INTRODUCTION

Electronic circuits are all around us. From a basic timer in a microwave oven to sophisticated circuits in our home computers—all of these devices depend upon some sort of circuitry. In today’s world, most circuits are very complex. However, these complex circuits are just a collection of small, basic circuits combined to create the enormous web of wires and parts.

This chapter introduces small, basic circuit components and builds upon these ideas with the introduction of general electronic principles and simple circuit examples. This introduction should help the reader see how complex circuits can be broken down into smaller, simpler systems.

SIMPLE CIRCUIT COMPONENTS AND CONCEPTS

In its simplest definition, a circuit is something that goes around in circles. An analogy of this can be found in rural areas where water is pumped up from a well in the ground and run through a faucet. From the faucet, the water runs down the drain and back into the ground. Over and over, the cycle is repeated.

In an electronic circuit, the same idea applies, but the basic difference is that electrons are circulating rather than water molecules. In this discussion, the analogy of a water system will be used to help understand how circuits work. Plumbing and electronic systems work similarly, and often times it is easier to visualize a water system. However, keep in mind that water and electrons are fundamentally very different from each other.

Wires

In electronic circuits, a wire is similar to the water pipe in a water system. In the plumbing world, the diameter of the pipe determines the capacity of how many gallons of water per minute the pipe can carry. In electric circuits, the wire diameter is related to the capacity of how many electrons per
second the wire can carry—better known as amps (A)\(^1\) of current. Usually, the wires in a circuit are short, and the resistance of the wires is negligible. (The concept of resistance is discussed later in this chapter in the section titled Resistors.) In the water analogy, this is like ignoring the friction in the pipe. Keep in mind that when wires are long, the resistance may no longer be negligible.

In the case of short wires used in typical circuits, the wire diameter is an indication of the wire current capacity in amps. Wire diameter is measured in units known as the American Wire Gage (AWG) standard. When using this standard, the smaller the AWG number, the larger the wire diameter, and therefore, the more electrons it can carry. Notice the reverse relationship of the AWG number to wire diameter and current capacity (see Figure 17.1).

\[ \text{12 AWG carries up to 23 AMPS} \]

\[ \text{6 AWG carries up to 55 AMPS} \]

Figure 17.1. When using American Wire Gage (AWG) standard units, the smaller the wire number the more electrons it can carry. For example, a 12 AWG wire can carry 23 amps, while a 6 AWG wire is larger and carries 55 amps.

**Voltage and Batteries**

Voltage is one of the most difficult electronics concepts to explain. For illustration, voltage has the same function as a hill in a physical analogy. The height of the hill has what is called gravitational potential, made possible by the presence of a gravitational field. The hill can be used to cause objects to move and flow down the hill. Likewise, voltage, also called electrical potential, is made possible by the presence of an electric field. Voltage can be used to cause the flow of electrons (current) through the electrical components in the circuit.

Voltage is caused by the separation of charge similar to how gravitational potential is caused by the separation in height for the hill. The separation of charge can be provided by a battery; therefore, a battery is a voltage source. In the presence of applied voltage, molecules are attracted to (or repelled from) each other, causing the electrons to flow in order to balance the separation of charge and return to a neutral reference value; i.e., “ground” discussed in the next section. Voltage, just like height, is a relative measurement. There is no absolute value for voltage, only a voltage difference.

1. 1 amp = 6.25 x 10\(^{18}\) electrons per second.
Many times voltage is measured across an electric component or from a reference position like “ground.”

Referring to the water analogy again, a water pump is used to pump water through a network of pipes. The higher the pressure produced by the pump, the higher the resulting flow of water. Similarly, voltage is like an “electric pressure,” although only on a conceptual level since voltage does not have the same type of measurement units as pressure. In a circuit, the battery provides a voltage that pushes the electrons through the wire, resistors and other electrical components.

![Figure 17.2](image_url)

Figure 17.2. A battery pushes electrons through a network of wires, just like a water pump pushes water through a network of pipes.

