Basic Electronics Tutorial

Introduction to LEDs, Transistors, and More

Dan Tran

4/27/21

ECE 3005

Electronics form the backbone of modern life, yet high school physics courses all too often leave students with only an abstract or vague understanding, which can leave many feeling disinterested in electronics as a whole.

This guide will walk you through some basic electronic circuits in an interactive and hands-on approach with the goal of building a more intuitive understanding and increasing interest in electronics. If you prefer an audio-visual approach, please watch along with this video.

Either way, it is highly encouraged that you acquire the necessary parts and build along with the guide yourself.

This guide can be viewed in a browser at: https://dtran76.github.io/Basic-Electronics-Tutorial/

Parts List				
Component	Quantity	Links to purchase		
1 kΩ resistor	2	Sparkfun	Digi-Key	Amazon
10 kΩ resistor	2	Sparkfun	Digi-Key	Amazon
10uF capacitor	2	Sparkfun	Digi-Key	Amazon
2N3904 NPN transistor	2	Sparkfun	Digi-Key	Amazon
5 mm LED (any color)	2	Sparkfun	Digi-Key	Amazon
9V battery (E/PP3)	1	Sparkfun	Digi-Key	Amazon
E/PP3 battery snap connector	1	Sparkfun	Digi-Key	Amazon
Breadboard	1	Sparkfun	Digi-Key	Amazon
Jumper wire set	1	Sparkfun	Digi-Key	Amazon

This guide was written by Dan Tran, a student at the Georgia Institute of Technology, as part of the spring 2021 ECE 3005 class.

Table of Contents

1. Breadboards

We'll be building all of our circuits on something called a breadboard. A breadboard, sometimes called a protoboard, is a tool used by engineers and hobbyists alike to prototype their circuit designs. The name "breadboard" comes from when electronics would be prototyped on an actual piece of wood, i.e. a cutting board for slicing bread. However, since their introduction in the '70s, the term now refers to the "solderless breadboard" variety, the kind we'll be using in this guide.

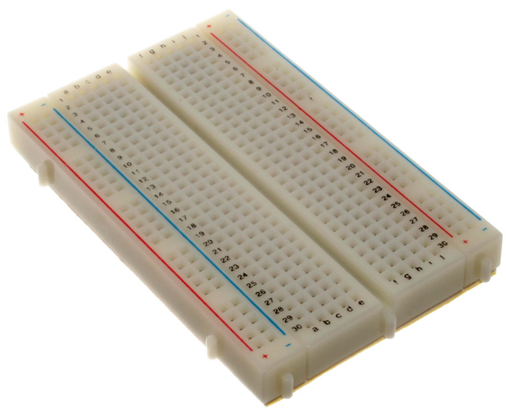

Figure 1.1. A typical solderless breadboard.

Solderless breadboards have many features that make them extremely convenient for prototyping electronics, some of the biggest of these being that:

- the breadboard comes pre-made with many connections, and
- any additional connections we make are non-permanent.

1.1 Pre-made connections

To illustrate this first point, see **Figure 1.2**. Underneath the plastic top of the breadboard are strips of metal that connect the holes. Since many of the holes are already pre-connected, this eliminates the need to connect our components together ourselves with wire. Breadboards come in many sizes, but the way the holes are connected is the same for all of them.

First, look to the sides of the breadboard to the areas marked with a plus and minus sign. Running down either length of the breadboard will be a set of red and blue—or red and black— lines. These strips are called the power rails and, as the name suggests, is typically where power and ground from a power source are connected.

The holes on the power rail are typically separated into groups of five with a small gap in between each group. All of the holes on the red side are connected, even across the gaps, and likewise, the holes on the blue side are connected. However, on some breadboards, this connection is broken halfway along the power rail, as shown in **Figure 1.3**. This is indicated by the red and blue lines being broken and by a gap that is noticeably larger than the normal, connected gaps. If using this kind of breadboard, one can simply bridge the gap with wires.

