how to build a

glitchy square-wave sequencer

1-bit music mayhem

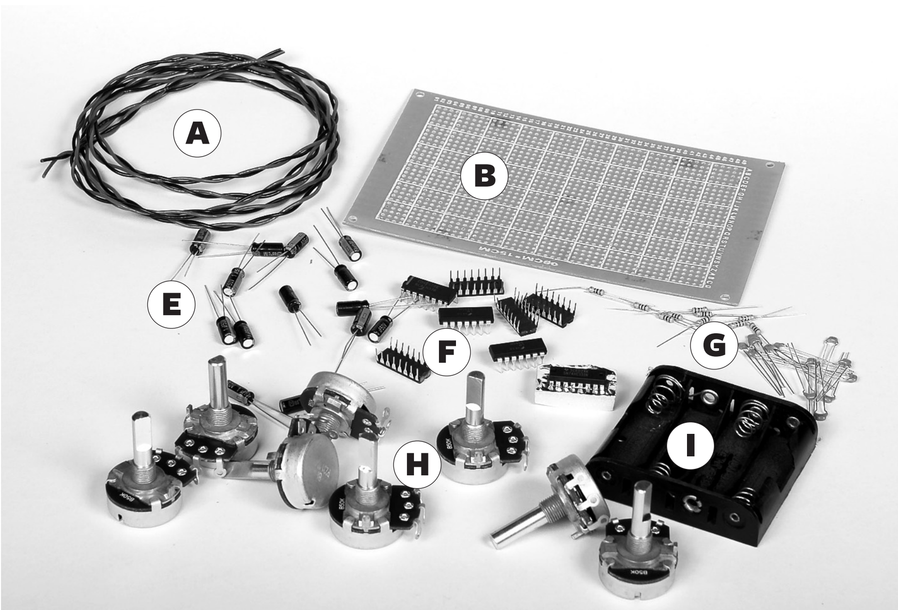
PHOTO BY ADAM COISH

TEXT AND IMAGES BY ROB CRUICKSHANK

THE SOUND OF A SQUARE-WAVE sequencer instantly brings to mind the sounds of some of the earliest video games, as well as—for some—the earliest computer music. A square wave is the simplest waveform to produce digitally, for it can be generated from a single digital line, without needing an analog-to-digital converter. You may be familiar with 8-bit music from video games or the chiptunes scene; we're going to make something even more primitive: it's 1-bit music. It's possible to get it to sound a bit like *Space Invaders* or *Pong*, but more sophisticated tunes—or even playing more than one note at a time—are beyond its capabilities. Don't expect it to hold a reliable pitch for anything really musical that you could sing along to. However, it's still a lot of fun to play with. It looks and sounds a bit like the old analog sequencers seen on modular synthesizers.

Be aware that this is a fairly involved circuit. If you haven't built anything electronic before, start with something else small, like the oscillator in MW108 *Build Your Own Tone Generator*. The eight oscillators in this project are each a version of that circuit. To do this project in hardware may seem unduly complicated, and it's fair to ask: why not do it instead with a microcontroller, such as an Arduino? Well because, by building this circuit, you'll have a chance to understand completely how it works, from beginning to end; it's a really good introduction to digital electronics; and you'll gain valuable experience in circuit layout and construction techniques. And because it's fun. Building a circuit can be relaxing in a way that programming seldom is.

set up



tools (NOT PICTURED)

Soldering iron with small tip, 40 watts or less. A temperature-controlled soldering station is highly recommended.

Small wire cutters.

Wire strippers suitable for 24-gauge wire.

Needle-nose pliers.

Safety glasses or goggles.

Indelible-ink marker and pencil.

Masking tape.

Double-sided tape.

Ruler marked in inches *and* millimetres.

Drill, with a series of drill bits 1⁄16 to ¼ inch.

Small screwdriver.

Multimeter.

Logic probe or oscilloscope (optional, but highly recommended).

materials

[A] **Insulated hookup wire: 24 gauge solid-core, 2 metres; 24 gauge stranded core in two colours, 2 metres.**

[B] **1 piece of circuit board: 10 cm X 15 cm or bigger.**

[C] **Rosin-core electronics solder (not pictured). Consider using the lead-free variety.**

[D] **1 case: we built the prototype in a cigar box. Your local cigar shop will often have empty boxes available for only a few dollars, or you could buy a full one and throw away the cigars. Whatever you use, make sure it's big enough for the circuit, batteries, and all 10 potentiometers (a.k.a. pots).**

[E] **Capacitors**

C1: 10µF electrolytic capacitor.

C2, C7, C12, C17, C22: 100µF electrolytic capacitor (5 required).

C3, C4, C5, C9, C11, C14, C16, C19, C21, C24, C26: 0.1µF monolithic ceramic capacitor (11 required).

C6, C8, C10, C13, C15, C18, C20, C23 C25: 1µF electrolytic capacitor (9 required).

NOTE: Any voltage rating for the electrolytic capacitor in this circuit is suitable, because any that you buy will be rated higher than the 6 volts used in the circuit. Capacitors rated for higher voltages will be physically bigger than those rated for lower voltages, but are functionally identical.

[F] **Integrated Circuits**

IC1: LM555CN timer.

IC2: 74HC161 counter. Make sure to use the HC (high-speed CMOS) version of this part.

