MIND MAKERS

A GUIDE TO

Electronic Bow & Social Impact Making

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"The goal of Mind Makers
is to just blow any preconceived notion
about who can do anything
out of the water."

– Isis Anchalee, Mind Makers Advisor

Mind Makers leaders and attendees of the first bow making workshop series
(From Left: Melody Schuster, Carla Houston, Mieszko Salaman, Michelle Easter, Sina J. Henrie, Nathan Esquenazi, Isis Anchalee & Michael Ellison)

Introduction

Mind Makers' mission is to encourage STEM diversity and empower and inspire children and underserved adults through education, outreach and service. Our vision is to build a diverse, technology proficient community that values knowledge sharing, redefines possibility and inspires a new generation of engineering enthusiasts.

The Mind Maker's initiative was launched with a single act of knowledge sharing when the founder held a workshop with the project team leaders to give them a taste of electronics education. The team all worked together, learning to lay out circuits, sew and solder. Each made their own remote controlled LED bow or bow tie, all which were lit with the touch of a button, held by the founder. Once finished, the single act of her transferring that knowledge to each one of them could be visualized with her pressing that button and illuminating the whole team.

With each workshop, the brightness increases literally and figuratively. To light up your community in the mood of the Mind Makers, follow the instructions which follow.

Objective

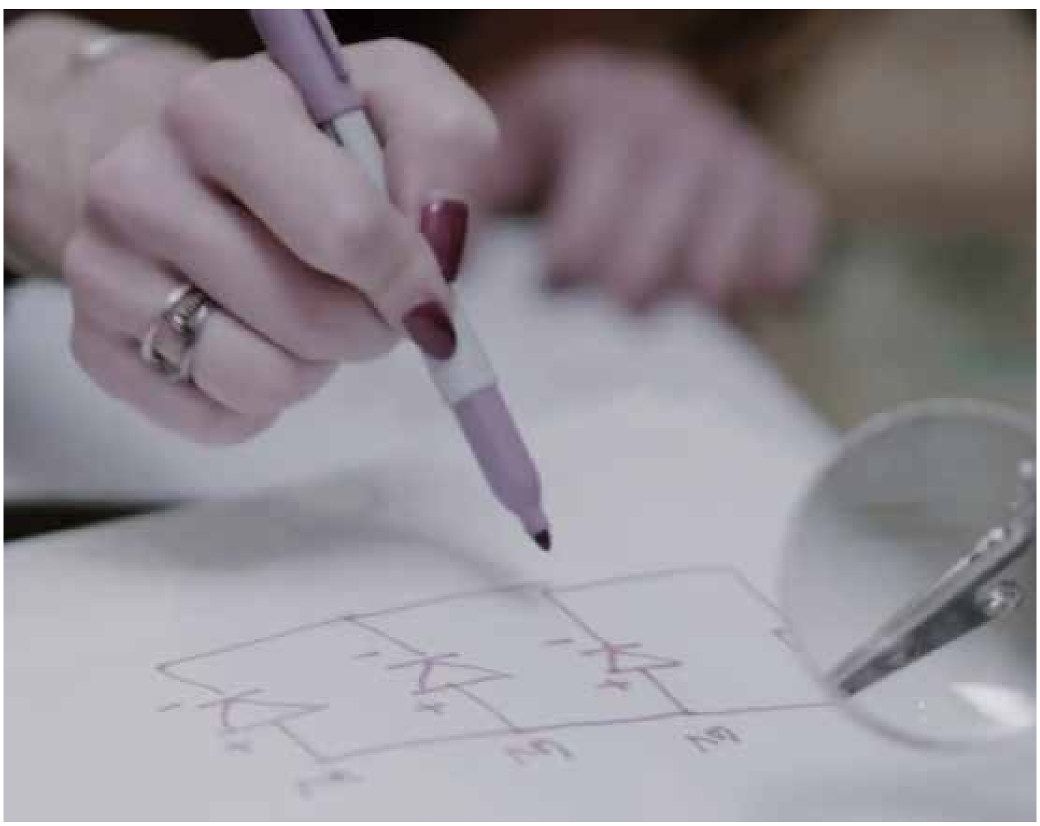
This document serves as a set of guidelines for running an introductory level electronics workshop focused on making interactive, personalized, wearable technology, in the form of RF controlled LED bows and bow ties. Workshop leaders should have experience with the concepts below and are expected to demonstrate theory and hands-on aspects assuming that workshop attendees have no prior related knowledge.

Workshop participants will learn the fundamental engineering concepts:

- Electrical laws
- Circuits
- Soldering

They will also practice the fundamental social concepts:

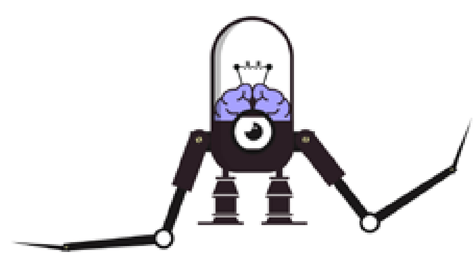
- Teamwork
- The value of teaching
- Paying it forward



Materials

The following list contains the materials needed for the workshop. A detailed sample bill of materials with links to recommended models can be found in *Appendix A: Bill of Materials*. Some items are tools or resources that may be shared among several people (indicated with '#'), but some are requirements for each individual bow (indicated with '@'). Some can also be substituted for cheaper options or bypassed (indicated with '$'), described in the *Tips and Details* section of this document.

- ☐ Soldering iron #
- ☐ Solder (rosin core) #
- ☐ Copper sponge # $
- ☐ RF Toggle Receiver @
- ☐ RF 2-button Remote #
- ☐ LED Sequins (5-10) @ $
- ☐ Battery pack with power switch @
- ☐ Rechargeable batteries - 3-6 Volts @
- ☐ Black fabric bow or ribbon @
- ☐ Black thread #
- ☐ Thin sewing needle @
- ☐ Black insulated 16-20 AWG wire #
- ☐ Small soldered breadboard (PCB) @
- ☐ Wire strippers #
- ☐ Helping hands # $
- ☐ Needle nose pliers #
- ☐ Wire cutters/nippers #
- ☐ Conductive thread # $
- ☐ Small, printed circuit board (PCB) @
- ☐ Headband, barrette, pins or other fasteners @
- ☐ Multimeter #
- ☐ Hot glue and glue sticks #



Theory

Voltage, Current & Resistance

A circuit is a closed loop connection between electronic elements made by conductive material through which electrons flow to deliver power or signals to the elements.

The three main building blocks of circuitry are voltage, current, and resistance. Voltage is an expression for the potential difference in electric charge between two points, is denoted by the letter “V”, and is measured in volts (V). It is the force that “pushes” electrons through a material. Current is the amount of electron flow that passes through a medium per unit of time, is denoted by the letter “I”, and is measured in Amps (A). Resistance impedes the flow of electric current in a medium, is denoted by the letter “R”, and is measured in Ohms (Ω).

Voltage comes from an energy source with the ability to move electrons (example: a battery). If the electrons move in one direction, the source is a direct current (or DC) supplier. In a closed circuit, current will continue to move at a constant rate unless impeded by a resistor. Usually, resistors are built into a circuit to harness the electricity produced by the moving electrons to perform a task. When electrons move through a resistor, some of their initial energy is reduced. But since “energy can neither be created nor destroyed”, according to the law of conservation of energy, the electron’s energy is not actually lost, but converted into heat energy. Simple circuits and resistors are common spectacles of everyday life, from lighting a light bulb to providing power to a motor.

