build your own tone generator

the voice of every synthesizer

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PHOTOGRAPHY BY ADAM COISH

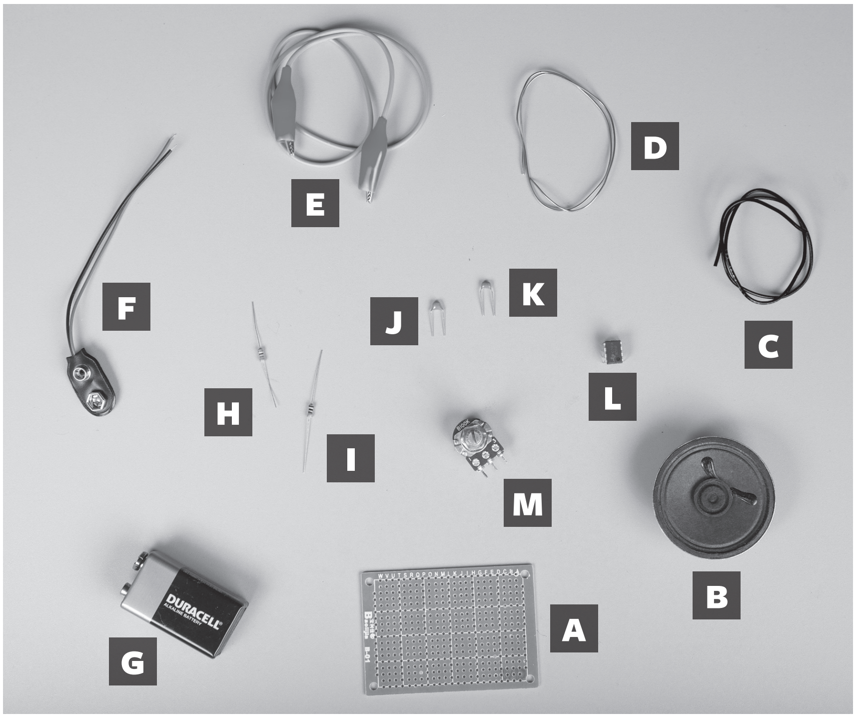
EVERY SYNTHESIZER STARTS with an oscillator. It's the part that generates the tones that are then shaped by filters and amplifiers. It's analogous to the string of a stringed instrument, or the reed of a reed instrument. Different oscillators produce different wave shapes—the one we're going to make produces square waves, or rather, something close to a square wave.

We'll use a venerable integrated-circuit chip called a 555 timer, whose invention dates back to 1971. It could well be the most popular chip ever made. It's a bit of a Swiss Army knife for timing applications, and a Web search will turn up hundreds of different circuit configurations using it. The circuit we'll build is technically an *astable multivibrator*, meaning it's a circuit which has two states, neither of which is stable—the circuit will flip back and forth, or *oscillate*, between them. It is this sudden flipping between states that gives the square-wave oscillator its characteristic wave shape, in contrast to other oscillators which have waveforms which vary continuously, producing shapes such as sine waves and triangle waves.

While a single oscillator is not the most expressive instrument, you can compare the output to early electronic instruments such as the ondes Martentot and the theremin. Simple oscillators were used in electronic music of the 1950s and '60s—for example, in Hugh LeCaine's oscillator bank of 1959. They have also found use in pop music—the lead singer of the '60s band Silver Apples, played a laboratory oscillator on stage, and in dub reggae oscillators can be heard through layers of delay and reverb (these are known as *dub sirens*). Of course, if the sound of a single oscillator is not enough, you can always build several, and combine them for a more complex sound, as LeCaine did.

