CHAPTER 29

Power Supplies: Carbon Footprints from AA to EEE

You will need:

- A DC "wall-wart" plug-in power supply.
- A diode, 1N4004 or equivalent.
- Some capacitors: 0.1, 100 uf, and as big as possible.
- A fixed-voltage positive regulator (LM7809 or LM7812).
- An LM317 variable voltage positive regulator.
- An 5 kOhm pot and assorted resistors.
- Hand tools, test meter, clip leads and soldering iron.
- A breadboard on which to test your circuit.
- A solderable circuit board on which to assemble your circuit.
- Some solid and stranded hookup wire.
- A few solar cells.
- Some fruits and vegetables and copper and galvanized nails.
- Spare change, paper towel, salt, water.
- A bicycle dynamo or small DC motor.

Oh dear, I feel like a father enrolling his son in a driver education class or explaining safe sex: I wish we could stop here, but one day you will leave home and must be prepared for the big world.

Although the Second Rule of Hacking barred you from touching an AC power cord, the time will come when batteries simply will not suffice. You will tire of the cost of replacing them, and the accompanying environmental guilt (although these concerns can be minimized by rechargeable batteries); or you will build a circuit that draws so much current that it drains the battery flat before you can say "Union Carbide." You will have to choose between living a long and virtuous (but possibly slightly constrained) life that adheres strictly to the 25-fold path of the Rules of Hacking, or enjoying the risky heretic pleasures of power supplies. As a stopgap solution to exposing your hands (and heart) to lethal voltages, you can advance to the ubiquitous "wall-wart" that powers so many domestic appliances these days (see Figure 29.1).

The power grid in North America delivers to your outlet a sine wave that fluctuates between 0 and 120 volts 60 times per second (in Europe, 240 volts at 50 cycles per second, in Japan 100 volts at 50 cycles). If you plugged a very strong speaker directly

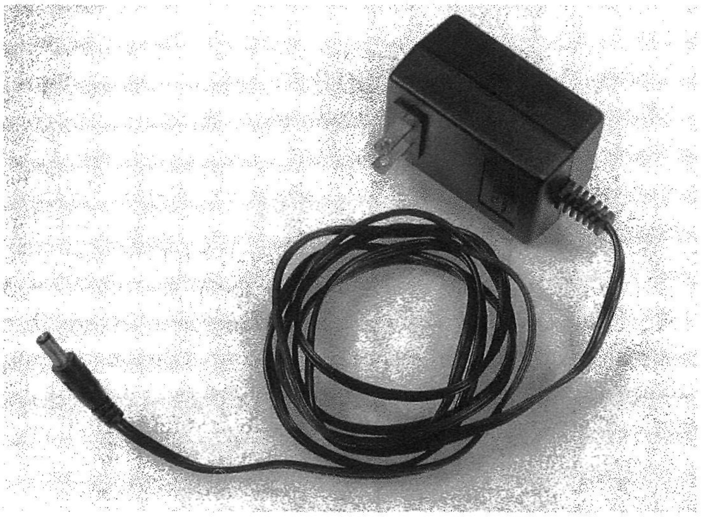

Figure 29.1
A typical wall-wart power supply.

into the wall (not recommended, by the way), you would hear a loud, low pitch around 2 octaves below middle C. The wall-wart consists of a transformer encased in plastic and wired directly to an AC plug. The transformer takes the 100/120/240 volts of alternating current (AC) and steps it down to the non-lethal range suitable for powering electronic circuitry. The advantage of the wall-wart supply is that the dangerous voltages remain (in theory) within the plastic lump, and the ends of the wires present a mild, relatively safe, more battery-like voltage. The traditional power supply found inside your TV or guitar amplifier, on the other hand, brings the wall voltage right into the chassis, where it can easily be touched (ouch!) as you tinker. So, if you *must* use the electrical grid, let the wall-wart be your condom.

You can find wall-warts everywhere, often very cheap or even free (left over from old answering machines, for example). Since the physical con-struction of the thing is an indication of the quality of workmanship inside, you are advised to select one that looks pretty solid, with no holes, cracks or wobbly parts (just keep our French Letter analogy in mind—without smirking, please).

There are two basic types of wall-wart. An *AC* wall-wart consists solely of a step-down transformer; it puts out a low voltage 60 or 50 hz signal, which must be further conditioned to make it useful for powering circuitry. A *DC* wall-wart contains some additional circuitry (a few diodes and a big capacitor, to be specific) required to smooth out the fluctuating signal into a voltage that more closely resembles the steady DC output of a battery.

The wall-wart should be marked with the following information:

- The *primary voltage* that the wall-wart can be plugged into, i.e. 120 (North America) or 240 (Europe) volts AC (VAC). Some modern, "premium" wall-warts (such as those provided with most laptop computers) handle any input voltage between 100 and 240 volts. Choose the appropriate primary voltage for the country in which you are working.
- The *secondary voltage* that appears at the loose end of the long dangling wire, usually in the range of 3–24 volts. Some wall-warts include a switch for selecting amongst different output voltages. We need a secondary voltage between 5–15 volts.

