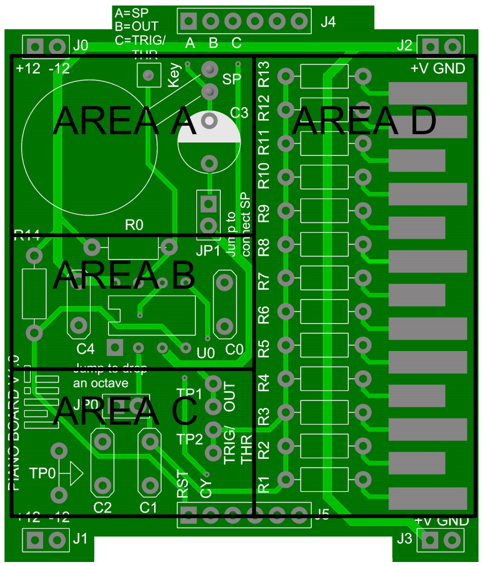
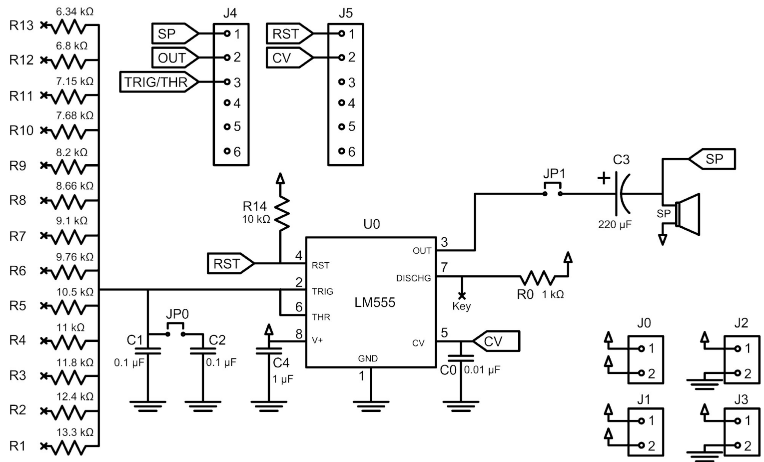
Massachusetts Institute of Technology
Electromechanical Systems Group
Electronics First: OSCILLATORS

Board and **Circuit Schematic:**





Materials:

Part	Quantity	Part Number	Vendor	Part	Quantity	Part Number	Vendor
Breadboard	1	377 − 2646 − ND	DigiKey	*R_7 9.1 kΩ Resistor*	1	RNMF14FAD9K10CT − ND	DigiKey
Breadboard Power Supply and Cable	1	-	-	*R_8 8.66 kΩ Resistor*	1	8.66KXBK − ND	DigiKey
Multimeter	1	MN35 − ND	DigiKey	*R_9 8.2 kΩ Resistor*	1	S8.2KCACT − ND	DigiKey
6-pin Header Pins	2	609 − 3263 − ND	DigiKey	*R_{10} 7.68 kΩ Resistor*	1	7.68KXBK − ND	DigiKey
2-pin Rail Connector Pins	4	952 − 2262 − ND	DigiKey	*R_{11} 7.15 kΩ Resistor*	1	7.15KXBK − ND	DigiKey
2 Pin Jumpers	2	S9337 − ND	DigiKey	*R_{12} 6.8 kΩ Resistor*	1	S6.8KCACT − ND	DigiKey
12 V Adapter (if needed)	1	102 − 4123 − ND	DigiKey	*R_{13} 6.34 kΩ Resistor*	1	RNF14FTD6K34CT − ND	DigiKey
Soldering Iron and Solder Wire	1 ea	T0052918199N − ND	DigiKey	R_{14} 10 kΩ Resistor	1	CF14JT10K0CT − ND	DigiKey
R_0 1 kΩ Resistor	1	RNF14FTD1K00CT − ND	DigiKey	0.01 µF Capacitor	1	399 − 9865 − 1 − ND	DigiKey
R_1 13.3 kΩ Resistor	1	13.3KXBK − ND	DigiKey	0.1 µF Capacitors	2	478 − 6008 − ND	DigiKey
R_2 12.4 kΩ Resistor	1	12.4KXBK − ND	DigiKey	220 µF Capacitor	1	493 − 12562 − 1 − ND	DigiKey
R_3 11.8 kΩ Resistor	1	11.8KXBK − ND	DigiKey	1 µF Capacitor	1	445 − 174260 − 1 − ND	DigiKey
R_4 11 kΩ Resistor	1	11.0KXBK − ND	DigiKey	Speaker	1	433 − 1106 − ND	Digikey
R_5 10.5 kΩ Resistor	1	10.5KXBK − ND	DigiKey	8 Pin DIP Socket	1	AE9986 − ND	Digikey
R_6 9.76 kΩ Resistor	1	9.76KXBK − ND	DigiKey	555 Timer IC	1	LM555CNNS/NOPB − ND	Digikey

