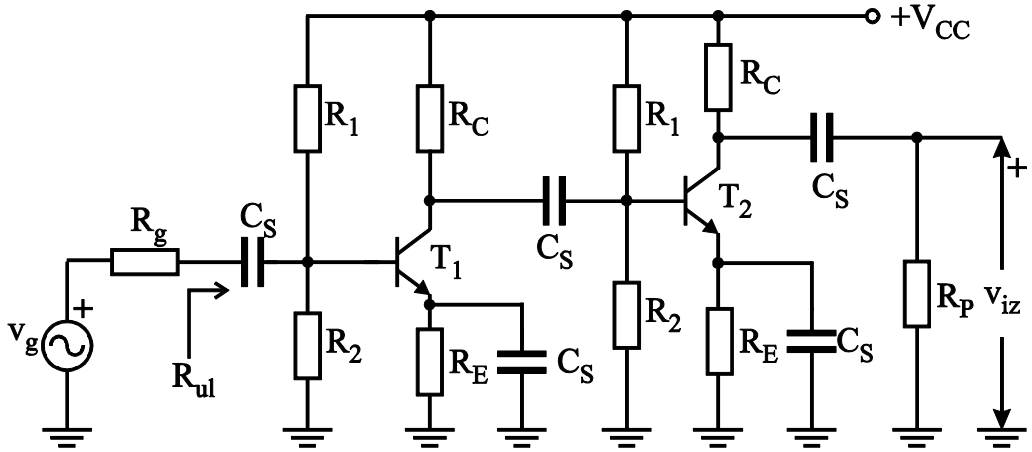
VIŠESTEPENI POJAČAVAČI I DIERERNCIJALNI POJAČAVAČ

1. ZADATAK

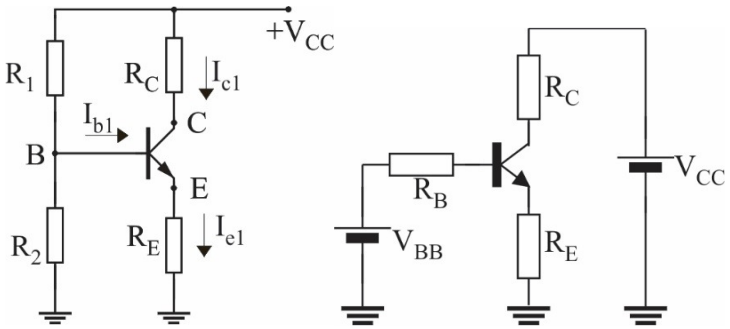
Na slici je prikazan je dvostepeni pojačavač sa bipolarnim tranzistorima. Upotrebljeni tranzistori su identični poznatih parametara: $V_{BE} = 0{,}7$ V; $\beta = 100$. Poznato je: $R_1 = 100$ kΩ; $R_2 = 47$ kΩ; $R_E = 3{,}9$ kΩ; $R_C = 6{,}8$ kΩ; $V_{CC} = 15$ V; $R_g = 5$ kΩ; $R_p = 2$ kΩ; $C_S \to \infty$. Odrediti:

a) Parametre pi modela tranzistora;

b) Naponsko pojačanje pojačavača $A = \frac{v_{iz}}{v_g}$.



a)



$$V_{BB} = \frac{R_2}{R_1 + R_2} \cdot V_{CC} = 4{,}8\ \text{V}$$

$$R_B = R_1 \parallel R_2 = 32\ k\Omega$$

$$V_{BB} - R_B \cdot I_B - V_{BE} - R_E \cdot (1 + \beta) \cdot I_B = 0$$

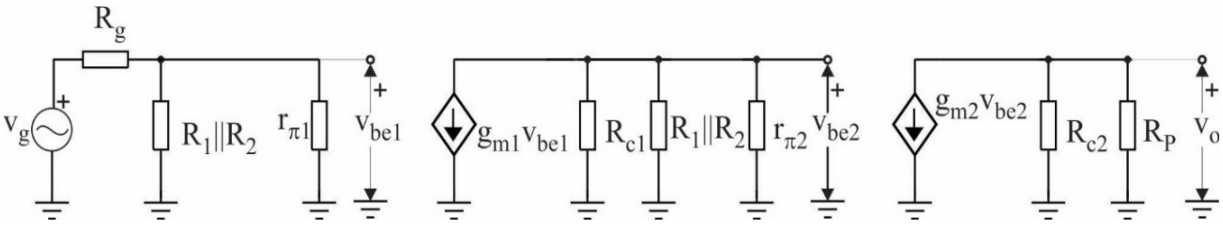
$$I_{B1} = I_{B2} = \frac{V_{BB} - V_{BE}}{R_B + R_E \cdot (1 + \beta)} = 9{,}7\ \mu A$$

