Do-It-Yourself Components

By Forrest M. Mims III

Fifty years ago, electronics experimenters often made many of the components they used. Some experimenters even devised components of their own invention, while others used plans published in books and magazines of the time.

A. Frederick Collins's *The Amateur Electrician's Handbook* (Thomas Y. Crowell Co., 1924) was one of the many guides for do-it-yourselfers. This book described how to make gold-leaf electroscopes, magnets, bells, motors, spark coils and the components required to assemble wireless transmitters and receivers.

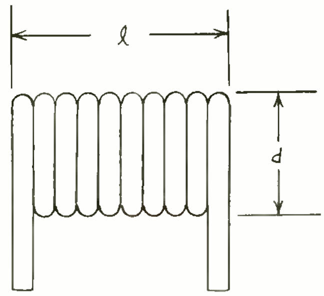
Today, with thousands of different components readily available from a host of sources, do-it-yourself components have almost become a thing of the past. Yet homemade components still have a role to play. They are an important teaching tool at the very least. Also, in an emergency, a defective piece of electronic equipment can sometimes be put back into operation with the help of a homemade component.

In this column, I'll describe a wide range of do-it-yourself components that you can make from readily available materials. Some of these components, like homemade coils, are traditional with the electronics hobbyist. Others, like homemade super capacitors are new. Even if you don't plan now to make any components, what follows can at some time in the future be of help to you.

Much of the material contained here applies to both do-it-yourself and conventional components. You'll gain a better appreciation of "store-bought" components when you finish reading this column, and some day you might decide to try your hand at making some components of your own.

Finding Materials

Most electronic parts suppliers are in the business of selling finished components. Fortunately, there are many alternative sources for such materials. For example, discarded radio and television receivers can be mined for coil forms and cores.



$$L = \frac{d^2 n^2}{18d + 40\ell}$$

$$n = \frac{\sqrt{L\,(18d + 40\ell)}}{d}$$

L = INDUCTANCE (MICROHENRIES)
n = NUMBER OF TURNS

Fig. 1. Coil formulas from the ARRL Handbook.

Hardware stores are an excellent source of plastic and aluminum tubing and heavy-gauge copper and aluminum wire. Craft shops sell various kinds of plastic and fabric as well as copper and brass sheets, and some sell steel wire. Hobby shops sell many kinds of small-diameter aluminum, brass and plastic tubing and rods, and some also sell unusual items like nichrome (nickel-chromium) wire. Welding supply companies sell iron rods that you can cut down to size for making magnets and relays.

If you think the materials you need are too specialized to find locally, use your imagination before giving up. I once needed some conductive paint or adhesive to build a miniature surface-mount circuit. The material I ordered wouldn't arrive for a week; so I tried to think of possible consumer uses for conductive paints and adhesives. Then I remembered that conductive paint is used to repair broken conductor paths in self-defrosting rear windows in automobiles. A quick call to a local supply store turned up a tiny bottle of conductive paint, thus solving my problem.

A Word About Safety: Before looking at how to make your own components, a few words about safety are in order. It is essential that a component—whether do-it-yourself type or otherwise—can be capable of withstanding the voltage placed across it and the current flowing through it. Otherwise, the component will fail and may take others with it.

A good example of an unsafe do-it-yourself component is a burnt-out fuse that has been wrapped with aluminum foil and reinserted in its holder. It's better —and *much* safer—to simply replace the fuse than to risk damaging the equipment it is designed to protect.

Inductors

Inductors have traditionally been among the most common of do-it-yourself components in electronics. Construction project details published in books and magazines often include detailed information on how to wind a coil or even transformer that is not available from the usual retail outlets. Many reference books contain formulas that you can use to determine the inductance of an existing coil and for winding a coil for a specified impedance.

One of the best references is *The 1989 ARRL Handbook for the Radio Amateur*. This must-have book, a new edition of which is published annually by the American Radio Relay League, belongs in every electronics experimenter's library. Among other things, it gives several formulas for winding coils. For a single-turn, air-wound coil, the number of turns (n) required to give a specified impedance (L) is calculated using the formula given in Fig. 1.

