A Brief Introduction to E-textile Interfaces

Materials have a way of informing and influencing our actions and emotions. Like when you feel the cool smoothness of a solid metal item versus holding a light and airy object made from plastic. You may prefer one from the other for reasons you can't quite put your finger on, but the tangible sensations will no doubt leave an impression. Electronic textiles (e-textiles) is the practice of building electronic circuits and components from thread, yarn, fabric and other soft and flexible materials like plastics and rubbers. This practice explores tangible materials and their visceral properties as well as their impact on communities, technology, and our environment. E-textiles welcomes and utilizes a variety of skills making it a great space for skill-sharing and collaboration. It's also great for beginners who wouldn't normally pick up a soldering iron or a sewing needle.

There are many exciting materials and techniques to build e-textile interfaces with. In this chapter, we will introduce techniques that are beginner friendly using materials that are easily obtainable and relatively inexpensive. We will build two circuits using traditional components on a breadboard then we will learn how to make and substitute hardware for textile-based components. We will move the breadboard to the body, then finally move the circuit from the breadboard onto a textile.

/////////////////SIDE BAR////////////The Joining of Craft and Electronics/////////////////SIDE BAR////////////

Modulated Frequency Circuit

Materials

- 1x 40106 IC
- 1x 47uF polarized capacitor (C1)
- 1x 0.1uF ceramic capacitor (C2)
- 3x 100kΩ potentiometers (R1, R2, R3)
- 1x 3V 2032 type coin-cell battery and battery holder
- Mini-sized breadboard
- Solid core hookup wire

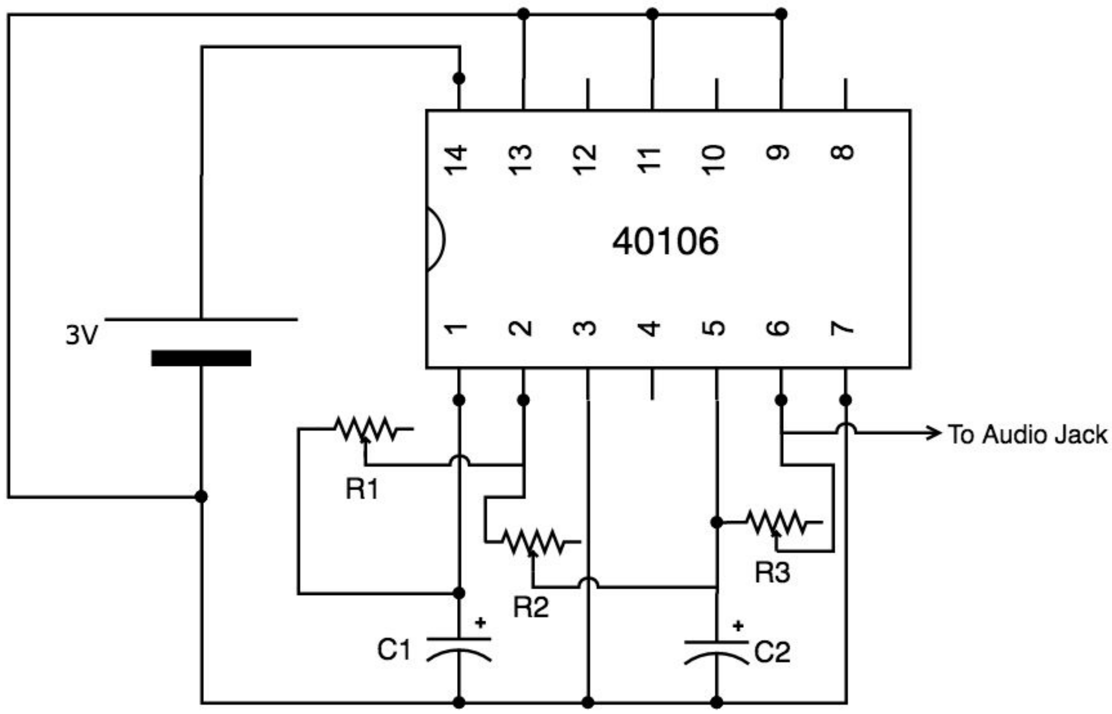


Figure 1.0 - Modulated Frequency schematic

Building the Circuit

Before we start swapping hard components for soft ones, it’s important to first have a working circuit with the traditional components in place. Testing and adding soft components one by one will help cut down on frustration and points of failure as we work.

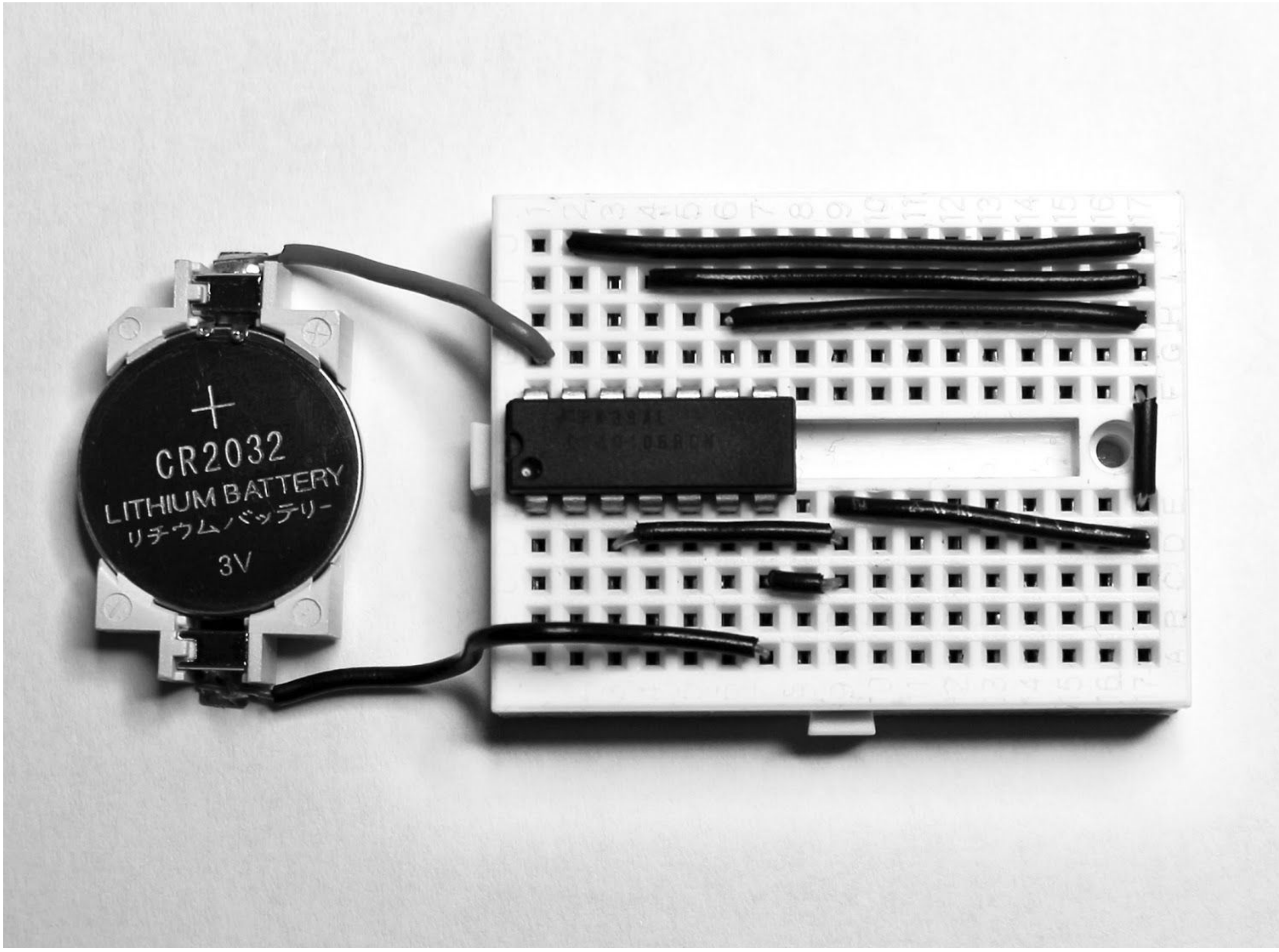


Figure 1.1 - Breadboard with 401060 IC, wires, and battery clip

All of our circuits will run off of a 3V 2032 type coin-cell battery, often used in low-voltage soft circuits. Insert the 40106 IC into the breadboard with the notch facing to the left. Next, connect the positive lead from the battery clip into pin 8 and the negative lead to pin 7. We will need ground on both sides of our breadboard, so take a small black wire and jump ground from one half of the board to the other. As a best practice, we should also ground any unused input pins of our IC.

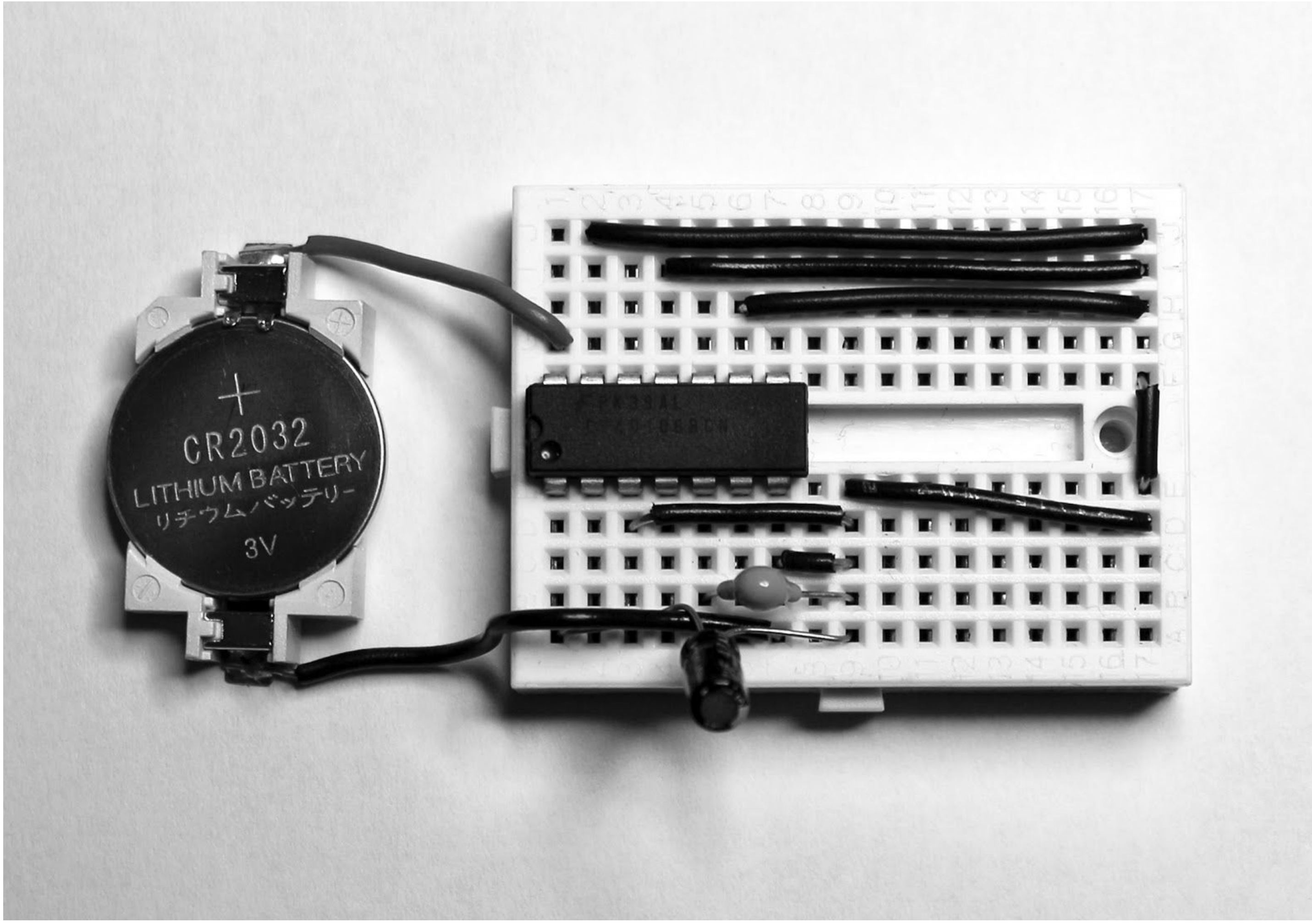


Figure 1.2 - Add capacitors C1 and C2

Connect the 47uF capacitor, labeled C1 in our schematic, pushing the long leg into the same row as pin 1 and the shorter leg into the ground bus. Connect C2, the 0.1uF capacitor, between pin 5 and ground.

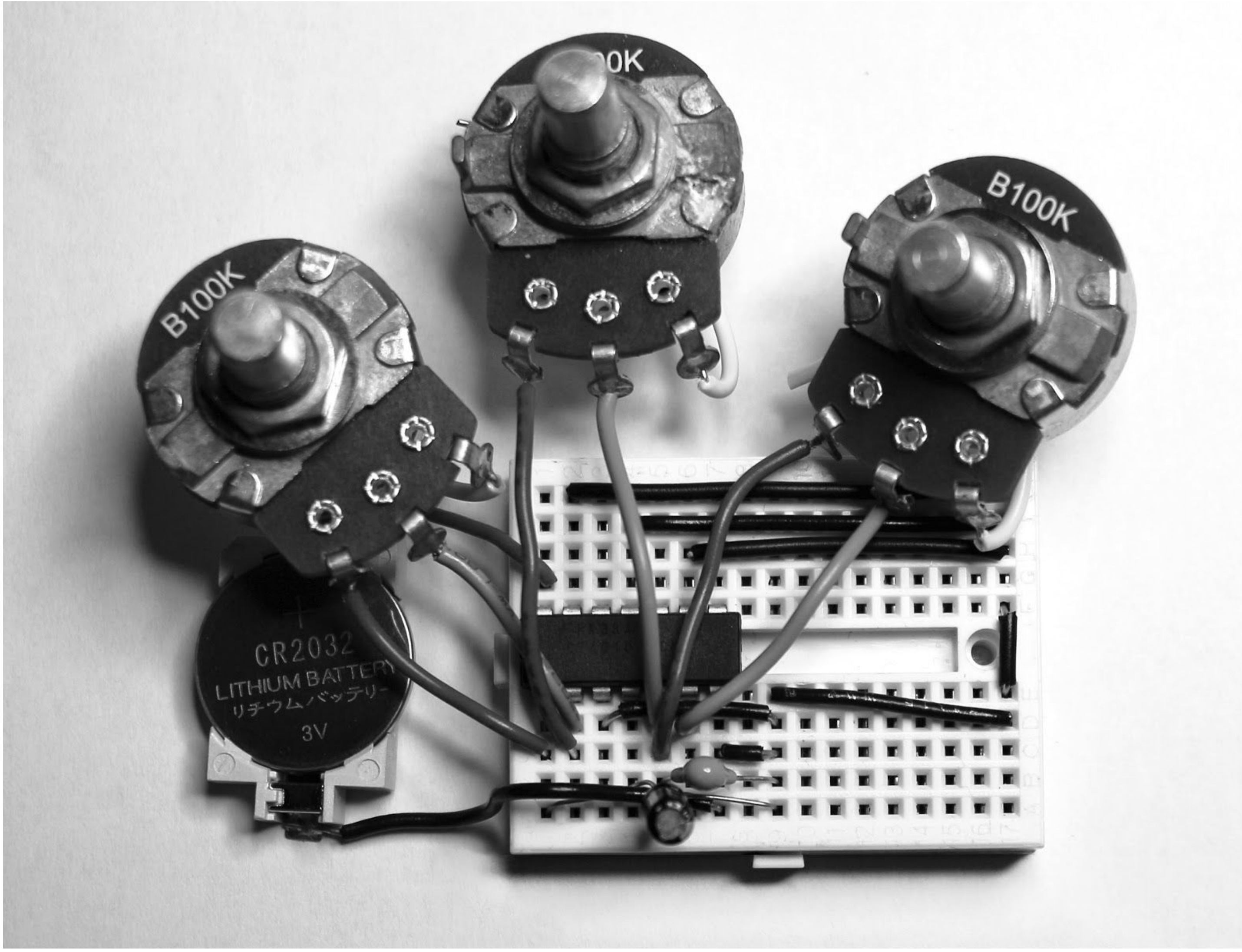


Figure 1.3 - Add the potentiometers R1, R2, R3

Now we will connect our potentiometers, or pots. These are the components we'll be swapping out later with our soft components. Connect the first and center wires of a 100kΩ pot, labeled as R1 in our schematic, between pins 1 and 2. Do the same thing with the second 100kΩ pot (R3), but between pins 5 and 6. Finally, connect pins 2 and 5 together with the third 100kΩ pot (R2).

