3 Three Theorems

This chapter deals with three theorems that are great tools in analysis of a circuit. They are useful as tools to simplify an electrical circuit instead of using brute force to find all the currents and voltages. They make sense when we are discussing linear circuits. They are applicable in a number of different situations and give us some valuable tools for getting a specific answer when that is all that is needed.

We use them in linear circuits today but must remember that they can be helpful in complicated non-linear circuits. These involve semiconductors and give us tools to analyze only a portion of the entire circuit when that is all that we need.

The Voltage-Divider

When the voltage across a circuit splits across more than one resistor, use the voltage divider theorem to calculate the voltage across a resistor. It is the one-step process. If one were to find current first, then voltage, that would require two steps. Thus, voltage divider is usually a faster way to a voltage than finding current.

Development of the Voltage Divider Formula:

We use I in the Fig. 3.1 to write V_2 as:

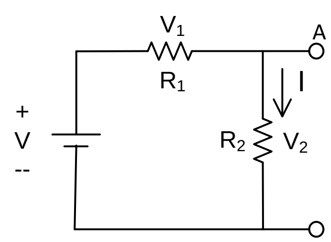


Fig. 3-1(a)

$$V_2 = R_2 \cdot I$$

$$V = (R_1 + R_2) \cdot I$$

We now write the ratio of V_2/V:

$$\frac{V_2}{V} = \frac{R_2}{R_1 + R_2}$$

or

$$\frac{V_2}{V} = \frac{R_2}{R_T}$$

where $R_T = R_1 + R_2$. Re-arranging, we get V_2:

$$V_2 = \frac{R_2}{R_T} V$$

This equation makes good sense since we have seen before that the ratio of the voltage is equal to the relative values of the series resistors. In this equation, the ratio is the ratio of the voltage across R_2 over the total Resistance – R_T.

If two resistors are in the voltage divider equation, the following equation is used:

$$\frac{V_2}{V} = \frac{R_2}{R_1 + R_2}$$

and

$$V_2 = \frac{R_2}{R_1 + R_2} \cdot V$$

We see in Fig. 3.1(b) the equation has just two resistors:

$$V_2 = \frac{R_2}{R_1 + R_2} V = \frac{7000}{10000} 10 = 7V$$

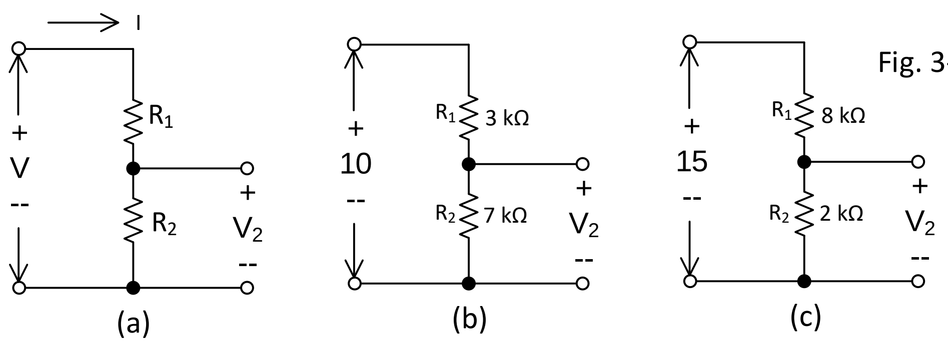
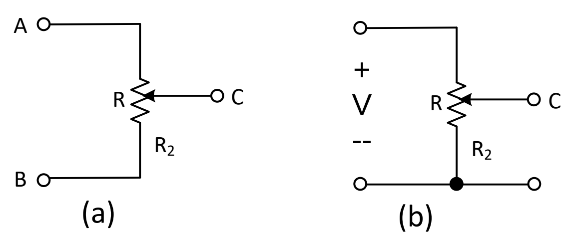


Fig. 3-1

Fig. 3-2



Also, in Fig. 3-1(c) the same equation is used and V_2 is:

$$V_2 = \frac{R_2}{R_T} V = \frac{2000}{10000} 15 = 3\ V$$

Splitting of Resistors –The Potentiometer

A potentiometer splits a resistance into two resistors. There are three terminals. When a potentiometer is turned, the resistance between two terminals increases while the other resistor decreases. The potentiometer may be turned all the way to zero in either direction, either to the left or to the right. Again,

$$V_2 = \frac{R_2}{R_T} V$$

Seeing Fig. 3.2b, the resistance of R_2 determines the value of V_2.

In Fig. 3-3a, we want to find the min and max voltages across the output. We also want to find the voltage at the mid-point of the wiper:

The wiper is totally counter-clockwise with zero resistance across the output:

$$V_2 = \frac{0}{R_T} V = \frac{0}{R_T} V = 0 \text{ V}$$

Now, with the wiper totally clockwise, with R_T across R_2:

$$V_2 = \frac{R_T}{R_T} V = \frac{10{,}000}{10{,}000} 2 = 2 \text{ V}$$

What is the voltage V_2 with the potentiometer in the in the middle?

$$V_2 = \frac{R_2}{R_T} V = \frac{5{,}000}{10{,}000} 2 = 1 \text{ V}$$

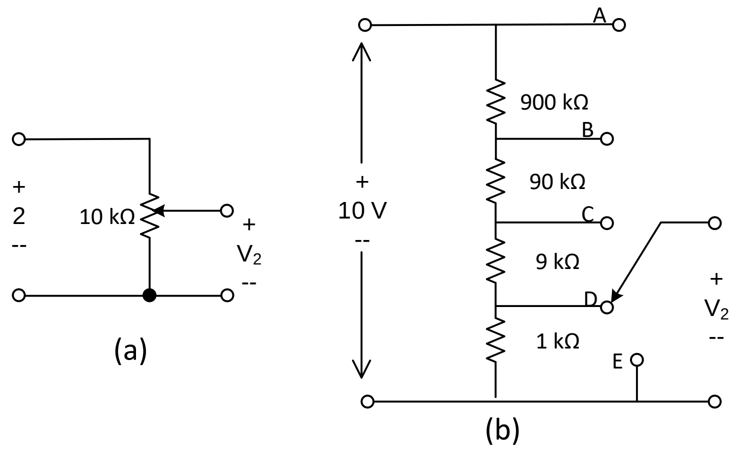
A second example of a switch picking a variety of resistances at terminals is shown in Fig 3-3b. Each resistance is a series resistor and is added as follows:

R_T = 900,000 + 90,000 + 9,000 + 1,000
= 1,000,000 Ω = 1 M Ω

At the various positions of the switch, a different voltage may be calculated. Find the values at the different switch positions A through E.

At position E, the voltage across the R_2 is zero or no resistance. Therefore, the voltage at E is 0.

Fig. 3-3



At D, R_2 = 1 kΩ and

$$V_2 = \frac{R_2}{R_T} V = \frac{1{,}000}{1{,}000{,}000} 10 = 10 \text{ mV}$$

At C, R_2 = 10 kΩ and

$$V_2 = \frac{10{,}000}{1{,}000{,}000} 10 = 0.1 \text{ V} = 100 \text{ mV}$$

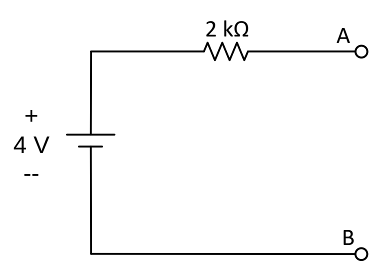
At B, R_2 = 100 kΩ and

$$V_2 = \frac{100{,}000}{1{,}000{,}000} 10 = 1 \text{ V}$$

The output steps from 10 mV to 100 mV to 1 V and finally 10 V for the switch positions.

Development of the Thevenin Circuit

When we look at an electronic circuit, we very rarely need to find all the voltages and all currents. Usually, we only have to find the equivalent circuit with a voltage and resistor in series. This is somewhat of a 'lego' approach to circuits but many times is all that is necessary. We see this as the 'world's simplest circuit' and resembles:

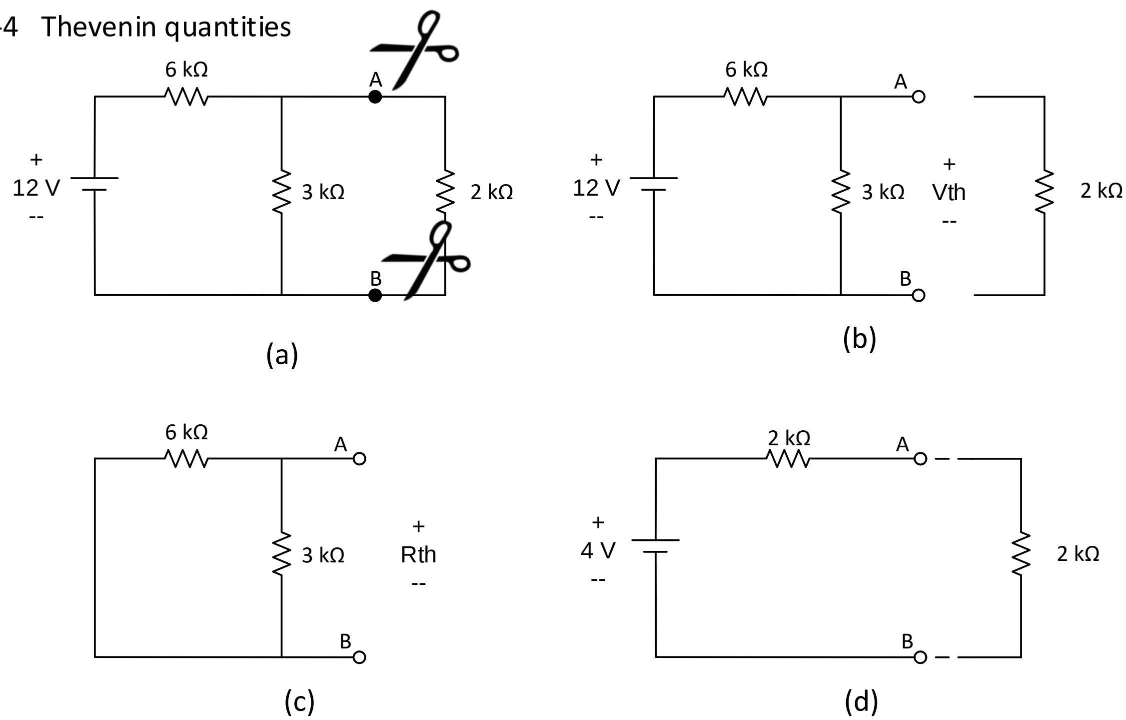


The 4V source is referred to as the Thevenin voltage. The 2kΩ resistor is the Thevenin resistance and the circuit is referred to as the Thevenin circuit. Some would even say 'Thevenize, thevenize everything before your eyes. That's why God made your eyes – to Thevenize.'