Figure 17.2 demonstrates the analogous relationship between a pump and a battery. The lower diagram shows a water pump, in which the plus symbol on the right side represents the output or pressure side of the pump and the negative symbol on the other side represents the suction or pull side. The diagram just above the water pump is the standard symbol for a battery, as used in schematic diagrams. Similar to the pump, the battery has a plus side (the positive voltage or push side), and a negative side (the pull side). In many circuit applications, the negative side of the battery is connected to reference “ground,” which is discussed further in the next section.

The voltage value (V) indicates how many amps the battery can push. A battery with a higher voltage will try to push higher amps (more electrons) through the wires and electric components. Therefore, it is important to choose the correct battery voltage for the circuit—too high a voltage can burn the wire by pushing more amps through the wire than it can handle. This is parallel to a plumbing system: if too much pressure is applied, it may exceed the capacity of the pipe and burst.

Engineers must always be aware of system limitations and work within those limits. In the simple circuit described thus far, the circuit’s physical limits can be met by either choosing a smaller battery voltage or a smaller gage (larger diameter) wire that can handle more current.

**Ground**

“Ground” is an important concept that connects entire circuits together. It is a neutral point or a reference point. In the physical example mentioned above, the bottom of the hill is analogous to the ground (GND) in an electric circuit. Voltage is frequently measured from this reference point.
Figure 17.3. In circuit schematics, the symbol for ground is frequently used in schematic diagrams to indicate that the wires are connected to each other.

Figure 17.3 provides the schematic symbol for ground (on the right) and the water analogy for ground (on the left). In circuit schematics, any wires connected to this symbol are connected to the same reference point (GND).

Figure 17.4. The top diagram shows an electronic circuit. The bottom diagram shows a parallel water system to illustrate what goes on inside the wires.

Plumbing and electronics often work similarly. Figure 17.4 shows how a circuit schematic (top diagram) is analogous to a water system (bottom diagram). Looking at the circuit schematic, begin at the battery and trace the electron flow through the wire and back down to ground. Notice that there are two ground symbols in the circuits diagram; this means that every point with a ground is connected together and are at the same voltage reference value—just like in the water diagram where the two ends of the pipe are at the same water level.

**Resistance**

In simple terms, resistance is something that holds back or makes things harder to do; it is basically a restriction to flow. Up to this point, the described circuit system only contains wires and a bat-
battery to push electrons through the wires, which are assumed to have negligible resistance. However, when electrical components such as resistors, LEDs, light bulbs, motors, etc., are added to a circuit, resistance becomes an important issue. This is because most components do not have negligible resistance. Several electrical components will be discussed in detail in the sections below.

**Ohm’s Law**

The unit Ohm (symbolized by the Greek letter Ω) is used to measure resistance. According to Ohm’s Law, 1 Ohm is a unit of electrical resistance equal to that of a conductor in which a current of one ampere is produced by an electric potential of one volt across its terminals. Thus, the basic variables in Ohm’s Law, voltage (V), resistance (Ω), and current (A), are closely related and cannot be determined independently. For example, if the battery voltage (V) has been selected and the resistance (Ω) has been calculated, the amperage (A) of current flowing in the electric components can be determined to ensure the capacity of those components is not exceeded. Likewise, Ohm’s Law can be used when any two of the variables are known to calculate the value of the unknown third variable using the equations in Figure 17.5.

![Figure 17.5.
Using Ohm’s Law, the values of voltage, current, resistance and power may be calculated from the above equations.](image)

For example, to calculate the voltage (V) from known resistance (R) and current (I) values, cover the symbol for the unknown value on the circle on the left in Figure 17.5. In this case, covering the “V” indicates that current (I) must be multiplied times resistance (R) to calculate the unknown voltage value. To determine current (I), cover the “I” to realize that it can be calculated by dividing “V” by “R.”

**Power**

The Ohm’s Law equations (Figure 17.5) also include the variable power, measured in watts (W), which is defined as one ampere moving through an electric potential of one volt. Power is also a unit of measure equal to the rate of energy transfer. Thus, electric components come with a power rating that informs the user what combinations of voltage and current may be safely applied without burning it up. An example is a light bulb, which is simply a resistor that gives off heat and light. A higher wattage light bulb draws more current from a given voltage, thereby transferring energy more quickly to provide a brighter light.
Resistors

Using the water analogy, a resistor is like a kink in a water hose. When a hose is folded to make a kink, the amount of water flowing through it can be controlled. A more severe kink in the hose lets even less water flow through it.