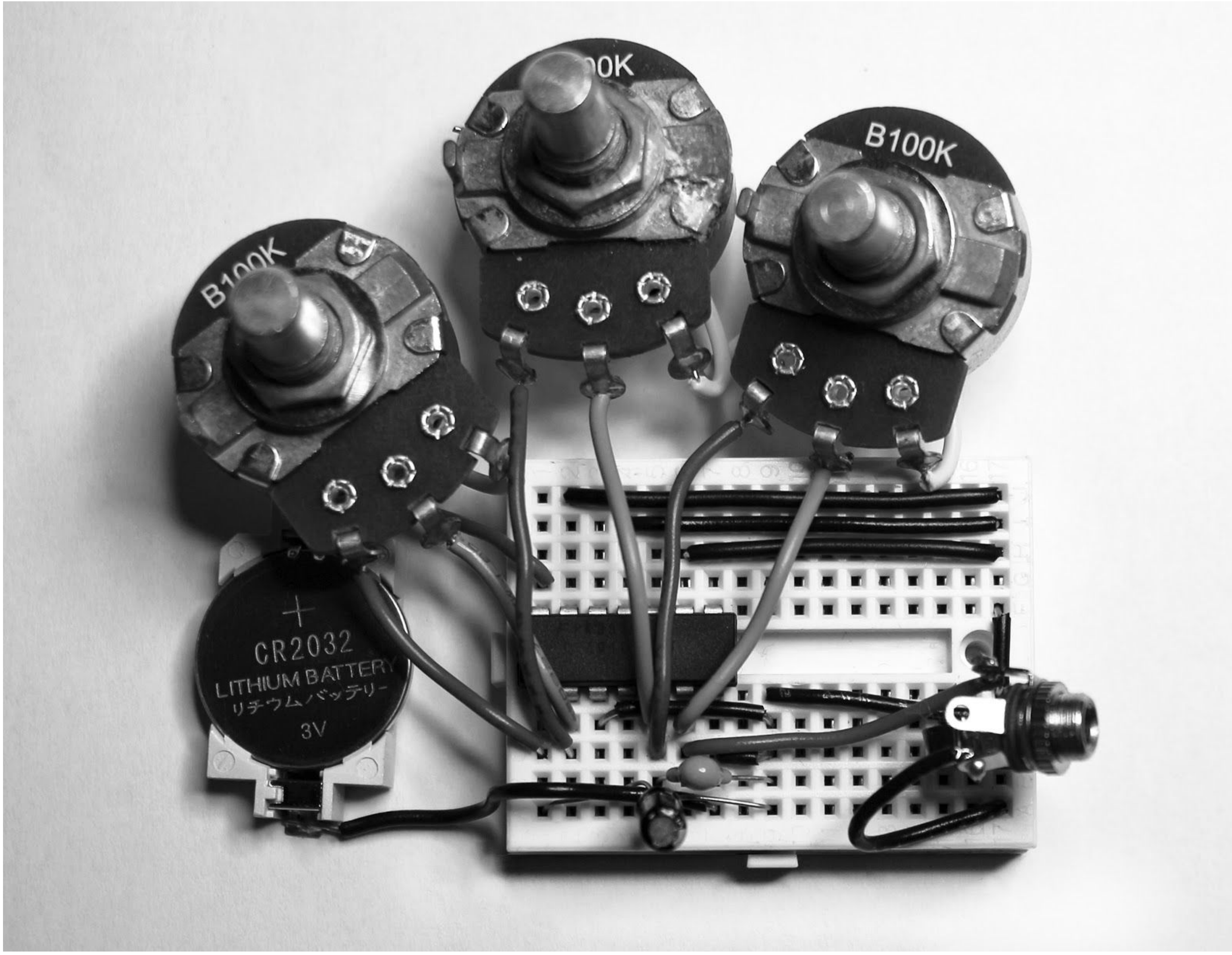


Figure 1.4 - Completed circuit with audio out socket

With our circuit complete, we are ready to hear some oscillations! Connect a 3.5mm mono audio socket between pin 6 and ground, and plug in your speaker. You should hear a square wave tone, pitched high or low depending on how your pots are set. If not, carefully check your wiring. Once you have confirmed that the circuit is working, it's time to make some soft components.

Make a Pom-Pom Pressure Sensor

Using conductive yarn we are going to make a pom-pom pressure sensor. The yarn is a mixture of polyester (80%) and AISI 316L stainless steel (20%). The stainless steel will not corrode and the yarn can be washed. When the pom-pom is squeezed the stainless steel threads compress together. The compressed threads give electricity a more direct path lowering the resistance in relation to the force applied.

Materials

- One bobbin of conductive yarn available at less.emf.com
- Wool yarn, worsted or chunky weight

- Scissors
- A scrap of thick cardboard

Figure 1.5 - Yarn, cardboard with slot and bobbin of yarn

Cut a rectangular cardboard with a slot cut from it. The sturdier the cardboard the better. Depending on the size of your cardboard pom-pom maker and the thickness of your yarn, the number of wraps needed may be more or less. You may want to make a test pom pom first before adding the conductive yarn. For chunky weight yarn do about 15 wraps of wool, then 15 wraps of conductive yarn, 15 of wool, 15 of conductive, and 15 more of wool.

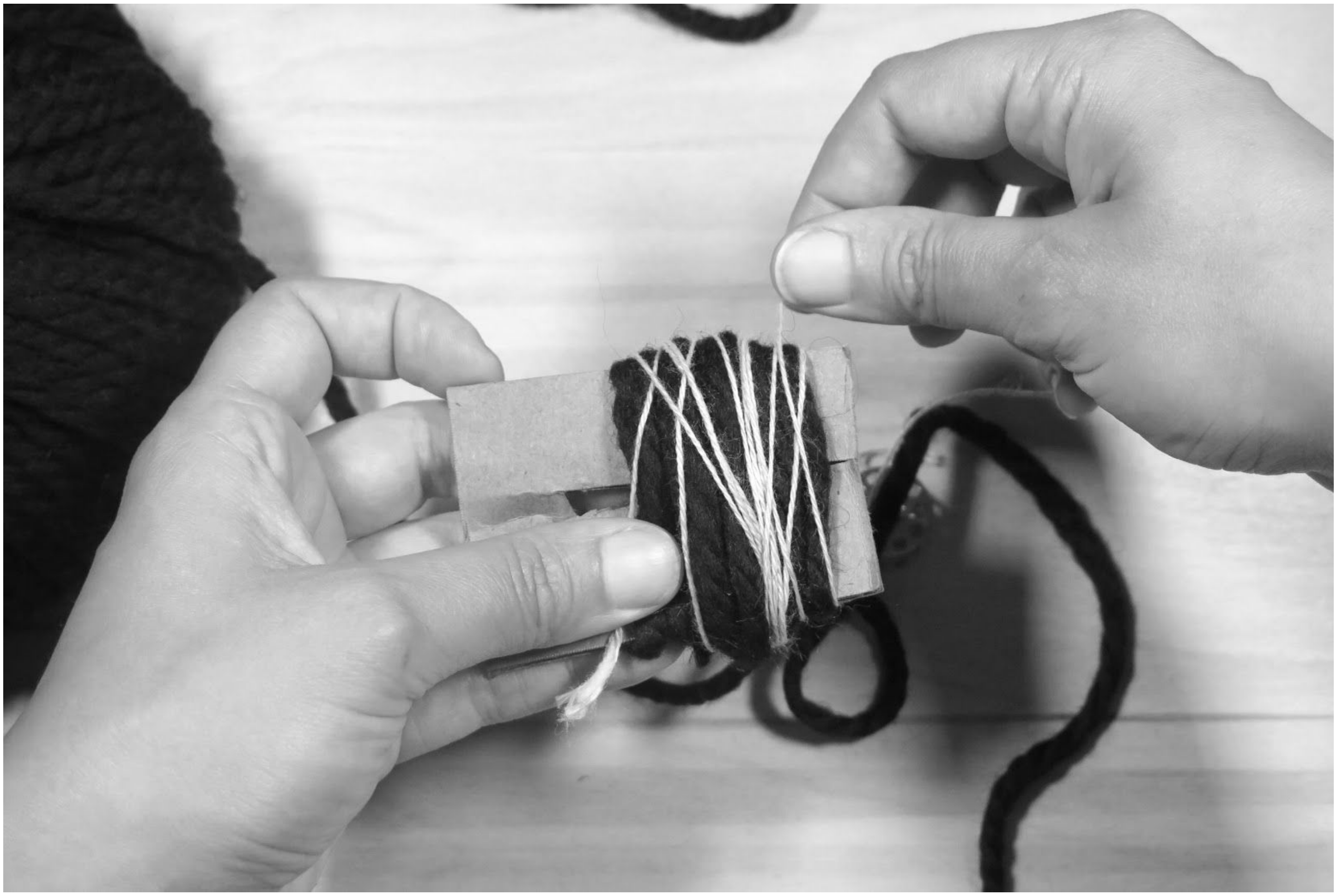
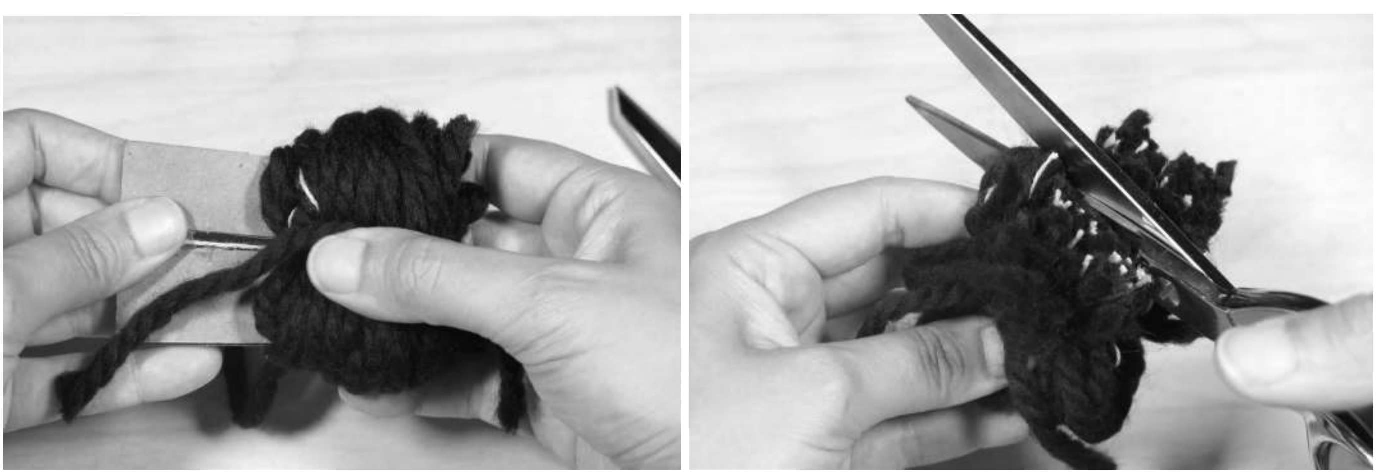


Figure 1.6 - Wrapping conductive yarn over the wool wraps

Take a short piece of yarn, slip it through the slot in the cardboard and wrap it around the middle of the bundle. Make one half of a square knot to hold the yarn in place and slide it off the cardboard. Tighten the yarn around the middle and finish tying the knot. Cut all of the loops in half and fluff it into a pom-pom. Trip the yarn to get a round pom-pom. Clip two alligator leads to a piece of conductive yarn on opposite sides of the pom-pom. Remove the R2 pot and clip the pom-pom to the jumper wires. Squeeze to change the sound!



Figures 1.7a - Sliding the yarn off the cardboard, 1.7b - Cutting the loops

Figure 1.8 - Alligator leads clipped to conductive yarn in the pom-pom

Knit a Stretch Sensor

Conductive yarn can be knitted into a sensor without additional tools using a technique called “finger knitting”. A knitted sensor can act as a stretch sensor or you can squeeze or twist it. Finger knitting produces a large and rather loopy knit stitch. To make the sensor thicker, knit the conductive yarn with a worsted, or heavier, weight yarn. This will help it retain its shape after deformation. To add even more elasticity, try knitting conductive yarn, regular yarn, and elastic thread together.

Materials

- One bobbin of conductive yarn available at less.emf.com
- Wool yarn, worsted or chunky weight
- Scissors

To start knitting a sensor, drape the conductive and regular yarn over your pointer finger leaving a 6” tail. Weave the yarn under and over the fingers to create four rows. This is called an e-wrap cast on. Diagram 1.10b illustrates this using the right hand.

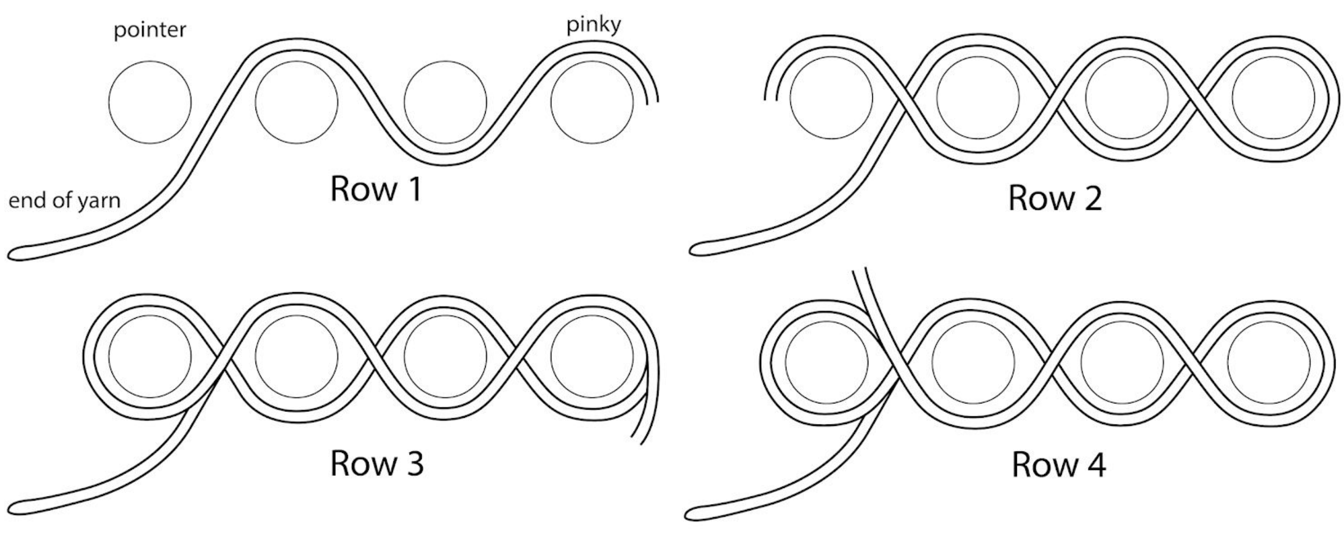
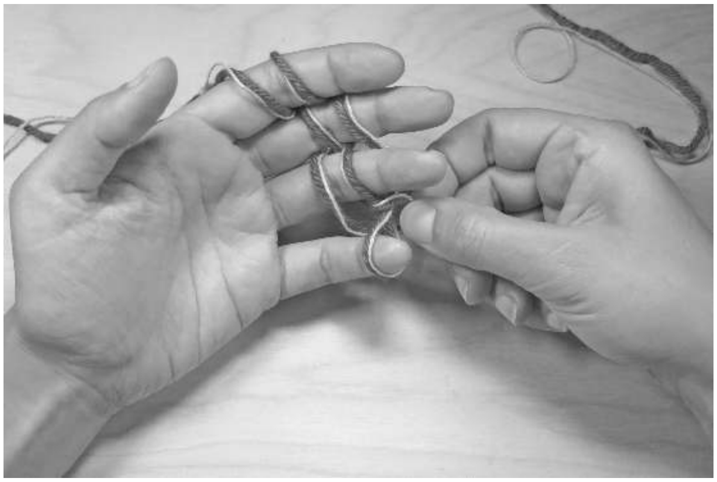


Figure 1.9 - Guide for finger knitting

Each finger should now have two strands of yarn. On the pinky, pull the bottom strand over the top strand and the tip of the finger. Do this to the next two fingers. When you get to the pointer finger take the end of the yarn and place it in between the pointer and middle finger.



Figures 1.10a - Pulling the bottom strand over the pinky, 1.10b - Placing the end of yarn between the pointer and middle

After moving the yarn end, the cast on is complete and you are ready to start knitting. Wrap the yarn around the pointer and weave the yarn through your fingers again to create two rows.

