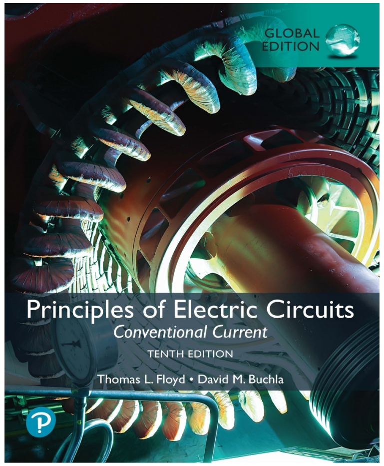
Principles of Electric Circuits: Conventional Current

Tenth Edition, Global Edition



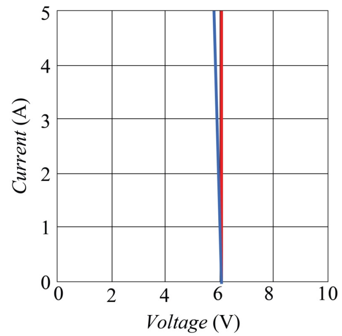
Chapter 8

Circuit Theorems and Conversions

Summary: Voltage sources (1 of 3)

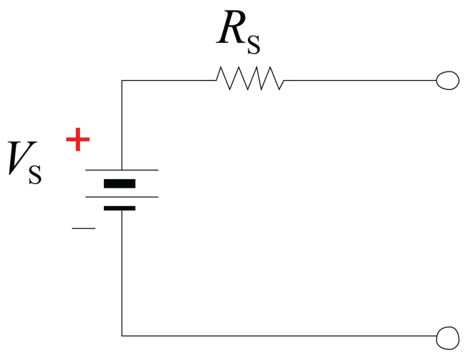
An ideal voltage source plots a vertical line on the *VI* characteristic as shown for an ideal 6.0 V source.

Actual voltage sources include the internal source resistance, which can drop a small voltage under load. The characteristic of a non-ideal source is not vertical.



Summary: Voltage sources (2 of 3)

A practical voltage source is drawn as an ideal source in series with the source resistance. When the internal resistance is zero, the source reduces to an ideal one.



Summary: Voltage sources (3 of 3)

Example:

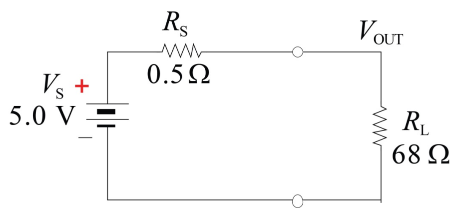
If the source resistance of a 5.0 V power supply is 0.5 Ω, what is the voltage across a 68 Ω load?

Solution:

Use the voltage-divider equation:

$$V_L = \left(\frac{R_L}{R_L + R_S}\right) V_S$$

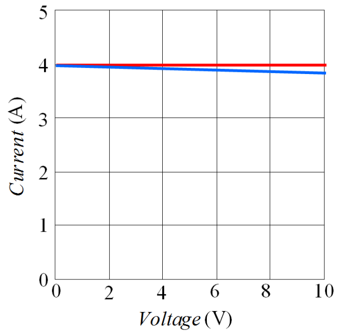
$$= \left(\frac{68\ \Omega}{68\ \Omega + 0.5\ \Omega}\right) 5\ \text{V} = 4.96\ \text{V}$$



Summary: Current sources (1 of 3)

An ideal current source plots a horizontal line on the *VI* characteristic as shown for the ideal 4.0 mA source.

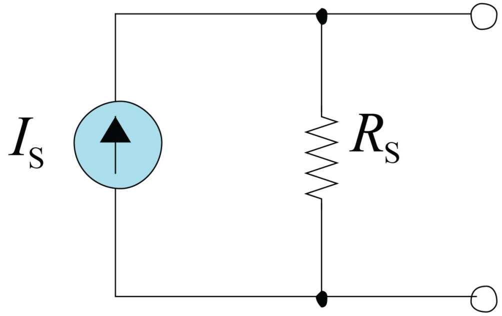
Practical current sources have internal source resistance, which takes some of the current. The characteristic of a practical source is not horizontal.