IC3: 74HC151 data selector. Make sure to use the HC (high-speed CMOS) version of this part.

IC4, IC5, IC6, IC7: LM556CN dual timer (4 required).

[G] **Resistors**

R2, R5, R8, R11, R14, R17, R20, R23, R26: 1k-Ohm ¼-watt resistor (9 required).

R3: 100k-Ohm ¼-watt resistor.

R6, R9, R12, R15, R18, R21, R24, R27: 220-Ohm ¼-watt resistor (8 required).

[H] **Variable Resistors—Potentiometers**

R1: 100k-Ohm linear taper potentiometer.

R4: 100k-Ohm logarithmic (audio) taper potentiometer.

R7, R10, R13, R16, R19, R22, R25, R28: 50k-Ohm linear taper potentiometer. (8 required).

NOTE: Potentiometers with a *reverse* logarithmic taper will work better for these and for R1, but are more difficult to find than linear taper parts.

[I] **1 four-slot AA battery holder.**

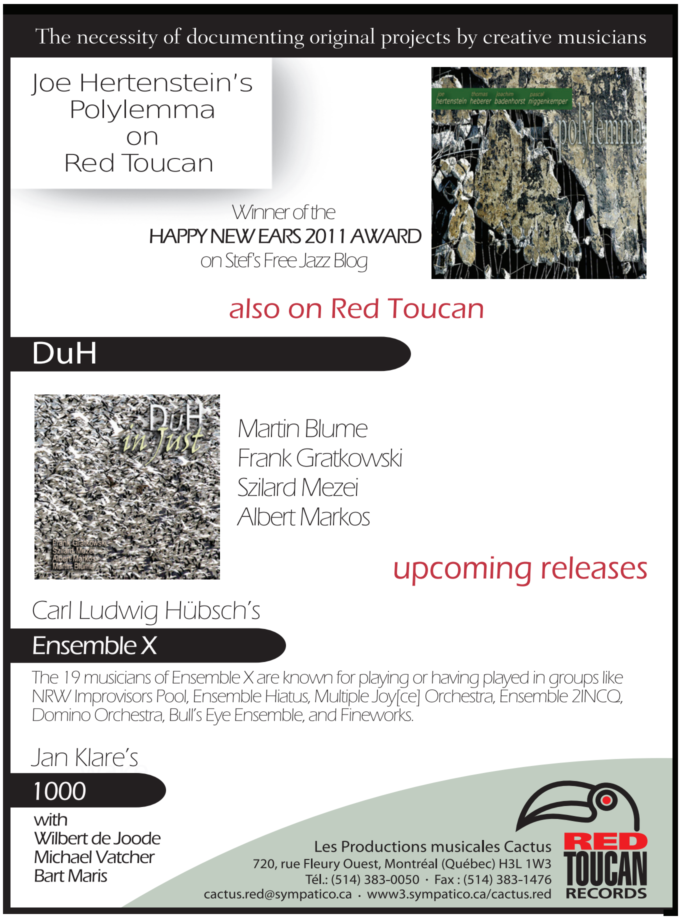
[J] **4 AA alkaline batteries (not pictured).**

[K] **10 potentiometer knobs (not pictured).**

NOTE: Make sure the knobs you buy fit the shafts of the potentiometers you use. There are a surprising number of combinations of the locations of knob pointers, setscrews, and the flat parts on pot shafts. Make sure you try out the knobs on the pot shafts before assembling, to make sure the maximum and minimum points are indicated correctly when everything is assembled.

[L] **4 6-32 or M3.5 machine screws and nuts (not pictured).**

[M] **1 output jack: ¼" guitar-style or RCA (female) jack (not pictured).**



The necessity of documenting original projects by creative musicians
Joe Hertenstein's Polylemma on Red Toucan
Winner of the HAPPY NEW EARS 2011 AWARD on Stef's Free Jazz Blog
also on Red Toucan
DuH
Martin Blume
Frank Gratkowski
Szilard Mezei
Albert Markos
upcoming releases
Carl Ludwig Hübsch's
Ensemble X
The 19 musicians of Ensemble X are known for playing or having played in groups like NRW Improvisors Pool, Ensemble Hiatus, Multiple Joy[ce] Orchestra, Ensemble 2INCQ, Domino Orchestra, Bull's Eye Ensemble, and Fineworks.
Jan Klare's
1000
with
Wilbert de Joode
Michael Vatcher
Bart Maris
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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, **<www.ladyada.net/learn/soldering/thm.html>**. Also see **<www.youtube.com/watch?v=I_NU2ruzyc4&feature=player_embedded>**.

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>**. Another good book is *Getting Started in Electronics* by Forrest M. Mims.

how to read and follow a schematic

<http://artsites.ucsc.edu/EMS/music/tech_background/schematics/ReadSchem.html>

you should understand integrated circuits—ICs, or chips

You should also look up the data sheets for the individual chips used in the project. The best resource for this is the Web site Octopart **<www.octopart.com>**. The data sheets for the ICs are available as multi-page PDFs.

