

# Chapter 1

## Introduction to Electronics

Electronics is about manipulating electricity to accomplish a particular task and is very much a hands-on endeavor. Since the result of building electronic circuits is usually a device that performs a task, this hands-on aspect should be self-evident. What is often obscured in the study of electronics is that even the most complicated electronic device is made up of many smaller and simpler circuits and components. Once you have an appreciation for some of these smaller circuits, it is rather easy to understand more complicated circuits. It should not be very surprising then that the focus of this book is on very practical things that, when several are combined, result in electronics and electronic systems of interest and use to those involved in optical engineering.

During their university training, many future engineers often discover in their first circuits class that electrical engineering is not for them. Some of these engineers still have the recurring nightmare that they have their final circuits test the next day! In spite of the loathing that those engineering circuits classes evoke, as topics go, understanding electronics is really not that difficult and can actually be fun if it is approached in the right way.

The right way that we will be using here is to break electronics into two main parts. The stuff you *need* to know and the fun stuff you *want* to know! Of course, before we can get to the fun stuff, we have to introduce some fundamental concepts and circuits. We will start our journey into the world of electronics by focusing on signals, simple circuits, common devices, and how to make measurements. Electronics is meant to be hands-on, so constructing some of the circuits will help you understand them, and you are encouraged to do so! Example calculations and MATLAB<sup>®</sup> scripts are provided to help you appreciate how electronics problems can be solved numerically. A brief introduction and refresher to MATLAB is provided in the Appendix, along with a Bibliography of suggested reading in case you want to find some additional information.

## 1.1 Ohm's Law

Electronics involves the manipulation of charges, currents, and voltages. When many charges are moving in the same direction, we tend to speak of them as currents, defined as the passage of charge per unit of time. Currents can only flow if there is a complete path from one side of a power source to the other, and if the total voltage around a closed loop is zero, according to a principle known as Kirchhoff's voltage law.<sup>1</sup> Charges move under the influence of voltage differences, and changes in voltage can occur as currents move through resistances. This relationship is reflected in the basic rule of electronics known as Ohm's law.<sup>1</sup>

Ohm's law is expressed as a mathematical relationship that governs the interplay of voltage, current, and resistance, and is often stated as

$$V = I \cdot R, \quad (1.1)$$

where  $V$  is the voltage in units of volts [V],  $I$  is the current in units of amperes [A], and  $R$  is the resistance in units of ohms [ $\Omega$ ]. The utility of the equation will be made clear shortly. For the moment, just remember that Ohm's law is frequently used in electronics problems; fortunately, it is not very complicated.

Power describes the rate at which energy is being used. If we know the current and the voltage, we can directly calculate the power from

$$P = V \cdot I, \quad (1.2)$$

where  $P$  is the power and is measured in watts [W]. Other relationships can be created for the power by substituting in Eq. (1.1) after rearranging for either voltage or current. The value of these simple equations will become clear in just a couple paragraphs when we start to investigate a basic circuit.

The first circuit we will look at is a traditional one for introducing electronics; it is a circuit that turns on a light source using a battery and a switch. To make this circuit more interesting, we will introduce the light-emitting diode (LED) as our light source. The LED is a semiconductor optoelectronic component that is much more energy efficient than an incandescent lamp. Today, these devices are nearly as popular as the old-style "grain-of-wheat" lamps, and we will use them in many of our example circuits.

An LED is an electrical device that converts electrical power to light. The operating characteristic for an LED can be described in the simplest sense as a forward voltage and a current; in other words, the LED is sensitive to the direction of current flow. We can use this information and Eq. (1.1) to determine the resistance of the LED and its operating power, as shown in Example 1.1.

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### Example 1.1

The forward voltage  $V_f$  and forward current  $I_f$  for an operating red LED are 2.2 V and 20 mA, respectively. Calculate the resistance and power used.

The resistance of the LED is

$$R = \frac{V}{I} = \frac{V_f}{I_f} = \frac{2.2 \text{ V}}{20 \text{ mA}} = 110 \ \Omega.$$

The power drawn by the LED is

$$P = V \cdot I = 2.2 \text{ V} \cdot 20 \text{ mA} = 44 \text{ mW}.$$

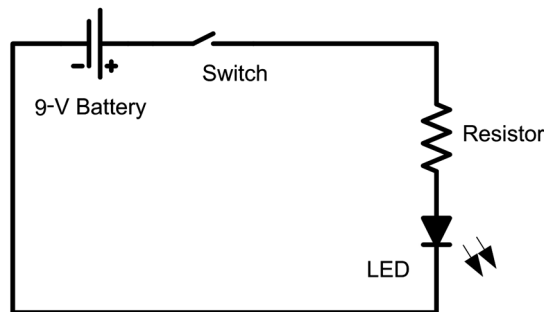
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As shown in Example 1.1, we can determine very practical information about the LED using our simple relationships. So far, we have used resistance as a calculated value without stating what it means. Resistance is the ability to impede the flow of current, usually by conversion to heat, and is a very useful property. Resistors are components that provide a fixed amount of voltage drop for a given current.

