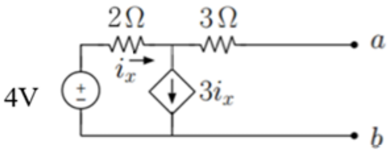
Homework 3

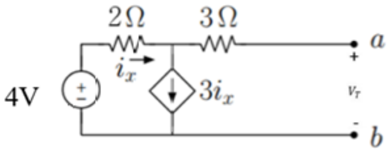
Due: Wednesday March 12, 2025, 11:59 pm

1. In the following circuit find the open-circuit voltage and the short-circuit current between nodes a to b and determine the Thevenin and Norton equivalent of the network between nodes a and b.



Solution:

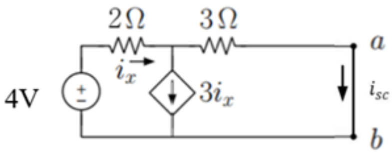
To find the open-circuit voltage, apply KCL at the upper node:



$$\frac{4 - V_T}{2} = 3i_x$$

$$\frac{4 - V_T}{2} = 3\left(\frac{4 - V_T}{2}\right)$$
$$V_T = 4\text{V}$$

To find the short circuit current, apply KVL at left inner loop:



$$4 = 2i_x + 3i_{sc}$$

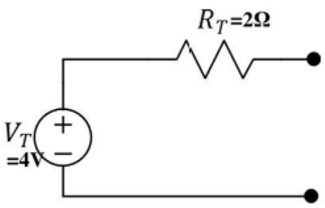
Since $i_x = -\frac{i_{sc}}{2}$, the short circuit current is:

$$2\left(-\frac{i_{sc}}{2}\right) + 3i_{sc} = 4$$
$$i_{sc} = 2A$$

To solve for R_T,

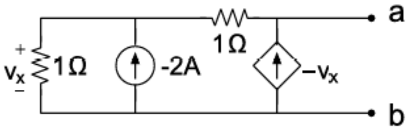
$$R_T = \frac{V_T}{i_{sc}} = 2\Omega$$

Therefore, the Thevenin equivalent is:



the Norton equivalent is:

2. Determine the Thevenin equivalent of the following network between nodes a and b, and then determine the available power of the network:



Solution:

To get the open-circuit voltage we analyze the circuit as shown in the problem statement. Applying KCL at the upper left node yields

$$-2 - v_x = v_x,$$

which gives

$$v_x = -1\text{V}.$$

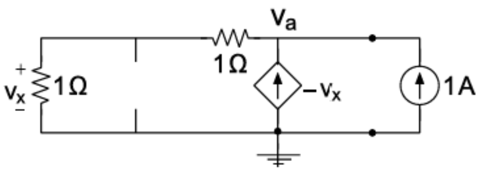
Loop equation around the outer loop can be written as

$$v_x - v_x - v_{\text{ab}} = 0,$$

which gives

$$v_{oc} = v_{\text{ab}} = 0.$$

Hence the Thevenin voltage is 0. It can be shown that the short-circuit current for the circuit is also 0. In this case we couldn't obtain the equivalent resistance by dividing v_{oc} by i_{sc}. To find R_{eq} we set the independent source to zero and add a test signal:



Writing the KCL equation for node v_a, we have

$$1 - v_x = v_x,$$

which gives

$$v_x = \frac{1}{2}\text{V}.$$

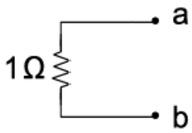
The same current flows through the two 1Ω resistors, which yields

$$v_{\text{a}} = 2v_x = 1\text{V}.$$

The equivalent resistance can thus be calculated as,

$$R_{eq} = \frac{v_a}{1\text{A}} = 1\Omega.$$

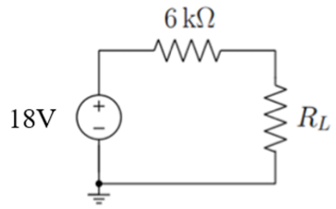
The Thevenin equivalent circuit is:



As a result, the available power is:

$$p_{\text{av}} = 0.$$

3. Consider the circuit below.



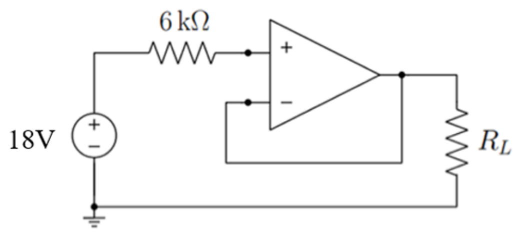
Calculate the absorbed power in R_L for

(a) $R_L = 3\,\text{k}\Omega$

(b) $R_L = 6\,\text{k}\Omega$

(c) $R_L = 12\,\text{k}\Omega$

Next, consider the circuit below, which implements a buffer between the source and the load. Assume the circuit behaves linearly and make use of the ideal op-amp approximations.



Calculate the absorbed power in R_L for

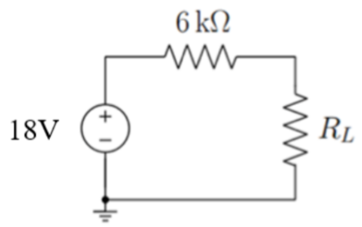
(d) $R_L = 3\,\text{k}\Omega$

(e) $R_L = 6\,\text{k}\Omega$

(f) $R_L = 12\,\text{k}\Omega$

(g) Compare your answers from parts (a)-(c) to parts (d)-(f) and comment on why the power absorbed by the load is different for the two circuit designs (e.g., consider why one circuit delivers more power to the load and where that power comes from).

