17 CIGAR-BOX SYNTHESIZER

The Cigar-Box Synthesizer is an honest-to-God *analog monosynth*, not unlike the early synthesizers from Korg, Roland, and Robert Moog. Our simple little synthesizer is *analog* in that it abuses plain old integrated circuits into directly producing continuously variable musical notes and a *monosynth* because it makes one note at a time and thus can play melodies and bass lines but not chords. The Cigar-Box Synthesizer builds its thick tone by layering three octaves of each note and offers a musically useful range of about two-and-a-half octaves, with raw punky squeals above the high end and thunky mellow clicks below the low end. The resulting space-age theremin sound is harnessed with

a dial-based pitch controller, which is much easier to master than the precise gestures of Leon Theremin and Clara Rockmore.

FIGURE 17-1: *The finished Cigar-Box Synthesizer*

The Cigar-Box Synthesizer is based on misusing two over-the-counter integrated circuits: a CD4093 Quad NAND Schmitt Trigger and a CD4040 12-Bit Binary/Ripple Counter. We're going to feed the first chip back on itself in order to make it function as an *oscillator*, producing a musically useful tone. If you're unfamiliar with the term oscillator, think of a metronome, which produces a click at regular intervals (remember that old-timey metronome with the pyramidal wooden case and oscillating pendulum click-click-clicking on Grandma's piano?). Run the metronome fast enough and your ear slurs those clicks together into a single burring tone. As the oscillator speeds up, the pitch of the tone increases.

The second chip functions as an *octave divider*; it will take the oscillator's tone and give back the same pitch one octave (or several octaves) lower. Since the oscillator is binary, it's actually producing a series of pulses, not a continuous tone. Slow them down and you hear them as discrete clicks. We feed that stream of pulses to the divider on its input, and at each output it generates one pulse for every two it receives, or one for every four, or one for every eight, and so on, thus producing ever-lower pitches exactly in tune with the input.

As with all ICs, references to the chips in this project assume you are looking at them from the top, with their dimples or half-circle notches to the left. In this position, the bottom left pin is number 1, the one to the immediate right is 2, then 3, all the way to the end of the row and wrapping around counterclockwise, as shown in Figure 17-2.

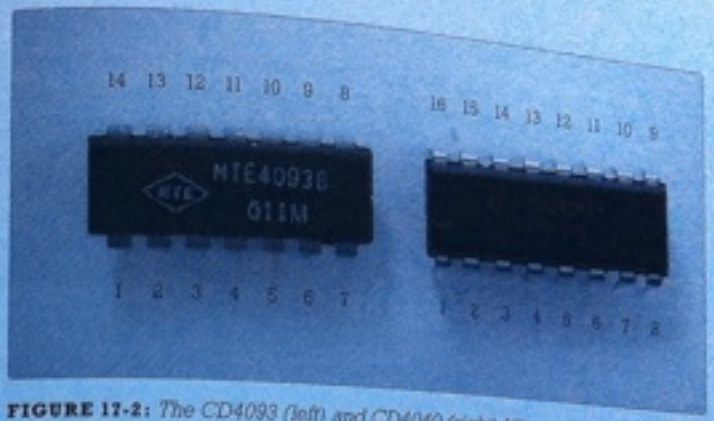


FIGURE 17-2: *The CD4093 (left) and CD4040 (right) ICs, with legs numbered*

Tools

- a standard soldering kit (See the appendix)
- an electric drill with 3/8" and 1/2" bits
- Gorilla Glue
- coarse-grit sandpaper and a sanding block
- an amp, such as the Dirt Cheap Amp built in Project 12

Supplies

- a CD4093 integrated circuit (Digi-Key stock #296-2068-5-ND), aka a Quad NAND Schmitt Trigger
- a CD4040 integrated circuit (Digi-Key stock #296-2048-5-ND), aka a 12-bit Binary/Ripple Counter[1]
- a 0.1 µF ceramic disk capacitor (These are usually marked *104*.)
- a 10 µF electrolytic capacitor
- a 100k ohm variable resistor, preferably linear tapers
- three 10k ohm variable resistors, preferably audio tapers, not linear tapers (See "Audio Tapers vs. Linear Tapers" on page 190 for details.)
- three 10k ohm resistors (coded with brown-black-orange stripes)
- a 1/4" mono phone jack (guitar jack)
- a length of coat hanger or similar stiff wire

1. There are plenty of CD4093 and CD4040s out there that will work fine; these are the cheapest at the time of writing. If you end up ordering something else, just be sure that it has a DIP layout and can tolerate being powered by 9 volts (most ICs in this family are fine with 5–20 volts).