In electronics, a resistor causes a “restriction” that controls the number of electrons that flow through the restriction and the rest of the circuit (see Figure 17.6). Resistance is important because it allows control of a variety of devices. Many devices, such as electric motors, run faster the more electrons are pushed through it.

Recall that the unit of measure for resistance is an Ohm ($\Omega$). The more resistance a resistor has, the bigger the number value ($\Omega$), and fewer electrons are allowed to flow. Thus, a 1000 $\Omega$ resistor is like a kink with a bigger opening than that of a 9000 $\Omega$ resistor.

Notice that the electronic symbol for a resistor (see Figure 17.6) has no polarity. Compare this to the battery symbol discussed earlier that had polarity indicated (a plus and minus symbol). In the case of the battery, it was important to know the direction of electron flow. But, in the case of a restriction, like a resistor, the function is the same no matter the flow direction.

**Color Code System**

Because electronic components are so small, it is difficult to write all of the value information on each resistor. Therefore, a color code system indicates the resistor values.
Using the resistor color chart in Figure 17.7, notice the three resistors with various numbers of color code bands. Three resistor examples are illustrated. The first resistor, with four color bands, provides the minimum resistor information. The second, a 5-band code, provides a little more information on the resistor. And, the third resistor, a 6-band, provides even more information.

Looking at the 4-band code resistor example, note that there are three bands close together with the fourth one located slightly separated from the first three. This far right band is the last one to be read. The first band (on the far left) is called the first digit, the second is the second digit, the third band is called the multiplier, and the final band indicates the tolerance of the resistor.

To determine the value of the 4-band resistor in Figure 17.7, note that its first band is \( \text{RED} \). Following the line down the chart indicates that red represents the number 2—the first digit. Next, the second band is \( \text{GRN} \) and represents a value of 5. The third band, the multiplier, is \( \text{ORN} \), and indicates a value of 1\(\text{K} \) (1\(\text{K} = 1000 \)). To determine the final value, take the first two color-band digits, 25, and multiply it by the multiplier, 1\(\text{K} \) (1000), resulting in the value of this resistor as 25 \(\times\) 1000 = 25000 Ohms.

The fourth band indicates the tolerance. In this example, it is \( \text{GLD} \)—a tolerance value of 5\%. Multiplying the resistor value (25000 Ohms) by .05 calculates this resistor’s tolerance; it is a 25000\(\text{W} \) resistor with a 5\% tolerance. Therefore, when measured, the actual value should fall between 23750\(\text{W} \) and 26250\(\text{W} \).
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SIMPLE CIRCUIT COMBINATION AND SAMPLE CALCULATIONS

Standard Units

In electronics, the numbers in many of the measurement units are usually very large or very small. To write all the zeros that represent these numbers would be cumbersome. So, like in many other technical fields, Standard Units are used as a shorter form to annotate values (Table 17.1). For example, the number 25,000,000,000 is written as 25G, pronounced "twenty-five Gig." To obtain the full value, the number in front of the letter designator is multiplied by the value of the Standard Unit.

Examples:

\[ 5.6\mu = (5.6) \times (0.000001) = 0.0000056 \]

\[ 47K = (47) \times (1000) = 47000 \]

After many references to the Standard Units chart, these short-hand units will become familiar and second-nature.

Table 17.1. Standard Units.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>G (Giga)</td>
<td>( x 10^9 (1,000,000,000) )</td>
</tr>
<tr>
<td>M (Mega)</td>
<td>( x 10^6 (1,000,000) )</td>
</tr>
<tr>
<td>K (Kilo)</td>
<td>( x 10^3 (1,000) )</td>
</tr>
<tr>
<td>m (milli)</td>
<td>( x 10^{-3} (0.001) )</td>
</tr>
<tr>
<td>( \mu ) (micro)</td>
<td>( x 10^{-6} (0.000 0001) )</td>
</tr>
<tr>
<td>n (nano)</td>
<td>( x 10^{-9} (0.000 000 001) )</td>
</tr>
<tr>
<td>p (pico)</td>
<td>( x 10^{-12} (0.000 000 000 001) )</td>
</tr>
</tbody>
</table>

Standard Electronic Units

In circuits, another standard notation is used to identify specific components since often there are many components of the same type. Table 17.2 shows all of these variables.

