Capitolul 8
Structuri analogice liniare

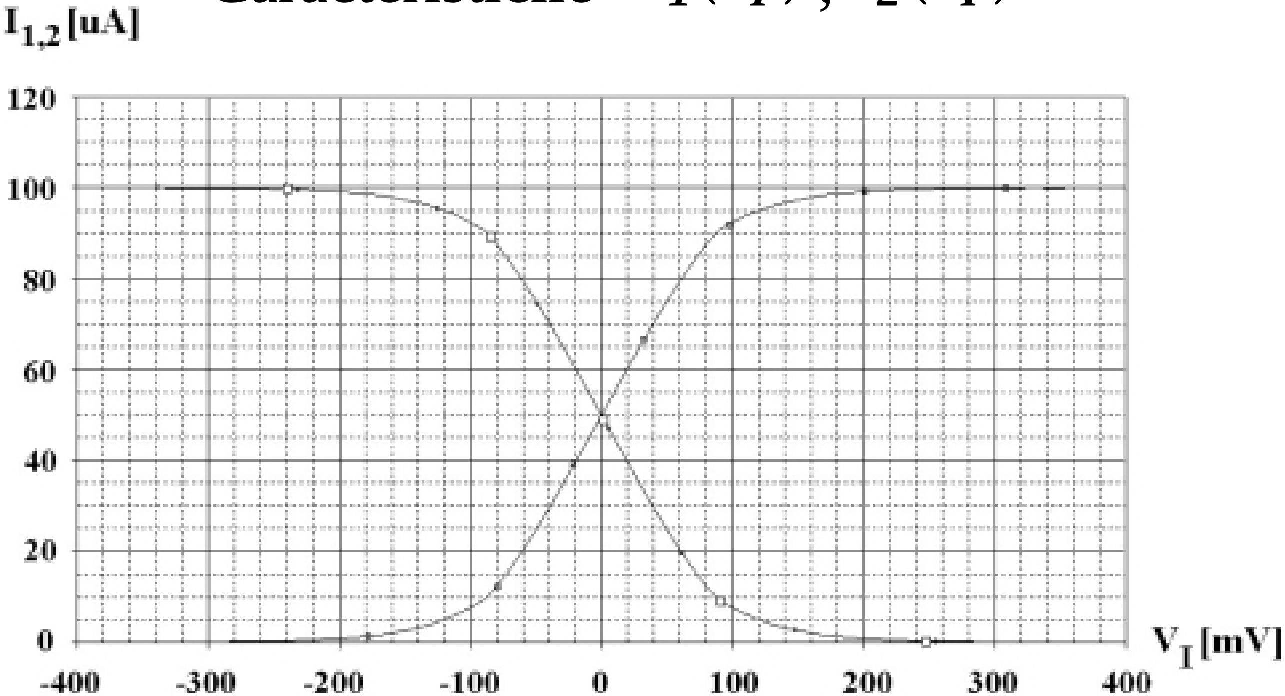
8.1. Liniarizarea caracteristicii de transfer a amplificatoarelor diferentiale

8.1. Liniarizarea caracteristicii de transfer a AD

• Functionarea amplificatoarelor diferentiale clasice este neliniara.
• In conditiile functionarii la semnal mic, caracteristica amplificatoarelor diferentiale poate fi aproximata cu o caracteristica liniara.
• Tehnicile de liniarizare permit obtinerea unei caracteristici liniare de transfer a AD, pentru amplitudini mari ale tensiunii de intrare.

Amplificatorul diferential MOS clasic

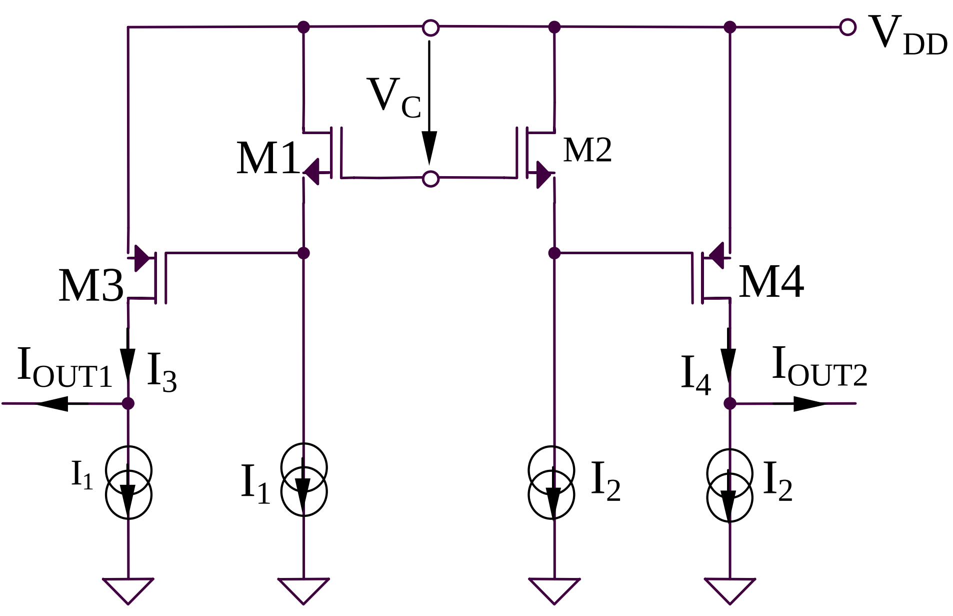
Caracteristicile $I_1(V_I)$, $I_2(V_I)$



8.1. Liniarizarea caracteristicii de transfer a AD

8.1.1. Tehnica de liniarizare utilizand circuite de extragere a radacinii patrate (I)

Circuit de extragere a radacinii patrate (I)



$$V_C = V_{SG3} - V_{GS1} = \sqrt{\frac{2}{K}}\left(\sqrt{I_3} - \sqrt{I_1}\right)$$

$$\sqrt{I_3} = \sqrt{I_1} + \sqrt{\frac{K}{2}} V_C$$

$$I_3 = I_1 + \frac{K}{2} V_C^2 + \sqrt{2KI_1} V_C$$

$$I_4 = I_2 + \frac{K}{2} V_C^2 + \sqrt{2KI_2} V_C$$

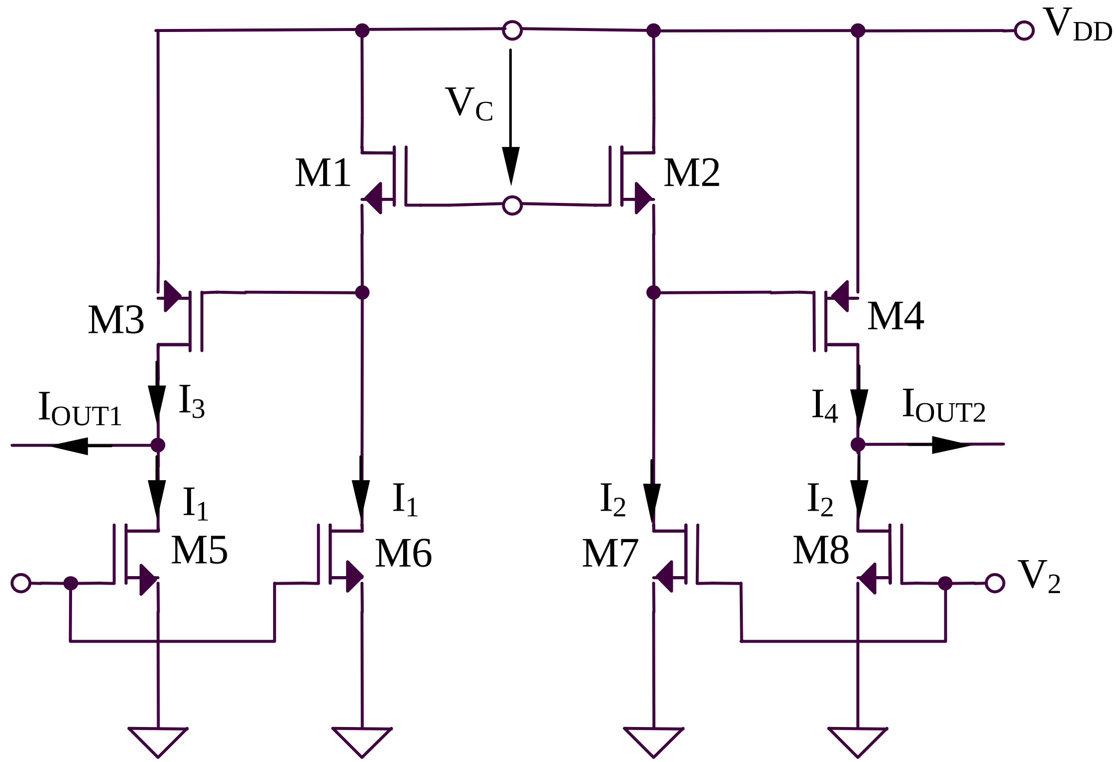
$$I_{OUT1} = I_3 - I_1 = \frac{K}{2} V_C^2 + \sqrt{2KI_1} V_C$$

$$I_{OUT2} = I_4 - I_2 = \frac{K}{2} V_C^2 + \sqrt{2KI_2} V_C$$

$$I_{OUT1} - I_{OUT2} = \sqrt{2K} V_C \left(\sqrt{I_1} - \sqrt{I_2}\right)$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.1. Tehnica de liniarizare utilizand circuite de extragere a radacinii patrate (I) (continuare)

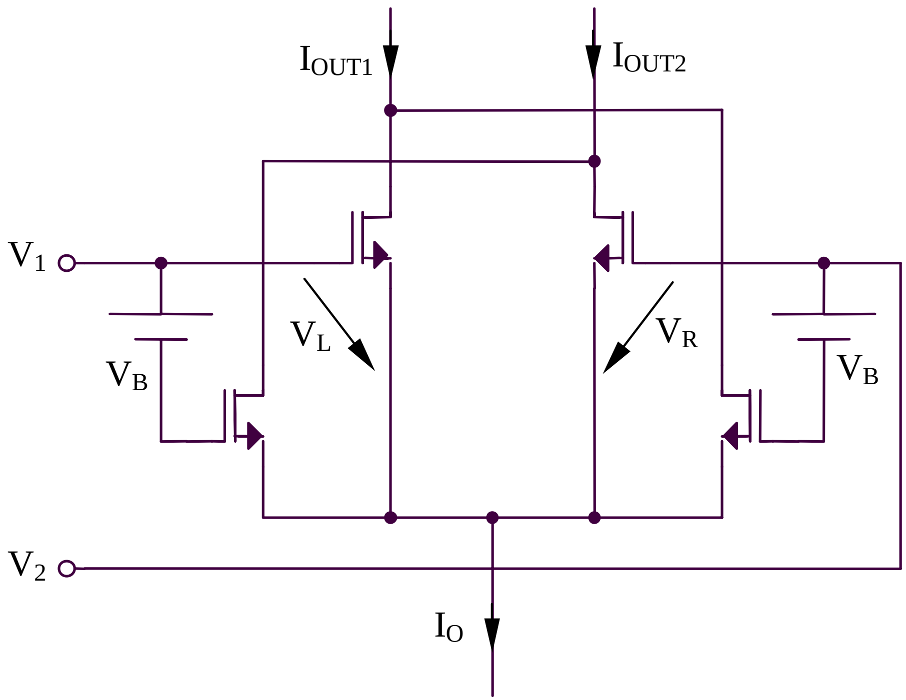


$$I_{OUT1} - I_{OUT2} = \sqrt{2K}\, V_C \sqrt{\frac{K}{2}} \left(V_{GS5} - V_{GS8}\right) = K V_C \left(V_1 - V_2\right)$$

$$G_m = K V_C$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.2. Tehnica de liniarizare utilizand circuite de extragere a radacinii patrate (II)



$$I_{OUT1} = \frac{K}{2}(V_L - V_T)^2 + \frac{K}{2}(V_R - V_B - V_T)^2$$

$$I_{OUT2} = \frac{K}{2}(V_R - V_T)^2 + \frac{K}{2}(V_L - V_B - V_T)^2$$

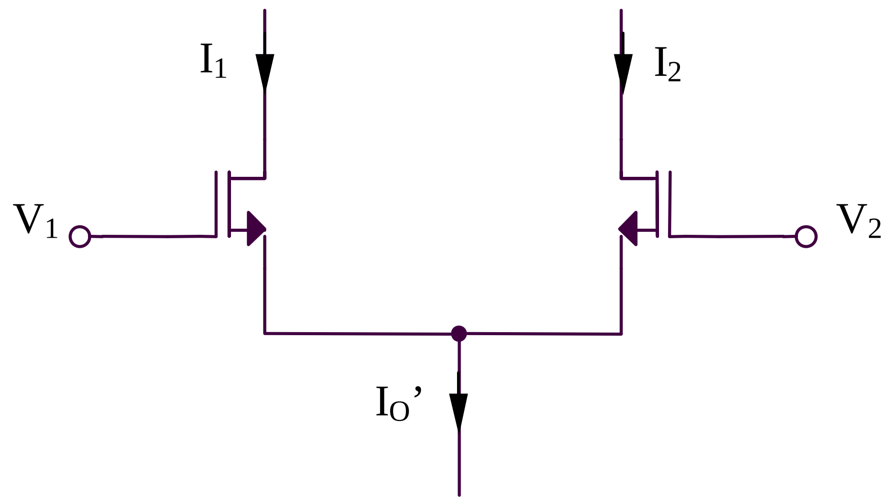
$$I_{OUT} = I_{OUT1} - I_{OUT2} = \frac{K}{2}(V_L - V_R)(V_L + V_R - 2V_T) + \frac{K}{2}(V_R - V_L)(V_L + V_R - 2V_B - 2V_T)$$

$$I_{OUT} = KV_B(V_L - V_R) = KV_B(V_1 - V_2)$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.3. Amplificator diferential liniarizat printr-o polarizare specifica in curent

AD clasic

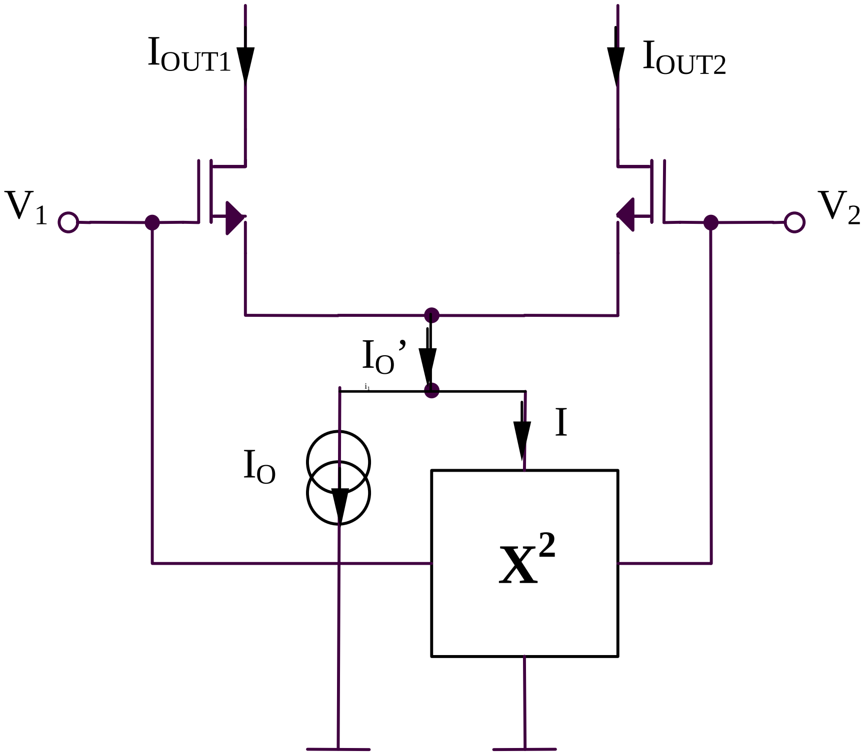


$$I_{OUT} = I_1 - I_2 = I_O' \sqrt{\frac{K(V_1 - V_2)^2}{I_O'} - \frac{K^2 (V_1 - V_2)^4}{4 I_O'^2}}$$

$$I_{OUT} = \frac{V_1 - V_2}{2} \sqrt{4 K I_O' - K^2 (V_1 - V_2)^2}$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.3. Amplificator diferential liniarizat printr-o polarizare specifica in curent (continuare)



