1) Consider the circuit shown in Figure 1.

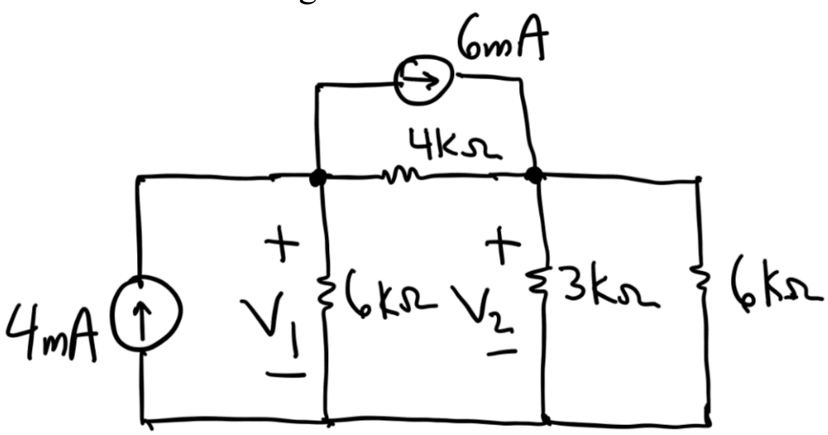


Figure 1. Circuit for Problem 1.

a) Find both $V_1$ and $V_2$ by the node voltage method.

b) Verify your by-hand answers for $V_1$ and $V_2$ in LTSpice. Write out the answers you got from LTSpice and attach any supporting evidence that you actually simulated the circuit to verify your work. The answers you write out for this part should be the same as the results you provided in part (a); if they don't match **by both sign and magnitude**, expect zero credit. Also, expect zero credit 1) if your by-hand and simulated results agree but the results are incorrect, 2) if you do not perform the LTSpice verification altogether, 3) if you only do the LTSpice verification but not the by-hand solution, or 4) if you do not label the voltage nodes and have LTSpice compute the values of $V_1$ and $V_2$ for you.

Make sure to include appropriate units with your numerical answers and list your answers in proper engineering notation format with 2 decimal places of precision! **That means no fractions, no square roots, no instances of π, etc.** Note that this applies to all problems in this course, not just this one!

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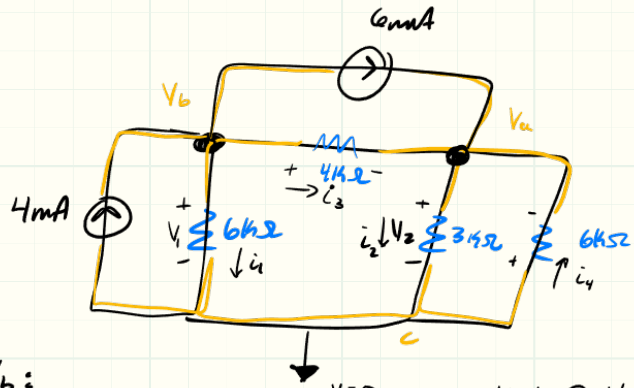



**KCL @ $V_b$:**

$4mA - 6mA - i_3 - i_1 = 0$

$-2mA - i_3 - i_1 = 0$

$2mA = -\frac{V_b - V_a}{R_3} - \frac{V_b - 0}{R_1}$

$2mA = -\frac{1}{R_3}(V_b - V_a) - \frac{1}{R_1}(V_b)$

$2mA = -\frac{1}{R_3}(V_b) + \frac{1}{R_3}(V_a) - \frac{1}{R_1}(V_b)$

① $2mA = \left(\frac{1}{R_3}\right)V_a + \left(-\frac{1}{R_1} - \frac{1}{R_3}\right)V_b \rightarrow$ into matrix

**KCL @ $V_a$:**

$6mA + i_3 - i_2 + i_4 = 0$

$6mA + \frac{V_b - V_a}{R_3} - \frac{V_a - 0}{R_2} + \frac{0 - V_a}{R_4} = 0$

$6mA + \frac{1}{R_3}(V_b - V_a) - \frac{1}{R_2}(V_a) - \frac{1}{R_4}(V_a) = 0$

$6mA + \frac{1}{R_3}(V_b) - \frac{1}{R_3}(V_a) - \frac{1}{R_2}(V_a) - \frac{1}{R_4}(V_a) = 0$