- Whether it has an *AC* or *DC output*. We need DC.
- The amount of power the transformer can provide, usually measured in *watts* (W), *amps* (A or MA), or *volt-amps* (VA). We want a transformer that puts out a minimum of 100 milliamps (ma), which may be indicated as 0.1 amps or 5–10 watts.

For example, a wall-wart might be labeled "120 vac input, 12 vdc output, 200 ma."

Built into the plastic casing should be a power plug appropriate to the outlets in your country. In some instances the wall-wart is more like a rug-rat, with a power cord instead of a built-in plug; sometimes this cord is attached to the plastic lump, and sometimes it plugs into a socket of some sort. Two wires should emerge from the other side of the wart; they may be a parallel pair, like speaker cable or lightweight lamp cord, or may be shielded cable, with one conductor wrapped around the other. At the end of this cord will be one of a zillion different types of minimally distinguishable little plugs—usually some form of tortiglioni-like "coaxial power connector." Some cables terminate in a system of interchangeable connectors of different style. It's convenient if the plug matches some loose female jack you have in your parts collection, or one you can buy locally. It's risky to buy one part or the other sight unseen: never trust measurements on packaging, always test that the male and female connectors fit together snugly. On the other hand, matching connectors are not essential: you can always cut off the plug and connect the bare wires directly to your circuit, or solder on a new plug from a matching plug and jack set you acquire elsewhere.

When adapting a battery-powered circuit to be powered by a wall-wart you must observe two critical factors:

- The wall-wart's voltage must be within the two limits we described above (i.e. greater than 5 volts but less than 15 volts), but the current capability can be anything *higher* than the minimum need to power the circuit. For example, a circuit requiring 20 ma can be powered by a supply producing 20 ma, 100 ma, or 1,000 ma. The circuit will only draw as much current as it needs (sort of like having an oversized gas tank in the Subaru you only use to go shopping around the corner).
- Check the polarity of the secondary connector or wires: you must know which is "+" and which is "–" before connecting the wall-wart to your circuit, or catastrophic pyrotechnics may result.

Sometimes the wall-wart will be marked with information specifying which part of the connector is "+" and which is "–." Sometimes one of the cables will have a convenient white stripe that distinguishes it from its mate. But it is always safer to confirm the polarity with a multimeter.

Set the meter to measure "DC Voltage." One probe plugs into the meter's "ground" or "–" input, while the other connects to something probably marked "voltage" in red. Touch one probe to one part of the connector, and the other to the other; if you've already removed the connector measure between the ends of the stripped wires. If the meter reads out a voltage with no prefix (i.e. "13.6"), then the wire/connector touching the ground probe is the "–" output, and the other is the "+." But if the meter puts a "–" before the number (i.e. "– 13.6"), you know that the connections are reversed, that the wire touching the minus probe of the meter is actually the "+" output and the other is "–." Confused? Try this test on a nice familiar 9-volt battery. Then test the wall-wart again.

Once you figure out which wire is which, mark them carefully: scribble a drawing of the connector with appropriate + and – markings, or wrap some colorful tape around the + wire. If the output voltage of your wall-wart measures *less* than 15 volts DC you can connect it more-or-less directly to your circuit as shown in Figure 29.2. You can either find a matching connector to whatever plug is attached to the wall-wart's cord, or you can cut off the plug and solder the wires directly to the board. Check the polarity one more time before you plug it in! As a safety precaution against frying your circuit with a backwards power supply, you can connect a diode across the power supply as shown in the figure.

Cheap wall-warts will usually have some "AC ripple" in their voltage output—a sign of skimping on parts in the conversion from AC to DC (you usually don't get what you don't pay for, I'm afraid). A circuit powered with such a supply may hum—under its breath or quite loudly, depending on the quality of the wart. If you alternate between a battery and wall-wart powering the same circuit you should be able to hear the difference. Until you get good at designing or choosing better power supplies, a battery will usually sound cleaner. One easy fix that usually helps is to add a big capacitor, say between 100–10,000 uF, between "+" and "–" supply on your circuit board. As mentioned in Chapter 18, big electrolytic capacitors have polarity, like a battery, which is marked on the body. Make sure you connect "–" to the ground bus, "+" to "+"

