HW.2

Q1. The circuit of fig 10.68 must provide a gain of 50 with $R_1 = R_2 = 5k\Omega$ If $V_{A,N} = 5V$ and $V_{A,P} = 4V$ calculate the required tail current

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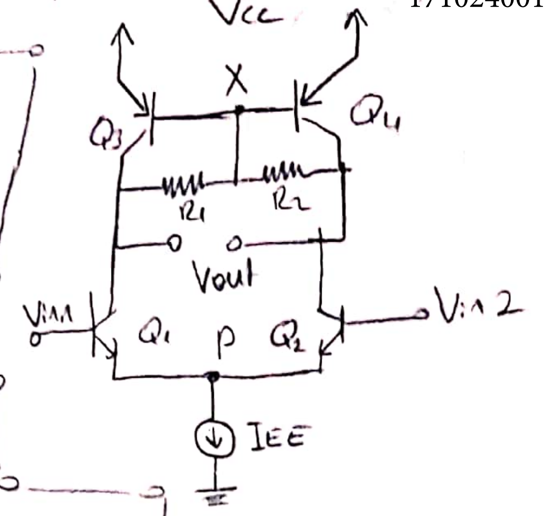
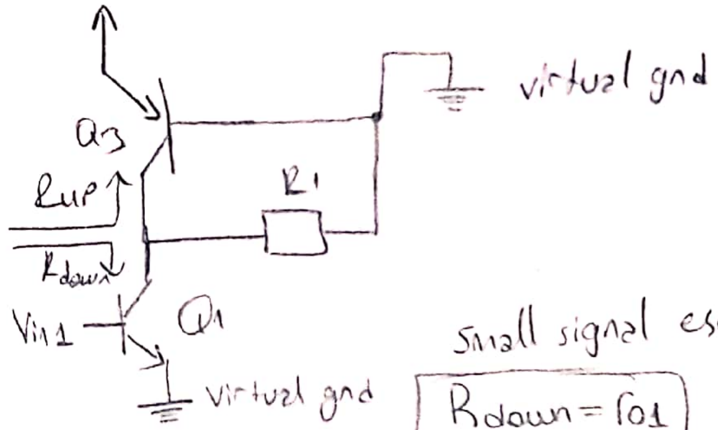


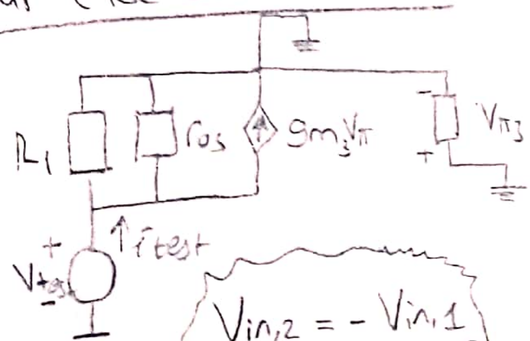
P, X = Virtual gnd- node'u için
Differential mode half circuit çizilecek olursa;



Small signal eşdeğer devresinde Rup ve Rdown görülür.

$\boxed{R_{down} = r_{o1}}$

Rup elde etmek için:



$$R_{up} = \frac{V_{test}}{I_{test}} = R_1 \,||\, r_{o3}$$

$V_{\pi 3} = 0$

$V_{in,2} = -V_{in,1}$

$$\frac{V_{out1}}{V_{in1}} = -g_{m1}\left[R_1 \,||\, r_{o3} \,||\, r_{o1}\right]$$

↳ Common emitter configuration

$$\frac{V_{out,2}}{V_{in2}} = \frac{V_{out}}{V_{in,1} - V_{in,2}} = -\frac{V_{out,2} - V_{out1}}{V_{in,2} - V_{in,1}} = -g_{m1}\left[R_1 \,||\, r_{o3} \,||\, r_{o1}\right]$$

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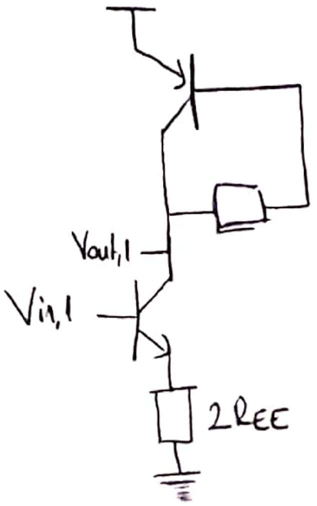
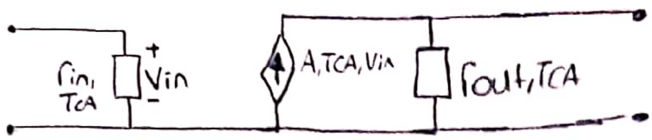
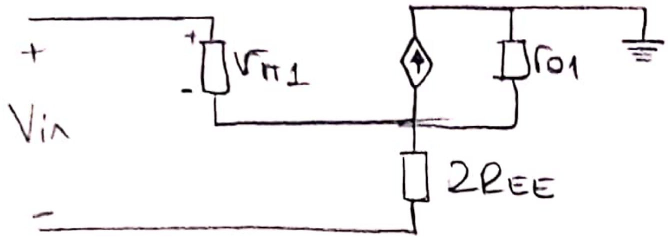
Common mode half circuit model çizilirse



REE: Akım kaynağı için çıkış empedansı



short the output, compute $\frac{i_{out}}{V_{in}}$



$$-\frac{V_{\pi,1}}{r_{\pi1}} + \frac{V_{in}-V_{\pi1}}{R_E} - g_m V_{\pi1} + \frac{V_{in}-V_{\pi1}}{r_{o1}} = 0$$

$$i_{out} - \frac{V_{in}-V_{\pi1}}{r_{o1}} + g_{m1} V_{\pi1} = 0$$

$$\frac{V_{in}}{R_E \| r_{o1}} = \frac{V_\pi}{r_\pi \| R_E \| \frac{1}{g_m} \| r_{o1}}$$

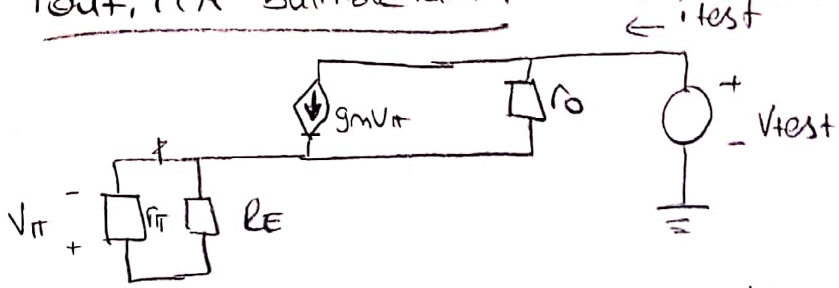
$$i_{out} + \frac{V_{\pi1}}{r_{o1} \| \frac{1}{g_m}} = \frac{V_{in}}{r_{o1}} \longrightarrow V_{\pi1} = V_{in} \frac{\frac{1}{g_{m1}} \| R_E}{R_E} \rightarrow V_{in} = \frac{V_{\pi1}}{\frac{1/g_{m1} \| R_E}{R_E}}$$

$$i_{out} + \frac{V_{\pi1}}{1/g_{m1}} = 0 \rightarrow \boxed{i_{out} = \frac{-V_{\pi1}}{1/g_{m1}}}$$

$$A_{TCA} = \frac{i_{out}}{V_{in}} = \frac{\frac{-\cancel{V_{\pi1}}}{1/g_{m1}}}{\frac{\cancel{V_{\pi1}}}{\frac{1/g_{m1} \| R_E}{R_E}}} = -\frac{R_E}{\frac{1}{g_{m1}} \cdot \underbrace{\frac{1}{g_{m1}} \| R_E}} = \frac{-g_{m1} \cdot R_E}{\frac{\frac{1}{g_{m1}} \cdot R_E}{\frac{1}{g_{m1}} + R_E}}$$

$$A_{TCA} = \frac{-g_{m1}}{\frac{1/\cancel{g_{m1}}}{\frac{1+g_{m1}R_E}{\cancel{g_{m1}}}}} = \boxed{\frac{-g_{m1}}{1+g_m R_E} = A_{TCA}}$$ ★