MATERIALS SOURCES

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

Active Tech in major cities across Canada, <www.active123.com>

Creatron in Toronto, <www.creatroninc.com>

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

These are excellent online sources:

Digi-Key, <www.digikey.com>

Mouser Electronics, <www.mouser.com>

make it

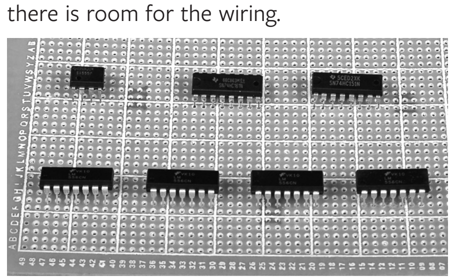
time required: a couple of weekends (30 hours) **complexity:** advanced **cost:** 40 dollars
what you need to know: how to solder, electronic construction techniques, the basics of integrated circuit; and you need to be comfortable using a power drill

NOTE: Due to the complexity of the circuit, wire-by-wire instructions are not detailed. Ensure that you have read and understand all the instructions before you begin. A good way to proceed is to make a copy of the schematic, and, as you install each part, and make each connection, mark it with a highlighter on the schematic. That way you can see at a glance if you've forgotten something, and it makes it easy to keep track of where you are, if you are building the project over several days.

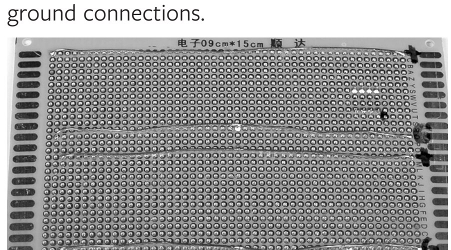
1 prep the circuit

1a. Fit the circuit board into the case you've chosen. If it does not fit, cut the board to size, leaving room for the battery holder to be placed into the box beside the circuit. Make sure there is clearance for the wiring and the potentiometers.

1b. Dry fit the circuit. Place all the ICs onto the circuit board without solder making sure there is room for the wiring.



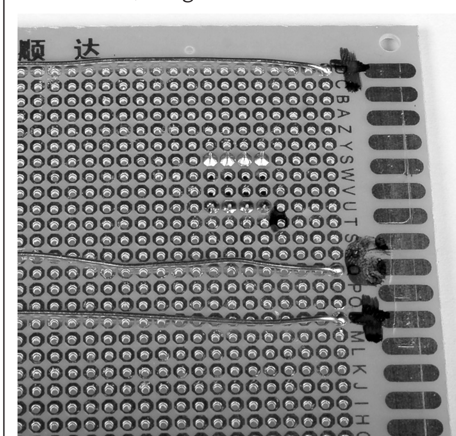
1c. Establish power buses on the circuit board. Use solid, uninsulated hookup wire or bus wire to make positive and negative connections on the underside of the board. NOTE: The power buses will be used to connect the positive and negative of the battery via the power switch S1, and to provide points for each chip's power and ground connections.



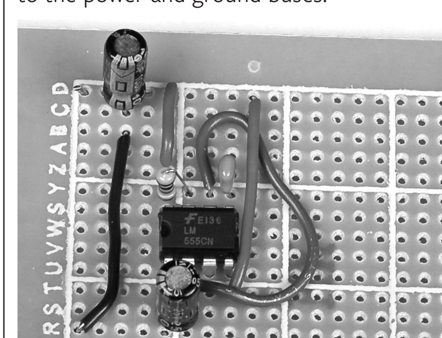
2 build the clock

2a. Mount the 555CN chip (IC1) on the circuit board. Make sure that pin 1 is at the lower left when looking at the board right side up.

2b. Mount R2 and C1, C2, and C3 nearby. NOTE: Make sure you identify pin 1 of the chip. It's a good idea to mark pin 1 on the underside of the board, using an indelible marker.



2c. Make all connections to IC1 as shown in the schematic. Don't forget the connections to the power and ground buses.



2d. Connect to pins 6 and 7 of 555CN chip (IC1) two pieces of stranded wire long enough to reach the potentiometer R1 when the board is installed in the case. It's better to make these slightly long, then trim them in final assembly rather than have them too short.

2e. Twist these wires together and label the wires with masking tape marked *tempo*.

3 build the counter

3a. Mount the 74HC161 counter chip (IC2) near IC1. Make sure that pin 1 is at the lower left when looking at the board right-side up.

3b. Mount C4 as near to IC2 as possible.

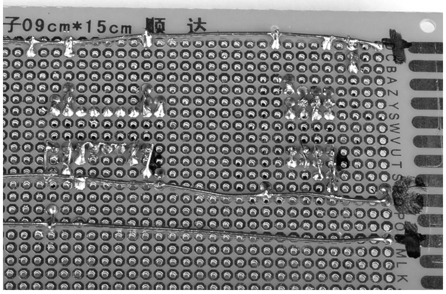
3c. Connect one lead of C4 to pin 14 of IC2 and the other to pin 7 of IC2.

3d. Connect pin 14 of IC2 to the positive supply, and pin 7 of IC2 to ground.

NOTE: C4 does not have polarity—it can be wired either way.

3e. Make all connections to IC2 as shown in the schematic, taking careful note of which pins are tied high (connected to the positive supply), and which are tied low (connected to ground).

3f. Connect pin 3 of IC1 (clock output) to the pin 2 of IC2 (clock input).



4 build the data selector

4a. Mount 74HC151 data selector chip (IC3), beside IC2. Make sure that pin 1 is at the lower left when looking at the board right-side up.

