Chapter 12

TICKLE THE CLOCK (LAYING OF HANDS II): FINDING THE CLOCK CIRCUIT IN TOYS

You will need:

- An electronic toy.
- Small screwdrivers.
- A Sharpie-style fine-tip permanent marker.
- Optional: two test leads with alligator clips and a resistor in the range of 1kOhm–4kOhm.

Hacking is a lot like hot-rodding your car: you don't need to be able to build a car from scratch to swap in a 4-barrel carburetor, but it helps to know what a carburetor looks like before you get too creative with the wrench. We'll use a simple but useful hack as a step toward identifying basic electronic components, and introduce some electronic axioms along the way.

How to Choose a Toy

As with the radio, select a toy that is expendable, not too tiny, and has a built-in speaker. A toy that makes sound is preferable to a mute one, and sampled sounds (like voices, animal sounds, or instruments) are more rewarding than simple beeps. The more buttons and switches the better, generally speaking. Keyboards are a gamble: some cheap Yamahas hack magnificently (the PSS-140 is especially satisfying), while others have curiously limited potential for interesting modification. Cheaper is usually better—the more expensive toys (and almost all that put out video) often use crystal clocks, which are more difficult to hack. And, of course: **THE TOY MUST BE BATTERY POWERED!**

Clocks

The majority of electronic toys manufactured since the late-1980s are essentially simple computers dedicated to running one program. In most, a crude clock circuit determines the pitch of the sounds and the speed of its blinking lights, graphics and/or program

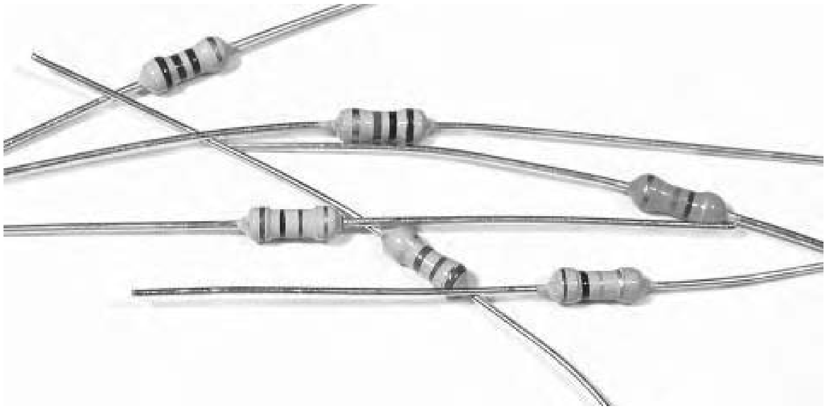


Figure 12.1 Some resistors.

sequence. (This is true for many older analog toy circuits as well.) If you can locate the clock circuit and substitute one component, you can transform a monotonous bauble into an economical source of surprisingly malleable sound material.

What's Under the Hood?

Open up the toy, carefully noting wire connections in case one breaks. Study the circuit board and try to identify the following types of components:

- Resistors: little cylinders encircled by colorful 1960s retro stripes (see figure 12.1).
- Capacitors, in two basic forms (see figure 12.2):
  Small discs of dull earth tones, or colorful squares;
  Cylinders, upright or on their side, fatter than resistors, with one stripe at most.
- Transistors: three wire legs supporting a small black plastic blob or metal can (see figure 12.3).

Figure 12.2 Some capacitors.