$r_{out,TCA}$ bulmak için :



$$(i_{test} - g_{m1} V_{\pi 1}) r_{o1} + \underbrace{i_{test} (r_{\pi 1} \| R_E)}_{-V_\pi} = V_{test}$$

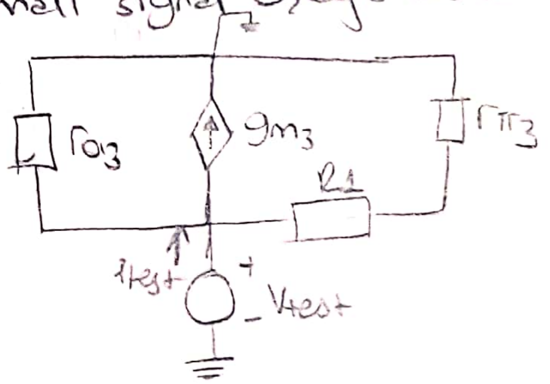
$$i_{test} \left[r_{o1} (1 + g_{m1} (r_{\pi 1} \| R_E)) + (r_{\pi 1} \| R_E) \right] = V_{test}$$

$$\frac{V_{test}}{i_{test}} \cong \boxed{r_{o1}(1 + g_{m1} R_E) = r_{out,TCA}} \text{ eq. 3}$$

$r_{\pi 1} >> R_E$

$r_{\pi 1} \| R_E << r_o (1 + g_{m1} R_E)$

R_{up} için devrenin üst kısım small signal eşdeğer devresi çizilirse.



$$-i_{test} + \frac{V_{test}}{r_{o3}} + g_{m3} V_{\pi 3} + \frac{V_{test}}{R_1 + r_{\pi 3}} = 0$$

$$\boxed{V_{\pi 3} = V_{test} \frac{r_{\pi 3}}{R_1 + r_{\pi 3}}}$$

$$-i_{test} + \frac{V_{test}}{r_{o3} \| \frac{R_1 + r_{\pi 3}}{1 + \beta_3}} = 0$$

$$\boxed{R_{up} = \frac{V_{test}}{i_{test}}}$$

$$\frac{V_{test}}{r_{o3} \| \frac{R_1 + r_{\pi 3}}{1 + g_{m3} r_{\pi 3}}} = i_{test} \rightarrow \boxed{\frac{V_{test}}{i_{test}} = r_{o3} \| \frac{R_1 + r_{\pi 3}}{1 + g_{m3} r_{\pi 3}}}$$

$$\boxed{R_{up} = r_{o3} \| \frac{R_1 + r_{\pi 3}}{1 + g_{m3} r_{\pi 3}}}$$

$$\boxed{R_{up} = r_{o3} \parallel \frac{R_1 + r_{\pi 3}}{1 + g_{m3} r_{\pi 3}}}$$

$$\boxed{A_{TCA} = \frac{-g_{m1}}{1 + g_{m1} R_E}}$$

$$\boxed{r_{out,TCA} = r_{o1}(1 + g_{m1} R_E)}$$

Common mode gain $= \frac{V_{out,1}}{V_{in,1}}$

$$\frac{V_{out,1}}{V_{in,1}} = A_{TCA}\left[r_{out,TCA} \parallel R_{up} \right]$$

$$= \frac{-g_{m1}}{1 + g_{m1} R_E} \left[\underbrace{r_{o1}(1 + g_{m1} R_E) \parallel \left(r_{o3} \parallel \frac{R_1 + r_{\pi 3}}{1 + g_{m3} r_{\pi 3}} \right)} \right]$$

$$\frac{1}{r_{o1}(1 + g_{m1} R_E)} + \cancel{\frac{1}{r_{o3}}}^{\,0} + \frac{1}{\frac{R_1 + r_{\pi 3}}{1 + g_{m3} r_{\pi 3}}}$$

$1 + g_{m1} R_E \gg$ $\quad$ $r_{o3} \gg$

$$\frac{V_{out,1}}{V_{in,1}} = \frac{-g_{m1}}{1 + g_{m1} R_E} \cdot \left(\frac{1}{\frac{R_1 + r_{\pi 3}}{1 + g_{m3} r_{\pi 3}}} \right) = \frac{-g_{m1}}{1 + g_{m1} R_E} \cdot \left(\frac{1 + g_{m3} r_{\pi 3}}{R_1 + r_{\pi 3}} \right)$$

$$CMRR = \frac{\text{Differential mode gain}}{\text{Common mode gain}} = \frac{V_{out,1}/V_{in,1}}{V_{out,1}/V_{in,1}} = \frac{-g_{m1}\left[R_1 \parallel r_{o3} \parallel r_{o1} \right]}{\frac{g_{m1}}{1 + g_{m1} 2R_{EE}} \cdot \frac{1}{\frac{R_1 + r_{\pi 3}}{1 + g_{m3} r_{\pi 3}}}}$$

$r_{o3} \gg R_1 \quad r_{o1} \gg R_1$

$$\boxed{\frac{-R_1 \cdot (1 + g_{m} 2R_{EE}) \cdot (R_1 + r_{\pi 3})}{(1 + g_{m3} r_{\pi 3})} = CMRR}$$

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Q_3 ve Q_4'ün I_b'leri ihmal edilebilir

V_T: Termal voltaj → 26mV

I_{C1}: Q_1'in collector akımı

$$\boxed{g_{m1} = \frac{I_{C1}}{V_T}}$$

$$\boxed{I_{C1} = I_{C2} = I_{C3} = I_{C4} = \frac{I_{EE}}{2}}$$

$R_1 = 5k\Omega$

$$r_{o3} = \frac{V_{A,P}}{I_{C3}} = \frac{4}{I_{EE}/2} = \boxed{\frac{8}{I_{EE}} = r_{o3}}$$

$$\boxed{g_{m1} = \frac{I_{EE}}{2V_T} = \frac{I_{EE}}{52\times10^{-3}}}$$

$$\boxed{r_{o1} = \frac{V_{A,N}}{I_{C1}} = \frac{5}{I_{EE}/2} = \frac{10}{I_{EE}}}$$

differential mode gain (dataşeetinden kaynaklı 50)

$$50 = g_{m1}[R_1 \,||\, r_{o3} \,||\, r_{o1}]$$

$$50 = \frac{I_{EE}}{2V_T}\cdot\left[5k \,||\, \frac{8}{I_{EE}} \,||\, \frac{10}{I_{EE}}\right]$$

$$50 = \frac{I_{EE}}{2V_T}\cdot\left[\underset{(8)}{\frac{1}{5000}} + \underset{(5000)}{\frac{I_{EE}}{8}} + \underset{8.500}{\frac{I_{EE}}{10}}\right]$$