## 1.2 Simple LED Circuits

Powering the LED requires a closed circuit path in the form of a battery that connects the power source to the LED, as well as a switch, which is a mechanical means of turning, connecting, and disconnecting the power to the LED. If we use the same LED as in Example 1.1, we will need a 2.2-V battery, which is a little hard to find. To step down the voltage from a more common battery, say a 9-V battery to provide 2.2 V, we use a resistor of the correct value. Resistors will be discussed in detail in the next section, but for now we will consider them as a means of clarifying the voltage drop relationship.

A circuit to operate the LED is shown in Fig. 1.1, where a battery is connected using wires through a switch to a resistor and an LED light source. When the switch is closed, it acts as a wire connecting both sides so that a current flows through the resistor and the LED. There is a voltage drop across the resistor that can be calculated using Eq. (1.1). If the voltage drop is too great, there might not be sufficient power for the LED to turn on, or at least the LED might not be bright enough to see. Increasing the battery voltage or



**Figure 1.1** A battery wired to a switch, resistor, and LED, and relevant features.

decreasing the resistance can be tried to make the LED turn on. This calculation is performed in Example 1.2.

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**Example 1.2**

Calculate the resistance needed so that a 9-V battery can be used to power an LED that requires 2.2 V and 20 mA to operate.

The resistance or load connected to a 9-V battery that will draw a total current of 20 mA is calculated from Ohm's law as

$$R = \frac{9 \text{ V}}{20 \text{ mA}} = 450 \ \Omega.$$

The LED has an operating resistance of 110  $\Omega$ , so a resistor of 450–110  $\Omega$  will be needed to lower the voltage. The voltage drop across the resistor with a current of 20 mA will be

$$V = \frac{340 \ \Omega}{20 \text{ mA}} = 6.8 \text{ V}.$$

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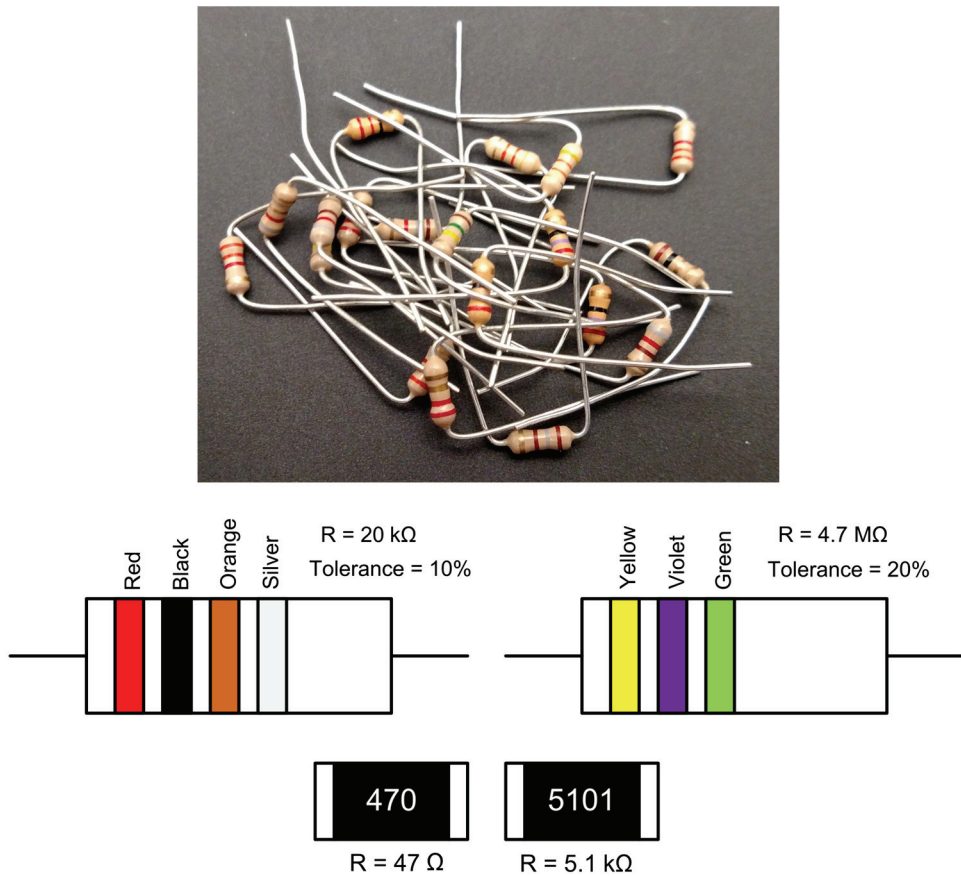
The conclusion from Example 1.2 could also be stated as: Knowing that the current through the LED is 20 mA and that the operating voltage is 2.2 V, we need to lower the voltage by 9 – 2.2 or 6.8 V using a 20-mA current or 340  $\Omega$ .