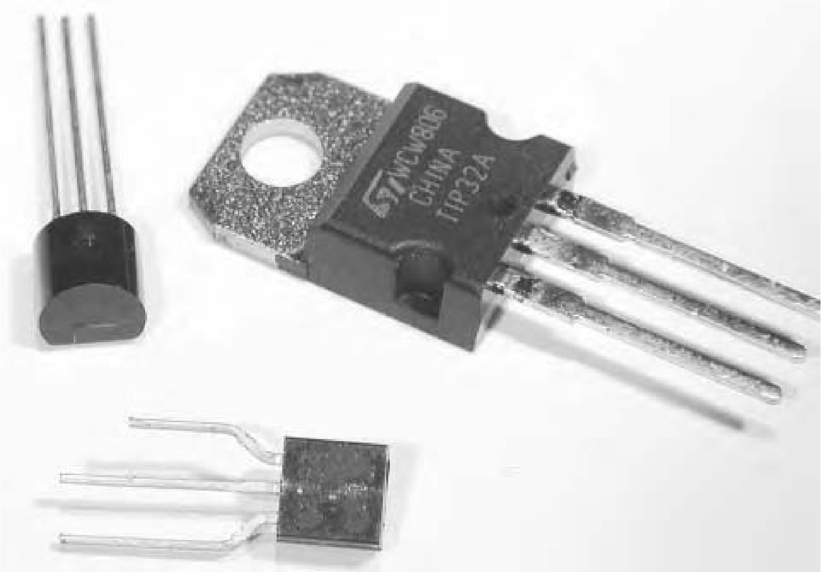


Figure 12.3 Some transistors.

Figure 12.4 Some diodes.

- Diodes: cylinders, smaller and less colorful than resistors, usually marked with one stripe, glass, or plastic (see figure 12.4).
- Integrated Circuits (ICs): usually black or grey, sometimes like rectangular bugs with legs on one, two or four sides; sometimes a malignant looking black circular blob oozing up from the circuit board (see figure 12.5).

Figure 12.5 Some Integrated Circuits.

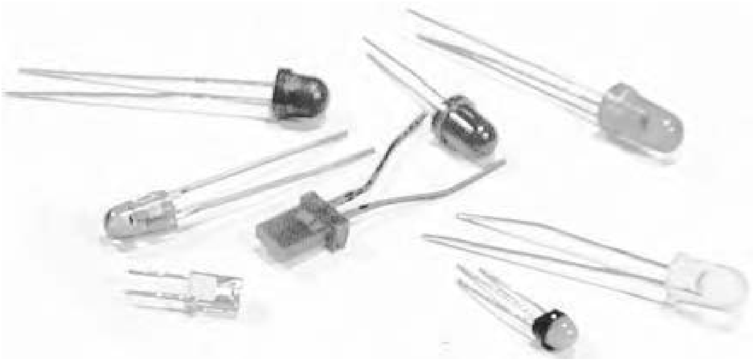


Figure 12.6 Some LEDs.

- LEDs (Light Emitting Diodes): colorful sources of light (see figure 12.6).
- Other things you'll learn about later.

More and more toys are being made these days with "surface mount devices" (SMDs)—insanely tiny, rectangular versions of the above building blocks (see figure 12.7). Until you gain some hands-on experience with them you can despair of distinguishing the various different types of components, and decoding and hacking these toys will be a doubly foggy experience.

We're looking for *resistors*, especially those lying near an IC, flanked by a disc or square capacitor.

Laying of Hands, Again

As with the radio hack we did earlier, your fingers are usually the most direct form of circuit manipulation and testing. Get the circuit making sound. Position it so that you can touch the solder-side of the circuit board, if possible while looking at the component

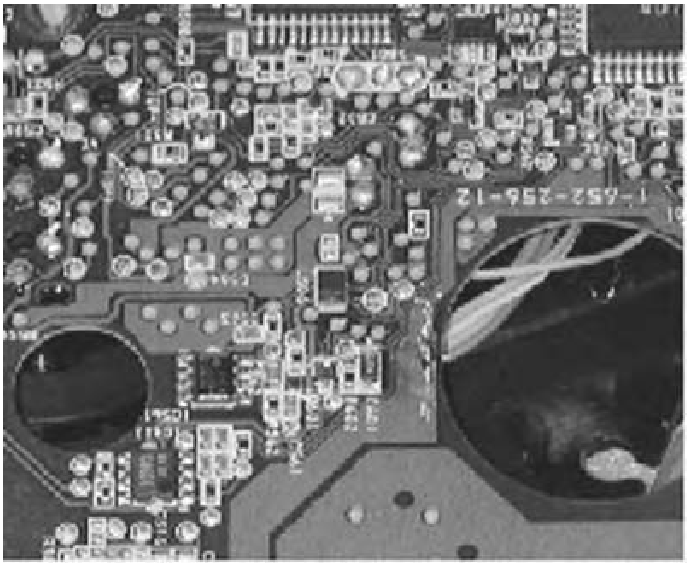


Figure 12.7 Circuit board with surface mount components.