Symbols

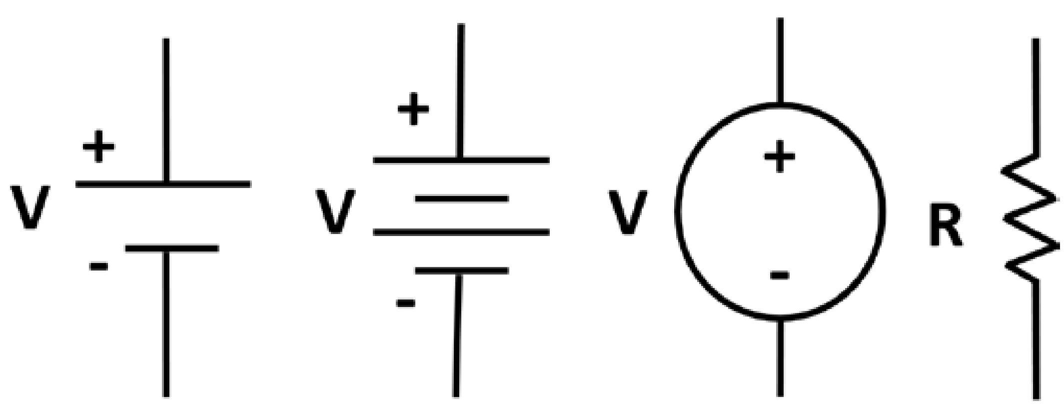


Figure 1 *(Above):* Fundamental circuit elements, the left three being direct current (DC) voltage sources. From left to right, a cell, a battery and DC supply, and a resistor are all shown.

The circuitry symbols shown above can be combined to build a circuit. The different symbols are always connected by lines, and these lines represent wires which tie the elements together. A basic circuit is shown below.

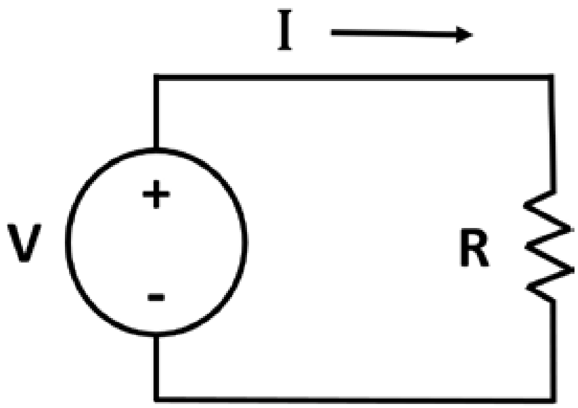


Figure 2 *(Left):* Basic circuitry elements combined in a simple circuit shown to the left.
V is voltage, I is current, and R is a resistance. The direction of electron(positive charge flow) flow is indicated by the arrow.

Parallel vs. Series

Circuit setup is generally divided into two categories: series and parallel. In a series circuit, electrons flow in one direction, usually through multiple resistors, and only follow one path to and from the voltage source. Parallel circuits have multiple paths electrons can flow through, and the current must be divided proportionally through the resistance of each path. See Figure 3.

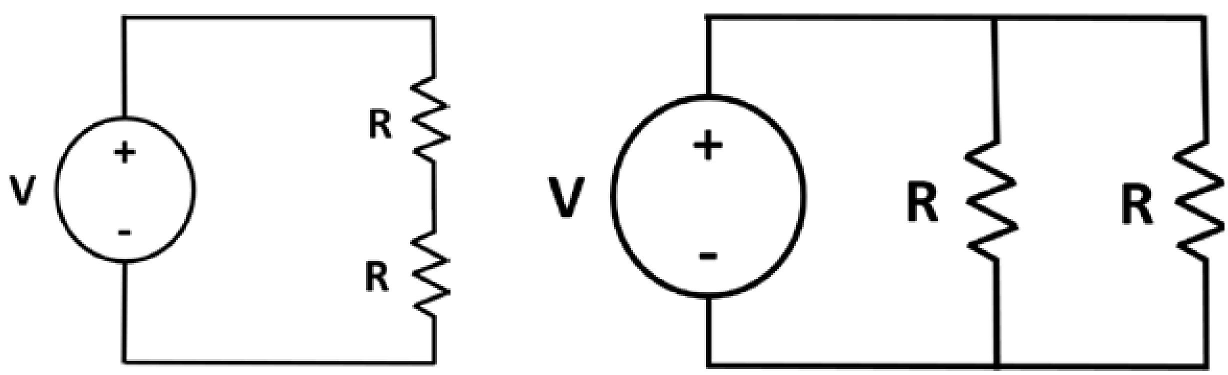
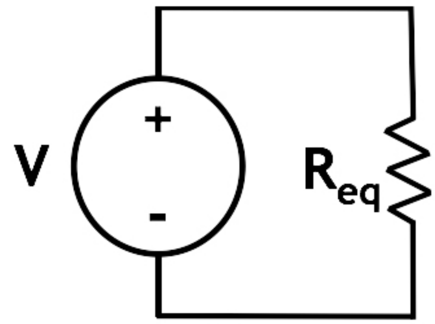


Figure 3 *(Above):* The left circuit shows two resistors connected in series with a DC power supply. The right circuit shows two resistors connected in parallel with a DC power supply.

Multiple resistors in a given circuit can be combined to find what is called the equivalent resistance to simplify the circuit as shown below.

Figure 4 *(Right):* The circuit in this image is a reduced version of a circuit with multiple resistors. By combining the resistors, the circuit is simplified and easier to solve.



The equivalent resistance is different for resistors that are in series and resistors that are in parallel. For resistors that are in series, the equivalent resistance is simply the sum of the individual resistors whereas the equivalent resistance for parallel resistors has to do with the inverse relationship of the resistors.

Resistors in Series: $R_{eq}=\sum_{k=1}^{n} R_k$

Resistors in Parallel: $R_{eq}=\left(\sum_{k=1}^{n} \frac{1}{R_k}\right)^{-1}$

Using these equations, the equivalent resistance of the first (series) circuit in Figure 3 would be R_1+R_2, and the equivalent resistance of the second (parallel) circuit would be

$$\frac{R_1R_2}{R_1+R_2}$$

Electrical Laws

As described above, voltage, current, and resistance are three important factors in building a circuit. These three components are combined in the root equation of electronics, called

Ohm's Law: $V=I \times R$,

where V stands for voltage and is measured in volts (V), I stands for current, and is measured in amps (A), and R stands for resistance and is measured in Ohms (**Ω**).

Ohm's law is a mathematical and physical relationship between these three values for any element in a simple circuit. The amount of voltage dropped across an element is equal to the result of multiplying the current passing through, in amps, by the resistance of the element, in Ohms.

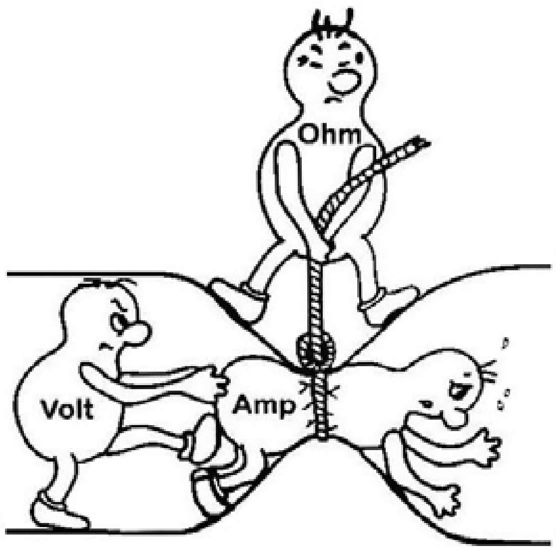


Image 1 *(Left):* A cartoon representation of the relationship between voltage, current and resistance and the meaning of Ohm's law. (Image from Sengpiel Audio).

Kirchhoff's Loop (Voltage) Law

is based on the principle of conservation of energy and states that the sum of the voltages in the closed loop of a circuit is equal to zero.

$$\sum_{k=1}^{n} V_k = 0$$

This makes sense because the positive terminal is said to have some voltage, and the point in the circuit which connects back to the negative terminal (ground), which is zero volts by definition. So all of the potential energy must be expended across the circuit to end up with zero volts at the completion of the circuit.

