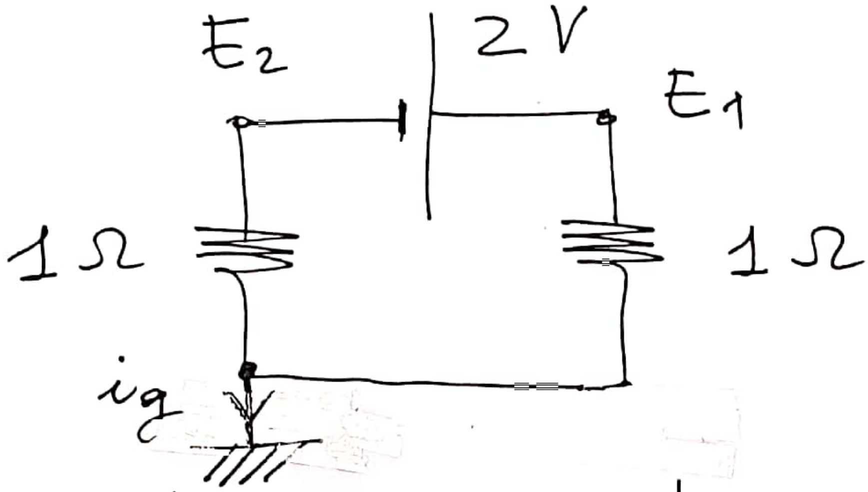
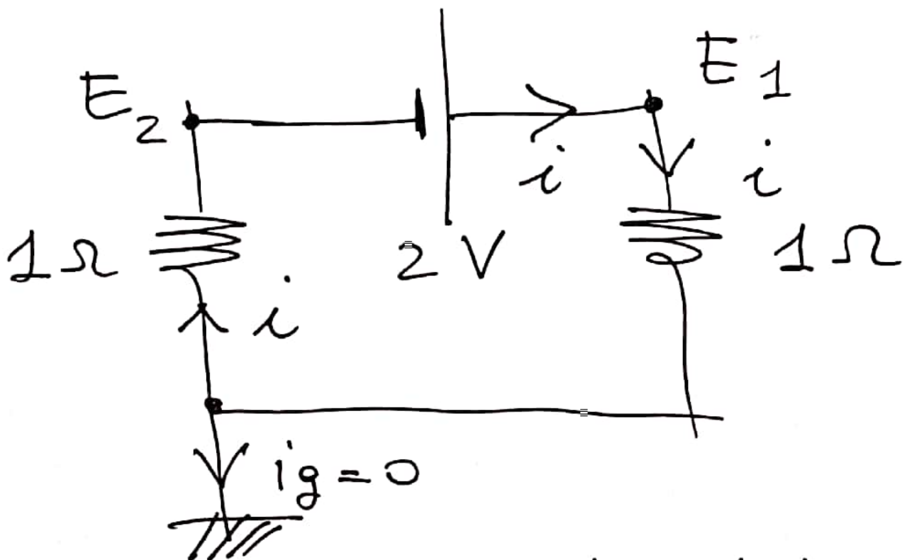
Esempio



? determinare il potenziale dei nodi E_1 e E_2 rispetto a terra.

Soluzione. Essendoci un solo collegamento a terra si ha $i_g = 0$



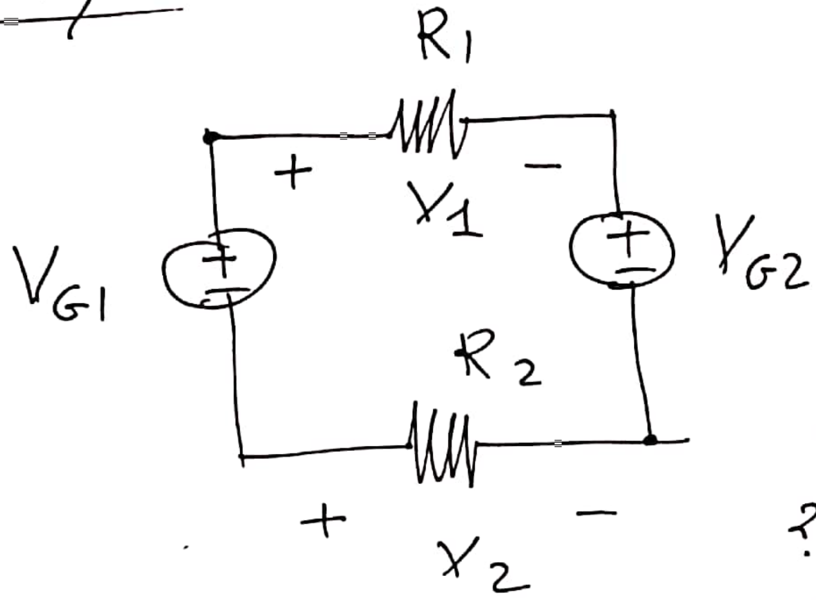
$KV: \; -2 + 1 \cdot i + 1 \cdot i = 0 \Rightarrow$

$i = 1 \text{ A} \Rightarrow$

$E_1 = 1 \cdot i = 1 \text{ V},$

$E_2 = -1 \cdot i = -1 \text{ V}.$

Esercizio ①



$R_1 = 2\,\Omega$

$R_2 = 3\,\Omega$

$V_{G1} = 15\,V$

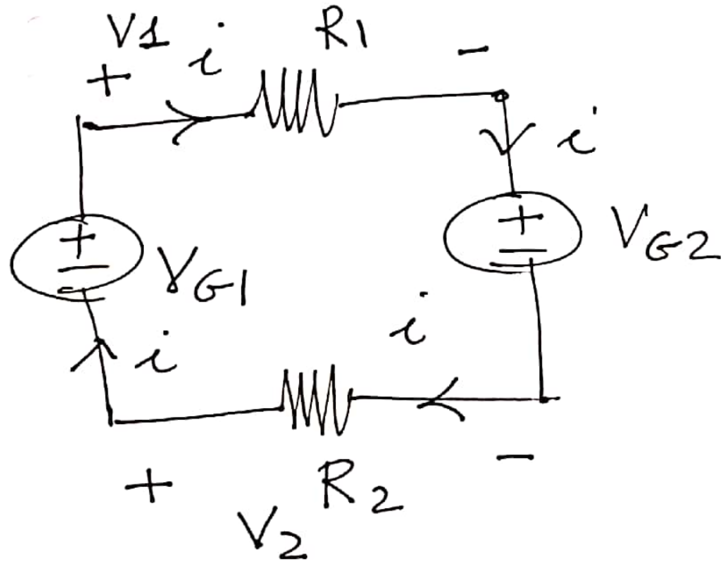
$V_{G2} = 10\,V$

? V_1, V_2,

? potenza assorbita da R_1 e R_2

? potenza erogata da V_{G1} e V_{G2}.

Soluzione Ho una sola maglia.
Indico con i la corrente di maglia.



KV: $-V_{G1} + V_1 + V_{G2} - V_2 = 0$

Relazioni costitutive

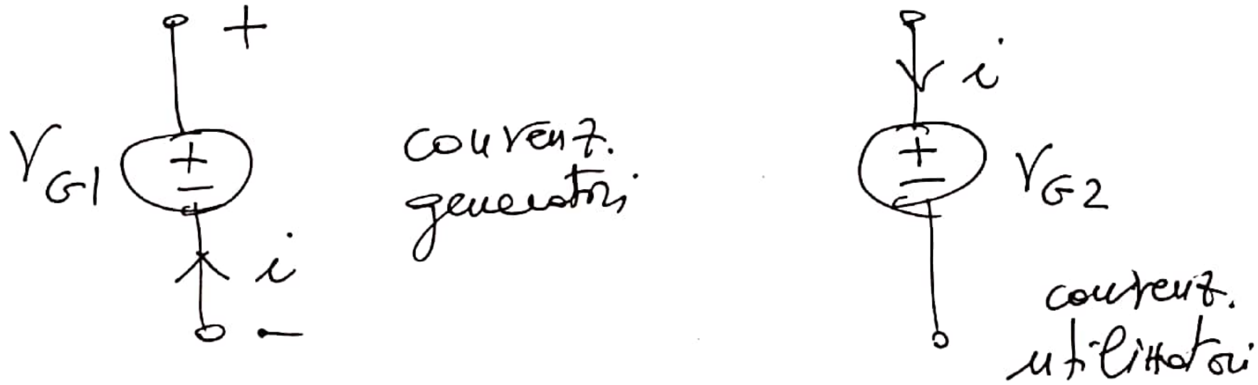
$V_1 = R_1 i$; $V_2 = -R_2 i$

$$-V_{G1} + R_1 i + V_{G2} - R_2 i = 0$$

$$\Rightarrow i = \frac{V_{G1} - V_{G2}}{R_1 + R_2} = 1 \text{ Ampère}$$

$V_1 = R_1 i = 2\,V$; $V_2 = -R_2 i = -3\,V$

$P_1 = R_1 i^2 = 2\,W$; $P_2 = R_2 i^2 = 3\,W$



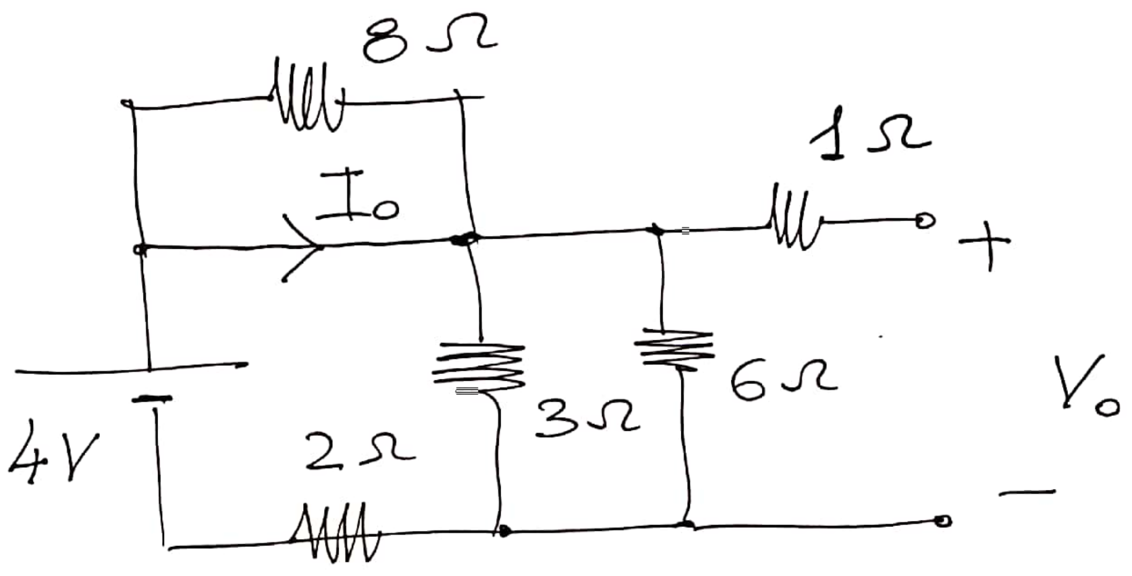
$P_{G1} = V_{G1}\, i = 15\,W$ erogata

$P_{G2} = -V_{G2}\, i = -10\,W$ erogata.

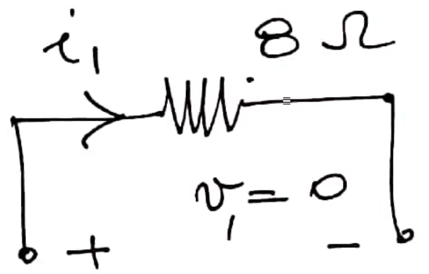
il generatore V_{G1} eroga una potenza vera di 15 W

il generatore V_{G1} assorbe una potenza vera di 10 W (si sta ricaricando).

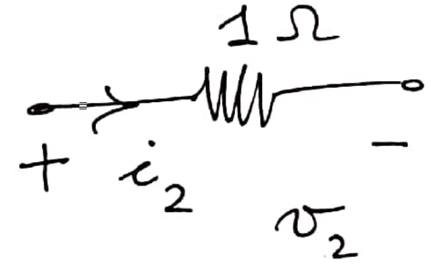
Esempio



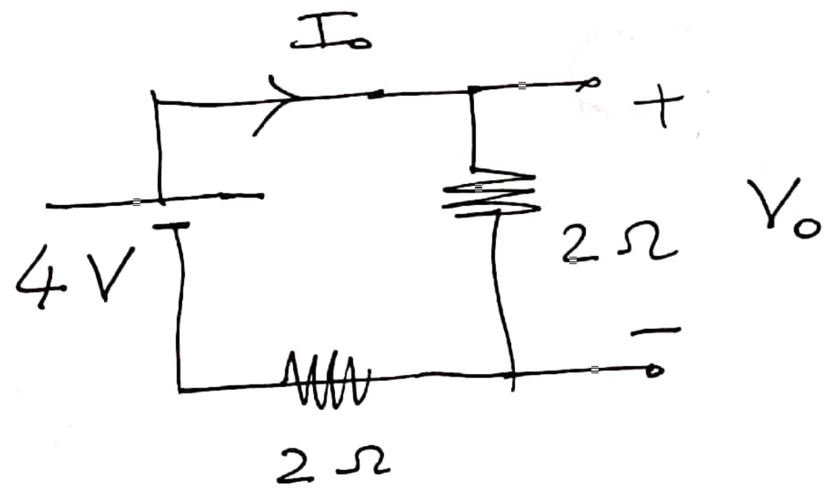
Soluzione Semplifichiamo il circuito.



$v_1 = 0 \Rightarrow i_1 = 0$



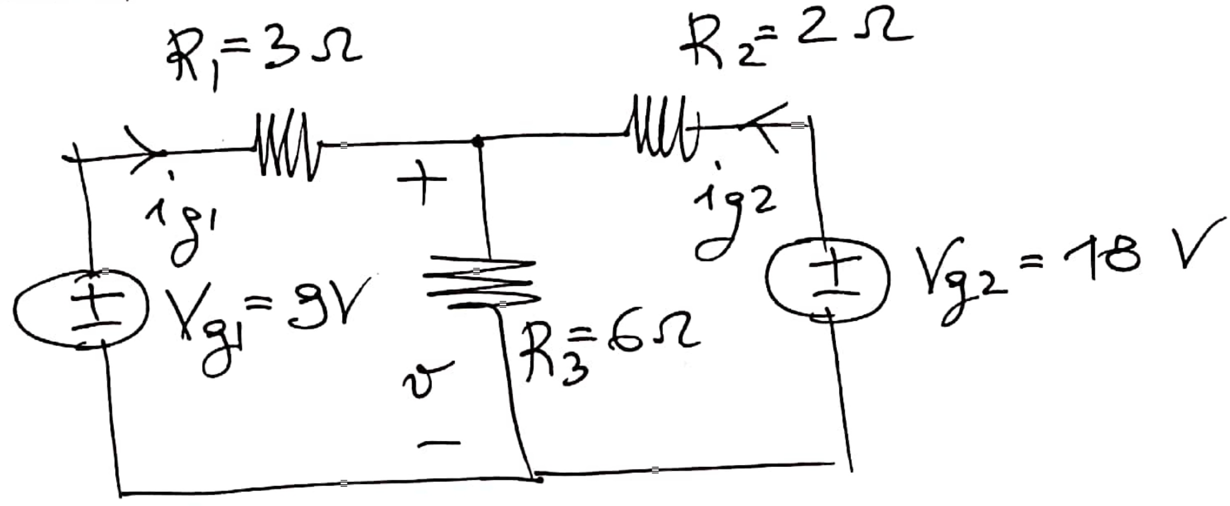
$i_2 = 0 \Rightarrow v_2 = 0$



$I_0 = 1$ Ampère

$V_0 = 2$ Volt.

Esempio



? correnti e potenze istantanee erogate dai 2 generatori

Soluzione

Usando Millmann

$$v = \frac{\frac{V_{g1}}{R_1} + \frac{V_{g2}}{R_2}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{\frac{9}{3} + \frac{18}{2}}{\frac{1}{3} + \frac{1}{6} + \frac{1}{2}} = 12 \text{ Volt}$$

$$KV: \; V_{G1} = R_1 \, i_{g1} + v \Rightarrow$$

$$i_{g1} = \frac{V_{G1} - v}{R_1} = -1 \text{ Ampère}$$

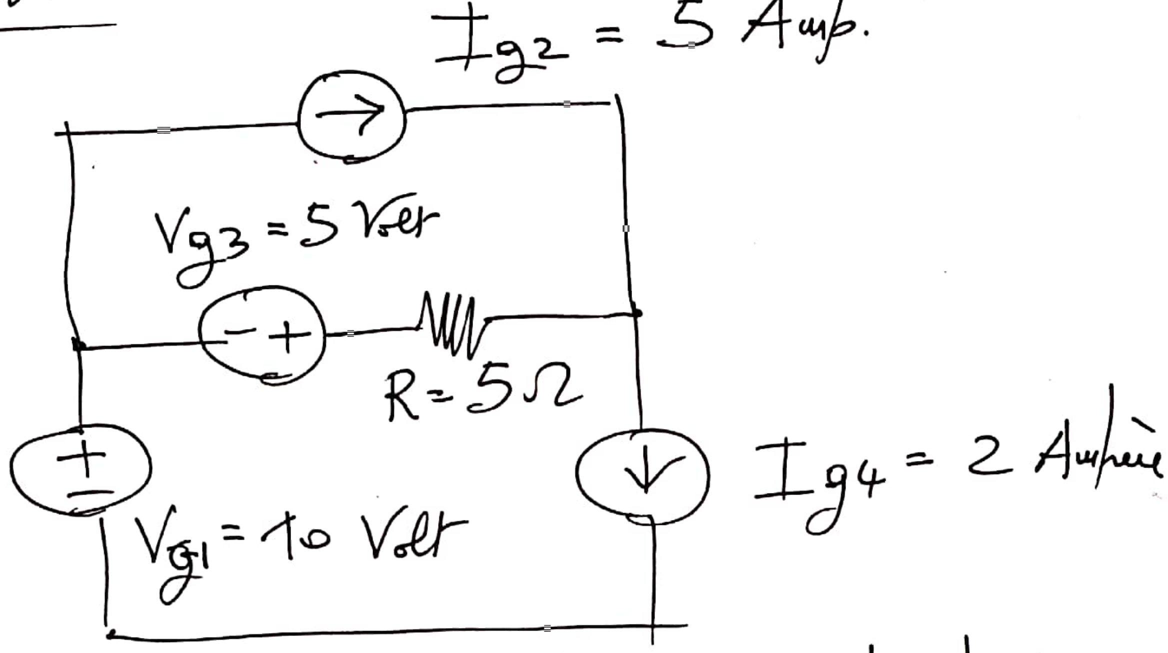
$$i_{g2} = \frac{V_{G2} - v}{R_2} = 3 \text{ Ampère}$$

Potenze erogate

$$P_{G1} = V_{g1} \cdot i_{g1} = -9\,W$$

$$P_{G2} = V_{g2} \cdot i_{g2} = 54\,W.$$

Esempio

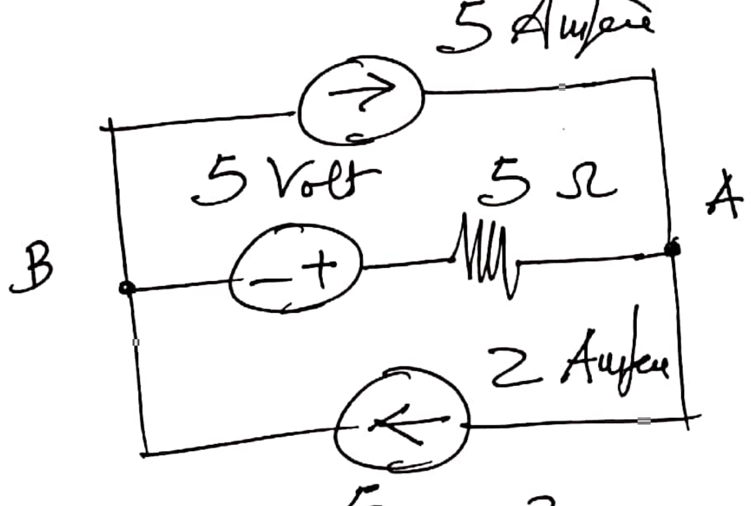


? determinare le potenze erogate dai 4 generatori.