Figure 12.8 Finding the clock resistor (finger on right).

side. Lick one fingertip and place it across various connections; in particular try to connect across points at either end of a resistor, so that your finger parallels the resistor's connection (see figure 12.8). When your finger bridges a resistor that is part of the clock circuit you should hear the pitch slide up a bit, or the tempo speed up. If the circuit has lots of connections, and you are having trouble finding the spot, concentrate on those resistors lying close by small capacitors, usually near the biggest IC on the board. If the circuit is too small for your fingers, clip a test lead to each end of a resistor in the range of 1–4kOhm, and touch the free ends of the leads to the ends of various resistors on the circuit board until you hear the pitch go up.

When you think you've found a hot spot, mark it on the circuit board with a Sharpie.

If the circuit incorporates the above-mentioned SMDs, most of the components *and* connections will be on the same side of the board, and it may be difficult to distinguish the capacitors from resistors. Go after the blips with *two* shiny solder blobs at either end, rather than three or more, and you're more likely to hit one of the timing components. Good luck—it can be very frustrating, and at a certain point you may want to give up, go out, and find yourself another (older) toy with bigger, more recognizable components.

If you have no success finding the spot, the toy may use a crystal for the clock timing, rather than a simple circuit with a resistor and capacitor. You'd best put it aside and try another. On the other hand, sometimes you'll get lucky and won't even need to lay a finger on the circuit board to find the clock resistor: some toys, such as the "Microjammer" guitars, include a pitch control knob or slider.

What's Happening?

Electric current flows through wire like water through a fat pipe. Resistors are like skinny pipes, or the rust-laden risers of NYC loft buildings: the higher the resistance (measured in chantworthy Ohms), the less current flows. Capacitors also resist the flow of electric current, but resist it more at some frequencies than others, in a manner that defies liquid analogies. Capacitance is measured in soukable Farads, usually in small enough amounts to be called “microfarads” or “picofarads.” (Yes, the vocabulary of hardware is much cuter than that of software.)

When a resistor and a capacitor are combined in the feedback loop of an amplifier, they resonate at a frequency that can be adjusted by changing the value of either of the two components; with enough gain the circuit starts to oscillate, just like a mike and speaker feeding back. Make the resistor or capacitor *smaller* and the frequency goes up; make either *larger* and the frequency goes down. When the frequency gets too high to hear, it enters the range of a useful clock rate for a computer or a digital toy (or a way to summon your dog).

When you place one resistor in parallel with another you *lower* the net resistance (think of it as adding an additional pipe for the current to flow through.) Your skin is a resistor (as we demonstrated in the previous chapter)—when you press your finger across the circuit board contacts you effectively decrease the size of the resistor on the other side of the board. More current flows and the pitch goes up.

Chapter 13

HACK THE CLOCK (LEARN A NEW ALPHABET): CHANGING THE CLOCK SPEED FOR COOL NEW NOISES

You will need:

- The electronic toy from the previous experiment.
- Some hookup wire.
- Test leads with alligator clips.
- A few resistors of different values.
- A potentiometer, 1megOhm or greater in value.
- Soldering iron, solder, and hand tools.

Wet fingers are fine for making the clock go faster. But we all know that the Third Law of the Avant-Garde states:

> **Slow it down, a lot.**

To slow it down we need to make the resistance *larger* instead of smaller. Which means removing the clock resistor (once you are sure which one it is) and replacing it with a larger one—instead of bridging it with your finger (as we did in the last chapter) which can only make the pitch go up.