Now many interesting details were introduced in this section as we made our decision on powering the LED. To understand this further, we need to look at how the basic electronic components are used. We will begin with a closer look at resistors.

**1.3 Resistors**

We have shown the nature of voltage and current in terms of driving force and moving charge provided by a battery, but we haven't said much about resistors. Resistors have many roles; in the last section, a resistor was used to drop the voltage going into the LED. Resistors do this, for the most part, by converting current to heat. Resistors are physical devices and are available in compact packages whose sizes relate to their ability to dissipate power without damage. The power-handling capability of a resistor is measured in units of watts.

Common resistors are made of carbon between two wires. It can be interesting to break one open and see inside! The physical size of the resistor relates to the amount of carbon in the resistors and to the amount of power a resistor can dissipate. The resistance value is indicated on a resistor by either a number or a set of colored bands that can be translated into the value in ohms.



**Figure 1.2** Top: A collection of various low-power resistors showing colored bands that define their resistance values. Bottom: Illustration of color bands and surface mount resistors with their values.

Colored bands, some examples of which are shown in Fig. 1.2, are the most common way to identify resistors.<sup>2</sup>

The colored bands, either three or four colored stripes around the body of the resistor, are located toward one end. The colored bands indicate the resistance value and the tolerance or how close the actual resistor value will be to the stated value. There are three common tolerance levels:  $\pm 5\%$  is represented by Gold,  $\pm 10\%$  is represented by Silver, and  $\pm 20\%$  is represented by only three bands.

The key to translating the individual colors into numbers is shown in Table 1.1. To simplify this discussion, the first three colored bands, referred to as A, B, and C, are used to indicate the value of the resistor. The resistor value can be determined from the following equation:

$$\text{Value} = (10A + B)10^C. \quad (1.3)$$

**Table 1.1** The four-band resistor color code decoded.

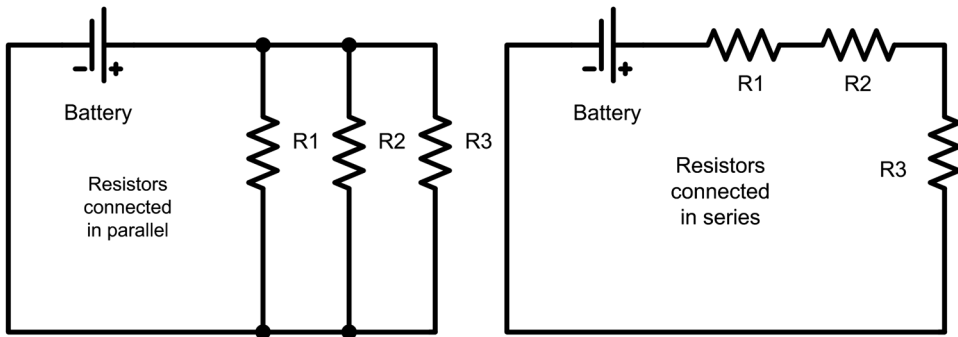
Color Band	Corresponding Number (A, B, C)	Multiplier ( $10^C$ )
Black	0	1
Brown	1	10
Red	2	100
Orange	3	1000
Yellow	4	10000
Green	5	100000
Blue	6	1000000
Violet	7	10000000
Gray	8	–
White	9	–
Gold	–	0.1
Silver	–	0.01

Notice that the third band C is used to multiply the first two digits by a factor of 10 raised to the power of C. A simple example can be used to show how this works: a three-band resistor of Red Red Orange would convert to numbers as 2 2 3 and thus be combined as 22 times 10 to the power 3, or 1000, for a resistor value of 22,000  $\Omega$ . As there are only three bands, the resistor has a tolerance of  $\pm 20\%$ , or  $R = 22000 \pm 4400 \Omega$ . If we measure the resistor's value, we would expect it to lie between 17,600 and 26,400  $\Omega$ .

So, really, the resistor color code is just shorthand for identifying the resistor value. The lower the tolerance range the more expensive the resistor is to purchase. There are also high-precision resistors that are considerably more costly to purchase so are used only for very specialized work.

The resistors with wire leads are referred to as “through hole” components; i.e., the wire ends can be poked into a hole for mounting and connection. The trend these days is toward smaller electronics, so parts are also being reduced in size. These parts mount differently and are soldered onto metal pads on the surface of an electronics board. Surface-mount resistors look like small black rectangles, as shown in the bottom of Fig. 1.2, and are often only a few millimeters in size. The numbers on these resistors refer to their resistance value, with the last number being the multiplier. There are some subtleties in the interpretation of surface-mount resistors as well as some new coding systems. For low-valued resistors, an R is used to indicate where the decimal point is located. For instance, R470 would indicate a 0.47- $\Omega$  resistor. The EIA-96 code is for 1% tolerance resistors and is a little more complicated to interpret; users should check with the manufacturer of their parts.<sup>3</sup>

There are occasions when a very precise resistor value is needed that is not a standard resistor value. Of course, one could purchase a large number of low-tolerance resistors and measure their individual values in the hope of finding the value needed; however, we can also construct the resistance we need by combining other resistors. We can wire resistors together in two common forms, series and parallel, as shown in Fig. 1.3.