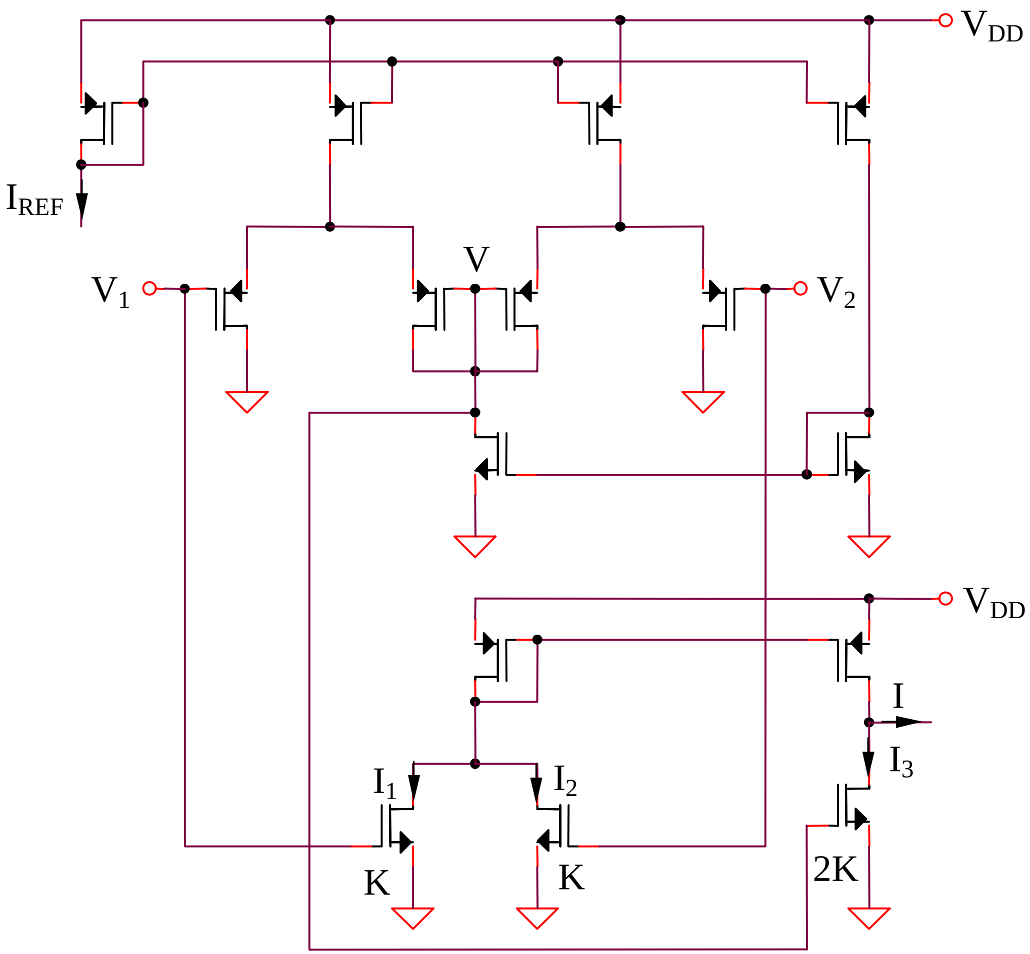
$$I_O' = I_O + I = I_O + \frac{K}{4}(V_1 - V_2)^2$$

$$I_{OUT} = \sqrt{KI_O}(V_1 - V_2) = G_m(V_1 - V_2)$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.3. Amplificator diferential liniarizat printr-o polarizare specifica in curent (continuare)

Circuit de ridicare la patrat



$$I = I_1 + I_2 - I_3 =$$

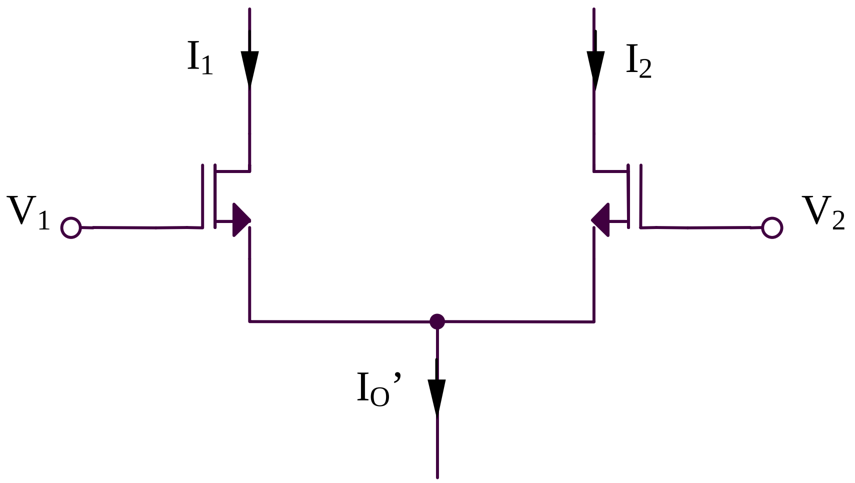
$$= \frac{K}{2}(V_1 - V_T)^2 + \frac{K}{2}(V_2 - V_T)^2 -$$

$$- K\left(\frac{V_1 + V_2}{2} - V_T\right)^2 = \frac{K}{4}(V_1 - V_2)^2$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.4. Amplificator diferential liniarizat prin anularea armonicilor

AD clasic



$$I_{OUT}(V_I) = -K^{1/2} I_O^{1/2} V_I + \frac{K^{3/2}}{8 I_O^{1/2}} V_I^3 + \frac{K^{5/2}}{128 I_O^{3/2}} V_I^5 + \ldots$$

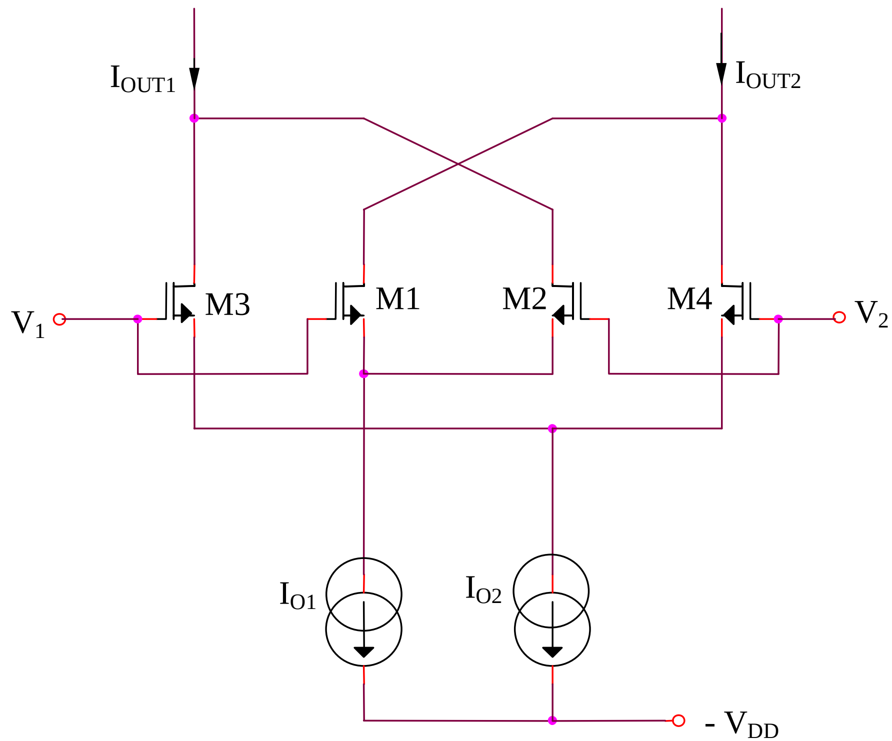
$$I_{OUT}(V_I) = a_1 V_I + a_3 V_I^3 + a_5 V_I^5 + \ldots$$

$$THD = \frac{a_3 V_I^3}{a_1 V_I} = \frac{K}{I_O} V_I^2$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.4. Amplificator diferential liniarizat prin anularea armonicilor (continuare)

AD anti-paralel



$$\left(I_{D2}-I_{D1}\right)\left(V_I\right)=-K_{1,2}^{1/2}I_{O1}^{1/2}V_I+\frac{K_{1,2}^{3/2}}{8I_{O1}^{1/2}}V_I^3+\frac{K_{1,2}^{5/2}}{128I_{O1}^{3/2}}V_I^5+\dots$$

$$\left(I_{D4}-I_{D3}\right)\left(V_I\right)=-K_{3,4}^{1/2}I_{O2}^{1/2}V_I+\frac{K_{3,4}^{3/2}}{8I_{O2}^{1/2}}V_I^3+\frac{K_{3,4}^{5/2}}{128I_{O2}^{3/2}}V_I^5+\dots$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.4. Amplificator diferential liniarizat prin anularea armonicilor (continuare)

AD anti-paralel

$$I_{OUT2} - I_{OUT1} = \left(I_{D2} + I_{D3}\right) - \left(I_{D1} + I_{D4}\right) = \left(I_{D2} - I_{D1}\right) - \left(I_{D4} - I_{D3}\right)$$

$$I_{OUT2} - I_{OUT1} = \left(K_{3,4}^{1/2} I_{O2}^{1/2} - K_{1,2}^{1/2} I_{O1}^{1/2}\right) V_I + \left(\frac{K_{1,2}^{3/2}}{8 I_{O1}^{1/2}} - \frac{K_{3,4}^{3/2}}{8 I_{O2}^{1/2}}\right) V_I^3 + \left(\frac{K_{1,2}^{5/2}}{128 I_{O1}^{3/2}} - \frac{K_{3,4}^{5/2}}{128 I_{O2}^{3/2}}\right) V_I^5 + \ldots$$

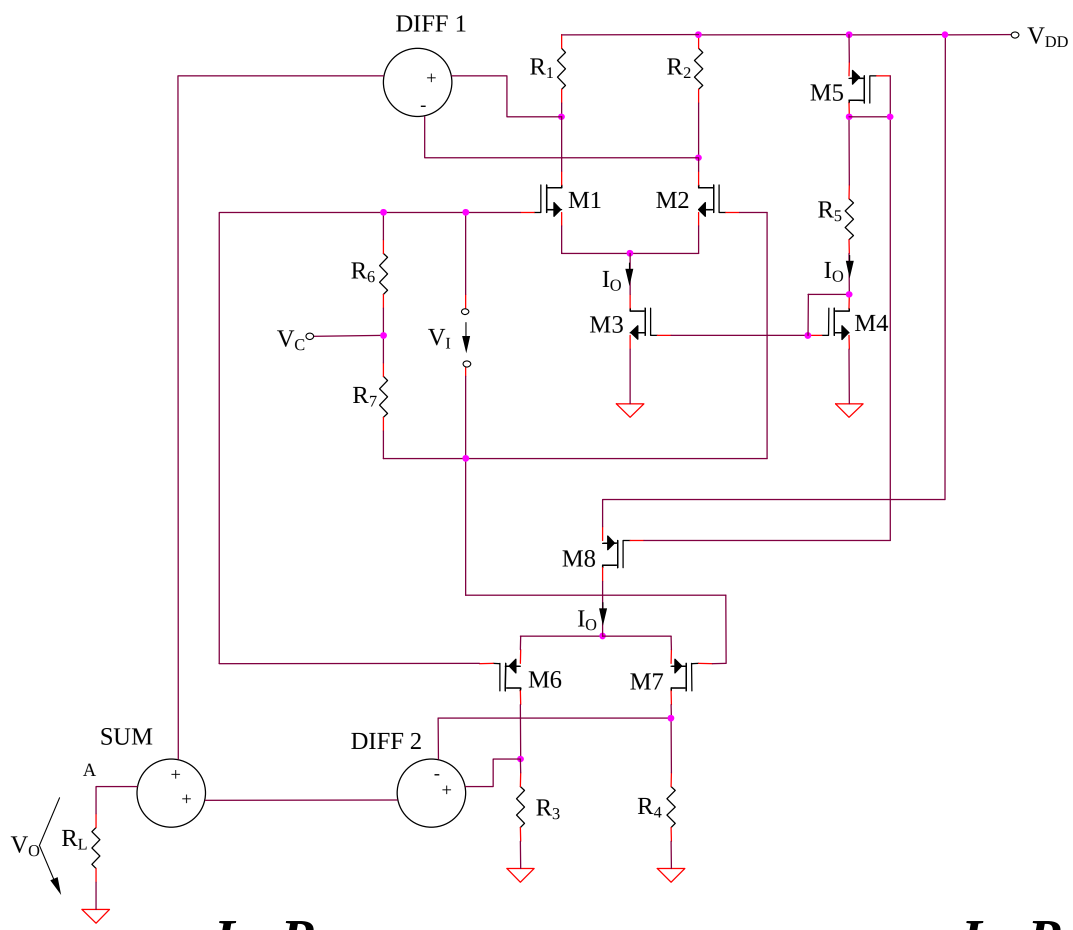
$$\frac{K_{1,2}^{3/2}}{8 I_{O1}^{1/2}} = \frac{K_{3,4}^{3/2}}{8 I_{O2}^{1/2}} \qquad \frac{I_{O1}}{I_{O2}} = \left(\frac{K_{1,2}}{K_{3,4}}\right)^3$$

$$I_{OUT2} - I_{OUT1} = -K_{1,2}^{1/2} I_{O1}^{1/2} \left[1 - \left(\frac{I_{O2}}{I_{O1}}\right)^{2/3}\right] V_I - \frac{K_{1,2}^{5/2}}{128 I_{O1}^{5/2}} \left[1 - \left(\frac{I_{O1}}{I_{O2}}\right)^{2/3}\right] V_I^5 + \ldots$$

$$THD' = \frac{V_I^4}{128} \left(\frac{K_{1,2}}{I_{O1}}\right)^2 \left(\frac{I_{O1}}{I_{O2}}\right)^{2/3}$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.5. Amplificator diferential cu domeniu extins al tensiunii de intrare de MC (I)