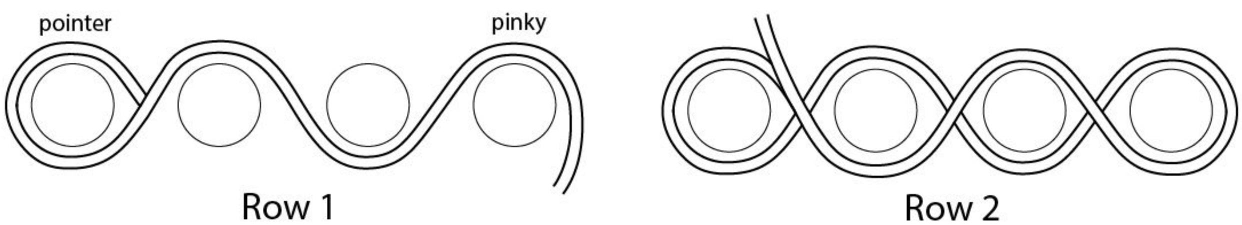
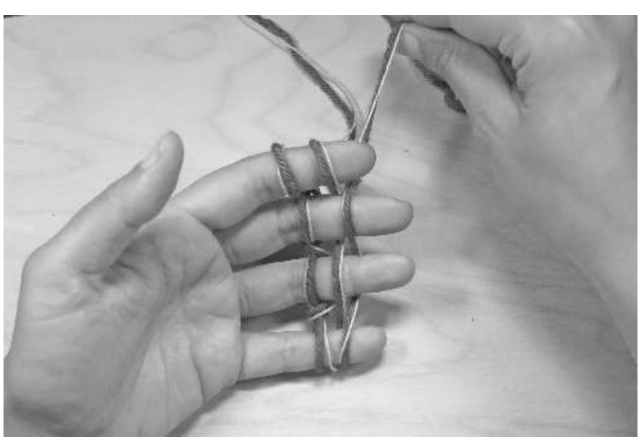


Figure 1.11

You will end up with two strands on each finger. To knit a row pull the bottom strand over the top strand and the tip of your finger again. Do this for each finger to complete the row. Continue to weave 2 rows and knit stitches in this manner until you get the length of sensor you want.



Figures 1.12a - Two strands on each finger, 1.12b - Knitting

Finishing is called binding off. To bind off cut the yarn leaving a 6” tail. Thread the end of the tail under the loop on the pinky, then the ring finger, index finger, and last the middle finger. Take the yarn off of the fingers and pull the tail gathering and securing the end.

Figure 1.13 - Pulling the tail

Grab two alligator leads and clip one to each end of the sensor, making sure the alligator teeth clip onto the conductive yarn. You now have two soft sensors to play with. Replace R1 with the stretch sensor and stretch to lower the resistance and change the sound!

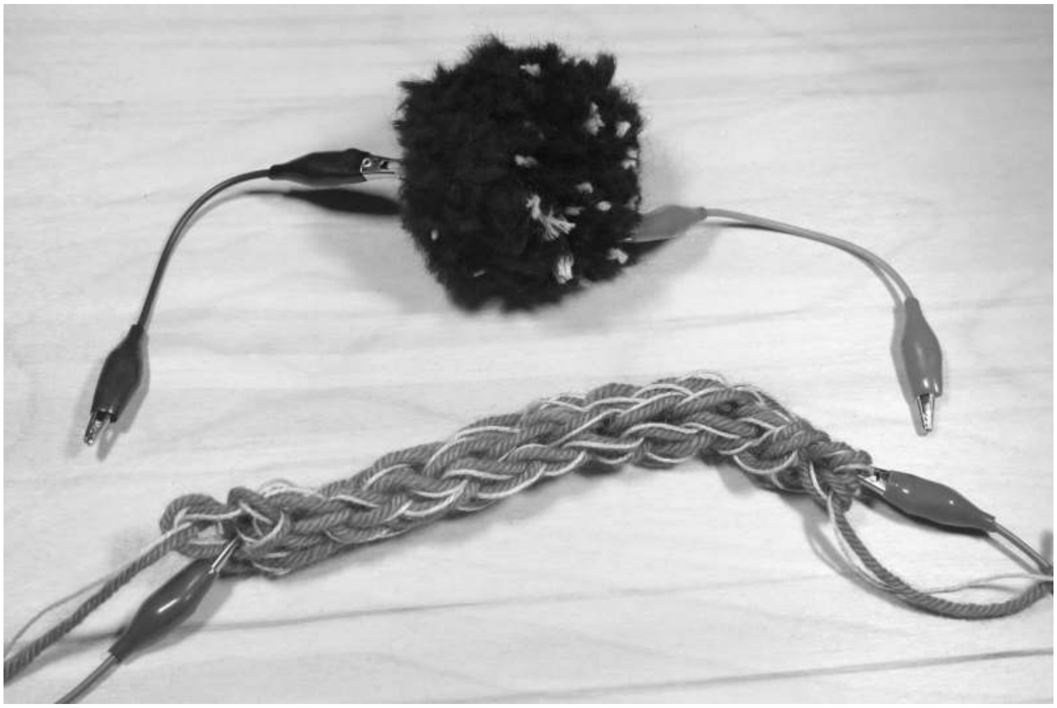


Figure 1.14 - Completed pom pom squeeze sensor and knitted stretch sensor

//////////////////SIDE BAR/////////////The Art of Building Soft Electrical Components//////////////////SIDE BAR/////////////

Resistor Ladder Circuit

Materials

- Modulated Frequency circuit
- 1x 100kΩ potentiometer (R1) (optional)
- 1x 100kΩ resistor (R2)
- 1x 47kΩ resistor (R3)
- 3x 10kΩ resistor (R4, R5, R6)

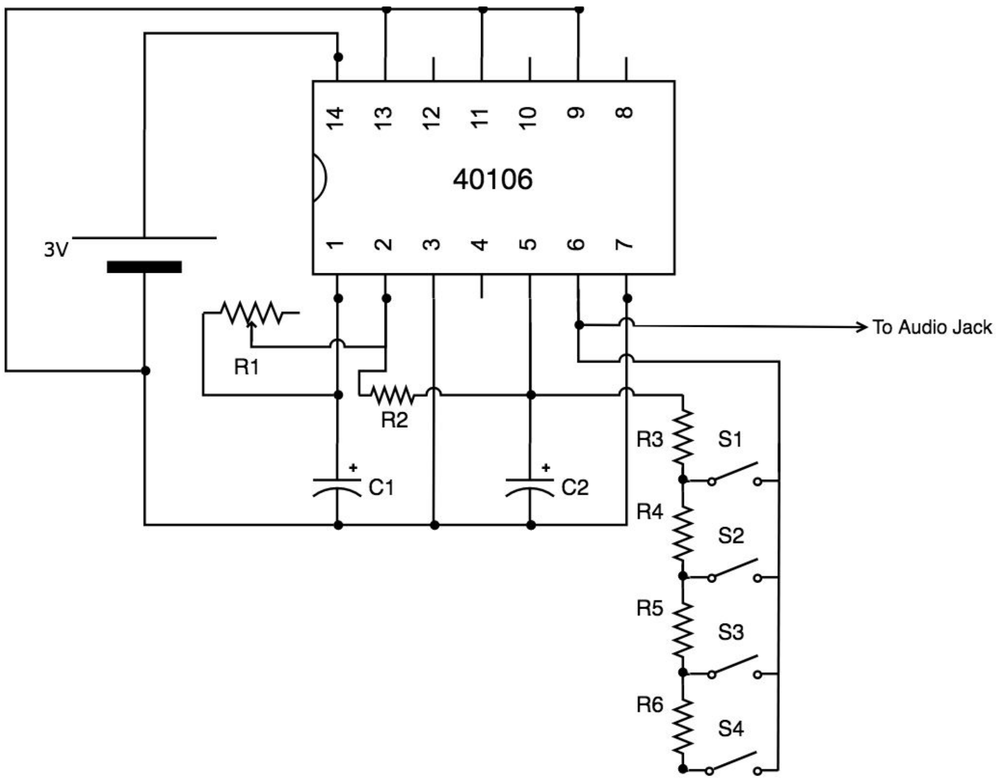


Figure 2.0 - Resistor Ladder schematic

A resistor ladder is simply a chain of resistors connected together in line to achieve effects like frequency division, which lets us generate a range pitches. To make our resistor ladder, we will start with our modulated frequency circuit by swapping a component and adding resistors and switches.

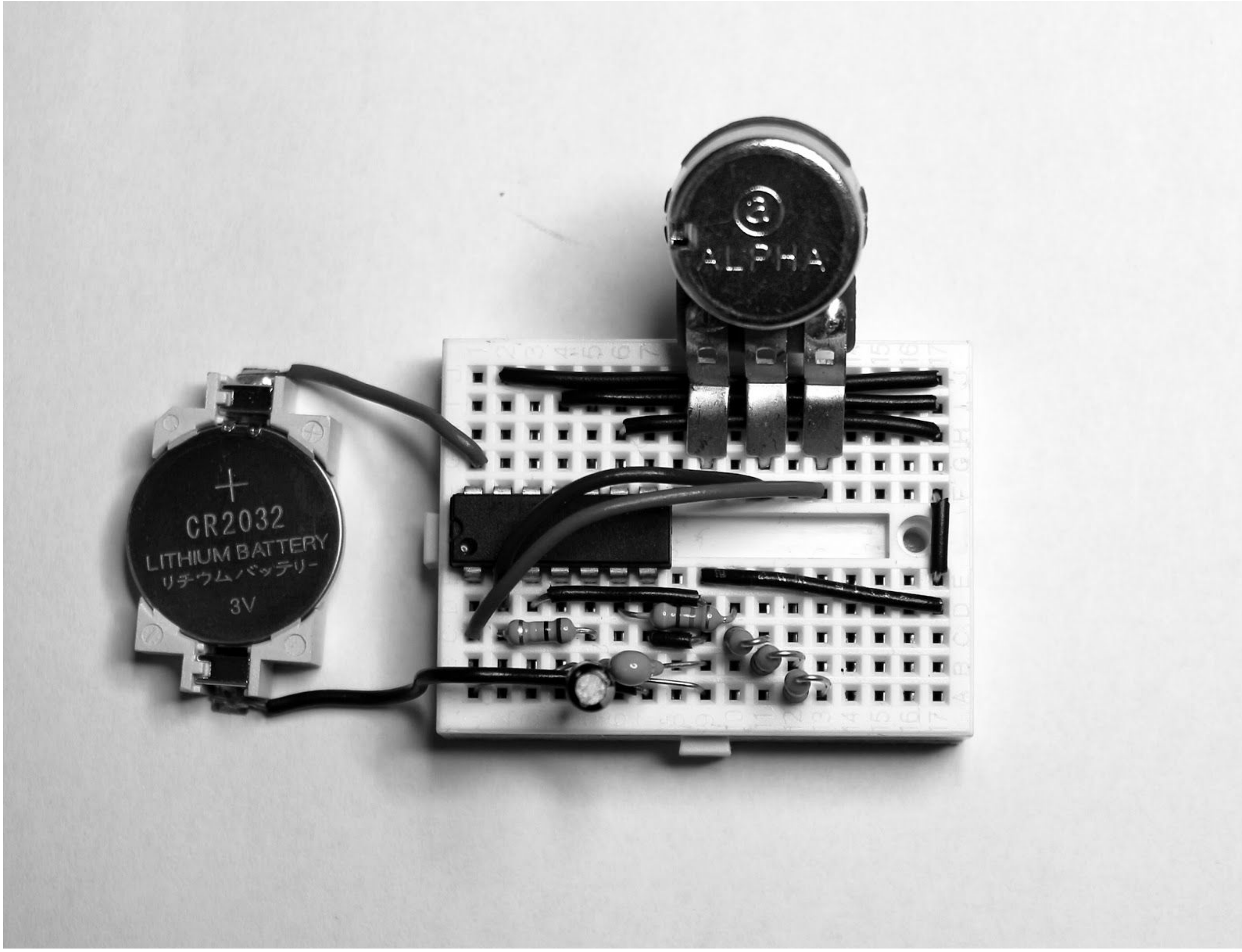


Figure 2.1 - Resistor ladder with resistors R3, R4, R5, and R6

To begin with, move R1 over to the other side and jump some wires over from pins 1 and 2 to the first and second legs. We are going to make this breadboard wearable, so swapping R1 for a panel mount pot that can plug directly into the breadboard (pictured in figure 2.0) isn't necessary but make things tidy and compact. Next, replace the 100kΩ pot we used for R2 with a 100kΩ resistor.

Now we build the resistor ladder. Take the 47kΩ resistor and push one leg in line with pin 5 of the IC in our breadboard and the other leg in another part of the breadboard. In order to fit the rest of our resistors on the mini breadboard, we'll need to bend the legs over so that the resistor takes on a U-shape and can fit into two adjacent holes. After doing that, take our three 10kΩ resistors and connect them in a line, one after another on the breadboard, with the first leg of each resistor in the same row as the last leg of the previous resistor.

In order to turn notes on and off, we will need several switches placed in between each stage of the resistor ladder and pin 6 of the IC. These switches could be regular momentary push buttons, but we will be making them from conductive fabric attached to our fingers.

Make Soft Switches

An advantage of a soft switch is that it can be comfortably placed onto the body. The hand is a convenient and especially expressive part of the body to build around. Five switch contacts will be plugged into the resistor ladder and put on the tips of each finger and one on the thumb. A note can then be played by touching the thumb contact to the fingertips.

Materials

- Sheet of 100% sheep's wool felt
- HeatnBond Ultrahold
- Iron-on conductive fabric
- Straight pins
- 22 gauge stranded wire preferably silicone coated
- Sewing needle
- Thread
- Iron
- Scissors

There are many kinds of conductive fabric created from different kinds of fibers and metals. There are ones that stretch, that are antimicrobial, and ones that change resistance when pressed. Look in Appendix B for places on where to get a variety to start experimenting with. In this chapter we are using a highly conductive copper plated polyester with a tarnish resistant finish. To secure it to our felt we could sew it down but that could be tricky and is surely time consuming. A quick and stable solution is to make the fabric iron-on. To prepare for use, iron a hot-melt adhesive specifically for making appliques, like HeatnBond Ultrahold, to one side of the fabric before any cutting is done.

Cut five strips of wool felt long enough to wrap around each fingertip and thumb on one hand. Cut five pieces of conductive fabric slightly thinner and the same length.

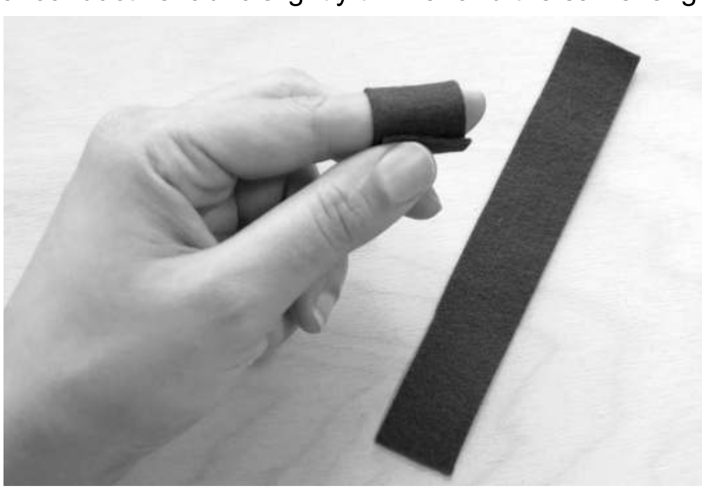


Figure 2.2a - Wrapped felt around fingertip

Figure 2.3 - Conductive fabric and felt strips

Figure 2.4 - Ironing down the conductive fabric onto the felt

Iron the conductive fabric onto the felt with the adhesive side down using an iron set to medium heat. Before we put them on the fingertips let's first put together some basic soft switches you can use anywhere. Grab two of the contacts and plug them in series with R1 where S1 is in figure 2.5. Clip one side to pin 1 and the other to R1. Touch the contacts together to hear sound. You have a basic soft switch: two low profile, soft, and flexible contacts that can go places that traditional switches can't.

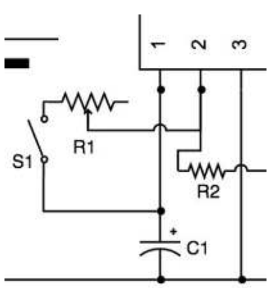


Figure 2.5

To create a kind of momentary pushbutton, put some netting fabric or a piece of foam with a hole(s) cut from it in between the two contacts and pin it together. The pins are conductive so do not pin through the contacts, that will create a short. The netting creates a space between them. When pressed, the contacts touch between the holes which closes the switch.

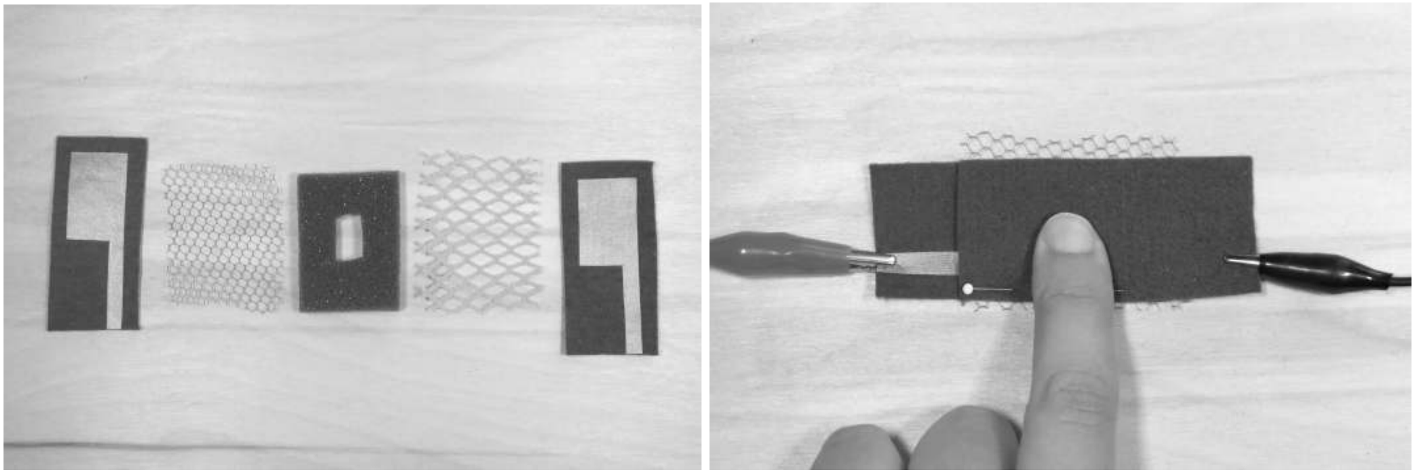


Figure 2.6a - Left to right: switch contact with lead, netting, foam, thicker netting, another contact with lead, 2.6b - Pressing a soft switch with netting in between

After you are done experimenting let's move all five contacts to the hand. Fit the strips onto each fingertip, and pin the ends into place.

