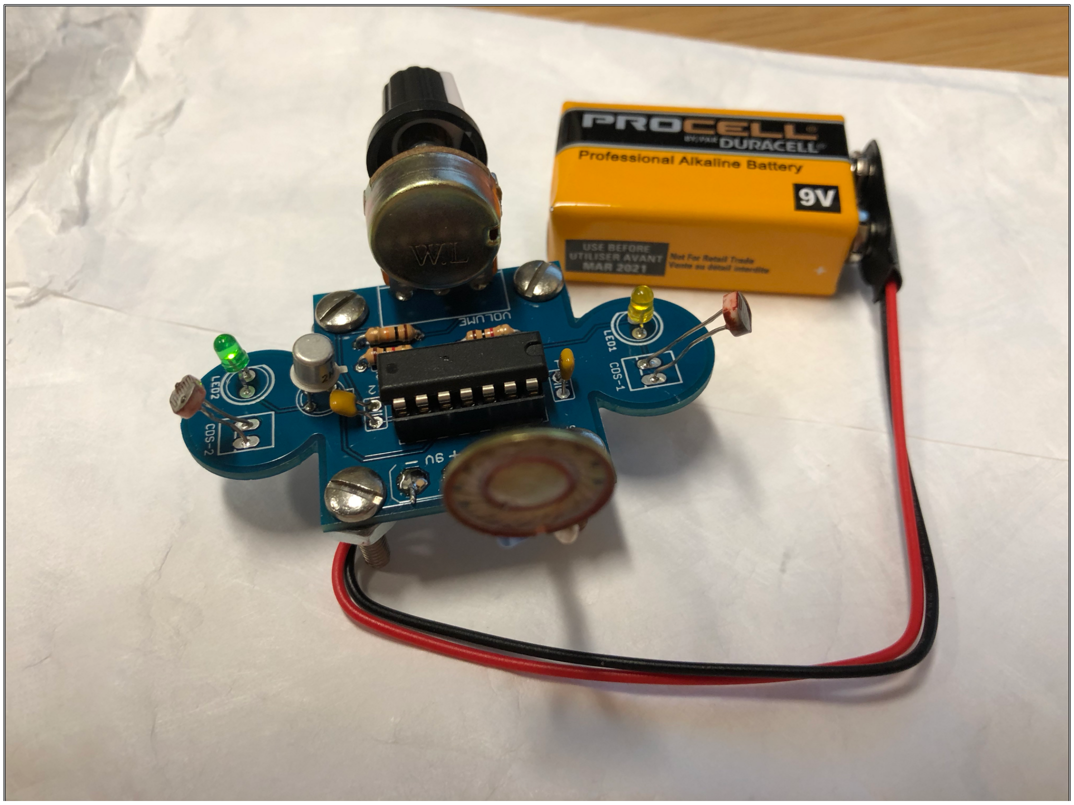
# Optical Theremin

http://www.github.com/YalePhysicsLabs/Optical_Theremin

*Designed by Stephen Irons at Yale University for the 2018 AAPT Summer Meeting*




The Theremin is a musical instrument that has the distinction of being the only one in which the musician never comes in physical contact with it. It is played by moving one's hands over and around two metal loops that act as antennas to change the pitch and the volume by detecting changes in capacitance. Professional Theremins can be expensive as well as difficult to play well.

In this project you will be constructing your own inexpensive Theremin that you can use to annoy and/or get the attention of your students. However, instead of using a radio antenna to detect changes in capacitance as a real Theremin does, we will use Cadmium Sulfide (CdS) photoresistors to achieve a similar effect. By changing the amount of light falling on the photo-resistor, we can change the pitch coming out of the speaker.

*Moog Etherwave Plus* Theremin

The heart of the Optical Theremin* are two 555 Timer integrated circuits. The 555 Timer is an extremely versatile device that can be used in a wide range of applications. As the name implies, its primary purpose is to act as a timer for electronic circuits. However, it can be used to make lamp flashers, pulse generators, logic clocks, tone generators, security alarms, pulse position modulation and many other devices. We will be using it as a tone or pulse generator and as a frequency divider. This means that unlike a "true" theremin, this

* This project is based on the Pocket Theremin project found at https://www.popsci.com/.

incarnation allows you to optically control the pitch in two separate ways rather than controlling the pitch and volume. In this theremin, the volume is controlled with a simple 1 turn potentiometer.
Since the circuit requires two 555 Timers we will be using an IC that contains two complete 555 Timers on a single chip (Unsurprisingly called the NE556 Timer).

