2 V_{out} \cdot r_{o1}}{r_{o3} \cdot (1 + g_{m3} \underbrace{(\frac{1}{g_{m3}} \| r_{o3})}_{\approx \frac{1}{g_{m3}}})} - g_{m1} r_{o1} (V_{ds1} - V_{ds2}) + V_{out} = 0$$

$\frac{1}{g_{m3}} << r_{o3}$

$$\boxed{= \frac{V_{out} \cdot \left(\frac{1}{g_{m3}}\right)}{r_{o3} \cdot 2} + \frac{2 V_{out} r_{o1}}{r_{o3} \cdot 2} + V_{out} = g_{m1} r_{o1} (V_{ds1} - V_{ds2})}$$

$$= V_{out} \left[\underbrace{\frac{\frac{1}{g_{m3}} + 2 r_{o1} + 2 r_{o3}}{2 r_{o3}}}_{I} \right] = g_{m1} r_{o1} (V_{ds1} - V_{ds2})$$

$$\Rightarrow V_{out} \cdot I = g_{m1} r_{o1} (V_{ds1} - V_{ds2}) \longrightarrow \frac{V_{out}}{(V_{ds1} - V_{ds2})} = \frac{g_{m1} r_{o1}}{I}$$

$V_{ds1} - V_{ds2} = V_{in1} - V_{in2}$

böylece $\frac{V_{out}}{V_{in1} - V_{in2}} \rightarrow$ kazanç verir.

$$\frac{V_{out}}{V_{in1} - V_{in2}} = g_{m1} \cdot r_{o1} \cdot \frac{1}{I} = g_{m1} \cdot r_{o1} \cdot \frac{2 r_{o3}}{\cancel{\frac{1}{g_{m3}}} + 2 r_{o1} + 2 r_{o3}}$$

$\frac{1}{g_{m3}} << r_{o1}$
$<< r_{o3}$

$$\frac{V_{out}}{\Delta V_{in}} = g_{m1} \cdot \frac{2 r_{o1} \cdot r_{o3}}{2 r_{o1} + 2 r_{o3}} = g_{m1} \cdot \underbrace{\left(\frac{1}{r_{o1}} + \frac{1}{r_{o3}}\right)}_{r_{o1} \| r_{o3}}$$

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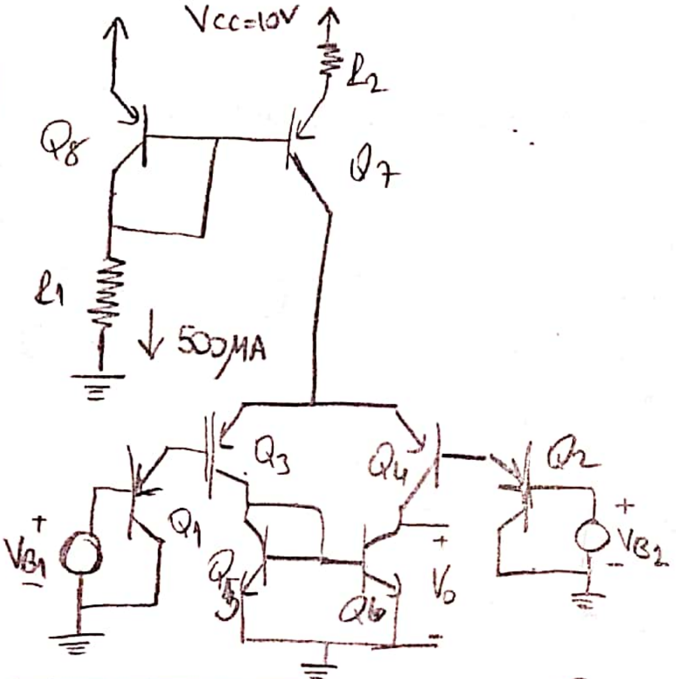
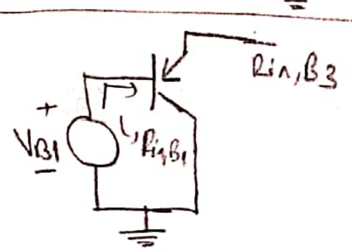
CamScanner ile tarandı

$$\frac{V_{out}}{\Delta V_{in}} = g_{m1} \cdot (r_{o1} \parallel r_{o3})$$

Q2 A differential amplifier is shown in Fig P 9.42. The transistors are identical. Assume $V_{BE} = 0.7V$, $V_T = 26mV$, $\beta_{F(npn)} = 100$ $\beta_{F(pnp)} = 50$, $V_A = 40V$ and $V_{CC} = 10V$. Calculate the values of R_1, R_2, A_d, R_{id}, A_c, R_{ic} and CMRR





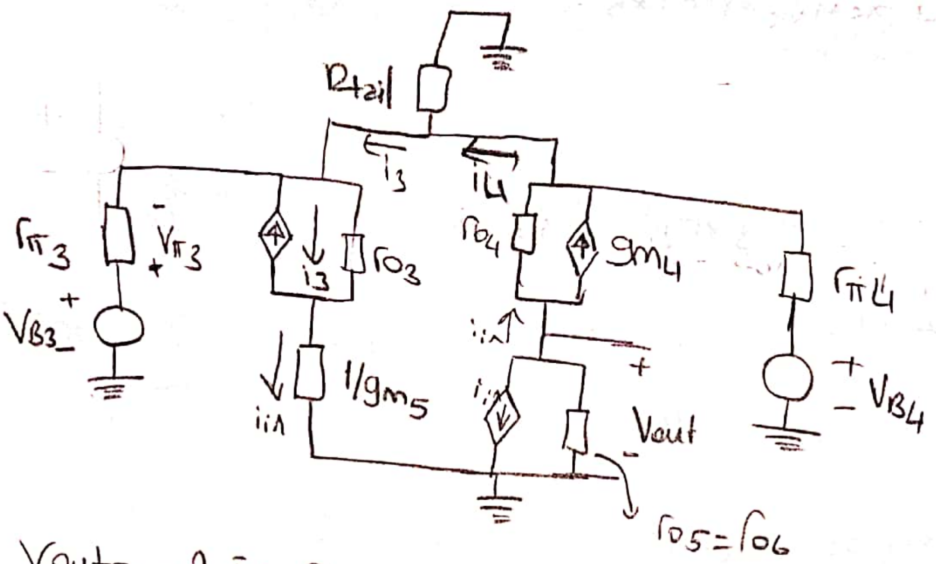
$R_{in,B1} \cong (1 + g_{m1} R_{in,B3}) r_{\pi 1}$

$R_{in,B2} \cong (1 + g_{m2} R_{in,B4}) r_{\pi 2}$

$$V_{B3} = V_{B1} \frac{R_{in,B3}}{R_{in,B3} + \frac{1}{g_{m1}}} \qquad V_{B4} = V_{B2} \frac{R_{in,B4}}{R_{in,B4} + \frac{1}{g_{m2}}}$$

$R_{in,B3} >> \frac{1}{g_{m1}}$ $\quad R_{in,B4} >> \frac{1}{g_{m2}}$ $\quad V_{B3} \approx V_{B1} \cdot 1$ $\quad V_{B4} \approx V_{B2}$

Differential Mode in small signal.