$$I_{C1} = I_{C2} = \beta \cdot I_B = 0{,}97\ mA$$

$$r_{\pi 1} = r_{\pi 2} = \frac{V_T}{I_B} = \frac{26\ mV}{9{,}7\ \mu A} = 2{,}6\ k\Omega$$

$$g_{m1} = g_{m2} = \frac{I_C}{V_T} = \frac{0{,}97\ mA}{26\ mV}\ 38{,}4\ mS$$

b)



$$\mathrm{A_n} = \frac{\mathrm{v_o}}{\mathrm{v_g}} = \frac{\mathrm{v_o}}{\mathrm{v_{be2}}} \cdot \frac{\mathrm{v_{be2}}}{\mathrm{v_{be1}}} \cdot \frac{\mathrm{v_{be1}}}{\mathrm{v_g}}$$

$$\frac{\mathrm{v_o}}{\mathrm{v_{be2}}} = -R_{C2} \parallel R_p \cdot g_{m2}$$

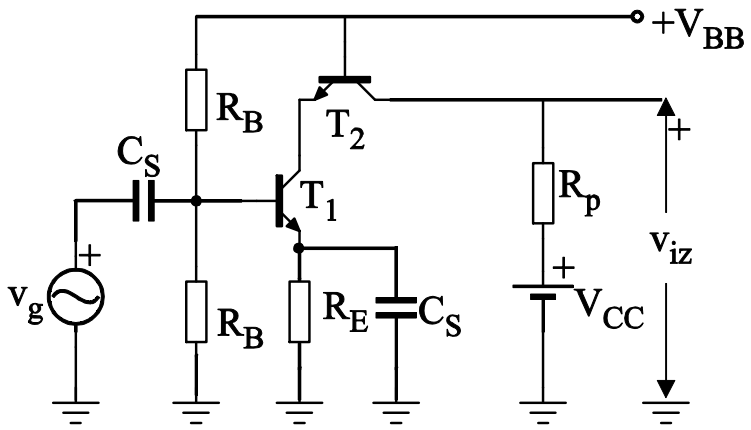
$$\frac{\mathrm{v_{be2}}}{\mathrm{v_{be1}}} = -R_{C1} \parallel R_1 \parallel R_2 \parallel r_{\pi 2} \cdot g_{m1}$$

$$\frac{\mathrm{v_{be1}}}{\mathrm{v_g}} = \frac{R_1 \parallel R_2 \parallel r_{\pi 1}}{R_g + R_1 \parallel R_2 \parallel r_{\pi 1}}$$

$$\mathrm{A_n} = \frac{\mathrm{v_o}}{\mathrm{v_g}} = \frac{\mathrm{v_o}}{\mathrm{v_{be2}}} \cdot \frac{\mathrm{v_{be2}}}{\mathrm{v_{be1}}} \cdot \frac{\mathrm{v_{be1}}}{\mathrm{v_g}} = 1309$$

2. ZADATAK

Za kolo pojačavača prikazano na slici odrediti pojačanje napona $A = \frac{v_{iz}}{v_g}$. Parametri tranizistora su: V_{BE}=0,6 V; β_1=50; β_2=100; h_{12E1}= h_{12E2}=0; h_{21E1}=50; h_{21E2}=100; h_{22E1}=h_{22E2}=0. Poznato je: R_B=200 kΩ; R_E=200 Ω; R_P=4 kΩ; V_{BB}=12 V; V_{CC}=24 V; $C_S \to \infty$.