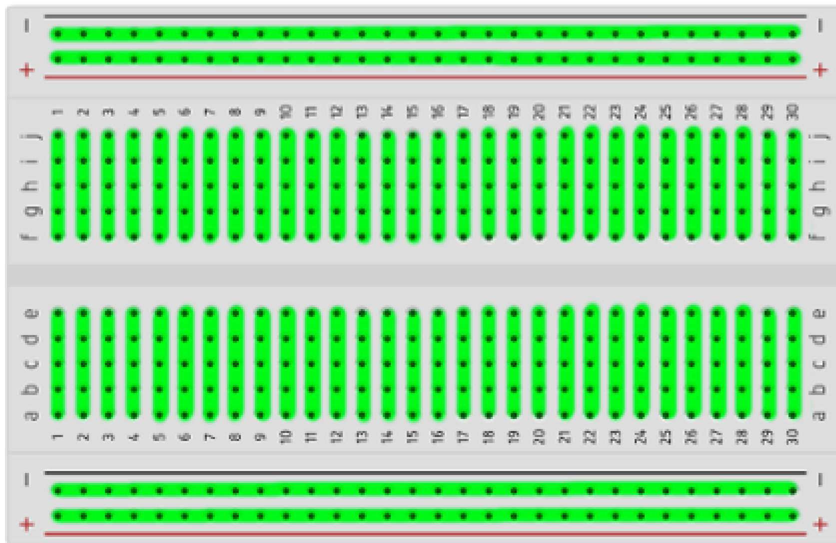

Figure 1.2. Breadboard with metal connections highlighted in green.

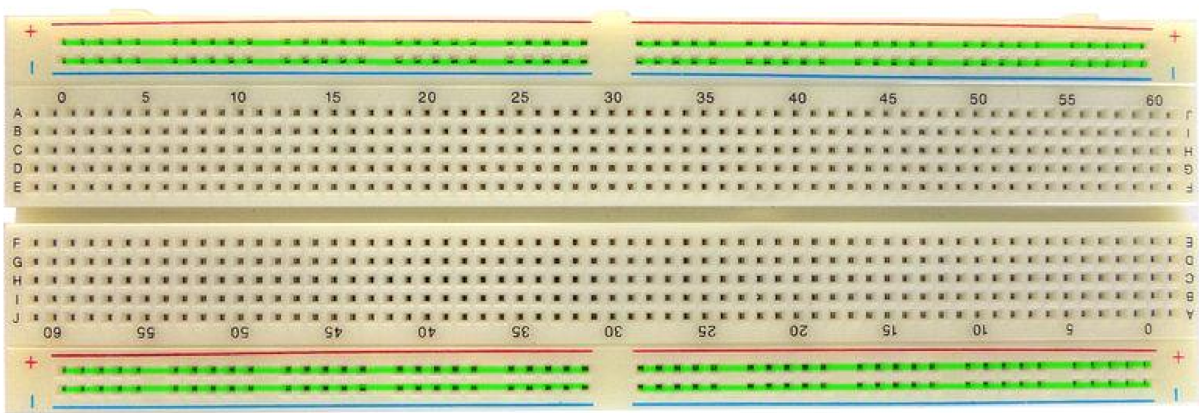

Figure 1.3. A breadboard with split power rails. The connections are shown in green.

Now, look at the holes in the center of the breadboard. The holes on each row are all connected to each other, but not across the center gap. This splits each row into two groups of five connected holes, called terminal strips. The terminal strips are where components are typically connected.

1.2 Non-permanent connections

Another big reason why breadboards are used is because all of the connections that we add are non-permanent.

Inside each hole is a metal clamp that attaches to anything we insert, connecting it to the metal underneath. To make a connection on the breadboard, simply insert a wire or component leg into a hole. If, at any point, we discover a mistake in wiring or just change our minds on something, changing the connections is as easy as unplugging the component and plugging it in elsewhere.

Since the connections are non-permanent, there is also the additional benefit that any circuit built on a breadboard can be completely unassembled, and the components and breadboard can be reused for other projects.

2. The first circuit: introduction to LEDs

Now that we understand how to use a breadboard, let's build our first circuit, a very simple circuit that just turns on an LED. The circuit schematic is shown in **Figure 2.1**.

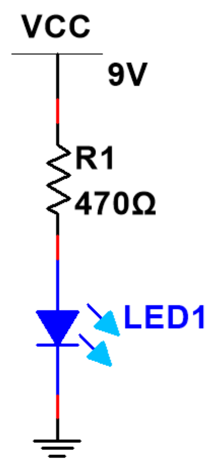

Figure 2.1. LED circuit schematic.

Parts List	
Component	Quantity
Breadboard	1
LED (5 mm, any color)	1
1 kΩ resistor	1
9V battery (E or PP3) w/ snap connector	1
Jumper wires	As needed

2.1 What is an LED?

A tylical LED is shown in **Figure 2.2**. LED is an acronym that stands for "light-emitting diode". The "light-emitting" portion is fairly self-explanatory, but what does "diode" mean?

A diode is an electrical device that only allows current to flow in one direction. While an oversimplification, this definition is more than suitable for the purposes of this guide. In an analogy to plumbing, think of a diode as a one-way valve. These types of valves allow water to flow in one direction, but they prevent any backflow into the pipe.