We'll build the oscillator without a fixed input device—you can experiment with a variety of input devices: knobs (potentiometers), various kinds of sensors, liquids, pencil lines, or even your own body. By varying the resistance of the input device you vary the amount of resistance that completes the circuit, and in so doing you vary the frequency—or pitch—of the oscillator. If you decide you like some particular device, you can solder it in and make it a permanent part of your tone generator (as long as it's not your body).

set up



MATERIALS SOURCES

If you live in a large city, you will have more options for buying parts and tools. Dedicated electronics retailers:

Active Components online
<**http://www.active123.com**>

Creatron in Toronto
<**www.creatroninc.com**>

Addison in Montreal
<**www.addison-electronique.com**>

There are excellent on-line sources:

Digikey <**www.digikey.com**>

Mouser <**www.mouser.com**>

materials

- **[A]** 1 small piece of circuit board
- **[B]** 1 8-ohm speaker
- **[C]** Insulated hookup wire, 22 gauge or smaller
- **[D]** Rosin-core electronics solder (consider using lead-free variety)
- **[E]** 1 alligator-clip test lead
- **[F]** 1 battery holder for a 9-volt battery
- **[G]** 1 9-volt battery
- **[H]** 1 1k-ohm quarter-watt resistor (coded with three bars: brown, black, and red)
- **[I]** 1 150-ohm quarter-watt resistor (coded with three bars: brown, green, and brown)
- **[J]** 1 0.1 μF capacitor (usually marked 104)
- **[K]** 1 0.01 μF capacitor (usually marked 103)
- **[L]** 1 555 timer chip. The chip you want should be an NE555 or an LM555, or be compatible with those, and be in an 8-pin DIP package
- **[M]** 1 100k-ohm potentiometer. Audio taper (type "a") is best, but linear (type "b") will work just fine

tools

- **[1]** Soldering iron, with small tip, 40 watts or less
- **[2]** Wire strippers
- **[3]** Small wire cutters
- **[4]** Needle-nose pliers

Not pictured:
1 set of helping hands (tool)
1 indelible-ink marker
Safety glasses or goggles

WHAT YOU NEED TO KNOW BEFORE BEGINNING

how to solder

There is a good collection of soldering resources on the Web site of Limor Fried, an engineer and artist who makes and sells electronic kits at <**www.ladyada.net/learn/soldering/thm.html**>. Also, search for "How and why to solder correctly" on <**www.youtube.com**>.

how to de-solder

<**www.youtube.com/watch?v=tOGhwss50ZE**>.

how to work with a circuit board

A page specifically about circuit-board techniques, as used in this project, can be found at <**itp.nyu.edu/physcomp/Tutorials/SolderingAPerfBoard**>. An excellent book for electronics beginners is *Make: Electronics*, from O'Reilly media, <**oreilly.com/catalog/9780596153755**>. ISBN: 0596153750

information on the 555 timer

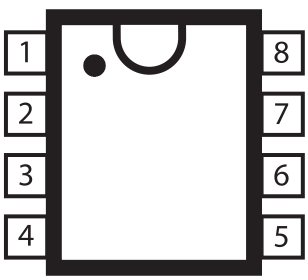
<**http://en.wikipedia.org./wiki/555_timer**>.

make it

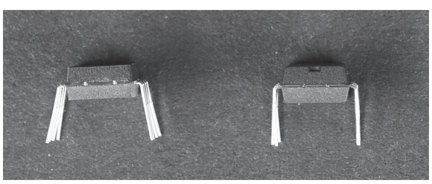
time: an afternoon **complexity:** easy **cost:** ten dollars
what you need to know: how to solder, plus basic electronic construction techniques.

1 prepare the 555 timer chip

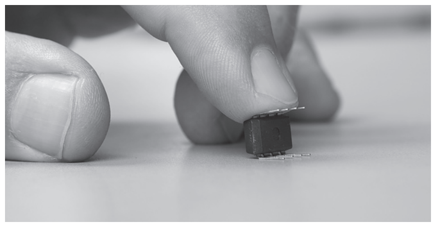
1a. Identify pin 1 of your chip. The key to identifying the pins is finding pin 1, which is to the left of the circular indentation at the uppermost corner of the chip. The remaining pins are numbered 2 through 8 in a counter-clockwise direction around the chip.



1b. Check the pins of your chip. When the chip is manufactured, the pins are not often at right angles to the chip, which prevents the chip from fitting into the holes of the circuit board.

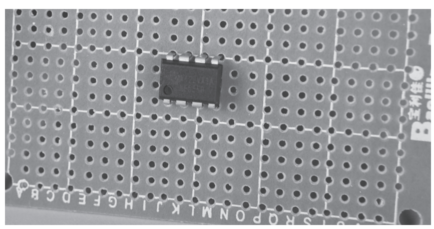


1c. Straighten the pins of the chip. If they are not at right angles to the chip, straighten by slightly bending them on a flat surface, as shown.