After determining the number of turns required to make a coil of a particular inductance, you must wind the coil. Air-core coils can be self-supporting or wound around a permanent form. Self-supporting coils are made from solid wire and usually consist of a dozen or fewer turns of the wire. For this application, No. 18 wire is a good choice of wire size to

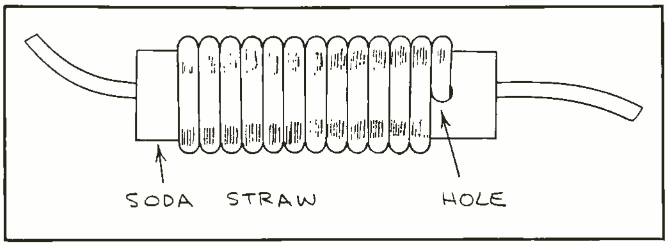


Fig. 2. A do-it-yourself coil wound on a soda-straw "coil form."

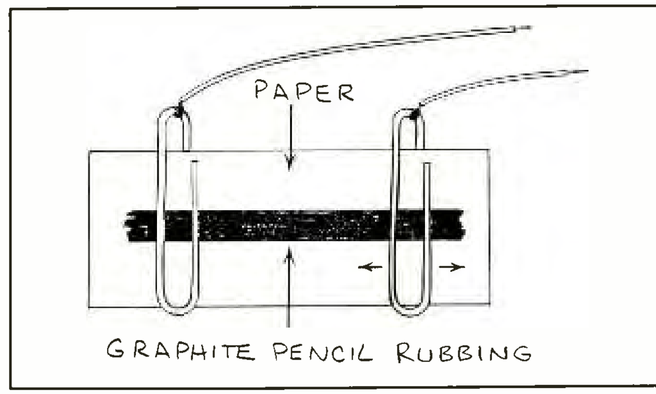


Fig. 3. A homemade adjustable resistor.

use. The wire doesn't have to be insulated, as long as the individual turns are kept from touching each other.

Wind a self-supporting coil on a form that is slightly smaller in diameter than the desired coil's diameter. When you slip the wound coil off the form, it will spring outward slightly.

Many different forms can be used for coils that require them. The main requirements are that the form be a good insulator and that it be sturdy enough to support the coil under any mechanical stresses that might be encountered in the environment in which the circuit containing the coil is used. Very small coils can be wound on short lengths of plastic soda straw, as illustrated in Fig. 1. I've often used this method to make the coils for tiny micro-power r-f transmitters. Larger coils can be wound around standard coil forms, plastic pill containers and even sections of plastic tubing.

For best results, drill two or three small holes in opposite ends of the coil form. Thread one end of the wire through the holes in one end of the form. If the coil is physically large, attach the opposite end of the wire to the knob on a closed door. Remove any kinks in the wire, and wrap the coil around the form while walking toward the knob to which the other end of the wire is attached. Finally, thread the finish end of the wire through the second set of holes drilled in the form.

If the coil requires a space between turns, wrap both a small-diameter string and the coil around the form. Then, after winding the coil, unwind the string.

Table 1. Characteristic Resistances in Ohms of 1 Foot of Wire Made From Different Materials

Material	Resistance
Aluminum	0.01050
Brass	0.02590
Gold	0.00904
Iron	0.03700
Copper	0.00638
Lead	0.08150
Silver	0.00603
Steel (piano wire)	0.04370
Nichrome	0.42190
Tungsten	0.02040

It's usually best to apply a protective sealant to the exposed turns of wire that make up the coil. I've used tape, wax and various glues. Lately, I've become impressed with hot-melt adhesive and will probably use this material to seal the next coil I wind.

Though coils are usually made from wire, they can also be fabricated by etching spiral patterns in an etched circuit board. This method is especially well suited for miniature r-f circuits.