NOTE: Make sure in the following steps that you leave lots of room on the circuit board for the eight signal lines that will come from the oscillator section.

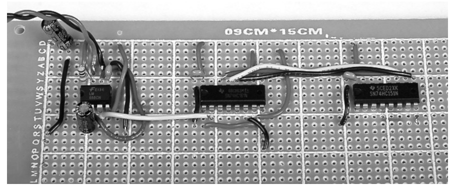
4b. Mount C5 as near to IC3 as possible.

4c. Connect one lead of C5 to pin 14 of IC3 and the other to pin 7 of IC3.

4d. Connect pin 14 of IC3 to the positive supply, and pin 7 of IC3 to ground.

4e. Connect pin 6 of IC3 to pin 7 of IC3.

4f. Connect the outputs QA, QB, and QC of IC2, to the inputs A, B, and C of IC3 as shown on the schematic.



4g. Mount R3 and C6 near IC3, and wire them as shown on the schematic:

i. Connect pin 5 of IC3 to one lead of R3.

ii. Connect a length of stranded wire to the other lead of R3.

iii. Connect a second length of stranded wire to ground.

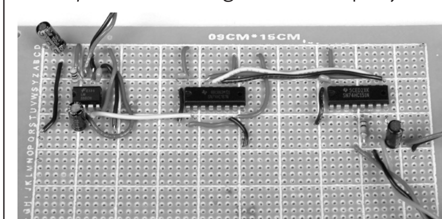
iv. Connect a third length of stranded wire to the + side of C6.

v. Twist these wires together and label the wires with masking tape marked *volume*. These wires will go to the volume pot.

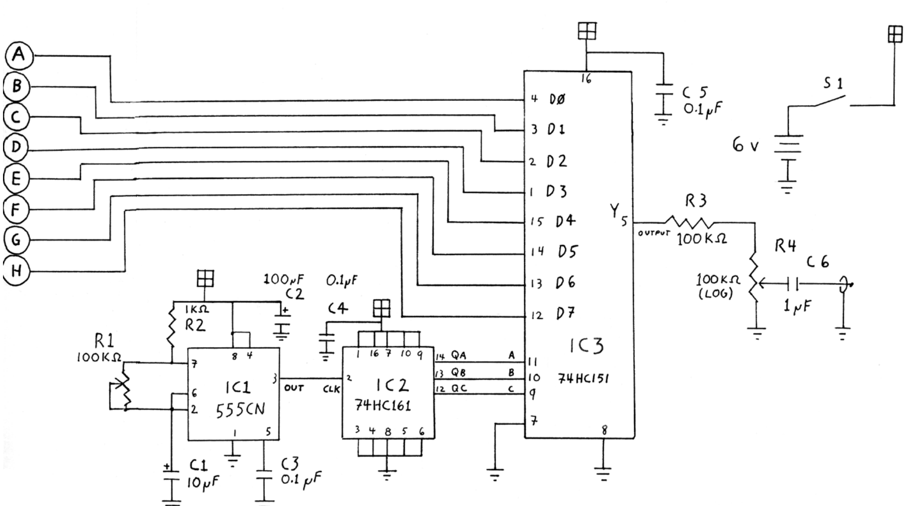
vi. Connect a length of stranded wire to the – side of C6.

vii. Connect a second length of stranded wire to ground.

viii. Twist these wires together and label the wires with masking tape marked *output*. These will go to the output jack.



SCHEMATIC FOR THE CLOCK, COUNTER, AND DATA SELECTOR



5 build the oscillators

NOTE: This is most of the work in building the project. There are a lot of parts and a lot of connections, but it's really the same circuit, built four times. You can also think of it as the same circuit built eight times, with each 556 chip being shared between two oscillators.

There are two ways to approach this stage:

- Build each circuit completely, then go on to the next, or
- Build it in assembly-line style, installing the corresponding part in each of the eight circuits at the same time, building all four at once.

Make sure you leave enough room for all the parts, as well as the wiring. It's easy to paint yourself into a corner trying to make things too tight. A little bit of preplanning and then dry-fitting the layouts goes a long way. You can make many of the connections on the underside of the board.

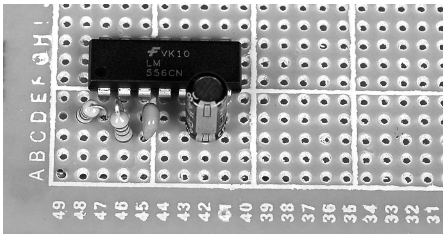
Build the first oscillator

5a. Mount the 556C dual-timer chip (IC4) on the circuit board. Make sure that pin 1 is at the lower left when looking at the board right-side up.

5b. Mount R5, R6, C8, and C9 near the pins 1 through 7 on one side of IC4.

5c. Mount R8, R9, C10, and C11 near pins 8 though 14 on the other side of IC4.

5d. Install C7 near pin 14 of IC4.



5e. Make the pin-to-pin connections on IC4.

i. Connect pin 4 to pin 10 and then make a connection from this pair to the + supply rail.

ii. Connect pin 6 to pin 2, and pin 8 to pin 12.

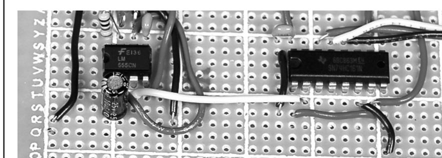
iii. Connect pin 14 to the positive power supply, and the + side of C7.

iv. Connect pin 7 to ground.

