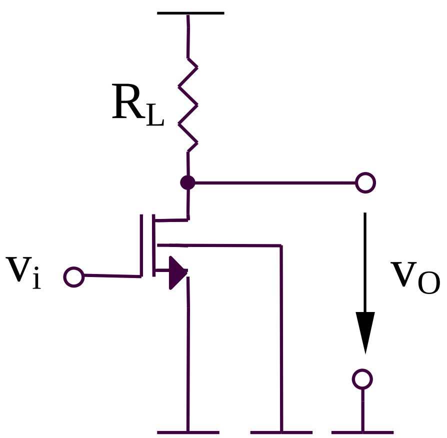
Capitolul 4

Amplificatoare elementare

4.1. Etaje de amplificare cu un tranzistor

4.1.1. Etajul sursa comuna



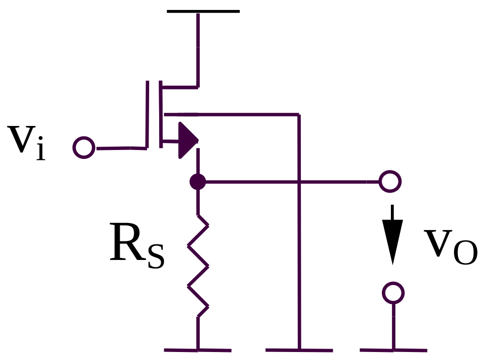
$$A_v = \frac{v_O}{v_I} = \frac{-g_m v_{GS}(R_L // r_{ds})}{v_{GS}}$$

$$A_v = -g_m\left(R_L // r_{ds}\right)$$

$$R_i = \infty$$

$$R_o = R_L // r_{ds}$$

4.1.2. Etajul drena comuna



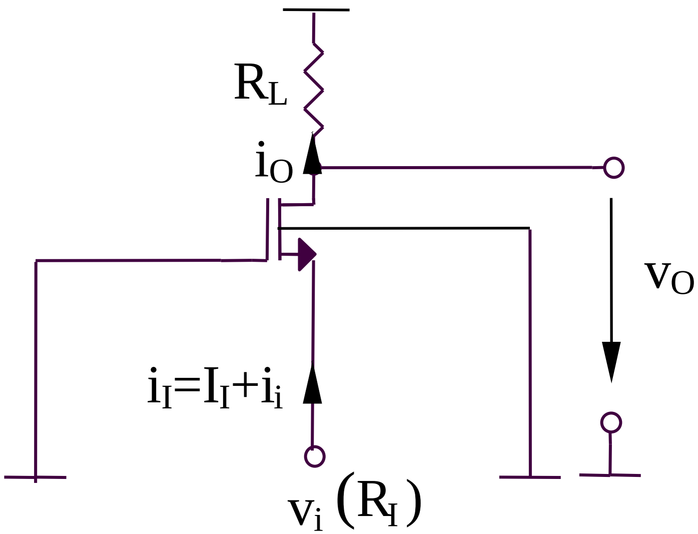
$$A_v = \frac{v_O}{v_I} = \frac{g_m v_{GS} R_s}{v_{GS} + g_m v_{GS} R_s}$$

$$A_v = \frac{g_m R_s}{1 + g_m R_s} \cong 1$$

$$R_i = \infty$$

$$R_o = \frac{1}{g_m} // R_s$$

4.1.3. Etajul grila comuna



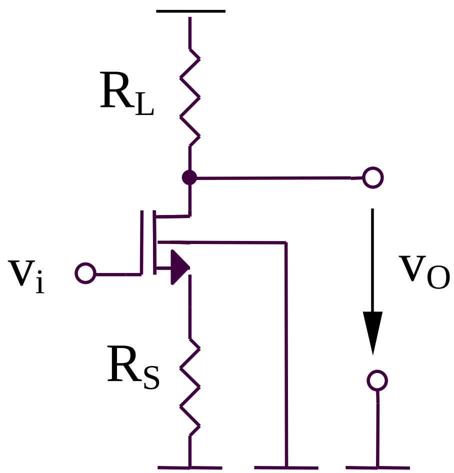
$$A_V = \frac{v_O}{v_I} = \frac{-g_m v_{GS} R_L}{-v_{GS}}$$

$$A_V = g_m R_L$$

$$R_i = \frac{1}{g_m}$$

$$R_o = R_L \,//\, r_{ds}\left(1 + g_m R_I\right)$$

4.1.4. Etajul sarcina distribuita (MOS)



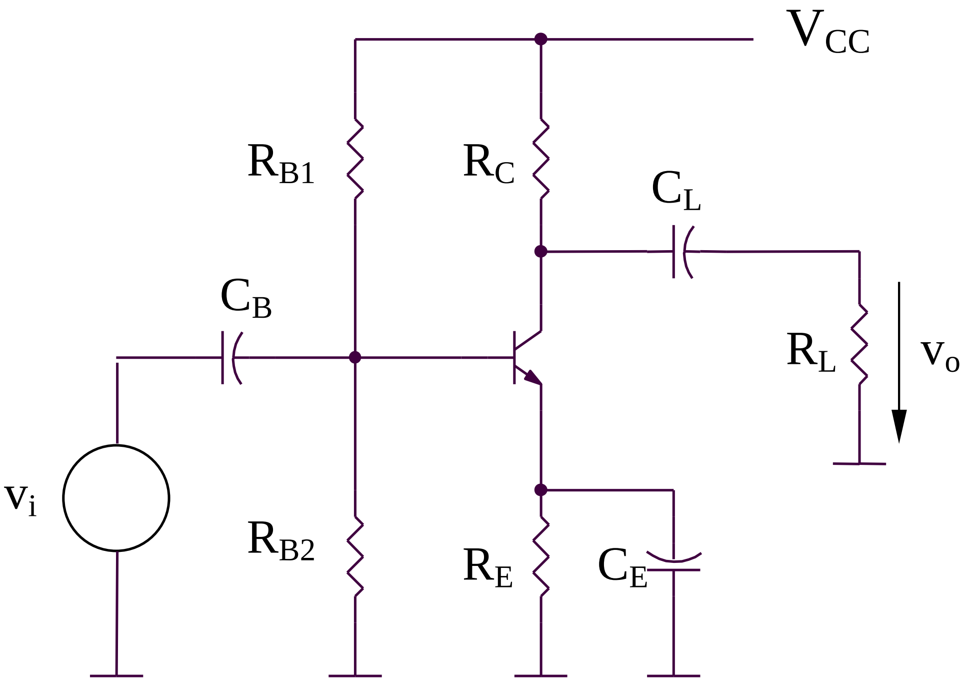
$$A_v = \frac{v_O}{v_I} = \frac{-g_m v_{GS} R_L}{v_{GS} + g_m v_{GS} R_s}$$

$$A_v = -\frac{g_m R_L}{1 + g_m R_s}$$

$$R_i = \infty$$

$$R_o = R_L \,//\, r_{ds}\left(1 + g_m R_S\right)$$

4.1.5. Etajul emitor comun

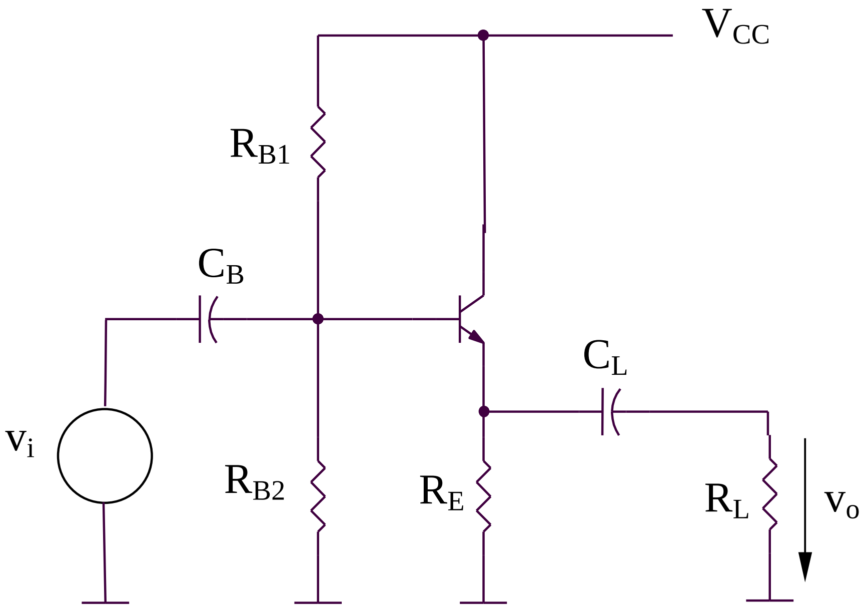


$$A_V = -g_m\left(R_C \,//\, R_L\right)$$

$$R_i = r_\pi \,//\, R_{B1} \,//\, R_{B2}$$

$$R_o = R_L \,//\, R_C \,//\, r_o$$

4.1.6. Etajul colector comun

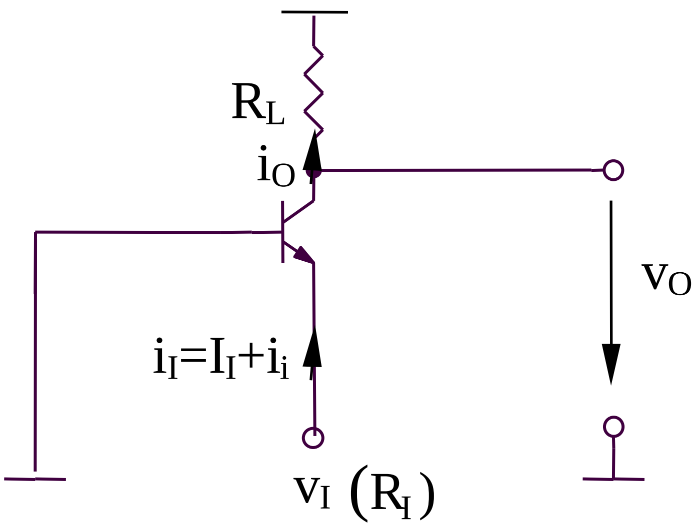


$$A_V = \frac{(\beta+1)(R_E \,//\, R_L)}{r_\pi + (\beta+1)(R_E \,//\, R_L)}$$

$$R_i = R_{B1} \,//\, R_{B2} \,//\, [r_\pi + (\beta+1)(R_E \,//\, R_L)]$$

$$R_o = R_E \,//\, R_L \,//\, 1/g_m$$

4.1.7. Etajul baza comuna



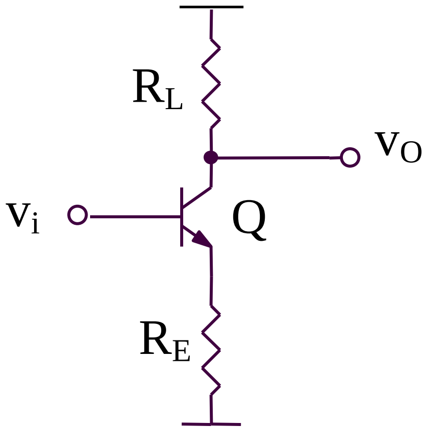
$$A_i = \frac{i_O}{i_I} \cong 1$$

$$A_V = \frac{v_o}{v_i} = g_m R_L$$

$$R_i = \frac{1}{g_m}$$

$$R_o = R_L \,//\, r_o\left(1 + \frac{\beta R_I}{r_\pi + R_I}\right)$$

4.1.8. Etajul sarcina distribuita (bipolar)



$$A_V = \frac{v_O}{v_i} = \frac{v_O}{i_C}\frac{i_C}{i_B}\frac{i_B}{v_i}$$

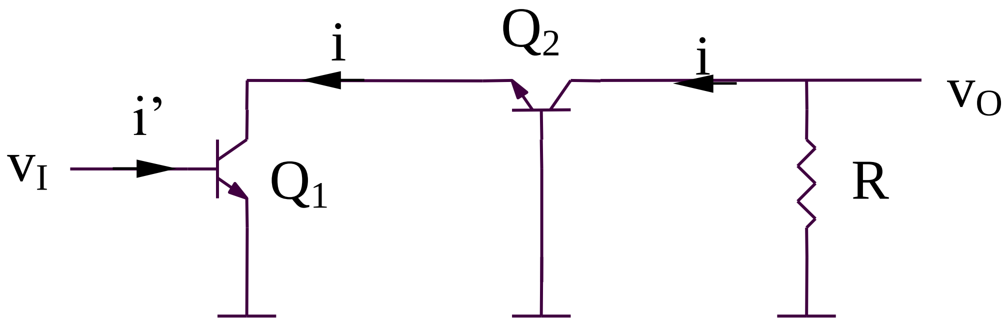
$$A_V = -\frac{\beta R_L}{r_\pi + (\beta + 1)R_E}$$

$$R_i = r_\pi + (\beta + 1)R_E$$

$$R_o = R_L \,//\, r_o\left(1 + \frac{\beta R_E}{r_\pi + R_E}\right)$$

4.2. Amplificatorul cascod

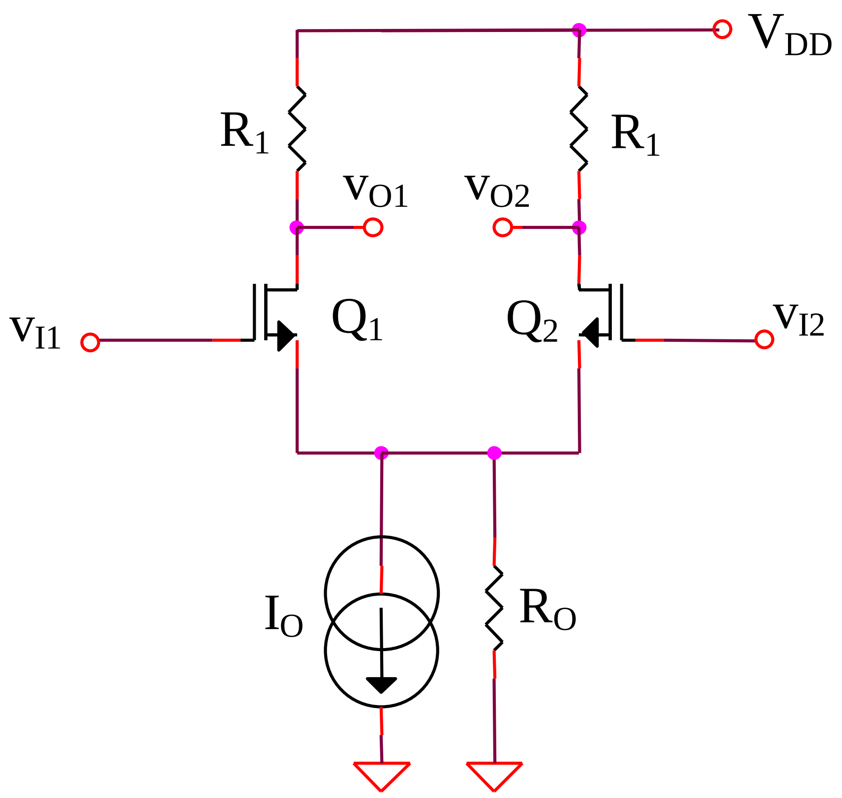
Avantajul amplificatorului cascod: raspuns in frecventa superior etajului emitor comun.



$$A_V = \frac{v_O}{v_I} = \frac{v_O}{i}\frac{i}{i'}\frac{i'}{v_I} = -R\beta\frac{1}{r_{\pi 1}} = -g_{m1}R$$

4.3. Amplificatoare diferentiale CMOS elementare

4.3.1. Amplificatorul diferential CMOS cu sarcina pasiva



Amplificatorul diferential

• reprezinta un bloc fundamental in proiectarea circuitelor integrate analogice
• caracteristicile tranzistoarelor trebuie sa fie identice
• aceeasi temperatura de functionare a tranzistoarelor
• rezistentele de sarcina de valoare egala

Tensiunea de iesire poate fi:

• diferentiala (simetrica):

$$v_O = v_{O1} - v_{O2}$$

• asimetrica:

$$v_O = v_{O1} \ \text{sau} \ v_{O2}$$

Analiza de semnal mare

$$v_{I1} - v_{I2} = v_{GS1} - v_{GS2} = \left(V_T + \sqrt{\frac{2i_{D1}}{K}}\right) - \left(V_T + \sqrt{\frac{2i_{D2}}{K}}\right) = \sqrt{\frac{2}{K}}\left(\sqrt{i_{D1}} - \sqrt{i_{D2}}\right)$$

$$i_{D1} + i_{D2} = I_O \qquad\qquad v_I = v_{I1} - v_{I2}$$

$$\Rightarrow i_{D1}^2 - I_O i_{D1} + \frac{1}{4}\left(I_0 - \frac{Kv_I^2}{2}\right)^2 = 0$$

Deci:

$$i_{D1} = \frac{I_O}{2} + \frac{I_O}{2}\sqrt{\frac{Kv_I^2}{I_O} - \frac{K^2 v_I^4}{4I_O^2}} \qquad\qquad i_{D2} = \frac{I_O}{2} - \frac{I_O}{2}\sqrt{\frac{Kv_I^2}{I_O} - \frac{K^2 v_I^4}{4I_O^2}}$$

pentru $v_I = \sqrt{\frac{2I_O}{K}}$ rezulta $i_{D1} = I_O, \quad i_{D2} = 0$

Tensiunea de iesire este (pentru iesire diferentiala):

$$v_O = R_1\left(i_{D2} - i_{D1}\right)$$

$$v_O = -I_O R_1 \sqrt{\frac{Kv_I^2}{I_O} - \frac{K^2 v_I^4}{4I_O^2}} = -\frac{R_1 v_I}{2}\sqrt{4KI_O - K^2 v_I^2}$$

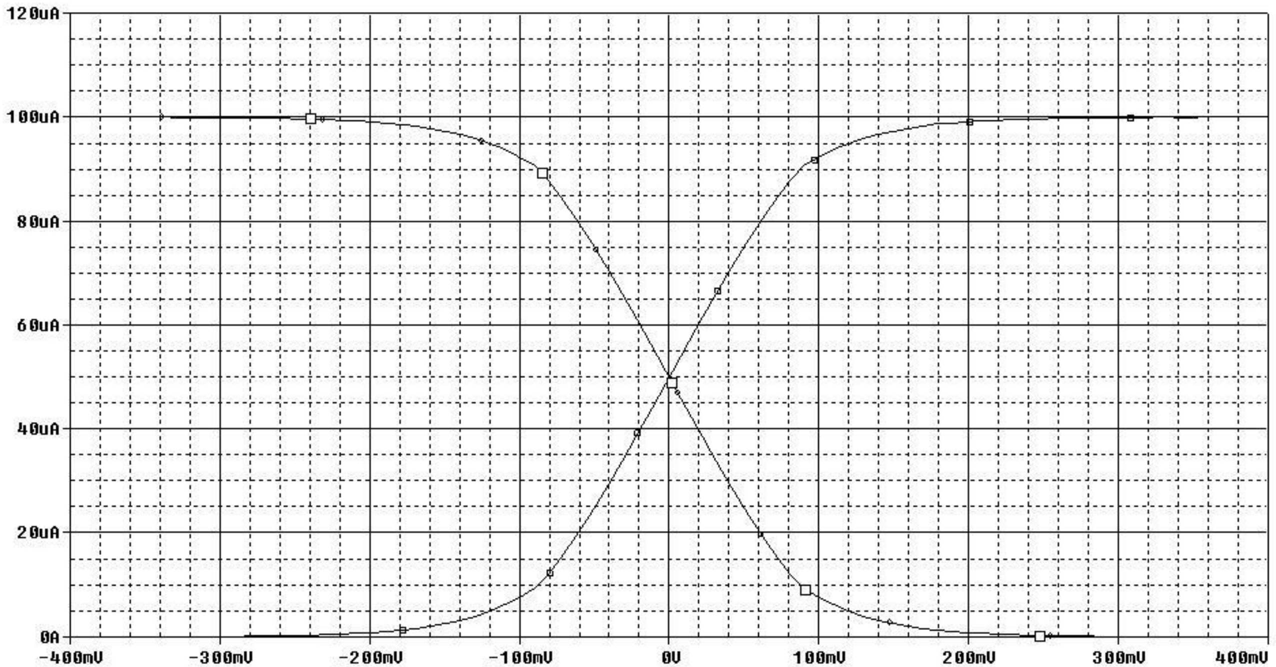
Dezvoltarea in serie Taylor a expresiei tensiunii de iesire este:

$$v_O(v_I) = -K^{1/2} I_O^{1/2} R_1 v_I + \frac{K^{3/2} R_1}{8 I_O^{1/2}} v_I^3 + \frac{K^{5/2} R_1}{128 I_O^{3/2}} v_I^5 + \dots$$