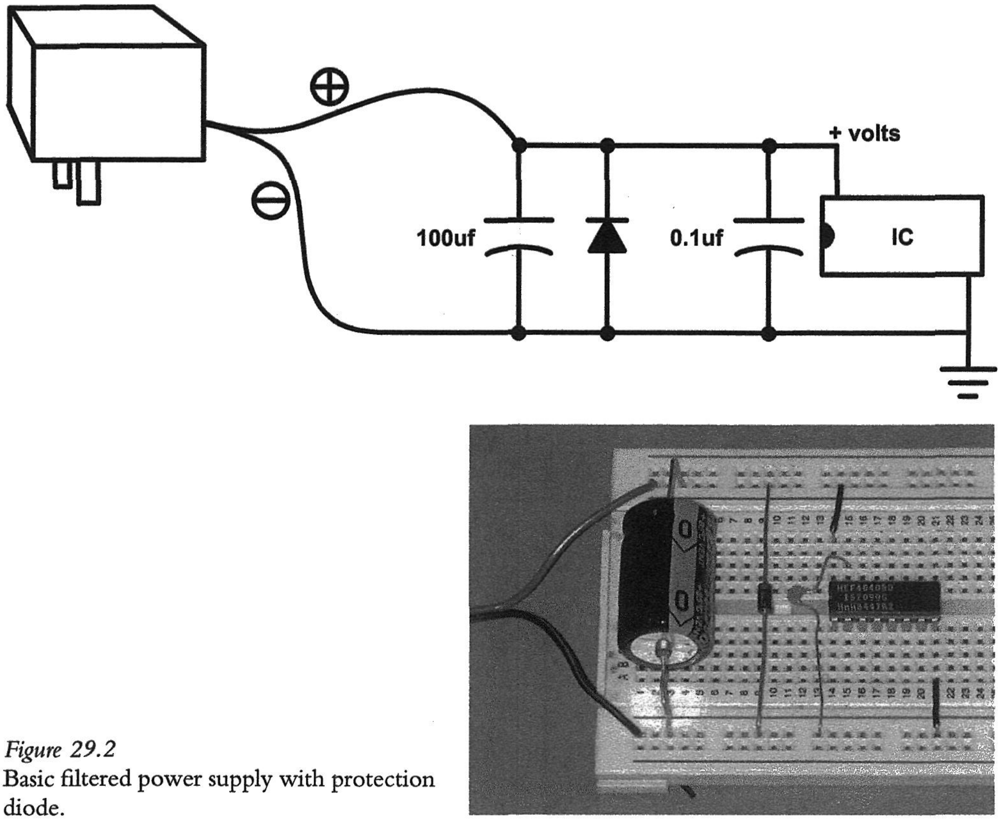

Figure 29.2
Basic filtered power supply with protection diode.

supply. Placing an additional 0.1 uF capacitor between the "+" and ground supply pins very near each chip also helps lower noise and reduce "crosstalk" between different parts of your circuit. Both these capacitors can be seen in Figure 29.2.

A quick measurement with a meter will show that even though a wall-wart might be marked "12 volts DC" in bright white letters, it could put out anything from 10 to 20 volts. The CMOS chips used in most of our circuits were chosen in part for their forgiving nature, but they have their limits—upper limits: they can run on power supplies from 3 volts to about 18 volts, but above 18 volts they can expire quite dramatically. A 9-volt battery sits comfortably between these two extremes. If you choose to use a wall-wart instead of a battery always measure its actual output voltage and polarity *before* connecting your circuit—don't rely on the markings on its case.

Rule #25: Never trust the writing on the wall-wart.

Alternatively, for a really quiet, reliable supply you can add a simple integrated circuit called a "voltage regulator" (see Figure 29.3). A regulator filters out the last of the AC ripple and sets the voltage to a precise level, which is specified by the last two digits of the chip's part number: 7812 = 12 volts, 7809 = 9 volts, 7805 = 5 volts, etc.

The input to the regulator must be at least 3 volts higher than it is expected to put out (i.e. 12 volts in for 9 volts out), and no higher than about 25 volts; so measure the output of your wall-wart with your meter to make sure it is within these limits. You can get regulators for a wide range of output voltages—the 7809 is a shoe-in for the 9-volt batteries we've been using, but the 7812 and 7805 are more commonly encountered at retailers, and our CMOS chips should run fine on any of these three. The basic design shown in Figure 29.4 works for any 78XX series regulator. It's normal for the regulator to get a bit hot—bolt the regulator's tab to a piece of metal to dissipate the heat (or you can buy yourself a fancy finned heat sink).

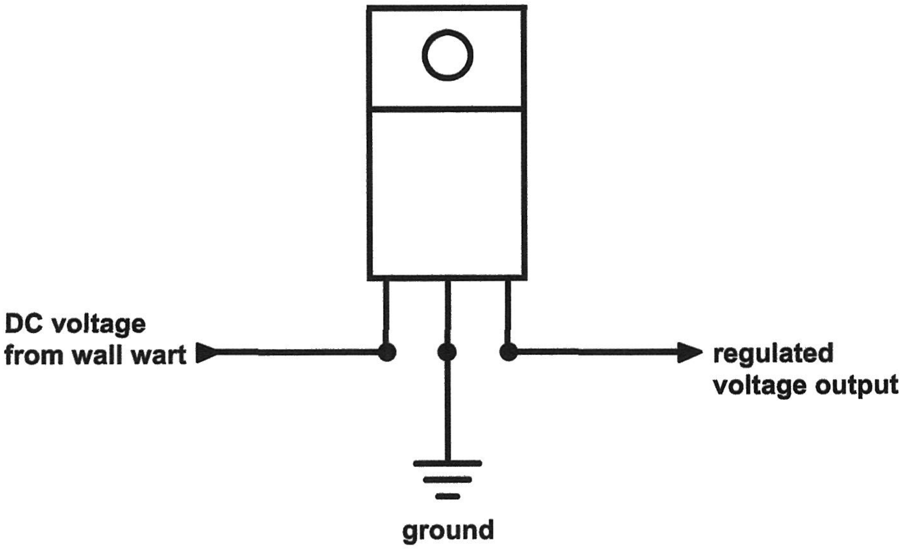

Figure 29.3 78XX-series voltage regulator pinout.

