

NOTE: This project does not include a complete parts list. In particular, the IC described here does not come in a dual-inline-package (DIP), and so a gull-wing package has to be soldered to an adaptor by an outside vendor. If you wish to pursue this project, please contact Prof. Anderson at Anderson@ece.osu.edu for more information.

Capacitive Touch Sensor Project:

A Handbook for Teachers

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1. Executive Summary

There has been a decrease in the United States in the number of students entering STEM (Science, Technology, Engineering, and Mathematics) fields. This document lays out the plans and goals for a capacitive touch sensing project for high school students with the goal of increasing interest in engineering among these students. Capacitive touch sensing is the form of touch sensing used on iPods, iPhones, and some other types of touch screens. The students will build a capacitive touch sensing circuit as well as touchpads out of different materials while learning about how the circuit uses capacitance to operate. Information is provided on some basic concepts of electricity and some of its components including voltage sources, resistors, and capacitors. This information will give the students some understanding of how capacitance is used by the circuit they build in order to perform touch sensing.

In addition to providing useful information for teaching students about the concepts used in the circuit they build, information about the actual building process is covered. The students will be building their circuit on a breadboard so this includes what a breadboard is and how it works. The main point covered is that a breadboard is used to interconnect electrical components for the purpose of building circuits. Different locations on the board are either electrically connected or disconnected which provides us an easy way to arrange the components depending on how we want them connected.

The circuit the students build will be using a touch sensing IC (integrated circuit). This IC is what actually performs the touch sensing when combined with a touchpad and other electrical components. The IC has 20 different pins or connection locations and this document contains information about what these pins do.

For the purpose of the actual building of the circuit a picture schematic is used. This isn't the standard type of schematic you would find because instead of symbols that may not be understood by everybody, actual picture representations of the components are laid out on a picture of the breadboard. This will provide both the students and the teachers an easy reference for building the circuit.

A troubleshooting section is included which provides some common problems that may be encountered with possible solutions to those problems. Many of these problems can be solved by swapping out components that may be bad and rechecking the circuit to make sure everything is connected correctly.

Upon completion of the project it is hoped that the students will have a new appreciation for the benefits of engineering and as a result will consider entering a field they otherwise would not have considered.

2. Basic Electricity Concepts

The basic principles of electricity can be described through a series of analogies related to water. For the purposes of this project the design requires the use of a voltage source, resistors, capacitors, and a touch sensing IC. Our voltage supply for this design will be a battery, which is analogous to a water pump. Similar to a pump doing work to take in water at low pressure and ejecting it at high pressure a battery takes in charge at a low voltage and ejects it at high voltage. Current in an electrical circuit is analogous to the rate of flow of water through pipes. Since voltage is like water pressure we can say increasing the voltage in a circuit will increase the current just like increasing the water pressure will increase the water flow rate. A resistor in an electrical circuit is analogous to constriction in the water pipe. This constriction will have more

resistance to water flow than the other areas of the pipe similar to how a resistor will have more resistance to current than the wire in the circuit. A capacitor is like a storage tank for water with a hole in it. The tank can take in water at any rate and then hold and expel it at a certain rate. This is similar to how a capacitor works in an electrical circuit. The capacitor holds charge and can then discharge at a certain rate to the rest of the circuit. These are the components and concepts that will be covered in this project.

3. Capacitive Touch Sensing

Using the properties of capacitors, touch can be used as an extremely effective method of input and control. The two main uses for capacitive touch sensors in commercial products today are a simple switch and multi-touch input, such as a tablet PC or an iPhone. What allows the human body to be sensed are the conductive electrolytes that it contains, which allows charge to be held and transferred.

A parallel-plate capacitor consists of two conductive layers of material with an insulating material called the dielectric in between them. Figure 2.1 shows the parallel plate capacitor formed by a finger and the copper traces of the sensing pad, with the glass overlay as the insulating dielectric [1]. Charge exists in the finger as conductive electrolytes and in the copper traces from a constant current being applied to it. The net difference in charge between the finger and the copper traces is what creates capacitance. The detection of this capacitance is the main operating principle in capacitive touch sensing.

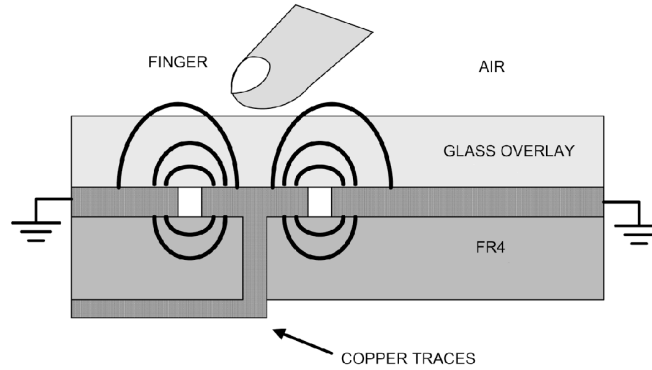


Figure 2.1: The parallel plate capacitor formed by finger and traces [1]

Figure 2.2 shows the three capacitances that are monitored by the detection circuit. C_1 represents the capacitance between the detection circuit and a baseline voltage referred to as the ground [2]. C_2 represents the capacitance between the person and the ground; C_3 represents the capacitance between the person and the detection electrode. While C_1 and C_2 are on the order of 100-300 pico-Farads (1×10^{-12} Farads), C_3 is only a few pico-Farads, making a change in C_3 difficult to detect. To overcome this, the detection circuit monitors C_x , which is defined in the following equation.

$$\frac{1}{C_x} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Using this equation, a small change in C_3 would result in a large change in C_x , therefore making it possible to detect when a capacitance exists between a person's finger and the detection electrode. Referring back to the water analogy for a capacitor as a water tank, we realize now that the capacitor is the ideal component in this type of sensing because of its ability to receive and discharge charge quickly, which allows for immediate response from the circuit.