Solution:



First, we can calculate the voltage across R_L.

$$V_L = 18\frac{R_L}{6k + R_L}$$

Next, we can calculate the absorbed power in R_L.

$$P_L = \frac{V_L^2}{R_L} = 324\frac{R_L}{(R_L + 6k)^2}$$

Therefore, the absorbed power is

$$(a)P_L = 0.012W$$
$$(b)P_L = 0.0135W$$
$$(c)P_L = 0.012W$$

Next, consider the circuit below, which implements a bu er between the source and the load. Assume the circuit behaves linearly and make use of the ideal op-amp approximations. Calculate the absorbed power in R_L for

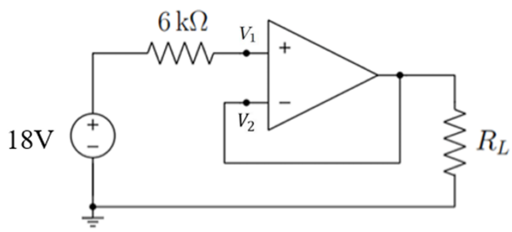
(d) $R_L = 3k\Omega$

(e) $R_L = 6k\Omega$

(f) $R_L = 12k\Omega$

Solution:

First, we need to calculate the voltage across R_L.



We will have a relationship between $V_1$and V_2 which is:

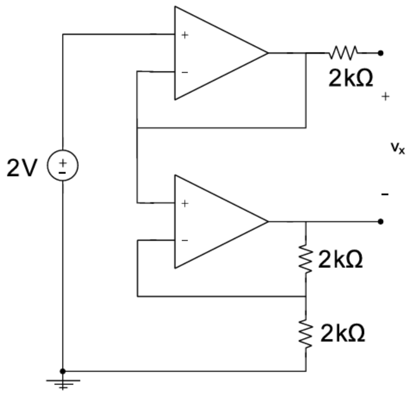
$$V_1 = V_2 = 18V$$

With the voltage and resistance of the load, we can calculate the consumed energy.

$$P_L = \frac{V_2^2}{R_L}$$

$$(a)P_L = 0.108W$$
$$(b)P_L = 0.054W$$
$$(c)P_L = 0.027W$$

4. In the op-amp circuit shown below, determine the voltage v_x assuming linear operation.



Solution:

Considering the ideal op-amp assumptions, we have $v^+ = v^- = 2$V for both op-amps. At the bottom of the circuit we identify a non-inverting amplifier with a gain of

$$G = 1 + \frac{2\text{k}\Omega}{2\text{k}\Omega} = 2,$$

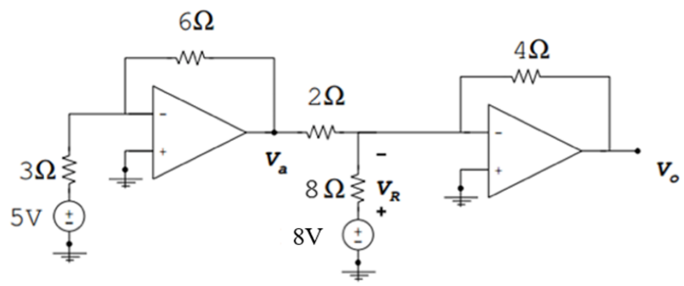
with the output

$$v_{bottom} = G \times 2\text{V} = 4\text{V}.$$

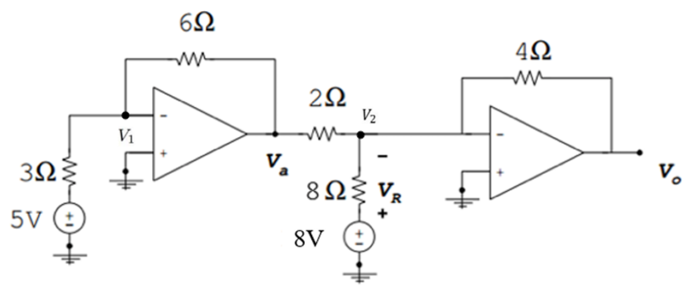
At the top of the circuit we have a voltage follower and no current flowing through the resistor. Consequently, the output v_{top} is 2V. Finally we obtain

$$v_x = v_{top} - v_{bottom} = 2\text{V} - 4\text{V} = -2\text{V}.$$

5. In the op-amp circuit shown below, determine the voltages V_a, V_R, and V_o. Assume the circuit behaves linearly and make use of the ideal op-amp approximation.



Solution:



To find the V_a, apply KCL at node V_1:

$$\frac{5 - V_1}{3} + \frac{V_a - V_1}{6} = 0$$

According to the characteristics of op-amp, V_1 becomes:

$$V_1 = 0V$$

Therefore, we can calculate V_a.

$$V_a = -10V$$

According to the characteristics of op-amp, V_2 becomes:

$$V_2 = 0V$$

Therefore, we can calculate V_R.

$$V_R = 8 - V_2 = 8V$$

To find the V_o, apply KCL at node V_2:

$$\frac{V_a - V_2}{2} + \frac{V_R}{8} = \frac{V_2 - V_o}{4}$$

$$V_o = -\frac{4V_a + V_R}{2} = 16V$$