- a playing card (or any fancy cardboard or thin plastic)
- a cylindrical control knob that fits over the shaft of your 100k ohm variable resistor, such as RadioShack part #274-403
- three more control knobs, either the same as above or something more stylish, such as RadioShack part #274-415
- a 9-volt battery clip
- a 9-volt battery
- a momentary push-button switch, such as a doorbell switch
- a cigar box or similar enclosure
- 24-gauge insulated hook-up wire (Stranded is better, and you might want to get several colors to help you keep connections straight.)
- 22- or 24-gauge bare bus wire
- a small printed circuit board, such as RadioShack #276-148
- double-sided foam tape
- (optional, but strongly recommended) a 14-pin IC socket and a 16-pin IC socket (You can substitute an 18- or 20-pin socket for the 16-pin one if it is easier to find; any of them will work fine.)

FIGURE 17-3: *Tools and supplies*

Building It

Step 1 Start with the pitch controller (shown in Figure 17-4), since that will need to dry overnight. Take a 5" length of coat hanger (or similar stiff wire), and curl one end so that it hooks snugly around the end of your cylindrical control knob. Cut a 1" circle of playing card; this will serve as a stylish knob cover. Put a penny-sized dollop of Gorilla Glue in the center of the playing-card circle. Press the top of the knob into the glue (forcing some out around its edges), and then hook the wire around it. Apply a little more glue to cover the wire (if needed), clean up any excess, and let this dry overnight. Remember that Gorilla Glue foams as it cures; an innocuous little smear can dry into a big foamy mess.

FIGURE 17-4: *Building the pitch controller arm*

Step 2 Now you'll install the ICs onto the printed circuit board (PCB). Take a look at the schematic in Figure 17-5.

* **NOTE:** *Although these ICs will put up with a fair amount of abuse, too much heat or a jolt of static will fry them. Using empty IC sockets and installing the chips in the final step is advised; for the sake of clarity, both the instructions and the illustrations show the chips in place.*

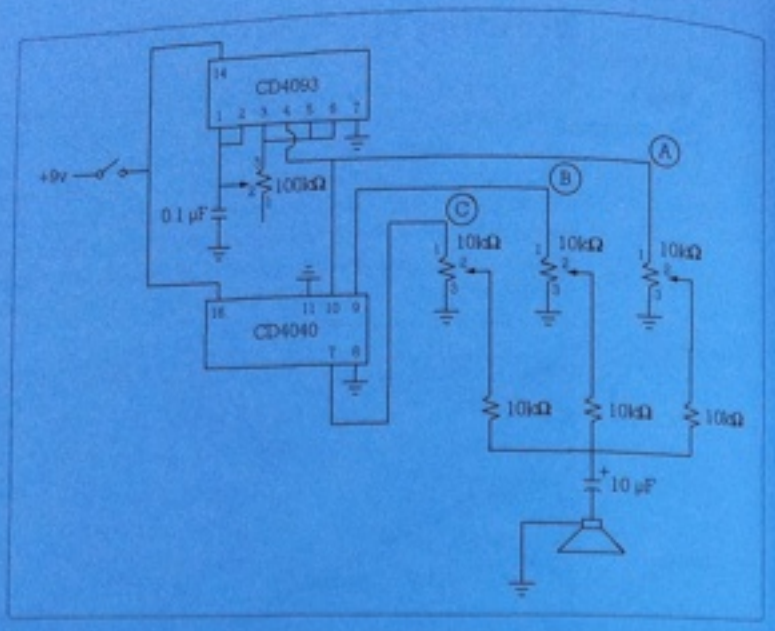


FIGURE 17-5: *The Cigar-Box Synthesizer circuit*

Step 3 Since these two chips are in the same family, they have similar layouts (even though the CD4093 only has 14 pins and the CD4040 has 16). Both get power on their final pin (upper-left corner), and both are tied to the ground by the last pin on their bottom row (that is, the one diagonal from the power pin: pin 7 on the CD4093 and pin 8 on the CD4040). Pin 11 on the CD4040 also ties to ground, so start by slipping the 14-pin socket for the CD4093 into the top of the circuit board (i.e., leaving two empty rows above it), and then adding the socket for the CD4040 four rows below (i.e., leaving three rows of empty holes between them; see Figure 17-6). Offset them so that pin 11 on the CD4040 (the lower chip) lines up with pin 7 of the CD4093. To ensure the sockets stay in place as you work, carefully flip the board now and bend down the corner pins on each IC socket.

