A.A. 2021-2022

Elementi di Elettronica (INF)

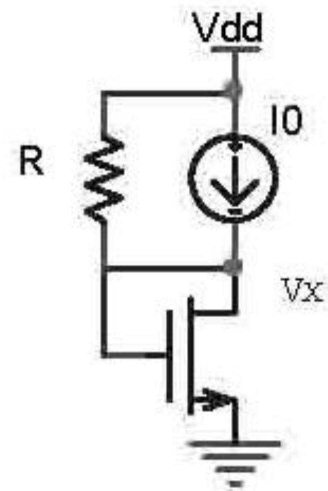
Prof. Paolo Crippa

Esercizi – P4

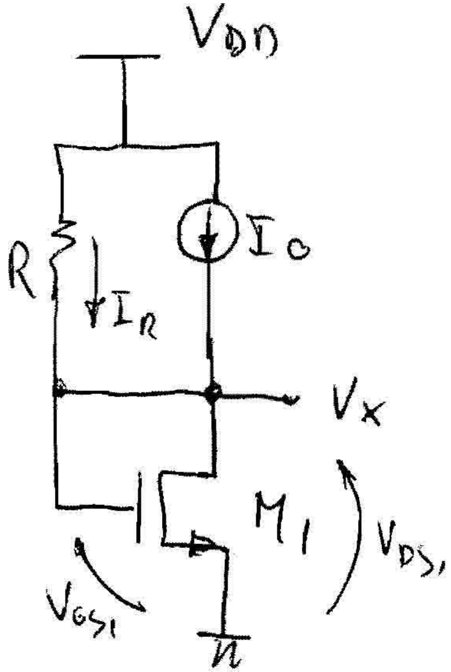
Circuiti con MOSFET e BJT: Es. 1c

4) Dati V_{dd}=5V, I_0=10μA, R=100KΩ, V_{TH}= 1V, β=10μA/V^2 ,trovare: la zona di funzionamento dei MOSFET e le seguenti tensioni e correnti

M: SAT TRI OFF I_D= ___,___ μA, V_{out}= _,____ V,



Es. 1c: Soluzione



$V_{DD} = 5\,V$

$I_O = 10\,\mu A$

$R = 100\,k\Omega$

$V_{TH} = 1\,V$

$\beta = 10\,\mu A/V^2$

M_1 ?

I_{D1} ?

V_{OUT} ?

$V_{GS1} = V_{DS1} \Rightarrow \boxed{M1 \text{ SAT}}$

$$I_{D1} = \frac{\beta_1}{2}\left(V_{GS1} - V_{TH1}\right)^2$$

$V_{GS1} = V_{DS1} = V_X$;

Es. 1c: Soluzione

$$I_R = \frac{V_{DD} - V_x}{R} \;;$$

$$I_{D_1} = I_0 + I_R \Rightarrow \boxed{I_0 + \frac{V_{DD} - V_x}{R} = \frac{\beta_1}{2}\left(V_x - V_{TH_1}\right)^2}$$

$$V_x = \begin{cases} +3.317 \\ -3.317 \end{cases} \; ?$$

$$V_{GS_1} = V_x \;; \quad NMOS \Rightarrow V_x = +3.317$$

$$I_{D_1} = \frac{\beta}{2}\left(V_x - V_{TH_1}\right)^2 = 26.84\,\mu A$$

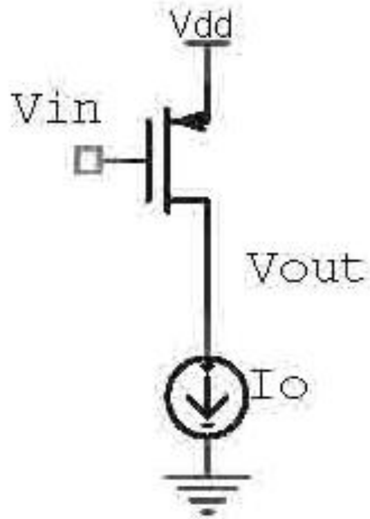
Circuiti con MOSFET e BJT: Es. 2c

4) Dati V_{dd}=5V, I_0=2μA, V_{in}=3V, V_{THP}= -1V, β=20μA/V^2 ,trovare: la zona di funzionamento dei MOSFET e le seguenti tensioni e correnti, disegnare il circuito equivalente ed il guadagno di tensione

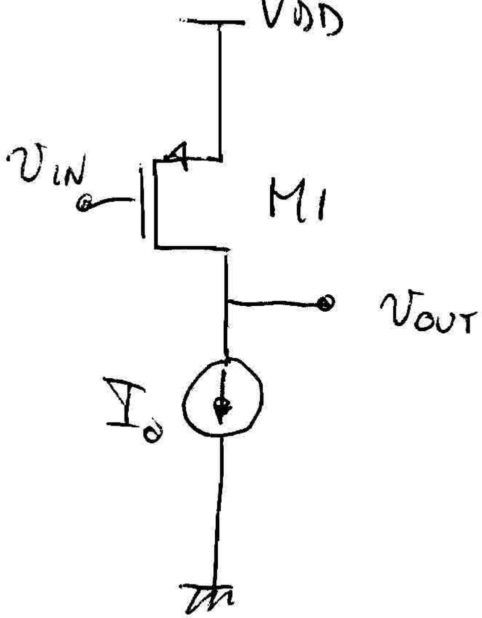
M: SAT TRI OFF I_{D1}= ___ , ___ μA, V_{out}= ___ , ___ V,

g_m= ___ , ___ μ Ω^{-1}, g_o= ___ , ___ μ Ω^{-1},

v_{out}/v_{in}= ___ , ___ (in forma simbolica) v_{out}/v_{in}=



Es. 2c: Soluzione



$V_{DD} = 5V$

$I_0 = 2\mu A$

$V_{IN} = 2V$

$V_{THp} = -1V$

$\beta_1 = 20 \mu A/V^2$

$I_{D1} = ?$

$V_{OUT} = ?$

$g_m = ?$

$g_o = ?$

$\frac{v_{out}}{v_{in}} = ?$

$V_{GS} = V_{IN} - V_{DD} = 3 - 5 = -2V \overset{?}{<} V_{TH_1} = -1$ OK $\boxed{M1\ ON}$

Hp: M_1 SAT

$I_{D1} = \frac{\beta_1}{2}(V_{GS} - V_{TH})^2 = \frac{20}{2} 10^{-6} \cdot (-2-1)^2 = 10 \mu A \neq I_0 = 2\mu A$

Es. 2c: Soluzione

$\Rightarrow$ $\boxed{\text{M1 TRI}}$ $\quad V_{DS1} > V_{GS1} - V_{TH1}$

$$I_D = \beta_1 \left[(V_{GS1} - V_{TH1}) V_{DS1} - \frac{V_{DS1}^2}{2} \right] = I_0$$

$$5 V_{DS}^2 + 10 V_{DS} + 1 = 0 \qquad V_{DS} = \begin{cases} -0.1055 \\ -1.894 \end{cases} \quad ?$$

$V_{DS} > V_{GS} - V_{TH} \Rightarrow$ $-1.894 > -2+1 = -1$ NO!

$-0.1055 > -1$ SI!

$\Rightarrow V_{DS} = -0.1055 \text{ V}$

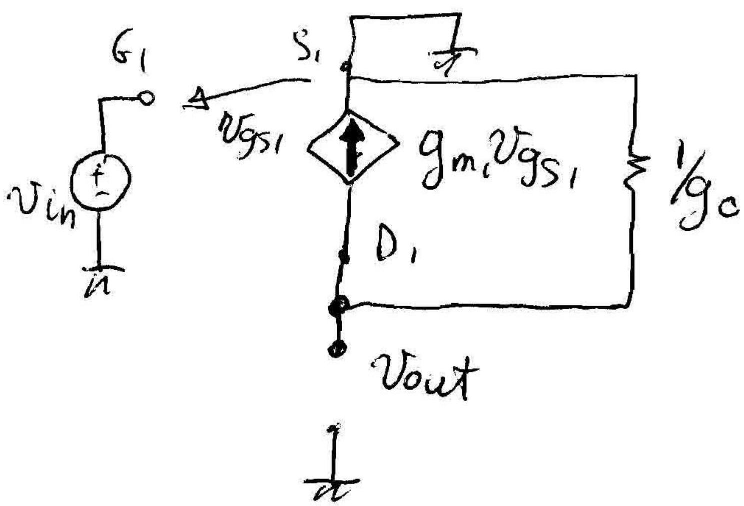
$V_{OUT} = V_{DD} + V_{DS} = V_{DD} - V_{SD} = 5 - 0.1055 = 4.8945 \text{ V}$

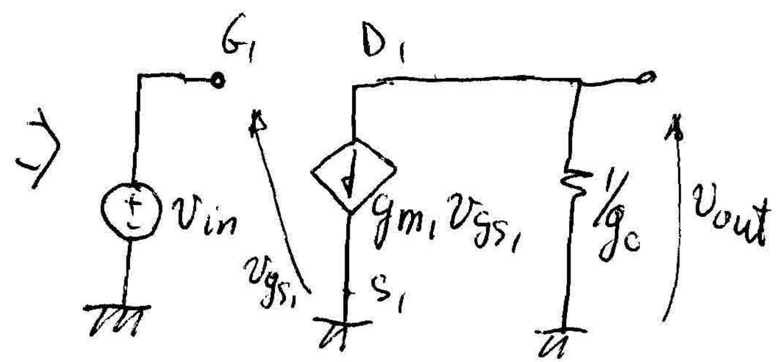
Es. 2c: Soluzione

$$g_{m1} = \beta V_{SD} = 20 \cdot 10^{-6} \cdot 0.1055 = 2.11 \mu S$$

$$g_o = \beta \left(V_{SG} + V_{TH} - V_{SD} \right) = 20 \; 10^{-6} \left(2 - 1 - 0.1055 \right)$$

$$= 17.89 \; \mu S$$

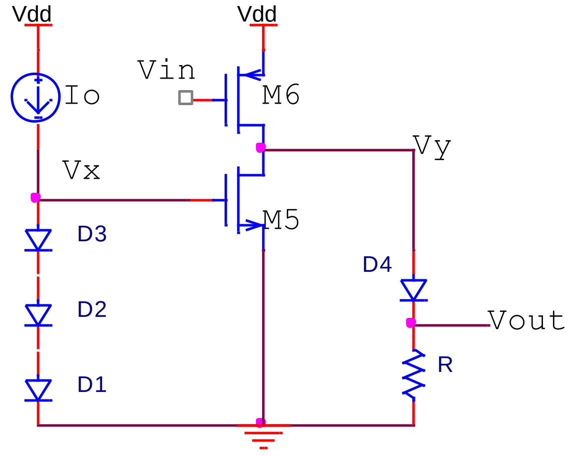




$$v_{out} = -g_{m1} v_{gs1} \cdot \frac{1}{g_o} \quad ; \quad v_{gs1} = v_{in} \qquad A_v = \frac{v_{out}}{v_{in}} = -\frac{g_{m1}}{g_o} = -0.118 \; V/V$$

Circuiti con MOSFET e BJT: Es. 3c

5) Dati V_{dd}=5V, V_{in}=3V, I_{in}=10μA, V_{TH5}=1V, V_{TH6}= -1V, $\beta_5=\beta_6$=200μA/V^2 , per i diodi V_γ=0.6V r_d=0Ω
Trovare il valore delle seguenti tensioni e correnti. Trovare inoltre la zona di funzionamento dei MOSFET e dei diodi.



M5: SAT TRI OFF M6: SAT TRI OFF

D1: ON OFF D2: ON OFF D3: ON OFF D4: ON OFF

I_{D1}= __ , ___ μA, I_{D4}= __ , ___ μA,

I_{D5}= __ , ___ μA, I_{D6}= __ , ___ μA,

V_x= _ , ___ V, V_y= _ , ___ V, V_{out}= _ , ___ V,

6) Trovare i parametri differenziali del circuito dell'esercizio 5 e disegnare il circuito equivalente

circuito equivalente :

gm5= ___ , ___ μ Ω^{-1},

go5= ___ , ___ μ Ω^{-1},

gm6= ___ , ___ μ Ω^{-1},

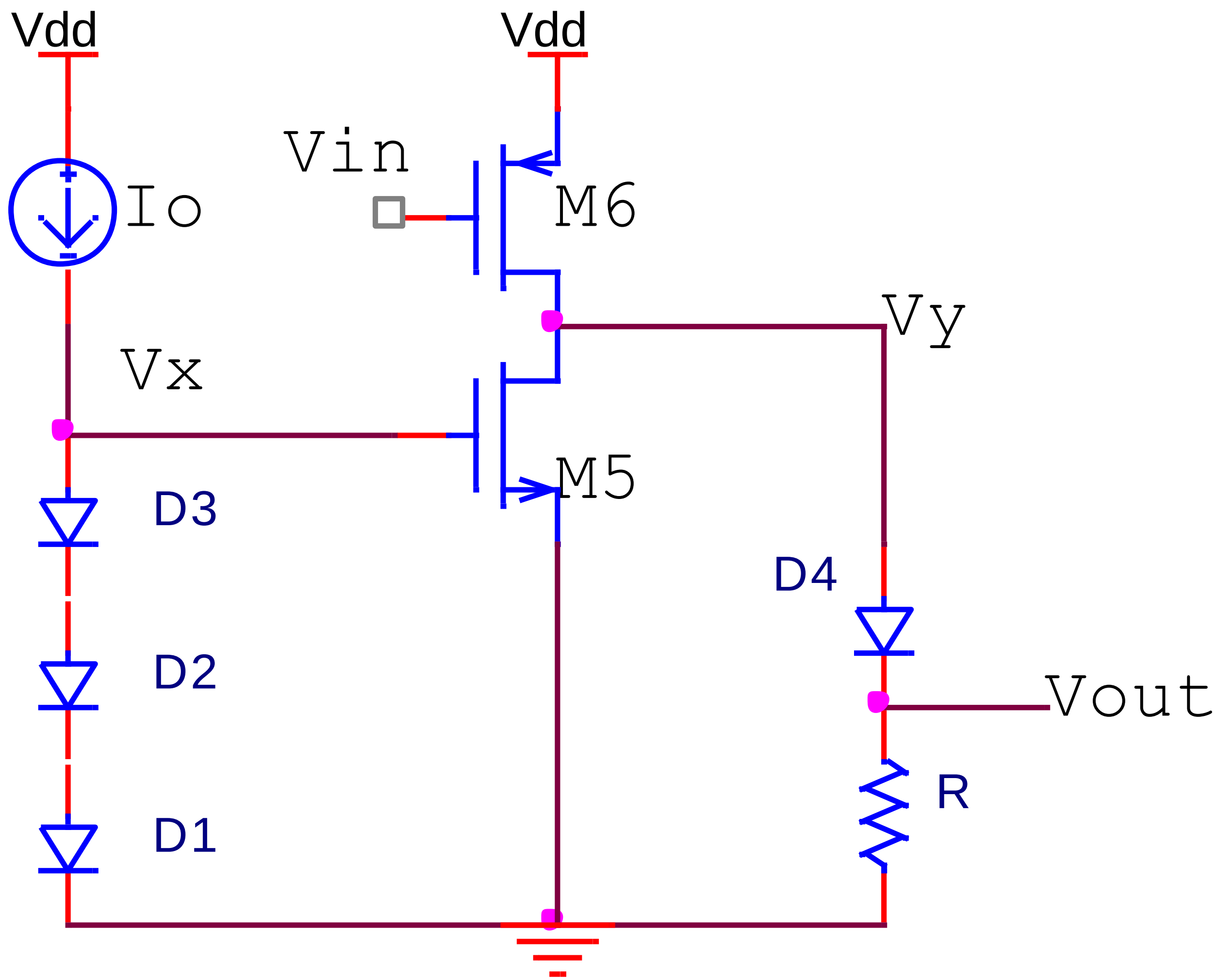
go6= ___ , ___ μ Ω^{-1},

7) Trovare il guadagno di tensione del circuito dell'es. 5

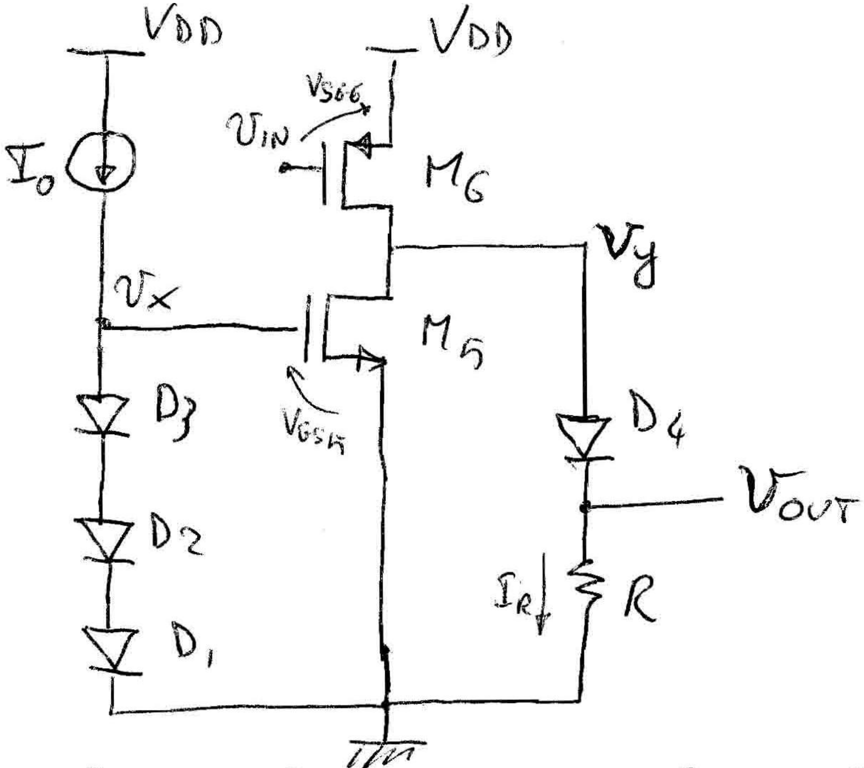
v_{out}/ v_{in} = __ , ___

(in forma simbolica) v_{out}/ v_{in} =

Circuiti con MOSFET e BJT: Es. 3c



Es. 3c: Soluzione



$V_{DD} = 5V$

$V_{IN} = 3V$

$I_0 = 10\mu A$ $R = 30\,k\Omega$

$|V_{TH}| = 1V$

$\beta_5 = \beta_6 = 200\mu A/V^2$

$\left.\begin{array}{l} V_\gamma = 0.6\,V \\ r_d = 0\,\Omega \end{array}\right\}$ D_1, D_2, D_3, D_4

$I_{D1} = ?$ $I_{D4} = ?$ $I_{D5} = ?$ $I_{D6} = ?$ $V_x = ?$ $V_y = ?$ $V_{OUT} = ?$

$I_{D1} = I_{D2} = I_{D3} = I_0 = \underline{10\mu A}$ $\Rightarrow$ $\boxed{D_1, D_2, D_3 \text{ ON}}$

$V_{GS6} = V_{IN} - V_{DD} = 3 - 5 = -2V < -1V = V_{TH6} \Rightarrow V_{GS6} < V_{TH6}$ $\boxed{M6 \text{ ON}}$

Hp. M6 SAT

Es. 3c: Soluzione

Hp. M6 SAT

$$I_{D6} = \frac{\beta_6}{2}\left(V_{GS_6} - V_{TH_6}\right)^2 = \frac{200\,10^{-6}}{2}\cdot\left(-2+1\right)^2 = 100\,10^{-6} = \underline{100\,\mu A}$$

$$V_{GS_5} = V_\gamma + V_\gamma + V_\gamma = 3\cdot 0.6 = 1.8\ V > V_{TH_5} = 1V \qquad \boxed{M5\ ON}$$

Hp M5 SAT

$$I_{D5} = \frac{\beta_5}{2}\left(V_{GS_5} - V_{TH_5}\right)^2 = \frac{200}{2}\cdot 10^{-6}\left(1.8-1\right)^2 = \underline{64\,\mu A}$$

$$I_R = I_{D6} - I_{D5} = 36\,\mu A$$

$$I_{D4} = \underline{36\,\mu A} \Rightarrow \boxed{D_4\ ON}$$

$$V_{OUT} = R\cdot I_R = 36\cdot 10^{-6}\cdot 30\cdot 10^3 = \underline{1.08\ V}$$

$$V_y = V_{OUT} + V_\gamma = \underline{1.68\ V} \qquad V_x = V_{GS_5} = \underline{1.8\,V}$$

Es. 3c: Soluzione

$V_{DS5} = V_y = 1.68V \overset{?}{>} V_{GS5} - V_{TH5} = 1.8 - 1 = 0.8$ OK

$\boxed{M5 \ SAT}$

$V_{DS6} = V_y - V_{DD} = 1.68 - 5 = -3.32 \overset{?}{<} V_{GS6} - V_{TH6} = -2 + 1 = -1$ OK

$\boxed{M6 \ SAT}$

$g_{m5} = \beta_5 (V_{GS5} - V_{TH5}) = 160 \mu S$

$g_{o5} = 0 \ \mu S$

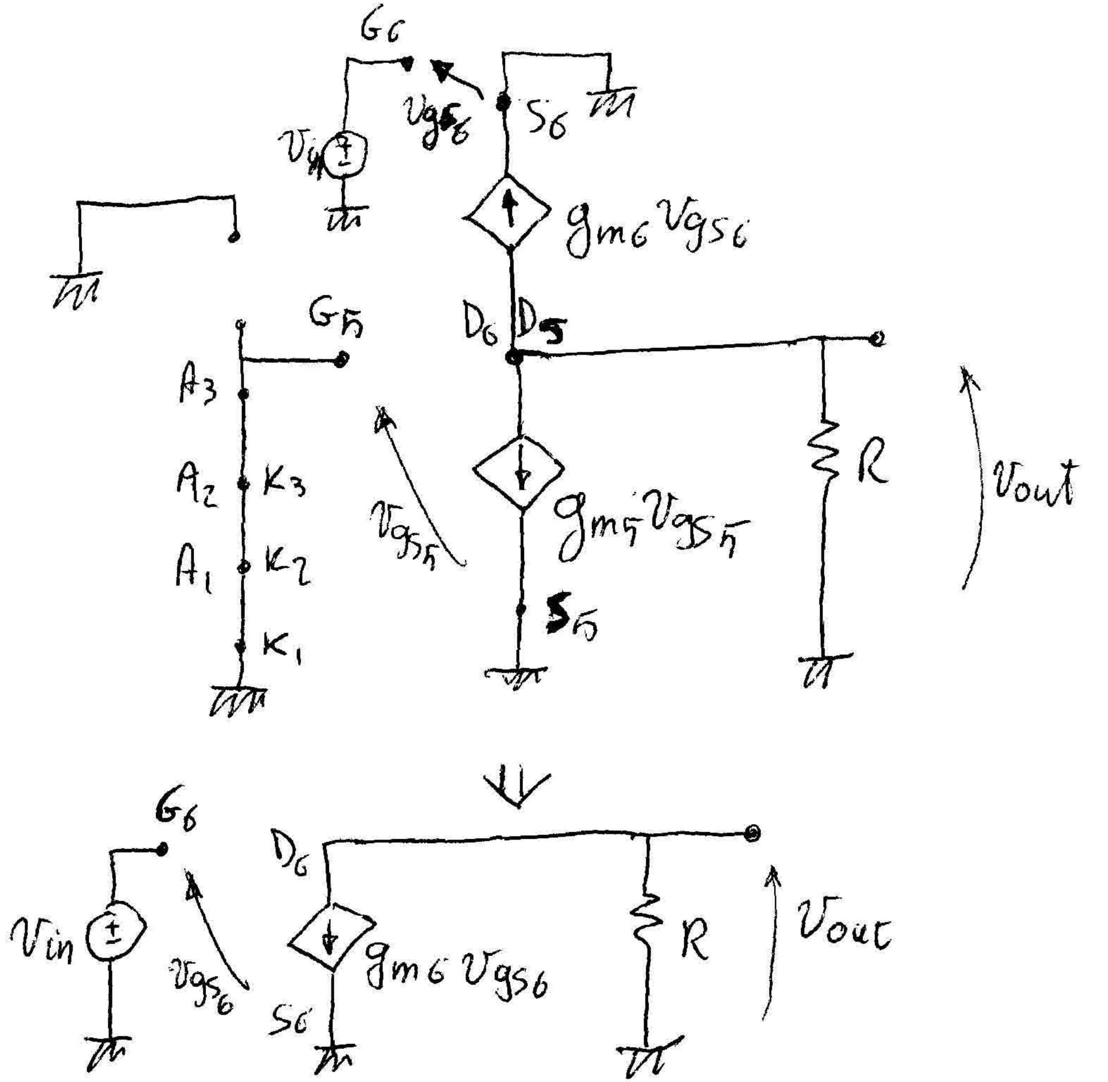
* $g_{m6} = \beta_6 (V_{SG6} + V_{TH6}) = 200 \cdot 10^{-6} (2 - 1) = 200 \mu S$

$g_{o6} = 0 \mu S$

$r_d = 0$

* $g_{m6} = -\beta_6 (V_{GS6} - V_{TH6}) = \sqrt{2 \beta_6 I_{D6}}$

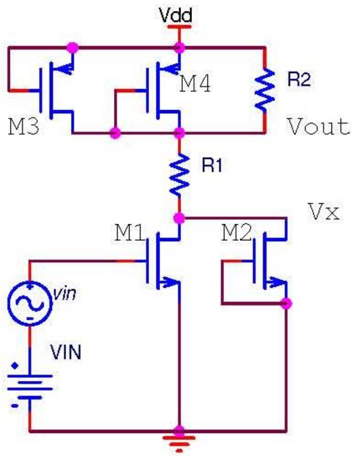
Es. 3c: Soluzione



$v_{out} = -g_{m6} v_{gs6} R$; $v_{gs6} = v_{in}$; $A_v = \dfrac{v_{out}}{v_{in}} = -g_{m6} R = -6\ V/V$

Circuiti con MOSFET e BJT: Es. 4c

5. Dato il circuito in figura ($V_{\text{dd}} = 5$ V, $V_{\text{in}} = 2$ V, $V_{\text{THn}} = 1$ V, $V_{\text{THp}} = -1$ V, $\beta_1 = \beta_2 = 20\ \mu\text{A/V}^2$, $\beta_3 = \beta_4 = 10\ \mu\text{A/V}^2$, $R1 = 50\ \text{k}\Omega$, $R2 = 1\ \text{M}\Omega$), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{D1}, I_{D2}, I_{D3}, I_{D4}, I_{R1}, I_{R2} e le tensioni V_{X}, V_{out}; *iii)* i parametri differenziali dei MOSFET.