$$50 = \frac{I_{EE}}{52\times10^{-3}}\cdot\left[\frac{8 + 9000 I_{EE}}{8.5000}\right]$$

$$50 = \frac{I_{EE}}{52\times10^{-3}}\cdot\left[\frac{9000 I_{EE} + 8}{40000}\right] = \frac{9000 I_{EE}^2 + 8 I_{EE}}{208} = 50$$

$$9000 I_{EE}^2 + 8 I_{EE} = 10400$$

$$I_{EE}^2 + \frac{8}{9000} I_{EE} - \frac{10400}{9000} = 0$$

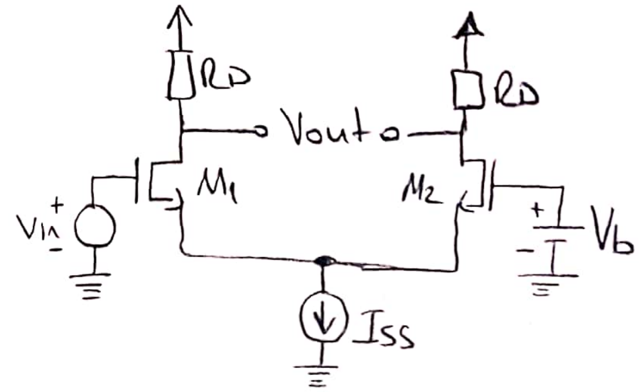
$$\frac{-b \mp \sqrt{b^2 - 4ac}}{2a} = \frac{\frac{-8}{9000} \mp \sqrt{\frac{64}{81000000} + 4.1.\frac{10400}{9000}}}{2} = \frac{\frac{-8}{9000} \mp 2.149}{2}$$

$$\boxed{I_{EE} = 1.074\ A}$$

$I_{EE} < 0$ olamaz bu yüzden ikinci kök gelmez.

5

Q2. A student has a single-ended voltage source constructs the circuits shown in Fig 10.75, hoping to obtain differential outputs. Assume perfect symmetry but $\lambda = 0$ for simplicity



(a) Viewing M_1 as a common-source stage degenerated by the impedance seen at the source of M_2, calculate v_x in terms of v_{in}.

(b) Viewing M_1 as a source follower and M_2 as a common gate stage, calculate V_y in terms of V_{in}

(c) Add the result obtained in (a) and (b) with proper polarities. If the voltage gain is defined as $(V_x - V_y)/V_{in}$, how does it compare with the gain of differentially - driven pairs?

(a) Small signal equivalent

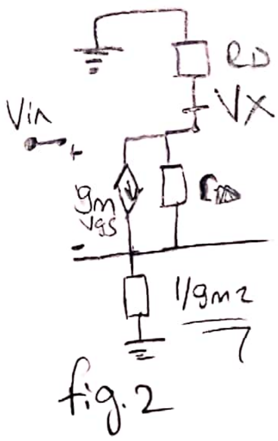


fig.2

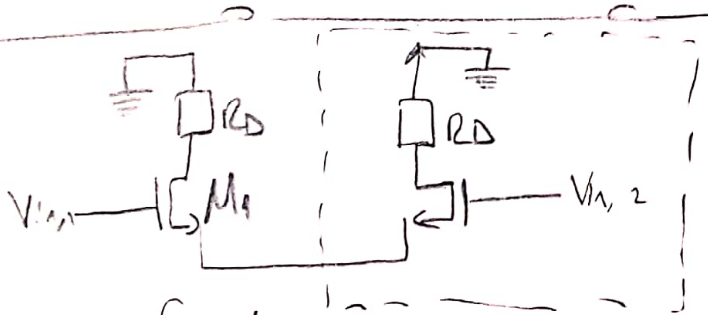


fig.1

$1/g_{m2}$ eşdeğer değerdir Devre önce fig 1'deki gibi incelenir sonrasında fig.2 elde edilir. fig.1'de taralı bölgenin small signal eşdeğer empedansı $\frac{1}{g_{m2}}$'dur. fig 2'de fig 1 devresini small signal eşdeğerinin M1 yarı devresi alınarak ve M_2 kısmı için source'a $\frac{1}{g_{m2}}$ eşdeğer empedansı entegre edilerek oluşturulmuştur.

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Q2.a.2 V_x'i V_{in} cinsinden yazabilmek için $\frac{R_d \cdot R_x}{R_d + R_x}$

$\frac{V_x}{V_{in}} = t$ t bir sbt olmak üzere t değeri bulunmalıdır.

$$\frac{V_x}{V_{in}} = t = -g_{m1} \cdot \frac{1}{1 + g_{m1}\frac{1}{g_{m2}}} \cdot \left[R_D \,//\, \underbrace{r_{out,TCA}}_{\text{hesaplanmalı}} \right]$$

$$r_{out,TCA} = (1 + \underbrace{g_{m1} r_{o1}}_{\beta_1}) \frac{1}{g_{m2}} + r_{o1}$$ $\lambda = 0$ verilmiş ve $r_{o1} = +\infty$

simetrinin korunması için $g_m = g_{m1} = g_{m2}$

$$\frac{V_x}{V_{in}} = -g_m \cdot \frac{g_m}{2g_m} \cdot \left[\frac{R_D \cdot \cancel{R_{out,TCA}}}{\underbrace{R_D + R_{out,TCA}}_{\cancel{R_{out,TCA}}}} \right]$$ $r_{o1} \to +\infty$, $r_{out,TCA} \to +\infty$

$$\boxed{\frac{V_x}{V_{in}} = \underbrace{-g_m \cdot \frac{1}{2} \cdot R_D}_{t}} \longrightarrow \boxed{V_x = \left(-g_m \cdot \frac{1}{2} \cdot R_D\right) V_{in}}$$

(b) V_y'yi V_{in} cinsinden bulabilmek için;

$\frac{V_y}{V_{in}} = t_2$, t_2 sbt

$t_2 = a_1 + a_2$ Cascade yapısı.

$a_1 \longrightarrow$ Common drain'den gelen

$a_2 \longrightarrow$ Common gate'den gelen

$$\frac{V_y}{V_{in}} = a_1 \cdot a_2$$

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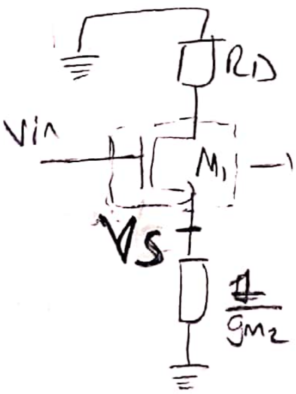
a_1 için



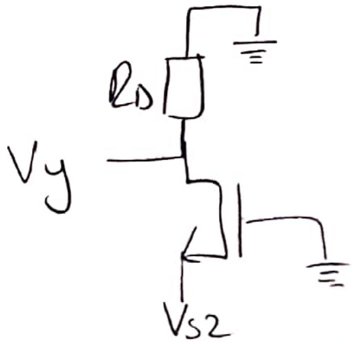
small signal eşdeğeri Fig 2'deki gibidir.

$$\frac{V_s}{V_{in}} = \frac{1/g_{m2}}{\frac{1}{g_{m2}} + \frac{1}{g_{m1}}} = \frac{\frac{1}{g_m}}{\frac{2}{g_m}} = \frac{1}{2} //$$