** Denotes Area D "Keyboard" Resistor*

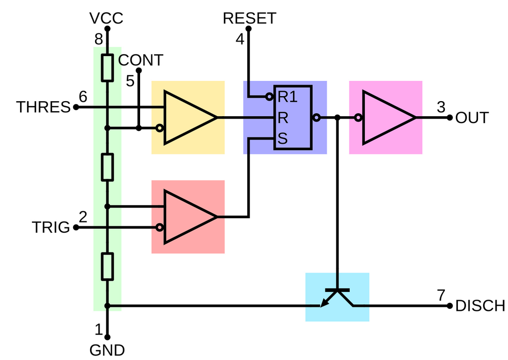
The Build:

Oscillators produce periodic waveforms, such as square waves. They are central to the operation of many electronic devices, and they can be found in everything from digital clocks to flashing car turn signals. Oscillators can also serve as tone-generating circuits, which use periodic waveforms to produce sound when connected to a speaker. In this lab, you will build a **tone generator**. The tone generator has a set of "keys" which generate tones of different frequencies when activated, much like a piano. Constructing this circuit will familiarize you with the basic function of a 555 timer integrated circuit. Selecting different resistance and capacitance values in the circuit creates different oscillation frequencies.

A TONE GENERATOR produces electrical waveforms in the audio frequency range (20 Hz to 20,000 Hz). These waveforms can be used to drive a speaker, or an amplifier and a speaker, to produce audible tones. The first commercial product produced by the Hewlett-Packard Company (HP) was an analog, adjustable tone generator purchased by The Walt Disney Company for creating animated cartoons. Today, tone generators appear in a wide range of consumer products including doorbells and sophisticated electronic music synthesizers.

Theory of Operation and Predictions

THE CIRCUIT IN THIS BUILD uses a 555 *Timer Integrated Circuit (IC)* to produce an oscillating signal. The 555 Timer can drive a speaker. The oscillating signal creates an audible tone. Changing the resistance in a circuit path around the 555 Timer alters the signal frequency and thus the tone pitch.