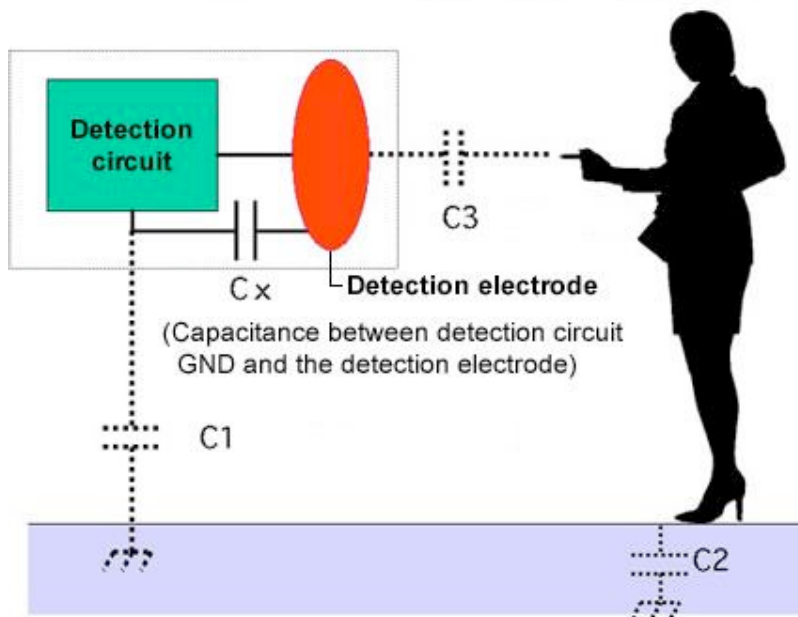


Figure 2.2: Capacitances measured by the detection circuit [2]

4. Using a Breadboard

A breadboard is a platform used to build and test electronic circuits and is a good starting point for any circuit design. The breadboard is easily reusable as there is no need for soldering any of the circuit components, meaning that none of the connections are permanent. Because of this, any necessary or desired modifications to the circuit you are working with are easy to do.

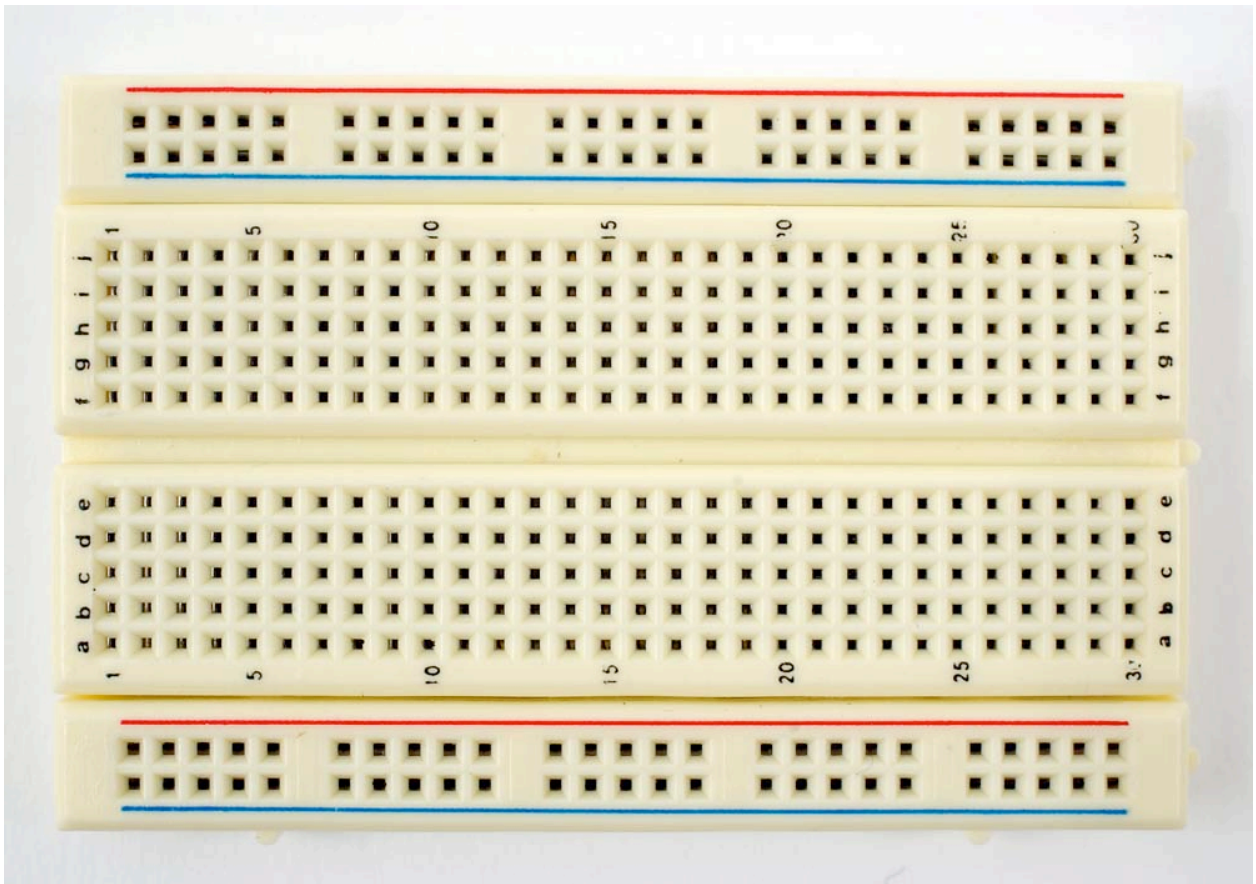


Figure 4.1: Image of a small breadboard used to build simple electronic circuits from [1]

As can be seen above in Figure 4.1 [3], a breadboard is a plastic board with a grid of holes on the top. Beneath these holes are strips of metal that provide the electrical connections. This grid of holes makes it easy to create and move around connections. Each hole provides an electrical contact for the various circuit components: integrated circuits, resistors, capacitors, LEDs, etc. This electrical connection is made by putting the leads or “legs” of a circuit component through the hole, and the metal of the lead touches the metal beneath the hole.

