

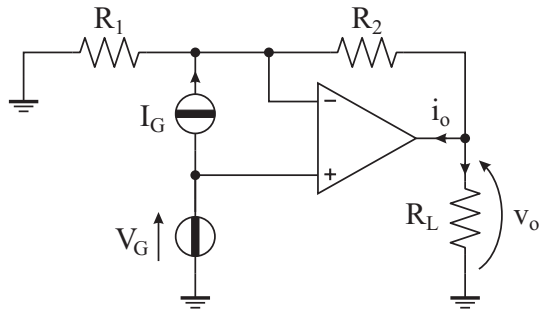
Esercizi di Elettronica

Amplificatori operazionali

Parte 1

www.die.ing.unibo.it/pers/mastri/didattica.htm

(versione del 14-4-2012)

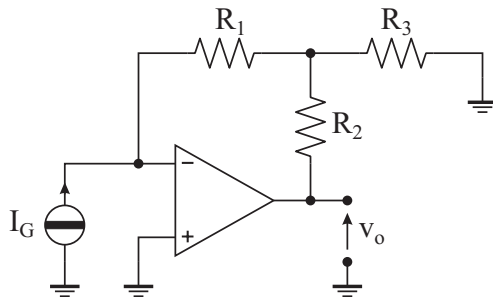
Esercizio n. 1

$$\begin{aligned} R_1 &= 2 \text{ k}\Omega \\ R_2 &= 10 \text{ k}\Omega \\ R_L &= 1 \text{ k}\Omega \\ V_G &= 4 \text{ V} \\ I_G &= 3 \text{ mA} \end{aligned}$$

Determinare la tensione v_o e la corrente i_o .

Risultati

$$v_o = -6 \text{ V} \quad i_o = 5 \text{ mA}$$

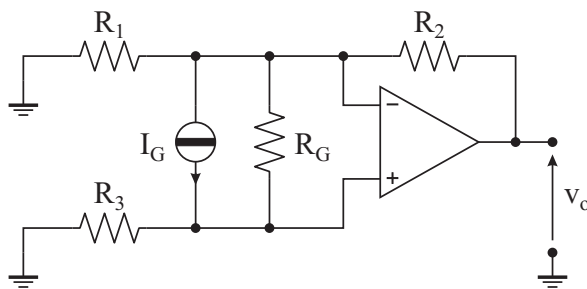
Esercizio n. 2

$$\begin{aligned} R_1 &= 40 \text{ k}\Omega \\ R_2 &= 80 \text{ k}\Omega \\ R_3 &= 20 \text{ k}\Omega \\ I_G &= 50 \text{ }\mu\text{A} \end{aligned}$$

Determinare la tensione v_o .

Risultato

$$v_o = -14 \text{ V}$$

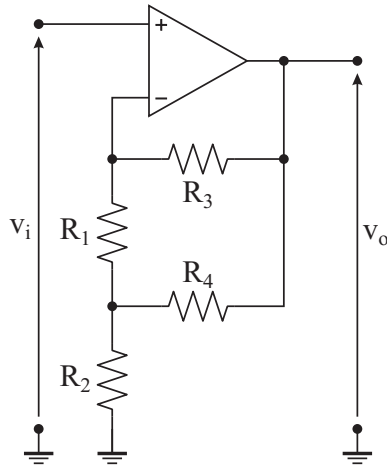
Esercizio n. 3

$$\begin{aligned} R_1 &= 20 \text{ k}\Omega \\ R_2 &= 30 \text{ k}\Omega \\ R_3 &= 10 \text{ k}\Omega \\ R_G &= 10 \text{ k}\Omega \\ I_G &= 200 \text{ }\mu\text{A} \end{aligned}$$

Determinare la tensione v_o .

Risultato

$$v_o = 11 \text{ V}$$

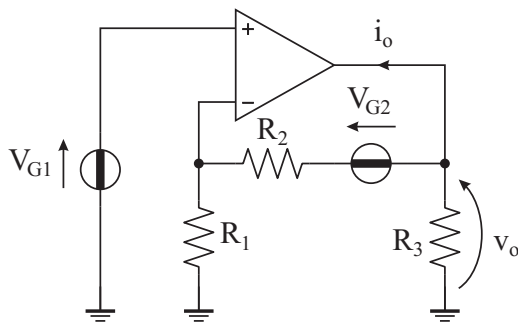
Esercizio n. 4

$$\begin{aligned} R_1 &= 1 \text{ k}\Omega \\ R_2 &= 3 \text{ k}\Omega \\ R_3 &= 3 \text{ k}\Omega \\ R_G &= 6 \text{ k}\Omega \\ v_i &= 6 \text{ V} \end{aligned}$$

Determinare la tensione v_o .