What does a truck have to do with our course you might ask?

This is a lego truck made entirely of 334,544 pieces and took 18 builders 2,000+ hours to build. It is a Chevy Silverado 1500. We will not be building anything like this but it is a cool concept and the lego idea is at work here in spades.

Fig. 3-4   Thevenin quantities



Thevenin voltage

The Thevenin voltage is that voltage across a pair of terminals with the circuit open at those terminals. Picture the circuit above and a pair of scissors. Cut the circuit at the A-B terminals. Then measure the voltage across the A-B terminals with the circuit now open and the 2 kΩ resistor not part of the new circuit. We remember the 2 kΩ resistor but not part of the circuit we are creating called the Thevenin circuit. The voltage between the A-B terminals is the new V_{th}. This voltage is the first component of the new world's simplest circuit or lego circuit.

In Figure 3-4b 23 use voltage divider to find V_{th}. It equals:

$$V_{th} = \frac{R_2}{R_T} V = \frac{3{,}000}{9{,}000} \cdot 12 = 4\ V$$

Thevenin resistance

The Thevenin resistance is the resistance between the same terminals where the cuts in the circuit occurred. To find this resistance, the voltage source is shorted and any current source is opened. The voltage source that is shorted is pictured as a line or wire with no source present

If we start at the A terminal and walk the circuit back and end at the B terminal, we notice that the two resistances in Fig. 3-4c are in parallel. The resultant Thevenin resistance is:

$$R_{th} = \frac{6000 \times 3000}{6000 + 3000} = 2\ k\Omega$$

Thevenin circuit

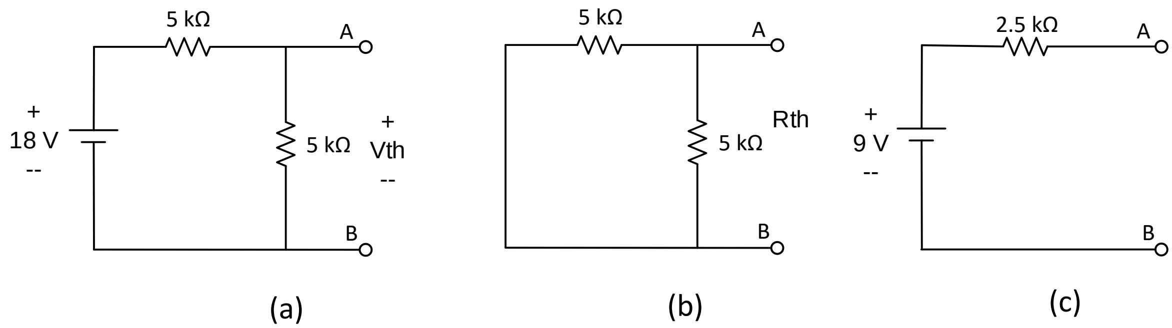
The Thevenin circuit is the world's simplest circuit with only a single voltage source and single resistance in series and open terminals at the right. We have found these values in Fig. 3-4a;

$V_{th} = 4$ V
$R_{th} = 2$ kΩ

Figure 3-4d shows the Thevenin circuit with the resistor previously removed ready to be re-attached which is usually the final step in the problem. The original circuit left of the A-B terminals is equal to the new Thevenin circuit with the 2 kΩ resistance re-attached.

Figure 3-5a begins with no circuit right of the A-B terminals. The circuit left of the terminals is to be simplified to the simplest circuit similar to the Thevenin circuit above:

Fig. 3-5 Applying the Thevenin theorem



First, use voltage divider with two equal resistors. Thevenin voltage is equal to half of the source or:

$$V_{TH} = 9\text{ V}$$

Shorting the source, we see the circuit of Fig. 3-5b. The Thevenin resistance equals:

$$R_{TH} = 2.5\text{ k}\Omega$$

The resultant Thevenin circuit is shown in Fig. 3-5c.

The next circuit of Fig. 3-6a, while similar to the previous examples, has an added resistor just left of the A terminal. This is known as a 'dangling resistor'. It would be part of a larger circuit but after the cut, it is left to dangle.

We note that no current passes through this dangling resistor since it goes nowhere so there is no voltage across it. The voltage is the same as the previous circuit with the V_{TH} found using voltage divider while ignoring the dangling resistor. However, when we calculate R_{TH}, the dangling resistor is used since the calculation of R_{TH} must include it.

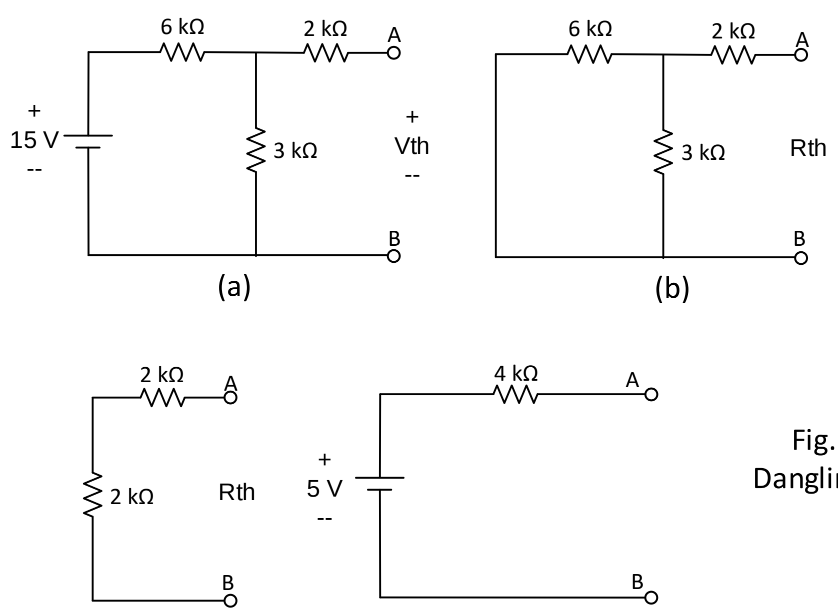


Fig. 3-6 The Case of the Dangling Resistor - Thevenin's theorem

$$V_{th} = \frac{R_2}{R_T} V = \frac{3{,}000}{9{,}000} 15 = 5\ V$$

The calculation to find R_{TH} between the circuit's A-B terminals is

$$R_{TH} = 2\ k\Omega + 2\ k\Omega = 4\ k\Omega$$

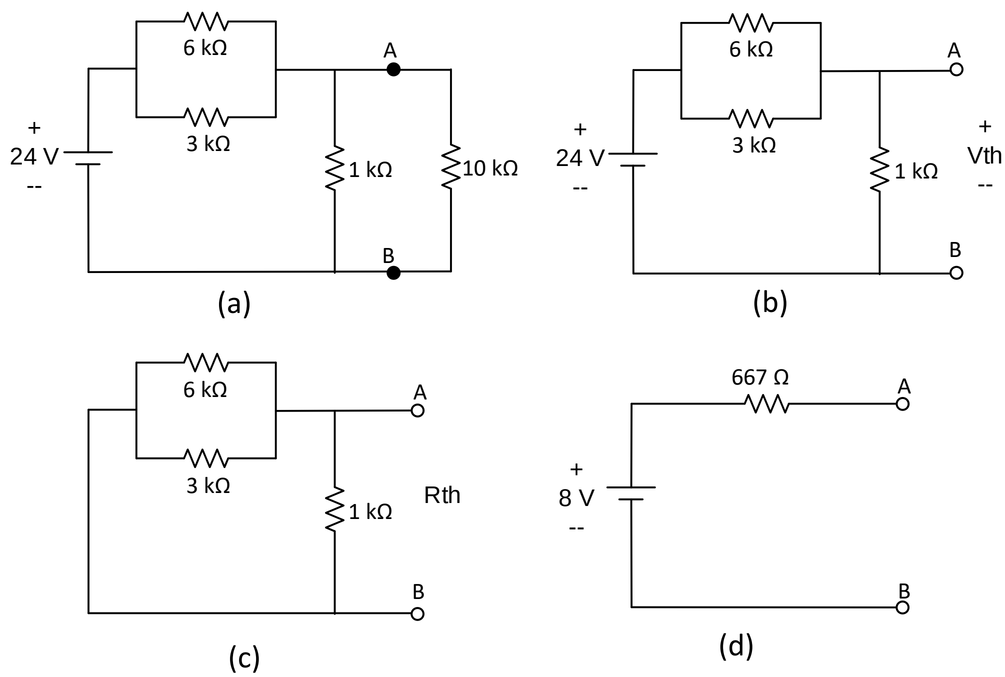
Fig. 3-6d gives the final Thevenin circuit.

Figure 3-7 gives a more complicated circuit left of the A-B terminals. We follow a similar tact in finding the V_{TH}, R_{TH} and final Thevenin circuit.

First, use the scissors to separate the circuit at the A-B terminals at the 10-kΩ resistor and get Fig. 3-7b. Combine the 6 kΩ and 3 kΩ to get the equivalent 2 kΩ. Solve for V_{TH}:

$$V_{TH} = \frac{R_2}{R_T} V = \frac{1{,}000}{3{,}000} 24 = 8\ V$$

Fig. 3-7 Applying Thevenin's theorem



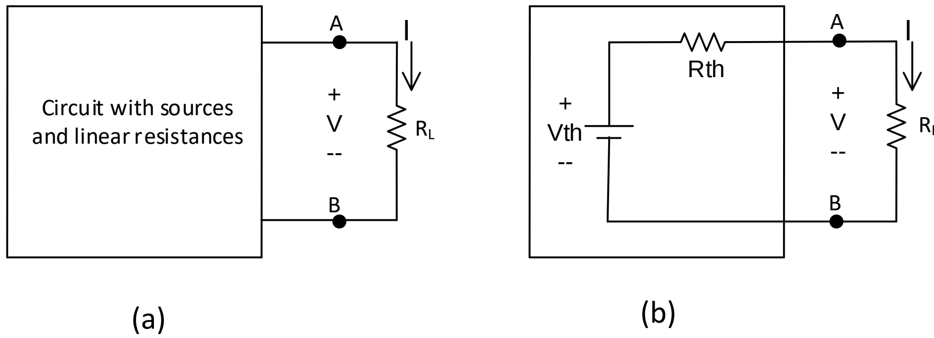
Now, short the 24 V source as seen in Fig. 3-7c. Find the equivalent resistance between A and B terminals. It is:

$$R_{TH} = \frac{2000 \times 1000}{2000 + 1000} = 667\ \Omega$$

Recombine the circuit in Fig. 3--7d which is the Thevenin equivalent circuit.