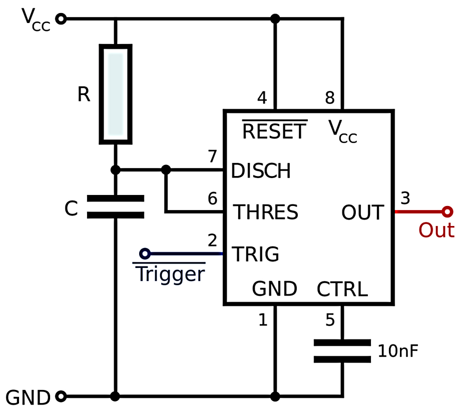
555 Timer Internal Diagram

The 555 Timer IC

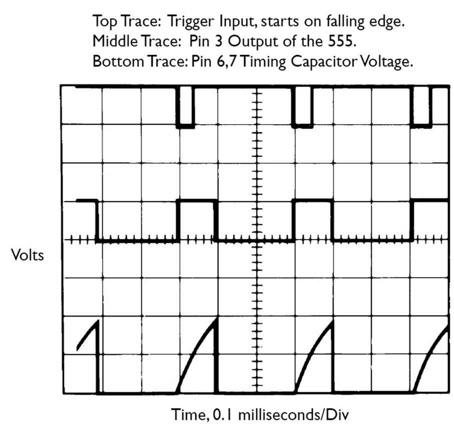
THE 555 TIMER IC HAS FOUND USE IN COUNTLESS DESIGNS with billions of units sold and has been called the "Swiss Army Knife" of circuits. As shown on the far left of the "555 Timer Internal Diagram," the IC is built around a divider of three resistors that provides analog reference signals at one third and two thirds of the power supply voltage. The internal resistor divider network in the IC effectively sets two distinct analog voltage thresholds, much like the high and low thresholds in a 74HC14 Schmitt inverter.

Two comparators are provided, with external inputs labeled "TRIG" and "THRES". The other, internal input of each comparator is connected to a node of the resistor divider. When the non-inverting input of one of these comparators is at a higher voltage than the inverting input (indicated with a circle on the comparator symbol), the output of the comparator goes to a "high" voltage. A "high" level output of the "TRIG" comparator "sets" or asserts the output of a flip-flop in the IC. On the other hand, a "high" level output from the "THRES" comparator "resets" the flip-flop. The reset signal is dominant, resetting the flip-flop regardless of the state of the "S" (set) input. The output of the flip-flop is "active low", that is, it is a low voltage near ground when the output is asserted or set. An inverter follows the flip-flop, creating the output of the IC at pin 3. Hence, when the flip-flop output is asserted, the output of the IC on pin 3 is "high." When the flip-flop is reset and the IC pin 3 output is "low," the "DISCH" pin 7 on the IC is automatically pulled to ground. The "DISCH" pin can be used to alter a current flow, e.g., discharge a component, outside of the IC. This particular arrangement of components has proven to enable a great variety of timing-related applications with only a few additional external components.

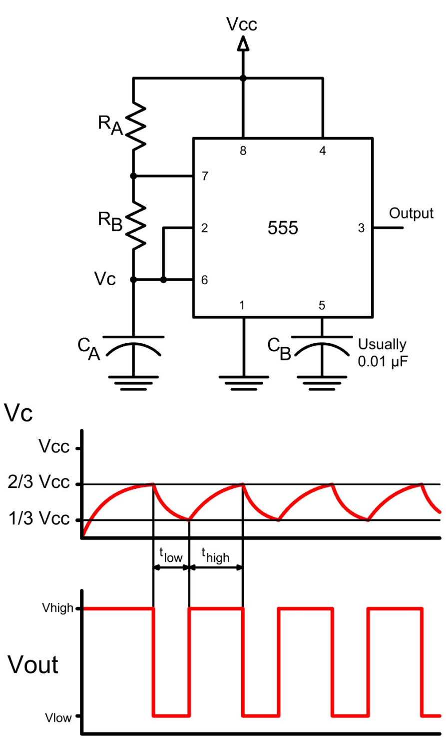
In its simplest configuration as a *monostable multivibrator*, or one-shot, the



Basic Monostable - A "One-Shot" Timer



Basic Monostable waveforms following repeated Trigger events.



Basic Astable Circuit and Waveforms

555 Timer IC generates a fixed-width pulse upon receiving an input signal to the TRIGGER pin. For example, a door with a switch on it might trigger a one-second pulse from the 555 Timer that activates an alarm light when the door is opened. The length of this fixed-width pulse, which has uses in many other control and timing applications, is set by an external RC network.