$V_{out} = -2\, i_{in}\, r_{o5}$

$i_4 = i_3 + i_{tail}$

$V_P = i_{tail} \cdot R_{tail} = (i_4 - i_3) R_{tail}$

$i_4 = i_3 + i_{tail}$

$$-i_3 + i_{o3} - g_{m3} V_{\pi 3} + \frac{(i_4 - i_3) R_{tail} - V_{B3}}{r_{\pi 3}} = 0$$

$V_{\pi 3} = V_{B3} - (i_4 - i_3) R_{tail}$

$i_{in} + g_{m3} V_{\pi 3} - i_{o3} = 0 \quad , \quad -i_{in} + i_{o4} + g_{m4} V_{\pi 4} = 0$

$$i_4 - i_{o4} - g_{m4} V_{\pi 4} + \frac{(i_4 - i_3) R_{tail} - V_{B4}}{r_{\pi 4}} = 0$$

$V_{\pi 4} = V_{B4} - (i_4 - i_3) R_{tail}$

$V_{B3} - V_{\pi 3} = V_{B4} - V_{\pi 4} \;,\quad V_{B3} - V_{B4} = V_{\pi 3} - V_{\pi 4}$

$i_{o3} r_{o3} + i_{in} \cdot \frac{1}{g_{m5}} + 2 i_{in} r_{o5} + i_{o4} r_{o4} = 0 \quad eq.1$

$i_{o3} = i_{in} + g_{m3} V_{\pi 3} \;,\quad i_{o4} = i_{in} - g_{m4} V_{\pi 4} \longrightarrow$ bu iki eşitlik eq.1'de yerine yazılırsa

$$\boxed{(i_{in} + g_{m3} V_{\pi 3}) r_{o3} + i_{in} \frac{1}{g_{m5}} + 2 i_{in} r_{o5} + (i_{in} - g_{m4} V_{\pi 4}) r_{o4} = 0}$$

eq.2

$r_{o3} = r_{o4}$ ve $g_{m3} = g_{m4}$

eşitlikleri eq.2'de yerine yazılırsa

$$(i_{in}+g_{m3}V_{\pi3})r_{o3}+i_{in}\cdot\frac{1}{g_{m5}}+2i_{in}r_{o5}+(i_{in}-g_{m4}V_{\pi4})r_{o4}=0$$

$r_{o3}=r_{o4}$, $g_{m3}=g_{m4}$

$$2i_{in}r_{o3}+2i_{in}r_{o5}+g_m r_{o3}V_{\pi3}-g_{m3}r_{o3}V_{\pi4}+i_{in}\frac{1}{g_{m5}}=0$$

$$=2i_{in}r_{o3}+2i_{in}r_{o5}+g_{m3}r_{o3}\underbrace{(V_{\pi3}-V_{\pi4})}_{V_{B3}-V_{B4}}+\cancel{i_{in}\frac{1}{g_{m5}}}^{\,0}$$

$\frac{1}{g_{m5}} \ll r_{o3}$

$$=2i_{in}(r_{o3}+r_{o5})+g_{m3}r_{o3}(V_{B3}-V_{B4})\quad,\quad \underline{-2i_{in}.r_{o5}=V_{out}}$$

$$=2i_{in}\cdot\frac{-2i_{in}r_{o5}}{-2i_{in}r_{o5}}\cdot(r_{o3}+r_{o5})=-g_{m3}r_{o3}(V_{B3}-V_{B4})$$

$$=-2i_{in}r_{o5}\left(\frac{r_{o3}+r_{o5}}{-r_{o5}}\right)=V_{out}\cdot\left(\frac{-(r_{o3}+r_{o5})}{r_{o5}}\right)=-g_{m3}r_{o3}(V_{B3}-V_{B4})$$

$$=\frac{V_{out}}{V_{B3}-V_{B4}}=g_{m3}.r_{o3}.\frac{1}{\left(\frac{r_{o3}+r_{o5}}{r_{o5}}\right)}\Rightarrow\frac{g_{m3}.r_{o3}.r_{o5}}{r_{o3}+r_{o5}}$$

$$\frac{V_{out}}{V_{B3}-V_{B4}}=g_{m3}\cdot\left(\underbrace{\frac{1}{\frac{1}{r_{o3}}+\frac{1}{r_{o5}}}}_{r_{o3}\|r_{o5}}\right)\rightarrow\frac{V_{out}}{V_{B3}-V_{B4}}=\underbrace{g_{m3}\cdot(r_{o3}\|r_{o5})}_{\text{differential mode gain}}$$

common mode gain $V_{B3}=V_{B4}$ ise $V_{out}=0$ olduğundan $A_c=0$

$$\text{CMRR}=\left|\frac{A_d}{A_c}\right|=\frac{g_{m3}(r_{o3}\|r_{o5})}{0}\cong+\infty$$

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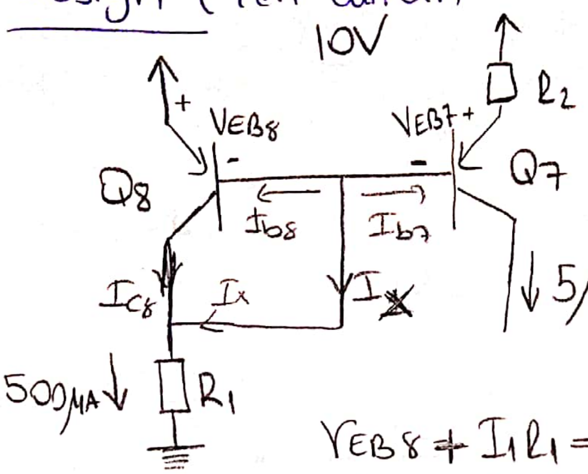
Design (Tail Current)