② $6mA = \left(\frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}\right)V_a - \left(\frac{1}{R_3}\right)V_b \rightarrow$ into matrix

$$\begin{bmatrix} 2mA \\ 6mA \end{bmatrix} = \begin{bmatrix} G_3 & -G_1 - G_3 \\ G_2 + G_3 + G_4 & -G_3 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \end{bmatrix} \quad \begin{cases} G_1 = 0.0001666 \\ G_2 = 0.0003333 \\ G_3 = 0.00025 \\ G_4 = 0.0001666 \end{cases}$$

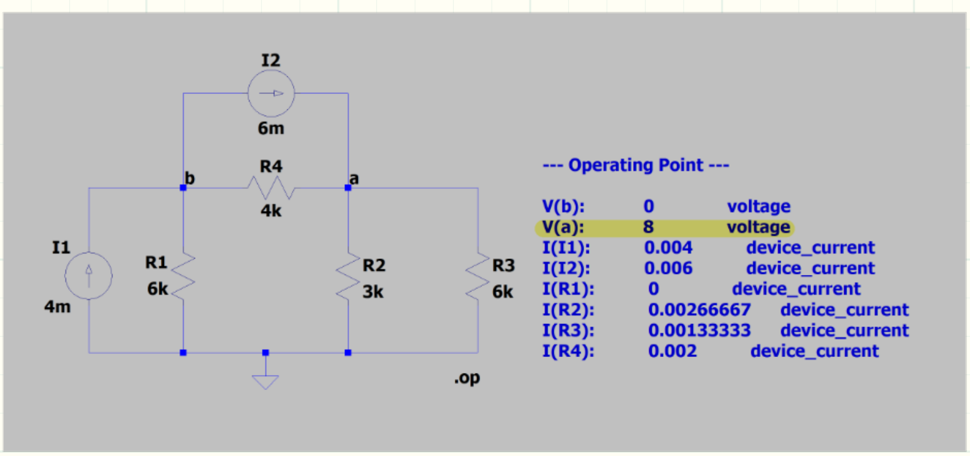
$$\begin{bmatrix} V_a \\ V_b \end{bmatrix} = \begin{bmatrix} 0.00025 & -0.000416 \\ 0.00075 & -0.00025 \end{bmatrix}^{-1} \begin{bmatrix} 0.002 \\ 0.006 \end{bmatrix} \longrightarrow$$

$V_a = 8V$, $V_b = 0V$

$V_1 = (V_b - 0) \rightarrow V_1 = 0V - 0 = 0V$

$V_2 = (V_a - 0) \quad V_2 = 8V - 0 = 8V$

$$\boxed{\begin{matrix} V_1 = 0V \\ V_2 = 8V \end{matrix}}$$



2) Consider the circuit shown in Figure 2.

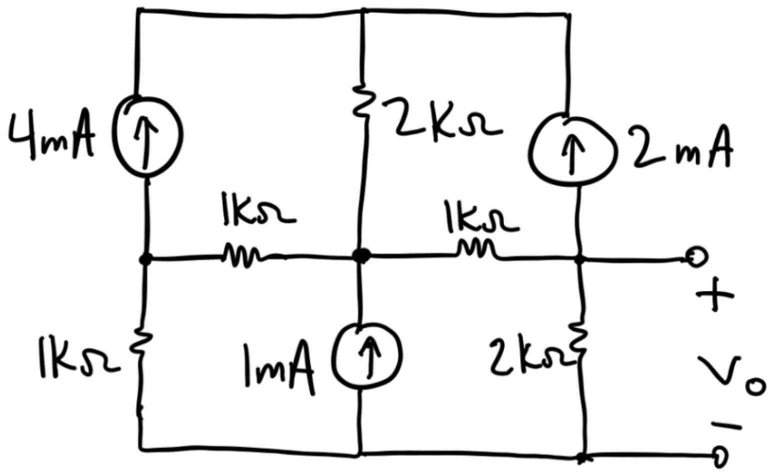



Figure 2. Circuit for Problem 2.

a) Find $V_0$ using the node voltage method.

b) Verify your by-hand answer for $V_0$ LTSpice. Write out the answer you got from LTSpice and attach any supporting evidence that you actually simulated the circuit to verify your work. The answer you write out for this part should be the same as the result you provided in part (a); if it doesn't match **by both sign and magnitude**, expect zero credit. Also, expect zero credit 1) if your by-hand and simulated results agree but the results are incorrect, 2) if you do not perform the LTSpice verification altogether, 3) if you only do the LTSpice verification but not the by-hand solution, or 4) if you do not label the voltage nodes and have LTSpice compute the value of $V_0$ for you.