Risultato

$$v_o = 9 \text{ V}$$

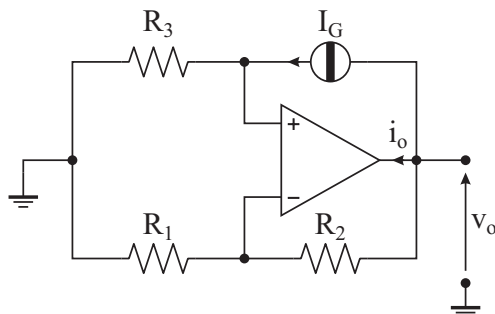
Esercizio n. 5

$$\begin{aligned} R_1 &= 3 \text{ k}\Omega \\ R_2 &= 4 \text{ k}\Omega \\ R_3 &= 2 \text{ k}\Omega \\ R_G &= 6 \text{ k}\Omega \\ V_{G1} &= 6 \text{ V} \\ V_{G2} &= 4 \text{ V} \end{aligned}$$

Determinare la tensione v_o e la corrente i_o .

Risultati

$$v_o = 10 \text{ V} \quad i_o = -7 \text{ mA}$$

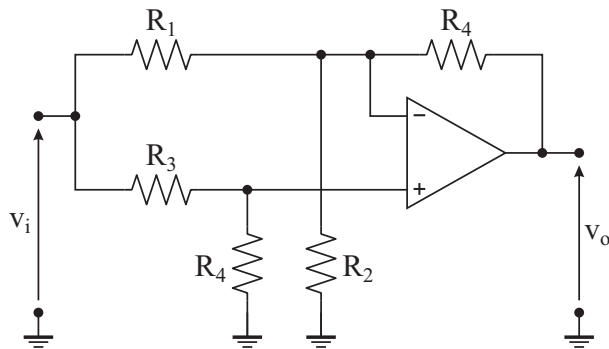
Esercizio n. 6

$$\begin{aligned} R_1 &= 6 \text{ k}\Omega \\ R_2 &= 3 \text{ k}\Omega \\ R_3 &= 2 \text{ k}\Omega \\ I_G &= 3 \text{ mA} \end{aligned}$$

Determinare la tensione v_o e la corrente i_o .

Risultati

$$v_o = 9 \text{ V} \quad i_o = -4 \text{ mA}$$

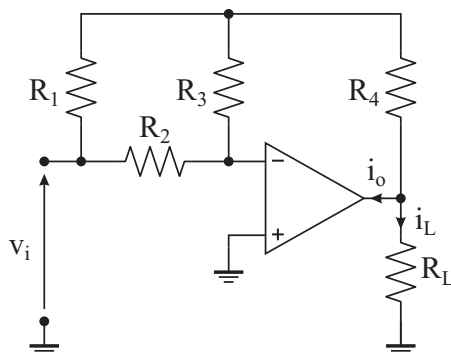
Esercizio n. 7

$$\begin{aligned} R_1 &= 10 \text{ k}\Omega \\ R_2 &= 30 \text{ k}\Omega \\ R_3 &= 15 \text{ k}\Omega \\ R_4 &= 30 \text{ k}\Omega \\ R_5 &= 120 \text{ k}\Omega \\ v_i &= 9 \text{ V} \end{aligned}$$

Determinare la tensione v_o e la resistenza di ingresso.

Risultati

$$v_o = -6 \text{ V} \quad R_{in} = 18 \text{ k}\Omega$$

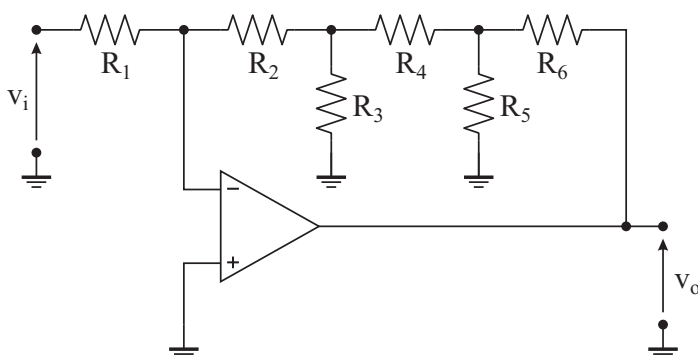
Esercizio n. 8

$$\begin{aligned} R_1 &= 5 \text{ k}\Omega \\ R_2 &= 15 \text{ k}\Omega \\ R_3 &= 5 \text{ k}\Omega \\ R_4 &= 20 \text{ k}\Omega \\ R_L &= 600 \Omega \\ v_i &= 1.5 \text{ V} \end{aligned}$$

Determinare le correnti i_o e i_L .