$I_B \approx 0$

$V_{EB8} + I_1 R_1 = V_{cc} \rightarrow$ eq.3

$-V_{EB8} + V_{EB7} + I_Q R_2 = 0 \rightarrow$ eq.4

$I_1 = I_s \cdot \exp\left(\frac{V_{EB8}}{V_T}\right) \rightarrow$ eq.5

$I_Q = I_s \exp\left(\frac{V_{EB7}}{V_T}\right) \rightarrow$ eq.6

$V_T = 26mV$

$V_{cc} = 10V$

$I_1 = 500\mu A$

$I_Q = 5\mu A$

$$\boxed{\begin{aligned} & V_{EB8} + 500\times10^{-6} R_1 = 10 \rightarrow \text{eq.3} \\ & -V_{EB8} + V_{EB7} + 5\times10^{-6} \cdot R_2 = 0 \\ & 500\times10^{-6} = I_S \cdot \exp\left(\frac{V_{EB8}}{26\times10^{-3}}\right) \\ & 5\times10^{-6} = I_S \cdot \exp\left(\frac{V_{EB7}}{26\times10^{-3}}\right) \end{aligned}}$$

I_{C8}

$I_s = 10^{-13} - 10^{-14} A \rightarrow$ tipik değer.

$I_s = 10^{-13} A$ için

$$\frac{5\times10^{-6}}{10^{-13}} = \exp\left(\frac{V_{EB7}}{26\times10^{-3}}\right) \text{eq6} \rightarrow \underbrace{\ln\left(\frac{5\times10^{-6}}{10^{-13}}\right)}_{17.727} = \frac{V_{EB7}}{26\times10^{-3}}$$

$$17.727 = \frac{V_{EB7}}{26\times10^{-3}}$$

$$\text{eq5} \Rightarrow 500\times10^{-6} = 10^{-13} \exp\left(\frac{V_{EB8}}{26\times10^{-3}}\right)$$

$$\ln(5\times10^{9}) = \frac{V_{EB8}}{26\times10^{-3}} \rightarrow \boxed{V_{EB8} = 0.580V}$$

$$\boxed{V_{EB7} = 0.460V}$$

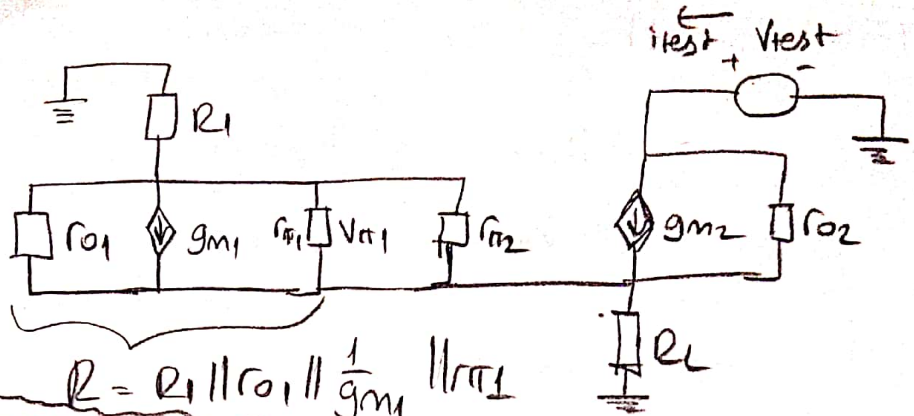
$$\text{eq.4} \rightarrow -0.580V + 0.460V + 5.10^{-6} \cdot R_2 = 0 \rightarrow 5\times10^{-6} \cdot R_2 = 0.1206$$

$$\boxed{R_2 = 24.130k\Omega}$$

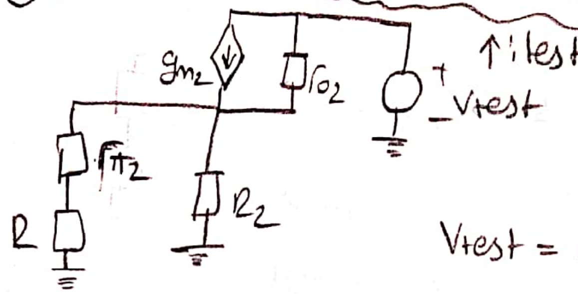
$$\text{eq3} \rightarrow 0.580 + 500\times10^{-6} \cdot R_1 = 10$$

$$\boxed{R_1 = 18.840k\Omega}$$

R_{tail} için



$$R = R_1 \| r_{o1} \| \frac{1}{g_{m1}} \| r_{\pi 1}$$



$$-V_{\pi 2} = i_{test}\,\frac{R_2}{R_2+r_{\pi 2}+R}\cdot r_{\pi 2}$$

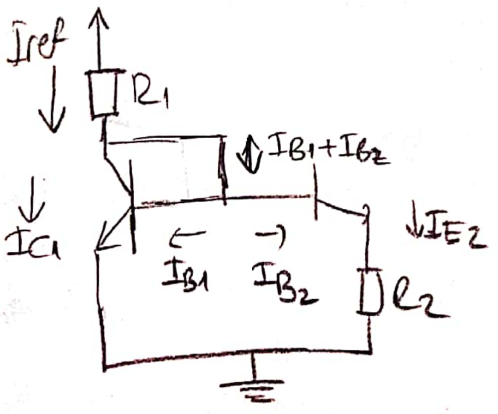
$$V_{test} = (i_t - g_{m2}V_{\pi 2})\,r_{o2} + i_{test}\cdot\frac{R_2(R+r_{\pi 2})}{R_2+r_{\pi 2}+R}$$

$$R_{out} = \frac{V_{test}}{i_{test}} = r_{o2} + g_{m2}r_{o2}\,\frac{R_2 r_{\pi 2}}{R_2+r_{\pi 2}+R} + \underbrace{\frac{R_2(R+r_{\pi 2})}{R_2+r_{\pi 2}+R}}$$

$$\frac{R_2 . r_{\pi 2}}{R_2+r_{\pi 2}+R} + \frac{R_2 . R}{R_2+r_{\pi 2}+R}$$

$$\boxed{R_{out} = r_{o2} + (g_{m2}r_{o2}+1)\,\frac{R_2 . r_{\pi 2}}{R_2+r_{\pi 2}+R} + \frac{R_2 . R}{R_2+r_{\pi 2}+R}}$$