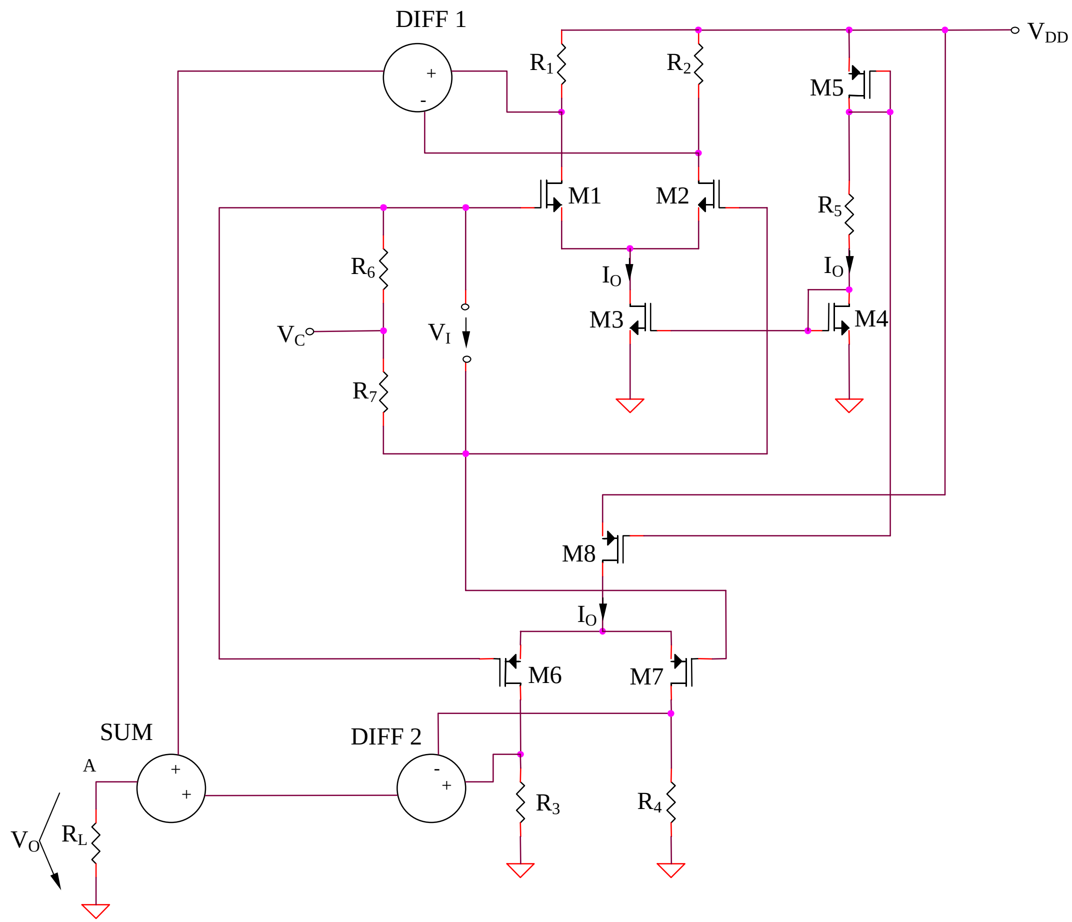


$$V_{IC\,max}^{NMOS} = V_{DD} - \frac{I_O R_1}{2} - V_{DS1sat} + V_{GS1} = V_{DD} - \frac{I_O R_1}{2} + V_T$$

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

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.5. Amplificator diferential cu domeniu extins al tensiunii de intrare de MC (I) (continuare)

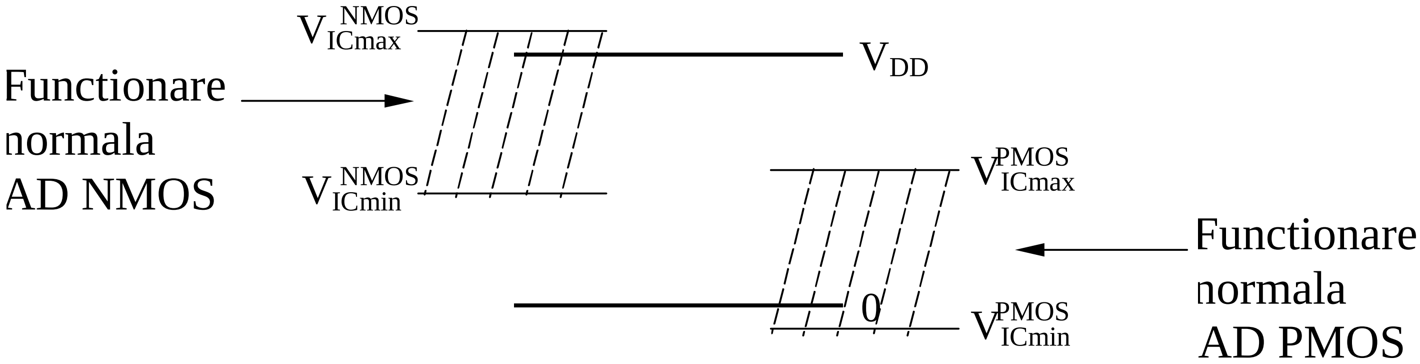


$$V_{IC\,max}^{PMOS} = V_{DD} - V_{SG6} - V_{SD8sat} = V_{DD} - V_{SG6} - V_{SG8} + V_T = V_{DD} - V_T - \left(\sqrt{2}+1\right)\sqrt{\frac{I_O}{K}}$$

$$V_{IC\,min}^{PMOS} = \frac{I_O R_3}{2} + V_{SD6sat} - V_{SG6} = \frac{I_O R_3}{2} - V_T$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.5. Amplificator diferential cu domeniu extins al tensiunii de intrare de MC (I) (continuare)



$$V_{IC\,max}^{NMOS} > V_{DD}$$

$$V_{IC\,max}^{PMOS} > V_{IC\,min}^{NMOS}$$

$$V_{IC\,min}^{PMOS} < 0$$

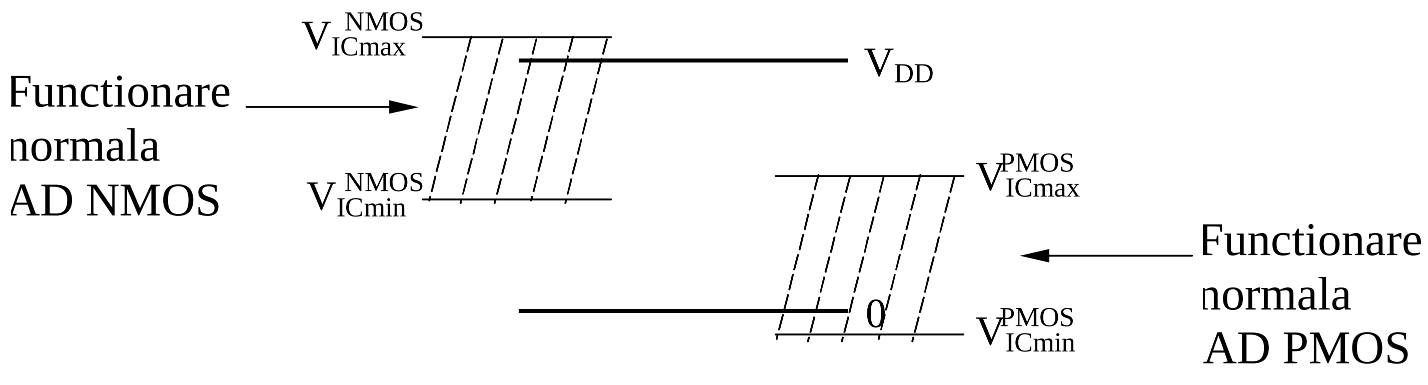
Rezulta:

$$I_O R_1 < 2V_T$$

$$V_{DD} > 2\left[V_T + \left(\sqrt{2}+1\right)\sqrt{\frac{I_O}{K}}\right]$$

8.1. Liniarizarea caracteristicii de transfer a AD

8.1.5. Amplificator diferential cu domeniu extins al tensiunii de intrare de MC (I) (continuare)

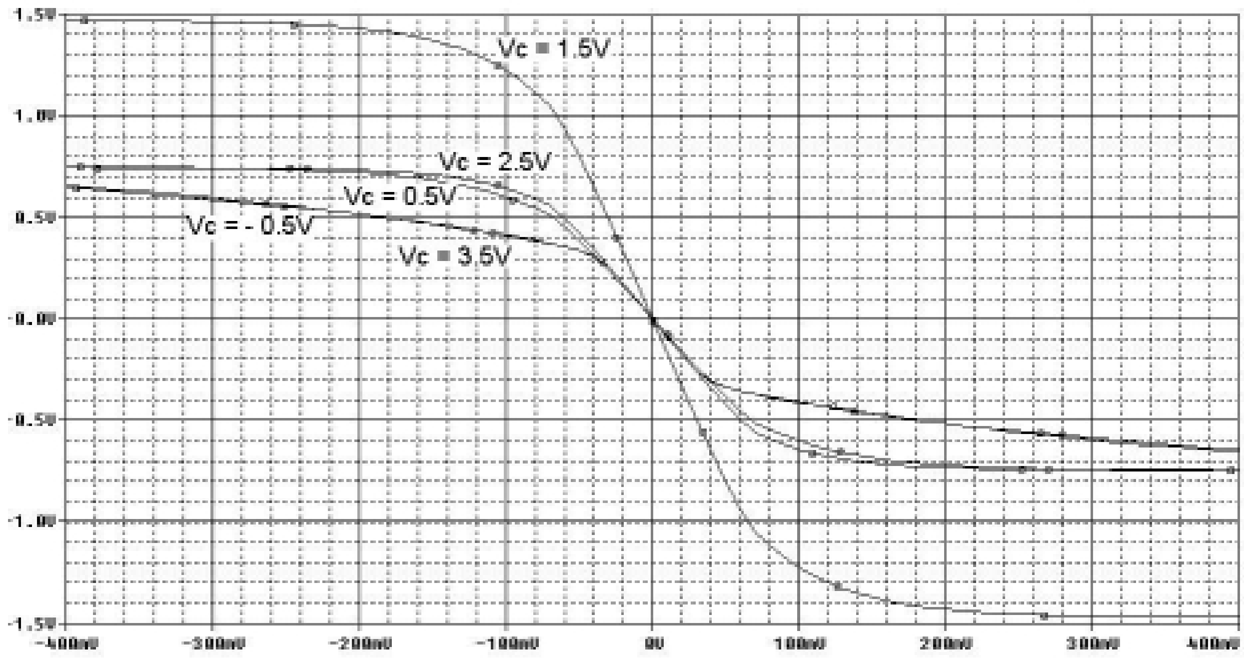


Domeniu V_{IC}	$V_{IC\,min}^{PMOS} < V_{IC} < V_{IC\,min}^{NMOS}$	$V_{IC\,min}^{NMOS} < V_{IC} < V_{IC\,max}^{PMOS}$	$V_{IC\,max}^{PMOS} < V_{IC} < V_{IC\,max}^{NMOS}$
AD NMOS	0	g_m	g_m
AD PMOS	g_m	g_m	0
AD paralel	g_m	2 g_m	g_m

8.1. Liniarizarea caracteristicii de transfer a AD

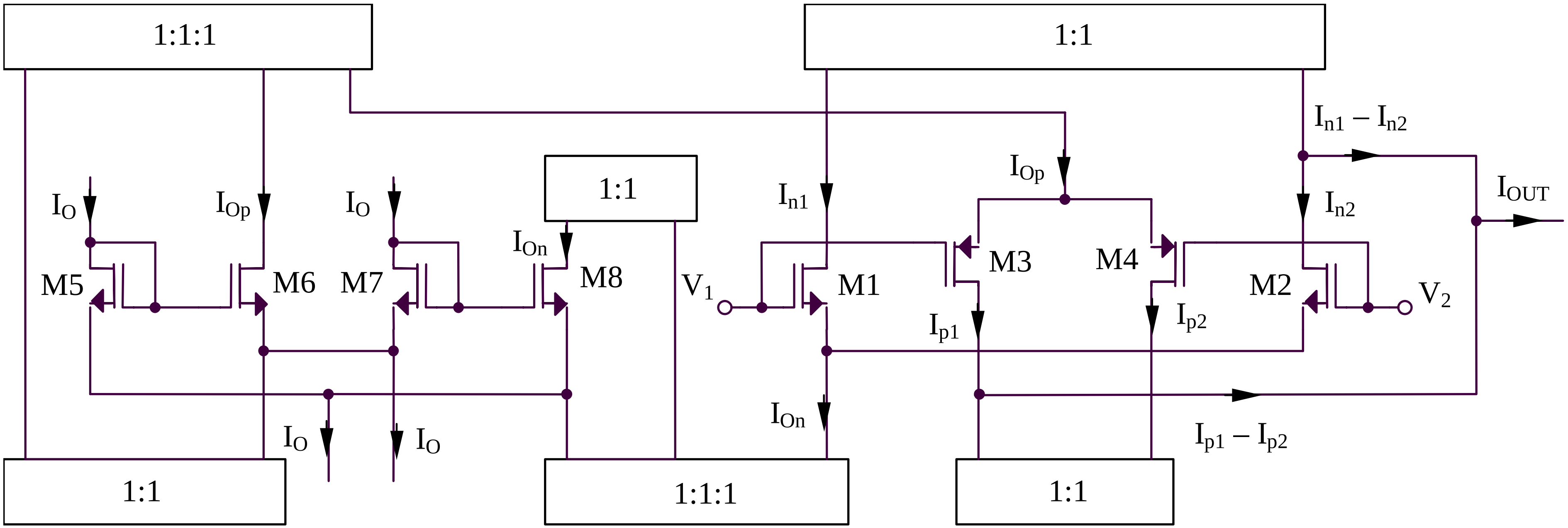
8.1.5. Amplificator diferential cu domeniu extins al tensiunii de intrare de MC (I) (continuare)

Caracteristica de transfer AD paralel



8.1. Liniarizarea caracteristicii de transfer a AD

8.1.6. Amplificator diferential cu domeniu extins al tensiunii de intrare de MC (II)



$$I_{OUT} = (I_{n1} - I_{n2}) + (I_{P1} - I_{P2}) = (g_{mn} + g_{mp})(V_1 - V_2)$$

$$g_{mn} = \sqrt{K_n I_{On}} \qquad g_{mp} = \sqrt{K_p I_{Op}}$$

$$I_{OUT} = \sqrt{K}\left(\sqrt{I_{Op}} + \sqrt{I_{On}}\right)(V_1 - V_2)$$

$$V_{GS5} + V_{GS7} = V_{GS6} + V_{GS8} \qquad \sqrt{I_{On}} + \sqrt{I_{Op}} = 2\sqrt{I_O}$$

$$I_{OUT} = 2\sqrt{KI_O}(V_1 - V_2)$$

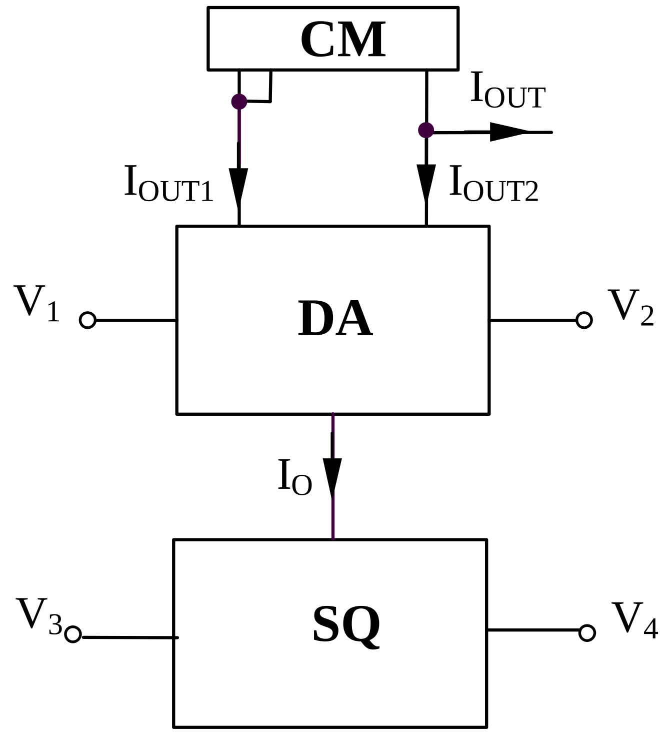
8.2. Circuite de multiplicare cu comportament liniar