Ferrite-core coils provide more inductance than air-core coils. Their construction is similar to air-core coils wound around a permanent form. However, an alternative means for anchoring the wire to the form may be required if the core is adjustable or removable.

Determining the specifications for a ferrite-core coil requires a knowledge of the ferrite's permeability (μ). The permeability of a core is a measure of the material's ability to conduct a magnetic flux. At high frequencies, the permeability of ferrites is greater than that of iron.

You can buy ferrite-core coil forms, but a cheaper approach is to use forms salvaged from old radio and television receivers. Electronics parts dealers often sell bags of used and new coils that contain enough raw material to supply your coil-winding requirements for some time.

Want to know more? Ferroxcube (5083 Kings Hwy., Saugerties, NY 12477) publishes an excellent reference, *Linear Ferrite Materials & Components* you might want to study. This book contains detailed information about the permeability of various ferrite materials and the design of ferrite inductors. Another excellent and especially well written reference is Eric Lowdon's *Practical Transformer Design Handbook* (Howard W. Sams, 1980).

Electromagnets & Solenoids

An electromagnet can easily be made by wrapping an insulated wire around an iron rod or bar and connecting the ends of this "coil" to a source of current. You can buy iron rods at a welding shop. Mild steel can also be used for this application, but iron is best. Hard steel will produce a smaller magnetic field than either iron or mild steel. The core material will become a permanent magnet when the current is removed.

Table 2. Resistance in Ohms of 1 Foot of Three Common Wire Materials

Gauge	Copper	Nichrome	Steel (piano wire)
20	0.0102	0.6592	0.0695
22	0.0161	1.0550	0.1100
24	0.0257	1.6710	0.1760
26	0.0408	2.6700	0.2790
28	0.0649	4.2510	0.4440
30	0.1030	6.7500	0.7060

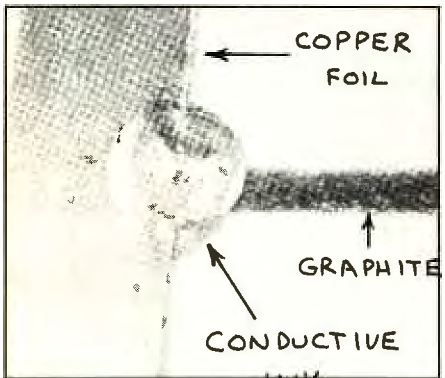


Fig. 4. Conductive ink connects graphite resistor to copper foil.

A solenoid is officially known as an electromechanical inductor. It's actually an electromagnet with a movable iron core. The wire coil of the solenoid is wound around a hollow form. When an iron rod is placed part-way into the hollow form and current is passed through the coil, the rod is immediately pulled into the center of the form. This explains why solenoids were once called "sucking magnets."

You can make miniature solenoids by wrapping magnet wire around a short length of plastic soda straw or small-diameter plastic tubing. I've used such solenoids as tactile stimulators. Mount the solenoid a short distance above a flat surface on which rests a small nail or pin armature inserted into the solenoid coil. When you apply a current to the coil, the armature will "jump" up and strike your finger. When you remove the current, gravity will pull the armature down to the surface below the solenoid coil until the next pulse of current arrives.

Resistors

You can easily make resistors from wire, conductive paint and even graphite pencil lead. Wire resistors are particularly important, since you can make them with very precise resistances.

The easiest way to make a wire resistor is to wind the necessary length of wire around a form. You can use a form salvaged from a choke or coil, or you can use a high-resistance resistor as the form. Start by soldering one end of the wire to one of the form's wire leads. Then wind the wire around the form and solder the free end of the wire to the other wire lead of the form. Since wire-wound resistors generally have relatively small resistances, the very-high resistance of a high-value resistor used as a form will have very little effect on the home-made resistor's overall value.