Large signal analysis



$$I_{ref} = \underbrace{I_{C1}}_{\beta I_{B1}} + I_{B1} + I_{B2} \rightarrow \boxed{I_{ref} = I_{B1}(\beta+1) + I_{B2}}$$

$$I_{ref} = \frac{V_{cc} - V_{BE1}}{R_1} = \frac{V_{cc} - V_T \ln \frac{I_{C1}}{I_S}}{R_1}$$

$$\boxed{I_{ref} = I_{B1}.(\beta+1) + I_{B2} = \frac{V_{cc} - V_T \ln\left(\frac{I_{C1}}{I_S}\right)}{R_1}} \rightarrow \text{eq.7}$$

$$I_{C1} = I_S \exp\left(\frac{V_{BE1}}{V_T}\right) \qquad I_{C2} = I_o = I_S \exp\left(\frac{V_{BE2}}{V_T}\right) = \beta I_{B2}$$

$$V_{BE1} = V_{B2} + (\beta+1).I_{B2}.R_2$$

$$V_T \ln \frac{I_{C1}}{I_{C2}} = \boxed{(\beta+1).I_{B2}R_2 = V_T \ln\left(\frac{I_{B1}}{I_{B2}}\right)} \rightarrow \text{eq.8}$$

eq.7 ve eq. 8 kullanılarak

$$I_{B1}(\beta+1)+I_{B2}=\frac{V_{CC}-V_T\ln\left(\frac{I_{C1}}{I_S}\right)}{R_1}$$

$\rightarrow 10^{-15}$ ve 10^{-12} arası

I_S tipik değer $10^{-13}A$

$V_T=26mV$

$V_{CC}=10V$

$\beta=100$

$R_1=18.840k\Omega$

$R_2=24.130k\Omega$

$$I_{B1}.101+I_{B2}=\frac{10-26\times10^{-3}\ln\left(\frac{100I_{B1}}{I_S}\right)}{18.840k\Omega}$$

$$101I_{B1}+\frac{26\times10^{-3}}{18.840k\Omega}.\ln\left(10^{11}I_{B1}\right)+I_{B2}=\frac{10}{18.840k\Omega}$$

eq.8 $\rightarrow$ $101I_{B2}.R_2=26\times10^{-3}\ln\left(\frac{I_{B1}}{I_{B2}}\right)$

$$101I_{B2}.24.130k\Omega=26\times10^{-3}\ln\left(\frac{I_{B1}}{I_{B2}}\right)$$

$$93.735\times10^{6}I_{B2}=\ln\left(\frac{I_{B1}}{I_{B2}}\right)$$

$$\boxed{I_{B1}=I_{B2}.e^{93.735\times10^{6}.I_{B2}}}\ \text{eq.9}$$

eq.7'de yerine yazalım.

$$101.I_{B2}.e^{\underbrace{93.735\times10^{6}}_{x}I_{B2}}+\frac{26\times10^{-3}}{18.840k\Omega}.\ln\left(10^{11}.I_{B2}.e^{93.735\times10^{6}I_{B2}}\right)+I_{B2}=\frac{10}{18.840k\Omega}$$

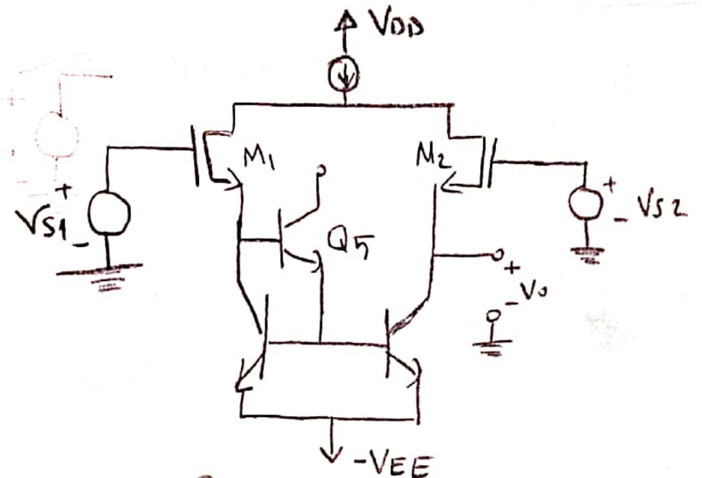
$$\ln(10^{11}.I_{B2})+\ln(e^{\cdots})$$

$$101I_{B2}e^{x.I_{B2}}+\frac{26\times10^{-3}}{18.840k\Omega}\left(\ln(10^{11}I_{B2})+x.I_{B2}\right)+I_{B2}=\frac{10}{18.840k\Omega}$$

$$I_{B2}(101e^{xI_{B2}}+1)+\frac{26\times10^{-3}}{18.840k\Omega}.\ln\left(10^{11}I_{B2}\right)+\frac{26\times10^{-3}}{18.840k\Omega}.xI_{B2}=\frac{10}{18.840k\Omega}$$

x bir sbt olduğundan I_2 burdan bulunur. eq.9'da yerine yazılarak I_{B1} ve I_{B2} bulunur.