We picture the Thevenin equivalent circuit as a 'lego' which can be built into more complicated circuits. It gives the same circuit as the original circuit but with only one voltage source and one resistor. It can be pictured in Fig. 3-8 as the lego block it represents.

Fig. 3-8 Thevenin's theorem

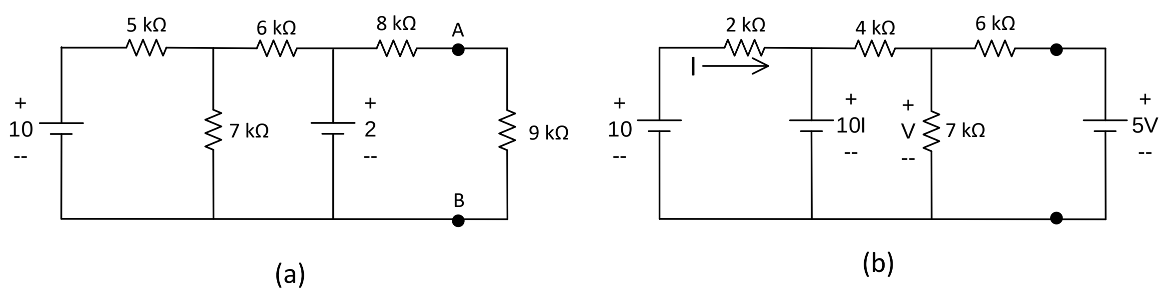


We will not try to prove this theorem, only to say that it works – most of the time. It works if the circuit is a linear circuit and there are only independent sources.

What is a linear circuit? It can be as simple as to say that the circuit has no semiconductor devices involved. This is - for the most part - true.

We haven't talked about independent and dependent sources yet. There are examples of each in Fig 3-9a and b. Fig. 3-9a shows independent courses. Fig. 3-9b shows a dependent source with 10i as the second source. The second example in Fig. 3-9b is not able to have the V_{TH} reduced to zero.

Fig. 3-9 Dependent and Independent sources



We will ignore dependent sources through the rest of this text. For now, the Thevenin circuit can be expected to find R_{TH} by shorting the voltage sources.

Use Theven to find a voltage or current at the output of a circuit. The example of Fig. 3-10 shows how this is done.

We first remove the load resistor and find the Thevenin circuit as before. In Fig. 3-10b, voltage divider gives:

$$V_{th} = \frac{R_2}{R_T}V = \frac{3{,}000}{9{,}000}12 = 4\ V$$

Next, find R_{TH} using the dangling resistor method giving the resistance of Fig. 3-10c and d.

$$R_{TH} = 3\ k\Omega$$

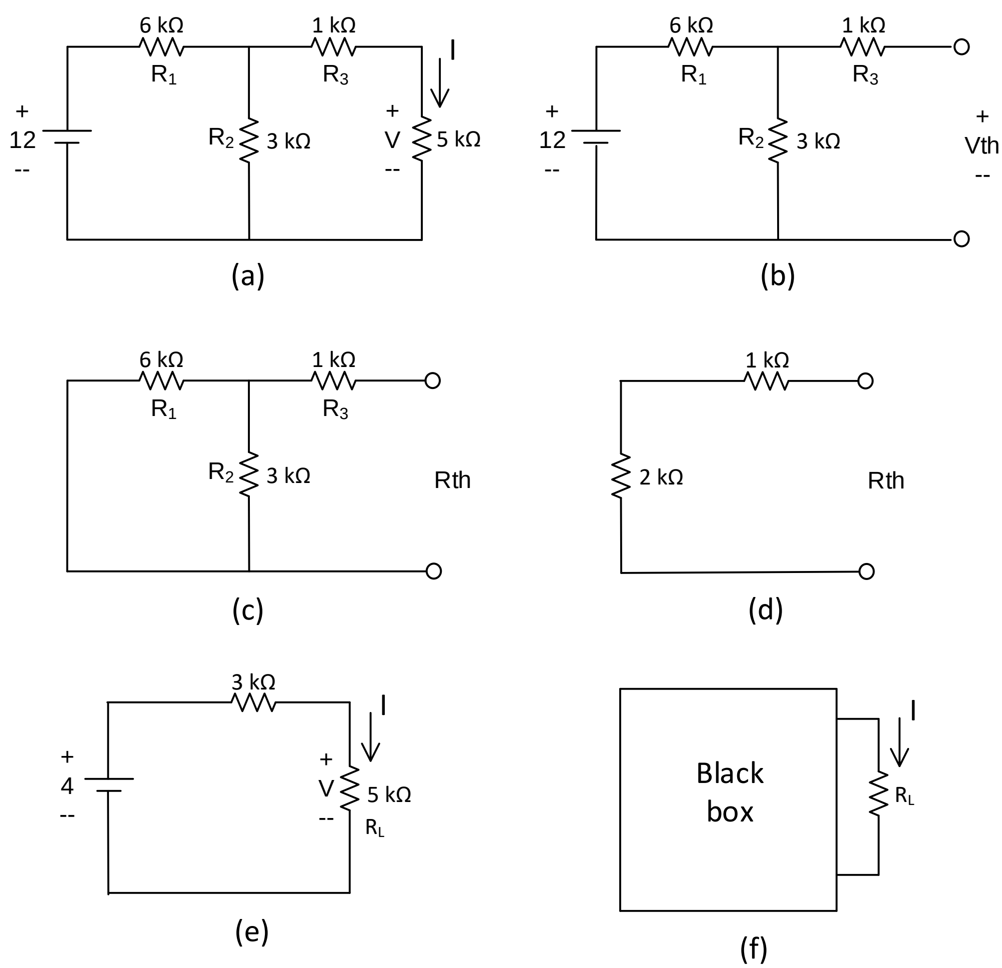
Finally, redraw the circuit and add the load previously removed to find I:

$$I = \frac{4}{8000} = 0.5\ mA$$

V across the 5 kΩ equals:

$$V = R_L I = 5000 \times 0.0005 = 2.5\ V$$

Fig. 3-10 Example of Thevenin's Theorem

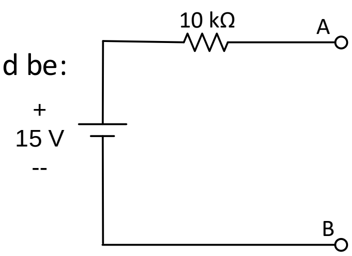


Now, go back and calculate the voltage across the load resistor using the methods of the last chapter to see if the answer is equal to the answer above.

Measurements from Black Box:

In Fig. 3-10f a black box is shown with resistance across the load R_L. With R_L removed, the voltmeter shows 15 V from A to B. With all voltages jumpered, the resistance from A to B measures 10 kΩ. Find the Thevenin equivalent circuit:

It would be:



Thevenize More Than Once

More complicated circuits can be reduced by applying the Thevenin principle more than once. This principle is shown in Fig. 3-11. First cut at C-D. Then patch the circuit and cut at A-B. This technique works very well to solve for the last current or voltage to the right in a complicated circuit such as this:

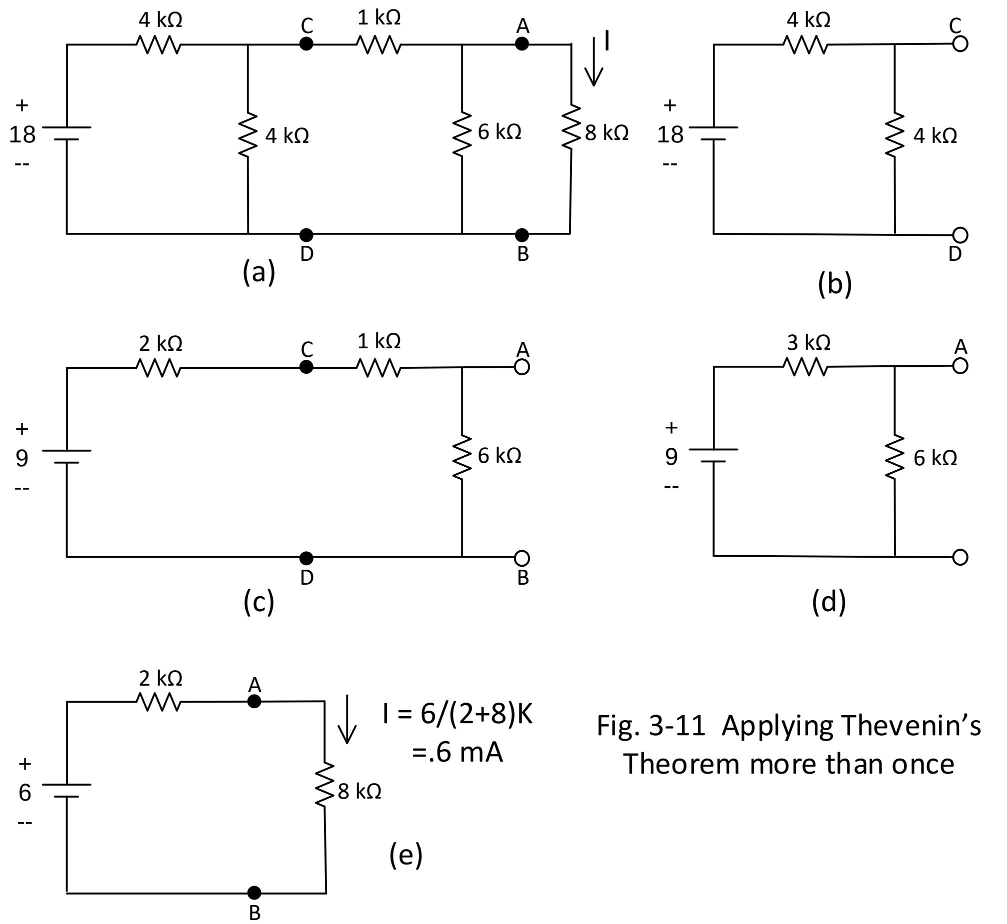


Fig. 3-11 Applying Thevenin's Theorem more than once

A number of alternative ways are useful for finding V_{TH} and R_{TH}. They include the Shorted Load Method and the Matched Load Method.