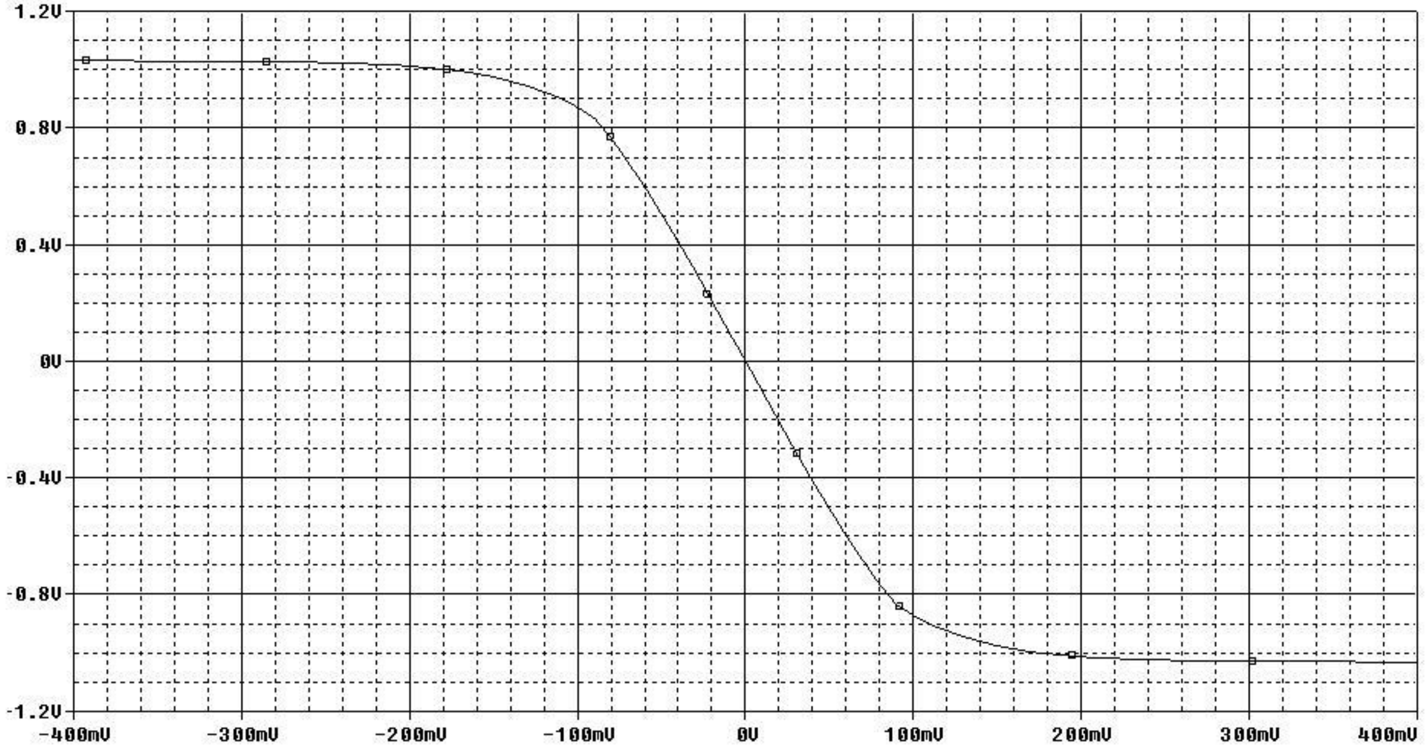
$$v_O(v_I) = a_1 v_I + a_3 v_I^3 + a_5 v_I^5 + \dots$$

Amplificarea de mod diferential:

$$A_{dd} = a_1 = -R_1 \sqrt{K I_O}$$



Caracteristicile $i_{D1}, i_{D2}(v_I)$



Caratteristica $v_O(v_I)$

Analiza de semnal mic

Tensiuni de mod diferential: v_{id}, v_{od}
Tensiuni de mod comun: v_{ic}, v_{oc}

$v_{id} = v_{i1} - v_{i2}$ - tensiunea diferentiala de intrare

$v_{od} = v_{o1} - v_{o2}$ - tensiunea diferentiala de iesire

$v_{ic} = \frac{v_{i1} + v_{i2}}{2}$ - tensiunea de mod comun de intrare

$v_{oc} = \frac{v_{o1} + v_{o2}}{2}$ - tensiunea de mod comun de iesire

$$\Rightarrow v_{i1} = v_{ic} + \frac{v_{id}}{2} \quad ; \quad v_{o1} = v_{oc} + \frac{v_{od}}{2}$$

$$v_{i2} = v_{ic} - \frac{v_{id}}{2} \quad ; \quad v_{o2} = v_{oc} - \frac{v_{od}}{2}$$

Amplificarile in tensiune

$$A_{dd} = \left.\frac{v_{od}}{v_{id}}\right|_{v_{ic}=0}$$ - amplificare de mod diferential

$$A_{cc} = \left.\frac{v_{oc}}{v_{ic}}\right|_{v_{id}=0}$$ - amplificare de mod comun

$$A_{cd} = \left.\frac{v_{od}}{v_{ic}}\right|_{v_{id}=0}$$ - amplificare mod comun - mod diferential

$$A_{dc} = \left.\frac{v_{oc}}{v_{id}}\right|_{v_{ic}=0}$$ - amplificare mod diferential - mod comun

Tensiunile de iesire (diferentiala si de mod comun) vor avea expresiile:

$$v_{od} = A_{dd}v_{id} + A_{cd}v_{ic}$$

$$v_{oc} = A_{dc}v_{id} + A_{cc}v_{ic}$$

Rezulta:

$$v_{o1} = \left(A_{dc} + \frac{A_{dd}}{2} \right) v_{id} + \left(A_{cc} + \frac{A_{cd}}{2} \right) v_{ic}$$

$$v_{o2} = \left(A_{dc} - \frac{A_{dd}}{2} \right) v_{id} + \left(A_{cc} - \frac{A_{cd}}{2} \right) v_{ic}$$

Pentru un amplificator diferential perfect simetric, $A_{dc} = 0$ si $A_{cd} = 0$, deci:

$$v_{o1} = \frac{A_{dd}}{2} v_{id} + A_{cc} v_{ic}$$

$$v_{o2} = -\frac{A_{dd}}{2} v_{id} + A_{cc} v_{ic}$$

Raportul de rejectie a modului comun (CMRR = Common-Mode Rejection Ratio) este:

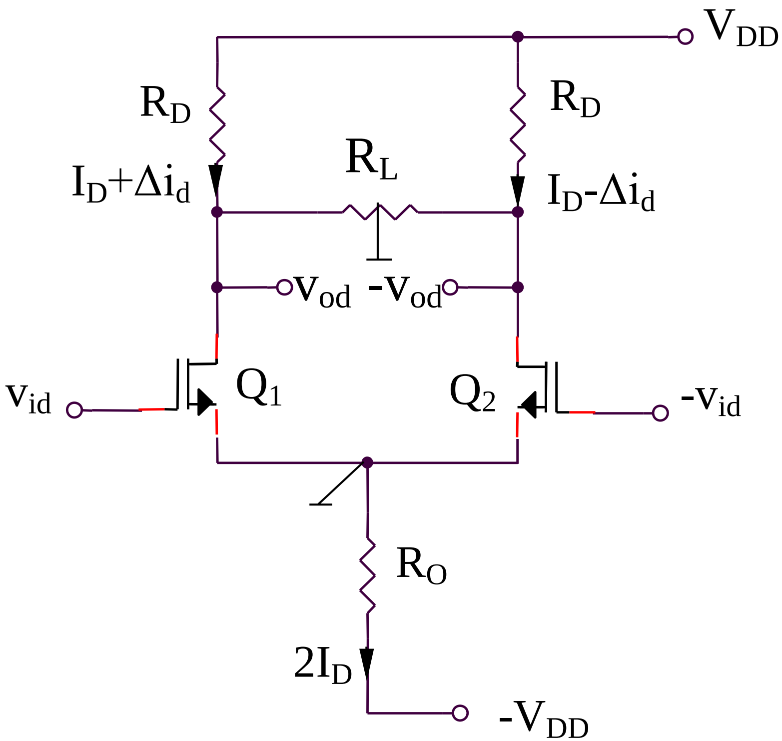
$$CMRR = \left| \frac{A_{dm}}{A_{cm}} \right| = \frac{\left| \frac{v_o}{v_{id}} \right|}{\left| \frac{v_o}{v_{ic}} \right|}$$

A_{dm} si A_{cm} sunt diferite pentru iesire diferentiala ($v_o = v_{od}$), respectiv simpla ($v_o = v_{o1}$ sau v_{o2}).

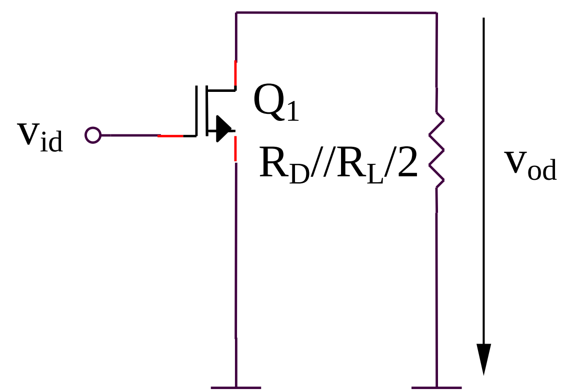
Determinarea amplificarilor de semnal mic: metoda semicircuitului

Mod diferential ($v_{id} \neq 0$, $v_{ic} = 0 \Rightarrow v_{i1} = v_{id}$, $v_{i2} = - v_{id}$)

S-a introdus o rezistenta de sarcina suplimentara (R_L).



(a)



(b)

Amplificarea in tensiune de mod diferential:

$$A_{dd} = \frac{v_{od}}{v_{id}} = -g_{m1}\left(R_D \,//\, \frac{R_L}{2} \right)$$

- iesire simetrica:

$$A = \frac{2v_{od}}{2v_{id}} = A_{dd}$$

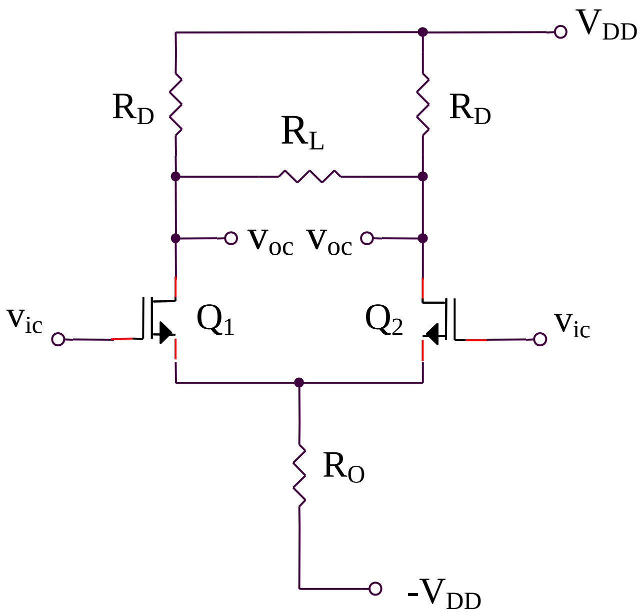
- iesire asimetrica:

$$A = \frac{v_{od}}{2v_{id}} = \frac{A_{dd}}{2}$$

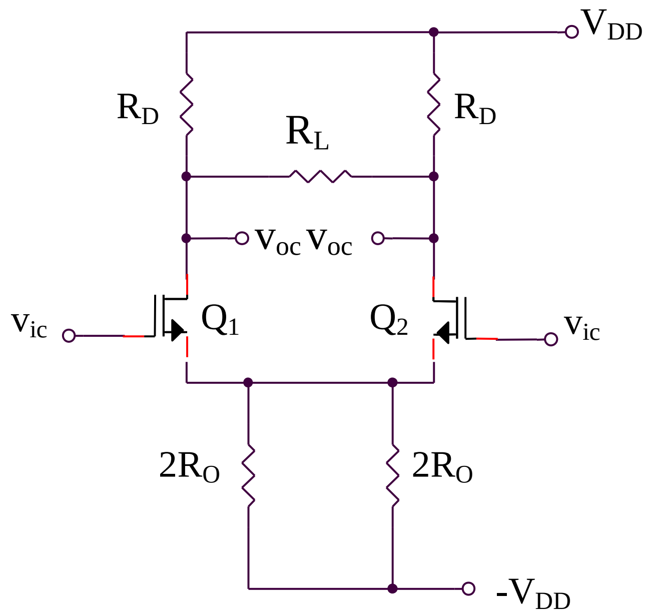
Rezistenta diferentiala de intrare:

$$R_{id} = \infty$$

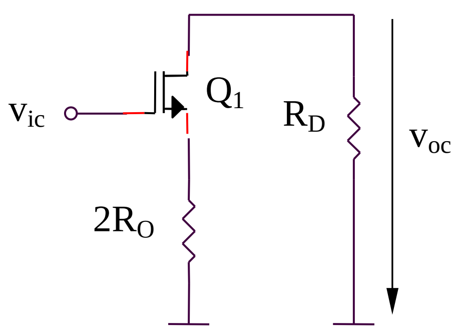
Mod comun ($v_{ic} \neq 0$, $v_{id} = 0 \Rightarrow v_{i1} = v_{ic}$, $v_{i2} = v_{ic}$)



(a)



(b)



(c)

Amplificarea in tensiune de mod comun:

$$A_{cc} = \frac{v_{oc}}{v_{ic}} = -\frac{g_{m1} R_D}{1 + g_{m1} 2 R_O} \cong -\frac{R_D}{2 R_O}$$

Rezistenta de intrare de mod comun:

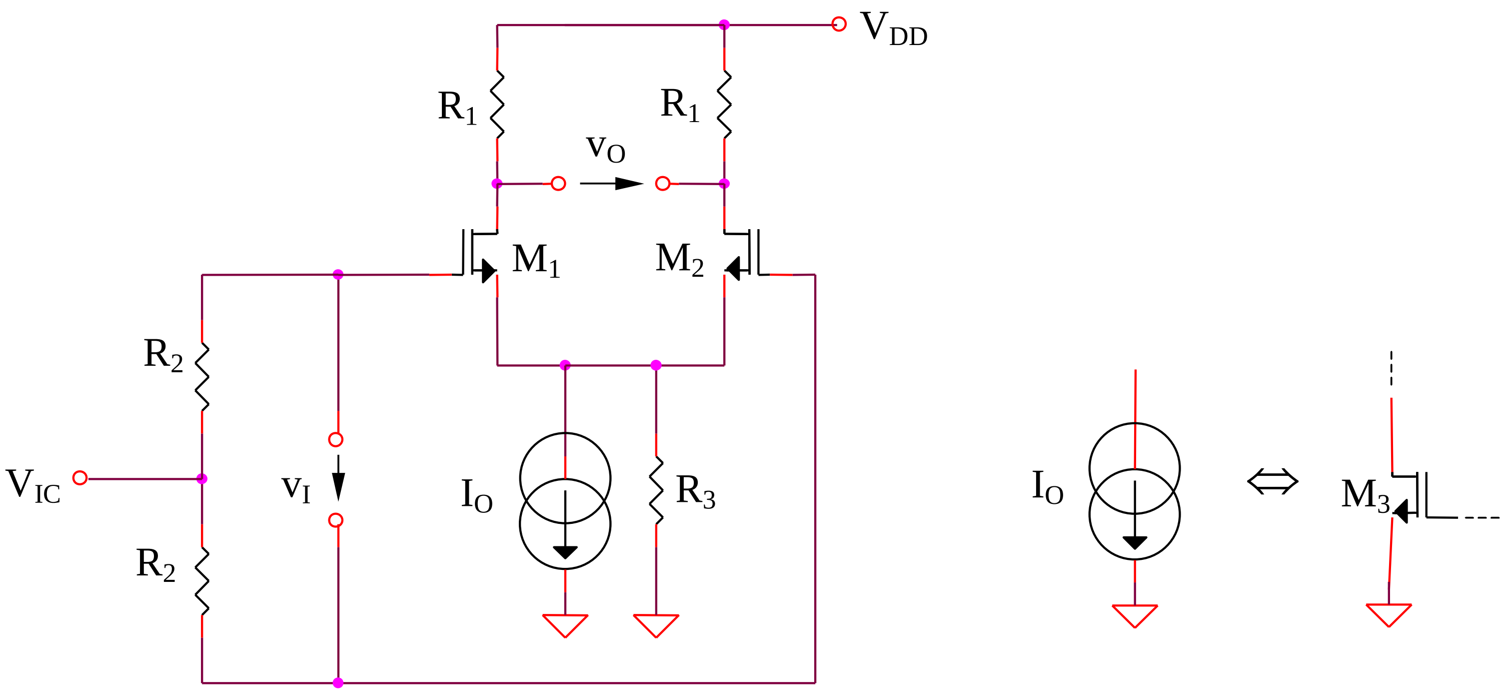
$$R_{ic} = \infty$$

Deci:

$$CMRR = \frac{2 g_{m1} R_L R_O}{2 R_D + R_L}$$

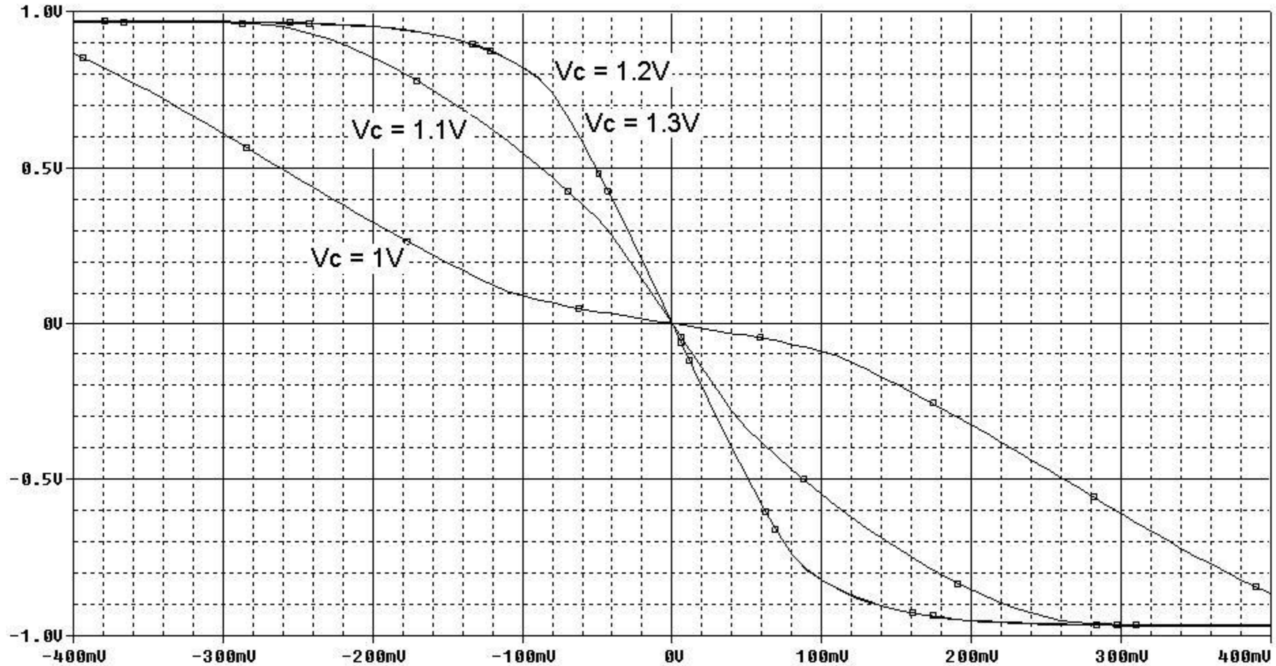
Pentru cresterea CMRR, trebuie marita valoarea rezistentei R_O, prin inlocuirea
Sursei de curent de polarizare printr-o sursa de curent de tip cascod.

Domeniul maxim al tensiunii de intrare de mod comun



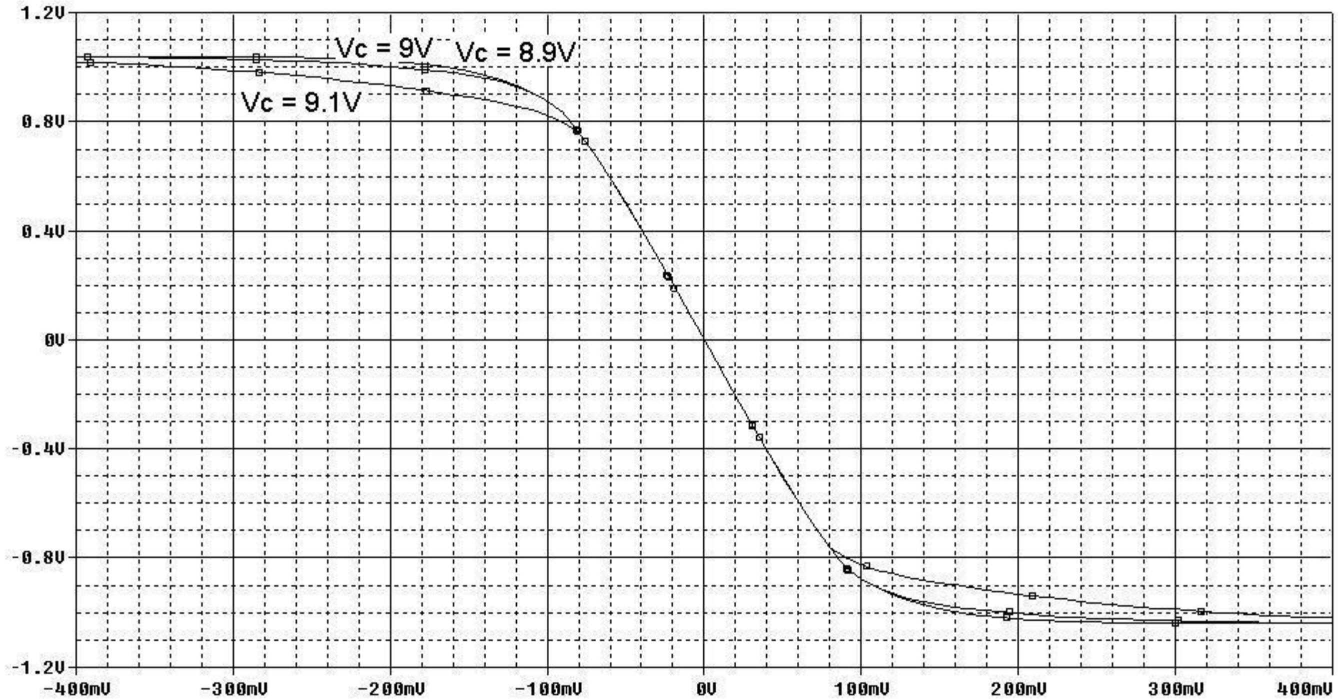
$$V_{IC}^{min} = v_{GS1} + v_{DS3sat} = v_{GS1} + v_{GS3} - V_T = V_T + \left(\sqrt{2}+1\right)\sqrt{\frac{I_O}{K}}$$

$$V_{IC}^{max} = V_{DD} - \frac{I_O R_1}{2} - v_{DS1sat} + v_{GS1} = V_{DD} - \frac{I_O R_1}{2} + V_T$$