R_1

Q: in H

b.2 a_2 (common gate için)



$$\frac{V_y}{V_{S2}} = g_{m2}R_D = \underline{g_m R_D}$$

$$\frac{V_y}{V_{in}} = \underbrace{\frac{V_y}{V_S}}_{g_m R_D} \cdot \underbrace{\frac{V_S}{V_{in}}}_{\frac{1}{2}} = \frac{g_m R_D}{2}$$

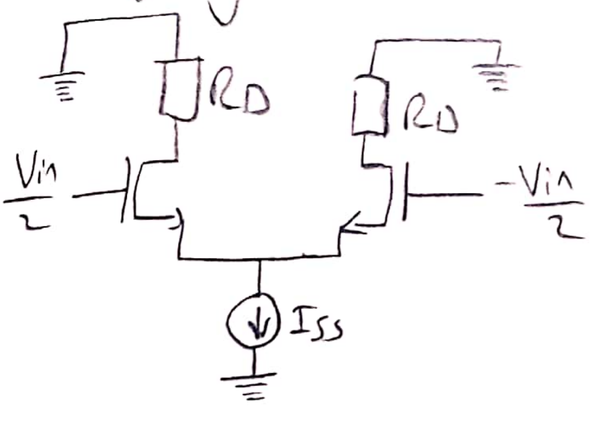
---

c $\dfrac{V_x}{V_{in}} = \dfrac{-g_m R_D}{2}$ $\qquad \dfrac{V_y}{V_{in}} = \dfrac{g_m R_D}{2}$

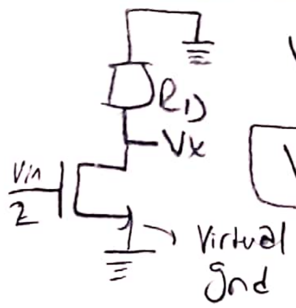
$$\boxed{\text{Voltage gain} = \frac{V_x - V_y}{V_{in}} = \underline{-g_m R_D}}$$

V_t

Differentially driven pairs ile de aynı voltage gain'i elde edip edemeyeceğimizi kontrol edelim



diff. mode half circuit



$$V_x = \left(\frac{V_{in}}{2}\right)\left[-g_{m1}(R_D \parallel \underbrace{r_{o1}}_{\uparrow +\infty})\right] \quad \lambda = 0$$

$$\boxed{V_x = -g_m R_D \frac{V_{in}}{2}}$$

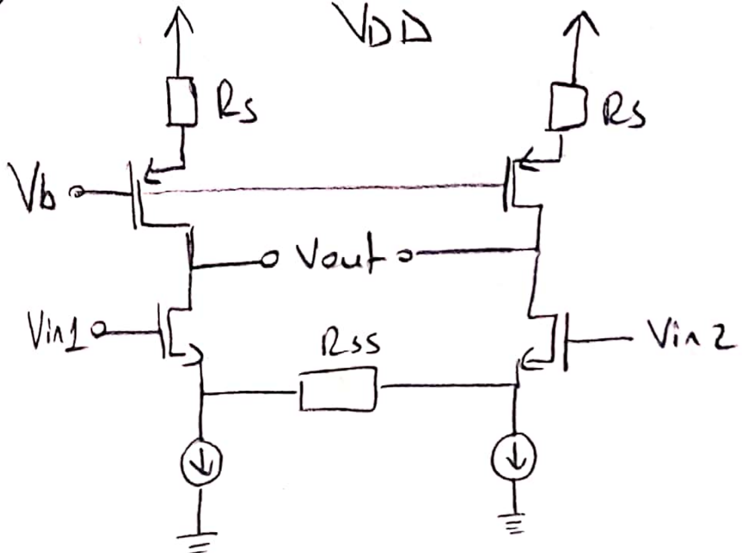
$$V_y = \left(\frac{-V_{in}}{2}\right) \cdot \left[-g_{m2}(R_D \parallel \underbrace{r_{o2}}_{+\infty})\right]$$

$$\boxed{V_y = g_m R_D \cdot \frac{V_{in}}{2}}$$

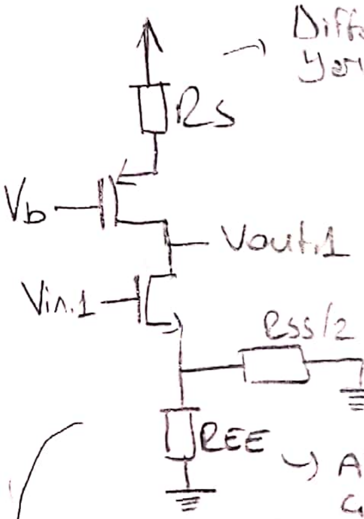
$$\frac{V_x - V_y}{V_{in}} = \frac{-g_m R_D \frac{V_{in}}{2} - g_m R_D \frac{V_{in}}{2}}{\cancel{V_{in}}}$$

$$= g_m R_D$$

Q3. Calculate the differential voltage gain of the circuits depicted in Fig 10.77. Assume perfect symmetry and $\lambda > 0$. You may need to compute the gain as $A_v = -G_m R_{out}$ in some cases,



Öncelikle Differential ve Common Mode yarı devreleri çizilmelidir.

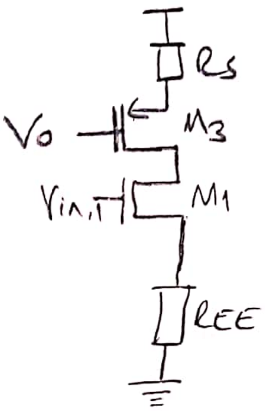


Differential mode yarı devresi

virtual gnd

Akım kaynağının çıkış empedansı

Common Mode yarı devresi



$$A_{TCA} = \frac{i_{out}}{V_{in}} = \frac{\dfrac{-\cancel{V_\pi}}{1/g_{m1}}}{\dfrac{\dfrac{\cancel{V_\pi}}{1/g_{m1} \,//\, R_E}}{g_{m1}}} = \frac{-g_{m1}}{1+g_{m1}R_E}$$

$$\boxed{R_E = R_{EE} \,//\, \frac{R_{SS}}{2}}$$

$$\underbrace{r_{out,TCA} = r_{o1}(1+g_{m1}R_{ED})}_{\text{syf 3 eq.3}}$$

$$R_{up} = (1+\underbrace{g_{m3}r_{o3}}_{\beta_3})R_s + r_{o3}$$

Differential mode h.c

$$A_{TCA_1} = -\frac{g_{m1}}{1+g_{m1}R_{E_1}}$$

$$R_{E_1} = R_{EE} \parallel \frac{R_{SS}}{2}$$

$$r_{out,TCA} = r_{o1}(1+g_{m1}R_{E_1})$$

$$R_{up} = (1+\underbrace{g_{m3}r_{o3}}_{\beta_3})R_S + r_{o3}$$

Common Mode

$$A_{TCA_2} = -\frac{g_{m2}}{1+g_{m2}R_{E_2}}$$

$R_{E_2} = R_{EE} \rightarrow$ R_{SS} üzerinden akım geçmiyor.

$$r_{out,TCA} = r_{o1}(1+g_{m2}R_{E_2})$$

$$R_{up} = (1+\underbrace{g_{m3}r_{o3}}_{\beta_3})R_S + r_{o3}$$

Differential Mode

$$\frac{V_{out}}{V_{in}} = \frac{-g_{m1}}{\underbrace{1+g_{m1}R_{E1}}_{B_1}} \cdot \underbrace{\left[r_{o1}(1+g_{m1}R_{E1}) \parallel (1+g_{m3}r_{o3})R_S + r_{o3}\right]}_{A_1}$$