Pearson

Summary: Current sources (2 of 3)

A practical current source is drawn as an ideal source with a parallel source resistance. When the source resistance is infinite, the current source is ideal.



Pearson

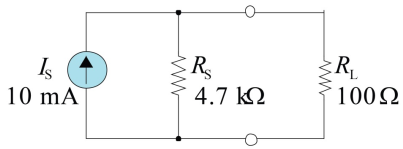
Summary: Current sources (3 of 3)

Example:

If the source resistance of a 10 mA current source is 4.7 kΩ, what is the current in a 100 Ω load?

Solution:

Use the current-divider equation:



$$I_L = \left(\frac{R_S}{R_L + R_S}\right) I_S$$

$$= \left(\frac{4.7\ \text{k}\Omega}{100\ \Omega + 4.7\ \text{k}\Omega}\right) 10\ \text{mA} = 9.8\ \text{mA}$$

Pearson

Summary: Source conversions

Any voltage source with an internal resistance can be converted to an equivalent current source and vice-versa by applying Ohm's law to the source. The source resistance, R_S, is the same for both.

To convert a voltage source to a current source, $I_S = \frac{V_S}{R_S}$

To convert a current source to a voltage source, $V_S = I_S R_S$

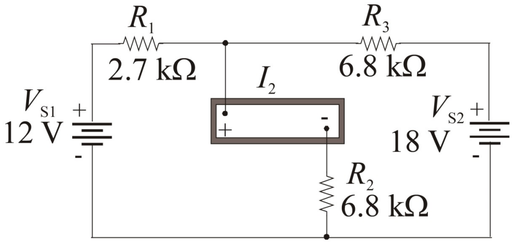
Pearson

Summary: Superposition theorem

The superposition theorem is a way to determine currents and voltages in a linear circuit that has multiple sources by taking one source at a time and algebraically summing the results.

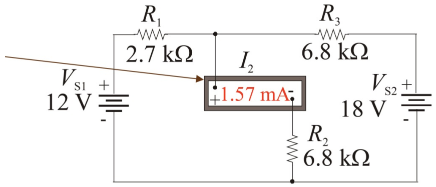
Example:

What does the ammeter read for I_2? (See next slide for the method and the answer).



Summary

What does the ammeter read for I_2?



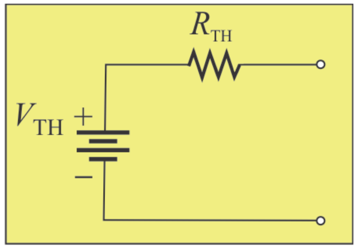
Set up a table of pertinent information and solve for each quantity listed:

Source 1:	$R_{T(S1)}$ = 6.10 kΩ	I_1 = 1.97 mA	I_2 = 0.98 mA
Source 2:	$R_{T(S2)}$ = 8.73 kΩ	I_3 = 2.06 mA	I_2 = 0.59 mA
Both sources			I_2 = 1.57 mA

The total current is the algebraic sum.

Summary: Thevenin's theorem (1 of 7)

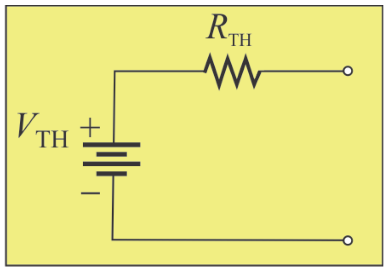
Thevenin's theorem states that any two-terminal, resistive circuit can be replaced with a simple equivalent circuit when viewed from two output terminals. The equivalent circuit is:



Summary: Thevenin's theorem (2 of 7)

V_{TH} is defined as the open circuit voltage between the two output terminals of a circuit.

R_{TH} is defined as the total resistance appearing between the two output terminals when all sources have been replaced by their internal resistances.