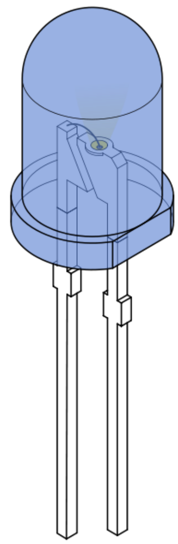

Figure 2.2. A blue 5 mm LED.

Diodes behave in the same way with electric current. In one direction, they have very little resistance and behave like a short circuit, i.e. as if it were just a piece of wire. In the other direction, they have very high resistance and behave like an open circuit, i.e. as if there were no wire there and the circuit was not completed. The symbol for a diode is shown in **Figure 2.3**. In this orientation, current can flow from left to right, but not right to left. Think of the triangle as an arrow which points in the direction that current can flow. The bar at the end of the arrow can then be thought of like a barrier that prevents current from flowing back into the arrow.

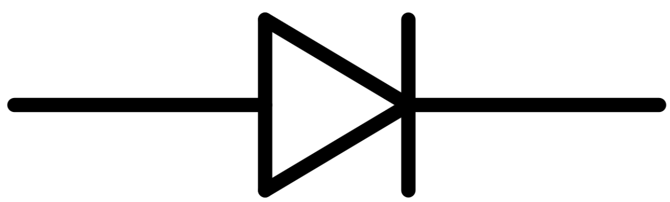

Figure 2.3. Diode circuit symbol.

An LED, like the name suggests, is simply a special type of diode that emits light while conducting. Notice how the legs of the diode are different lengths. The longer leg is the “positive” side (anode) which corresponds to the left side in **Figure 2.3**, and the shorter leg is the “negative” side (cathode) which corresponds to the right side. The negative side is also marked by a flat notch on the LED itself.

2.2 Building the circuit

First, plug the LED in anywhere on the breadboard. The legs of the LED shouldn't be connected together, so have them be on seperate terminal strips (rows). Keep note of which side is positive and negative.

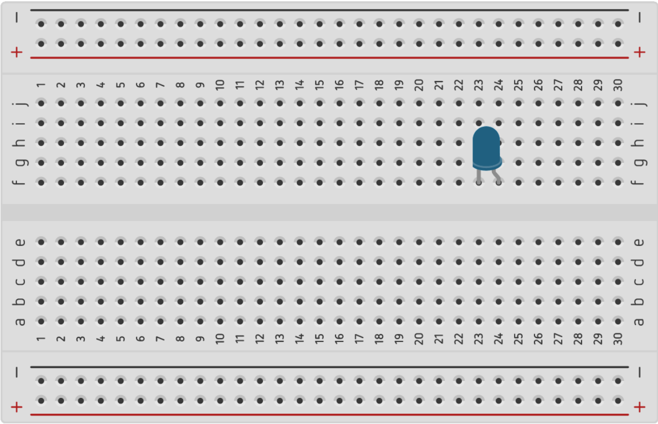

Figure 2.4. LED inserted. The positive side is on the right.

When an LED conducts, it will have zero resistance. Using Ohm's Law, we can see that the current will be infinite. A real LED will still have some small level of resistance, so the current won't be infinite, but it will still be enough to break the LED. To solve this, we need to add a current-limiting resistor.

Add a 1 kΩ resistor in series with the LED by inserting one leg in the same terminal strip as the positive leg of the LED. If you can't read resistor color codes, use an online calculator such as this one by Digi-Key or just match the colors to **Figure 2.5**. Resistors don't have a polarity ("direction") like LEDs do, so it doesn't matter which way it's plugged in. Like the LED, the other leg can go anywhere else as long as it's on a different terminal strip.

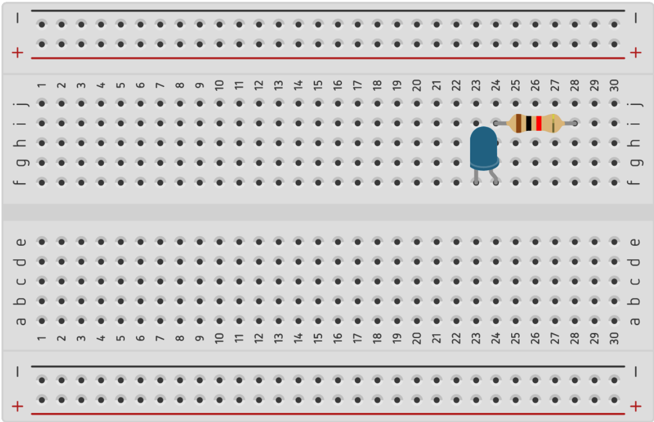

Figure 2.5. Resistor added.