Study the example schematic of a 555 configured as a "One-Shot Timer." Initially, the external timing capacitor, connected to pins 6 and 7, is held discharged by the discharge transistor inside the 555. A timing pulse starts when the 555 receives a low input on pin 2, the TRIGGER pin. This sets the internal flip-flop in the 555, turns off the internal discharge transistor, and raises the output on pin 3 to a high voltage. With the discharge transistor off, the capacitor in the RC circuit connected to pins 6 and 7 begins to charge. When the capacitor voltage on pins 6 and 7 rises to two-thirds of the input voltage, the THRES comparator output goes high and resets the flip-flop, making the flip-flop output high and the 555 output on pin 3 low. The discharge transistor is now on again, and will hold the timing capacitor discharged until another timing trigger is applied to pin 2.

Feeding an output of this configuration back into the trigger pin creates an *astable multivibrator*, or oscillator, similar to the one you may have constructed with a 74HC14 in a previous lab. In this build, the timer on your board will be configured as an oscillator to produce a square wave whose frequency can be adjusted through an external RC network.

Astable mode means that the system has no stable state - the output is "flip-flopping" between a high (V_{high}) and low (V_{low}) voltage. The amount of time V_{out} is low (t_{low}) is determined by the $R_B\ C_A$ time constant in the external RC circuit. The amount of time V_{out} is high (t_{high}) is determined by the time constant from *both* resistors, R_A and R_B, and capacitor C_A.

The 555 timer also provides a connection to the internal resistor divider network through the CTRL (CONTROL VOLTAGE) pin, allowing for finer timing control and interesting applications such as pulse-width and frequency modulation. Study the monostable and astable circuits carefully. Understanding the operation of the 555 Timer in these configurations is a challenge that invites you to hone your skill in understanding important electronic building blocks like the comparator, flip-flop, transistor, and inverter. The 555 Timer is a marvelous example of how such building blocks can form systems with fascinating and useful complexity.

Tone Generation

THIS BUILD WILL CREATE A SIMPLE ELECTRONIC MUSICAL INSTRUMENT using a 555 Timer IC. We will need the ability to create a range of different audio frequencies for a small electronic "piano." The board uses a 555 configured as an oscillator to make tones. Different frequencies are played by selecting different values for R_B. Changing R_B alters t_{low} and t_{high} and therefore the frequency of the output square wave. The rectangular pads in **AREA D** serve as piano keys. Each pad is connected to a different choice of resistor for R_B. Collectively, the bank of resistors can be thought of as the various potential values of R_B. When you touch one of the 13 "keyboard" pad contacts with a wire (called a *key striker*) from **AREA A**, the circuit is completed through the associated resistor, and a tone is produced. Move the wire to a different keyboard pad with a different resistor and you will produce a different tone. Study the board schematic on the cover page and compare it to the 555 circuit schematic "Basic Astable Operation" to understand how this works.

$$t_{low} = 0.693 R_B C_A$$

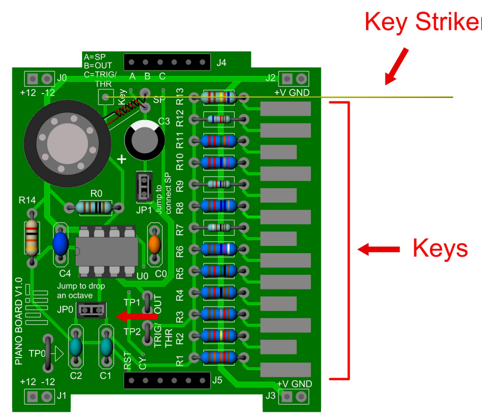
$$t_{high} = 0.693 (R_A + R_B) C_A$$

Astable equations for high and low periods

$$f = \frac{1}{t_{high} + t_{low}}$$

Frequency of the astable output waveform

You could also change the output frequency by changing the timing capacitor. In the example of the 555 astable oscillator, one capacitor, C_A, fixes the oscillation frequency along with the timing resistors. Imagine, however, that the capacitance was variable or selectable like the resistance. You would have another way of changing the output tone. This build actually provides two capacitors C_1 and C_2 on the board, the *octave capacitors*. You can select the use of one or both to change octave.