Circuite de multiplicare cu functionare in tensiune

8.2. Circuite de multiplicare cu comportament liniar

8.2.1. Circuit de multiplicare liniarizat cu functionare in tensiune (I)

Schema bloc (I) a circuitului de multiplicare

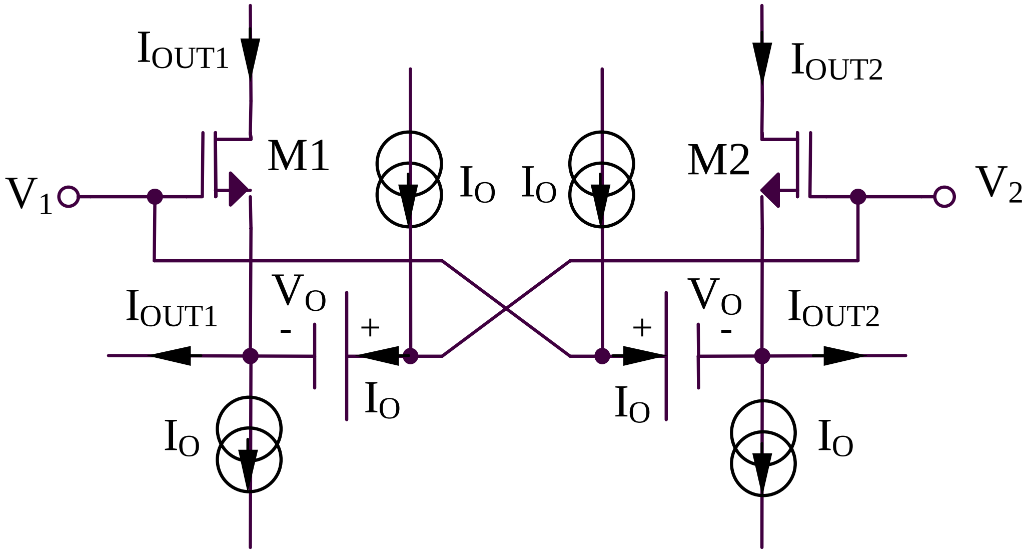


DA = amplificator diferential
SQ = circuit de ridicare la patrat

8.2. Circuite de multiplicare cu comportament liniar

8.2.1. Circuit de multiplicare liniarizat cu functionare in tensiune (I)

Structura interna a blocului "DA"



$$I_{OUT1} = \frac{K}{2}(V_{GS1} - V_T)^2 \qquad I_{OUT2} = \frac{K}{2}(V_{GS2} - V_T)^2$$

$$V_1 - V_2 = V_O - V_{GS2} = V_{GS1} - V_O$$

$$V_{GS1} = V_O + (V_1 - V_2) \qquad V_{GS2} = V_O - (V_1 - V_2)$$

8.2. Circuite de multiplicare cu comportament liniar

8.2.1. Circuit de multiplicare liniarizat cu functionare in tensiune (I)

Structura interna a blocului "DA"

Rezulta:

$$I_{OUT1} = \frac{K}{2}\left[\left(V_O - V_T\right) + \left(V_1 - V_2\right)\right]^2 \qquad I_{OUT2} = \frac{K}{2}\left[\left(V_O - V_T\right) - \left(V_1 - V_2\right)\right]^2$$

$$I_{OUT} = I_{OUT1} - I_{OUT2} = 2K\left(V_O - V_T\right)\left(V_1 - V_2\right)$$

$$V_O = V_T + \sqrt{\frac{2I_O}{K}}$$

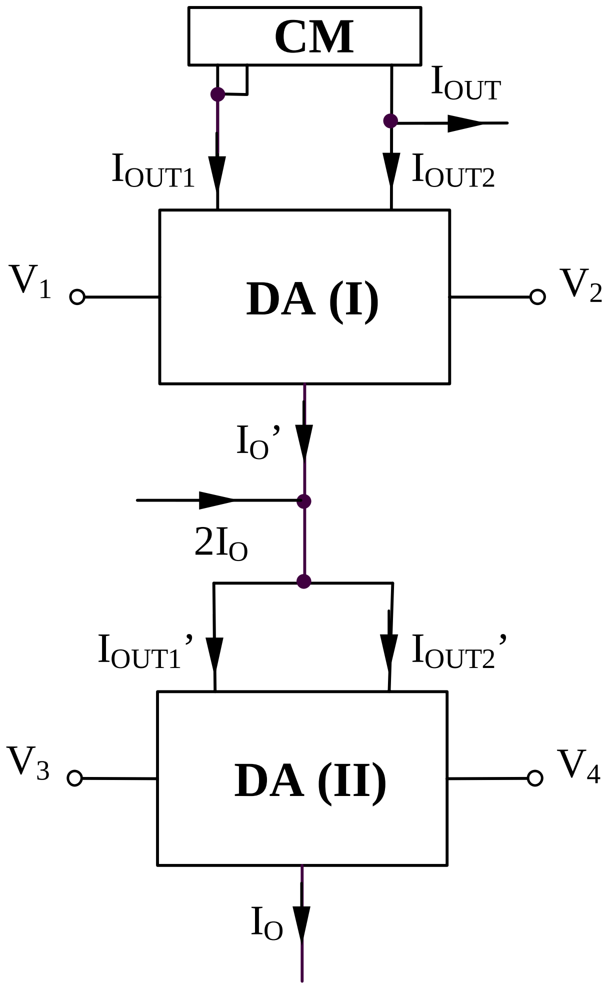
Deci:

$$I_{OUT} = \sqrt{8KI_O}\left(V_1 - V_2\right)$$

8.2. Circuite de multiplicare cu comportament liniar

8.2.1. Circuit de multiplicare liniarizat cu functionare in tensiune (I)

Schema bloc (II) a circuitului de multiplicare



$$I_{OUT1}' + I_{OUT2}' = K(V_O - V_T)^2 + $$
$$+ K(V_1 - V_2)^2 = 2I_O + K(V_1 - V_2)^2$$

$$I_{OUT} = I_{OUT1} - I_{OUT2} = \sqrt{8KI_O'}\,(V_1 - V_2)$$

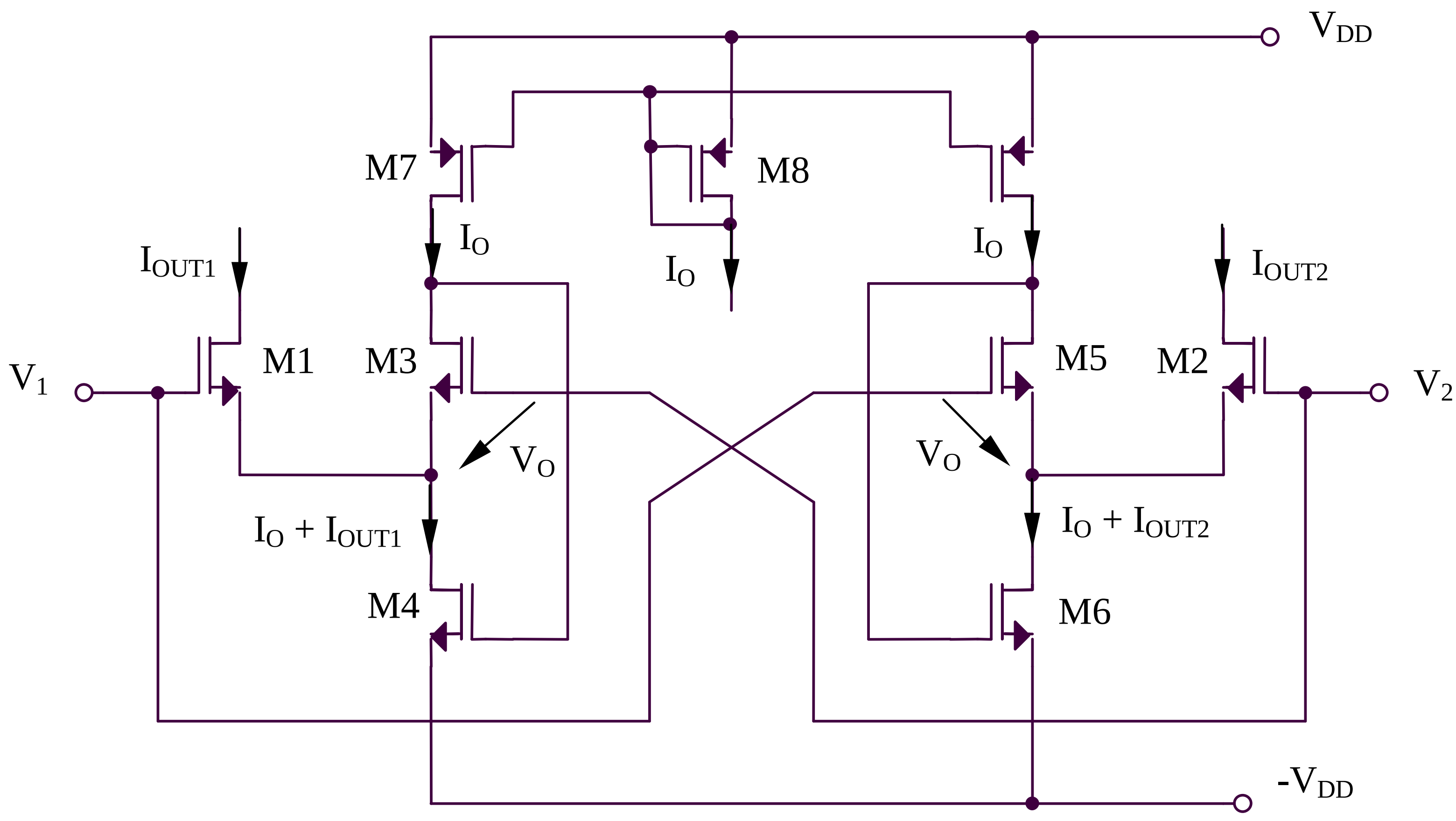
$$I_O' = I_{OUT1}' + I_{OUT2}' - 2I_O = K(V_3 - V_4)^2$$

$$I_{OUT} = \sqrt{8}\,K(V_1 - V_2)(V_3 - V_4)$$

8.2. Circuite de multiplicare cu comportament liniar

8.2.1. Circuit de multiplicare liniarizat cu functionare in tensiune (I)

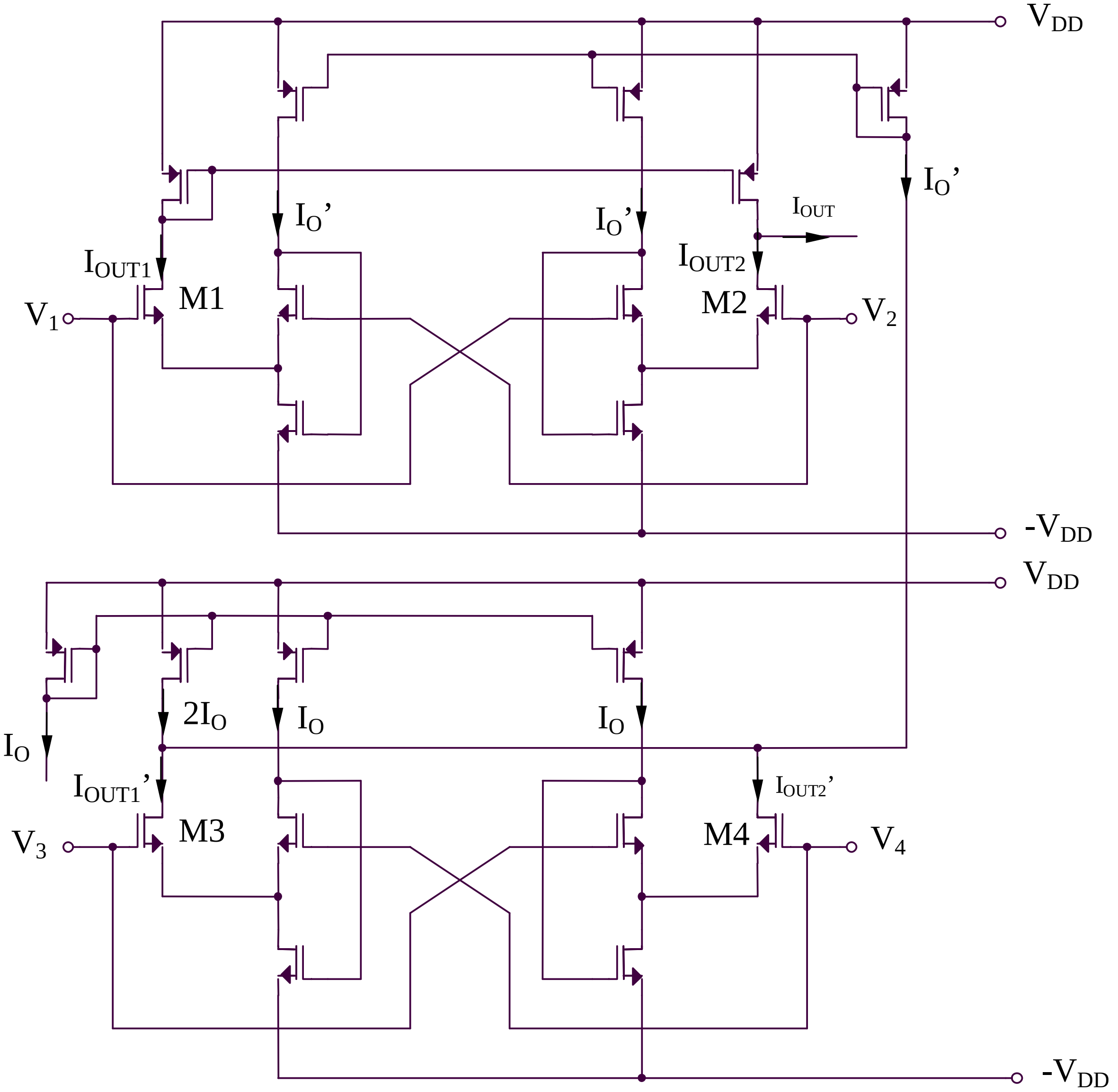
Implementarea (I) a blocului “DA”