The Optical Theremin kit contains the following components:

- 1 – Prefabbed printed circuit board (PCB)
- 1 – Dual 556 Timer Microchip
- 1 – 14 Pin chip socket
- 2 – 1kΩ Resistor (R1, R2)
- 1 – 10kΩ Resistor (R3)
- 2 – CdS Photoresistors (CDS-1,CDS-2)
- 2 – 0.01 µF Capacitors (C1, C2)
- 2 – 3mm LEDs (LED1, LED2)
- 1 – 2N2222A Transistor
- 1 – 5kΩ pot with knob (VOLUME)
- 1 – 150Ω Speaker
- 2 speaker wires (red and black) (SPKR)
- 1 – 9V battery snap (9V)
- 2 – Pieces of shrink tubing
- Zip-tie for strain relief

Solder the components onto the PCB as indicated. Please note the following cautions:

- The LEDs should be installed so the low voltage side (usually the shorter leg) is closer to the flat side of the silk screen image.
- Line up the tab of the 2N2222A with the tab on the silk screen image.
- Solder in the chip socket holder so the notch is lined up with the notch on the silk screen image
- Install the 556 timer in the socket so the notch is aligned with the notch of the socket
- The speaker has very small and delicate attachment points, so be careful soldering the red and black wires on.
- Install the CdS sensors (orientation doesn't matter) so that the sensors are at least ½ an inch above the circuit board. This will allow you to adjust their orientation.
- Standoff screws with nuts (not included) can be installed at the corners to create a stand or install in a box. The zip tie can then be used to secure the battery snap wires to a support leg.

## Theremin operation

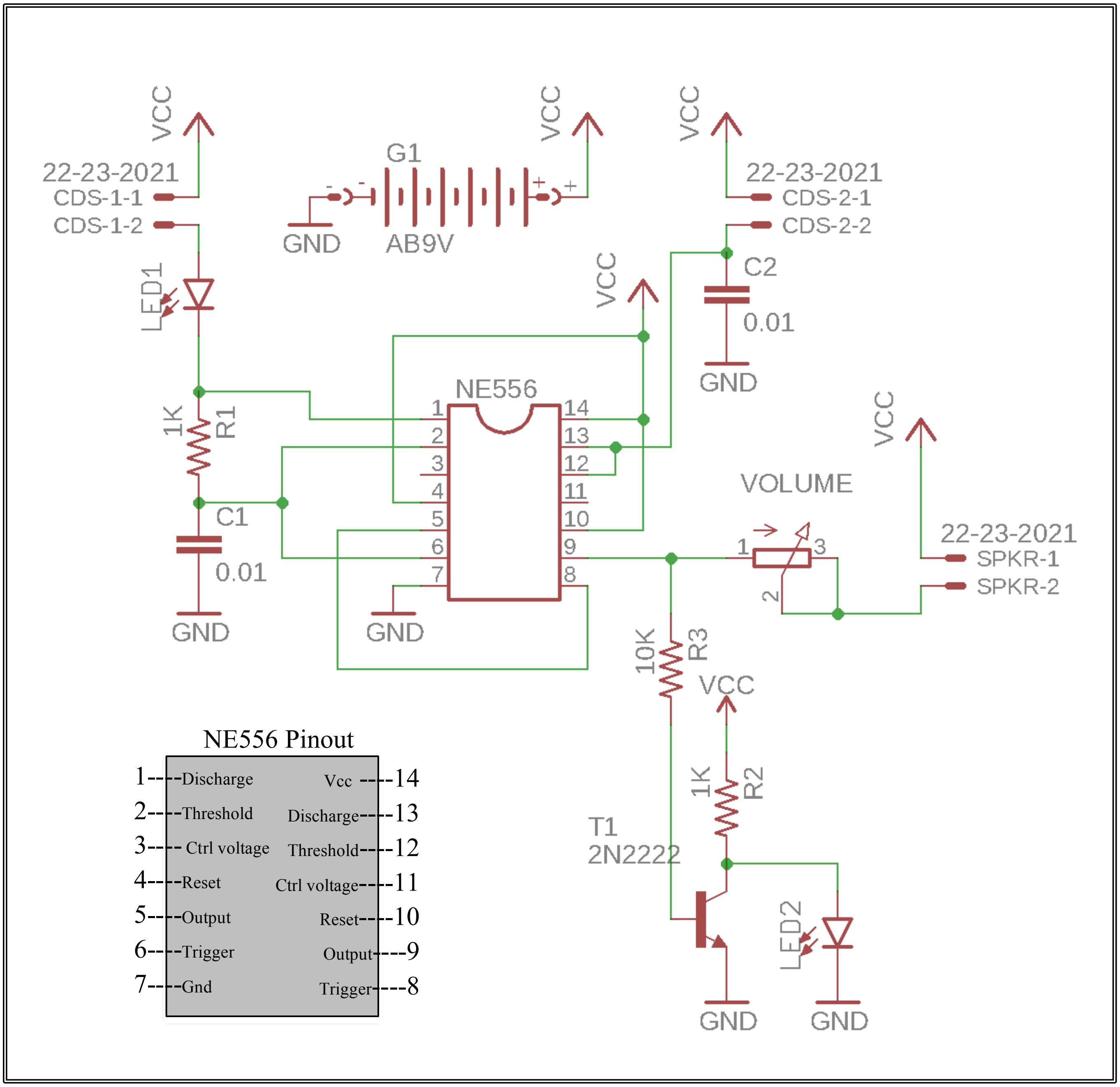
Set the potentiometer to a midrange position. Place pieces of shrink tubing over the CdS sensors so that the sensor faces are 2 – 5 mm inside the tube. Attach a Fresh 9V battery to the battery snap. At this point, you should hear a tone. If you don't, double check your circuit making sure all parts are soldered in properly. Experiment with moving your hands over the tube openings to produce weird science fiction effects. If it's too loud, adjust the volume by adjusting the potentiometer. If you like, you can get fancy and make a box for your Theremin using the size 6 screw holes in the corner of the PCB. A number of electronic hobby web sites sell them. Below are a few sites worth visiting for a box or any of the parts included in this kit.