**Figure 1.3** Two circuits showing resistors connected in parallel (left) and in series (right).

*In this book we use the convention that straight wires that cross are not connected unless there is a dot at the crossing point.*

Resistors can be combined into an effective value based on two mathematical expressions shown in Eqs. (1.4) and (1.5) for series and parallel resistors, respectively:<sup>1</sup>

$$R_{series} = \sum_i R_i, \quad (1.4)$$

$$\frac{1}{R_{parallel}} = \sum_i \frac{1}{R_i}, \quad (1.5)$$

where  $R_i$  show the individual resistors, and  $i = 1, 2, 3 \dots N$ , where  $N$  is the maximum number of individual resistors to be summed.

There are some interesting limiting cases for combining resistors in series and parallel. If we have two identical resistors of value  $R$  connected in series, then the effective resistance is  $2R$ , while if they are connected in parallel, the effective resistance is  $R/2$ . If we have two resistors that are several orders of magnitude different in value, when they are connected in series, the effective resistance is approximately the larger of the two resistors; when they are connected in parallel, the effective resistance is the smaller of the two resistors. This is demonstrated in Example 1.3.

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### Example 1.3

Two resistors,  $R1 = R$  and  $R2 = 1000R$  are connected first in series and then in parallel. Using Eqs. (1.3) and (1.4), calculate the effective resistance in each case.

$$R_{series} = R1 + R2 = R + 1000R = 1001R \sim 1000R,$$

$$\frac{1}{R_{parallel}} = \frac{1}{R1} + \frac{1}{R2} = \frac{1}{R} + \frac{1}{1000R} = \frac{1000 + 1}{1000R} \sim \frac{1}{R},$$

$$\text{or } R_{parallel} = R.$$


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**Table 1.2** Common unit multiplier names and values.

Prefix	Value
k (kilo)	$10^3$
M (mega)	$10^6$
p (pico)	$10^{-12}$
n (nano)	$10^{-9}$
$\mu$ (micro)	$10^{-6}$
m (milli)	$10^{-3}$

As resistor values become larger, it is common to introduce multipliers to the unit notation based on various multipliers of 10. The letters used to represent the multipliers are taken from the metric system. As such, a resistor of 1000  $\Omega$  is commonly shown as 1 k $\Omega$ , and a resistor of 1,000,000  $\Omega$  as 1 M $\Omega$ . The common abbreviations for electronics are shown in Table 1.2. A script is shown in Example 1.4 that implements Eqs. (1.3) and (1.4) for rapid calculation of combined resistor values based on they way they are connected.

Example 1.4 is our first MATLAB script, making this a great place to get familiar with how to write a simple calculator. The goal is very modest—calculating the value of a combination of two resistors—but it also illustrates how to write a simple script. Notice that there are many lines that begin with “%” symbols.<sup>4</sup> These lines are called comments and are tell the reader of the script what is occurring. They are ignored by the computer and can also come after the “;” symbols, which suppress printing output. The first noncomment lines clear the variables and the command window. The next lines input the data values and provide information to the screen. Once the calculations are performed, their values are formatted and printed to the screen. Implement this script in your version of MATLAB and explore the effects of various changes.

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### Example 1.4

Write a MATLAB script to calculate the equivalent resistance of a 200- $\Omega$  and 400- $\Omega$  resistor connected first in series and then in parallel.

```
% Example_1_4.m
% SWT 9-4-15

% This script takes two resistor values and calculates the
% effective series and parallel resistance.

% Housekeeping
clear all; % clears the variable list and starts fresh
clc; % clears the command window

% Input values
%% Use the MATLAB input() command to request data
```



```

fprintf('Effective resistance calculator\n\n');
prompt = 'Enter the value of resistor 1 in ohms: ';
R1 = input(prompt);

prompt = 'Enter the value of resistor 2 in ohms: ';
R2 = input(prompt);

%% Calculation
% Perform required calculations
Rseries = R1 + R2;
Rparallel = 1 / (1/R1 + 1/R2);

%% Output
% Echo the results to the screen
fprintf('\nR1 is: %6.1f ohms R2 is: %6.1f ohms\n', R1, R2)
fprintf('Rseries is: %6.1f ohms\n', Rseries)
fprintf('Rparallel is: %6.1f ohms\n', Rparallel)

Result:
R1 is: 200.0 ohms R2 is: 400.0 ohms
Rseries is: 600.0 ohms
Rparallel is 133.3 ohms

