CHAPTER 15

Beyond the Pot: Photoresistors, Pressure Pads, and Other Ways to Control and Play Your Toy

You will need:

- Electronic toys and radios from the previous experiments.
- Some hookup wire.
- Test leads with alligator clips.
- An assortment of resistors and pots.
- A few different photoresistors.
- A flashlight.
- A soda straw (opaque if possible), or a short piece of heat shrink tubing.
- Some loose change.
- Anti-static foam from packaging integrated circuits.
- A small sheet of corroded conductive metal, such as iron, copper, or aluminum.
- A lead from a mechanical pencil.
- Some paper and a soft pencil.
- Some fruit and or/vegetables.
- A telephone pickup coil and small amplifier.
- A multimeter.
- Soldering iron, solder, and hand tools.

You've opened a toy, tickled the clock, replaced its timing resistor with a potentiometer, and learned a bit of theory about swapping resistors—what's next in the way of toy hacks?

PHOTORESISTORS

A photoresistor (or photocell, as it is sometimes called) is a device that changes its value in response to light level: the resistance gets *smaller* when it is exposed to a bright light, and gets *larger* in the dark. It takes the form of a small disk, whose diameter can range from 1/8 inch to 1 inch; two wires come out of one side, and the other side displays a pleasing zigzag pattern of fine lines (see Figure 15.1). The side with lines is more sensitive to light than the other, but the back is translucent enough that light striking the back will affect the resistance as well. The lowest resistance in bright light is anywhere from

100 to 2,000 Ohms, depending on the kind of photoresistor; the "dark resistance" is very large, typically around 10 megOhms. Because this is higher than most pots, and because most clock circuits use pretty large resistors, photoresistors are a convenient variable resistor for slowing down toys a lot.

Photoresistors are pretty cheap, especially when bought from "surplus" outlets online. Some retail sources provide data on the range of resistance, sometimes not. In addition to different "light" (minimum) and "dark" (maximum) resistances, different photoresistors will respond at different speeds to changes in light level—some are more sluggish than others. All these factors affect how they perform in a musical circuit. You can test them with a multimeter, but ultimately your ear is the best guide to picking a good photoresistor for your circuit. Don't be disappointed if it takes a while to find the perfect one.

Select a photoresistor. Remove the pot from the clock circuit of the toy you've been working with for the past few chapters, or find and remove the clock resistor in another toy. Using clip leads, attach the two leads of the photoresistor where the pot tabs were connected, or solder the photoresistor directly in to the holes left when you removed the resistor (see Figure 15.2). Turn on the toy and listen to how the circuit

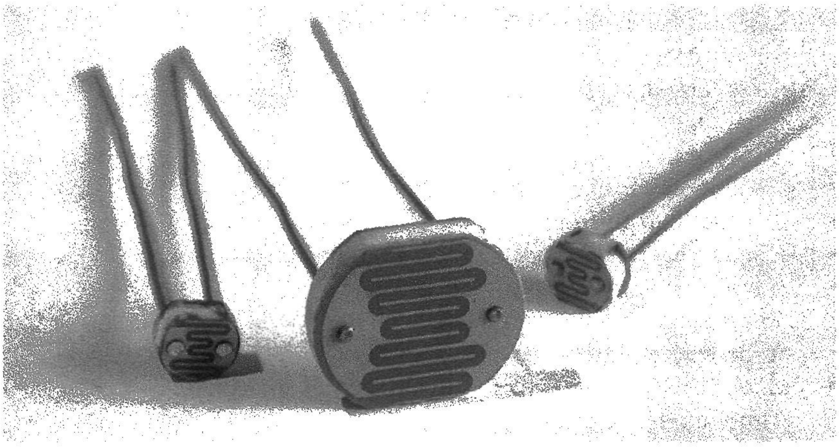

Figure 15.1
Some photoresistors.

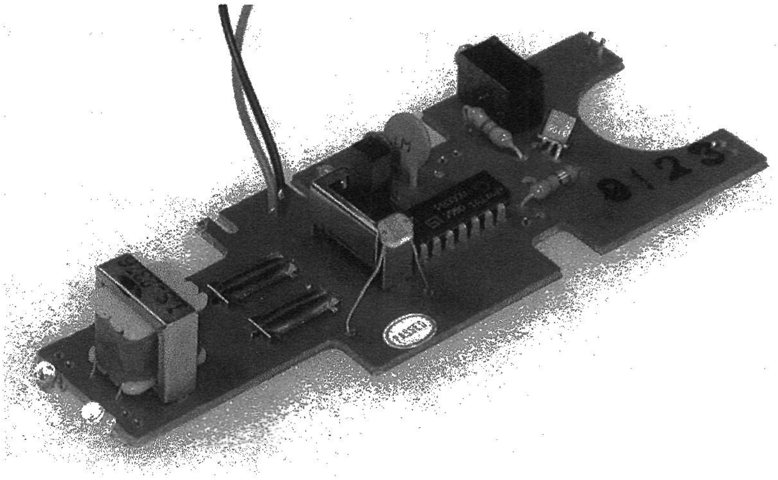

Figure 15.2
Photoresistor in place of clock resistor.

behaves when you pass your hand over the photoresistor or shine a flashlight on it. If you have more than one type of photoresistor swap them in and out, and listen to how different ones affect the circuit.

For maximum resistive range you must go from totally black (no light at all) to high illumination—carry your circuit into a closet and play it with a flashlight. More practically, you can mount the photoresistor at one end of an opaque tube (such as a drinking straw painted black, or a short piece of heat shrink tubing) to make it very directional in its light sensitivity: it will only respond to light aimed directly down the tube (see Figure 15.3). This is the core technology of certain carnival shooting galleries, where each "gun" fires a light towards similarly blinkered targets.

You can put the photoresistor in your mouth and make a very expressive controller that responds to changes in both the light level as you open and close your mouth, and in the conductivity of your saliva-laden tongue across the photoresistor's bare legs (a suggestively naughty extension of the licked-finger-on-circuit-board effect).

DON'T EVER *THINK* OF TRYING THIS WITH ANY CIRCUIT THAT IS EVEN BATTING ITS EYELASHES AT A WALL OUTLET!