The Key Striker and Keys

1.) Assume $C_A = 0.1\ \mu$F, R_A is fixed at 1 kΩ, and R_B is variable based on whatever "key" you are hitting with the key striker. What would be the frequency of the tone for a "first key" selecting $R_B = 6.34$ kΩ?
2.) What would be the frequency of the tone if you moved the key striker to a "second key" selecting $R_B = 13.3$ kΩ?
3.) Which key would produce the higher-pitched sound?
4.) Now assume that C_A is not one 0.1 μF capacitor, but two 0.1 μF capacitors connected in parallel. What would be the frequency of the tone for the "first key" with $R_B = 6.34$ kΩ? *(Note - the capacitance of parallel capacitors adds!)*
5.) With two 0.1 μF capacitors, what would be the frequency of the tone if you moved the key striker to a "second key" with $R_B = 13.3$ kΩ?
6.) Compare the tones you would produce with one capacitor to the tones you would produce with two. Which condition yields the higher-pitched tones?

f:

Prediction 1

f:

Prediction 2

Prediction 3

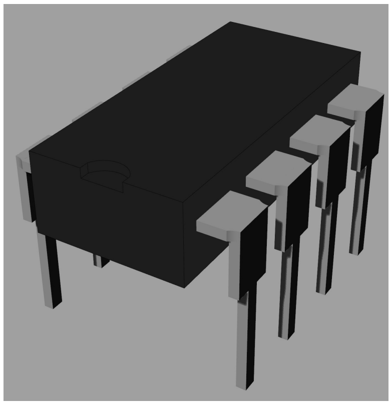
f:

Prediction 4

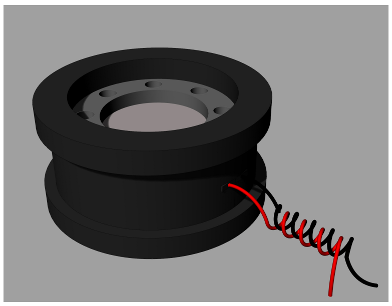
f:

Prediction 5

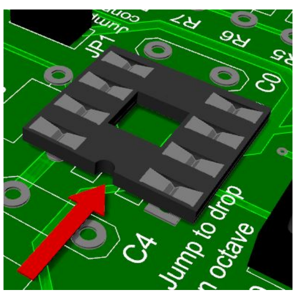
Prediction 6



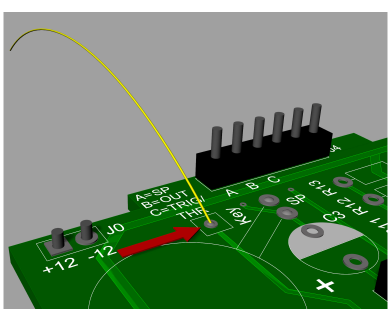
555 Timer



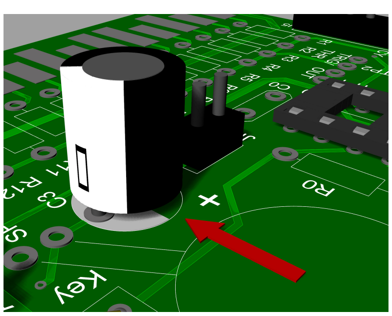
Speaker



DIP Socket Location



Key Striker Location



Coupling Capacitor C_3 Location

Assembly

THE 555 TIMER OPERATING IN ASTABLE MODE IS THE HEART OF THIS BUILD. A speaker converts the output signal of the 555 to audible tones. To organize assembly, the board has been divided into separate areas. The cover page shows a diagram identifying the build areas.

DIP Socket Installation

Install the 8-pin DIP socket in **AREA B**. Ensure that the semi-circular notch at the top of the socket lines up with the corresponding notch illustrated in silkscreen **U0** on the board. **AREA B** has two rows of 4 through-hole pads. Press the 8 socket wire legs through the corresponding pads on the board. Make good solder connections between each of the 8 socket pins and the metal pads on the underside of the circuit board. *Do not insert the 555 Timer IC into the socket yet - you will do that at the end.*

Key Striker Construction

Add the key striker in **AREA A**. Take a length of insulated wire approximately 4 inches long and strip 1/4 inch of insulation from both ends. Solder one end into the contact point in the box labeled **KEY**. Make your soldered joint on the bottom of the board. This will be your electronic “finger” to touch the "keys" and produce a tone.