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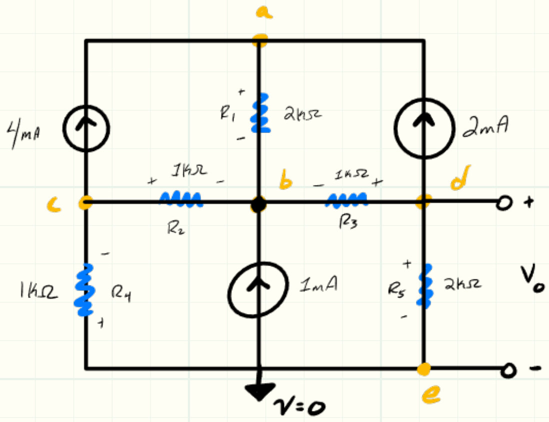



a.) $4mA + 2mA - i_1 = 0$

$i_1 = 6mA$

$6mA = G_1(V_a - V_b)$

$6mA = (G_1)V_a - (G_1)V_b$

b.) $i_1 + i_2 + i_3 = 1mA$

$1mA = G_1(V_a - V_b) + G_2(V_c - V_b) + G_3(V_d - V_b)$

$1mA = G_1V_a - G_1V_b + G_2V_c - G_2V_b + G_3V_d - G_3V_b$

$1mA = (G_1)V_a + (-G_1 - G_2 - G_3)V_b + (G_2)V_c + (G_3)V_d$

$1mA = (-G_1)V_a + (G_1 + G_2 + G_3)V_b + (-G_2)V_c + (-G_3)V_d$

---

$$\begin{bmatrix} 0.006A \\ -0.001A \\ -0.004A \\ -0.002A \end{bmatrix} = \begin{bmatrix} G_1 & -G_1 & 0 & 0 \\ -G_1 & (G_1+G_2+G_3) & -G_2 & -G_3 \\ 0 & -G_2 & (G_2+G_4) & 0 \\ 0 & -G_3 & 0 & (G_3+G_5) \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix}$$

$$\left\{ \begin{aligned} G_1 &= 0.0005 \\ G_2 &= 0.001 \\ G_3 &= 0.001 \\ G_4 &= 0.001 \\ G_5 &= 0.0005 \end{aligned} \right\}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} = \begin{bmatrix} 0.0005 & -0.0005 & 0 & 0 \\ -0.0005 & 0.0025 & -0.001 & -0.001 \\ 0 & -0.001 & 0.002 & 0 \\ 0 & -0.001 & 0 & 0.0015 \end{bmatrix}^{-1} \begin{bmatrix} 0.006 \\ 0.001 \\ -0.004 \\ -0.002 \end{bmatrix}$$