Place a fan between a light source (such as a flashlight) and the photoresistor, or reflect light off a record turntable (put some delicately crumpled aluminum foil on the turntable instead of a record)—you should hear a vibrato effect or other wobbly modulation, which changes as you vary the speed of the fan or turntable.

If the toy has blinking lights or LEDs you can tape the photoresistor against one of the lights and the toy will modulate itself, producing possibly interesting patterns. Two toys with blinking lights and photoresistor-controlled clocks can modulate each

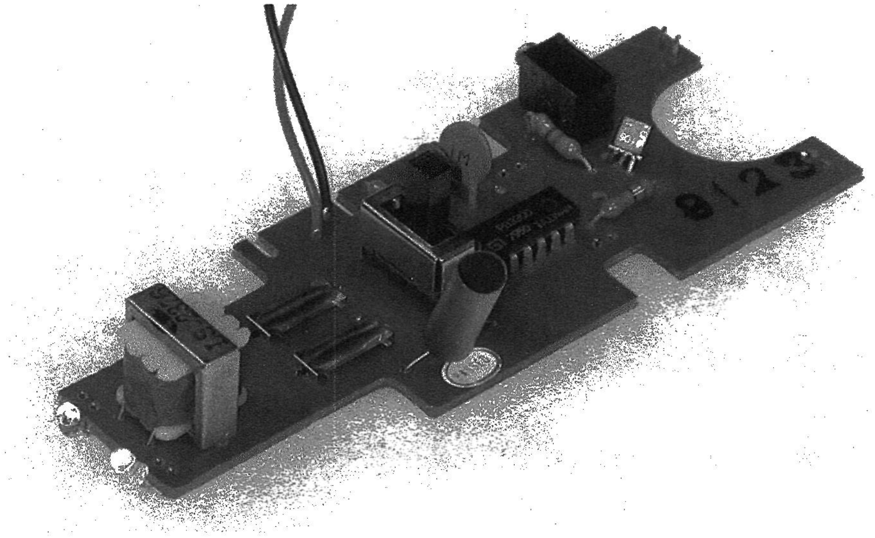

Figure 15.3 A shy photoresistor, hiding inside a section of heat shrink tubing.

other—curiously erotic electronics! The more toys, the greater your chances of creating artificial life.

A photoresistor can be a good compromise between the fluid, if somewhat unpredictable (and occasionally dangerous), effect of the finger on the circuit board and the more controllable but less expressive potentiometer. You can use it as a very responsive *performance* interface to interpret hand shadows or flashlight movement, or as an installation sensor, reacting to ambient light and the shadows cast by visitors. We'll look at more photoresistor applications in Chapter 18 and beyond.

As I mentioned earlier, although the zigzagged side is more sensitive to light than the backing, most photoresistors are made of translucent material, so that light striking the back will affect its resistance as well. It is important to cover the back if you want the greatest range. Besides burying the photoresistor in an opaque straw, you can seal off the back with black paint or electrical tape.

If you want to have both the gestural quality of the photoresistor and the controllability of the pot, you can combine the two: if you wire a pot in *series* with a photoresistor (see Figure 15.4), the pot will determine the *maximum* frequency of the clock in full light, and darkness will cause the speed to go *down* from that maximum. If you wire the pot in *parallel* with the photoresistor (see Figure 15.5), the pot will set the *minimum* frequency of the clock in full darkness, from which the speed will go *up* as light increases. (If this sounds confusing, just try it).

As I mentioned earlier, in total darkness, the photoresistor has a very large resistance—as high as 20 mOhm—much higher than any commonly available pot. If you want really low frequencies out of your toy a photoresistor is the way to go—moreover, multiple photoresistors can be strung together in series to drive a clock down into the glacially slow range.

ELECTRODES

Let's not forget the heady spontaneity of our youthful experiments with flesh-controlled circuitry back in Chapter 11. If you want to use your fingers to connect points on the board that are widely separated, or you just want a more formal playing surface, dimes or other silver-plated coins make excellent electrodes (copper tarnishes too quickly to

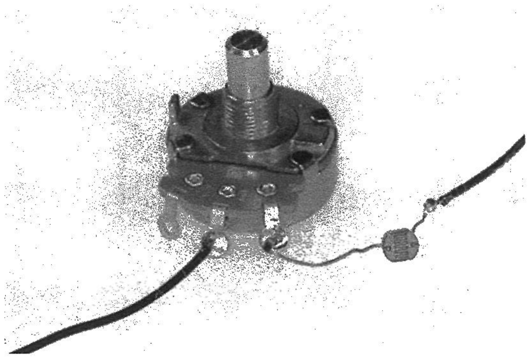

Figure 15.4
A potentiometer and photoresistor in series.

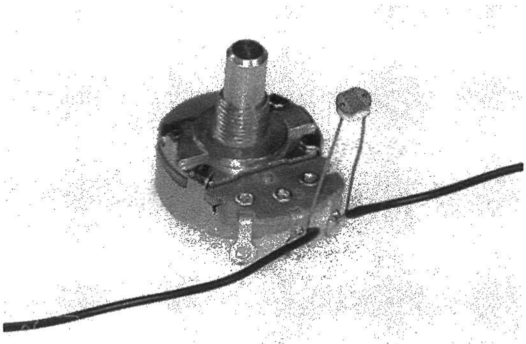

Figure 15.5
A potentiometer and photoresistor in parallel.

use in an urban or coastal environment—just take a look at the Statue of Liberty). Strip 1/4 inch of insulation off both ends of a few 5-inch pieces of wire. Solder one end of each wire to one of the "sensitive points" you've found on the circuit board, and solder the other end to a coin. Arrange the coins in a pattern that lets you bridge them easily with your fingers, but avoid direct shorts (see Figure 15.6). By the way, I was told as a child that it is illegal to solder or similarly deface US currency, so you might refrain from performing this one in the presence of the Secretary of the Treasury.