Risultati

$$i_o = 18 \text{ mA} \quad i_L = -17.5 \text{ mA}$$

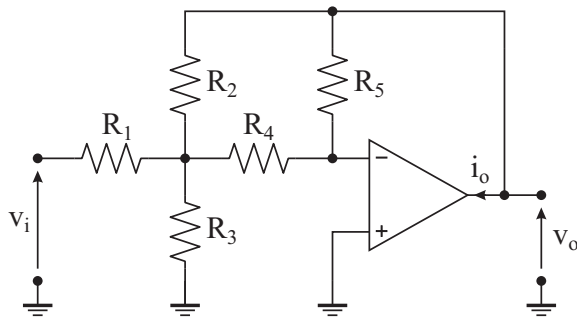
Esercizio n. 9

$$\begin{aligned} R_1 &= 1 \text{ k}\Omega \\ R_2 &= 1 \text{ k}\Omega \\ R_3 &= 1 \text{ k}\Omega \\ R_4 &= 1 \text{ k}\Omega \\ R_5 &= 1 \text{ k}\Omega \\ R_6 &= 1 \text{ k}\Omega \\ v_i &= 1 \text{ V} \end{aligned}$$

Determinare la tensione v_o .

Risultato

$$v_o = -8 \text{ V}$$

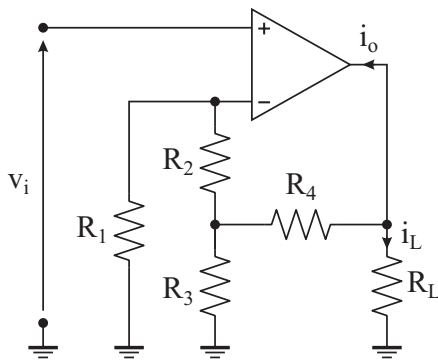
Esercizio n. 10

$$\begin{aligned} R_1 &= 1 \text{ k}\Omega \\ R_2 &= 6 \text{ k}\Omega \\ R_3 &= 2 \text{ k}\Omega \\ R_4 &= 2 \text{ k}\Omega \\ R_5 &= 10 \text{ k}\Omega \\ v_i &= 6 \text{ V} \end{aligned}$$

Determinare la tensione v_o e la resistenza di ingresso.

Risultati

$$v_o = -10 \text{ V} \quad R_{in} = 1.5 \text{ k}\Omega$$

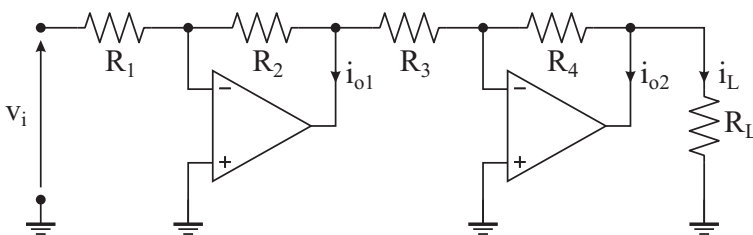
Esercizio n. 11

$$\begin{aligned} R_1 &= 5 \text{ k}\Omega \\ R_2 &= 5 \text{ k}\Omega \\ R_3 &= 2.5 \text{ k}\Omega \\ R_4 &= 10 \text{ k}\Omega \\ R_L &= 1 \text{ k}\Omega \\ v_i &= 1 \text{ V} \end{aligned}$$

Determinare le correnti i_o e i_L .

Risultati

$$i_o = -13 \text{ mA} \quad i_L = 12 \text{ mA}$$

Esercizio n. 12

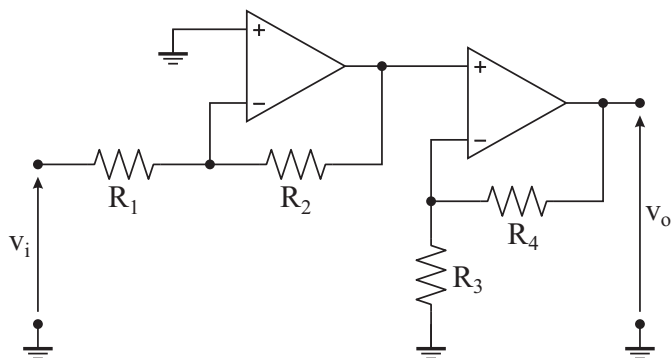
$$\begin{aligned} R_1 &= 10 \text{ k}\Omega \\ R_2 &= 100 \text{ k}\Omega \\ R_3 &= 5 \text{ k}\Omega \\ R_4 &= 10 \text{ k}\Omega \\ R_L &= 5 \text{ k}\Omega \\ v_i &= 0.5 \text{ V} \end{aligned}$$

Determinare le correnti i_{o1} , i_{o2} e i_L .