✱ **NOTE:** *Remember that all of the pins are numbered from the top, but all of the soldering gets done from the bottom; once you flip the board over, the numbers will be reversed!*

Step 4 Start by soldering all of the *jumpers* (lengths of wire connecting pins on the ICs). Snip a 1" length of the bare bus wire, crimp it, and slide it into the first two holes corresponding with pins 1 and 2 of the CD4093 socket. Now flip the board over and solder this jumper to pins 1 and 2; be careful not to inadvertently create a solder bridge to any of the other legs of the socket. Solder similar jumpers between pins 3 and 5 on the CD4093 socket and another between pins 5 and 6. Then place a

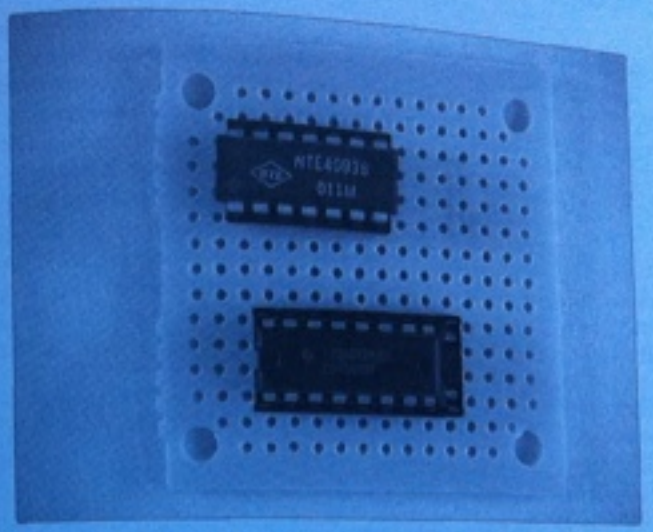


FIGURE 17-6: *The socketed chips on the circuit board, viewed from the top (notice that the 16-pin CD4040 is in an 18-pin socket; the two empty slots are on the socket's right end)*

jumper from pin 7 of the CD4093 socket toward pin 11 of the CD4040 socket, leaving one empty hole between the jumper and pin 11 of the CD4093 socket; don't solder this jumper yet (you'll do that in Step 5). The installed jumpers are shown in Figure 17-7.

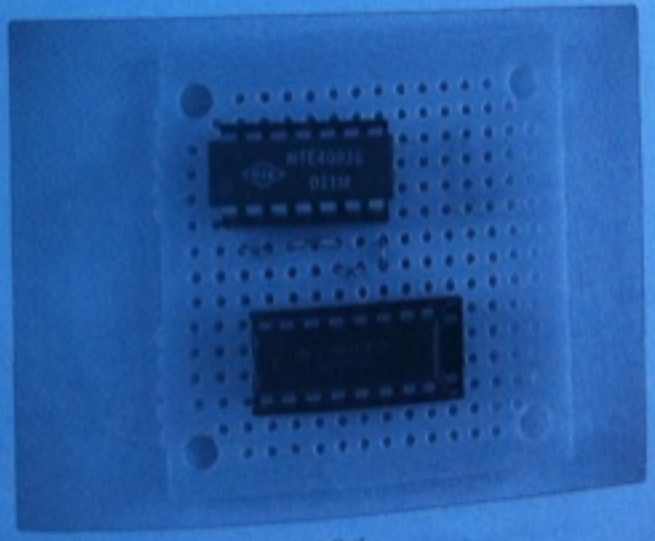


FIGURE 17-7: *Four jumpers installed*

Step 8 Time to finish off the circuit board. Cut a 1 1/4" length of insulated wire (this wire will carry an audio signal, so use white). Strip and tin both ends. Slip one end into the second open hole adjacent to pin 4 of the CD4093 socket, and solder it to pin 4 (this can be a little tricky, since you don't want to short it to the jumper connecting pins 3 and 5). Slip the other end through the hole closest to pin 10 on the CD4040 socket, as shown in Figure 17-10, but don't solder it yet.