$R_{E1} = R_{EE} \parallel \frac{R_{SS}}{2}$ $\quad R_{SS} \ll R_{EE}$ ise $\boxed{R_{E1} = \frac{R_{SS}}{2}}$

$$\frac{V_{out}}{V_{in}} = \frac{-g_{m1}}{1+g_{m1}\frac{R_{SS}}{2}} \cdot \left[r_{o1}\left(1+g_{m1}\frac{R_{SS}}{2}\right) \parallel (1+g_{m3}r_{o3})R_S + r_{o3}\right]$$

Common mode

$$\frac{V_{out}}{V_{in}} = \frac{-g_{m1}}{\underbrace{1+g_{m2}R_{E_2}}_{B_2}} \cdot \underbrace{\left[r_{o1}(1+g_{m2}R_{E_2}) \parallel (1+g_{m3}r_{o3})R_S + r_{o3}\right]}_{A_2}$$

$R_{SS} \ll R_{EE}$ olduğundan $\longrightarrow$ $\frac{A_1}{A_2} < 1$ olmalı

$$\frac{\frac{\cancel{-g_{m1}}}{1+g_{m1}\cdot\frac{R_{SS}}{2}}}{\frac{\cancel{g_{m1}}}{1+g_{m2}\cdot R_{EE}}} = \frac{1+g_{m2}\cdot R_{EE}}{1+g_{m1}\frac{R_{SS}}{2}} > 1$$

çünkü $A_1 < A_2$ olmalı

$B_1 \cdot A_1 = B_2 \cdot A_2$ ise $A_1 < A_2$ ise $B_1 > B_2$ olmalı.

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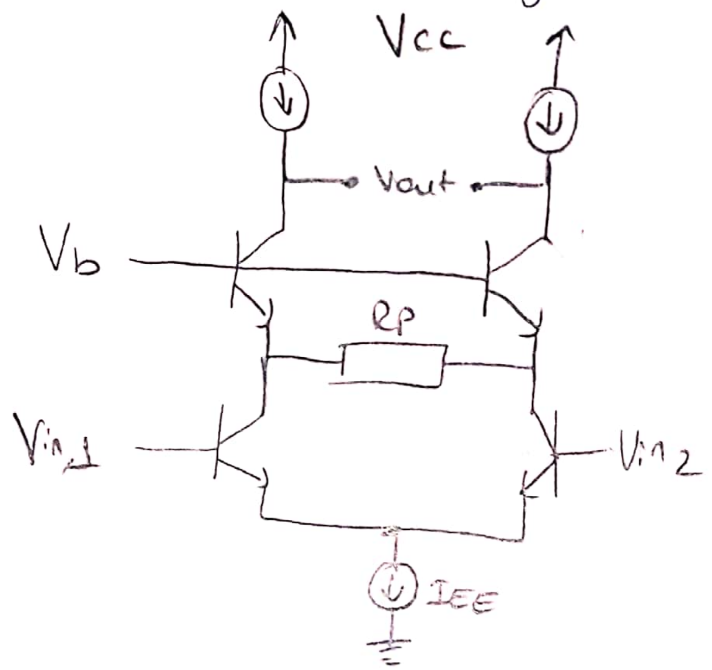
... ... in the circuit

$$\frac{1+g_{m_2}R_{EE}^{\;\;B_1}}{1+g_{m_1}\frac{R_{SS}}{2}\;B_2} > 1$$

Q4. Due to a manufacturing error, a parasitic resistance, R_P, has appeared in the circuit of Fig. 10.78 Calculate the voltage gain



Common base amp. small signal esdeğeri

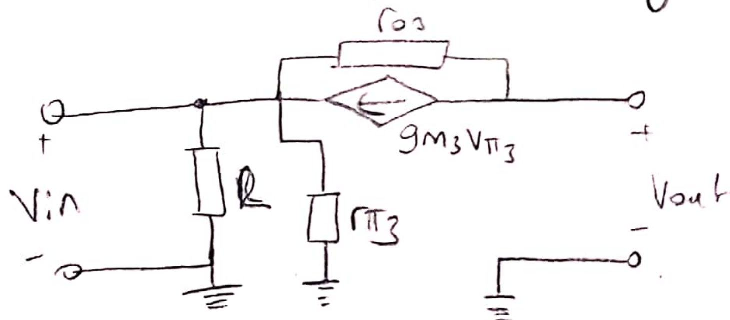
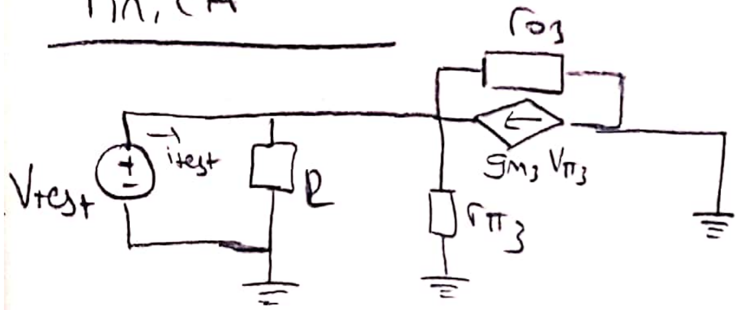


fig. 3

fig 3 devresinde girişe Vtest bağlanır çıkış kısa devre edilirse $r_{in,CA}$ elde edilir.

$r_{in,CA}$



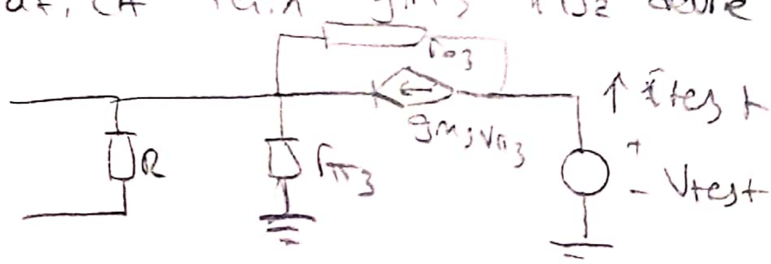
$$-i_{test} + \frac{V_{test}}{R} + \frac{V_{test}}{r_{\pi 3}} + \frac{V_{test}}{r_{o3}} - g_{m3}V_{\pi 3} = 0$$

$$V_{test} = -V_{\pi 3}$$

$$\frac{V_{test}}{i_{test}} = r_{in,CA} = R \parallel r_{\pi 3} \parallel r_{o3} \parallel \frac{1}{g_{m3}} \approx R \parallel \frac{1}{g_{m3}}$$

$$\boxed{r_{in,CA} = R \parallel \frac{1}{g_{m3}}} \qquad r_{o3}, r_{\pi 3} \gg \frac{1}{g_{m3}}, R$$