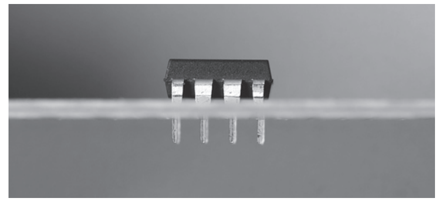


2 mount the 555 timer chip to the circuit board

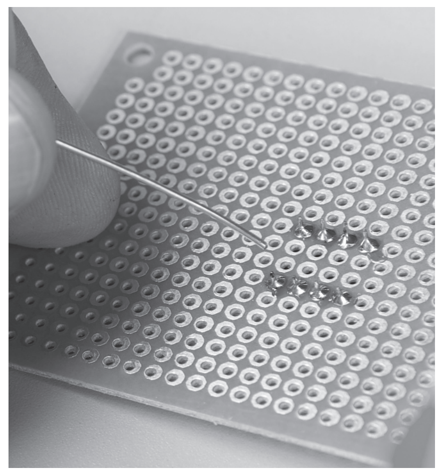
2a. Orient the chip on the circuit board, making sure that pin 1 is positioned to the lower left, as shown.



2b. You will solder and make connections on the underside of the board, so make sure all the pins of the chip go through the board, and are not bent underneath the chip. Don't force them.



2c. Flip the board upside down and solder the chip in place at all eight pins.



2d. Mark pin 1. On the underside of the board, with an indelible marker write 1 to keep the correct orientation when you're working on the circuit board. Note: because this is a mirror image of the board top, the remaining pins are numbered 2 through 8 in a clockwise fashion around the chip.

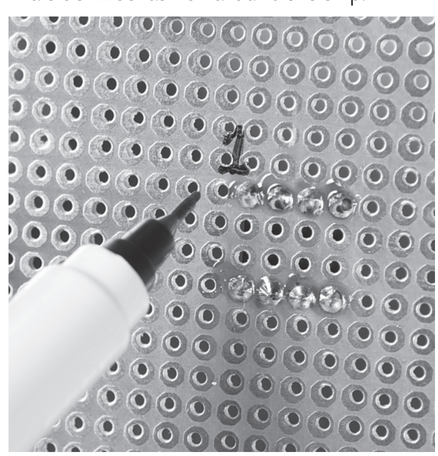
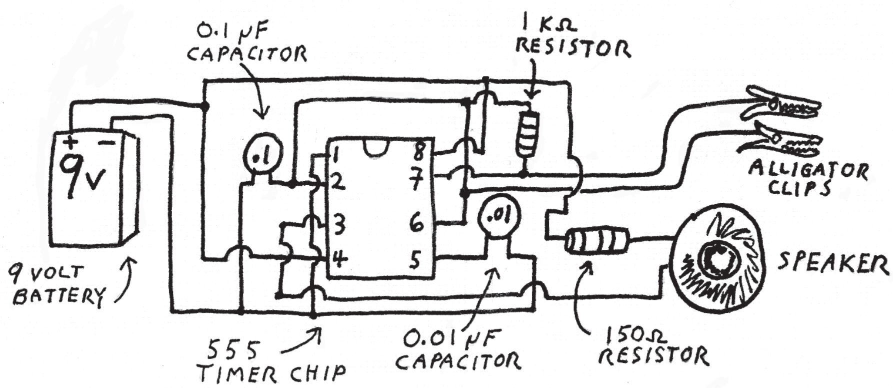
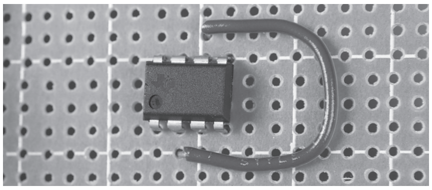


figure 1: VARIABLE-INPUT OSCILLATOR, PICTORIAL DIAGRAM

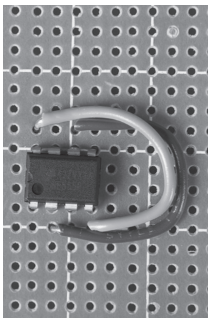


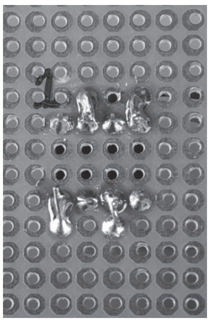
3 wire up the circuit

3a. Using a length of hookup wire, solder a connection between pins 6 and 2 of the chip.