Table 17.2. Standard Electronic Units

<table>
<thead>
<tr>
<th>Schematic Symbol Letter</th>
<th>Component Type</th>
<th>Unit of Measure</th>
<th>Unit Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_x</td>
<td>Battery</td>
<td>Volts</td>
<td>(V or E, ( V_{CC}, V_{EE} ))</td>
</tr>
<tr>
<td>R_x</td>
<td>Resistor</td>
<td>Ohms</td>
<td>(( \Omega ))</td>
</tr>
<tr>
<td>I_x</td>
<td>Current</td>
<td>Ampere</td>
<td>(A)</td>
</tr>
<tr>
<td>P</td>
<td>Power</td>
<td>Watts</td>
<td>(W)</td>
</tr>
</tbody>
</table>
Table 17.2, the left column indicates the letter notation found next to the schematic symbol in a circuits diagram, and the x just below provides the component number. For example, R_{13} is resistor number 13, and C_{2} is capacitor number 2.

### Single Resistor Circuit

Understanding some simple example problems will apply the information discussed thus far. In the left example of Figure 17.8, the voltage and resistance values are known; the current value is unknown. By taking the known voltage (12V) and dividing it by the resistance (100 Ω), the current is calculated (120mA). In the example on the right, the problem is similar; except the unknown variable to solve for is the resistance. For example, suppose the voltage is known because the battery has been chosen. If it is then determined that 240mA of current is needed for the rest of the circuit, the appropriate size resistor of 50 Ohms is calculated.

\[ V = 12V \quad R = 100 \text{ Ohms} \quad I = ? \]

**Solution:**
\[ I = \frac{V}{R} \]
\[ I = \frac{12V}{100} \]
\[ I = 0.120 \text{ A} = 120\text{mA} \]

\[ V = 12V \quad R = ? \quad I = 240\text{mA} \]

**Solution:**
\[ R = \frac{V}{I} \]
\[ R = \frac{12V}{240\text{mA}} \]
\[ R = 50 \text{ Ohms} \]

Figure 17.8. These two example problems involve circuits with one resistor each. Solve for the unknown variables.

### Power Calculations

To calculate power, refer to the first example in Figure 17.9, and use the cover-up method as described earlier. The variables are volts (V), current (I) and power (P). With a given voltage (12 V) and current (300mA), the power value may be calculated (3.6 W of power).

<table>
<thead>
<tr>
<th>Schematic Symbol Letter</th>
<th>Component Type</th>
<th>Unit of Measure</th>
<th>Unit Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_{x}</td>
<td>Capacitor</td>
<td>Farads</td>
<td>(F)</td>
</tr>
<tr>
<td>D_{x}</td>
<td>Diode</td>
<td>Peak Inverse Voltage</td>
<td>(PIV)</td>
</tr>
</tbody>
</table>
The power value calculated in this example is the power that the resistor is using, or better yet, the power it absorbs. Power does not only apply to resistors, but it also applies to every component found in electrical circuits. Other components, such as batteries, generate (or output) power. Electric components either provide or absorb power.

The examples in the Figure 17.9 show that the power the battery outputs is about equal to the power the resistor absorbs. In the real world, nothing is perfect and power losses are unavoidable. In basic circuit analysis, it is commonly assumed that all circuits are ideal and any losses are negligible. Thus, the battery output equals how much power the resistor absorbs.

**Resistors in Series Circuit**

Electronic terminology describes a "series" combination of resistors as those that are connected, in succession, one after another.

![Resistors in Series Circuit Diagram](image)

Figure 17.10. Electronic schematic circuit diagram illustrating two resistors in series.