$V_a = 16.4V$ $V_b = 4.4V$ $V_c = 0.2V$ $V_d = 1.6V$

c.) $i_4 - 4mA - i_2 = 0$

$4mA = -i_2 + i_4$

$4mA = -G_2(V_c - V_b) + G_4(0 - V_c)$

$4mA = -G_2V_c + G_2V_b - G_4V_c$

$4mA = (G_2)V_b + (-G_2 - G_4)V_c$

$-4mA = (-G_2)V_b + (G_2 + G_4)V_c$

d.) $-2mA - i_5 - i_3 = 0$

$2mA = -i_5 - i_3$

$2mA = -G_5(V_d - 0) - G_3(V_d - V_b)$

$2mA = -G_5V_d - G_3V_d + G_3V_b$

$2mA = (G_3)V_b + (-G_3 - G_5)V_d$

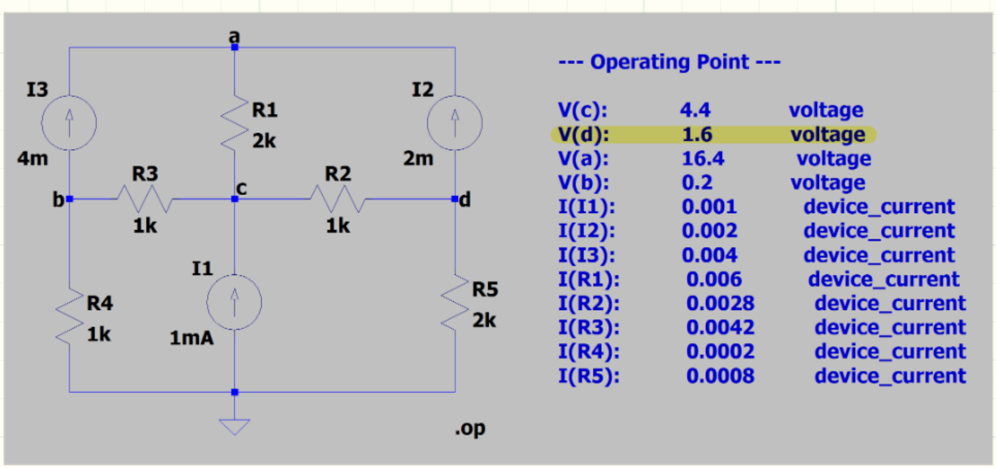
$-2mA = (-G_3)V_b + (G_3 + G_5)V_d$

---

$V_o = V_d - V_e$

$V_o = 1.6V - 0$

$\boxed{V_o = 1.6V}$



3) Consider the circuit shown in Figure 3.

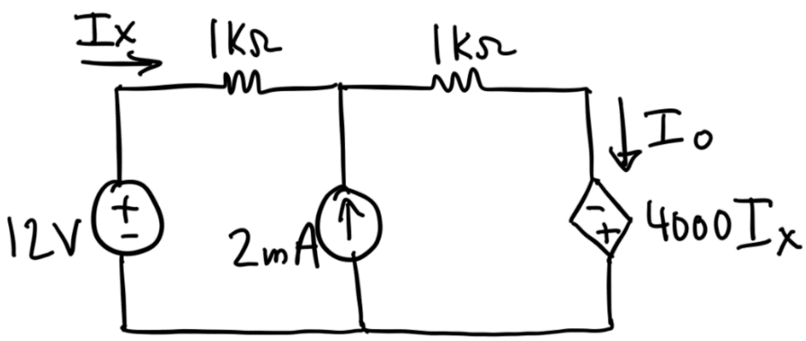



Figure 3. Circuit for Problem 3.

a) Find $I_0$ using the node voltage method.

b) Verify your by-hand answer for $I_0$ in LTSpice. Write out the answer you got from LTSpice and attach any supporting evidence that you actually simulated the circuit to verify your work. The answer you write out for this part should be the same as the result you provided in part (a); if it doesn't match **by both sign and magnitude**, expect zero credit. Also, expect zero credit 1) if your by-hand and simulated results agree but the results are incorrect, 2) if you do not perform the LTSpice verification altogether, 3) if you only do the LTSpice verification but not the by-hand solution, or 4) if you do not use a properly oriented 0-V voltage source ammeter to capture the $I_0$ current in simulation.

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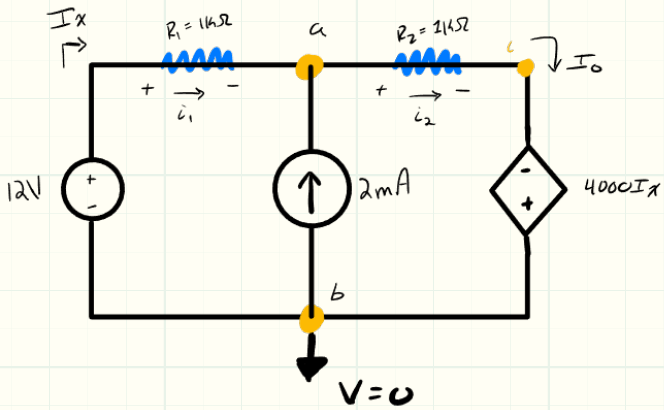
Austin Riha




$$\left[\begin{array}{l} I_x = \dfrac{12V - V_a}{1000} \\ (0V - V_c) = 4000 I_x \end{array}\right]$$