A nice way to combine the control certainty of a potentiometer with the gestural possibilities of finger-on-circuitry is to parallel the pot and a pair of electrodes, as we did with the photoresistor in Figure 15.5. When you solder your hookup wires to the lugs of the pot leave an extra inch of bare wire sticking up through the solder hole. When you go to mount the pot in the box that will hold the circuit (see Chapter 17), drill small holes to line up with the wire ends and two more about 1/2 inch away. Lead the bare wires up through the panel at the pot and then down again, so that they form two parallel strips (see Figure 15.7). You will have convenient electrode contacts immediately adjacent to the knob so you can slip your finger back and forth between precision adjustment and touchy-feely playing (you could also solder coins to these wires for a larger playing surface).

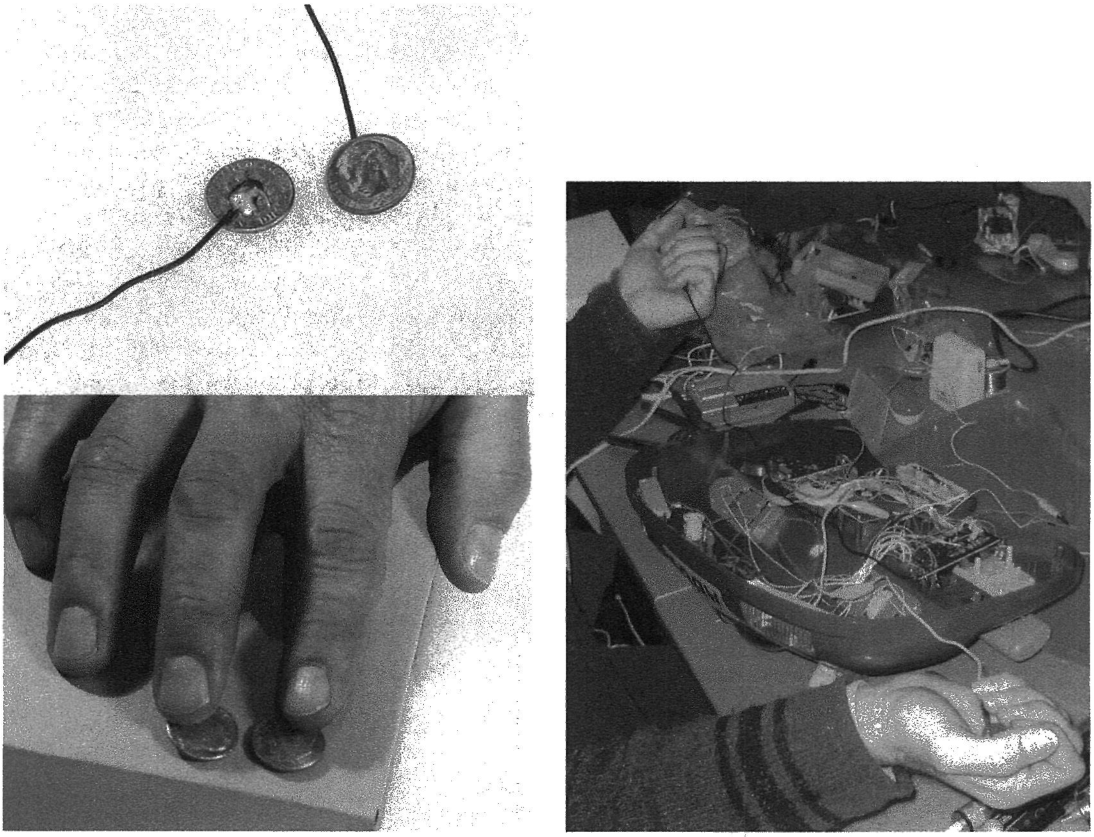

Figure 15.6 Coin electrodes and their performance.

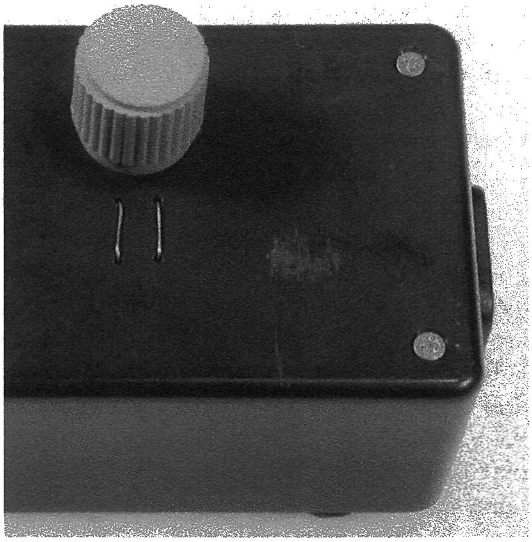

Figure 15.7
A potentiometer with electrodes in parallel.

CHEAP PRESSURE SENSORS

The squashy black "anti-static foam" in which integrated circuits are sometimes packaged has interesting electrical properties. Put a piece between two coin electrodes and measure the resistance with a multimeter as you squeeze them together—it gets lower as you apply more pressure (see Figure 15.8). This homemade pressure sensor can be used in place of a pot or photoresistor to make a pressure-sensitive controller for performance or installation (under chair legs to measure weight, for example). Anti-static foam can be bought in sheets from various online retailers, if you can't find an engineer's garbage pail from which to scrounge.

Vegetables and fruit also have resistive value. This value changes as they dry out or are squished. You can substitute small slices of produce for the anti-static foam in the above experiment, or poke bare wires directly into carrots or apples. (As some of you may remember from childhood science experiments, it is also possible to make a battery out of fruit or vegetables, but this lesson will wait until Chapter 29.)

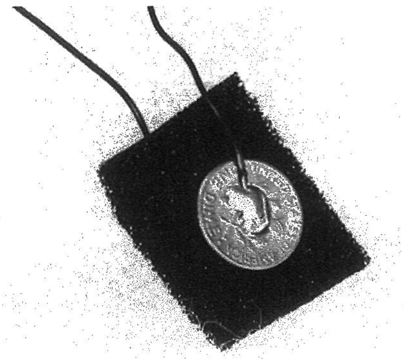

Figure 15.8
Pressure sensor made from anti-static foam and two dimes.

ARTY

A pencil lead from a mechanical pencil makes an excellent, if delicate resistor (see Figure 15.9). Attach two clip leads to the clock resistor contact points in your toy. Clip one wire to one end of the pencil lead, and scrape the jaws of the other along the lead. Resistance is proportional to the distance separating the contact points, so the pitch of the toy should go down as you move the clip further from the end. (Most potentiometers are simply a neatly packaged strip of carbon with a moving wiper.)

