



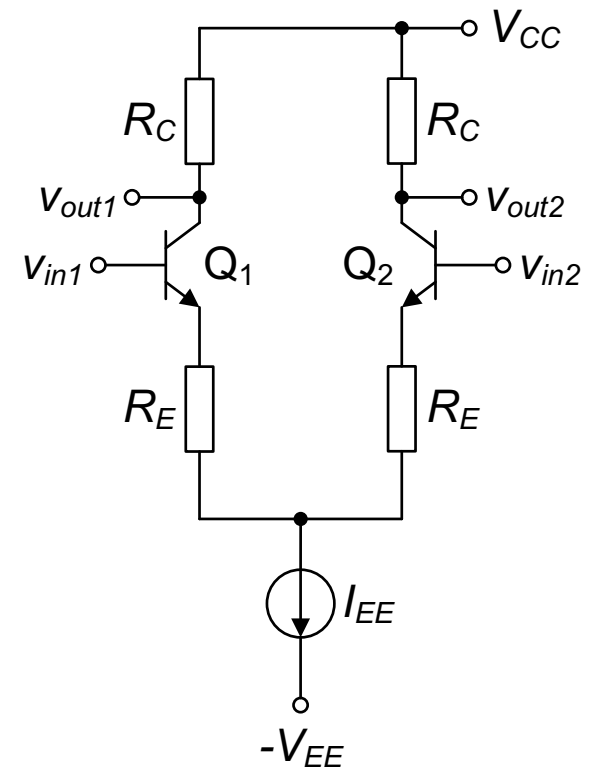
VJEŽBE 10

OSNOVE ELEKTRONIKE, ETR, IV SEMESTAR

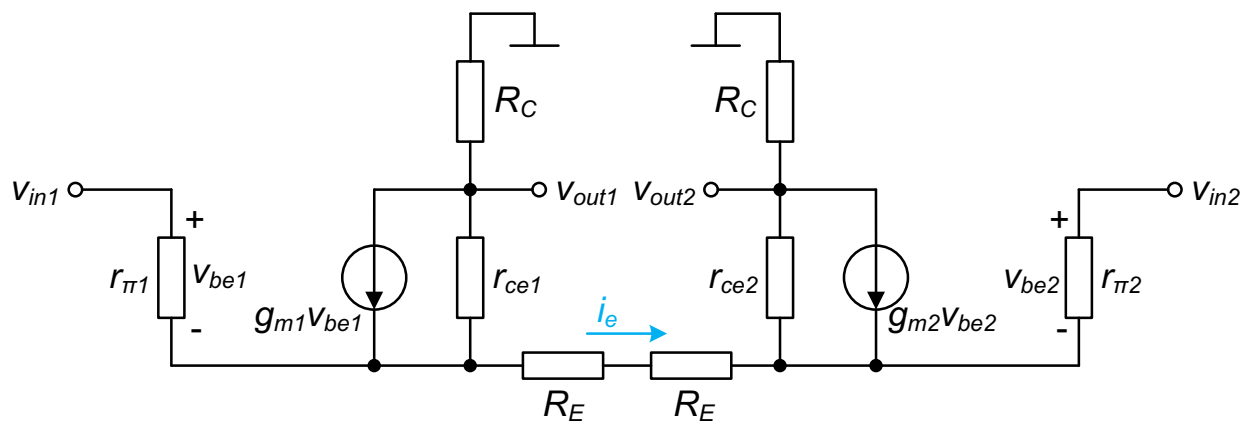
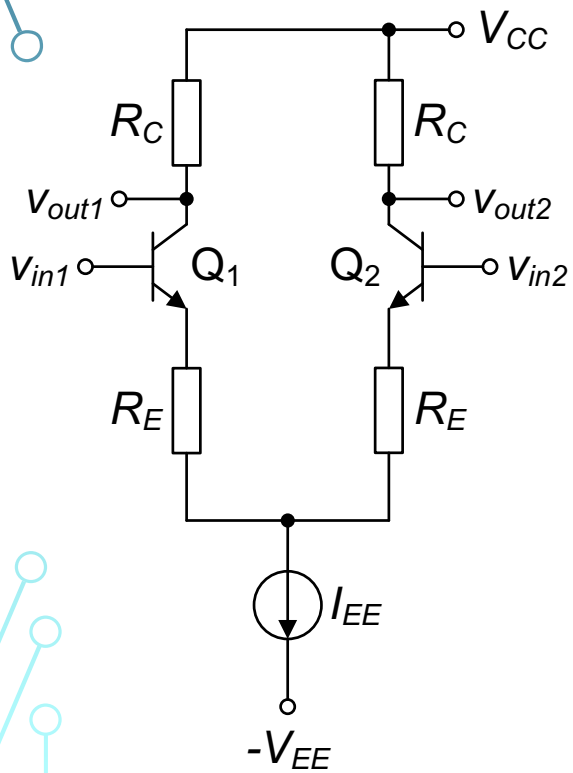
DOC. DR. MILENA ERCEG