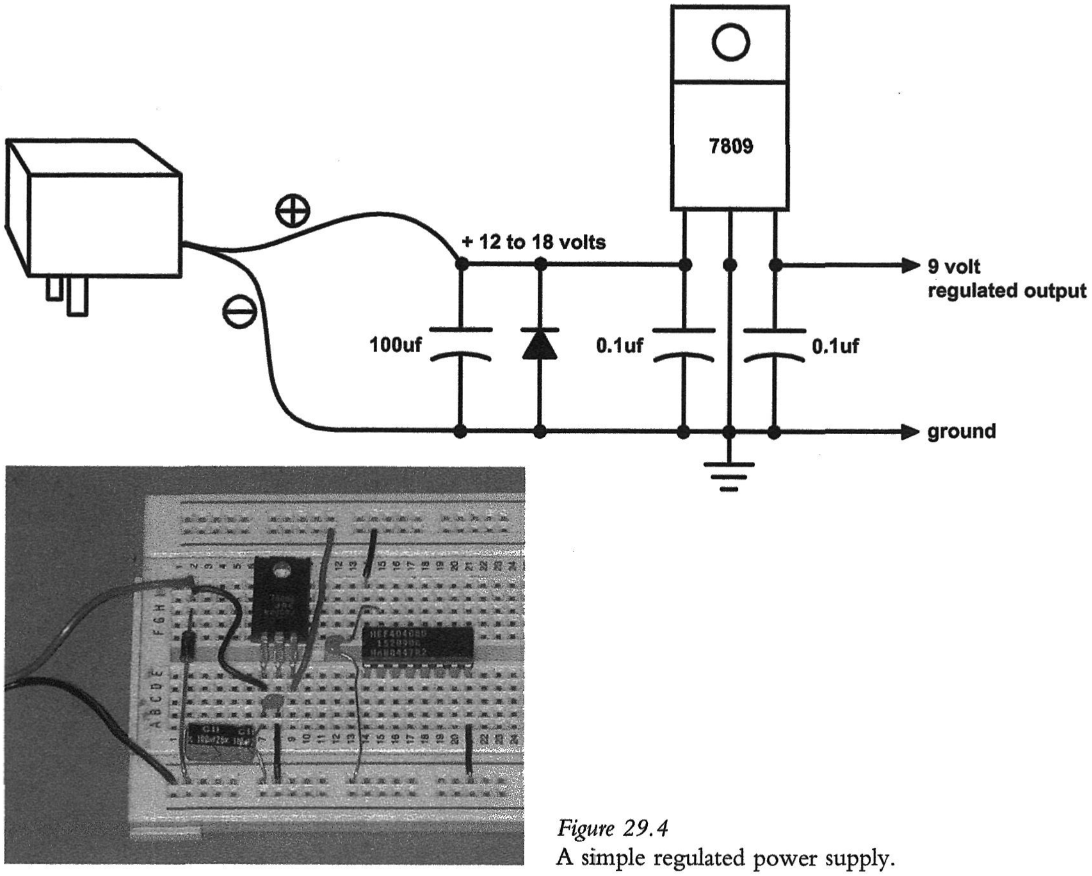

Figure 29.4
A simple regulated power supply.

If you have had success with the voltage starve circuit we described in Chapter 20 (Figure 20.14) you can implement it with a wall-wart (with or without regulator) feeding the pot just the same as a battery. Or you can build a power supply whose output voltage can be adjusted quite precisely, using a slightly different regulator: the LM317T (see pinout in Figure 29.5). The potentiometer in the circuit shown in Figure 29.6 lets you adjust the voltage anywhere between about 1.2 volts and almost the voltage coming out of the wall-wart. The LM317 looks similar to the 78XX regulators, with three legs, but the connections to the pins are different, so double-check your wiring before plugging in the wall-wart.

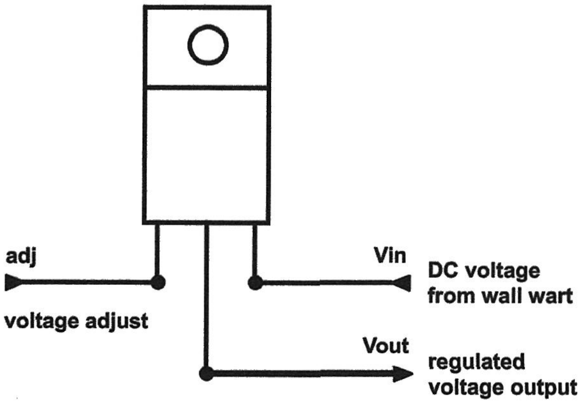

Figure 29.5
LM317 voltage regulator pinout.

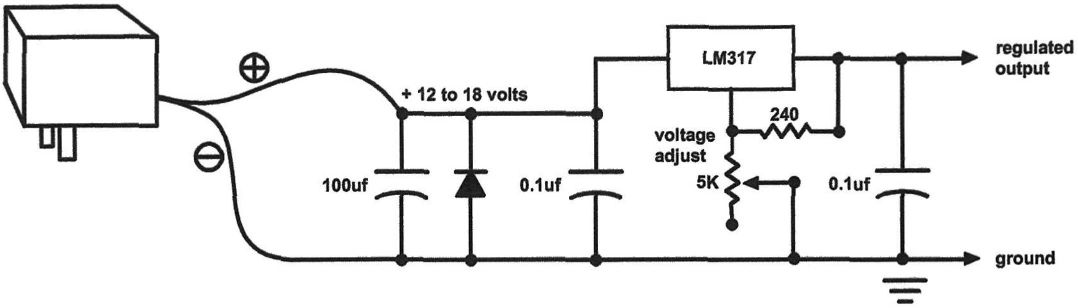

Figure 29.6 Variable voltage power supply with LM317.