Coupling Capacitor Construction

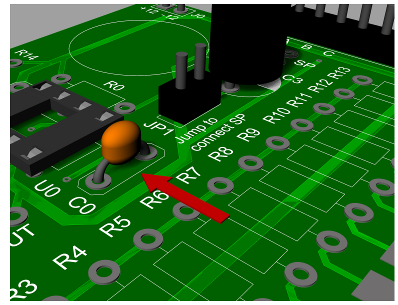
Add the speaker coupling capacitor in **AREA A**. This capacitor ensures that only AC signals reach the speaker by blocking out any DC components. Install the 220 μF capacitor into the pads for C_3 which contains a circle inscribing two contact points. *Polarity matters.* Position your capacitor so that the side with the negative pin (marked with a negative sign and white stripe on the body) aligns with the part of the circle that is shaded white. Complete the necessary soldered connections beneath the board.

Reference-Smoothing Capacitor Construction

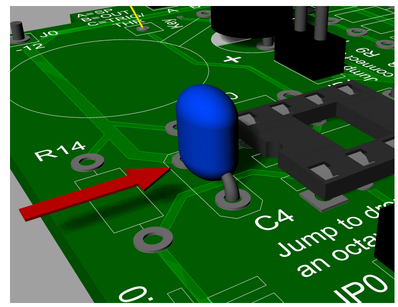
Add the reference-smoothing capacitor in **AREA B**. Insert the legs of the 0.01 μF capacitor into the two PCB pads labeled for C_0 to the right of the socket. Pull the leads through until the capacitor is against the surface of the board. Solder the proper capacitor pads beneath the board, and, when your joints have cooled, trim any excess wire. *Save your trimmed pieces of wire - you will use them to construct test points later.*

Bypass Capacitor Construction

Add the bypass capacitor in **AREA B**. Bypass capacitors effectively "smooth out" the input voltages and protect circuit components from any irregularities in the power supply. Insert the legs of the 1 μF capacitor into the two pads for C_4. Solder the capacitor pads beneath the board, and trim any excess wire.



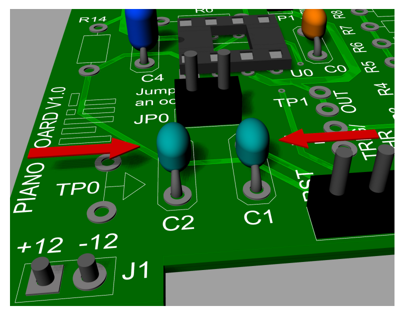
Capacitor C_0 Installation



Bypass Capacitor Location

Octave Capacitors

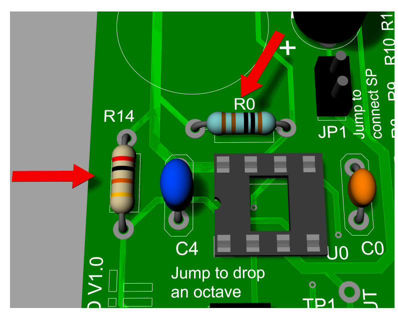
Place the octave capacitors in **AREA C**. You have two 0.1 μF capacitors - solder them into the pads for C_1 and C_2. The capacitors can be connected **in parallel** via a jumper at **JP0**. The jumper lets you choose whether one or two capacitors will serve as the timing capacitance for the 555 Timer, effectively selecting one octave or another for frequency generation.