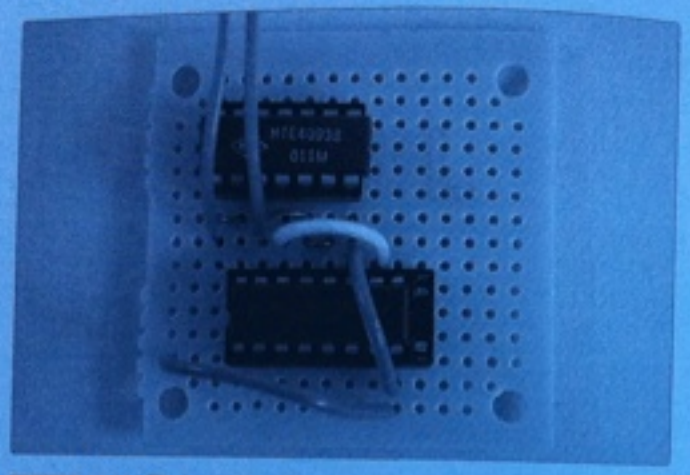


FIGURE 17-10: *The board thus far*

Step 9 Slip pot A's input wire into the next open hole at pin 10 of the CD4040 socket, and solder it and the wire from Step 8 to pin 10. Solder the input of pot B to pin 9 and the input of pot C to pin 7.

Step 10 Now you'll add power. Cut and strip two wires, one 1 1/2" long and the other several inches (neither will carry an audio signal, so keeping them short isn't vital; these are power connections, so red is a good color). Solder one end of the 1 1/2" wire to pin 16 (the upper-left corner pin) of the CD4040 (i.e., the lower) socket. Run the other end to pin 14 (also the upper left) of the CD4093 socket. Add one end of the longer wire to pin 14, and solder both wires to pin 14 of the CD4093 socket. Solder the other end of the longer wire to one terminal of your push-button switch.

Step 11 Strip the ends of your 9-volt battery clip, and solder the red lead to the remaining terminal on your push-button switch. Run the black lead from the clip to the common ground along the left edge of your circuit board (choose the open hole closest to the flying ground from Step 5).

Step 12 Connect one leg of the 0.1 µF ceramic capacitor to pin 1 of the CD4093 and the other to the common ground. Solder the leg to pin 1 (you'll solder the other leg to the common ground in Step 13). This capacitor sets the range for the pitch your oscillator will produce; you could use anything from 0.1 µF to 0.001 µF and still be mostly in the audible range; the larger the value of the capacitor, the lower the pitch.

Step 13 Next, begin installing the Cigar Box Synthesizer's guts (shown in Figure 17-11) in its enclosure. In order to minimize noise, we need to keep the ground connection through the mixer as short as possible. Start by mounting pots A, B, and C (from left to right in that order) on the side of the enclosure that will face you as you play (both pots and jacks usually need 1/2" or 3/8" holes); a little sanding will smooth any ragged edges. Many pots have a little protruding spike, used to anchor the pot to its enclosure and keep it steady through repeated tweaking (see Figure 17-12). When you install the pot, either drill a tiny hole to accommodate the anchor or use a pair of pliers to snap it off. Mount the output jack on the same face of the enclosure as the mixer.

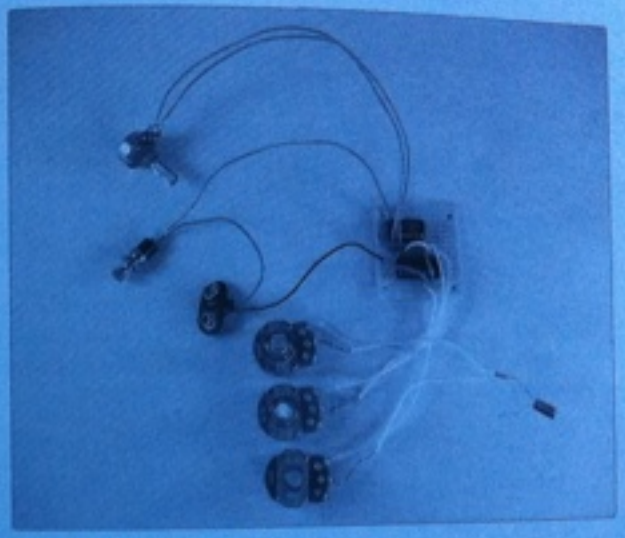


FIGURE 17-11: *The mostly finished guts*

FIGURE 17-12: *A close-up of a potentiometer's anchor*

To wire the ground for the pots, solder the end of your spool of bare bus wire to the sleeve of the jack (jack lugs are diagramed in the appendix) and then to lug 3 of each pot, being careful not to short the ground against the other connections (it's fine for the ground wire to rest against the metal bodies of the pots). Finally, uncoil enough bus wire to reach the common ground on the left edge of the circuit board, snip the bus from the spool, slide the bus wire into the circuit board, and solder the common ground (you should have four wires there: the black lead from the battery, the remaining leg of your ceramic capacitor, the green wire from Step 5, and the bare bus line you just added).