Figure 2.7

Pinning is a temporary and potentially uncomfortable solution. To secure each ring use a common sewing stitch called the running stitch.

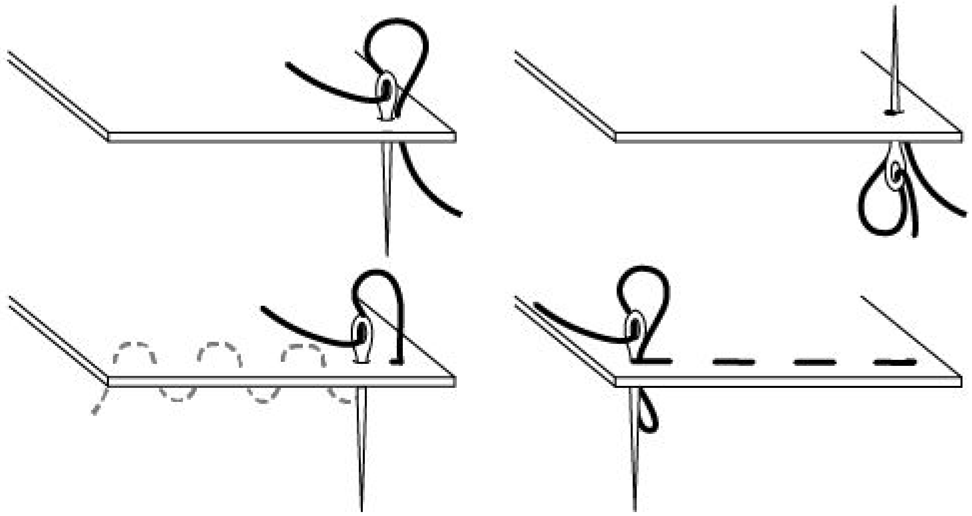


Figure 2.8 - Illustration of the running stitch and securing the thread

Push a threaded needle through the fabric and then back through at about the same spot making a tiny stitch. Go back and forth to make at least two tiny stitches to prevent the thread from being pulled out. This eliminates the need for a knot which will keep things less bulky. This becomes especially helpful when sewing with conductive thread. Make a few stitches until you get to the end and secure the thread as you did in the beginning. Cut off the hanging tails. Do this for all five felt rings.

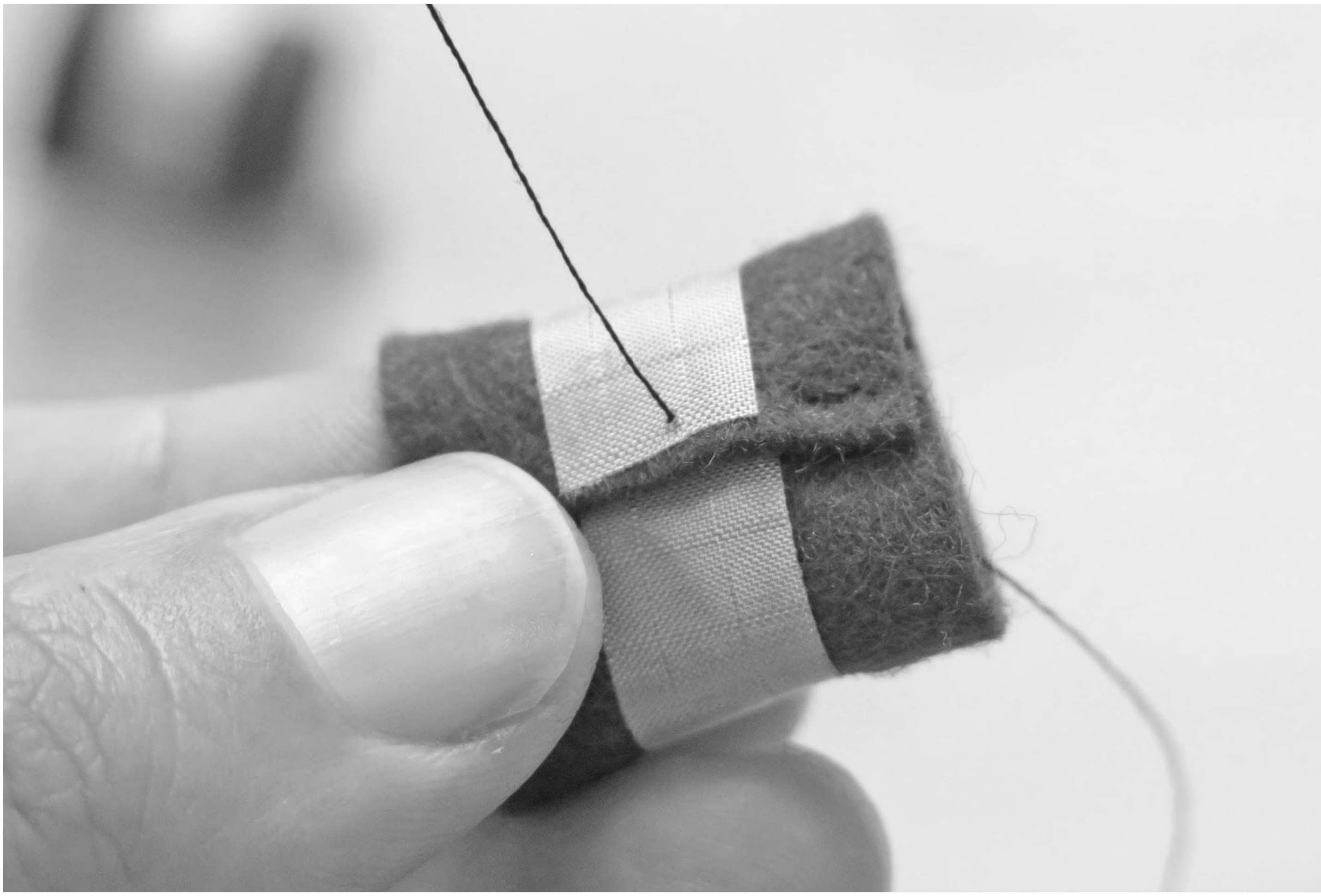


Figure 2.9 - Sewing a felt ring closed

Fabric to breadboard connections

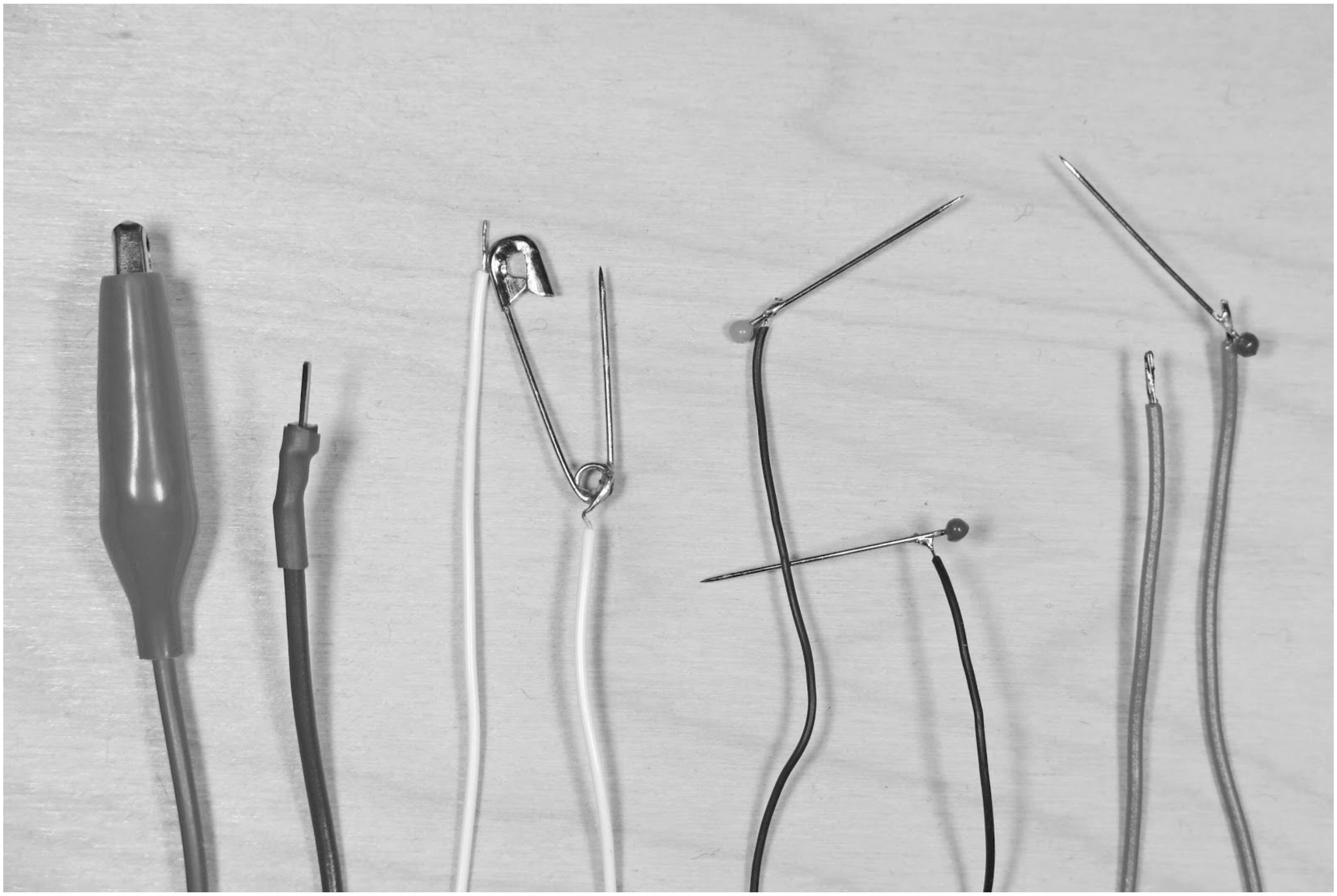


Figure 2.10 - Connectors

Alligator leads become bulky and can get easily pulled off. Straight pins soldered to stranded wire make a good connector between a breadboard and a soft switch while experimenting. Use silicone coated stranded wire when possible, it is heat resistant and very flexible, making it great for e-textiles. To connect your five contacts to the breadboarded circuit, cut five pieces of wire about 8” long and solder a straight pin to the end. Stranded wire is more flexible than solid but it can be difficult to plug in and can slip out. To help these two issues, tin the stripped ends to stiffen them or solder on a male header. Once done, pin one end to a contact and plug the other into the breadboard.

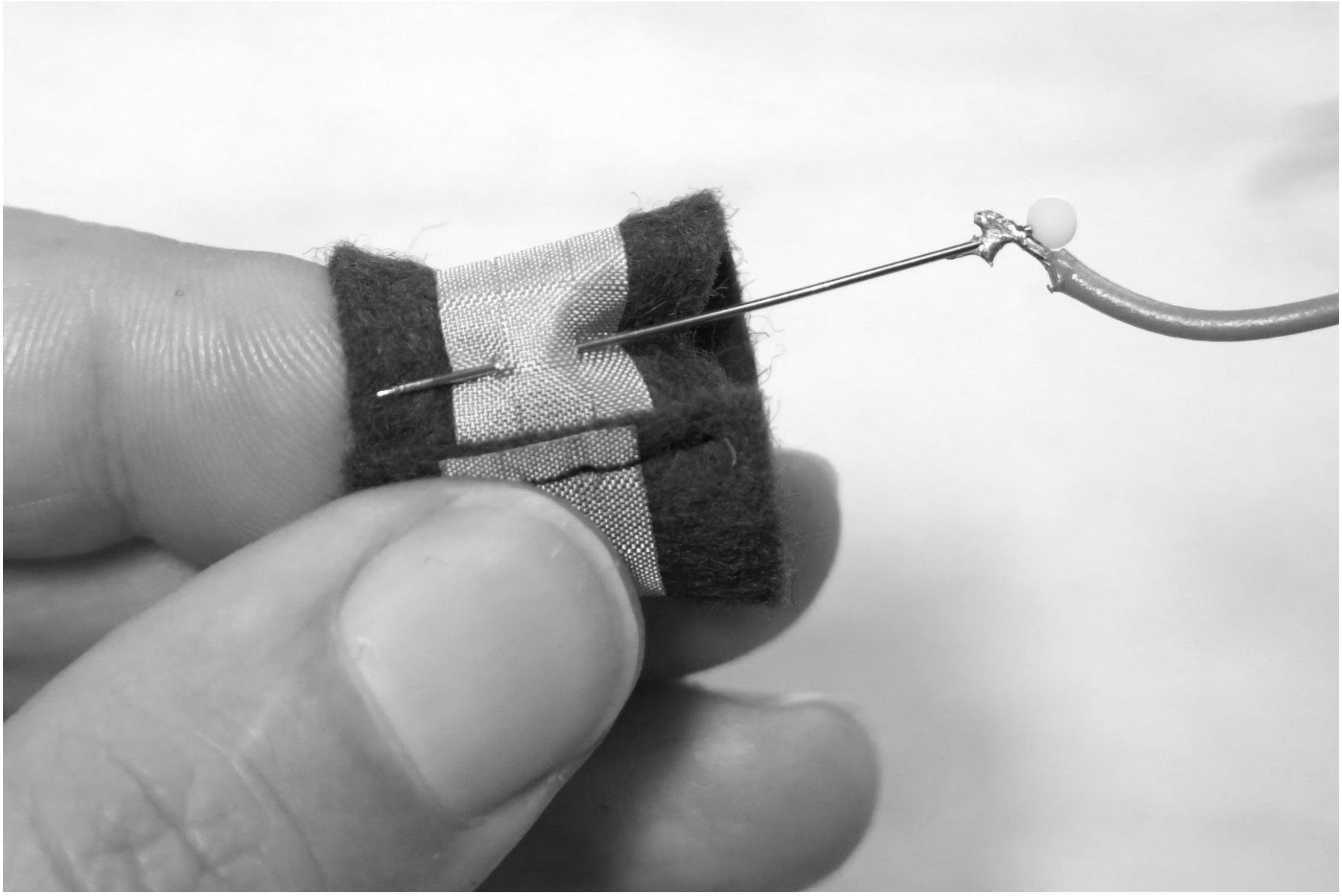


Figure 2.11 - Pin connected to a contact

For the four fingers, plug one between R3 and R4, R4 and R5, R5 and R6, and the fourth at the end to R6. The fifth thumb contact gets connected to pin 6 and acts as the other side for all four switches, S2, S3, S4, and S5.

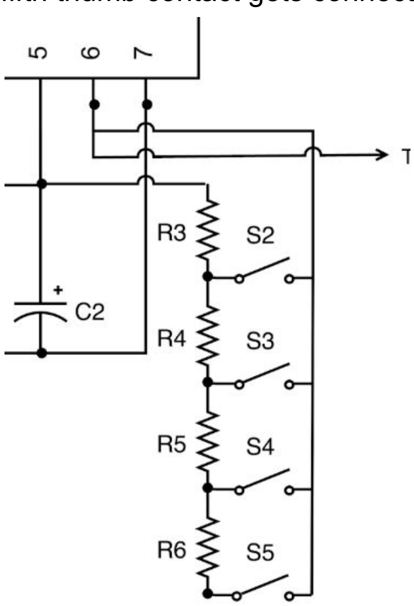


Figure 2.12

Make the breadboard wearable

Materials

- Double-sided Velcro
- Hot glue gun and glue sticks

Hook & loop is handy for quickly attaching sensors and circuits to the body. With double-sided hook & loop you can put the breadboarded circuit onto your wrist. Size some hook and loop to your wrist with the hook facing out. Hot glue a piece of loop to the bottom of your breadboard and stick it to the wrist strap. You now have a wearable prototyping platform.

Use hot glue or hook and loop to secure the jack, battery, and pot if it's on wires, to the strap. Wrap the breadboard around your wrist and slip the rings onto your fingertips. Touch each finger with your thumb to play different frequencies. If no sounds comes when S5 or S4 are closed turn R2 to a higher resistance.