Caracteristicile $v_O(v_I)$ pentru tensiuni de intrare de mod comun multiple

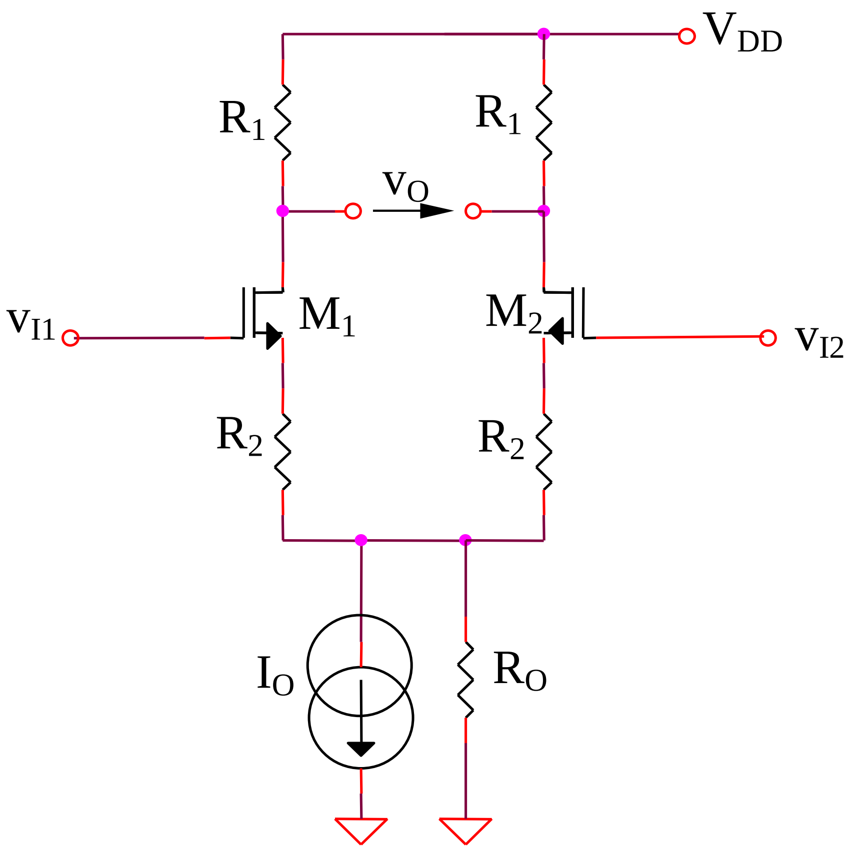
$$V_C^{min} = V_{IC}^{min} \cong 1,2V$$



Caracteristicile $v_O(v_I)$ pentru tensiuni de intrare de mod comun multiple

$$V_C^{max} = V_{IC}^{max} \cong 9V$$

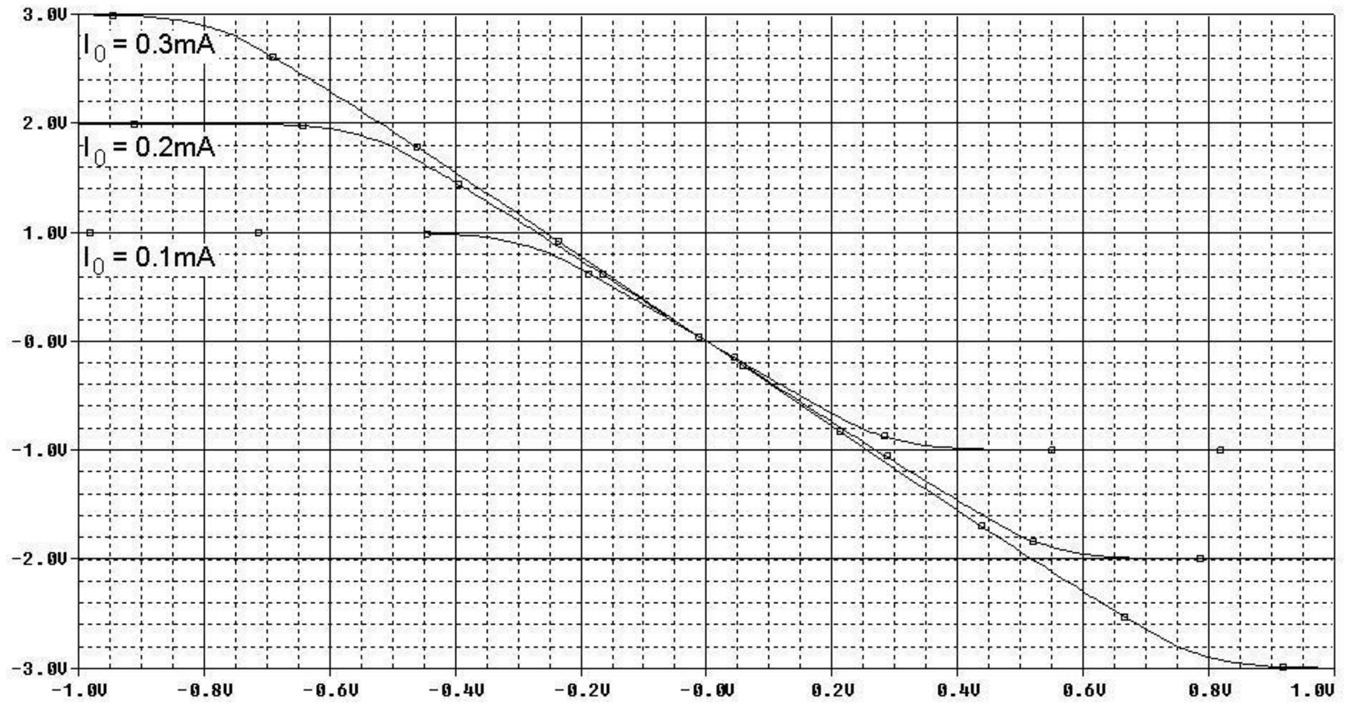
Cresterea domeniului maxim al tensiunii de intrare de mod diferential asociat unei functionari liniare este posibila prin introducerea unor rezistente in sursele tranzistoarelor.



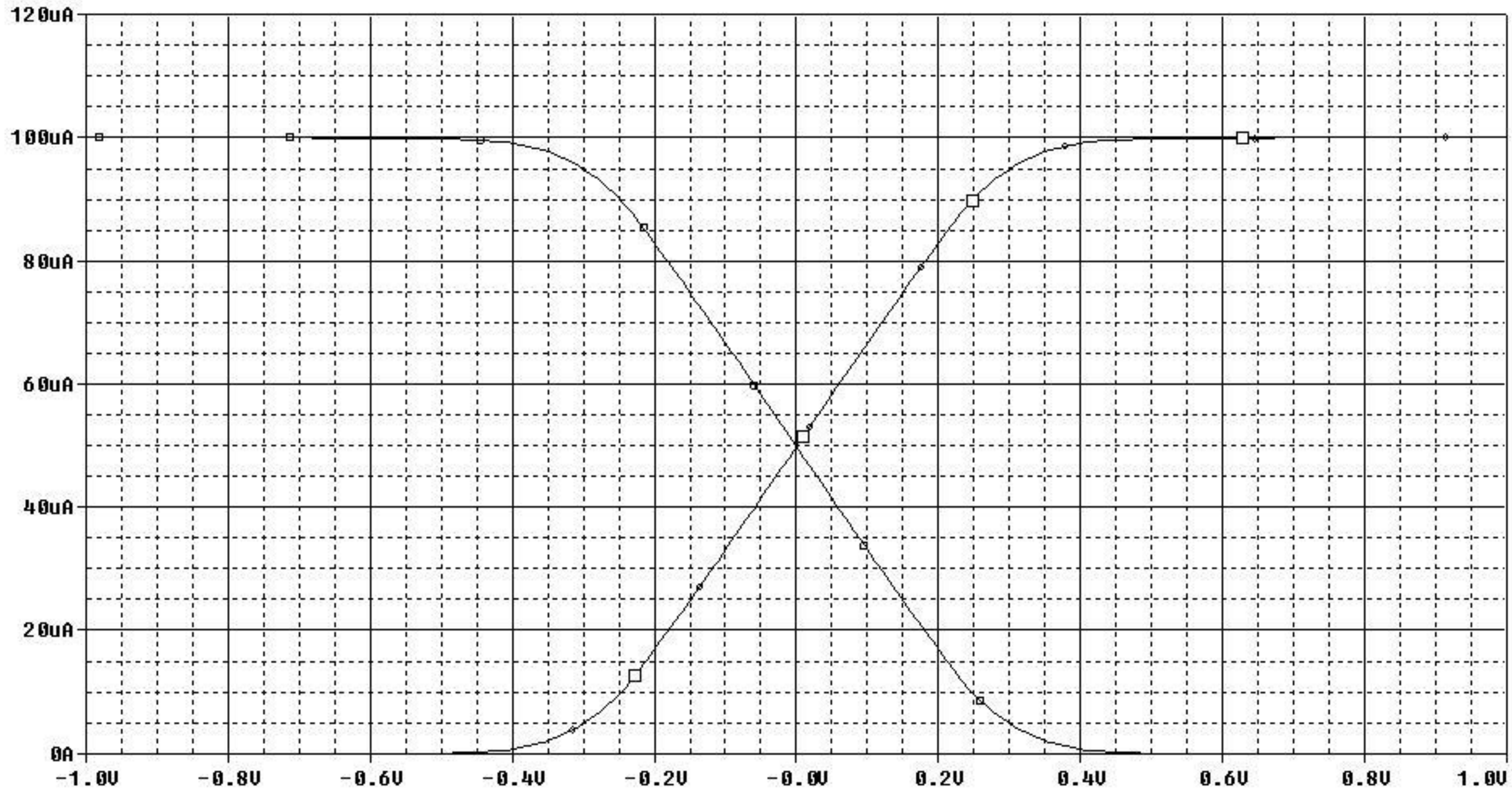
$$A_{dd} = -\frac{g_m R_1}{1 + g_m R_2} \qquad A_{cc} = -\frac{g_m R_1}{1 + g_m (R_2 + 2R_O)}$$

$$V_{IC\,min} = v_{GS1} + v_{DS3sat} + \frac{I_O R_2}{2} = v_{GS1} + v_{GS3} - V_T + \frac{I_O R_2}{2} = V_T + \left(\sqrt{2} + 1\right)\sqrt{\frac{I_O}{K}} + \frac{I_O R_2}{2}$$

$$V_{IC\,max} = V_{DD} - \frac{I_O R_1}{2} - v_{DS1sat} + v_{GS1} = V_{DD} - \frac{I_O R_1}{2} + V_T$$



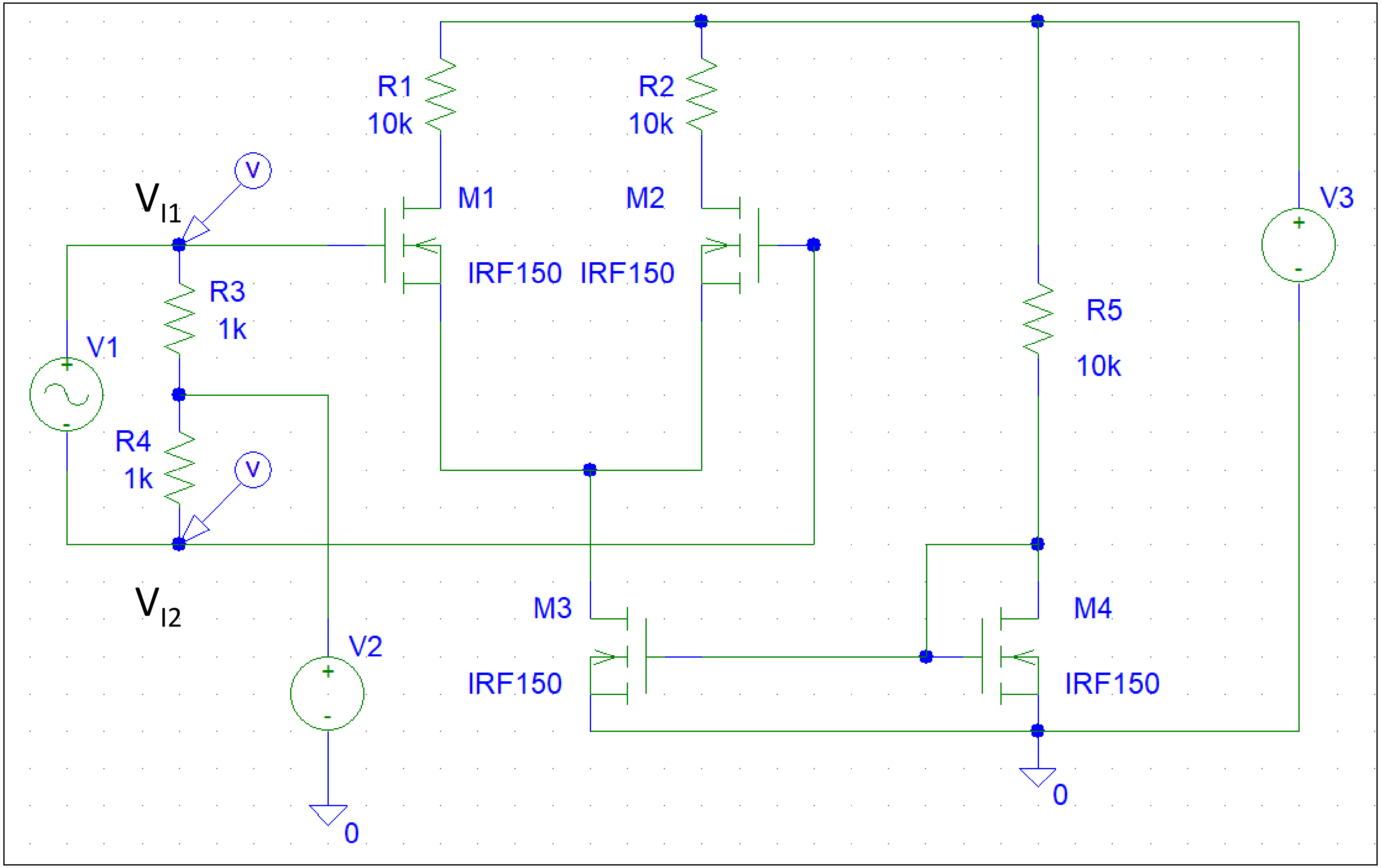
Caracteristicile $v_O(v_I)$ pentru curenti de polarizare multipli



Caracteristicile $i_{D1}, i_{D2}(v_I)$

SIMULARI pentru amplificatorul diferential CMOS
Analiza de mod diferential si semnal mic

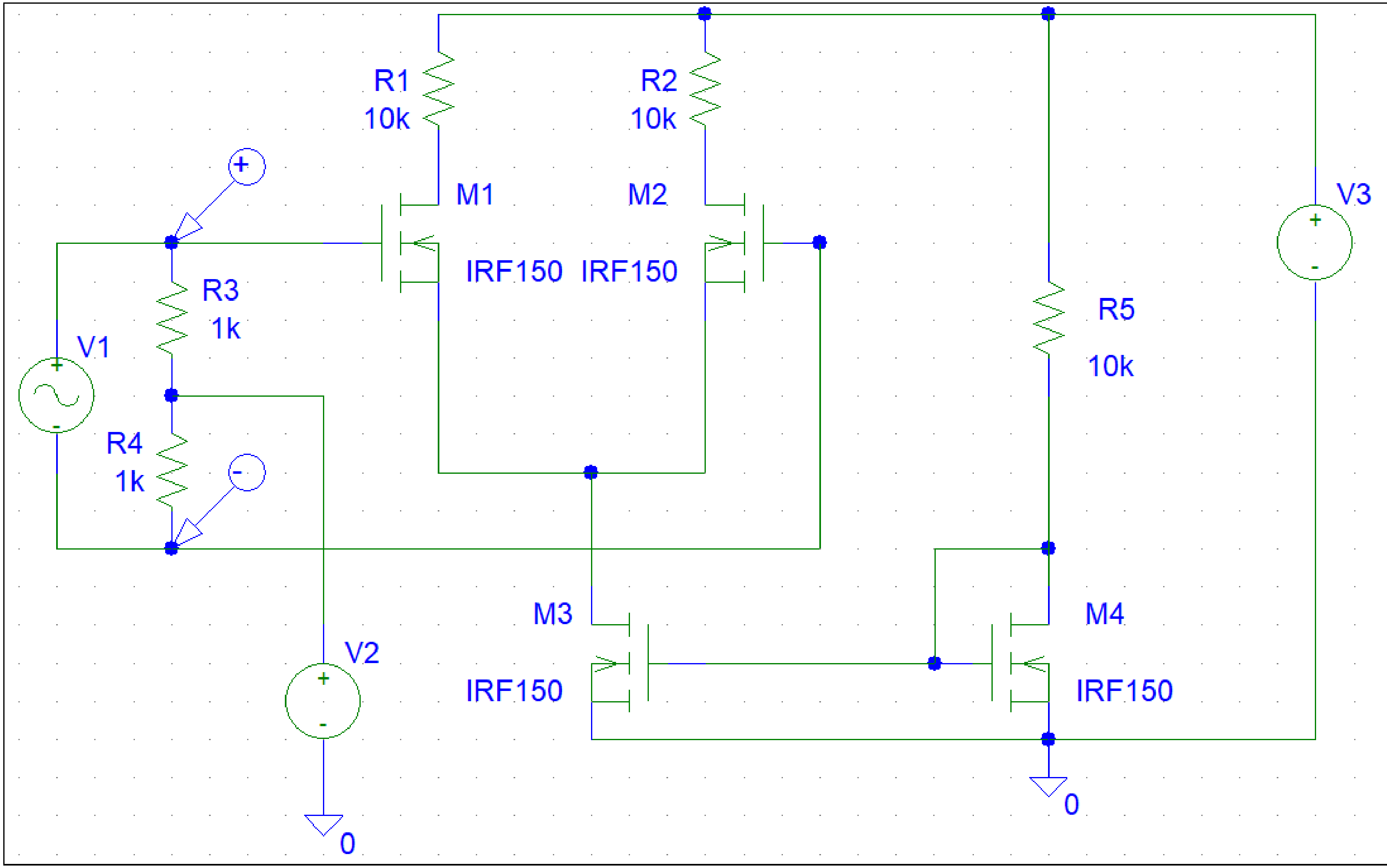
<u>SIM 4.1</u>: $V_{I1}(t)$, $V_{I2}(t)$



v1(t) = (2mV) sin (ωt)

V2 = 3V

SIM 4.2: V1(t)

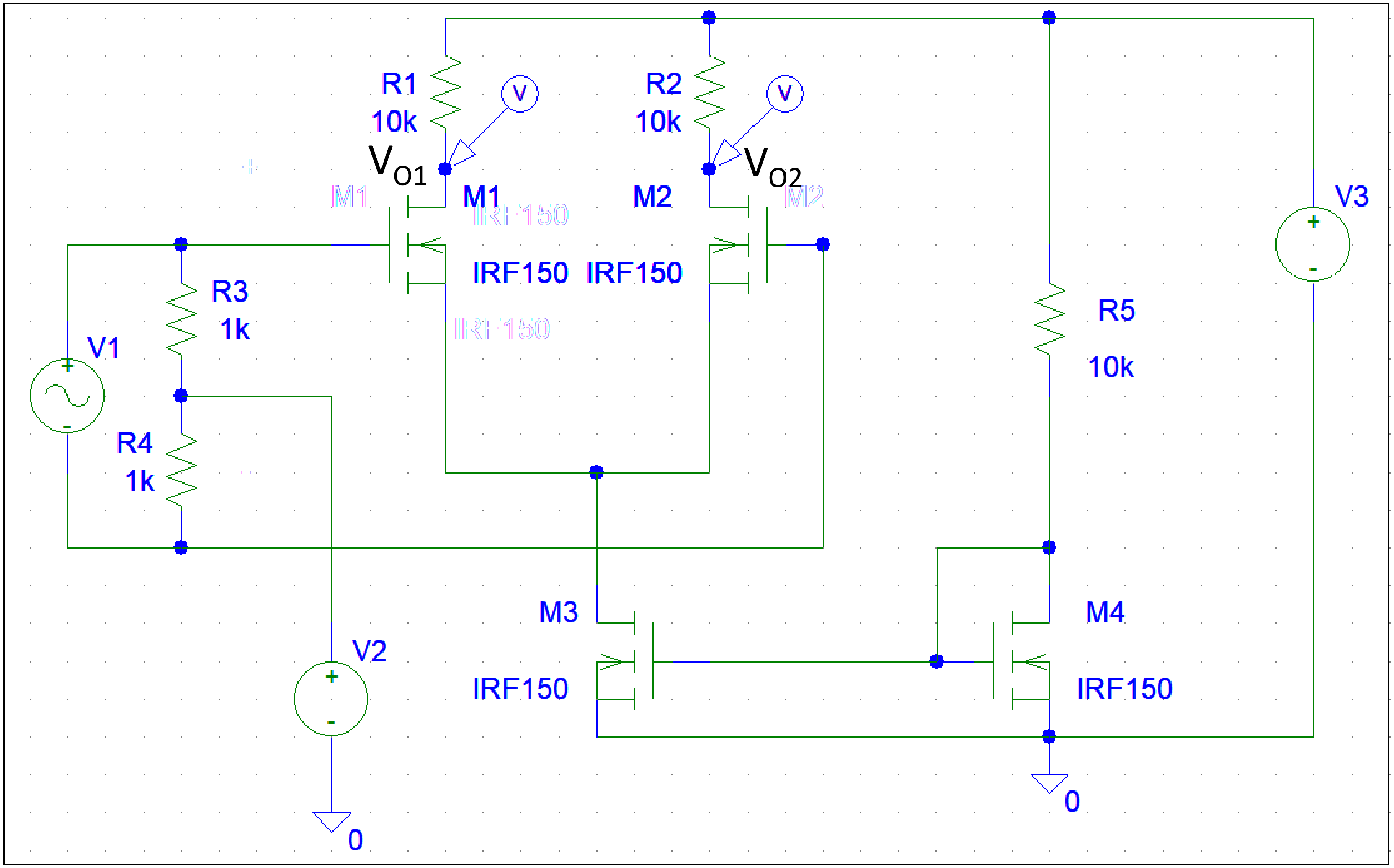


v1(t) = (2mV) sin (ωt)