The use of graphite as a resistor is not limited to pencil leads themselves. Draw two blots near the edge of a piece of paper, and clamp the jaw of a clip lead to the paper at each blot; clip the other ends of the leads to the clock resistor contact points in your toy (see Figure 15.10). Draw a line between the two blots and get the toy running—as you widen the pencil line linking the blots, or draw additional lines, the pitch should go up. Why? The wider the graphite path between the clips the lower the resistance (think fat pipes versus skinny pipes). Patrick McCarthy has made functional potentiometers using this technique (see Chapter 30 and his video on the DVD).

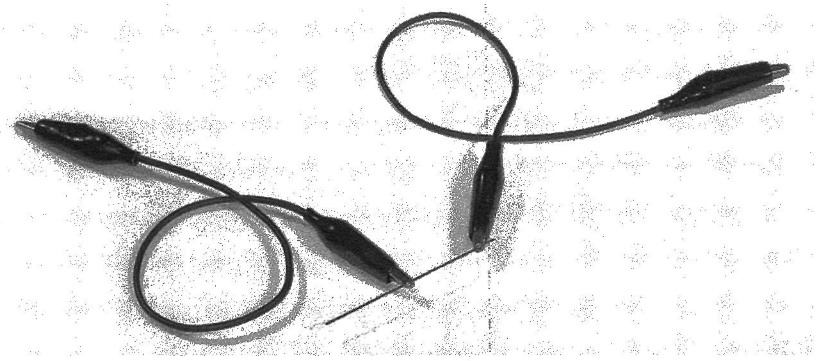

Figure 15.9
A pencil lead resistor.

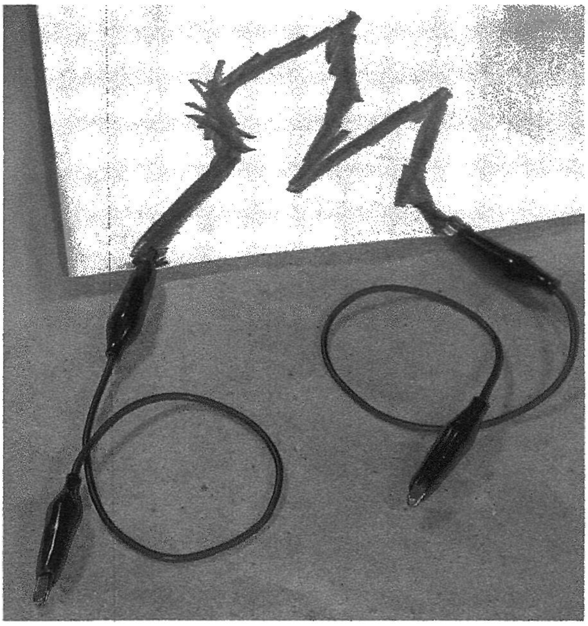

Figure 15.10
Drawing a resistor.

You can also use a strip of magnetic tape as an open-air resistor (old VHS tape works great): use two probes pressed against the surface, or an alligator clip at one end and one movable probe. As with the pencil line, resistance is proportional to distance. T. Escobedo's "Synthstick" is a glissando-based instrument, sort of a cross between a Theremin and a Stylophone, based on this principle.

ALMOST A SHORT CIRCUIT

Enough of clocks! There's more to life than pitch change. Sometimes a toy can be induced to make curious sounds if you make new connections between various locations on the circuit board. Take a resistor of about 100 Ohms and bend it into the shape of a croquet wicket. While listening to the toy, press one end of the resistor to a solder point on the solder side of the board; then touch the other end to various other points—if the circuit board is large you may need to use a clip lead to reach all over (see Figure 15.11 and audio track 13). You may (or may not) get some interesting-sounding circuit malfunctions. Disconnect *immediately* any connection that seems to cause heat, smoke, or flame.

Try different value resistors, but avoid shorting out the board with straight wire unless it's the only thing that works (see the 7th Rule of Hacking). If you find that the best sounds happen with the smallest value resistor, you can try plain wire, but do so gingerly and be prepared to remove the wire as soon as you feel or smell trouble. You can also try using pots or capacitors instead of resistors. You can go back to your radio and experiment with using resistors to jump between the hot spots you bridged with your damp finger.

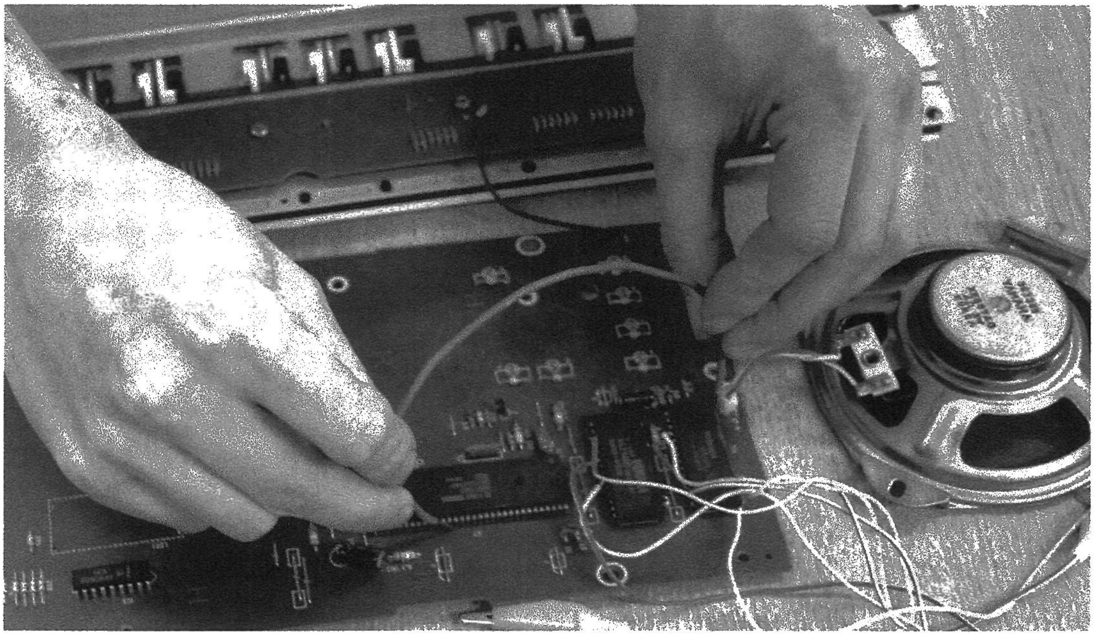

Figure 15.11 Phil Archer bridging the circuit board.