Figure 17.10 illustrates the electronic symbol for resistors in series. In this circuit, the electron flow direction begins at the battery, proceeds through the first resistor and then flows through the second resistor.
Chapter 17: Electronics and Circuits

Referring to Figure 17.11, the top diagram illustrates a circuit with a battery and two resistors in series. In a series circuit like this, the resistors may be added together: 100 Ω plus 189 Ω gives a value of 289 Ω, called an equivalent resistor. For ease of calculation, the two resistors are replaced with an equivalent resistance (lower diagram).

Making an equivalent circuit makes no difference to the battery; it only feels a total resistance due to all the components in the circuit. It is like a person lifting a box with several rocks in it. She cannot distinguish that there is more than one rock inside, but she can feel the total weight (resistance) of the rocks. Once the two resistors are replaced with an equivalent resistance, it is simple to do the calculations as usual, given resistances and current, to determine the unknown battery voltage value.

Keep in mind that current in a **series circuit** is the same throughout its path. In this example, the current going through R_1 is the same as the current going through R_2.

**Resistors in Parallel Circuit**

Alternately, multiple resistors can also be connected “in parallel.” An example of a circuit with resistors in parallel is shown in Figure 17.12. All the input leads are connected, together and all the outputs are connected together. Basically, the circuit divides into several branches, one that contains R_1 and the other that contains R_2.
Using the water analogy again, resistors in parallel are similar to a situation in which a pipe brings water to both a kitchen and a bathroom sink simultaneously. The pipes for each sink come from the same pump source, and the sink drains each attach to the same drain source. In this case, each faucet feels the same pressure. The valve on the faucet provides a "resistance." If the kitchen faucet is open more than the bathroom faucet, there is more water flow through the kitchen branch. Yet, the combined flow of both the kitchen and the bathroom faucets equals the total flow rate coming from the pump source.

Similarly, in electronics each resistor feels the same voltage, which permits the connection of several circuits to utilize the same voltage source. In the top circuit diagram of Figure 17.12, $R_1$ and $R_2$ each have a branch. These two branches are really separate circuits that share the same voltage source, and each resistor works independently from the other. Because they work independently, each will have a different current flowing through them. As in the water analogy, the sum of the currents running through each branch is the total current, provided by the battery.

Notice how the parallel configuration is different than the series configuration. Since the resistor values in each branch feel the same 12V from the battery, the current in each branch can be different. This was not the case for the series configuration, in which the voltage is shared and the current through each resistor must be the same. To calculate the current ($I$) value for the parallel resistors circuit in Figure 17.12, the actual circuit is simplified by replacing the two resistors with an equivalent circuit. However, since the flow in each branch is different, the resistor values cannot be simply added together to determine an equivalent resistance. Rather, the following formula has been derived to determine the equivalent resistance:

$$R_{\text{equivalent}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}}$$
Calculate the equivalent resistance by using the given resistance values from Figure 17.12 (100Ω for R₁ and 150Ω for R₂) in the formula. Take the reciprocals of each resistor and add them together, then take the reciprocal again to obtain a final equivalent resistance of 60Ω. Replace the resistance to get a simple circuit and calculate the current as usual. Keep in mind that this is the total current being calculated. Take the given voltage (12 V) and divide it by the equivalent resistance (60Ω) to calculate the total current (200mA).

The total power value may also be calculated in the same way as the resistors in series example, where the sum of the power that each resistor uses is the total power consumed by the circuit. In power calculations, whether it is a series or parallel circuit, the sum of the power used by all components is the total power used. Multiply the given voltage (12V) by the calculated current (I_{total} = 200mA) for a total power (W_{total}) of 2.4 W. To verify these numbers, it is useful to calculate the power used by each resistor and add them together. Their sums should add up to 2.4 W (see Figure 17.13).

The example illustrated in Figure 17.13 may be expanded by calculating the power through R₁. The value of the resistor R₁ is given, and since this is a parallel circuit, R₁ and R₂ are connected to the same source. Therefore, they both feel a voltage of 12V, and this same voltage value is used for both resistors in the calculation. Using the formula \( P = \frac{V^2}{R} \), \( P_{R1} = \frac{(12)^2}{100} \) or 1.44Ω and \( P_{R2} = \frac{(12)^2}{150} \) or .960Ω. Adding them together (resulting in a value of 2.40W) confirms the total power calculation.