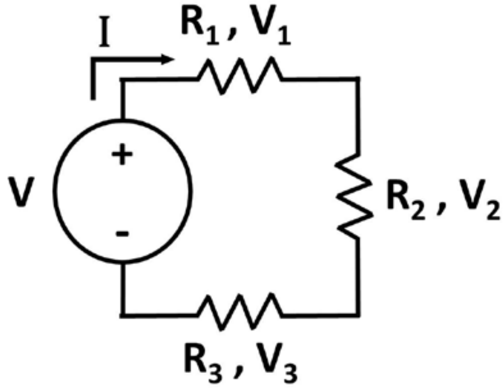
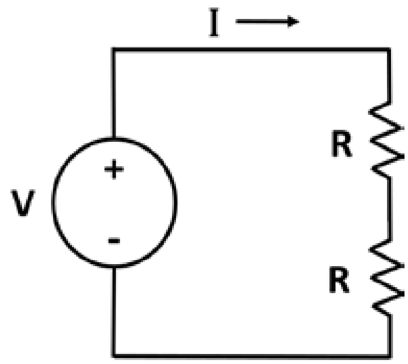


Figure 5 *(Left):* Illustration showing Kirchhoff's loop law. The sum of all the voltages in the closed loop (V1, V2 & V3) equals the voltage of the DC Power Supply, V.

Figure 6 *(Right)* shows a simple circuit that we can analyze using Ohm's law and Kirchhoff's loop law. Since the current only has one path to travel, we know that it is constant throughout the circuit.



We also know that two resistors have the same value, meaning the voltage potential drop over each resistor must be equivalent; therefore, the voltage drop over each resistor is ½V. This holds true to Kirchhoff's Voltage Law:

$$\sum_{k=1}^{n} V_k = V - \frac{1}{2}V - \frac{1}{2}V = 0$$

and it also hold true to Ohm's law, as the current in each resistor can be found:

$$I = \frac{V}{R} = \frac{V}{2R}$$

proving that the current is the same across both resistors.

Kirchhoff's Current Law is based on the principle of conservation of electric charge and states that the summation of the currents entering a given node is equivalent to the summation of the currents exiting that node.

$$\sum_{k=1}^{n} I_k = 0$$

This has a "what goes up must come down" feel to it, but more like "what goes in must come out". All current going into a junction flows out through any available pathways, favoring any path of least resistance.

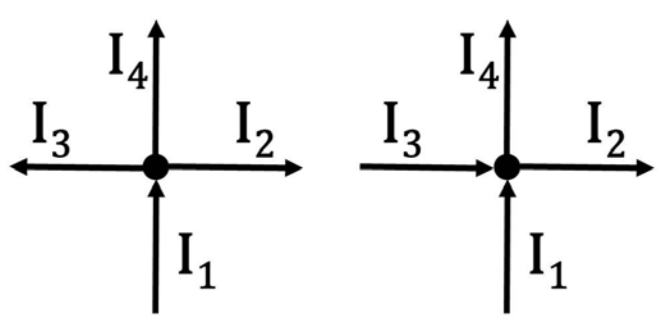


Figure 7 *(Above)*: Illustration of Kirchhoff's Current Law. On the left, current flowing into the node (I_1) leaves the node along paths 2, 3 and 4 (I_2, I_3 & I_4). On the right, current flowing into the node (I_1 & I_3) leaves the node along paths 2 and 4 (I_2 & I_4).

Kirchhoff's Current Law can be used in combination with Ohm's law to understand the simple circuit in Figure 8. Unlike the circuit with resistors in series, this circuit has resistors in parallel, creating multiple paths for the current to travel. In this situation, the current will be split proportionally to the resistance of each path. Since the two paths in this example have equal resistance, the current will be divided evenly. We can see that at the node where current "I" is split, Kirchhoff's Current Law holds true:

$$\sum_{k=1}^{n} I_k = I - \frac{1}{2}I - \frac{1}{2}I = 0$$

Furthermore, we can see that Ohm's law also holds true, and the voltage is equivalent over each branch of the parallel circuit as should be expected. The voltage can be calculated as:

$$V = \frac{IR}{2}$$

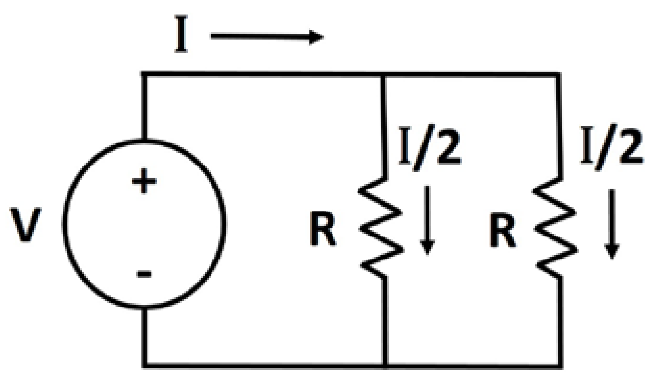


Figure 8 *(Above):* Parallel circuit used to demonstrate KCL and Ohm's Law.

LEDs in Circuits

A diode is like a one-way electrical valve. Current can travel only in one direction through a diode, from "high" (+) to "low" (-). The most well known diode is the LED (light emitting diode), which uses about ~6-10x less power than incandescent bulbs while achieving the same brightness and dramatically reduces CO_2 emissions as well. In a circuit diagram, the LED is represented by the symbol in Figure 9 below, but is often shown as the similar symbol for the diode as well. The arrows pointing away from the triangle represent photons of light. The shape of the diode resembles an arrow indicating the direction of the current, moving from high to low, and the flat line at the negative side represents the electrical brick wall any current would meet if it tried to move from the negative to the positive terminals of the LED.

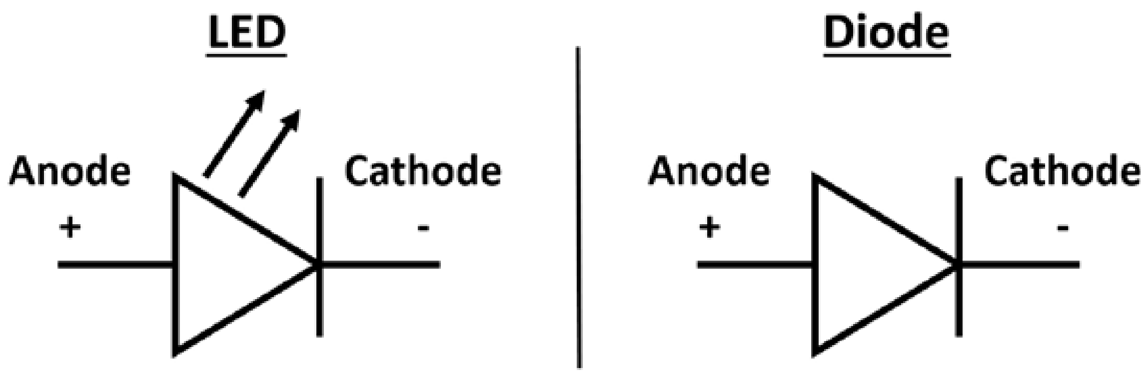


Figure 9 *(Above):* Left panel shows LED symbol used in circuit diagrams. Right panel shows diode symbol used in circuit diagrams.

LEDs work thanks to semiconductor material inside, which emits light (photons) when a certain voltage is applied. Varying semiconductor materials require slightly different voltages to release photons, and the result for each material is a different color of light emitted.

Applying too low of a voltage results in a dimly lit LED, and too high of a voltage can send too much current through and consequently burn it out. In this workshop, we are using LED sequins which have a resistor already built in to reduce the amount of current flowing through. If you use an LED without an on-board resistor, make sure to place an appropriate resistor in series with each LED to limit the current flow. See the information on how to do that in the *Tips and Details* section of this document. See Figure 10 below for schematics.