M1 : SAT TRI OFF
M2 : SAT TRI OFF

M3 : SAT TRI OFF
M4 : SAT TRI OFF

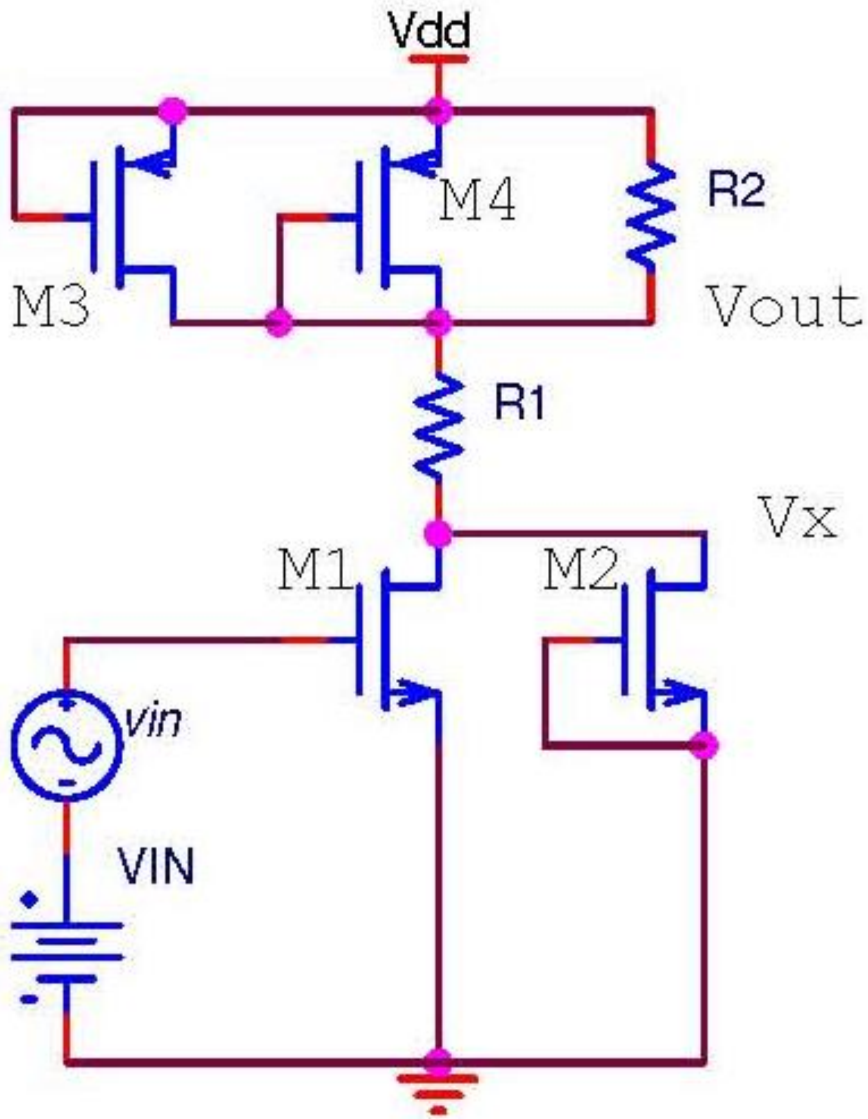
I_{D1} =	.	μA	g_{m1} =	. μS
I_{D2} =	.	μA	g_{o1} =	. μS
I_{D3} =	.	μA	g_{m2} =	. μS
I_{D4} =	.	μA	g_{o2} =	. μS
I_{R1} =	.	μA	g_{m3} =	. μS
I_{R2} =	.	μA	g_{o3} =	. μS
V_{X} =	.	V	g_{m4} =	. μS
V_{out} =	.	V	g_{o4} =	. μS

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{\text{out}}/v_{\text{in}}$

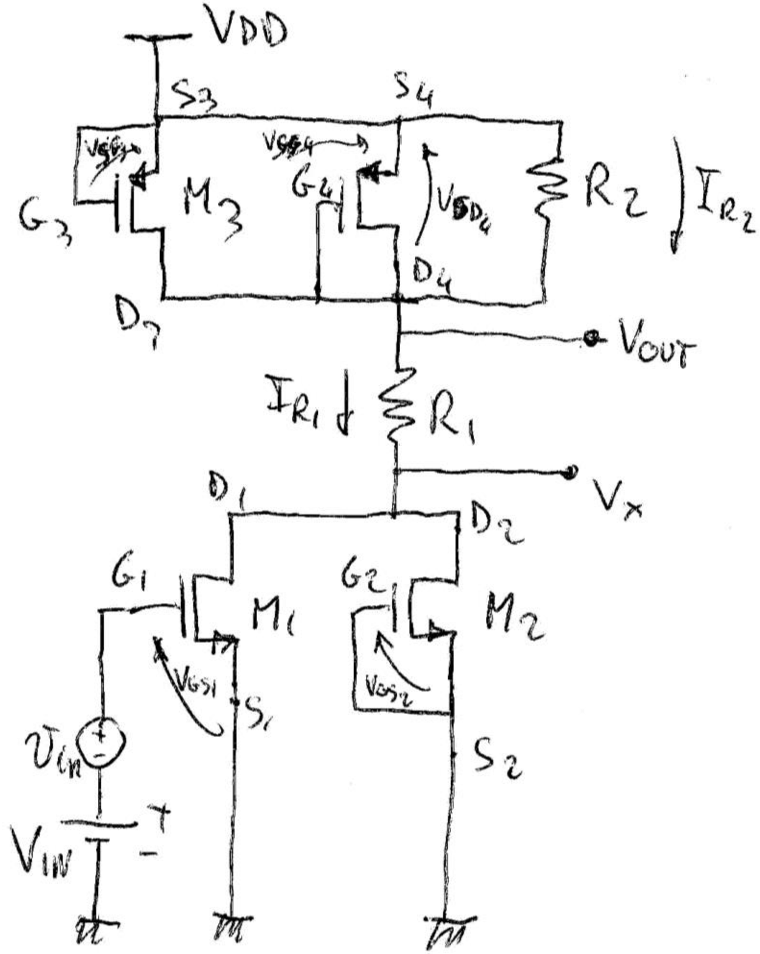
(espressione simbolica) $v_{\text{out}}/v_{\text{in}} =$

$v_{\text{out}}/v_{\text{in}} =$. V/V

Circuiti con MOSFET e BJT: Es. 4c



Es. 4c: Soluzione



$V_{DD} = 5V$

$V_{IN} = 2V$

$V_{THN} = 1V$

$V_{THP} = -1V$

$\beta_1 = \beta_2 = 20 \mu A/V^2$

$\beta_3 = \beta_4 = 10 \mu A/V^2$

$R_1 = 50\, k\Omega$

$R_2 = 1\, M\Omega$

$V_{GS3} = 0 \overset{?}{>} V_{TH3} = -1V \overset{SI}{\Rightarrow}$ $\boxed{M3\ OFF}$ $\quad I_{D3} = \underline{0\ \mu A}$

$V_{GS2} = 0 \overset{?}{>} V_{TH2} = 1V \overset{NO}{\Rightarrow}$ $\boxed{M2\ OFF}$ $\quad I_{D2} = \underline{0\ \mu A}$

Es. 4c: Soluzione

$V_{GS_4} = V_{DS_4} \Rightarrow V_{DS_4} \leq V_{GS_4} - V_{TH_4} \Rightarrow \boxed{M4\ SAT}$

Hp M1 SAT $\quad V_{GS_1} > V_{TH_1} \quad V_{DS_1} \geq V_{GS_1} - V_{TH_1}$

$V_{GS_1} = V_{IN} = 2V > V_{TH} = 1V$

$\boxed{M_1\ ON}$

$$I_{D1} = \frac{\beta_1}{2}\left(V_{GS_1} - V_{TH_1}\right)^2 = \frac{20\ 10^{-6}}{2}(2-1)^2 = \underline{10\mu A}$$

$$I_{R_1} = I_{D_1} + I_{D2} = I_{D_1} = \underline{10\mu A}$$

$$I_{D_4} = \frac{\beta_4}{2}\left(V_{GS_4} - V_{TH_4}\right)^2$$

$$V_{GS_4} = V_{DS_4} = -I_{R2} R_2 \quad ; \quad I_{R_2} = -V_{GS_4}/R_2$$

$$I_{D_4} + I_{R_2} = I_{R1}$$

Es. 4c: Soluzione

$$\frac{\beta_4}{2}\left(V_{GS_4}-V_{TH_4}\right)^2-\frac{V_{GS4}}{R_2}=I_{R_1}$$

$$\frac{\beta_4}{2}\left(V_{GS_4}^2+V_{TH_4}^2-2V_{GS_4}V_{TH_4}\right)-\frac{V_{GS4}}{R_4}=I_{R_1}$$

$$\frac{\beta_4}{2}V_{GS_4}^2-\left(\beta_4V_{TH_4}+\frac{1}{R_2}\right)V_{GS_4}+\frac{\beta_4}{2}V_{TH_4}^2-I_{R_1}=0$$

$$5\cdot10^{-6}\,V_{GS_4}^2-\left(10\cdot10^{-6}\cdot(-1)+1\cdot10^{-6}\right)V_{GS_4}+5\cdot10^{-6}\cdot1-10\cdot10^{-6}=0$$

$$5V_{GS_4}^2+9V_{GS_4}-5=0$$

$$V_{GS_4}=\begin{cases}-2.245\ V\\ +\cancel{0.445}\ V\end{cases}$$

Es. 4c: Soluzione

$V_{GS4} = V_{DS4} = -2.245 \text{ V}$

$V_{out} = V_{DD} + V_{GS4} = 5 - 2.245 = \underline{2.755 \text{ V}}$

$(V_{DD} - V_{SG4})$

$\underline{I_{R2}} = -\dfrac{V_{GS4}}{R_2} = \underline{2.245\ \mu A}$

$I_{D4} = I_{R1} - I_{R2} = 10 - 2.245 = 7.755\ \mu A$

$\underline{V_x} = V_{OUT} - I_{R1} \cdot R_1 = 2.755 - 10 \cdot 10^{-6} \cdot 50 \cdot 10^3 = \underline{2.255 \text{ V}}$

$V_{DS1} = V_x = 2.255 \overset{?}{>} V_{GS1} - V_{TH1} = 2 - 1 = 1$ ok $\boxed{\text{M1 SAT}}$

Es. 4c: Soluzione

$$g_{m1} = \beta_1 \left(V_{GS1} - V_{TH1}\right) = \sqrt{2\beta_1 I_{D1}} = \sqrt{2 \cdot 20\, 10^{-6}\, 10 \cdot 10^{-6}} = 20 \mu S$$

$$g_{o1} = 0 \ \mu S$$

$$g_{m2} = 0 \ \mu S$$

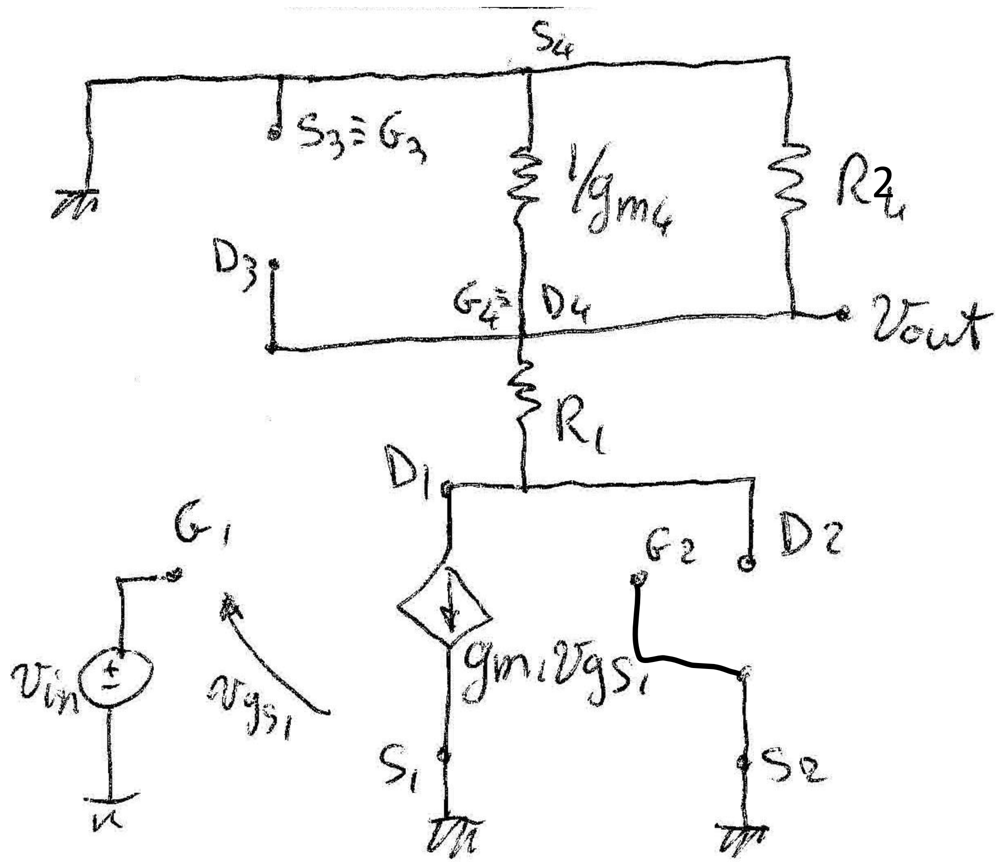
$$g_{o2} = 0 \ \mu S$$

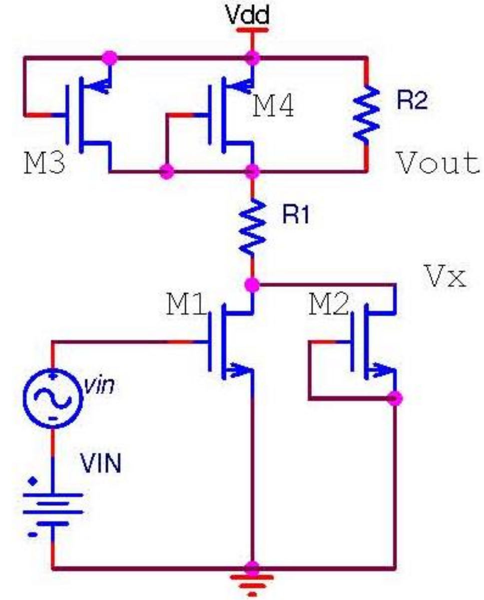
$$g_{m3} = 0 \ \mu S$$

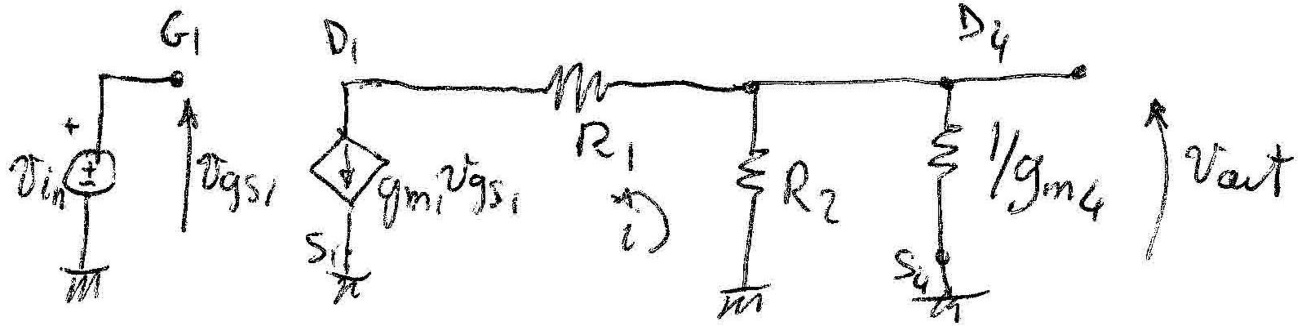
$$g_{o3} = 0 \ \mu S$$

$$g_{m4} = \beta_4 \left(V_{SG4} + V_{TH4}\right) = 10 \cdot 10^{-6} \left(2.245 - 1\right) = 12.45 \mu S$$

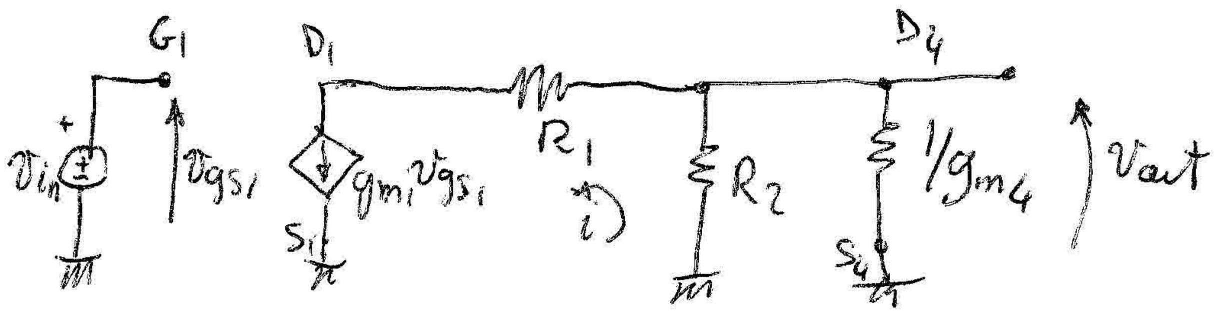
Es. 4c: Soluzione







Es. 4c: Soluzione



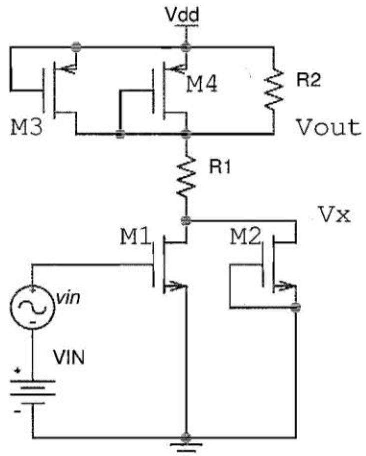
$v_{gs1} = v_{in}$; $i = g_{m1} v_{gs1}$; $v_{out} = -i\left(R_2 /\!/ \frac{1}{g_{m4}}\right) = -i\,\dfrac{R_2/g_{m4}}{R_2 + \frac{1}{g_{m4}}}$

$v_{out} = -i\,\dfrac{R_2}{1+g_{m4}R_2} = -\dfrac{g_{m1}R_2}{1+g_{m4}R_2}\,v_{in}$; $A_v = \dfrac{v_{out}}{v_{in}} = -\dfrac{g_{m1}R_2}{1+g_{m4}R_2}$

$A_v = -1.487$ V/V

Es. 4c: Soluzione

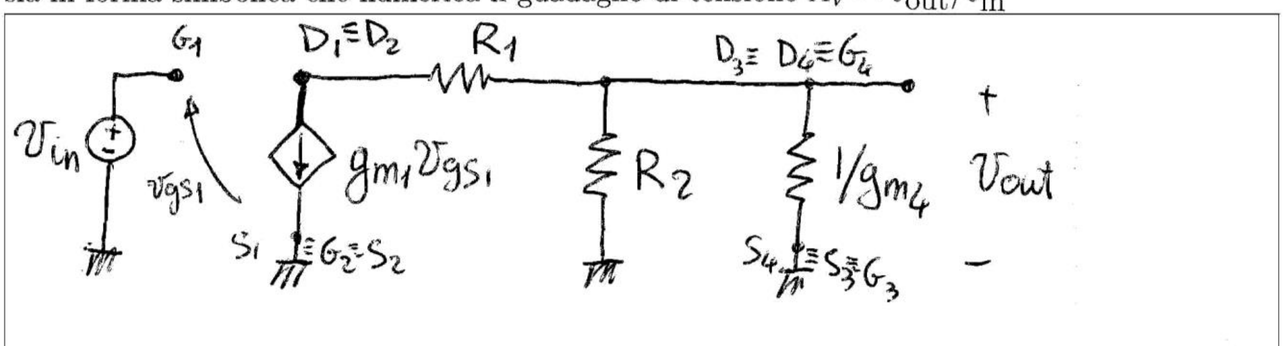
5. Dato il circuito in figura ($V_{dd} = 5$ V, $V_{in} = 2$ V, $V_{THn} = 1$ V, $V_{THp} = -1$ V, $\beta_1 = \beta_2 = 20\ \mu A/V^2$, $\beta_3 = \beta_4 = 10\ \mu A/V^2$, $R1 = 50\ k\Omega$, $R2 = 1\ M\Omega$), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{D1}, I_{D2}, I_{D3}, I_{D4}, I_{R1}, I_{R2} e le tensioni V_X, V_{out}; *iii)* i parametri differenziali dei MOSFET.



M1 : ~~SAT~~ TRI OFF
M2 : SAT TRI ~~OFF~~
M3 : SAT TRI ~~OFF~~
M4 : ~~SAT~~ TRI OFF

I_{D1} =	10.000 µA	g_{m1} =	20.000 µS
I_{D2} =	0.000 µA	g_{o1} =	0.000 µS
I_{D3} =	0.000 µA	g_{m2} =	0.000 µS
I_{D4} =	7.755 µA	g_{o2} =	0.000 µS
I_{R1} =	10.000 µA	g_{m3} =	0.000 µS
I_{R2} =	2.246 µA	g_{o3} =	0.000 µS
V_X =	2.254 V	g_{m4} =	12.450 µS
V_{out} =	2.754 V	g_{o4} =	0.000 µS

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{out}/v_{in}$

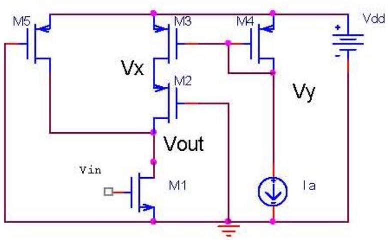


(espressione simbolica) $v_{out}/v_{in} = -g_{m1}R_2/(1+g_{m4}R_2)$

$v_{out}/v_{in} = -1.487$ V/V

Circuiti con MOSFET e BJT: Es. 5c

5. Dato il circuito in figura ($V_{dd} = 6$ V, $V_{in} = 3$ V, $V_{THn} = 0.5$ V, $V_{THp} = -0.5$ V, $I_a = 5$ µA, $\beta_1 = 40$ µA/V^2, $\beta_2 = 2$ µA/V^2, $\beta_3 = \beta_4 = 40$ µA/V^2, $\beta_5 = 2$ µA/V^2), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{D1}, I_{D2}, I_{D3}, I_{D4}, I_{D5} e le tensioni V_X, V_y, V_{out}; *iii)* i parametri differenziali dei MOSFET.