You can find the resistance of various gauges and kinds of wire in reference works like *Handbook of Tables and Formulas* and *Reference Data for Engineers*, both published by Howard W. Sams & Co. Copper wire is easiest to find, but it has a very low resistance. Wire made from most other materials has a higher characteristic resistance. Examples of the resistance of 1 foot of No. 18 wire taken from the sixth edition of the *Handbook of Chemistry and Physics* (CRC Press, Inc., 1987, pp. F-120 and F-121) are listed in Table 1.

Higher-gauge (that is, smaller-diameter) wire provides higher resistance. For example, the resistances from the *Handbook of Chemistry and Physics* for 1 foot of various gauges of three common wire materials are listed in Table 2.

During the past few years, I've spent considerable time designing and building miniature circuits using surface-mount components. An important technique I've learned is that it's possible to make miniature resistors with graphite pencil lead and conductive paint.

You can easily experiment with graphite resistors with a pencil, some paper and a VOM. First, draw a heavy line on the paper with the pencil. Next, draw over the line a dozen or so times. Then touch the probes of your VOM, set to the resistance function, to the line. Depending on the separation of the probes along the line and thickness of the graphite layer deposited on the paper, you can measure a resistance from a few thousand to a few million ohms. If your VOM doesn't respond, you probably didn't use a pencil whose "lead" is made from graphite. If this is the case, find a pencil that does have graphite lead and try again.

Figure 3 shows a homemade adjustable graphite resistor with paper-clip terminals. The "substrate" is a strip of paper cut from a common 3 × 5-inch card or a business card. You can alter the resistance of the resistor by sliding one of the paper clips along the graphite line.

I've built surface-mount circuits on paper substrates by attaching the components to the paper with glue. I connect the terminals of the components to each other with conductive paint, I make my resistors by drawing small squares or lines with a graphite pencil. Such resistors can be connected to the rest of the circuit with thin lines of conductive paint. Figure 4 is a macrophotograph of the junction between a line of conductive ink and a graphite resistor that I formed on a business card.

If the resistance of your homemade graphite resistor is too high, you can easily add more graphite. If it's too low, you simply take care in scraping away some of the graphite. In both cases, use an ohmmeter to monitor your work. The fin-

Table 3. Dielectric Constants of Some Common Plastics		
Material	**At 1 kHz**	**At 1 MHz**
Polyethylene	2.26	2.26
Polyvinyl chloride	4.55	3.30
Plexiglas	3.12	2.76
Polystyrene	2.55	2.55

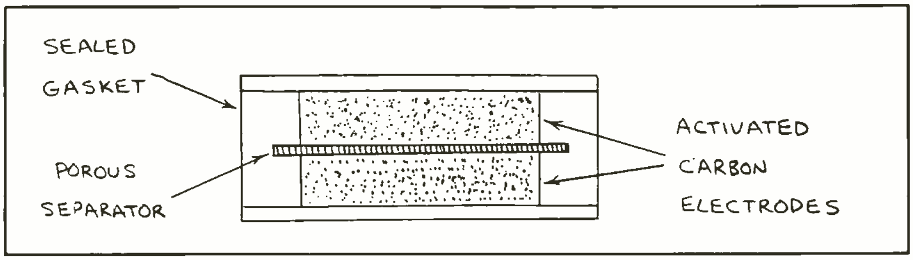


Fig. 5. Internal construction details of a super capacitor.

ished resistor can be protected from the elements with a thin coating of adhesive.

Various kinds of conductive paint can also be used to make resistors. As with graphite resistors, you'll have to experiment with various application methods to arrive at resistors that have specific ohmic values.

Capacitors

If you build radio-frequency (r-f) circuits, you're probably already familiar with what is called the "gimmick capacitor." This capacitor, which can have a capacity of up to a few tens of picofarads, is made by twisting together two short lengths of insulated wire. While the circuit is operating, short lengths of the ends of the two wires are clipped away until the circuit performs as desired. Though I haven't yet tried one in this role, a gimmick capacitor should also be able to fine-tune a quartz crystal h-f oscillator.

Small-capacity fixed capacitors can also be made by forming circular or square shapes of copper foil on opposite sides of a double-sided printed-circuit board. Thin p.c. blank of course, yields higher-capacity capacitors. Other components can be attached to the same circuit board, or a circuit board by itself can be made into a separate capacitor.