Next, connect the LED and resistor to the power rails. Use wires to bridge over the free end of the resistor to the positive rail, and the negative leg of the LED to the negative rail. Finally, connect the battery connector by inserting the red wire into the positive rail and the black wire into the negative rail. Connect the battery, and the LED should light up.

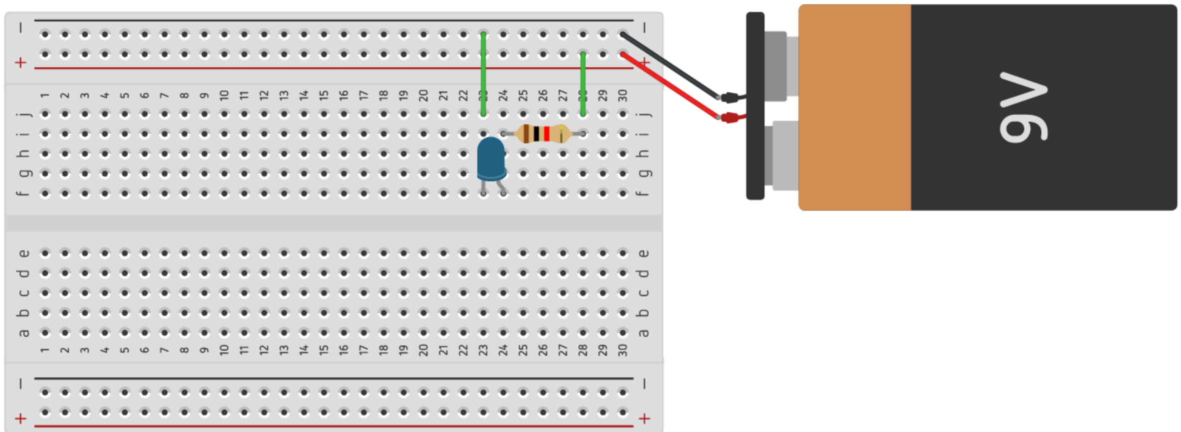

Figure 2.6. Fully assembled LED circuit.

3. Bistable system: introduction to transistors

Now we can move on to a slightly more complicated circuit, shown in **Figure 3.1**, which will use transistors.

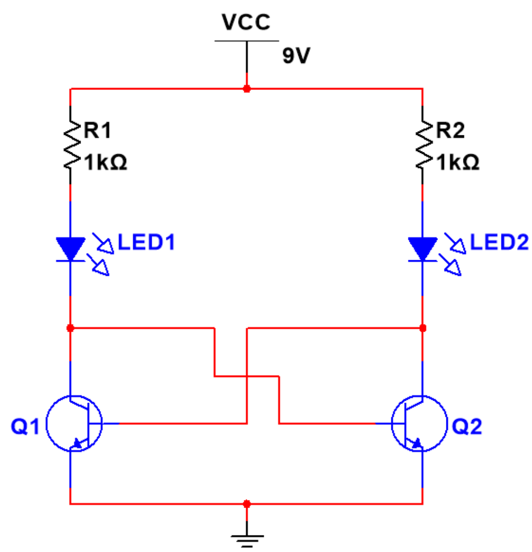

Figure 3.1. Bistable circuit schematic.

Parts List	
Component	Quantity
NPN transistor (2N3904)	1
LED (5 mm, any color)	1
1 kΩ resistor	1
All parts from previous sections	-

3.1 What is a transistor?

A transistor is an electrical device that can act like an electrically controlled switch. Again, this is an oversimplification, but it should suffice for this guide. Look at the symbol for a transistor in **Figure 3.2**.

A transistor has three legs: collector, emitter, base. Again with a plumbing analogy, think of the transistor as a valve. The collector and emitter can be thought of as the pipe that the base can open or shut depending on how much voltage it sees. If the voltage is high enough at the base, current flows between the collector and emitter. The arrow on the symbol is always drawn on the emitter side and shows which direction current will flow.

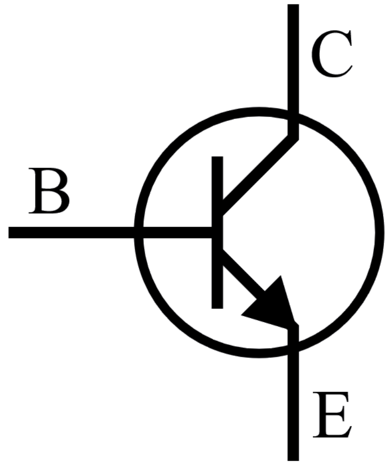

Figure 3.2. Transistor circuit symbol.