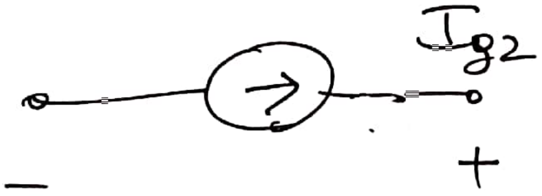
Soluzione. Si ha

$P_{g1} = 10 \cdot 2 = 20$ W

Eliminiamo V_{G1} e applichiamo Millmann

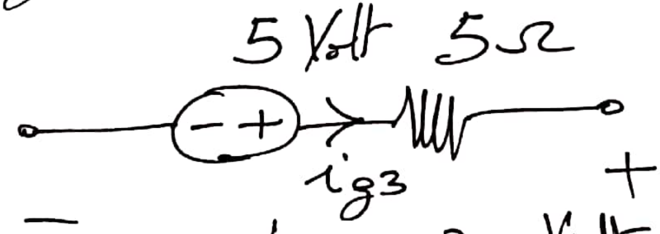


$$V_{AB} = \frac{5 + \frac{5}{5} - 2}{\frac{1}{5}} = 20 \text{ Volt.}$$



$$V_{AB} = 20 \text{ Volt.}$$

$$P_{g2} = V_{AB} \cdot I_{g2} = 100 \text{ W}$$



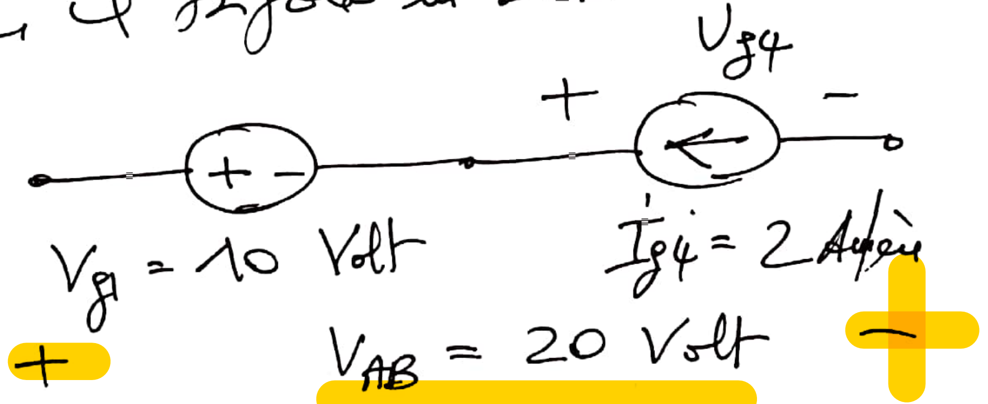
$$V_{AB} = 20 \text{ Volt}$$

$$KV: \quad 20 = -5 \cdot i_{g3} + 5 \Rightarrow$$

$$i_{g3} = -3 \text{ Ampère} \Rightarrow$$

$$P_{g3} = 5 \cdot (-3) = -15 \text{ W}.$$

Attenzione .... torniamo un attimo indietro per il bipolo in basso



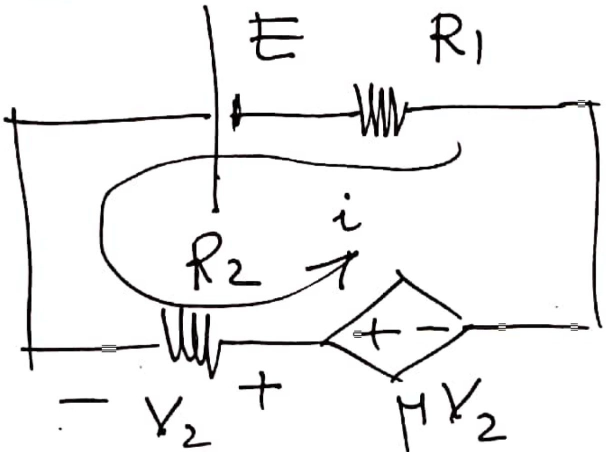
$$V_{AB} = 20 \text{ Volt}$$

$$KV: \quad 20 = -V_{g4} - 10 \Rightarrow$$

$$V_{g4} = -30 \text{ Volt} \Rightarrow$$

$$P_{g4} = V_{g4} \cdot I_{g4} = -60 \text{ W}.$$

Esempio



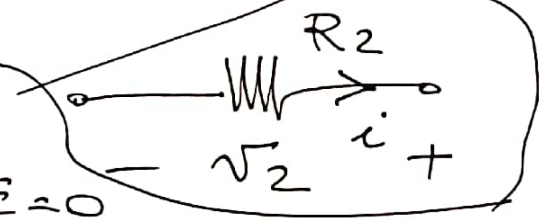
? v_2

Soluzione. Introduco la corrente incognita i

KV: $-v_2 + \mu v_2 + R_1 i - E = 0$

Elimino grandezza di controllo v_2:

$$v_2 = -R_2 i$$



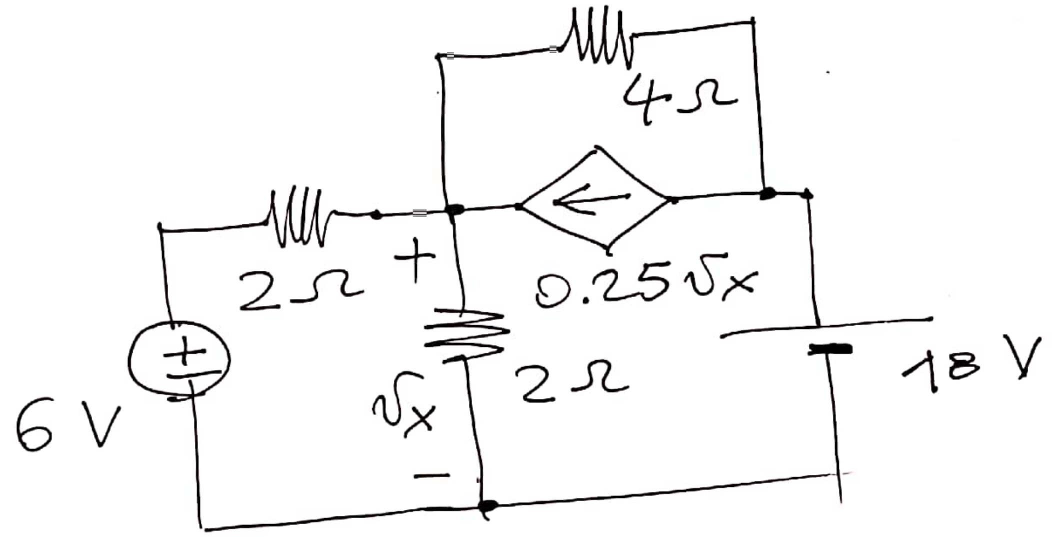
$$R_2 i - \mu R_2 i + R_1 i - E = 0$$

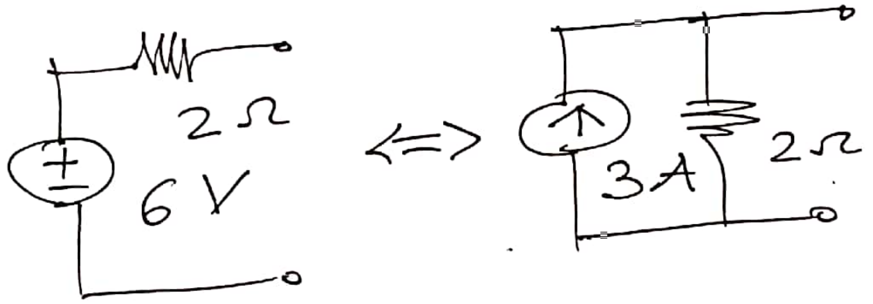
$$[(1-\mu)R_2 + R_1]\, i = E \Rightarrow$$

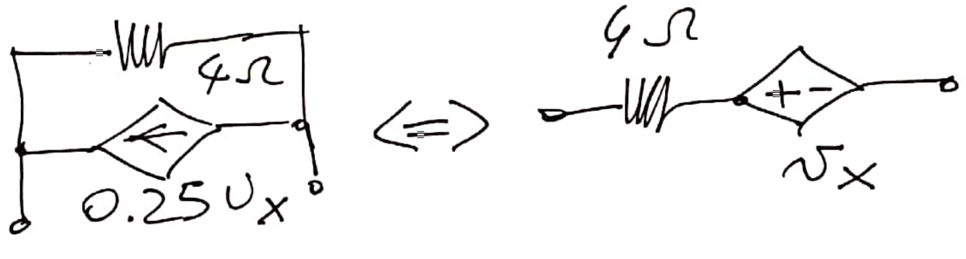
$$i = \frac{E}{(1-\mu)R_2 + R_1} \Rightarrow$$

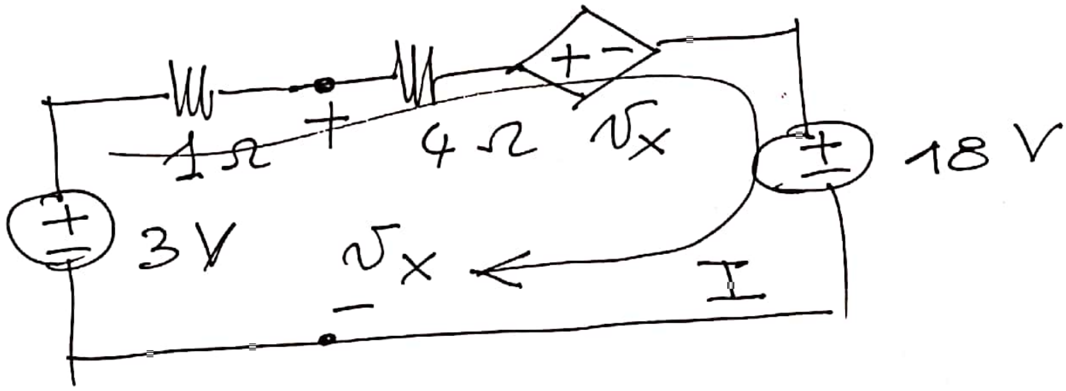
$$v_2 = \frac{R_2 E}{(\mu-1)R_2 - R_1}.$$

Esempio: Calcolare v_x usando equivalenze per generatori.

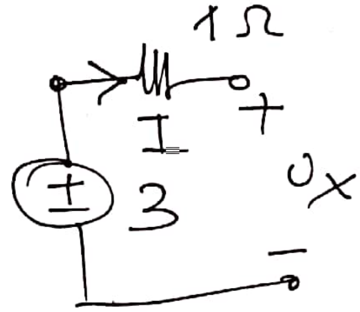








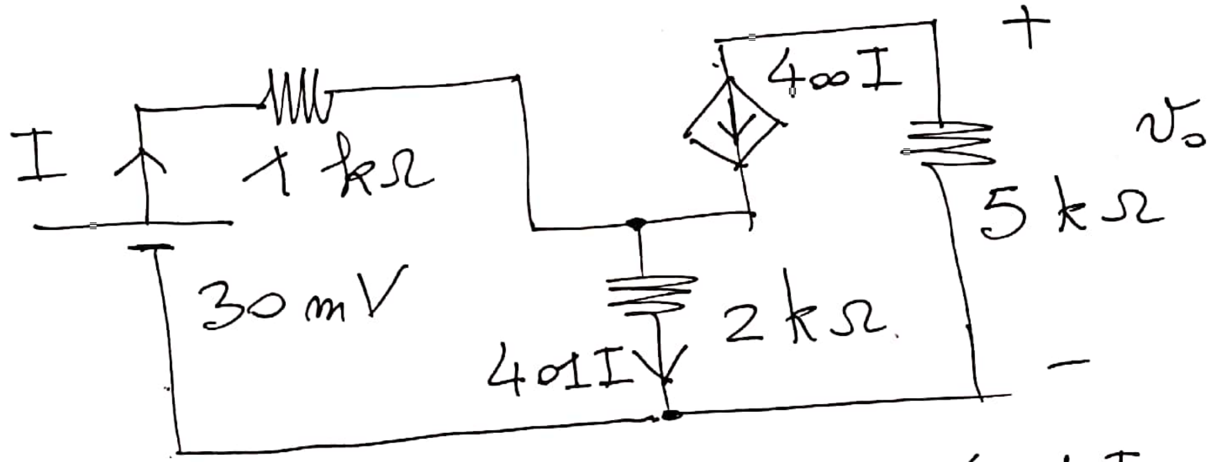
$$\begin{cases} 3 = 5I + v_x + 18 \\ v_x = -I + 3 \end{cases}$$



- 2 eq.ni in 2 incognite
- risolvendo

$$v_x = \frac{15}{2} \text{ Volt.}$$

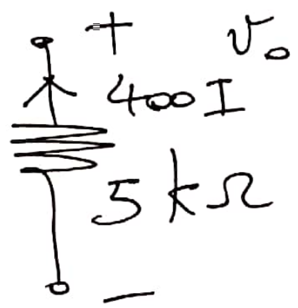
Esempio: Determinare v_o per il circuito a transistor.



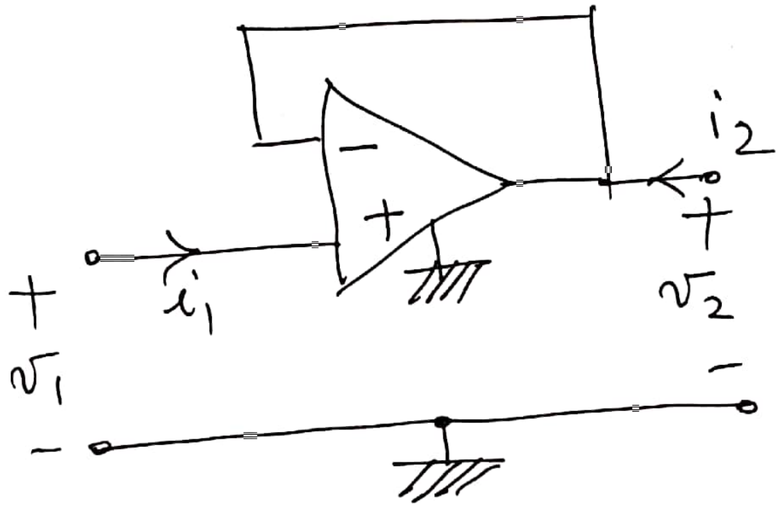
KV: $30\times10^{-3} = 1000\,I + 2000\times 401\times I = 803000\,I \Rightarrow$

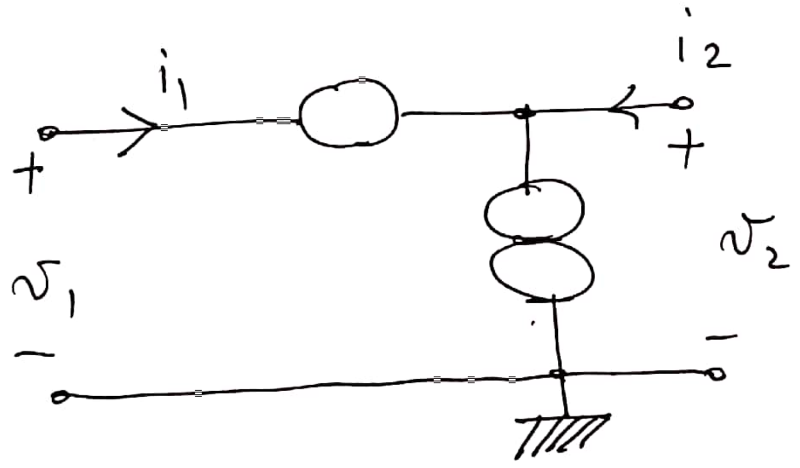
$$I = 3.73\times10^{-8} \text{ Ampère}$$

$$v_o = -5000\times400\times I = -0.075\text{ V} = -75\text{ mV}$$



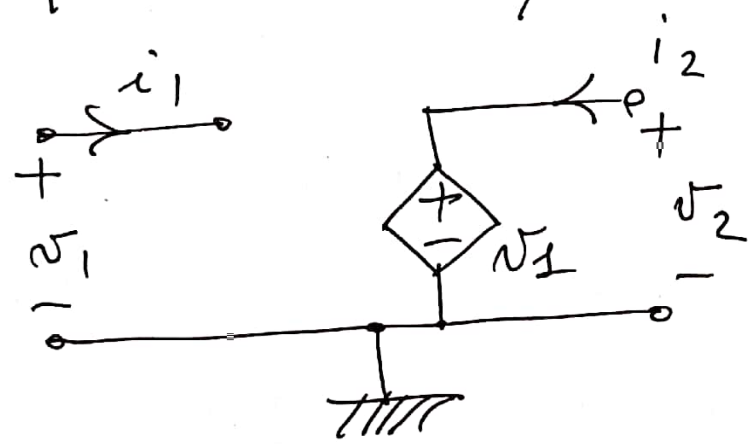
Esempio Circuito separatore (buffer)