Step 14 Finish the audio output by soldering the negative leg (the one lining up with the thick stripe) of the mixer's 10 µF electrolytic capacitor to the tip lug on the output jack (again, see the appendix for a detailed look at wiring a jack).

Step 15 To finish packaging the Cigar Box Synthesizer, drill two holes in the top of the box: one for the trigger switch and one for the pitch controller (see Figures 17-13 and 17-14)—a few swipes with the sandpaper will take out the splinters. Position the trigger in the upper-left corner, so it's clear of the pitch controller's arm. The most musically useful portion of the pitch controller's range of motion is the middle third, so place the hole for the tone-controller pot in the lower-right corner of the box top (as illustrated in Figure 17-14).

Once this pot is firmly mounted on the enclosure, twist its shaft so that it is turned fully clockwise or counterclockwise and can be twisted no further. Attach the tone-controller knob so that its wire extension arm points to the lower-right corner of the box (as shown in Figure 17-14).

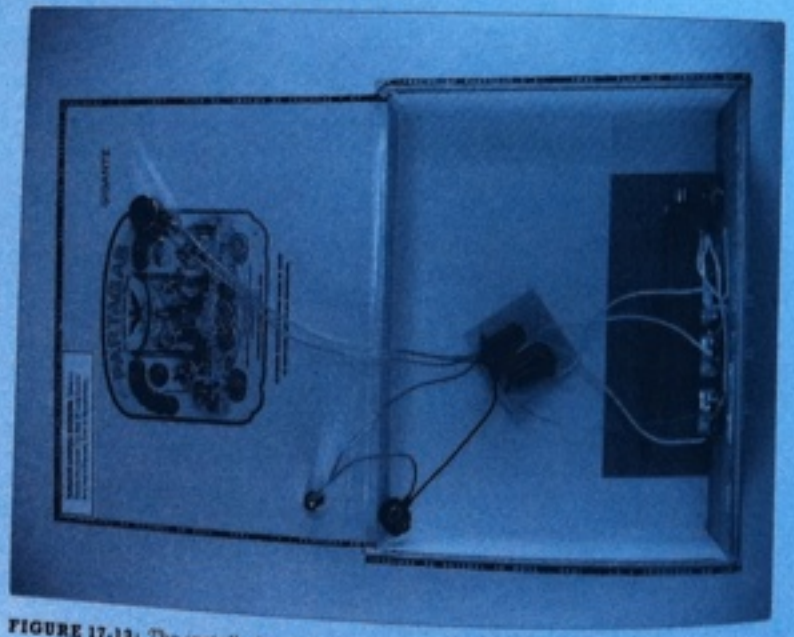


FIGURE 17-13: *The installed guts*

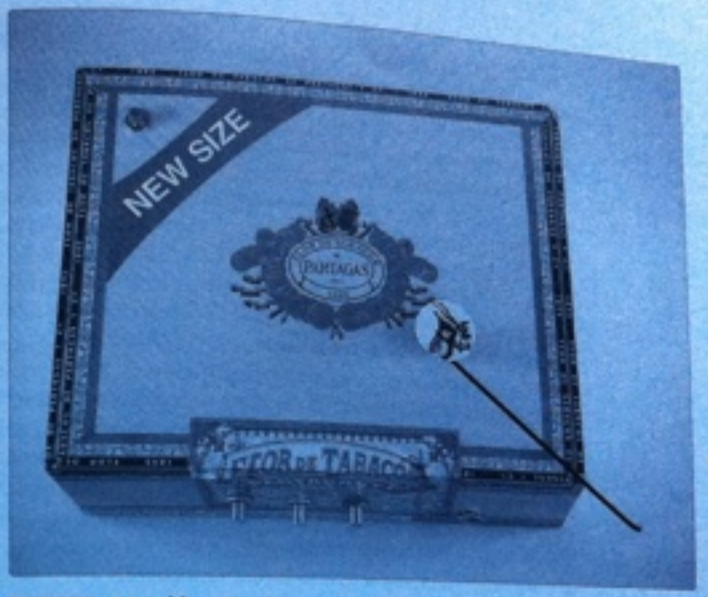


FIGURE 17-14: *Mounting the tone-controller knob*

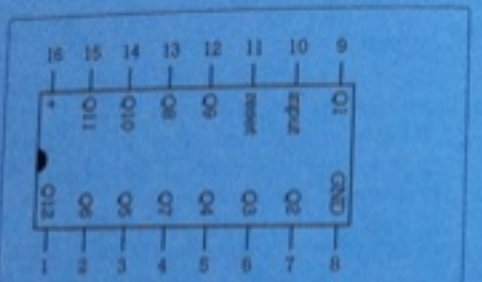
Step 16 Finish off construction by using double-sided foam tape to secure the circuit board to the inside of the cigar box. Make sure all of the switches, pots, and jacks are secure, then add knobs to the mixer pots. It's also a good idea to use a little double-sided tape to hold the 9-volt battery in place (a metal clip–style 9-volt battery holder, like RadioShack part #270-326, is even better).

Step 17 The Cigar-Box Synthesizer is ready to play right now, although it's a touch more playable if you mark out the scale on the lid of the box. Get out your chromatic tuner, and pull the arm of your pitch controller around so that it just touches the edge of the box nearest you. Hit the trigger, and see what note you are near, then nudge the arm clockwise until you've got a solid natural (that is, neither sharp nor flat) note. Mark its position in pencil,[2] then keep nudging the arm clockwise, adding each subsequent natural note; they'll be very close at first and gradually space out to about 1" apart as the pitch gets lower. If you find that your pitch starts very low and gets higher as you turn clockwise, it's because, in Step 6, you soldered the second wire to lug 1 of the 100k pot instead of lug 3.