ZADATAK 1

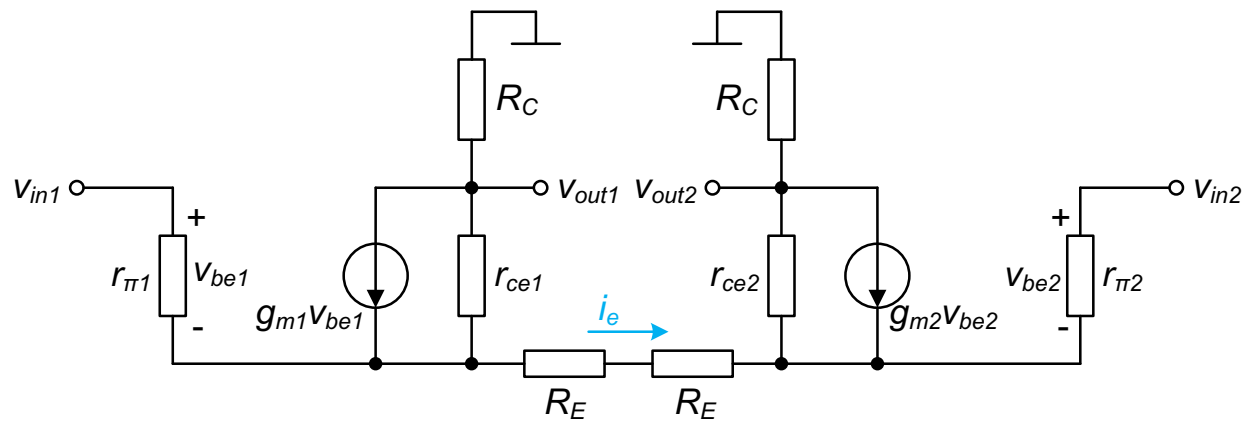
Za kolo prikazano na slici, odrediti diferencijalno naponsko pojačanje $A_d = (v_{out1} - v_{out2}) / (v_{in1} - v_{in2})$. Bipolarni tranzistori imaju identične karakteristike, rade u direktnom aktivnom režimu, i kroz njih teku iste jednosmjerne struje. Poznati su parametri modela za male signale, kao i otpornosti R_C i R_E .



ZADATAK 1



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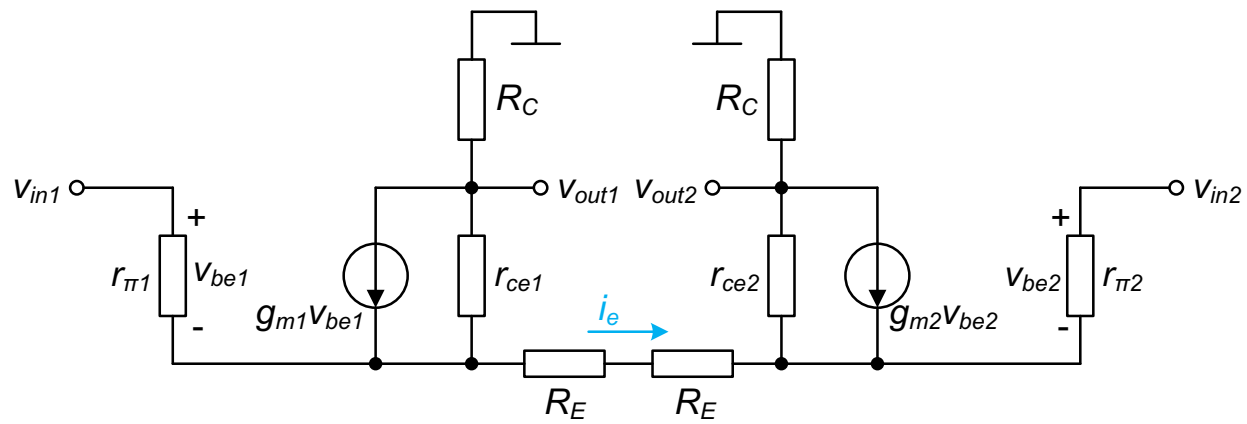


$$g_{m1}v_{be1} + \frac{v_{out1} + v_{be1} - v_{in1}}{r_{ce1}} + \frac{v_{out1}}{R_C} = 0$$

$$g_{m1}r_{ce1} \gg 1:$$

$$v_{be1} \approx \frac{v_{in1}}{g_{m1}r_{ce1}} - \frac{1}{g_{m1}} \left(\frac{1}{r_{ce1}} + \frac{1}{R_C} \right) v_{out1}$$

ZADATAK 1

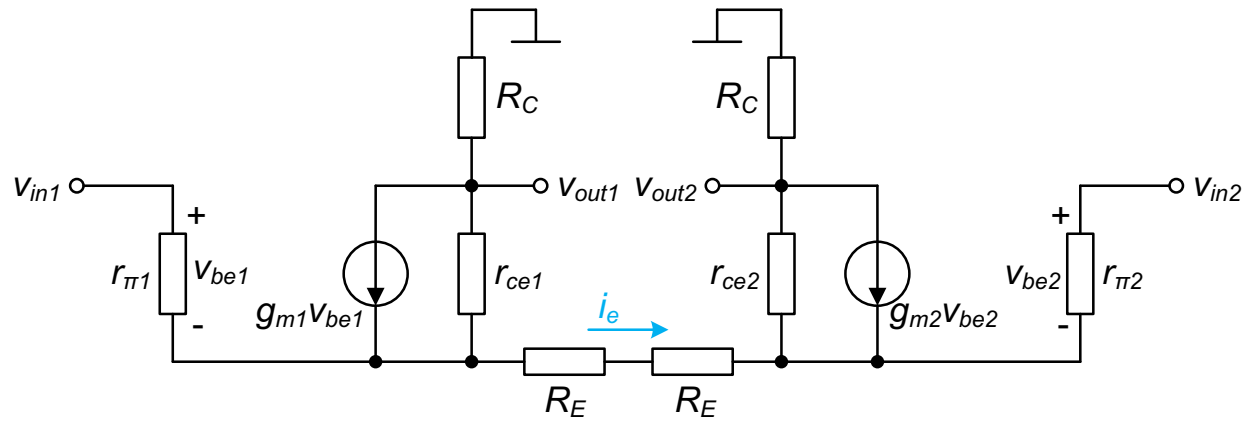


$$g_{m2}v_{be2} + \frac{v_{out2} + v_{be2} - v_{in2}}{r_{ce2}} + \frac{v_{out2}}{R_C} = 0$$

$$g_{m2}r_{ce2} \gg 1:$$

$$v_{be2} \approx \frac{v_{in2}}{g_{m2}r_{ce2}} - \frac{1}{g_{m2}} \left(\frac{1}{r_{ce2}} + \frac{1}{R_C} \right) v_{out2}$$

