CHAPTER 12

Tickle the Clock: 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 1 kOhm–4 kOhm.

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 four-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, especially for our first experiments—the more expensive toys, and almost all that put out video, often use crystal clocks, which are more difficult to hack (these include sophisticated handheld games such as Gameboys, robot toys such as Furbies, and more sophisticated music keyboards). However, lately there has also been an increase in the number of super-cheap toys coming from China that are really impossible to hack (this will be explained very soon), so beware. To the degree that one can distinguish such detail when trawling through thrift shops, toys from the 1990s hack more easily than more recent ones, and usually have a richer sound palette than most from the 1980s or earlier (with a few notable exceptions: the venerable "Speak and Spell," introduced in 1978, is worshipped by Circuit Benders).

And, of course: **THE TOY MUST BE BATTERY POWERED!**

CLOCKS

The majority of electronic toys manufactured since the early 1990s 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 sequence. 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. Keep the batteries connected, as we did with the radio in the previous chapter (and, similarly, this might require some ingenuity, clip leads and electrical tape). Expose both sides of the circuit board.

Study the 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 disks 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).
- Diodes: glass or plastic cylinders, smaller and less colorful than resistors, usually marked with one stripe (see Figure 12.4).
- Integrated circuits (ICs): usually black or grey, resembling rectangular bugs with legs along one or more sides, or malignant looking black circular blobs oozing up from the circuit board (see Figure 12.5).

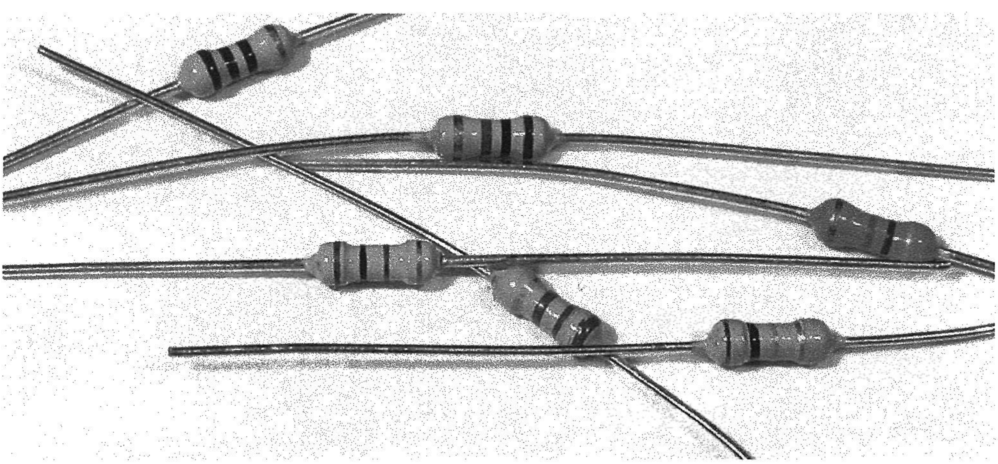


Figure 12.1 Some resistors.

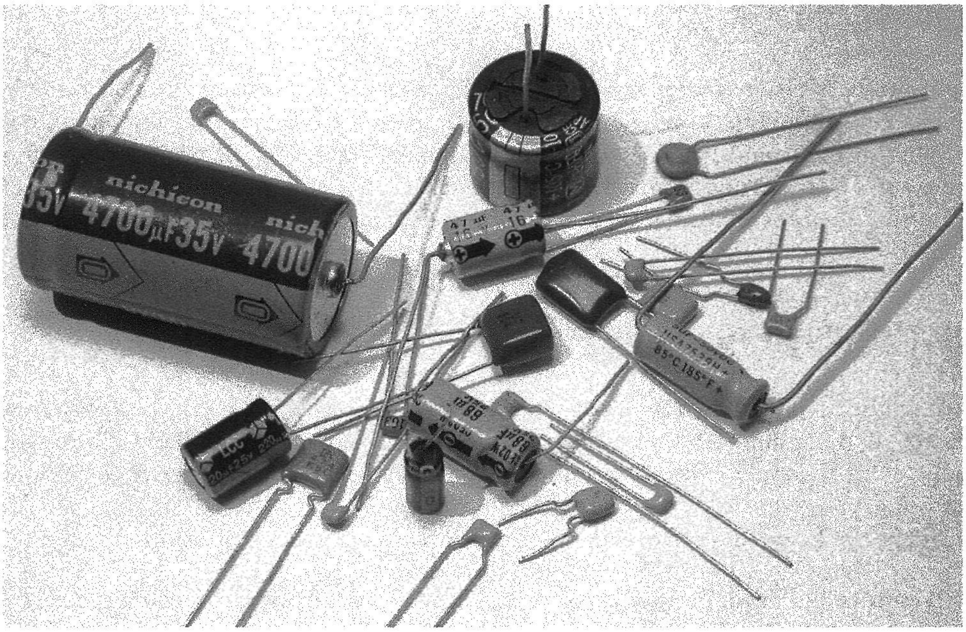


Figure 12.2
Some capacitors.