First, the Shorted Load Method. It is not always practical to short the load and is not advisable especially in many electrical installations but on paper, it works. The method involves shorting the load. This gives the current commonly referred to as I_{SL} or I Shorted Load. It can be seen from the thevenin circuit that:

$$V_{TH} = I_{SL} \cdot R_{TH}$$

Measuring I_{SL} is necessary as well as one of the other two (V_{TH} or R_{TH}) to find the third element.

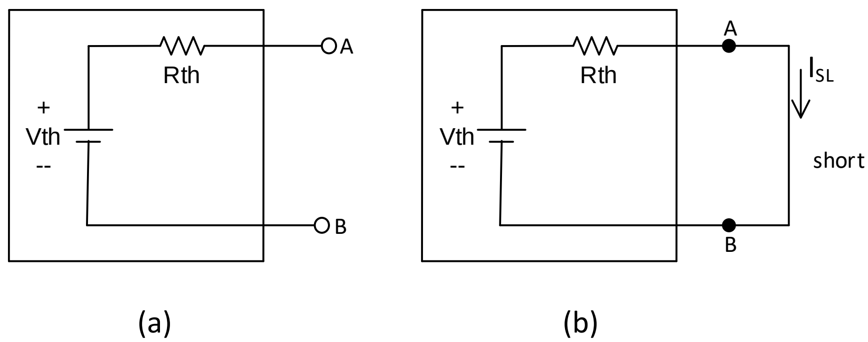
In Fig. 3-12b, we know V_{TH} and R_{TH}. The unknown is I_{SL}:

$$I_{SL} = \frac{V_{TH}}{R_{TH}}$$

We assign V_{TH} = 10 V and R_{TH}= 2 kΩ to find I_{SL}:

$$I_{SL} = \frac{10}{2000} = 5 \text{ mA}$$

Fig. 3-12 Shorted load method



Given values for V_{TH} and I_{SL}, one can find R_{TH}:

$$R_{TH} = \frac{V_{TH}}{I_{SL}}$$

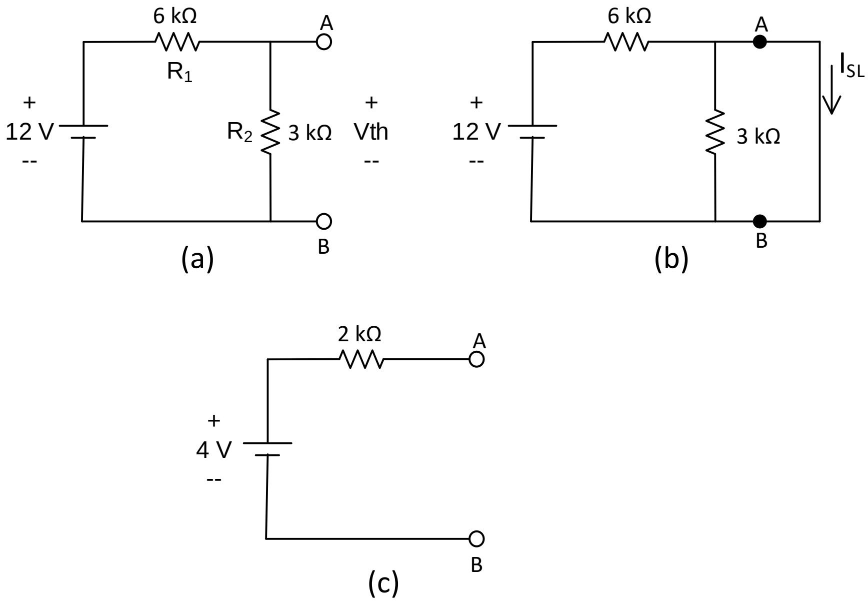
Fig. 3-13 shows finding R_{TH} by indirectly by measuring I_{SL} and given V_{TH}. First, measure $V_{TH} = V_{AB}$:

V_{TH} = 4 V

Next, short the circuit from A to B and measure the current from A to B:

I_{SL} = 2 mA

Fig. 3-13 Example of Shorted load method



We now calculate R_{TH}:

$$R_{th} = \frac{V_{TH}}{I_{SL}} = \frac{4}{0.002} = 2\ \text{k}\Omega$$

We can also look at the circuit and analyze R_{TH} from our previous experience as 2 kΩ. Remember this method is usually safe with small loads but with larger sources, it may not be. If not sure of the V or R, don't mess with the I.

Next, the Matched-load Method. The matched load method sets a variable resistor across the A-B terminals and monitors the value at which $V_{AB} = .5\ V_{TH}$. The value on the variable resistor is exactly equal to R_{TH}.

$$R_{match} = R_{TH}$$

The example below of Fig. 3-14a shows the method at work. In Fig. 3-14b, the variable resistor or rheostat is adjusted until the load voltage is exactly half the Thevenin voltage:

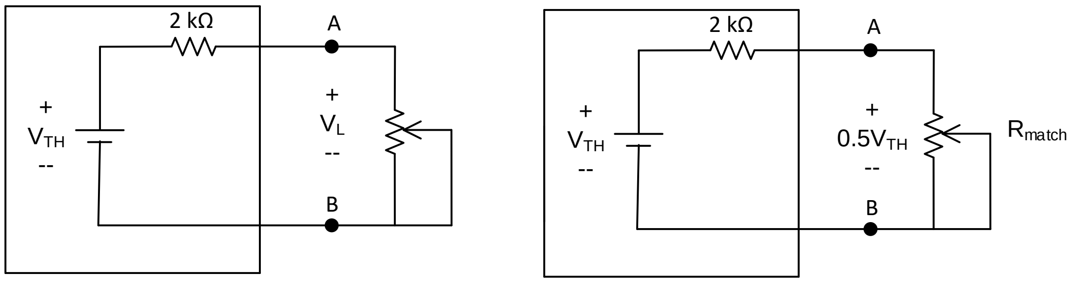
$$V_L = 0.5V_{TH}$$

To measure VL, remove the variable resistor and measure it with an ohm-meter. This reading equals R_{TH}.

In Fig. 3-14c, we see another example in which:

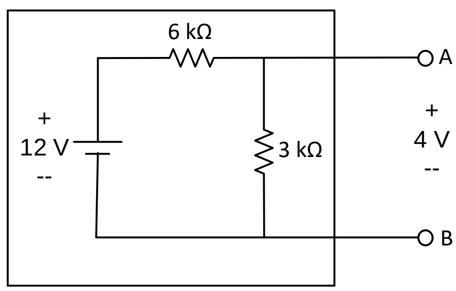
$$V_{TH} = 4\ \text{V}$$
$$R_{TH} = 2\ \text{k}\Omega$$

Fig. 3-14 Matched Load method

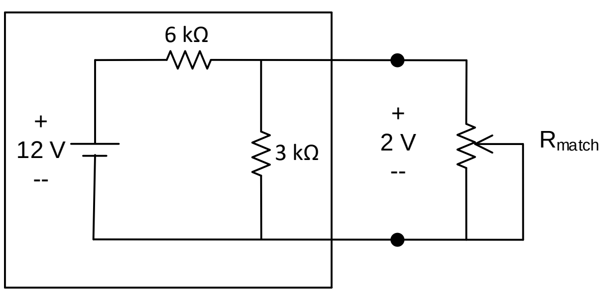


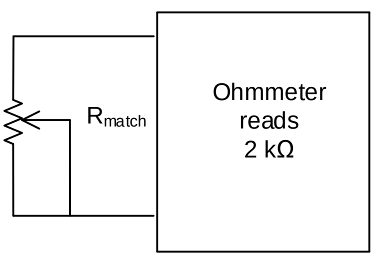
(a) (b)

Fig. 3-15 Example of matched-load method



(a)





(b) (c)

The matched load method is potentially not as destructive as the shorted load method. There is no risk of a high current that can damage equipment as is possible with the shorted load method. Either method can provide insight into a circuit's R_{TH} and V_{TH} values by methods other than calculation.

Using a Flashlight Battery to Determine a Thevenin Circuit

Let's use a flashlight battery to determine a simple thevenin equivalent circuit. The circuit of a flashlight battery resembles any black box circuit seen previously (see Fig. 3-16a). Finding V_{TH} is very easy. It can be found using a voltmeter connected similar to Fig. 3-16b. The resistance R_{TH} is difficult to find since it is not possible to separate the resistance of a battery from the voltage source. The other variable is I_{SL} and this variable can be found by shorting the terminals from A to B with an ammeter.

The voltage is read as $V_{TH} = 1.5$ V. The ammeter in Fig. 3-16c gives $I_{SL} = 1.5$ A. The value R_{TH} can then be calculated and the Thevenin Circuit drawn in Fig. 3-16d.

$$R_{TH} = \frac{V_{TH}}{I_{SL}} = \frac{1.5\ \text{V}}{1.5\ \text{A}} = 1\Omega$$

See in Fig. 3-16d the Thevenin Equivalent Circuit for the flashlight battery.

Fig. 3-16e gives the symbol for a battery. There is no implied resistance as we just found in the battery of Fig. 3-16a-d. The approximation can be made because the resistance found is so small that it is treated as insignificant to the circuit. If a battery is used in a circuit, it has an internal resistance and actually can be represented by Fig. 3-16f.