For the specific type of transistor we will be using (2N3904), hold the transistor up to the symbol with the legs pointing into the page and with the round side pointing towards the base (left). The legs on the transistors will now line up with the symbol, from top to bottom: collector, base, emitter.

3.2 Building the circuit

When changing anything on the breadboard, it's a good idea to first remove the power supply. Before beginning, unplug the battery. Next, remove the connection to the negative rail and add a transistor with the collector leg connected to the negative leg of the LED.

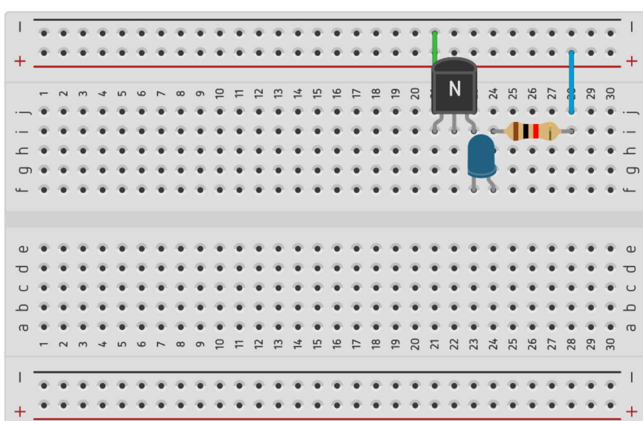

Figure 3.3. Transistor added.

One side of the circuit is now complete. The other side is exactly the same as the first, so duplicate this setup elsewhere on the board. In this example, the circuit will just be mirrored across the center gap.

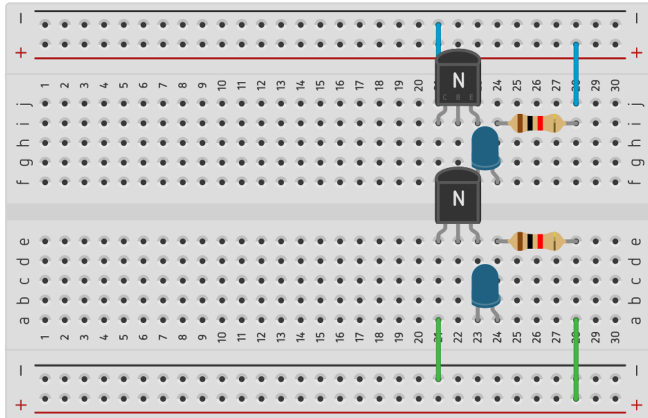

Figure 3.4. Circuit duplicated across the gap.

Connect the base of the transistor on top to the collector of the transistor on the bottom.

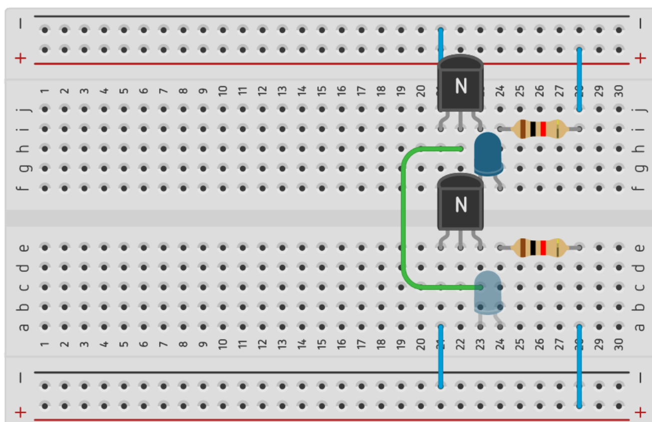

Figure 3.5. Base of top transistor connected to collector of bottom transistor.

Do the same for the transistor on the bottom.

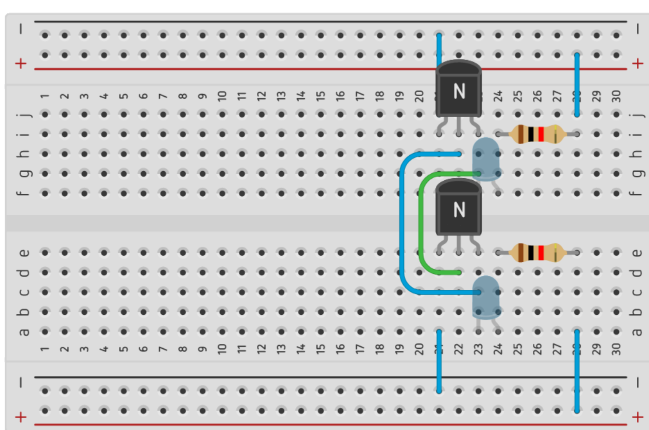

Figure 3.6. Base of bottom transistor connected to collector of top transistor.