8.2. Circuite de multiplicare cu comportament liniar

8.2.1. Circuit de multiplicare liniarizat cu functionare in tensiune (I)

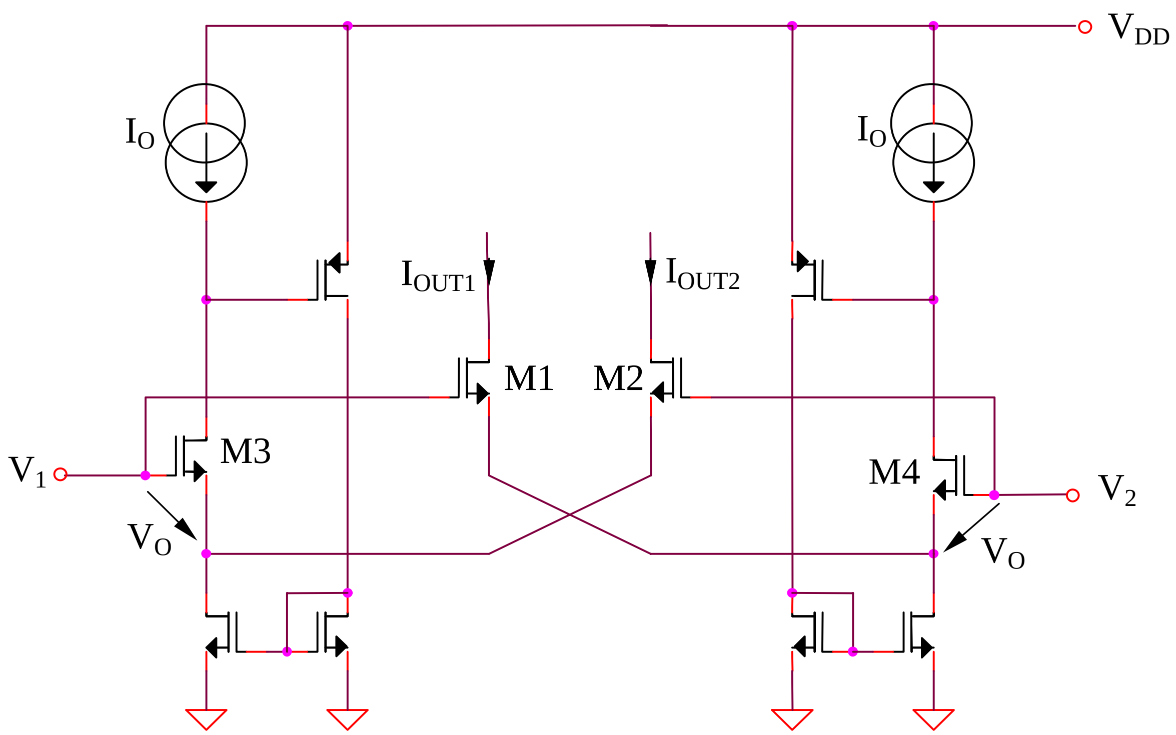
Implementarea (I) a circuitului de multiplicare



8.2. Circuite de multiplicare cu comportament liniar

8.2.1. Circuit de multiplicare liniarizat cu functionare in tensiune (I)

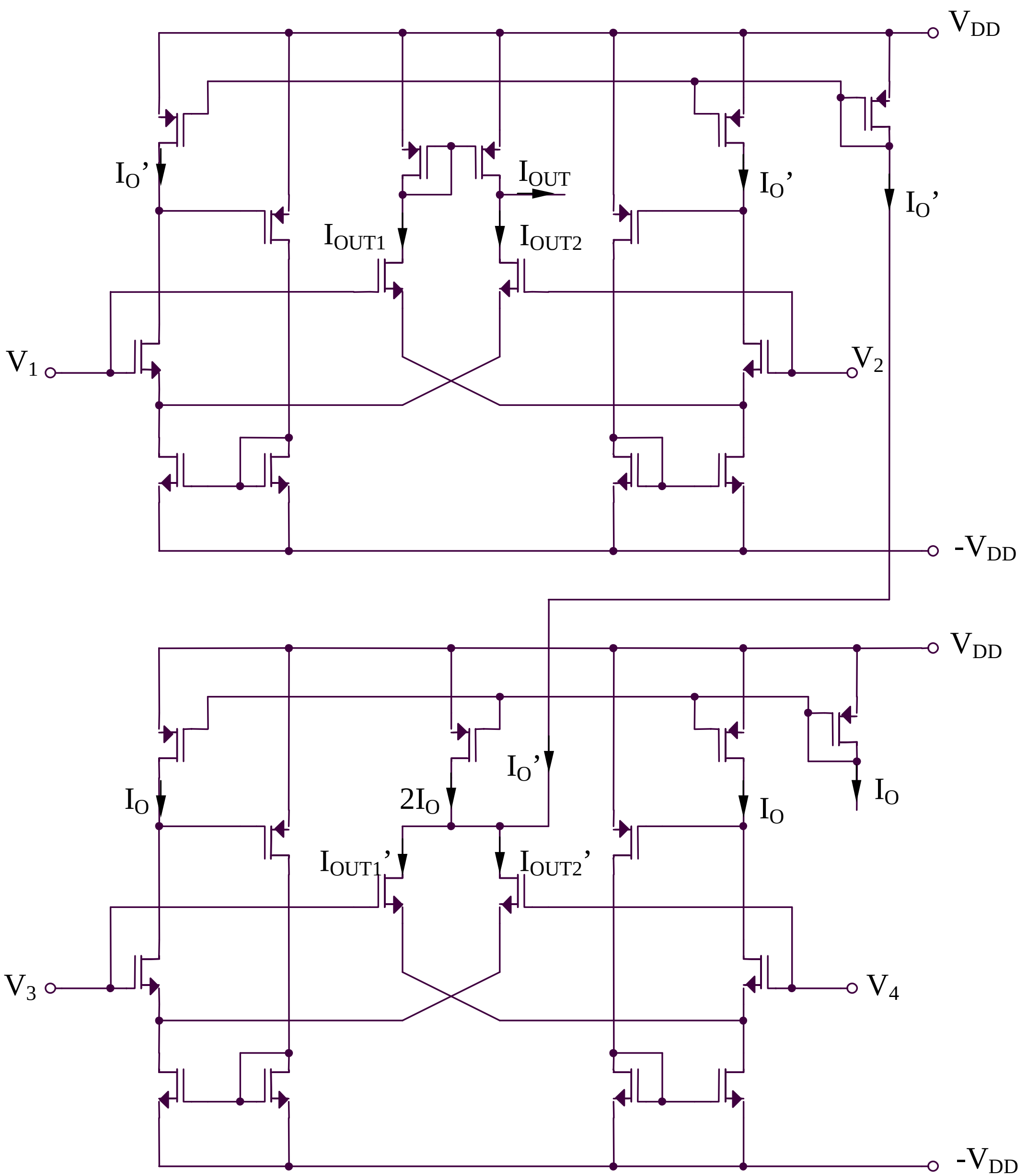
Implementarea (II) a blocului “DA”



8.2. Circuite de multiplicare cu comportament liniar

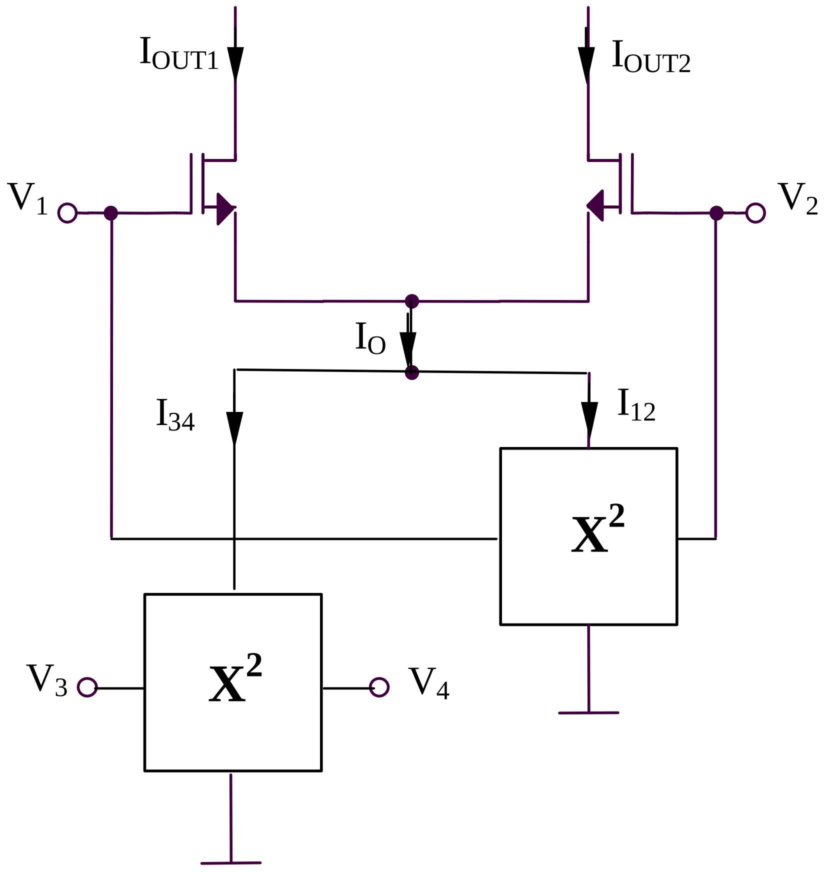
8.2.1. Circuit de multiplicare liniarizat cu functionare in tensiune (I)

Implementarea (II)
a circuitului de multiplicare



8.2. Circuite de multiplicare cu comportament liniar

8.2.2. Circuit de multiplicare liniarizat cu functionare in tensiune (II)



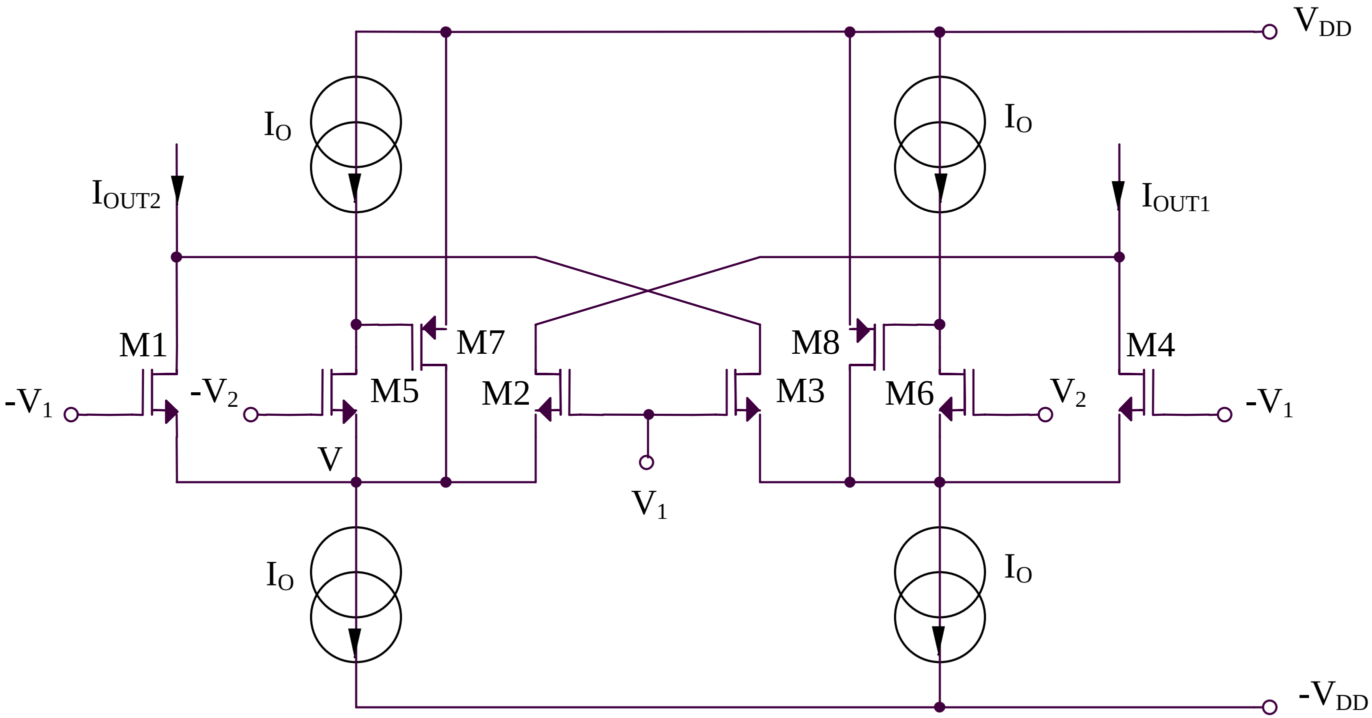
$$I_{OUT} = \frac{V_1 - V_2}{2}\sqrt{4KI_O - K^2(V_1 - V_2)^2}$$

$$I_O = I_{12} + I_{34} = \frac{K}{4}(V_1 - V_2)^2 + \frac{K}{4}(V_3 - V_4)^2$$

$$I_{OUT} = \frac{K}{2}(V_1 - V_2)(V_3 - V_4)$$

8.2. Circuite de multiplicare cu comportament liniar

8.2.3. Circuit de multiplicare liniarizat cu functionare in tensiune (III)



$$I_{OUT} = I_{OUT1} - I_{OUT2} = \left(I_{D2} + I_{D4}\right) - \left(I_{D1} + I_{D3}\right)$$

$$I_{D1} = \frac{K}{2}\left(-V_1 - V - V_T\right)^2$$

$$V = -V_2 - V_{GS5} = -V_2 - V_T - \sqrt{\frac{2I_O}{K}}$$

$$I_{D1} = \frac{K}{2}\left(-V_1 + V_2 + \sqrt{\frac{2I_O}{K}}\right)^2$$

8.2. Circuite de multiplicare cu comportament liniar

8.2.3. Circuit de multiplicare liniarizat cu functionare in tensiune (III) - continuare

$$I_{D2} = \frac{K}{2}\left(V_1 + V_2 + \sqrt{\frac{2I_O}{K}}\right)^2$$

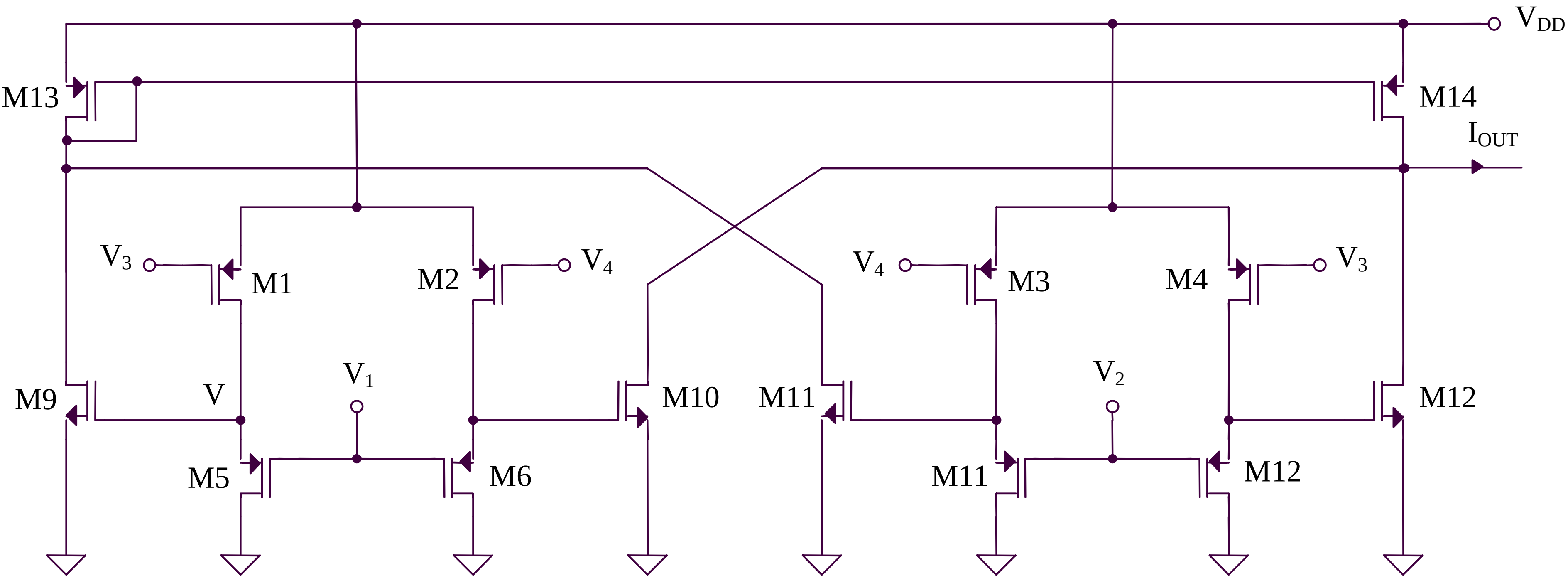
$$I_{D3} = \frac{K}{2}\left(V_1 - V_2 + \sqrt{\frac{2I_O}{K}}\right)^2$$

$$I_{D4} = \frac{K}{2}\left(-V_1 - V_2 + \sqrt{\frac{2I_O}{K}}\right)^2$$

$$I_{OUT} = \frac{K}{2}2V_1\left(2V_2 + 2\sqrt{\frac{2I_O}{K}}\right) + \frac{K}{2}(-2V_1)\left(-2V_2 + 2\sqrt{\frac{2I_O}{K}}\right) = 4KV_1V_2$$