2. You'll want to do this in pencil because (1) it's easy to inadvertently nudge the knob cover out of alignment on the potentiometer shaft, thus knocking your tuning into disarray, and (2) analog circuits are notoriously unstable in the long term: as the capacitors age and the weather changes, so will this little Cigar-Box Synthesizer's tuning. Taping a strip of white paper to the top and marking the notes out there makes it easy to read and easy to update.

Expanding the Cigar-Box Synthesizer

As designed, this Cigar-Box Synthesizer only mixes two of the octaves that the CD4040 offers. The straight signal produced by the oscillator (the CD4093) is on pot A and is mixed with the tone one octave lower (pin 9 on the CD4040) and two octaves lower (pin 7 of the CD4040). Technically, each output on the CD4040 (pins 1 through 9, 11, and 12 through 15) is producing a fraction of the number of pulses that the chip receives on its input (pin 10). Pin 9, for example, puts out one pulse for every two that come in (thus producing a tone one octave below the input), pin 7 produces one pulse for every four that come in (i.e., two octaves below the input), and so on. Each of the remaining open pins on the CD4040 offers another signal, one octave lower than its predecessor (see the diagram in Figure 17-15). Most of the signals on the higher outputs are so slow that they register as "bonks" instead of continuous notes, but there is no reason you couldn't add them to your mix or have them go to separate outputs via either pots (like the mixer we built in Step 7) or switches. As a rule, any time you bring several audio signals together, you want to buffer each with a 10k ohm resistor (as we've done on the mixer in Step 7), so if you add switches in order to bring out the bonks on pins 2 and 3 (i.e., outputs Q5 and Q6), then put a 10k resistor on the output side of the switch, and solder it to the positive leg of the 10 µF capacitor on the existing mixer.



output	in:out	powered pitch	
Q1	2:1	1 octave down	
Q2	4:1	2 octaves down	
Q3	8:1	3 octaves down	
Q4	16:1	4 octaves down	
Q5	32:1	5 octaves down	
Q6	64:1	6 octaves down	These usually just sound as beats.
Q7	128:1	7 octaves down	
Q8	256:1	8 octaves down	
Q9	512:1	9 octaves down	
Q10	1024:1	10 octaves down	
Q11	2048:1	11 octaves down	
Q12	4096:1	12 octaves down	

FIGURE 17-15: *The pin-out diagram for the CD4040*

The CD4093 likewise hides additional secrets. Look at its logical diagram (Figure 17-16), and you'll see that its two sides are symmetrical. Rotate the chip 180 degrees, and you can build a whole separate synthesizer just like the first. Pretend pin 8 is 1, pin 9 is 2, and so on: Jumper pins 8 to 9 and 10 to 12 to 13, connect pin 8 to 10 with another 100k pot, ground pin 8 through a 0.1 µF capacitor, then run pin 11 to the tip of a jack, and—*BadaBoom Disco!*—you have two identical synthesizers for the price of one.