Risultati

$$i_{o1} = 1.05 \text{ mA} \quad i_{o2} = -3 \text{ mA} \quad i_L = 2 \text{ mA}$$

Esercizio n. 13



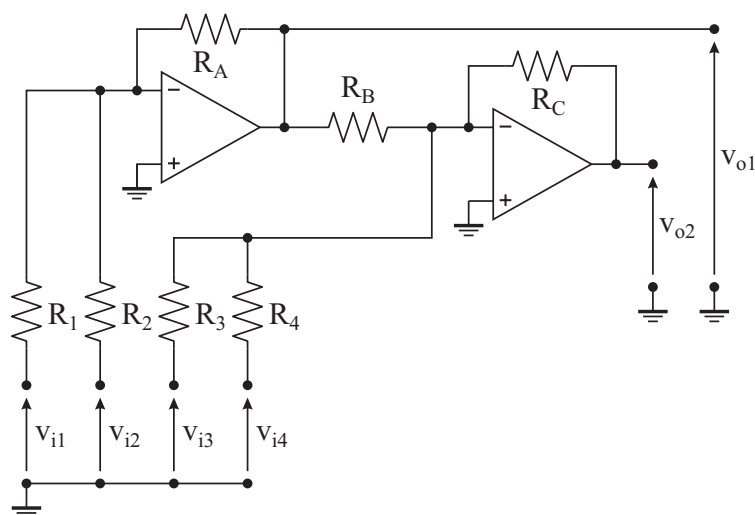
- $R_1 = 15 \text{ k}\Omega$
- $R_2 = 1.2 \text{ M}\Omega$
- $R_3 = 10 \text{ k}\Omega$
- $R_4 = 150 \text{ k}\Omega$
- $v_i = 5 \text{ mV}$

Determinare la tensione v_o .

Risultato

$v_o = -6.4 \text{ V}$

Esercizio n. 14



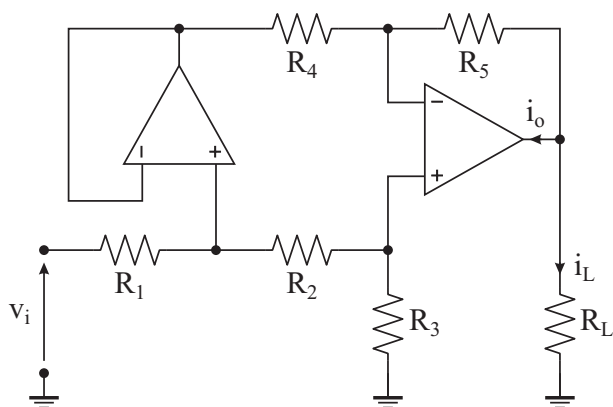
- $R_1 = 20 \text{ k}\Omega$
- $R_2 = 40 \text{ k}\Omega$
- $R_3 = 30 \text{ k}\Omega$
- $R_4 = 20 \text{ k}\Omega$
- $R_A = 10 \text{ k}\Omega$
- $R_B = 10 \text{ k}\Omega$
- $R_C = 10 \text{ k}\Omega$
- $v_{i1} = 10 \text{ V}$
- $v_{i2} = 8 \text{ V}$
- $v_{i3} = 6 \text{ V}$
- $v_{i4} = 4 \text{ V}$

Determinare le tensioni v_{o1} e v_{o2} .

Risultati

$v_{o1} = -7 \text{ V}$ $v_{o2} = 3 \text{ V}$

Esercizio n. 15

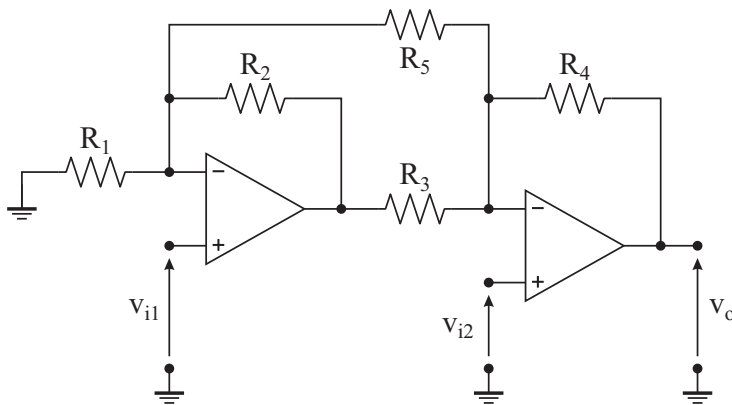


- $R_1 = 30 \text{ k}\Omega$
- $R_2 = 30 \text{ k}\Omega$
- $R_3 = 30 \text{ k}\Omega$
- $R_4 = 10 \text{ k}\Omega$
- $R_5 = 40 \text{ k}\Omega$
- $R_L = 1.8 \text{ k}\Omega$
- $v_i = 9 \text{ V}$

Determinare le correnti i_o e i_L .