8.2. Circuite de multiplicare cu comportament liniar

8.2.4. Circuit de multiplicare liniarizat cu functionare in tensiune (IV)



Rezulta:

$$V_{DD} - V_3 = V - V_1$$

$$V = V_1 - V_3 + V_{DD}$$

$$I_{D9} = \frac{K}{2}\left(V_{GS9} - V_T\right)^2 = \frac{K}{2}\left(V - V_T\right)^2 = \frac{K}{2}\left[\left(V_1 - V_3\right) + \left(V_{DD} - V_T\right)\right]^2$$

8.2. Circuite de multiplicare cu comportament liniar

8.2.4. Circuit de multiplicare liniarizat cu functionare in tensiune (IV) - continuare

$$I_{D9} = \frac{K}{2}\left[(V_1 - V_3) + (V_{DD} - V_T)\right]^2$$

$$I_{D10} = \frac{K}{2}\left[(V_1 - V_4) + (V_{DD} - V_T)\right]^2$$

$$I_{D11} = \frac{K}{2}\left[(V_2 - V_4) + (V_{DD} - V_T)\right]^2$$

$$I_{D12} = \frac{K}{2}\left[(V_2 - V_3) + (V_{DD} - V_T)\right]^2$$

$$I_{OUT} = I_{D9} + I_{D11} - I_{D10} - I_{D12}$$

$$I_{OUT} = \frac{K}{2}(V_4 - V_3)(2V_1 - V_3 - V_4 + 2V_{DD} - 2V_T) +$$

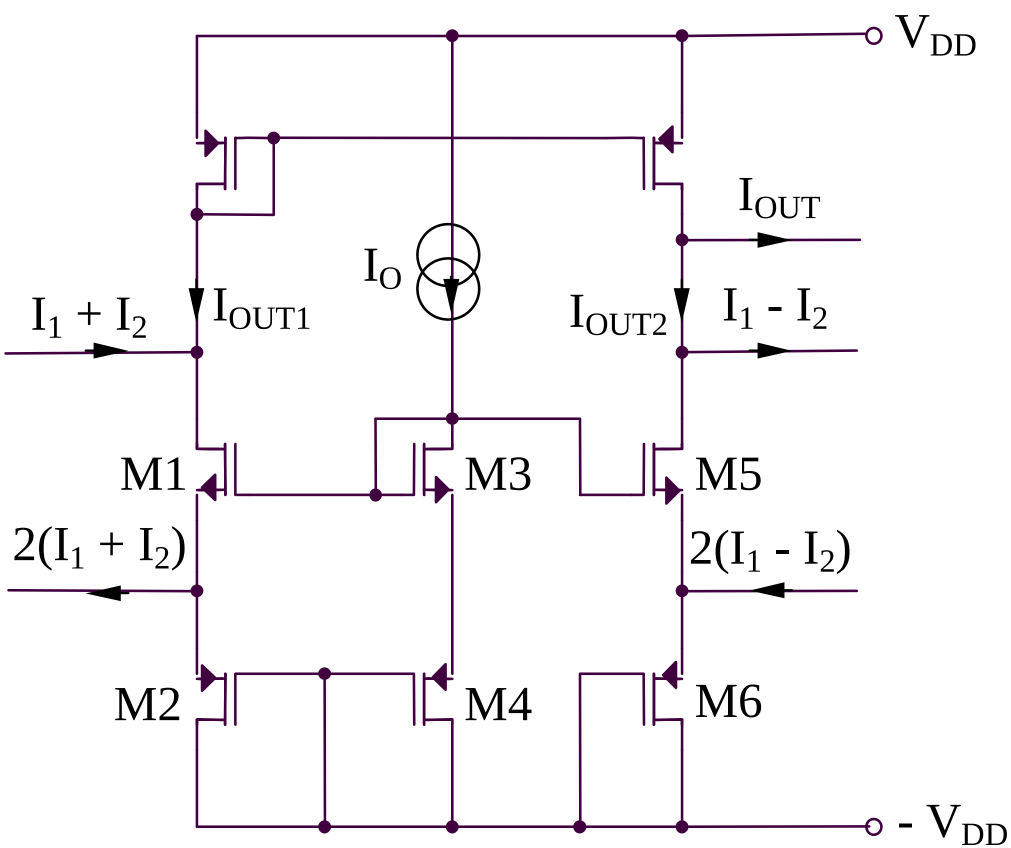
$$+ \frac{K}{2}(V_3 - V_4)(2V_2 - V_3 - V_4 + 2V_{DD} - 2V_T)$$

$$I_{OUT} = K(V_2 - V_1)(V_3 - V_4)$$

Circuite de multiplicare/divizare cu functionare in curent

8.2. Circuite de multiplicare cu comportament liniar

8.2.5. Circuit de multiplicare/divizare liniarizat cu functionare in curent (I)



$$V_{GS1} + V_{SG2} = V_{GS3} + V_{SG\$}$$

$$V_{GS} = V_T + \sqrt{\frac{2I_D}{K}}$$

Rezulta:

$$\sqrt{I_{OUT1} + (I_1 + I_2)} + \sqrt{I_{OUT1} - (I_1 + I_2)} = 2\sqrt{I_O}$$

Deci:

$$I_{OUT1} = I_O + \frac{(I_1 + I_2)^2}{4I_O}$$

Similar:

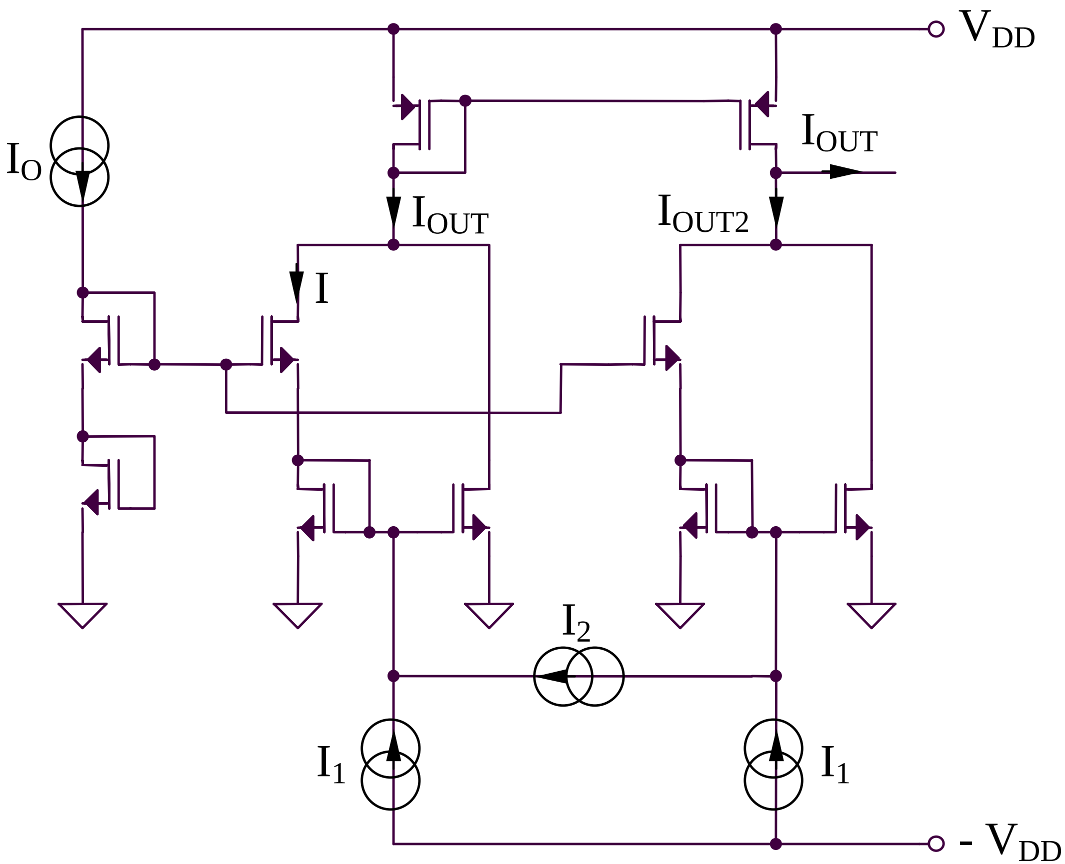
$$I_{OUT2} = I_O + \frac{(I_1 - I_2)^2}{4I_O}$$

In concluzie:

$$I_{OUT} = I_{OUT1} - I_{OUT2} = \frac{I_1 I_2}{I_O}$$

8.2. Circuite de multiplicare cu comportament liniar

8.2.6. Circuit de multiplicare/divizare liniarizat cu functionare in curent (II)



$$2V_{GS}(I_O) = V_{GS}(I) + V_{SG}(I + I_1 + I_2)$$

Rezulta:

$$\sqrt{I} + \sqrt{I + (I_1 + I_2)} = 2\sqrt{I_O}$$

de unde:

$$I = I_O - \frac{I_1 + I_2}{2} + \frac{(I_1 + I_2)^2}{16 I_O}$$

Deci:

$$I_{OUT1} = 2I + (I_1 + I_2)$$

$$I_{OUT1} = 2I_O + \frac{(I_1 + I_2)^2}{8 I_O}$$

Similar:

$$I_{OUT2} = 2I_O + \frac{(I_1 - I_2)^2}{8 I_O}$$

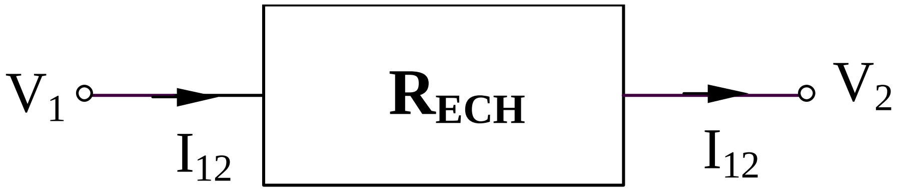
In concluzie:

$$I_{OUT} = I_{OUT1} - I_{OUT2} = \frac{I_1 I_2}{2 I_O}$$

8.3. Structuri rezistive active

8.3. Structuri rezistive active

8.3.1. Notiuni generale



$$R_{ECH} = \frac{V_1 - V_2}{I_{12}}$$

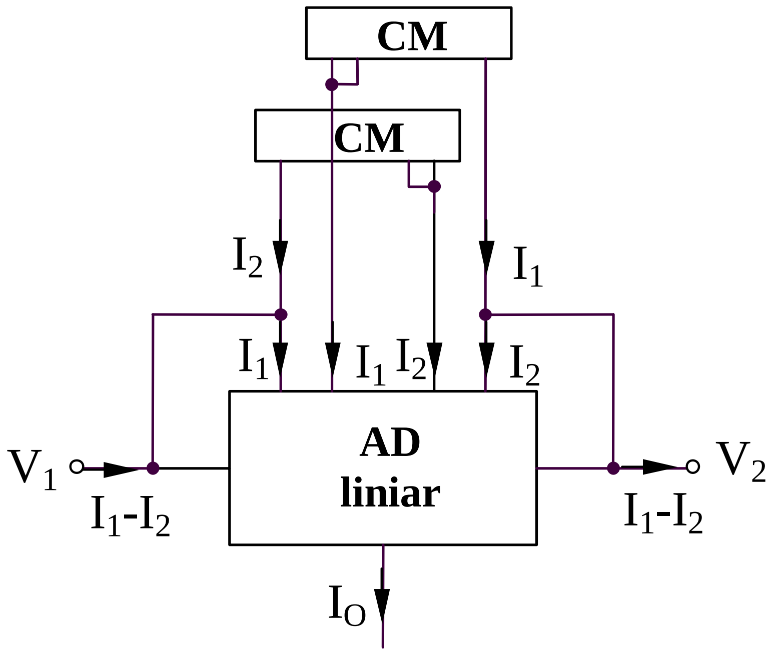
Avantaje:

- reducerea ariei ocupate
- posibilitatea controlului rezistentei echivalente
- obtinerea unor rezistente pozitive/negative

8.3. Structuri rezistive active

8.3.2. Structuri rezistive active utilizand un amplificator diferential liniar

Schema bloc - rezistenta pozitiva

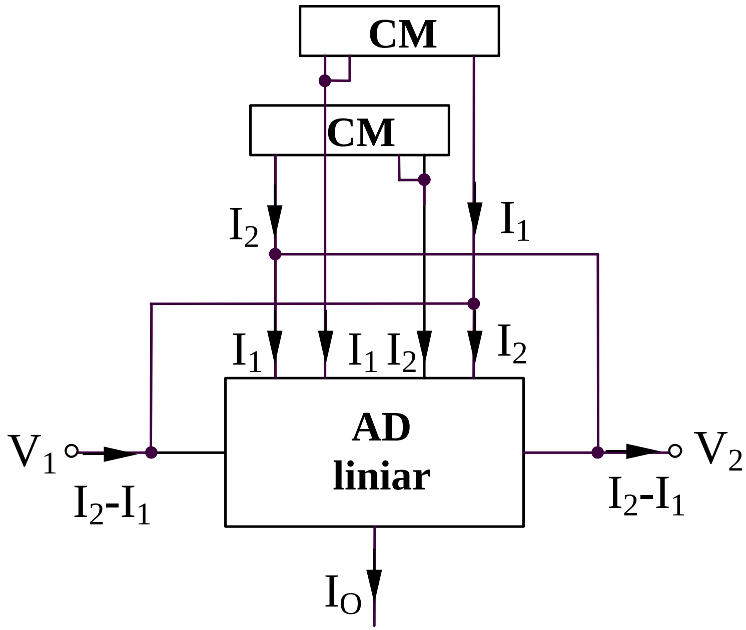


$$R_{ECH} = \frac{V_1 - V_2}{I_1 - I_2} = \frac{1}{G_m}$$

8.3. Structuri rezistive active

8.3.2. Structuri rezistive active utilizand un amplificator diferential liniar

Schema bloc - rezistenta negativa

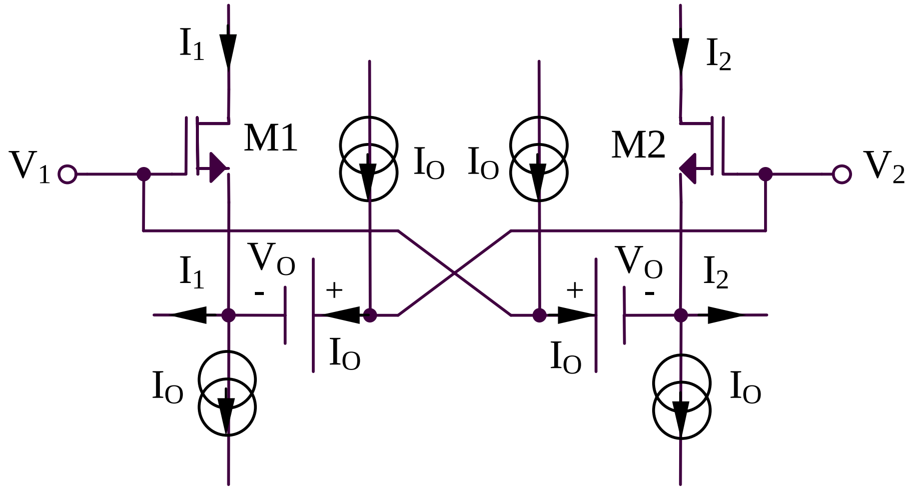


$$R_{ECH} = \frac{V_1 - V_2}{I_2 - I_1} = -\frac{1}{G_m}$$

8.3. Structuri rezistive active

8.3.2. Structuri rezistive active utilizand un amplificator diferential liniar

Structura amplificatorului diferential (I)