1. Locate the clock resistor you identified in the previous experiment. Wedge a small flat-bladed screwdriver under the resistor. Melt the solder on the underside of the circuit board at one end of the resistor, and lever the screwdriver to lift that end free from the solder connection (see figure 13.1). Now grip the resistor with a pair of pliers and pull it free of the board as you melt the other solder joint. Put it somewhere safe and don't lose it! If the circuit already has a pitch-control potentiometer ("pot"), de-solder and remove it entirely.
2. Strip and tin the ends of two pieces of hookup wire (approximately 3–6 inches long). Press the end of one into one of the holes left after removing the resistor from the component side of the circuit board. Melt the solder on the solder side of the board as you press the end of the wire through the hole. Touch up the solder joint with a bit of fresh solder to make sure it is solid. Repeat with the second wire into the other hole. Your circuit board should now have two colorful whiskers sprouting from among the other, vertically challenged components (see figure 13.2). If you removed a pot from the board, there may be more than two holes; solder a wire to each of them.

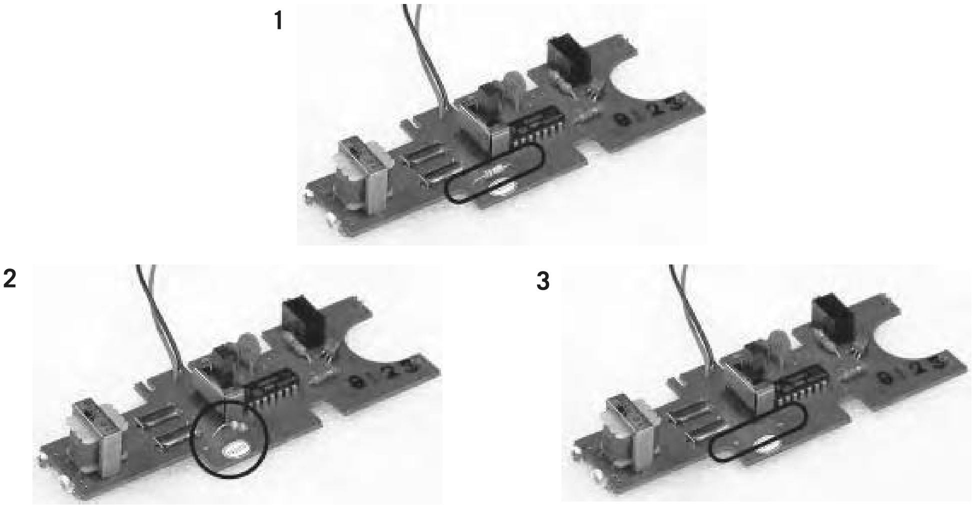


Figure 13.1 Removing a resistor.

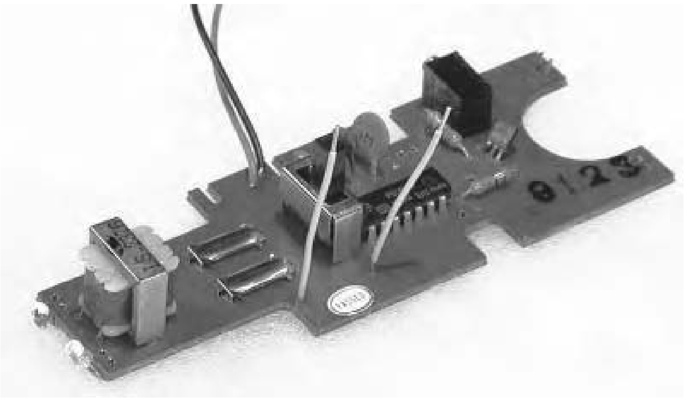


Figure 13.2 Resistor whiskers.

The copper traces on printed circuit boards can be very delicate, and the twisting of the wires as you go through the following experiments can tear the trace, sometimes irreparably. It is a good idea to provide some kind of "strain relief" for them. The easiest method is to bend them gently so they lie flat against the board, and then tape them down with electrical tape to prevent them from moving at the point they pass through the board (see figure 13.3).