Octave Capacitors

Resistors

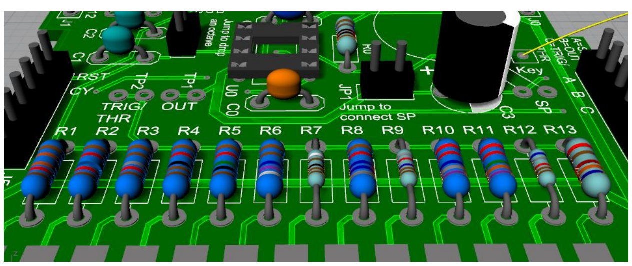
Add the two resistors in **AREA B**. Using the resistor band color code, identify and install the 1 kΩ resistor into the pads labeled R_0, and install the 10 kΩ resistor into the pads labeled R_{14}. Make soldered connections at the proper locations on the bottom side of the board.



Resistor Placement

Keyboard Construction

Build your keyboard in **AREA D**.

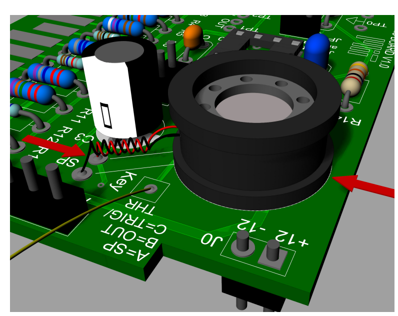


Keyboard Timing Resistors

There are 13 keys and 13 corresponding resistors which need to be installed in slots R_1-R_{13}. Refer to the “Materials” list and schematic at the beginning of this lab to see which resistors need to be soldered into which locations. Work carefully! The resistors must be inserted in the correct locations to ensure that the keyboard tones are in the correct order.

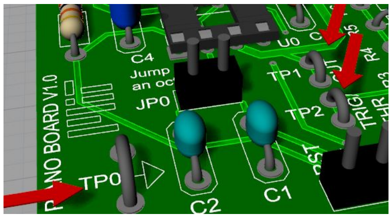
Speaker Installation

Add the speaker in **AREA A**. Remove the plastic cover from the adhesive strip on the bottom of the speaker and install it inside the large circle in the upper left corner of the board. Take the red and black wires sticking out the side of

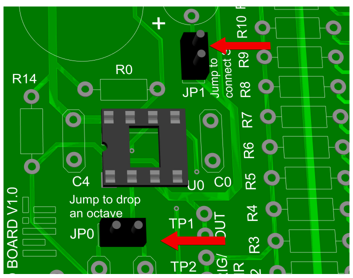


Speaker Positioning

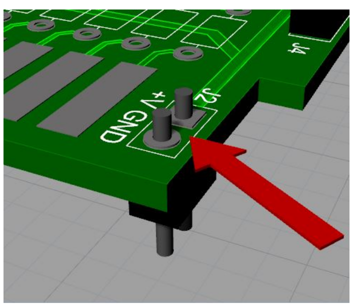
the speaker and install them into the pads labeled **SP** directly above capacitor C_3. The black wire should be soldered into the upper contact (closer to **J4**), and the red wire should be in the lower contact. Make your soldered joints on the bottom of the board.



Test Point Soldering Locations



Jumper Pin Installation



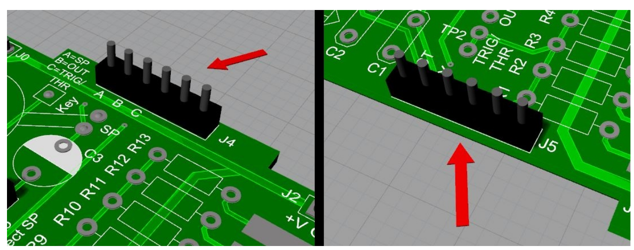
Rail Connector Pin Installation

Test Points

Place the test points in **AREA E**. Take one of the resistor wire cuttings you saved earlier and bend it into an arc, inserting each end into the pads for **TP0**. Trim the length of the wire as necessary. Make soldered joints on the bottom of the board. This is a ground clip. Repeat this process for **TP1** and **TP2**. **TP1** connects to the OUTPUT (pin 3) of the 555 timer. **TP2** is connected to the TRIGGER (pin 2) and THRESHOLD (pin 6) of the timer.