M1 : SAT TRI OFF
M2 : SAT TRI OFF
M3 : SAT TRI OFF
M4 : SAT TRI OFF
M5 : SAT TRI OFF

$I_{D1} = \square\square\square.\square\square\square$ µA
$I_{D2} = \square\square\square.\square\square\square$ µA
$I_{D3} = \square\square\square.\square\square\square$ µA
$I_{D4} = \square\square\square.\square\square\square$ µA
$I_{D5} = \square\square\square.\square\square\square$ µA
$V_y = \square\square\square.\square\square\square$ V
$V_X = \square\square\square.\square\square\square$ V
$V_{out} = \square\square\square.\square\square\square$ V

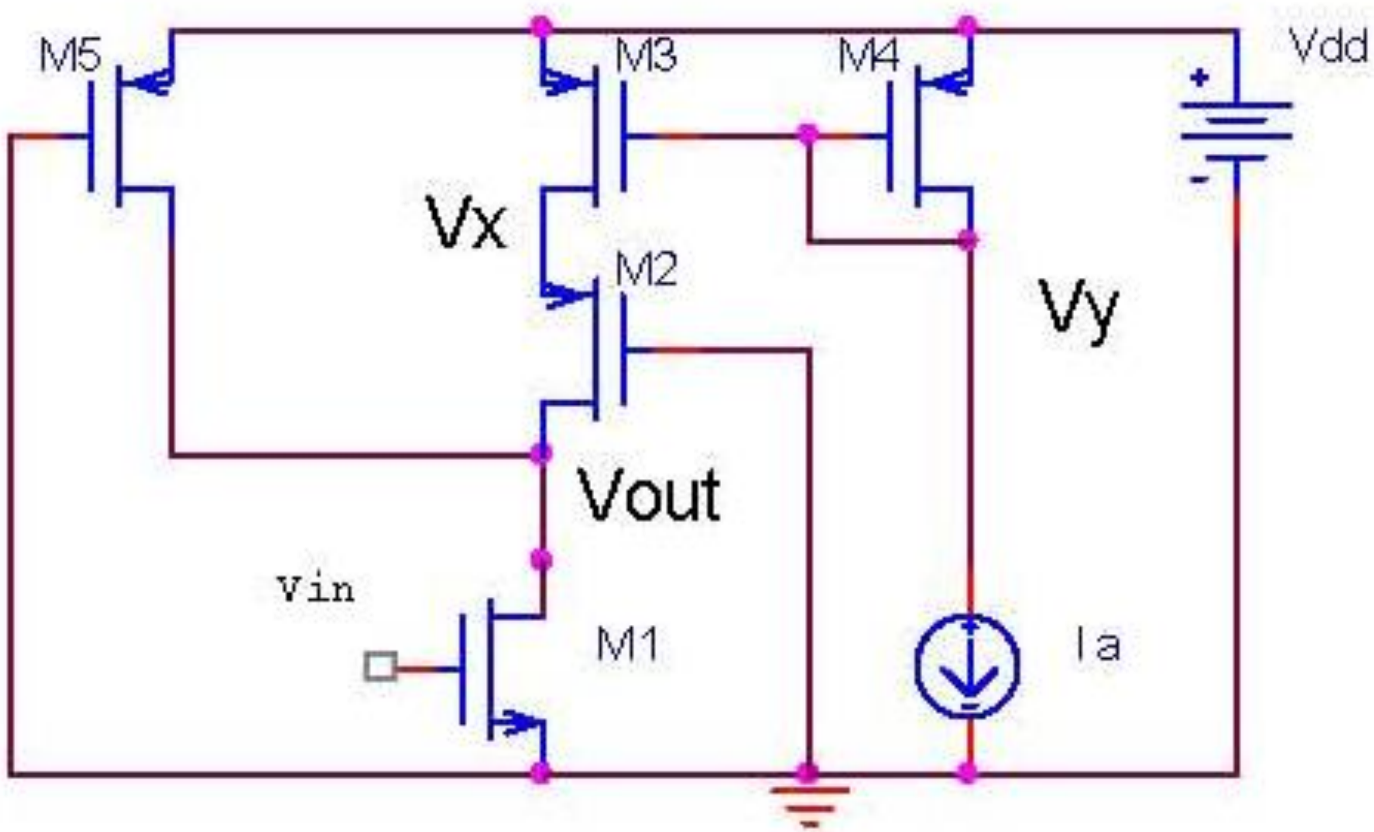
$g_{m1} = \square\square\square.\square\square\square$ µS
$g_{o1} = \square\square\square.\square\square\square$ µS
$g_{m2} = \square\square\square.\square\square\square$ µS
$g_{o2} = \square\square\square.\square\square\square$ µS
$g_{m3} = \square\square\square.\square\square\square$ µS
$g_{o3} = \square\square\square.\square\square\square$ µS
$g_{m4} = \square\square\square.\square\square\square$ µS
$g_{o4} = \square\square\square.\square\square\square$ µS
$g_{m5} = \square\square\square.\square\square\square$ µS
$g_{o5} = \square\square\square.\square\square\square$ µS

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{out}/v_{in}$

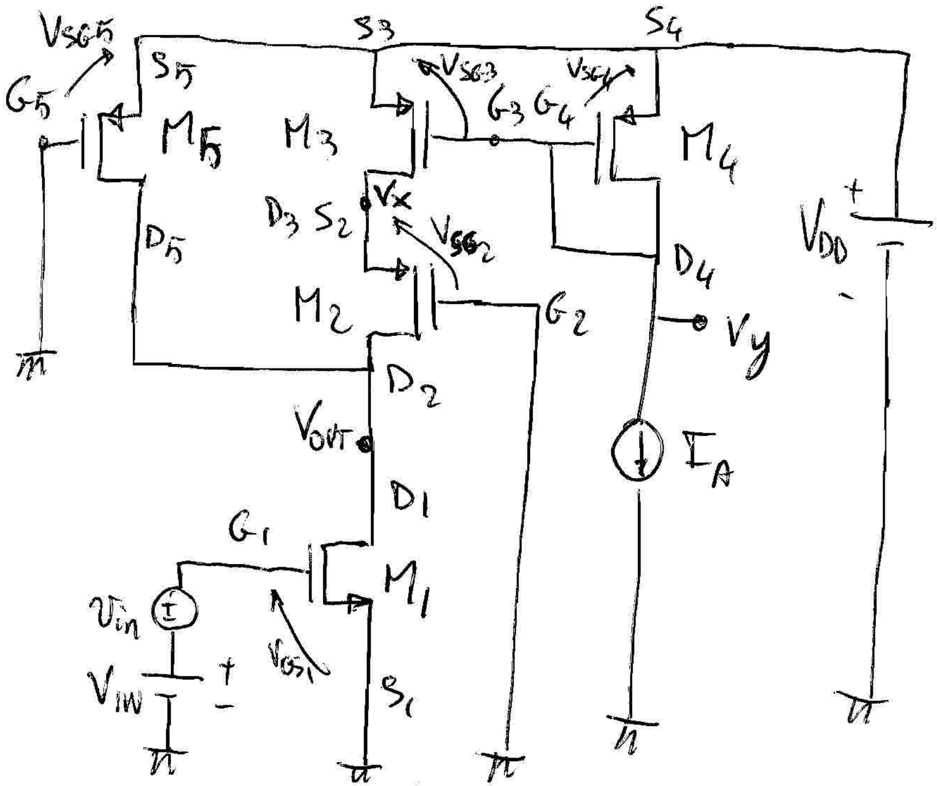
(espressione simbolica) $v_{out}/v_{in} =$

$v_{out}/v_{in} = \square\square\square.\square\square\square$ V/V

Circuiti con MOSFET e BJT: Es. 5c



Es. 5c: Soluzione



$V_{DD} = 6V$ $\quad |V_{TH}| = 0.5V$

$V_{IN} = 3V$

$I_A = 5 \mu A$

$\beta_1 = 40 \mu A/V^2$

$\beta_3 = \beta_4 = 40 \mu A/V^2$

$\beta_2 = 2 \mu A/V^2$

$\beta_5 = 2 \mu A/V^2$

Hp.

$\boxed{M4 \ SAT}$ $\quad V_{GS_4} > V_{TH_4} \quad V_{DS_4} > V_{GS_4} - V_{TH_4}$

$$I_{D_4} = \frac{\beta_4}{2}\left(V_{GS_4} - V_{TH_4}\right)^2 \qquad I_{D_4} = I_A = \underline{5 \mu A}$$

Es. 5c: Soluzione

$$V_{GS4} = -\sqrt{\frac{2I_{D4}}{\beta_4}} + V_{TH4} = -0.5 - 0.5 = -1\ V$$

$$V_y = V_{DD} - V_{SG4} = V_{DD} + V_{GS4} = 6 - 1 = \underline{5\ V}$$

$$V_{GS3} = V_{GS4} = -1\ V \qquad \boxed{M3\ ON}$$

Hp M3 SAT $\quad V_{DS3} < V_{GS3} - V_{TH3}$

$$I_{D3} = \frac{\beta_3}{2}\left(V_{GS3} - V_{TH3}\right)^2 \underset{\beta_3 = \beta_4}{\Rightarrow} I_{D3} = I_{D4} = \underline{5\ \mu A}$$

Hp M2 SAT

$$I_{D2} = I_{D3} = \underline{5\ \mu A}$$

Es. 5c: Soluzione

$$V_{GS2} = \pm\sqrt{\frac{2I_{D2}}{\beta_2}} + V_{TH2} = \pm\sqrt{5} - 0.5 \begin{cases} -2.736 \\ \cancel{1.736} \end{cases}$$

$$V_X = V_{SG2} = -V_{GS2} = \underline{2.736\ V}$$

$$V_{DS3} = V_X - V_{DD} = 2.736 - 6 = -3.264 \overset{?}{<} V_{GS3} - V_{TH3} = -1 + 0.5 = -0.5 \quad ok$$

$\boxed{\text{M3 SAT}}$

Hp M5 SAT

$$V_{GS5} = 0 - V_{DD} = -6\ V$$

$$I_{D5} = \frac{\beta_5}{2}\left(V_{GS5} - V_{TH5}\right)^2 = \frac{2 \cdot 10^{-6}}{2}\left(-6 + 0.5\right)^2 = \underline{30.25\ \mu A}$$

$$I_{D1} = I_{D5} + I_{D2} = \underline{35.25\ \mu A}$$

Es. 5c: Soluzione

Hp M1 SAT

$$I_{D1} = \frac{\beta_1}{2}(V_{GS1} - V_{TH1})^2 = \frac{40\,10^{-6}}{2}(3-1)^2 = 80\mu A \neq 35.25\mu A$$

$V_{GS1} = V_{IN}$

$\Rightarrow \boxed{M1\ TRI}$ $\quad V_{DS1} < V_{GS1} - V_{TH1}$

$$I_{D1} = \beta_1\left[(V_{GS1} - V_{TH1})V_{DS1} - \frac{V_{DS1}^2}{2}\right]$$

$$V_{DS1}^2 - 5V_{DS1} + 1.7625 = 0$$

$$V_{DS1} = \begin{cases} 0.382\ V \\ \cancel{4.6185}\ V \quad \text{NO!} \end{cases}$$

$V_{DS1} < V_{GS1} - V_{TH1} = 2.5\ V$

Es. 5c: Soluzione

$V_{DS1} = 0.382\,V \qquad V_{OUT} = V_{DS1} = \underline{0.382\ V}$

$V_{DS5} = V_{OUT} - V_{DD} = -5.618 \overset{?}{<} V_{GS5} - V_{TH5} = -6 + 0.5 = -5.5$ ok

$\boxed{M5\ SAT}$

$V_{DS2} = V_{OUT} - V_x = 0.382 - 2.736 = -2.354 \overset{?}{<} V_{GS2} - V_{TH2} = -2.736 + 0.5$

$= -2.236$ ok

$\boxed{M2\ SAT}$

Es. 5c: Soluzione

$$g_{m1} = \beta_1 V_{DS1} = 15.264\ \mu S$$

$$g_{o1} = \beta_1 (V_{GS1} - V_{TH1} - V_{DS1}) = 84.736\ \mu S$$

$$g_{m2} = \beta_2 (V_{SG2} + V_{TH2}) = 4.472\ \mu S$$

$$g_{o2} = 0\ \mu S$$

$$g_{m3} = \beta_3 (V_{SG3} + V_{TH3}) = 20\ \mu S$$

$$g_{o3} = 0\ \mu S$$

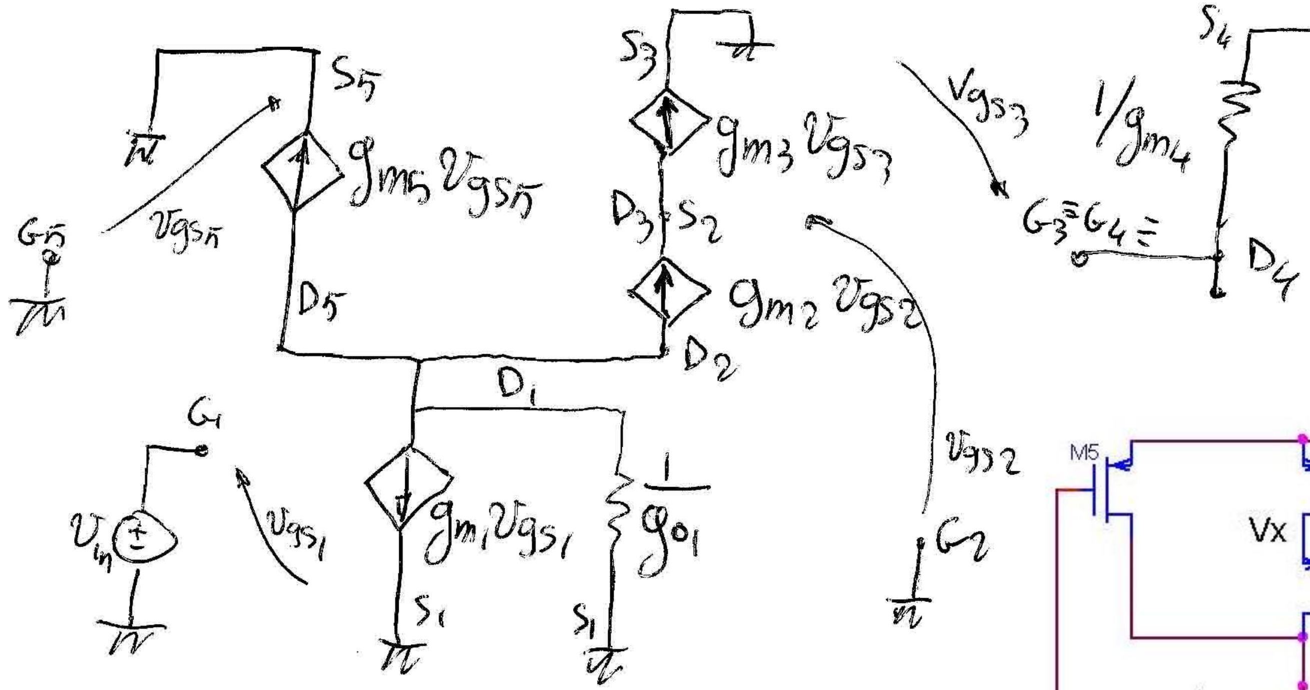
$$g_{m4} = \beta_4 (V_{SG4} + V_{TH4}) = 20\ \mu S$$

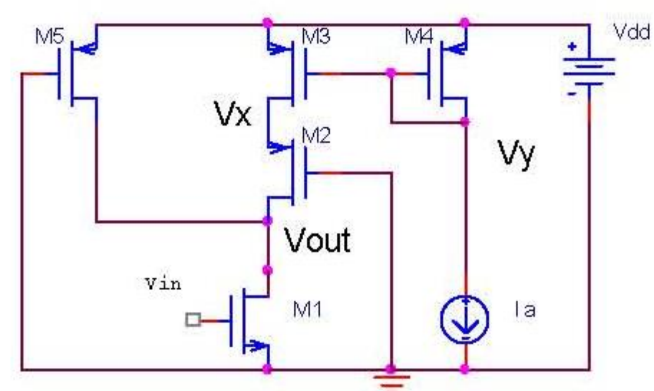
$$g_{o4} = 0\ \mu S$$

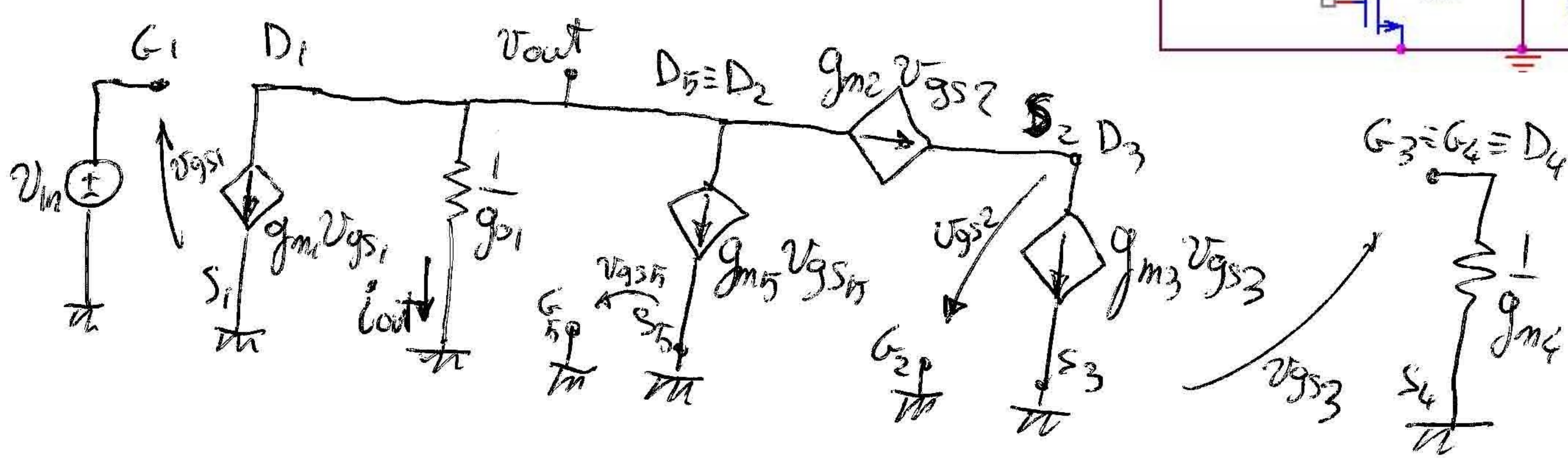
$$g_{m5} = \beta_5 (V_{SG5} + V_{TH5}) = 11.0\ \mu S$$

$$g_{o5} = 0$$

Es. 5c: Soluzione







Es. 5c: Soluzione

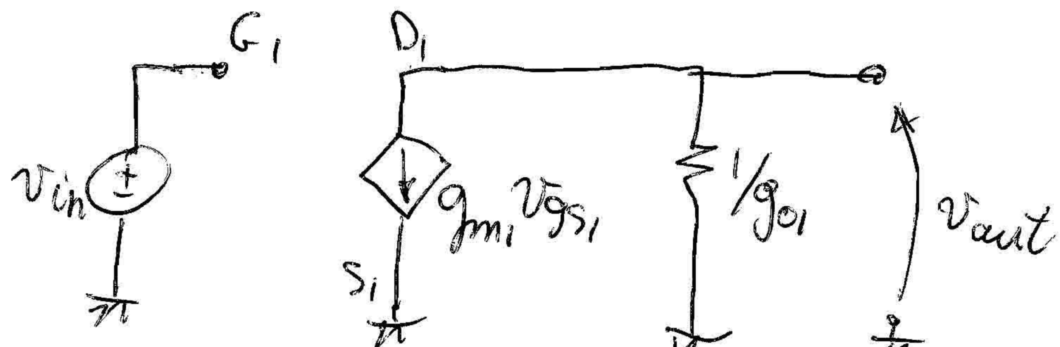
$v_{gs3} = 0$; $g_{m2} v_{gs2} = g_{m3} v_{gs3} \Rightarrow v_{gs2} = 0$

$v_{gs5} = 0$

$$i_{out} = -g_{m1} v_{gs1} - \cancel{g_{m5} v_{gs5}} - \cancel{g_{m2} v_{gs2}} = -g_{m1} v_{gs1}$$

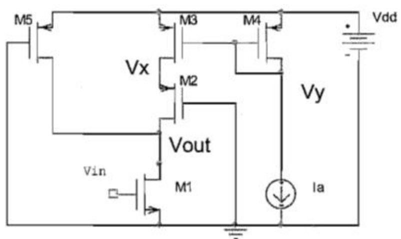
$v_{gs1} = v_{in}$; $v_{out} = i_{out} \cdot \frac{1}{g_{o1}}$ $\quad v_{out} = \frac{-g_{m1}}{g_{o1}} v_{in}$

$$A_v = \frac{v_{out}}{v_{in}} = -g_{m1}/g_{o1} \qquad A_v = -0.180 \ V/V$$



Es. 5c: Soluzione

5. Dato il circuito in figura ($V_{\text{dd}} = 6\text{ V}$, $V_{\text{in}} = 3\text{ V}$, $V_{\text{THn}} = 0.5\text{ V}$, $V_{\text{THp}} = -0.5\text{ V}$, $I_{\text{a}} = 5\ \mu\text{A}$, $\beta_1 = 40\ \mu\text{A/V}^2$, $\beta_2 = 2\ \mu\text{A/V}^2$, $\beta_3 = \beta_4 = 40\ \mu\text{A/V}^2$, $\beta_5 = 2\ \mu\text{A/V}^2$), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{D1}, I_{D2}, I_{D3}, I_{D4}, I_{D5} e le tensioni V_{x}, V_{y}, V_{out}; *iii)* i parametri differenziali dei MOSFET.

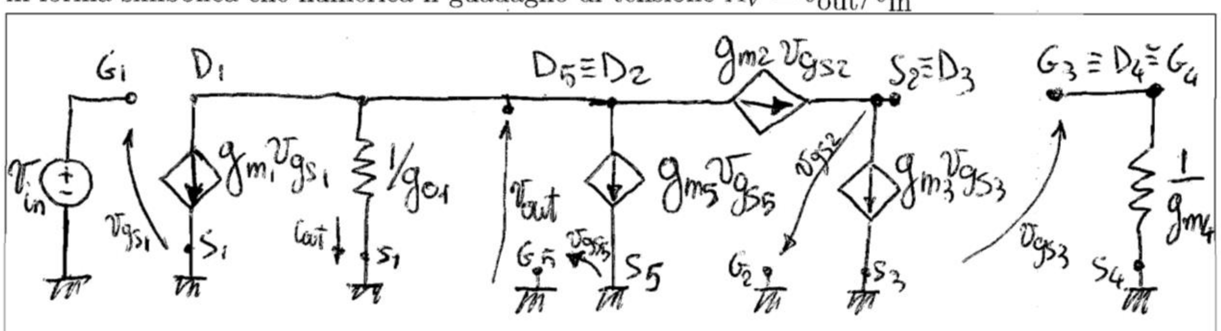


M1 :	SAT	~~TRI~~	OFF
M2 :	~~SAT~~	TRI	OFF
M3 :	~~SAT~~	TRI	OFF
M4 :	~~SAT~~	TRI	OFF
M5 :	~~SAT~~	TRI	OFF

I_{D1} =	35.250	μA
I_{D2} =	5.000	μA
I_{D3} =	5.000	μA
I_{D4} =	5.000	μA
I_{D5} =	30.250	μA
V_{y} =	5.000	V
V_{x} =	2.736	V
V_{out} =	0.382	V

g_{m1} =	15.264	μS
g_{o1} =	84.736	μS
g_{m2} =	4.472	μS
g_{o2} =	0.006	μS
g_{m3} =	20.000	μS
g_{o3} =	0.000	μS
g_{m4} =	20.000	μS
g_{o4} =	0.600	μS
g_{m5} =	11.000	μS
g_{o5} =	0.000	μS

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{\text{out}}/v_{\text{in}}$

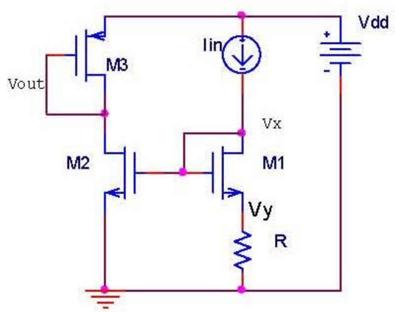


(espressione simbolica) $v_{\text{out}}/v_{\text{in}} =$ $-g_{m1}/g_{o1}$

$v_{\text{out}}/v_{\text{in}} =$ -0.180 V/V

Circuiti con MOSFET e BJT: Es. 6c

5. Dato il circuito in figura ($V_{\mathrm{dd}} = 5$ V, $I_{\mathrm{in}} = 5$ µA, $V_{\mathrm{THn}} = 1$ V, $V_{\mathrm{THp}} = -1$ V, $R = 100$ kΩ $\beta_1 = \beta_2 = 10$ µA/V^2, $\beta_3 = 15$ µA/V^2), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{D1}, I_{D2}, I_{D3} e le tensioni V_{X}, V_{y}, V_{out}; *iii)* i parametri differenziali dei MOSFET.