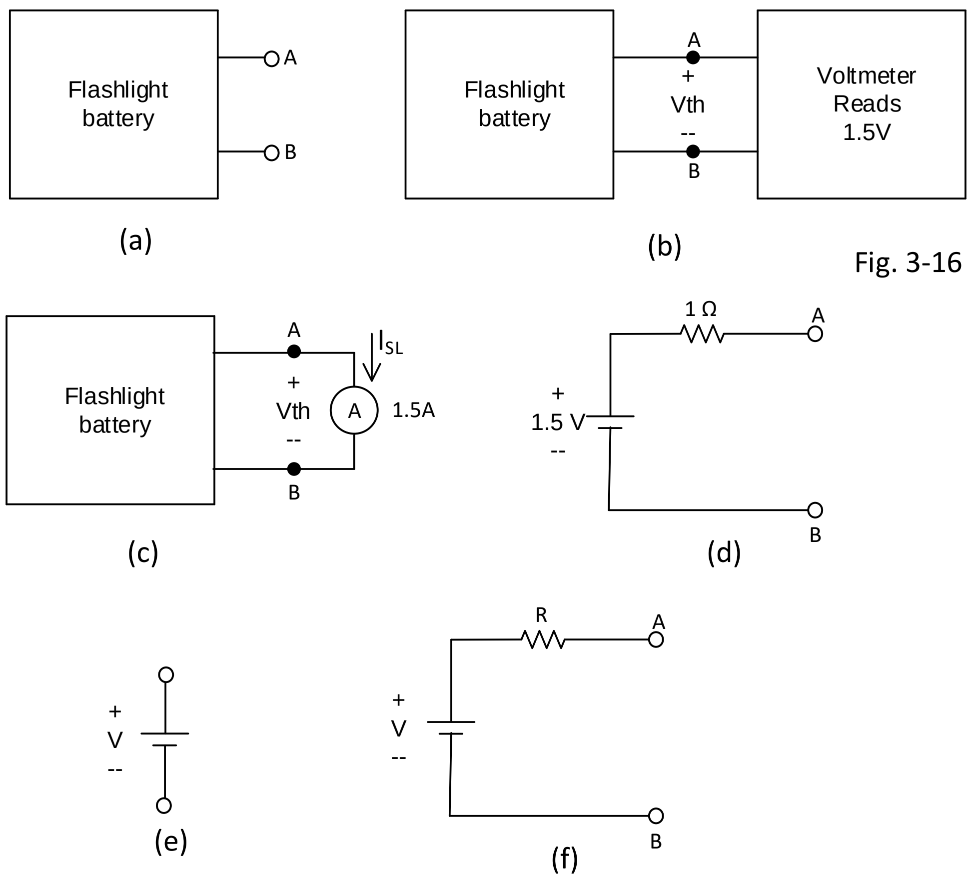
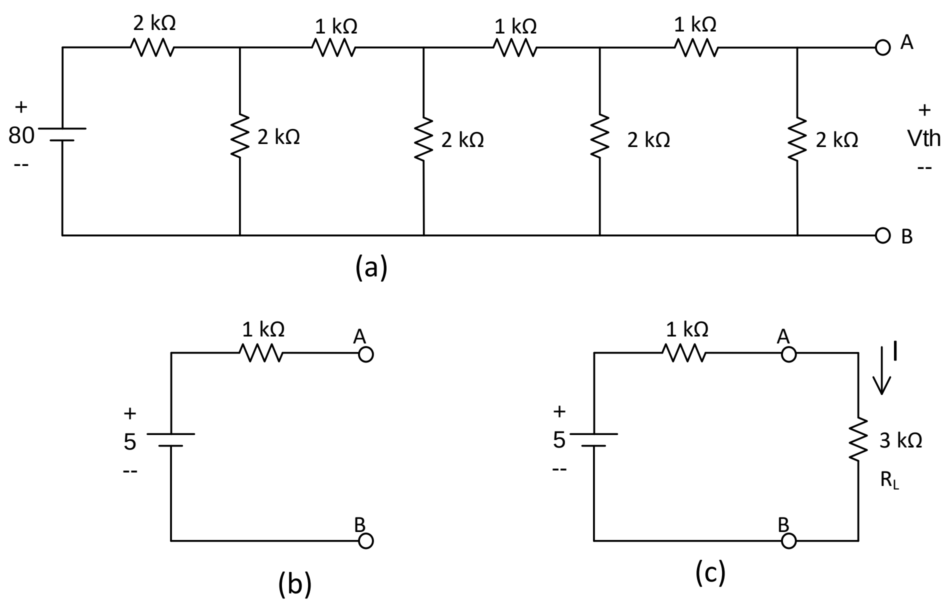


Fig. 3-16 Thevenin circuit of Flashlight

In general, the voltmeter contributes no appreciable resistance to the circuit it measures because the impedance of the voltmeter is so high. The same can be said for the ammeter but in the opposite direction. The ammeter is placed in series with the circuit being measured. Low resistance is very important for an ammeter to not change the circuit. This is usually the case. Their inclusion in a circuit does effect the circuit and if exact answers are required, their resistances must be included.

The circuit of Fig. 3-17 is very complicated. However, it can be crunched to a very manageable circuit if all that is required is the current or voltage at the far right. Usually, this is the case. We crunch this circuit one window at a time until we reach the Thevenin circuit just left of the A-B terminals. We then insert the load resistance, in this case 3 kΩ, and find the current and voltage across it.

Fig. 3-17 Applying Thevenin's Theorem

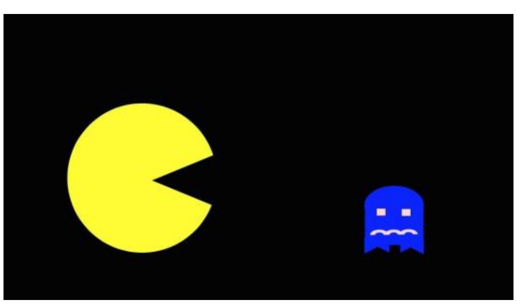


Shown in Fig. 3-17c is the final crunched circuit and the calculation of I and V:

$$I = \frac{5}{1000 + 3000} = 1.25 \text{ mA}$$

$$V = R_L \cdot I = 3000 \times 0.00125 = 3.75 \text{ V}$$

The above circuit and the game below have what in common?



You may not remember this game but your parents would. Or your grandparents. Look it up and play it. It is much more fun than the problem above but involves the same principle.

Multiple Source Circuits

When a circuit is found to have more than one source, the following method may be used to find the unknown voltage or current. Several examples will show the principle of finding these combination circuits using the concept of superposition.

We have to believe that multiple source circuits can be broken into simpler circuits and superposition allows us to do this. The circuit below in Fig. 3-18 has two sources, a 15 V source at the left and a 30 V source at the right. The unknown is the current in the middle through the 3 kΩ resistor. If we re-draw the circuit with the right source shorted and a second circuit with the left source shorted, we can find the current through the 3 kΩ resistor in each circuit. Then we add the two answers together for the final answer.

We refer to the two separate currents as I_1 and I_2. We add the two together and find the total current I.

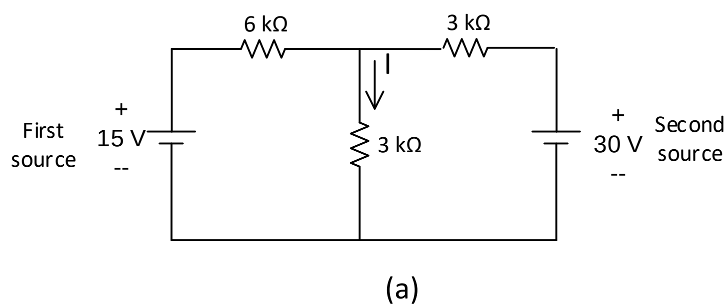
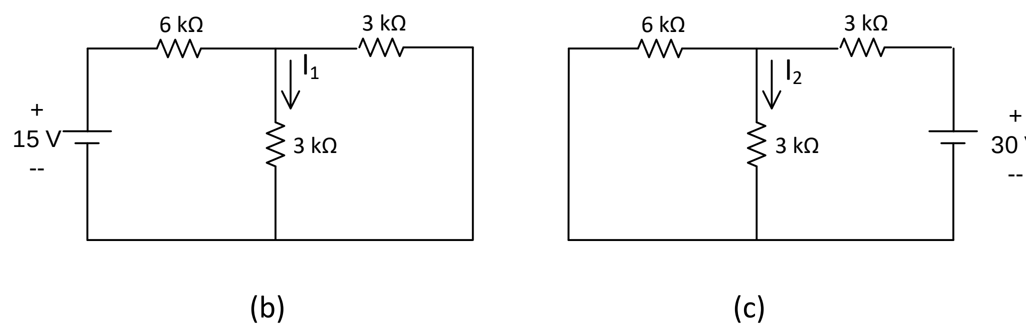


Fig. 3-18 Superposition Theorem
(a) Original circuit
(b) First source circuit
(c) second-source circuit



Using the techniques of the past chapter, we find that the voltage across the 3 kΩ resistor of Fig 3-18b as 3 V. Solving for I_1, we find I_1 equals 1 mA. We use the same techniques to find the voltage across the same 3 kΩ resistor from the 30 V supply equal to 12 V and I_2 = 4 mA. We use the superposition theorem to find the total current:

$$I = I_1 + I_2 = 1\text{ mA} + 4\text{ mA}$$
$$= 5\text{ mA}$$

We have found the answer using Superposition to the original problem of the current through the 3-kΩ resistor.

Figure 3-19 has two voltage sources. The unknown current sought is the current through the 4 kΩ resistor.

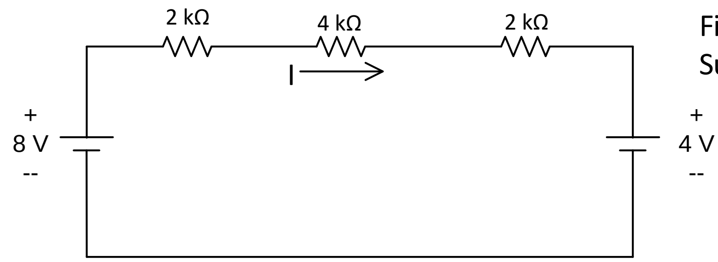
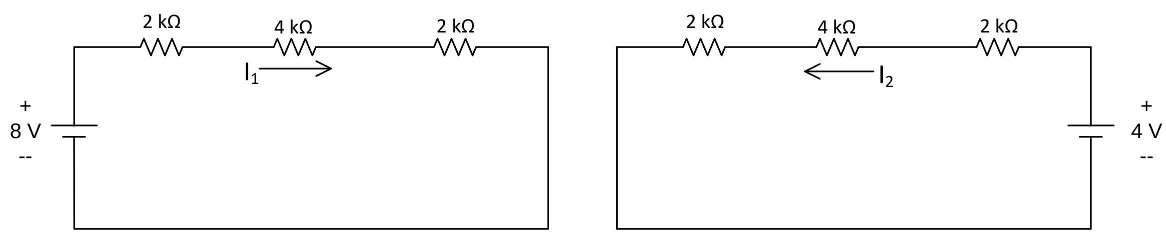


Figure 3-19 Example of Superposition Theorem

(a)

We again turn to the superposition theorem and re-draw the circuit in Fig. 3-19b and c.