Once you find a useful connection you can solder the resistor permanently into place, or add a switch to connect and disconnect it as a performable change (see next chapter for switch information).

This technique is at the heart of Reed Ghazala's wonderful "Circuit Bending" philosophy of hardware hacking (see Art & Music 9 "Circuit Bending"), and is a very powerful and creative tool for extracting unusual sounds from almost any found circuit.

If you're feeling suicidal, you can follow Phil Archer's or hans koch's example and dribble water on the circuit board—watch their videos on the DVD, and watch out!

RUSTY

A corroded metal plate and a nail can serve as a quasi-random variable resistor, as we demonstrated with the jumping speaker in Chapter 5. Choose any two points on the circuit board that produce a change when they are connected to one another—this could be the clock resistor solder pads, or any of the hot spots we've just described bridging with resistors. Solder a short wire to each point, long enough to be grasped in the jaws of a clip lead. Clip the other end of one of the leads to a nail and the other lead to a sheet of rough or corroded metal (copper flashing, rusty baking sheet, file, etc.). Lightly scrape the nail across the metal and listen to the circuit twitter—the corrosion and intermittent hop, skip, and jump of the nail over the rough micro topography yields an ever-fluctuating resistance that can be steered (if not exactly controlled) by adjusting the pressure and speed of movement.

MOTOR-MOUTH

Noise, flashing lights, and frenetic activity—the essential attributes of any disaster are also the core components of a successful toy. After messing around with the sounds and lights, don't forget the motors that make tickled Elmo twitch and Billy Bass flap his tail. Some pretty sophisticated computer code goes into this electromagnetic choreography, and you can eavesdrop on it by placing a telephone tap coil on a motor and connecting the coil to your amplifier. There is often a beautiful rhythmic interplay between the toy's sounds, blinking lights, and movements, and a thorough hack can bring all this futurist polyphony to the ear. And don't forget to try another coil on the toy's speaker to make the basic sounds louder and more "hi-fi" (as we did with the radio in Chapter 11).

INTERCONNECTING TOYS

Once you've opened and hacked a few toys don't be afraid to experiment with interconnecting them. First connect a clip lead between the grounds ("–" end of the batteries) of both toys. Then use another clip lead to make random connections between any point on one toy and any on the other. Use a jumper between the clocks and you may get the toys to cross modulate each other; if you connect clock points between two circuits and remove the resistor from one, you can sometimes drive both in sync from a single clock.

ART & MUSIC 9

CIRCUIT BENDING

Traditionally, making functional electronic objects has necessitated a fair grasp of theory and a pretty clear idea of what you wanted to make *before* you picked up your soldering iron. David Tudor, Gordon Mumma, Composers Inside Electronics, and other musical designers began chipping away at these assumptions in the 1960s and 1970s. Being self-taught, they had only piecemeal knowledge of electronic theory and were less concerned about doing things "properly" than about making something that sounded cool. Immersed in a musical ethos that valued chance, they were highly receptive to accidental discoveries—in the pursuit of the "score within the circuit," they relished wandering down side paths, rather than race-walking toward a predetermined goal.

Then in the mid-1990s Qubais Reed Ghazala pushed serendipity back to the fore of electronic practice with his fervent advocacy of what he dubbed "Circuit Bending." Like Waisvisz (see Art & Music 7 "The Cracklebox," Chapter 11), as an adolescent in the late 1960s Ghazala encountered the sounds of accidental circuit interaction: an open amplifier left in his desk drawer shorted against some metal and began whistling. After some experimentation, Ghazala added switches so he could control the shorting, and Circuit Bending was born. He developed a series of techniques for modifying found circuitry—especially electronic toys, whose sonic sophistication grew in direct response to the boom of semiconductor technology in the 1980s—without the benefit of the manufacturer's schematics, or any engineering knowledge whatsoever. In 1992 he began publishing instructive articles in *Experimental Musical Instruments* (an influential journal for instrument builders) and acquired a cult following. In 1997 he launched his Web site and today a cursory Web search will reveal news groups, festivals, and workshops for Circuit Bending all over the world.

Circuit Bending is freestyle sound design with a postmodern twang—the perfect escape for artists bored by the powerful, but often stultifyingly rational, software tools that increasingly dominate music production, yet still hooked on the digitally inspired cut-and-paste aesthetic of scavenging, sampling, and reworking found materials. With its defiantly anti-theoretical stance and emphasis on modifying cheap consumer technology, bending has a natural egalitarian appeal (as well as some odd orthodoxies: looking at my instruments as I was setting up a demonstration at the "Bent 2004" Festival at The Tank Gallery in New York City, an audience member inquired, "Are they bent or hacked?" When I looked baffled he elaborated: "'Bent' means you have *no* idea what you are doing when you open up the circuit; 'hacked' means you have *some* idea"). But Bending's try-anything extreme experimentalism can produce wonderful results never anticipated by the original designers of the device being bent.

Some Benders specialize in particular adaptations: German musician Joke Nies has made a specialty of hacking an early digital instrument called the "Omnichord" (see Figure 15.12 and his video on the DVD); my ex-student Jon Satrom has based his VJ career on a specific V-Tech children's toy (see Art & Music 10 "Visual Music" in Chapter 24, Figure 24.6, and his video on the DVD). Texas Instrument's "Speak and Spell" has been a favorite from the day it was introduced in 1978, long before the term "Bending" came into use. Web sites abound with detailed instructions for specific cuts and jumpers on the boards of particular toys.