M1 : SAT | TRI | OFF
M2 : SAT | TRI | OFF
M3 : SAT | TRI | OFF

$I_{D1} =$ ___ . ___ µA
$I_{D2} =$ ___ . ___ µA
$I_{D3} =$ ___ . ___ µA
$V_{\mathrm{y}} =$ ___ . ___ V
$V_{\mathrm{X}} =$ ___ . ___ V
$V_{\mathrm{out}} =$ ___ . ___ V

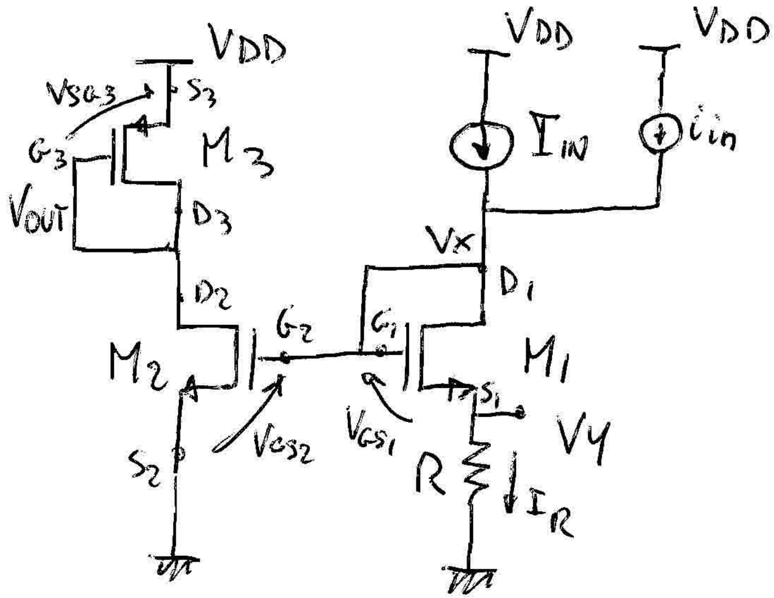
$g_{m1} =$ ___ . ___ µS
$g_{o1} =$ ___ . ___ µS
$g_{m2} =$ ___ . ___ µS
$g_{o2} =$ ___ . ___ µS
$g_{m3} =$ ___ . ___ µS
$g_{o3} =$ ___ . ___ µS

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di transresistenza $A_R = v_{\mathrm{out}}/i_{\mathrm{in}}$

(espressione simbolica) $v_{\mathrm{out}}/i_{\mathrm{in}} =$

$v_{\mathrm{out}}/i_{\mathrm{in}} =$ ___ . ___ V/A

Es. 6c: Soluzione



$V_{DD} = 5V$

$I_{IN} = 5 \mu A$

$V_{TH_N} = 1V$

$V_{THP} = -1V$

$R = 100 k\Omega$

$\beta_1 = \beta_2 = 10 \mu A/V^2$

$\beta_3 = 15 \mu A/V^2$

$\boxed{M1 \ SAT}$ $\quad V_{GS_1} = V_{DS1}$

$\boxed{M3 \ SAT}$ $\quad V_{GS_3} = V_{DS3}$

$I_{IN} = I_{G1} + I_{G2} + I_{D1} = I_{D1} \qquad I_{D1} = I_{IN} = \underline{5 \mu A}$

$I_R = I_{D1} \ ; \quad V_y = I_R \cdot R = 5 \cdot 10^{-6} \cdot 100 \cdot 10^3 = 0.5 \ V$

Es. 6c: Soluzione

$$I_{D_1} = \frac{\beta_1}{2}\left(V_{GS_1} - V_{TH_1}\right)^2 \Rightarrow V_{GS_1} = \sqrt{\frac{2I_D}{\beta_1}} + V_{TH_1} = 1+1 = 2V$$

$$V_x = V_{GS_1} + V_y = 2+0.5 = \underline{2.5\ V}$$

$$V_{GS2} = V_x = 2.5V > 1V = V_{TH_2} \qquad M_2\ ON$$

$$Hp\ M2\ SAT \qquad V_{DS} \geq V_{GS_2} - V_{TH_2}$$

$$I_{D2} = \frac{\beta_2}{2}\left(V_{GS_2} - V_{TH_2}\right)^2 = \frac{\overset{5}{\cancel{10}}\,10^{-6}}{2}\left(\underbrace{2.5-1}_{1.5}\right)^2 = \underline{11.25\,\mu A}$$

$$I_{D3} = I_{D2} = \underline{11.25\,\mu A}$$

$$I_{D3} = \frac{\beta_3}{2}\left(V_{GS_3} - V_{TH_3}\right)^2 \Rightarrow V_{GS_3} = -\sqrt{\frac{2I_{D3}}{\beta_3}} + V_{TH_3} = -\sqrt{\frac{2\cdot 11.25\,10^{-6}}{15\cdot 10^{-6}}} - 1 = -2.225V$$

Es. 6c: Soluzione

$V_{SG3} = +2.225\,V$

$V_{OUT} = V_{DD} + V_{GS3} = V_{DD} - V_{SG3} = 5 - 2.225 = \underline{2.775\,V}$

$V_{DS2} = V_{OUT} = 2.775 \overset{?}{>} V_{GS2} - V_{TH2} = 2.5 - 1 = 1.5\,V$ ok

$\boxed{M_2 \text{ SAT}}$

Es. 6c: Soluzione

$$g_{m1} = \beta_1 (V_{GS1} - V_{TH1}) = \sqrt{2\beta_1 I_{D1}} = 10 \cdot 10^{-6} (2-1) = 10\,\mu S$$

$$g_{o1} = 0\ \mu S$$

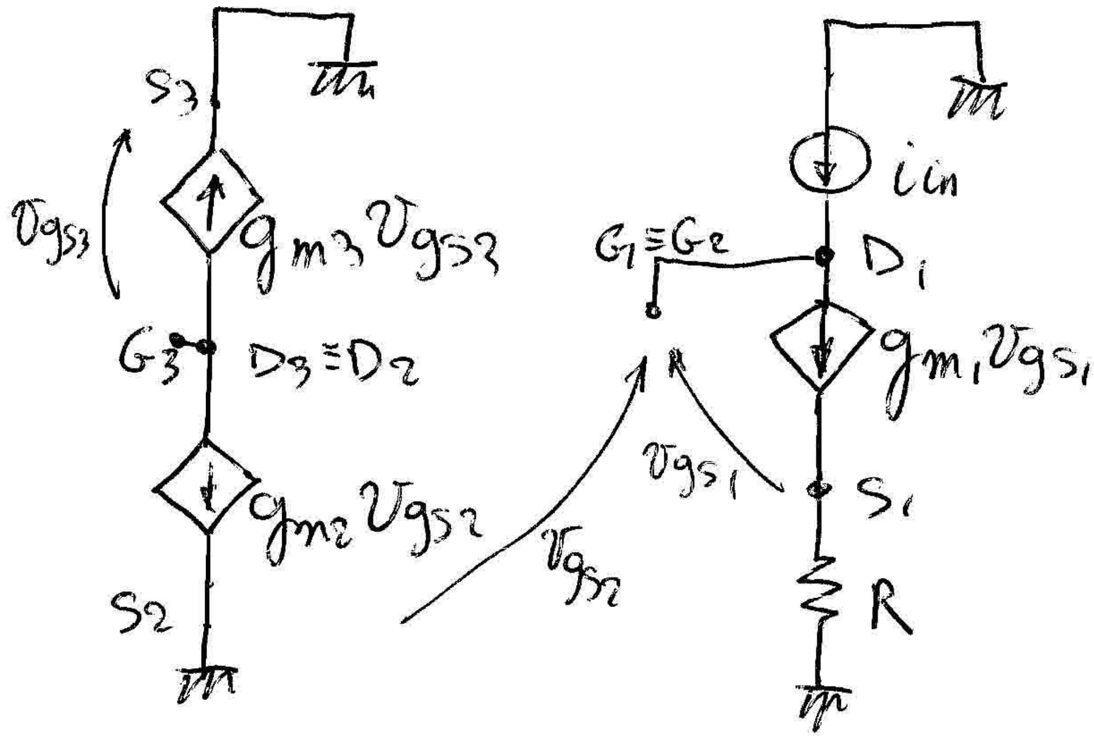
$$g_{m2} = \beta_2 (V_{GS2} - V_{TH2}) = \sqrt{2\beta_2 I_{D2}} = 10 \cdot 10^{-6} \cdot (2.5-1) = 15\,\mu S$$

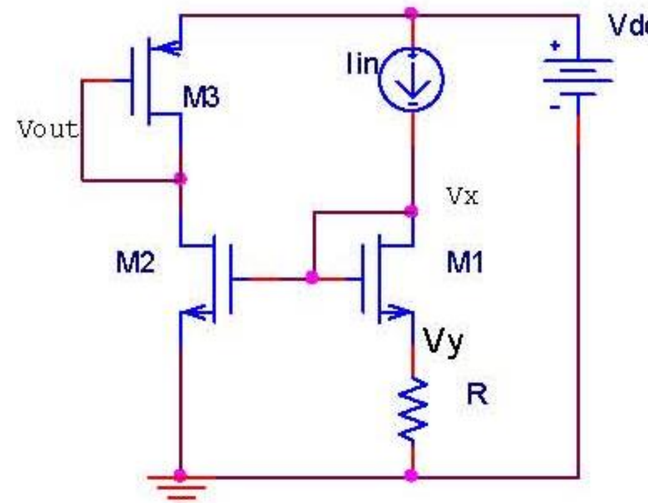
$$g_{o2} = 0\ \mu S$$

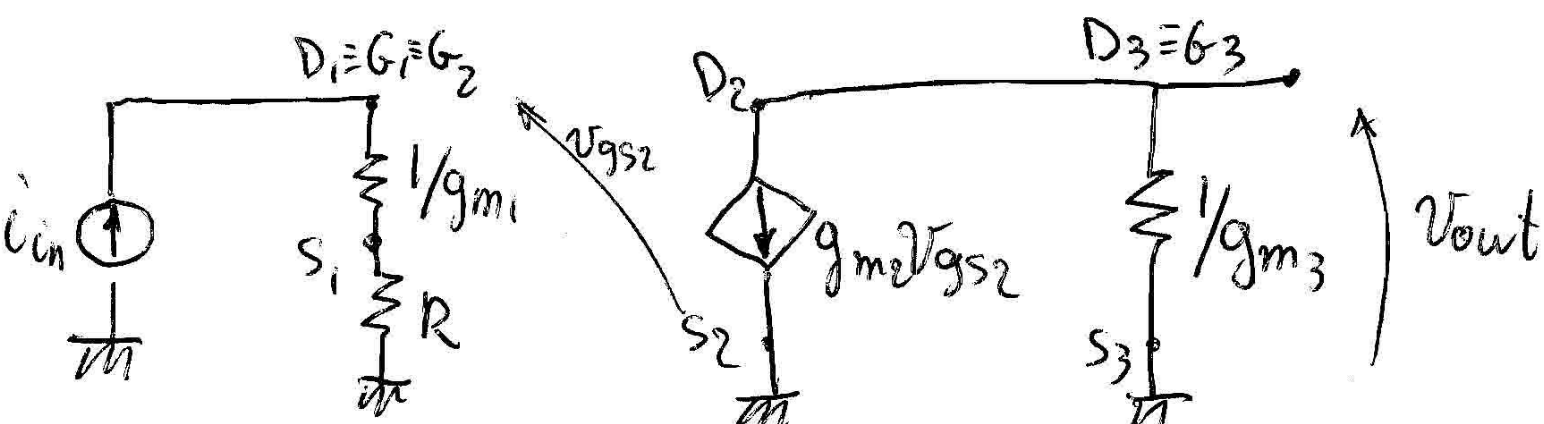
$$g_{m3} = \beta_3 (V_{SG3} + V_{TH3}) = \sqrt{2\beta_3 I_{D3}} = 15 \cdot 10^{-6} \cdot (2.225-1) = 18.375\,\mu S$$

$$g_{o3} = 0\,\mu S$$

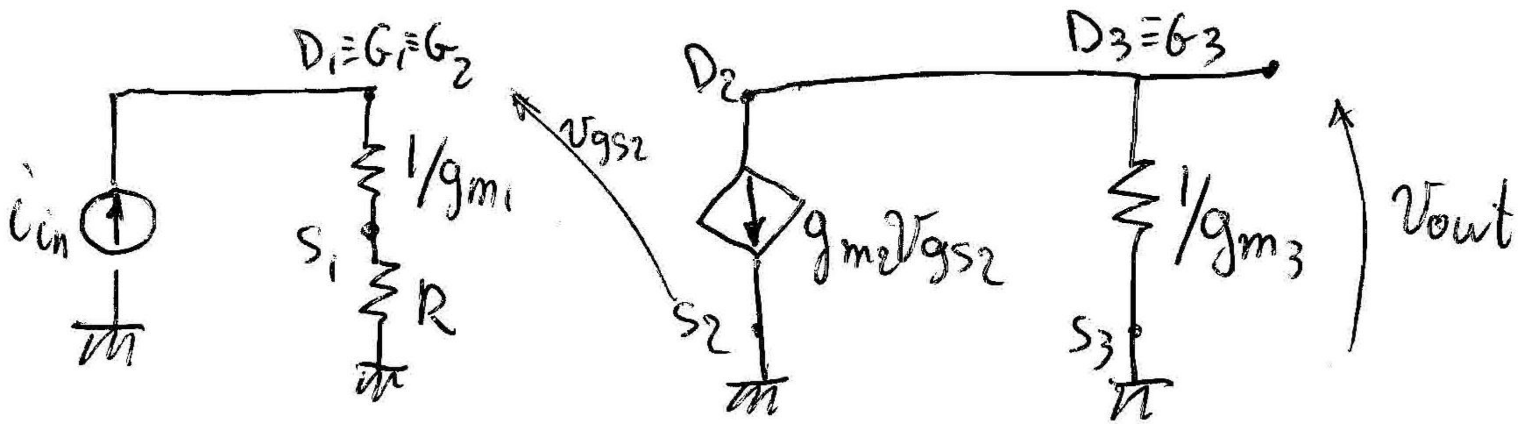
Es. 6c: Soluzione







Es. 6c: Soluzione

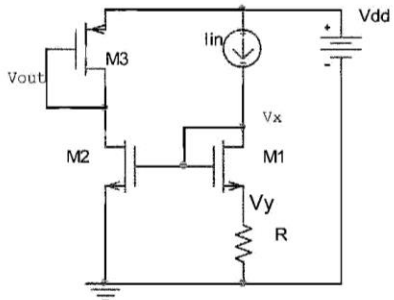


$$v_{out} = -g_{m2}\, v_{gs2} \cdot \frac{1}{g_{m3}} \; ; \qquad v_{gs2} = i_{in} \cdot \left(\frac{1}{g_{m1}} + R\right)$$

$$v_{out} = -\frac{g_{m2}}{g_{m3}}\left(\frac{1}{g_{m1}} + R\right) i_{in} \qquad \frac{v_{out}}{i_{in}} = -\frac{g_{m2}}{g_{m3}}\left(\frac{1}{g_{m1}} + R\right)$$

Es. 6c: Soluzione

5. Dato il circuito in figura ($V_{dd} = 5$ V, $I_{in} = 5$ µA, $V_{THn} = 1$ V, $V_{THp} = -1$ V, $R = 100$ kΩ $\beta_1 = \beta_2 = 10$ µA/V^2, $\beta_3 = 15$ µA/V^2), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{D1}, I_{D2}, I_{D3} e le tensioni V_x, V_y, V_{out}; *iii)* i parametri differenziali dei MOSFET.



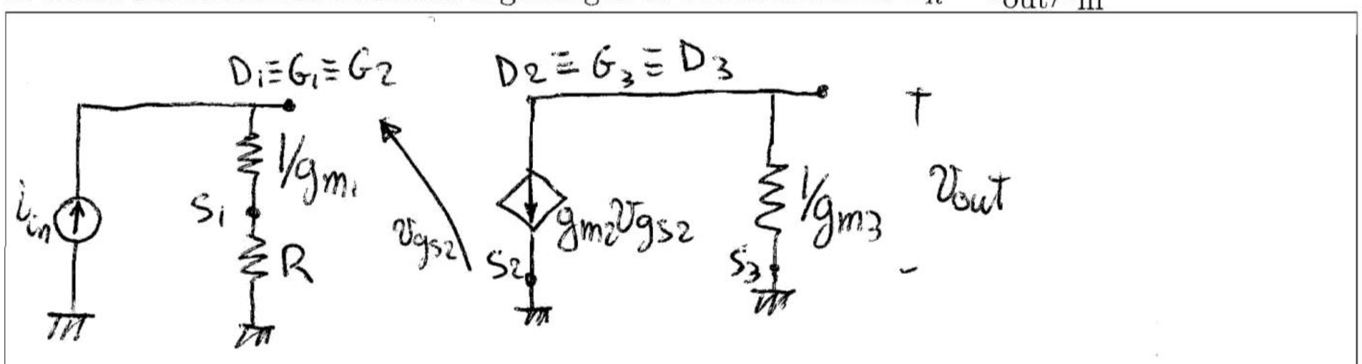
M1 : ~~SAT~~ TRI OFF

M2 : ~~SAT~~ TRI OFF

M3 : ~~SAT~~ TRI OFF

I_{D1} =	5.000	µA	g_{m1} =	10.000	µS
I_{D2} =	11.250	µA	g_{o1} =	0.000	µS
I_{D3} =	11.250	µA	g_{m2} =	15.000	µS
V_y =	0.500	V	g_{o2} =	0.000	µS
V_x =	2.500	V	g_{m3} =	18.371	µS
V_{out} =	2.775	V	g_{o3} =	0.000	µS

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di transresistenza $A_R = v_{out}/i_{in}$



(espressione simbolica) $v_{out}/i_{in} = -(g_{m2}/g_{m3}) \cdot (R + 1/g_{m1})$

$v_{out}/i_{in} = -166.666$ ~~V/A~~ kΩ

Circuiti con MOSFET e BJT: Es. 7c

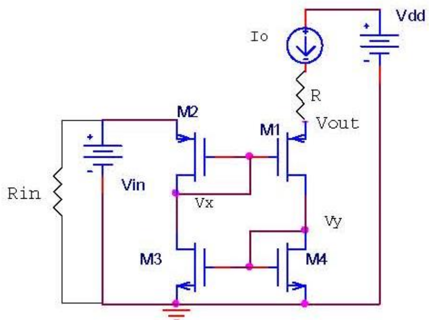
5. Dato il circuito in figura ($V_{\rm dd} = 8$ V, $V_{\rm in} = 6$ V, $I_{\rm O} = 200$ µA, $V_{\rm THn} = 1$ V, $V_{\rm THp} = -1$ V, $R_{\rm in} = 100\,{\rm k}\Omega$, $R = 1\,{\rm k}\Omega$, $\beta_1 = \beta_2 = \beta_4 = 200\,\mu{\rm A/V}^2$, $\beta_3 = 400\,\mu{\rm A/V}^2$), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{D1}, I_{D2}, I_{D3}, I_{D4} e le tensioni $V_{\rm X}$, $V_{\rm y}$, $V_{\rm out}$; *iii)* i parametri differenziali dei MOSFET.

M1 : SAT | TRI | OFF

M2 : SAT | TRI | OFF

M3 : SAT | TRI | OFF

M4 : SAT | TRI | OFF



$I_{D1} =$ ___ . ___ µA

$I_{D2} =$ ___ . ___ µA

$I_{D3} =$ ___ . ___ µA

$I_{D4} =$ ___ . ___ µA

$V_{\rm y} =$ ___ . ___ V

$V_{\rm X} =$ ___ . ___ V

$V_{\rm out} =$ ___ . ___ V

$g_{m1} =$ ___ . ___ µS

$g_{o1} =$ ___ . ___ µS

$g_{m2} =$ ___ . ___ µS

$g_{o2} =$ ___ . ___ µS

$g_{m3} =$ ___ . ___ µS

$g_{o3} =$ ___ . ___ µS

$g_{m4} =$ ___ . ___ µS

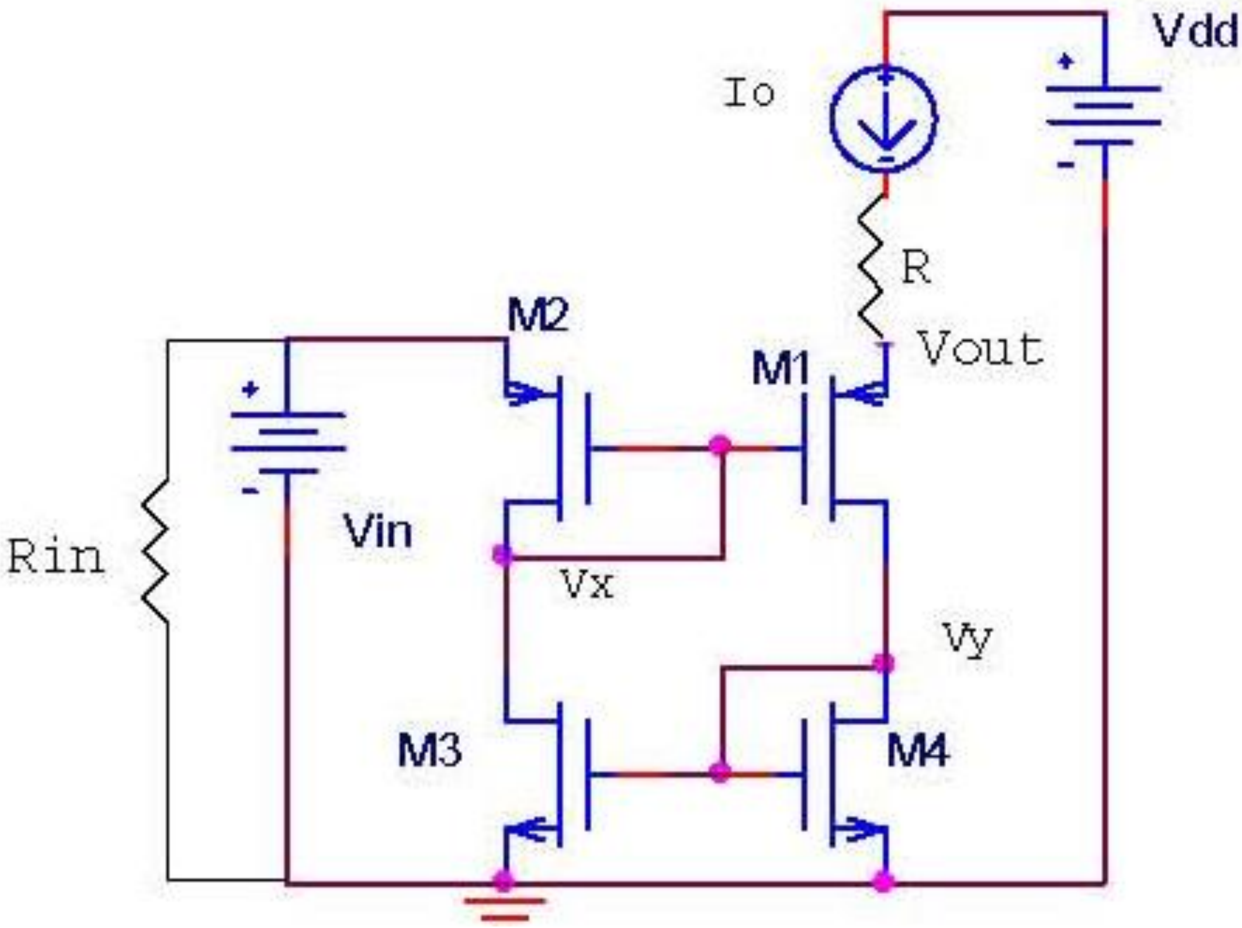
$g_{o4} =$ ___ . ___ µS

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_v = v_{\rm out}/v_{\rm in}$