Connect each side to their respective power rails. The positive rails should connect to the resistor end, and the negative rails should connect to the emitter of the transistor. Since the battery will only be plugged into one rail (the top one), power needs to be brought to the other side. Use wires to connect the positive and negative rails on either side together. Finally, plug the battery back in, and one of the LEDs should turn on.

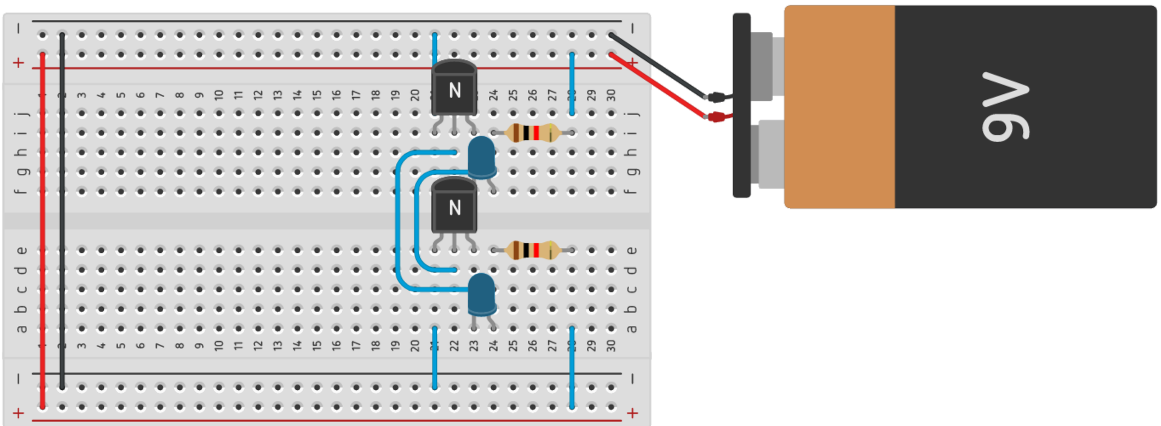

Figure 3.7. Fully assembled circuit.

3.3 What is happening?

While electricity is typically simplified to propagate instantaneously (i.e. they move through a wire or component at an infinite speed), real signals take some very small amount of time to travel across a wire or component.

When the circuit is powered on, the voltage "races" down either side of the circuit. The components on each side are not exactly equal: all of the components, even down to the wiring inside the breadboard, will have very slight differences in their properties. These differences will result in very slight increases or decreases in the speed of the physical electrons in the wire, which ultimately means that the voltage will reach the base of one of the transistors before the other.

When this happens, that transistor will "turn on", allowing current to flow in the collector-emitter side. Since the LED is in series with this, it will also turn on. Notice the way that the transistors are connected in the circuit: the collector one transistor is connected to the same point as the base the other, and vice versa. This means that the collector of one shares the same voltage as the base of the other.

When one of the transistors turns on, the resistance between its collector and emitter drops to close to zero, which according to Ohm's Law, means that the voltage should also drop close to zero. This voltage is the same as the base voltage as the other transistor. Since the base voltage is now close to zero, the other transistor will never turn on as long as the first transistor conducts, leaving the system stuck in this state with one LED turned on.

3.4 An interesting modification

The system we just built is known as a bistable system. This means that there are two possible states that it can get “stuck” in when powered on: either the left LED will turn on, or the right LED will. The only way we can really know which one of these states it gets stuck in is to build the circuit and power it on.

Once powered on, the system is essentially stuck in this state unless an external influence was to be applied (ex. removing the battery, adding a connection, removing a connection, etc.). This is known as a stable state. For this circuit, the simplest way to switch to the other state would be to somehow “turn off” the conducting transistor. The transistor only conducts when there is a high enough voltage at the base, so to turn it off, we need to pull the base voltage to zero, which we can do by connecting it to ground (the negative power rail).

Try this on your own breadboard. With the battery still plugged in, add a wire from the base of the transistor on the side with the lit LED to the negative power rail (or anywhere else that the negative rail is connected to). Notice that the LED immediately turns off and that the other LED turns on. When the resistor stops conducting, the collector voltage increases, which increases the base voltage of the other transistor and turns it on.

Since the other side is now conducting, the system is now “stuck” in this new state. The LED will continue to stay on, even if we remove the wire we just added. To change it back to the first state, do the same thing on the other side. Add a wire from the base of the transistor to the negative power rail and now the first LED should turn back on.