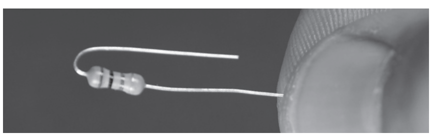


3b. Using a length of hookup wire, solder a connection between pins 4 and 8 of the chip.

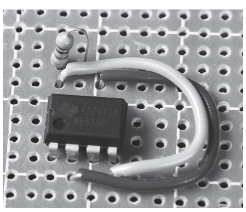




3c. Prepare the 1k-ohm resistor, bending leads as shown.

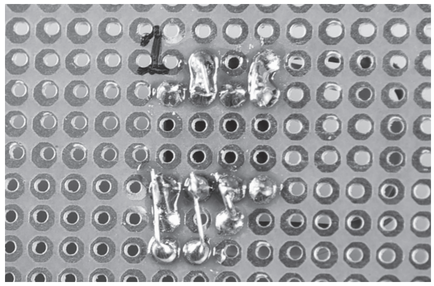


3d. Mount the 1k-ohm resistor as shown. Note: the resistor can go in either way—there is no positive or negative lead.

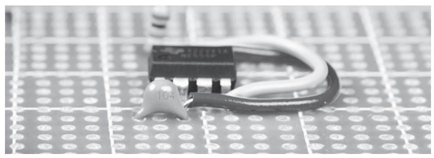


3e. Solder a connection between the other lead of the resistor to pin 7 of the chip.

3f. Solder a connection between one lead of the resistor to pin 8 of the chip.



3g. Mount the first 0.1 μF capacitor as shown. Note: these capacitors, like the resistors, do not have polarity—they can go in either way.



3h. Solder a connection between one lead of the capacitor to pin 1 of the chip.

3i. Solder a connection between the other lead of the capacitor to pin 2 of the chip.

3j. Mount the second 0.01 μF capacitor as shown.

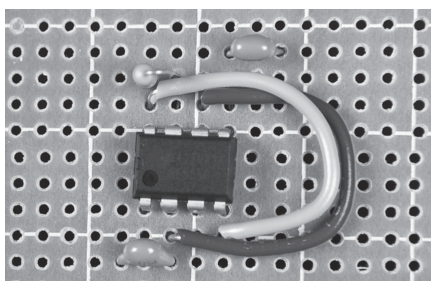
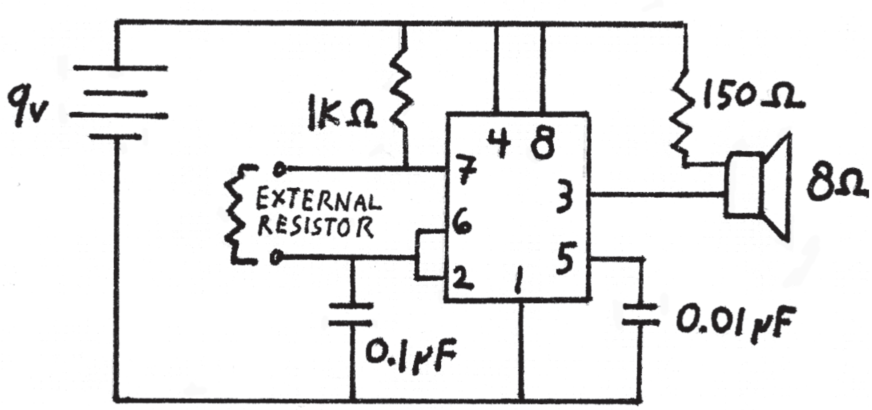


figure 2: VARIABLE-INPUT OSCILLATOR, CIRCUIT SCHEMATIC



GLOSSARY

Capacitor. A device that stores electrical charge. It is used in this circuit to determine the frequency of the oscillator.

Capacitance. A measure of the amount of energy a capacitor can store.