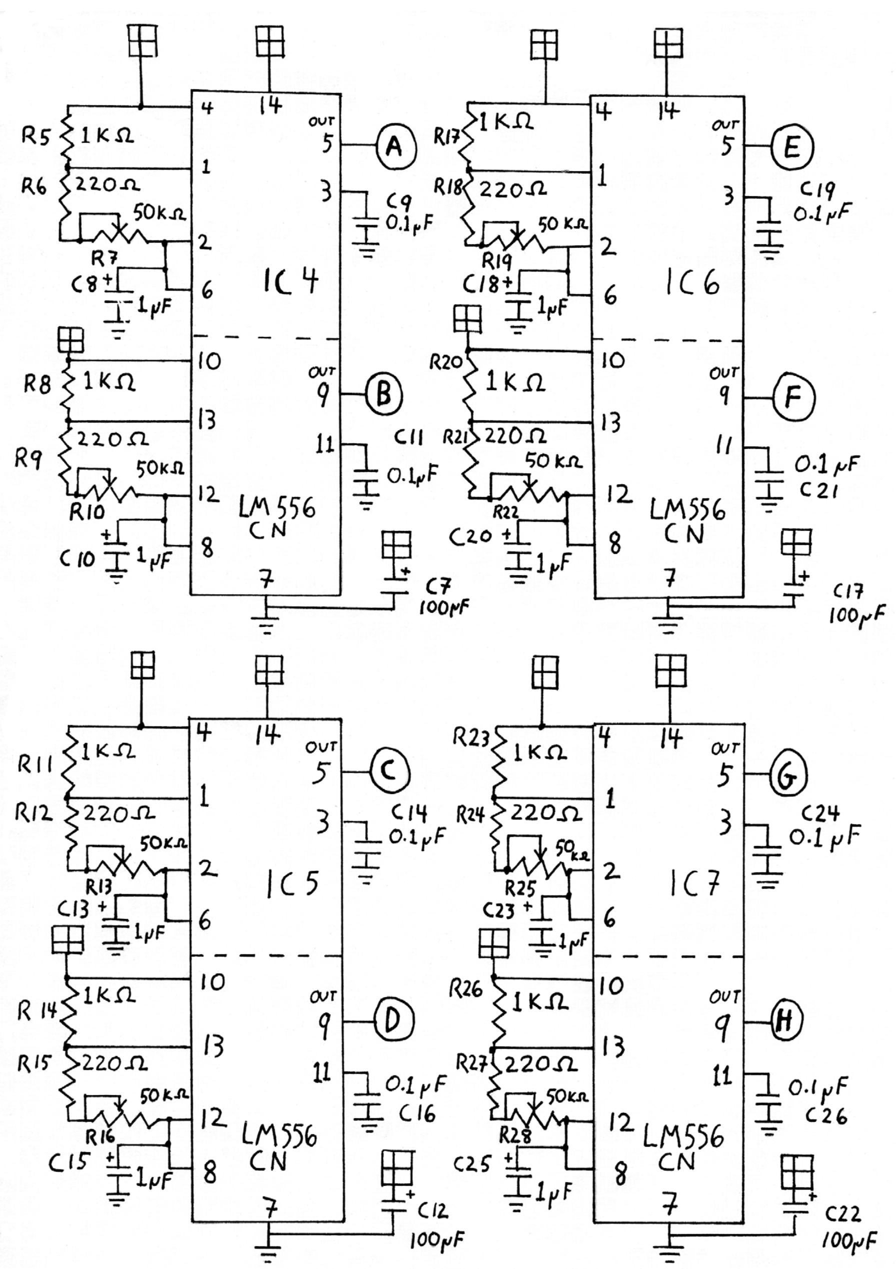
v. Connect the – side of C7 to ground.

5f. Connect the various resistors and capacitors to their associated pins, and also to + or ground, as applicable.

NOTE: If you have laid the circuit out well, you should be able to do much of this by simply using the component leads, and connecting them directly to the pins. Make sure to use insulated hookup wire if there is any chance of a connection touching a point to which it should not connect, or if the connection has to span a long distance.



SCHEMATIC FOR OSCILLATORS



NOTE: The connections in the following steps are separated on the schematic, and indicated by the circled letters A (for first oscillator circuit) through H (for eighth oscillator circuit), indicating which outputs of ICs 4, 5, 6, and 7 should connect to which inputs of IC3. Take careful note of the pin numbers on IC3.

5g. Connect pin 5 of IC4 to pin 4 of IC3 (the first data input: D0).

5h. Connect pin 9 of IC4 to pin 3 of IC3 (the second data input: D1).

NOTE: When you wire the remaining oscillators, they will connect, in order, to inputs D2 though D7.

Connect a long pair of leads from one side of R6 and pin 2 of IC4 as was done for the clock circuit.

5i. Twist these two wires together and label with masking tape marked *R7*.

5j. Connect a long pair of leads from one side of R9 and pin 12 of IC4.

5k. Twist these two wires together and label with masking tape marked *R10*.

NOTE: You will want to arrange the potentiometers in order on the case, when doing this step, so make sure leads from all oscillators are long enough to reach their associated potentiometer.