Summary: Thevenin's theorem (3 of 7)

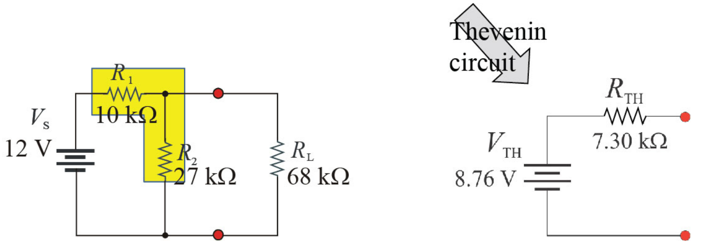
Example:

Find the Thevenin voltage and resistance for the circuit.

To find V_{TH}, apply a voltage divider to R_1 and R_2.

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_S = \left(\frac{27\text{ k}\Omega}{10\text{ k}\Omega + 27\text{ k}\Omega}\right)12\text{ V} = 8.76\text{ V}$$

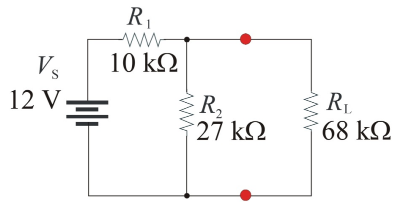
$$R_{TH} = 10\text{ k}\Omega \,||\, 27\text{ k}\Omega = 7.30\text{ k}\Omega$$



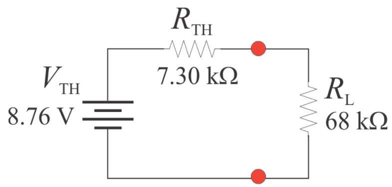
Summary: Thevenin's theorem (4 of 7)

Follow up:

What is the voltage across R_L?



Since we know the Thevenin circuit, the easiest way to answer the question is to use it and apply the voltage divider theorem.

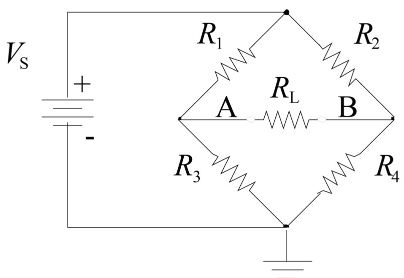


$$V_L = \left(\frac{R_L}{R_{TH} + R_L}\right)V_{TH} = \left(\frac{68\text{ k}\Omega}{7.3\text{ k}\Omega + 68\text{ k}\Omega}\right)8.76\text{ V} = 7.91\text{ V}$$

Summary: Thevenin's theorem (5 of 7)

Thevenin's theorem is useful for solving the Wheatstone bridge. One way to Thevenize the bridge is to create two Thevenin circuits - from A to ground and from B to ground.

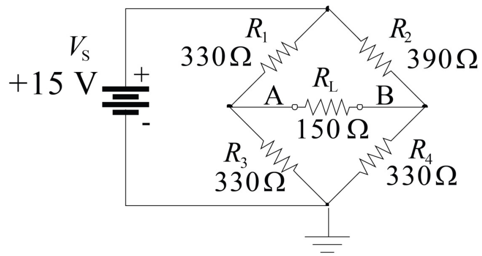
The resistance between point A and ground is $R_1||R_3$ and the resistance from B to ground is $R_2||R_4$. The voltage on each side of the bridge is found using the voltage divider rule.



Summary: Thevenin's theorem (6 of 7)

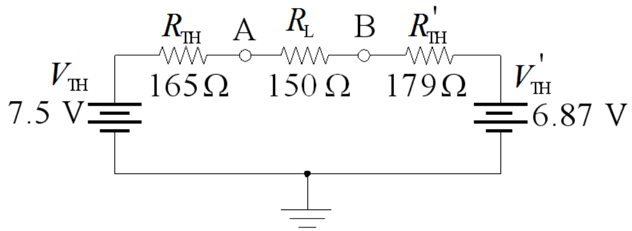
Example:

For the bridge shown, $R_1||R_3$ = 165 Ω and $R_2||R_4$ = 179 Ω. The voltage from A to ground (with no load) is 7.5 V and from B to ground (with no load) is 6.87 V.