4. The astable oscillator

Using the bistable system we just built, we will now be building a very famous circuit known as the astable oscillator, also known as the astable multivibrator. The circuit schematic shown in **Figure 4.1**. As you can see, only a few modifications are needed to our bistable system to create an astable oscillator.

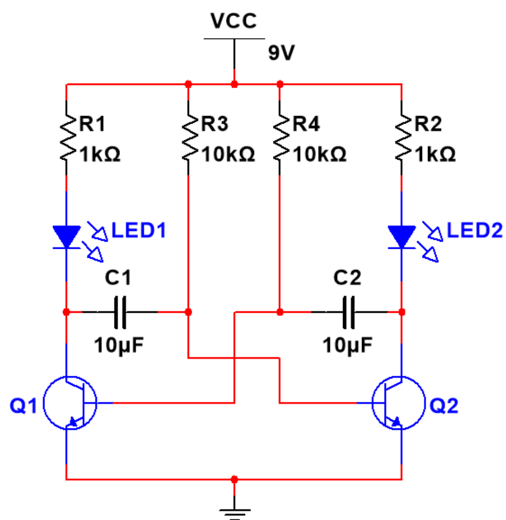

Figure 4.1. Astable oscillator circuit schematic.

Parts List	
Component	Quantity
1 µF capacitor	2
10 kΩ resistor	2
All parts from previous sections	-

4.2 Electrolytic and ceramic capacitors

There are two types of capacitors, electrolytic and ceramic, as shown in **Figure 4.2**.

Electrolytic capacitors are cylindrical in shape and, like LEDs, have a positive side and a negative side. They have a long and short leg like LEDs and a stripe on the body indicating the negative side. The capacitance value will also be printed on the body. When using electrolytic capacitors, be sure to plug them in the correct way, or they may explode. While not very dangerous, it can leave a bad smell in the room, and the capacitor will be unusable, so always double-check before plugging in power.

Ceramic capacitors, on the other hand, are flat and circular in shape and do not have a polarity, so they can be plugged in either way like a resistor. However, they don't have the capacitance printed on the body, only a code. If you can't read this code, use an online calculator like [this one by Electronics 2000](#).

Figure 4.2. Various capacitors with a match for scale. The two on top are capacitive, and the two on the bottom are ceramic. The smallest on the left is a surface-mount capacitor.

If you don't know which type of capacitor you have, the capacitors in the purchase links in the parts list at the beginning of this guide are all electrolytic capacitors.

4.3 Building the circuit

First, disconnect the battery and add two capacitors anywhere on the breadboard. Connect the positive sides to the negative side of each LED.

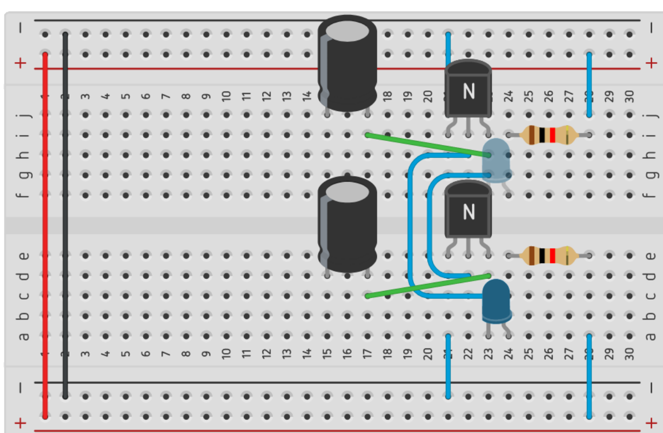

Figure 4.3. Capacitors added. The positive side is on the right.

Next, add a 10 kΩ resistor in parallel with our existing LED, resistor, and capacitor. There isn't much space were the current components are, so place the 10 kΩ resistor further down on the breadboard. If you can fit in it, go ahead and place near the other components instead.

A component being in parallel just means that both ends of it are attached to the same points as the respective sides of the component it is in parallel with. For our purposes, this just means we have to attach one side of the 10 kΩ resistor to the power rail, and the other side to the negative side of the capacitor. Do this for both sides.

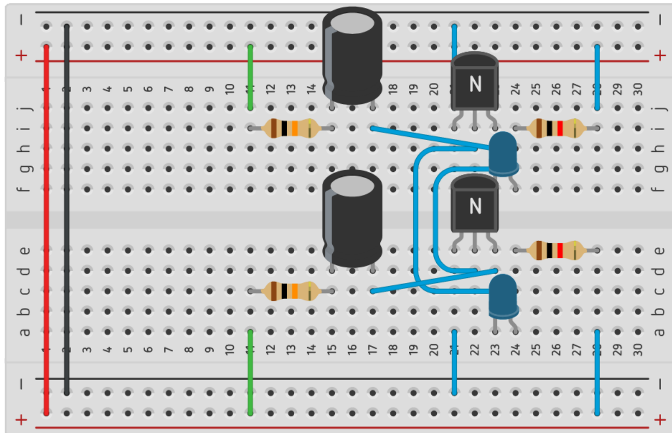

Figure 4.4. Resistors added.