Q3: A Bi CMOS amplifier is shown in fig P9.47. The PMOS parameters are $V_t=-3V$ and $V_{GS}=-6V$ at $I_D=1mA$. The BJT Parameters are $\beta_F(npn)=100$ $\beta_F(pnp)=50$ and $V_A=40V$. Assume $V_{DD}=-V_{EE}=15V$ and $I_Q=200\mu A$ $A_d=?$ $A_{cc}=?$ CMRR



$I_Q=200\mu A$ $\quad I_{D1}=I_{D2}=100\mu A$ $\quad I_{D_2}=\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_t)^2$

$$1mA=\underbrace{\frac{1}{2}\mu_p C_{ox}\frac{W}{L}}_{\beta}\underbrace{(6-|-3V|)^2}_{9}=\frac{9}{2}\mu_p C_{ox}\frac{W}{L}=1mA$$

$$\boxed{\mu_p C_{ox}\frac{W}{L}=2.22\times10^{-4}}$$

$$100\mu A=\frac{1}{2}\cdot2.22\times10^{-4}\cdot(V_{SG}-3)^2$$

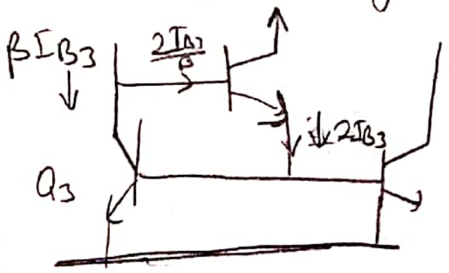
$0.900=(V_{SG}-3)^2 \rightarrow \sqrt{0.900}=|V_{SG}-3|=0.949 \rightarrow V_{SG}=3.949V$ veya

$3-V_{SG}$ $\quad V_{SG}=2.051V$

$V_{SG}>3V$ olan zorunlu

$$\boxed{V_{SG}=3.949V}$$

Small signal analysis



$$g_{m3}=g_{m4}=\frac{\beta I_{B3}}{V_T}$$

$$\boxed{r_{\pi3}=r_{\pi4}=\frac{\beta}{g_{m3}}=\frac{V_T}{I_{B3}}}$$

$$\boxed{g_{m5}=\frac{2\beta I_{B3}}{(\beta+1)V_T}}$$

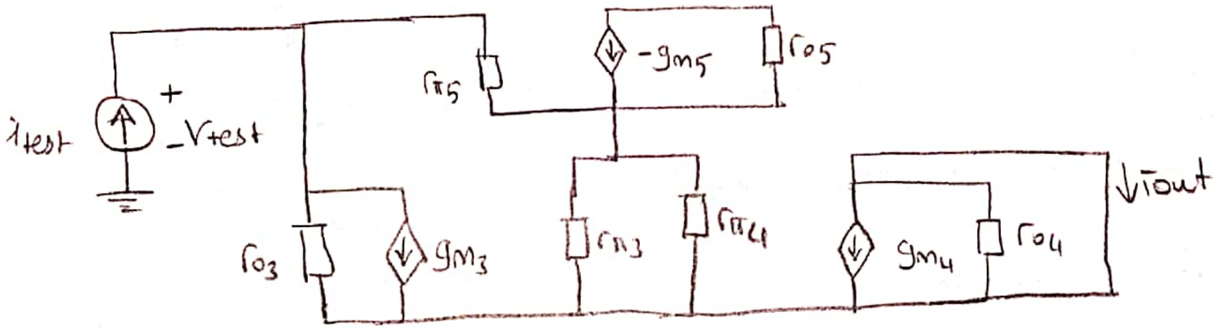
$$\boxed{r_{\pi5}=\frac{(\beta+1)V_T}{2I_{B3}}}$$

$$r_{o3}=r_{o4}=\frac{V_A}{\beta I_{B3}}$$

$$r_{o5}=\frac{(\beta+1)V_A}{2\beta I_{B3}}$$

b)

$r_{in,CA}$ A_{CA}



$$V_{test} = V_{\pi 3} + V_{\pi 5} \qquad -i_{test} + \frac{V_{test}}{r_{o3}} + g_{m3}V_{\pi 3} + \frac{V_{test} - V_{\pi 3}}{r_{\pi 5}} = 0$$

$$-g_{m5}V_{\pi 5} + \frac{V_{\pi 3}}{r_{o5}} + \frac{V_{\pi 3}}{r_{\pi 3}} + \frac{V_{\pi 3}}{r_{\pi 4}} + \frac{V_{\pi 3} - V_{test}}{r_{\pi 5}} = 0$$

$$g_{m3} \gg \frac{1}{r_{\pi 5}}$$

$$i_{test} = \frac{V_{test}}{r_o \| r_{\pi 5}} + V_{\pi 3}\left[g_{m3} - \frac{1}{r_{\pi 5}}\right]$$

tipik değer

$$i_{test} = \frac{V_{test}}{r_o \| r_{\pi 5}} + V_{\pi 3} g_{m3} = 0$$

$V_A = 100V$ $V_T = 26mV$

$\beta = 100$

$$r_{o3} = \frac{100V}{100 I_{B3}} = \frac{1}{I_{B3}}$$

$$r_{\pi 5} = \frac{100 \cdot (26mV)}{2 I_{B3}} = \frac{1.3}{I_{B3}}$$

$$\frac{V_{\pi 3}}{\frac{1}{g_{m5}} \| \cancel{r_{o5}} \| r_{\pi 3} \| r_{\pi 4} \| \cancel{r_{\pi 5}}} = \frac{V_{test}}{\frac{1}{g_{m5}} \| r_{\pi 5}} = \frac{V_{test}}{r_{\pi 5}/(1+\beta)}$$

$$\frac{1}{g_{m5}} \ll r_{o5} \qquad r_{\pi 3} \ll r_{\pi 5}$$

$$\frac{V_{\pi 3}}{\frac{1}{g_{m5}} \| \underbrace{\frac{r_{\pi 3}}{2}}} \rightarrow \frac{1}{g_{m5}} = \frac{V_T}{2 I_{B3}} \rightarrow \frac{V_{\pi 3}}{\underbrace{r_{\pi 3}/4}_{\frac{V_T}{4 I_{B3}}}} = \frac{V_{test}}{\underbrace{r_{\pi 5}/(1+\beta)}_{\frac{V_T}{2 I_{B3}}}} \qquad \boxed{2V_{\pi 3} = V_{test}}$$

$r_{\pi 3} \| r_{\pi 4}$

$r_{\pi 3} = r_{\pi 4}$

$$\frac{r_{\pi 3}}{2} = \frac{V_T}{2 I_3}$$

$$\frac{1}{g_{m5}} = \frac{r_{\pi 3}}{2}$$

... and input resistance of the amplifier

$$i_{test} = \frac{V_{test}}{r_{o3} \| r_{\pi 5}} + \frac{V_{test}}{2/g_{m3}} \qquad \frac{2}{g_{m3}} \ll r_{o3} \qquad r_{\pi 5} = \frac{2V_T}{\beta I_{B3}}$$