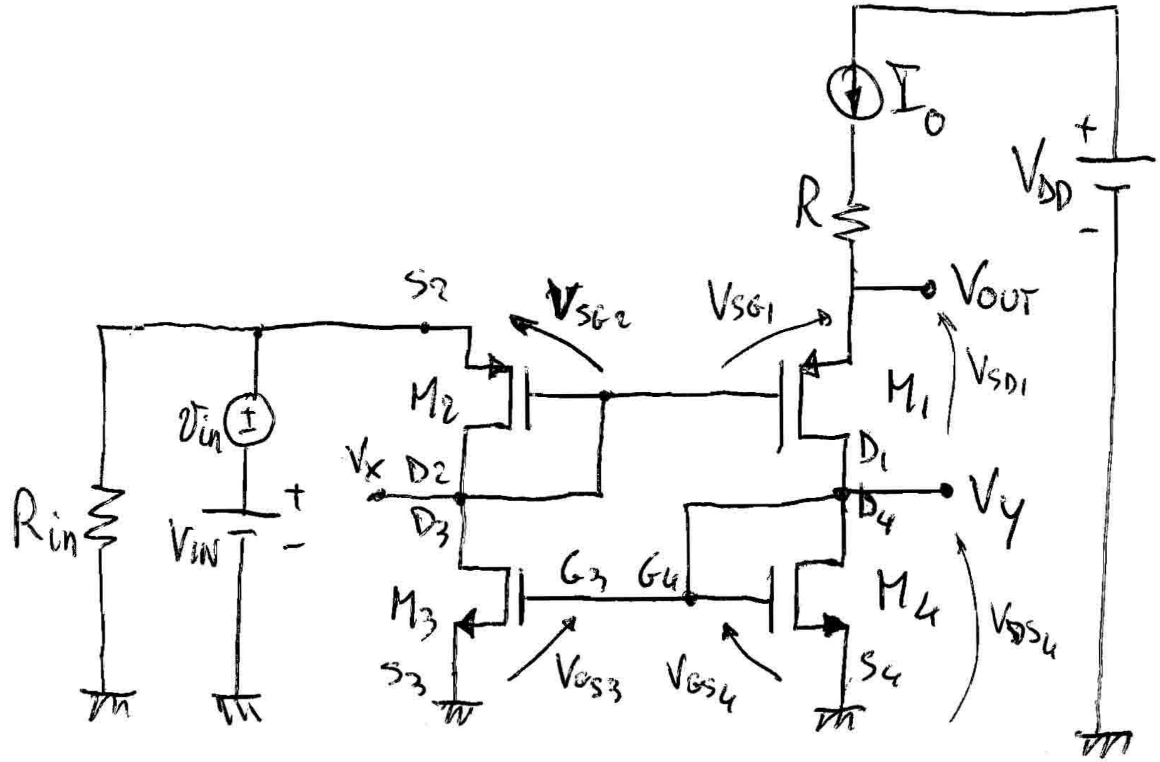
(espressione simbolica) $v_{\rm out}/v_{\rm in} =$

$v_{\rm out}/v_{\rm in} =$ ___ . ___ V/V

Es. 7c: Soluzione



Es. 7c: Soluzione



$I_o = 200\mu A$

$V_{DD} = 8V$

$V_{IN} = 6V$

$R_{in} = 100k\Omega$

$R = 1k\Omega$

$\beta_1 = \beta_2 = \beta_4 = 200\mu A/V^2$

$\beta_3 = 400\mu A/V^2$

$\boxed{M4\ SAT}$ $\quad V_{GS4} = V_{DS4}$

$I_{D4} = I_{D1} = I_0 \qquad \underline{I_{D4} = 200\mu A} \qquad \underline{I_{D1} = 200\mu A}$

$$I_{D4} = \frac{\beta_4}{2}\left(V_{GS4} - V_{TH4}\right)^2 \Rightarrow V_{GS4} = \sqrt{\frac{2I_{D2}}{\beta_4}} + V_{TH4} = \sqrt{2}+1 = 2.414\ V$$

Es. 7c: Soluzione

$$V_y = V_{GS_4} = \underline{2.414\ V}$$

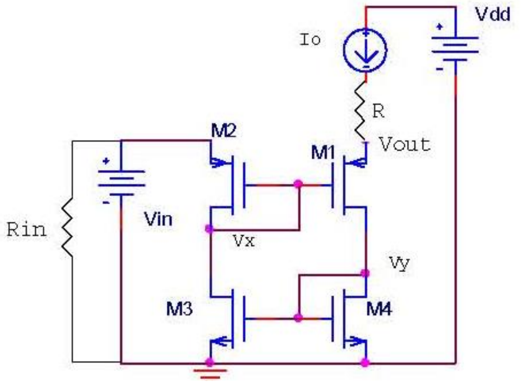
Hp M3 SAT $\quad V_{GS_3} > V_{TH_3} \quad V_{DS_3} > V_{GS_3} - V_{TH_3}$

$$I_{D3} = \frac{\beta_3}{2}\left(V_{GS_3} - V_{TH_3}\right)^2 \; ; \quad V_{GS_3} = V_{GS_4} = 2.414V > V_{TH_3} = 1V \; \boxed{M_3\ ON}$$

$$\frac{I_{D3}}{I_{D4}} = \frac{\frac{\beta_3}{2}\left(V_{GS_3} - V_{TH_3}\right)^2}{\frac{\beta_4}{2}\left(V_{GS_4} - V_{TH_4}\right)^2} = \frac{\beta_3}{\beta_4} = 2 \qquad I_{D3} = 2I_{D4} = \underline{400\mu A}$$

$\boxed{\text{M2 SAT}}$ $\quad V_{SG_2} = V_{SD2}$

$$I_{D2} = I_{D3} = \underline{400\,\mu A}$$



Es. 7c: Soluzione

$$V_{SG2} = \sqrt{\frac{2 I_{D2}}{\beta_2}} - V_{TH2} = \sqrt{\frac{2 \cdot 400 \cdot 10^{-6}}{200 \cdot 10^{-6}}} + 1 = 2 + 1 = 3\,V$$

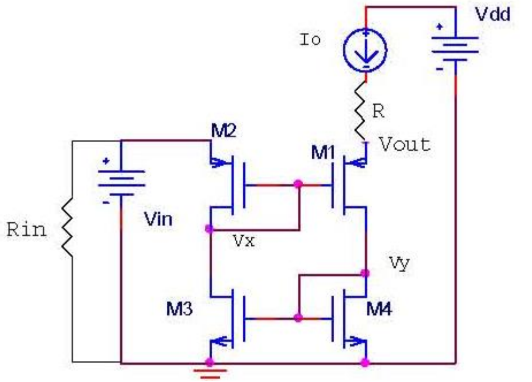
$$V_X = V_{IN} - V_{SG2} = 6 - 3 = \underline{3\,V}$$

$$V_{DS3} = V_X = 3 \overset{?}{>} V_{GS3} - V_{TH3} = 2.414 - 1 = 1.414 \quad \text{ok}$$

$$\boxed{M3 \text{ SAT}}$$

Hp. M1 SAT

$$I_{D1} = \frac{\beta_1}{2}\left(V_{GS1} - V_{TH1}\right)^2 = 200\,\mu A$$



Es. 7c: Soluzione

$$V_{GS1} = -\sqrt{\frac{2I_{D1}}{\beta_1}} + V_{TH1} = -\sqrt{2} - 1 = -2.414\ V$$

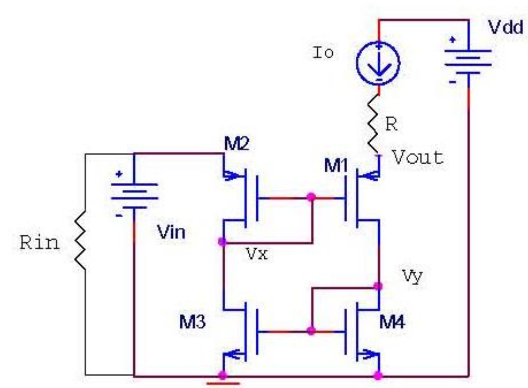
$$V_{SG1} = -V_{GS1} = 2.414\ V$$

$$V_{OUT} = V_{SG1} + V_x = 2.414 + 3 = \underline{5.414\ V}$$

$$V_{SD1} = V_{OUT} - V_y = 5.414 - 2.414 = 3V \qquad V_{DS1} = -V_{SD1} = 3V$$

$$V_{DS1} = -3 \overset{?}{<} V_{GS1} - V_{TH1} = -2.414 + 1 = -1.414 \quad \text{ok}$$

$$\boxed{M1\ \text{SAT}}$$



Es. 7c: Soluzione

$$g_{m1} = \sqrt{2\beta_1 I_{D1}} = 282.8\ \mu S$$

$$g_{o1} = 0\ \mu S$$

$$g_{m2} = \sqrt{2\beta_2 I_{D2}} = 400\ \mu S$$

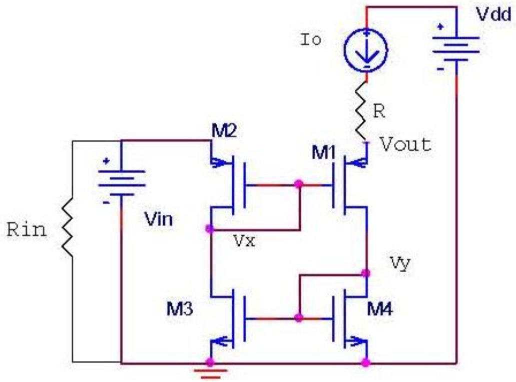
$$g_{o2} = 0\ \mu S$$

$$g_{m3} = \sqrt{2\beta_3 I_{D3}} = 565.6\ \mu S$$

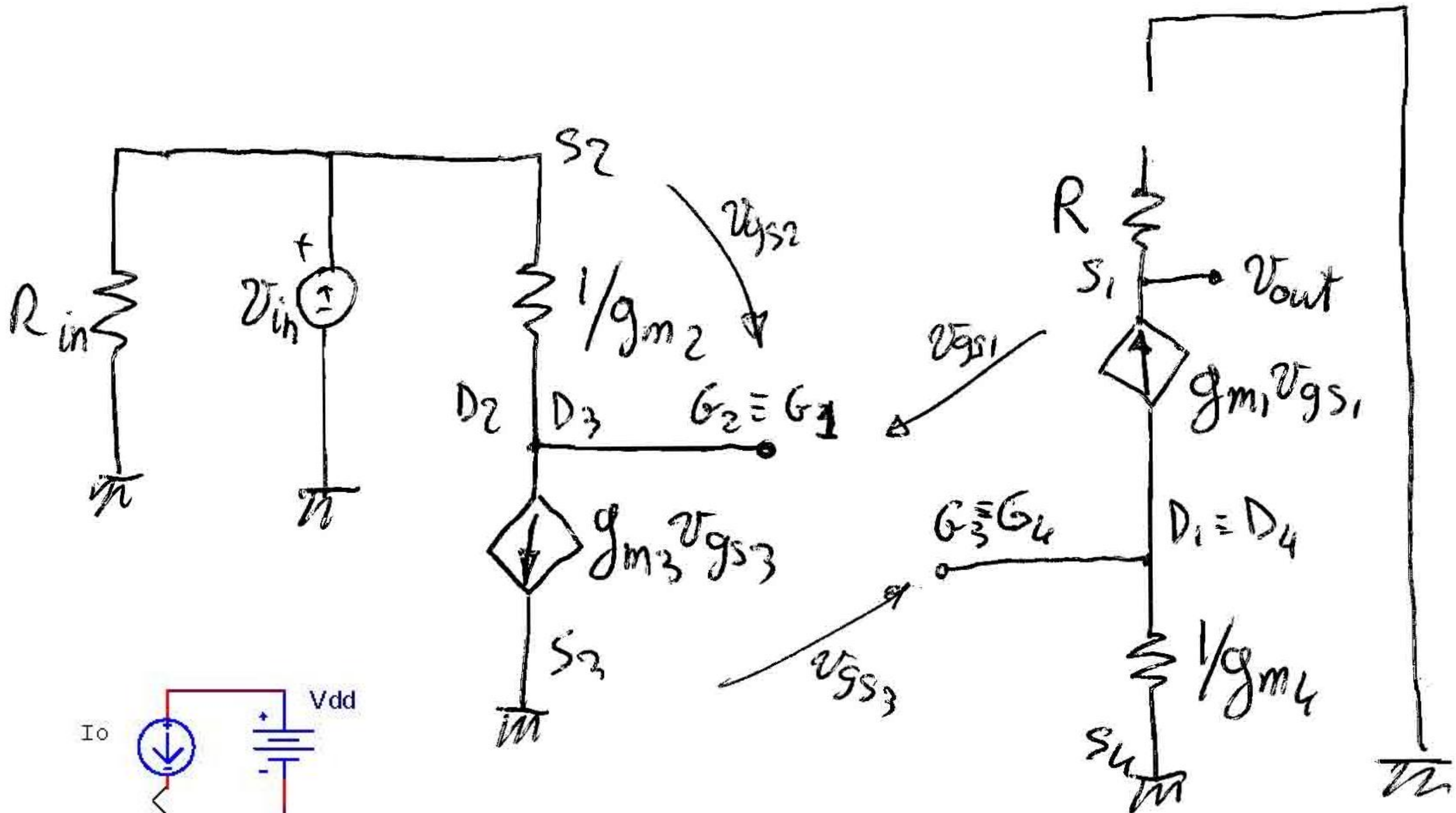
$$g_{o3} = 0\ \mu S$$

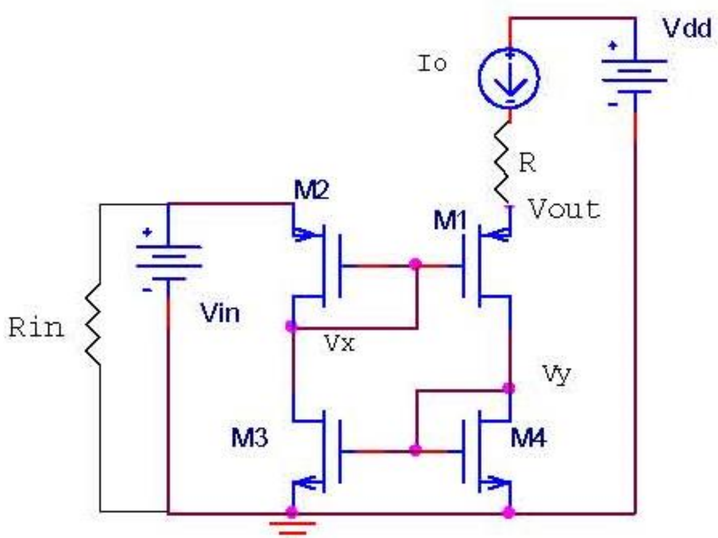
$$g_{m4} = \sqrt{2\beta_4 I_{D4}} = 282.8\ \mu S$$

$$g_{o4} = 0\ \mu S$$

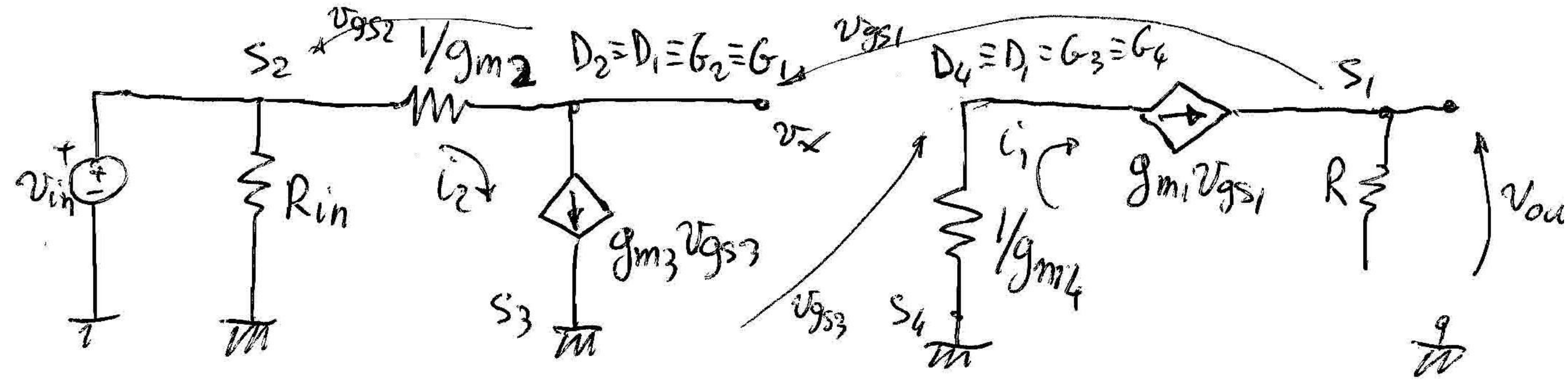


Es. 7c: Soluzione





Es. 7c: Soluzione



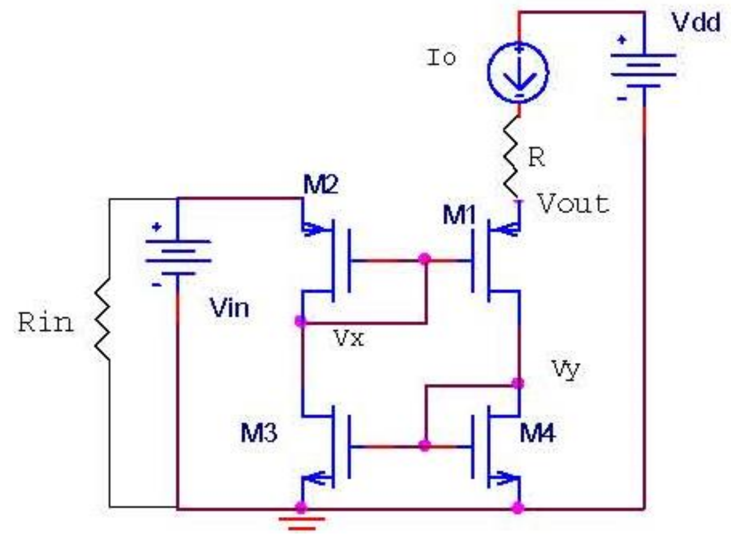
$$g_{m1} v_{gs1} = 0 \quad \Rightarrow \quad v_{gs1} = 0$$

$$v_{gs3} = -i_1 \frac{1}{g_{m4}} = -\frac{g_{m1} v_{gs1}}{g_{m4}} = 0$$

$$i_2 = g_{m3} v_{gs3} = 0 \qquad v_x = v_{in}$$

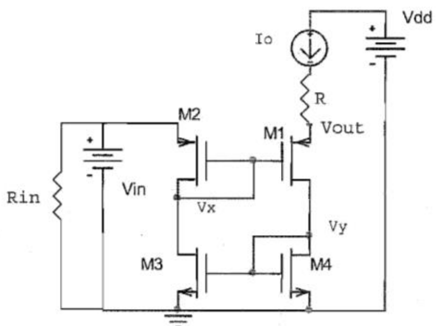
$$v_{gs2} = i_2 \cdot \frac{1}{g_{m2}} = 0$$

$$v_{in} = \cancel{v_{gs2}} + \cancel{v_{gs1}} + v_{out} \qquad v_{out} = v_{in} \qquad \frac{v_{out}}{v_{in}} = 1$$



Es. 7c: Soluzione

5. Dato il circuito in figura ($V_{\mathrm{dd}} = 8$ V, $V_{\mathrm{in}} = 6$ V, $I_{\mathrm{O}} = 200$ µA, $V_{\mathrm{THn}} = 1$ V, $V_{\mathrm{THp}} = -1$ V, $R_{\mathrm{in}} = 100$ kΩ, $R = 1$ kΩ, $\beta_1 = \beta_2 = \beta_4 = 200$ µA/V^2, $\beta_3 = 400$ µA/V^2), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{D1}, I_{D2}, I_{D3}, I_{D4} e le tensioni V_{X}, V_{Y}, V_{out}; *iii)* i parametri differenziali dei MOSFET.

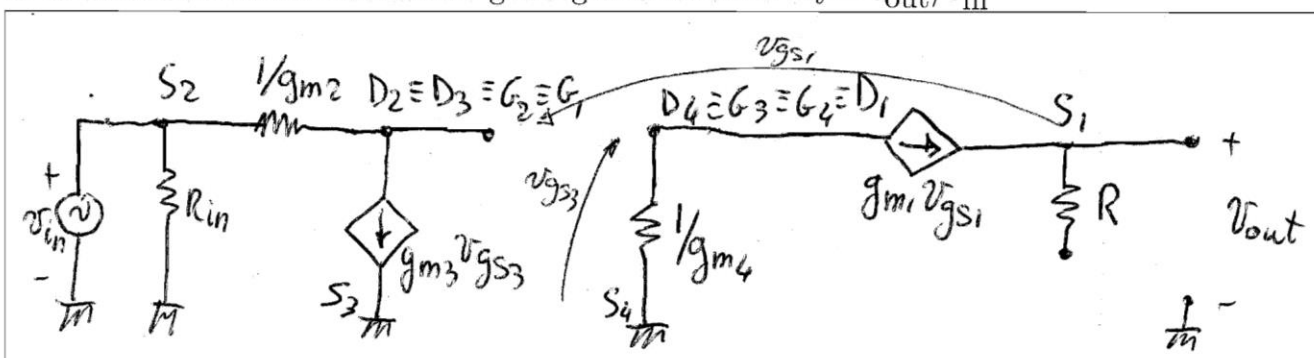


M1 :	~~SAT~~	TRI	OFF
M2 :	~~SAT~~	TRI	OFF
M3 :	~~SAT~~	TRI	OFF
M4 :	~~SAT~~	TRI	OFF

I_{D1} =	200.000	µA
I_{D2} =	400.000	µA
I_{D3} =	400.000	µA
I_{D4} =	200.000	µA
V_{y} =	2.414	V
V_{X} =	3.000	V
V_{out} =	5.414	V

g_{m1} =	282.800	µS
g_{o1} =	0.000	µS
g_{m2} =	400.000	µS
g_{o2} =	0.000	µS
g_{m3} =	565.600	µS
g_{o3} =	0.000	µS
g_{m4} =	282.800	µS
g_{o4} =	0.000	µS

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_v = v_{\mathrm{out}}/v_{\mathrm{in}}$

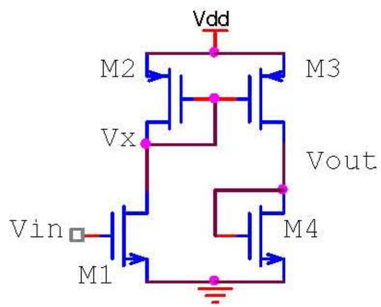


(espressione simbolica) $v_{\mathrm{out}}/v_{\mathrm{in}} = 1$

$v_{\mathrm{out}}/v_{\mathrm{in}} =$ 1.000 V/V

Circuiti con MOSFET e BJT: Es. 8c

5. Dato il circuito in figura ($V_{dd} = 5$ V, $V_{in} = 3$ V, $V_{THn} = 1$ V, $V_{THp} =$ -1 V, $\beta_1 = \beta_2 = 20$ µA/V^2, $\beta_3 = \beta_4 = 40$ µA/V^2), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{D1}, I_{D2}, I_{D3}, I_{D4} e le tensioni V_X, V_{out}; *iii)* i parametri differenziali dei MOSFET.