GLOSSARY

Binary. A number system using only two symbols: 0 and 1.

Bit. Short for binary digit.

Capacitor. A device that can store an electric charge.

Chip. The informal name for an integrated circuit.

Circuit Board. A board, usually fiberglass, perforated with holes to mount components in.

Digital. Having only two voltage levels, high and low, which represent the binary digits 0 and 1.

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

Ground. The common point to which all signals return in a circuit.

Integrated Circuit (IC or chip). A component containing an entire electronic circuit fabricated on a tiny piece of silicon.

Kilo. A prefix meaning 1000. One kilo Ohm, usually written 1kOhm, or 1 kΩ, is 1000 Ohms.

Leads. Pronounced *leeds*. The wires protruding from an electronic component such as a resistor.

Logic Circuit. A digital circuit.

Logic Probe. A device that can show levels in a digital circuit.

µ. The Greek letter *mu*, used to denote *micro* or *1 millionth*. 1µF is read as *one microFarad* and is equal to one millionth of a Farad.

µF. MicroFarad. See µ.

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

Oscilloscope. A device that can show a real-time graph of voltage over time.

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

Pins. The connection points of a chip, also known as *legs*.

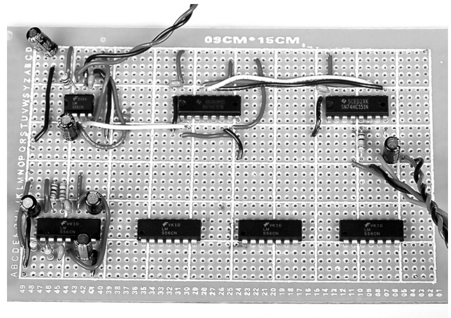
Potentiometer. A variable resistor, often called a "pot" for short. The name is derived from an early use in circuits to measure electrical potential, also known as voltage.

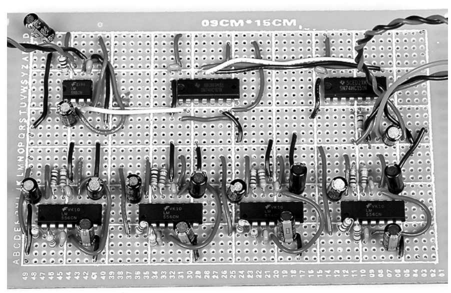
RCA Connector. A small connector, also known as a phono connector, invented by the Radio Corporation of America, and often used in home audio.

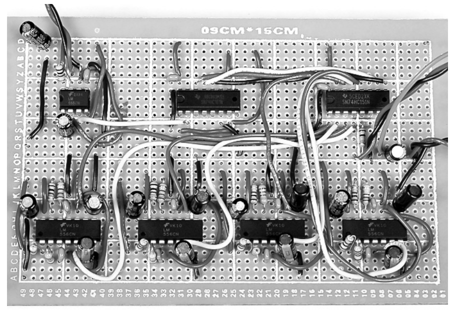
Resistor. A device that limits electrical current.

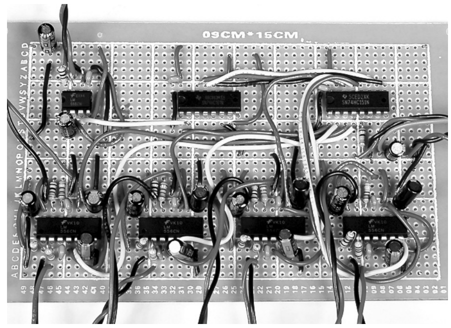
Shield. The outer wires in an audio cable, which surround the centre conductor and are connected to signal ground.

5l. Repeat the procedure in steps 5a to 5k to connect ICs 5, 6, and 7.





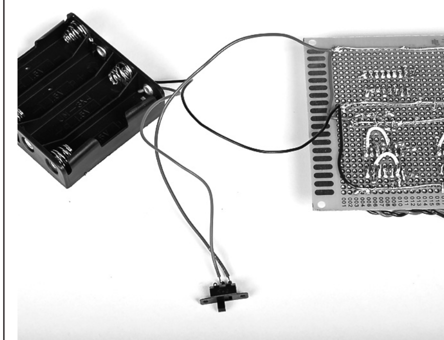




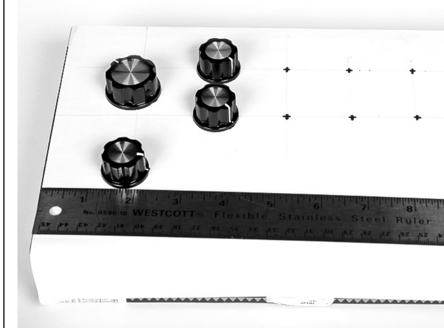
6 final assembly

6a. Connect the black (-) wire of the battery pack to the ground rail(s) of your circuit.

6b. Connect the red (+) wire to one side of switch S1, and the other side of S1 to the positive supply rail(s) of your circuit. If you have used multiple supply rails, make sure they are all properly connected.



6c. Mount the potentiometers in the case. You will need room for the eight frequency pots, plus the tempo pot and volume pot.



NOTE: It's a good idea to label them, since you will be working on the backside of the panel, and it's easy to get the order mixed up.