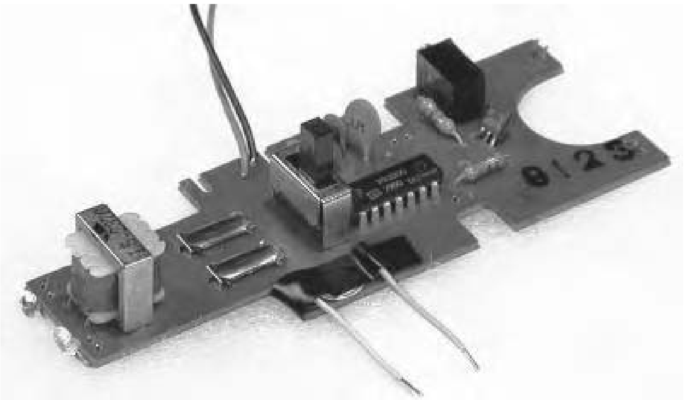


Figure 13.3 Whisker strain relief.

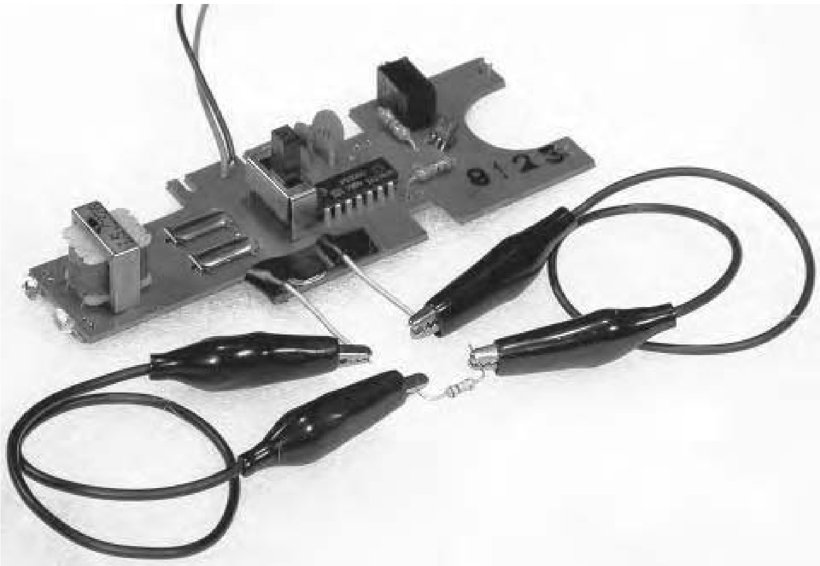


Figure 13.4 A remote resistor.

3. Attach a clip lead to the free end of each of the wires. Clip the resistor you removed between the other ends of the clip leads, effectively re-inserting it to the circuit (see figure 13.4). If you didn't damage anything in de-soldering, the circuit should behave as it did before the operation. If it doesn't, you may need to "restart" the toy by removing and reinstalling the batteries (see Rule #12, below).
4. Those colorful stripes around the resistor indicate its value. Look at the decoder chart in figure 13.5 below:

Resistor Color Codes

Color	Value	Multiplier
black	0	1
brown	1	10
red	2	100
orange	3	1,000
yellow	4	10,000
green	5	100,000
blue	6	1,000,000
violet	7	10,000,000
gray	8	100,000,000
white	9	1,000,000,000

Color	Tolerance (for end band only)
no color	+/– 20 percent
silver	+/– 10 percent
gold	+/– 5 percent

Figure 13.5 Resistor color codes.

Study your resistor. The first two stripes represent number values, the third is a multiplier, and a final gold or silver band the tolerance. So if the bands go: brown, black, yellow, silver:

Brown = 1
Black = 0
Yellow = multiply by 10,000
silver= +/–10 percent tolerance
So we get: 10 x 10,000=100,00 Ohms (or 100kOhms) +/–10 percent

Another example: orange (3) orange (3) red (x 100) gold = 3300 +/– 5 percent. Get it?