$r_{out,CA}$ için giriş kısa devre çıkışa Vtest



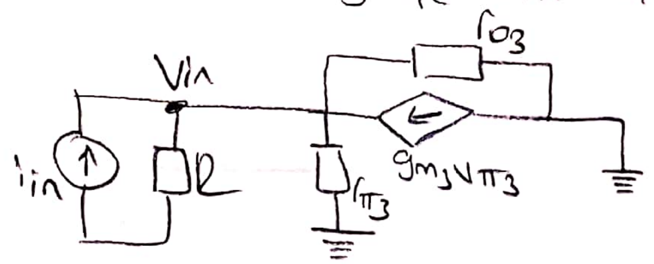
$$i_{test} \cdot \left[r_{o3} + (1 + \underbrace{g_{m3} r_{o3}}_{\beta_3}) (r_{\pi 3} \parallel R) \right] = V_{test}$$

$$\frac{V_{test}}{i_{test}} = r_{out,CA} = \left[r_{o3} + (1 + g_{m3} r_{o3}) (r_{\pi 3} \parallel R) \right]$$

$$r_{\pi 3} \gg R$$

$$\boxed{r_{out,CA} = \left[(1 + g_{m3} r_{o3}) \cdot R + r_{o3} \right]}$$

A_{CA} için girişe i'in çıkış kısa devre



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

$$i_{out} + g_{m3} V_{\pi 3} - \frac{V_{in}}{r_{o3}} = 0$$

$$\frac{V_{in}}{i_{in}} = R \,||\, r_{\pi 3} \,||\, r_{o3} \,||\, \frac{1}{g_{m3}}$$

$$\boxed{i_{in} = \frac{V_{in}}{R \,||\, r_{\pi 3} \,||\, r_{o3} \,||\, \frac{1}{g_{m3}}}}$$

$$\boxed{i_{out} = \frac{V_{in}}{1/g_{m3} \,||\, r_{o3}}} \cong \frac{V_{in}}{1/g_{m3}}$$

$r_{o3}, r_{\pi 3} >> R, \frac{1}{g_{m3}}$

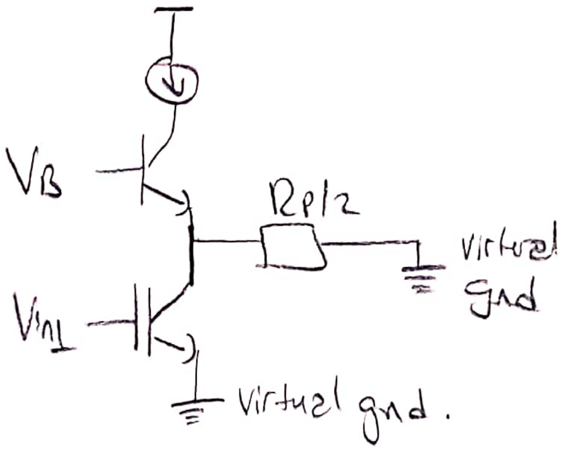
$$\frac{V_{in}}{\frac{1}{g_{m3}} \,||\, R}$$

$$A_{CA} = \frac{i_{out}}{i_{in}} \cong \frac{\frac{\cancel{V_{in}}}{1/g_{m3}}}{\frac{\cancel{V_{in}}}{\frac{1}{g_{m3}} \,||\, R}} = \frac{\frac{1}{g_{m3}} \,||\, R}{1/g_{m3}}$$

$$A_{CA} = \frac{\frac{1}{g_{m3}} \,||\, R}{1/g_{m3}}$$

$$A_{CA} = \frac{\cancel{\frac{1}{g_{m3}}} \cdot R}{\left(1/g_{m3} + R\right) \cdot \cancel{\frac{1}{g_{m3}}}} = \frac{R}{\frac{1+g_{m3}R}{g_{m3}}} = \boxed{\frac{g_{m3} . R}{1+g_{m3} . R} = A_{CA}}$$

Differential mode yarı devresi



$$A_{TCA} = -g_{m1} \qquad A_{CA} = \frac{g_{m3}R}{1+g_{m3}R}$$

$$R_{es} = r_{o1} \,//\, R_p/2$$

$G = A_{TCA} \cdot A_{CA}$ (TCA ve CA kaskatlanmasından dolayı)

$R_{out} = r_{out,CA}$

$$\text{voltage gain} = \frac{V_{out}}{V_{in}} = G \cdot R_{out} = -g_{m1} \cdot \left(\frac{g_{m3} \cdot R}{1+g_{m3}R}\right) \cdot \left((1+g_{m3}r_{o3})R + r_{o3}\right)$$

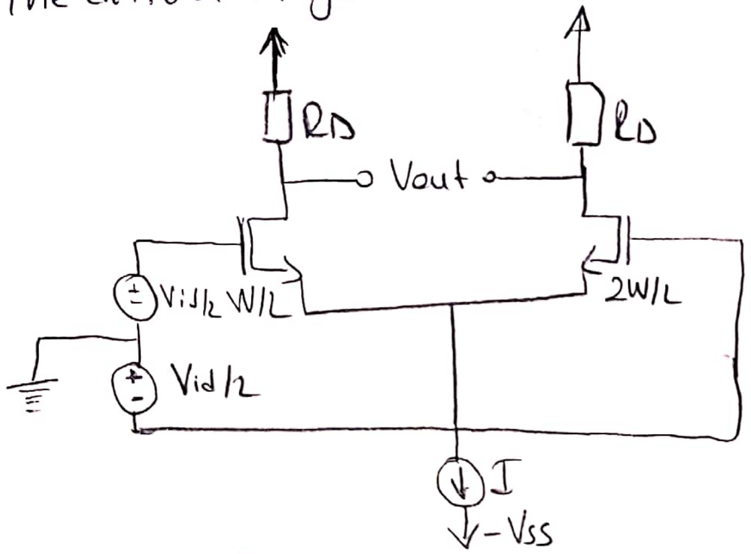
$$r_{out,CA} = \left((1+g_{m3}r_{o3})R + r_{o3}\right)$$

$$\boxed{\text{voltage gain} = -g_{m1}\left(\frac{g_{m3}R}{1+g_{m3}R}\right) \cdot \left((1+g_{m3}r_{o3})R + r_{o3}\right)}$$

Q5. A design error has resulted in a gross mismatch in the circuit of Fig P7.14. Specifically, Q_2 has twice the W/L ratio of Q_1. If V_{id} is a small sine-wave signal, find:

ⓐ I_{D1} and I_{D2} ⓑ V_{ov} for each of Q_1 and Q_2.

ⓒ The differential gain A_d in terms of R_D, I and V_{ov}



$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_t)^2 \qquad I = I_{D1} + I_{D2}$$

$V_{G1} = V_{G2} = 0$

$V_{S1} = V_{S2} = V_S \rightarrow$

$$I_{D1} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(0-V_S-V_t)^2$$

$$I_{D2} = \frac{1}{2}\mu_n C_{ox}\frac{2W}{L}(0-V_S-V_T)^2$$

$$= \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(-V_S-V_T)^2 + \frac{1}{2}\mu_n C_{ox}\frac{2W}{L}(-V_S-V_T)^2 = \frac{3}{2}\mu_n C_{ox}\frac{W}{L}(-V_S-V_T)^2$$

$\boxed{2I_{D1} = I_{D2}}$

$$I = \frac{3}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_T)^2 \rightarrow \sqrt{\frac{2I}{3\mu_n C_{ox}\frac{W}{L}}} = V_{GS}-V_T$$

$$g_m = \frac{2I_D}{(V_{GS}-V_T)} \rightarrow g_{m1} = \frac{2I_{D1}}{\sqrt{\frac{2I}{3\mu_n C_{ox}\frac{W}{L}}}} \qquad g_{m2} = \frac{2I_{D2}}{\sqrt{\frac{2I}{3\mu_n C_{ox}\frac{W}{L}}}}$$

$I_{D1} = \frac{I}{3}$

$I_{D2} = \frac{2I}{3}$

$$\boxed{g_{m1} = \frac{2I}{3\cdot\sqrt{\frac{2I}{3\mu_n C_{ox}\frac{W}{L}}}}} \qquad \boxed{g_{m2} = \frac{4I}{3\sqrt{\frac{2I}{3\mu_n C_{ox}\frac{W}{L}}}}}$$

