CHAPTER 14

Ohm's Law for Dummies: How to Understand Resistors

You will need:

- The electronic toy from the previous experiment, or a new one.
- Some stranded and solid hookup wire.
- Test leads with alligator clips.
- An assortment of resistors.
- A potentiometer (1 megOhm or greater in value).
- A multimeter.
- Soldering iron, solder, and hand tools.

Now it's time for a smidgen of theory—sorry.

MEASURING RESISTANCE

A multimeter is a device for measuring various electronic properties, such as testing the voltage of a battery to see if it's dead or alive, or checking the value of a resistor. Meters come with analog readouts (a wiggling needle) or digital displays—simple digital meters are cheap these days and generally more useful. Most meters have a multi-position rotary switch for selecting different measurement modes (DC voltage, AC voltage, current, resistance, etc.) and the range of values measured and displayed within each mode.

Grab a meter, turn it on, and select the resistance/Ohm setting (Ω). Measure some resistors to confirm your prediction of value from the color code (as learned in the last chapter), and to acquaint yourself with this new tool. Most meters have a few ranges for resistance—experiment and see how changing the range affects the readout. You will notice that a handful of "identical" resistors (i.e. all the ones marked orange-orange-yellow for 330 kOhm) will probably indicate slightly different values—an indication of the 5 percent or 10 percent tolerance, as indicated by the gold or silver last band (and mentioned in the previous chapter). Measure between the nose and ears of a pot as you turn the shaft, and observe the seesaw change in resistance (you may need to use clip leads between the meter's probes and the terminals of the pot unless you have three hands or are skilled with chopsticks). Check the resistance of your skin—you'll need to use the highest setting in the Ohm range. Notice that the resistance decreases the harder you press the probes into your skin (ouch!), the closer together you place them, or the wetter your fingers are (digital confirmation of the experiments you've done in previous chapters).

SERIES AND PARALLEL (OHM'S LAW)

You may recall that a finger pressed on a circuit puts your mom-made resistor in *parallel* to the existing components, *lowering* the net resistance, *increasing* the speed of the clock and raising the pitch of the toy. In order to lower the pitch you had to remove the on-board resistor and substitute a pot of larger value. This demonstrates an aspect of Ohm's Law (a fundamental underpinning of electronic theory, worshipped by engineers of many lands) so essential to hacking that we will appropriate it:

Rule #13 (Ohm's Law for Dummies): The net value of two resistors connected in parallel is a little bit less than the smaller of the two resistors; the net value of two resistors connected in series is the sum of the two resistors.

To make a clock *slower* than it already is you must add a pot in *series* with the resistor on the board, making the net resistance *larger*: de-solder one end of the resistor and connect the pot between this loose end of the resistor and the hole out of which it came (see Figure 14.1). Because the toy will never run faster than its "stock" speed, this configuration minimizes the risk of freeze and crash.

To make the clock only go *faster* you connect the pot in *parallel* to the on-board resistor (essentially substituting it for your finger in the test we did in Chapter 12): leave the resistor in place in the circuit, and solder wires from the two tabs of the pot to the two pads at the ends of the resistor (see Figure 14.2).

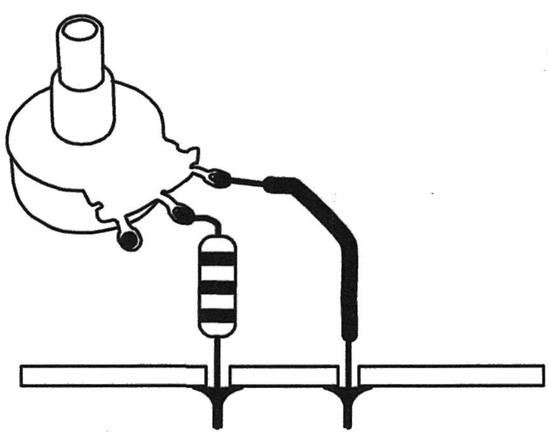

Figure 14.1
Potentiometer and resistor in series.

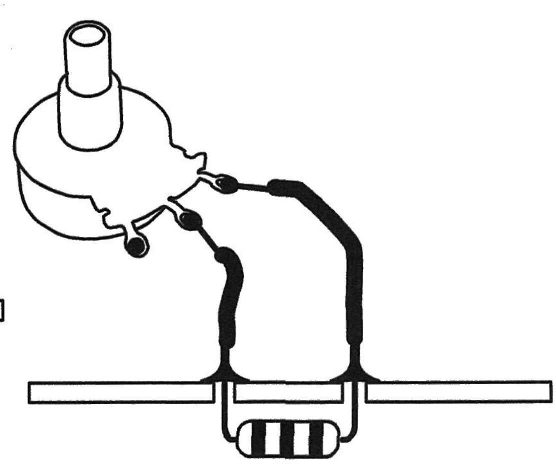

Figure 14.2
Potentiometer and resistor in parallel.