M1 : SAT | TRI | OFF
M2 : SAT | TRI | OFF
M3 : SAT | TRI | OFF
M4 : SAT | TRI | OFF

$I_{D1} =$ ___ . ___ µA
$I_{D2} =$ ___ . ___ µA
$I_{D3} =$ ___ . ___ µA
$I_{D4} =$ ___ . ___ µA
$V_X =$ ___ . ___ V
$V_{out} =$ ___ . ___ V

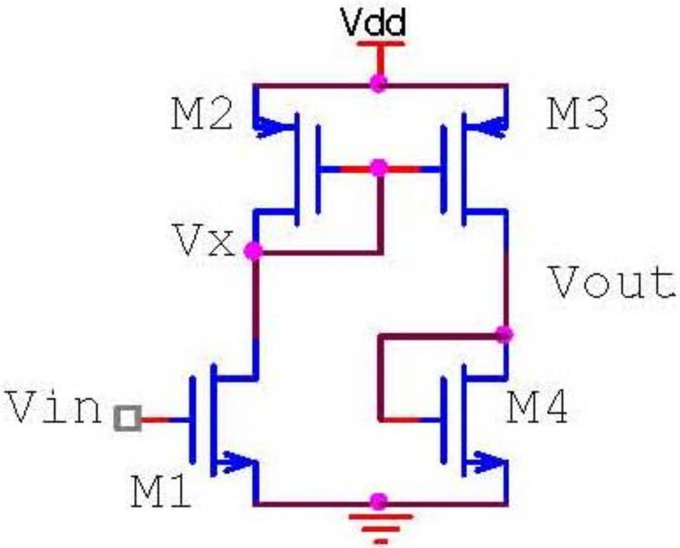
$g_{m1} =$ ___ . ___ µS
$g_{o1} =$ ___ . ___ µS
$g_{m2} =$ ___ . ___ µS
$g_{o2} =$ ___ . ___ µS
$g_{m3} =$ ___ . ___ µS
$g_{o3} =$ ___ . ___ µS
$g_{m4} =$ ___ . ___ µS
$g_{o4} =$ ___ . ___ µS

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{out}/v_{in}$

(espressione simbolica) $v_{out}/v_{in} =$

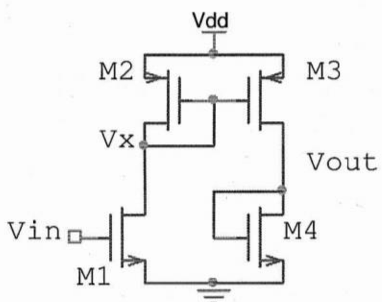
$v_{out}/v_{in} =$ ___ . ___ V/V

Es. 8c: Soluzione



Es. 8c: Soluzione

5. Dato il circuito in figura ($V_{dd} = 5$ V, $V_{in} = 3$ V, $V_{THn} = 1$ V, $V_{THp} = -1$ V, $\beta_1 = \beta_2 = 20\ \mu A/V^2$, $\beta_3 = \beta_4 = 40\ \mu A/V^2$), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{D1}, I_{D2}, I_{D3}, I_{D4} e le tensioni V_X, V_{out}; *iii)* i parametri differenziali dei MOSFET.



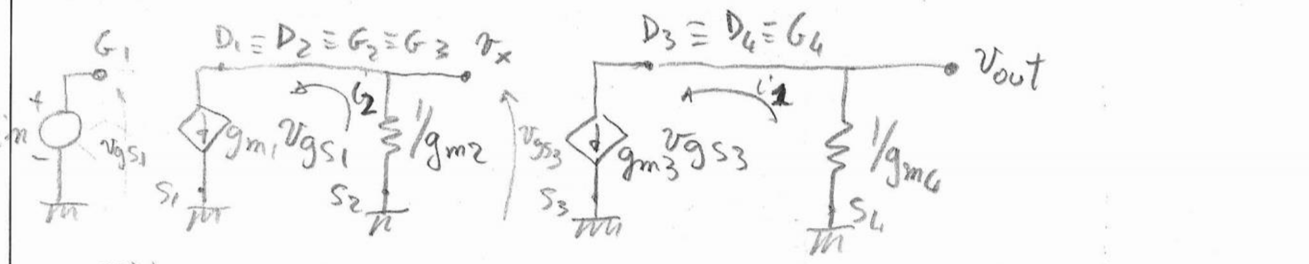
M1 : ~~SAT~~ TRI OFF
M2 : ~~SAT~~ TRI OFF
M3 : ~~SAT~~ TRI OFF
M4 : ~~SAT~~ TRI OFF

I_{D1} = 40.000 μA
I_{D2} = 40.000 μA
I_{D3} = 80.000 μA
I_{D4} = 80.000 μA
V_X = 2.000 V
V_{out} = 3.000 V

g_{m1} = 40.000 μS
g_{o1} = 0.000 μS
g_{m2} = 40.000 μS
g_{o2} = 0.000 μS
g_{m3} = 80.000 μS
g_{o3} = 0.000 μS
g_{m4} = 80.000 μS
g_{o4} = 0.000 μS

$$I_{D_i} = \frac{\beta_i}{2}\left(V_{GS_i} - V_{TH_i}\right)^2$$

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{out}/v_{in}$



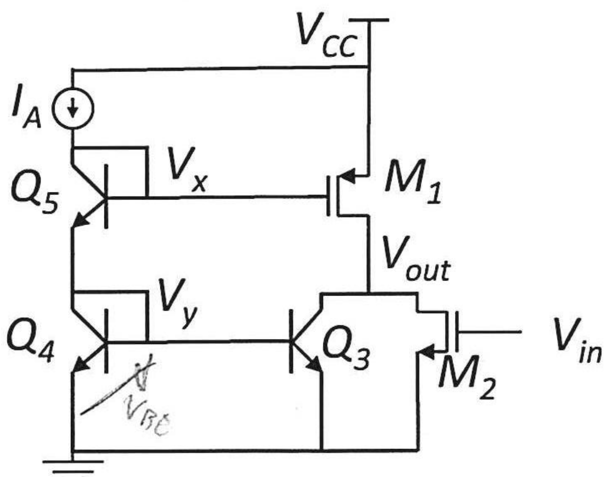
$v_{out} = i_1/g_{m4}$; $i_1 = g_{m3} v_{gs3}$, $v_{gs3} = v_x$; $v_x = i_2/g_{m2}$; $i_2 = g_{m1} v_{gs1}$; $v_{gs1} = v_{in}$

(espressione simbolica) $v_{out}/v_{in} = (g_{m1}\, g_{m3})/(g_{m2}\, g_{m4})$

v_{out}/v_{in} = 1.000 V/V

Circuiti con MOSFET e BJT: Es. 9c (14.01.2014)

5. Dato il circuito in figura ($V_{cc} = 5\,\mathrm{V}$, $V_T = 25\,\mathrm{mV}$, $V_\gamma = 0.6\,\mathrm{V}$, $V_{THn} = 1\,\mathrm{V}$, $V_{THp} = -1\,\mathrm{V}$, $\beta_{M1} = \beta_{M2} = 800\,\mu\mathrm{A/V^2}$, $\beta_{Q3} = \beta_{Q4} = \beta_{Q5} = 100$, $I_A = 1.5\,\mathrm{mA}$, $V_{in} = 2\,\mathrm{V}$), determinare: *i)* la zona di funzionamento di MOSFET e BJT; *ii)* le correnti I_{D1}, I_{D2}, I_{C3}, I_{C4}, I_{C5}, e le tensioni V_X, V_Y, V_{out}; *iii)* i parametri differenziali di MOSFET e BJT.



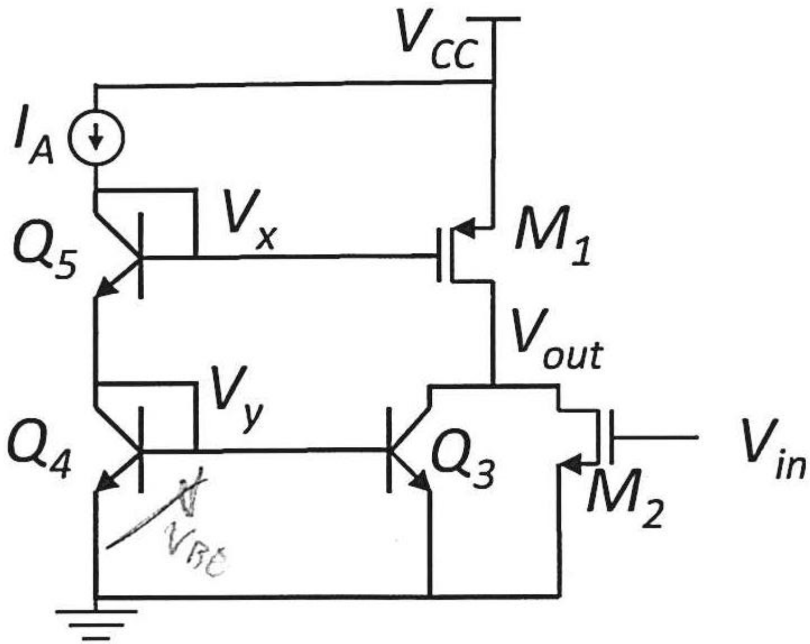
Q3 :	OFF	SAT	~~DIR~~	INV
Q4 :	OFF	SAT	~~DIR~~	INV
Q5 :	OFF	SAT	~~DIR~~	INV

M1 :	SAT	~~TRI~~	OFF
M2 :	~~SAT~~	TRI	OFF

I_{D1} =	1.871	mA
I_{D2} =	0.400	mA
I_{C3} =	1.471	mA
I_{C4} =	1.471	mA
I_{C5} =	1.485	mA
V_x =	1.200	V
V_y =	0.600	V
V_{out} =	3.979	V

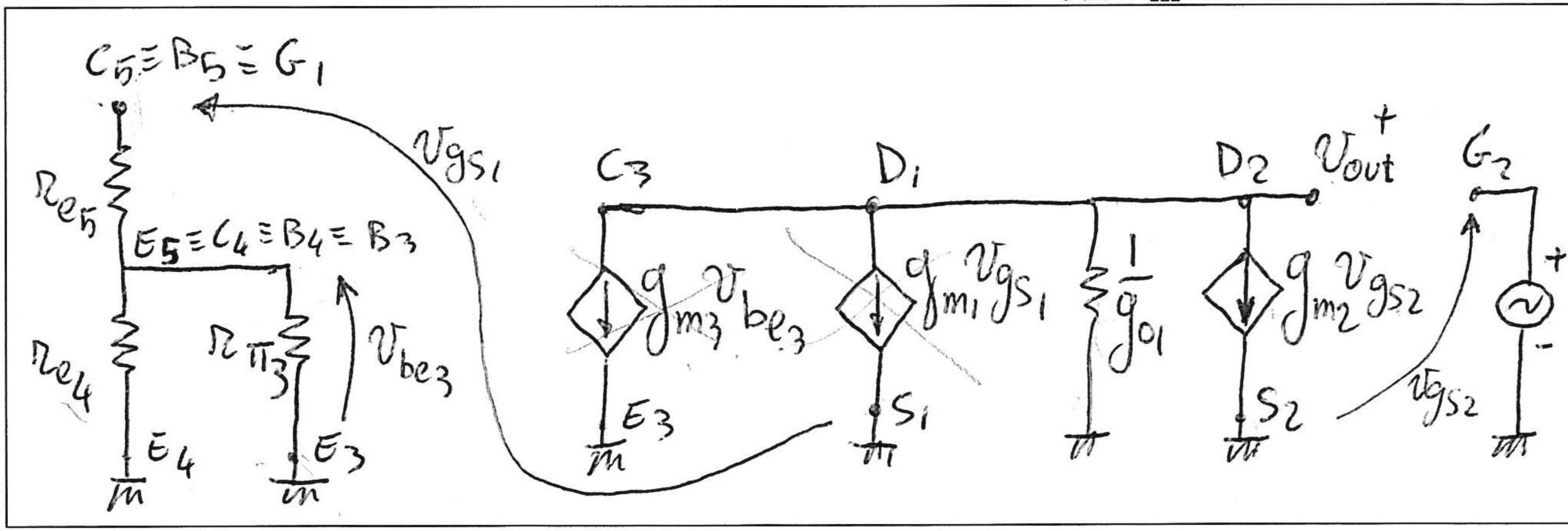
g_{m1} =	0.817	mS
g_{o1} =	1.423	mS
g_{m2} =	0.800	mS
g_{o2} =	0.000	mS
g_{m3} =	58.824	mS
$r_{\pi 3}$ =	1.700	kΩ
g_{m4} =	58.824	mS
$r_{\pi 4}$ =	1.700	kΩ
g_{m5} =	59.406	mS
$r_{\pi 5}$ =	1.683	kΩ

Es. 9c (14.01.2014): Soluzione



Es. 9c (14.01.2014): Soluzione

Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{\text{out}}/v_{\text{in}}$

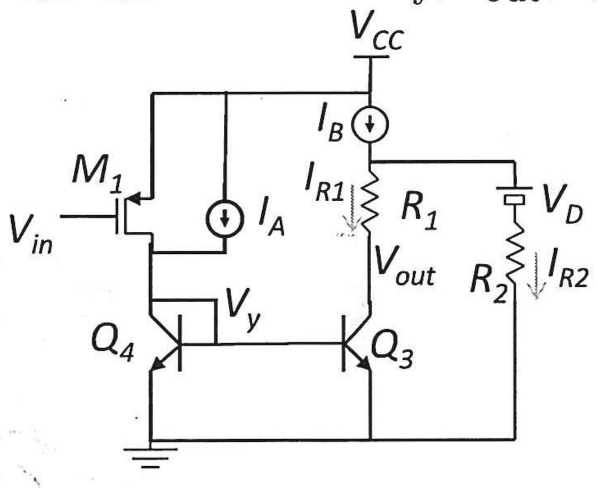


$v_{\text{out}}/v_{\text{in}} = -g_{m2}/g_{o1}$

$v_{\text{out}}/v_{\text{in}} = \boxed{-}\ \boxed{}\boxed{}\boxed{0}\,.\,\boxed{5}\boxed{6}\boxed{2}$ V/V

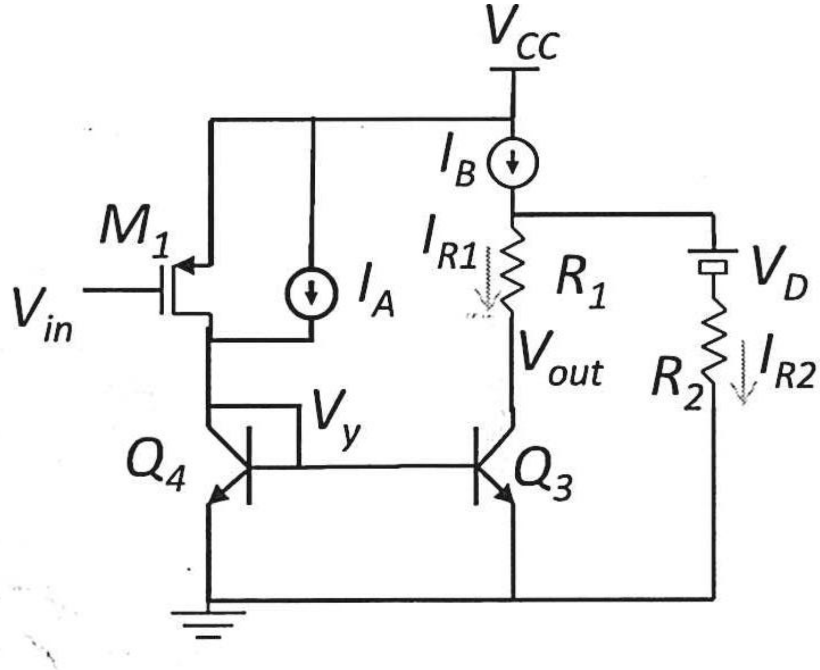
Circuiti con MOSFET e BJT: Es. 10c (04.02.2014)

5. Dato il circuito in figura ($V_{cc} = 5$ V, $V_T = 25$ mV, $V_\gamma = 0.6$ V, $V_{THp} = -1$ V, $R_1 = 100\ \Omega$, $R_2 = 1\ \text{k}\Omega$, $\beta_{M1} = 400\ \mu\text{A/V}^2$, $\beta_{Q3} = \beta_{Q4} = 30$, $V_{in} = 2$ V, $V_D = 4$ V, $I_A = 500\ \mu$A, $I_B = 2$ mA), sapendo che il MOSFET lavora in saturazione e i BJT in normale diretta, determinare: *i)* le correnti I_{D1}, I_{C3}, I_{C4}, I_{R1}, I_{R2}, e le tensioni V_y, V_{out}; *ii)* i parametri differenziali di MOSFET e BJT.



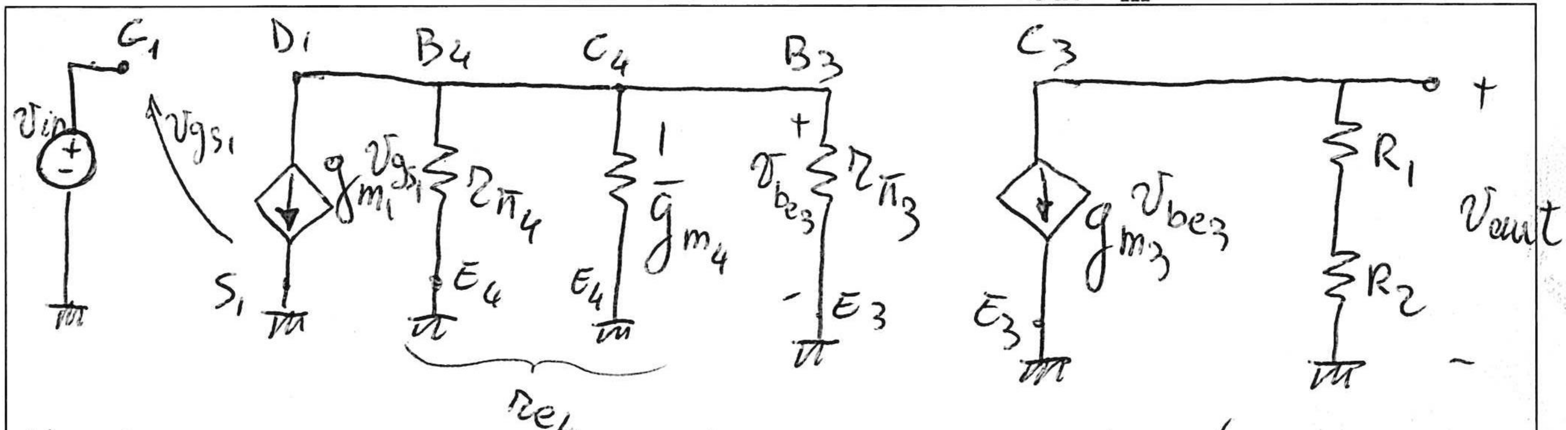
I_{D1} =	0.800	mA			
I_{C3} =	1.219	mA	g_{m1} =	0.800	mS
I_{C4} =	1.219	mA	g_{o1} =	0.000	mS
I_{R1} =	1.219	mA	g_{m3} =	48.760	mS
I_{R2} =	0.781	mA	$r_{\pi 3}$ =	0.615	kΩ
V_y =	0.600	V	g_{m4} =	48.760	mS
V_{out} =	4.659	V	$r_{\pi 4}$ =	0.615	kΩ

Es. 10c (04.02.2014): Soluzione



Es. 10c (04.02.2014): Soluzione

Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{\text{out}}/v_{\text{in}}$



$v_{out} = -g_{m3} v_{be3} \cdot (R_1 + R_2)$; $v_{be3} = -g_{m1} v_{gs1} \left(\underbrace{r_{\pi 4} /\!/ \frac{1}{g_{m4}}}_{r_{e4}} /\!/ r_{\pi 3} \right)$;

$v_{gs1} = v_{in}$;

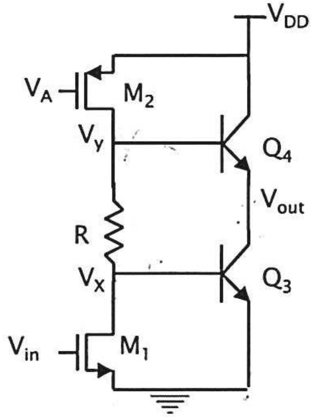
$$v_{\text{out}}/v_{\text{in}} = g_{m1} \left(r_{\pi 3} /\!/ r_{\pi 4} /\!/ \frac{1}{g_{m4}} \right) g_{m3} (R_1 + R_2)$$

$$= g_{m1} (r_{\pi 3} /\!/ r_{e4}) g_{m3} (R_1 + R_2)$$

$v_{\text{out}}/v_{\text{in}} =$ + 0.825 V/V

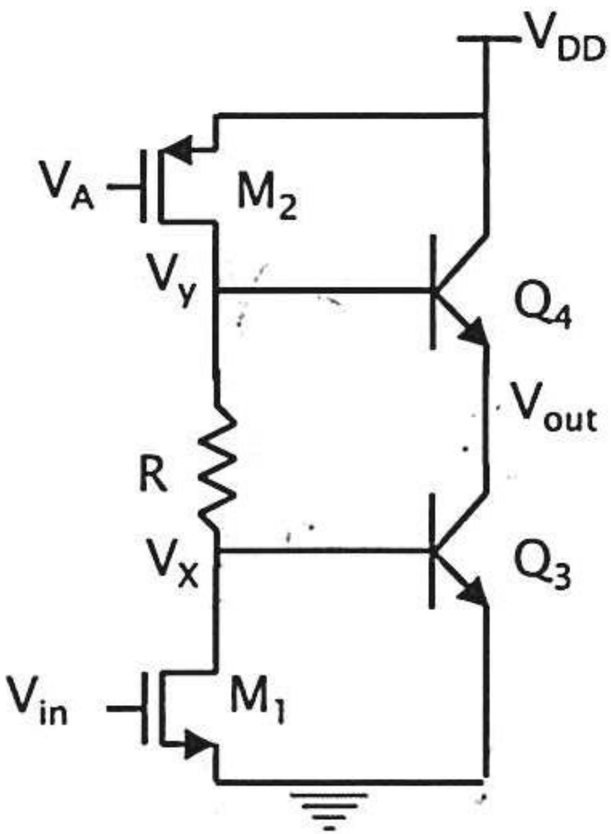
Circuiti con MOSFET e BJT: Es. 11c (07.07.2015)

5. Dato il circuito in figura ($V_{DD} = 5$ V, $V_A = 3.5$ V, $V_{IN} = 1$ V, $V_{THn} = 0.5$ V, $V_{THp} = -0.5$ V, $V_T = 25$ mV, $V_\gamma = 0.6$ V, $\beta_{M1} = 200\ \mu A/V^2$, $\beta_{M2} = 100\ \mu A/V^2$, $\beta_{Q3} = 100$, $\beta_{Q4} = 50$, $R = 100$ kΩ, ipotizzando e verificando che M1 e M2 siano saturi e che Q3 e Q4 siano in normale diretta), determinare: *i)* le correnti I_{D1}, I_{D2}, I_{C3}, I_{C4}, I_R e le tensioni V_x, V_y, V_{out}; *ii)* i parametri differenziali dei MOSFET e dei BJT.