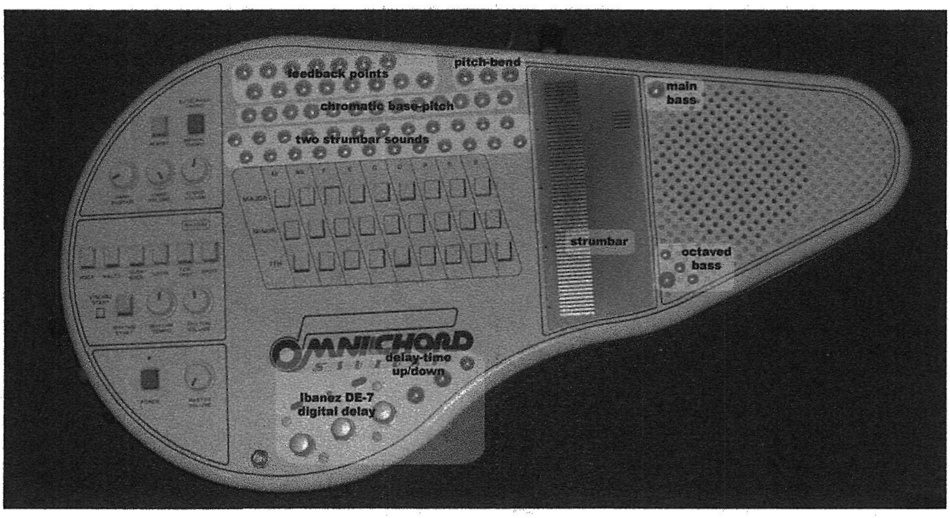

Figure 15.12 Bent Omnichord, Joker Nies.

Phil Archer (UK) and John Bowers (UK) are representative of the emerging generation of hackers, who effortlessly combine bending with Tudor-era contact mike technology and sophisticated computer programming. Archer did the "classic" bend to his Yamaha PSS-380 keyboard: exposing the circuit-board, placing the inverted instrument on the performer's lap, and making arbitrary connections between components on the board with a stripped piece of wire (see Figure 15.11 and audio track 13). "These connections," he writes, "induce tones, bursts of noise and corrupted 'auto-accompaniment' sequences from the device which are unpredictable in their details but generally 'steerable' overall with practice. The precision and control afforded by the standard keyboard interface is eschewed in favour of direct contact with the circuit, and the performer is continually forced to rethink and re-evaluate their relationship with the instrument in light of the sonic results." Most of his other instruments have a Frankenstein quality: a midget Hawaiian guitar whose single string is played by the sled mechanism from a CD player (see Figure 15.13); a set of small percussion instruments whacked and scraped by motors from a dot matrix printer; a music box mechanism activating "Bent" electronic keyboards and a keyboard played by dripping water (see Archer's video on the DVD).

John Bowers—in an ongoing struggle against his training as a computer scientist—"reinvented" what he has dubbed the "Victorian Synthesizer" (see Chapter 5 and audio track 4): it produces sounds with speakers animated directly by batteries, bereft of intervening electronic circuitry. Corroded metal, mercury-filled tilt-switches, and a handful of screws and washers complete instruments that could indeed have been built in the nineteenth century. His other "Infra-Instruments" combine similar electro-mechanical technology (mixing bowls filled with motors, magnets, contact mikes, and guitar pickups (see Figure 15.14); microphones embedded in a plank of wood; strings, stones, and guitar pickups strewn across a table with computers and rock effect boxes.

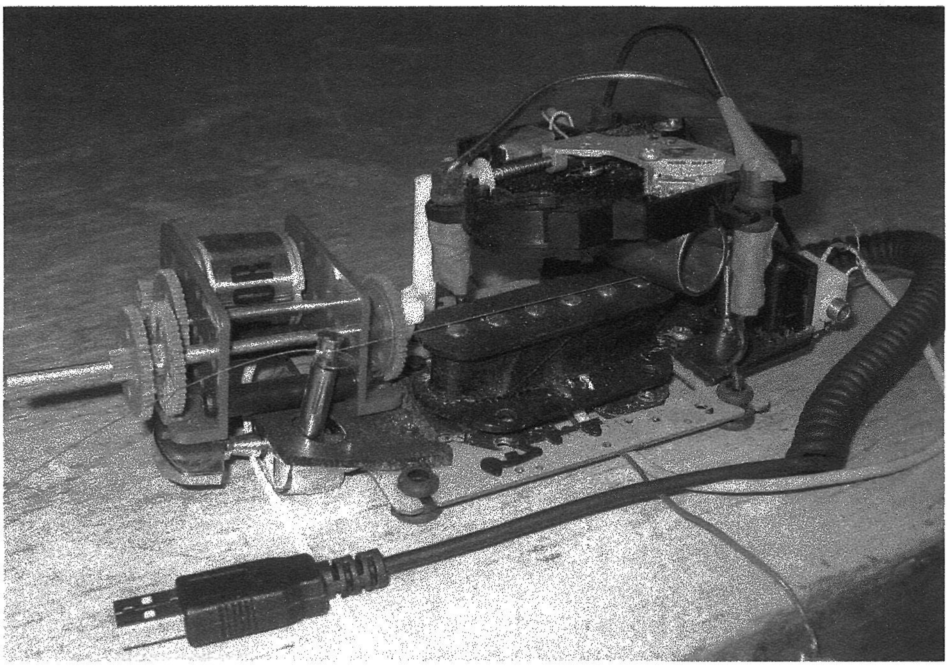

Figure 15.13 "CD Player Slide Guitar," Phil Archer.