5. What are the color bands of the resistor you removed?
   ____
   ____
   ____
   ____
   What is its value? __________
6. Go to your resistor assortment and find a resistor at least twice as big, and one about 1/2 the value. Clip the larger one into the circuit and the pitch should go down. Replace it with the smaller one and the pitch should go up. If either one does not work it may be so extreme a value that the circuit shuts down, so replace it with one whose value is somewhere between the original resistor and the non-functional one. In the event of such a crash, observe the 12th Rule of Hacking:

Rule #12: After a hacked circuit crashes you may need to disconnect and reconnect the batteries before it will run again.

(Count to five before replacing them.)

7. Substituting resistors should give you a good idea of what values produce what kind of sound, but you will probably want to vary the pitch/speed more fluidly. A potentiometer is a continuously variable resistor. In order to extend the pitch downward you need a pot whose maximum value is *greater* than the resistor you removed. Since most clock circuits use rather large resistors (100kOhm or larger) you will probably need a pot whose maximum value is 1megOhm (1,000,000 Ohms) or greater.

Pots have three terminals, which are labeled A, B, and C in figure 13.6. The resistance between the outer two (A and C) is fixed at the designated value of the pot, which is the

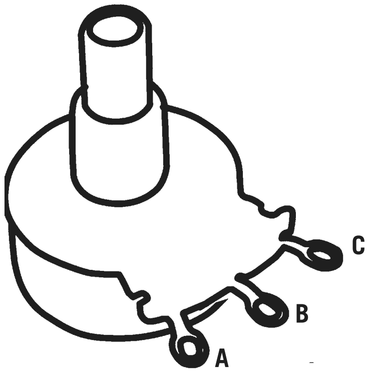


Figure 13.6 The three terminals of a potentiometer.

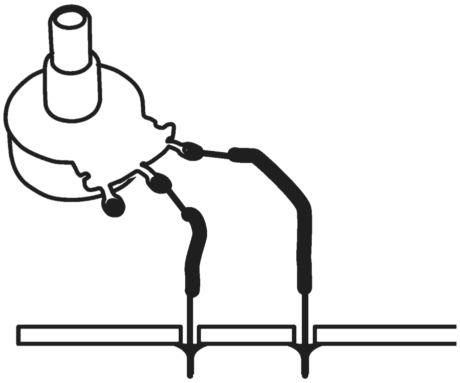
Figure 13.7 Pot substitute for a clock resistor.

pot's absolute maximum resistance (i.e., 1megOhm). As you rotate the shaft of the pot clockwise the resistance between the center terminal B and the outer terminal A goes *up* from 0 Ohms to the maximum value, while the resistance between B and the other outer terminal C goes *down* from the maximum to 0—like a seesaw. Reversing the pot's rotation tips the seesaw back the other way.

Remove the resistor from the clip leads attached to the whiskers on your circuit board. Clip the free end of one of the leads to the center terminal (B) of your pot, and clip the other to the end terminal C (see figure 13.7). Rotate the pot and listen. The circuit will probably crash if you raise the pitch past a certain point and you'll have to restart it (see Rule #12, above). But as long as you stay below that point in the pot's rotation you should be able to coax a pretty wide range of sounds out of your circuit. If the toy appears to shut down when the clock is at its slowest, but restarts on its own when the pitch is raised again, the problem may be simply that the sound is going too low to be heard on the built-in speaker; try putting a telephone pickup on the speaker and amplify it through a bigger speaker (as suggested for the radio in chapter 11).

If there is no appreciable change in pitch or tempo you may have picked the wrong resistor as the clock timing component. Solder it back into the board and use your finger to search again for the hot spot.

If you removed a pitch-varying pot from the circuit (instead of a fixed resistor) you will have to experiment with connecting the terminals of your new pot to various combinations of leads from the circuit board before you find the correct hookup. Substituting a pot of larger value than the built-in one should give you a wider range of pitch/speed variation. Note: one could also change the clock frequency by varying the *capacitor* in the clock circuit, rather than the resistor, but it is difficult to make a capacitor continuously variable over a wide range, and therefore this is generally a less practical approach to the problem of "playing" the clock.