The Thevenin circuits for each side of the bridge are shown on the following slide.

Summary: Thevenin’s theorem (7 of 7)

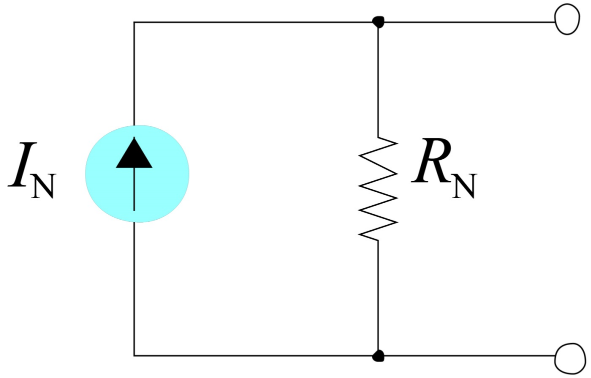


Putting the load on the Thevenin circuits and applying the superposition theorem allows you to calculate the load current. The load current is: 1.27 mA

The dual Thevenin circuits used in this analysis have the advantage of retaining the ground from the original circuit.

Summary: Norton’s theorem (1 of 4)

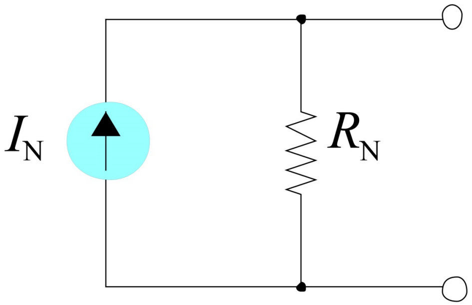
Norton’s theorem states that any two-terminal, resistive circuit can be replaced with a simple equivalent circuit when viewed from two output terminals. The equivalent circuit is:



Summary: Norton’s theorem (2 of 4)

I_N is defined as the output current when the output terminals are shorted.

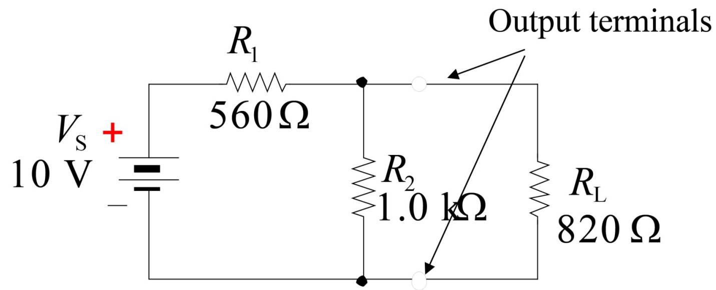
R_N is defined as the total resistance appearing between the two output terminals when all sources have been replaced by their internal resistances.



Summary: Norton’s theorem (3 of 4)

What is the Norton current for the circuit? 17.9 mA

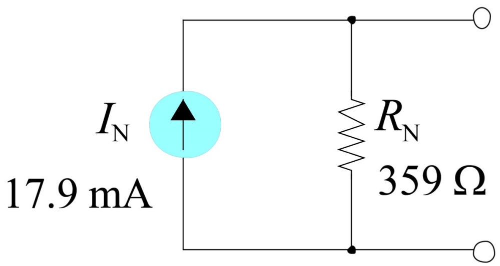
What is the Norton resistance for the circuit? 359 Ω



The Norton circuit is shown on the following slide.

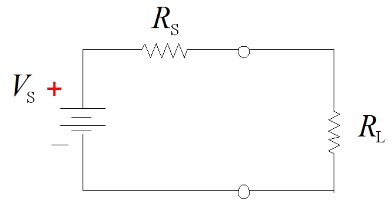
Summary: Norton's theorem (4 of 4)

The Norton circuit (without the load) is:



Summary: Maximum power transfer (1 of 5)

The maximum power is transferred from a source to a load when the load resistance is equal to the internal source resistance.



The maximum power transfer theorem assumes the source voltage and resistance are fixed.