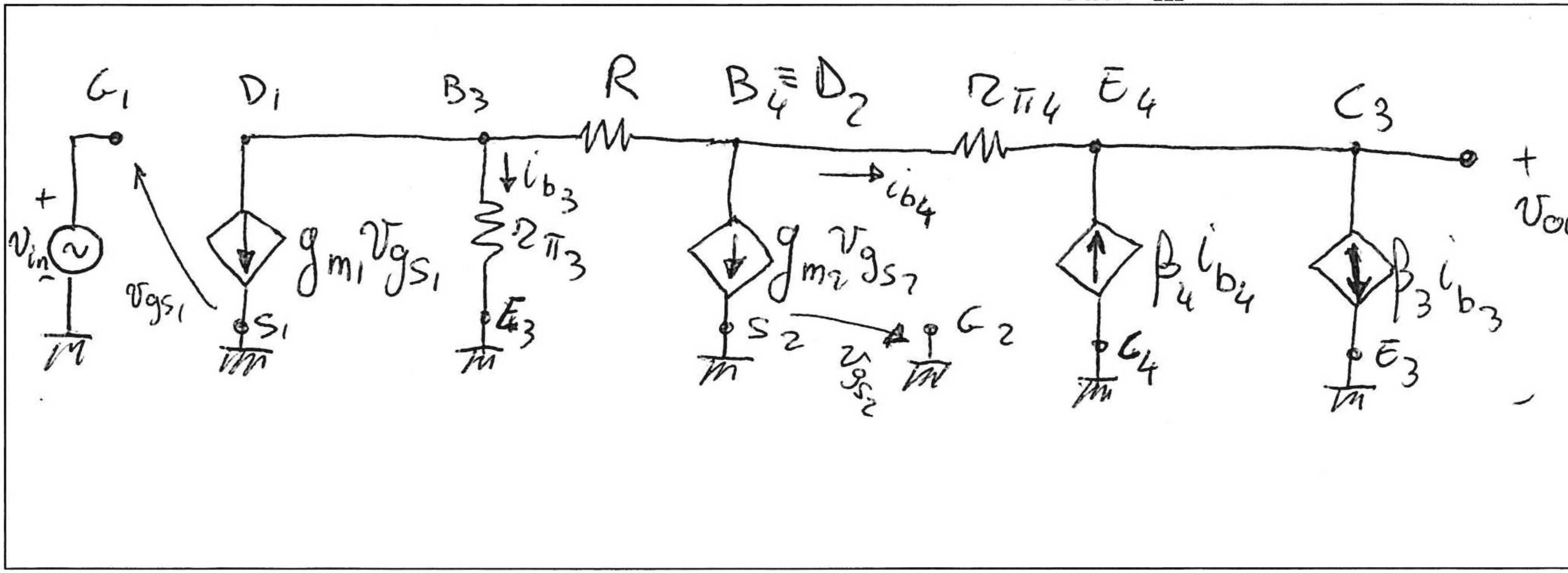
I_{D1} =	25.000	μA	g_{m1} =	100.000	μS
I_{D2} =	50.000	μA	g_{o1} =	0.000	μS
I_{C3} =	844.3	μA	g_{m2} =	100.000	μS
I_{C4} =	827.8	μA	g_{o2} =	0.000	μS
I_R =	33.443	μA	g_{m3} =	33.772	mS
V_x =	0.600	V	$r_{\pi 3}$ =	2.961	kΩ
V_y =	3.944	V	g_{m4} =	33.112	mS
V_{out} =	3.344	V	$r_{\pi 4}$ =	1.510	kΩ

Es. 11c (07.07.2015): Soluzione



Es. 11c (07.07.2015): Soluzione

Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{\mathrm{out}}/v_{\mathrm{in}}$

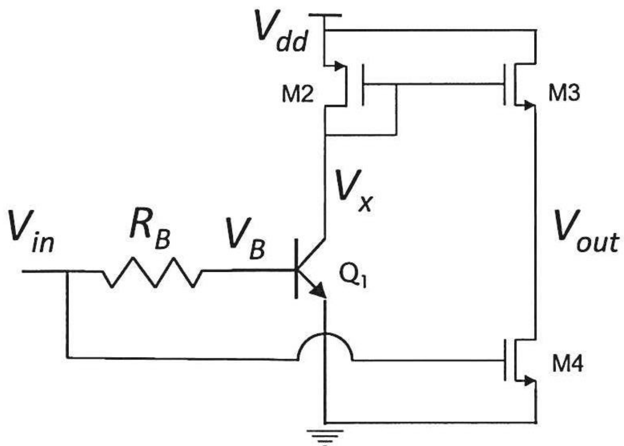


$$v_{\mathrm{out}}/v_{\mathrm{in}} = \left(R + r_{\pi 4} - r_{\pi 3}\,\frac{1+\beta_4}{\beta_3}\right)\cdot\frac{g_{m1}}{1+\frac{1+\beta_4}{\beta_3}}$$

$v_{\mathrm{out}}/v_{\mathrm{in}} =$ + 3.163 V/V

Circuiti con MOSFET e BJT: Es. 12c (25.02.2016)

5. Dato il circuito in figura ($V_{DD} = 5$ V, $R_B = 100$ kΩ, $V_T = 25$ mV, $V_\gamma = 0.6$ V, $V_{THn} = 1$ V, $V_{THp} = -1$ V, $\beta_{Q1} = 20$, $\beta_{M2} = 400\ \mu A/V^2$, $\beta_{M3} = 200\ \mu A/V^2$, $\beta_{M4} = 100\ \mu A/V^2$, $V_{IN} = 2$ V) e supponendo il BJT in normale diretta, determinare: *i)* la zona di funzionamento dei MOSFET, *i)* le correnti I_B, I_C, I_{D2}, I_{D3}, I_{D4}, e le tensioni V_x, V_{out}; *ii)* i parametri differenziali dei MOSFET.



M2 : ~~SAT~~ TRI OFF

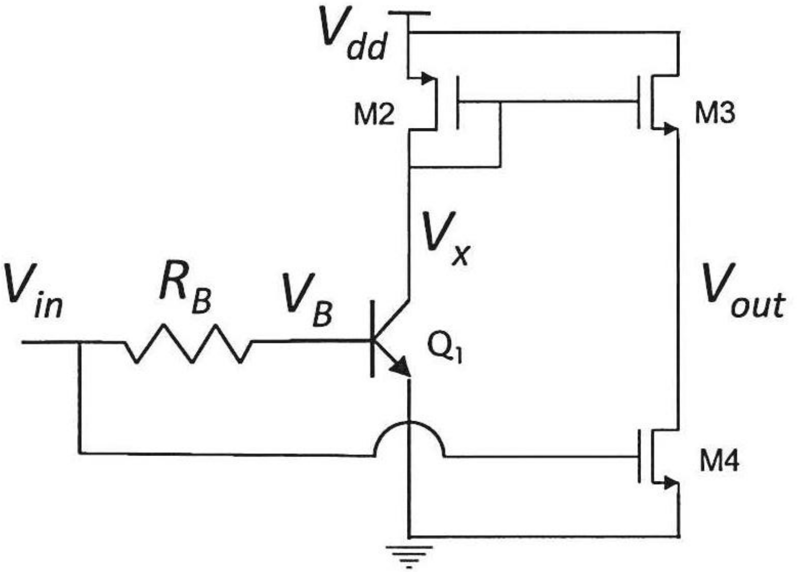
M3 : ~~SAT~~ TRI OFF

M4 : ~~SAT~~ TRI OFF

I_B =	0.014	mA
I_C =	0.280	mA
I_{D2} =	0.280	mA
I_{D3} =	0.050	mA
I_{D4} =	0.050	mA
V_x =	2.817	V
V_{out} =	1.110	V

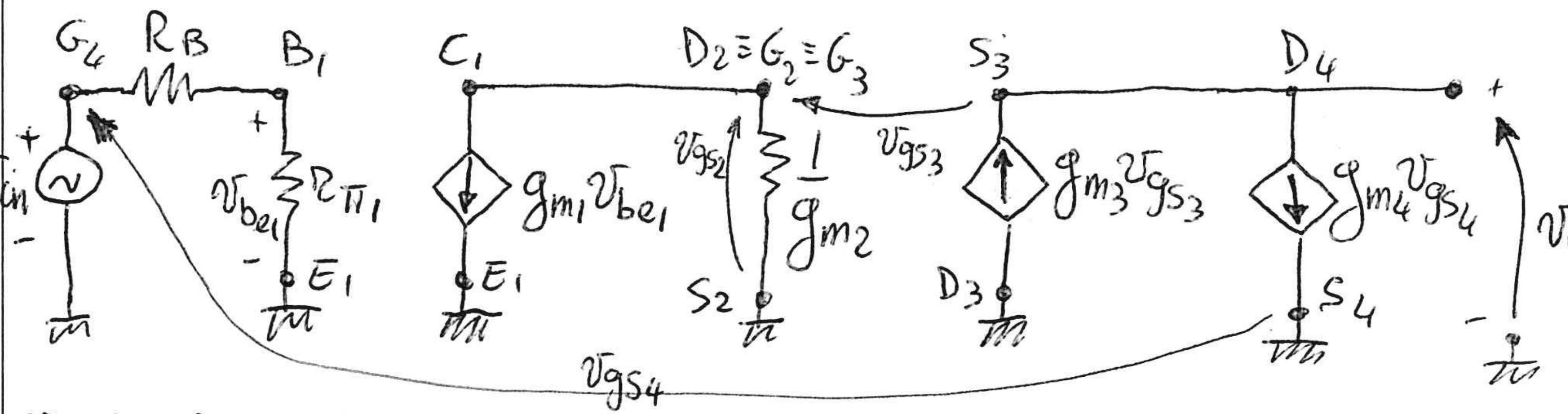
g_{m1} =	11.2	mS
$r_{\pi 1}$ =	1.786	kΩ
g_{m2} =	473.286	µS
g_{o2} =	0.000	µS
g_{m3} =	141.421	µS
g_{o3} =	0.000	µS
g_{m4} =	100.000	µS
g_{o4} =	0.000	µS

Circuiti con MOSFET e BJT: Es. 12c (25.02.2016)



Circuiti con MOSFET e BJT: Es. 12c (25.02.2016)

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{\text{out}}/v_{\text{in}}$



$v_{out} = v_{gs2} - v_{gs3}$; $g_{m3} v_{gs3} = g_{m4} v_{gs4}$; $v_{gs4} = v_{in}$; $v_{gs2} = -g_{m1} v_{be1} \cdot \frac{1}{g_{m2}}$

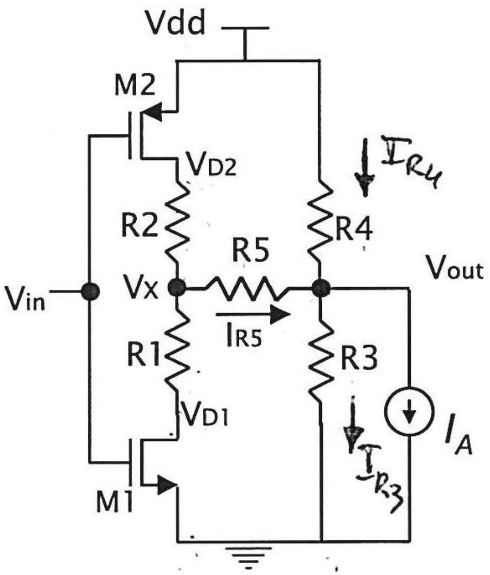
$v_{be1} = \left[r_\pi / (r_\pi + R_B) \right] \cdot v_{in}$;

$$v_{\text{out}}/v_{\text{in}} = -\frac{g_{m1}}{g_{m2}} \cdot \frac{r_{\pi 1}}{r_{\pi 1} + R_B} - \frac{g_{m4}}{g_{m3}}$$

$v_{\text{out}}/v_{\text{in}} =$ - 1.122 V/V

Circuiti con MOSFET e BJT: Es. 13c (09.02.2016)

5. Dato il circuito in figura ($V_{DD} = 5$ V, $I_A = 100$ µA, $R_1 = R_2 = 500\ \Omega$, $R_3 = R_4 = 2$ kΩ, $R_5 = 1$ kΩ, $V_{THn} = 1$ V, $V_{THp} = -1$ V, $\beta_{M1} = 100$ µA/V^2, $\beta_{M2} = 200$ µA/V^2, $V_{IN} = 2.2$ V), determinare: *i)* la zona di funzionamento di MOSFET, *i)* le correnti I_{D1}, I_{D2}, I_{R3}, I_{R4}, I_{R5}, e le tensioni V_x, V_{D1}, V_{D2}, V_{out}; *ii)* i parametri differenziali dei MOSFET.



$I_{D1} = 0.072$ mA

$I_{D2} = 0.324$ mA

$I_{R3} = 1.326$ mA

$I_{R4} = 1.174$ mA

$I_{R5} = 0.252$ mA

$V_x = 2.904$ V

$V_{D1} = 2.868$ V

$V_{D2} = 3.066$ V

$V_{out} = 2.652$ V

M1 : ~~SAT~~ TRI OFF

M2 : ~~SAT~~ TRI OFF

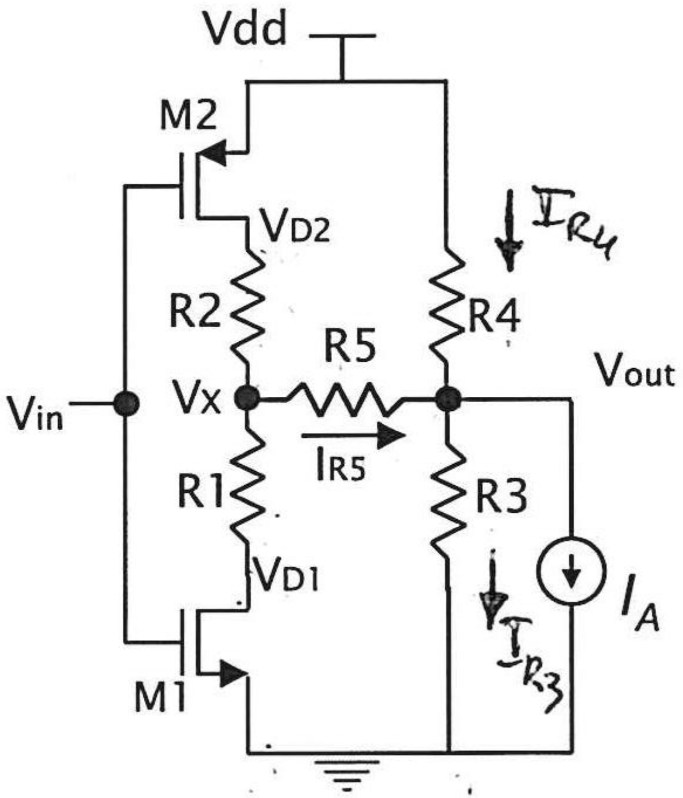
$g_{m1} = 120.000$ µS

$g_{o1} = 0.000$ µS

$g_{m2} = 360.000$ µS

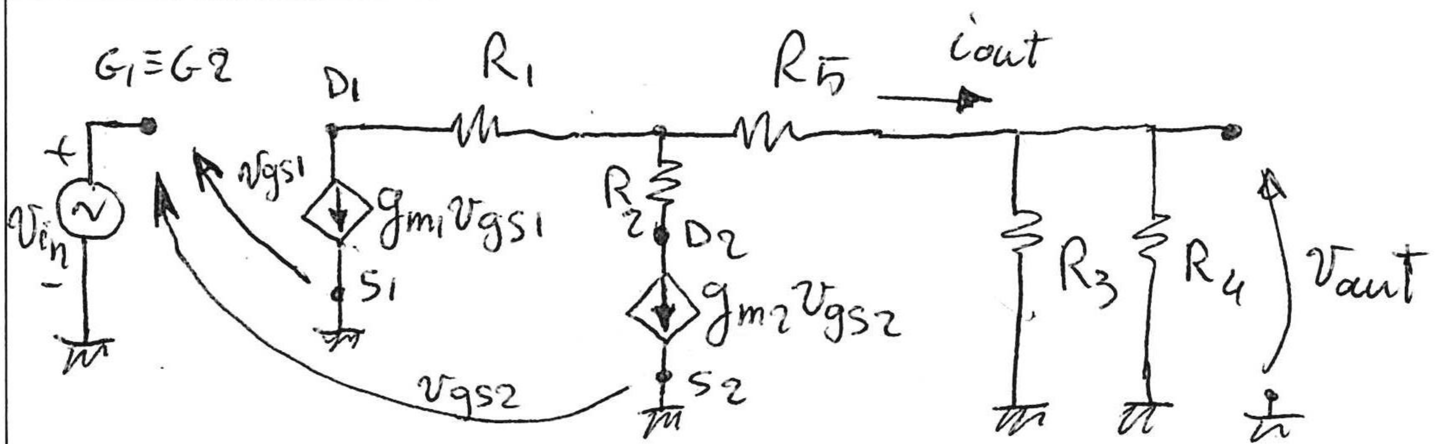
$g_{o2} = 0.000$ µS

Circuiti con MOSFET e BJT: Es. 13c (09.02.2016)



Circuiti con MOSFET e BJT: Es. 13c (09.02.2016)

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{\text{out}}/v_{\text{in}}$



$v_{gs1} = v_{in}$;

$v_{gs2} = v_{in}$;

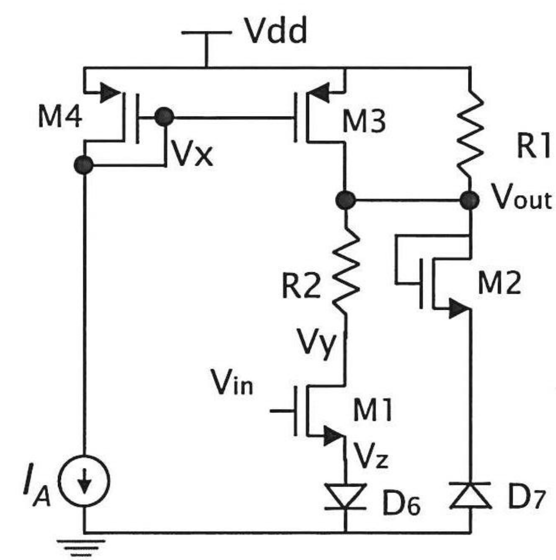
$i_{out} = -g_{m1} v_{gs1} - g_{m2} v_{gs2}$; $\quad v_{out} = R_3 /\!/ R_4 \, i_{out} = \frac{R_3 R_4}{R_3 + R_4} i_{out}$

$v_{\text{out}}/v_{\text{in}} = -(g_{m1} + g_{m2}) \frac{R_3 R_4}{R_3 + R_4}$

$v_{\text{out}}/v_{\text{in}} =$ - 0.480 V/V

Circuiti con MOSFET e BJT: Es. 14c (12.01.2016)

5. Dato il circuito in figura ($V_{\mathrm{DD}} = 5\ \mathrm{V}$, $I_{\mathrm{A}} = 100\ \mu\mathrm{A}$, $V_\gamma = 0.6\ \mathrm{V}$, $V_{\mathrm{THn}} = 1\ \mathrm{V}$, $V_{\mathrm{THp}} = -1\ \mathrm{V}$, $\beta_{\mathrm{M1}} = \beta_{\mathrm{M2}} = 400\ \mu\mathrm{A/V^2}$, $\beta_{\mathrm{M3}} = \beta_{\mathrm{M4}} = 800\ \mu\mathrm{A/V^2}$, $V_{\mathrm{IN}} = 3.3\ \mathrm{V}$, $R_1 = 20\ \mathrm{k\Omega}$, $R_2 = 1\ \mathrm{k\Omega}$), determinare: *i)* la zona di funzionamento di MOSFET e diodi, *i)* le correnti I_{D1}, I_{D2}, I_{D3}, I_{D4}, I_{R1}, e le tensioni V_{X}, V_{y}, V_{out}; *ii)* i parametri differenziali dei MOSFET.



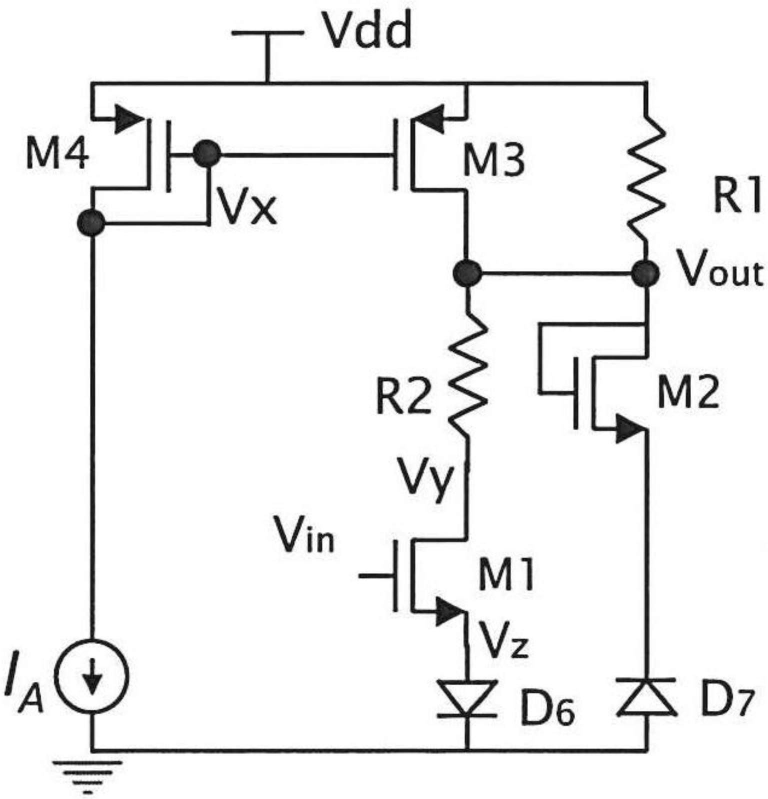
M1 :	SAT	~~TRI~~	OFF
M2 :	SAT	TRI	~~OFF~~
M3 :	~~SAT~~	TRI	OFF

M4 :	~~SAT~~	TRI	OFF
D6 :	~~ON~~	OFF	
D7 :	ON	~~OFF~~	

I_{D1} =	281.8	µA
I_{D2} =	0.0	µA
I_{D3} =	100.0	µA
I_{D4} =	100.0	µA
I_{R1} =	181.8	µA
V_{X} =	3.5	V
V_{y} =	1.083	V
V_{out} =	1.365	V

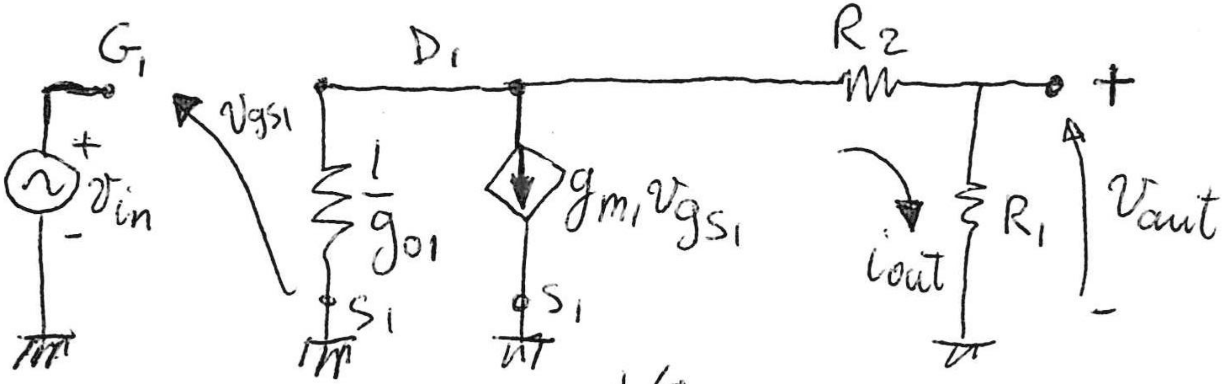
g_{m1} =	193.2	µS
g_{o1} =	486.8	µS
g_{m2} =	0.0	µS
g_{o2} =	0.0	µS
g_{m3} =	400.0	µS
g_{o3} =	0.0	µS
g_{m4} =	400.0	µS
g_{o4} =	0.0	µS

Circuiti con MOSFET e BJT: Es. 14c (12.01.2016)



Circuiti con MOSFET e BJT: Es. 14c (12.01.2016)

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{\text{out}}/v_{\text{in}}$



$$v_{out} = i_{out} \cdot R_1$$

$$v_{gs1} = v_{in}$$

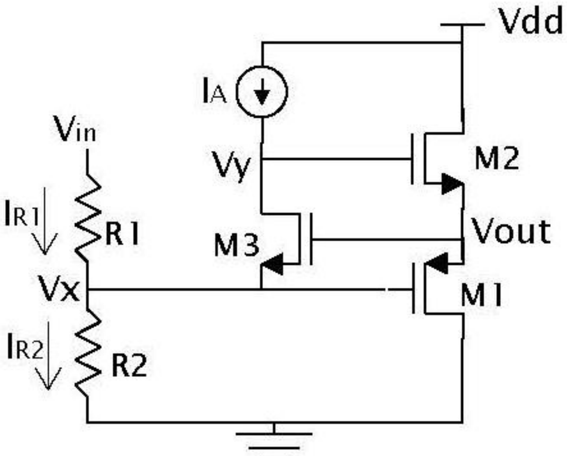
$$i_{out} = -g_{m1} v_{gs1} \cdot \frac{1/g_{o1}}{1/g_{o1} + R_1 + R_2}$$

$$v_{\text{out}}/v_{\text{in}} = -\frac{g_{m1} \cdot R_1}{1 + g_{o1}(R_1 + R_2)} = -\frac{g_{m1}}{\frac{1}{R_1} + g_{o1}\left(1 + \frac{R_2}{R_1}\right)}$$

$v_{\text{out}}/v_{\text{in}} = -0.4$ V/V

Circuiti con MOSFET e BJT: Es. 15c (09.01.2018)

5. Dato il circuito in figura ($V_{\mathrm{dd}} = 6\,\mathrm{V}$, $V_{\mathrm{in}} = 1\,\mathrm{V}$, $I_{\mathrm{A}} = 50\,\mu\mathrm{A}$, $R_1 = 10\,\mathrm{k}\Omega$, $R_2 = 40\,\mathrm{k}\Omega$, $V_{\mathrm{THn}} = 1\,\mathrm{V}$, $V_{\mathrm{THp}} = -1\,\mathrm{V}$, $\beta_{\mathrm{M1}} = \beta_{\mathrm{M2}} = 100\,\mu\mathrm{A/V^2}$, $\beta_{\mathrm{M3}} = 200\,\mu\mathrm{A/V^2}$), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{R1}, I_{R2}, I_{D1}, I_{D2}, I_{D3}, e le tensioni V_{x}, V_{y}, V_{out}; *iii)* i parametri differenziali dei MOSFET.