Aluminum foil and plastic films can be used to make higher-capacity capacitors. Electronics reference books list the dielectric constants of various types of plastics. The dielectric constants of several common plastics are listed in the *Handbook of Chemistry and Physics* on page E-55 and in Table 3. Values given are for room temperature and will change with deviations from this reference.

Lengths of coaxial cable can also be used to make capacitors with faster rise and fall times than are possible with conventional capacitors. This kind of capacitor has been used to supply high-current drive pulses for laser diodes. The length of the drive pulse can be reduced by trimming the length of the coaxial cable.

Super Capacitors

Super capacitors are the newest member of the capacitor family. These remarkable devices have farad-level capacities. Indeed, they can store enough charge to enable them to perform as a back-up power source for low-power CMOS memory and microprocessor circuits. They can also supply short-duration power for LEDs, relays and even small motors.

Since super capacitors are a relatively new development, they might appear to be rather exotic devices. Yet you can make your own with commonly available materials.

Figure 5 shows the construction details of a basic super capacitor. The conductors that store the charge are opposing layers of activated charcoal that are separated by an insulating layer of porous plastic film. A sulfuric-acid electrolyte permits charges to be transported through the plastic film. Activated charcoal is a highly porous substance that has an enormous surface area. This permits an enormous charge to be stored on the surface of each layer of charcoal.

A single super capacitor has a breakdown potential of about 1.2 volts, which is the point at which its electrolyte begins to decompose. Commercial super capaci-

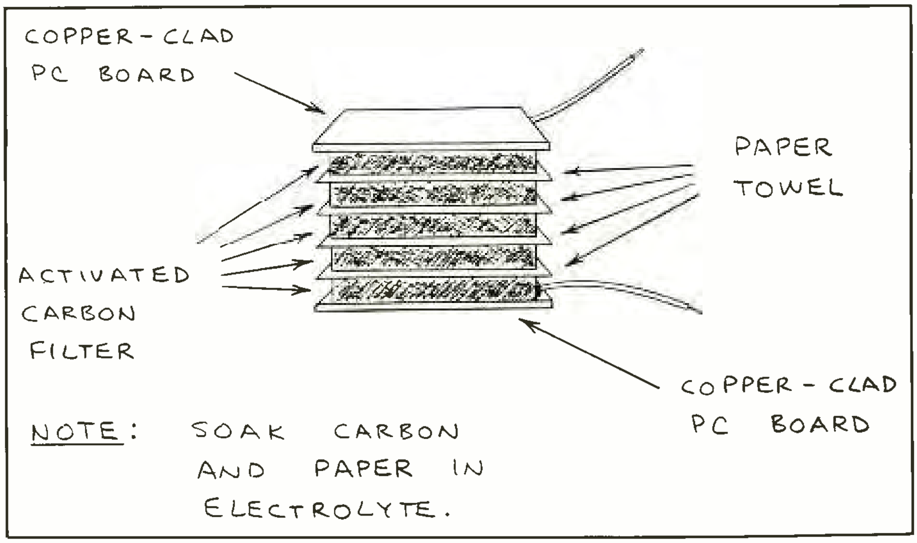


Fig. 6. A homemade super capacitor.