GOING GREEN

If you feel like kicking your Duracell habit, but also want to stay off the grid, consider some alternative power suggestions that will reduce your carbon footprint to smaller than the business end of a stiletto heel. The obvious first step, as I suggested way back in Chapter 1, is to invest in some rechargeable batteries in lieu of the disposable kind. The newer NiMH (Nickel-Metal Hydride) batteries are much more efficient than any alkaline cell, packing more current (i.e. run time of your circuit) into a lighter package. They are available in many configurations, from AAA to D, as well as 9 volt. You can charge them quickly from any AC outlet, or invest in a solar charging unit.

Speaking of solar, there's no reason—aside from cloud coverage—that you can't power your circuits directly off old Sol. Solar power panels are pretty abundant these days, and they are decreasing in price as they increase in power. You can sometimes buy one that substitutes directly for a battery or wall-wart, providing anything from 5–28 volts at 500 milliamps or more of current (check out marine supply stores). But they can be a bit pricey. A more economical (and educational) alternative is to seek out—usually online—the individual cells that make up these panels. The cells are rated for voltage and current output. They have a pretty low output voltage—usually around 1.5 volts—but come in a wide range of current ratings, typically a function of the size (see Figure 29.7). Sometimes the cells are combined to add up to higher voltage. Pick a model whose *current* is sufficient for your circuit needs—100 milliamps (ma) is sufficient for most of our CMOS circuits, 500 ma if you're powering a small amplifier, such as the LM386 from Chapter 28, as well. Then buy enough to add up the voltage you need for your circuit. Bearing in mind that the CMOS circuits we've been powering on a 9-volt battery can run on voltages as low as 3 volts, you may be able to get away with only a handful of cells (see Figure 29.8).

A critical component in Figure 29.8 is the capacitor. Remember how, in Chapter 18, I compared the capacitor to a bucket? In this circuit the capacitor is your canteen in the desert, tiding you over between oases (or a cistern collecting rainwater so you can continue to shower after the storm has passed). The capacitor acts a little bit like a rechargeable battery whose strength is proportional to its size in uf. Without it the circuit responds directly to the amount of light present: when the sun shines the circuit runs; when a cloud passes the circuit shuts off. If we insert a medium-size capacitor, say

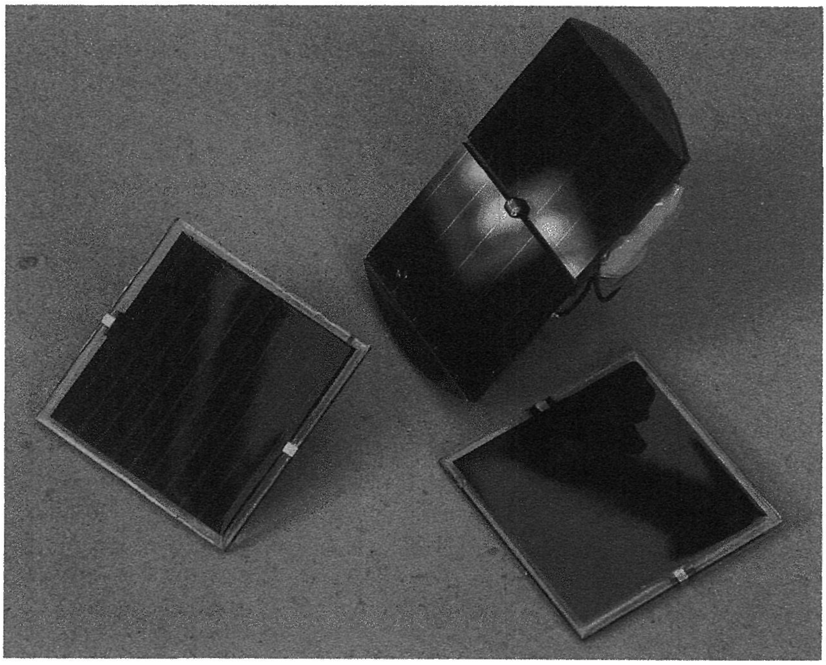

Figure 29.7 Assorted solar panels (center unit with rechargeable batteries attached).