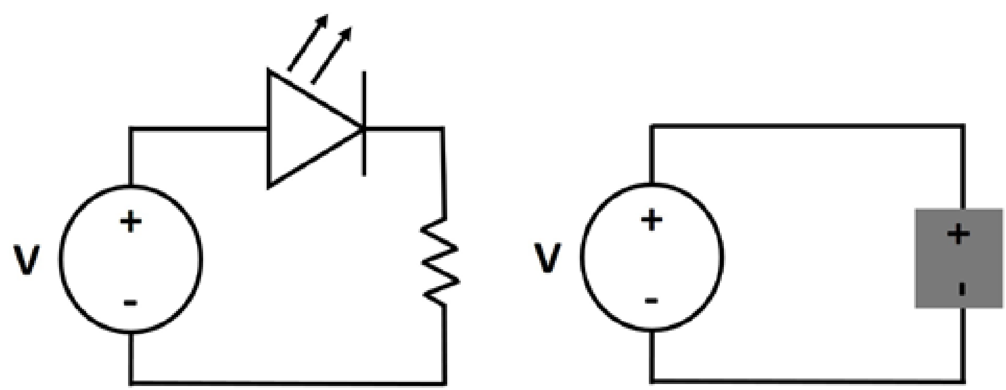
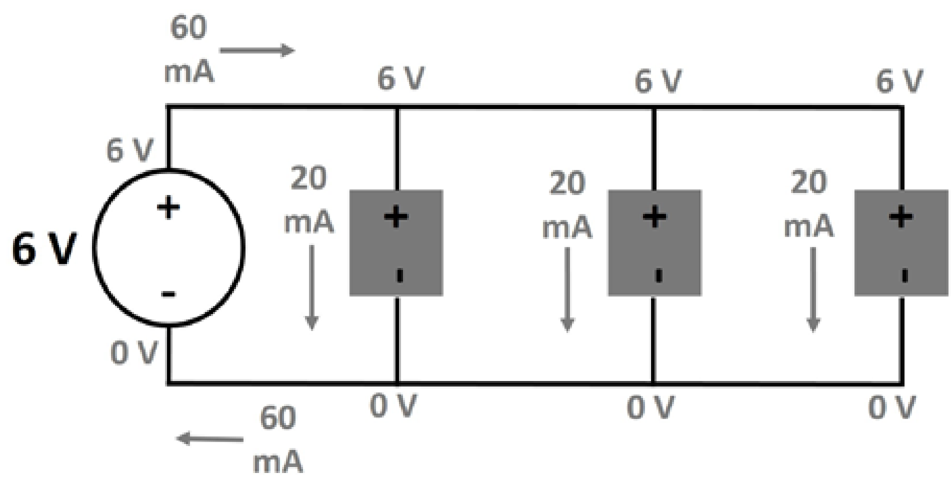


Figure 10 *(Above):* Left panel: Basic LED circuit, with voltage source, LED and resistor. Right panel: LED circuit where LED has onboard resistor (like the LED Sequins we use) and we define the gray box to be the LED-resistor combination for the rest of the document. (For simplicity).

For multiple LED sequins on one power supply, either a series or parallel configuration can be used. Each LED needs a certain voltage, so for three LEDs each with a 6 V voltage drop across it, we have the two situations shown in Figure

11 and Figure 12 below, for parallel and series, respectively. By using Kirchhoff's laws, we see that for a parallel circuit, only a 6V power supply is needed, but for a series circuit, an 18V supply is needed. However, in parallel the current across each branch of the circuit needs to be high enough to light the LED, each around 20 milliamps (20 mA, or 0.000020 amps), so the power supply must output a total of 60 milliamps. The series circuit has the same 20 mA running through each LED since there is only one path, so the power supply only needs to output 20 mA to light all LEDs.



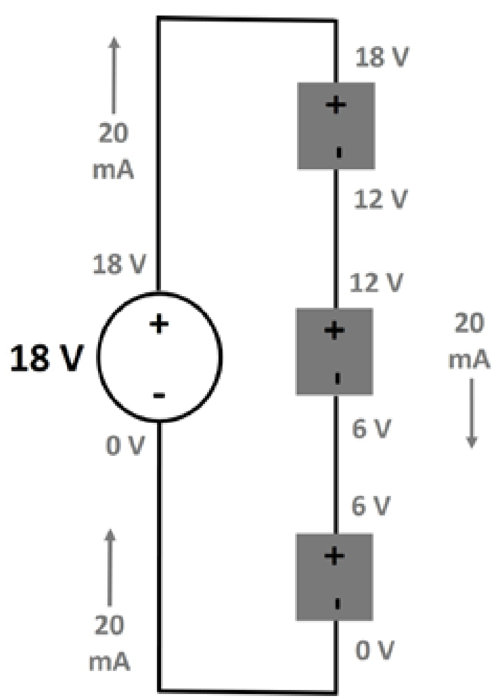


Figure 11 *(Above):* Parallel configuration for three sequins, each requiring a 6V supply and 20 mA of current. The total circuit requires 6V and 60 mA.

Figure 12 *(Left):* Series configuration for three sequins, each requiring a 6V input supply and 20 mA, requiring an 18V total supply and only 20 mA of total current.

For a project where you can plug into the wall or into a big power supply with a high voltage, you may want to choose a series configuration, but for a project that you have to wear, a smaller power supply is more desirable. Keep in mind that the increased current draw in the parallel configuration means battery life will drop, but this can be mitigated pretty easily with rechargeable batteries. In general, when you are working with components and you want to know the recommended operating conditions (like the voltage and current they require), always consult the component's datasheet for technical specifications. See *Appendix B: Resources* for a tutorial on reading datasheets.

Radio Frequency Communication (RF)

Radio waves are generated using alternating current and are magnified using an antenna. The radio that you listen to in your car is an example of radio waves which are transmitted from large antennas. Given that there are more than 100 radio stations in the greater Los Angeles area, in order to receive a specific station, you need to “tune” your radio. The way that your radio receives the data is through a vibrating (oscillating) crystal that is tunable and allows for the vibration frequency to be changed. When you “tune” your radio (change channels), you are telling the crystal in your radio to oscillate at a given frequency that corresponds to a specific channel (radio station) which allows it to pick up the signal from that antenna. Frequency is measured in hertz (Hz, 1/sec, or cycles per second), and your favorite FM radio station is the frequency at which it is broadcasted as measured in MHz (megahertz, 10^6/sec). For example, FM 106.7 has a frequency of 106.7 MHz or 106,700,000 Hz.

Radio waves can also be used at home to add a fun, wireless element to your project. To do this, it is necessary to have a transmitter which generates the radio waves and a receiver which detects the waves and performs an action. The wave generated by a transmitter is proportional to the size of the antenna; therefore, a small, handheld device will have a limited range. The simple RF T4 receiver shown in Image 2, below, is an electronics board that has the capability of turning on 4 switches using radio waves at a pre calibrated frequency of 315 MHz. Each of these switches corresponds to a pin (output) on the electronics board. These pins work individually as toggle switches, meaning they can each be turned on and off independently. Connecting some element to each digital pin and turning the switch on performs some type of action, such as turning on an LED. When a transmitter (the remote control in our case) emits a radio wave at at the correct frequency, the receiver will be triggered to toggle the pin, on or off, depending on its current state.