V2 = 3V

Amplitudine MICA a tensiune de mod diferential (V1 = 2mV)

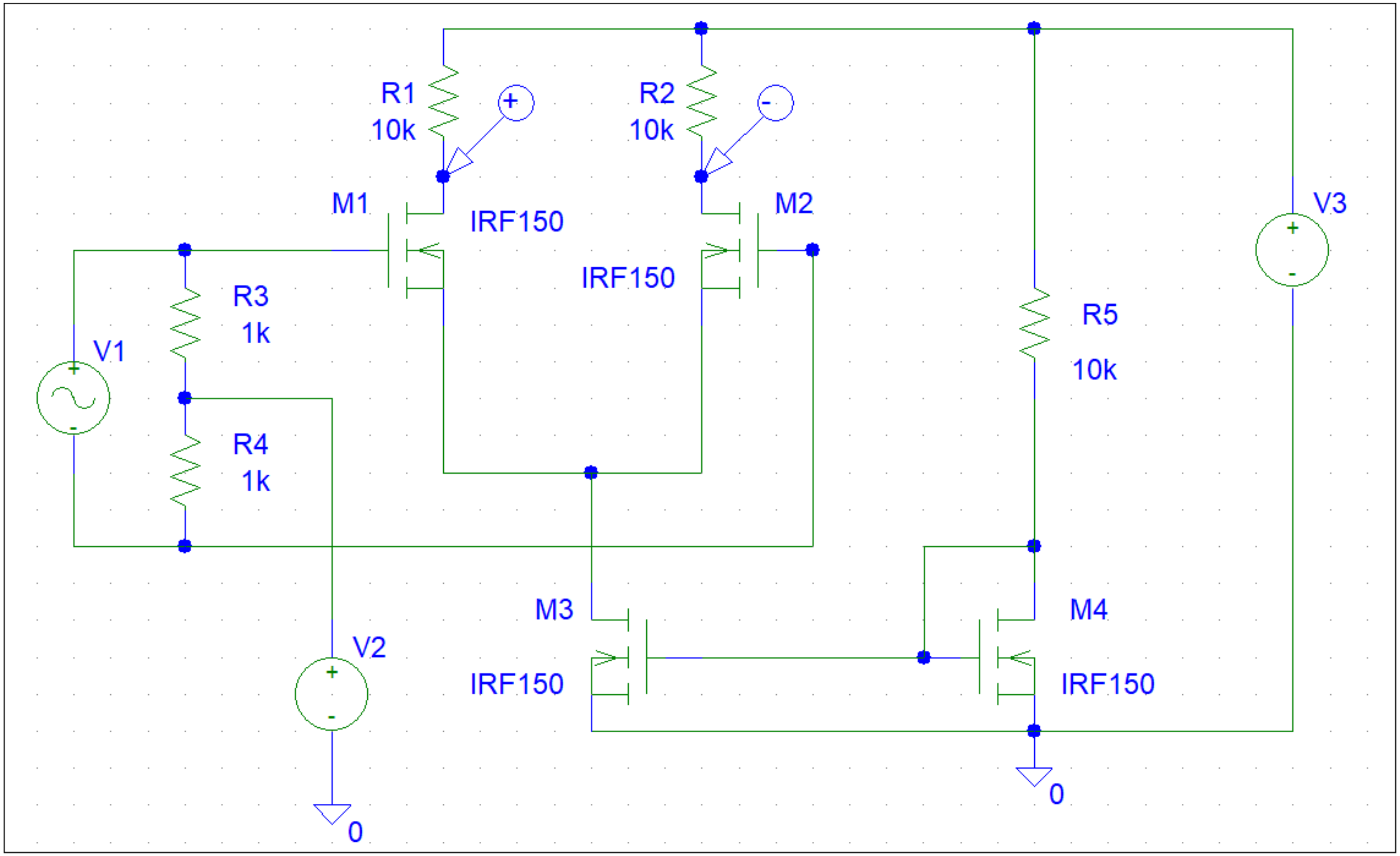
SIM 4.3: $V_{O1}(t)$, $V_{O2}(t)$



Amplitudine MICA a tensiune de mod diferential (V1 = 2mV)

SIM 4.4: Vo(t)

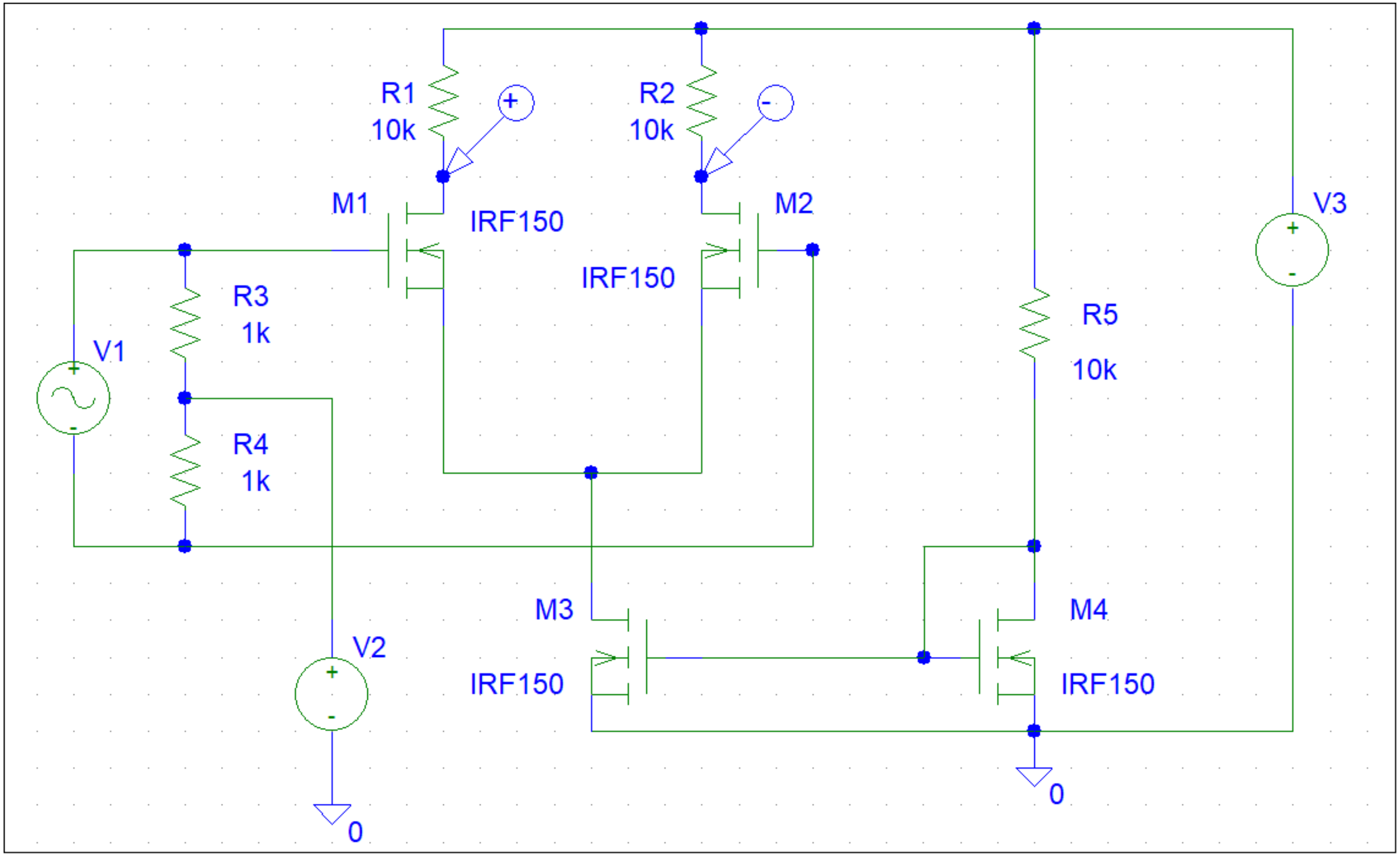
Analiza Fourier



Amplitudine MARE a tensiune de mod diferential (V1 = 15mV)

SIM 4.5: Vo(t)

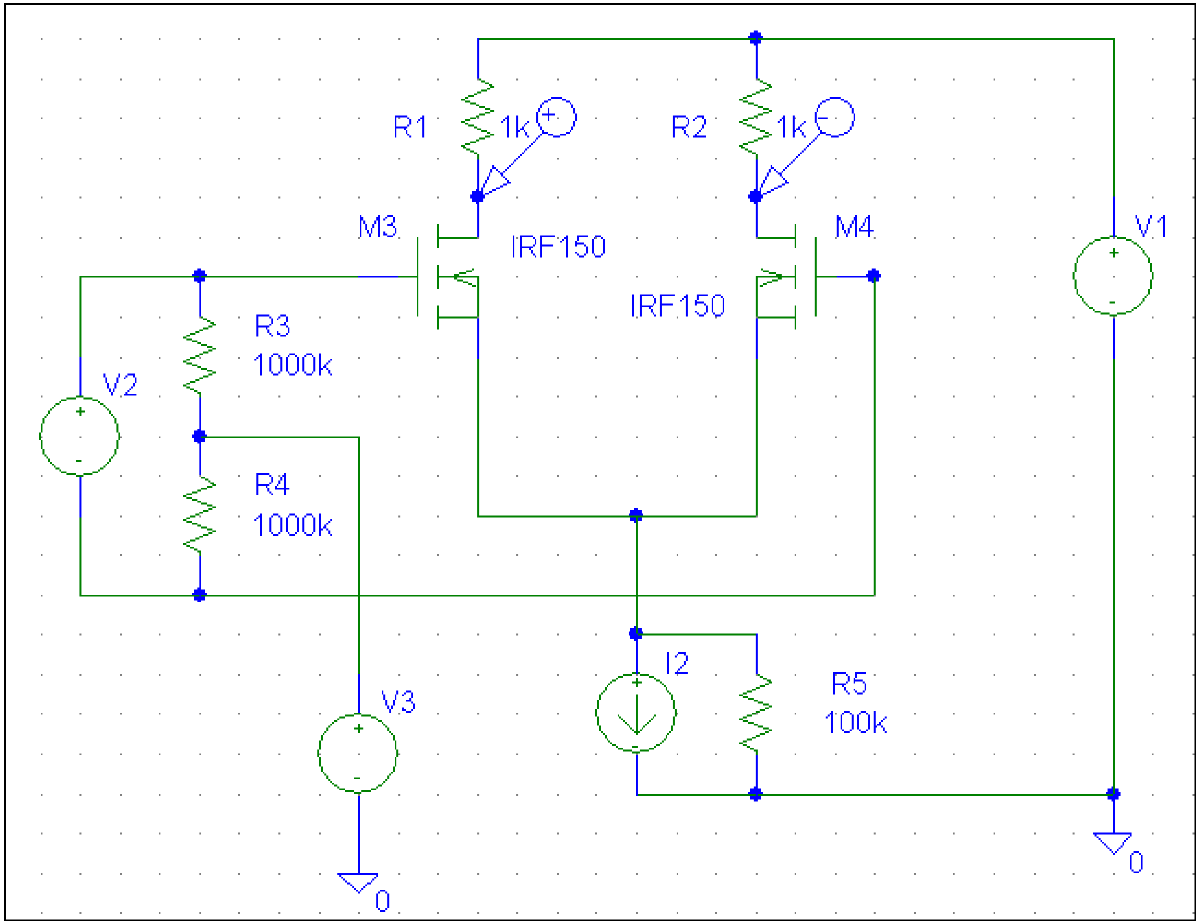
Analiza Fourier



SIMULARI pentru amplificatorul diferential CMOS
Analiza de mod diferential si semnal mare

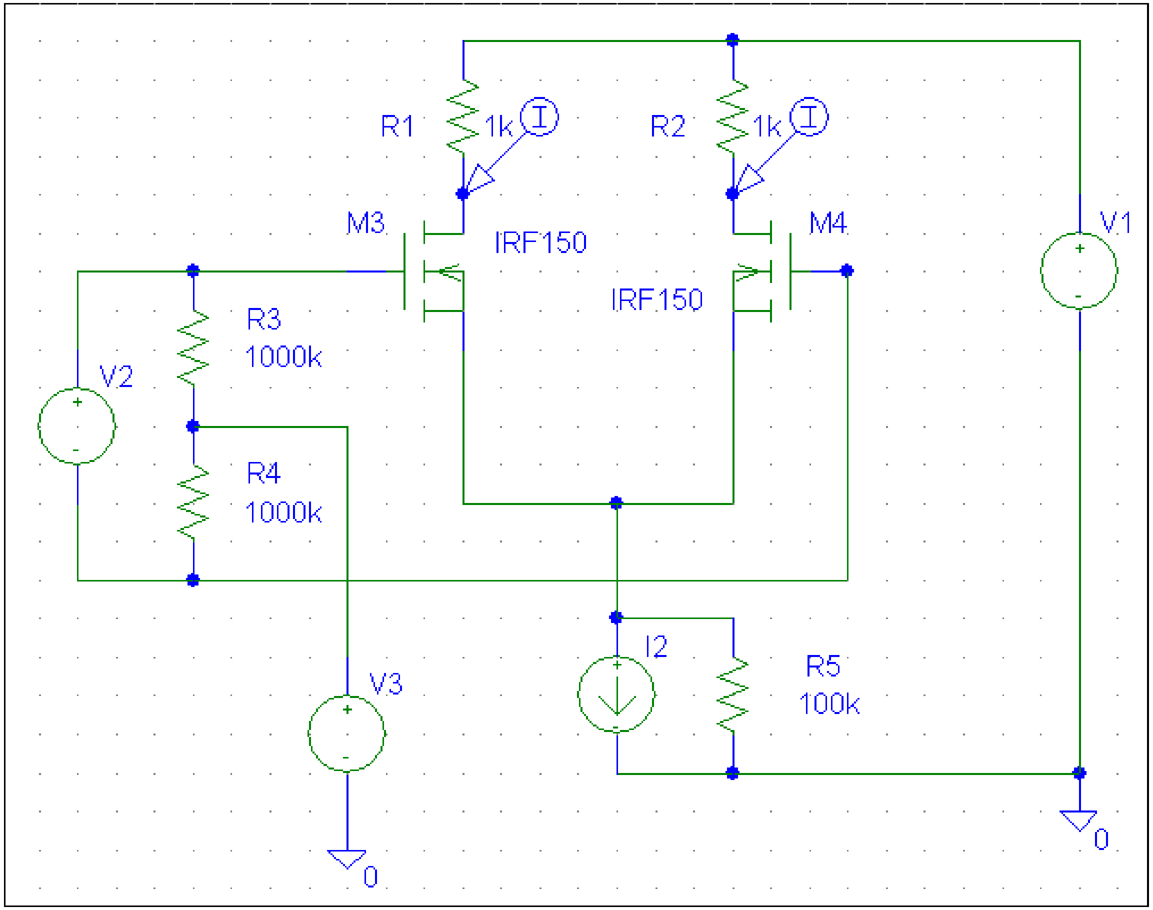
SIMULARI pentru amplificatorul diferential CMOS
Analiza de mod diferential si semnal mare

SIM 4.6: V_O (V2)



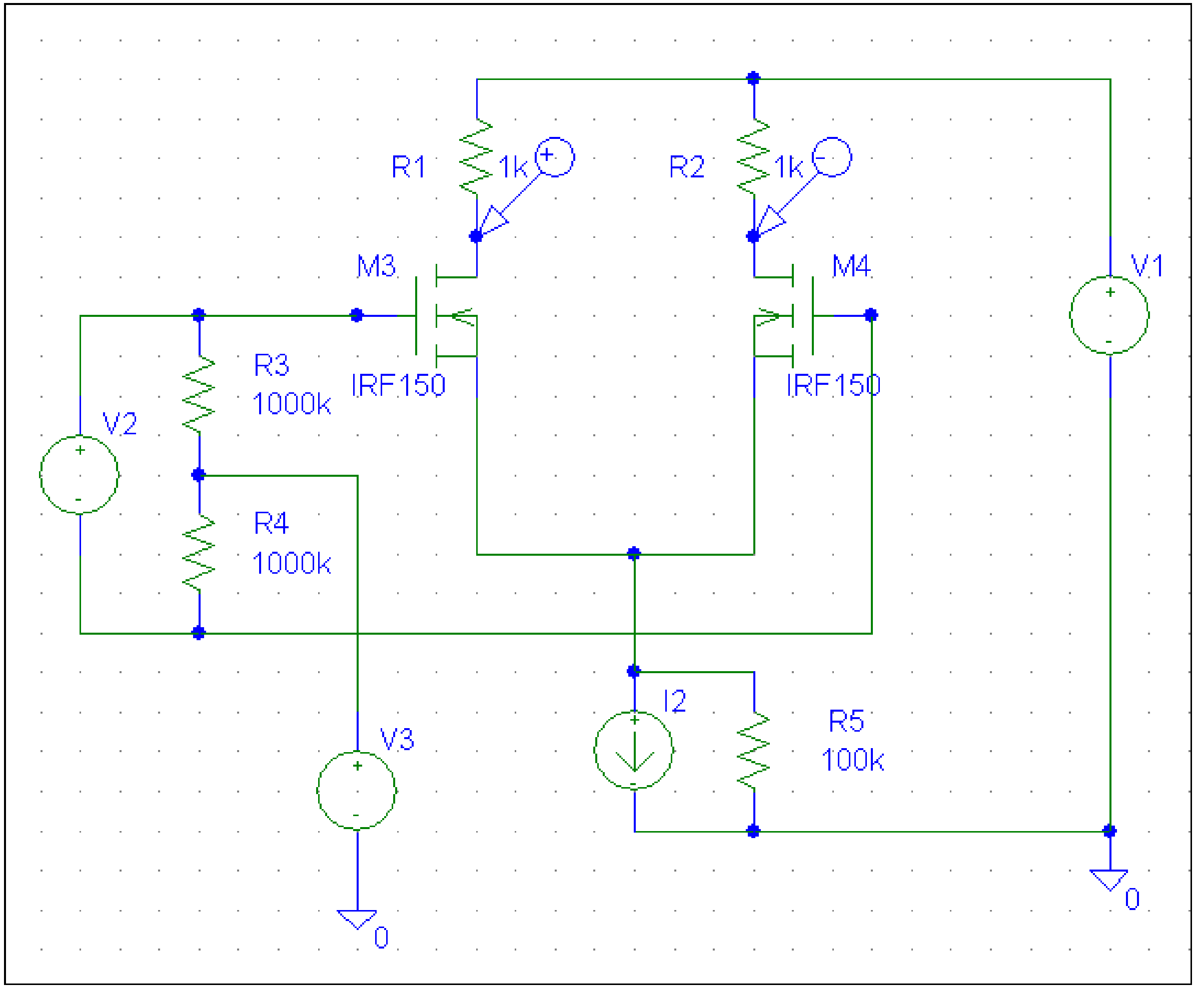
SIMULARI pentru amplificatorul diferential CMOS
Analiza de mod diferential si semnal mare

SIM 4.7: i_{D1}, i_{D2} (V2)



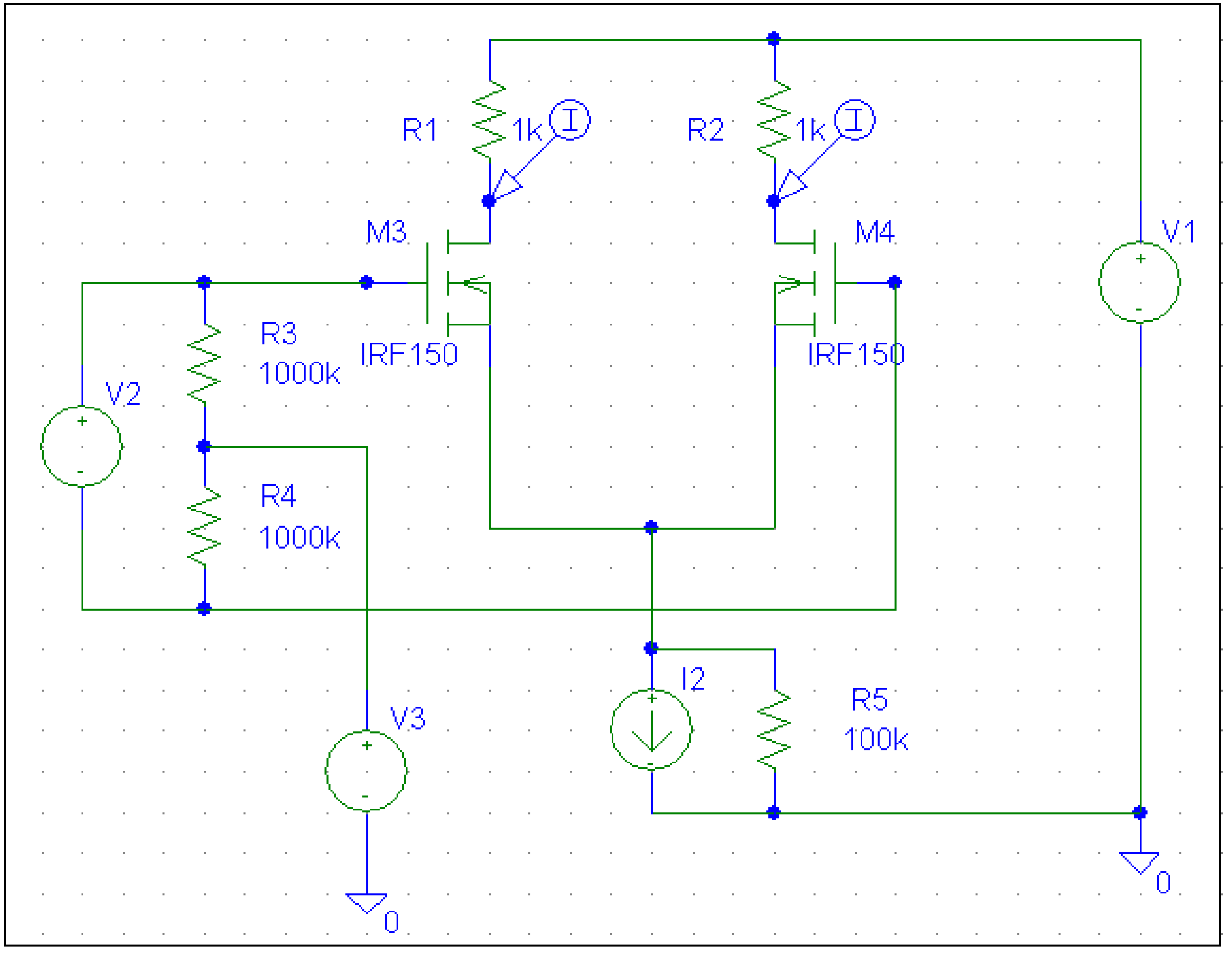
SIMULARI pentru amplificatorul diferential CMOS
Analiza de mod diferential si semnal mare