With just that, the astable oscillator is now complete. Plug the battery back in, and the LEDs should now start blinking.

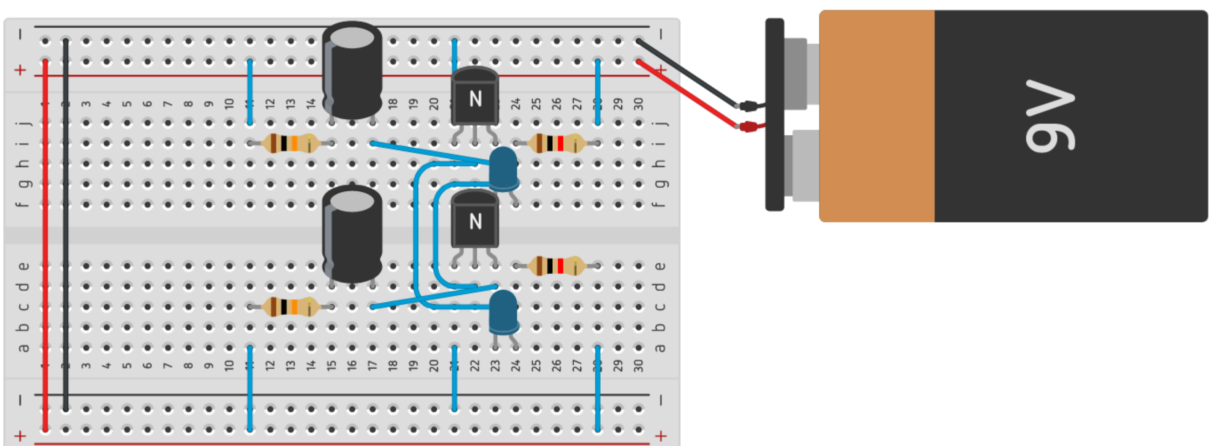

Figure 4.5. Completed astable oscillator.

4.3 What is happening?

Like the bistable system, when the astable oscillator is plugged into power, voltage races down either side. Capacitors behave like short circuits to sudden changes in voltage, so in this simplified model, they won't affect the voltage race. Eventually, the voltage reaches the base of one of the transistors first, say the top one. This turns it on, which drops the collector voltage. Again, capacitors are short circuits to sudden changes in voltage, so the voltage on the other side of the capacitor, i.e. the base voltage of the other transistor, will also drop, keeping the other transistor off. So far, everything is just like the bistable system.

After the system enters this first state, the capacitor on the top side will begin to charge through the 10 kΩ resistor. This slowly raises the voltage on the negative end of the capacitor (the side connected to the base of the bottom transistor), and eventually, this voltage will be high enough to turn on the bottom transistor. Current can now flow on the bottom side, turning on the bottom LED and discharging the bottom capacitor.

When the bottom transistor turns on, its collector voltage drops, which also drops the voltage on the other side of the bottom capacitor, which is the same as the base voltage of the top transistor. This turns the top transistor off, switching the system to its second state.

From here, the cycle repeats itself and continues indefinitely. This is where the "astable oscillator" name comes from: "astable" because there is no state that it gets "stuck" in forever, and "oscillator" because it switches between two states.

Conclusion

With the astable oscillator complete, hopefully you've learned something along the way, and most importantly, have had fun doing so. Many of the descriptions in this guide have been a vast simplification, but with this baseline knowledge, you should know enough to start learning more on your own. Provided below are links to more information about everything in this guide.

More information

1. PN Junction - the physics underlying a diode and other semiconductor devices
2. Diodes and Rectifiers - article about diodes, including equations
3. Light-emitting diode - Wikipedia article about LEDs
4. Transistors - tutorial on transistors, including equations, operation modes, and simple applications
5. BJT Astable Multivibrator - covers the astable multivibrator (oscillator) with variations
6. 555 Oscillator Tutorial - the astable oscillator with a 555 timer IC with variations
7. Astable Multivibrator Simulation - excellent visualization on the operation of an astable oscillator

Image sources

All images are original unless listed below. All listed below are from Wikimedia Commons, listed in order used:

1. Figure 1.1
2. Figure 1.3 - edited
3. Figure 2.2
4. Figure 2.3
5. Figure 3.2
6. Figure 4.2