The circuit is put together using the holes on the breadboard. The components are placed around the board with the lead wires placed in the appropriate holes to connect them in the desired configuration. Each row of the breadboard is electrically connected by the metal strip

beneath it and forms a node, which is a point in a circuit where two components are connected. Connections between components are formed by putting their legs in a common node. The image below (Figure 4.2, [4]) provides a good illustration of how the metal strips are laid out underneath the board. It is important to note that the top and bottom rows of holes (the power bus and ground bus) are connected horizontally, while the rest of the holes are connected vertically. Each solid line forms a single node. This concept of the rows making separate nodes is also shown in Figure 4.3 [3]. In this image, each color represents a single node.

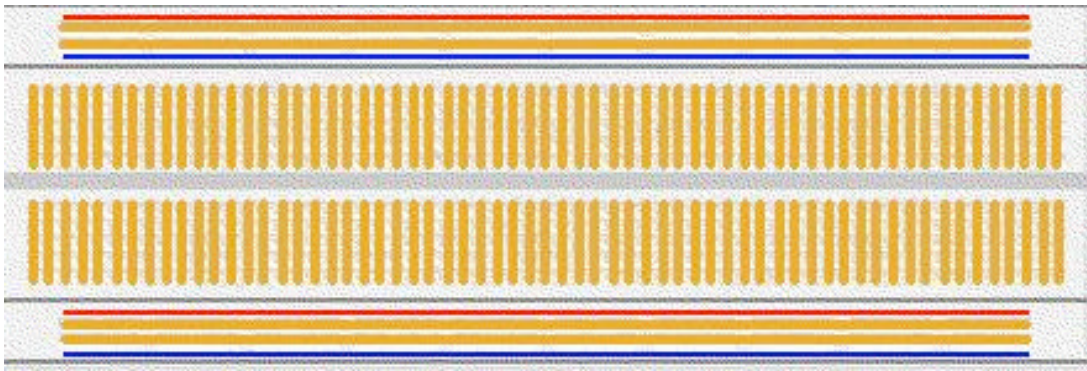


Figure 4.2: Layout of the electrical connections in a breadboard from [4].

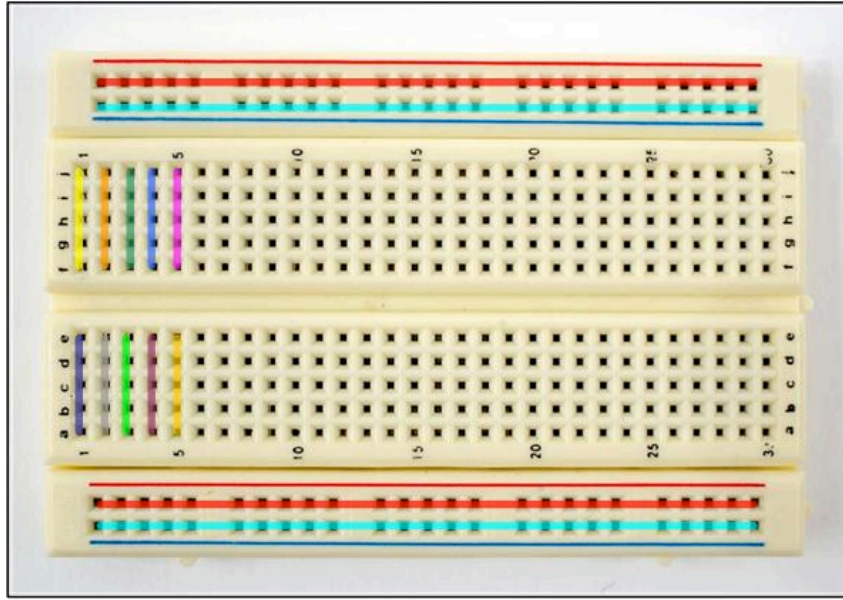


Figure 4.3: Modified image of the breadboard from [3] to illustrate the different nodes on the breadboard. Each color signifies a single node.

To power the breadboard, the holes next to the red and blue lines are used. The red row of holes on the breadboard is known as the power bus, and provides the power connection to the circuit. The blue row of holes is known as the ground bus, and provides a ground or reference voltage for the circuit. By connecting the red wire of your power source to the red power bus and the black wire of your power source to the blue ground bus, you are able to provide the power connections for a circuit. All of the red and blue holes are connected, and anytime a circuit requires a connection to either the power or ground you can simply use the nearest appropriate hole.

To connect the integrated circuit (IC) chip provided for this project, always place the IC over the middle groove running the length of the breadboard. Instead of the longer metal leads like those on capacitors or resistors, the IC has two rows of shorter metal pins that go through the breadboards holes. (It is important to stress to the students that they be careful with these pins as they can be bent or broken off. This effectively breaks the IC chip as it can no longer be properly connected.) There are a couple of reasons why it is necessary the IC is placed over the

groove. First and foremost, this ensures that the pins from the IC are all connected to separate nodes, which is necessary for the IC to work properly. Secondly, this groove provides a helpful method for removing the IC from the breadboard – you can simply place the head of a pen in the groove under the IC and use the pen as a lever to gently pop the IC out of the board. An image showing an example of a properly connected IC is shown below in Figure 4.4 [3].