SIM 4.8: V_O (V2), I2 - parametru



SIMULARI pentru amplificatorul diferential CMOS
Analiza de mod diferential si semnal mare

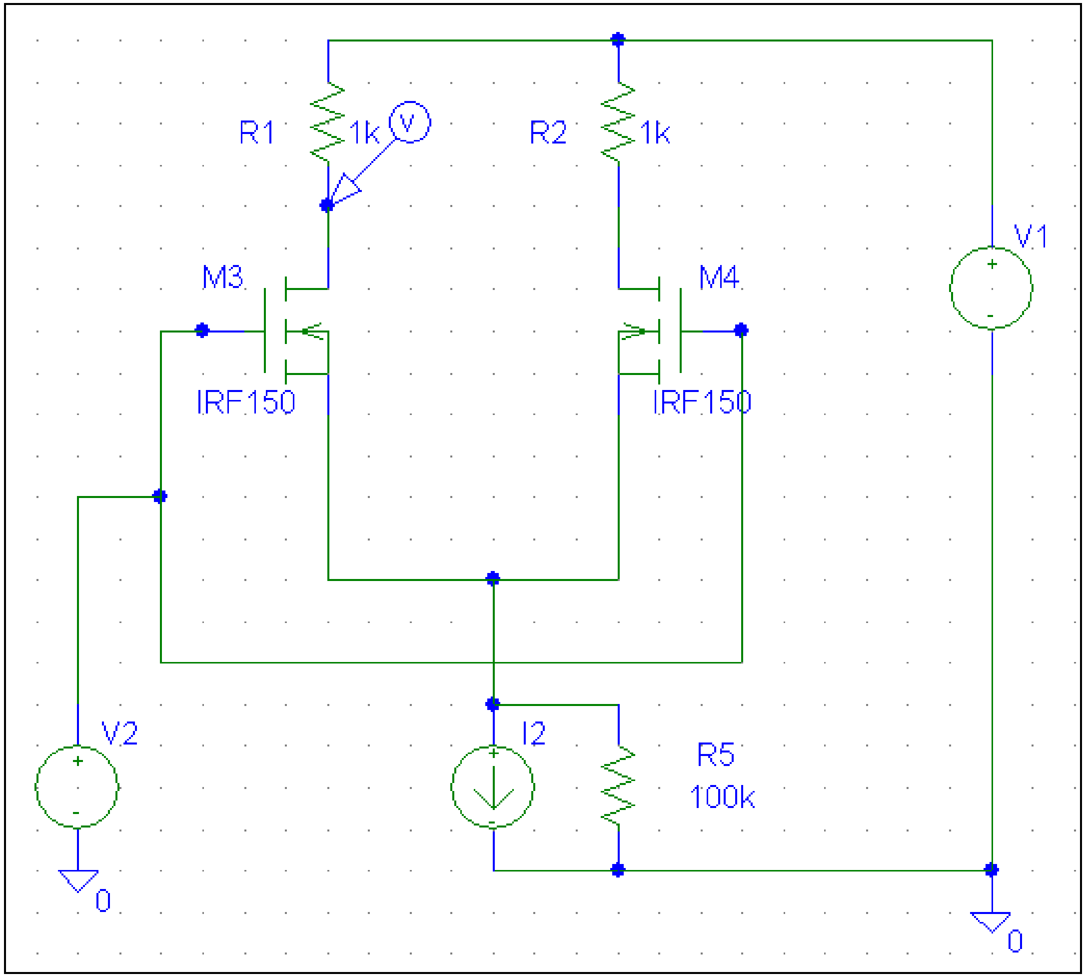
SIM 4.9: i_{D1}, i_{D2} (V2), I2 - parametru



SIMULARI pentru amplificatorul diferential CMOS
Analiza de mod comun si semnal mare

SIMULARI pentru amplificatorul diferential CMOS
Analiza de mod comun si semnal mare

SIM 4.10: V_{C1} (V2)



Tensiunea de offset de intrare

Daca cele doua tranzistoare nu sunt identice, este necesara aplicarea unei tensiuni de intrare nenule (numita tensiune de offset de intrare) in vederea anularii tensiunii de iesire.

$$V_{IO} = v_{GS1} - v_{GS2} = (V_{T1} - V_{T2}) + \left(\sqrt{\frac{2i_{D1}}{K'(W/L)_1}} - \sqrt{\frac{2i_{D2}}{K'(W/L)_2}} \right)$$

$$V_{IO} = \Delta V_T + \sqrt{\frac{2(i_D + \Delta i_D/2)}{K'\left[(W/L) - \Delta(W/L)/2\right]}} - \sqrt{\frac{2(i_D - \Delta i_D/2)}{K'\left[(W/L) + \Delta(W/L)/2\right]}}$$

$$V_{IO} = \Delta V_T + \sqrt{\frac{2i_D}{K'(W/L)}}\left[\sqrt{1 + \frac{\Delta i_D}{2i_D} + \frac{\Delta(W/L)}{2(W/L)}} - \sqrt{1 - \frac{\Delta i_D}{2i_D} - \frac{\Delta(W/L)}{2(W/L)}} \right]$$

Similar amplificatorului diferential bipolar, rezulta:

$$V_{IO} = \Delta V_T + \frac{V_{GS} - V_T}{2}\left[\frac{\Delta i_D}{i_D} + \frac{\Delta(W/L)}{(W/L)} \right]$$

Dar:

$$\left(i_D + \frac{\Delta i_D}{2}\right)\left(R - \frac{\Delta R}{2}\right) = \left(i_D - \frac{\Delta i_D}{2}\right)\left(R + \frac{\Delta R}{2}\right)$$

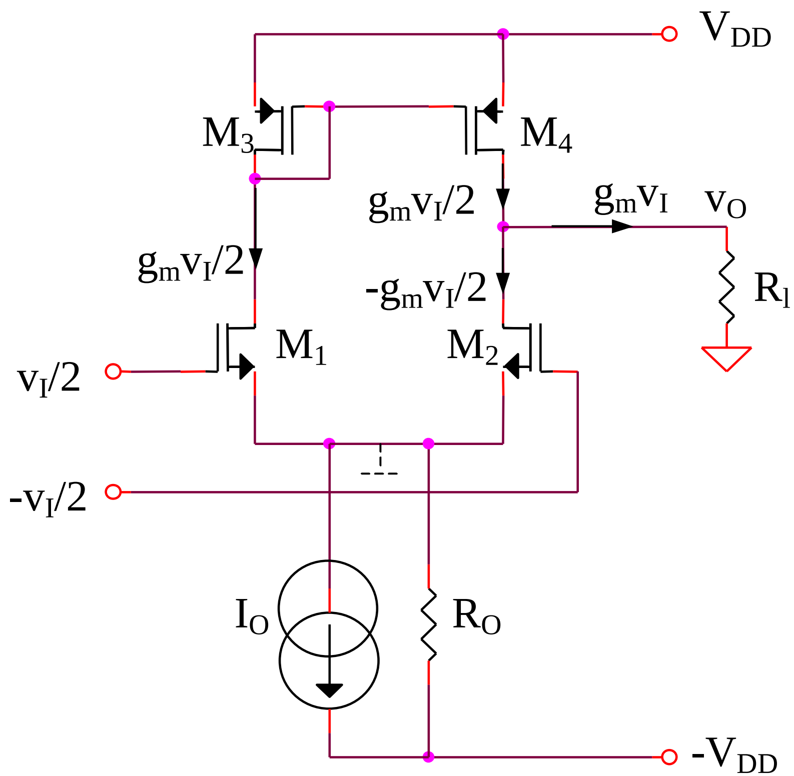
echivalent cu:

$$\frac{\Delta i_D}{i_D} = \frac{\Delta R}{R}$$

Rezulta:

$$V_{IO} = \Delta V_T + \frac{V_{GS} - V_T}{2}\left[\frac{\Delta R}{R} + \frac{\Delta (W/L)}{(W/L)}\right]$$

4.3.2. Amplificatorul diferential CMOS elementar cu sarcina activa

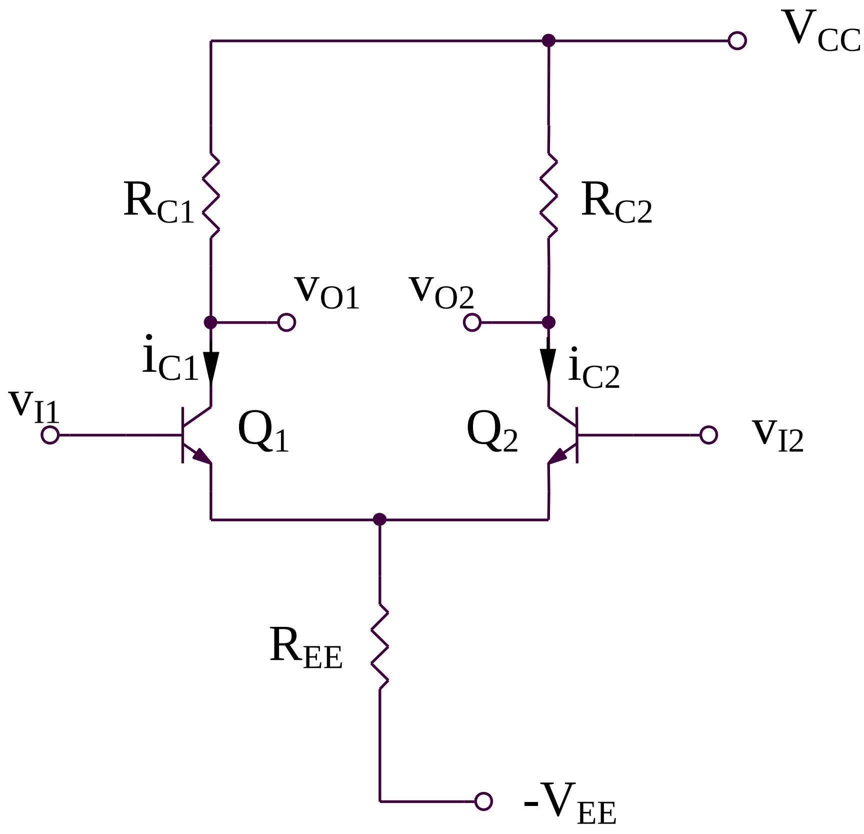


$$A_{dd} = g_m \left(r_{ds2} // r_{ds4} // R_l \right)$$

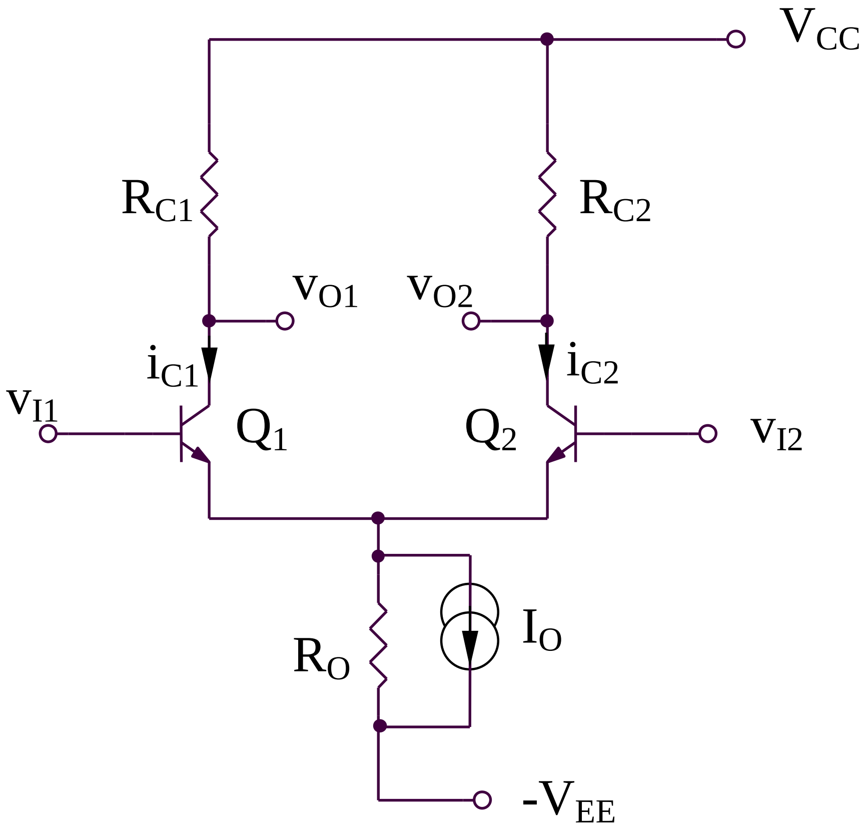
$$A_{dd} \Big|_{R_l \to \infty} = g_m \left(r_{ds2} // r_{ds4} \right) = g_m \frac{r_{ds}}{2} = \frac{1}{2\lambda} \sqrt{\frac{K}{I_O}}$$

4.4. Amplificatoare diferentiale bipolare elementare

4.4.1. Amplificatorul diferential bipolar elementar cu sarcina pasiva



(a)



(b)

Analiza de semnal mare

$$I_O = i_{E1} + i_{E2}$$

$$I_O = \frac{i_{C1} + i_{C2}}{\alpha}$$

$$\alpha I_O = I_S\left(e^{\frac{v_{BE1}}{V_{th}}} + e^{\frac{v_{BE2}}{V_{th}}}\right)$$

$$\alpha I_O = I_S e^{\frac{v_{BE1}}{V_{th}}}\left(1 + e^{\frac{v_{BE2} - v_{BE1}}{V_{th}}}\right)$$

Dar:

$$i_{C1} = I_S e^{\frac{v_{BE1}}{V_{th}}}$$

$$v_{BE2} - v_{BE1} = v_{I2} - v_{I1}$$

Expresiile curentilor de colector:

$$i_{C1} = \frac{\alpha I_O}{1 + e^{\frac{v_{I2} - v_{I1}}{V_{th}}}}$$

$$i_{C2} = \frac{\alpha I_O}{1 + e^{\frac{v_{I1} - v_{I2}}{V_{th}}}}$$

Expresiile i_{C1} si i_{C2} se pot dezvolta in serii Taylor:

$$\frac{i_{C1}(x)}{I_O} = \frac{1}{1+e^{-x}} = \frac{1}{2} + \frac{x}{4} - \frac{x^3}{48} + \ldots$$

$$\frac{i_{C2}(x)}{I_O} = \frac{1}{1+e^{x}} = \frac{1}{2} - \frac{x}{4} + \frac{x^3}{48} - \ldots$$

$$x = \frac{v_{I1} - v_{I2}}{V_{th}}$$

$$\alpha = 1$$

Deci, tangenta la caracteristica $i_{C1}(x)/I_O$ are urmatoarea ecuatie:

$$y = \frac{1}{2} + \frac{x}{4}$$

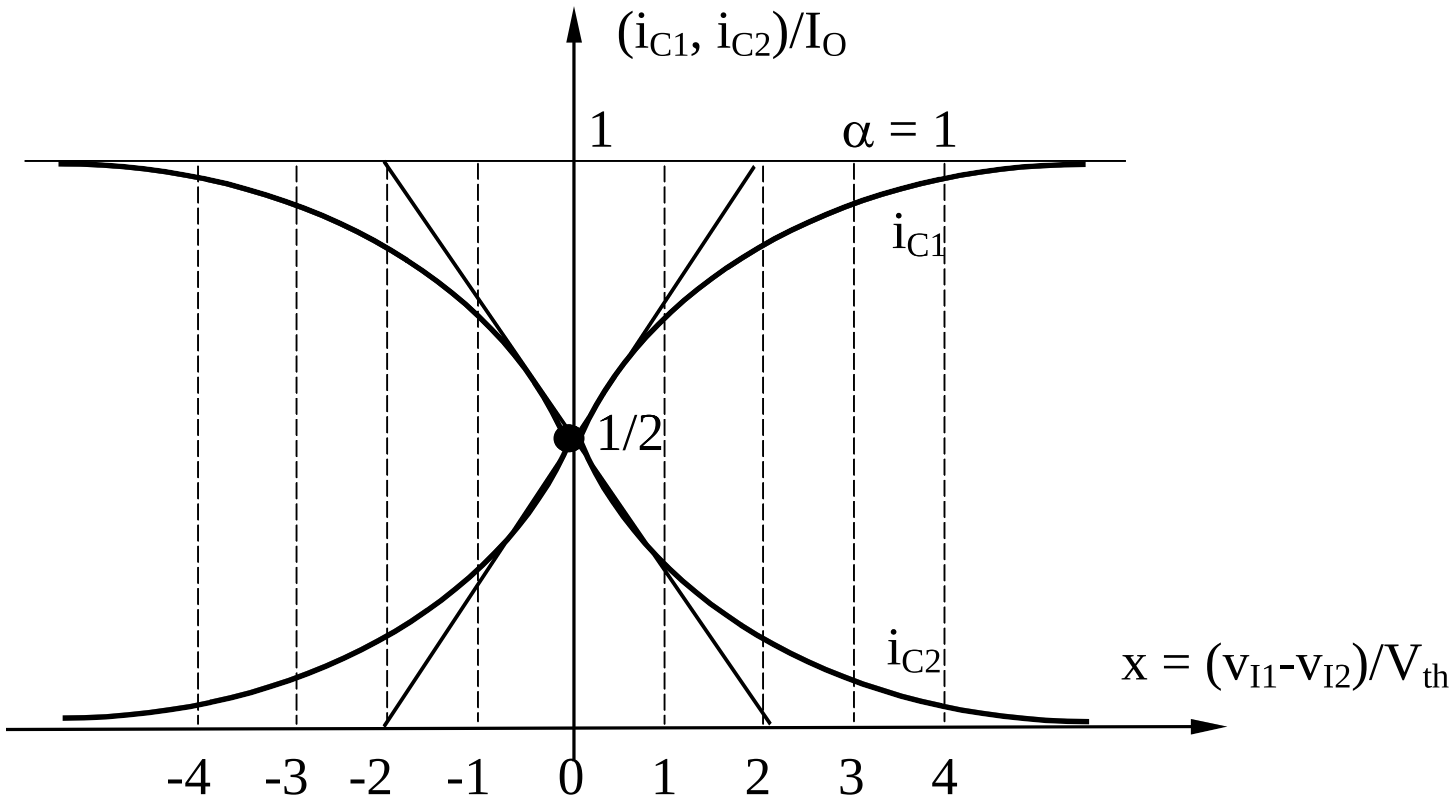
Daca:

$$y = 0 \Rightarrow x = -2 \Rightarrow v_{I1} - v_{I2} = -2V_{th} = -50mV$$

Remarci:

- pentru $v_{I1} = v_{I2}$ (sau x = 0), $i_{C1} = i_{C2} = I_O/2$
- pentru o functionare aproximativ liniara, amplitudinea maxima a tensiunii de intrare trebuie sa fie mai mica decat $2V_{th}$ (x =2), deci aproximativ 50mV