Chip. An informal name for an integrated circuit, a complex electronic circuit constructed on a tiny piece of silicon.

Circuit Board. A board, usually fibreglass, perforated with holes for mounting components in.

DIP. Dual Inline Pin. Refers to the physical configuration, or "package" of the chip.

Farad. A unit of capacitance, named after Michael Faraday.

Frequency. The rate at which an oscillator's waveform repeats.

Ground. The common point in a circuit, where all signals return.

Hertz. A measure of frequency, named after Heinrich Hertz, previously called Cycles Per Second, or cps. The frequency A440, used as a tuning standard in Western music, is 440 Hertz.

Kilo. A prefix meaning 1000. One kilo ohm, usually written 1k-ohm, or 1 kΩ, is 1000 ohms.

Multivibrator. An electronic circuit having two states, which may or may not be stable.

Mμ. The Greek letter mu, used as a prefix meaning micro, or 1 millionth. "0.1 μF" is pronounced point one microfarad.

Oscillator. An electronic circuit having repetitive cyclical behaviour.

Ohm. A unit of electrical resistance, named after Georg Ohm.

Pins. The electrical connections to a chip, also called legs.

Potentiometer. A variable resistor, often called a pot for short. The name is derived from an early use in circuits to measure electrical potential, also known as voltage.

Resistor. A device that limits electrical current.

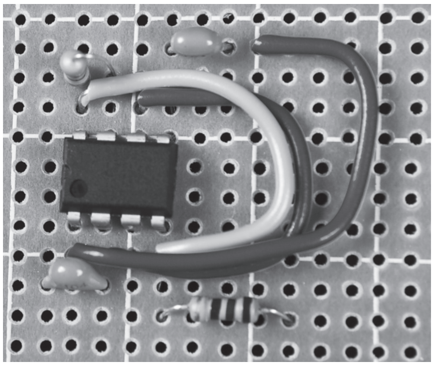
Wire Gauge. A system for specifying wire sizes. Smaller diameter wires have larger gauge numbers.

Ω. The Greek letter omega, used as a symbol for ohms.

3k. Solder a connection between one lead of the second capacitor and pin 5 of the chip.

3l. Using a length of hookup wire, solder a connection between the other lead of the second capacitor and pin 1 of the chip.

3m. Mount the 150-ohm resistor as shown.



3n. Solder a connection between one lead of the resistor to pin 4 of the chip.

TROUBLESHOOTING

If there is no sound, *immediately* disconnect the battery!

1. Make sure you are using a fresh battery.

2. Check if the chip is hot.

Be careful. Touch it quickly, as if you were testing an iron. If it's hot, three things are possible:

- **The power to the chip is wired backwards.**
- **The output is short-circuited.**
- **You did not correctly identify pin 1, and therefore wired the chip backwards.**

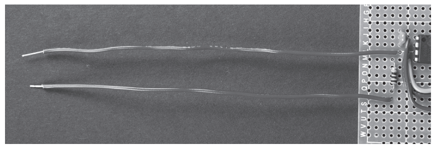
3. If there is no sound, and the chip is not hot:

- **Check that all connections have been made to the correct pins, and that there are no solder "bridges" between adjacent pins. If any solder connections look suspicious, reheat them with the soldering iron to remelt the solder. Make sure that the power is not connected to the circuit while soldering.**
- **Check that you have not mixed up the resistors and capacitors. It's possible that your circuit may "sort of" work if you've done this.**
- **If you've made a mistake, you can often correct it using de-soldering braid, available where you buy electronics supplies.**

4 mount the loudspeaker to the circuit

4a. Cut a 3-inch piece of hookup wire and solder it to pin 3 of the chip.

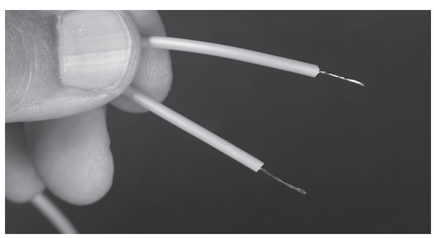
4b. Cut a 3-inch piece of hookup wire and solder it to the free end of the 150-ohm resistor, as shown. These will be your loudspeaker leads.