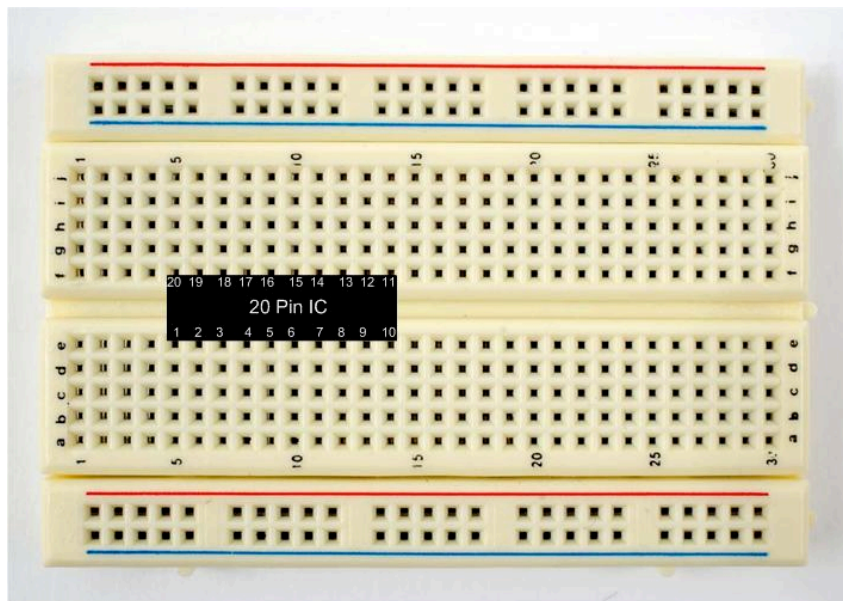


Figure 4.4: Modified image of the breadboard from [3] to illustrate proper connection of the IC chip to the breadboard.

Here are listed some general tips for using a breadboard:

- For safety reasons, leave the power source (here, a battery pack) disconnected until ready to test the circuit. This will both increase your battery life and prevent any minor shocks.
- Always use the power and ground bus side lines to provide power connections. Do not power directly from the power source.
- If possible, use red wires for power connections and black wires for ground connections.

- Keep wires as short as possible to allow easiest view of connections for troubleshooting. Keeping your breadboard circuit from getting cluttered can save lots of time later.

5. IC Touch Sensor

The type of touch sensor IC used here is B6TS-04LT. The B6T touch sensing IC is a 16-bit micro-controller, designed to detect touch sensing by measuring the change in the capacitance. The touch sensor detects the capacitance of the output channel. By touching the output of one channel, the person is changing the capacitance between the output and the ground with the body capacitance. The touch sensor detects that change and will make the output of that channel go to low voltage which can be regarded as zero.

The touch sensor IC, as purchased, cannot be connected to the breadboard directly because of the style of package it comes in. The sensor comes in as a gull wing package. The pin outs are designed to put into special boards such as a PC board. The pins of those sensors are so tiny that the sensors cannot be used for breadboard directly. Fortunately, after soldering to adaptors, the sensors can be used for breadboards.

The pin arrangement diagram is shown in Figure 5.1 below:

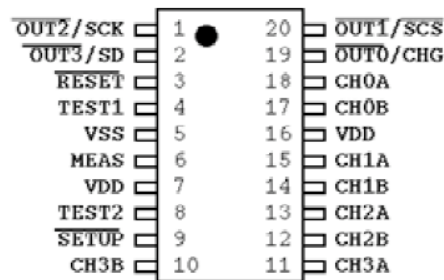


Figure 5.1: Pin Arrangement Diagram

The dot on the surface of the Touch Sensor IC indicates the direction of pin outs of B6TS-04LT touch sensor. Pin 19, 20, 1 and 2 are the output pins of all four channels in the

sensor. When one channel is connected to resistors and capacitors correctly, the output of that channel will be zero which indicates the circuit is working properly. For example, when pin 18 and 17 (measurement pins of channel 0) are connected correctly, the voltage of pin 19 (output pin of channel 0) will be zero.

In order to make the sensor work, pin 3, 4 and 8 will be connect to the power bus (high voltage) through a $10\text{k}\Omega$ resistor for each pin. Besides, pin 5 should be connected to ground directly and pin 7 and 16 should be connected to the power bus directly. The basic connections are shown in Figure 5.2 below:

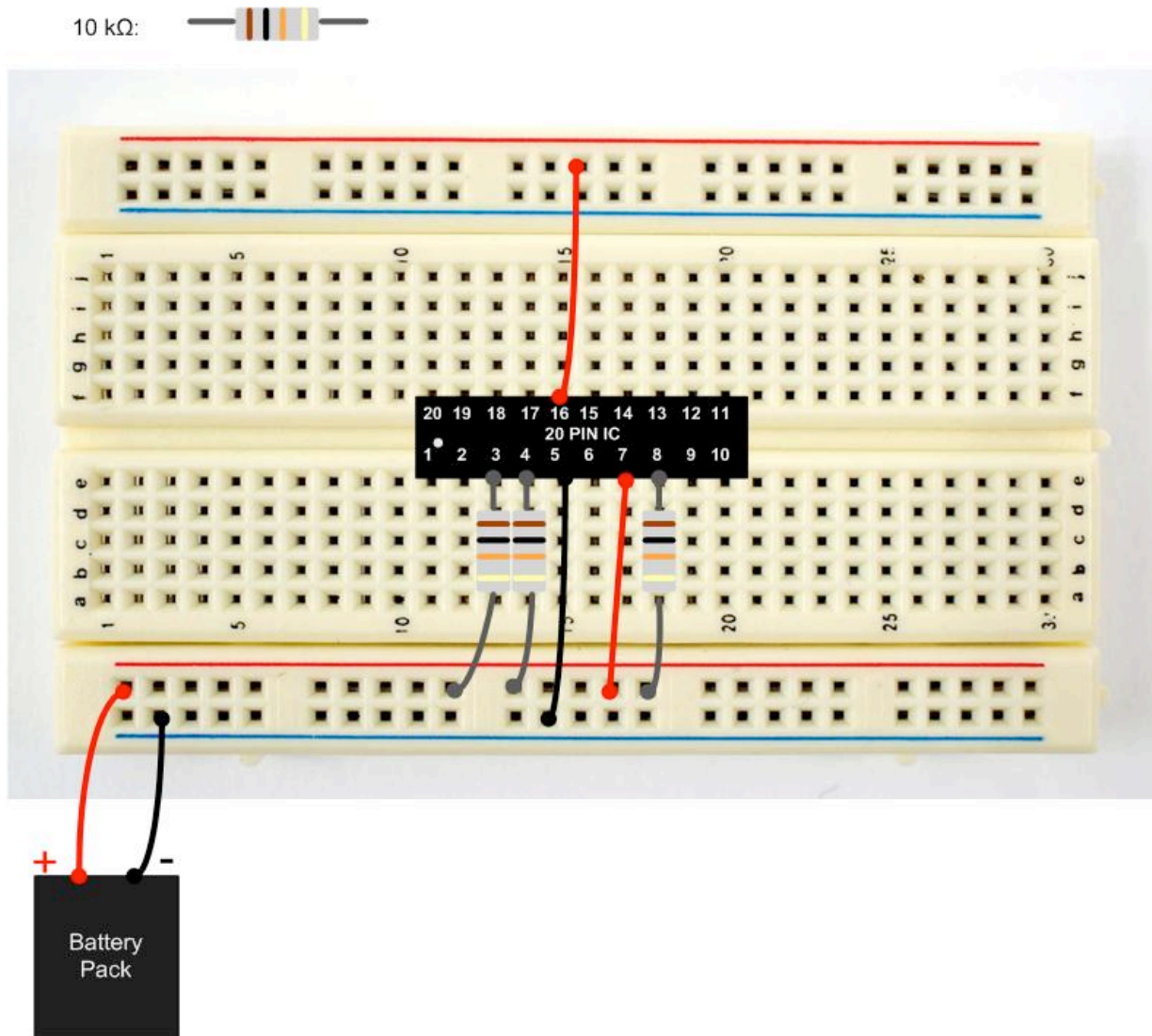


Figure 5.2: Touch Sensor with pin 3, 4, 5, 7, 8 and 16 connected

6. Project Design Circuit

The normal measurement mode is used in the design circuit for this project. All the channels work properly under this mode. The /SETUP (pin 9) and MEAS (pin 6) pins are both connected to the power bus (high voltage) through a 10kΩ resistor for each pin. The connection for normal measurement mode is shown in Figure 6.1 below:

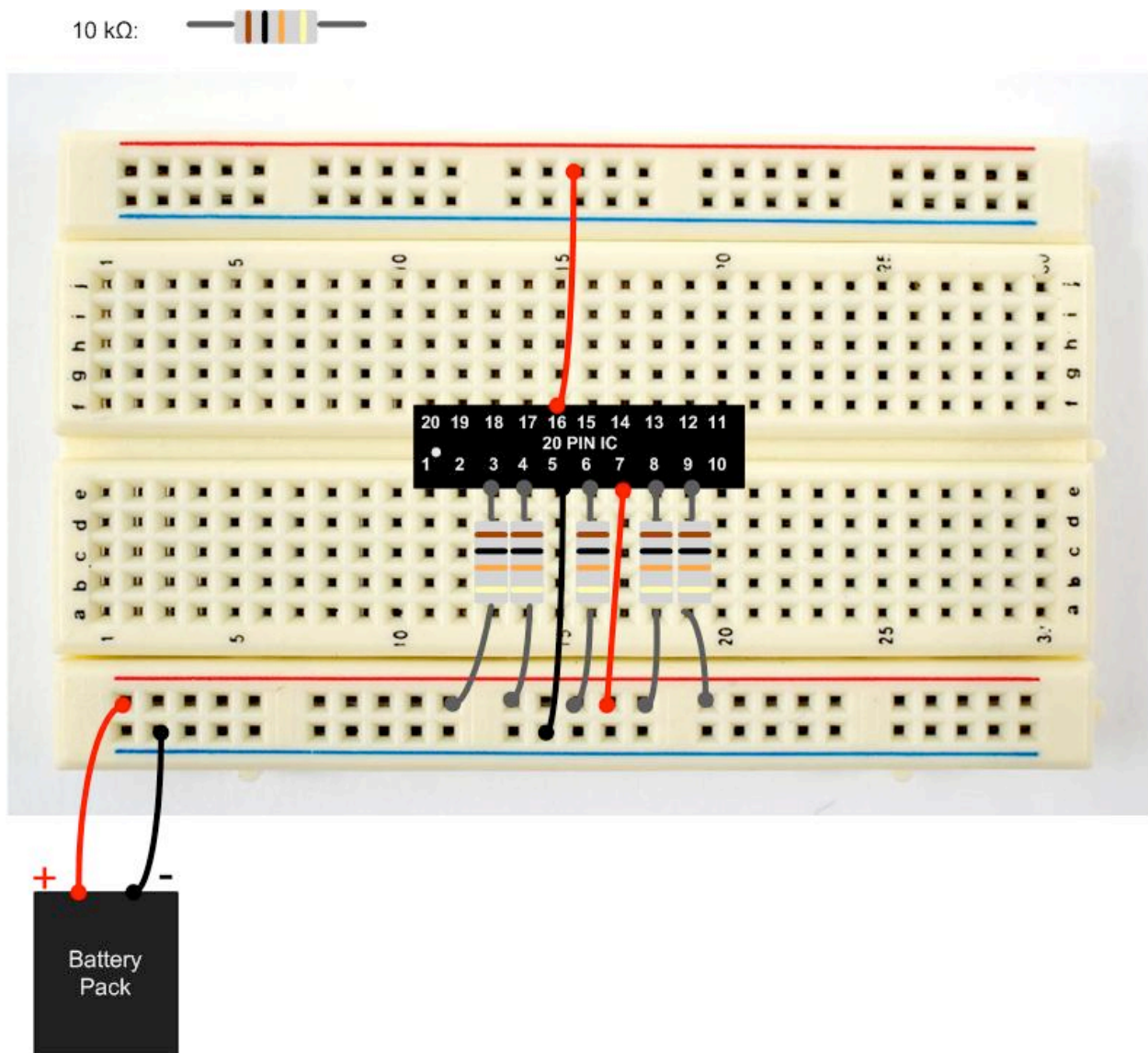


Figure 6.1: Circuit Diagram in normal measurement mode

Under the normal measurement mode, students can start to build one channel touch sensing circuit now. The circuit diagram with pin 10 and pin 11 (measurement pins for channel 3) connected is shown in Figure 6.2 below:

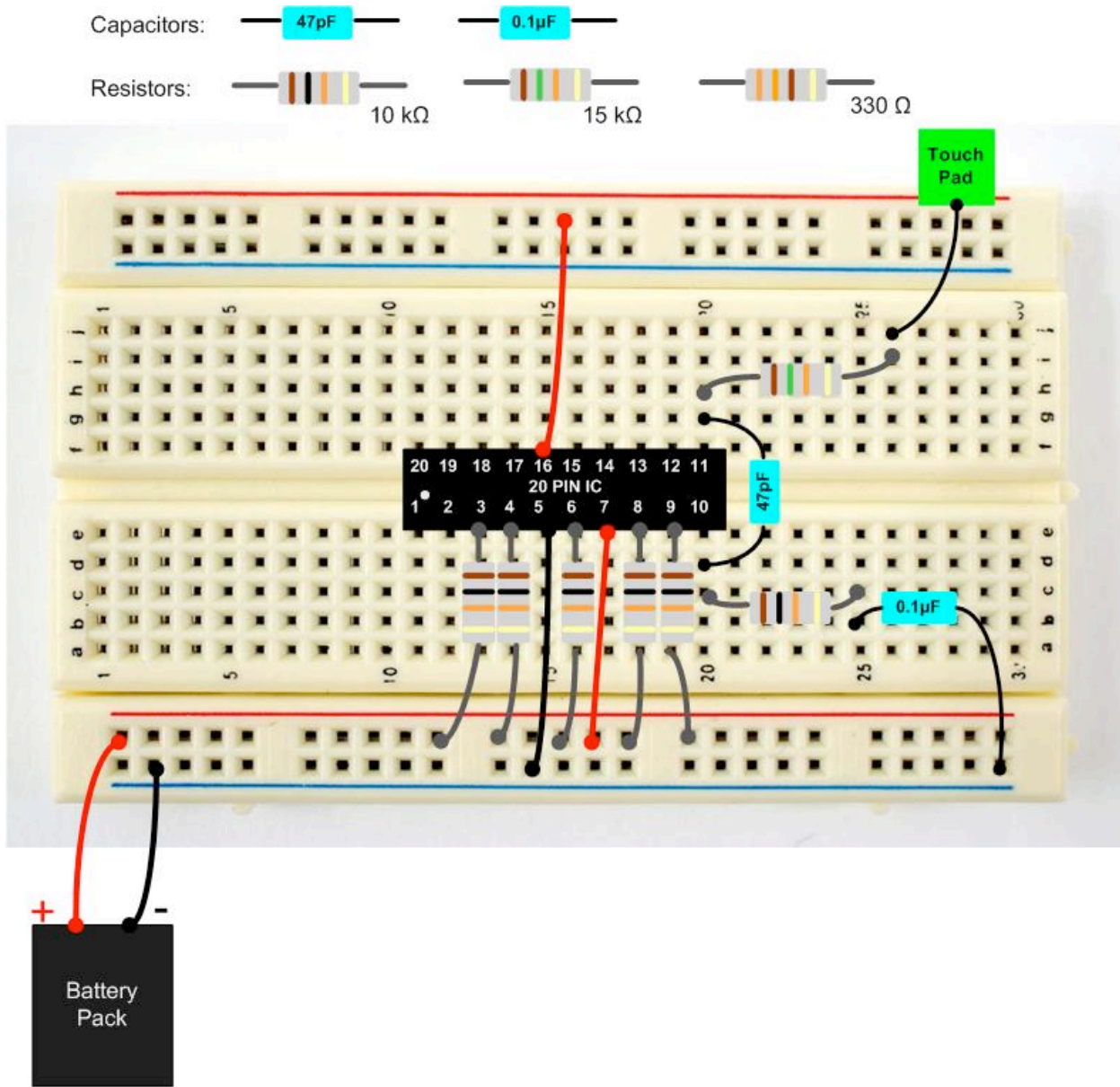


Figure 6.2: Circuit Diagram for Channel 3

The touch pad in Figure 6.2 above can be made by any kind of conductive material. For example, the touch pad can be a penny, or a piece of conductive glass.