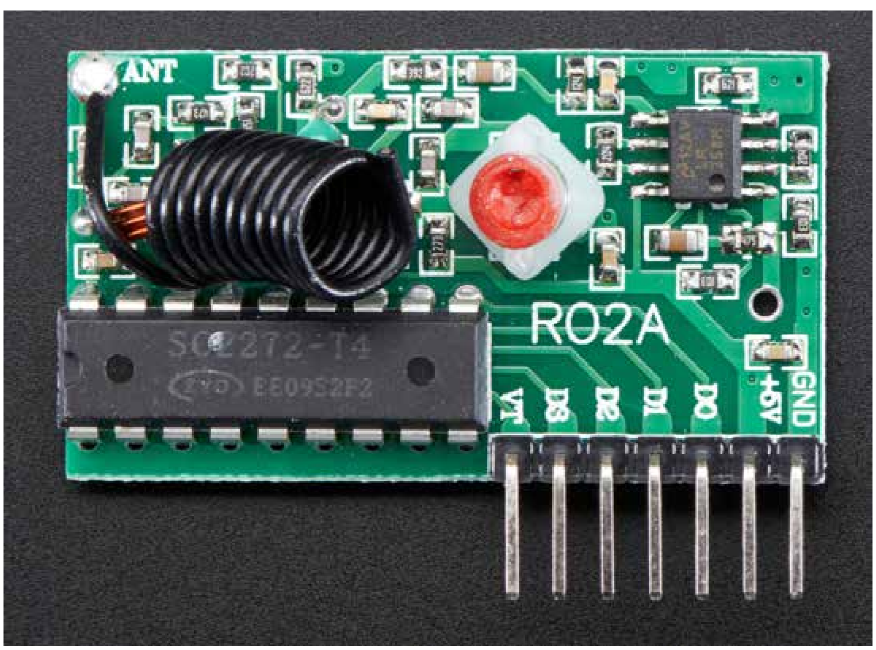


Image 2 *(Left):* Radio frequency receiver module with toggle control of four different digital output pins (D0, D1, D2, D3). “Simple RF T4 Receiver - 315MHz Toggle Type” (Original image from Adafruit, receiver available at www.adafruit.com)

Procedure

1. Plan Component Placement & Sew Bow

Think about how you want to physically attach the RF board, the battery pack and breadboard onto the bow, and then how you want to attach it to your person. The components take up some space and have some weight so make sure the weight is balanced and centered so the bow sits how you want it to once you're wearing it. Also consider the backs and connections of these components are conductive so they have to be insulated from each other when mounting them. This can be achieved by wrapping each in ribbon when you're finished and sewing them into the bow, and/or covering finished solder points or bare metal parts with hot glue.

If you don't have pre-made bows (we prefer black organza or chiffon so it is chic and diffuses the LEDs nicely), make your bow out of ribbon and sew it together at the center seam. You can either attach your LEDs with the ribbon laid out flat and then fold it up and sew it what you're done, or sew it first and do your sewing and soldering from inside the loops.

Check out a few of the ways the Mind Makers did this in the images below. Options for ways to attach the bow to yourself include headbands, hair clips, safety pins (beware of metal pins touching circuit) and many other possibilities.

Image 3 *(Above):* From the left panel, the front view, top view and back view of Sina's bow. Sina sewed in a double bow layer, with the bottom seam sewed shut, to hold (but leave accessable from the top for access of power switch) her battery pack and breadboard on one side, and her RF board on the other. This bow also was made primarily with conductive thread.

Image 4 *(Above):* From the left panel, the front view and back view of Michael's bowtie. Since the bowtie was smaller, the breadboard connections were coated in hot glue, and it was taped to the back of the tie. The RF module and battery pack were tucked and double-stick-taped to the inside of a dress shirt collar.

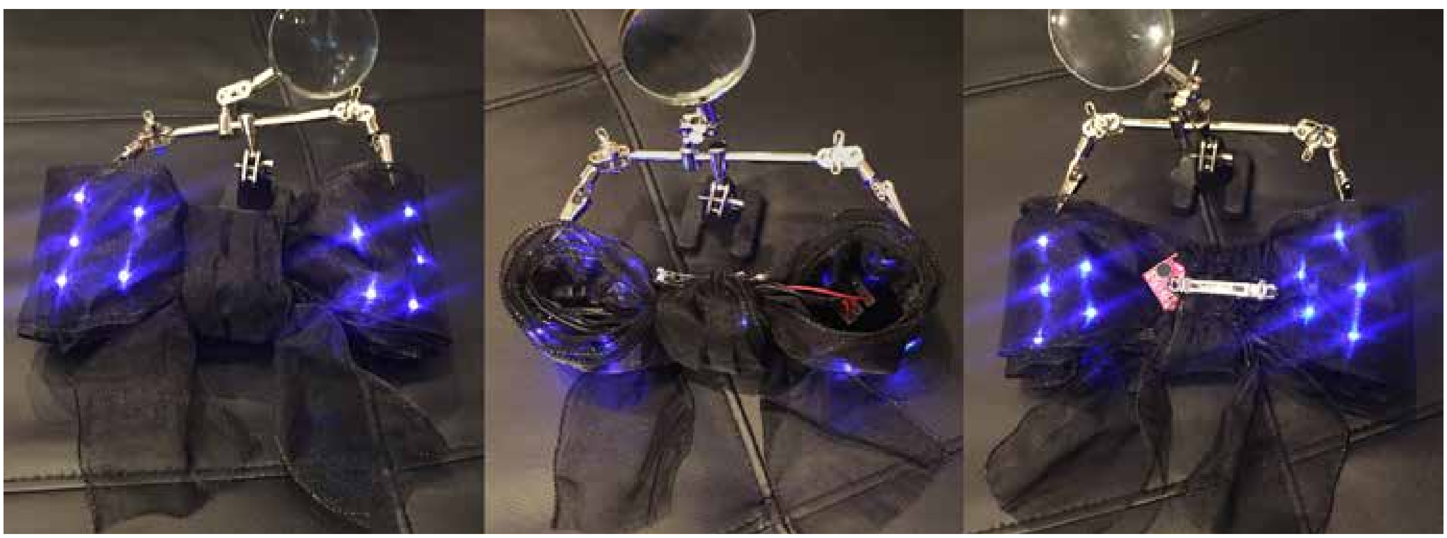


Image 5 *(Above):* From the left panel, the front view, top view and back view of Michelle's bow. Michelle sewed a bow with four concentric layers of ribbon, with the bottom seam sewed shut for the innermost loop to hold (but leave accessable from the top for access of power switches) her 3 battery packs on one side, and her RF board on the other. She also had a sound sensor (shown in right panel) and microcontroller which she secured to the center of the bow using wrapped layers of ribbon stitched in place with thread. This bow was made with cotton thread and black jumper wires for the circuit. The additional battery packs were required to power the higher-power LEDs and the microcontroller, which was programmed to control the LED colors based on the ambient noise levels.

2. Layout & Attach LEDs

Determine the pattern you want your LEDs to be in on the bow. You can secure the LEDs to the fabric with pins if you like. Keep in mind that the LEDs only allow current flow in one direction since they're diodes and we want to to connect them in parallel. This means it's best to orient them such that the positive sides are aligned with each other and the same for the negative sides.

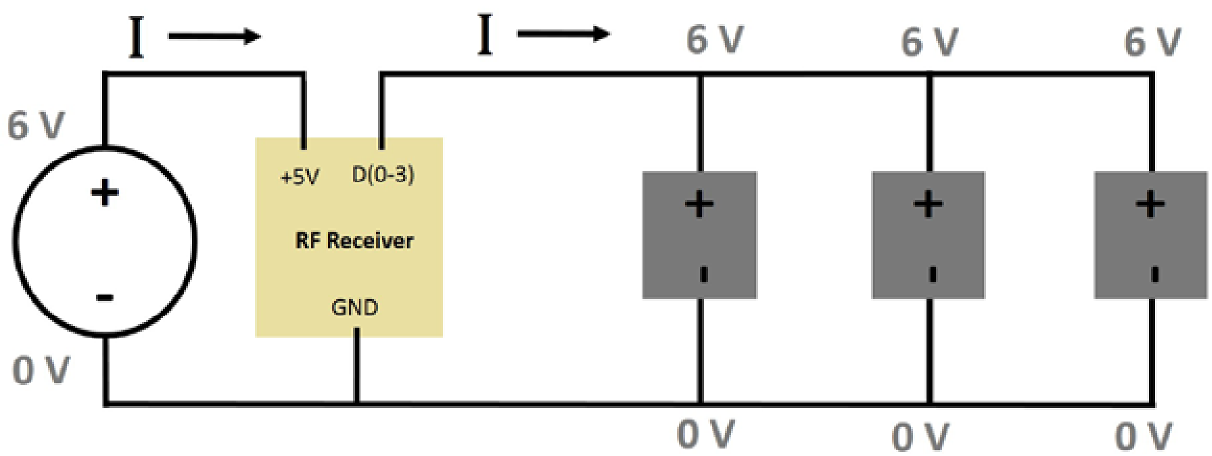


Figure 13 *(Above):* UUsing the LED Sequins, the following diagram shows the parallel connection of 3 sequins with the rest of the circuit. The materials list indicates 5-10, so extend your circuit for the number of LEDs you have in that range. The RF receiver takes power from the battery, and sends it out to the LEDs from the digital output pin only when triggered by the remote.