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$$V_{o1} = -g_{m1} \, V_d/2 \, R_D$$

$$V_{o2} = -g_{m2} \left(-V_d/2\right) . R_D$$

Differential mode gain $= \dfrac{V_{o2} - V_{o1}}{V_d}$

$$\frac{V_{o2} - V_{o1}}{V_d} = \frac{g_{m2} . \frac{\cancel{V_d}}{2} . R_D + g_{m1} \frac{\cancel{V_d}}{2} R_D}{\cancel{V_d}} =$$

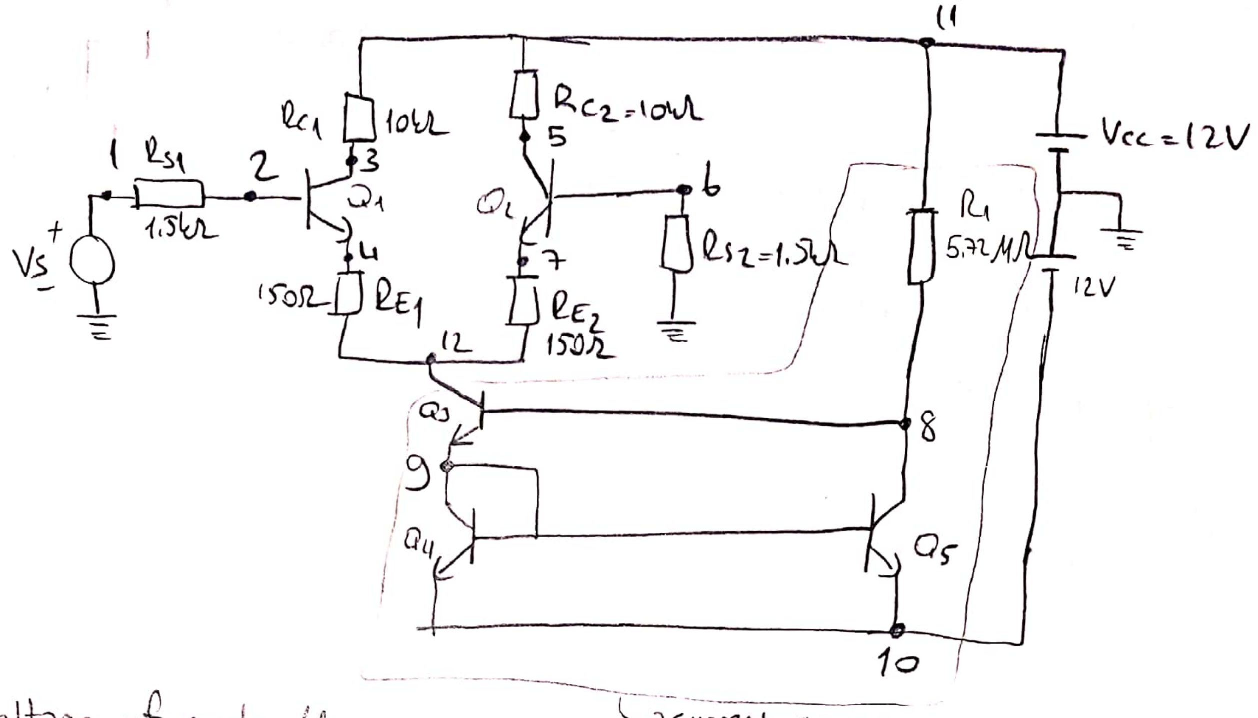
$$= \frac{4I}{3\sqrt{\frac{2I}{3\mu_n C_{ox} \frac{W}{L}}}} . \frac{R_D}{2} + \frac{2I}{3\sqrt{\frac{2I}{3\mu_n C_{ox} \frac{W}{L}}}} . \frac{R_D}{2}$$

$$= \left(\frac{4I}{3} + \frac{2I}{3}\right) . \frac{R_D}{2} . \frac{1}{\sqrt{\frac{2I}{3\mu_n C_{ox} \frac{W}{L}}}}$$

$$= 2I . \frac{R_D}{2} . \frac{1}{\sqrt{\frac{2I}{3\mu_n C_{ox} \frac{W}{L}}}} = \boxed{\frac{I . R_D}{\sqrt{\frac{2I}{3\mu_n C_{ox} \frac{W}{L}}}} = \text{differential gain}}$$

Q6. A differential amplifier is shown in Fig. P9.39. The transistors are identical. Assume $V_{BE} = 0.7V$, $V_T = 26mV$, $\beta_F = 50$, and $V_A = 40V$. Calculate the values of A_d, R_{id}, A_c, R_{ic} and CMRR

V_1



V_{11} = Voltage of node 11

$V_{11} = 12V \quad V_{10} = -12V \quad V_8 = -V_{10} + \underbrace{V_{BE4}}_{0.7} + \underbrace{V_{BE3}}_{0.7}$

$V_{11} = 12V, \; V_{10} = -12V, \; V_8 = -10.6V$

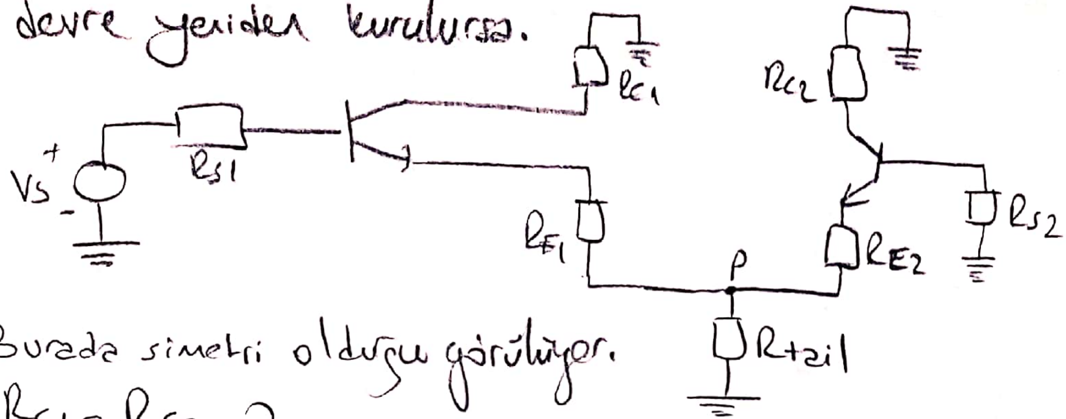
$$I_{ref} = \frac{V_{11} - V_8}{5.72M\Omega} = \boxed{3.951\mu A = I_{ref}}$$

$I_{ref} \approx I_{TAIL}$

$$\frac{V_A}{I_{tail}} = r_{o3} \qquad \frac{V_{tail}}{V_A} = \left(1 + \frac{\beta_3}{2}\right) \qquad R_{tail} = \frac{V_{tail}}{I_{tail}} = \underbrace{\frac{V_{tail}}{V_A} \cdot \frac{V_A}{i_{tail}}}_{\left(1 + \frac{\beta_3}{2}\right) \cdot r_{o3}}$$

$$\boxed{R_{tail} = r_{o3} \cdot \left(1 + \frac{\beta_3}{2}\right)}$$

Devrede current source devresi yerine Rtail eşdeğeri eklenerek devre yeniden kurulursa.



Burada simetri olduğu görülüyor.