$$V_{BB} = \frac{R_B}{R_B + R_B} \cdot V_{CC} = 12\ V$$

$$R_{BB} = R_B \parallel R_B = 100\ k\Omega$$

$$V_{BB} - R_{BB} \cdot I_B - V_{BE} - R_E \cdot (1+\beta) \cdot I_B = 0$$

$$I_{B1} = \frac{V_{BB} - V_{BE}}{R_{BB} + R_E \cdot (1+\beta)} = 49\ \mu A$$

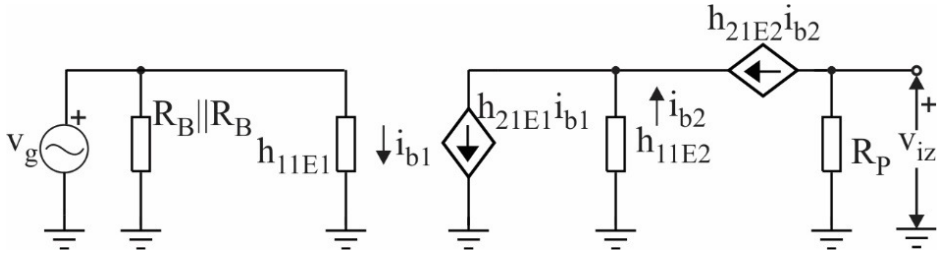
$$I_{C1} = I_{E2}$$

$$\beta_1 \cdot I_{B1} = (1+\beta_2) \cdot I_{B2}$$

$$I_{B2} = \frac{\beta_1}{(1+\beta_2)} \cdot I_{B1} = 24\ \mu A$$

$$h_{11E1} = \frac{V_T}{I_{B1}} = \frac{26mV}{49\mu A} = 0{,}5\ k\Omega$$

$$h_{11E2} = \frac{V_T}{I_{B2}} = \frac{26mV}{24\mu A} = 1\ k\Omega$$



$$i_{b1} = \frac{v_g}{h_{11E1}}$$

(c1) $\quad -i_{b2} + h_{21E1} \cdot i_{b1} - h_{21E2} \cdot i_{b2} = 0$

(c2) $v_{iz} = -h_{21E2} \cdot i_{b2} \cdot R_p$

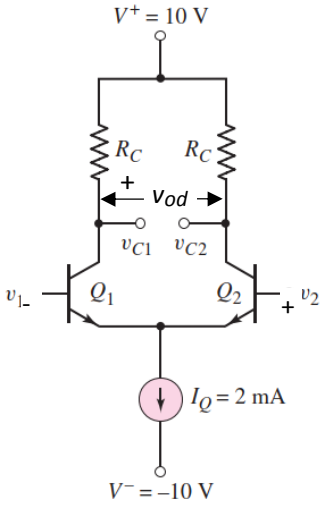
$$i_{b2} = \frac{h_{21E1} \cdot i_{b1}}{1 + h_{21E2}} = \frac{h_{21E1}}{1 + h_{21E2}} \cdot \frac{v_g}{h_{11E1}}$$

$$v_{iz} = -h_{21E2} \cdot R_p \cdot \frac{h_{21E1}}{1 + h_{21E2}} \cdot \frac{v_g}{h_{11E1}}$$

$$A_n = \frac{v_{iz}}{v_g} = -h_{21E2} \cdot R_p \cdot \frac{h_{21E1}}{1 + h_{21E2}} \cdot \frac{1}{h_{11E1}} = 400$$

3. ZADATAK

Isprojektovati kolo sa slike tako da pri ulaznim naponima v1=-5 mV i v2=5 mV daje izlazni napon $v_o = v_{c1} - v_{c2} = 1\ V$. Parametri tranzistora su: β=180; V_{BE}= 0,7 V; $V_A = \infty$. Za tako isprojektovano kolo odrediti maksimalnu srednju vrednost ulaznog napona v_{CM}. Napon između kolektora i emitora u zasićenju iznosi $V_{CES} = 0{,}2\ V$.

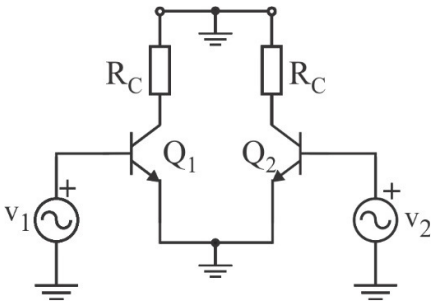


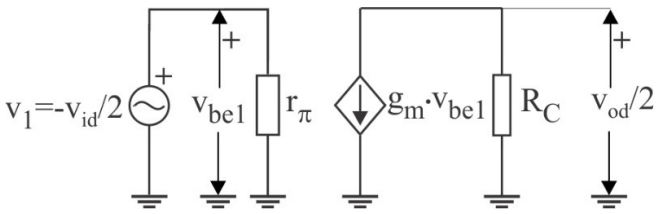
Rešenje:

Diferencijalno pojačanje se određuje pri asimetričnoj pobudi ($v_1 = -v_2$) .

$$A_d = \frac{v_{od}}{v_{id}}\bigg|_{v_1 = -v_2} = \frac{v_{c1} - v_{c2}}{v_2 - v_1}\bigg|_{v_1 = -v_2} = \frac{1\ V}{10\ mV} = 100$$