ZADATAK 1



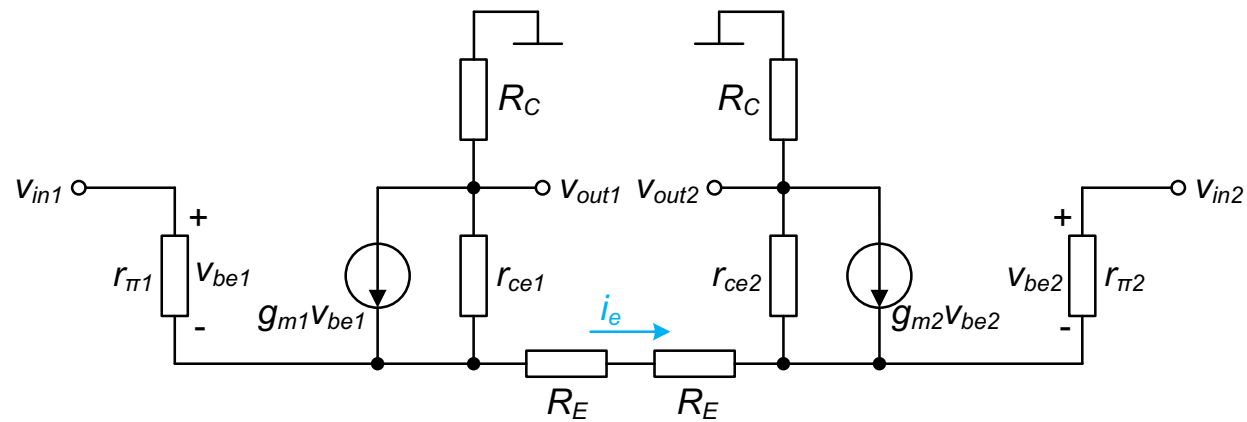
$$i_e = g_{m1}v_{be1} + \frac{v_{be1}}{r_{\pi1}} + \frac{v_{out1} + v_{be1} - v_{in1}}{r_{ce1}}$$

$$i_e = -g_{m2}v_{be2} - \frac{v_{be2}}{r_{\pi2}} - \frac{v_{out2} + v_{be2} - v_{in2}}{r_{ce2}}$$

Sabiranjem prethodne dvije jednačine, uzimajući u obzir da je $g_{m1} = g_{m2}$, $r_{ce1} = r_{ce2}$ i $r_{\pi1} = r_{\pi2}$, dobija se:

$$2i_e = \left(g_{m1} + \frac{1}{r_{\pi1}} + \frac{1}{r_{ce1}} \right) (v_{be1} - v_{be2}) + \frac{1}{r_{ce1}} (v_{out1} - v_{out2}) - \frac{1}{r_{ce1}} (v_{in1} - v_{in2})$$

ZADATAK 1

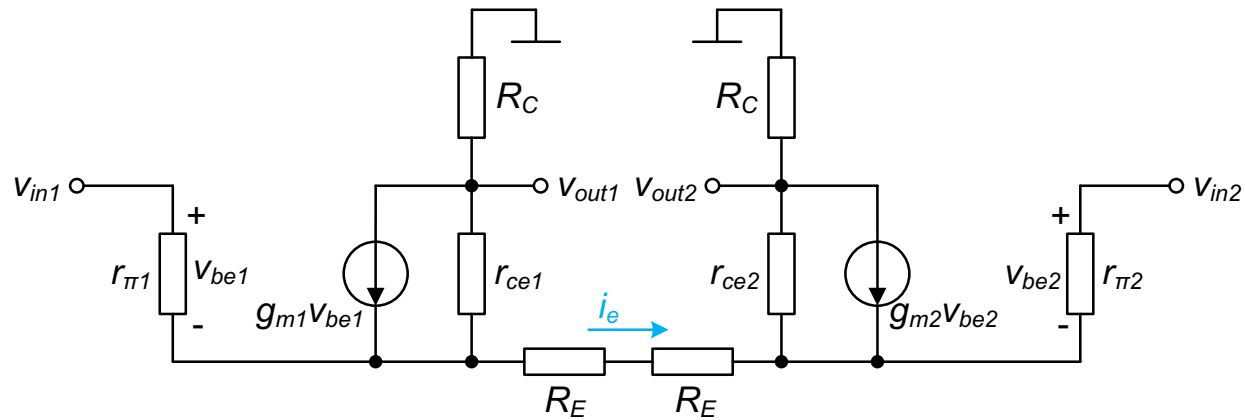


$$2i_e = \left(g_{m1} + \frac{1}{r_{\pi 1}} + \frac{1}{r_{ce1}} \right) (v_{be1} - v_{be2}) + \frac{1}{r_{ce1}} (v_{out1} - v_{out2}) - \frac{1}{r_{ce1}} (v_{in1} - v_{in2})$$

$$g_{m1} r_{ce1} \gg 1, g_{m1} r_{\pi 1} \gg 1:$$

$$2i_e \approx g_{m1} (v_{be1} - v_{be2}) + \frac{1}{r_{ce1}} (v_{out1} - v_{out2}) - \frac{1}{r_{ce1}} (v_{in1} - v_{in2})$$