To confirm the current calculations, compute the individual currents for each resistor and add them together. The example in Figure 17.13 illustrates that the sum of the currents does confirm the total current calculation from Figure 17.12 of 200mA. In contrast, recall that in a series circuit, the current is the same throughout the circuit and is equal to the total current. Whereas, in a parallel cir-
cuit, the current in each component must be summed together to determine the total current drawn from the battery.

**Voltage Drop**

Recall that voltage is a relative measurement taken as a difference between two points. Voltage drop is the difference in voltage, measured from one side of the resistor to the other. This is similar to a kinked water hose: on one side of the kink is higher pressure and on the other side is lower pressure. If there is just one resistor in series with the battery, the voltage drop across the resistor is equal to the voltage of the battery.

![Figure 17.14. Example circuit with voltage drop calculation.](image)

In a series circuit, the sum of the voltage change across each resistor is equal to the battery voltage. In Figure 17.14, the voltage across each resistor is calculated and added together. Note that the sum of these is equal to the battery voltage. In addition, the sum of the power used by each resistor is equal to the power the battery puts out. In contrast, for a parallel circuit configuration, no voltage drop calculation is necessary. Recall that the battery provides the same voltage to each parallel resistor; i.e., the voltage drop across one resistor equals the voltage drop across the second resistor, etc., which all equal the battery voltage.

### ADDITIONAL CIRCUIT COMPONENTS

#### Diodes

Diodes are like one-way check valves that allow current to flow in only one direction. They can be used to protect circuits and convert alternating current (AC) into direct current (DC). Since many components can only function in one direction, diodes are also used to protect the circuit from a battery connected backwards.
The lower two diagrams in Figure 17.15 illustrate a diode’s function using the water analogy. As water flows in a pipe from the plus side to the negative side, the gate (“diode”) opens, allowing water to flow through. When water flow is reversed, the gate closes, preventing water from flowing through. The top diagram in Figure 17.15 is the schematic symbol for a diode as used in circuit diagrams. Note that unlike resistors, it is critical to place the diode in the right location in relation to the direction of the electron flow.

**Standard Diodes**

Looking at the two regular diodes illustrated in Figure 17.16, notice that each diode has a bar at one end. This bar represents the negative side of the diode, or the part that points towards the ground side. The numbers represent the model type, which can be referenced in a data book.
Diodes have many values that characterize their performance. The two main values of concern in this discussion are the maximum current that can flow through it and the peak inverse voltage (PIV):

- The maximum current value represents the limit of forward current flow. When a diode is used in a circuit, it is important that the amount of current that flows through the circuit is less than the maximum that the diode can handle.

- The PIV is the maximum reverse voltage the diode can hold. Referring back to the diagram in Figure 17.15 in which the water pipe has a one-way gate, if the pressure in the reverse direction is higher than the gate can hold, it would break. In electronics lingo, the diode would “burn up.”

For safety concerns, when determining the type of diode required for a circuit, the general rule of thumb guideline is to select a diode with a PIV and maximum current value that is about 20% higher than the current flow required. For example, in a circuit that uses a 12V battery and a current flow of 1.5A, a diode is needed to protect the circuit from someone connecting a battery backwards. Realizing that the battery in reverse produces a PIV of 12V, the chosen diode must have a PIV of more than 12V. Using the general rule of thumb of selecting a value that is about 20% higher allows a 20% margin of error for safety. Using this 20% margin results in a selected diode rated at 14.4PIV and 1.8A max current flow. Remember these are only safe minimums; higher values may be used. In addition, there are many other types of diodes that do the same thing but with slightly different characteristics.