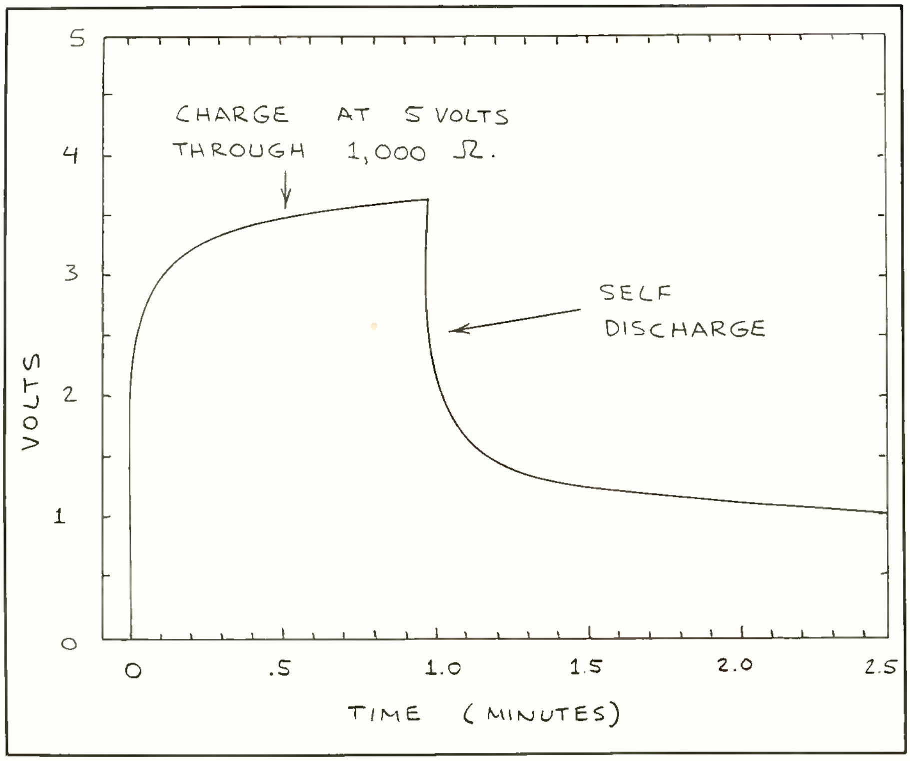


Fig. 7. Plot of charge/discharge cycle of a homemade super capacitor.

tors are made by stacking several cells in series with each other to provide working potentials of 5 volts or more.

Construction of a super capacitor resembles that of some kinds of electrovoltaic cells. But a super capacitor should not be confused with conventional cells and batteries. No chemical reaction occurs when a super capacitor charges or discharges. Also, the terminals of a super capacitor are not polarized.

You can find out more about super capacitors and their applications by referring to "Electronics Notebook" in the March 1989 issue of *Modern Electronics.* Shortly after writing that column, I decided to attempt construction of a homemade super capacitor. First, I visited the pet department at a nearby store to buy some activated charcoal, since the stuff is used in filters for aquarium tanks. While looking for a box of activated charcoal, I noticed various kinds of fibrous filter elements impregnated with activated charcoal. For $1.38, I purchased a sheet measuring about 5.5 × 4 inches and blister packages under the label Black Magic: The Power Filter Cartridge is made by Aquarium Pharmaceuticals, Inc.

Back in my shop, I cut five 1-inch squares from the cartridge sheet and four slightly larger squares of paper towel. Then I stacked alternate layers of each. Finally, I placed the copper sides of two 1-inch-square pieces of single-sided printed-circuit blank against the opposite sides of the stack, as illustrated in Fig. 6. The sandwich was held together with a small C clamp.

All that remained to make a working super capacitor was to drench the assembly with electrolyte. Instead of sulfuric acid, which is rather dangerous, I used concentrated lemon juice. After pouring a spoonful of juice over the capacitor, I connected a power supply to the homemade module and allowed the assembly to charge at several volts for a few minutes. After removing the charging source, I connected a red LED across the capacitor. The LED glowed brightly for several seconds before gradually beginning to dim.

Next, I monitored the charge/discharge cycle of the homemade super capacitor with a chart recorder. Figure 7 shows the charge on the capacitor after it was allowed to charge for 1 minute through a 1,000-ohm resistor connected to a 2-volt power supply and then self-discharge.

Figure 8 shows the discharge curve of the same capacitor after it was charged by a 5-volt supply for 10 minutes and then discharged through a red LED and 680-ohm series resistor. The LED glowed for 45 seconds.