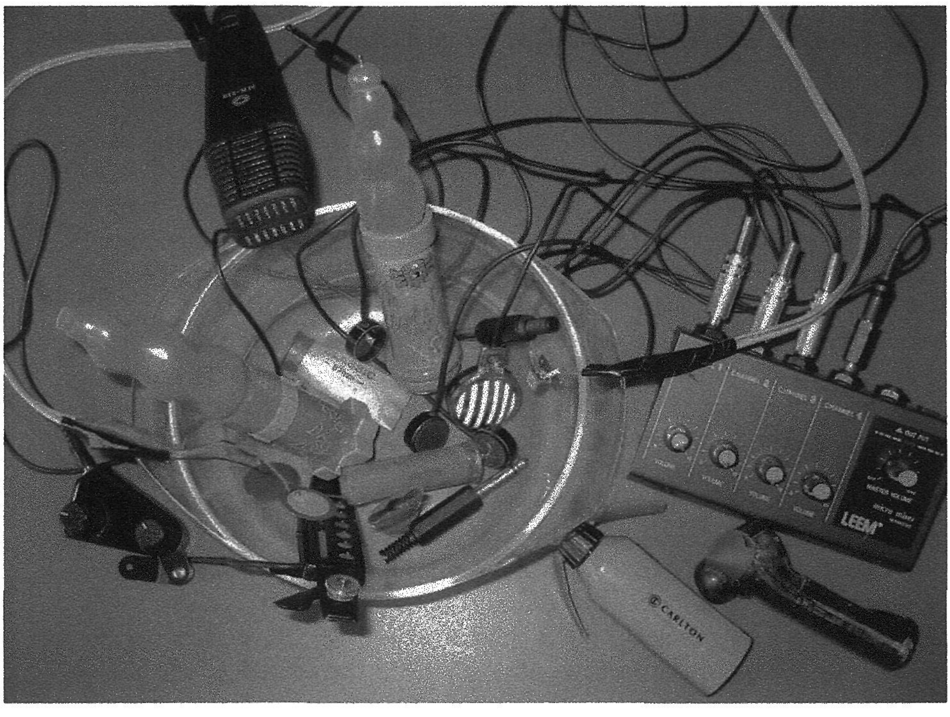

Figure 15.14 "Mixing Bowl," John Bowers.

Notable younger Benders include Knut Aufermann (Germany/UK), Xentos "Fray" Bentos (UK), David Novack (USA), Vic Rawlings (USA), Sarah Washington (UK), Chris Weaver (UK), and Dan Wilson (UK). Britain's particularly vibrant bending scene (including an "all bending ensemble," P. Sing Cho—see audio track 14) has roots in the prevalence of toys as affordable, alternative noisemakers among improvisers in the 1970s—most significantly Steve Beresford. As Sarah Washington says, echoing Tudor from four decades earlier, "I am an improvising musician . . . the choice of sounds is down to the circuit—whatever it comes up with is fine with me" (see Figure 15.15).

(For more information on the current state of Circuit Bending see Chapter 30.)

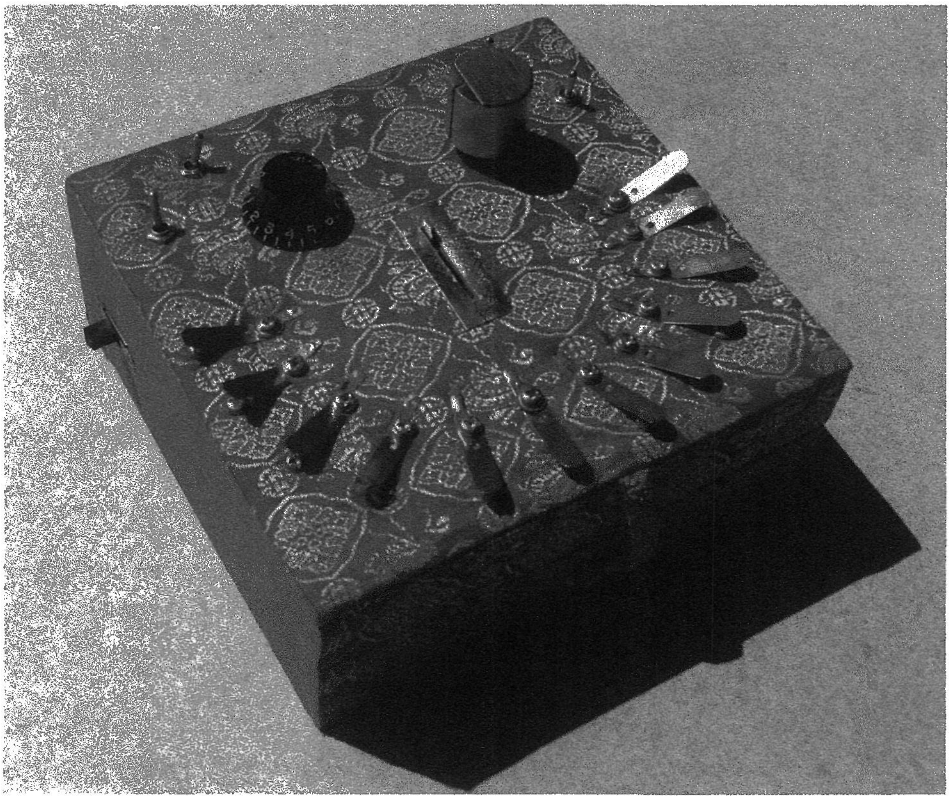

Figure 15.15 "Mao Tai," Sarah Washington.

Remember that you can also link circuits through blinking lights and photoresistors, as described earlier in this chapter.

Lest you get too distracted by the gizmo-factor of all these add-ons, don't forget the humble laying of hands. On larger circuit boards with multiple components (such as musical keyboards) a few damp fingers brushed against the circuit board can raise delightful havoc with the normal behavior of the toy—the Yamaha PS-140 is especially susceptible to fleshly corruption (see Figure 15.16). British bending iconoclast Dan Wilson lets worms crawl across his circuit boards (see Chapter 30 and his video on the DVD).

BEYOND TOYS

Most of the techniques described in this chapter can be used to extend the radio you opened up in Chapter 11 as well: electrodes can pull the radio's ticklish spots to the outside of a box, and make it easier to bridge multiple points with your fingers; pots, photoresistors, pressure pads, resistors, and rusty nails can be used to link these points as well. Toys and radios are cheap and plentiful, and thus an obvious flashpoint for hacking insurgency, but the same methods can be applied to almost any electronic circuit: CD players (see Figure 15.17), rock effect pedals ("stomp boxes") (see Figure 15.18), cassette players (see Figure 11.4), answering machines—you'll never know until you try them. Vic Rawlings (US) uses wire brushes, nails, fingers, and assorted metal junk to play a complicated array of effect pedals—see his video on the DVD and Figure 15.19. Neal Spowage (UK) has hacked metal detectors to make his "Electro Magnetic Wands" (see his video on the DVD).