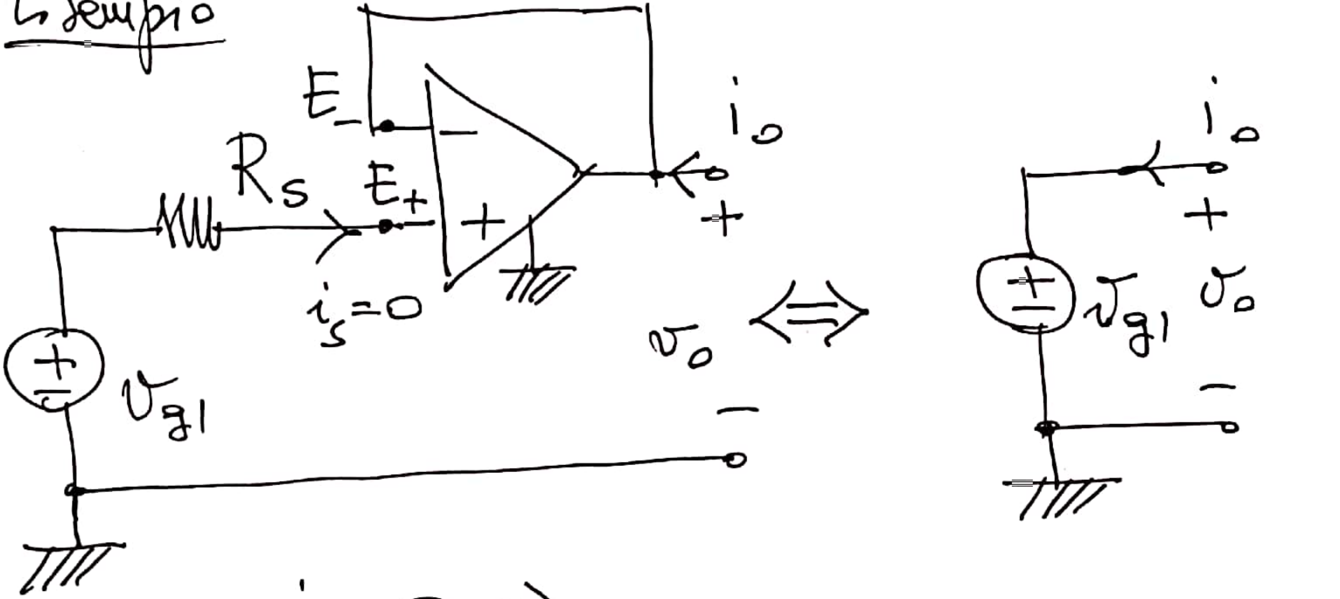
$$\begin{cases} v_2 = v_1 \\ i_1 = 0 \end{cases}$$

relazioni costitutive

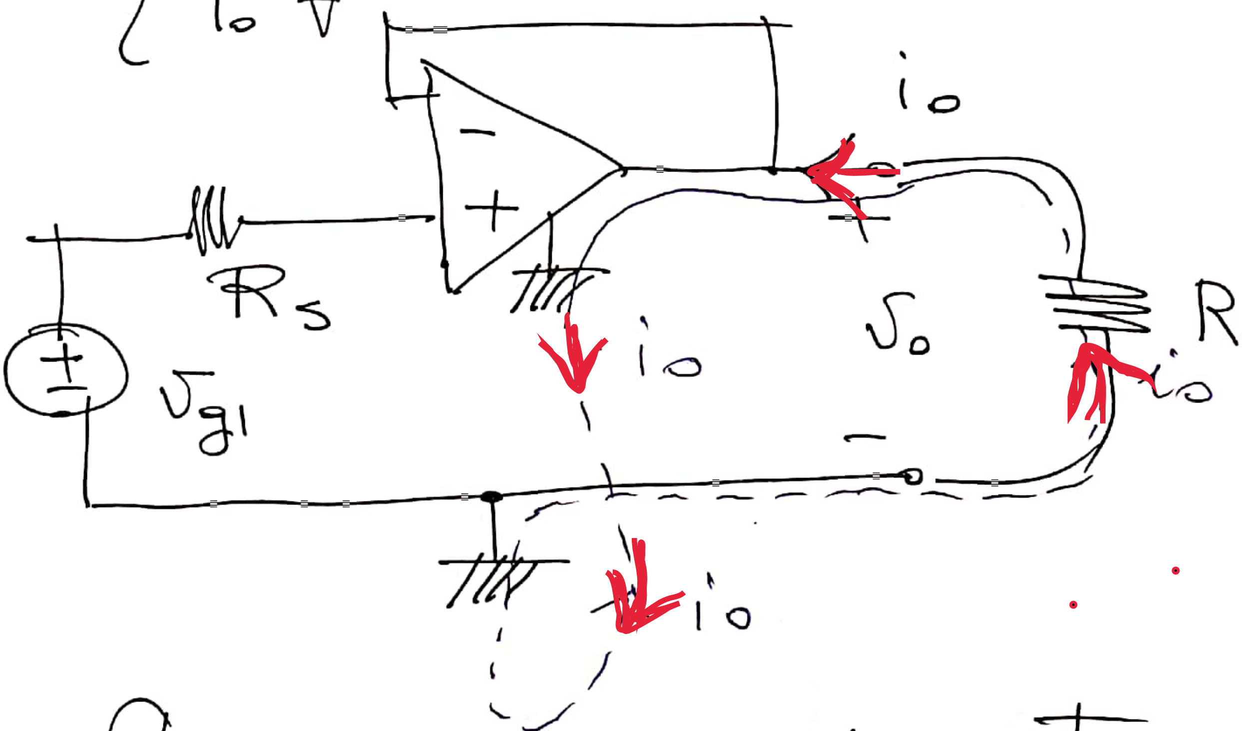


Impiego c.to separatore

Esempio

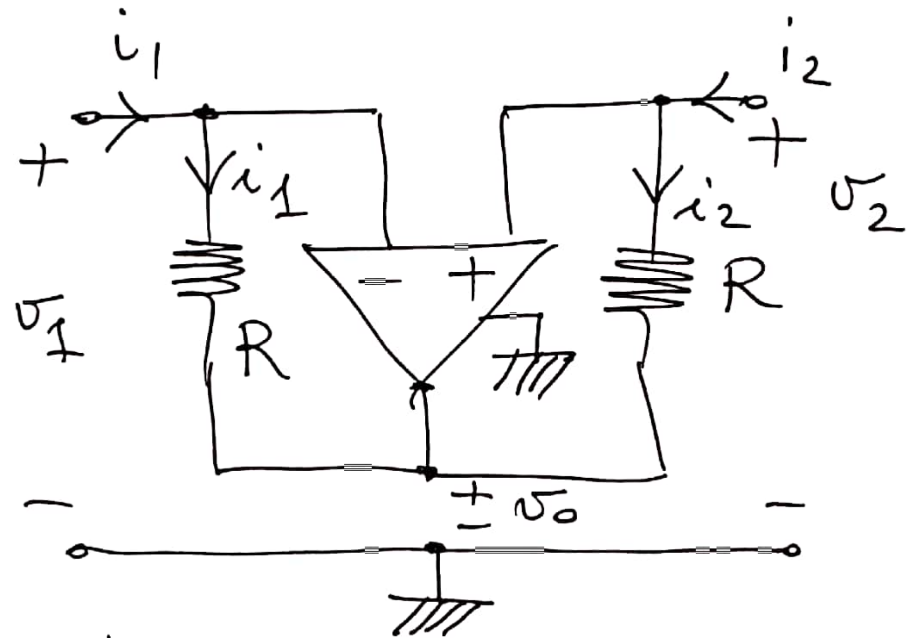


$$i_s = 0 \Rightarrow \begin{cases} v_o = E_- = E_+ = v_{g1} \\ i_o \ \forall \end{cases}$$



Notare la circolazione di corrente nel circuito.

Invertitore di corrente (I-NIC)

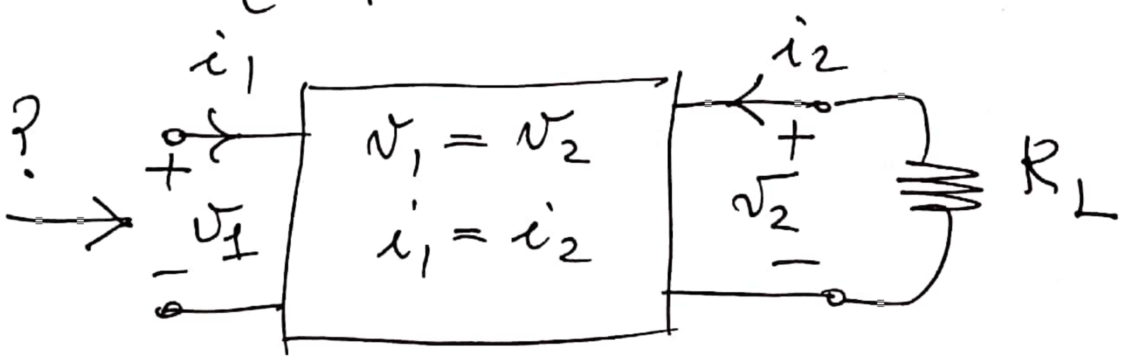


Si ha: $v_1 = v_2$

$$i_1 = \frac{v_1 - v_0}{R} \quad ; \quad i_2 = \frac{v_2 - v_0}{R}$$

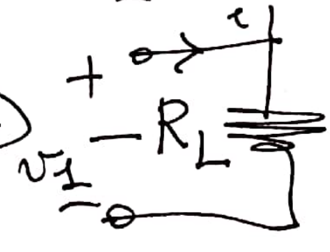
$$\Rightarrow \quad i_1 = i_2$$

$$\Rightarrow \quad \begin{cases} v_1 = v_2 \\ i_1 = i_2 \end{cases} \quad \underline{\text{I-NIC}}.$$

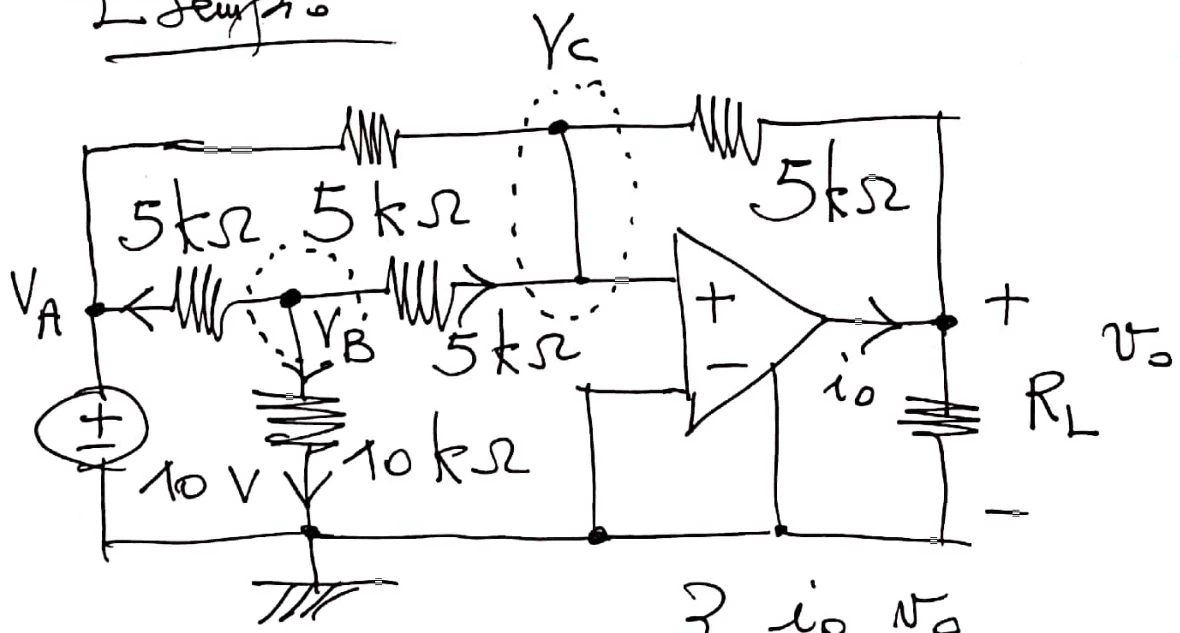


$$\frac{v_1}{i_1} = \frac{v_2}{i_2}, \quad \text{ma} \quad v_2 = -R_L i_2.$$

$$\Rightarrow \quad \frac{v_1}{i_1} = -R_L \quad \ldots \iff$$



Esempio



? i_o, v_o.

4 nodi A, B, C, D;

4 incognite V_A, V_B, V_C, V_D

Ma: $V_A = 10\,V$, $V_C = 0$.

$\Rightarrow$ 2 sole incognite V_B e V_o

KI nodi B e C.

B
$$\frac{v_B - 10}{5\times10^3} + \frac{v_B}{5\times10^3} + \frac{v_B}{10\times10^3} = 0$$

$$2v_B - 20 + 2v_B + v_B = 0 \Rightarrow$$

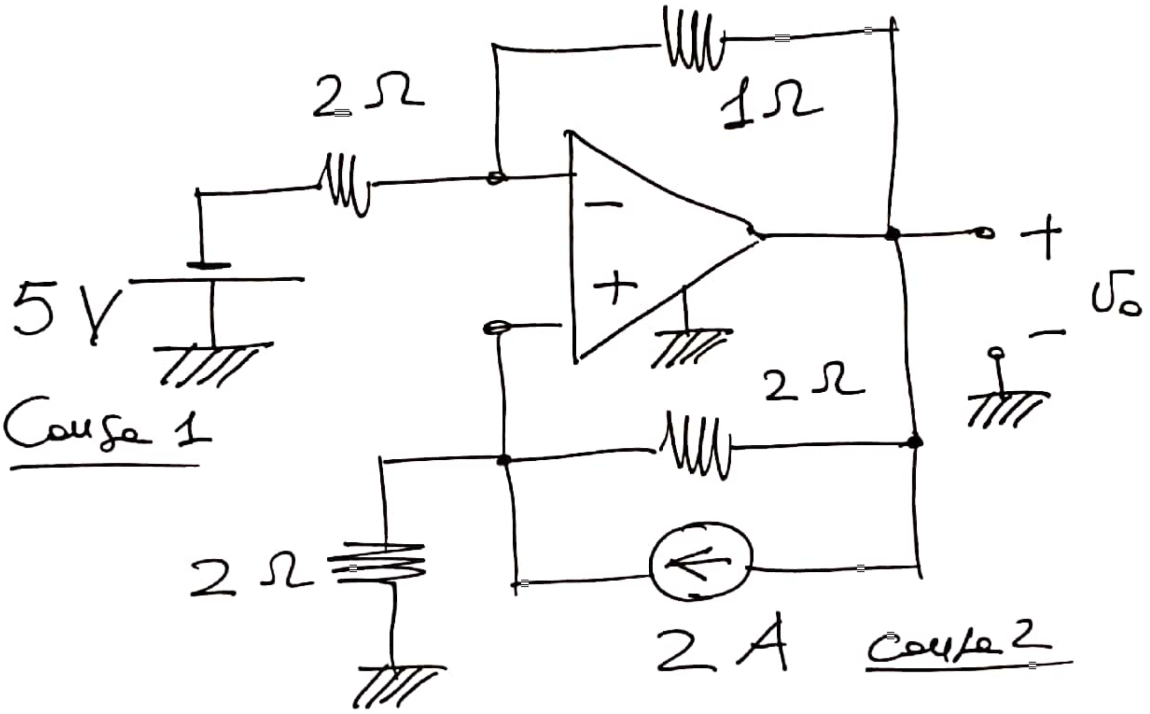
$$\boxed{v_B = 4\,V}$$

C
$$\frac{10-0}{5\times10^3} + \frac{v_o - 0}{5\times10^3} + \frac{v_B - 0}{5\times10^3} + 0 = 0$$

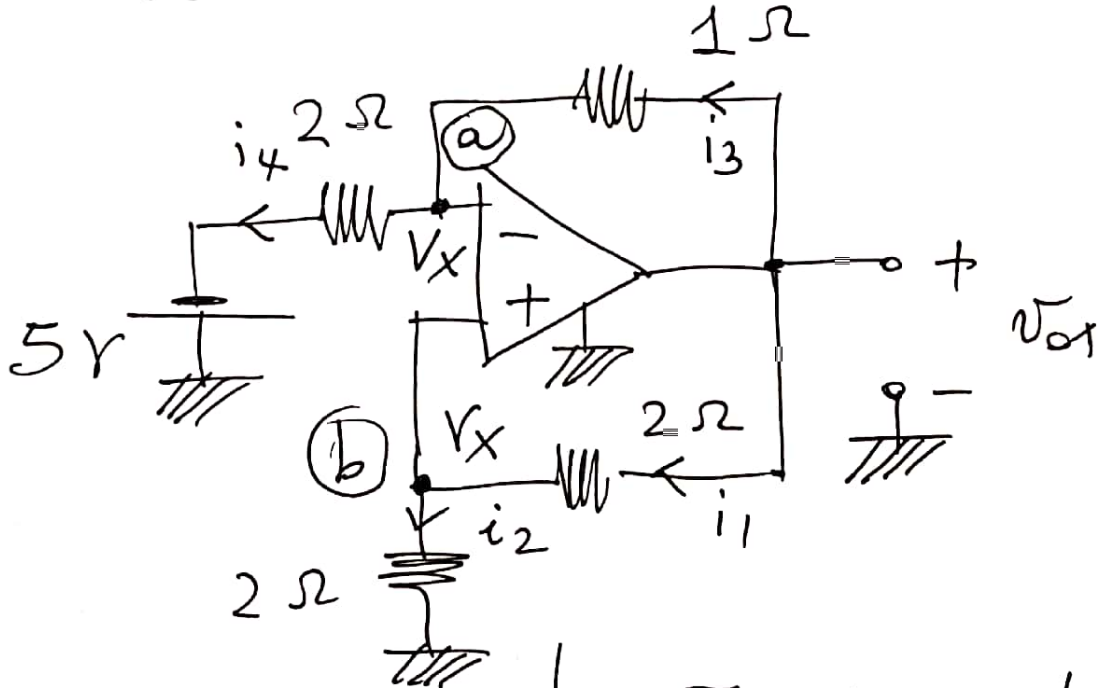
$$10 + v_o + 4 = 0 \qquad \boxed{v_o = -14\,V}.$$

①

Esempio Determinare v_o usando il p.s.e.



$$v_o = v_{o1} + v_{o2}$$



1 sola incognita v_x in aggiunta a v_{o1}

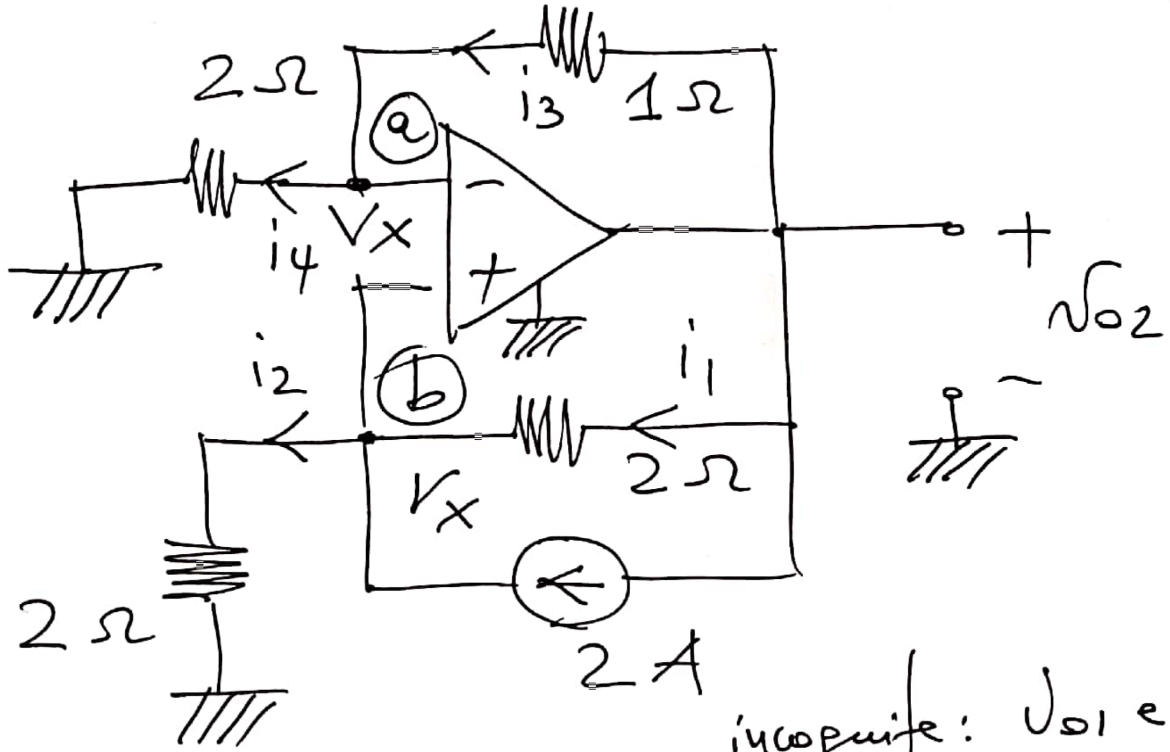
KI nodo (b): $i_1 = i_2$, cioè

$$\frac{v_{o1} - v_x}{2} = \frac{v_x - 0}{2} \Rightarrow v_x = \frac{v_{o1}}{2}$$

KI nodo (a): $i_3 = i_4$

$$v_{o1} - \frac{v_{o1}}{2} = \left[\frac{v_{o1}}{2} + 5\right]\frac{1}{2} \Rightarrow \boxed{v_{o1} = 10\ V}$$