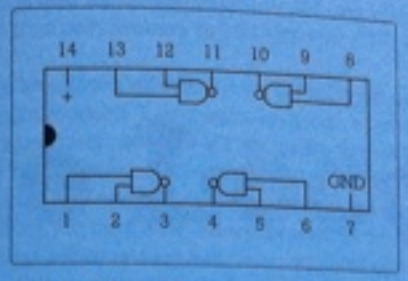


FIGURE 17-16: *Logic diagram of the CD4093 Dual-Quad inverter*

In order to shape the Cigar-Box Synthesizer's tone (some folks find the CD4093 oscillator's native square wave a little grating), you can add both *low-* and *high-pass filters* (there are circuit diagrams in Figure 17-17). The former filters out high tones and lets lower ones pass through, and the latter filters out low tones and lets high ones through—you are familiar with these as the treble and bass knobs on your stereo. They're simple and go on the audio output, just before the jack.

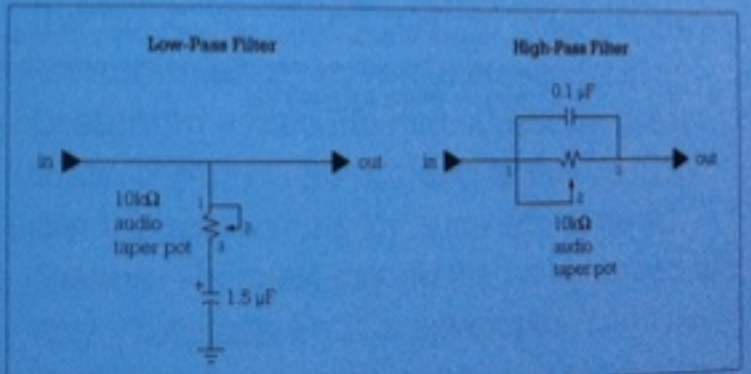


FIGURE 17-17: *A low-pass filter (left) and high-pass filter (right), yes, they look remarkably similar*

The low-pass filter will cut the high end, which manifests itself as the characteristic square-wave sound of an early '80s synthesizer: a reedy, fat squelch. I've used *very high* capacitor values, because the Cigar-Box Synthesizer has such an aggressive tone. These are based on classic guitar tone controls, where the caps are usually much smaller: between 0.01 µF and 0.05 µF for the low-pass filter and between 470 pF and 0.002 µF for the high-pass filters. If you decide to add low- and high-pass filters to other projects (like the Dirt-Cheap Amp in Project 12 or the $10 Electric Guitar in Project 13), you might be happier with lower values than those illustrated in Figure 17-17; start with a 0.1 µF ceramic disc capacitor (labeled 104) in the low-pass filter.

Finally, you can get rid of the pitch controller pot altogether and replace it with either a homemade *ribbon controller* (à la T. Escobedo's synthstick; see "Resources" below) or your own body. For the latter, just remove the 100k pot and mount a pair of brass knobs to the top of the box about 1" apart, making sure the knobs and their hardware aren't touching each other. Run a wire from pin 1 of the CD4093 to one of the knobs and another wire from pin 3 to the second knob. Grab both knobs in one hand; you won't feel the electricity, but your skin will act as a variable resistor: Touching the knobs gently will give you a low pitch that will steadily rise as you squeeze harder.

Resources

- If you enjoy this sort of low-tech, lo-fi electro music, get a copy of Nicolas Collins's *Handmade Electronic Music*, which is full of projects and great ideas for ways to tune up and freak out.
- This design—much like the effects earlier in this section—owes a great deal to the cornucopia of effects and musical instruments T. Escobedo shared on his FolkUrban website (including his synthstick, which uses a very cool and easy homemade ribbon controller). Sadly, Escobedo's site is no longer online, but I've archived some of his projects on this book's website: *http://www.danieriknelson.com/sbsb/*.