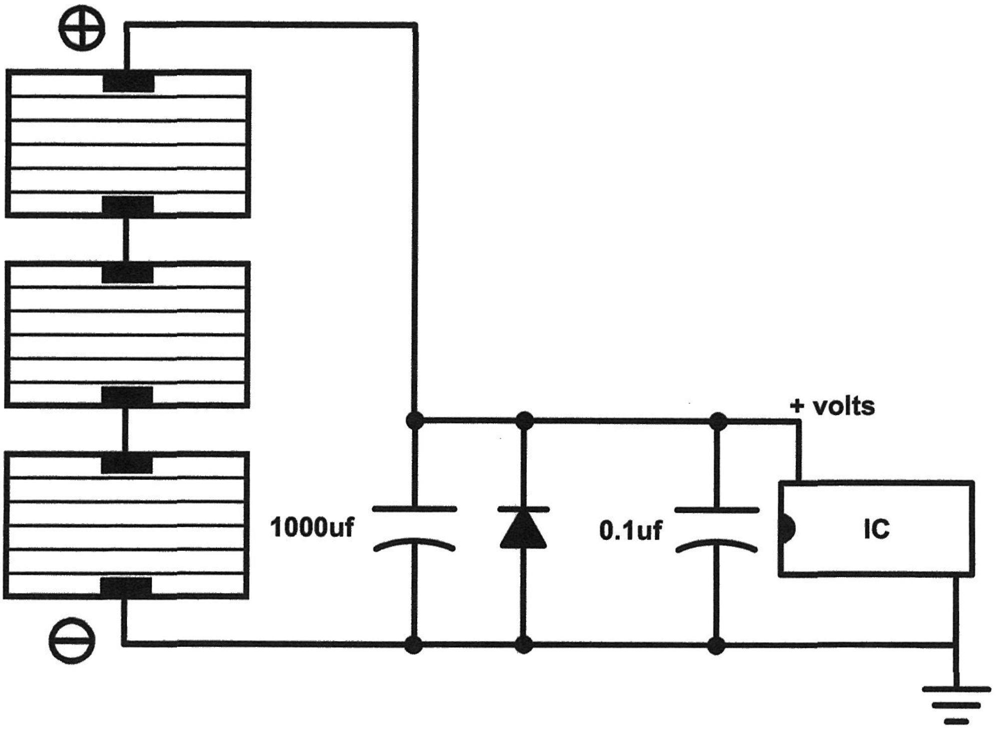

Figure 29.8 Direct solar power of a circuit by adding voltage output from multiple solar cells.

1,000 uf, it will retain enough energy to bridge the gap caused by a scudding cloud, but not enough to keep it running overnight. If we get an insanely large capacitor, say around 1 farad (not micro-farad), such as are used in some memory backup applications, it holds the charge much longer, acting much more like a rechargeable battery. Finally, we can substitute actual rechargeable batteries (usually a set of 1.5-volt cells stacked to add up to your desired voltage) for the capacitor, and modify our design slightly, as shown in Figure 29.9. At this point whatever we hang off this circuit is really being powered by the battery, not the sun, and the battery is in turn being "trickle charged" by the sun, weather permitting. Be sure that the series voltage of your photocells is *greater* than the battery voltage, or the batteries won't charge, and *less* than the maximum voltage for the circuit (i.e. 15 volts), or the chip might fry.

As on a few other occasions in this book, I should explain that Figure 29.9 is a simplified design. Proper battery chargers can get quite complex—these days many incorporate microprocessors that regulate the charging current and monitor the cell's condition to minimize the charge time and maximize the battery's lifetime. If you are serious about the long-term survival and performance of your project you should consider either springing for a commercially available solar-powered battery charger, or type those key words into Google and spend a few minutes downloading schematics by people who know more about this arcania than I do.

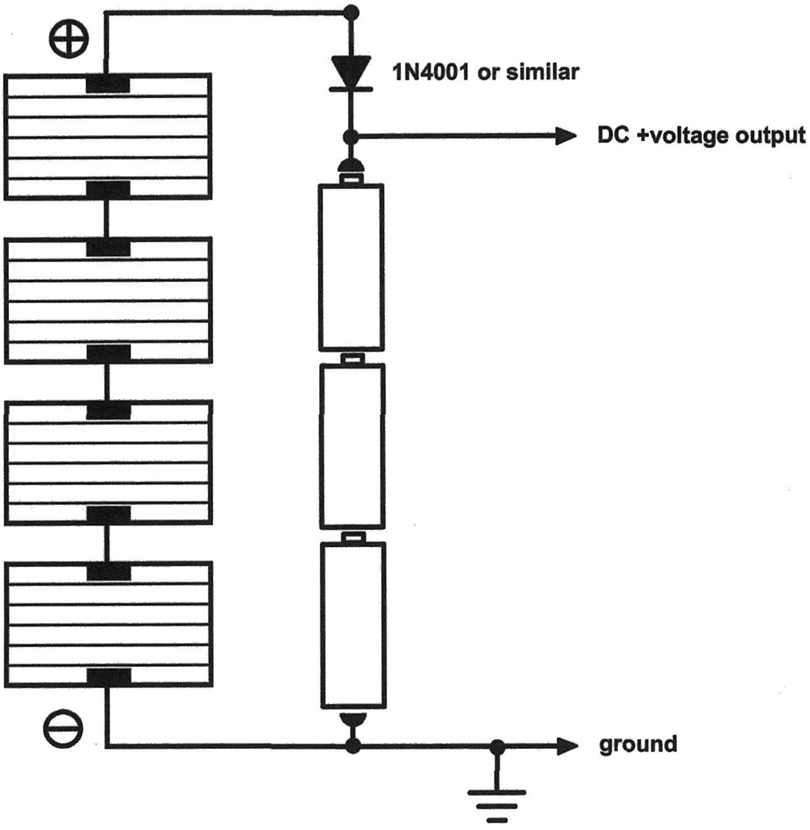

Figure 29.9 Solar-powered battery charging circuit.