```

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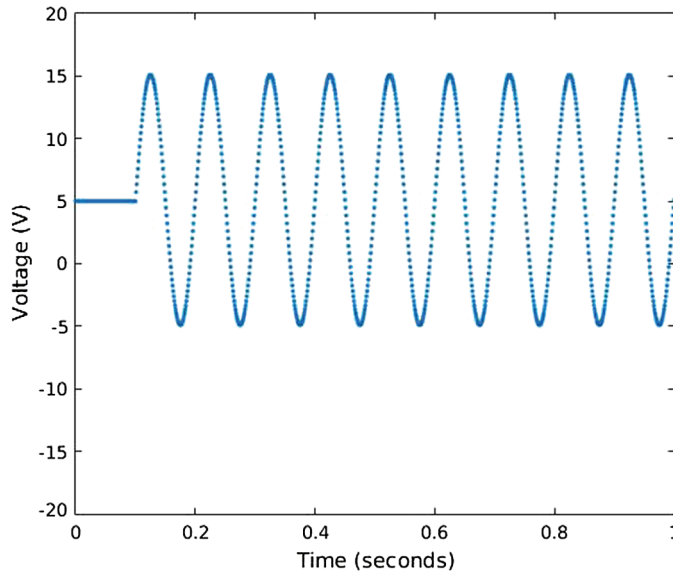
## 1.4 Signals

A voltage applied to a circuit can be constant or it can vary with time. Time-varying voltages can be used as power sources such as the AC voltage in a house, or can be thought of as signals containing information such as a radio transmission. The general expression for a time-varying voltage is shown as

$$V(t) = V_{DC} + v(t) = V_{DC} + \sum_{i=1}^N V_i \sin(\omega_i t + \delta_i), \quad (1.6)$$

where  $V_{DC}$  is a steady state voltage, and  $V(t)$  is a time-varying signal. In the case of a single frequency, the time-varying signal will have an amplitude  $V_1$  and a sine function driven by  $\omega_1 = 2\pi f_1$  (where  $f_1$  is a frequency, and  $t$  is time) and a phase  $\delta_1$  from a reference. Steady state signals are often referred to as DC for direct current, and time-varying signals as AC for alternating current.<sup>5,6</sup> The function is shown in Fig. 1.4.

Time-varying signals are often called periodic and can have functional forms other than sinusoidal. Ramps, steps, square functions, and many others are often encountered in electronics. When time-varying signals are involved, there can be many different frequencies. When working with time-varying signals, to account for components that have frequency dependence, the



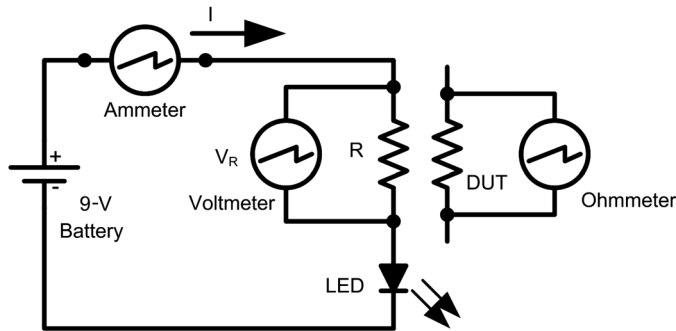
**Figure 1.4** A time-varying signal based on Eq. (1.6), showing  $V_{DC} = 5$  V at the start and then a superimposed sinusoidal signal  $V_1 = 10$  V.

components used to control the voltage and currents are said to have impedance rather than resistance. Such frequency-dependent components include capacitors and inductors as well as many semiconductor devices.

Impedance is the broader term for talking about resistance to current flow in a circuit and is a function of frequency. Impedance includes the effects of resistance, capacitance, and inductance, the latter two of which include devices known as capacitors and inductors. Both capacitors and inductors have the ability to store energy and release it as well as to impede the flow of current. These devices will be discussed in later sections so, while introduced here, are not fully described. Don't worry. Capacitors and inductors will be included in later discussions.<sup>5,6</sup>

## 1.5 Measuring Instruments

There are many measuring instruments available for use in electronics, but for most applications the volt-ohm meter (VOM), or, as it is commonly referred to today, the digital-volt meter (DVM) is most often used. The DVM typically allows the measurement of voltage, current, and resistance at a minimum and can have manually adjustable scales or can automatically change ranges. It is necessary to understand where to place the DVM in a circuit to make measurements; otherwise, the numbers returned will not make sense. Figure 1.5 shows our earlier LED circuit with measurement devices added in their proper places. The voltmeter measures the voltage



**Figure 1.5** A simple circuit with measurement points and connections shown. Notice that the ohmmeter is used when the resistor is out of the circuit.

drop across the resistor, while the ammeter measures the current that is flowing in the circuit.<sup>2</sup> When using the ohmmeter, the resistor should not be connected to the rest of the circuit and is shown here as a separate device under test (DUT).