Prema bisekcionoj teoremi, koja važi za simetrična kola, pri asimetričnoj pobudi ($v_1 = -v_2$) svi čvorovi na osi simetrije se spajaju sa masom.





$$v_2 = -v_1 = \frac{v_{id}}{2}$$

$$v_{be1} = v_1$$

$$v_{o1} = -R_C \cdot g_m \cdot v_{be1}$$

$$v_{o1} = -R_C \cdot g_m \cdot v_1 = R_C \cdot g_m \cdot v_2$$

$$v_{o2} = -R_C \cdot g_m \cdot v_2$$

$$A_d = \frac{v_{od}}{v_{id}}\Big| v_1 = -v_2 = \frac{v_{o1} - v_{o2}}{v_2 - v_1} = \frac{2 \cdot R_C \cdot g_m \cdot v_2}{2 \cdot v_2} = R_C \cdot g_m$$

$$I_{C1} = I_{C2} = \frac{I_Q}{2}$$

$$g_{m1} = g_{m2} = \frac{I_{C1}}{V_T} = \frac{I_Q}{2 \cdot V_T} = \frac{1\ mA}{52\ mV} = 38,4\ mS$$

$$R_C = \frac{A_d}{g_m} = 2,6\ k\Omega$$

b)

Kada se poveća srednja vrednost jednosmernog napona (istovremeno se poveća jednosmerni napon na oba ulaza za isti iznos) dolazi do povećanja napona na emitorima tranzistora, jer je $V_E = V_{in} - V_{BE}$.

Jednosmerni napon na kolektorimia oba tranzistora je uvek isti bez obzira na promenu srednje vrednosti jednosmernog napona.

$$V_C = V^+ - R_C \cdot I_C = 10\ V - 2,6\ k\Omega \cdot 1\ mA = 7,4\ V$$

$$V_E = V_1 - V_{BE} = V_{ICM} - V_{BE}$$

$$V_{CE} = V_C - V_{ICM} - V_{BE}$$

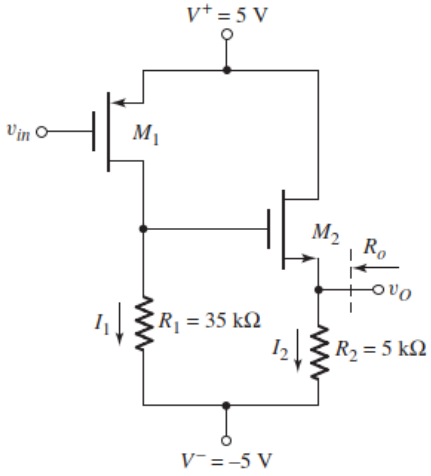
Maksimalna srednja vrednosti jednosmernog napona na ulazu, $V_{ICM(max)}$, odgovara situaciji kada su tranzistori u diferencijalnom paru na granici između zasićenja i aktivne oblasti rada ($V_{CE} = V_{CES}$).

$$V_{CES} = V_C - V_{ICM(max)} - V_{BE}$$

$$V_{ICM(max)} = V_C - V_{CES} + V_{BE}$$

$$V_{ICM(max)} = 7,4V - 0,2V - 0,7\ V = 6,5\ V$$

4. Zadatak



Parametri tranzistora M_1 su: A_1=0,2 mA/V^2; V_{tp}= -0,8 V; $\lambda_1 = 0.01$ V^{-1}. Parametri tranzistora M_2 su: A_2=0,8 mA/V^2; V_{tn}= 0,8 V; $\lambda_2 = 0.01$ V^{-1}. Odrediti:

a) Vrednost jednosmerne komponente napona na ulazu tako da jednosmerni napon na izlazu bude jednak nuli

b) Naponsko pojačanje $A_n = \frac{v_o}{v_{in}}$

c) Izlaznu otpornost R_O.