MY FIRST BIO-FUEL

Those of you with dim memories of grade school science fair projects with potatoes and nails and light bulbs might be wondering about the possibility of building your own battery with the contents of your crisper bin. Not only can it be done, but with proper lobbying you might convince Congress to subsidize your efforts to free American electronic music from the shackles of foreign oil.

The potato battery functions on the same basic principle as a traditional battery: when two strips of different metals (typically copper and zinc) are inserted into an acid solution (in this case the moisture inside the potato) an electrochemical reaction takes place, which generates a potential difference between the metal strips. A pair of electrodes (as the metal strips are called) inserted into a potato will generate around 1 volt at a very small current. Individual bio-cells can then be added in series and parallel to produce higher voltages and more current, respectively.

A copper penny or strip of copper wire can serve as your positive electrode, and a galvanized nail for the negative one. Insert them into a potato, lemon, or apple, and measure the voltage with a multimeter. Put several electrode pairs in series as shown in Figure 29.10—you can use a separate vegetable or fruit for each pair, or insert multiple electrodes in a single large tuber. Make sure none of the electrodes touch each other. A quick check with the meter should confirm that your power station is putting out around one volt per potato. You can connect an LED and, if the orientation is right, it should light up. Hook up your new battery to a simple oscillator circuit and see if it runs. If it doesn't you might need to add a few more potatoes in *series* to increase the *voltage*, or in *parallel* if your circuit requires more *current.*

The voltage output of this kind of battery is a function of the metals used for the electrodes, rather than your choice of produce: copper and zinc (present in galvanized hardware) yield about 1.1 volts per cell. Substituting magnesium for the zinc increases this to about 1.6 volts (I'm not sure what the most convenient source of magnesium

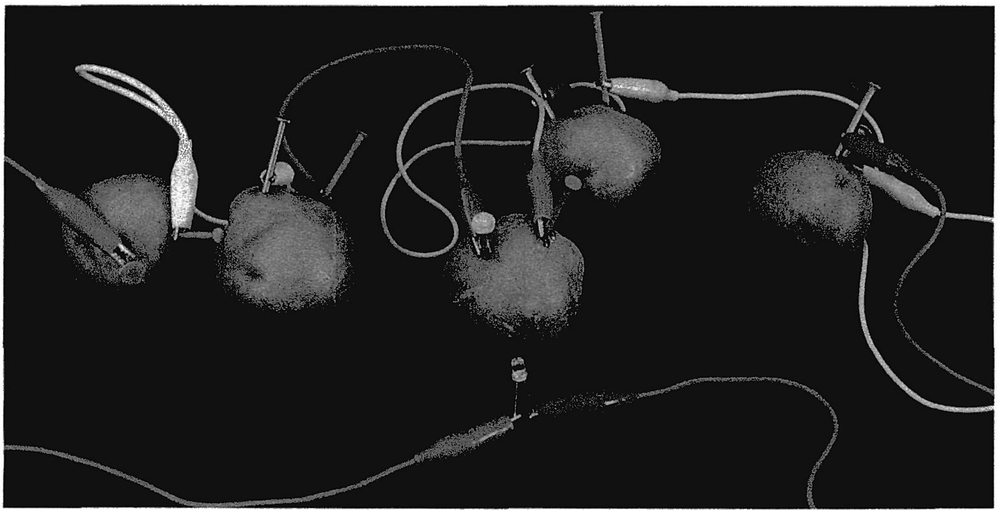

Figure 29.10 Adding multiple potatoes in series to increase voltage.

scrap would be). The lifetime of your battery is primarily a function of how long it retains its moisture, so you might experiment with more succulent options, such as lemons, grapefruit, etc. And do bear in mind that these earthy batteries put out a very small amount of current—if you're lucky our wonderfully low-power CMOS oscillators will whistle comfortably on potato juice, but don't expect to run an amplifier or motor this way.

You may remember that earlier, in Chapters 15 and 18, we discussed using bits of vegetables and fruits as alternative resistors in toy clocks and oscillators (see also Figure 30.27). The resistive character of these materials is primarily a function of their moisture content, although we can speculate now that their electrolytic interaction with the wires we used to make the connections might also influence the behavior of our circuits: two wires of the same metal (i.e. copper) should not induce voltage, but different metals can. You might experiment with the contents of your garden for both a power supply and a timing component in your circuits. Too bad we can't grow our own chips . . . . (David Tudor once told me a story of a Brazilian electronic-music composer who, in the early 1960s, was making his own transistors by baking crystals in his oven but, sadly, I didn't think to follow up this lead before Tudor passed away.)

One last observation: the voltage output of these bio-batteries is not as steady as your basic Duracell. In fact, the chemical process at play generates a fair amount of noise—a capacitor added to our power supply circuit should smooth this out if it's problematical. On the other hand, if instead of connecting the electrodes to a circuit or LED you wire them to the tip and sleeve of your headphones, you can *listen* directly to the crackly sound of a singing potato. Not loud enough? Connect the electrodes to the input of your amp or mixer, and turn it up.