②



incognite: v_{o1} e v_x

KI nodo b : $i_1 + 2 = i_2$

$$2 + \frac{V_{o2} - V_x}{2} = \frac{V_x - 0}{2}$$

KI nodo a : $i_3 = i_4$

$$\frac{V_{o2} - V_x}{1} = \frac{V_x - 0}{2}$$

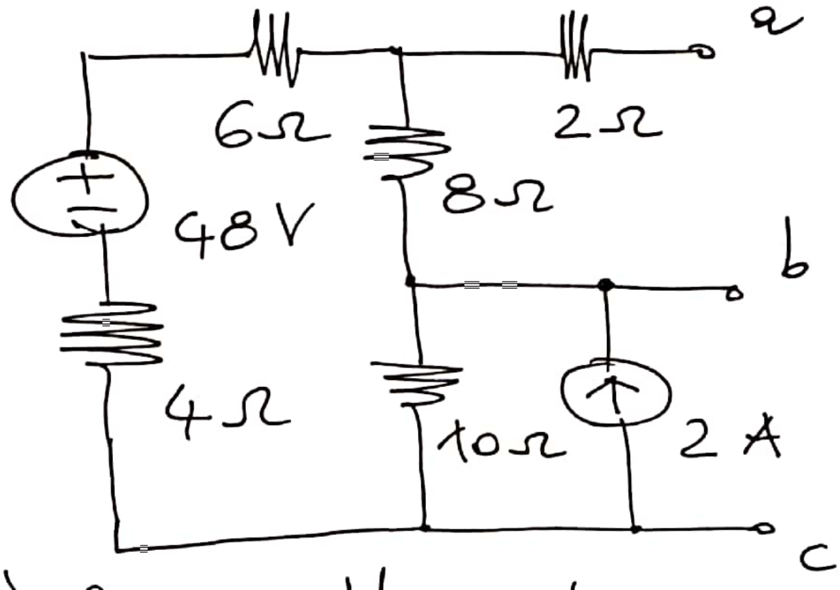
risolvendo ottengo: $v_{o2} = 12\ V.$

Allora

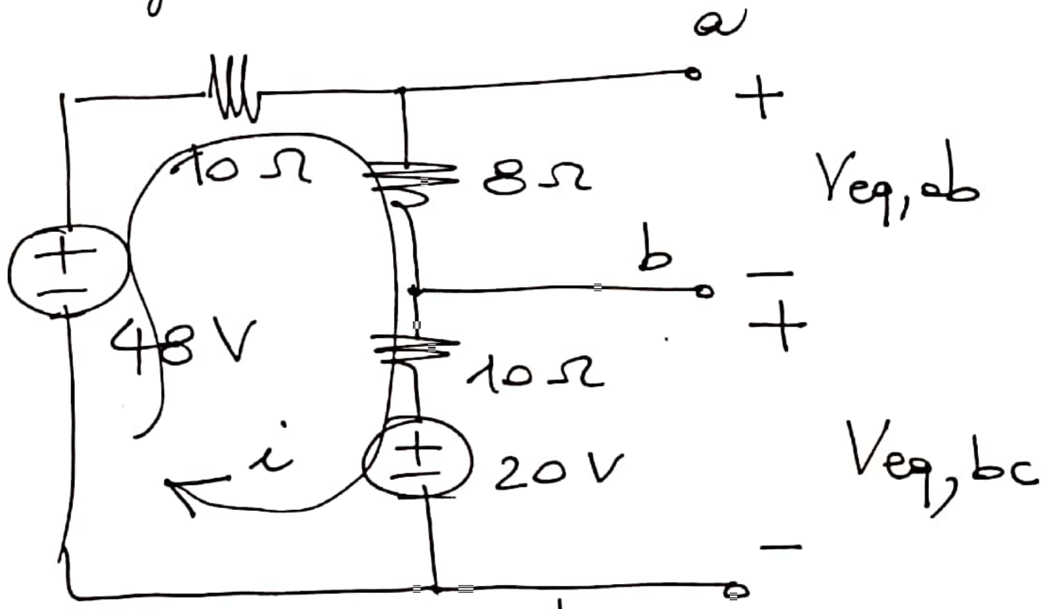
$V_o = V_{o1} + V_{o2} = 10 + 12 = 22\ V.$

Esempio

? Thevenin bipolo ab e bipolo bc



Soluzione Mi riconduco a un circuito ad una sola maglia



Tensioni equivalenti:

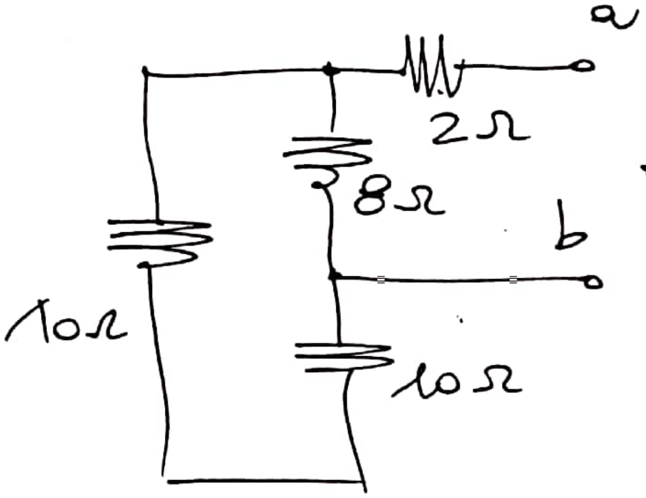
KV: $-48 + 10i + 8i + 10i + 20 = 0 \Rightarrow$

$i = 1\ A$

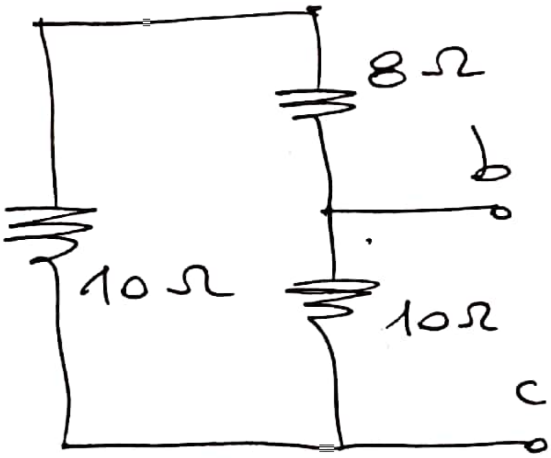
$V_{eq,ab} = 8i = 8\ V$

$V_{eq,bc} = 10i + 20 = 30\ V$

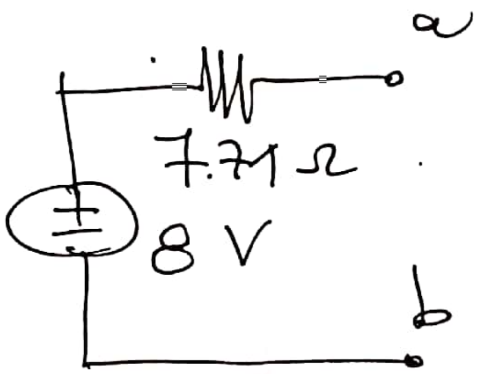
Resistenze equivalenti:

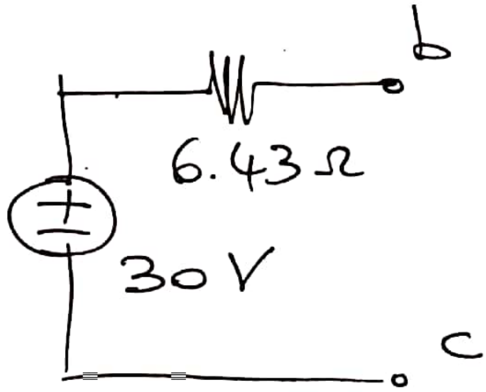


$$R_{eq,ab} = 2 + 8 \parallel 20 \simeq 7.71\,\Omega$$

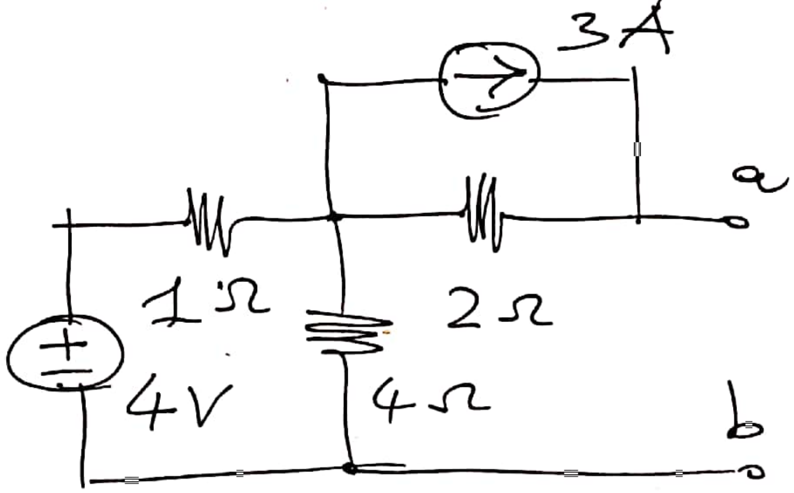


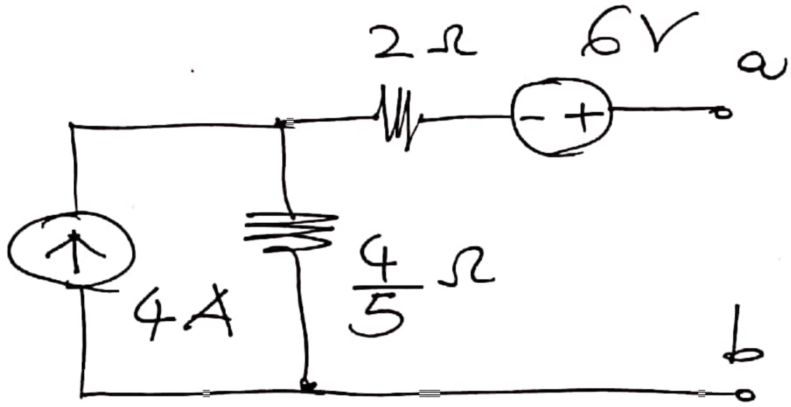
$$R_{eq,bc} = 10 \parallel 18 \simeq 6.43\,\Omega.$$

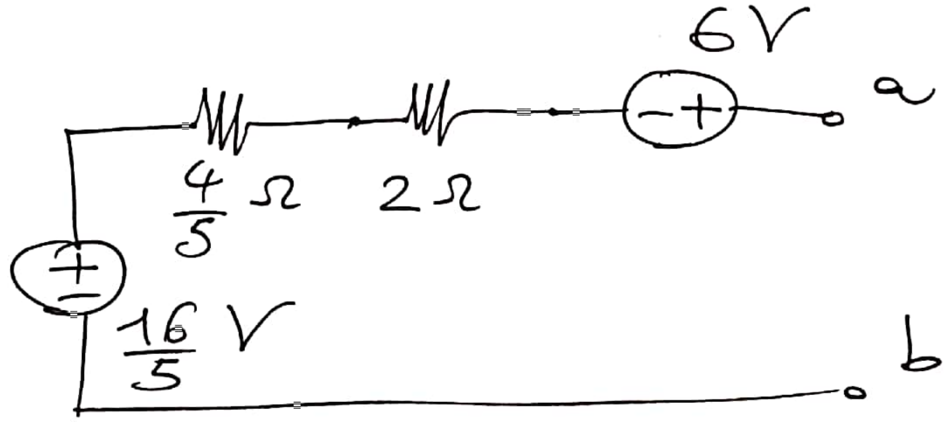


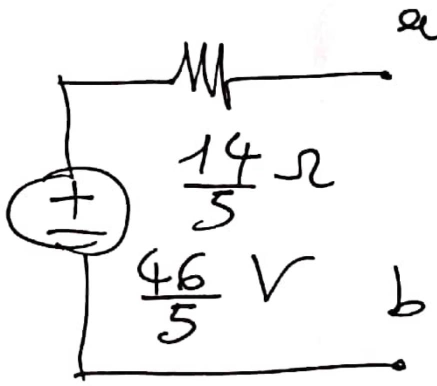


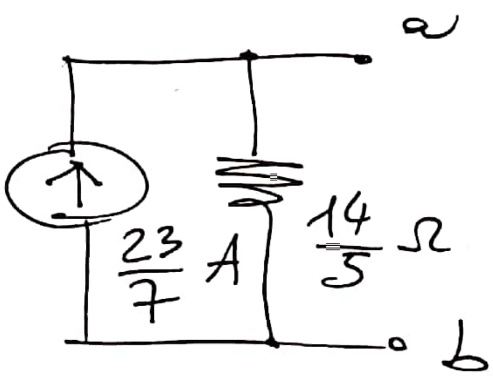
Esempio 3 Norton bipolo ab



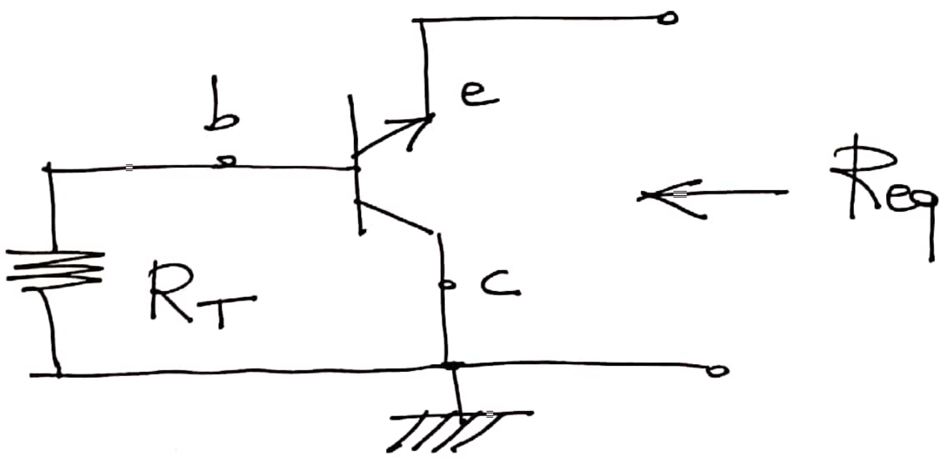




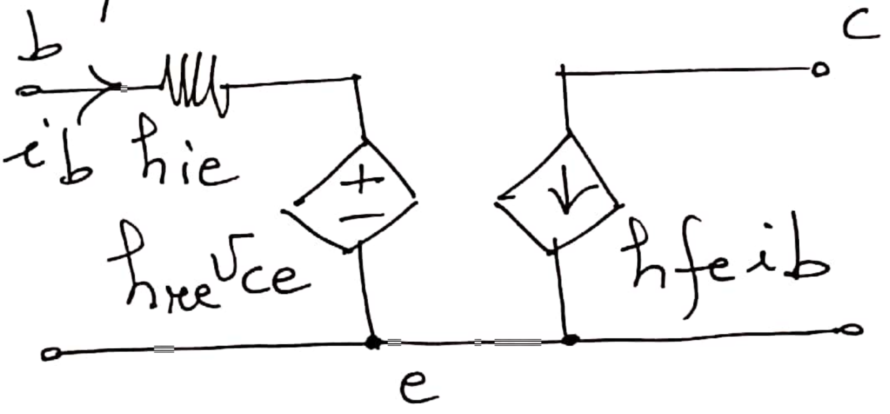


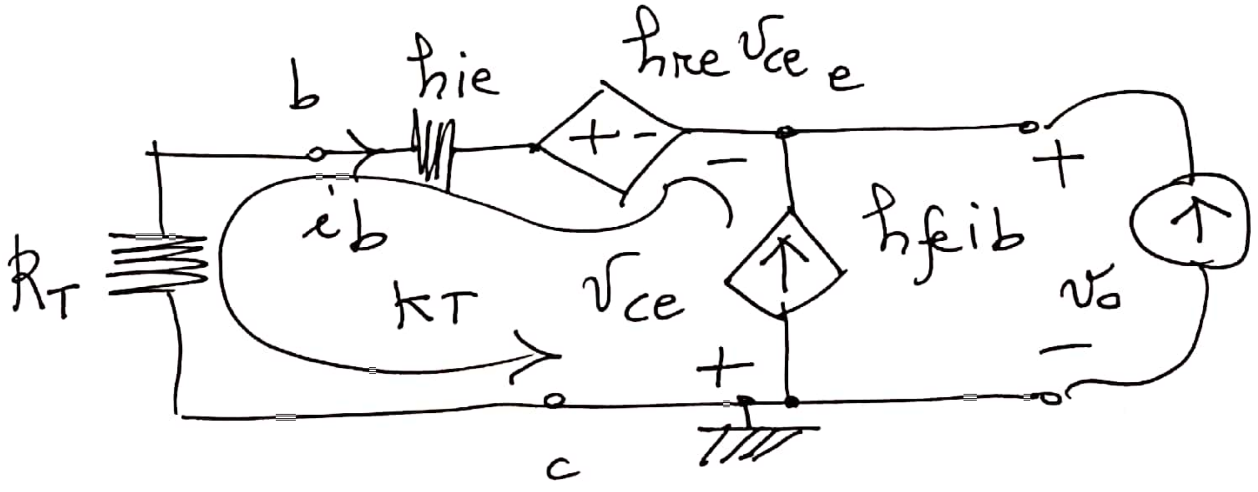


Esempio: Determinare R_{eq} usando per il BJT il modello a parametri ibridi a emettitore comune con $h_{oe} = 0\ \Omega^{-1}$.



Soluzione: usiamo il modello con $h_{oe} = 0\ \Omega^{-1}$





Troviamo le grandezze di controllo i_b e v_{ce} in funzione di i_o, v_o, e altri parametri noti. Si ha:

$$v_{ce} = -v_o$$

KI nodo e $\Rightarrow$

$$i_b + h_{fe} i_b = (1+h_{fe}) i_b = -i_o$$

$$\Rightarrow i_b = -\frac{i_o}{1+h_{fe}}$$

KV maglia indicata $\Rightarrow$

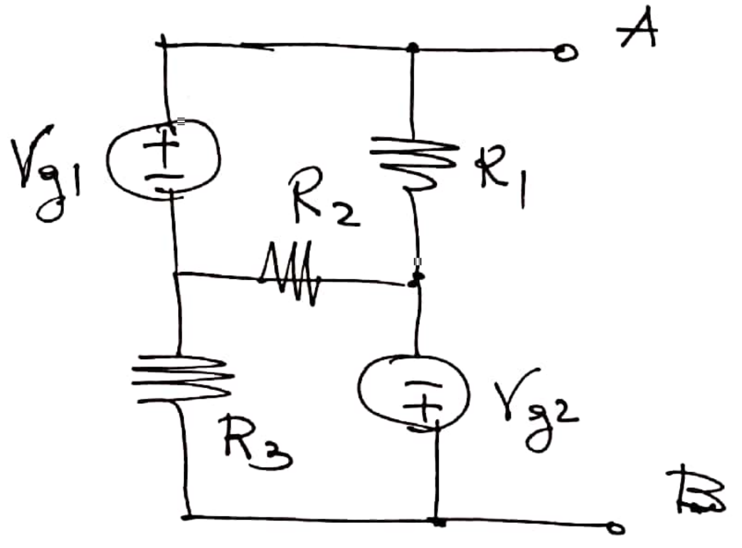
$$v_o = -h_{re} v_{ce} - (h_{ie} + R_T) i_b$$

$$= h_{re} v_o + \frac{h_{ie}+R_T}{1+h_{fe}} i_o \Rightarrow$$

$$v_o (1-h_{re}) = \frac{h_{ie}+R_T}{1+h_{fe}} i_o \Rightarrow$$

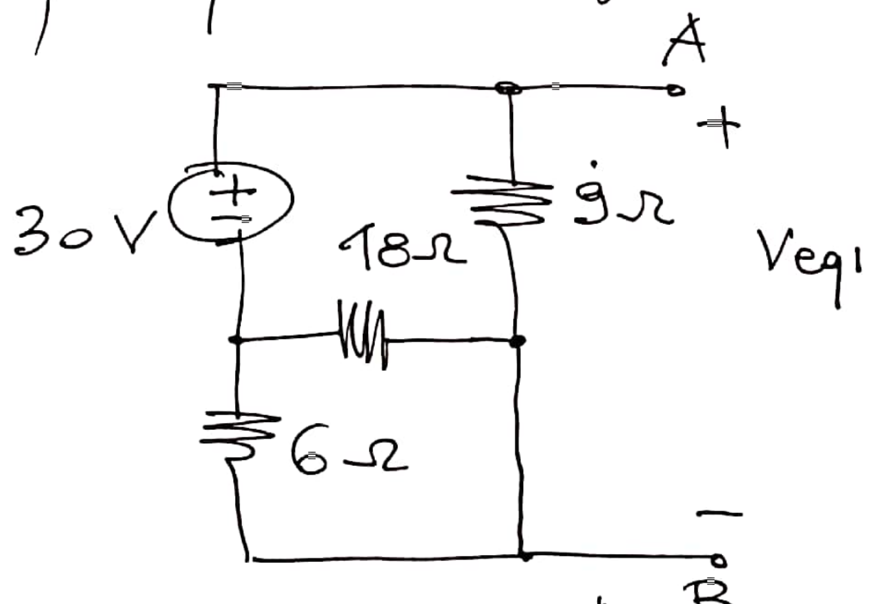
$$R_{eq} = \frac{v_o}{i_o} = \frac{h_{ie}+R_T}{(1+h_{fe})(1-h_{re})}.$$