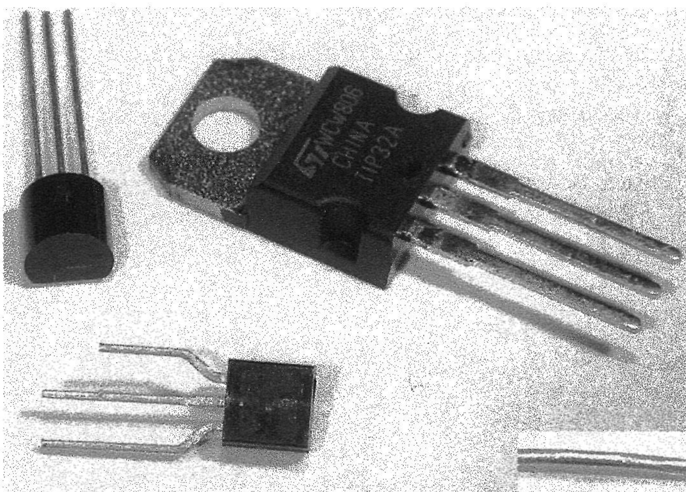


Figure 12.3
Some transistors.

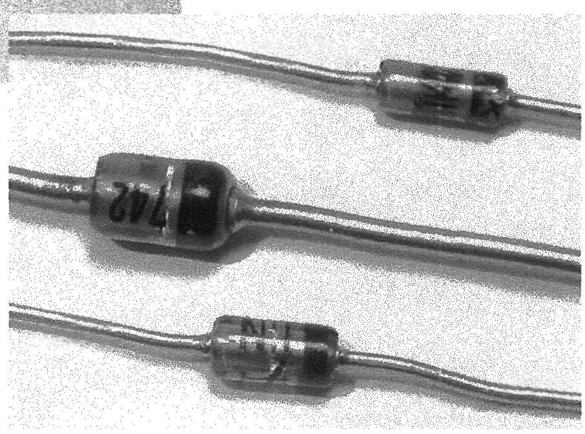
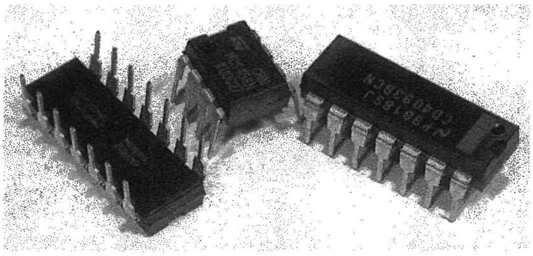


Figure 12.4
Some diodes.



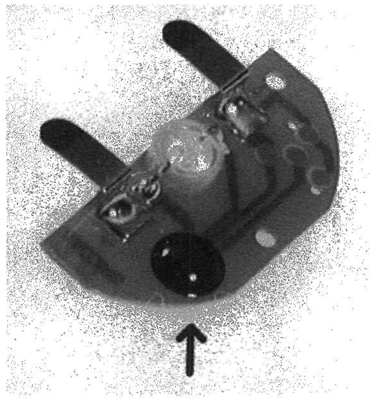


Figure 12.5
(above and right)
Some integrated circuits.

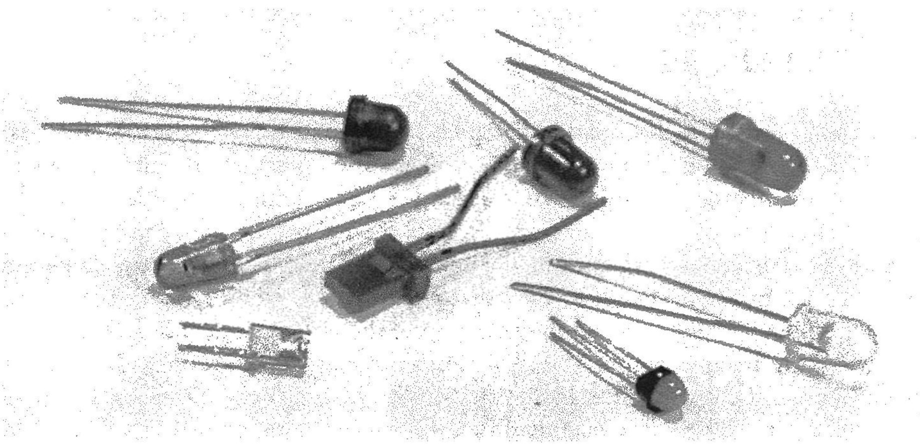


Figure 12.6 Some LEDs.