From some of the manufacturer's literature about super capacitors, I had assumed that the activated-charcoal/insulator/activated-charcoal layers must be squeezed tightly together. This is true only if the end terminals are conductive plastic. The copper terminals I used didn't require the pressure of a C clamp. Consequently, a rubber band would have worked just as well.

These simple experiments prove that super capacitors can be built by experimenters. One fascinating possibility is to make a giant super capacitor inside a plastic food container or even a small aquarium. While a capacitor this size would require a considerable charging time, it would store a massive charge.

Caution: Be sure to follow appropriate safety procedures when assembling super capacitors. Always wear protective clothing and goggles if you use sulfuric acid! Protect others and the environment by properly storing and disposing of sulfuric acid. The internal resistance of a super capacitor will limit the maximum discharge current. Nevertheless, use caution to avoid the possibility of electrical shock.

Batteries

Electrovoltaic cells were at one time among the most common of do-it-yourself components. Now hundreds of different kinds of power cells and batteries of almost unlimited size, voltage and capacity are available. Nevertheless, there is still a role for homemade power cells. I've used them to power tiny radios and oscillators. Since homemade power cells can be made very small and in various shapes, you might be able to use them in applications for which no conventional cell is suited.

from a silver dime and a small piece of magnesium ribbon purchased from a hobby shop. Place a piece of paper towel soaked in lemon juice on the dime and follow up with the magnesium ribbon. This assembly will produce more than 1.24 volts and will easily light a red LED connected across the dime (+) and magnesium (–).

You can easily make a water-activated
that will power micro-power
uits. Figure 9 shows the details
nany different arrangements
make such a power cell. The
making this cell is to soak
towel in salt water. After the
dries, cut it into small strips.
r connection wires to a gal-
or strip of zinc and a piece of
. Then assemble the cell by
ied piece of salt-impregnated
l on the copper sheet and
ne copper and paper around
ed nail or zinc strip.

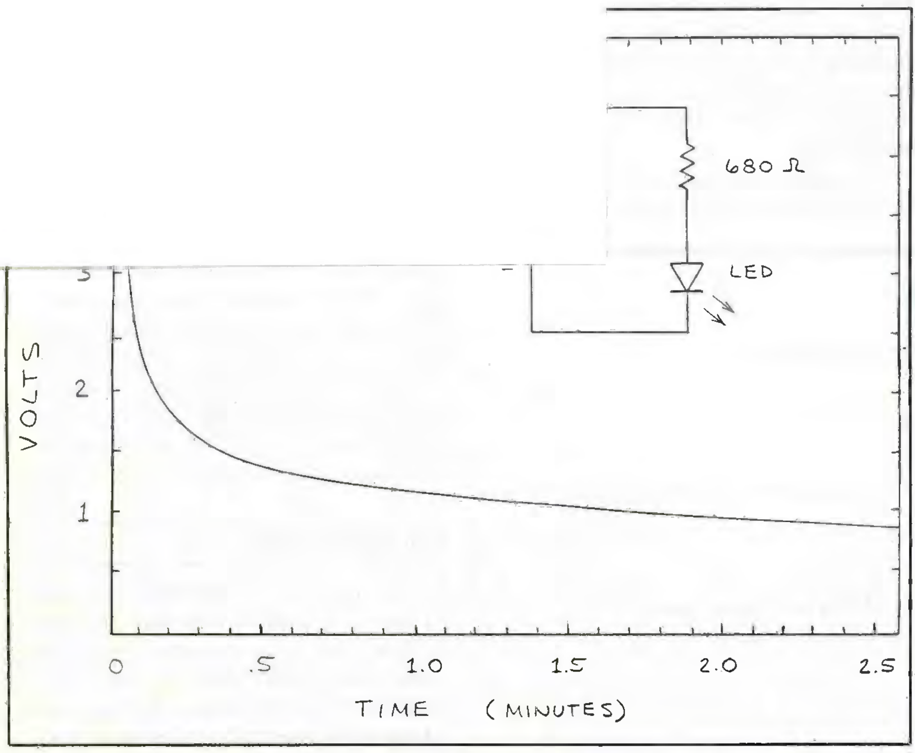


Fig. 8. Plot of discharge characteristic of homemade super capacitor through a light-emitting diode.