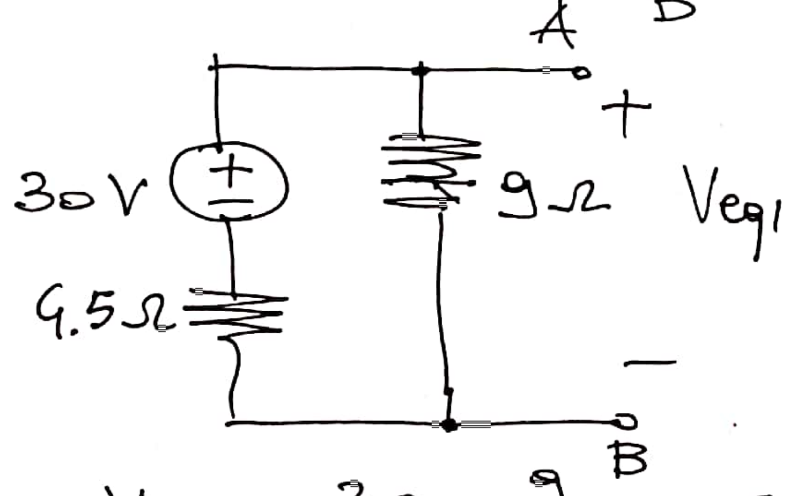
Esempio ? Thevenin, Norton bipolo AB



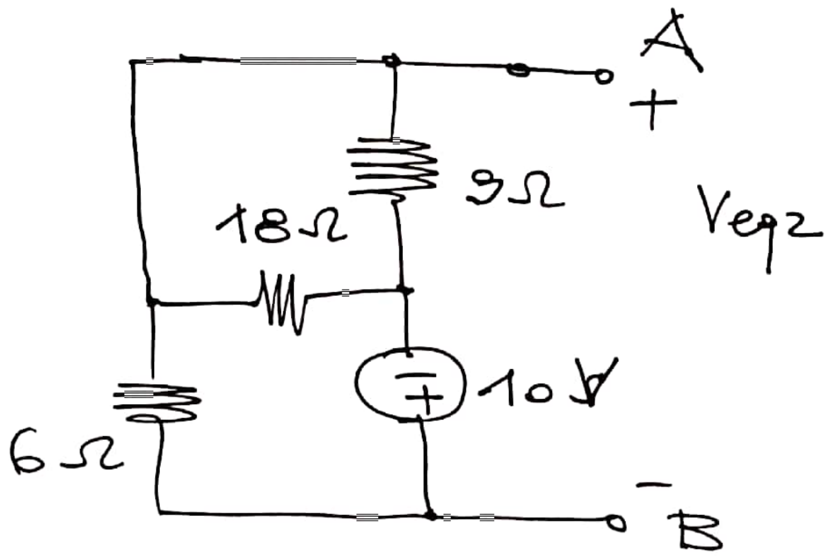
$R_1 = 9\ \Omega$
$R_2 = 18\ \Omega$
$R_3 = 6\ \Omega$
$V_{g1} = 30\ V$
$V_{g2} = 10\ V$

Soluzione Uso p.s.e. per determinare Veq.



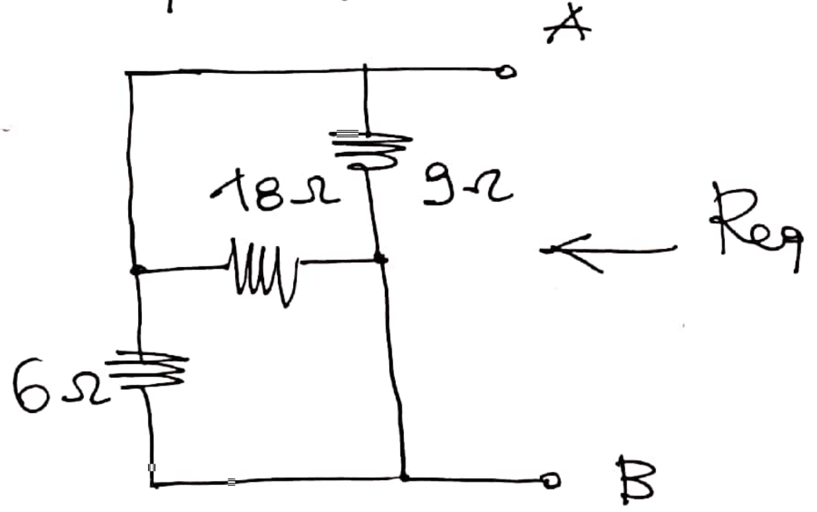


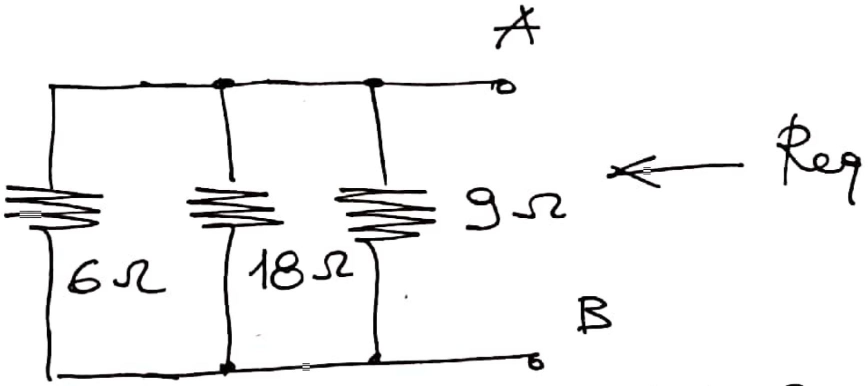
$$V_{eq1} = 30 \times \frac{9}{4.5+9} = 20\ V$$



$$V_{eq2} = -10 \times \frac{6}{6+6} = -5\,V$$

$$V_{eq} = V_{eq1} + V_{eq2} = 15\,V.$$

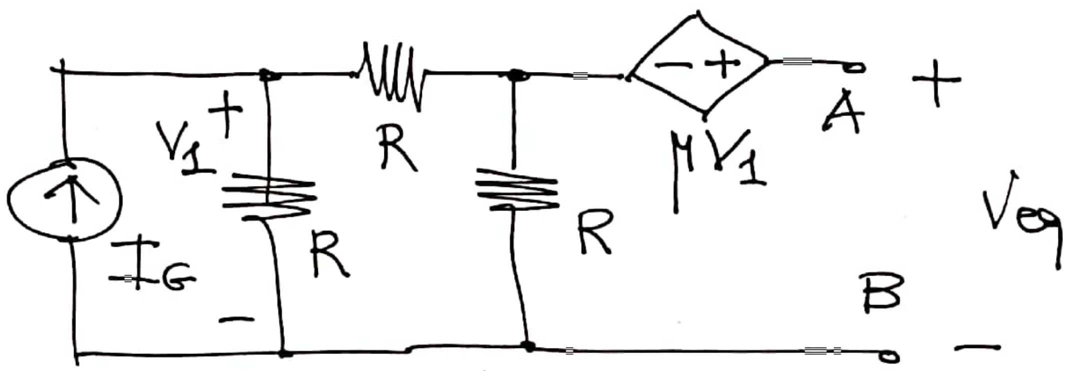




$$G_{eq} = \frac{1}{6} + \frac{1}{18} + \frac{1}{9} = \frac{3+1+2}{18} = \frac{1}{3}\,\Omega^{-1}$$

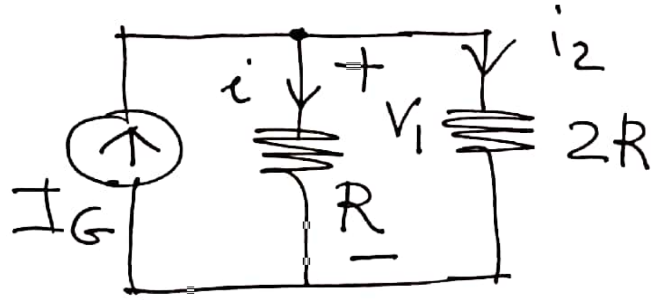
$$R_{eq} = 3\Omega \; ; \; i_{cc} = G_{eq} V_{eq} = 5\,A.$$

Esempio ? Thevenin, Norton bipolo AB

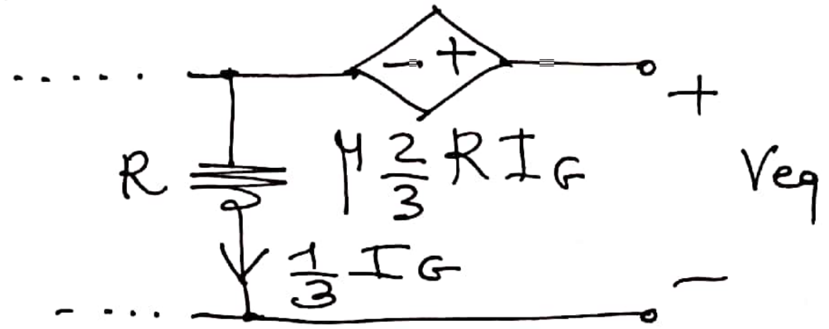


Soluzione Utilizziamo la definizione di V_{eq} e R_{eq}.
Usando partitore di corrente

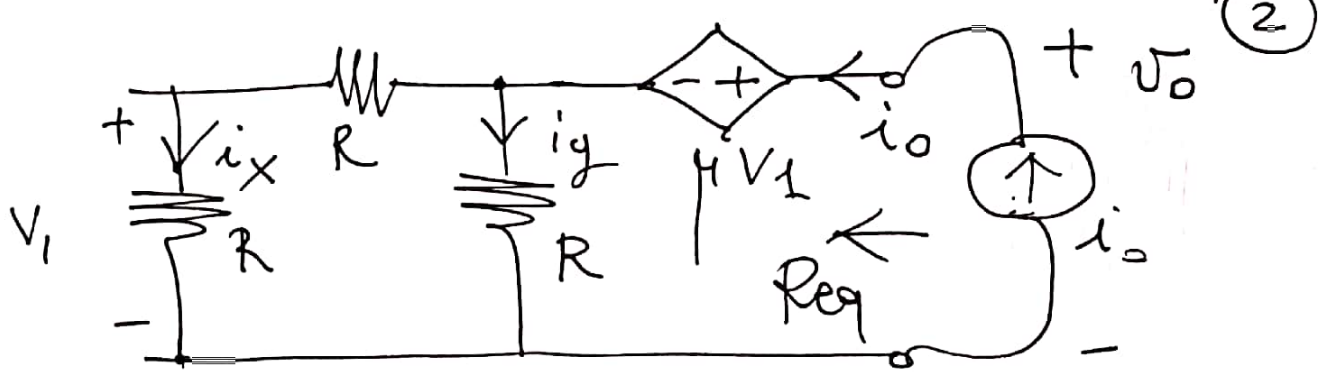
$$i_1 = \frac{2}{3} I_G \,, \quad i_2 = \frac{1}{3} I_G$$



quindi $V_1 = \frac{2}{3} R I_G$.



$$V_{eq} = \frac{2}{3} \mu R I_G + \frac{1}{3} R I_G$$



Partitore di corrente:

$$i_x = \frac{1}{3} i_o \Rightarrow V_1 = \frac{1}{3} R i_o$$

$$i_y = \frac{2}{3} i_o \Rightarrow$$

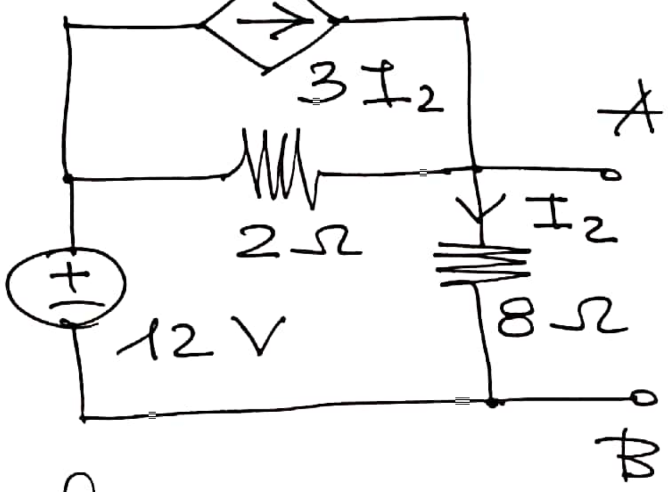
$$v_o = \mu V_1 + R i_y = \frac{1}{3} \mu R i_o + \frac{2}{3} R i_o$$

$$\Rightarrow R_{eq} = \frac{v_o}{i_o} = \frac{1}{3} \mu R + \frac{2}{3} R .$$

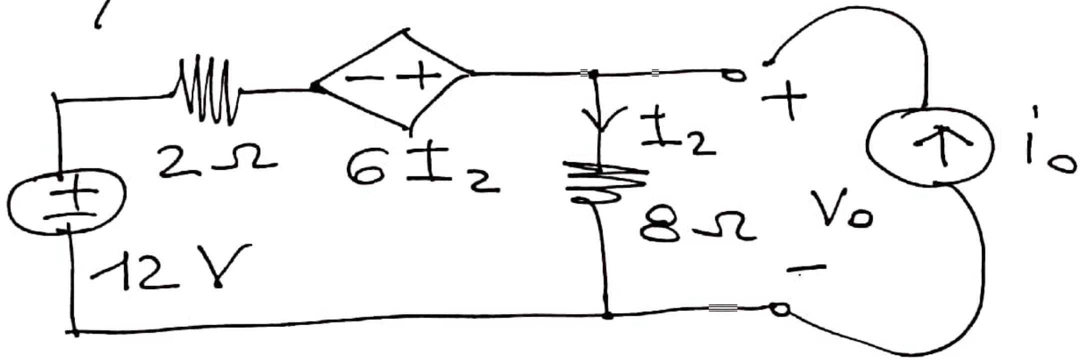
Infine:

$$i_{c.c.} = \frac{v_{eq}}{R_{eq}} = I_G \frac{1+2\mu}{2+\mu} .$$

Esempio ? Thevenin, Norton dipolo AB



Soluzione



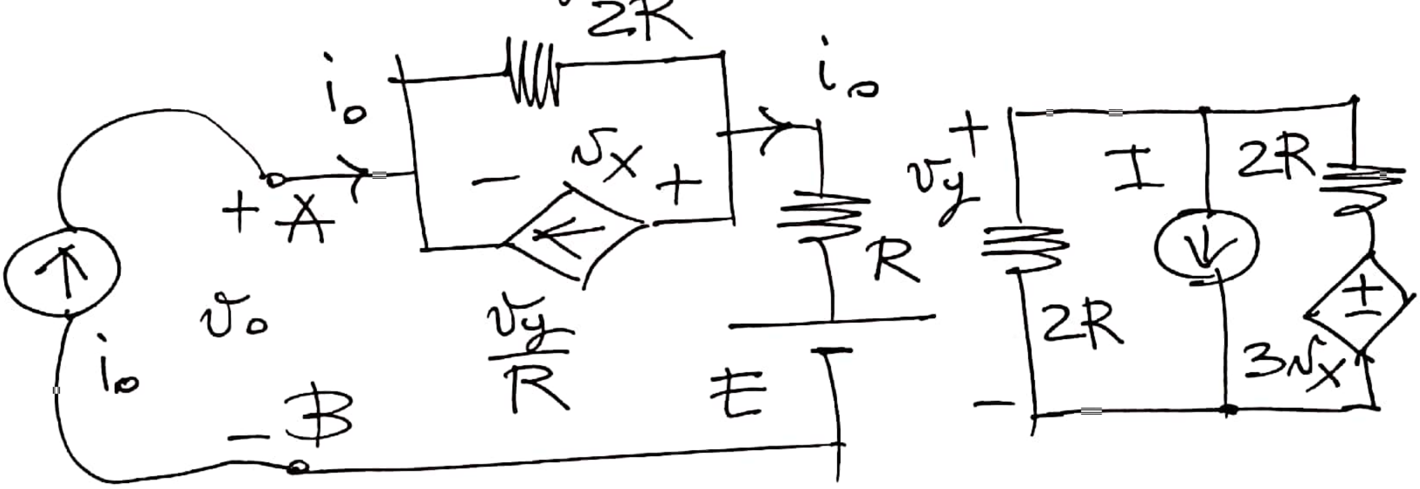
$$I_2 = \frac{V_0}{8}$$

Millmann: $$v_0 = \frac{\frac{12 + 6\times\frac{V_0}{8}}{2} + i_0}{\frac{1}{2}+\frac{1}{8}} = \frac{6 + \frac{3}{8}V_0 + i_0}{\frac{5}{8}} = \frac{48 + 3V_0 + 8i_0}{5}$$

$$5v_0 = 48 + 3V_0 + 8i_0; \quad 2V_0 = 48 + 8i_0$$

$$v_0 = \underbrace{24}_{Veq} + \underbrace{4}_{Req} i_0; \quad i_{c.c.} = \frac{Veq}{Req} = 6\,A.$$

Esempio ? Thevenin bipolo AB con metodo "rapido".