ZADATAK 1



$$2i_e \approx g_{m1}(v_{be1} - v_{be2}) + \frac{1}{r_{ce1}}(v_{out1} - v_{out2}) - \frac{1}{r_{ce1}}(v_{in1} - v_{in2})$$

$$v_{in1} - v_{be1} - 2R_E i_e + v_{be2} - v_{in2} = 0$$

$$v_{in1} - v_{in2} - (v_{be1} - v_{be2}) - g_{m1}R_E(v_{be1} - v_{be2}) - \frac{R_E}{r_{ce1}}(v_{out1} - v_{out2}) + \frac{R_E}{r_{ce1}}(v_{in1} - v_{in2}) = 0$$

$$\left(1 + \frac{R_E}{r_{ce1}}\right)(v_{in1} - v_{in2}) - (1 + g_{m1}R_E)(v_{be1} - v_{be2}) - \frac{R_E}{r_{ce1}}(v_{out1} - v_{out2}) = 0$$

ZADATAK 1

$$\left(1 + \frac{R_E}{r_{ce1}}\right)(v_{in1} - v_{in2}) - (1 + g_{m1}R_E)(v_{be1} - v_{be2}) - \frac{R_E}{r_{ce1}}(v_{out1} - v_{out2}) = 0$$

$$v_{be1} \approx \frac{v_{in1}}{g_{m1}r_{ce1}} - \frac{1}{g_{m1}}\left(\frac{1}{r_{ce1}} + \frac{1}{R_C}\right)v_{out1}$$

$$v_{be2} \approx \frac{v_{in2}}{g_{m2}r_{ce2}} - \frac{1}{g_{m2}}\left(\frac{1}{r_{ce2}} + \frac{1}{R_C}\right)v_{out2}$$

$$v_{be1} - v_{be2} \approx \frac{v_{in1} - v_{in2}}{g_{m1}r_{ce1}} - \frac{1}{g_{m1}}\left(\frac{1}{r_{ce1}} + \frac{1}{R_C}\right)(v_{out1} - v_{out2})$$

$$\left(1 + \frac{R_E}{r_{ce1}}\right)(v_{in1} - v_{in2}) - (1 + g_{m1}R_E)\left[\frac{v_{in1} - v_{in2}}{g_{m1}r_{ce1}} - \frac{1}{g_{m1}}\left(\frac{1}{r_{ce1}} + \frac{1}{R_C}\right)(v_{out1} - v_{out2})\right] - \frac{R_E}{r_{ce1}}(v_{out1} - v_{out2}) = 0$$

ZADATAK 1

$$\left(1 + \frac{R_E}{r_{ce1}}\right)(v_{in1} - v_{in2}) - (1 + g_{m1}R_E) \left[\frac{v_{in1} - v_{in2}}{g_{m1}r_{ce1}} - \frac{1}{g_{m1}} \left(\frac{1}{r_{ce1}} + \frac{1}{R_C} \right) (v_{out1} - v_{out2}) \right] - \frac{R_E}{r_{ce1}} (v_{out1} - v_{out2}) = 0$$

$$\left(1 + \frac{R_E}{r_{ce1}} - \frac{1}{g_{m1}r_{ce1}} - \frac{R_E}{r_{ce1}}\right)(v_{in1} - v_{in2}) = \left(-\frac{1}{g_{m1}r_{ce1}} - \frac{1}{g_{m1}R_C} - \frac{R_E}{r_{ce1}} - \frac{R_E}{R_C} + \frac{R_E}{r_{ce1}}\right)(v_{out1} - v_{out2})$$

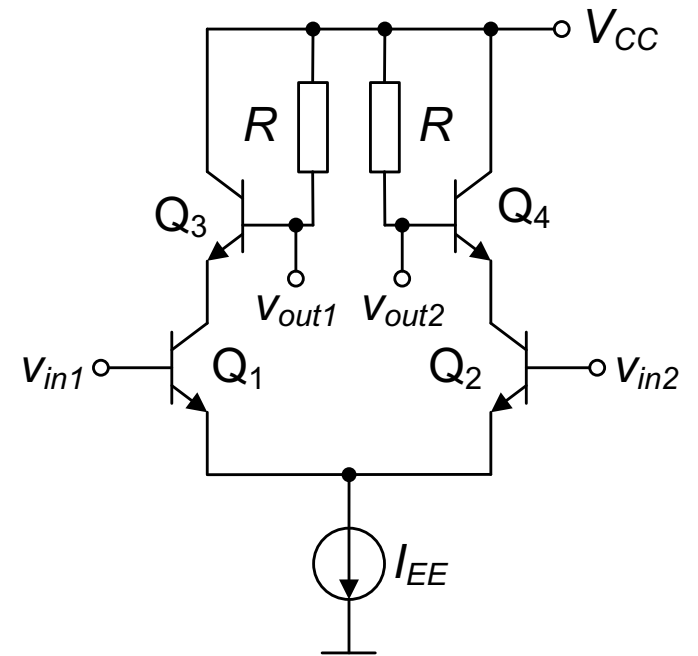
$$A_d = \frac{v_{out1} - v_{out2}}{v_{in1} - v_{in2}} \approx -\frac{1}{\frac{1}{g_{m1}} \left(\frac{1}{r_{ce1}} + \frac{1}{R_C} \right) + \frac{R_E}{R_C}} = -\frac{g_{m1}r_{ce1}R_C}{R_C + r_{ce1} + g_{m1}r_{ce1}R_E}$$

Ukoliko je $g_{m1}r_{ce1}R_E \gg R_C$:

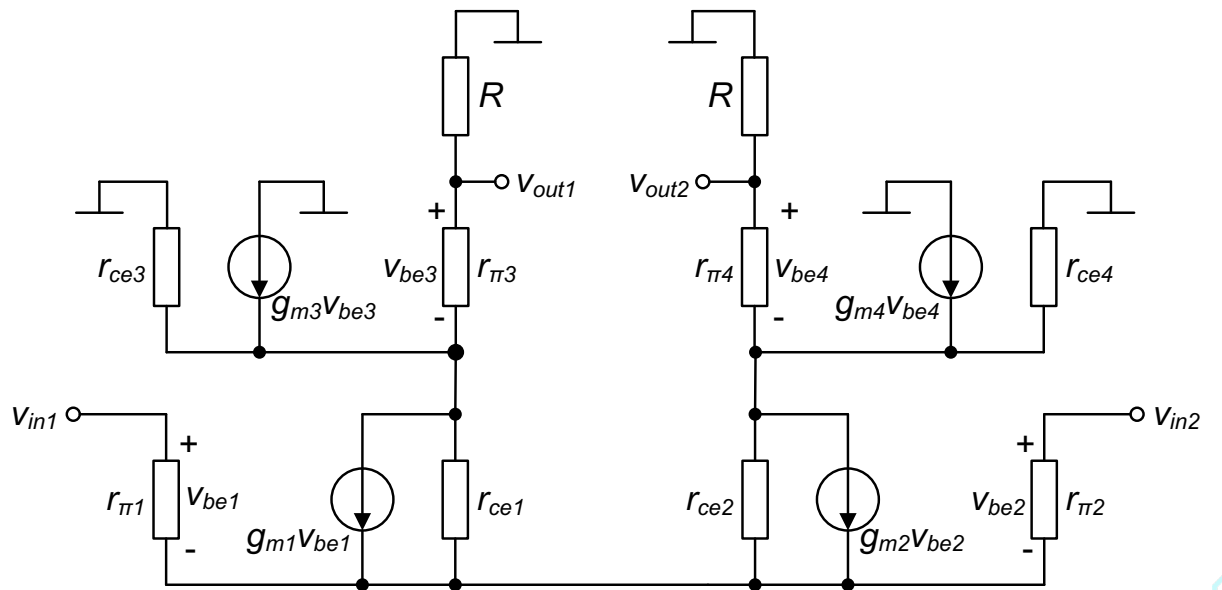
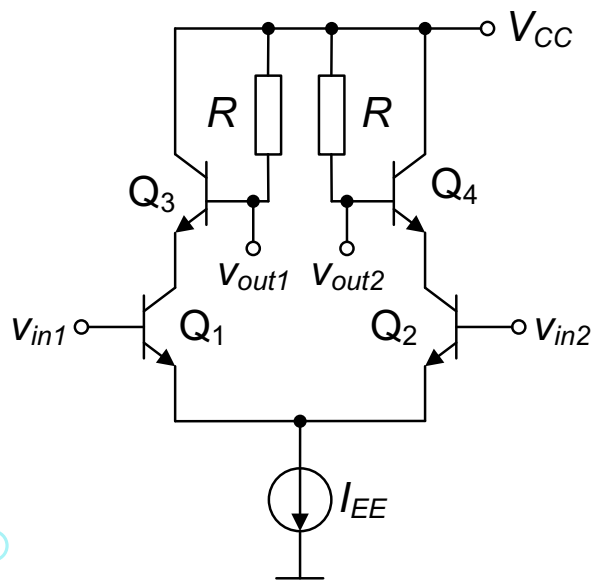
$$A_d \approx -\frac{g_{m1}R_C}{1 + g_{m1}R_E}$$

ZADATAK 2

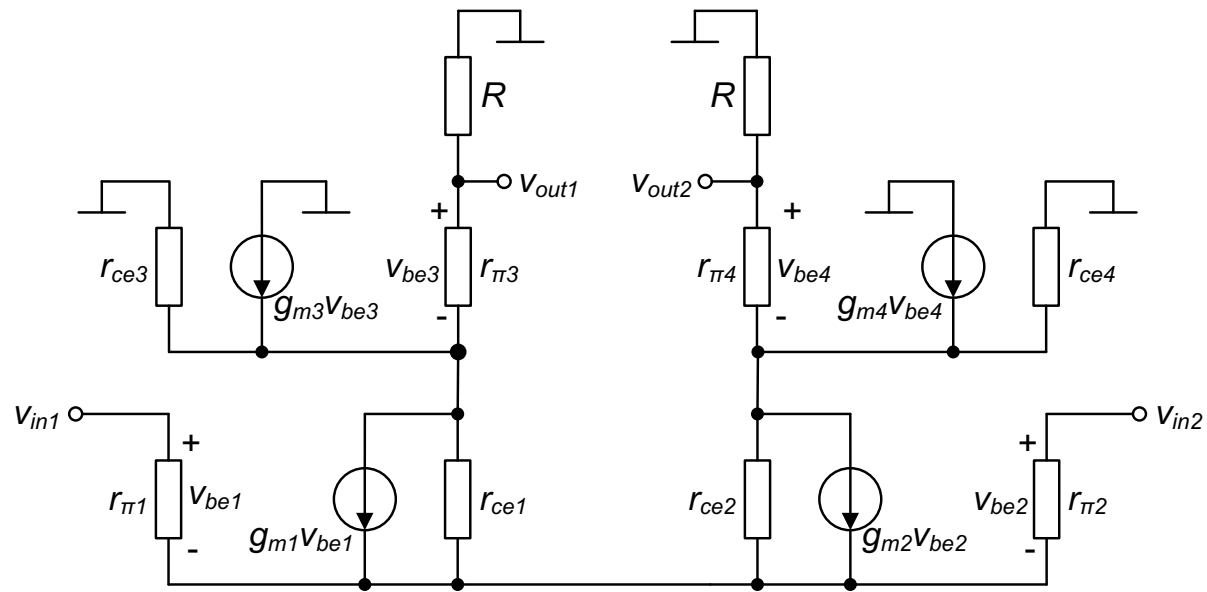
Za kolo prikazano na slici, odrediti diferencijalno naponsko pojačanje $A_d = (v_{out1} - v_{out2}) / (v_{in1} - v_{in2})$. Bipolarni tranzistori imaju identične karakteristike, rade u direktnom aktivnom režimu, i kroz njih teku iste jednosmjerne struje. Poznati su parametri modela za male signale, kao i otpornost R .