- 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. If you have a choice, start your experiments on a toy with the larger, more traditional and more easily identifiable components described above (another reason to scavenge an older, used toy in a thrift shop, rather than buy something new at the mall).

We're looking for *resistors*, especially those lying near an IC, flanked by a disk or square capacitor. The frequency of the simple, easily-hackable clocks in most toys is controlled by a resistor and a capacitor working together (explanation follows—be patient). If the toy was really cheap and its circuit board appears to have one shiny black blob and not a single resistor, you may be holding one of the unhackable new Chinese toys: the clock is hidden inside that blob, where you can't get at it, so you might as well hand the toy on to a grateful child and start over in a thrift shop somewhere.

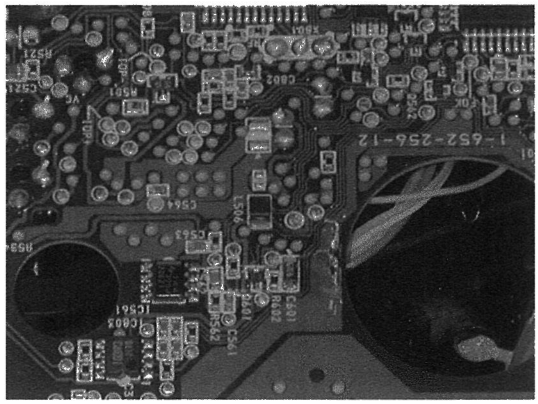


Figure 12.7
Circuit board with disturbingly small surface mount components.

LAYING OF HANDS, AGAIN

As with the radio experiment we did in the previous chapter, your fingers are the best tool here. 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 side. Lick one fingertip and place it across various solder pads; 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 1–4 kOhm, 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. Sometimes resistors are identified by the letter "r" followed by a number, in a minuscule font, either on the component itself or (more

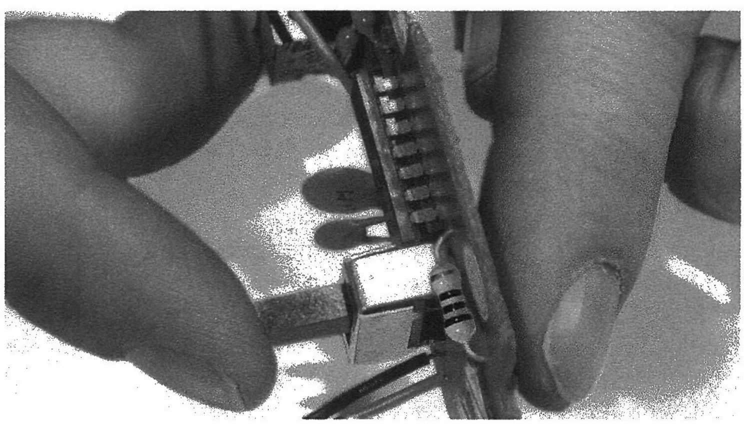


Figure 12.8
Finding the clock resistor (finger on right).

likely) immediately adjacent to it on the circuit board; likewise capacitors are sometimes labeled with a "c" plus a number. 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 might be one of the new, super-cheap Chinese models described above. Or it may use a crystal for the clock timing, rather than a simple circuit with a resistor and capacitor (as mentioned earlier, this is especially true for more advanced musical keyboards, toys with video output, and complex or expensive toys). Crystals often take the form of a small shiny metal cylinder or a three-legged epoxy-dipped blob, usually brightly colored. If you suspect a crystal is at work you'd best put the toy 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 a simple liquid analogy. 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.)

Many oscillator designs rely on *feedback*: a speaker feeding back into a microphone is essentially an oscillator; when your damp finger bridges the right contacts on a radio circuit it produces feedback around an amplifier stage and sets the circuit oscillating. A clock circuit, whether in a cheap toy or an expensive computer, is just an oscillator, designed to run at a specific, carefully chosen frequency. In the simple clock circuit used in most toys a resistor and a capacitor are built into the feedback loop of a kind of amplifier. With enough gain this circuit starts to feed back, just like a mike and speaker, at a frequency determined by the values of the resistor and capacitor. 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 overall 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 add a second pipe alongside the resistor on the other side of the board, decreasing the net resistance. More current flows and the pitch goes higher.

If the explanation is confusing, don't worry about it. For better or for worse, we'll revisit the secret lives of resistors and capacitors in a more clinical fashion when we get to building our own oscillators in Chapter 18. Until then just let your fingers do the thinking.

Got it? Good. But what do we do if we want to make the pitch *lower*? Read on ....