Pin Installation

Install one 6-pin header into **J4** at the top of your board. Insert the other 6-pin header into **J5** at the bottom of the board. Make soldered joints on the underside of the board.



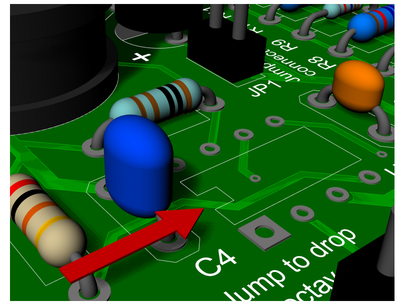
Header Pin Installation

Use the same procedure to install 2-pin headers into **JP0** and **JP1**. These are *jumper points* where you can install 2-pin jumpers that change the function of the circuit. Installing a jumper at point **JP0** changes the output tone by an octave by putting C_1 and C_2 in parallel. Adding a jumper at **JP1** connects the speaker. You must insert a jumper at **JP1** to hear tones!

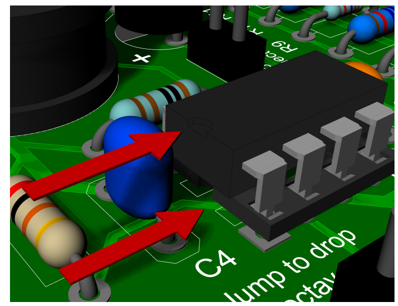
Next, install 2-pin rail connectors into **J0, J1, J2, and J3**. These are installed in the reverse direction, with the base of the pin on the underside of the board, and the location of the soldered joint on the top of the board. *BEFORE SOLDERING*, insert the bottom of the pins into your breadboard, and *then* make your soldered connections on the circuit board to ensure proper alignment.

555 Timer Installation

Once all of your soldered joints are completely cooled, install the 555 timer into the socket. *Orientation matters.* Ensure that the notch on the topside of the timer body aligns with the indent shown on the board.



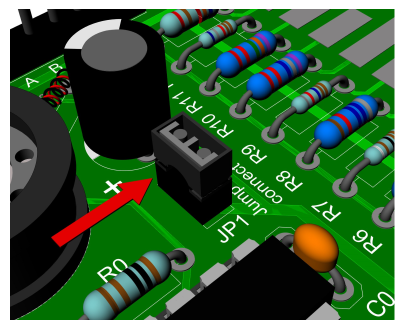
555 Timer Location



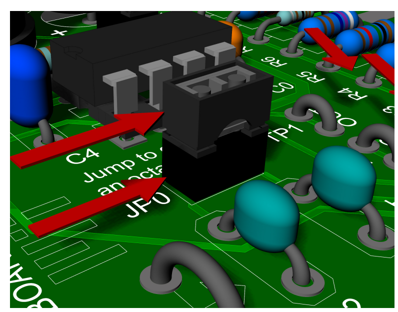
555 Timer Orientation

Testing

Add one 2-pin jumper to the pins you installed in **JP1**. This connects the speaker to the circuit. Carefully connect your circuit board to the breadboard in line with the power supply module. Ensure that the pins of all boards are fully inserted into the breadboard contact holes. Ensure that your power cord is properly fitted into the appropriate port on the power supply module. Check that the power supply indicator light is illuminated.



2-pin Jumper Installation at JP1



2-pin Jumper Installation at JP0

Playing your Piano

1.) Touch the key pad connected to R_{13} with your key striker. Listen carefully to the sound you make. Now repeat this process with the key at R_1. Which of these keys produced the higher-pitched tone? Does this concur with your prediction?
2.) Install a 2-pin jumper to the pins in **JP0**. Touch the keys at R_{13} and R_1 again. Are the tones higher pitched with the pins are jumped or un-jumped? Does this concur with your prediction?

Test 1 - Check against Prediction 3

Jumped	Un-jumped
(Circle One)	

Test 2 - Check against Prediction 6