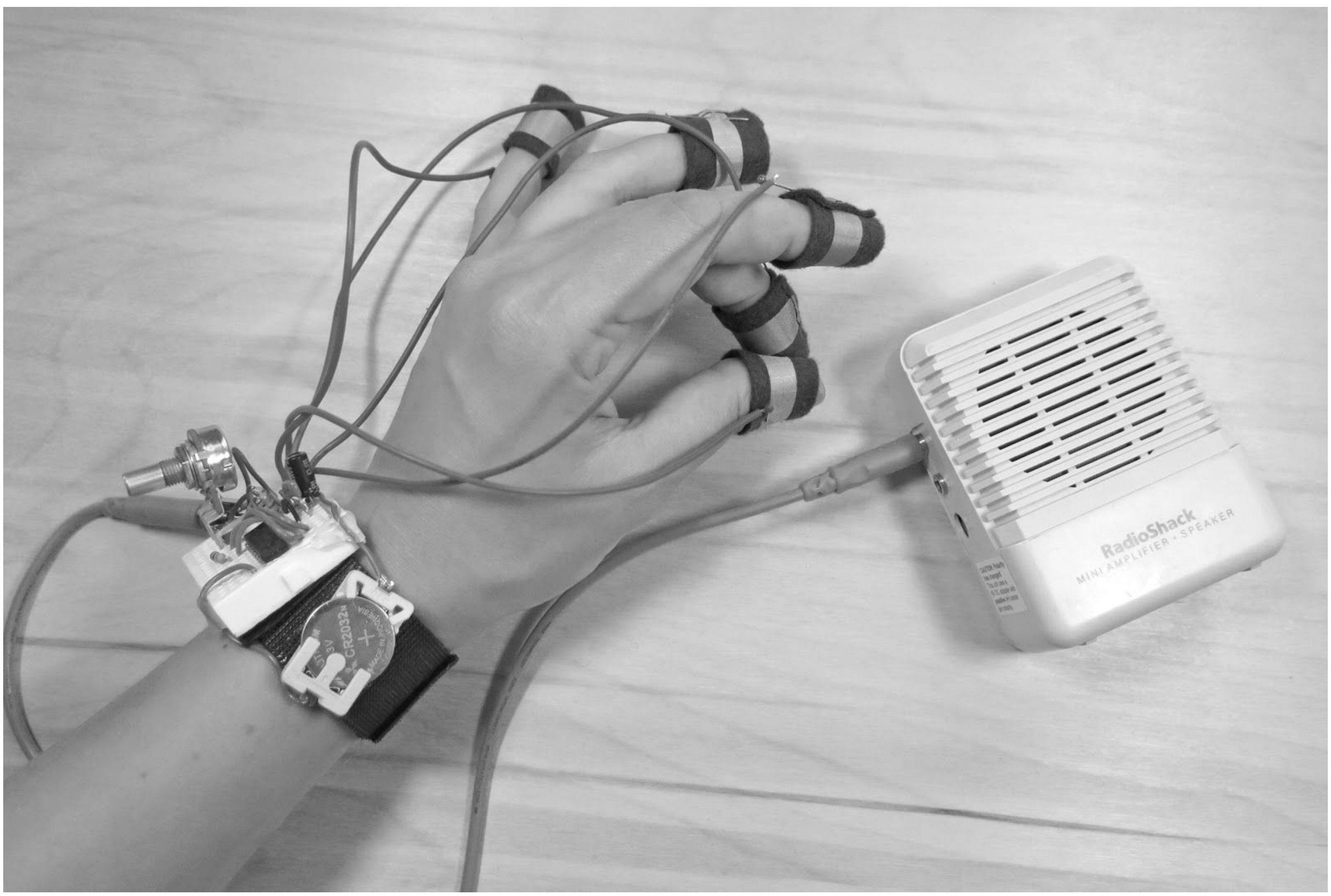


Figure 2.13 - Playing a note

Playing single notes can be fun but things become a lot more interesting once sensors are added to the mix. Let's learn how to put a handmade FSR onto the finger to modulate frequencies with the bend of a finger.

/////////////////SIDE BAR////////////Creating the Tools for the Practice/////////////////SIDE BAR////////////

Make a wearable force sensor

Materials

- Velostat
- Sheet of 100% sheep's wool felt
- Jersey knit (t-shirt material)
- Fabric pen
- Iron-on conductive fabric
- Sewing needle
- Thread
- Iron
- Scissors
- Multimeter

We are going to make a force sensing resistor (FSR) using a plastic called Velostat. Velostat is a carbon impregnated polymer that is electrically conductive. When force is applied, its resistance to electrical current goes down. There are fabrics that do this however, as of writing this chapter they are unavailable to the general public. Velostat can be cut it into any shape to create custom resistive sensors. The final resistance of a piece of Velostat is dependent on its width and length.

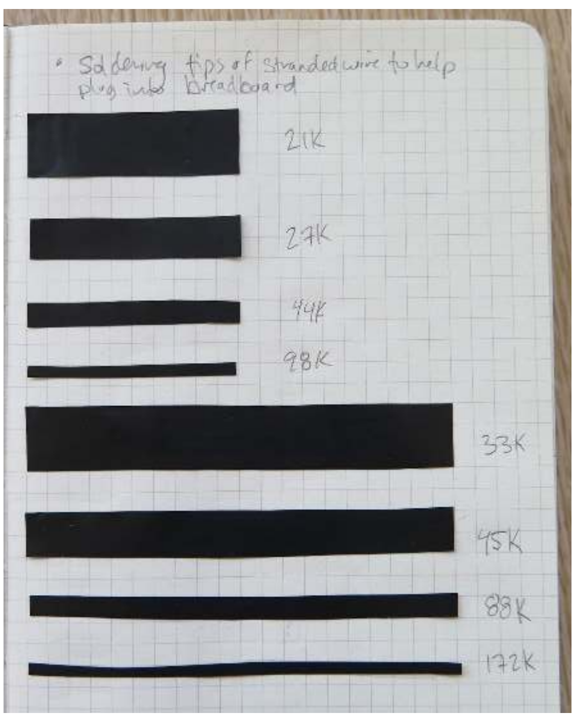


Figure 2.14 - Comparing of resistance values of different lengths and widths of cut Velostat

When a handmade FSR is placed on an elbow or a finger the force of the bend changes the resistance making it a type of bend sensor. To get a decent reading the sensor needs to be held in place up against the bend it is sensing. This can be done by sewing it to a glove, shirt, or handmade accessory. We are going to sew a small finger sleeve to sew our sensor to.

To make a finger-sized bend sensor and a sleeve to hold it to your finger, cut the following:

- 1 strip of Velostat 3/8” x 2 1/2”
- 2 L shaped pieces of conductive fabric 1/4” wide x 2 1/4” long
- 2 strips of felt 3/4” wide and 3” long
- Small square of jersey knit

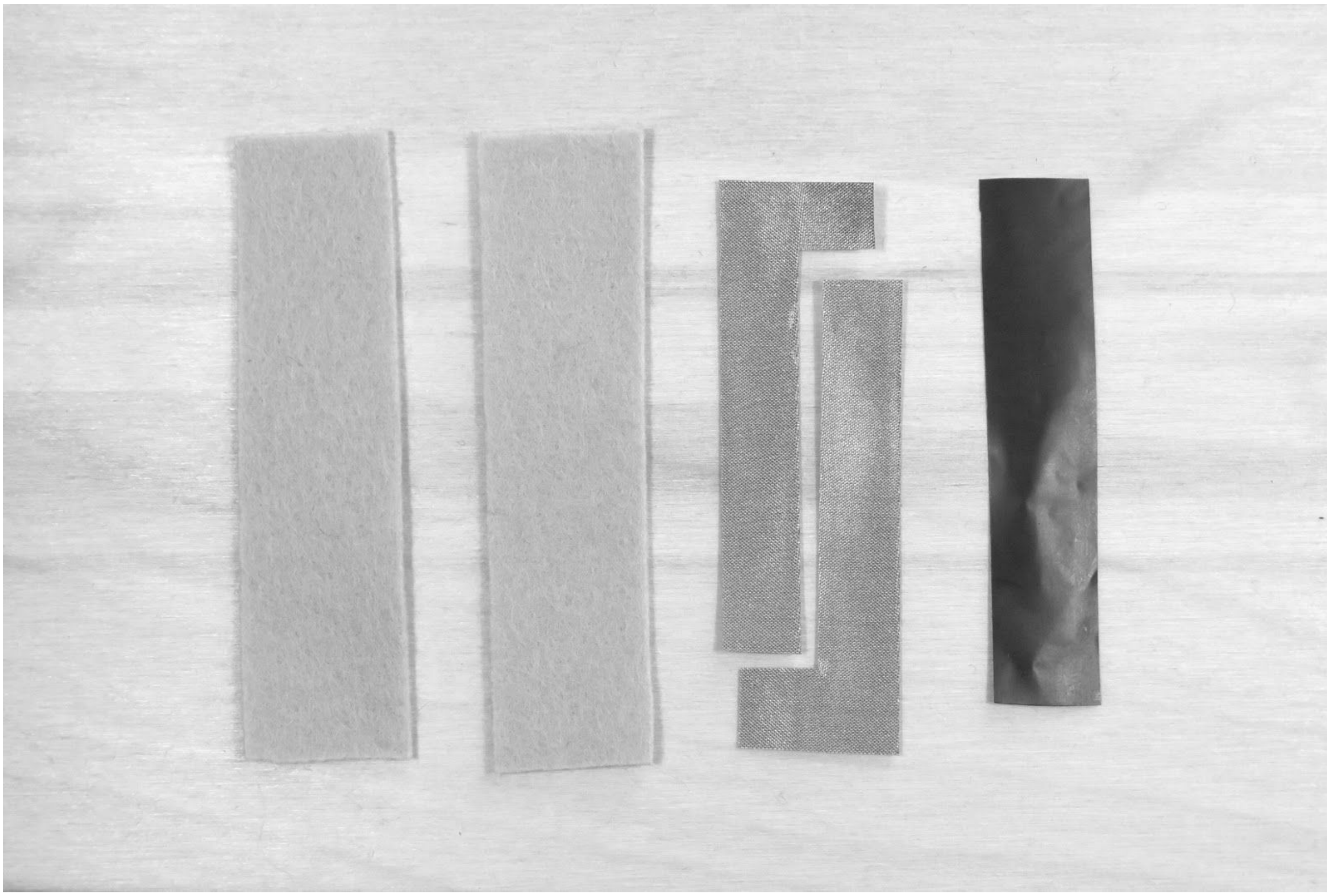


Figure 2.15 - Felt, conductive fabric, and Velostat

Iron down the contacts and cover one with the Velostat. Sew it down with a couple of stitches at both ends to hold in place.

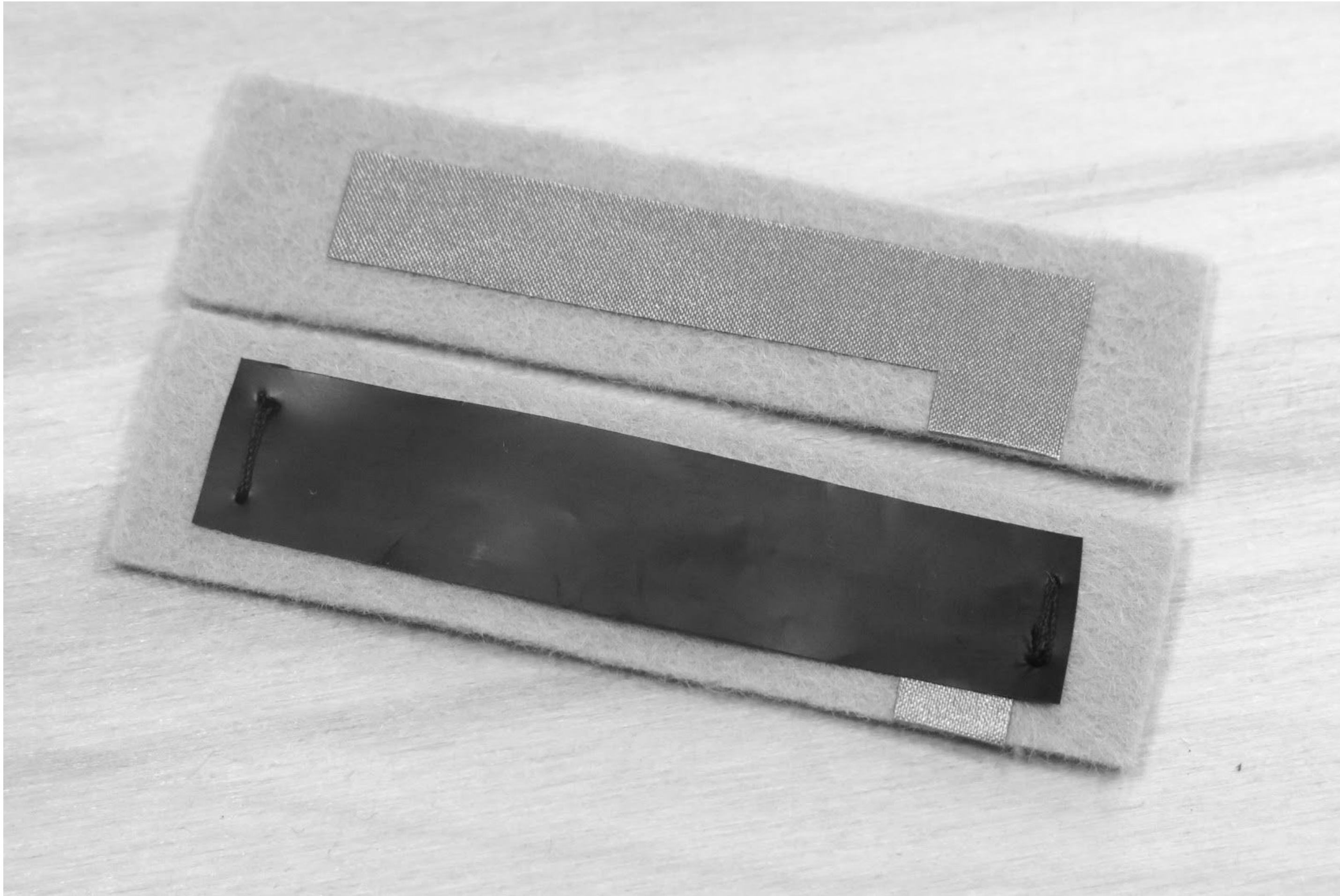
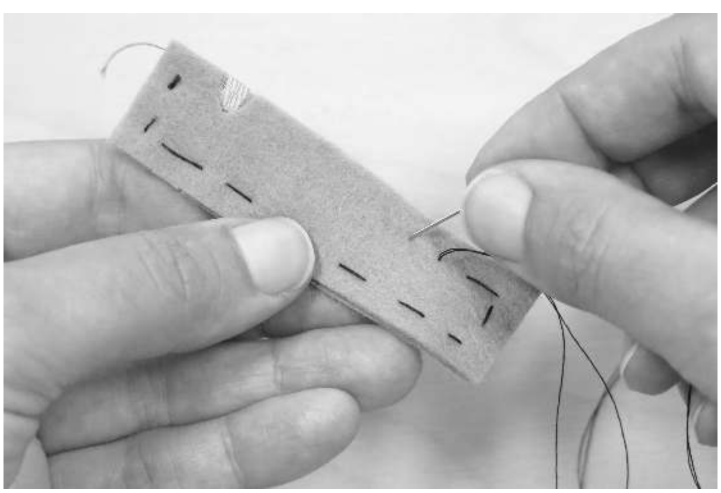


Figure 2.16 - Velostat stitched over one contact

Pin the sensor together and connect it to a multimeter. Press it to watch the resistance go down in relation to the force applied. It's important that when stacked, the two contacts do not touch each other creating a short that will bypass the Velostat. This is why the Velostat piece needs to be larger than the contacts and the leads are on opposite sides from each other when closed. If your multimeter displays a 0 or low number the conductive fabric is shorting. Plug the sensor into the resistor ladder circuit where R1 is and listen to the timbre change when pressed or bent. To finish, sew around the edges. Cut a couple of openings to expose the leads if you like.



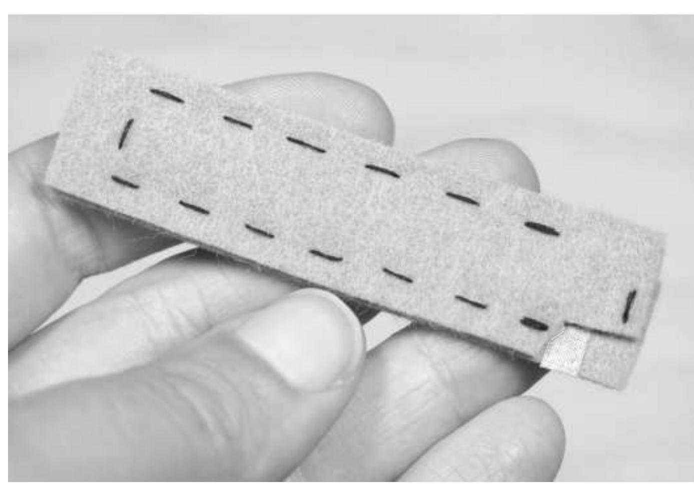


Figure 2.17a - Sewing the sensor closed, 2.17b - Finished sensor

To sew the sleeve, pin the knit fabric around your finger to fit snug over the knuckle. Careful not to make it too tight or the bend sensor will press too much against your finger, reducing the range of resistance you have to play with. Take the sleeve off and mark where the pins are with a fabric pen.