(b) (c) Figure 3-19 cont

I_1 is the current in the circuit with the 8 V source at left. I_2 is the current in the circuit with the 4 V source at the right. The two currents oppose each other with I_1 flowing left to right and I_2 flowing right to left. Total current I is the sum of these two currents. What is it?

The first circuit gives the following current (to the right):

$$I_1 = \frac{8}{8000} = 1 \text{ mA}$$

The second circuit gives the following current (to the left):

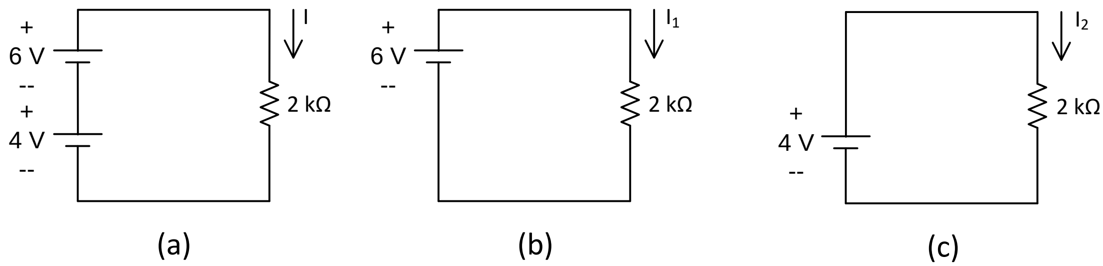
$$I_2 = \frac{4}{8000} = 0.5 \text{ mA}$$

Adding the two and inserting the minus sign for current flowing right to left, we have:

I = 1 mA – 0.5 mA
= 0.5 mA

Fig. 3-20 is another example of multiple sources flowing through a single resistor. This example also follows the path of re-drawing the circuit twice, once with one of the voltage sources present and the other source shorted. The final answer again is the sum of the two single-source answers.

Figure 3-20



We calculate I_1 in Fig. 3-20b as follows:

$$I_1 = \frac{6}{2000} = 3 \text{ mA}$$

We calculate I_2 in Fig. 3-20c as follows:

$$I_2 = \frac{4}{2000} = 2 \text{ mA}$$

Adding the two currents together yields:

$$I = 3 \text{ mA} + 2 \text{ mA}$$
$$= 5 \text{ mA}$$

By observation, we can see that the 4 V and 6 V sources can be replaced by a 10 V source yielding the following directly (without using Superposition). You should always look for ways to combine sources and simplify your efforts.

$$I = \frac{10}{2000} = 5 \text{ mA}$$

Superposition is possible with more than two sources. Each source adds its part:

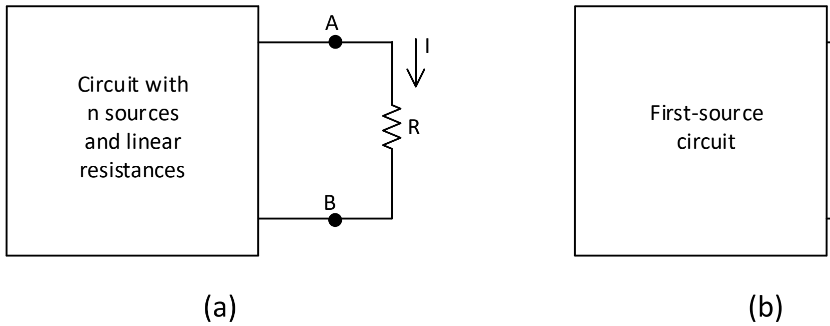
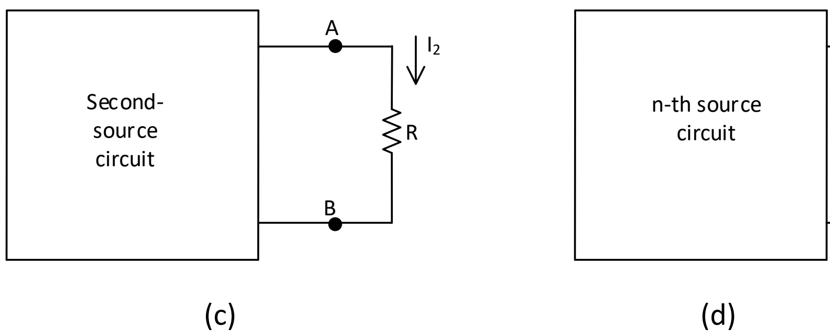


Figure 3-21



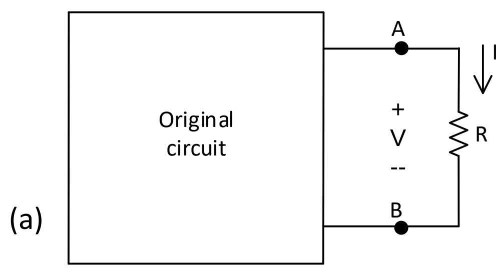
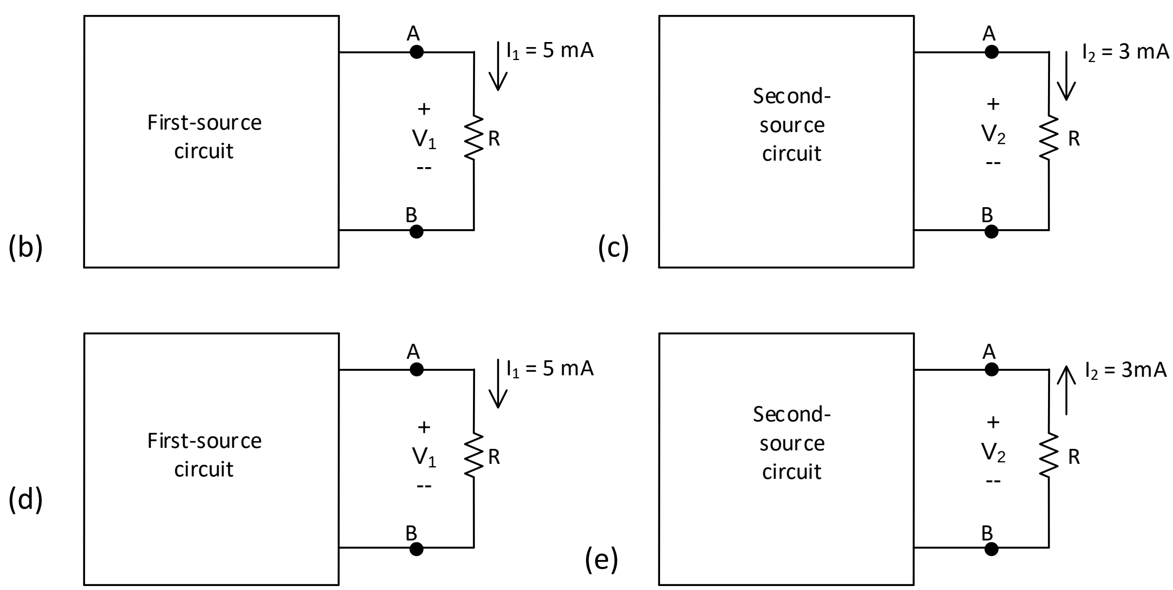


Fig. 3-22 An Example of Algebraic Summing



Figures 3-21 and 3-22 above give a good example of many source circuits being split into a number of circuits each with only one source. We can continue this principle for any number of sources as long as the resistances in the circuit are linear and the sources are not dependent, the same as for Thevenin. In Eq. 3-10, use the algebraic sum. This means taking the direction of individual currents into account. When an individual current is in the same direction shown for the original current, add the magnitude of the individual current. But when the individual current is opposite the direction shown in the original current, subtract its magnitude. We have used current in the examples to this point. Voltages can also be added in a similar manner.

In Fig. 3-22a we see the original circuit. Here the current I is pointing down.-32a shows an original circuit with current I down. Figs 3-22b and c show the two currents from separate sources both in the same direction (down). Here currents add:

$$I = 5\ \text{mA} + 3\ \text{mA} = 8\ \text{mA}$$

Fig. 3-22d and e show the two currents with opposite direction. Here the second current is subtracted from the first:

$$I = 5\ \text{mA} - 3\ \text{mA} = 2\ \text{mA}$$

Voltages:
As mentioned before, superposition works equally well for voltages as well as currents. We can say in general for voltages with multiple sources:

$$V = V_1 + V_2 + \cdots + V_n$$

For Fig. 3-22b and c above, we could assign values $V_1 = 5$ V and $V_2 = 3$ V. Then V = 8 V.

Now We Use All Three – Voltage Divider, Thevenin and Superposition Together. In the circuit of Fig. 3-23a, we are asked to find the Thevenin Circuit between terminals A-B. Fig. 3-23b shows the original circuit with the 18 V supply only and Fig. 3-23c shows the circuit with only the 9 V supply.