**Light-Emitting Diodes (LED)**

Another type of diode is a light-emitting diode (LED). An LED acts just like a standard diode except it lights up only when current flows through in the forward direction, unlike a resistor or light bulb that lights up or works in either direction. Also unlike a regular light bulb, an LED uses less power to produce light (thus using less energy and lasting longer). An LED also serves as a protection device for the circuit since it prevents current from flowing in the opposite direction. But, note that running about 30mA through an LED is a general rule of thumb.
In the lower row of diagrams in Figure 17.17, there are two basic LED types: circular and square. The left and middle of these diagrams show the same circular LED from a bottom view and a side view. The right diagram shows a square LED.

There are two ways to determine which are the plus and the minus side of an LED. The best way, which works for both shapes of LEDs, is to look at the two elements inside. The biggest element is the negative lead; it is connected to the side going to ground. The smaller lead indicates the side where the electrons enter the LED. The second method of determining the polarity works only for the circular shaped LEDs. By looking at the bottom view of the circular LED, it is clear that the LED has a flat side that resembles a capital “D.” The lead closest to the flat side is the negative side and is connected to the ground side of the circuit. The other lead is the positive side and is connected towards a power source (such as a battery).
In the example illustrated in Figure 17.18, the circuit includes an LED being used as a light. There is a 12V battery, an LED and a resistor used to limit the amount of current that will go through the LED. As mentioned earlier, the general rule is to allow no more than 30mA through an LED. Based on this information, the required resistance of $400\,\Omega$ is calculated using 12V and 30 mA and Ohm's Law. This example is typical of the calculation to determine an appropriate resistor value in order to safely limit the amount of current going into the LED.

**Capacitors**

Capacitors may be considered like “storage tanks” for electrons. They are mainly used for timing, filtering and smoothing out the flow of electrons. Using the water analogy, capacitors could be compared to a water tank. Imagine a bucket of water with a hole at the bottom and a hose at the top filling the bucket. Even if the hose was turned on and off erratically filling the bucket, the flow of water coming out at the bottom would flow consistently. This is a form of smoothing out the flow; even as the input flow of water surges the output still remains fairly constant.

Continuing with the water analogy, imagine a water tank that takes 5 seconds to fill and the same time to drain. If the water flowing into the bucket was turned on for 3 seconds and then turned off for 3 seconds (in circuits, this is called a “duty cycle”), the water flow coming out of the bucket would still be consistent. If the input duty cycle was increased to 6 seconds on / 6 seconds off, the output flow would surge. This is because the bucket would drain completely before the input flow would turn on again (a 6 second delay is greater than a 5 second drain time), causing a surge of flow in the output. In this case, to compensate for the input duty cycle, a bigger bucket would be needed to provide a slower drain time. This same idea applies when selecting capacitors in electronic circuits.

The occurrence of voltage spikes or surge can be detrimental to many circuit components. A good way to protect circuits from surge damage is to use capacitors, in the same way the right-sized water tank was used to even out the flow of water.

Capacitors are also used to regulate current in timer circuits. (An example timer circuit using an IC chip is shown in the next section; in which, the size of the capacitor determines the timing of a
blinking LED.) In a timer circuit, the rate at which the capacitor fills and discharges determines the flow of electrons. If the input flow to the capacitor remains constant, then so does the time it takes the capacitor to fill and discharge. The size of the capacitor determines the fill and discharge time, which can vary from a fill time of only a few millionths of a second to several seconds.

**Capacitor Types**

There are several different types of capacitors, polarized and non-polarized. Polarized capacitors have a positive and a negative side. The plus side of the capacitor should be connected towards the positive side of the circuit, and the negative side should be connected towards the negative side. Notice that on the schematic symbol for a polarized capacitor (Figure 17.19) the side with an arc is the negative side, while the other side is the positive side. Figure 17.19 also illustrates two common types of polarized capacitors: radial and axial.

When looking at the radial type, the way to tell which side of the capacitor is negative is to search for the side of the can with several oval marks. The lead that is closest to these marks is the negative side of the capacitor, and logically the other side is the positive.

The positive end of an axial capacitor, however, is the side with the black insulation material surrounding the lead. The negative side of the lead is surrounded by the same conductive material as the lead itself.