$V_o = V_{S2} = 0$

$V_o = V^- + R_2 \cdot I_{D2} = 0$

$I_{D2} = \frac{-V^-}{R_2} = \frac{5V}{5\ k\Omega} = 1\ mA$

$I_{D2} = A_2 \cdot (V_{GS2} - V_{tn})^2$

$V_{G2} = V_{GS2} = \sqrt{\frac{I_{D2}}{A_2}} + V_{tn} = 1{,}92\ V$

$I_1 = I_{D1} = \frac{V_{G2} - V^-}{R_1} = \frac{6{,}92\ V}{35\ k\Omega} = 0{,}917\ mA$

$V_{GS1} < V_{tp}$

$V_{GS1} = -\sqrt{\frac{I_{D2}}{A_2}} + V_{tp} = -1{,}8\ V$

$V_{in} = V^+ + V_{GS1} = 3{,}2\ V$

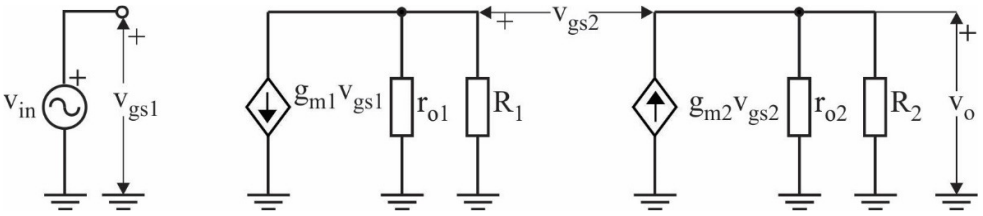
b)

$g_{m1} = 2 \cdot \sqrt{A_1 \cdot I_{D1}} = 0{,}39\ mS$

$r_{o1} = \frac{1}{\lambda \cdot I_{D1}} = 507\ k\Omega$

$g_{m2} = 2 \cdot \sqrt{A_2 \cdot I_{D2}} = 1{,}78\ mS$

$r_{o2} = \frac{1}{\lambda \cdot I_{D2}} = 100\ k\Omega$



$v_{gs1} = v_g$

$v_{g2} = -g_{m1} \cdot v_{gs1} \cdot r_{o1} \parallel R_1$

$v_{s2} = g_{m2} \cdot v_{gs2} \cdot r_{o2} \parallel R_2$

$\boldsymbol{v_{gs2}} = -g_{m1} \cdot v_{gs1} \cdot r_{o1} \parallel R_1 - g_{m2} \cdot v_{gs2} \cdot r_{o2} \parallel R_2$

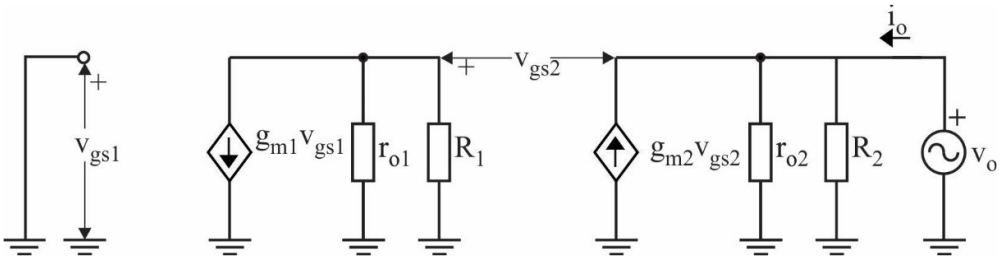
$\mathrm{v_{gs2}} = \dfrac{-g_{m1} \cdot v_{gs1} \cdot r_{o1} \parallel R_1}{1 + g_{m2} \cdot r_{o2} \parallel R_2}$

$\mathrm{v}_o = g_{m2} \cdot v_{gs2} \cdot r_{o2} \parallel R_2 = -g_{m2} \cdot r_{o2} \parallel R_2 \cdot \dfrac{g_{m1} \cdot v_{gs1} \cdot r_{o1} \parallel R_1}{1 + g_{m2} \cdot r_{o2} \parallel R_2}$

$\mathrm{v}_o \approx -g_{m2} \cdot R_2 \cdot \dfrac{g_{m1} \cdot v_{gs1} \cdot R_1}{1 + g_{m2} \cdot R_2}$

$\mathrm{A} = \dfrac{\mathrm{v_o}}{v_g} = -\dfrac{g_{m2} \cdot R_2 \cdot g_{m1} \cdot R_1}{1 + g_{m2} \cdot R_2} = 12{,}27$

c)



$v_{gs1} = 0$

$v_{g2} = 0$

$v_{gs2} = -v_o$

$i_o = \dfrac{v_o}{R_2} + \dfrac{v_o}{r_o} - g_{m2} \cdot v_{gs2}$

$R_{iz} = \dfrac{v_o}{i_o} = \dfrac{1}{\dfrac{1}{R_2} + \dfrac{1}{r_o} + g_{m2}} \approx \dfrac{1}{g_{m2}} = 560\ \Omega$