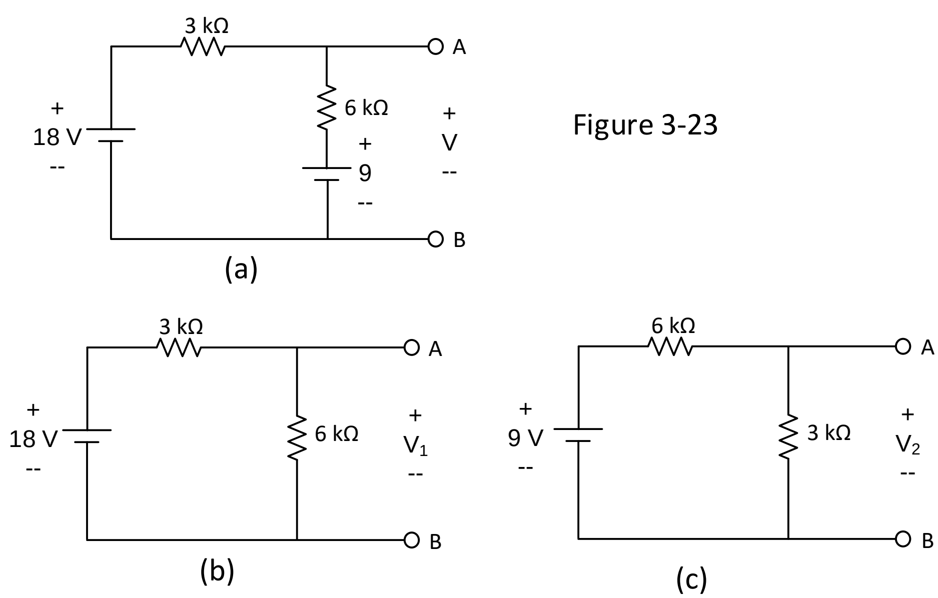


Figure 3-23

Notice in Fig. 3-23c that the circuit is re-drawn to more easily see the value across A-B with only the 9 V source. Labels for V_{AB} for the 18 V source circuit of Fig. 3-23b is V_1 and for the 9 V source of Fig. 3-23c is V_2.

Using only the first source (18 V), we find:

$$V_1 = \frac{6000}{3000 + 6000} 18 = 12 \text{ V}$$

Using only the second-source (9 v), we find:

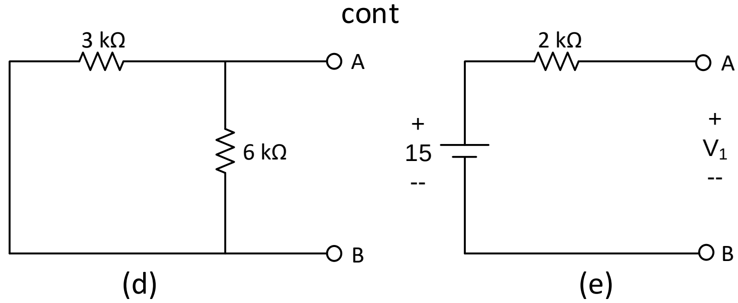
$$V_2 = \frac{3000}{6000 + 3000} 9 = 3 \text{ V}$$

V_1 and V_2 are both of polarity + to – from A to B. Therefore:

$$V_{TH} = V_1 + V_2 = 12 + 3$$
$$= 15 \text{ V}$$

Thus, by using Superposition and Voltage Divider, we have found V_{TH} of the circuit in Fig. 3-23a.

Figure 3-23
cont



Finding R_{TH} requires no use of Superposition since both sources are shorted leaving (see Fig. 3-23d):

$$R_{TH} = 3000 \parallel 6000$$

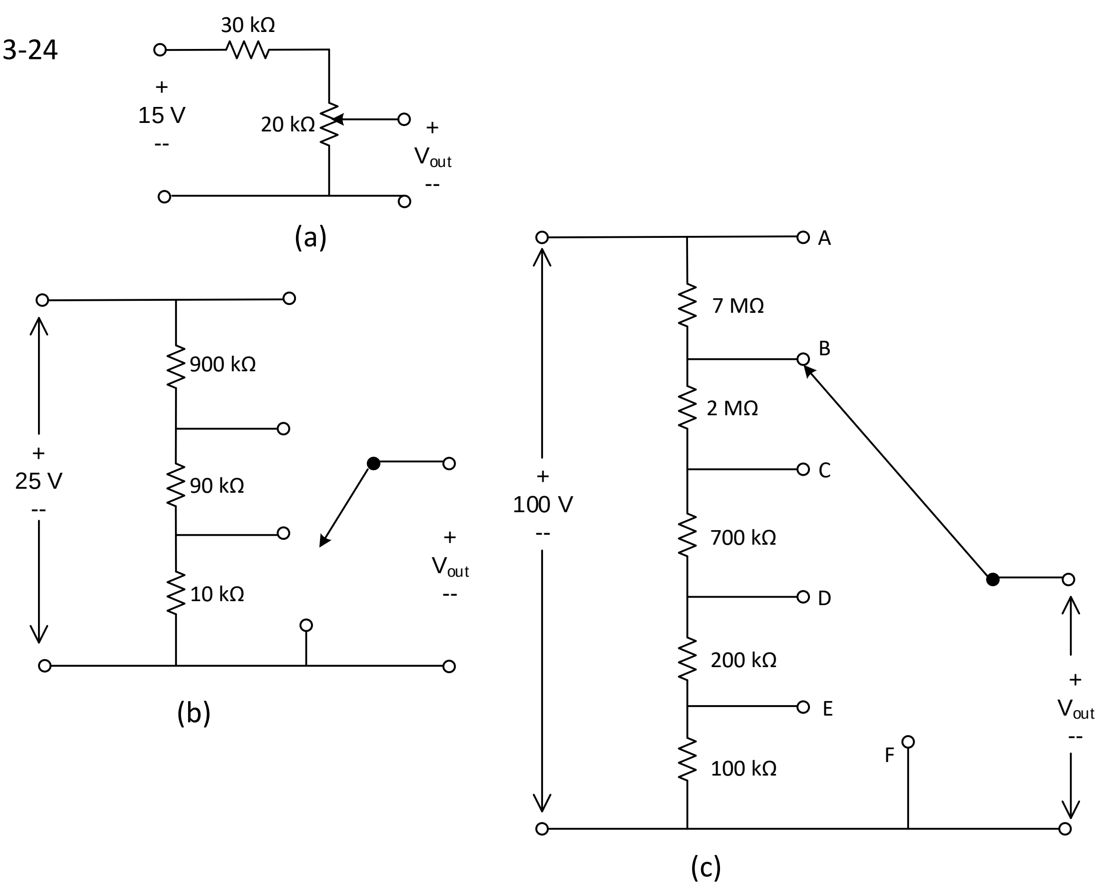
Figure 3-23e is the final solution to for this Thevenin Equivalent Circuit.

This example gives a good insight into the three theorems we have introduced in this chapter. They should be used whenever applicable to solve complicated circuit problems.

Problems

3-1. In Fig. 3-24a, find V_{out} when the wiper is at the top, at the bottom, at the middle.
3-2. In Fig. 3-24b, find V_{out} at each of the four switch positions.
3-3. In Fig. 3-24c, find V_{out} at each of the switch positions A through F?
3-4. For the circuit in Fig. 3-25a, find V_{TH}? R_{TH}?
3-5. For the circuit in Fig. 3-25b, find V_{TH}? R_{TH}?
3-6. For the circuit in Fig. 3-25c, find V_{TH}? R_{TH}?
3-7. For the circuit in Fig. 3-25d, find V_{TH}? R_{TH} if the wiper is middle point of the 20-kΩ pot.
3-8. Find the current through a 75-kΩ resistor connected across the A-B terminals of Fig. 3-25a. What is the voltage across the resistor?
3-9. Find the current through a 60-kΩ resistor connected across the A-B terminals of Fig. 3-25b. What is the voltage across the resistor? Will the voltage decrease or increase across the A-B terminals when the resistor is added to the circuit?
3-10. Find the current through a 12.5-kΩ resistor connected across the A-B terminals of Fig. 3-25c. What is the voltage across the resistor?

Fig. 3-24

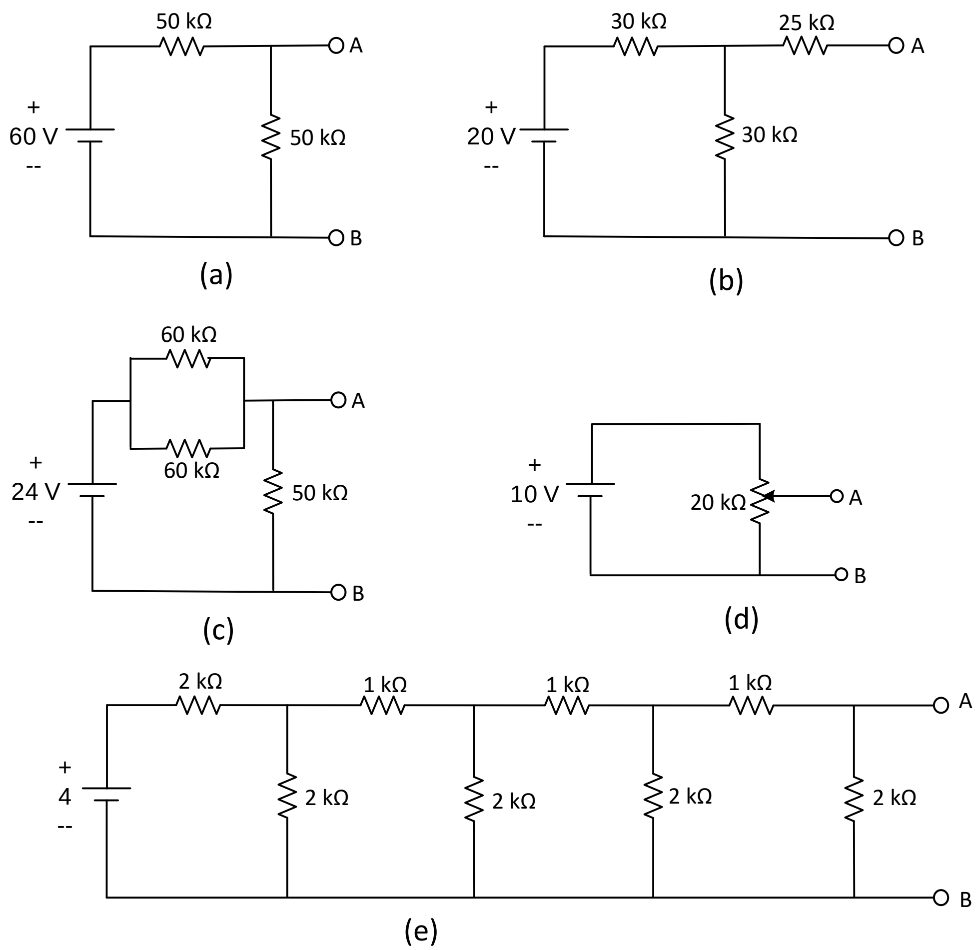


3-11. Find the current through a 10-kΩ resistor connected across the A-B terminals of Fig. 3-25d with the wiper in the middle position of the wiper. Next, connected to the top of the wiper. What is the voltage across the 10-kΩ resistor at each of these positions of the pot.
3-12. Find V_{TH} and R_{TH} for Fig. 3-25e. Now, connect a 1-kΩ resistance between A and B and determine current and voltage between A and B.