While a single DVM can perform each of the three measurements shown in Fig. 1.5, it can only perform the measurements one at a time. Each of the different measurement types will be considered individually:

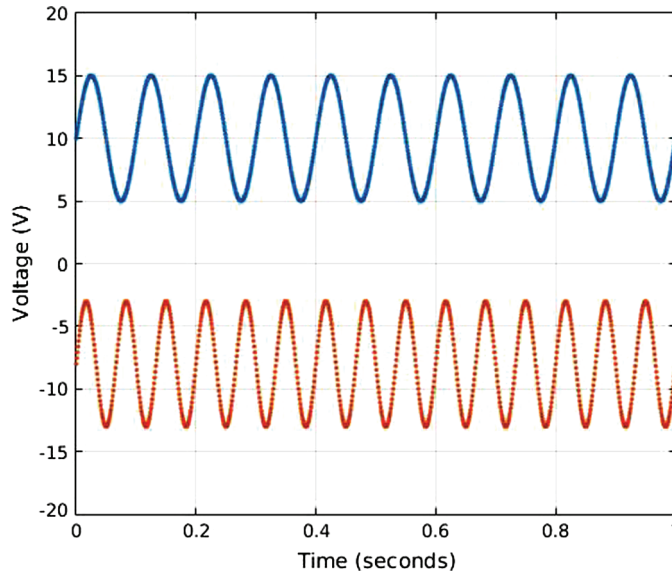
**Ammeter:** To measure the current, we need the ammeter to be connected to our circuit in series, and the circuit needs to be powered. That is to say, we need to break the circuit and then reconnect the two ends with the ammeter. In this way the current flows through the ammeter. Care needs to be taken as to how much current we measure to make sure it is within the allowed range of the meter.

**Voltmeter:** The voltmeter measures the voltage across a device and so connects in parallel with the device. The circuit must be on in order to measure the voltage drop across a device.

**Ohmmeter:** The ohmmeter has its own internal power source, so the DUT must not be powered for this measurement. In general, we don't want the DUT to be in the circuit so that the rest of the circuit doesn't affect the measurement of the DUT.

One interesting observation is that when we measure the voltage drop across a resistor of known value, we are actually able to back calculate the current! In Fig. 1.5 we will expect to see that the ammeter's measurement of the current  $I$  will equal the ratio of  $V_R/R$  that we measure with the voltmeter!

Most DVMs are able to measure DC voltages using different meter settings. However, sometimes we would prefer to see the alternating signal displaced as a voltage-versus-time trace; this is where the DVM loses its usefulness. Voltage-time measurements are possible using a different



**Figure 1.6** An example of an oscilloscope trace showing two signals of different frequencies, but the same amplitude. Notice the frequency difference between the upper and lower signals.

instrument known as the oscilloscope, which is a very practical tool in electronics work.

The oscilloscope is one of the most versatile tools in the electronics instrumentation arsenal. Its role is to provide the most detailed view of a signal that can be obtained, and it can display multiple signals, their relationships to each other, and specific regions of interest. Modern oscilloscopes, often referred to as digital oscilloscopes, can perform mathematical functions such as adding and differencing signals, signal averaging, Fourier transforms, and much more. Figure 1.6 shows an oscilloscope view of two signals of the same amplitude with different frequencies and offset voltages.

With these two tools—the DVM and the oscilloscope—a wide range of measurements is possible within an electronic circuit. It is very important to review the owner’s manual for any electronics testing instrument you are going to use in order to avoid dangerous situations or damage to your instrument. Example 1.5 shows a MATLAB script to generate Fig. 1.6.

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### Example 1.5

Write a MATLAB script to plot two sinusoidal signals with offset voltages of +10 and  $-10$  V, frequencies of 10 and 15 Hz, and a phase shift of 2.

```
% Example_1_5  
% SWT 9-3-15
```

```
% Generates two sinusoidal signals for comparison

%% Housekeeping
clear all;
clc;

%% Parameters
Vo = 5; Vdc(1) = 10; Vdc(2) = -10; % in volts
freq(1) = 10; freq(2) = 15; % in Hz
delta(1) = 0; delta(2) = 0;

%% Calculations
for idx=1:2
    omega(idx) = 2*pi*freq(idx);
end

maxCount = 1000; maxTime = 1; % seconds
for count = 0:maxCount
    time = count/maxCount*maxTime;
    for idx=1:2
        V(idx) = Vdc(idx) + Vo*sin(omega(idx)*time) . . .
+ delta(idx);
    end
    t(count+1) = time; VV1(count+1) = V(1); VV2(count+1) = V
(2);
end

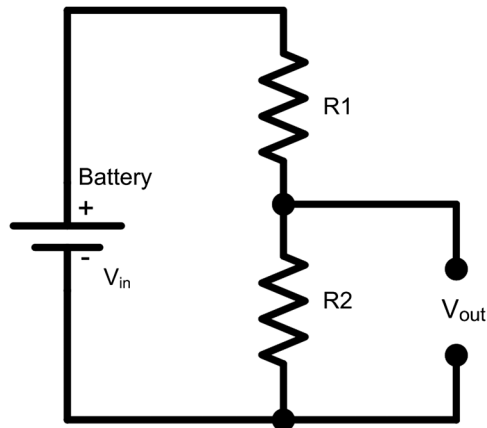
%% Output
figure(1); plot(t, VV1, t, VV2, '.');
axis([0 1 -20 20]); xlabel('Time (seconds)');
ylabel('Voltage (V)');
grid on;
```

Results: See Fig. 1.6.