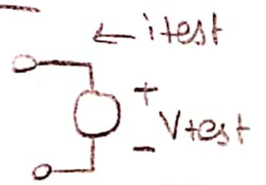
$$\frac{V_{test}}{i_{test}} \cong \frac{2}{g_{m3}} = \frac{2V_T}{\beta I_{B3}} \qquad \frac{V_{test}}{i_{test}} = \boxed{r_{in,CA} = \frac{2}{g_{m3}}}$$

A_{CA} gain

$$V_{\pi 3} = V_{\pi 4} = \frac{V_{test}}{2} \qquad g_{m4} V_{\pi 4} = -i_{out} \qquad g_{m4} \frac{V_{test}}{2} = -i_{out}$$

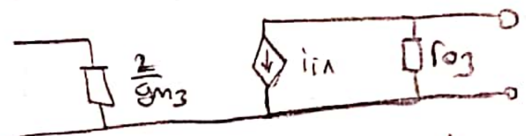
$$\frac{g_{m4}}{2} \cdot \frac{2 i_{test}}{g_{m3}} = -i_{out} \qquad \frac{i_{out}}{i_{test}} = \boxed{-1 = A_{CA}}$$

r_{out}, CA gain

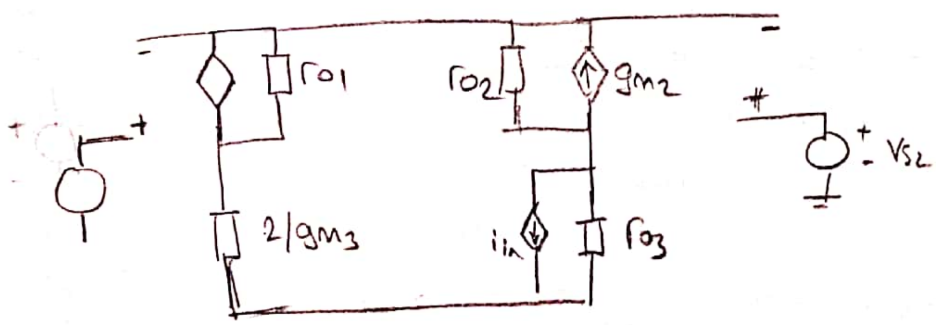


$\boxed{r_{out,CA} = r_{o4} = r_{o3}}$

$V_{test} = 0$



small signal equivalent with active load.



$$\frac{2}{g_{m3}} i_{in} + 2 i_{in} r_{o3} + (i_{in} - g_{m2} V_{gs2}) r_{o2} + (i_{in} + g_{m1} V_{gs1}) r_{o1} = 0$$

note $g_{m1} = g_{m2}$, $r_{o1} = r_{o2}$, $V_{out} = -2 i_{in} r_{o3}$

small

$$i_{in} \left[\cancel{\frac{2}{g_{m3}}} + 2r_{o3} + \underbrace{r_{o2} + r_{o1}}_{2r_{o1}} \right] + g_{m1} r_{o1} (V_{gs1} - V_{gs2}) = 0$$

$$2 i_{in} (r_{o3} + r_{o1}) = -g_{m1} r_{o1} (V_{gs1} - V_{gs2})$$

... and input resistance of the amplifier

$V_{S1} - V_{gs1} = V_{S2} - V_{gs2} \rightarrow V_{S1} - V_{S2} = V_{gs1} - V_{gs2}$

$$\left[-2 i_{in} r_{o3}\right]\left[-\frac{r_{o3}+r_{o1}}{r_{o3}}\right] = -g_m r_{o1}(V_{S1}-V_{S2})$$

$$\frac{V_{out}}{V_{S1}-V_{S2}} = g_{m1}\left[\frac{r_{o1}.r_{o3}}{r_{o1}+r_{o3}}\right] = g_{m1}\Bigg[\underbrace{\frac{1}{\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}}_{r_{o1}\|r_{o3}}\Bigg] = g_{m1}(r_{o1}\|r_{o3})$$

common mode için

$V_{S1} = V_{S2} \rightarrow V_{out} = 0 \quad A_C = 0$

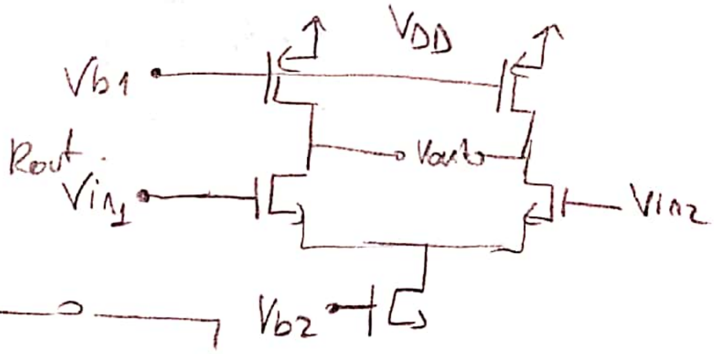
$$CMRR = \left|\frac{A_d}{A_c}\right| = \frac{g_{m1}(r_{o1}\|r_{o3})}{0} \approx +\infty \approx CMRR$$

Q4. Calculate the common mode gain of the circuit depicted in Fig 10.87. Assume $\lambda \neq 0$, $g_m r_o \gg 1$, and use the relationship $A_d = -G_m R_{out}$

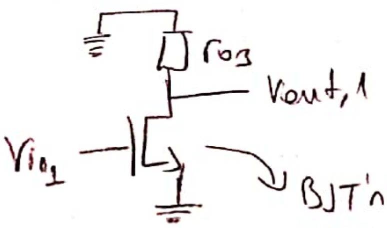
$M_5 \rightarrow$ current source

$R_{out,CS}$ = current source için

$R_{out,CS} = r_{o5}$



Differential Mode

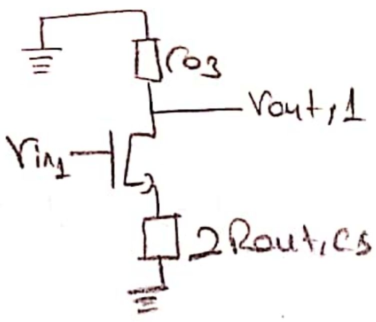


BJT'nin small signal'i ile değişmeli

$$\frac{V_{out,1}}{V_{in,1}} = -g_{m1}(r_{o1}\|r_{o3})$$

$$A_d = \frac{V_{out,1} - V_{out2}}{V_{in,1} - V_{in2}} = -g_{m1}(r_{o1}\|r_{o3})$$