When pin 10 and pin 11 (measurement pins of channel 3) are correctly connected, the voltage of pin 2 (output pin of channel 3) is zero. A LED and a resistor between pin 2 and the power (high voltage) will be added into the circuit. When someone touches the touch pad, the LED will light up. The circuit diagram is shown in Figure 6.3 below:

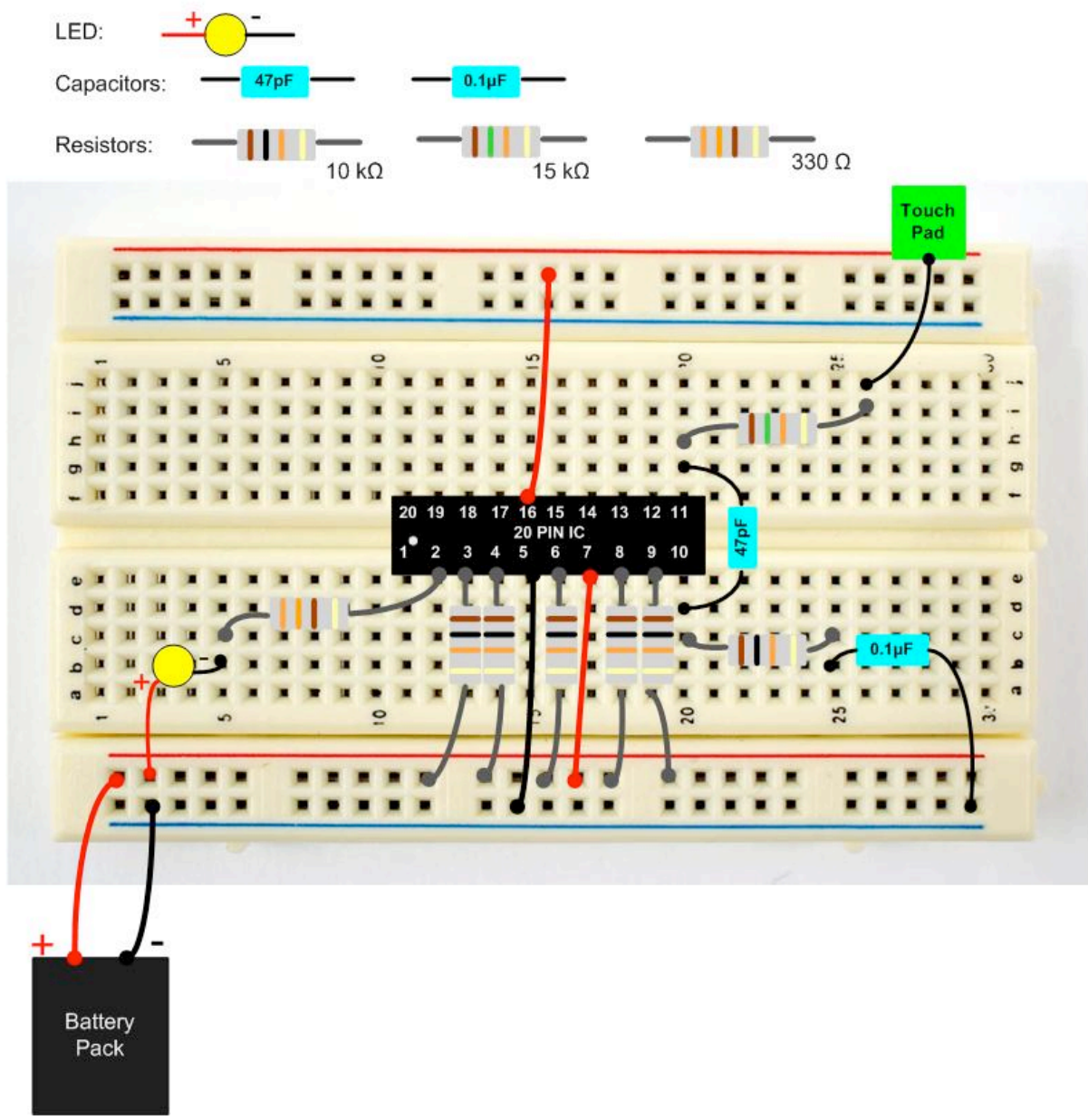


Figure 6.3: Channel 3 connected with LED in its output

There is a difference in the two leads of an LED. In Figure 6.3 above, the positive lead of LED goes into the power bus (high voltage) and the other lead connects pin 2 (output pin of channel 3) through a 330Ω resistor. The longer lead is the positive lead of the LED. The side view and top view of a LED are shown in Figure 6.4 below:

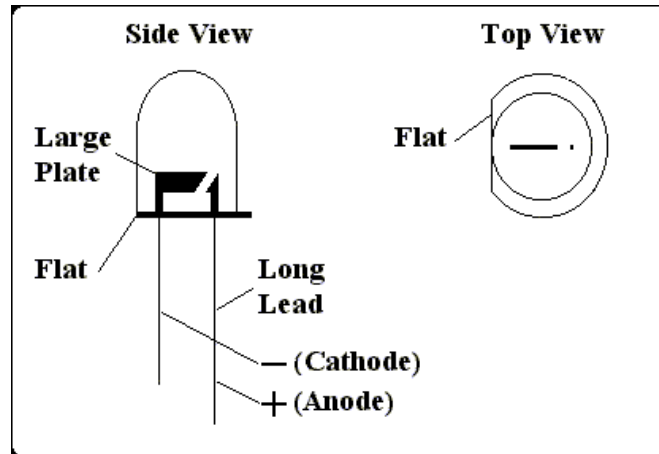


Figure 6.4: Side view and top view of a LED from [5]

When the students understand how one channel works, they can start to build all four channels in the sensor. The circuit diagram with all four channels connected is shown in Figure 6.5 below:

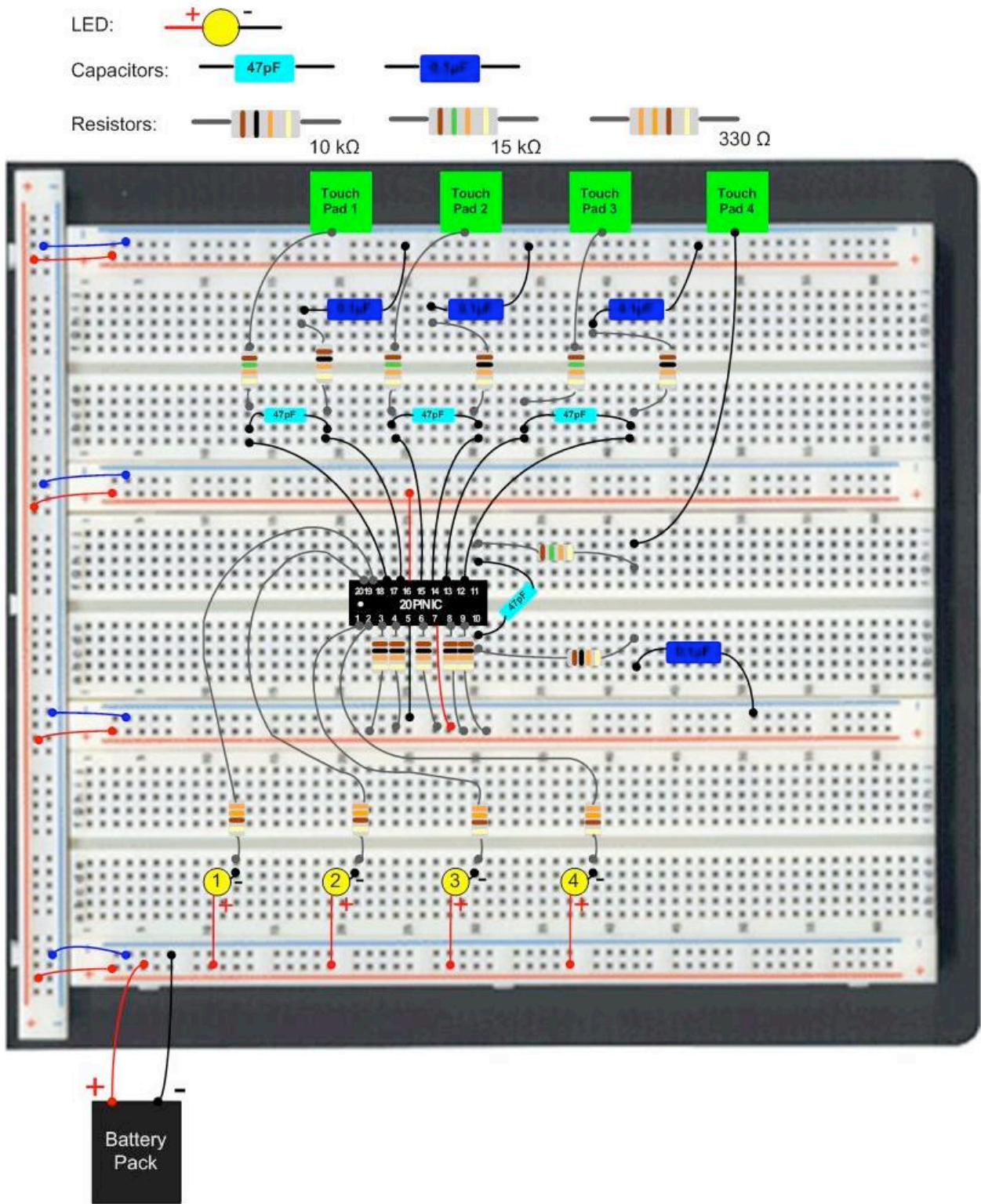


Figure 6.5: Four Channel Circuit Diagram

By touching one touch pad, the student can light up the corresponding LED. For example, by touching touch pad 1, the student can light up LED 1. If the student touches touch pad 1 and 2, he can light up both LED 1 and 2. By touching all four touch pads at the same time, all the LEDs will be lit up.

7. Conclusion

Upon completion of the circuit the students can connect different typed of touchpad materials to their circuit via a wire and experiment with what works and what doesn't. You'll find that conductive elements such as conductive glass, aluminum foil, and pennies work very well while non conductive elements such as standard glass, plastic, or wood won't work as well or may not work at all. This can then be related back to the electrical concepts described earlier. The conductive material connects our body's capacitance directly to the circuit making detection easy while the non conductive materials separate our body from the circuit to the point where the capacitance may not be detected. The change in capacitance detected by the circuit needed to break some threshold in order to trigger detection depends on the touchpad material used. The capacitance seen by the circuit when touched by a human finger may or may not break that threshold. The students can also try touching a touchpad with something that doesn't have any capacitance such as a pencil. This will drive home the point that it isn't the physical act of touching the touchpad that triggers the detection but instead the capacitance of the human body that is being detected. Hopefully the students will have learned something about electricity, capacitance, and its uses. The students will also now have further knowledge as to the benefits of engineering which may results in them considering that field later in life.

8. References

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9. Appendix

A. Troubleshooting

Things to check if the touch sensing circuit isn't working:

1. If the LED is not illuminating check that the switch on the battery pack is in the on position. If the LED still doesn't illuminate try replacing the batteries.

2. If the LED never illuminates try replacing it with another LED.

3. If the LED operates such that it turns on when the sensor is not touched and off when it is touched flip the LED around so that the pin currently connected to the resistor goes to power and the pin currently going to power connects to the resistor.

4. If the LED is very dim, check to make sure the correct resistance is being used in series with the LED. This resistance is $330\ \Omega$ which has the three color bands as orange, orange, and then brown.

5. If the LED is always on regardless of whether or not you touch the touchpad, turn the switch on the battery pack off and then turn it back on to reset the circuit.

6. If the LED doesn't turn on when the sensor is touched even after checking that the batteries are fine and the LED has been replaced, check all the circuit connections to ensure they are correct.

7. If all the connections are correct try another channel on the IC. If another channel works there is something wrong with the previous channel in the IC and it can't be used or the IC needs to be replaced.

8. If the other channels do not work either check to see if the IC is warm. If so disconnect power and try again later. If the IC still doesn't work it likely needs to be replaced.