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## 1.6 Voltage Dividers and Regulators

Most circuits require a power supply, and more often than not the power supply is a battery providing a DC voltage. Batteries come in a wide range of voltages and current capacities, but usually a little more effort is required to get the voltages that we want to use for our circuit. As an example, when was the last time you found a 5-V battery in the local store? Yet many electronic devices work on 5 V. Fortunately, it is fairly easy to choose a 9-V battery as a supply and just step the voltage down to the required value.



**Figure 1.7**  $R1$  and  $R2$  are connected in series to form a voltage divider. By carefully choosing the resistor values,  $V_{out}$  can be set between the value of the ground and the battery voltage.

Let's consider a simple way of getting 5 V from a 9-V battery and introduce the voltage divider structure,<sup>2</sup> as shown Fig. 1.7. The voltage divider lets us use two resistors connected in series such that they will have the same current running through them.

The voltage divider rule is given as

$$V_{out} = \frac{R2}{R1 + R2} V_{in}, \quad (1.7)$$

where  $V_{in}$  is the battery voltage in the circuit, and  $R1$  and  $R2$  are the resistors. The quick calculations in Example 1.6 show how it works.

---

### Example 1.6

Calculate the relationship between resistors to be used in a voltage divider to get an output voltage of 5 V using a 9-V battery as the source.

$$\frac{V_{out}}{V_{in}} = \frac{R2}{R1 + R2} = \frac{5 \text{ V}}{9 \text{ V}}.$$

Rearranging this equation yields

$$R1 = \frac{5}{4} R2.$$


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If a value of  $R2$  was chosen to be 400  $\Omega$ , then  $R1$  would need to be 500  $\Omega$  and the total resistance in the circuit would be 900  $\Omega$ . Since we are using a 9-V battery, this circuit is drawing a current of 9/900 or 10 mA through the voltage

divider to achieve the 5-V output that we wanted. Example 1.7 shows a MATLAB script that uses the `input()` command to take in the values of the resistors and the input voltage.

---

**Example 1.7**

Construct a voltage divider calculator using MATLAB and determine the output voltage from two 1000- $\Omega$  resistors with a load of 1 k $\Omega$  and 1 M $\Omega$ . The program takes an input voltage value in volts.

```
% Example_1_7.m
% SWT 9-4-15

% This script calculates the output of a voltage divider
% and the effect of a load resistor in parallel with the
% second resistor.

% Housekeeping
clear all; % clears the variable list and starts fresh
clc; % clears the command window

% Input values
%% Use the MATLAB input() command to request data
fprintf('Voltage divider calculator\n\n');
prompt = 'Enter the input voltage: ';
VI = input(prompt); % in volts

prompt = 'Enter the value of resistor 1 in ohms: ';
R1 = input(prompt);

prompt = 'Enter the value of resistor 2 (ohms): ';
R2 = input(prompt);

prompt = 'Enter the value of the load resistance (ohms): ';
RL = input(prompt);

% Calculation
%% Perform required calculations
REffective = 1 / (1/R2 + 1/RL);
VO = VI * REffective / (R1 + REffective);

% Output
%% Echo the results to the screen
fprintf('\nVout is: %6.1f V\n', VO)
```

```
fprintf('REffective is: %6.1f ohms\n', REffective)
```

```
Results 1 kohm load:
Vout is: 3.0V
REffective is: 500.0 ohms
```

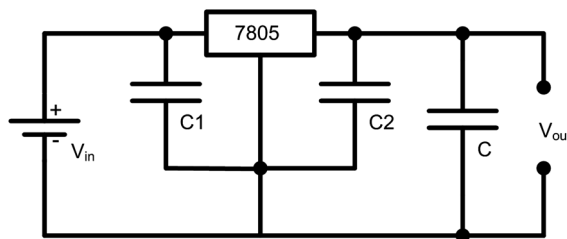
```
Results 1 Mohm load:
Vout is: 4.5 V
REffective is: 999.0 ohms
```

While we are easily able to get the voltage that we want, is that all there really is to this problem? The voltage output is typically used to drive a load. This load can be represented by another resistor connected in parallel to  $R_2$ . We saw earlier that there will be a change in the circuit if we add another resistor to the circuit. Let's consider a load resistor of  $400\ \Omega$ . Using Eq. (1.4), the effective parallel resistance would be  $200\ \Omega$ ; thus, we would no longer have 5 V available as the output from the voltage divider. Of course, if the load was closer to  $1\ \text{M}\Omega$ , there would not be a problem.