Common mode



$$A_C = \frac{V_{out,1}}{V_{in,1}} = \frac{-g_{m1}}{1+g_{m1}\cdot 2R_{out,CS}} \cdot \left[r_{o3} \,||\, R_{out,TCA}\right]$$

$$r_{out,TCA} = (1+g_{m1}r_{o1}) \cdot 2R_{out,CS} + r_{o1}$$

$$r_{o3} \ll R_{out,TCA}$$

$$A_C = \frac{-g_{m1}}{1+g_{m1}\cdot 2R_{out,CS}} \cdot \underbrace{\left[r_{o3} \,||\, R_{out,TCA}\right]}_{\approx r_{o3}} = \frac{-g_{m1}\cdot r_{o3}}{1+g_{m1}\cdot 2R_{out,CS}}$$

$$CMRR = \left|\frac{A_d}{A_C}\right| = \frac{\cancel{-g_{m1}} \dfrac{r_{o1}\cdot \cancel{r_{o3}}}{r_{o1}+r_{o3}}}{\dfrac{\cancel{-g_{m1}\cdot r_{o3}}}{1+g_{m1}\cdot 2R_{out,CS}}} = \boxed{\frac{r_{o1}\cdot(1+g_{m1}\cdot 2R_{out,CS})}{r_{o1}+r_{o3}}}$$

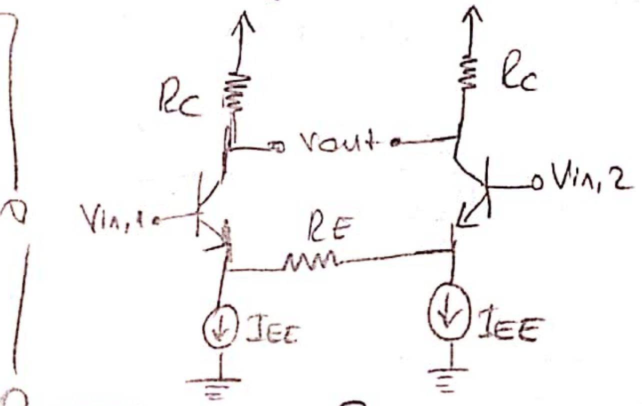
Q5. The differential pair depicted in Fig 10.95 must provide a gain of 5 and a power budget of 4 mW. Moreover, the gain of the circuit must change by less than 2% if the collector current of either transistor changes by 10%. Assuming $V_{CC} = 2.5V$ and $r_A = \infty$, design the circuit. (Hint: 10% change in I_C leads to a 10% change in g_m)

$V_{in,1} = V_{in,2}$ (DC değerleri)

R_E üzerinden akım akmaz.

$V_{E1} = V_{E2}$ olmalı bu yüzden

$V_{B1} = V_{B2}$



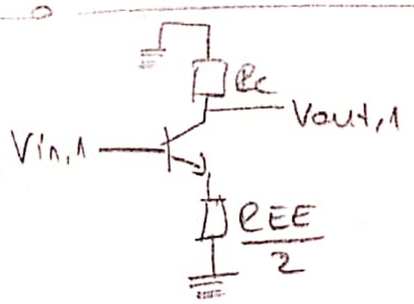
$V_{CC} \cdot 2I_{EE} = \text{DC Power}$

$2.5 \cdot 2 I_{EE} < 4mW$

$I_{EE} < \frac{4}{5} mA = 0.8mA$

$\boxed{I_{EE} < 0.8mA}$

Differential mode half circuit



$$A_d = \frac{V_{out,1}}{V_{in,1}} = \frac{-g_{m1}}{1 + g_{m1}\frac{R_{EE}}{2}} \cdot R_C$$

$$g_{m1} = \frac{I_{C1}}{V_T} = \frac{I_{EE}}{25mV}$$

$$A_d = 5 = \left| \frac{-\frac{I_{C1}}{V_T} \cdot R_C}{1 + \frac{I_{C1}}{V_T} \cdot \frac{R_{EE}}{2}} \right|$$

$\left|\frac{\Delta I_D}{I_D}\right| < \%2$ olmalı

$\left|\frac{\Delta I_C}{I_C}\right| = \%10$ iken

$$= \left| \frac{\Delta I_D}{I_D} \cdot \frac{I_C}{\Delta I_C} \right| < \frac{2}{10} \rightarrow \boxed{\left| \frac{\Delta I_D}{\Delta I_C} \cdot \frac{I_C}{I_D} \right| < \frac{1}{5}} \rightarrow$$

$$\boxed{A_d = \frac{-2I_C \cdot R_C}{2V_T + I_C \cdot R_{EE}}}$$

$$\frac{\partial A_d}{\partial I_C} = -R_C \left[\frac{2 \cdot (2V_T + I_{C1} R_{EE}) - R_{EE}(2I_{C1})}{(2V_T + I_{C1} R_{EE})^2} \right]$$

$$\frac{\partial A_d}{\partial I_{c1}} = -R_c \left[\frac{4V_T + \cancel{2I_c R_{EE}} - \cancel{R_{EE} 2I_{c1}}}{(2V_T + I_{c1} R_{EE})^2} \right] = \frac{-R_c . 4V_T}{(2V_T + I_{c1} R_{EE})^2}$$

$$\frac{\partial A_d}{\partial I_{c1}} \cdot \frac{I_{c1}}{A_d} = \frac{-R_c . 4V_T}{(2V_T + I_{c1} R_{EE})^2} \cdot \left(\frac{\cancel{I_{c1}}}{\frac{-R_c . 2\cancel{I_{c1}}}{2V_T + I_{c1} . R_{EE}}} \right)$$

$$= \frac{-R_c . 4V_T}{(2V_T + I_{c1} . R_{EE})^{\cancel{2}}} \cdot \frac{(\cancel{2V_T + I_{c1} . R_{EE}})}{-R_c} = \boxed{\frac{4V_T}{2V_T + I_{c1} . R_{EE}}} = \frac{\partial A_d}{\partial I_{c1}} \cdot \frac{I_{c1}}{A_d}$$

$$\left| \frac{\partial A_d}{\partial I_{c1}} \cdot \frac{I_{c1}}{A_d} \right| = \left| \frac{4V_T}{2V_T + I_{c1} R_{EE}} \right| < \frac{1}{5} \qquad 20V_T < 2V_T + I_c R_{EE}$$