Once you know how you want them attached, use the nonconductive thread to attach the LED Sequins to the bow in your desired pattern. Make sure your connection is strong enough so the LEDs won't fall off but be sure to leave some of the metallic contacts surrounding each (+/-) hole to solder jumper wires to in the next steps. (Or, you can use conductive thread to mount them and create your circuit in one step, as described in the *Tips and Details* section of this document).

Image 6 *(Above):* Left panel shows LED sequins sewn to the fabric using non conductive thread. Note all LEDs face the same direction for easy connection between sequins with jumper wire in next step. Right panel shows outward facing side of LED sequin is veiled by two layers of the sheer fabric to soften brightness and reduce prominence of wires and circuitry.

3. Solder LEDs into Circuit

Once all LEDs are attached to the fabric, solder the pieces of insulated wire to connect them in a parallel circuit (+ to + and - to -). Cut each wire to length by sizing it against the distance between the LEDs and use the wire strippers to strip just the ends of the insulation off (no more than ¼"). Remember to include one "end" LED, from which the positive lead will connect into the voltage for the circuit and the ground will connect to a common ground. Keep in mind that this positive lead will be connecting to the digital output pin of the RF receiver, where the voltage is sent when the right button is pressed, when you are sizing these wires. For tips on soldering, see the *Tips and Details* section of this document.

Image 7 *(Left):* Jumper wires soldered between several LEDs.

4. Test & Debug LED Circuit

Before moving forward and adding more components, it is wise to test the circuit so far. You can do this by connecting the positive lead that interfaces to your parallel circuit to the positive end of your power supply and the negative lead to the ground. If your battery pack comes with a connector, it might be more convenient to cut it off and using the battery leads directly, since you will need to connect them to the power breakout board in the next step anyways.

Image 8 *(Above):* Isis tests her circuit with help from Michelle and smiles from Sina

If the LEDs do not all light up when you apply voltage and turn on the switch, any of the following (and others) could be true:

- There is a bad connection somewhere
    - A solder connection isn't making contact with the conductive pad of the LED sequin
        - Apply solder - Try heating the surface of the pad with the tip of the iron and melting the solder directly between the wire and the pad
    - You accidentally connected + and - somewhere
        - Use the iron to melt the solder at the joint you want to disconnect and remove the wire when it melts. Then connect it where it goes.
    - There is a bit of solder or wire touching one of the conductive parts on the sequin board *(See Image 9 below)*
        - Melt away the connection and make sure make sure
- Your batteries are dead, dying or are in backwards

Read the *Tips and Details* section of this document for information about how to use a multimeter to help find bad connections. When you get it working, gently compress the bow to test that the connections are good enough such that when the bow is handled, the lights stay on.

Image 9 *(Left):* The resistor (top arrow) and the LED (bottom arrows) mounts on the sequin board, indicated in the photo, are conductive. Make sure they don't touch anything conductive in your circuit (like your connections to the +/- pads). (Modified from original image from Adafruit)

5. Build Power Breakout Board

TThe power breakout board is where power is distributed to the components of the circuit. We like using a miniature PCB (printed circuit board) since the soldered connections of wire to the metallic rings around each through-hole in the board serve as both electrical and mechanical connections to the circuit, and a breadboard is a pretty fundamental component in electronics which is great to get acquainted with. We use the small board from Adafruit, shown in Image 10, below.

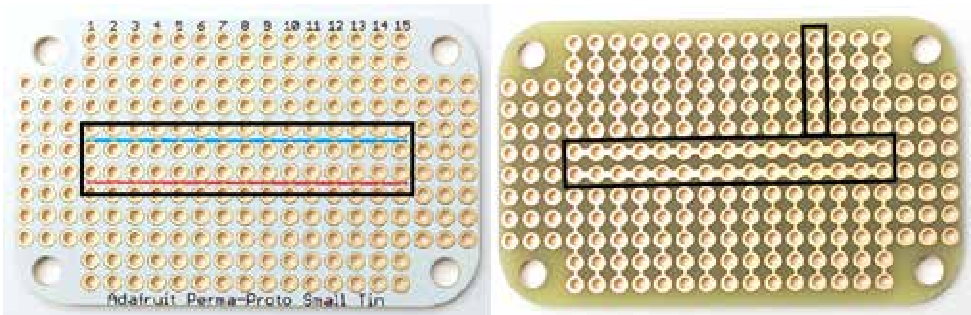
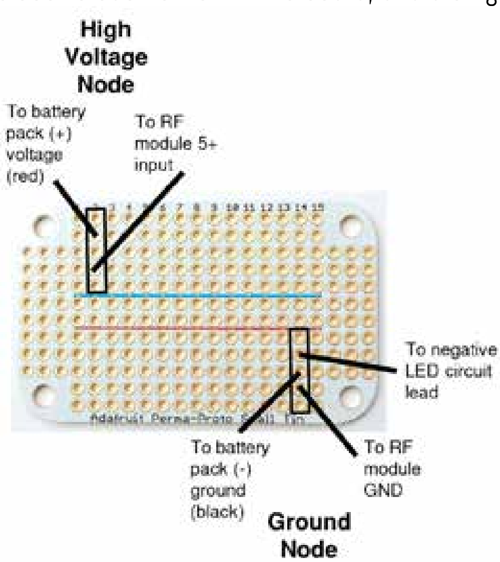


Image 10 *(Above):* Front and back of a miniature PCB board. The conductive connections between holes along different rows and columns is shown by the copper links, indicated in the right panel by the black boxes. In the left panel, the ground (blue) and power (red) "rails" are shown by the black box. (Image and PCB board from Adafruit.)

To make sure the whole circuit is closed, we need voltage and ground connections for each element. The necessary connections are shown in Image 11. Note that although there are three connections to ground (one for each element, the LED circuit, the RF board and the power supply) there are only two for high voltage since in this circuit the RF board sends high voltage to the LEDs. (Reference back to Figure 13 to see how this looks in the full circuit diagram.)

Turn the power switch off when connecting the battery pack to the board. Since the power and ground rails are so close to each other in this board, and a single frayed wire touching the wrong part of the circuit can short the circuit, we recommend making the nodes for power and ground at opposite sides of the board, as shown in Image 11, left. Solder each wire to the board, making sure that if you wiggle it gently, it has enough solder that it stays firmly connected. Be sure to insulate the board from metallic contact by coating solder joints in hot glue or wrapping the board in fabric. The larger holes are for mounting, are designed for use with screws, and can be used to sew through to connect the board to the bow as well.



See *Appendix B: Resources,* to learn about solderless breadboards, which are great for prototyping with connections which are not as permanent as soldering to a PCB.

Image 11 *(Left):* An example of a power breakout layout for a small PCB. (Original image and board from Adafruit.