ZADATAK 2



ZADATAK 2

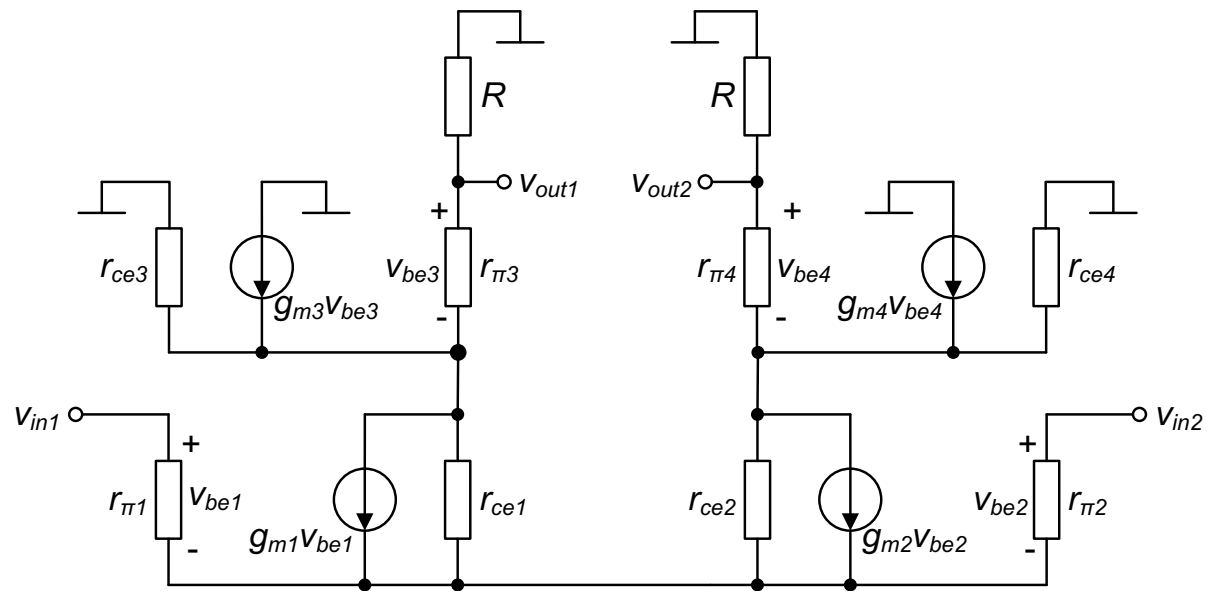


$$v_{be3} = -\frac{r_{\pi3}}{R} v_{out1}$$

$$v_{be4} = -\frac{r_{\pi4}}{R} v_{out2}$$

$$g_{m1} v_{be1} + \frac{v_{out1} - v_{be3} + v_{be1} - v_{in1}}{r_{ce1}} = g_{m3} v_{be3} + \frac{v_{be3}}{r_{\pi3}} + \frac{-v_{out1} + v_{be3}}{r_{ce3}}$$

ZADATAK 2

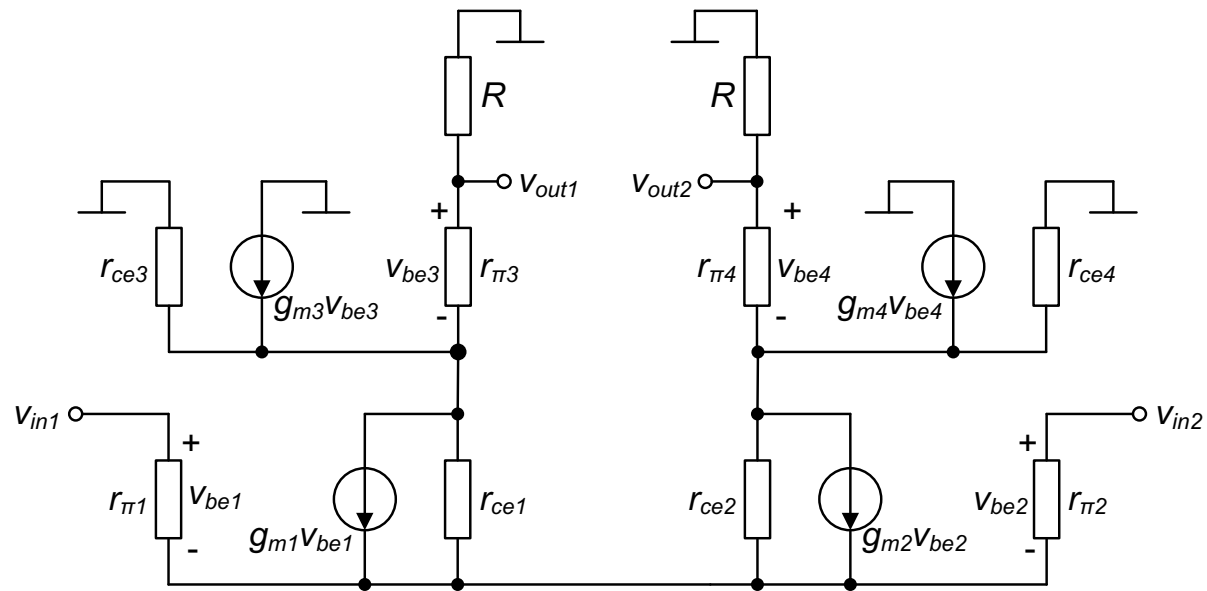


$$g_{m1}v_{be1} + \frac{v_{out1} - v_{be3} + v_{be1} - v_{in1}}{r_{ce1}} = g_{m3}v_{be3} + \frac{v_{be3}}{r_{\pi3}} + \frac{-v_{out1} + v_{be3}}{r_{ce3}}$$

$$g_{m1}r_{ce1} \gg 1 \text{ i } g_{m1}r_{\pi1} \gg 1:$$

$$g_{m1}v_{be1} \approx g_{m3}v_{be3} + \frac{v_{in1}}{r_{ce1}} - \left(\frac{1}{r_{ce1}} + \frac{1}{r_{ce3}} \right) v_{out1}$$