$R_{C1} = R_{C2}$, $R_{E1} = R_{E2}$, $R_{S1} = R_{S2}$ $\Big\}$ $g_{m1} = g_{m2}$

$$g_{m1} = \underbrace{\frac{I_{tail}}{2}}_{I_{C1} = I_{C2}} \cdot \frac{1}{V_T} = \frac{I_{tail}}{52mV}$$

$$R_P = R_{tail} \,//\, [R_E + 1/g_m] \qquad R_{id} \cong [1 + g_m(R_{E1} + R_P)]\, r_{\pi 1}$$

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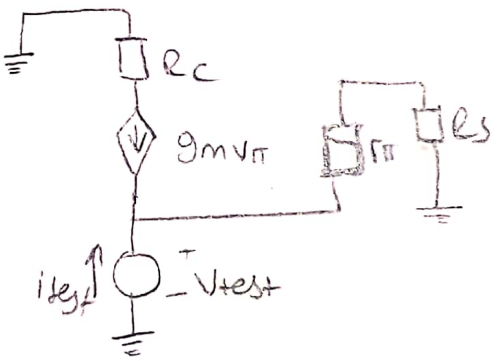
common base gain



$$V_o = -g_m v_\pi R_C$$

$$V_o = -g_m R_C \left(-V_{test} \frac{r_\pi}{r_\pi + R_S}\right)$$

$$\frac{V_o}{V_{test}} = g_m R_C \cdot \underbrace{\frac{r_\pi}{r_\pi + R_S}}_{1} \qquad r_\pi >> R_S$$

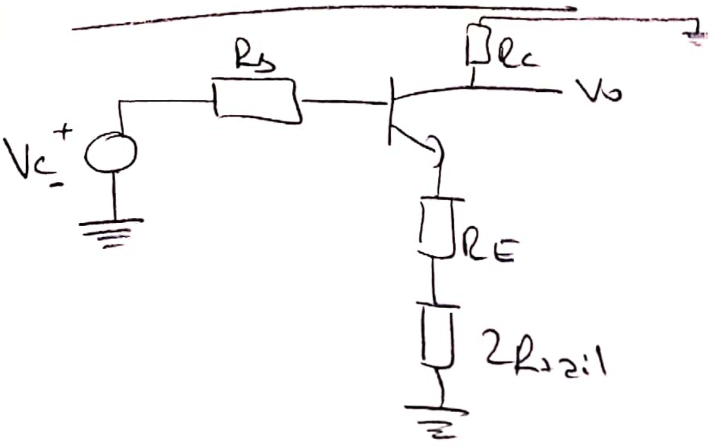
$$\frac{V_o}{V_{test}} = \underline{g_m R_C}$$

$$\frac{V_{E1}}{V_{B1}} = \frac{R_E + R_P}{R_E + R_P + 1/g_m}$$

$$\left.\begin{aligned} \frac{V_{B1}}{V_S} &= \frac{R_{id}}{R_S + R_{id}} \\ \frac{V_P}{V_{B1}} &= \frac{R_P}{R_P + R_E} \\ \frac{V_{E2}}{V_P} &= \frac{1/g_m}{\frac{1}{g_m} + R_E} \end{aligned}\right\} \text{Voltage divider}$$

$$\frac{V_{C2}}{V_S} = A_d = \frac{\cancel{R_E + R_P}}{R_E + R_P + \frac{1}{g_m}} \cdot \frac{R_{id}}{R_S + R_{id}} \cdot \frac{R_P}{R_P + R_E} \cdot \frac{1/g_m}{1/g_m + R_E}$$

Common mode half circuit



$$A_c = \frac{V_o}{V_c} = \frac{V_{B1}}{V_c}\cdot\frac{V_o}{V_{B1}} = \frac{R_{ic}}{R_{ic}+R_S}\left[-g_m\frac{1}{1+g_m(R_E+2R_{tail})}\underbrace{(R_C \parallel r_{out,TCA})}_{R_C \ll r_{out}\ \ R_C}\right]$$

$$A_c = \frac{R_{ic}}{R_{ic}+R_S}\left[-g_m\frac{1}{g_m(R_E+2R_{tail})+1}(R_C)\right]$$

$$\boxed{CMRR = \left|\frac{A_d}{A_c}\right| = \frac{\dfrac{R_{id}\cdot R_P\cdot\frac{1}{g_m}}{\left(R_E+R_P+\frac{1}{g_m}\right)\cdot(R_S+R_{id})\cdot\left(\frac{1}{g_m}+R_E\right)}}{\left(\dfrac{R_{ic}}{R_{ic}+R_S}\right)\cdot\left(-g_m\cdot\dfrac{1}{g_m(R_E+2R_{tail})+1}\cdot R_C\right)}}$$

$$R_{ic} = [1+g_m(R_E+2R_{tail})]r_o$$

$$r_{o3} = \frac{V_A}{I_{tail}} = 10.124\ M\Omega$$

$$R_{id} = [1+g_m(R_{E1}+R_P)]r_{\pi 1}$$

$$\boxed{R_{tail} = r_{o3}\left(1+\frac{\beta_3}{2}\right) = 263.22\ M\Omega}$$

$$\boxed{g_m = \frac{I_{tail}}{52mV} = 7.598\times10^{-5}\ \Omega^{-1}}$$

$$R_{id} = [1+7.598\times10^{-5}(150+6.66m\Omega)].$$

$$\boxed{R_{id} = 1.01\ \Omega}$$

$$R_P = \frac{1}{R_{tail}} + \frac{1}{R_E + 1/g_m}$$

$$\frac{1}{150} + \frac{1}{13k}$$

$$R_{ic} = [1+7.59\times10^{-5}(2\cdot263.22\times10^{6}\Omega)]$$

$$\boxed{R_{ic} = [1+19741.5] = 19.742\ k\Omega}$$

$$\boxed{R_P \cong \frac{1}{150} = 6.66\ m\Omega}$$

$$CMRR = \left|\frac{A_d}{A_c}\right| = \frac{\dfrac{R_{id} \cdot R_P \cdot \frac{1}{g_m}}{\left(R_E + R_P + \frac{1}{g_m}\right) \cdot (R_s + R_{id}) \cdot \left(\frac{1}{g_m} + R_E\right)}}{\left(\dfrac{R_{ic}}{R_{ic} + R_s}\right) \cdot \left(\dfrac{-g_m \cdot R_C}{(R_E + 2R_{tail}) \cdot g_m + 1}\right)}$$

$$\frac{1}{g_m} = 13.161 k\Omega$$

$$= \frac{\dfrac{(1.01) \cdot (6.6\cancel{6} \times 10^{-3}) \cdot (13.161 \times 10^3)}{(\cancel{150} + 6.66 \times 10^{-3} + 13.161 k\Omega) \cdot (1.5 k\Omega + \cancel{1.01\Omega}) \cdot (13.161 k\Omega + \cancel{150})}}{\left(\dfrac{19.742 k\Omega}{19.742 k\Omega + 1.5 k\Omega}\right) \cdot \left(-7.598 \times 10^{-5} \cdot \left(\dfrac{10 k\Omega}{7.598 \times 10^{-5}(150 + 2.263.2 M\Omega) + 1}\right)\right)}$$

$$= \frac{\dfrac{88.528}{2.598 \times 10^{11}}}{(0.929) \cdot (39965) + 1} = \frac{(88.528) \cdot (37.128 \times 10^3)}{2.598 \times 10^{11}}$$

$$\boxed{CMRR = 1.2651 \times 10^{-5}}$$