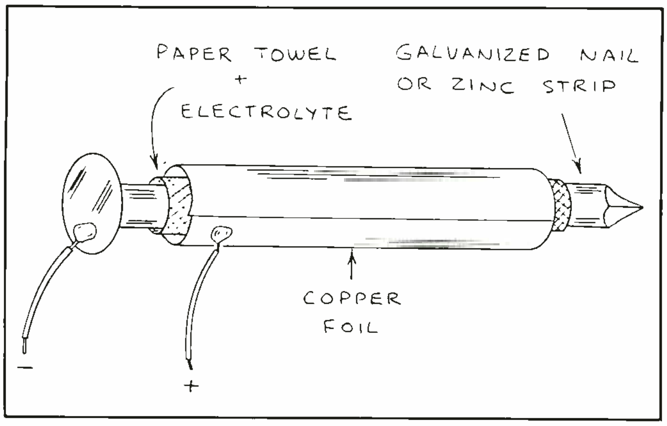


Fig. 9. Construction details of a do-it-yourself power cell.

Table 4. Measured Cell Voltages With Different Electrode Metals and Electrolytes

Electrodes		Electrolyte Salt	Electrolyte Acid
Copper (+)	Zinc (−)	0.759	1.000
Copper (−)	Silver (+)	0.200	0.131
Copper (+)	Magnesium (−)	1.400	1.484
Copper (+)	Aluminum (−)	0.570	0.720
Zinc (−)	Silver (+)	0.720	0.828
Zinc (+)	Magnesium (−)	0.622	0.546
Zinc (−)	Aluminum (+)	0.248	0.350
Aluminum (+)	Magnesium (−)	0.778	0.820
Aluminum (−)	Silver (+)	0.395	0.450
Silver (+)	Magnesium (−)	1.242	1.231

To activate the cell, place a few drops of water or even saliva on the exposed paper towel emerging from each of its ends. Alternatively, simply dip the entire cell in water for a moment.

Homemade power cells are an experimenter's delight. You can build up a stockpile of materials from which you can quickly assemble working power cells. You can make the cells in countless sizes and shapes. You can wire them in series with each other to achieve greater voltages. And you can experiment with various metals to achieve different cell potentials. Table 4 shows the voltage I measured for various combinations of five different metal electrodes and two different electrolytes.

The copper for these measurements was the foil on a pc blank; the zinc was the head of a galvanized roofing nail; the aluminum was ordinary aluminum foil; the silver was a silver coin; and the magnesium was purchased at a hobby shop. The salt electrolyte was made by mixing table salt with warm water, while the citric acid was powdered lemon drink. A piece of paper towel was soaked in each electrolyte and placed between the metals being tested.

Output voltages given in Table 4 are the peaks I measured in each case. In most cases, the measured voltage began to decline after the electrodes were pressed against the electrolyte paper. In some cases, the voltage increased to twice or more its initial level after 20 seconds or so. The results you obtain may differ according to the materials you use; so be sure to keep a record of your experiments.

Both the voltage and available current of a chemical power cell decline as one of the electrodes is dissolved or is coated with a film of hydrogen bubbles. The electrolyte of commercial power cells is designed to reduce or delay these factors.

When a homemade cell no longer functions, you can quickly restore it to its original condition. To do so, first disassemble the cell and discard the electrolyte paper. Rinse away any remaining electrolyte from the metal surfaces and allow the metal to dry. Then buff the metal surfaces with fine sandpaper until they are bright and shiny. Finally, reassemble the cell with a new sheet of electrolyte between the metal surfaces.

Going Further

In this column, I've described only some of the many kinds of electronic and electromechanical components you can make from readily available materials. I hope you'll try your hand at making some of the components described here. Maybe you'll even device some additional kinds of do-it-yourself components. **ME**