Risultati

$i_o = 5.3 \text{ mA}$ $i_L = -5 \text{ mA}$

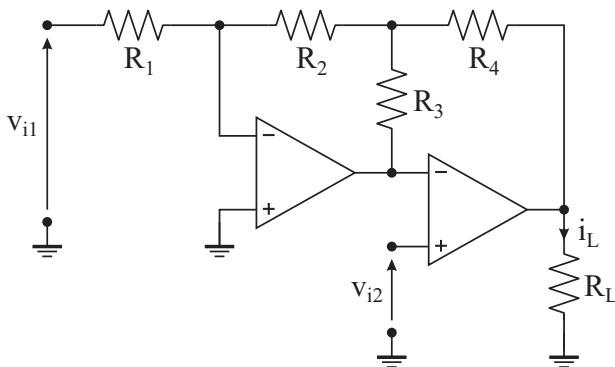
Esercizio n. 16

$$\begin{aligned} R_1 &= 1 \text{ k}\Omega \\ R_2 &= 5 \text{ k}\Omega \\ R_3 &= 4 \text{ k}\Omega \\ R_4 &= 10 \text{ k}\Omega \\ R_5 &= 3 \text{ k}\Omega \\ v_{i1} &= 2 \text{ V} \\ v_{i2} &= 5 \text{ V} \end{aligned}$$

Determinare la tensione v_o .

Risultato

$$v_o = 10 \text{ V}$$

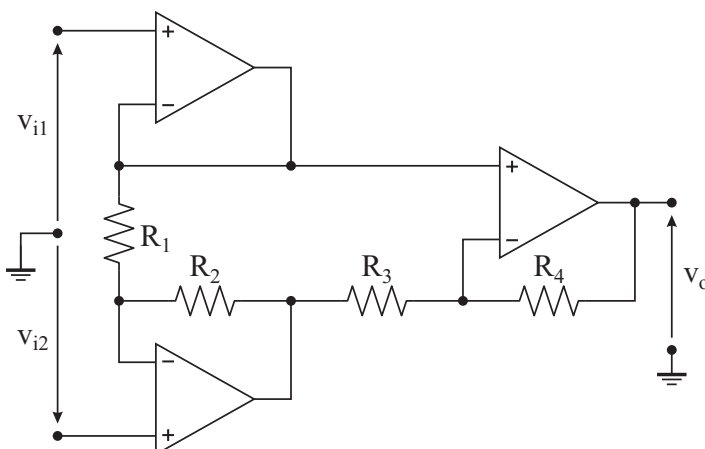
Esercizio n. 17

$$\begin{aligned} R_1 &= 20 \text{ k}\Omega \\ R_2 &= 30 \text{ k}\Omega \\ R_3 &= 20 \text{ k}\Omega \\ R_4 &= 100 \text{ k}\Omega \\ R_L &= 1 \text{ k}\Omega \\ v_{i1} &= 2 \text{ V} \\ v_{i2} &= 4 \text{ V} \end{aligned}$$

Determinare la corrente i_L .

Risultato

$$i_L = -8 \text{ mA}$$

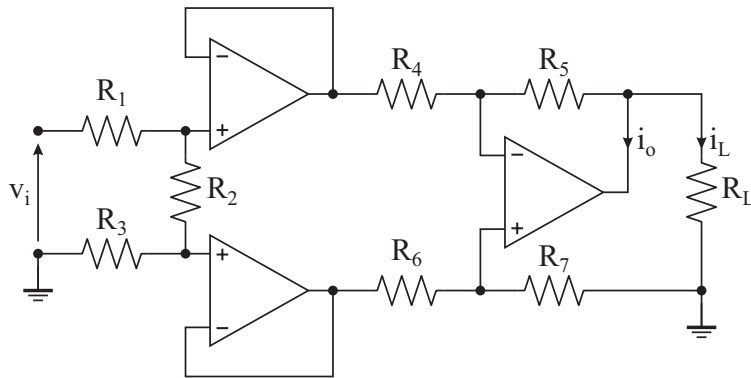
Esercizio n. 18

$$\begin{aligned} R_1 &= 20 \text{ k}\Omega \\ R_2 &= 180 \text{ k}\Omega \\ R_3 &= 40 \text{ k}\Omega \\ R_4 &= 150 \text{ k}\Omega \\ v_{i1} &= 500 \text{ mV} \\ v_{i2} &= 300 \text{ mV} \end{aligned}$$

Determinare la tensione v_o .

Risultato

$$v_o = 8 \text{ V}$$

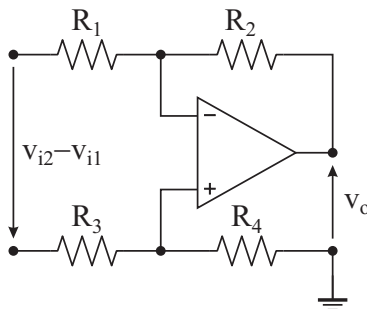
Esercizio n. 19

$$\begin{aligned} R_1 &= 1 \text{ k}\Omega \\ R_2 &= 2 \text{ k}\Omega \\ R_3 &= 3 \text{ k}\Omega \\ R_4 &= 1 \text{ k}\Omega \\ R_5 &= 5 \text{ k}\Omega \\ R_6 &= 1 \text{ k}\Omega \\ R_7 &= 5 \text{ k}\Omega \\ R_L &= 1 \text{ k}\Omega \\ v_i &= 6 \text{ V} \end{aligned}$$

Determinare le correnti i_o e i_L .