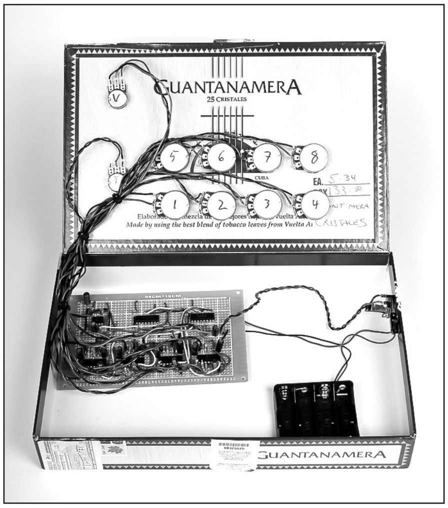
instructions continue on page 54 ▸

how it works

THE PROJECT USES three basic building blocks of digital circuits.

1. CLOCK
The term *clock* has a specific meaning in digital electronics—it is a repetitive signal that controls when actions take place in a circuit. When you buy a computer, the speed of its clock, measured in megaHertz, or gigaHertz, is often a selling feature. In this project, the 555 chip controls the rate of the sequencer and therefore is the clock for this circuit. The eight oscillators built with the 556 chips are also technically, clock circuits. The eight oscillators in this project are all built using a circuit configuration called an *astable multivibrator*. The timing of the circuit is based on the values of the timing resistor—in our case, a potentiometer—and a timing capacitor.

2. BINARY COUNTER
The 555 clock feeds into a 74HC161 *binary counter* chip. This chip takes a clock as input,

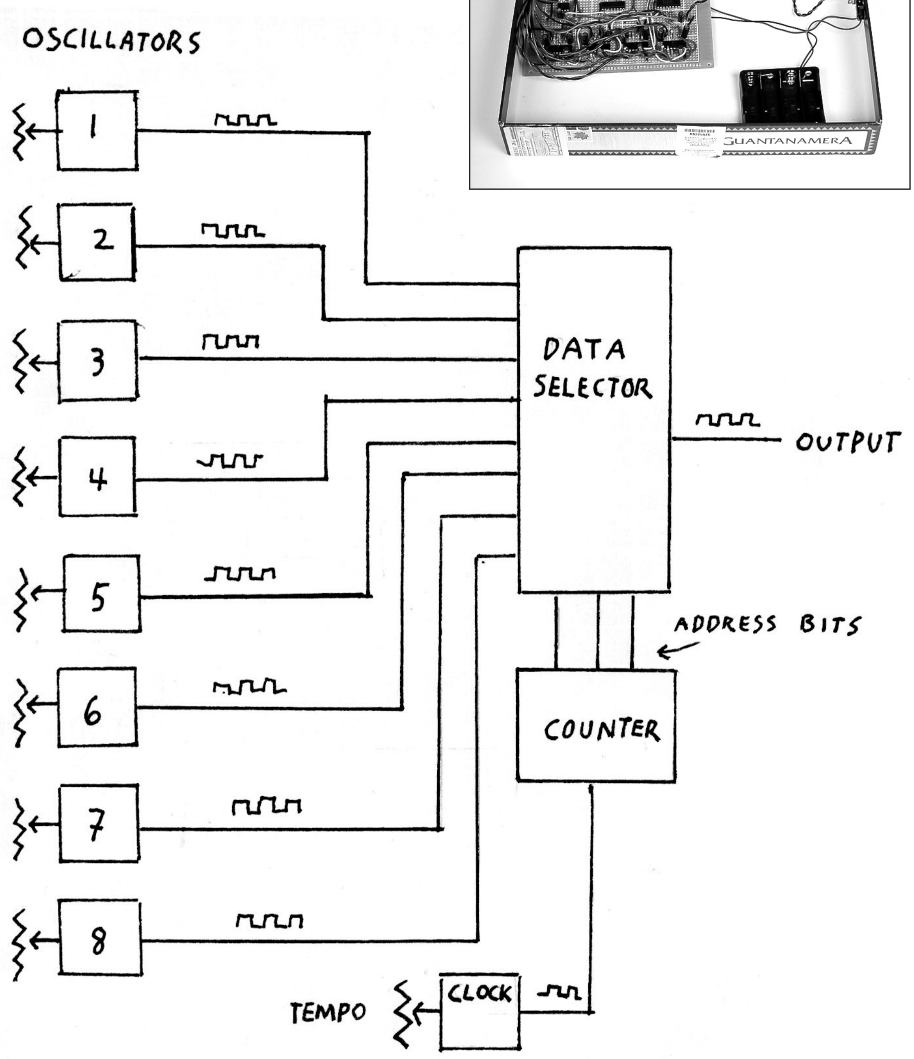


and outputs a binary counting sequence on its four outputs. The binary number system only uses two symbols: 0 and 1. In digital electronics, a 1 is represented by a voltage on an output or input, and a 0 by the absence of a voltage. The output bits (*bit* is an abbreviation of *binary digit*) are labelled A, B, C, and D. The A bit is the Least Significant Bit (LSB) and is written furthest to the right. The count sequence goes like this:

DCBA
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111
and then back to
0000
and so on.

You can see that four bits have sixteen possible combinations of 1s and 0s. We're only making an eight-step sequencer, so we're only going to use the lowest three bits, A, B, and C, and discard the D bit. Note that the count pattern of these three bits repeats twice. If you look up the data sheet for the chip, the outputs are labelled QA, QB, and QC.