$$-V_c = 4000 I_x$$

$$V_c = -4000\left[\frac{12V - V_a}{1000}\right]$$

$$V_c = \frac{-4000(12V - V_a)}{1000}$$

$$V_c = -4(12V - V_a)$$

$$V_c = 4V_a - 48V$$

## KCL @ $V_a$:

$$i_1 + 2mA = i_2$$

$$\frac{12V - V_a}{R_1} + 2mA = \frac{V_a - V_c}{R_2}$$

$$\frac{12V - V_a}{R_1} - \frac{V_a - V_c}{R_2} = -0.002$$

$$\frac{1}{1k\Omega}\left[12V - V_a - V_a + V_c\right] = -0.002$$

$$12V - 2V_a + V_c = -2A$$

$$12V - 2V_a + (4V_a - 48V) = -2A$$

$$2V_a - 36V = -2V$$

$$2V_a = 34V$$

$$V_a = 17V$$

## Solving $I_o$

$$V_c = 4V_a - 48V$$

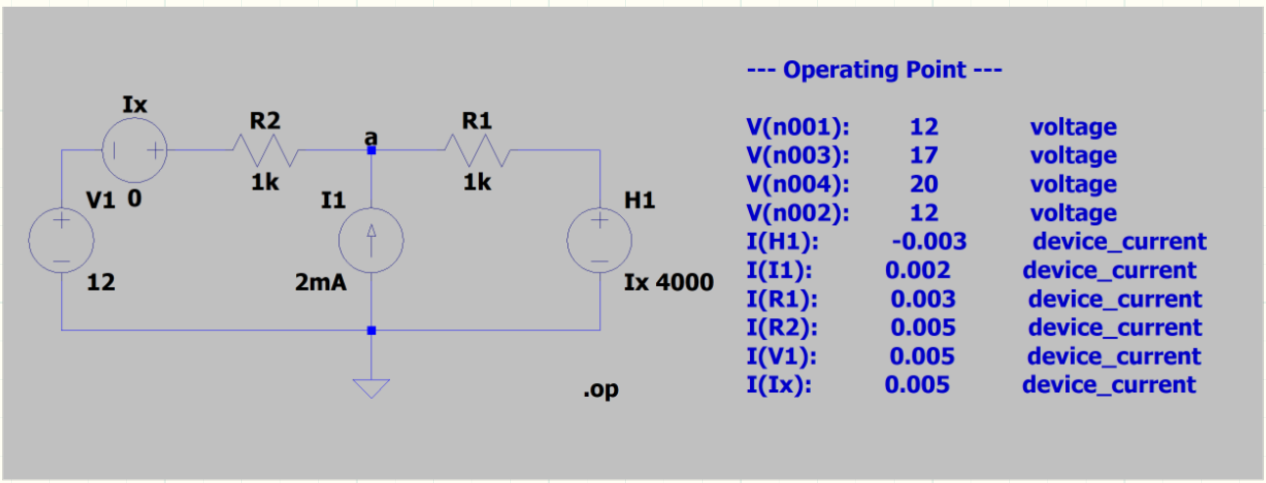
$$V_c = 4(17V) - 48V$$

$$V_c = 20V$$

$$I_o = i_2 = \frac{V_a - V_c}{R_2}$$

$$I_o = \frac{17V - 20V}{1000\Omega} = -0.003A$$

$$\boxed{I_o = -3mA}$$



4) Consider the circuit shown in Figure 4.

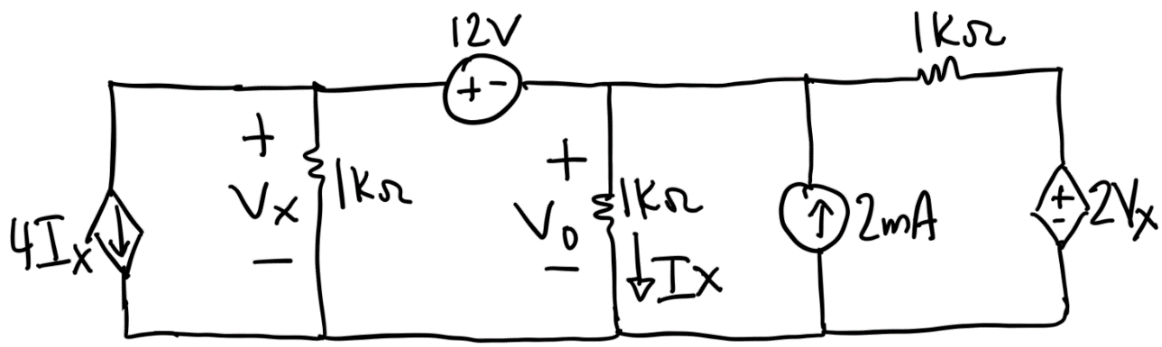
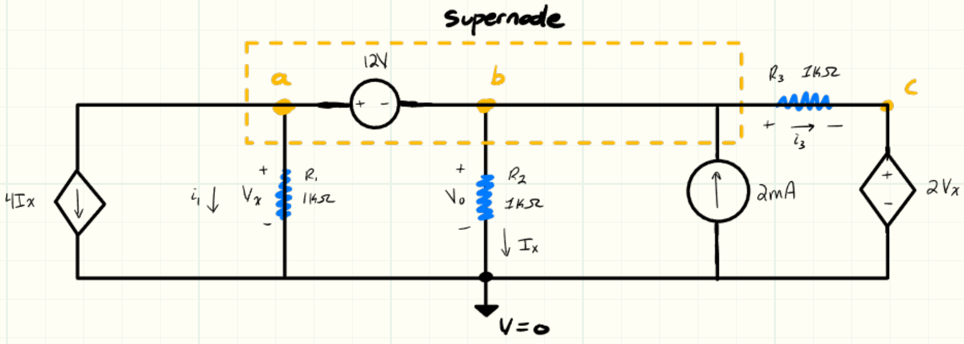