ZADATAK 2

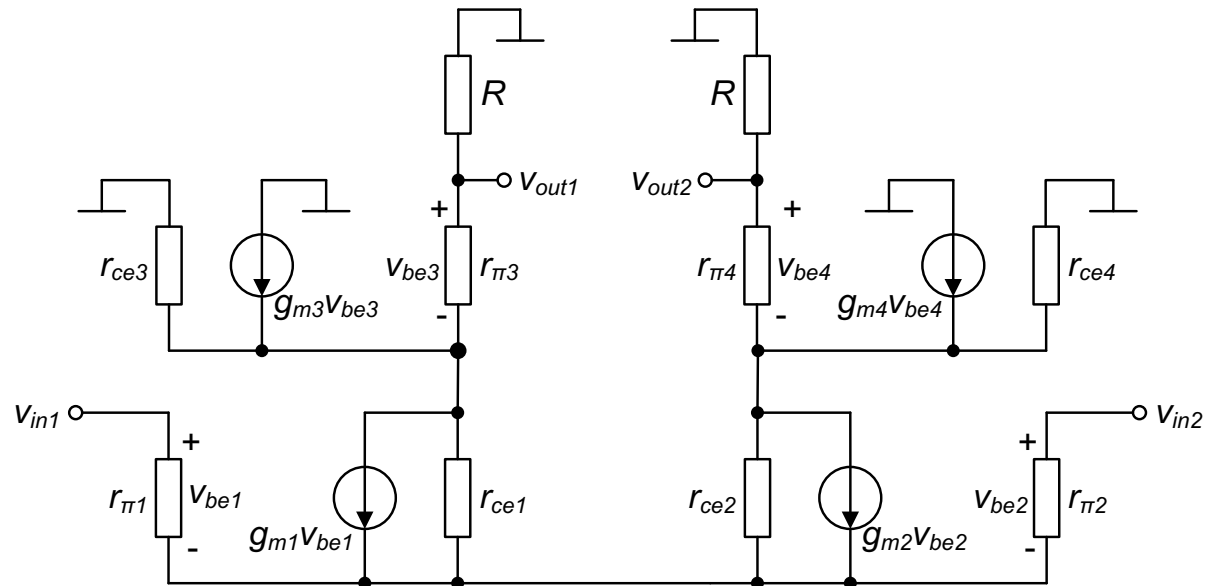


$$g_{m1}v_{be1} \approx g_{m3}v_{be3} + \frac{v_{in1}}{r_{ce1}} - \left(\frac{1}{r_{ce1}} + \frac{1}{r_{ce3}} \right) v_{out1}$$

$$v_{be3} = -\frac{r_{\pi3}}{R} v_{out1}$$

$$v_{be1} \approx \frac{v_{in1}}{g_{m1}r_{ce1}} - \frac{1}{g_{m1}} \left(\frac{1}{r_{ce1}} + \frac{1}{r_{ce3}} + \frac{g_{m3}r_{\pi3}}{R} \right) v_{out1}$$

ZADATAK 2

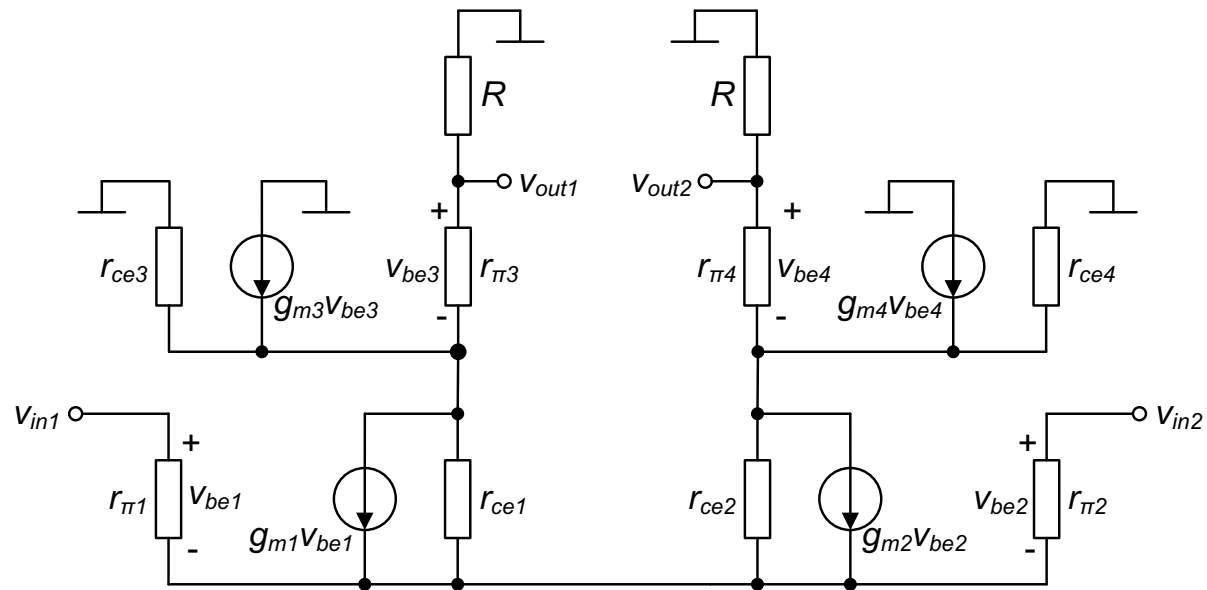


$$g_{m2}v_{be2} + \frac{v_{out2} - v_{be4} + v_{be2} - v_{in2}}{r_{ce2}} = g_{m4}v_{be4} + \frac{v_{be4}}{r_{\pi4}} + \frac{-v_{out2} + v_{be4}}{r_{ce4}}$$

$$g_{m2}r_{ce2} \gg 1 \text{ i } g_{m2}r_{\pi2} \gg 1:$$

$$g_{m2}v_{be2} \approx g_{m4}v_{be4} + \frac{v_{in2}}{r_{ce2}} - \left(\frac{1}{r_{ce2}} + \frac{1}{r_{ce4}} \right) v_{out2}$$