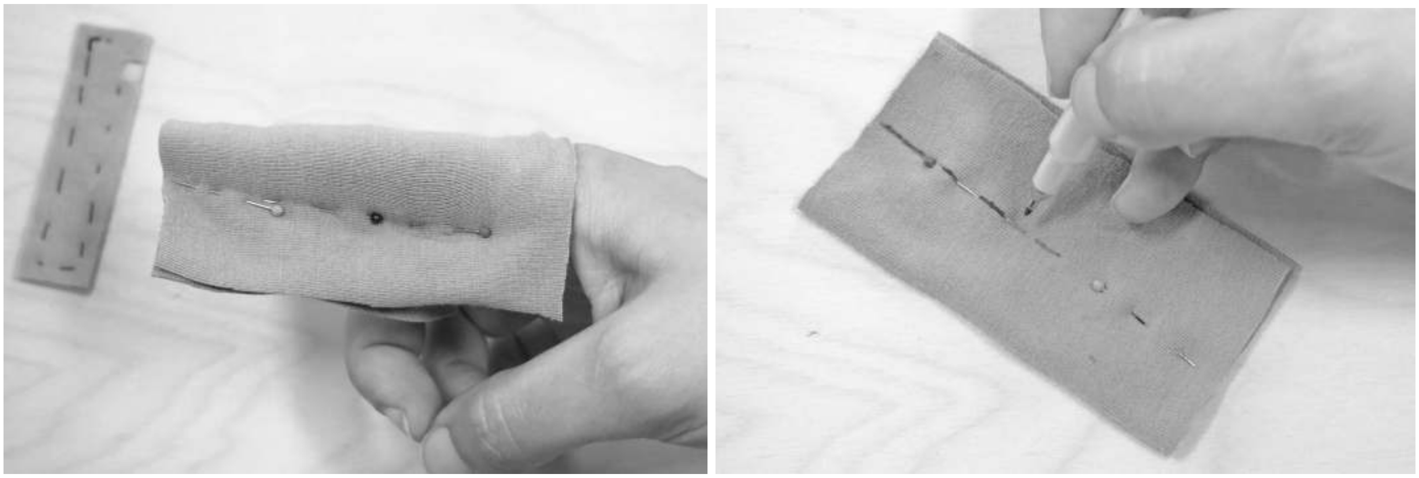


Figure 2.18a - Fitting fabric to finger with pins, 2.18b - Marking fabric

Remove the pins, center the sensor in between the marked lines and sew down.

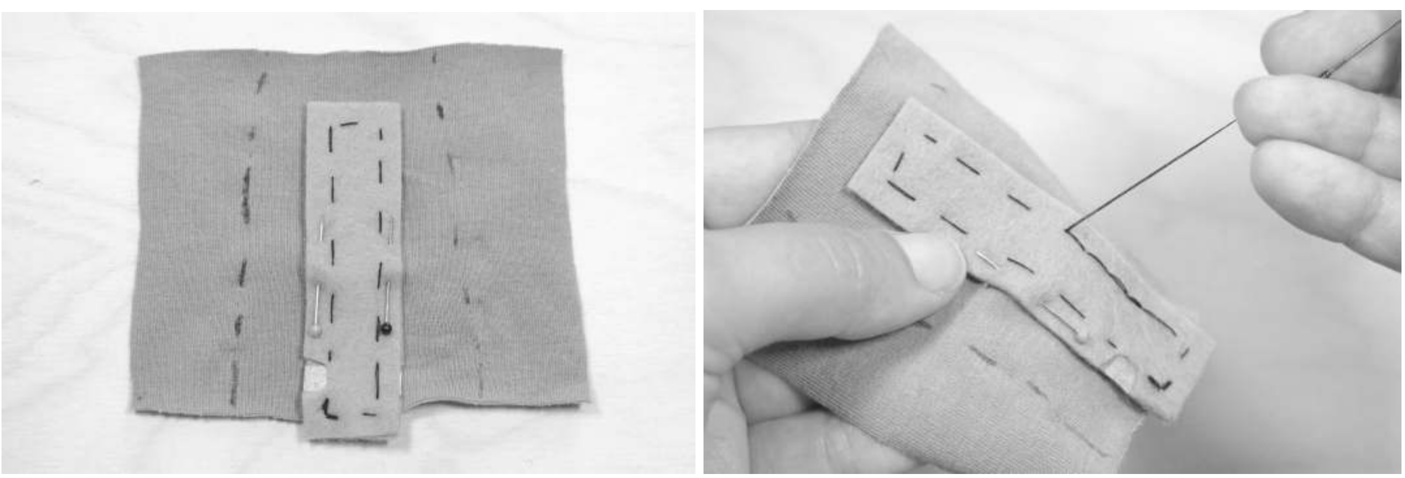


Figure 2.19a - Placing the sensor, 2.19b - Sewing the sensor to the sleeve

Next, sew the two sides together along the markings to create the sleeve. Trim the excess fabric.

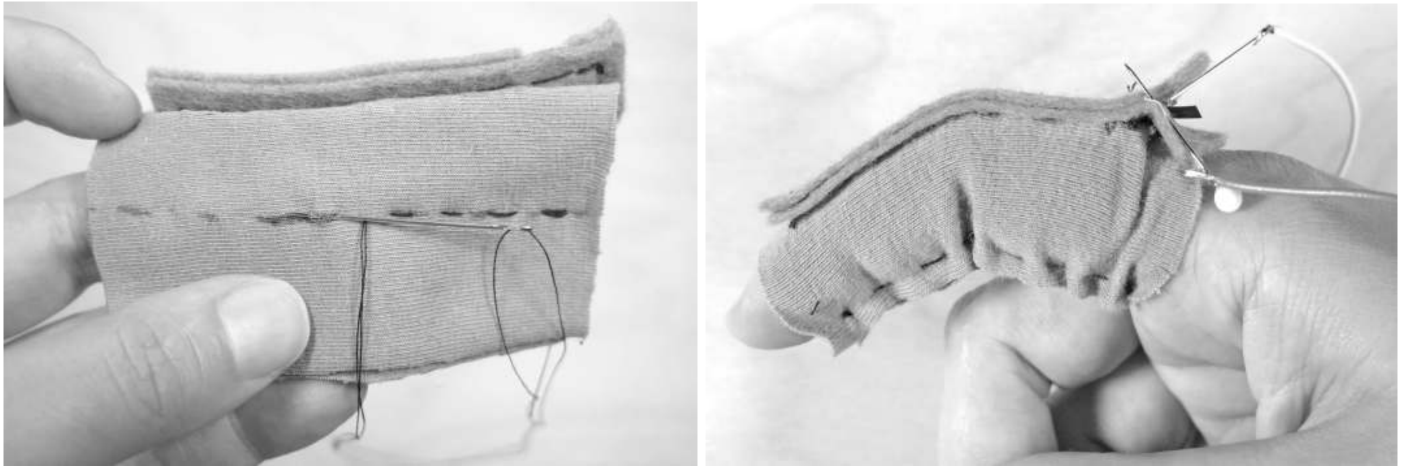


Figure 2.20a - Sewing the sleeve's seam, 2.20b - Finished sleeve with sensor on finger

Solder up two more wire to pin connectors, pin one to each tab and slide it over the finger. Plug it back into the circuit and bend your finger to modulate the second oscillator. Touch each finger tip with your thumb to change the pitch. If you get tired of hearing the sensor all the time, try putting a soft switch in series, using any bare fingertip.

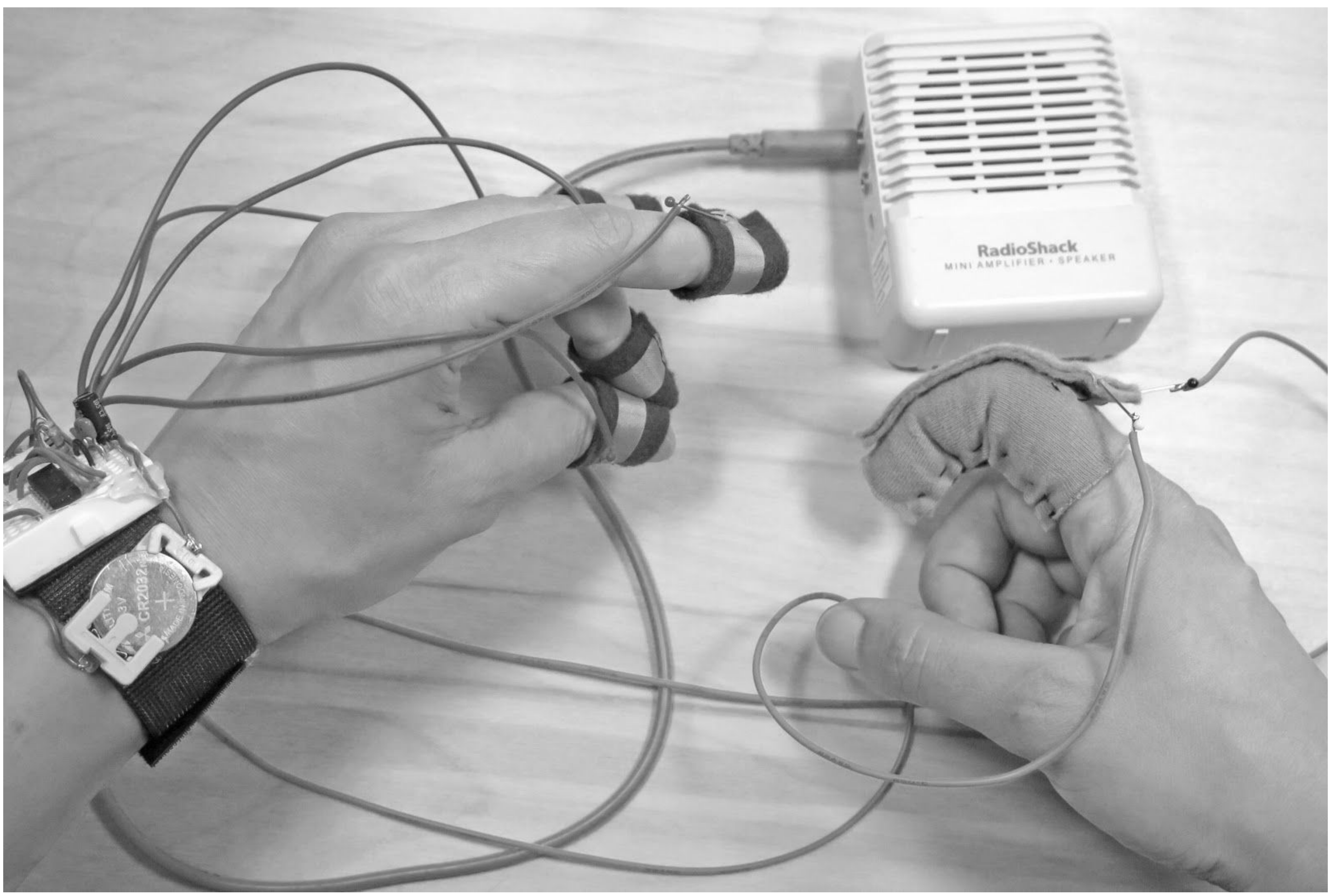


Figure 2.21 - Playing with the sensor

As soon as you start moving, wires may want to wiggle their way out of the breadboard. To reduce the amount of stress and keep them in the breadboard let's add some strain relief. Hot glue all of the hanging wires to the side of the breadboard, giving them a little slack at the breadboard end.