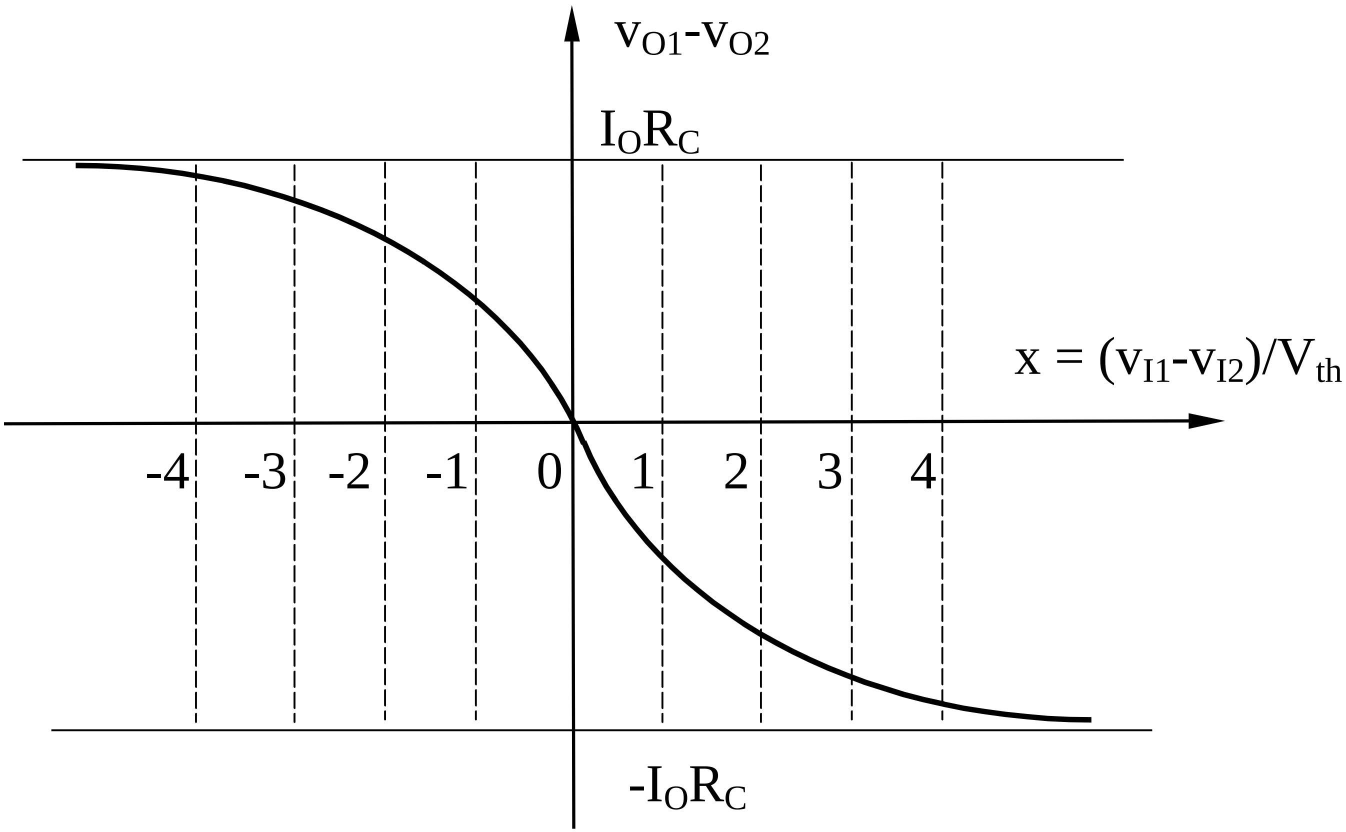
Caracteristicile statice $(i_{C1}, i_{C2})/I_O = f\,[(v_{I1}-v_{I2})/V_{th}]$ ale amplificatorului diferential bipolar



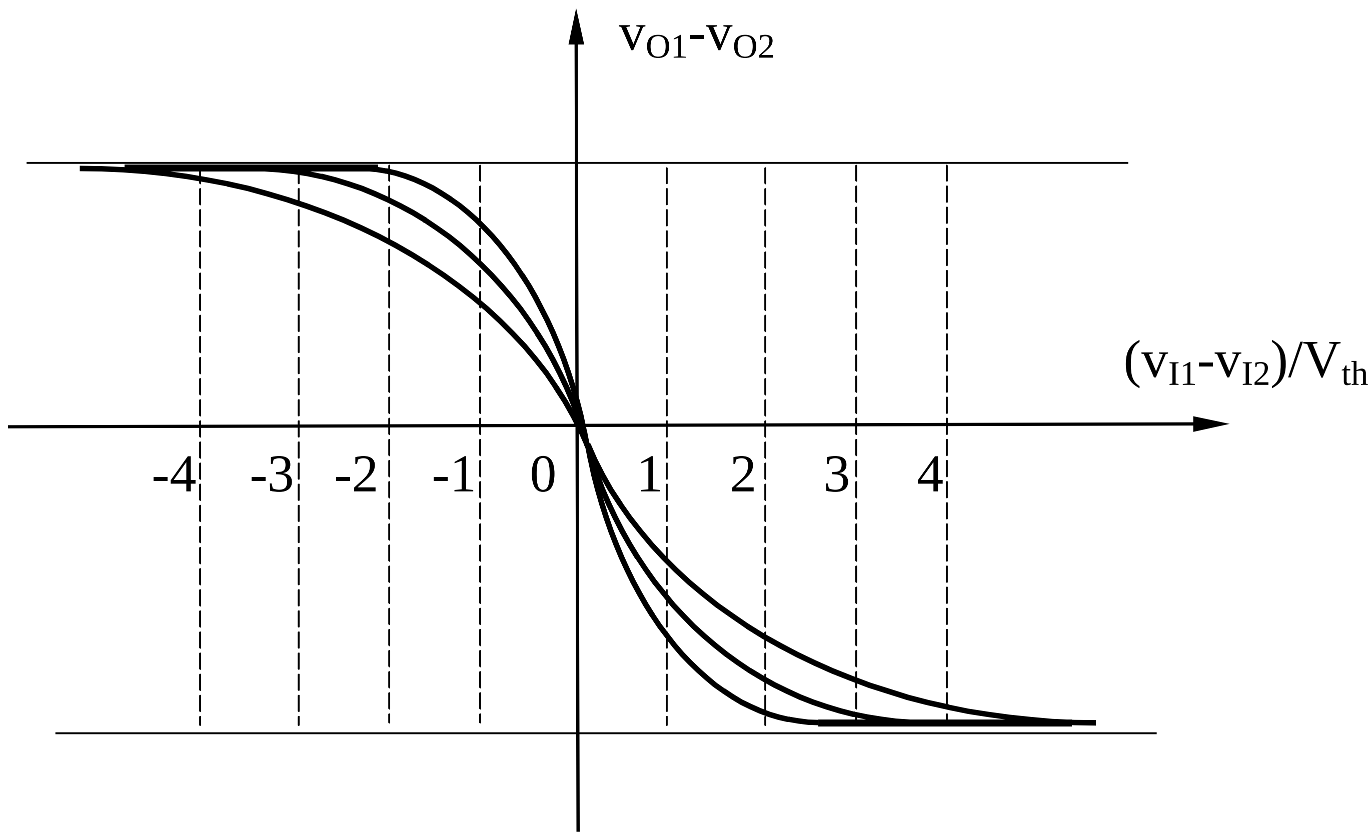
Tensiunea de iesire simetrica are expresia:

$$v_O = v_{O1} - v_{O2} = (i_{C2} - i_{C1})R_C = \left(-\frac{x}{2} + \frac{x^3}{24} - ...\right) I_O R_C$$

Caracteristica statica v_{O1}-v_{O2} = f [(v_{I1}-v_{I2})/V_{th}] a amplificatorului diferential bipolar



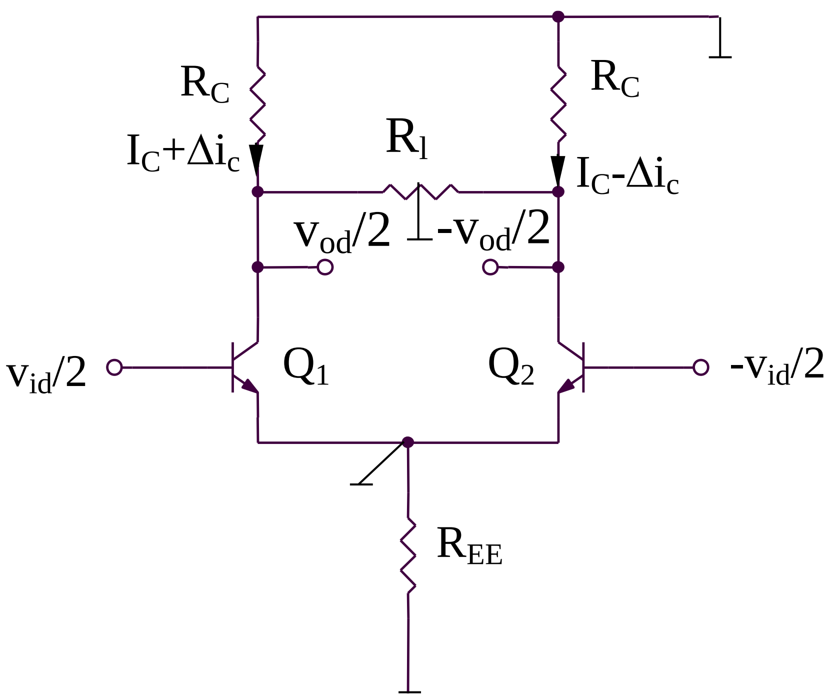
Cresterea domeniului maxim al tensiunii de intrare (pentru o functionare liniara) – prin introducerea unor rezistente serie in emitor



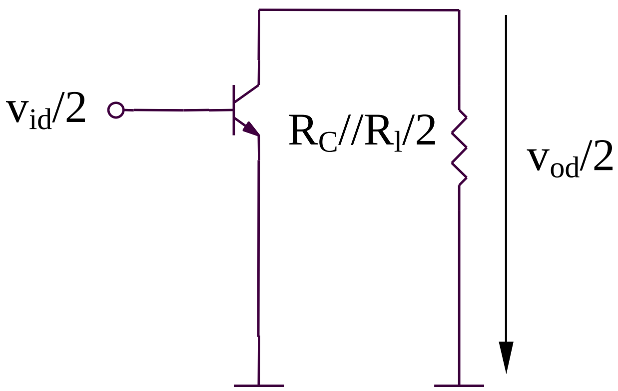
Analiza de semnal mic

Determinarea amplificarilor: metoda semicircuitului

Mod diferential ($v_{id} \neq 0$, $v_{ic} = 0 \Rightarrow v_{i1} = v_{id}/2$, $v_{i2} = - v_{id}/2$)
S-a introdus rezistenta de sarcina suplimentara (R_l).



(a)



(b)

Amplificarea semicircuitului:

$$A = \frac{v_{od}/2}{v_{id}/2} = \frac{v_{od}}{v_{id}} = -g_m\left(R_C // \frac{R_l}{2}\right)$$

Amplificarea de mod diferential:

- iesire diferentiala (simetrica):

$$A_{dd} = \frac{v_{od}/2 - (-v_{od}/2)}{v_{id}/2 - (-v_{id}/2)} = \frac{v_{od}}{v_{id}} = A = -g_m\left(R_C // \frac{R_l}{2}\right)$$

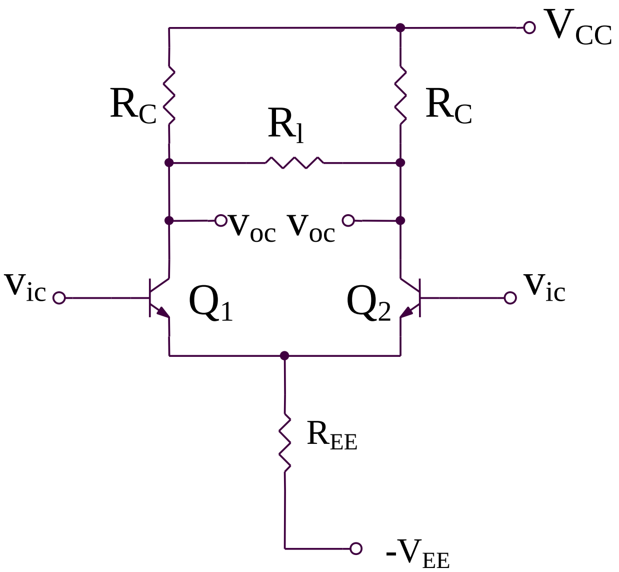
- iesire simpla (asimetrica)

$$A_{dd} = \frac{v_{od}/2}{v_{id}/2 - (-v_{id}/2)} = \frac{1}{2}\frac{v_{od}}{v_{id}} = \frac{A}{2} = -\frac{1}{2}g_m\left(R_C // \frac{R_l}{2}\right)$$

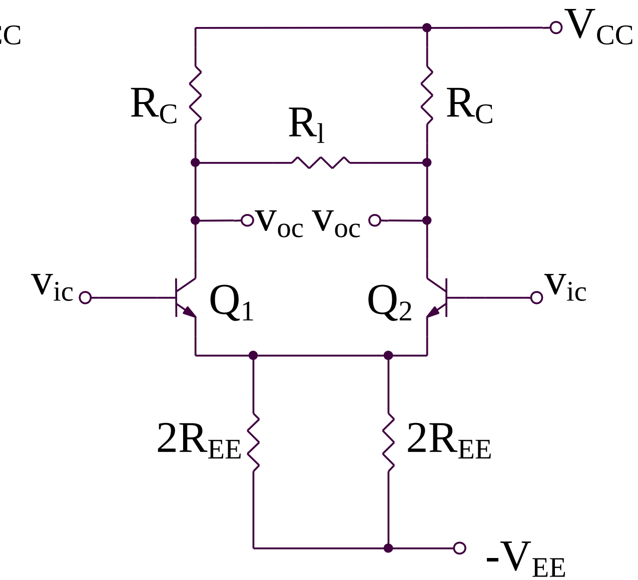
Rezistenta de intrare de mod diferential:

$$R_{id} = 2r_\pi$$

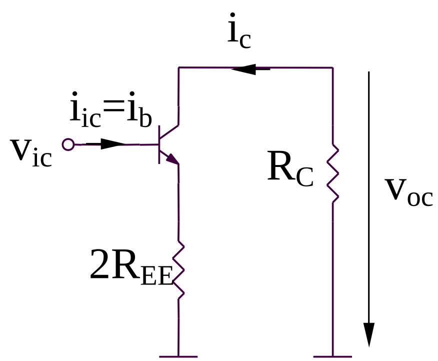
Mod comun ($v_{ic} \neq 0, v_{id} = 0 \Rightarrow v_{i1} = v_{ic}, v_{i2} = -v_{ic}$)



(a)



(b)



(c)

Amplificarea de mod comun:

$$A_{cc} = \frac{v_{oc}}{v_{ic}} = -\frac{\beta_0 R_C}{r_\pi + (\beta_0 + 1) 2 R_{EE}} \cong -\frac{R_C}{2 R_{EE}}$$

Rezistenta de intrare de mod comun:

$$R_{ic} = \frac{v_{ic}}{i_{ic}} = r_\pi + (\beta_0 + 1) 2 R_{EE}$$

Raportul de rejectie a modului comun (CMRR) - caracterizeaza capacitatea amplificatorului diferential de a amplifica semnalele de mod diferential si de a rejecta semnalele de mod comun.

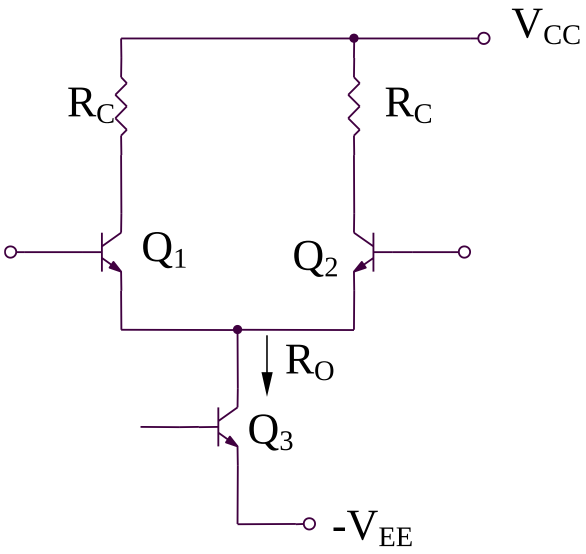
- pentru iesire diferentiala (v_{od} = 0 pentru v_{ic}, deci $A_{cm} = A_{cd} = 0$), deci:

$$CMRR = \left|\frac{A_{dm}}{A_{cm}}\right| = \left|\frac{A_{dd}}{A_{cd}}\right| = \left|\frac{-g_m R_C}{0}\right| = \infty$$

- pentru iesire simpla ($v_o = v_{o1}$ sau v_{o2})

$$CMRR = \left|\frac{A_{dm}}{A_{cm}}\right| = \left|\frac{A_{dd} / 2}{A_{cc}}\right| = \left|\frac{-g_m R_C / 2}{-R_C / 2 R_{EE}}\right| = g_m R_{EE}$$

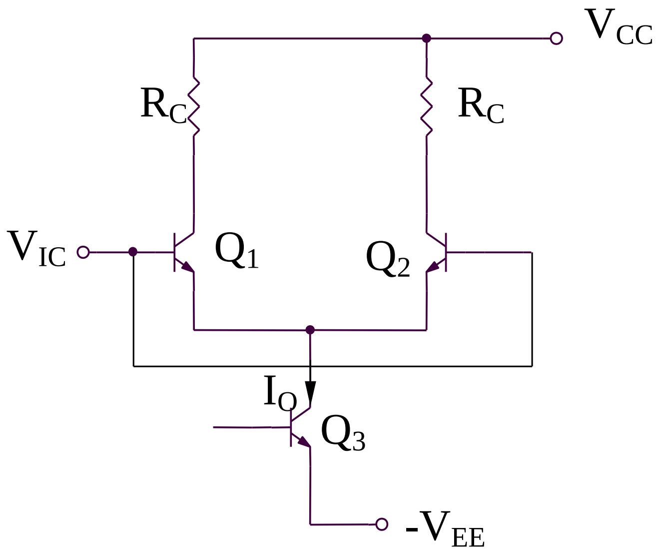
Pentru cresterea CMRR, este necesara inlocuirea rezistentei R_{EE} cu o sursa de curent.



R_O reprezinta rezistenta de iesire a sursei de curent.

$$A_{cc} = -\frac{R_C}{2R_O}$$

Determinarea domeniului maxim al tensiunii de intrare de mod comun



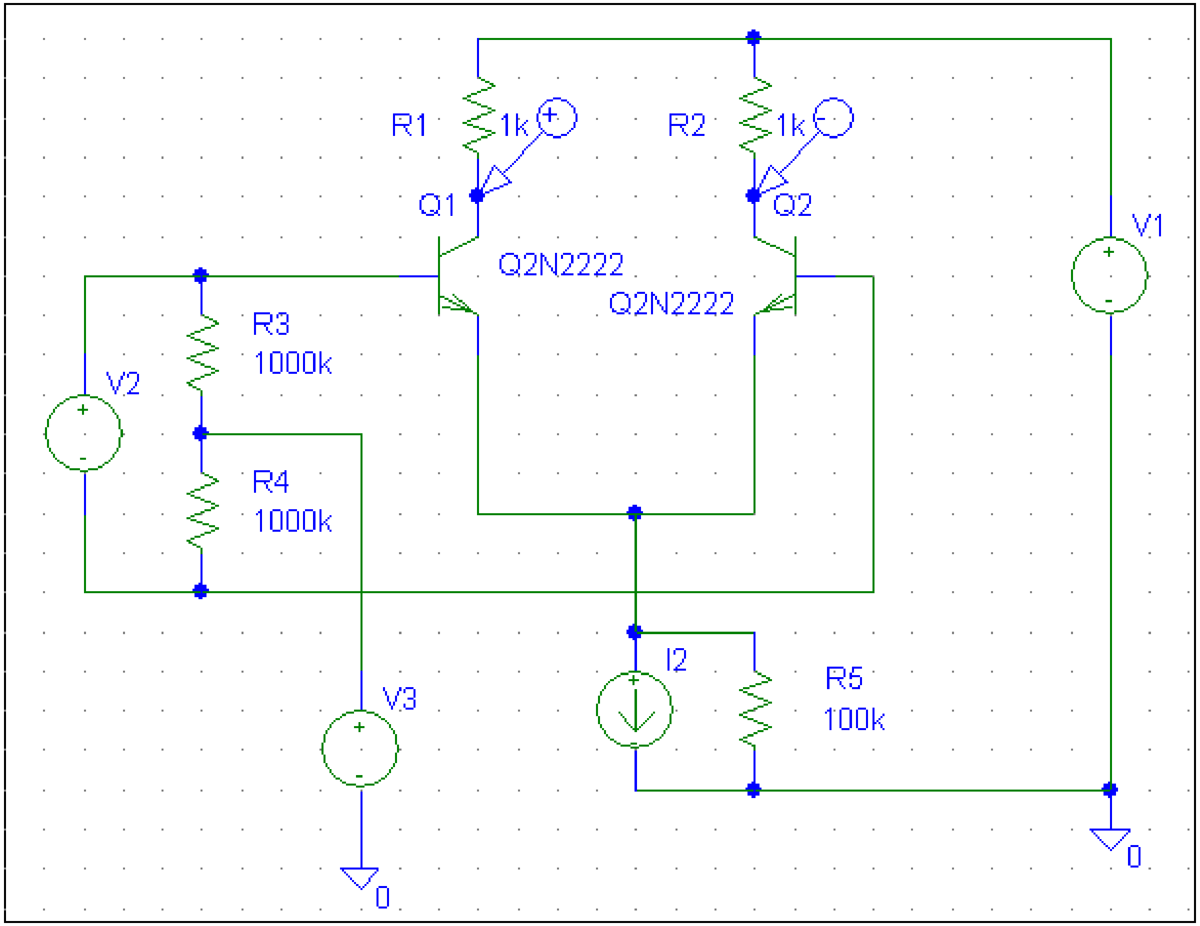
$$V_{IC}^{max} = V_{CC} - R_C \frac{I_O}{2} - V_{CE1sat} + V_{BE1}$$

$$V_{IC}^{min} = -V_{EE} + V_{CE3sat} + V_{BE1}$$

SIMULARI pentru amplificatorul diferential bipolar
Analiza de mod diferential si semnal mare