Risultati

$$i_o = 12.5 \text{ mA} \quad i_L = -10 \text{ mA}$$

Esercizio n. 20

$$\begin{aligned} R_1 &= 10.1 \text{ k}\Omega \\ R_2 &= 99 \text{ k}\Omega \\ R_3 &= 9.9 \text{ k}\Omega \\ R_4 &= 101 \text{ k}\Omega \end{aligned}$$

Determinare il rapporto di reiezione di modo comune dell'amplificatore differenziale rappresentato nella figura.

Risultato

$$\text{CMRR} = 48.8 \text{ dB}$$

Risoluzioni

Esercizio n. 1

$$i_1 = \frac{V_G}{R_1} = 2 \cdot \text{mA}$$

$$i_2 = i_1 - I_G = -1 \cdot \text{mA}$$

$$v_o = V_G + R_2 \cdot i_2 = -6 \text{ V}$$

$$i_L = \frac{v_o}{R_L} = -6 \cdot \text{mA}$$

$$i_o = i_2 - i_L = 5 \cdot \text{mA}$$

Esercizio n. 2

$$v_1 = I_G \cdot R_1 = 2 \text{ V}$$

$$v_3 = v_1 = 2 \text{ V}$$

$$i_3 = \frac{v_3}{R_3} = 100 \cdot \mu\text{A}$$

$$i_2 = I_G + i_3 = 150 \cdot \mu\text{A}$$

$$v_o = -(R_1 \cdot I_G + R_2 \cdot i_2) = -14 \text{ V}$$

Esercizio n. 3

$$v_{RG} = 0 \text{ V} \quad i_{RG} = 0 \text{ A}$$

$$v_3 = I_G \cdot R_3 = 2 \text{ V}$$

$$v_1 = v_3 = 2 \text{ V}$$

$$i_1 = \frac{v_3}{R_1} = 100 \cdot \mu\text{A}$$

$$i_2 = I_G + i_1 = 300 \cdot \mu\text{A}$$

$$v_o = v_1 + R_2 \cdot i_2 = 11 \text{ V}$$

Esercizio n. 4

$$i_3 = i_1$$

$$\frac{v_o - v_i}{R_3} = \frac{v_i - v_A}{R_1}$$

$$v_o = \left(1 + \frac{R_3}{R_1}\right) \cdot v_i - \frac{R_3}{R_1} \cdot v_A$$

$$i_2 = i_1 + i_4$$

$$\frac{v_A}{R_2} = \frac{v_i - v_A}{R_1} + \frac{v_o - v_A}{R_4}$$

$$\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_4}\right) \cdot v_A = \frac{v_i}{R_1} + \frac{v_o}{R_4}$$

$$\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_4} + \frac{R_3}{R_1 \cdot R_4}\right) \cdot v_A = \left(\frac{1}{R_1} + \frac{1}{R_4} + \frac{R_3}{R_1 \cdot R_4}\right) \cdot v_i$$

$$v_A = \frac{R_2 \cdot (R_1 + R_3 + R_4)}{R_1 \cdot R_4 + R_2 \cdot (R_1 + R_3 + R_4)} v_i = 5 \text{ V}$$

$$v_o = \left(1 + \frac{R_3}{R_1}\right) \cdot v_i - \frac{R_3}{R_1} \cdot v_A = 9 \text{ V}$$