~~**Figure 14.3** Potentiometer alone.~~

~~To make the clock go slower *and* faster you remove the resistor entirely and connect a pot of *larger* value than the removed resistor in its place (see figure 14.3).~~

~~Finally, if you want the toy to go slower and faster but never crash, put the original resistor in series with the pot with clip leads, then substitute progressively smaller resistors for your original value until you find one that lets the circuit run at the maximum speed before crashing, with the pot in the fully clockwise (i.e., 0 Ohm) position.~~

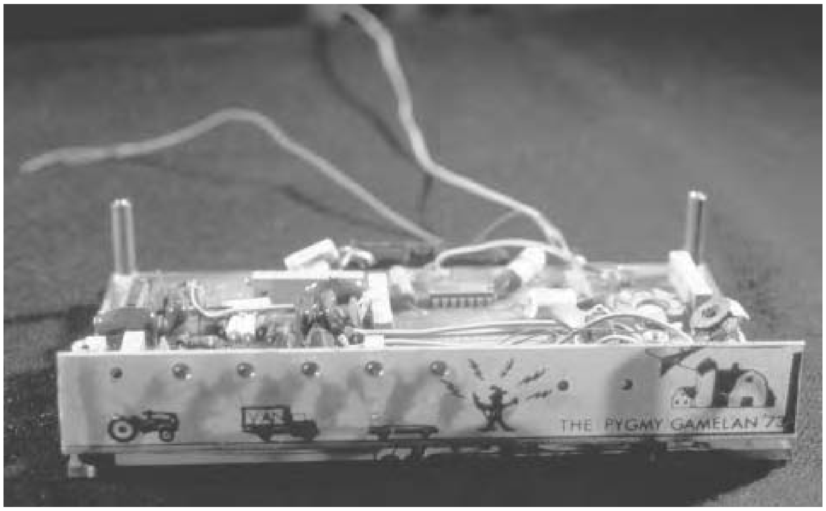
~~If all this doesn't make sense in the abstract, check it out. Use the meter to measure some series and parallel combinations of fixed resistors. Then try some of these modifications to a toy clock circuit until you feel comfortable with The Law.~~

~~Theory class is over. Take a moment to read about some of the first artists to puzzle over Ohm's law as they struggled to make their own electronic instruments (see "Composing Inside Electronics"), then get back to work.~~

Composing Inside Electronics

The 1970s were a pivotal time in the evolution of the technology and culture of electronic music. Synthesizers were still impractically expensive for young musicians, but Integrated Circuits—the guts of those costly machines—were getting cheaper in inverse proportion to their sophistication. New chips contained 90 percent of a functional circuit designed by someone who really knew what he was doing; the remaining 10 percent could be filled in by someone relatively clueless. The trick was finding the right chips: in the days before the World Wide Web, information was much more segregated, with precious few leaks. When data did trickle down from the engineers to amateurs, through magazines with titles like *Popular Electronics* or *Wireless World*, it was often passed from hand to hand like samizdat literature.

A musical community formed around this exchange of information. It included the "Composers Inside Electronics" who worked with Tudor (see "David Tudor and *Rainforest*," chapter 8,) students of David Behrman (see track 11 on the CD) and Robert Ashley at Mills College in Oakland, California (including Kenneth Atchley, Ben Azarm, John Bischoff, Chris Brown, Laetitia de Compiegne Sonami, Scot Gresham-Lancaster, Frankie Mann, Tim Perkis, Brian Reinbolt, and Mark Trayle), students of Alvin Lucier at Wesleyan University in Middletown, Connecticut (Nicolas Collins and Ron Kuivila), of Serge Tcherepnin at California



“Pygmy Gamelan” (1973), electronic circuit composition, Paul De Marinis.