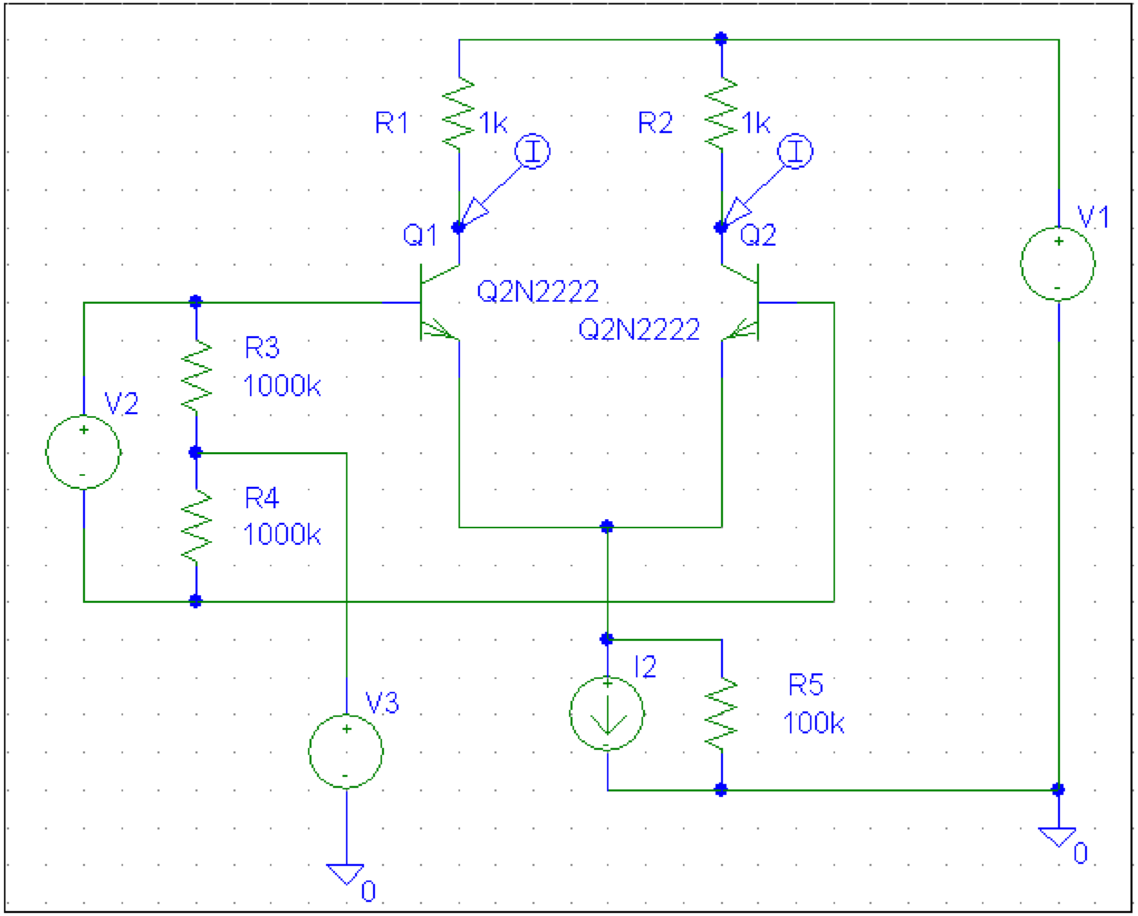
SIMULARI pentru amplificatorul diferential bipolar
Analiza de mod diferential si semnal mare

SIM 4.11: V_O (V2)



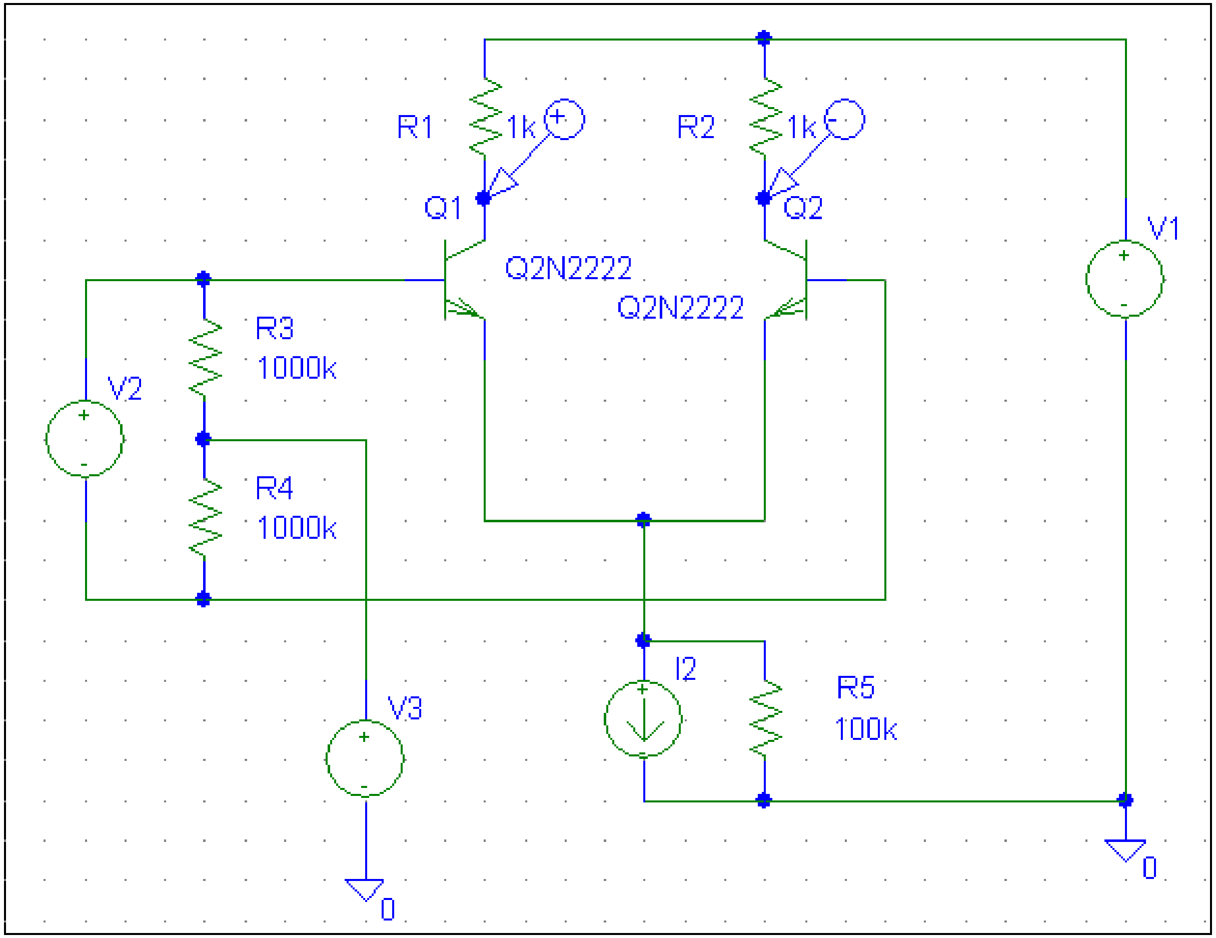
SIMULARI pentru amplificatorul diferential bipolar
Analiza de mod diferential si semnal mare

SIM 4.12: i_{C1}, i_{C2} (V2)



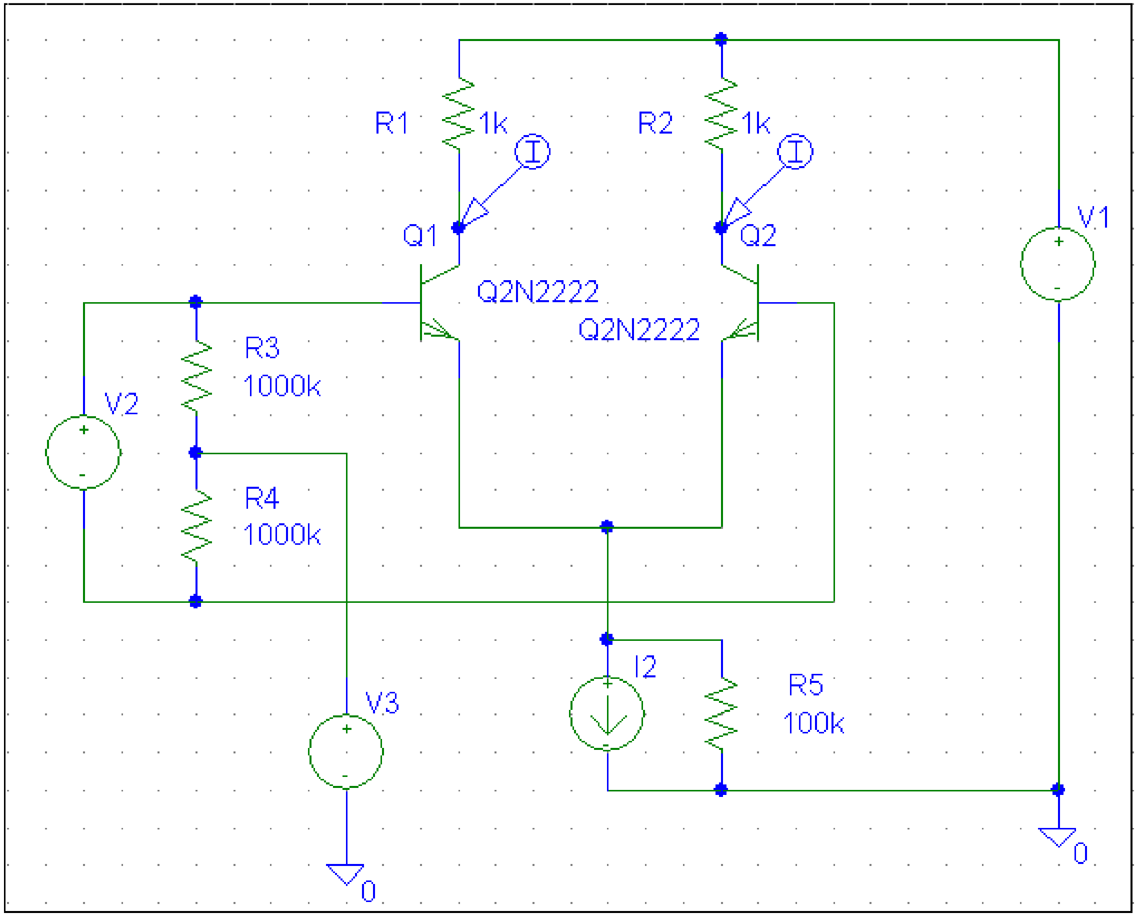
SIMULARI pentru amplificatorul diferential bipolar
Analiza de mod diferential si semnal mare

SIM 4.13: V_O (V2), I2 - parametru



SIMULARI pentru amplificatorul diferential bipolar
Analiza de mod diferential si semnal mare

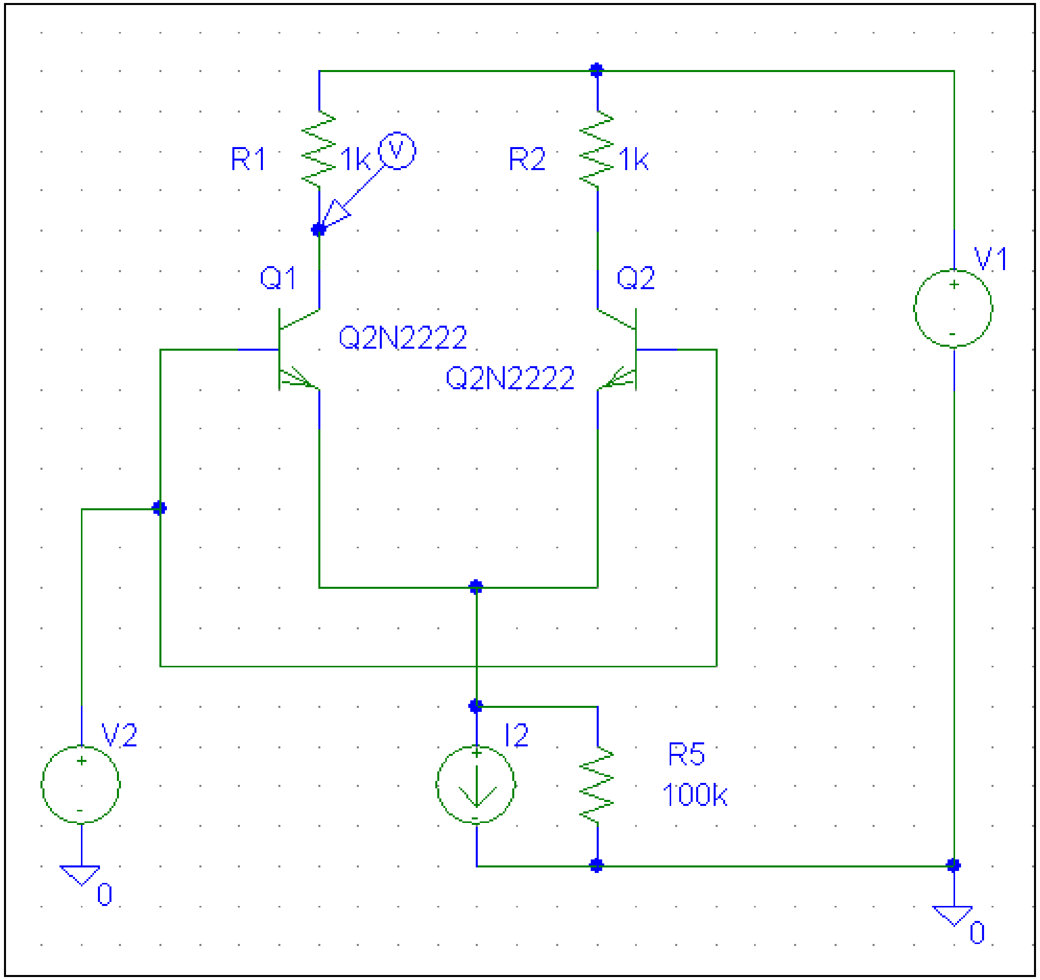
SIM 4.14: i_{C1}, i_{C2} (V2), I2 - parametru



<u>SIMULARI pentru amplificatorul diferential bipolar</u>
<u>Analiza de mod comun si semnal mare</u>

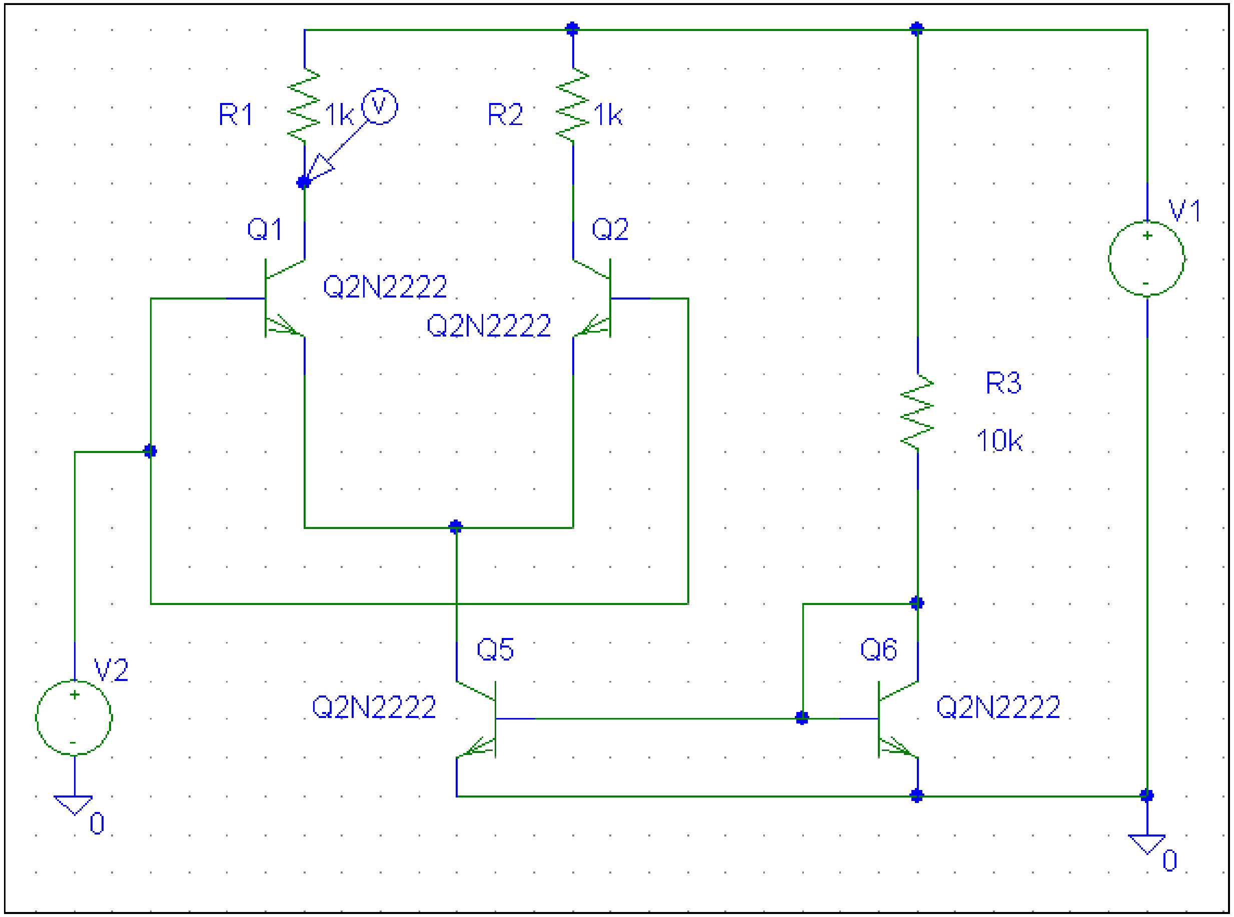
SIMULARI pentru amplificatorul diferential bipolar
Analiza de mod comun si semnal mare

SIM 4.15: V_{C1} (V2)



<u>SIMULARI pentru amplificatorul diferential bipolar</u>
<u>Analiza de mod comun si semnal mare</u>

<u>SIM 4.16</u>: V_{C1} (V2), V_{A5} - parametru



Tensiunea de offset (decalaj) de intrare

Daca cele doua tranzistoare nu sunt identice, este necesara aplicarea unei tensiuni de intrare nenule (numita tensiune de offset de intrare) in vederea anularii tensiunii de iesire.

$$v_{IO} = v_{BE1} - v_{BE2} = V_{th} \ln\left(\frac{i_{C1}}{i_{C2}} \frac{I_{S2}}{I_{S1}} \right)$$

Deoarece:

$$i_{C1} R_{C1} = i_{C2} R_{C2}$$

rezulta:

$$v_{IO} = V_{th} \ln\left(\frac{R_{C2}}{R_{C1}} \frac{I_{S2}}{I_{S1}} \right)$$

Se definesc parametrii ce descriu asimetriile astfel:

$$x = \frac{x_1 + x_2}{2}$$

$$\Delta x = x_1 - x_2$$

$$x_1 = x + \frac{\Delta x}{2}$$

$$x_2 = x - \frac{\Delta x}{2}$$

Rezulta:

$$v_{IO} = V_{th} \ln\left(\frac{R_C - \frac{\Delta R_C}{2}}{R_C + \frac{\Delta R_C}{2}} \frac{I_S - \frac{\Delta I_S}{2}}{I_S + \frac{\Delta I_S}{2}} \right) = V_{th} \ln\left(\frac{1 - \frac{\Delta R_C}{2R_C}}{1 + \frac{\Delta R_C}{2R_C}} \frac{1 - \frac{\Delta I_S}{2I_S}}{1 - \frac{\Delta I_S}{2I_S}} \right)$$

Pentru:

$$\Delta R_C << R_C \;\; si \;\; \Delta I_S << I_S$$

$$x = \Delta R_C / 2R_C \;\; sau \;\; x = \Delta I_S / 2I_S$$

se poate utiliza aproximarea:

$$\frac{1-x}{1+x} \cong (1-x)(1-x) \cong 1 - 2x$$

Deci:

$$v_{IO} = V_{th}\, ln\left[\left(1 - \frac{\Delta R_C}{R_C}\right)\left(1 - \frac{\Delta I_S}{I_S}\right)\right] \cong -V_{th}\left(\frac{\Delta R_C}{R_C} + \frac{\Delta I_S}{I_S}\right)$$

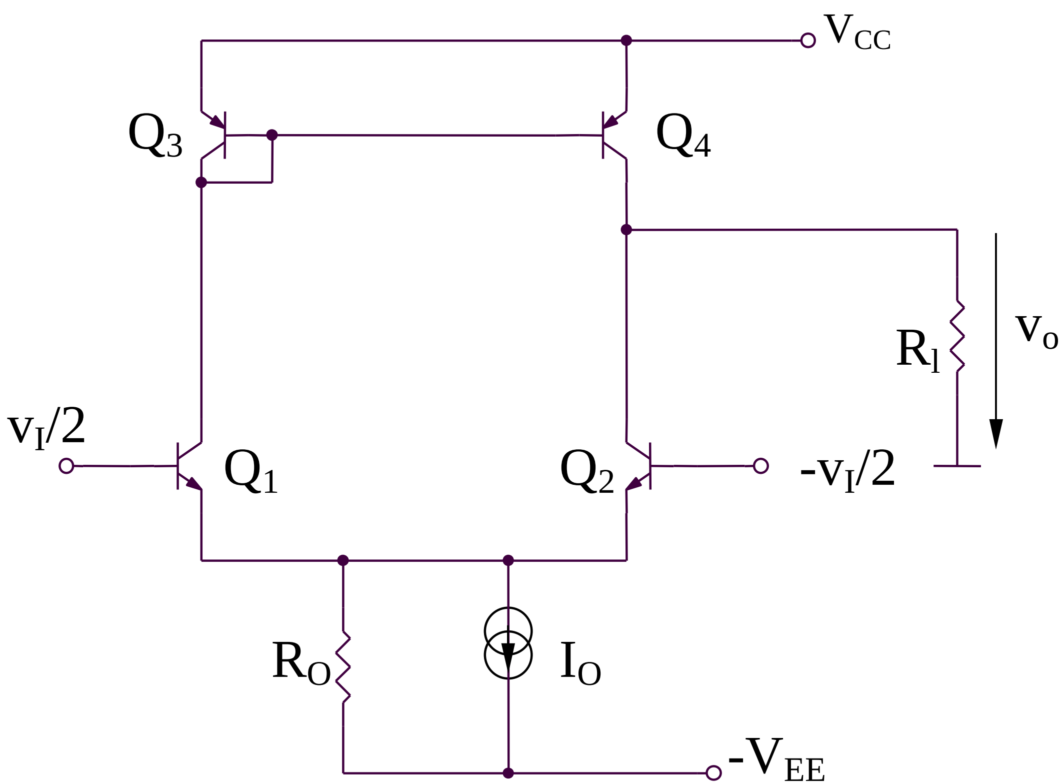
deoarece:

$$ln(1+x) \cong x, \;\; pentru \;\; x << 1$$

Exemplu:

$$\frac{\Delta R_C}{R_C} = 0{,}01; \;\; \frac{\Delta I_S}{I_S} = 0{,}05 \Rightarrow v_{IO} = 1{,}5 mV$$