To make the clock go slower *and* faster you remove the on-board 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 (as in Figure 14.1), then substitute progressively smaller resistors for your original value until you find one that lets the circuit run at the maximum speed without 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 pot and resistor variations on 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 Art & Music 8 "Composing Inside Electronics"), then get back to work.

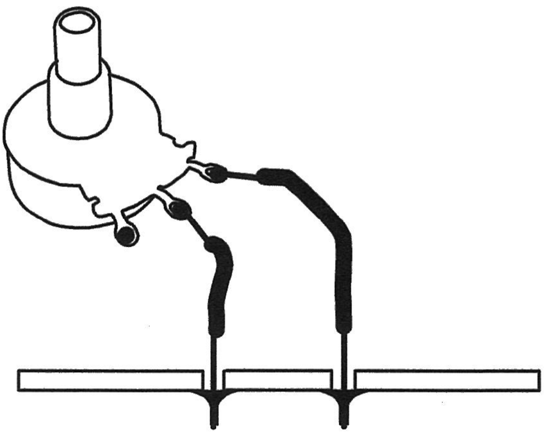

Figure 14.3
Potentiometer alone.

ART & MUSIC 8

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 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 David Tudor (see Art & Music 4 "David Tudor and 'Rainforest'," Chapter 8,) students of David Behrman (see audio track 11) 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 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 the weak electronic field emanated by the human body ("Pygmy Gamelan," 1973; see Figure 14.4), 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) formed "Voice Crack" in 1972, and over the next 30 years honed their skills at "cracking" everyday electronics; they became virtuoso performers with their new instruments, including circuits for extracting sound from blinking lights (see audio track 19), radio-controlled cars, radio interference, and obsolete Dictaphones (see Figure 14.5 and Andy Guhl's video on the DVD). 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 14.6 and audio track 12) four oscillators are controlled by photoresistors 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 over the course of a dozen minutes.

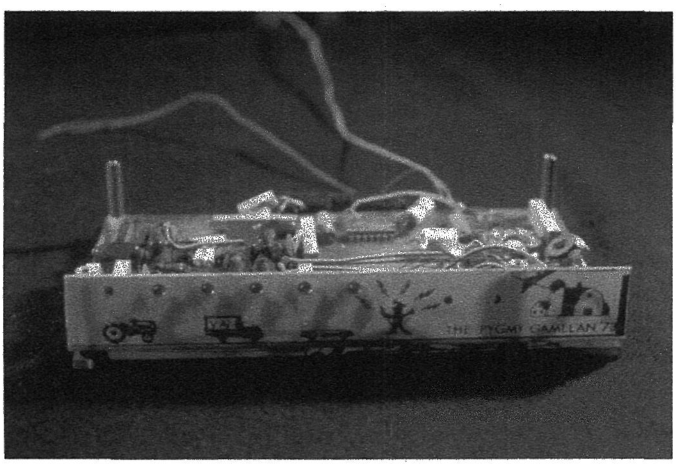

Figure 14.4
"Pygmy Gamelan" (1973), electronic circuit composition, Paul De Marinis.

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 invested in the Kim-1—a single A4-sized circuit board that resembled an autoharp with a calculator glued on top. 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 mistakes by reprogramming 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 Art & Music 9 Chapter 15), brought "chipetry" back into fashion.

Figure 14.5 Circuitry by Norbert Möslang.

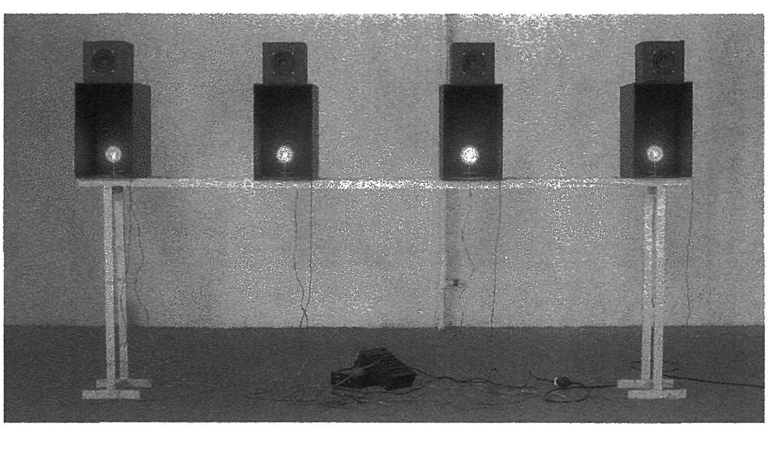

Figure 14.6 "Ohrenbrennen" (Ear-burn), Christian Terstegge.