![Polarized Capacitors](image)

Figure 17.19. The top right diagram is the electronic symbol for a capacitor. The lower two diagrams illustrate the two types of polarized capacitors: radial and axial.
Non-polarized capacitors, as illustrated in Figure 17.20, can be connected in any direction. For the most part, it is fairly simple to distinguish between polarized and non-polarized capacitors. However, the axial non-polarized is easily confused with the axial polarized. In the axial diagram in Figure 17.20, notice that unlike the polarized type, the non-polarized type has both leads insulated from the body, shown in black.

A capacitor value is rated in two ways: the maximum voltage pressure (MVP) it can handle and how much capacity it has to store electrons. The MVP rating is in voltage; the capacity rating is in Farads (F), usually in pico Farads (pF) or microFarads (µF).

Examine a polarized capacitor in Figure 17.19; its values can usually be read directly off of the capacitor. But, since a non-polarized type (Figure 17.20) is often physically very small and difficult to read, a special numbering system has been developed to indicate its value (Figure 17.21).
In Figure 17.22, the top circuit has a polar capacitor and the lower circuit has a non-polar capacitor, both providing the same function. In circuits, many things can cause voltage to fluctuate, such as heat, vibrations, magnetic fields, etc. In Figure 17.22, the use of capacitors in this very basic circuit keeps the LED at a constant level of brightness. Often, people see the lights in their homes flicker; this can be due to a surge in voltage, although in most circuits, the situation is a little more complicated.

**Integrated Circuits (IC Chips)**

Integrated circuits, called IC chips, are circuits that are so miniature that they can only be seen through a powerful microscope. Their small size makes it possible for devices such as laptop computers to exist and also allows for faster circuit design. Conceptually, imagine an IC chip as a “black box” that accepts an input, manipulates the signal and outputs something different. For example, a 555-timer IC chip is a timing device. This particular IC chip measures the time it takes the capacitor to fill (charge) and drain (discharge). And, by changing the value of the capacitor one can change the amount of time the IC chip outputs electrons. Once an IC chip is assigned a voltage, it will output current proportional to that voltage for a given time and then shut off. It is not required that a person know the specifics on how the IC chip works inside in order to make it work!

**Reading an IC Chip**

Although chips come in different sizes and shapes, reading an IC chip is quite simple. The IC chip illustrated in the top diagram of Figure 17.23 has white numbers and letters, which can be looked up in a data book to learn the chip’s specifications. To use an IC chip, think of it as a box that performs some function once the proper signal and voltage is connected to the proper pin. Notice the dot on the lower left corner of the chip illustrations; this indicates that the pin coming out of the chip in this corner is pin number one. The rest of the pins are dot numbered in a counter clockwise...
direction starting from pin 1. Thus, the numbering ends with pin 8 on the opposite end of pin 1. On a
14-pin chip, the pin opposite pin 1 would be pin 14.

The two lower diagrams in Figure 17.23 are two types of common electronic symbols for IC
chips. Notice that the one on the left resembles the chip and the one on the right does not, but it is
more commonly used. The right schematic has all of the same pins, however, except that they are
not in any particular order. Looking at the left symbol, the letters indicate what to connect to each pin.
For example, connect pin 1 directly to ground, connect pin 8 (Vcc) to the plus side of the battery, etc.
Be careful not exceed the voltage limit found on the data sheets specifications for an IC chip.

**SIMPLE CIRCUIT EXAMPLE**

As an example that summarizes all of the electronic components previously described,
Figure 17.24 illustrates a blinking light circuit that turns a light on and off.
To obtain the desired result—a blinking light—this circuit measures how full the capacitor is. When the capacitor reaches 2/3 of its capacity, it turns on the LED; when it drains to 1/3 of its capacity, it turns off the LED. A bigger capacitor takes longer to charge and discharge; a smaller capacitor takes less time to charge and discharge, making the blink rate of the LED faster. Thus, by changing the capacitor size, the rate of the blinking light can be controlled.

**CONCLUSION**

The intent of this chapter’s introduction to electronics and circuits is to provide the reader with enough information to be able to recognize electronic components and their role in simple circuits, as well as introduce how to read an electronic schematic circuit design, and make basic calculations to create a safe, functioning circuit. The next step is to get a bread board and actually design and build one!
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