Summary: Maximum power transfer (2 of 5)

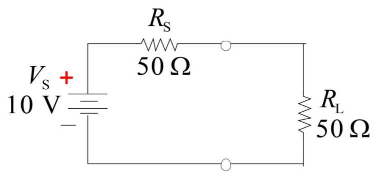
Example:

What is the power delivered to the matching load?

Solution:

The voltage to the load is 5.0 V. The power delivered is

$$P_L = \frac{V^2}{R_L} = \frac{(5.0\text{ V})^2}{50\ \Omega} = 0.5\text{ W}$$



Summary: Maximum power transfer (3 of 5)

You can view a plot of power as a function of resistance for a given circuit using a graphics calculator. Let's graph the data for the previous problem over a series of load resistors using the TI84 Plus CE calculator. (This procedure is specific to this calculator.)

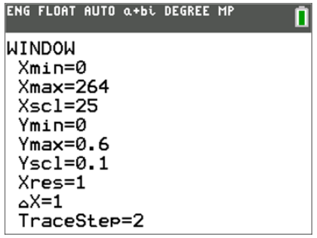
Store 10 in a variable named V (the Thevenin voltage) and 50 in a variable named R (the Thevenin resistance). To enter the value of V, press

Enter the equation as $Y_1 = (V^2/(R^2 + 2RX + X^2))X$, which is the equation for power to the load (Y_1) as a function of load resistance (see Example 8-18 in the text.)

Summary: Maximum power transfer (4 of 5)

Set up the parameters for your graph by pressing [window].

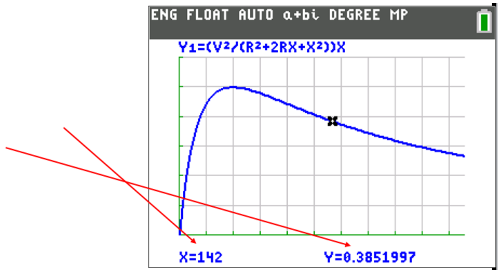
A sample of window settings for this problem are shown to the right. When you set ΔX (the cursor increment), the X_{MAX} may change depending on the input parameters. The settings shown will trace resistance values in 2 Ω increments.



Summary: Maximum power transfer (5 of 5)

Press [graph] and [trace] to show the plot and parameters.

The cursor can be moved to display different values. The position shown indicates that a load resistance of 142 Ω will dissipate 385 mW of power.

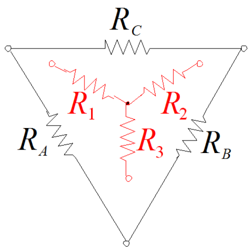


Summary: Δ-to-Y and Y-to-Δ conversion (1 of 2)

The Δ-to-Y and Y-to-Δ conversion formulas allow a three terminal resistive network to be replaced with an equivalent network.

For the Δ-to-Y conversion, each resistor in the Y is equal to the product of the resistors in the two adjacent Δ branches divided by the sum of all three Δ resistors.

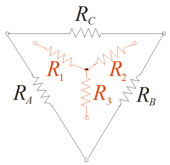
For example, $R_1 = \dfrac{R_A R_C}{R_A + R_B + R_C}$



Summary: Δ-to-Y and Y-to-Δ conversion (2 of 2)

The Δ-to-Y and Y-to-Δ conversion formulas allow a three terminal resistive network to be replaced with an equivalent network.

For the Y-to-Δ conversion, each resistor in the Δ is equal to the sum of all products of Y resistors, taken two at a time divided by the opposite Y resistor.



For example, $R_A = \dfrac{R_1R_2 + R_2R_3 + R_1R_3}{R_2}$

Key Terms (1 of 2)

Current source A device that ideally provides a constant value of current regardless of the load.

Maximum power transfer Transfer of maximum power from a source to a load occurs when the load resistance equals the internal source resistance.

Norton's theorem A method for simplifying a two-terminal linear circuit to an equivalent circuit with only a current source in parallel with a resistance.

Superposition theorem A method for analysis of circuits with more than one source.