3-13. Use the flashlight battery example from the text and the data: V_{TH} = 1.5 V and I_{SL} = 2 A to find R_{TH} of the battery.

3-14. Again, use the flashlight battery example and the data: : V_{TH} = 9.0 V and I_{SL} = 1.25 A to find R_{TH} of the battery.

Fig. 3-25



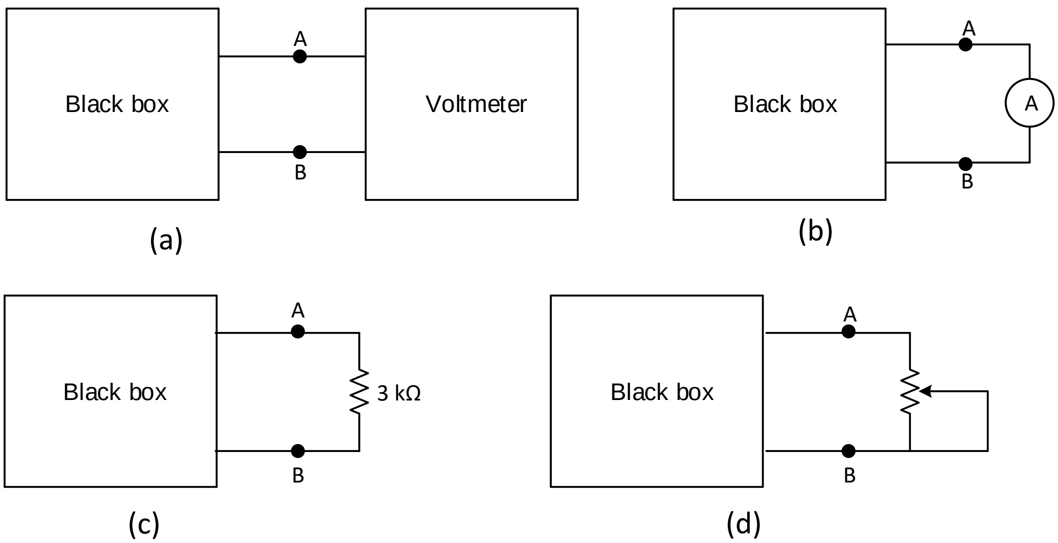
3-15. Given that the voltmeter of Fig. 3-26a has very high resistance and the ammeter of Fig. 3-26b has very low resistance, find R_{TH} of the black box if the reading of V_{AB} = 100 mV and I_{SL} = 0.1 mA.

3-16. Given that the voltmeter of Fig. 3-26 has very high resistance and the ammeter of Fig. 3-26b has very low resistance, find R_{TH} of the black box if the reading of V_{AB} = 2 V and I_{SL} = 1 mA. Now connect a 3-kΩ resistor across the A-B terminals (shown in Fig. 3-26c) and calculate the current through and voltage across A-B.

3-17. Fig. 3-26d is a black box with V_{TH} = 10 V and I_{SL} = 2 mA. Now attach a variable resistance between A-B and turn until V_{AB} = 5 V. What is the resistance of the variable resistor at this point? Next move the variable resistor until load voltage is 7.5 V. Calculate the new value of the variable resistor.

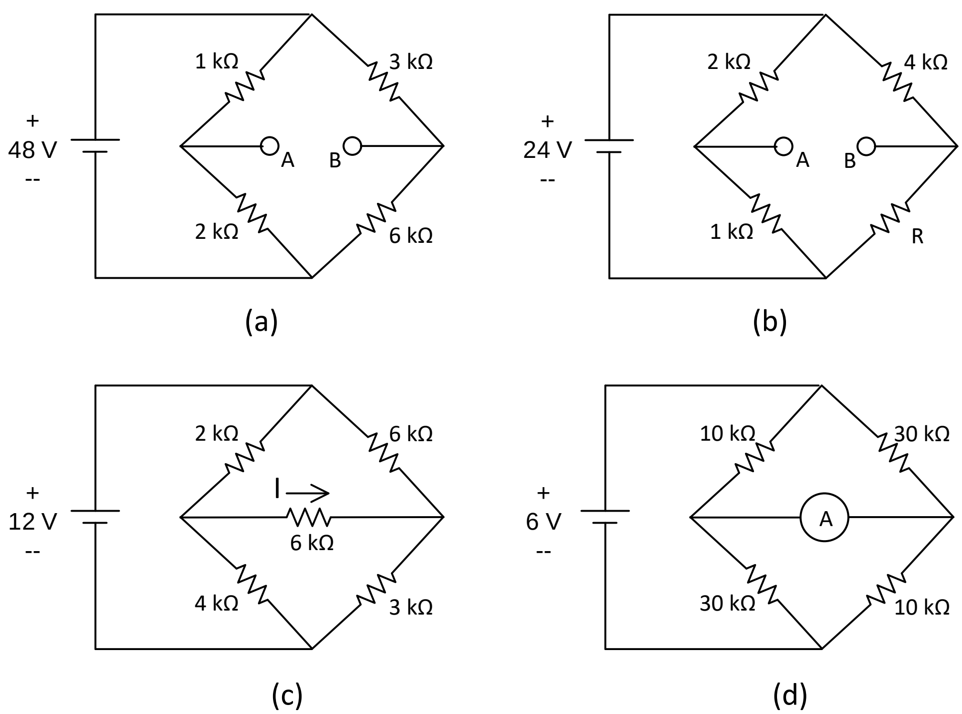
3-20. V_{TH} of a black box = 4 V. Adding a resistor between A-B of 8 kΩ drops V_{AB} to 2 V. Find $_{ISL}$. Next, remove the 8 kΩ resistor and calculate the current through a 32-kΩ resistor attached between A and B.

Figure 3-26



3-21. In Fig. 3-27a, find the voltage of the 2-kΩ resistor. Of the 6 kΩ resistor. Between A and B.

Fig. 3-27



3-22. In Fig. 3-27b, find the voltage across the 1-kΩ resistor. Next, R = 8 kΩ. Find the voltage of this resistor. Find the value of R that reduces V_{AB} to zero.

3-23. Find I in Fig. 3-27c.

3-24. Find I in Fig. 3-27d. Assume the ammeter has very low resistance.

3-25. For Fig. 3-27a, the 1-kΩ has a tolerance rating +/- 1 percent. Assume all other resistances are their nominal value. Find the max voltage between terminals A and B.

3-26. For Fig. 3-27d, assign an internal resistance of 50 Ω for the ammeter. Then, calculate the current through the ammeter. Does this value for the meter significantly change the current?

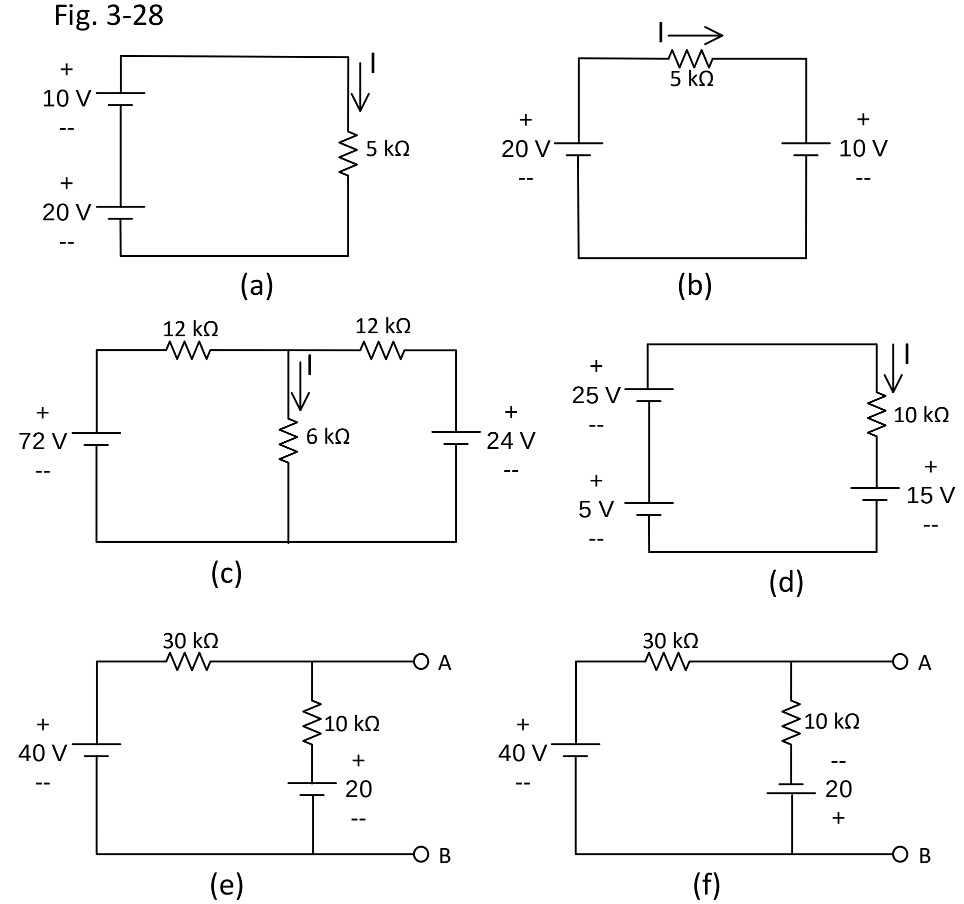
3-27. For Fig. 3-27d find the current between A and B for the following values of resistance between A and B:

a. R = 1 kΩ
b. R = 2 kΩ
c. R = 3 kΩ
d. R = 0 Ω

3-28. For Fig. 3-28a, find I.

3-29. For Fig. 3-28b, find I.

Fig. 3-28



3-30. For Fig. 3-28c, find I.

3-31. For Fig. 3-28d, find I.

3-32. For Fig. 3-28e, find V_{TH}, R_{TH}.

3-33. For Fig. 3-28f, find V_{TH}, R_{TH}.

3-34. For Fig. 3-28e, attach a 10-kΩ resistor across A-B and find V_{AB}.

3-35. For Fig. 3-28f, attach a 12.5 kΩ resistor across A-B and find V_{AB}.