ZADATAK 2

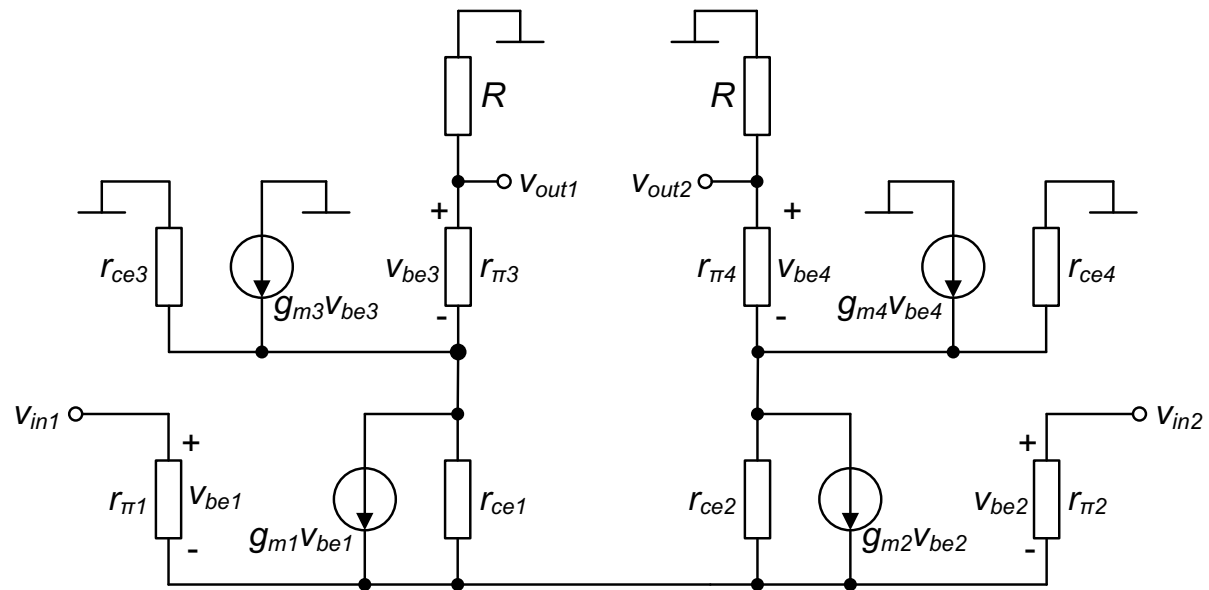


$$g_{m2}v_{be2} \approx g_{m4}v_{be4} + \frac{v_{in2}}{r_{ce2}} - \left(\frac{1}{r_{ce2}} + \frac{1}{r_{ce4}} \right) v_{out2}$$

$$v_{be4} = -\frac{r_{\pi4}}{R} v_{out2}$$

$$v_{be2} \approx \frac{v_{in2}}{g_{m2}r_{ce2}} - \frac{1}{g_{m2}} \left(\frac{1}{r_{ce2}} + \frac{1}{r_{ce4}} + \frac{g_{m4}r_{\pi4}}{R} \right) v_{out2}$$

ZADATAK 2



$$v_{in1} - v_{be1} + v_{be2} - v_{in2} = 0$$

ZADATAK 2

$$v_{in1} - v_{be1} + v_{be2} - v_{in2} = 0$$

$$v_{be1} \approx \frac{v_{in1}}{g_{m1}r_{ce1}} - \frac{1}{g_{m1}} \left(\frac{1}{r_{ce1}} + \frac{1}{r_{ce3}} + \frac{g_{m3}r_{\pi3}}{R} \right) v_{out1}$$

$$v_{be2} \approx \frac{v_{in2}}{g_{m2}r_{ce2}} - \frac{1}{g_{m2}} \left(\frac{1}{r_{ce2}} + \frac{1}{r_{ce4}} + \frac{g_{m4}r_{\pi4}}{R} \right) v_{out2}$$

$$(v_{in1} - v_{in2}) \left(1 - \frac{1}{g_{m1}r_{ce1}} \right) + \frac{1}{g_{m1}} \left(\frac{1}{r_{ce1}} + \frac{1}{r_{ce3}} + \frac{g_{m3}r_{\pi3}}{R} \right) (v_{out1} - v_{out2}) = 0$$

$$A_d = \frac{v_{out1} - v_{out2}}{v_{in1} - v_{in2}} \approx - \frac{1}{\frac{1}{g_{m1}} \left(\frac{1}{r_{ce1}} + \frac{1}{r_{ce3}} + \frac{g_{m3}r_{\pi3}}{R} \right)} = - \frac{g_{m1}r_{ce1}r_{ce3}R}{R(r_{ce1} + r_{ce3}) + g_{m3}r_{\pi3}r_{ce1}r_{ce3}}$$

Ukoliko je $g_{m3}r_{ce3}r_{\pi3} \gg R$:

$$A_d \approx - \frac{g_{m1}R}{g_{m3}r_{\pi3}}$$