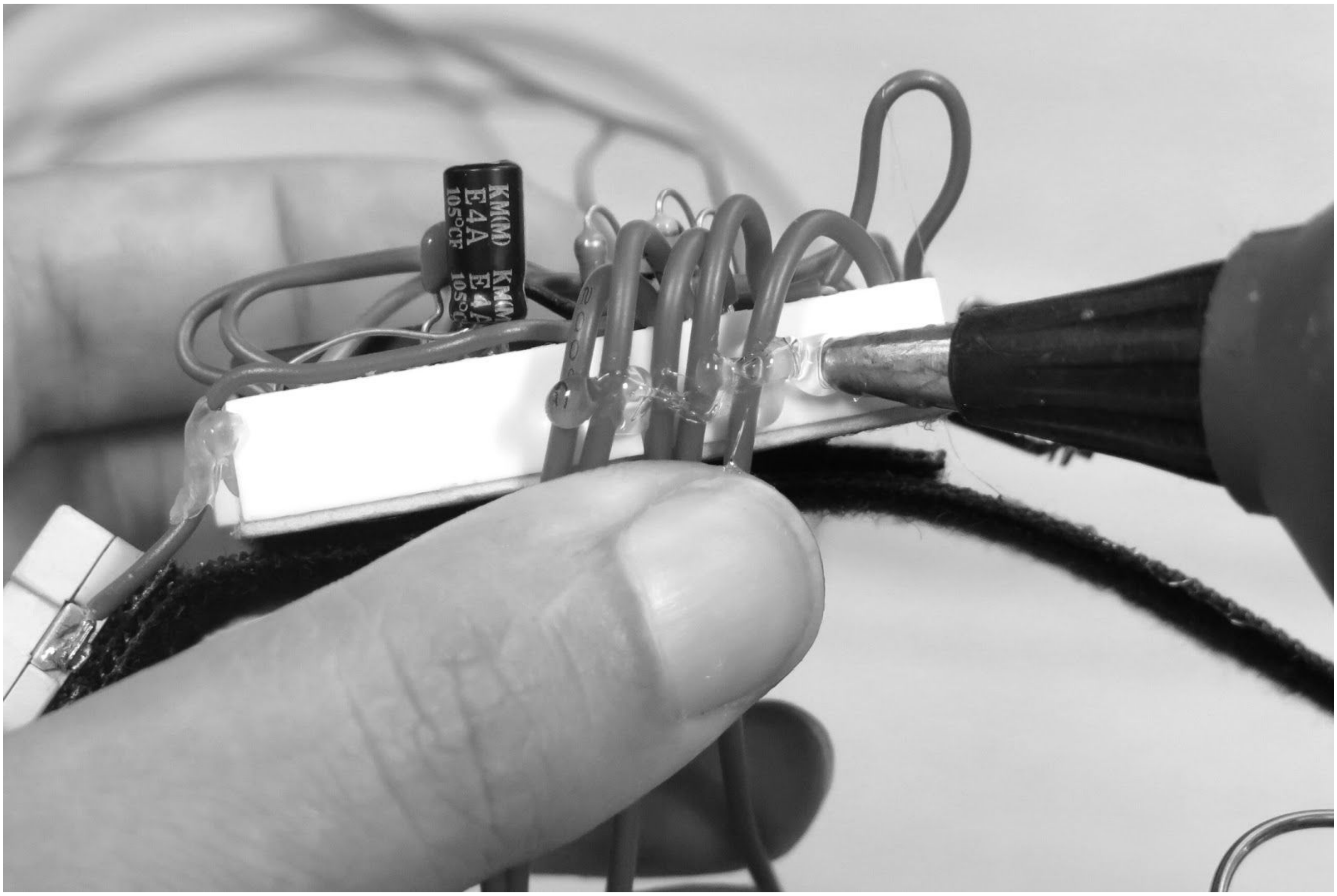


Figure 2.22 - Hot gluing the wires to the breadboard

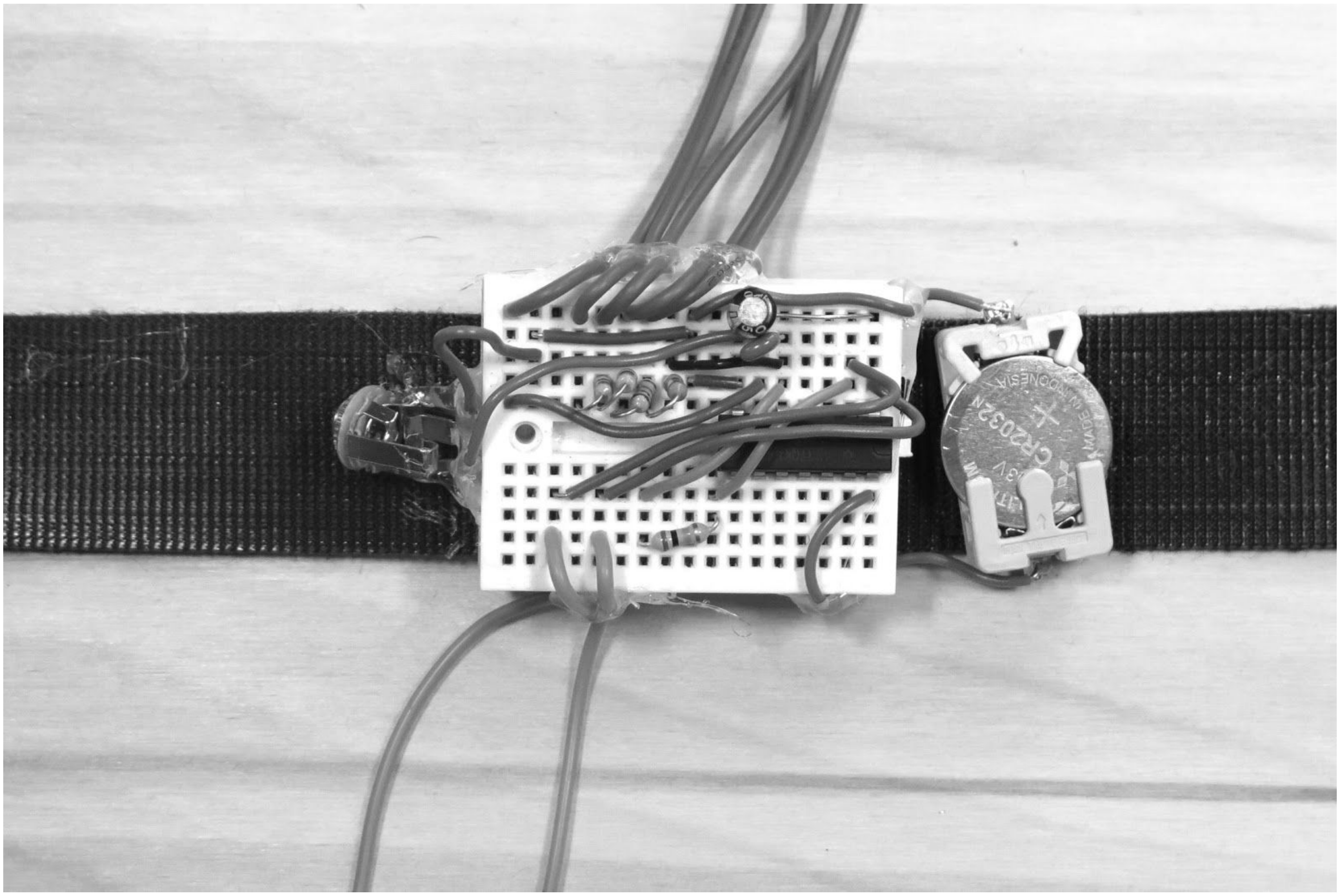


Figure 2.23 - Finished with hot-glued wires

Take the circuit off the breadboard

Components can be transferred and secured to fabric in a few different ways. We will go over a method that emphasizes modularity and make a soft breakout board. We will solder the components to a protoboard and break out the points in the circuit to conductive fabric pads that get connected to soft components. For connections, you can either pin, alligator clip, snap, sew or solder all your soft components together! Yes, this fabric is solderable! Keeping it modular means we can still experiment rather than deciding now on a circuit layout and design.

The protoboard should be two-sided and fashioned after a breadboard, if you can only obtain a one-sided board you will need to use it with the copper traces up and solder from the top. It’s doable but trickier to implement. It will be sewn down using conductive thread and it’s important that the thread makes contact with an exposed metal portion of the trace.

There are five contacts for the resistor ladder switches and two contacts for the bend sensor. This makes seven connections needing to be broken out from the circuit.

To make more room to sew, things have been slightly shifted from the original breadboard layout. Follow the diagram to solder up the circuit to the protoboard to ensure everything will fit nicely the first time. Use low-profile female headers in place of the resistors if you want to be able to swap them out. Start by soldering the IC socket then solder all the components, headers (if using them), and wires.

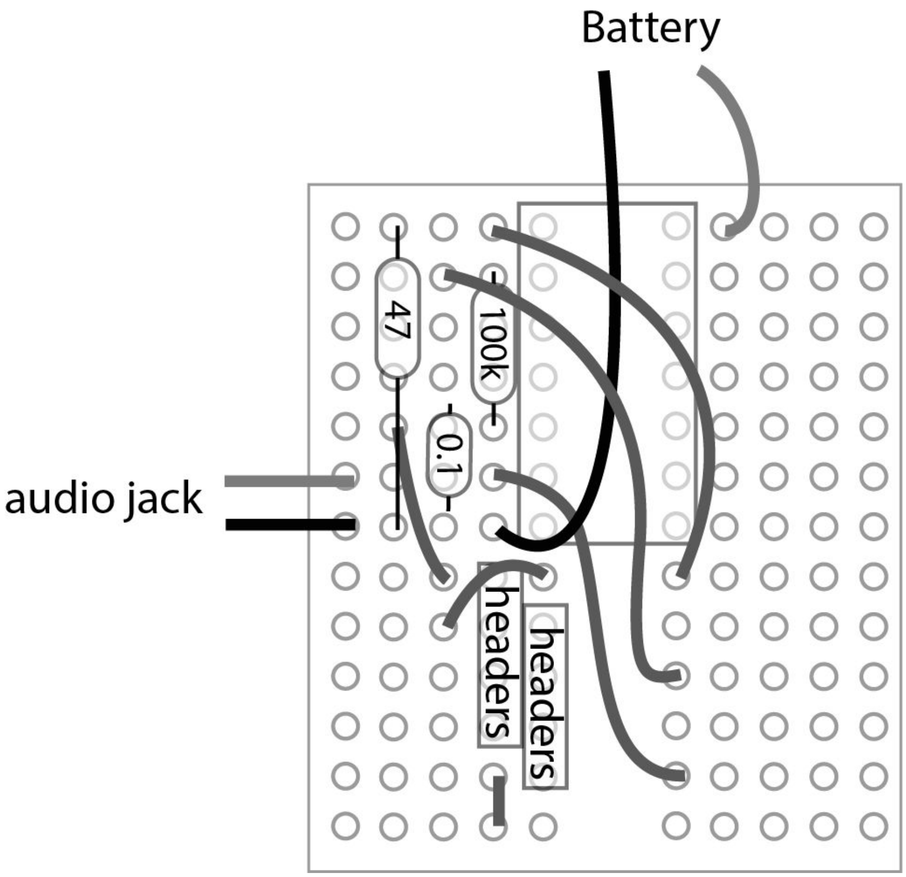


Figure 2.25 - Soldering diagram

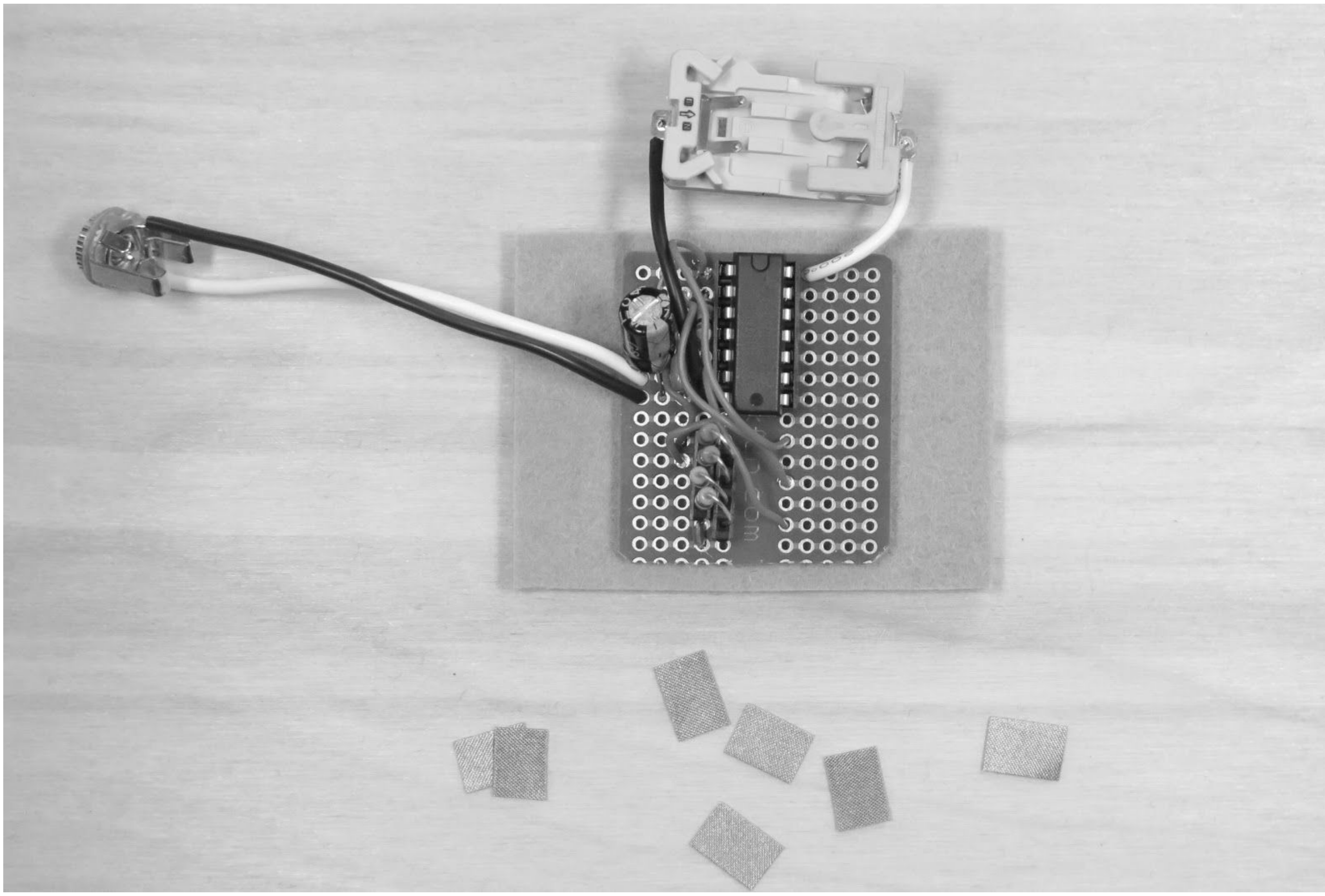


Figure 2.26 - Cut felt and conductive pads with finished protoboard circuit

Cut a piece of felt 2.25” x 1.75” and seven small pieces of conductive fabric for the pads. Iron four down on the side where the resistor ladder is and three on the opposite side where pin 6 leads to and the sensor connections. Using a regular thread stitch through an unused row of the board to help hold it down on.

The conductive thread we are using is stainless steel so it will not corrode and is washable. The resistance is fairly low with a reading of about 14 Ohms per foot. The resistance is in relation to the length which can add up and is important to take into account if you use it for traces in a circuit design. Conductive thread can be tricky to start working with. It’s basically an exposed wire that can fray and shift making it easy to create shorts as well as unreliable connections if you don’t keep things neat and plan ahead.

Here are some tips and rules to follow when working with it:

- Plan and visual traces and connections before you start sewing to ensure you have room so they do not touch. If a trace needs to cross another make a bridge like in figure x.x.
- Make small and tight stitches.
- Use the stitch in one place method instead of making a knot. If you do make a knot, secure it with hot glue or clear nail polish.
- Always cut remaining tails off.
- Stitch at least three times when making a connection.
- Check a connection and trace with a multimeter each time you make one.

To give a visual target mark the rows you will be sewing to. Then draw the connections from one pad to the row it needs to connect with making sure each row to pad connection are as far from each other as possible.

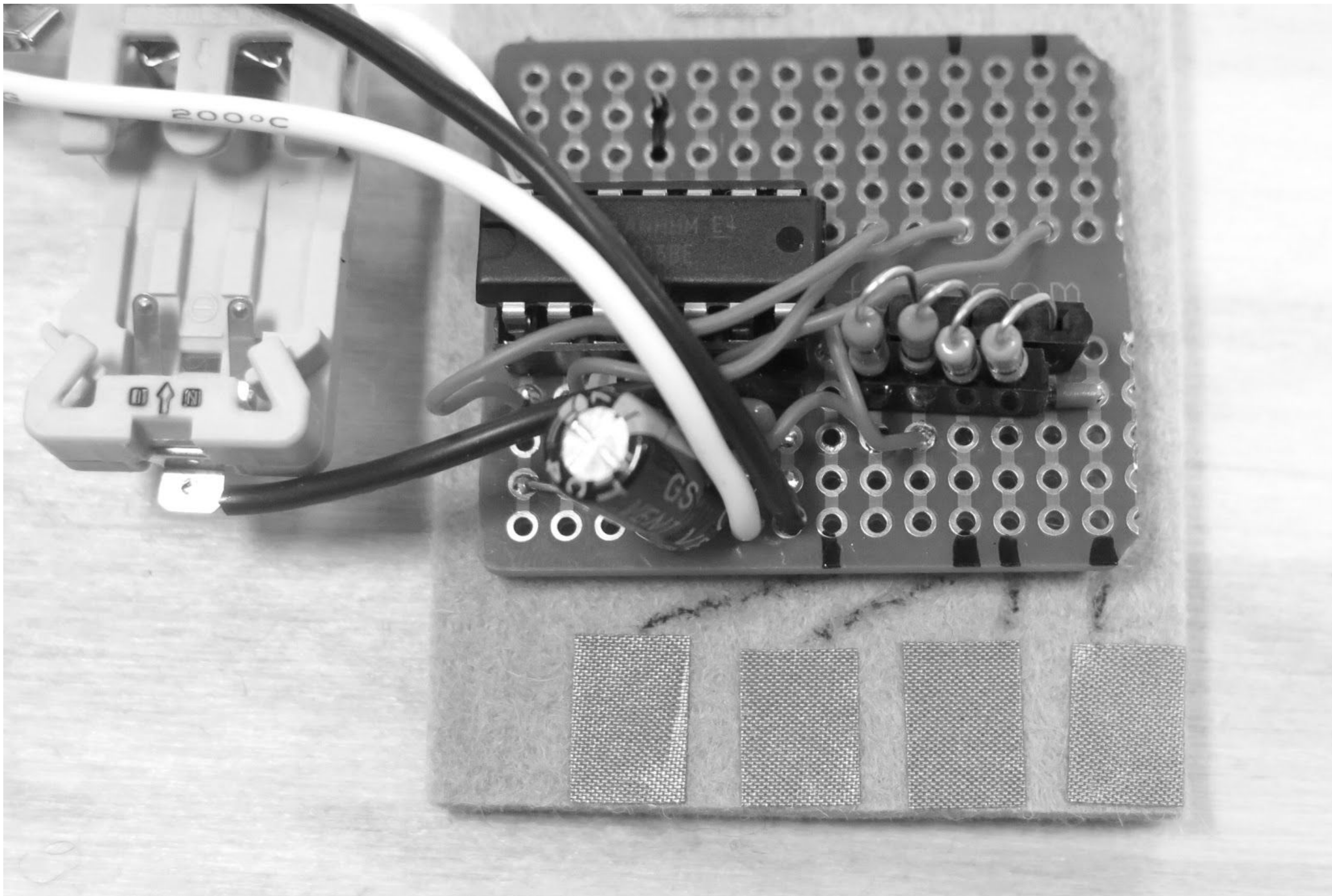


Figure 2.27 - Marked board and felt

Using conductive thread, stitch to one pad and remember the rule of making at least three stitches! Afterward, slide the needle under the surface of the felt to bury the thread, protecting it, and bring the needle up next to the marked row. Stitch through the hole on the protoboard, ideally making a stitch in the one above also to ensure a good electrical connection.

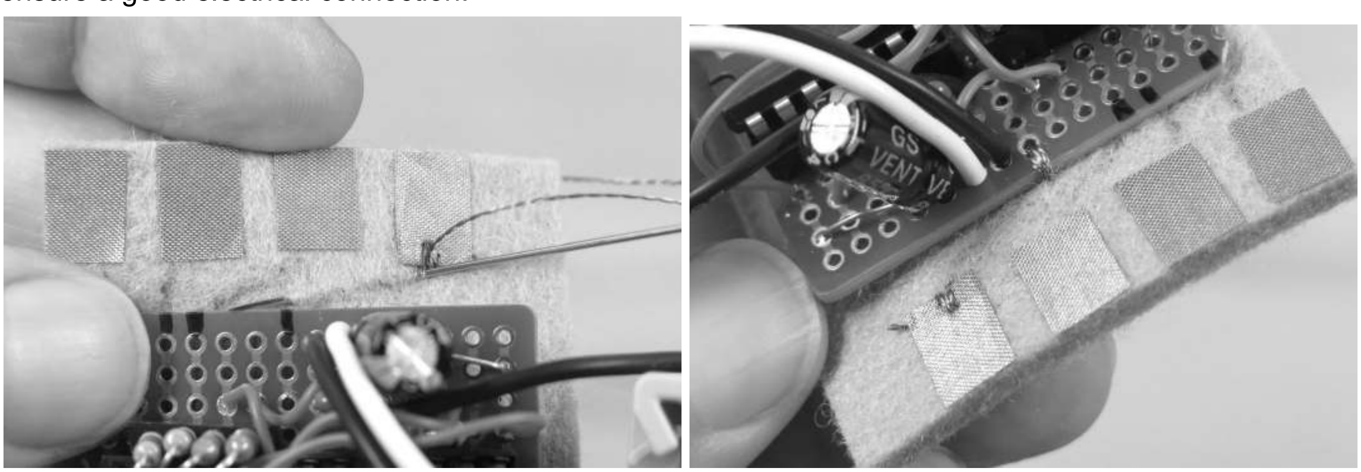


Figure 2.28a - Conductive thread stitches on conductive fabric pad, 2.28b - Conductive thread stitches going through protoboard hole

Once finished, cut your two tails and check the connection with the multimeter before moving on. Do this for the remaining six pads.