Esercizio n. 5

$$v_1 = V_{G1}$$

$$i_1 = \frac{v_1}{R_1} = 2 \cdot \text{mA}$$

$$i_2 = i_1$$

$$v_o = v_1 + R_2 \cdot i_2 - V_{G2} = 10 \text{ V}$$

$$i_o = -i_2 - \frac{v_o}{R_3} = -7 \cdot \text{mA}$$

Esercizio n. 6

$$v_3 = I_G \cdot R_3 = 6 \text{ V}$$

$$v_1 = v_3$$

$$i_1 = \frac{v_1}{R_1} = 1 \cdot \text{mA}$$

$$i_2 = i_1$$

$$v_o = v_1 + R_2 \cdot i_2 = 9 \text{ V}$$

$$i_o = -I_G - i_2 = -4 \cdot \text{mA}$$

Esercizio n. 7

$$v_A = v_i \frac{R_4}{R_3 + R_4} = 6V$$

$$v_B = v_A = 6V$$

$$i_1 = \frac{v_i - v_B}{R_1} = 300 \mu A$$

$$i_2 = \frac{v_B}{R_2} = 200 \mu A$$

$$i_5 = i_1 - i_2 = 100 \mu A$$

$$v_o = v_B - R_5 \cdot i_5 = -6V$$

$$i_3 = \frac{v_i - v_A}{R_3} = 0.2 \text{ mA}$$

$$R_{in} = \frac{v_i}{i_1 + i_3} = 18 \text{ k}\Omega$$

Esercizio n. 8

$$i_2 = i_3$$

$$\frac{v_i}{R_2} = -\frac{v_A}{R_3}$$

$$v_A = -\frac{R_3}{R_2} \cdot v_i = -0.5V$$

$$i_4 = i_1 + i_3$$

$$\frac{v_A - v_o}{R_4} = \frac{v_i - v_A}{R_1} - \frac{v_A}{R_3}$$

$$v_o = R_4 \left(\frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_4} \right) \cdot v_A - \frac{R_4}{R_1} \cdot v_i = -10.5V$$

$$i_L = \frac{v_o}{R_L} = -17.5 \text{ mA}$$

$$i_o = \frac{v_A - v_o}{R_4} - i_L = 18 \text{ mA}$$

Esercizio n. 9

$$i_1 = \frac{v_i}{R_1} = 1 \text{ mA}$$

$$i_2 = i_1 = 1 \cdot \text{mA}$$

$$v_2 = R_2 \cdot i_2 = 1 \text{ V}$$

$$v_3 = v_2 = 1 \text{ V}$$

$$i_3 = \frac{v_3}{R_3} = 1 \cdot \text{mA}$$

$$i_4 = i_2 + i_3 = 2 \cdot \text{mA}$$

$$v_4 = R_4 \cdot i_4 = 2 \text{ V}$$

$$v_5 = v_2 + v_4 = 3 \text{ V}$$

$$i_5 = \frac{v_5}{R_5} = 3 \cdot \text{mA}$$

$$i_6 = i_4 + i_5 = 5 \cdot \text{mA}$$

$$v_o = -(v_5 + R_6 \cdot i_6) = -8 \text{ V}$$

Esercizio n. 10

$$i_4 = i_5$$

$$\frac{v_A}{R_4} = \frac{-v_o}{R_5}$$

$$v_o = -\frac{R_5 \cdot v_A}{R_4}$$

$$i_1 = i_2 + i_3 + i_4$$

$$\frac{v_i - v_A}{R_1} = \frac{v_A - \left(-\frac{R_5 \cdot v_A}{R_4} \right)}{R_2} + \frac{v_A}{R_3} + \frac{v_A}{R_4}$$

$$v_A = \frac{v_i}{R_1 \cdot \left(\frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{R_4 + R_5}{R_2 \cdot R_4} \right)} = 2 \text{ V}$$

$$v_o = -\frac{R_5 \cdot v_A}{R_4} = -10 \text{ V}$$

$$i_1 = \frac{v_i - v_A}{R_1} = 4 \cdot \text{mA}$$

$$R_{\text{in}} = \frac{v_i}{i_1} = 1.5 \cdot \text{k}\Omega$$

Esercizio n. 11

$$i_2 = -i_1$$

$$\frac{v_i - v_A}{R_2} = -\frac{v_i}{R_1}$$

$$v_A = \frac{R_2 + R_1}{R_1} \cdot v_i = 2V$$

$$i_3 = i_2 + i_4$$

$$\frac{v_A}{R_3} = \frac{v_i - v_A}{R_2} + \frac{v_o - v_A}{R_4}$$

$$v_o = R_4 \left(\frac{1}{R_3} + \frac{1}{R_2} + \frac{1}{R_4} \right) \cdot v_A - \frac{R_4}{R_2} \cdot v_i = 12V$$

$$i_L = \frac{v_o}{R_L} = 12 \cdot \text{mA}$$

$$i_o = \frac{v_A - v_o}{R_4} - i_L = -13 \cdot \text{mA}$$

Esercizio n. 12

$$A_{V1} = \frac{-R_2}{R_1} = -10$$

$$A_{V2} = -\frac{R_4}{R_3} = -2$$

$$v_o = A_{V1} A_{V2} v_i = 10V$$

$$i_L = \frac{v_o}{R_L} = 2 \cdot \text{mA}$$

$$v_2 = A_{V1} v_i = -5V$$

$$v_3 = v_2$$

$$i_2 = \frac{v_2}{R_2} = -0.05 \cdot \text{mA}$$

$$i_3 = \frac{v_3}{R_3} = -1 \cdot \text{mA}$$

$$i_{o1} = -i_2 - i_3 = 1.05 \cdot \text{mA}$$

$$i_4 = i_3$$

$$i_{o2} = i_4 - i_L = -3 \cdot \text{mA}$$

Esercizio n. 13

$$A_{V1} = \frac{-R_2}{R_1} = -80$$

$$A_{V2} = 1 + \frac{R_4}{R_3} = 16$$

$$v_o = v_i \cdot A_{V1} \cdot A_{V2} = -6.4V$$

Esercizio n. 14

$$v_{o1} = -R_A \cdot \left(\frac{v_{i1}}{R_1} + \frac{v_{i2}}{R_2} \right) = -7V$$