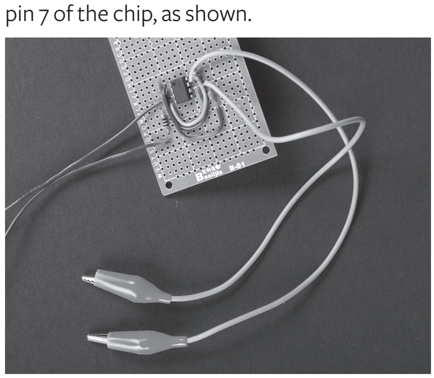
4c. Solder your speaker leads directly to your loudspeaker, as shown. Note: you don't need to worry about polarity, although the speaker will be marked to indicate the positive terminal, with a + sign, or a red terminal.

4d. Cut the alligator-clip lead in half, and strip the cut ends as shown. You will now have two separate alligator clip leads.

4e. "Tin" the leads with a small amount of solder, to keep them from fraying.

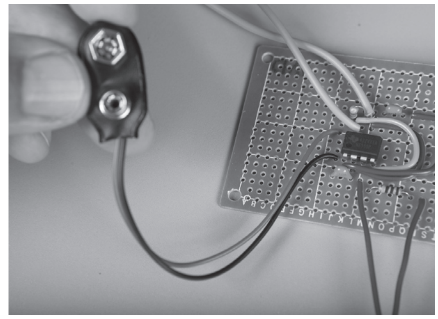


4f. Solder the stripped end of one alligator clip to pin 6 of the chip, and the other clip to pin 7 of the chip, as shown.



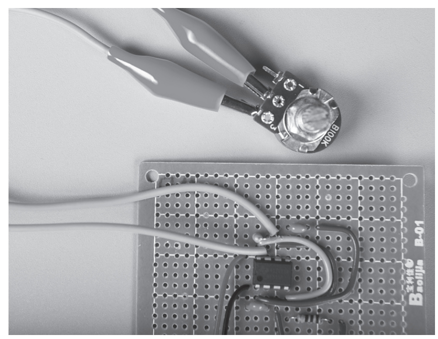
4g. Solder the red lead from the battery clip to pin 8 of the chip.

4h. Solder the black lead from the battery clip to pin 1 of the chip, as shown.

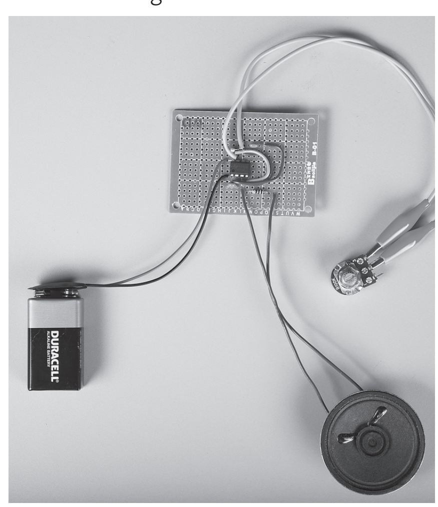


5 testing your circuit

5a. Connect one alligator-clip lead to the middle terminal of the 100k-ohm potentiometer and another to one of the outer terminals, as shown. Leave the other terminal free. Set the potentiometer to about mid-point.



5b. Connect the 9-volt battery. You should hear a tone from the speaker. If you don't hear anything, disconnect the battery immediately, and go to the troubleshooting section.



use it

Besides the potentiometer, you can connect any resistive element between the two alligator-clip leads to produce different frequencies. Lower resistances produce higher frequencies, and vice-versa.

Some things to try:

Various fixed resistors.

Your own body. Try holding the leads with dry and wet fingers and notice the difference. There are no hazardous voltages involved, although you may feel a tingle.

Soil or wood. You can use long nails as moisture sensors, either in the ground or hammered into a board.