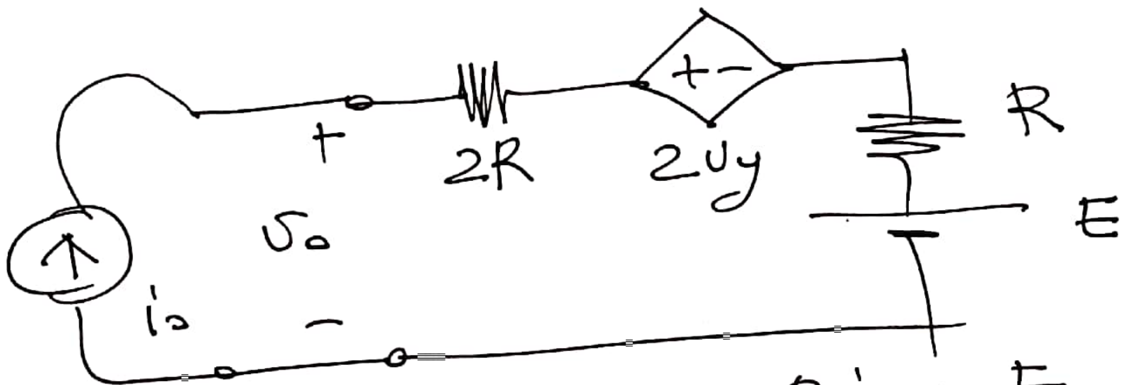
Soluzione

$$v_0 = -v_x + Ri_0 + E \Rightarrow$$

$$v_x = -V_0 + Ri_0 + E$$

Millmann: $$v_y = \frac{\frac{3v_x}{2R} - I}{\frac{1}{2R} + \frac{1}{2R}} = \frac{3}{2}v_x - RI$$

$$\Rightarrow \quad v_y = -\frac{3}{2}V_0 + \frac{3}{2}Ri_0 + \frac{3}{2}E - RI$$

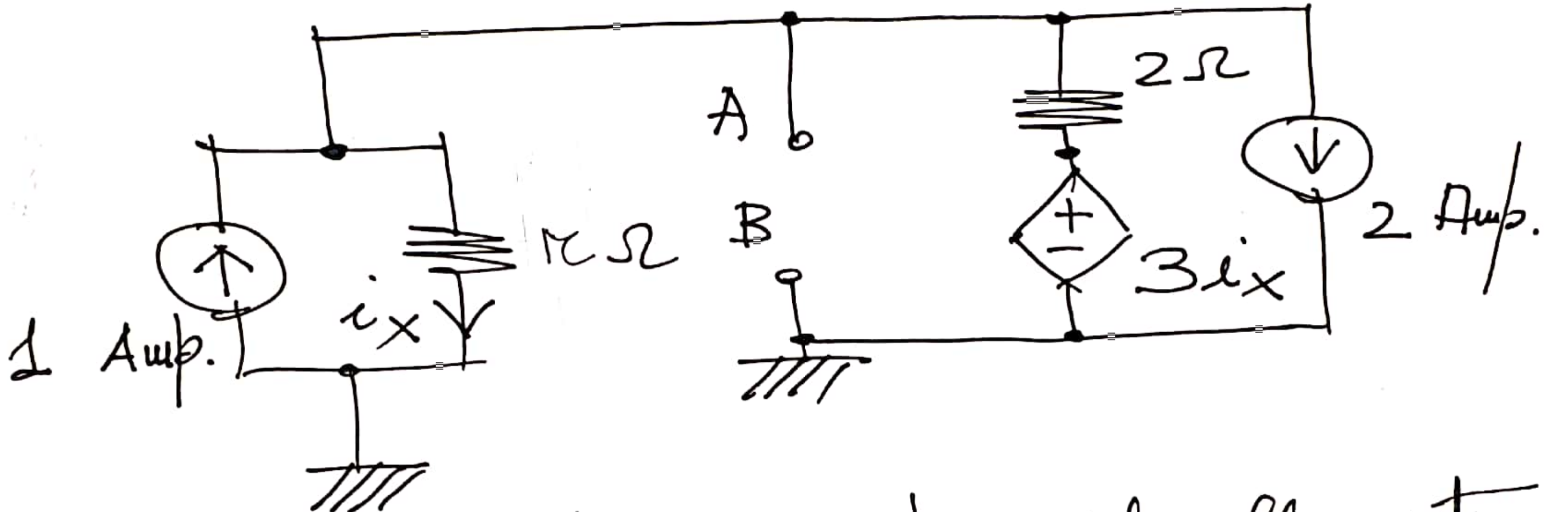


$$v_0 = 2Ri_0 + 2v_y + Ri_0 + E$$

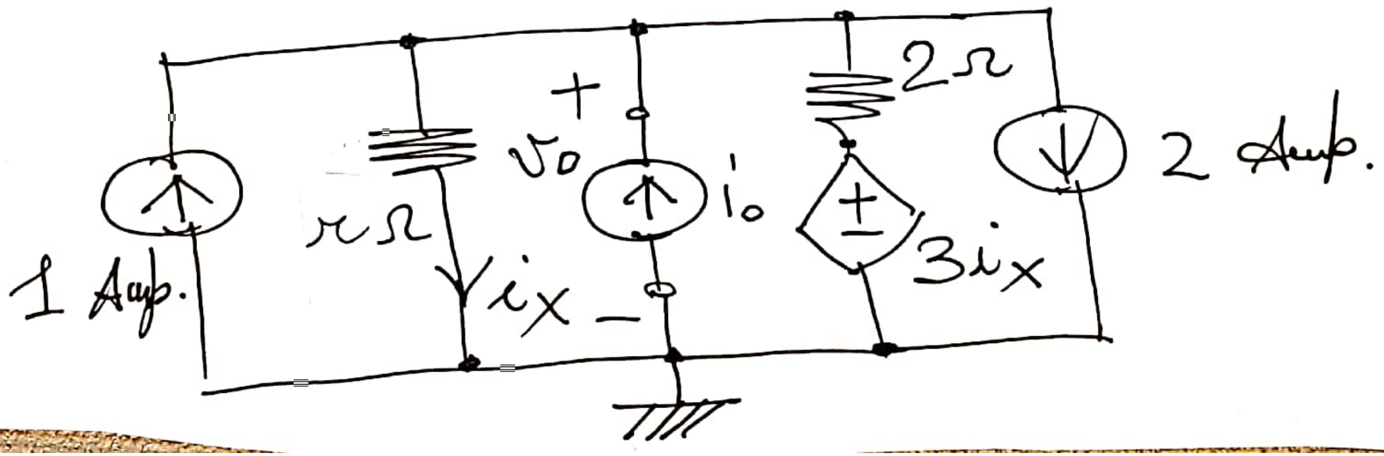
Sostituendo v_y ottengo

$$V_0 = \underbrace{\frac{3}{2}R}_{R_{eq}} i_0 + \underbrace{E - \frac{R}{2}I}_{V_{eq}}$$

Esempio Determinare l'equivalente di Thevenin del bipolo A–B per $r \in \mathbb{R}$.



Soluzione. Ridisegno usando un solo collegamento di terra.



$g \doteq \frac{1}{R}$ Per Millmann

$$v_0 = \frac{1-2+\frac{3}{2}i_x+i_0}{g+\frac{1}{2}} = \frac{-1+\frac{3}{2}i_x+i_0}{g+\frac{1}{2}}$$

$$\left(g+\frac{1}{2}\right)v_0 = -1+\frac{3}{2}i_x+i_0$$

$$i_x = g v_0$$

$$\left(g+\frac{1}{2}\right)v_0 = -1+\frac{3}{2}g v_0+i_0$$

$$\left(\frac{1}{2}-\frac{1}{2}g\right)v_0 = -1+i_0$$

$g \neq 1 \Rightarrow$

$$v_0 = \underbrace{-\frac{1}{\frac{1}{2}-\frac{1}{2}g}}_{v_{eq}} + \underbrace{\frac{1}{\frac{1}{2}-\frac{1}{2}g}}_{R_{eq}} i_0$$

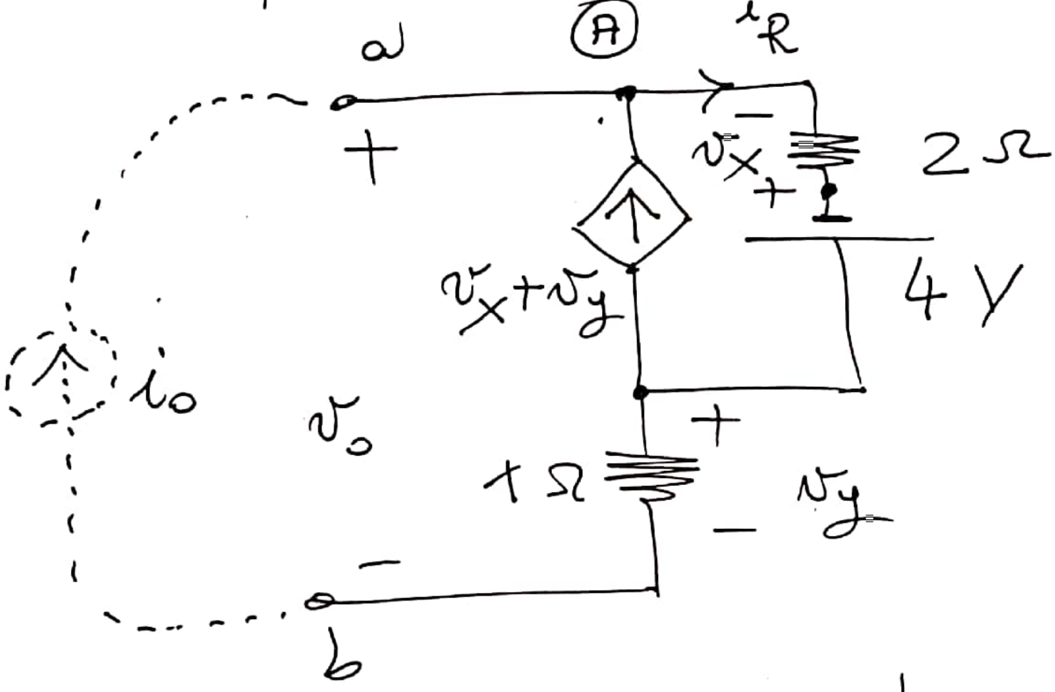
$g = 1$

$$0 = -1+i_0 \Rightarrow$$

$$i_0 = 1 \Rightarrow$$

il bipolo non è controllabile in corrente.

Esempio ? Thevenin bipolo ab



Soluzione : con metodo rapido...

$$\boxed{v_y = 1 \cdot i_o}$$

KI nodo A :

$$i_o + v_x + v_y = i_R = -\frac{v_x}{2}$$

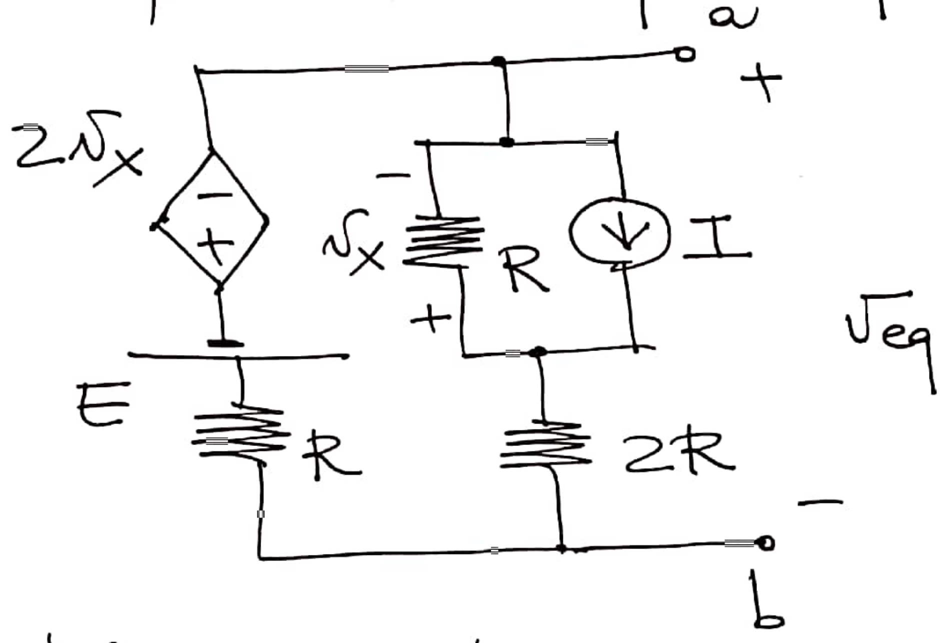
$$i_o + \frac{3}{2} v_x = -v_y = -i_o$$

$$\frac{3}{2} v_x = -2 i_o \Rightarrow \boxed{v_x = -\frac{4}{3} i_o}$$

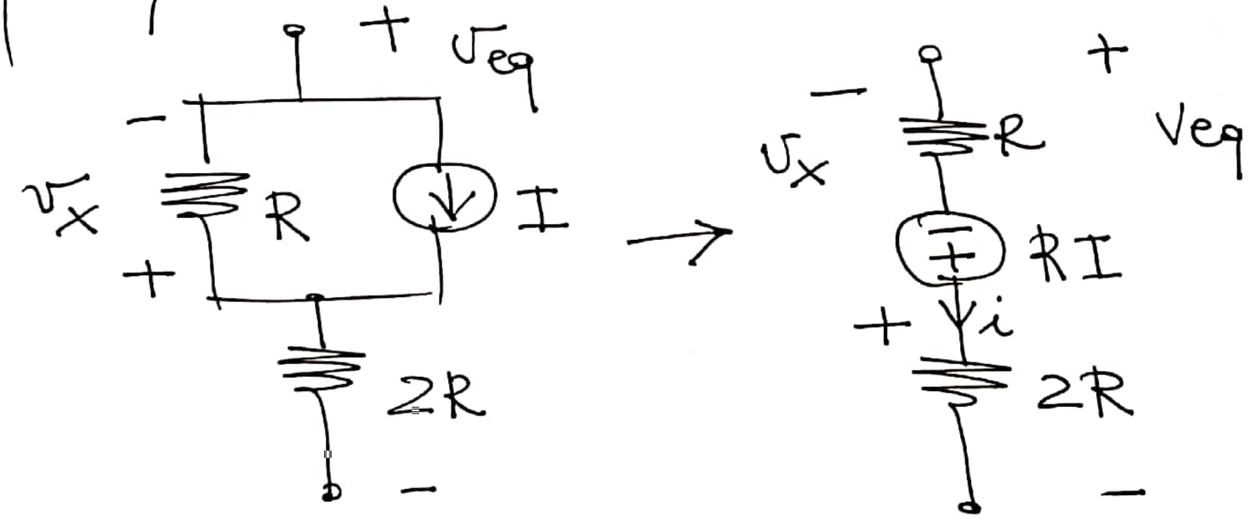
$$v_o = -v_x - 4 + v_y = \frac{4}{3} i_o - 4 + i_o$$

$$v_o = \underbrace{\frac{7}{3}}_{R_{eq}} i_o \underbrace{- 4}_{v_{eq}}$$

Esempio ? Thevenin bipolo ab usando definizione di Veq e Req



Soluzione: Determiniamo v_x



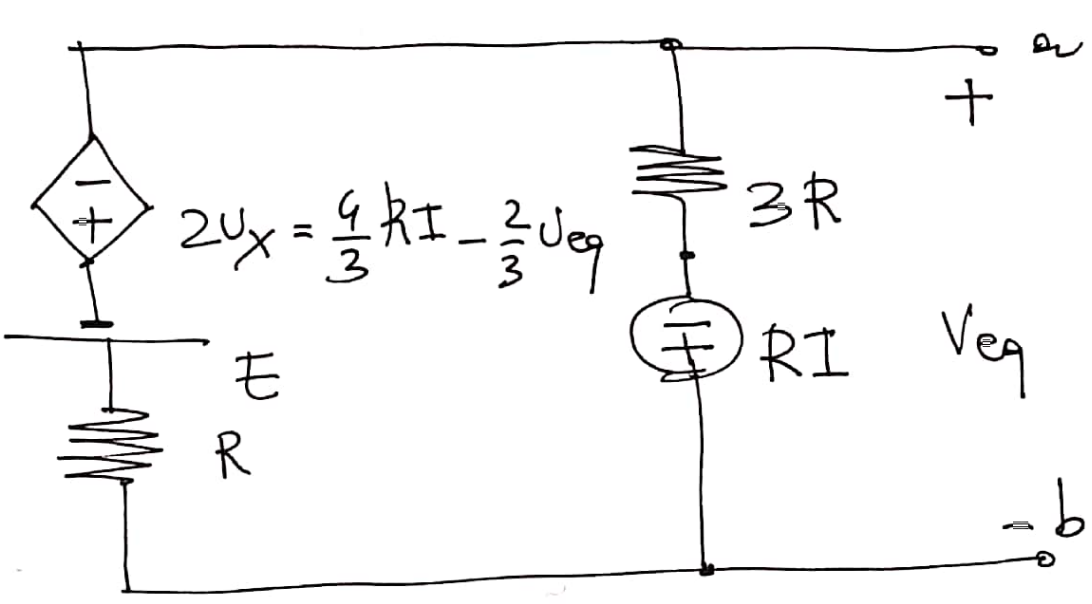
$$V_{eq} = Ri - RI + 2Ri = 3Ri - RI \Rightarrow$$

$$i = \frac{V_{eq} + RI}{3R}$$

$$v_x = -Ri + RI = -\frac{1}{3}V_{eq} - \frac{RI}{3} + RI$$

$$\boxed{v_x = \frac{2}{3}RI - \frac{1}{3}V_{eq}}$$

(5)



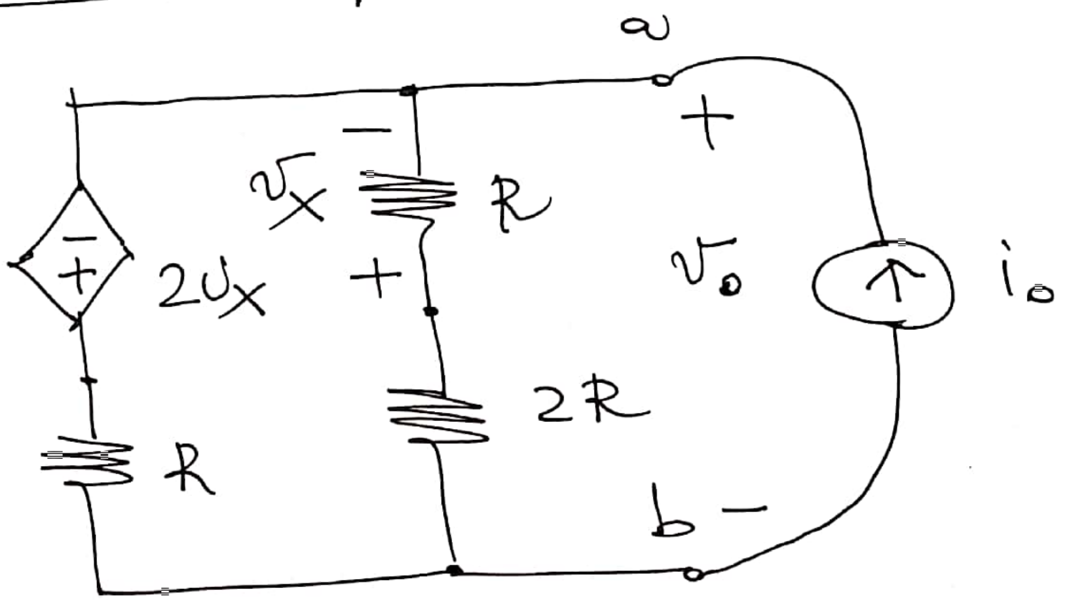
<u>Millmann</u>:

$$v_{eq} = \frac{-\dfrac{E + \frac{4}{3}RI - \frac{2}{3}v_{eq}}{R} - \dfrac{RI}{3R}}{\dfrac{1}{R} + \dfrac{1}{3R}}$$

.... risolvendo

$$v_{eq} = -\frac{3}{2}E - \frac{5}{2}RI.$$

<u>Resistenza equivalente</u>:



Millmann:

$$v_o = \frac{-\frac{2v_x}{R} + i_o}{\frac{1}{R} + \frac{1}{3R}} = -\frac{3}{2} v_x + \frac{3}{4} R i_o$$

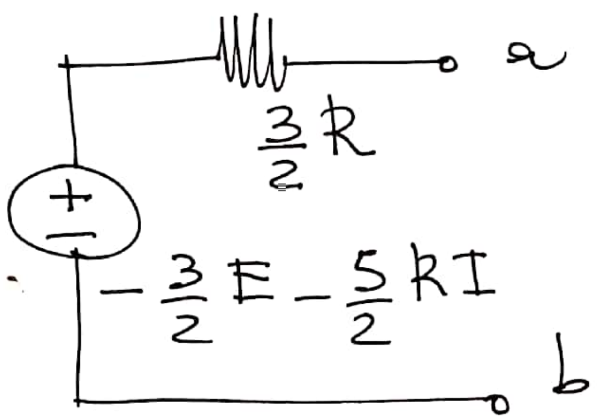
$$v_x = -v_o \frac{R}{3R} = -\frac{v_o}{3}$$

Sostituendo:

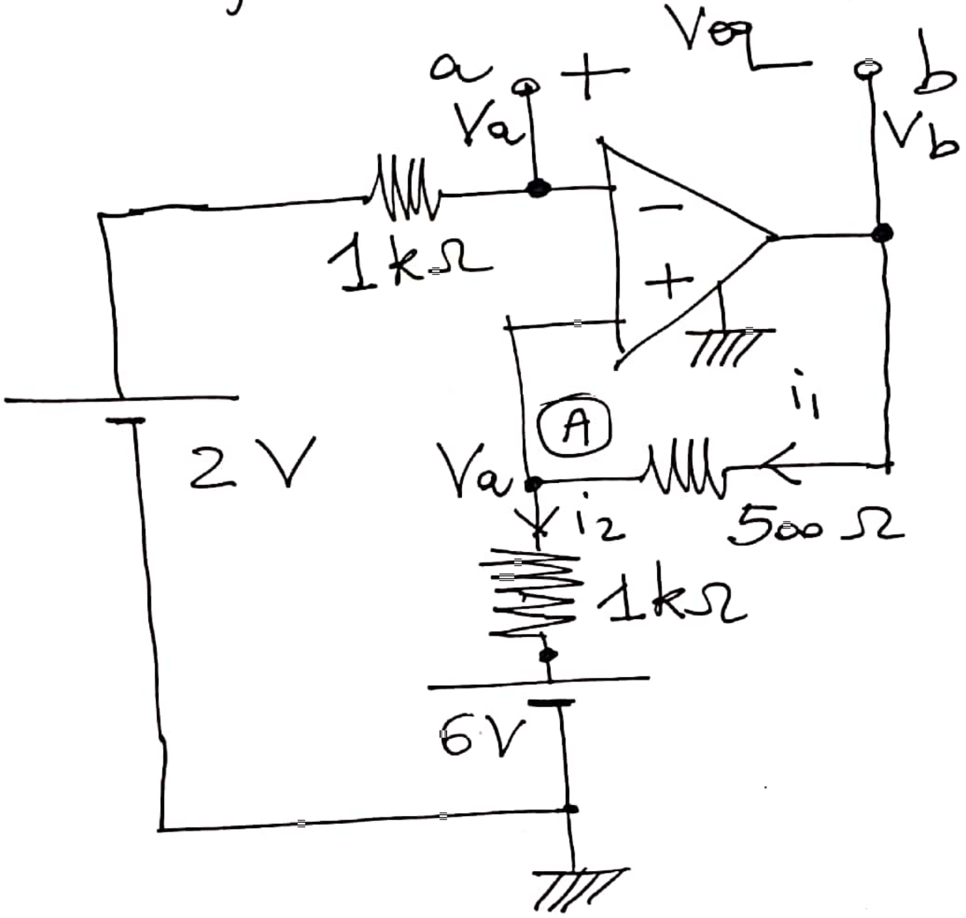
$$v_o = -\frac{3}{2}\left(-\frac{v_o}{3}\right) + \frac{3}{4} R i_o = \frac{v_o}{2} + \frac{3}{4} R i_o$$

$$v_o = \frac{3}{2} R i_o \Rightarrow$$

$$R_{eq} = \frac{3}{2} R$$



Esempio ? Thevenin bipolo ab



Soluzione

$V_{eq} = V_a - V_b \; ; \; V_a = 2\,V$

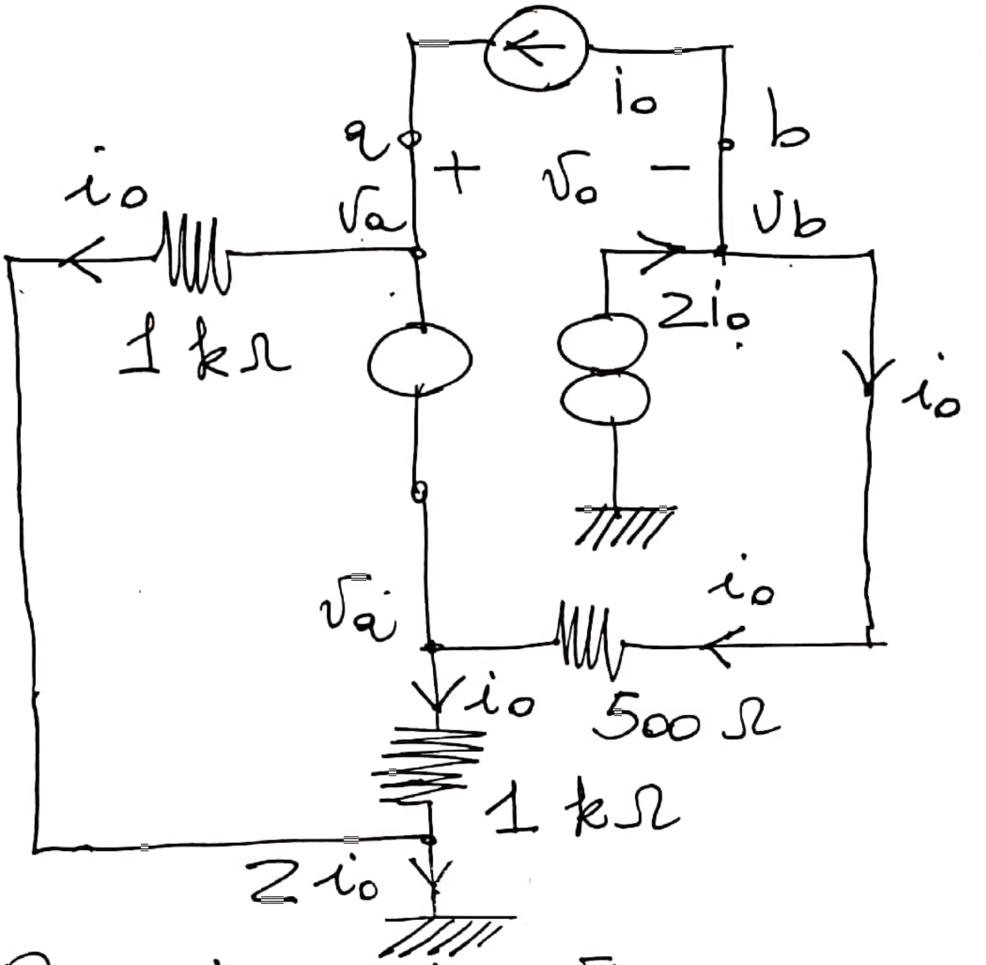
KI nodo A : $i_1 = i_2$

$$\frac{V_b - 2}{500} = \frac{2-6}{1000}$$

$2V_b - 4 = -4 \Rightarrow v_b = 0 \Rightarrow$

$$\boxed{v_{eq} = v_a - v_b = 2\,V}$$

Scansionato con CamScanner



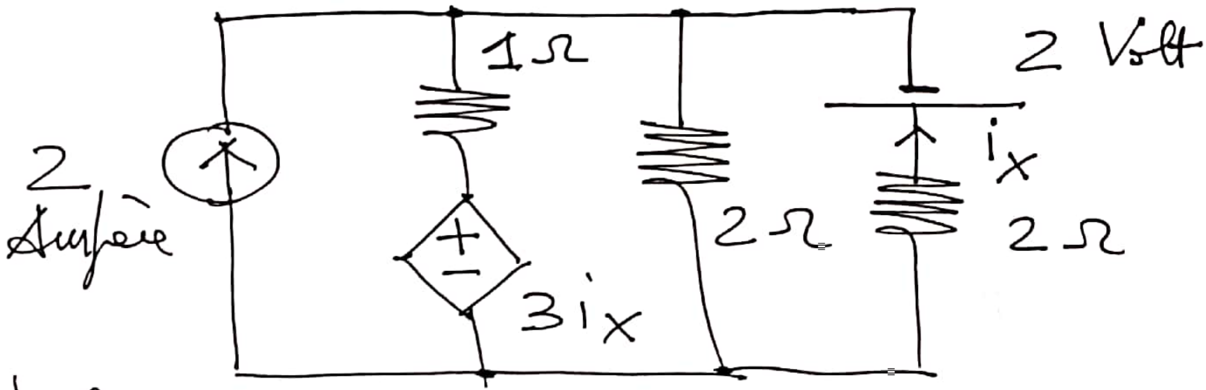
$$R_{eq} = \frac{v_o}{i_o} = \frac{v_a - v_b}{i_o}$$

$v_a = 1000\, i_o$; $v_b = 1000\, i_o + 500\, i_o$
$= 1500\, i_o$

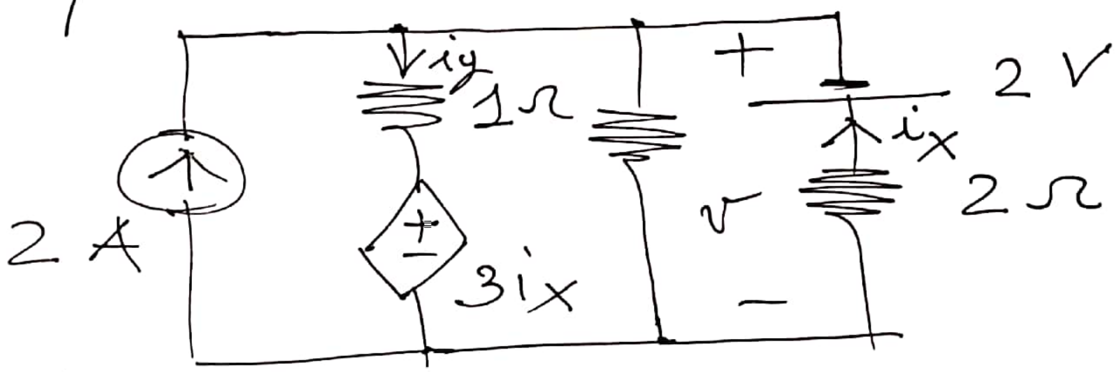
$v_a - v_b = -500\, i_o \Rightarrow$

$$R_{eq} = \frac{v_o}{i_o} = -500\,\Omega.$$

Esempio Verificare il teorema di Tellegen per il circuito in figura.



Soluzione.



Si ha:

$$v = \frac{2 + 3i_x - \frac{2}{2}}{1 + \frac{1}{2} + \frac{1}{2}} = \frac{1}{2} + \frac{3}{2} i_x$$

$$v = -2 - 2i_x \Rightarrow i_x = -1 - \frac{v}{2}$$

da cui

$$v = -\frac{4}{7}\,V \;;\; i_x = -\frac{5}{7}\,A.$$

Inoltre:

$$i_x = -1 - \frac{1}{2}\left(-\frac{4}{7}\right) = -\frac{5}{7}\,A$$

$$v = i_y + 3i_x \Rightarrow i_y = v - 3i_x = -\frac{4}{7} + \frac{15}{7} = \frac{11}{7}\,A.$$

Potenze assorbite dai bipoli:

$$P_{\substack{\text{gen.re}\\ \text{corrente}}} = -2 \cdot v = \frac{8}{7}\ W$$

$$P_{1\Omega} = 1 \cdot i_y^2 = \frac{121}{49}\ W$$

$$P_{\substack{\text{gen.re}\\ \text{controllato}}} = 3 i_x \cdot i_y = 3\left(-\frac{5}{7}\right)\left(\frac{11}{7}\right) = -\frac{165}{49}\ W$$

$$P_{\substack{2\Omega\\ sx}} = \frac{v^2}{2} = \frac{1}{2}\,\frac{16}{49} = \frac{8}{49}\ W$$

$$P_{\text{batteria}} = 2 \cdot i_x = -\frac{10}{7}\ W$$

$$P_{\substack{2\Omega\\ dx}} = 2 \cdot i_x^2 = 2 \cdot \frac{25}{49} = \frac{50}{49}\ W$$

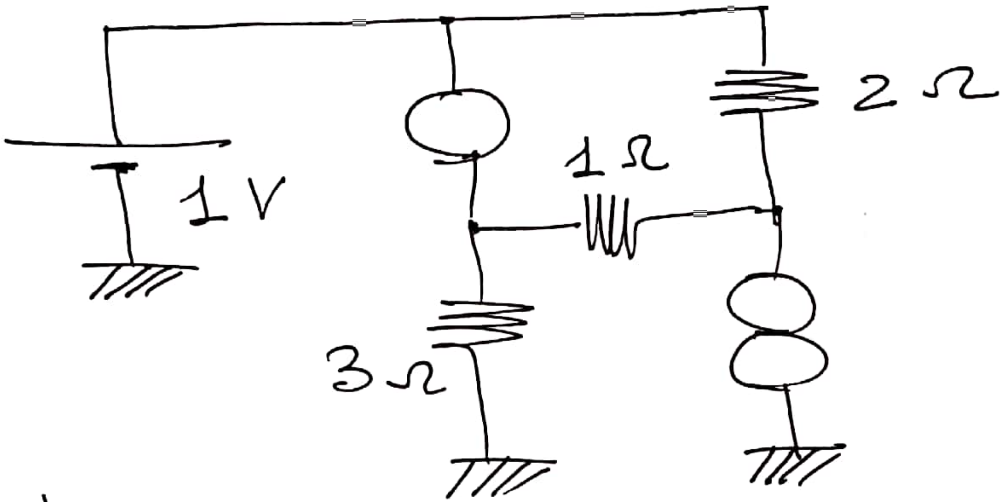
Si ha:

$$\frac{8}{7} + \frac{121}{49} - \frac{165}{49} + \frac{8}{49} - \frac{10}{7} + \frac{50}{49} =$$

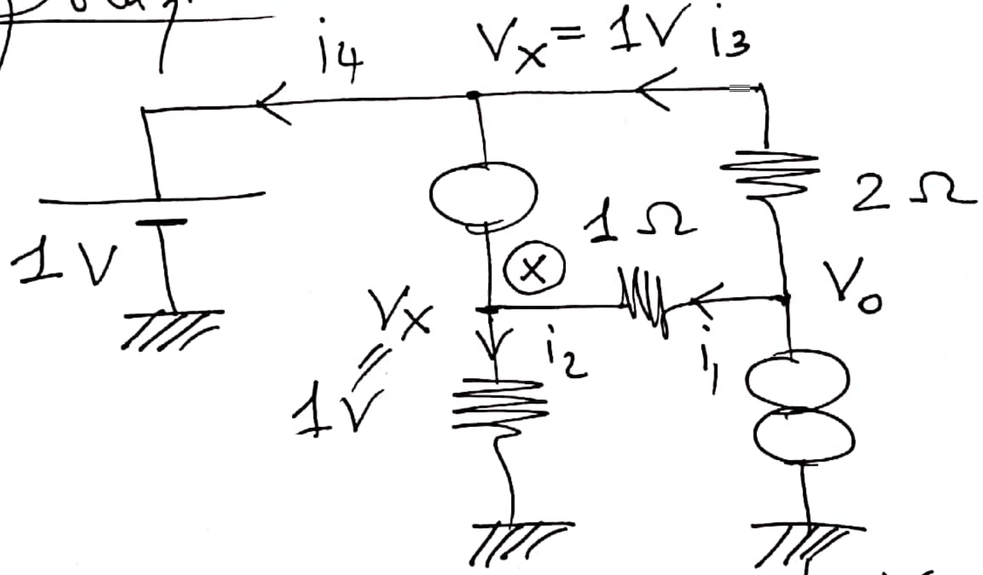
$$= \frac{56 + 121 - 165 + 8 - 70 + 50}{49} = 0.$$

Tellegen è verificato.

Esempio Verificare il teorema di Tellegen per il circuito in figura.



Soluzione

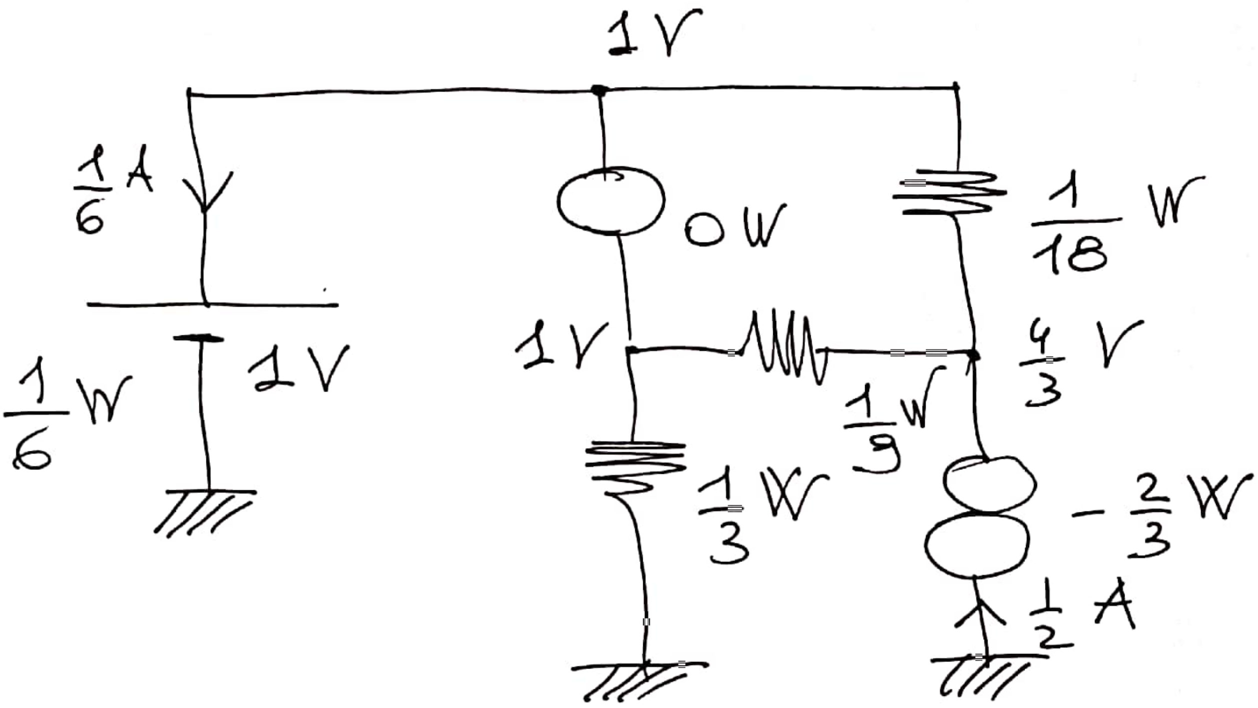


$V_x = 1\,V$; unica incognita V_0

KI nodo ⊗ : $\frac{V_0 - 1}{1} = \frac{1}{3} \Rightarrow \boxed{V_0 = \frac{4}{3}\,V}$

$\Rightarrow i_1 = i_2 = \frac{1}{3}\,A$; $i_3 = i_4 = \frac{1}{6}\,A$.

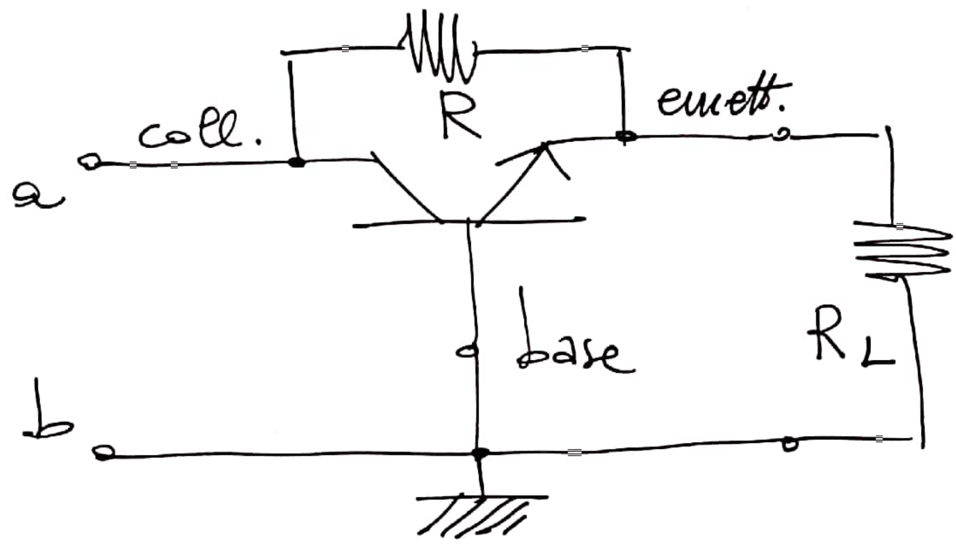
Ne segue la situazione delle potenze assorbite come in figura.