$$v_{o2} = -R_C \cdot \left(\frac{v_{o1}}{R_B} + \frac{v_{i3}}{R_3} + \frac{v_{i4}}{R_4} \right)$$

$$v_{o2} = R_C \cdot \left(\frac{R_A}{R_B} \cdot \frac{v_{i1}}{R_1} + \frac{R_A}{R_B} \cdot \frac{v_{i2}}{R_2} - \frac{v_{i3}}{R_3} - \frac{v_{i4}}{R_4} \right) = 3V$$

Esercizio n. 15

$$v_2 = v_i \cdot \frac{R_2}{R_1 + R_2 + R_3} = 3V$$

$$v_3 = v_i \cdot \frac{R_3}{R_1 + R_2 + R_3} = 3V$$

$$v_4 = v_2$$

$$i_4 = \frac{v_4}{R_4} = 0.3 \text{ mA}$$

$$i_5 = i_4$$

$$v_o = v_3 - R_5 \cdot i_5 = -9V$$

$$i_L = \frac{v_o}{R_L} = -5 \text{ mA}$$

$$i_o = i_5 - i_L = 5.3 \text{ mA}$$

Esercizio n. 16

$$i_1 = \frac{v_{i1}}{R_1} = 2 \text{ mA}$$

$$i_5 = \frac{v_{i2} - v_{i1}}{R_5} = 1 \cdot \text{mA}$$

$$i_2 = i_1 - i_5 = 1 \cdot \text{mA}$$

$$v_A = v_{i1} + R_2 \cdot i_2 = 7 \text{ V}$$

$$i_3 = \frac{v_{i2} - v_A}{R_3} = -0.5 \cdot \text{mA}$$

$$i_4 = i_3 + i_5 = 0.5 \cdot \text{mA}$$

$$v_o = v_{i2} + R_4 \cdot i_4 = 10 \text{ V}$$

Esercizio n. 17

$$i_1 = \frac{v_{i1}}{R_1} = 100 \cdot \mu\text{A}$$

$$i_2 = i_1 = 100 \cdot \mu\text{A}$$

$$i_3 = \frac{-v_{i2} + R_2 \cdot i_2}{R_3} = -50 \cdot \mu\text{A}$$

$$i_4 = i_2 + i_3 = 50 \cdot \mu\text{A}$$

$$v_o = -R_2 \cdot i_2 - R_4 \cdot i_4 = -8 \text{ V}$$

$$i_L = \frac{v_o}{R_L} = -8 \cdot \text{mA}$$

Esercizio n. 18

$$v_1 = v_{i1} - v_{i2} = 0.2 \text{ V}$$

$$i_1 = \frac{v_1}{R_1} = 10 \cdot \mu\text{A}$$

$$v_A = v_{i1} = 0.5 \text{ V}$$

$$v_B = v_A - v_1 - R_2 \cdot i_1 = -1.5 \text{ V}$$

$$v_3 = v_B - v_A = -2 \text{ V}$$

$$i_3 = \frac{v_3}{R_3} = -50 \cdot \mu\text{A}$$

$$v_o = v_A - R_4 \cdot i_3 = 8 \text{ V}$$

Esercizio n. 19

$$v_2 = v_i \cdot \frac{R_2}{R_1 + R_2 + R_3} = 2V$$

$$v_{AB} = v_2$$

$$v_o = -\frac{R_5}{R_4} \cdot v_{AB} = -10V$$

$$i_L = \frac{v_o}{R_L} = -10mA$$

$$v_A = v_i \cdot \frac{R_2 + R_3}{R_1 + R_2 + R_3} = 5V$$

$$v_B = v_i \cdot \frac{R_3}{R_1 + R_2 + R_3} = 3V$$

$$v_D = v_B \cdot \frac{R_7}{R_6 + R_7} = 2.5V$$

$$v_C = v_D$$

$$v_4 = v_A - v_C = 2.5V$$

$$i_4 = \frac{v_4}{R_4} = 2.5mA$$

$$i_5 = i_4$$

$$i_o = i_5 - i_L = 12.5mA$$

Esercizio n. 20

$$A_1 = \frac{R_2}{R_1} = 9.802$$

$$A_2 = \frac{R_4}{(R_3 + R_4)} \cdot \left(1 + \frac{R_2}{R_1}\right) = 9.838$$

$$A_d = \frac{A_1 + A_2}{2} = 9.82$$

$$A_c = A_2 - A_1 = 0.036$$

$$CMRR = \frac{A_d}{A_c} = 274.978$$

$$CMRR_{dB} = 20 \cdot \log_{10}(CMRR) = 48.8$$