Key Terms (2 of 2)

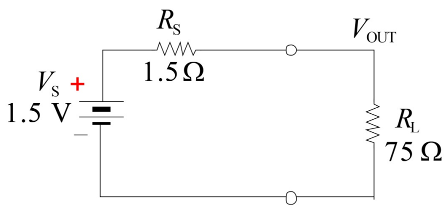
Terminal equivalency The concept that when any given load resistance is connected to two sources, the same load voltage and load current are produced by both sources.

Thevenn's theorem A method for simplifying a two-terminal linear circuit to an equivalent circuit with only a voltage source in series with a resistance.

Voltage source A device that ideally provides a constant value of voltage regardless of the load.

Quiz (1 of 11)

1. The source resistance from a 1.50 V D-cell is 1.5 Ω. The voltage that appears across a 75 Ω load will be
   a. 1.47 V
   b. 1.50 V
   c. 1.53 V
   d. 1.60 V



Quiz (2 of 11)

2. The internal resistance of an ideal current source
   a. is 0 Ω
   b. is 1 Ω
   c. is infinite
   d. depends on the source

Quiz (3 of 11)

3. The superposition theorem *cannot* be applied to
   - a. circuits with more than two sources
   - b. nonlinear circuits
   - c. circuits with current sources
   - d. ideal sources

Quiz (4 of 11)

4. The circuit for a Thevenin equivalent is a
   - a. resistor in series with a voltage source
   - b. resistor in parallel with a voltage source
   - c. resistor in series with a current source
   - d. resistor in parallel with a current source

Quiz (5 of 11)

5. The circuit for a Norton equivalent is a
   - a. resistor in series with a voltage source
   - b. resistor in parallel with a voltage source
   - c. resistor in series with a current source
   - d. resistor in parallel with a current source

Quiz (6 of 11)

6. A signal generator has an output voltage of 2.0 V with no load. When a 600 Ω load is connected to it, the output drops to 1.0 V. The Thevenin resistance of the generator is
   - a. 300 Ω
   - b. 600 Ω
   - c. 900 Ω
   - d. 1200 Ω.

Quiz (7 of 11)

7. A signal generator has an output voltage of 2.0 V with no load. When a 600 Ω load is connected to it, the output drops to 1.0 V. The Thevenin voltage of the generator is

   a. 1.0 V

   b. 2.0 V

   c. 4.0 V

   d. not enough information to tell.

Quiz (8 of 11)

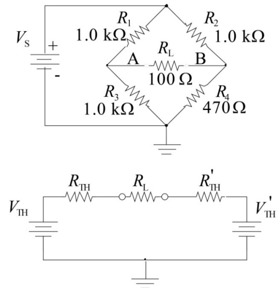
8. A Wheatstone bridge is shown with the Thevenin circuit as viewed with respect to ground. The total Thevenin resistance (R_{TH} + R_{TH}') is

   a. 320 W

   b. 500 W

   c. 820 W

   d. 3.47 kW.



Quiz (9 of 11)

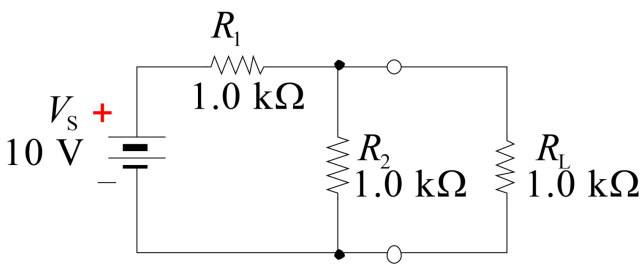
9. The Norton current for the circuit is

   a. 5.0 mA

   b. 6.67 mA

   c. 8.33 mA

   d. 10 mA



Quiz (10 of 11)

10. Maximum power is transferred from a fixed source when

    a. the load resistor is ½ the source resistance

    b. the load resistor is equal to the source resistance

    c. the load resistor is twice the source resistance

    d. none of the above

Quiz (11 of 11)

Answers:

1. a
2. c
3. b
4. a
5. d
6. b
7. b
8. c
9. d
10. b

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