$$I_1 - I_2 = 2K(V_O - V_T)(V_1 - V_2)$$

$$V_O = V_{GSO} = V_T + \sqrt{\frac{2I_O}{K}}$$

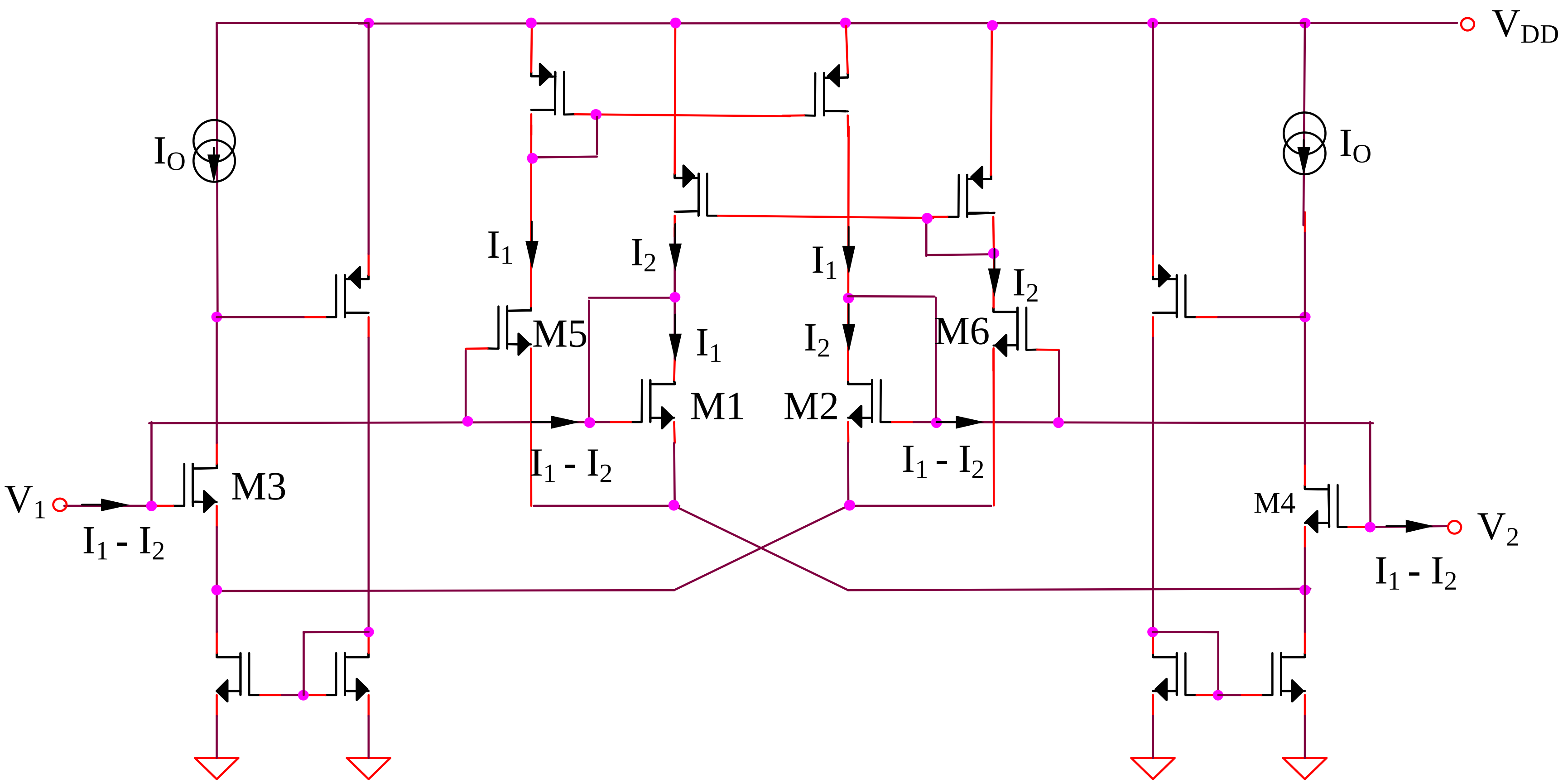
$$\Rightarrow I_1 - I_2 = \sqrt{8KI_O}(V_1 - V_2)$$

$$R_{ECH} = \frac{1}{\sqrt{8KI_O}}$$

8.3. Structuri rezistive active

8.3.2. Structuri rezistive active utilizand un amplificator diferential liniar

Implementarea (I) a structurii rezistive active ($R_{ECH} > 0$)

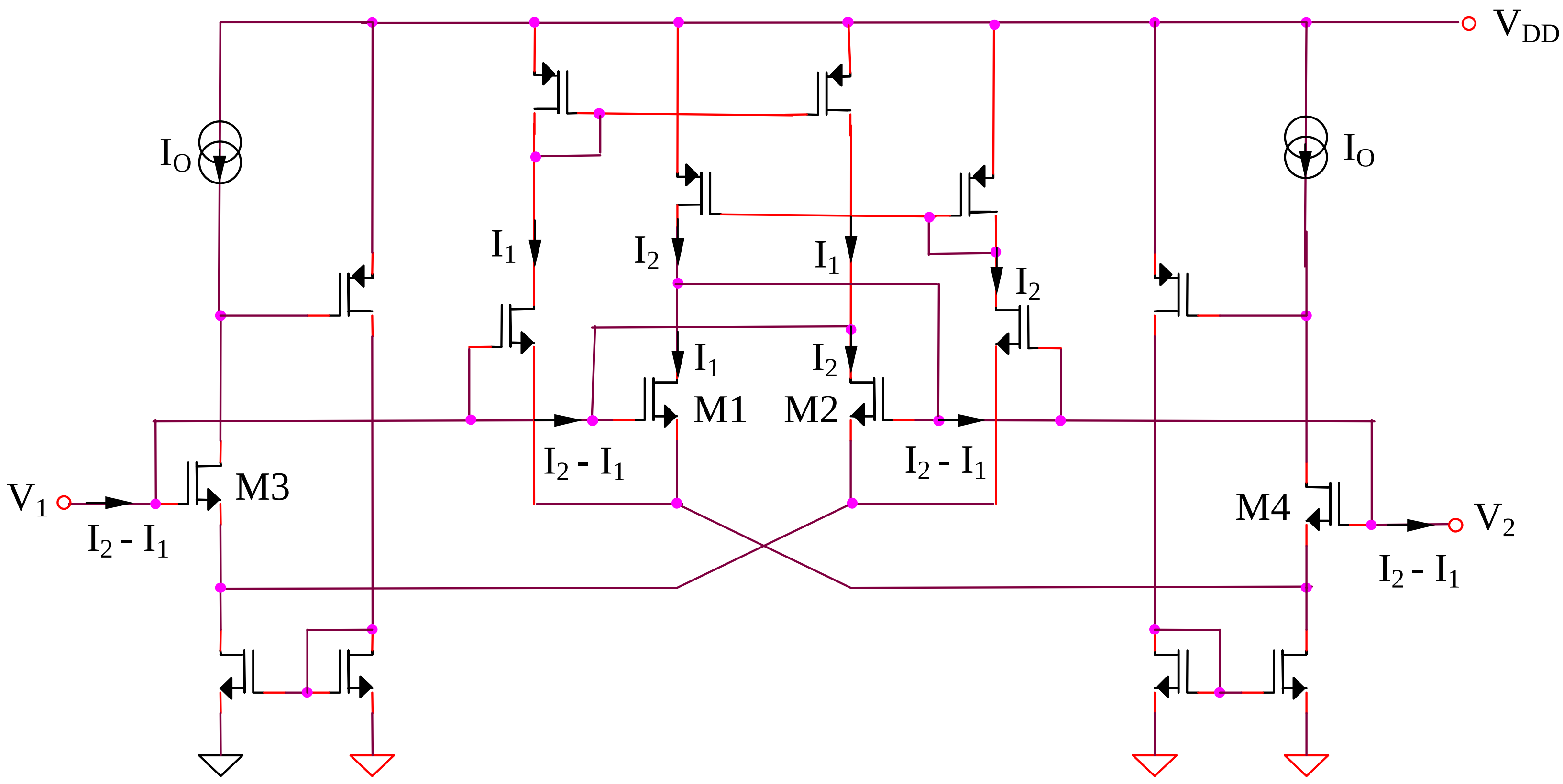


$$R_{ECH} = \frac{1}{\sqrt{8KI_O}}$$

8.3. Structuri rezistive active

8.3.2. Structuri rezistive active utilizand un amplificator diferential liniar

Implementarea (I) a structurii rezistive active (R_{ECH} < 0)

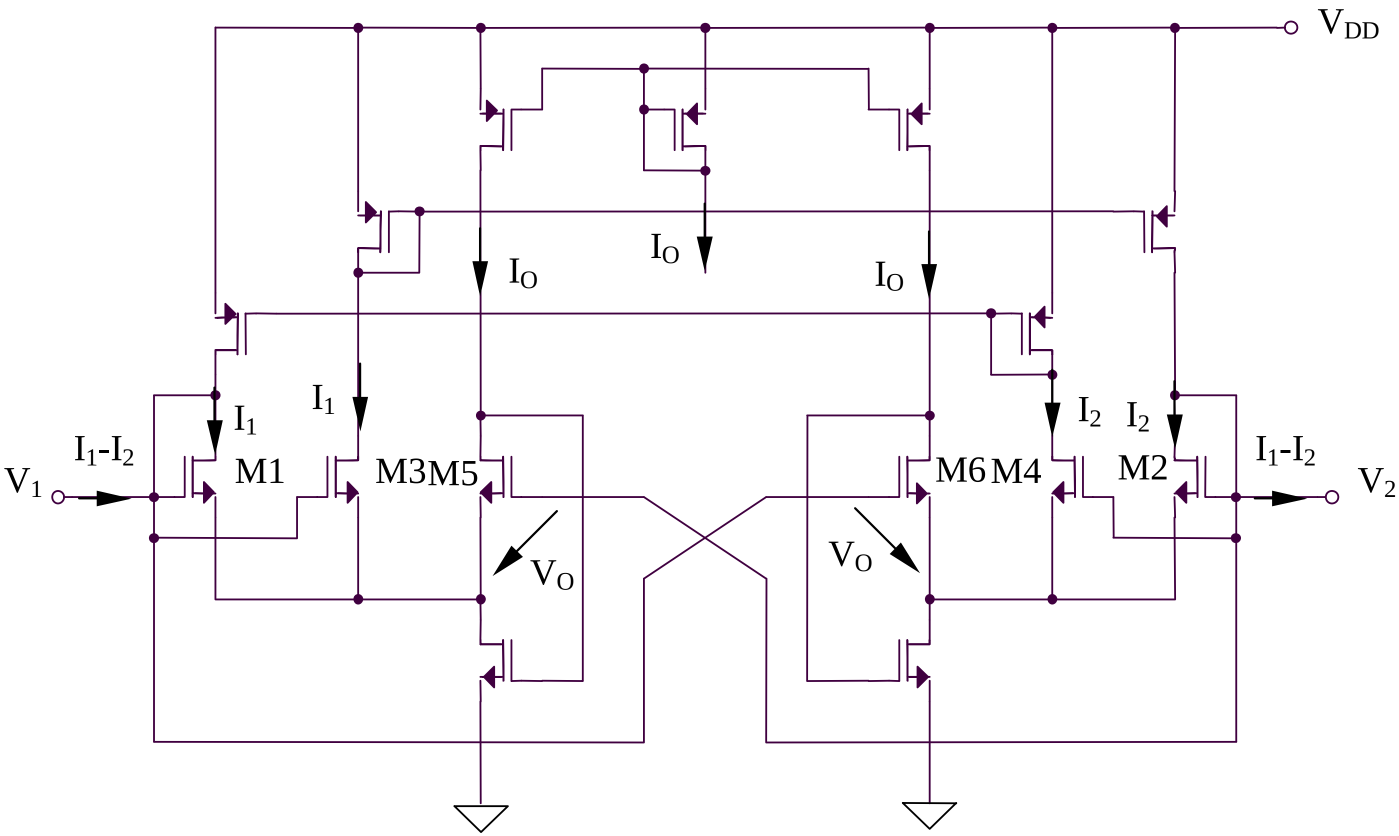


$$R_{ECH} = -\frac{1}{\sqrt{8KI_O}}$$

8.3. Structuri rezistive active

8.3.2. Structuri rezistive active utilizand un amplificator diferential liniar

Implementarea (II) a structurii rezistive active ($R_{ECH} > 0$)

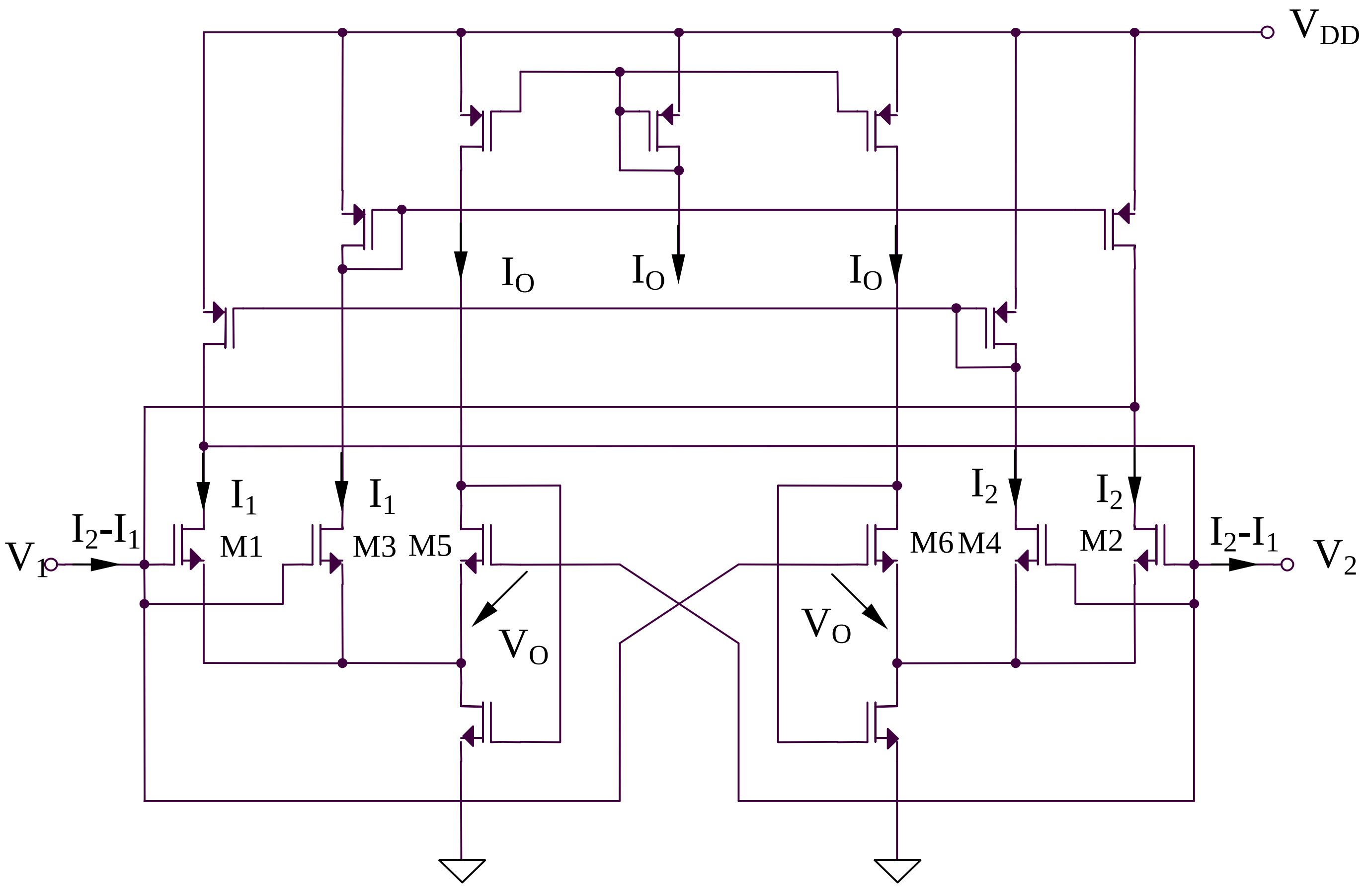


$$R_{ECH} = \frac{1}{\sqrt{8KI_O}}$$

8.3. Structuri rezistive active

8.3.2. Structuri rezistive active utilizand un amplificator diferential liniar

Implementarea (II) a structurii rezistive active ($R_{ECH} < 0$)