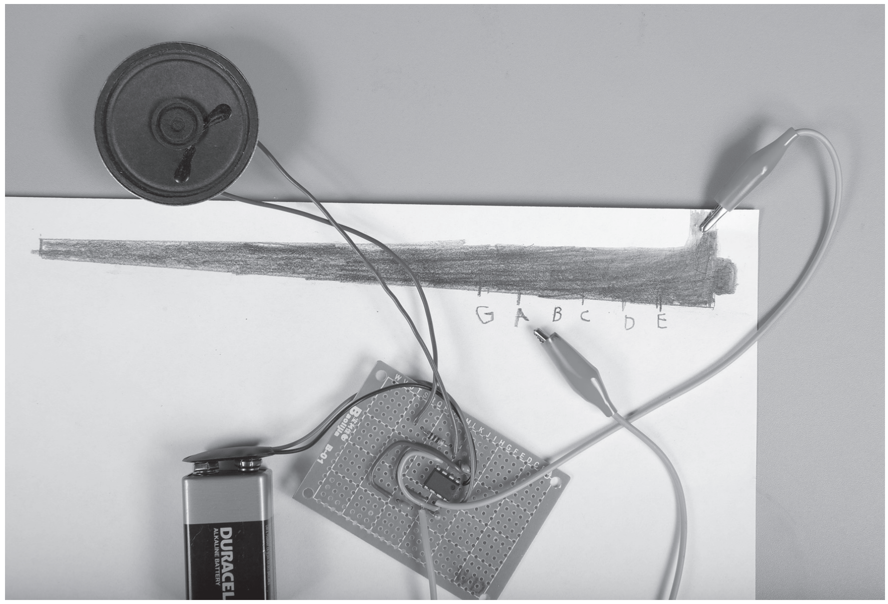
Pencil drawings. Use a very soft pencil, such as a 2B or softer, and for best results draw very heavy lines. Clip one lead to a spot on the drawing, and move the other lead around. See if you can draw a properly tuned keyboard.

Flexible-bend sensors. For sources of these, search the Web for “flex sensor,” “bend sensor,” or “stretch sensor,” using your favourite Web search engine.

Light-dependent resistors, also known as cadmium sulphide photocells. You can make a surprisingly expressive light-theremin out of your oscillator. Try exposing the sensor to small flashing lights, such as bicycle lights, to produce rhythms.

Try various speakers. Pretty much any speaker you can find can be used.

You could try placing the speaker in various resonant objects. Add things that modify the sound. Look up the ondes Martenot to see the various kinds of speakers that it used, or read about David Tudor’s piece *Rainforest* for some inspiration.



Food or liquids. Please do not consume them, being sure to discard them after they have been in contact with the leads.

You may wish to build your circuit into some sort of permanent enclosure. You can get purpose-made project boxes at the place where you buy electronic parts, but you may also consider repurposing old electronic devices, such as radios or answering machines. You can often rewire the existing knobs to control the oscillator, and use the existing speakers for the output. Or you could use such things as cigar boxes, usually available for a few dollars from a cigar store.

TOP: A properly tuned drawing of a oscillator keyboard. By varying the amount of pencil grafite (darkness and thickness of line) you can make a playable keyboard.

LEFT: The leads of the oscillator can be immersed into liquids or attached to food, such as sushi. By varying the resistance of the input device you vary the amount of resistance that completes the circuit, and in so doing you vary the frequency—or pitch—of the oscillator.

ABOVE: The oscillator leads can be attached to photocells and played by altering the light source.

HOW IT WORKS

Often, when we need some sort of timing function in an electronic circuit, we use a combination of a resistor and a capacitor. A capacitor is like a bucket for electrons. Just as with a real bucket, we can fill it at one rate and empty it at the same rate, or empty it faster or slower than we filled it.

The rate of filling the capacitor with electrons is determined by the resistor which we connect to it. The product of the value of the resistor in ohms, and that of the capacitor in farads is called the time constant, and is given in seconds. As a rule of thumb, a given resistor-capacitor combination will charge up to the applied voltage in five time constants.

In our circuit, the timing of the waveform is controlled by the 1k-ohm resistor, the resistance connected between the alligator-clip leads, and the 0.1μF capacitor. The 555 timer “looks at” the voltage on the capacitor (via pins 2 and 6) and begins to charge the capacitor through both the 1k resistor and the variable resistor. At this time, the waveform on the output pin goes high. When the voltage on the capacitor reaches two thirds of the supply voltage, the output goes low, and the capacitor begins to be discharged by pin 7, this time only through the variable resistor. When the voltage falls to one third of the supply voltage, the cycle repeats.