6. Connect RF Module

Prepare the RF receiver to connect into the circuit. To do this, make two wire leads, each long enough to reach the power breakout board, given your layout of your bow design. Strip the ends of the wires and solder one to the +5V pin and the other to the ground (GND) pin, both of which will connect to the power breakout board. Also, solder the LED positive lead to a digital output pin on the RF board. Be careful not to join solder between the pins of the board, since this can short your circuit. Use heat shrink, if you have it, (or hot glue) to insulate the connection if you want to make sure the pins won't accidentally contact. Important to note- although the voltage input pin is marked as "+5V", the pin can handle 5-10 V to accommodate different power supplies. Be sure to insulate the pins board from metallic contact with each other or other parts of the circuit by coating solder joints in hot glue.

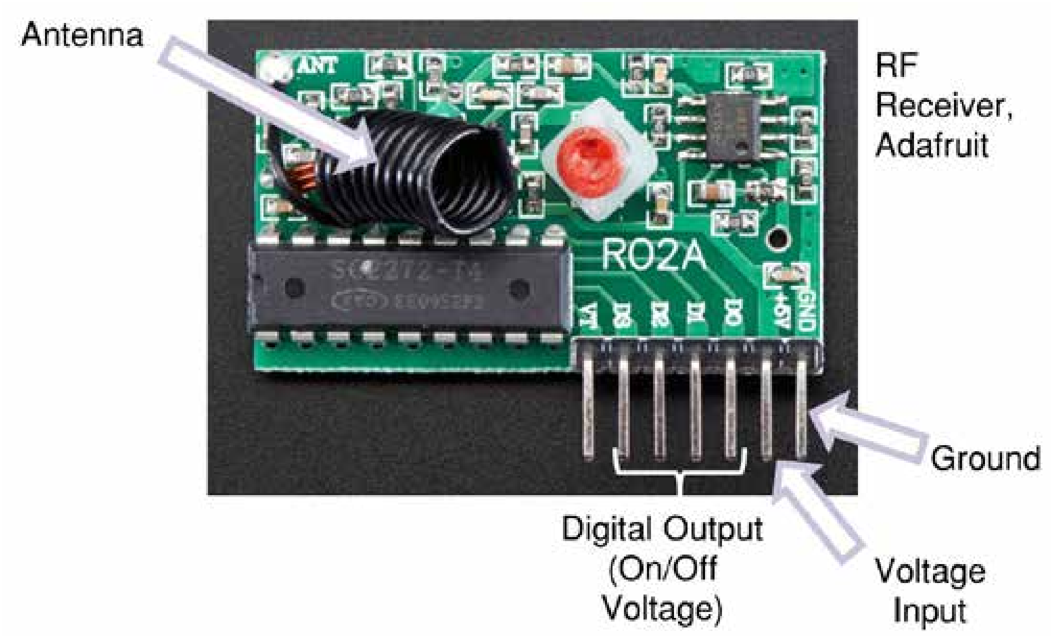


Image 12 *(Above):* Radio frequency receiver module with toggle control. Pins of interest are ground (marked GND, far right), voltage input (marked +5V, second from right) and the digital output pins, D0-3. (Original image from Adafruit, receiver available at www.adafruit.com)

7. Test RF Control

Now you should be able to turn on your power switch and test your circuit by toggling the corresponding button on the remote. If the circuit doesn't light up as expected, refer to step 4 and try to debug your circuit by testing all your newly added connections.

If you use the multimeter to measure the voltage at the RF board digital output pin when toggling the remote and you see no change in voltage as you toggle, assuming the remote batteries aren't dead, the RF board could be bad. Try swapping it with another and testing again.

8. Mount Components to Bow

Once the circuit is working, mount the RF and power boards and the battery pack into the bow, if you so choose. Refer back to step 1 for ideas but remember to keep the battery pack somewhat accessible, so the switch can be used and the batteries replaced, and the circuit connections isolated from each other. Hair clips, headbands, safety pins or any other method can be used to attach the bow to your person, assuming no metal components touch conductive elements.

Image 13 *(Above):* Possible component placement for a final bow.

Tips & Details

Soldering vs Conductive Thread

In place of soldering, conductive thread can be used to connect the LEDs into the circuit while attaching them to the bow. Some people may find sewing the LEDs directly to the bow may be easier and some may prefer to sew the LEDs to the bow with non-conductive thread and use insulated jumper wires to make the circuit connections between the LEDs.

The conductive thread is smoother and therefore knots can tend to slip undone, but also results in a softer, less structured bow overall. However, much care must be taken to ensure that not a single fiber from the threads is touching the metallic connections on the center of the LED sequin board (see image below) or any other thread in the circuit. (Only the pads on the edges should be contacted and they should not have a connection between them or to any other point on the board.) Clear nail polish can be used to coat the conductive thread knots (once the LED is attached to the bow) to prevent their fraying and touching undesired points.

Regular thread holds knots more easily and the frayed threads do not affect the circuit, no matter what they touch. The insulation of the jumper wire protects from accidental shorts while wearing the bow, so it is easier to ensure the integrity of the circuit in that regard. However, an extra step of soldering is required to make the circuit connections. Try to avoid touching the thread or fabric with the soldering iron since it will burn the thread and put holes in the fabric.

Image 14 *(Left):* Arrows indicate parts of LED sequin board which cannot be contacted by wires or conductive thread used to form the circuit. (Modified from original image from Adafruit, Adafruit LED Sequins)

LED Sequins vs LEDs

LED Sequins are easy to use for this project because they are small, they have a resistor built in, and they have two holes on the board which are convenient for sewing through to attach to fabric. You can give them 3-6V, depending on your preferred battery, and they will work nicely, but for more than 5-10 sequins, they start to dim with the increased current requirement.

They are an easy option but they aren't the cheapest choice. If you want to cut costs for a large workshop (although the cost per unit drops with increasing order size) you can order LEDs and resistors in bulk for cheap on Amazon and sew them in or stab the component leads through the fabric or do any other creative method for mounting them to the bow. For standard LEDs, the positive side is usually indicated with the longer lead and the negative side with a flattened side of the plastic portion. See Image 15.

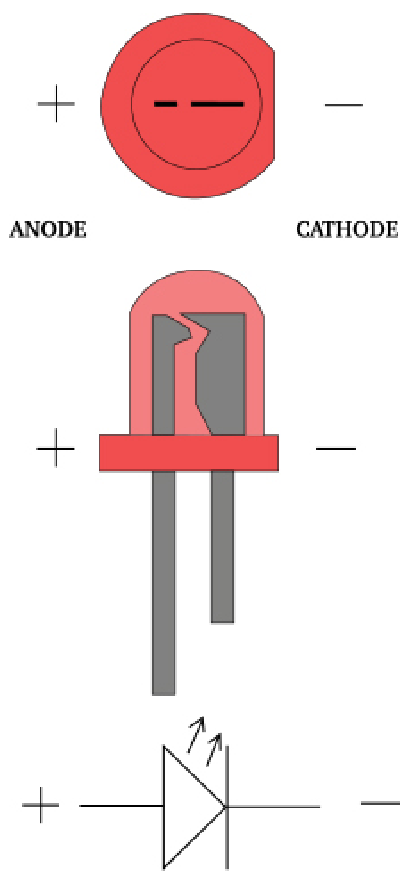


Image 15 *(Left):* Standard packaging for an LED compared to the LED circuit symbol, with physical markers indicating positive and negative (ground) sides. Image from Wikipedia Commons, (By Adam850 Image:Led2.PNG, Public Domain, https://commons.wikimedia.org/w/index.php?curid=2204213)

If you go the resistor and LED route, there are two ways to size resistors for the color you choose. The simplest way (without doing math) is to reference the Resistor Sizing for LEDs material in *Appendix B: Resources*. The LED Color Chart can be used to get the voltage across and the current through each different color of resistor. Those numbers can be plugged into the LED Calculator, along with the voltage of the battery (source voltage) to find the necessary resistance of the resistor to put in series with each LED. If you want to calculate the resistance by hand (with math!), it is just a matter of applying Ohm's Law and Kirchhoff's Loop Law, using the voltage values in the LED Color Chart. A tutorial, LED Current Limiting Resistors, also in *Appendix B: Resources*, can be used if you get stuck.