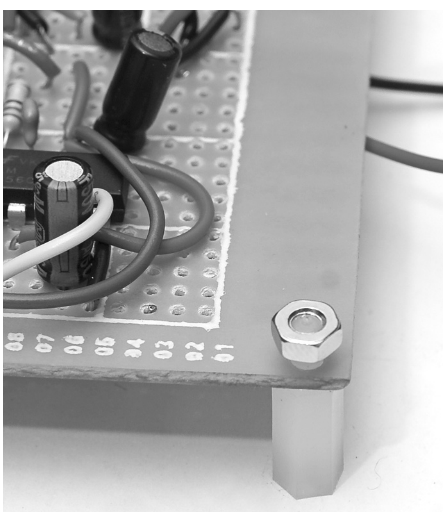
3. DATA SELECTOR
From our counter, we send the three bits to the 74HC151 *data selector* chip. This chip selects one of its eight *data* inputs and sends it to its output based on the binary number sent to its *select* inputs, which are labelled, A, B, and C. And you will probably not be surprised to learn that each of the eight data inputs is fed by the output of one of the oscillators. So, if we feed "000" to the select inputs, it selects the first oscillator—digital circuits like to count starting with 0. If we give it 001, it selects the second, and so on.



▶ continued from page 52

6d. Mount S1 and the output jack.

6e. Mount the circuit board in the case. You can simply use machine screws from the hardware store or special “standoffs” from an electronics shop.



6f. Connect the pair of wires from IC1 to lugs 1 and 2 of the tempo potentiometer (R1).

6g. Connect a short piece of wire between lugs 2 and 3 of the tempo potentiometer.

6h. Connect the eight pairs of wires from the oscillator section to the frequency potentiometers: R7, R10, R13, R16, R19, R22, R25, and R28, ensuring that the wires from the oscillators connect to the correct lugs on the potentiometers 1 and 2, as shown on the illustration.

6i. Connect a short piece of wire between lugs 2 and 3 on each potentiometer. NOTE: The polarity of the wires themselves does not matter.

6j. Connect the volume potentiometer leads from 4g–v to the volume pot, ensuring that the wire from R3 goes to lug 1, the wire from the – side of C6 goes to lug 2, and the wire from ground to lug 3.

6k. Connect the pair of wires from step 4g–viii to the output jack, ensuring the ground wire is on the ground lead, and the wire from the – side of C6 goes to the tip, or hot lead.

7 testing

7a. Connect the unit to an amplifier, and turn it on. Turn up the volume potentiometer until you hear sound. If you hear nothing, immediately turn the circuit off and consult the troubleshooting section below.

7b. Adjust R1 to near the lowest level, and you should be able to hear the sequencer stepping through tones. Make sure there are no gaps—you should be able to hear each oscillator in turn. Check that the tempo potentiometer controls the rate and that each frequency potentiometer increases the frequency when turned clockwise.

7c. If anything seems amiss, turn the circuit off and consult the troubleshooting section below.

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TROUBLESHOOTING

It is best to have a logic probe or oscilloscope to troubleshoot the circuit. A multimeter, while good for checking voltages, cannot respond to the rapidly changing digital signals in this circuit. A logic probe is a reasonably inexpensive tool that is handy to own if you are interested in working with digital electronics. An oscilloscope is a major investment, but you may be able to get access to one at a hacker space or a school electronics lab.

Check each chip to see if it is hot:

- Touch each chip as if you were touching a hot iron.
- If you find a hot chip, turn the power off and solve the problem before turning it back on.
- A hot chip is usually caused by a backward connection or an output shorted to one of the power rails.

If there is no sound at all:

- Check the power and ground connections to each chip with a voltmeter. Or, using a logic probe, verify that the power pins are at a high level (usually indicated by a red light) and ground is at a low level (green). If neither light comes on, you have a floating pin. Find and fix the missing connection.
- Check that the audio output is connected properly and is not shorted out. A logic probe on pin 5 of IC4 should show both high and low lights on.

If only one tone is heard—no sequencing.

- Check pin 3 of IC1 with a logic probe to verify that the signal is changing from high to low at a rate that you can easily see with the logic probe. Verify that this same signal appears on pin 2 of IC2 and on pin 14 of IC2. A signal with half the rate should appear on pin 13 of IC2. And a signal with half that rate (one-quarter of the rate at pin 2) should appear on pin 12.
- If these signals are not present, check that all the pins of the IC2 that should be tied high or low are at the correct levels. If these signals are correct, verify that they are reaching pins 11, 10, and 9 of IC3, and that all of IC3s pins are at the correct levels.

If one or more tones can’t be heard:

- Check the outputs (pins 5 and 9) of the 556 chips in the oscillator section of the circuit with the logic probe. You should see both the high and low lights on simultaneously. This shows you that the circuit is oscillating (at a rate too fast for your eyes to see). If you are checking the outputs with an oscilloscope, you should see a square wave. If only one light is on or if both are off, find and correct any errors in that oscillator’s circuitry.
- Check that the output signals above show up on the appropriate input pins of IC3. If an oscillator is lacking an output, or the output is there but not showing up on the input of IC3, check the connections and the part values associated with that oscillator and the connections to IC3.