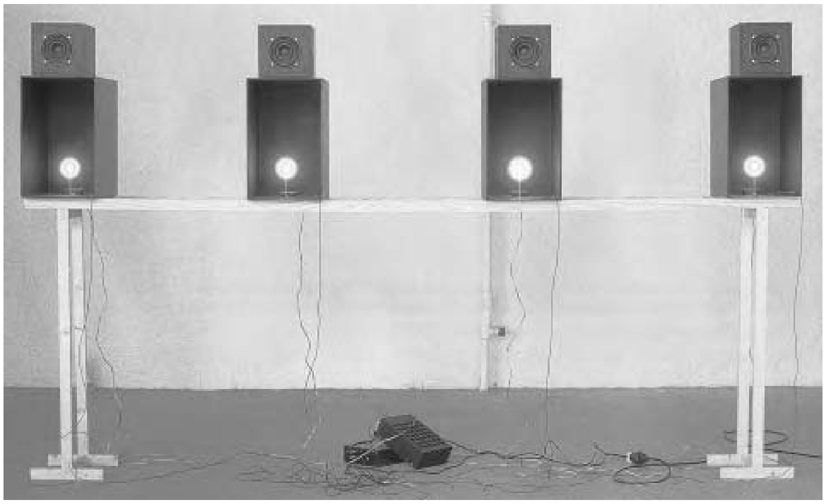
Institute of The Arts in Valencia, California (Rich Gold), and other musicians and artists scattered throughout the United States and (more thinly) Europe. Some participants were mere muddlers, who built beautiful, oddball circuits seemingly out of pure ignorance and good luck. Others became astonishingly talented, if idiosyncratic, designers. The prolific Paul De Marinis included bits of vegetables as electrical components so his circuits would undergo a natural aging process (“CKT,” 1974), incorporated sensors that responded to a person’s electronic field (“Pygmy Gamelan,” 1973; see figure above), and built automatic music composing circuits that anticipated later trends in computer music (“Great Masters of Melody,” 1975)—one of which could be played by a bird (“Parrot Pleaser,” 1974.)

The European electronic music scene of the time was much more stratified—there was a well-established state-funded tradition of collaboration between composers and professional engineers, and homemade music circuitry never caught on there to the degree that it did in the United States (I have never seen a photograph of Stockhausen holding a soldering iron). There were notable exceptions, however. Andy Guhl and Norbert Möslang (Switzerland; see top, next page) formed “Voice Crack” in 1972, and over the next thirty years honed their skills at “cracking” everyday electronics and became virtuoso performers with their new instruments, including circuits for extracting sound from blinking lights (see track 19 on the CD), radio-controlled cars, radio interference, and obsolete Dictaphones. Christian Terstegge (Germany) has been making elegant sound installations and performances with homemade circuitry since the early 1980s. In his 1986 work, “Ohrenbrennen” (“Ear-burn”; see figure bottom, next page and track 12 on the CD) four oscillators are controlled by photocells inside small altar-like boxes containing candles; the pitches of the oscillators rise in imperfect unison, punctuated by swoops that trace the sputtering of the candles as they burn down.

Toward the end of the 1970s the first affordable microcomputers came on the market. Cajoled by the visionary Jim Horton (USA), a handful of musicians

Circuitry by Norbert Möslang.

invested in the Kim-1—a single A4-sized circuit board that resembled an autoharp with a calculator glued on. Programming this thing in machine language (and storing the program as fax-like tones on a finicky cassette tape recorder) was an arduous, counterintuitive, headache-inducing process, but coding offered one great advantage over building circuits: it was easier to correct a mistake by re-programming than by re-soldering. Over the next ten years Apple, Commodore, Atari, Radio Shack, and others introduced increasingly sophisticated machines (and eventually disk drives) which gradually reduced the angst-factor of programming, and homemade circuits faded into anachronism, until the anti-computer backlash of "Circuit Bending," as proselytized by Reed Ghazala (see chapter 15), brought "chipetry" back into fashion.



"Ohrenbrennen" (Ear-burn), Christian Terstegge.