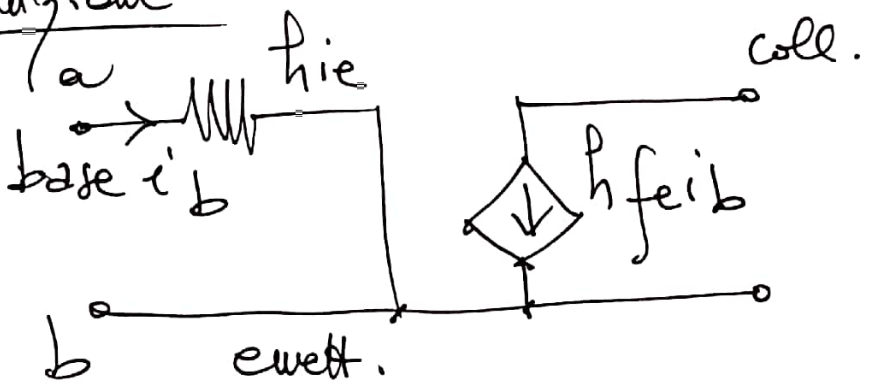
$$\frac{1}{6}+\frac{1}{3}+\frac{1}{9}+\frac{1}{18}=\frac{12}{18}=\frac{2}{3}\text{ W.}$$

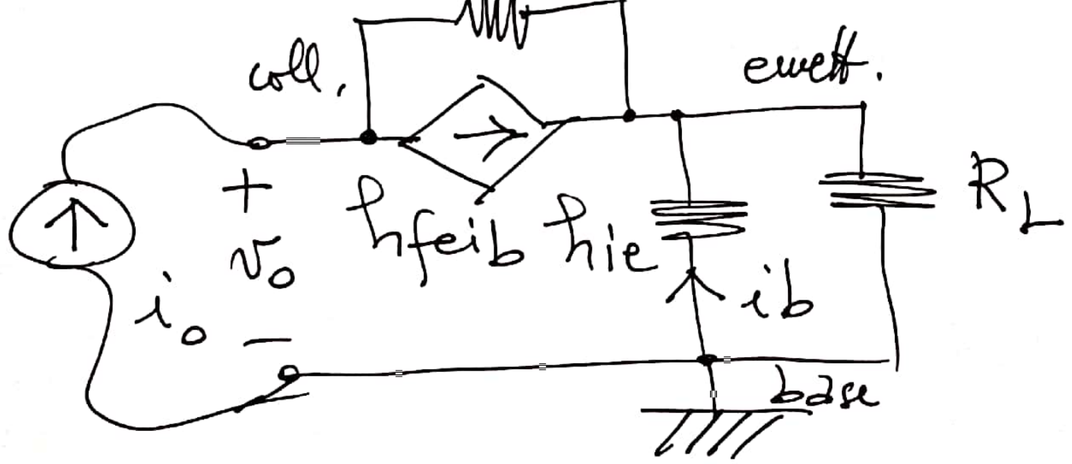
È verificato il teorema di Tellegen.

Esempio. ? R_{eq} bipolo ab usando per il transistor il modello a parametri h a emettitore comune con $h_{re} = 0$ e $h_{oe} = 0 \ \text{Ohm}^{-1}$. 1



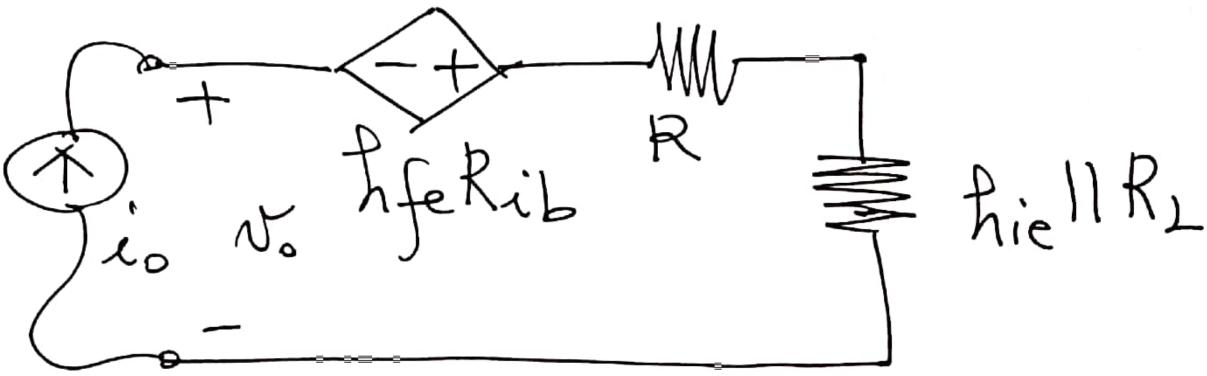
Soluzione





2

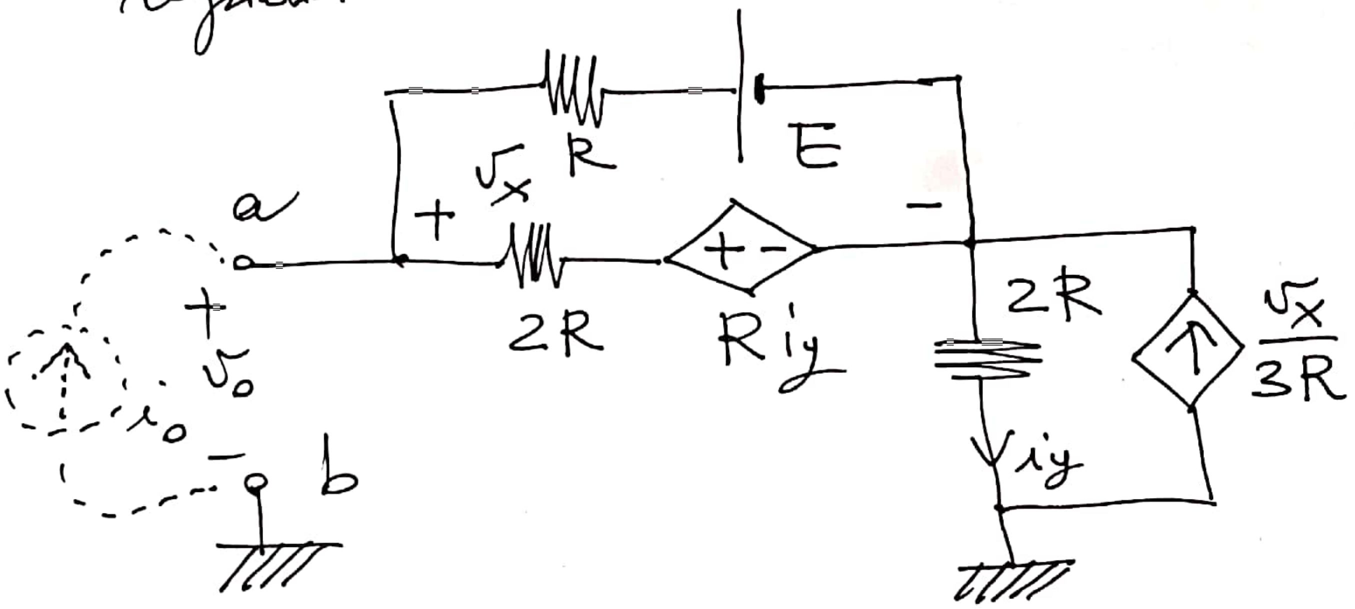
$$i_b = -i_0 \frac{\frac{1}{h_{ie}}}{\frac{1}{h_{ie}} + \frac{1}{R_L}} = -i_0 \frac{R_L}{R_L + h_{ie}}$$



$$v_0 = -h_{fe} R i_b + R i_0 + h_{ie} \| R_L \, i_0$$
$$= h_{fe} \frac{R R_L}{R_L + h_{ie}} i_0 + R i_0 + h_{ie} \| R_L \, i_0$$

$$\Rightarrow R_{eq} = \frac{v_0}{i_0} = h_{fe} \frac{R R_L}{R_L + h_{ie}} + R + h_{ie} \| R_L .$$

Esempio Determinare l'equivalente di Thevenin del bipolo a b usando il metodo rapido. ①



Soluzione Si ha

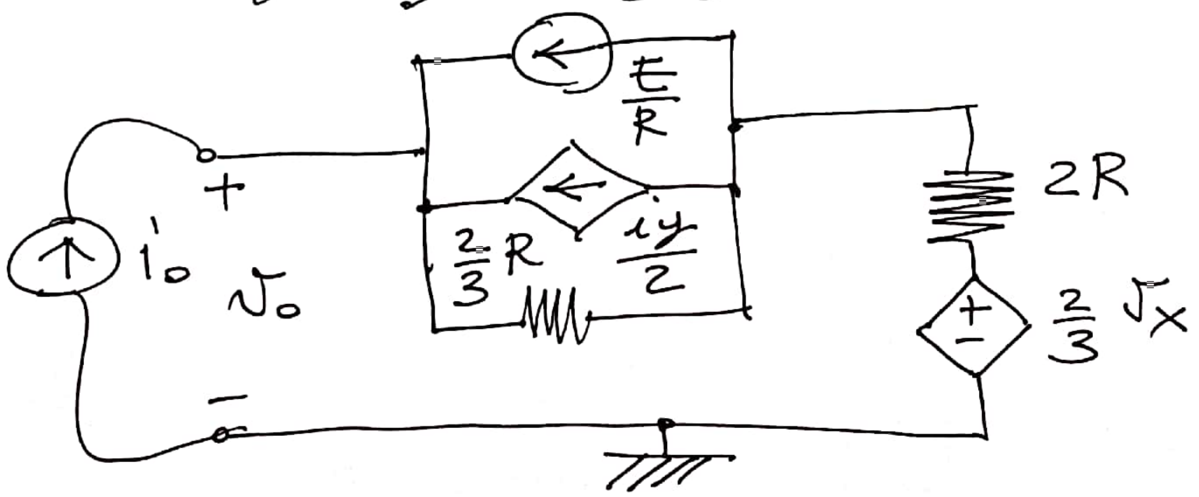
$$i_o = i_y - \frac{v_x}{R}$$

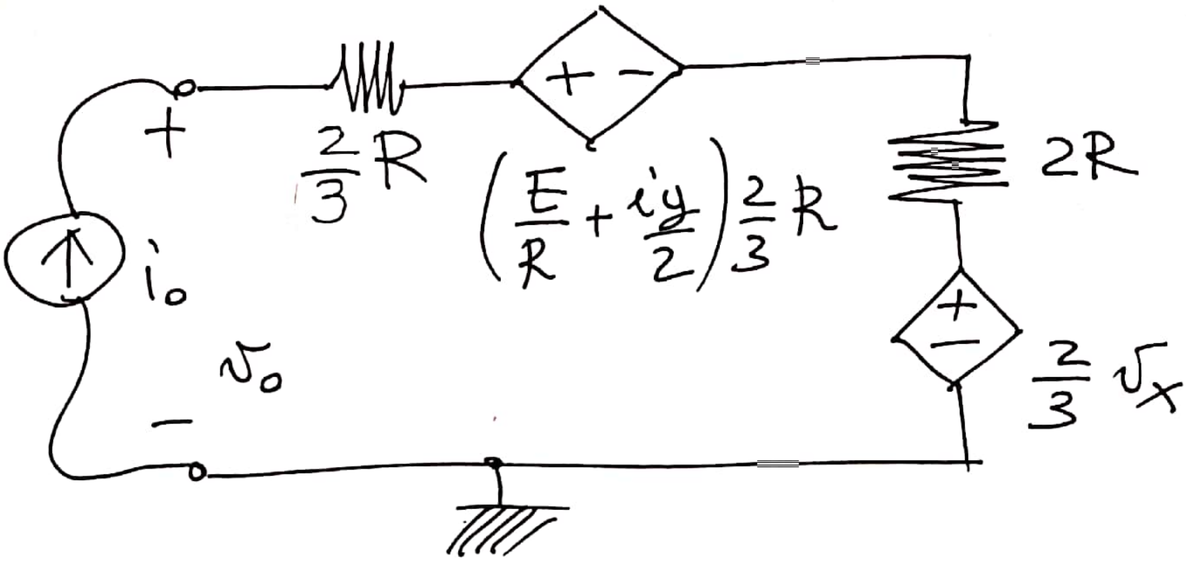
$$v_o = v_x + 2Ri_y$$

Risolvendo:

$$v_x = \frac{3}{5} v_o - \frac{6}{5} R i_o$$

$$i_y = \frac{3}{5} i_o + \frac{v_o}{5R}$$





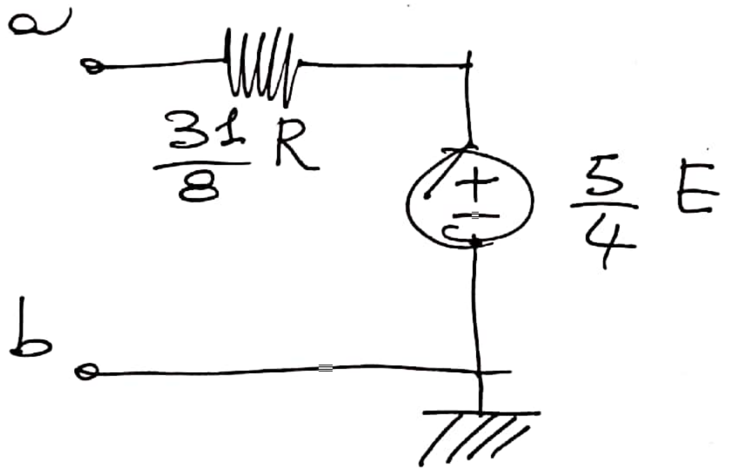
$$v_o = \frac{8}{3}Ri_o + \frac{2}{3}E + \frac{Ri_y}{3} + \frac{2}{3}v_x$$

$$= \frac{8}{3}Ri_o + \frac{2}{3}E + \frac{Ri_o}{5} + \frac{v_o}{15} + \frac{2}{5}v_o - \frac{4}{5}Ri_o$$

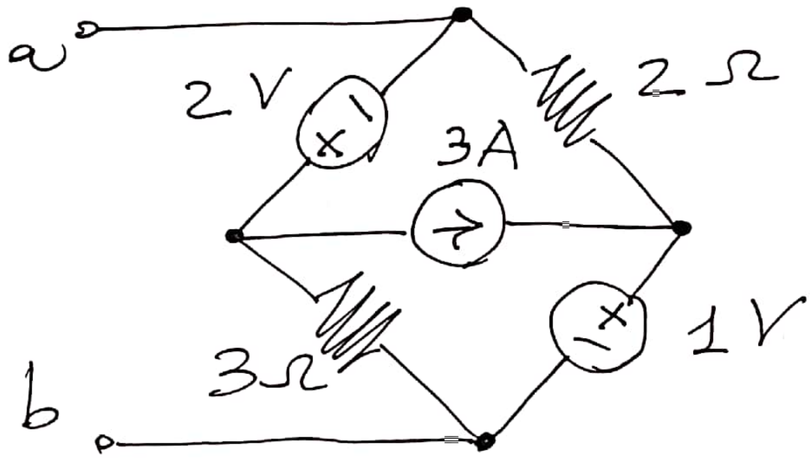
Riarrangiando:

$$v_o = \frac{31}{8}Ri_o + \frac{5}{4}E.$$

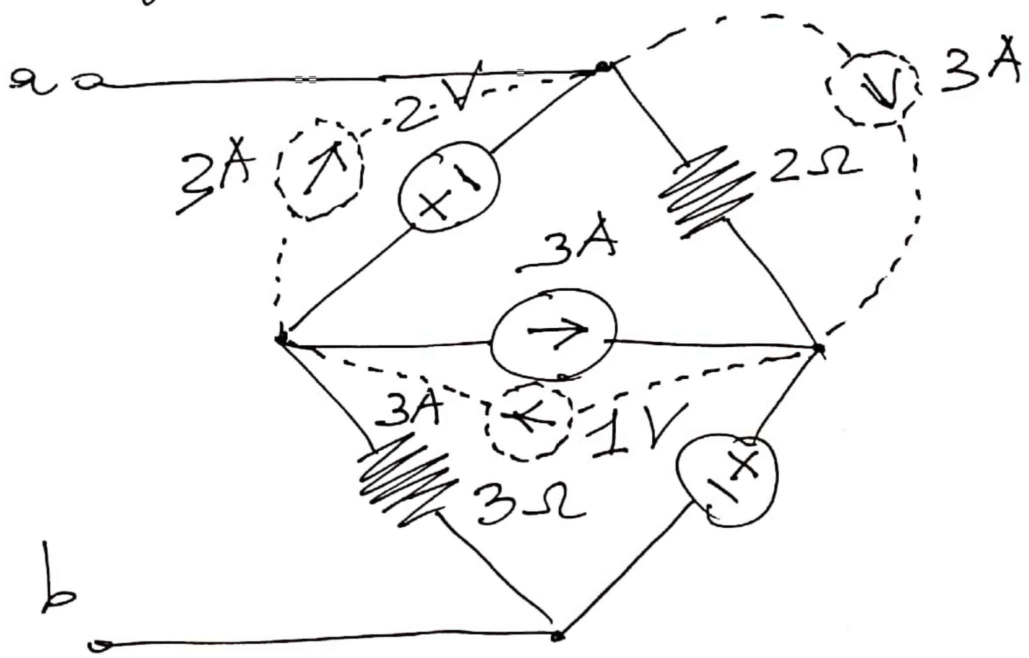
Quindi:

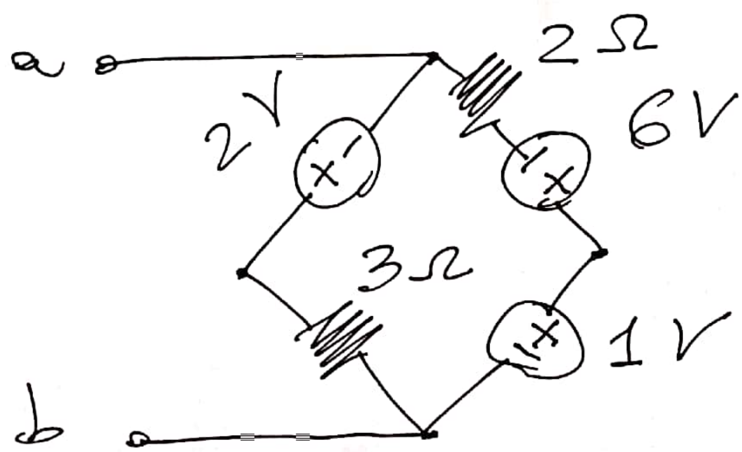


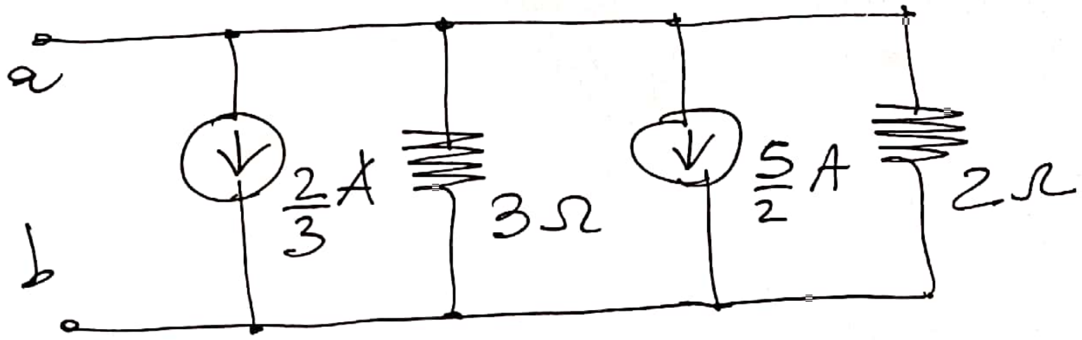
Esempio. ? Norton bipolo ab usando trasformazioni circuitali.

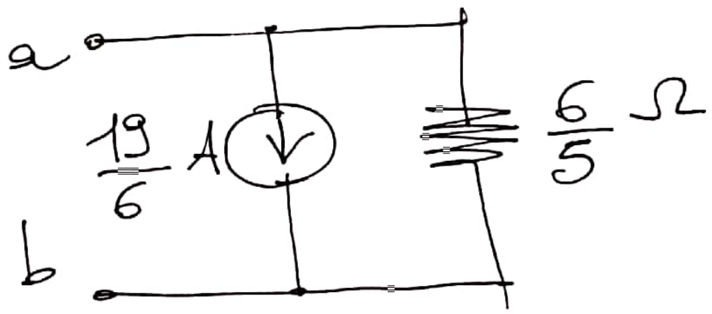


Soluzione :









Norton