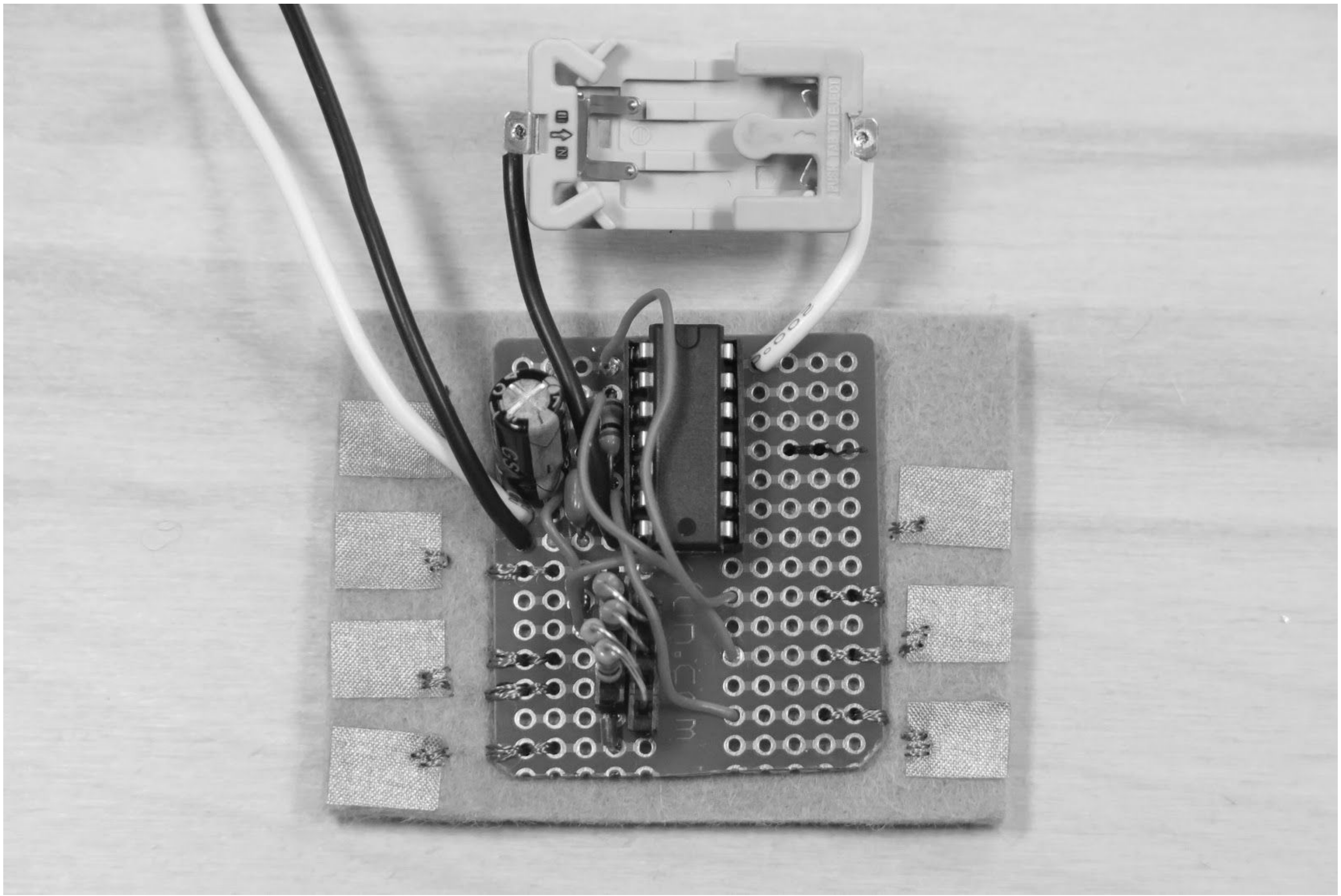


Figure 2.29 - Finished soft breakout board

To test, clip a sensor to pad 6 and 7 and an alligator lead to any of pins 1-4. Power it up and plug it in. Press the sensor and touch the lead to pin 6. You should hear a pitch change and a note played. If not, check your connections. Use the fabric pads as electrodes, instead of the sensor bridge 6 and 7 with one finger to put yourself in the circuit. Since they are already exposed, soft circuits are excellent for laying your hands on.

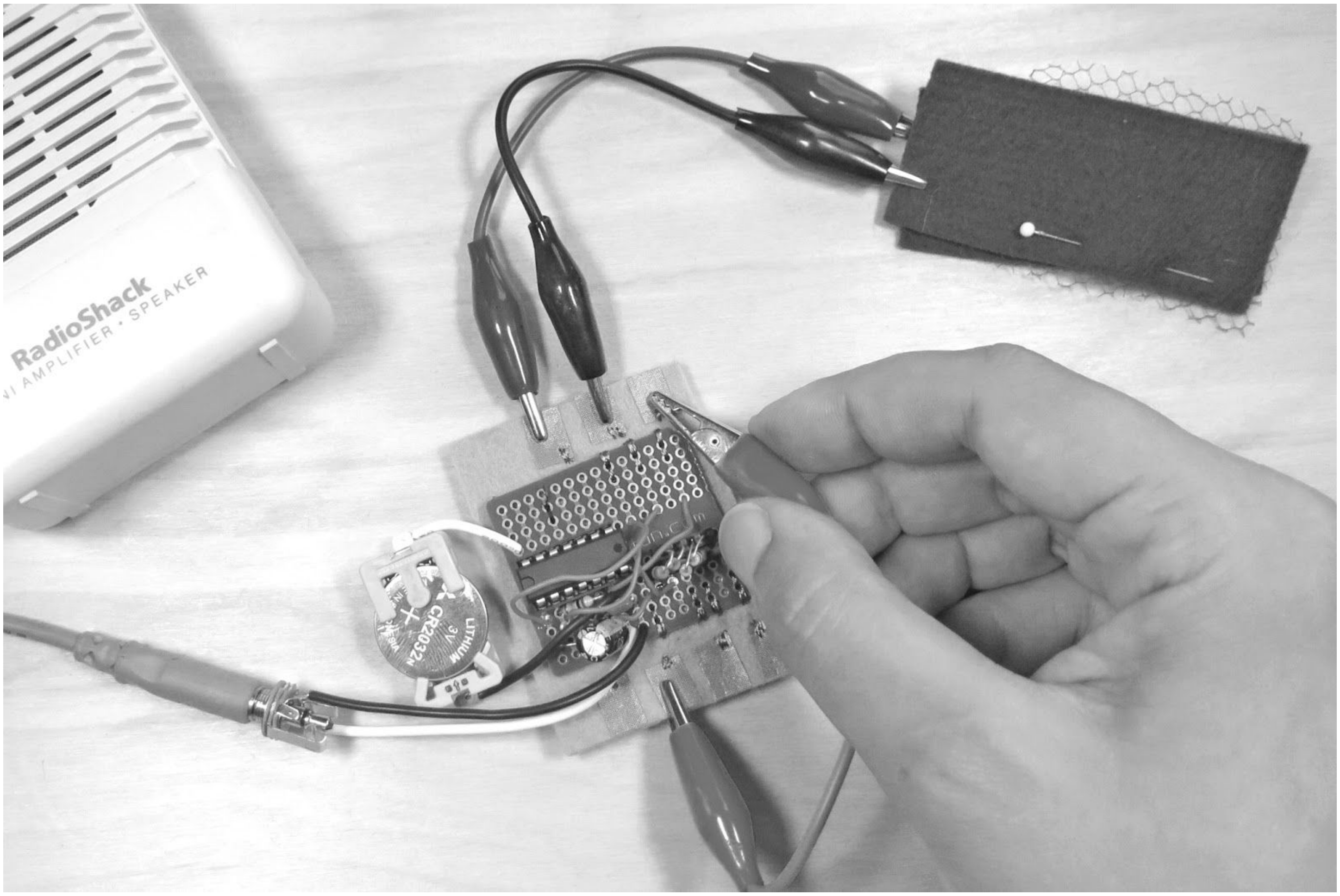


Figure 2.30 - Testing resistor ladder switches

Fiber to Fiber Connections

From here, use all the components you have made and start connecting and playing around. Put soft contacts between two hands, or in between pleated fabric. Try different configurations using alligator leads and pin connections. To keep it wearable, cut a hand-sized square piece of felt with a wrist strap to mount the soft board to. Or, lay the components onto another piece of felt and create a soft interactive surface that folds, squishes, and stretches. Once you are ready to commit to a circuit layout you can sew, solder or snap everything together using conductive thread, fabric, or wire.

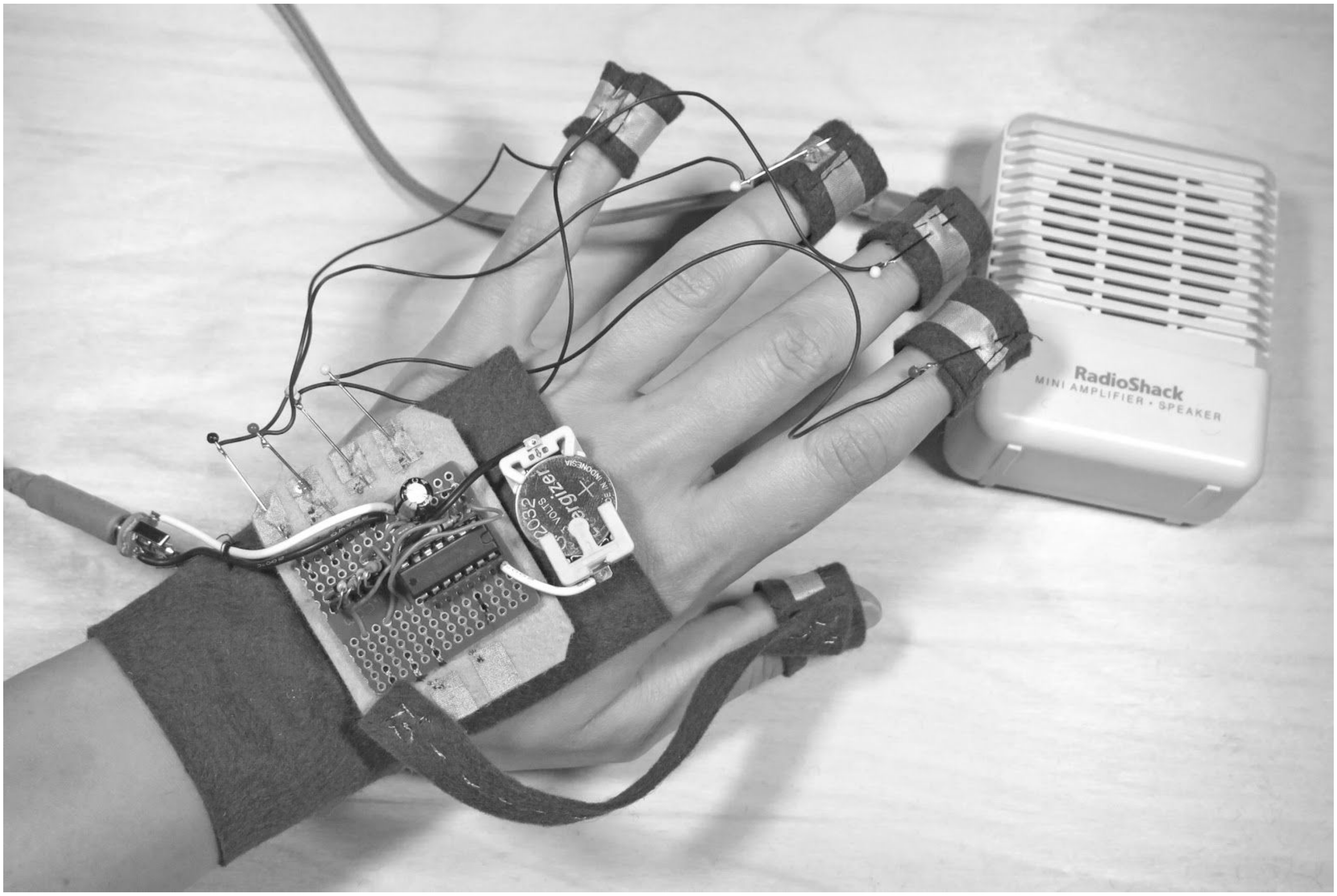


Figure 2.31 - Soft breakout board made wearable with pinned and snap connections

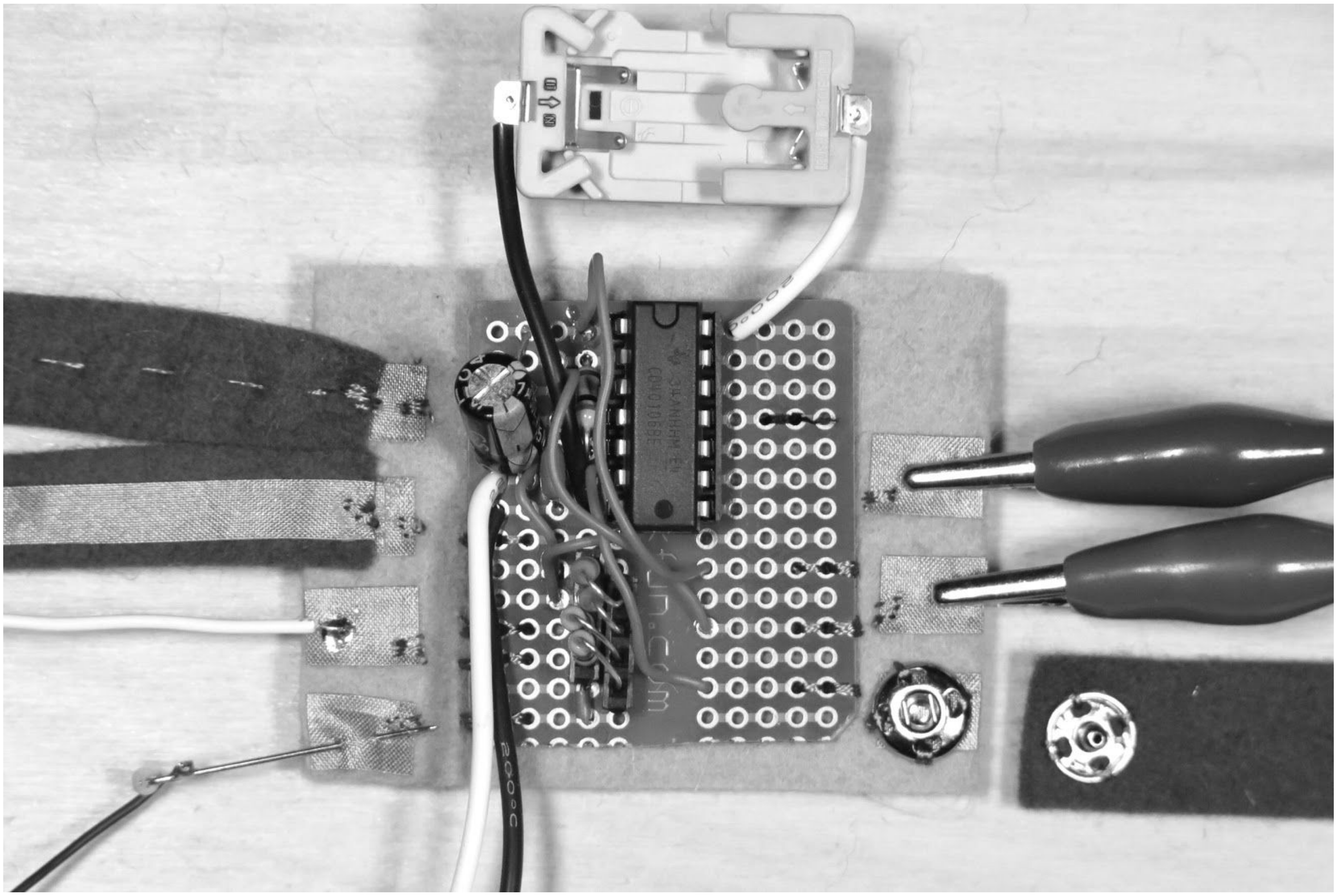


Figure 2.32 - From upper left going counterclockwise: Conductive thread trace with sewn connection, fabric trace with sewn connection, soldered wire, pin connection, sewn snap, alligator clips

Snaps
Snaps are a very popular connector in e-textiles. Sew them to conductive fabric using conductive thread. They make great switches too!

Stitches
Use conductive fabric or a running stitch of conductive thread to create a traces then stitch that to conductive fabric.

Solder
Soldering is achievable on some conductive fabric like the one we use in this chapter. However, the connections are delicate and you will need strain relief. Using hot glue over a connection to help stabilize the joint so it doesn't break off.

Pins
Solder a pin to the other end of your fabric to breadboard wires so both ends can pin into conductive fabric to make a connection.