This device constantly draws power, whether you can hear anything or not. Make sure you disconnect the battery when not in use or the battery will drain in a few hours.

**Electronics Parts Vendors to obtain additional components**

- Mouser Electronics (http://www.mouser.com)
- Digikey (http://www.digikey.com)
- Newark Electronics (http://www.newark.com)

## CIRCUIT DIAGRAM FOR OPTICAL THEREMIN




*Created with EagleCAD by S. Irons*

# How does the Optical Theremin work?

To understand how the Optical Theremin produces the sound, we must first determine how the circuit uses the 555 Timers to produce a tone.

Each 555 Timer has the following property:

- **OUT** will go high (to Vcc) when the input on **TRIGGER** falls below 1/3 Vcc. This also starts a timing interval. It will stay high until the threshold condition is met (described below).
- **OUT** will go low (to GND) when the input on **THRESHOLD** rises above 2/3 Vcc. At this instant, **DISCHARGE** will become a low impedance short to ground, otherwise it is a effectively infinite resistance. This also signals the end of the timing interval.
- **CTRL** and **RESET** are not important in this application and are set to N/C and Vcc respectively.

Consider the first timer (on the left hand side of the 556). Imagine the following: The first 555 is connected to Vcc but the CdS photocell is not. Since the voltage into **TRIGGER** and **THRESHOLD** is undefined, **OUT** is showing a voltage of zero or GND.

1. You connect the photoresistor to Vcc. This immediately defines the voltage at **THRESHOLD** and **TRIGGER** to be GND. This causes **OUT** to swing to high(Vcc) and begin an interval.
2. The capacitor will begin to charge with a characteristic time constant given by $t = (R_{CdS} + R)C$.
3. Once the voltage on the capacitor reaches 2/3 Vcc (also **THRESHOLD**), **OUT** will be driven low(to GND). This ends the interval. At this point, **DISCHARGE** becomes a short to ground, allowing the capacitor to discharge through the 1K resistor with a shorter time constant.
4. As soon as voltage on the capacitor drops below 1/3 Vcc, **OUT** goes high again and the process repeats. This gives us a square wave output, which, if we choose our resistors and capacitors correctly would produce an audible tone if connected to a speaker.

Looking at the right hand side of the circuit, we see that the **TRIGGER** of the second 555 Timer takes a square wave input of a particular frequency. Imagine that the input to the **TRIGGER** swings low.

1. **OUT** will go high since **TRIGGER** is below 1/3 Vcc and begin the interval.
2. Meanwhile, the RC network consisting of the CdS photoresistor and capacitor is charging up with a time constant that is shorter than the one on the left side.
3. When the voltage on **THRESHOLD** reaches 2/3 Vcc, **OUTPUT** goes low and the capacitor is immediate discharged through **DISCHARGE**, but begins charging again immediately.
4. Since this time constant is much shorter than the one on the right. It essentially divides the frequency of the input to the **TRIGGER**, producing a tone at the second **OUT** that is a fraction of the signal coming from the **OUT** of the first timer.

By changing the resistance of the two photoresistors, you dynamically change the output tone in two different and continuous ways. This produces the weird vibrato type effects.

**Note on the LEDs**

The LEDs are just an aesthetic add-on to visually show how the resistance in the CdS cells are changing with varying light levels. They can be omitted without affecting the performance of the device. In the case of LED1, merely replace it with a continuous wire. For LED2, you should remove the transistor/LED network, including the 10K resistor hanging off pin 9.