KITCHEN SINK

As long as you're rummaging about in your refrigerator for alternatives to Union Carbide, you might scan your kitchen for some paper towel and salt. As Cy Tymony has shown in his wonderful book, *Sneaky Uses For Everyday Things*, you can build potato-like batteries from nothing more than spare change, wet paper towel, and table salt. Each cell requires one penny and one nickel, for the copper and zinc electrodes respectively (sorry, Euro-toting hackers, you're out of luck). You can solder a wire to each. Fold a piece of paper towel into a coin-sized pad, dampen it, sprinkle it with salt, and sandwich it between your coins. Measure the voltage between the two electrodes and it should be in the potato range. The clever thing about this style of homemade battery is that you can just stack your change in a folded strip of paper towel to build up whatever voltage you want, rather than digging up a spud per volt. Wire cells in parallel to increase the current capacity.

HAND JOBS

For the ultimate in self-sufficiency consider combining alternative energy resources with a physical fitness regimen. A *generator* is a device to convert repetitive mechanical motion into electricity. Most function electromagnetically, and bear the same relationship to an electric motor as a microphone has to a speaker: spinning a shaft rotates a coil in a field of fixed magnets, inducing a current flow. Traditional power plants use coal-, oil-, or gas-powered turbines to spin these generators; hydroelectric dams channel water past turbine blades; wind farms are popping up all over. Our Dutch hackers will immediately think of the whirring little dynamo on the front wheel that powers the bicycle headlight—these can easily be adapted to stationary exercise bikes, skateboards, egg beaters, spinning wheels, fishing reels, water wheels, windmills, steam engines, etc. Whether a response to soaring energy prices, or merely a green affectation, generators are showing up in a number of common consumer products: flashlights that light when you squeeze or shake them, radios and laptops with hand-cranks, etc. The generator element can be removed from any of these devices and re-wired to power your circuit.

As you might infer from the interchangeability of speakers and microphones, any DC motor can be used as a generator: connect the motor terminals to an LED, spin the shaft, and see the light (see Figure 29.11).

As with our solar circuits, the critical factor is smoothing the erratic output of the generator so that the circuit doesn't shut down when you park the bike or the wind dies down. The solutions are basically the same as those shown elsewhere in this chapter: add a big capacitor, or configure the generator as a charger for a rechargeable battery. Then again, if you had interesting results from the voltage starve circuit you may find that a relatively unfiltered generator makes a good "performable power supply." Ithai Benjamin's and Alejandro Abreu's "Synthinetic" (see Figure 29.12 and their video on the DVD) and Phil Archer's "Music Boxes" (see Figure 30.6 in the next chapter and his video on the DVD) are lovely examples of this type of power supply in action.

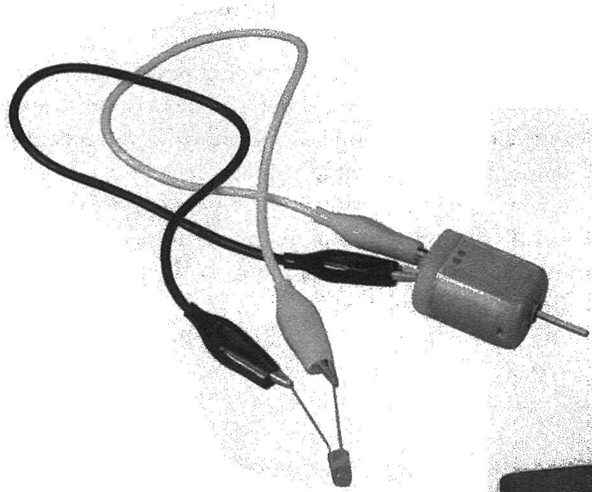

Figure 29.11
Motor-as-generator: spin the shaft and watch the LED light.

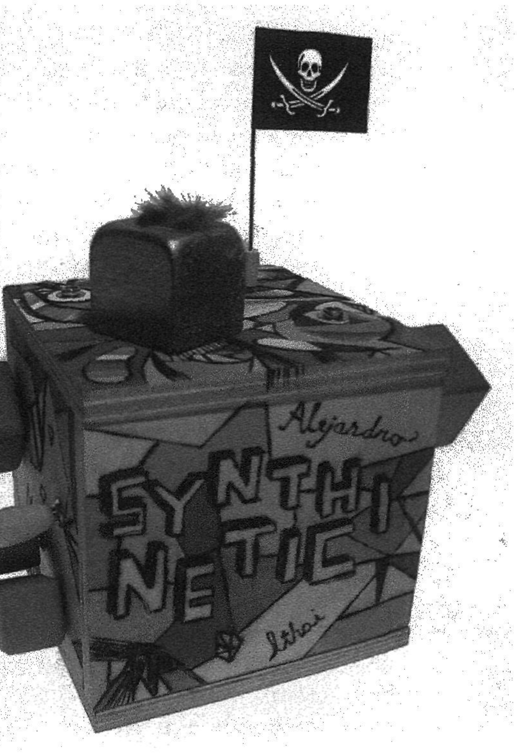

Figure 29.12
"Synthinetic" by Ithai Benjamin and Alejandro Abreu, using motor as generator.