Figure 15.16 Mike Challis (UK) playing his hacked Yamaha PS-140 by touching circuit board directly through a hole cut into the case.

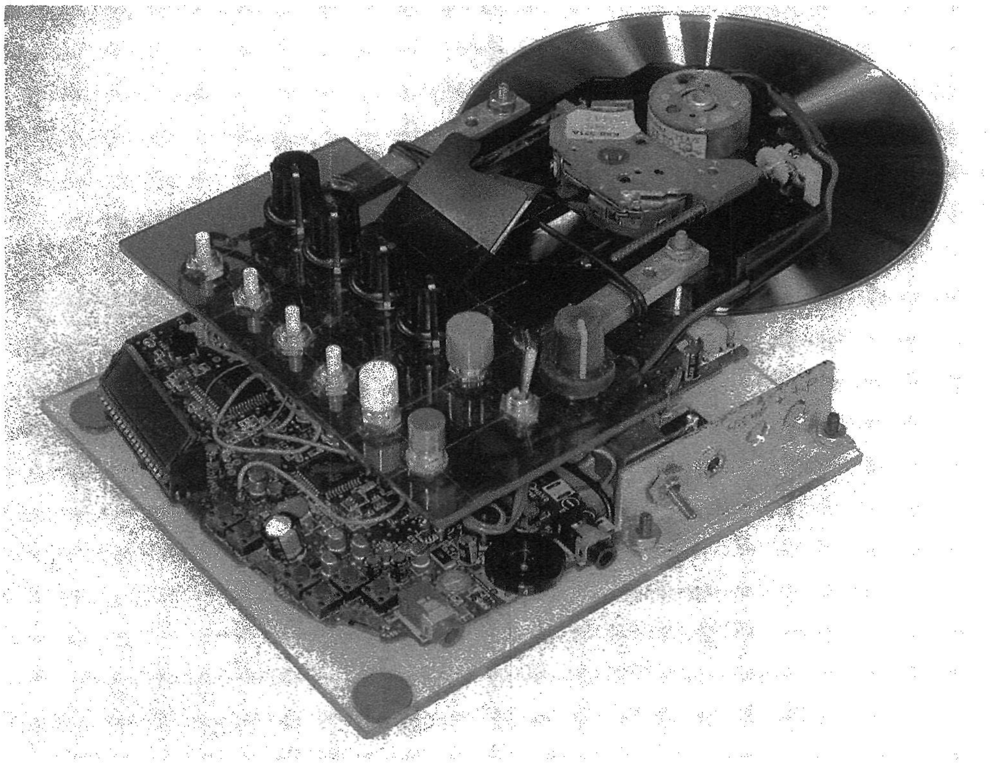

Figure 15.17 "Sled Dog," hand-scratchable hacked CD player by Nicolas Collins.

Figure 15.18 Hacked guitar effect pedal by Chris Powers (US), with electrode contacts for toes.

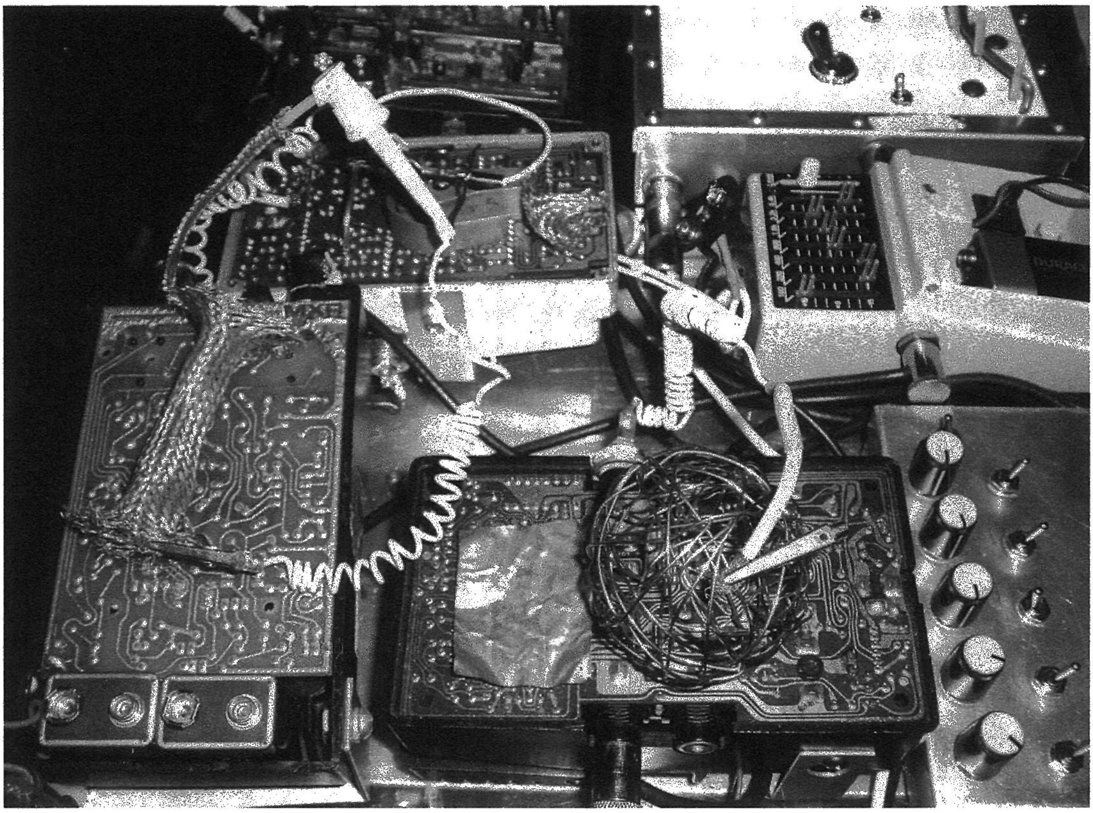

Figure 15.19 Performance setup by Vic Rawlings, showing open circuits with wire ball.

You can buy dozens of different kinds of electronic kits—from strobe lights to electronic wind chimes—from online retailers (see Appendix A) and experiment with these kinds of modifications as you build them—hacking goes faster if you don't have to disassemble first. After savoring bespoke electronics you'll never accept off-the-rack again.