$$18 \underbrace{V_T}_{26mV} < \underbrace{I_{c1}}_{\approx I_{EE}} R_{EE}$$

$$\Rightarrow \boxed{468 mV < I_{EE} R_{EE}}$$

$I_{EE} < 0.8 mA$ $\qquad 468 mV < I_{EE} R_{EE}$

$$|A_d| = \frac{2 I_{EE} . R_c}{2V_T + I_{EE} R_{EE}} = 5$$

$I_{EE} = 0.6 mA$ ise

$468 mV < 0.6 mA . R_{EE}$

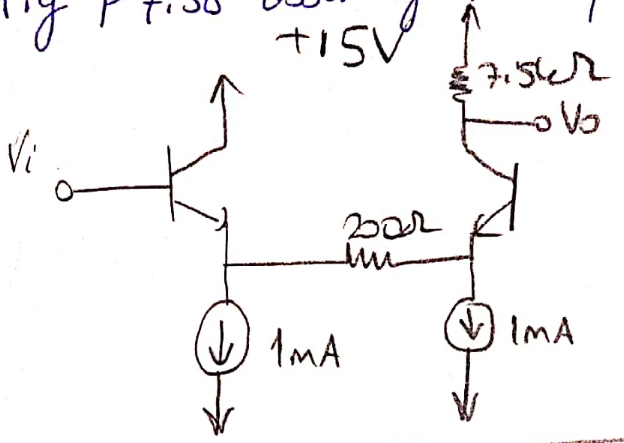
$780 \Omega < R_{EE}$

$R_{EE} = 800 \Omega$ seçilebilir.

$$|A_d| = \frac{2 . (0.6 \times 10^{-3}) R_c}{2 . 26 \times 10^{-3} + (0.6 \times 10^{-3}) . 800} = 5$$

$$= \frac{1.2 R_c \times 10^{-3}}{0.532} = 5 \longrightarrow \boxed{R_c = 2.216 k\Omega}$$

Q6. Find the voltage gain and input resistance of the amplifier in fig P7.38 assuming that $\beta = 100$



DC biasing

Q_1 ve Q_2 $V_i = 0$ ise denge durumunda

$V_i = 0V$ ise (DC için)

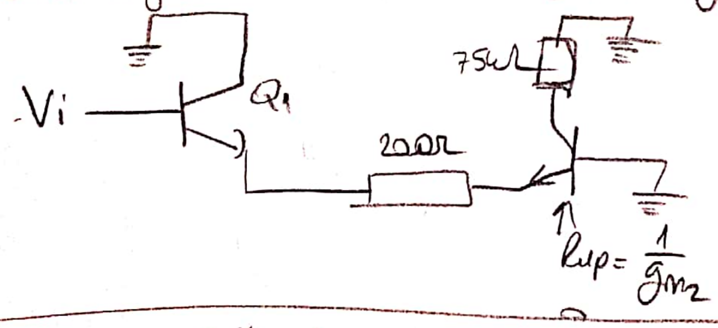
$I_{C1} = I_{C2} = 1mA$

$$g_m = \frac{I_{C1}}{V_T} = \frac{1mA}{26mV} = 0.038 = g_{m1} \cong g_{m2}$$

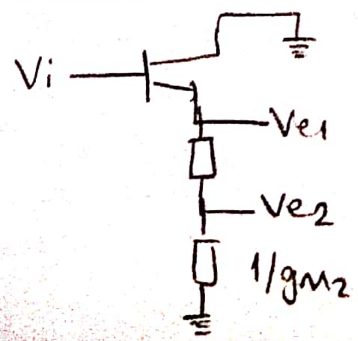
$$r_{\pi 1} \cong r_{\pi 2} = \frac{\beta}{g_{m1}} = \frac{100}{0.038} = 2.6315k\Omega$$

small signal

small signalde kaskatlanmış yapı görürüz common kollektör ve common base



Common Collector



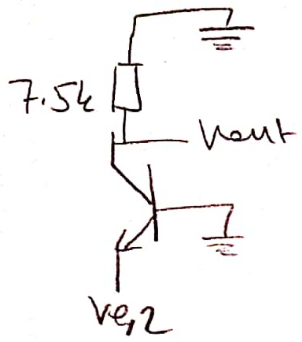
$$\frac{V_{e1}}{V_i} \approx \frac{200\Omega + 1/g_{m2}}{200\Omega + \frac{1}{g_{m2}} + \frac{1}{g_{m1}}} < 1$$

$$\frac{V_{e2}}{V_{e1}} = \frac{1/g_{m2}}{200\Omega + 1/g_{m2}}$$

$$\boxed{\frac{V_{e2}}{V_i} = \frac{V_{e2}}{V_{e1}} \cdot \frac{V_{e1}}{V_i} = \frac{1/g_{m2}}{200 + 1/g_{m2} + 1/g_{m1}}}$$

eq.10

Common Base



$$\frac{V_{out}}{V_{e2}} = g_{m2} \cdot 7.5k\Omega$$

$$\frac{V_e}{V_i} = \frac{1/g_{m2}}{200 + \frac{1}{g_{m2}} + \frac{1}{g_{m1}}} \rightarrow eq.10$$

$$\boxed{\frac{V_{out}}{V_i} = \frac{V_{out}}{\cancel{V_{e2}}} \cdot \frac{\cancel{V_{e2}}}{V_i} = \frac{1 \cdot 7.5k\Omega}{200 + \frac{1}{g_{m2}} + \frac{1}{g_{m1}}}} = \frac{7.5k\Omega}{200+25+25} =$$

$$= \frac{7500}{250} = \underline{\underline{30}}$$

$$\frac{1}{\frac{1mA}{25mV}} = 25\Omega$$

$$\beta \cdot 25 = 100 \cdot 25 = 2500$$

$$R_i = \left[1 + g_{m1}\left[200 + \overset{25}{\frac{1}{g_{m2}}}\right]\right] r_{\pi 1}$$

$$= R_i = \left[1 + \left(g_{m1} \cdot 200 + 1\right)\right] r_{\pi 1} = \underbrace{2 r_{\pi 1}}_{5k\Omega} + \underbrace{200 g_{m1} \cdot r_{\pi 1}}_{\beta \,\approx\, 20k\Omega}$$

$\boxed{R_i = 25k\Omega}$ bulunur