M1 : SAT TRI OFF

M2 : SAT TRI OFF

M3 : SAT TRI OFF

$I_{R1} =$. μA

$I_{R2} =$. μA

$I_{D1} =$. μA

$I_{D2} =$. μA

$I_{D3} =$. μA

$V_{\mathrm{x}} =$. V

$V_{\mathrm{y}} =$. V

$V_{\mathrm{out}} =$. V

$g_{m1} =$. μS

$g_{o1} =$. μS

$g_{m2} =$. μS

$g_{o2} =$. μS

$g_{m3} =$. μS

$g_{o3} =$. μS

Circuiti con MOSFET e BJT: Es. 15c (09.01.2018)

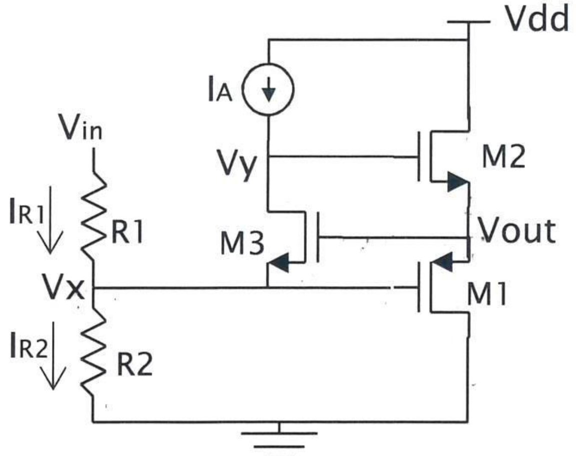
6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{\text{out}}/v_{\text{in}}$

$v_{\text{out}}/v_{\text{in}} =$

$v_{\text{out}}/v_{\text{in}} = \square\square\square\square.\square\square\square$ V/V

Es. 15c (09.01.2018): Soluzione

5. Dato il circuito in figura ($V_{dd} = 6$ V, $V_{in} = 1$ V, $I_A = 50$ µA, $R_1 = 10$ kΩ, $R_2 = 40$ kΩ, $V_{THn} = 1$ V, $V_{THp} = -1$ V, $\beta_{M1} = \beta_{M2} = 100\ \mu A/V^2$, $\beta_{M3} = 200\ \mu A/V^2$), determinare: *i)* la zona di funzionamento dei MOSFET; *ii)* le correnti I_{R1}, I_{R2}, I_{D1}, I_{D2}, I_{D3}, e le tensioni V_x, V_y, V_{out}; *iii)* i parametri differenziali dei MOSFET.



M1 : ~~SAT~~ TRI OFF

M2 : ~~SAT~~ TRI OFF

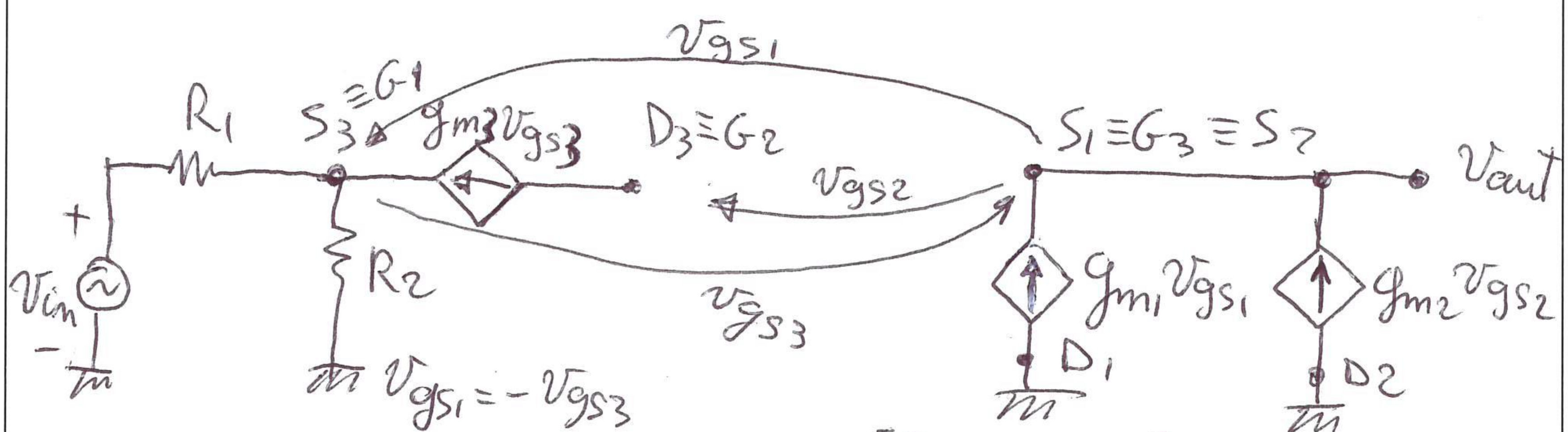
M3 : ~~SAT~~ TRI OFF

I_{R1} =	20.000	µA
I_{R2} =	30.000	µA
I_{D1} =	25.000	µA
I_{D2} =	25.000	µA
I_{D3} =	50.000	µA
V_x =	1.200	V
V_y =	4.614	V
V_{out} =	2.907	V

g_{m1} =	70.711	µS
g_{o1} =	0.000	µS
g_{m2} =	70.711	µS
g_{o2} =	0.000	µS
g_{m3} =	141.421	µS
g_{o3} =	0.000	µS

Es. 15c (09.01.2018): Soluzione

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di tensione $A_V = v_{\text{out}}/v_{\text{in}}$



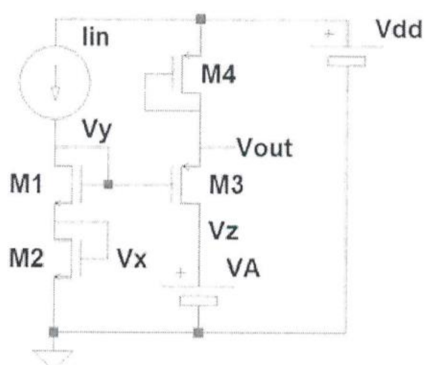
$v_{gs1} = v_{g1} - v_{s1}$ $\quad v_{s1} = V_{out}$; $v_{g1} = [R_2/(R_1+R_2)] \cdot v_{in}$; $g_{m3} v_{gs3} = 0$

$$v_{\text{out}}/v_{\text{in}} = \frac{R_2}{R_1+R_2}$$

$v_{\text{out}}/v_{\text{in}} =$ + 0.800 V/V

Circuiti con MOSFET e BJT: Es. 16c (08.01.2019)

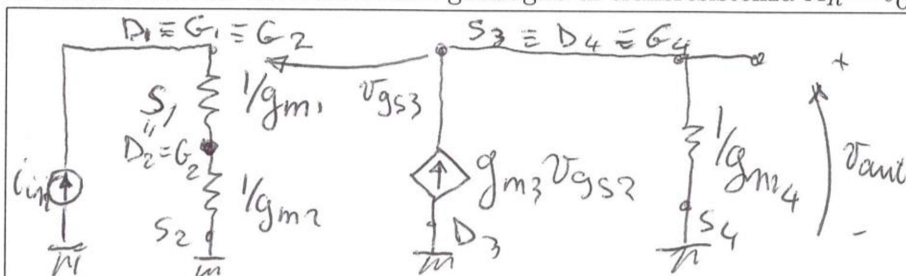
5. Dato il circuito in figura ($V_{\mathrm{dd}} = 10$ V, $V_{\mathrm{A}} = 1$ V, $I_{\mathrm{IN}} = 100$ µA, $V_{\mathrm{THn}} = 1$ V, $V_{\mathrm{THp}} = -1$ V, $\beta_{\mathrm{M1}} = \beta_{\mathrm{M2}} = \beta_{\mathrm{M3}} = \beta_{\mathrm{M4}} = 200$ µA/V^2), determinare: *i)* la zona di funzionamento e i parametri differenziali dei MOSFET; *ii)* le correnti e le tensioni indicate.



M1 :	~~SAT~~	TRI	OFF
M2 :	~~SAT~~	TRI	OFF
M3 :	~~SAT~~	TRI	OFF
M4 :	~~SAT~~	TRI	OFF

I_{D1} =	100.000 µA	g_{m1} =	200.000 µS
I_{D2} =	100.000 µA	g_{o1} =	0.000 µS
I_{D3} =	400.000 µA	g_{m2} =	200.000 µS
I_{D4} =	400.000 µA	g_{o2} =	0.000 µS
V_{x} =	2.000 V	g_{m3} =	400.000 µS
V_{y} =	4.060 V	g_{o3} =	0.000 µS
V_{z} =	1.000 V	g_{m4} =	400.000 µS
V_{out} =	7.000 V	g_{o4} =	0.000 µS

6. Relativamente all'esercizio precedente, disegnare il circuito equivalente alle variazioni e calcolare sia in forma simbolica che numerica il guadagno di transresistenza $A_R = v_{\mathrm{out}}/i_{\mathrm{in}}$



$v_{out} = g_{m3} v_{gs3} \frac{1}{g_{m4}}$;

$v_{gs3} = v_{g3} - v_{s3}$;

$v_{g3} = i_{in}\left(\frac{1}{g_{m1}} + \frac{1}{g_{m2}}\right)$; $\quad v_{s3} = v_{out}$

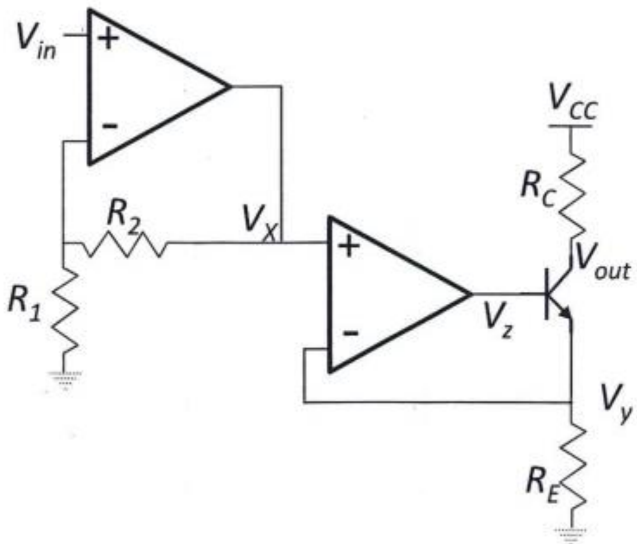
$$v_{\mathrm{out}}/i_{\mathrm{in}} = \frac{g_{m3}}{g_{m3}+g_{m4}}\left(\frac{1}{g_{m1}} + \frac{1}{g_{m2}}\right)$$

$v_{\mathrm{out}}/i_{\mathrm{in}} =$ + 5.000 kΩ

Circuiti con OP-AMP: Es. 1d

Dato il circuito ($V_{\text{in}} = 0.5\ \text{V}$, $V_{\text{CC}} = 5\ \text{V}$, $R_1 = R_2 = 1\ \text{k}\Omega$, $R_{\text{E}} = 1\ \text{k}\Omega$, $R_{\text{C}} = 2\ \text{k}\Omega$, $\beta = 50$, $V_{BE} = 0.6\ \text{V}$), determinare: *i)* l'espressione simbolica che lega V_{out} a V_{in}; *ii)* i valori numerici indicati.

$$V_{\text{out}} = V_{CC} - R_C \cdot \frac{\beta}{1+\beta} \frac{1}{R_E} \left(1 + \frac{R_2}{R_1}\right) V_{IN} = V_{CC} - V_{IN} \frac{R_C (R_1 + R_2) \beta}{R_E R_1 (\beta + 1)}$$



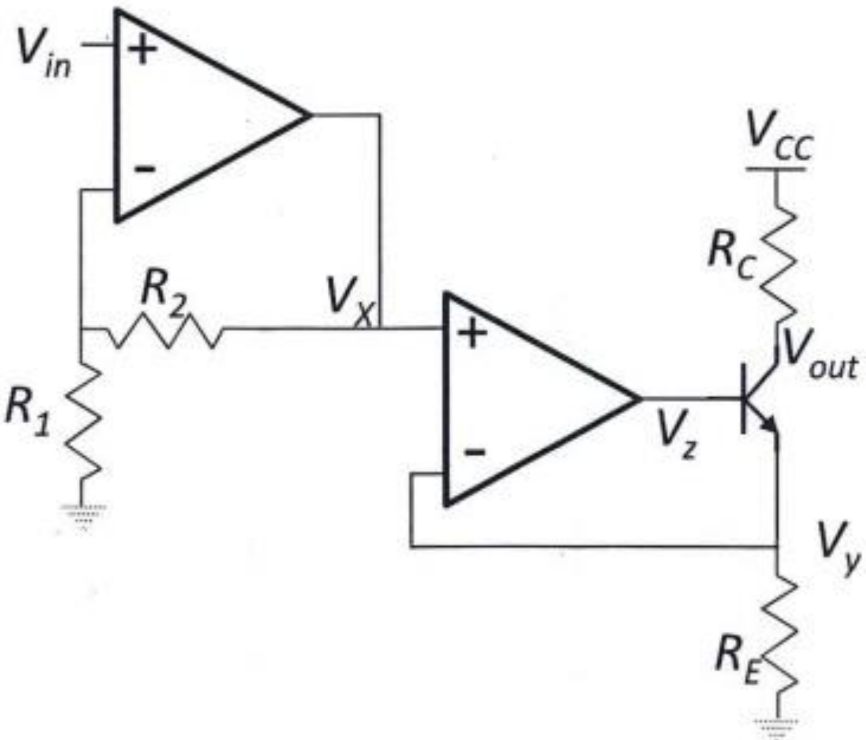
$V_{\text{x}} = 1.000\ \text{V}$

$V_{\text{y}} = 1.000\ \text{V}$

$V_{\text{z}} = 1.600\ \text{V}$

$V_{\text{out}} = 3.039\ \text{V}$

Circuiti con OP-AMP: Es. 1d



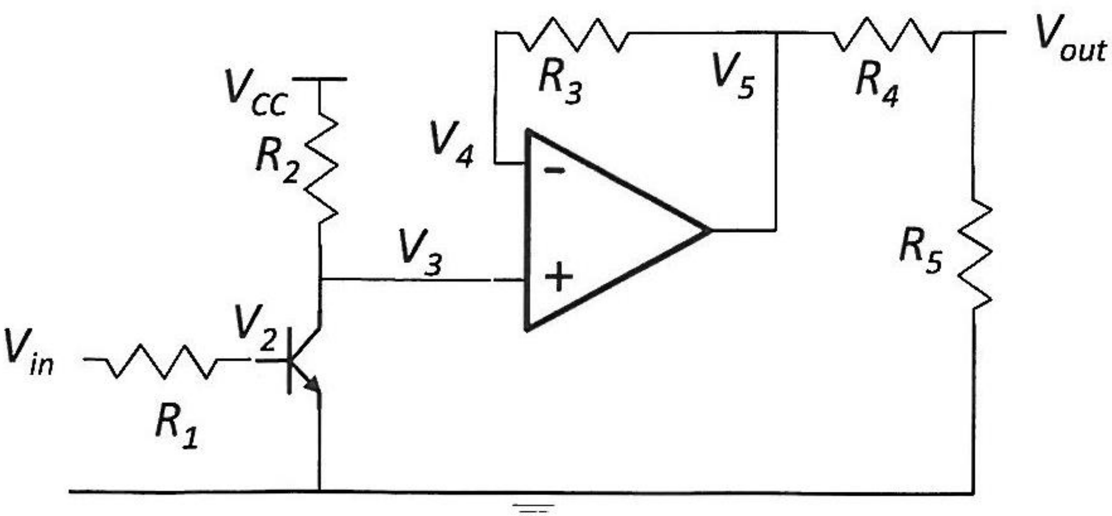
Circuiti con OP-AMP: Es. 2d

Dato il circuito ($V_{\text{in}} = 1\,\text{V}$, $V_{\text{CC}} = 3\,\text{V}$, $R_1 = 50\,\text{k}\Omega$, $R_2 = 1\,\text{k}\Omega$, $R_3 = R_4 = R_5 = 10\,\text{k}\Omega$,), determinare: *i)* l'espressione simbolica che lega V_{out} a V_{in}; *ii)* i valori numerici indicati.

$V_{BE} = 0.6$ V

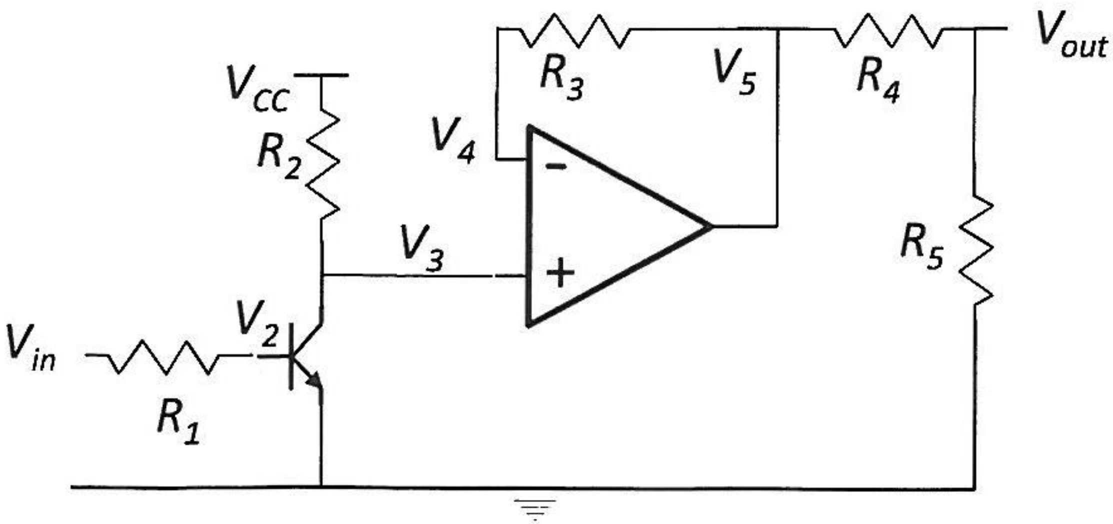
$\beta = 100$

$$V_{\text{out}} = \frac{R_5}{R_4 + R_5}\left[V_{CC} - R_2 \beta \frac{(V_{IN} - V_{BE})}{R_1}\right]$$



V_2 =	+	0.600	V
V_3 =	+	2.200	V
V_4 =	+	2.200	V
V_5 =	+	2.200	V
V_{out} =	+	1.100	V

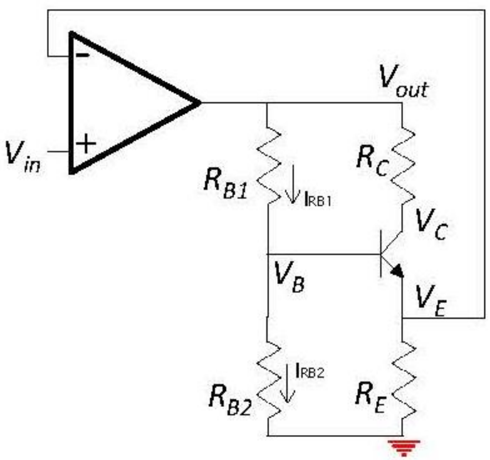
Circuiti con OP-AMP: Es. 2d



Circuiti con OP-AMP: Es. 3d (09.01.2018)

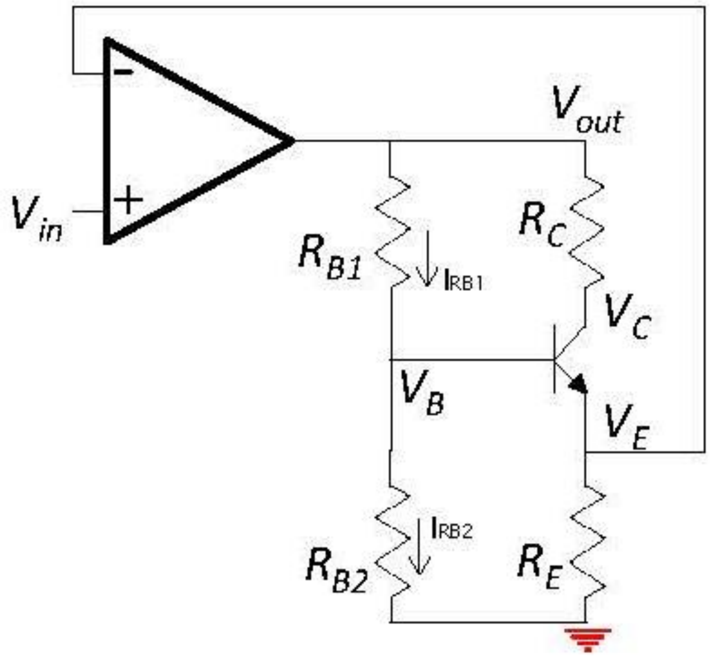
4. Dato il circuito in figura ($V_{\text{in}} = 1$ V, $R_{\text{B1}} = R_{\text{B2}} = 20$ kΩ, $R_{\text{E}} = 1$ kΩ, $R_{\text{C}} = 1$ kΩ, $\beta = 100$, $V_\gamma = 0.6$ V), determinare: *i)* l'espressione simbolica che lega V_{out} a V_{in}; *ii)* i valori numerici indicati.

$V_{\text{out}} =$



$I_E =$	.	mA
$I_C =$	.	mA
$I_B =$	.	µA
$I_{RB1} =$	.	µA
$I_{RB2} =$	.	µA
$V_{\text{E}} =$	.	V
$V_{\text{B}} =$	.	V
$V_{\text{C}} =$	.	V
$V_{\text{out}} =$	.	V

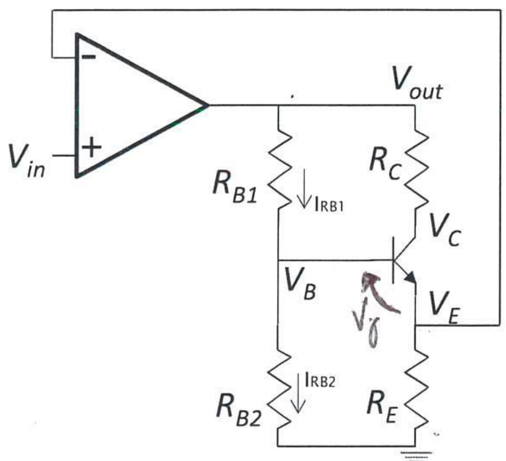
Circuiti con OP-AMP: Es. 3d (09.01.2018)



Es. 3d (09.01.2018): Soluzione

4. Dato il circuito in figura ($V_{\text{in}} = 1\ \text{V}$, $R_{\text{B1}} = R_{\text{B2}} = 20\ \text{k}\Omega$, $R_{\text{E}} = 1\ \text{k}\Omega$, $R_{\text{C}} = 1\ \text{k}\Omega$, $\beta = 100$, $V_\gamma = 0.6\ \text{V}$), determinare: *i)* l'espressione simbolica che lega V_{out} a V_{in}; *ii)* i valori numerici indicati.

$$V_{\text{out}} = V_{in}\left(1 + \frac{R_{B1}}{(\beta+1)R_E} + \frac{R_{B1}}{R_{B2}}\right) + V_\gamma\left(1 + \frac{R_{B1}}{R_{B2}}\right)$$



I_E =	+	1.000	mA
I_C =	+	0.990	mA
I_B =	+	9.901	µA
I_{RB1} =	+	89.901	µA
I_{RB2} =	+	80.000	µA
V_{E} =	+	1.000	V
V_{B} =	+	1.600	V
V_{C} =	+	2.408	V
V_{out} =	+	3.398	V