Soldering

Solder is like conductive glue. It is a soft metal that melts at a relatively low temperature. It is used in circuits to connect metal components together, like two wires or a wire and a breadboard, when you want current to flow through the connection in the circuit. The best way to learn how to solder is to try it, after someone shows you. In the meantime, Sparkfun has a great tutorial that details soldering pretty thoroughly, which can be found in *Appendix B: Resources*. If you know nothing about soldering, read that, watch the video at the bottom of the page and then come back and continue reading.

It is important to keep the tip of the soldering iron clean when you solder. For this workshop, the

materials list indicates that we use copper sponges and rosin-core solder to keep the tip of the soldering iron clean. If copper sponges aren't available regular dish sponges or paper towels folded up thick can be saturated with water and used instead. Any other combination of flux or tip tinner can be used as well. Another valuable tool on the materials list is a set of "helping hands". Two different varieties are shown below.

Image 16 *(Above):* Left panel shows soldering using helping hands tool. Right panel shows soldering using helping hands of a friend.

Multimeters & Circuit Debugging

One of the handy use for a multimeter is testing continuity. That means, determining if two points are connected through a conductive path. For example, if you take a solid piece of wire and test continuity between the two ends, the multimeter will make a noise indicating that the wire is continuous (assuming there's no break in the wire somewhere).

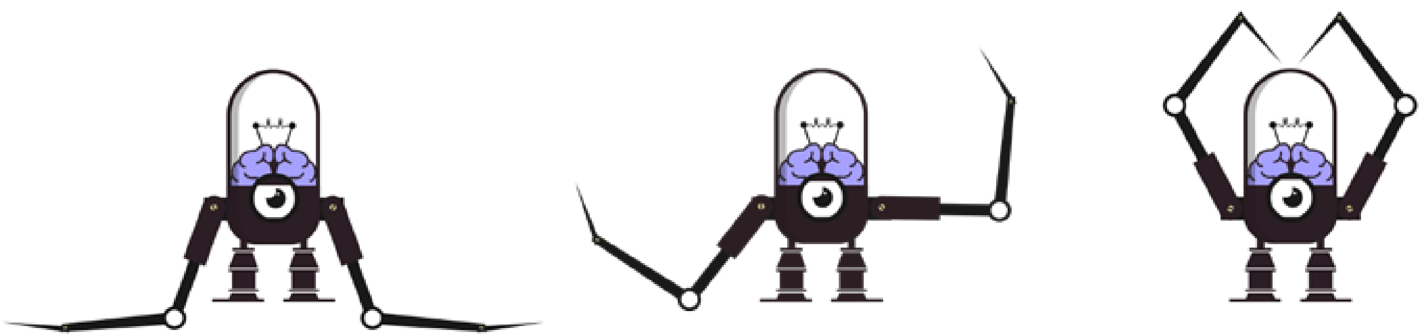
To use a multimeter to test for continuity, turn the dial to point to the symbol that looks like a "signal" indicator (see Figure 14, below), and connect each lead to each of the two points you want to test. This is a great way to debug your circuit. You can test between all of the positive leads to make sure they are all connected and do the same for the negatives (grounds). If there is a problem and your LEDs aren't working, you can test for continuity between positive and negative. They should not be connected, otherwise you have a short somewhere, meaning there is some drop of solder, or strand of wire or conductive thread touching something it shouldn't be.

Figure 14 *(Left):* An example of the continuity setting symbol of a typical multimeter. Sometimes a diode symbol is shown alongside on in place of this symbol.

Check out *Appendix B: Resources* for a good resource for learning more about using a multimeter.

"It might be a task,
it might be a very hard journey,
but if you put your mind to it
you can do it."

– Melody Schuster, Mind Makers Operations Manager



Moving Forward

Mind Makers' mission is to encourage STEM diversity and empower and inspire children If you are the workshop attendee and this becomes an illuminating experience for you, pass it on! Give another part of society the ability to light up lives by hosting your own workshop and sharing your knowledge.

We encourage you to reach out to Mind Makers with any questions you may have or to receive advice and support in establishing your own electronics workshop. Be the one to start a propagating wave of engineering education in your community and help to make these mindful matters, matter.

Appendix A: Bill of Materials (BOM)

Bow Making Workshop BOM					
Class size: ~15 students (5 extra bow kits purchased for margin)					
Item Description	**Item Number**	**Vendor**	**Unit Cost**	**Qty**	**Total**
RF Toggle Receiver	1097	Adafruit	$4.46	20	$89.20
Soldering Iron kit	B017H69UN2	Amazon	$25.59	7	$179.13
Copper Sponge	B00FZPGDLA	Amazon	$8.94	5	$44.70
Wire strippers	B0176J6DU8	Amazon	$13.99	5	$69.95
Solder	1886	Adafruit	$5.95	7	$41.65
Needle nose pliers	B000NPT5TO	Amazon	$5.46	5	$27.30
Helping hands	B000RB38X8	Amazon	$6.58	10	$65.80
RF Single-button Remote	1392	Adafruit	$6.95	4	$27.80
Wire snippers	B001BQCY4W	Amazon	$5.92	5	$29.60
LED pixels - Red	1755	Adafruit	$3.95	5	$19.75
LED pixels - Pink	1792	Adafruit	$3.95	5	$19.75
LED pixels - Blue	1757	Adafruit	$3.95	5	$19.75
Battery pack	783	Adafruit	$1.95	20	$39.00
Batteries - 3V CR2032 Li Coin Cells (20 pc)	B008XBK7PG	Amazon	$8.39	4	$33.56
Black thread - 1 spool 400 yd	B00172V5VI	Amazon	$4.93	5	$24.65
Sewing needle kit, 25 ct	B000SL447Q	Amazon	$3.48	2	$6.96
Black insulated 18-30 AWG wire, 25 ft (Silicone)	2517	Adafruit	$4.95	5	$24.75
Small soldered breadboard (PCB) - 3 pc	1214	Adafruit	$7.95	6	$47.70
Multimeter	B00KHP6EIK	Amazon	$12.98	7	$90.86
Black sheer organza ribbon, 1.5" wd, 50 yds	B00BT0EK56	Amazon	$5.65	2	$11.30
Black sheer wired organza ribbon, 1.5" wd 25 yds	B00SQL2KOY	Amazon	$4.33	3	$12.99
Alligator Test Leads, 10 pc	B00MQFKLZQ	Amazon	$5.49	1	$5.49
Black fabric-covered headbands - 10 pc	B00NFOOHUM	Amazon	$10.99	1	$10.99
Black barrettes - 2 pc	B003EDBG1M	Amazon	$6.00	4	$24.00
Hot glue gun w/glue sticks	B001AQRLM8	Amazon	$7.99	5	$39.95
Metal bow tie clips - 10 pc	B00C0E889Y	Amazon	$11.95	1	$11.95
				Total:	$1,018.53

Appendix B: Resources

Datasheet Tutorial

How to Read a Datasheet
https://www.sparkfun.com/tutorials/223

Soldering Tutorial

Through-Hole Soldering *by Sparkfun*
https://learn.sparkfun.com/tutorials/how-to-solder---through-hole-soldering

Multimeter Tutorial

How to Use a Multimeter *by Sparkfun*
https://learn.sparkfun.com/tutorials/how-to-use-a-multimeter

Solderless Breadboard Tutorial

How to Use a Breadboard *by Sparkfun*
https://learn.sparkfun.com/tutorials/how-to-use-a-breadboard

Resistor Sizing

LED Color Chart
http://www.oksolar.com/led/led_color_chart.htm

LED Calculator
http://led.linear1.org/1led.wiz

LED Current Limiting Resistors *by Sparkfun*
https://www.sparkfun.com/tutorials/219

mindmakersproject.org