As such, we need a better way to create our desired voltage that is not as sensitive to the effect of adding a low resistance load. This is quite a common problem, so some very elegant solutions are available; one of the best is the voltage regulator. The voltage regulator is a rather sophisticated device, but it is so commonly used that we will introduce it now, along with a brief description (without much background detail at this point) of how to use it.

Voltage regulators are semiconductor devices designed to maintain a constant voltage level. Here, we treat them as a “black box” and demonstrate how they are used, starting with Fig. 1.8.

The 7805 voltage regulator lowers the battery voltage to 5 V. Regulators come in many voltage ranges; the number 5 in the 7805 indicates that it provides a 5-V regulated output. Often, the final capacitor  $C$  is not required and is there to act as a source of extra charge if needed. This is a very practical



**Figure 1.8** A voltage regulator used to convert a 9-V battery supply into 5 V.  $C_1$  and  $C_2$  are low-valued capacitors to support the 7805 device, while  $C$  is a larger filter capacitor.  $C$  might not always be required if the regulator is close to where the power is needed.



and simple power supply, and many different source configurations can be used in place of the battery.

When a load is not attached, the power draw of the voltage regulator is very low, making it ideal to be supplied by a battery. Voltage regulators are available in a wide range of values such as the 7812, 7815, and so forth. The major advantage of the voltage regulator is that it provides its rated voltage over wide-range current requirements. The limitations and proper operation of a voltage regulator can be found in the device data sheets.

## 1.7 Device Data Sheets

There is a wide range of electronics devices, and we have just begun to become familiar with a few of them. No one can remember all of the detailed specification of the myriad of electronic devices, so how can we know how to use a particular device, maybe one we have never seen before?

Not to worry. All of the information needed to work with a particular device is contained in the device data sheet. Everything from the operating specifications, performance data, size and shape information, and sometimes practical configuration diagrams are provided in the data sheet. These sheets are usually supplied by the device manufacturer and are usually available on the vendor's or the manufacturer's website.

So what does a data sheet look like? Data sheets contain a lot of information, as they try to provide all of the information important to the designer. This is where the Internet becomes a wonderful resource. Go to your favorite web search tool and look up the 7805 voltage regulator and you will see find a wide range of suppliers and many different data sheet sources. Take a look at one of the data sheets to become familiar with the type of information that they contain. There is a lot, but don't let this concern you at this point; as we move forward we will be talking more about data sheets, the symbols they use, and how to use them.

This brings up an important consideration. Many manufacturers don't want to be involved in day-to-day sales of low volumes of parts, so they enlist the help of companies that specialize in electronic part sales. This makes it somewhat easier to buy parts, as you only have to deal with one distributor for many electronics parts. This can really save on shipping costs.

## 1.8 Practice Problems

1. A voltage divider uses a 500- and a 900- $\Omega$  resistor in series with a 10-V battery.
  - a) What is the color code you would expect to see for these resistors if they are 20% tolerance?
  - b) What is the effective series resistance?

- c) What is the current through each resistor?
- d) What is the voltage drop through each resistor?
2. Three resistors are connected in parallel with values of 1000, 3000, and 1,000,000  $\Omega$ . What is the effective parallel resistance?
3. Three resistors are connected in series with values of 1000, 2000, and 3000  $\Omega$ . What is the effective series resistance?
4. What is the value of a resistor with the four-color code of yellow, purple, yellow, gold?
5. Design a circuit to power an LED that has a forward voltage of 2.5 V and a forward current of 18 mA using a 9-V battery and a voltage regulator as the supply.

#### Answers

1. (a) Violet Black Brown and White Black Brown; (b) 1400  $\Omega$ ; (c) 7.1 mA; (d) 3.6 V and 6.4 V
2. 750  $\Omega$
3. 6000  $\Omega$
4. 470 k $\Omega \pm 5\%$

#### References

1. C. K. Alexander and M. N. O. Sadiku, *Fundamentals of Electric Circuits*, Fifth Edition, McGraw-Hill, New York (2013).
2. B. Grob, *Basic Electronics*, Eighth Edition, McGraw-Hill, New York (1997).
3. Resistor Guide: [www.resistorguide.com](http://www.resistorguide.com). Last accessed: 4-14-16.
4. H. Moore, *MATLAB<sup>®</sup> for Engineers*, Fourth Edition, Prentice-Hall, Upper Saddle River, New Jersey (2014).
5. P. Horowitz and W. Hill, *The Art of Electronics*, Cambridge University Press, Cambridge (2015).
6. A. S. Sedra and K. C. Smith, *Microelectronic Circuits*, Oxford University Press, Oxford (2015).