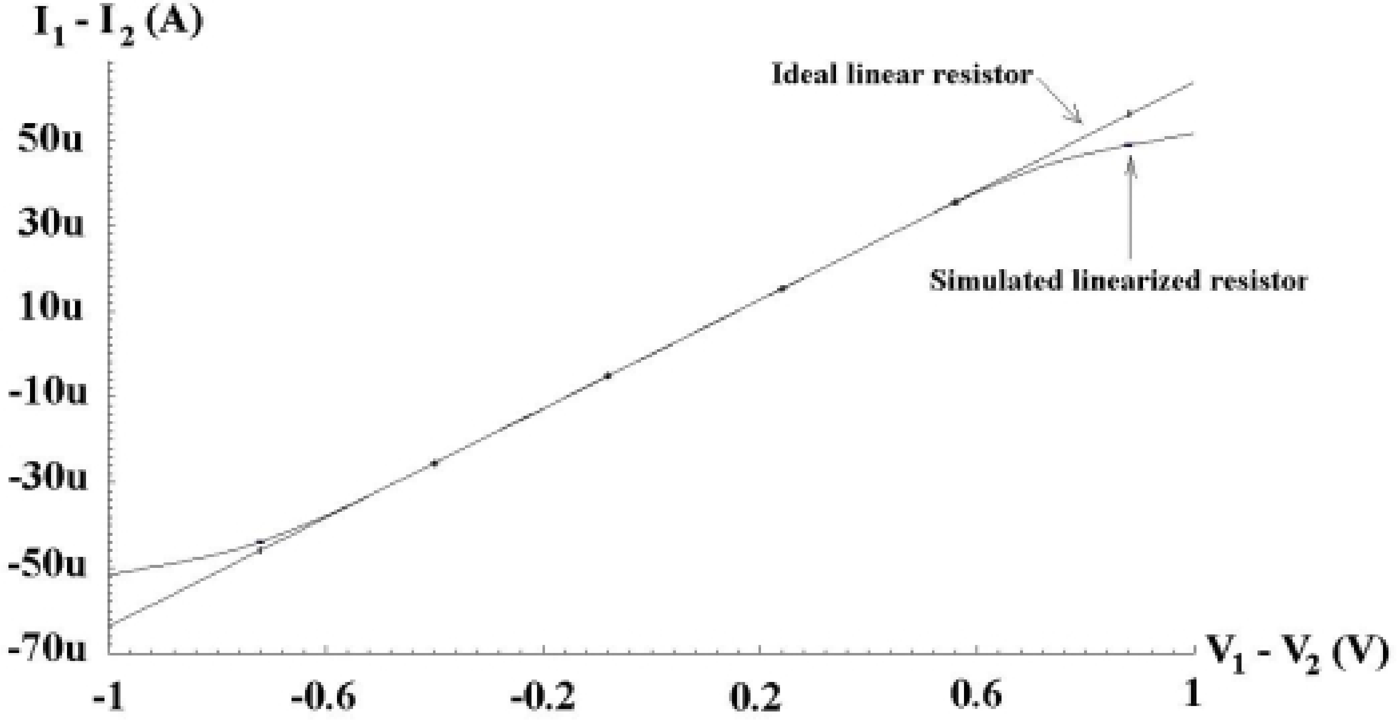


$$R_{ECH} = -\frac{1}{\sqrt{8KI_O}}$$

8.3. Structuri rezistive active

8.3.2. Structuri rezistive active utilizand un amplificator diferential liniar

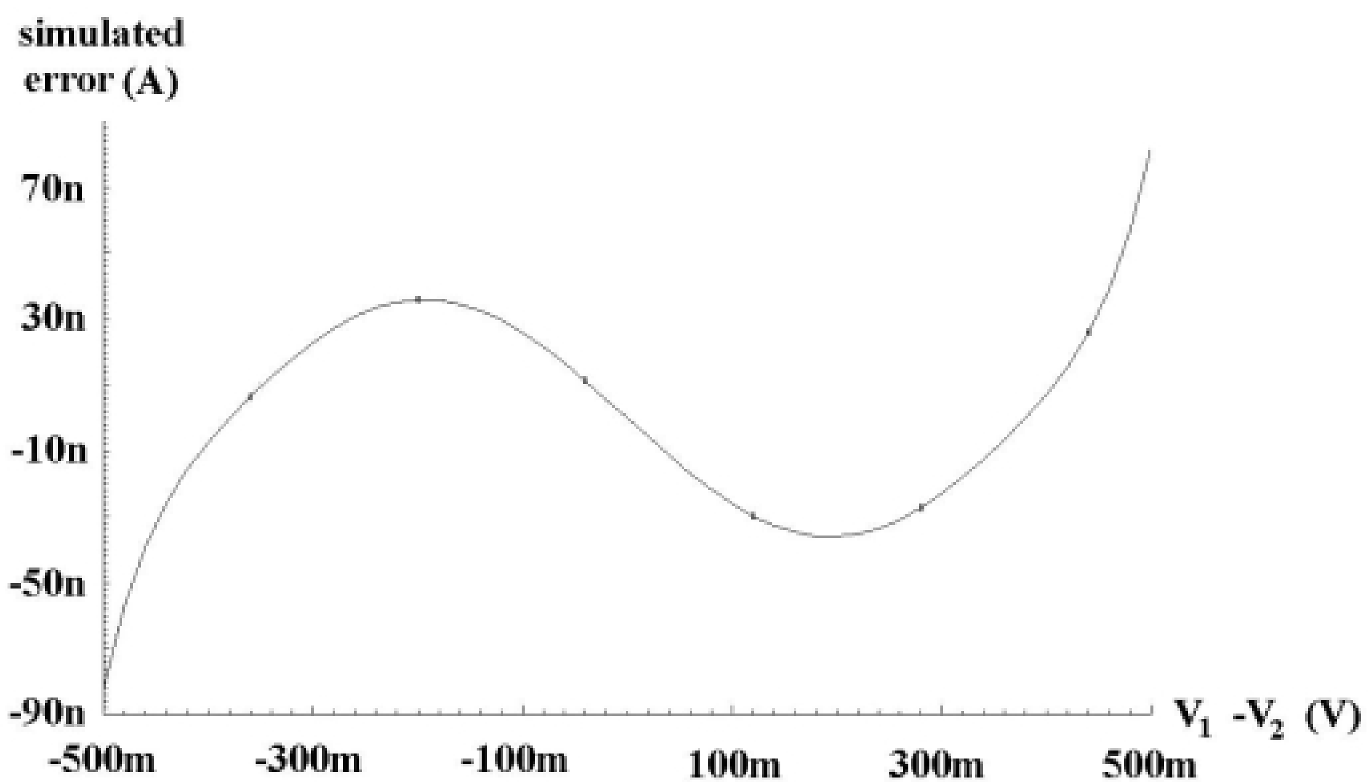
Simularea caracteristicii curent-tensiune a structurii rezistive active



8.3. Structuri rezistive active

8.3.2. Structuri rezistive active utilizand un amplificator diferential liniar

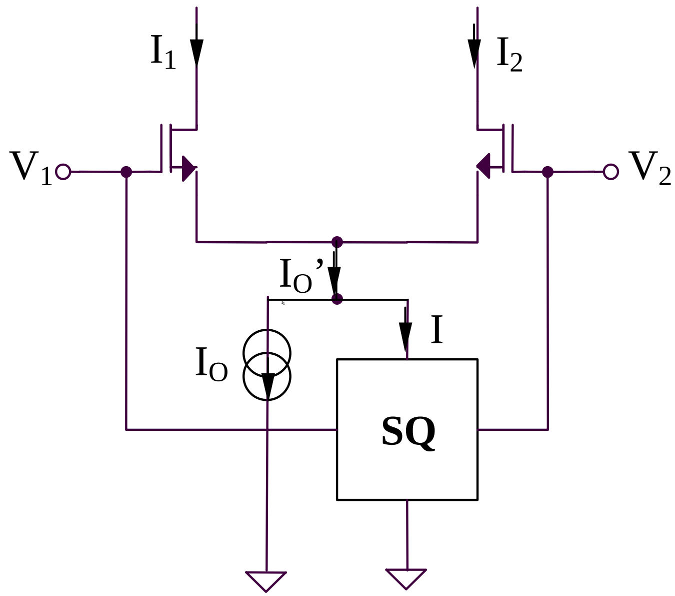
Simularea erorii de liniaritate a structurii rezistive active



8.3. Structuri rezistive active

8.3.3. Structuri rezistive active utilizand un amplificator diferential liniar

Structura amplificatorului diferential (II)



$$I_O' = I_O + I = I_O + \frac{K}{4}(V_1 - V_2)^2$$

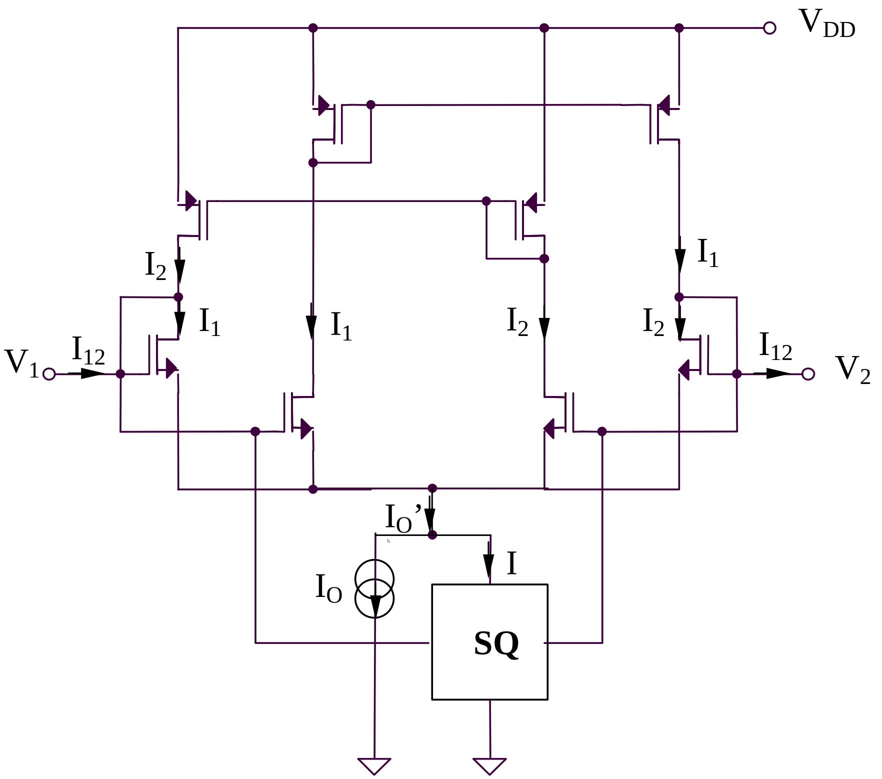
$$I_1 - I_2 = \frac{V_1 - V_2}{2}\sqrt{4KI_O' - K^2(V_1 - V_2)^2} = \sqrt{KI_O}(V_1 - V_2) = G_m(V_1 - V_2)$$

$$R_{ECH} = \frac{1}{\sqrt{KI_O}}$$

8.3. Structuri rezistive active

8.3.3. Structuri rezistive active utilizand un amplificator diferential liniar

Implementarea structurii rezistive active (R_{ECH} > 0)

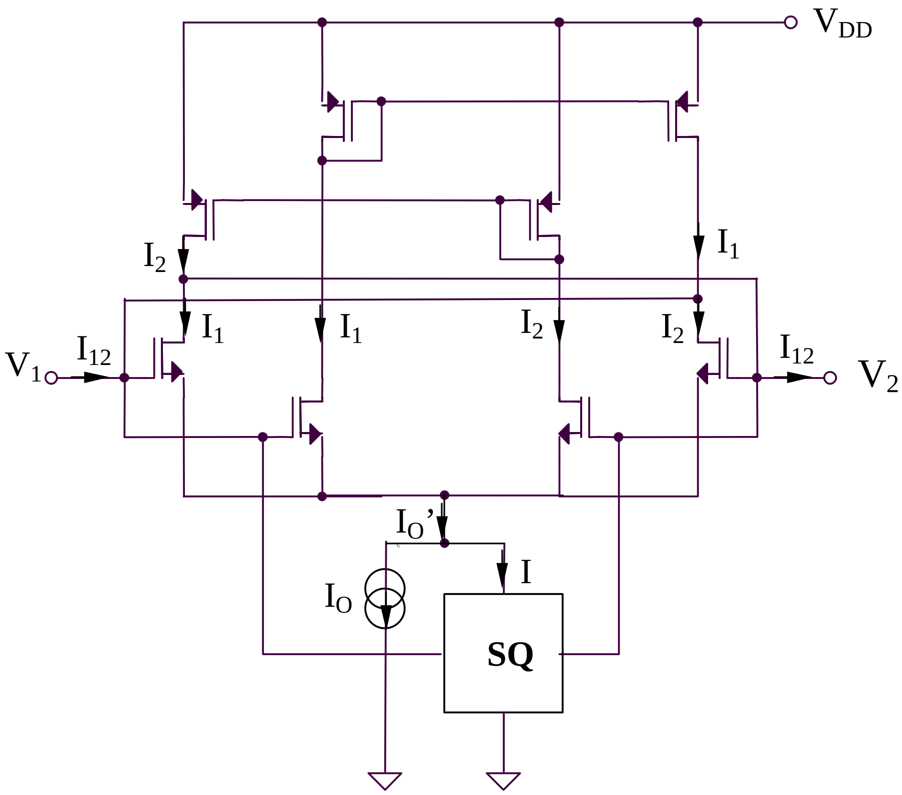


$$R_{ECH} = \frac{V_1 - V_2}{I_{12}} = \frac{1}{\sqrt{KI_O}}$$

8.3. Structuri rezistive active

8.3.3. Structuri rezistive active utilizand un amplificator diferential liniar

Implementarea structurii rezistive active (R_{ECH} < 0)



$$R_{ECH} = -\frac{1}{\sqrt{KI_O}}$$