4.4.2. Amplificatorul diferential bipolar elementar cu sarcina activa



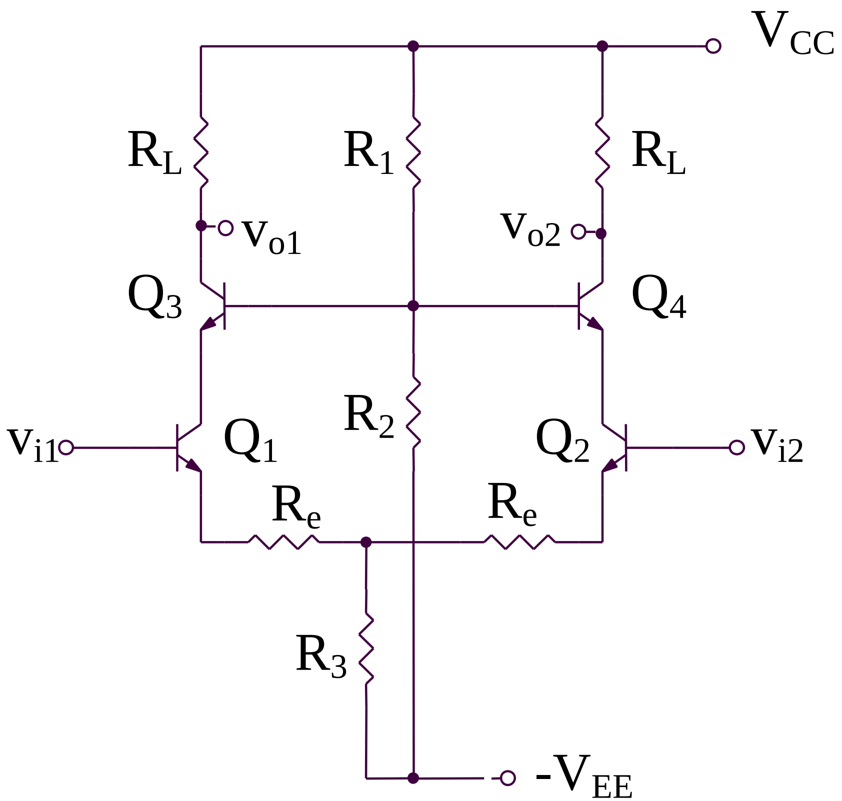
$$v_O = \left(g_{m1} \frac{v_I}{2} + g_{m2} \frac{v_I}{2} \right) \left(R_l \,//\, r_{o2} \,//\, r_{o4} \right) = g_{m1} v_I \left(R_l \,//\, r_{o2} \,//\, r_{o4} \right)$$

$$A_{dd} = g_{m1} \left(R_l \,//\, r_{o2} \,//\, r_{o4} \right)$$

$$A_{dd} \Big|_{R_l \to \infty} = g_{m1} \left(r_{o2} \,//\, r_{o4} \right) = \frac{g_{m1} r_{o2}}{2} = \frac{I_{C1}}{2V_{th}} \frac{V_A}{I_{C1}} = \frac{V_A}{2V_{th}}$$

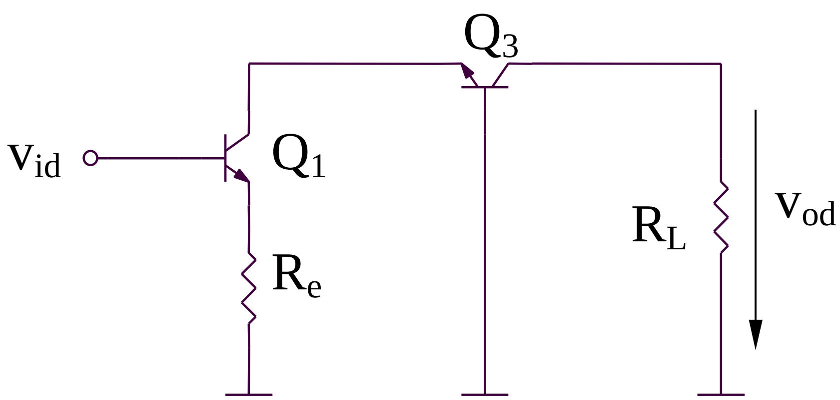
4.5. Amplificatorul diferential bipolar cascod

4.5. Amplificatorul diferential bipolar cascod

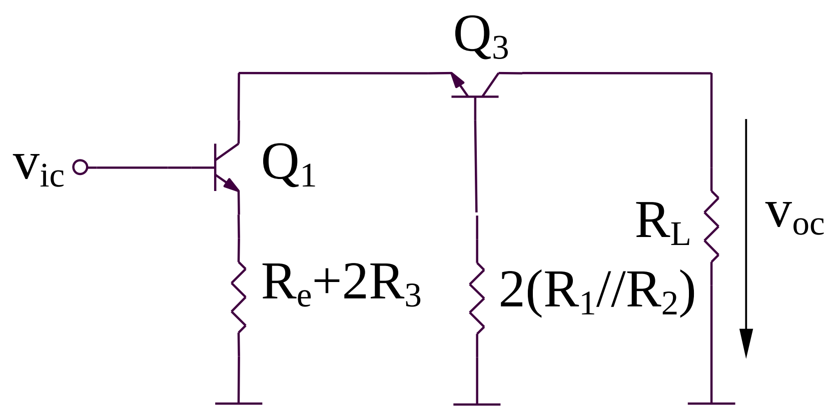


Mod diferential

Mod comun



Semicircuitul de mod diferential



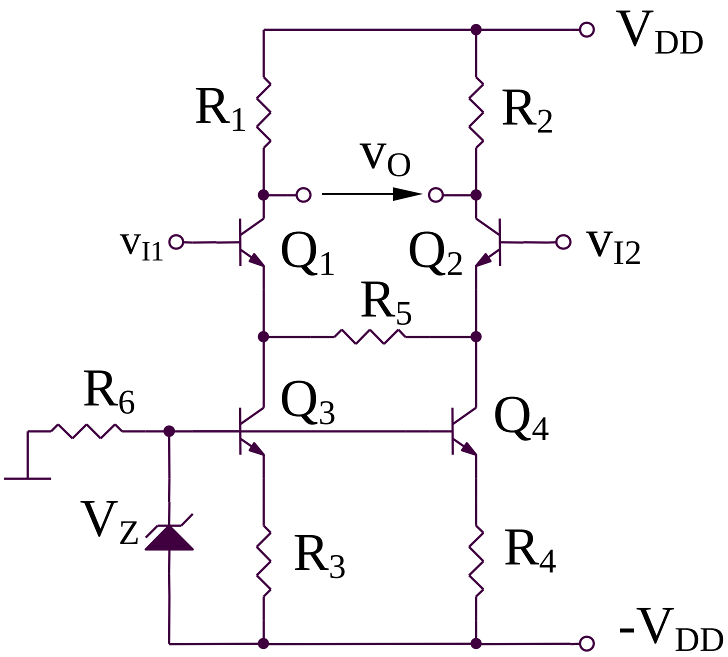
Semicircuitul de mod comun

$$A_{dd} = -\frac{\beta R_L}{r_\pi + (\beta + 1)R_E}$$

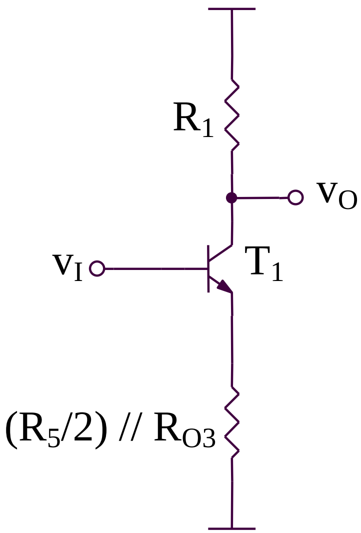
$$A_{cc} = -\frac{\beta R_L}{r_\pi + (\beta + 1)(R_E + 2R_3)}$$

4.6. Amplificator diferential polarizat cu o sursa dubla de curent

4.6. Amplificator diferential polarizat cu o sursa dubla de curent

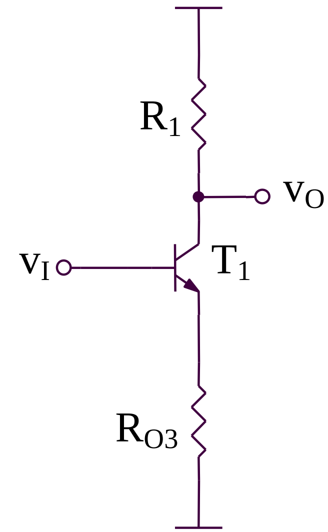


Mod diferential



Semicircuitul de mod diferential

Mod comun



Semicircuitul de mod comun

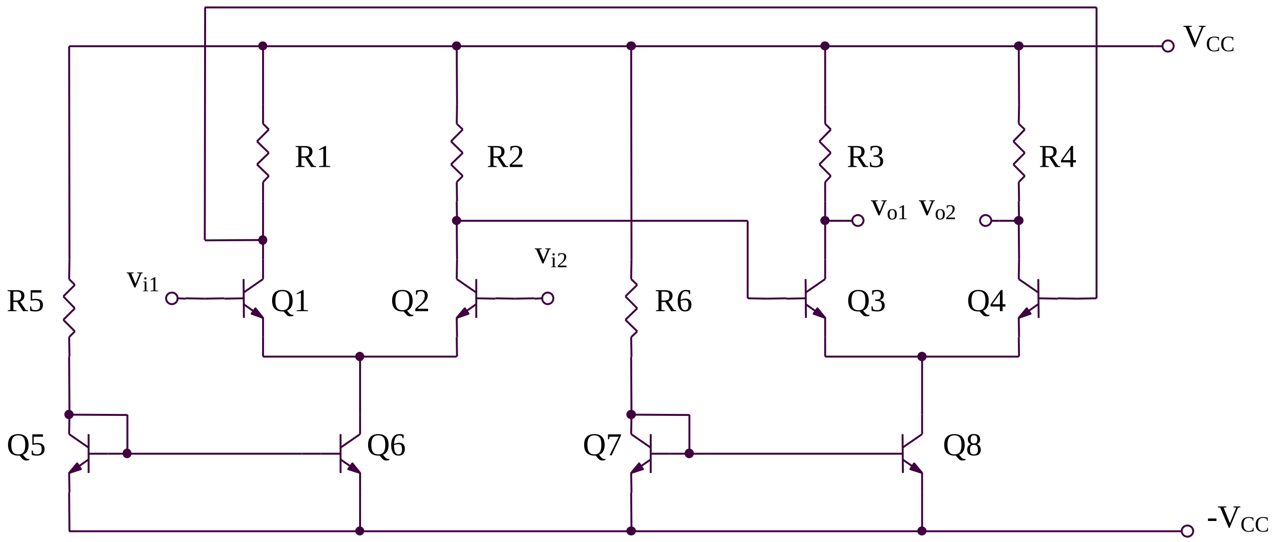
$$A_{dd} = -\frac{\beta R_1}{r_{\pi 1} + (\beta + 1)\left(\frac{R_5}{2} // R_{O3}\right)}$$

$$A_{cc} = -\frac{\beta R_1}{r_{\pi 1} + (\beta + 1) R_{O3}} \cong -\frac{R_1}{R_{O3}}$$

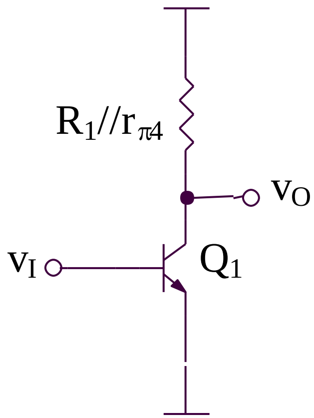
$$R_{O3} = r_{o3}\left(1 + \frac{\beta R_3}{r_{\pi 3} + R_3 + R_6 // r_Z}\right)$$

4.7. Structura cu 2 amplificatoare diferentiale

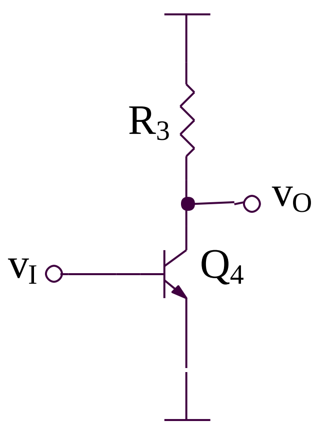
4.7. Structura cu 2 amplificatoare diferentiale



Mod diferential

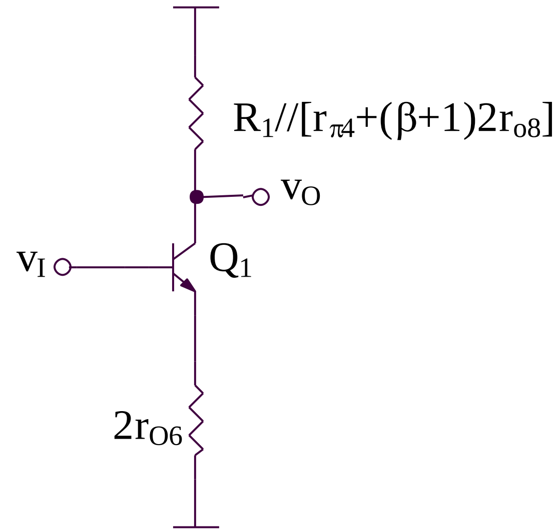


Semicircuitul de mod diferential (I)

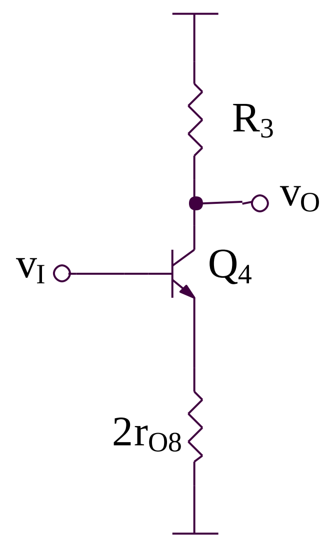


Semicircuitul de mod diferential (II)

Mod comun



Semicircuitul de mod comun (I)



Semicircuitul de mod comun (II)

Amplificarea de mod diferential (I)

$$A_{dd1} = -g_{m1}\left(R_1 \mathbin{//} r_{\pi 4}\right)$$

Amplificarea de mod comun (I)

$$A_{cc1} = -\beta \frac{R_1 \mathbin{//} \left[r_{\pi 4} + (\beta + 1) 2 r_{o8}\right]}{r_{\pi 1} + (\beta + 1) 2 r_{o6}}$$

Amplificarea de mod diferential (II)

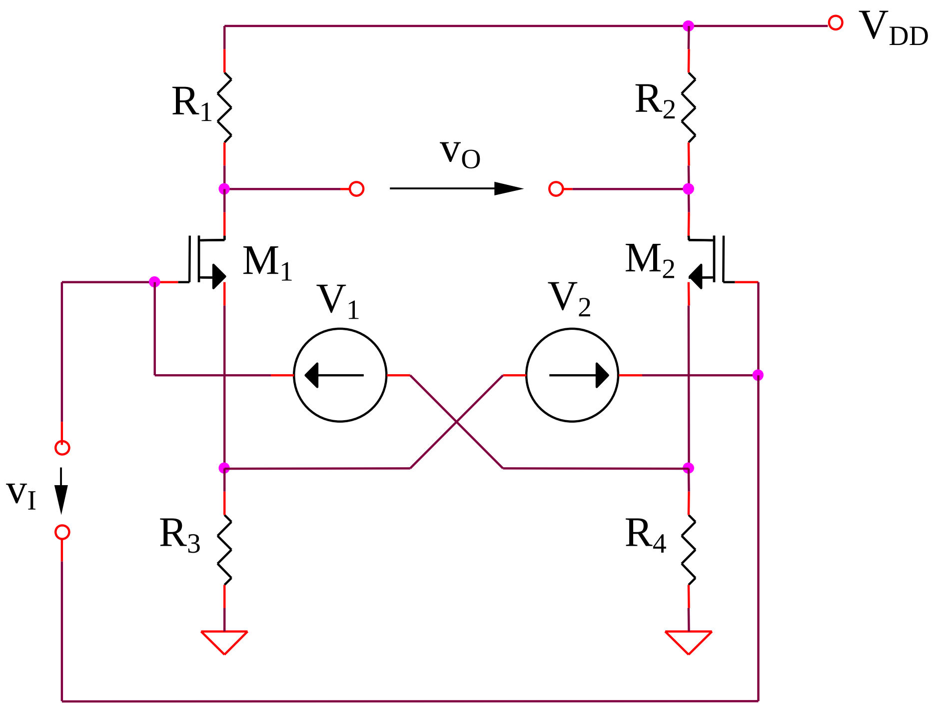
$$A_{dd2} = -g_{m4} R_3$$

Amplificarea de mod comun (II)

$$A_{cc2} = -\beta \frac{R_3}{r_{\pi 1} + (\beta + 1) 2 r_{o8}}$$

4.8. Amplificator diferential CMOS cu caracteristica de transfer liniarizata

4.8. Amplificator diferential CMOS cu caracteristica de transfer liniarizata



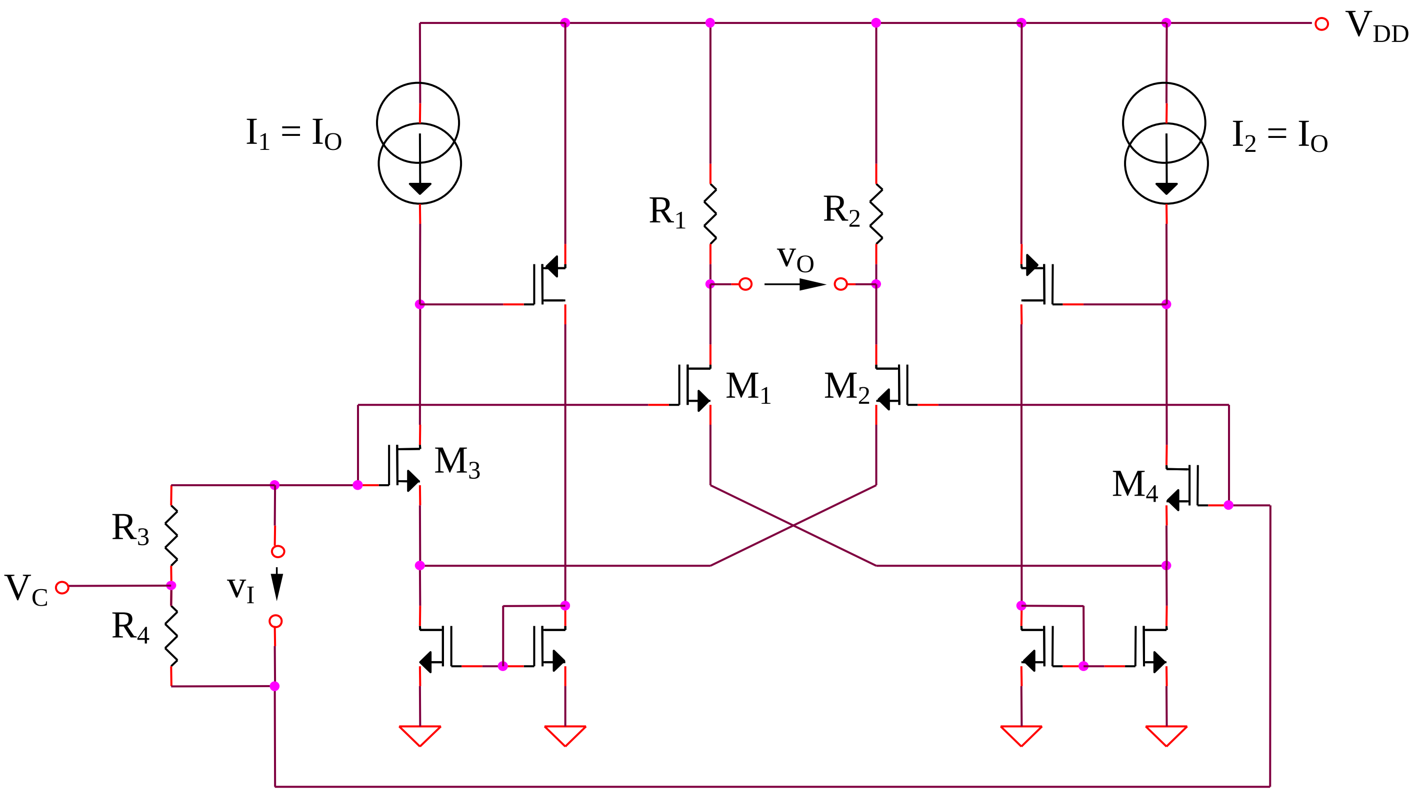
$$i_{D1} = \frac{K}{2}\left(v_{GS1} - V_T\right)^2 \qquad i_{D2} = \frac{K}{2}\left(v_{GS2} - V_T\right)^2$$

$$v_O = R_1\left(i_{D2} - i_{D1}\right) = \frac{KR_1}{2}\left(v_{GS2} - v_{GS1}\right)\left(v_{GS2} + v_{GS1} - 2V_T\right)$$

$$v_I = V_1 - v_{GS2} = v_{GS1} - V_2 \Rightarrow \begin{cases} v_{GS1} - v_{GS2} = 2v_I \\ v_{GS1} + v_{GS2} = 2V \end{cases} \Rightarrow$$

$$\Rightarrow \begin{cases} v_O = -2KR_1\left(V - V_T\right)v_I \\ A_{dd} = \dfrac{v_O}{v_I} = -2KR_1\left(V - V_T\right) \end{cases} \qquad V_1 = V_2 = V$$

Implementare posibila



$$V_1 = V_2 = V_{GS3} = V_{GS4} = V_T + \sqrt{\frac{2I_O}{K}} \quad \Rightarrow A_{dd} = -2R_1\sqrt{2KI_O}$$