Figure 4. Circuit for Problem 4.

a) Find $V_0$ using the node voltage method.

b) Verify your by-hand answer for $V_0$ LTSpice. Write out the answer you got from LTSpice and attach any supporting evidence that you actually simulated the circuit to verify your work. The answer you write out for this part should be the same as the result you provided in part (a); if it doesn't match **by both sign and magnitude**, expect zero credit. Also, expect zero credit 1) if your by-hand and simulated results agree but the results are incorrect, 2) if you do not perform the LTSpice verification altogether, 3) if you only do the LTSpice verification but not the by-hand solution, or 4) if you do not label the voltage nodes and have LTSpice compute the value of $V_0$ for you.

Austin Riha




**KCL @ Supernode:**

$$4I_x + i_1 + I_x + i_3 = 2mA$$

$$5I_x + i_1 + i_3 = 2mA$$

$$5I_x + \left[\frac{V_x}{R_1}\right] + \left[\frac{V_b - 2V_x}{R_3}\right] = 2mA$$

$V_x = V_a$ ; $R_1 = R_2 = R_3 = 1k\Omega$ ; $V_a - 12V = V_b$

$$5I_x + \frac{V_a}{R_1} + \frac{(V_a - 12) - 2V_a}{R_3} = 2mA$$

$$5I_x + \frac{V_a}{R} + \frac{-V_a - 12}{R} = 2mA$$

$$5I_x - \frac{12}{R} = 2mA$$

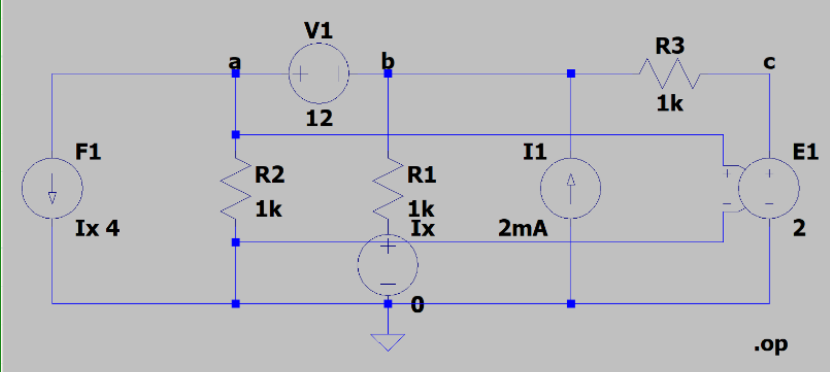
$$I_x = \frac{2mA + 12/R}{5}$$

$I_x = 0.0028A$ $\quad V = IR$

$I_x = 2.8mA$ $\quad V_o = I_x \cdot R_2$

$$V_o = 0.0028A \cdot 1000\Omega$$

$$\boxed{V_o = 2.8V}$$




--- Operating Point ---

| | | |
|---|---|---|
| V(a): | 14.8 | voltage |
| V(c): | 29.6 | voltage |
| V(b): | 2.8 | voltage |
| V(p001): | 0 | voltage |
| I(F1): | 0.0112 | device_current |
| I(I1): | 0.002 | device_current |
| I(R1): | 0.0028 | device_current |
| I(R2): | 0.0148 | device_current |
| I(R3): | 0.0268 | device_current |
| I(E1): | -0.0268 | device_current |
| I(V1): | -0.026 | device_current |
| I(Ix): | 0.0028 | device_current |