NEW layers of conducting patterns
You will find three main sub-
Some popular forms of printed-circuit boards.

PC-board breakthrough

DON LANCASTER

Circuit-board fundamentals
Printed circuit boards first be-
came popular in the early 1950's because of their overwhelming ad-
advantages over point-to-point wir-
ing. The PC wiring pattern was
always the same, virtually eliminat-
ing wiring errors. Stray inductance
and capacitance were much lower
and far more uniform. And the
manufacturing could be totally au-
tomated. Production times be-
came much shorter, and labor
costs dropped sharply. So did size
and weight.

A printed-circuit board often
will consist of an insulating
substrate that has one or more
layers of conducting patterns
placed on or in it. Figure 1 shows
some popular forms of printed-cir-
cuit boards.

You will find three main sub-
strate materials in use today. They
include phenolic, FR-4 (or G-10)
glass epoxy, and CEM-1 composite
epoxies. While phenolic is the
cheapest, it does chip and shatter
easily, and should be heated be-
fore punching or drilling. It is
often used for single-sided layouts
in toys, appliances, and any other
high-volume applications. For us
hackers, phenolic is nearly
useless.

Glass epoxy is pretty near the
same stuff that a fiberglass boat is
made of. It has great electrical and
mechanical properties, and is
nearly ideal for any double-sided
and multilayer boards. Hacker dis-
advantages are that glass epoxy
costs more and dulls drills at an
amazing rate. Carbide drills are
just about mandatory for all but
the shortest of production runs.

The CEM-1 material has only a
pair of fiberglass layers impreg-
nated into an epoxy body. Because
it's cheaper and easier to drill than
glass epoxy, it's a good choice for
hacker use. It also drills and
punches well. Glass-epoxy boards
are well suited for all but the most
precise and exacting needs. They
even come in a wide variety of
colors.

The simplest variation is a
single-sided board. The substrate

is most often 1/8th of an inch thick,
and has a single layer of copper foil
laminated to one surface only. Two
popular thicknesses of copper are
used. One-ounce copper is
around 0.0035 inches thick; two-
ounce copper is double that, or
around 0.00270 inches thick.

Thus, one-ounce copper is a tad
over one mil thick, and two-ounce
copper is somewhat over two mils
thick. Two-ounce copper is
normally reserved for higher-current
uses or where extreme reliability is
needed.

On a traditional single-sided cir-
cuit board, most of the com-
ponents get mounted on the bare
side of the board, giving us a
component side and a foil side
to work with. That allows a dlp, a
re-flow, or wave soldering of all the
parts at once. The components
tend to pull the foil toward the
substrate, rather than trying to
peel the foil from the board.

Single-sided boards limit both
your minimum size and how much
you can connect where, unless you
go to an unacceptable number of
interconnecting jumpers. Be-
cause of that, most modern boards
are double-sided, and have foil on
both surfaces. While the most
common means of routing con-
nections between the two board
sides is with plated-through holes,
hacker alternatives are eyelets,
wire tabs, the component leads by
themselves, or individual socket
pins. Mill-Max is a leading source
of low-cost socket pins, and
Stimpson is a good eyelet source.
A double-sided plate-through

NEED HELP?

Phone or write your Hardware
Hacker questions directly to:
Don Lancaster
Synergetics
Box 809
Thatcher, AZ 85552
(602) 428-4073

Our Stupendously Major New
breakthrough for this month is a
brand new way of doing hacker
printed-circuit boards that I'll call
the direct toner method. Believe it
or not, all you need is an iron and
your favorite word processor.

This new process is ridiculously
faster, simpler and cheaper than
any of the old ways. Since it's so
new, we sure could use your per-
sonal help in further testing and
debugging.

But first, let's review some of
the older ways of making printed-cir-
cuit boards. We might start off by
going over some...
The plate-through board can be hacker-faked by using component leads, eyelets, wire tabs, or small tanks such as those involved that are hard to get in small quantities. Worsely, the next step beyond double-sided plate-through boards is multi-layer boards, where circuitry is placed inside the substrate, as well as on both surfaces. Typically, there will be four layers. Your horizontal runs will dominate on the top surface, followed by a lower power-supply plane, a ground plane that is lower still, and the vertical runs that dominate the bottom surface.

As you might guess, all four-layer boards are quite expensive and are extremely hard to modify, but they do offer superior shielding and extreme component densities. Multi-layer PC boards as dense as 24 layers have been built. Quite often, the multi-layer PC board will be the most expensive part of an electronic system.

Flexible boards are also becoming popular. They are often thinner and use a Kapton substrate. Uses include mounting connectors, and for highly dense or unusual packaging, Rogers Corp is a leading source of flexible PC-board supplies.

Creating a printed-circuit

There are a number of good ways to create a final printed-circuit board. In general, those methods that put new conductors on an insulating substrate are additive; those that remove unwanted conductors from unneeded areas are subtractive. Very often, both additive and subtractive techniques will be used in combination.

Four of the traditional board-production techniques include direct, mechanical, silk screen, and photographic.

In the direct method, an etch-resistant pattern is applied by hand to the printed-circuit stock. Most any paint, lacquer, instant transfer, or ink will work, as will the tape and dots intended for initial layout work. So does a fingerprint or spilled root beer. Bishop Graphics is a leading supplier of PC tape and dots, and Datak is one source for instant-transfer products. There are also some rubber-stamping layout aides being offered.

Actually, the direct method is more hassle than it is worth, and ends up just about totally useless. Some problems here are pattern alignment, preventing fingerprints, tape lifting, a lack of uniformity, and too many defects.

The mechanical methods physically remove unwanted copper, usually by routing, special drills, or by milling. They're another concept that looks much better on paper than in the real world. Several specialized systems are usable for the mechanical PC layouts. Invariably, they are both laughingly and obscenely overpriced.

The silk-screen PC method is quite simple and is widely used commercially, especially for sin-

**FIG. 1—SEVERAL POPULAR TYPES of printed-circuit boards. Note that a double-sided plate-through board can be hacker-faked by using component leads, eyelets, wire tabs, or low-cost individual pin sockets.**
gle-sided boards of fairly low tolerances. The process is exactly the same as silk screening a T-Shirt or a greeting card. Oversize artwork is created, usually at a 2:1 or sometimes 4:1 scale. A litho negative gets shot from the artwork, which in turn creates a photo master for the screen. High-resolution screens are used, often in a 20XX density.

To print a board, etch-resistant ink is placed on the screen, and a squeegee is used to force the ink through the open portions of the screen. The board is then etched to remove all copper that is not covered by the inked image.

The advantages of the silk-screen method are that it is cheap, fast, and relatively low tech. One disadvantage is that the $30 setup charge per screen gets out of hand when you want only a single prototype board. A second is the inability to do very fine lines or precisely aligned work.

Ulano is one major source of silk-screen films. The screens themselves are available from such

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| LaserWriter Corner (Mac/PC) | 25.50 |
| PostScript Show & Tell | 35.50 |
| Intro to PostScript VHS Video | 35.50 |
| PostScript Perspective Draw | 35.50 |
| PostScript Beginner Stuff! | 35.50 |
| PostScript Technical Illustrations | 35.50 |
| PostScript Work In Progress | 35.50 |
| PostScript OHS stuff | 18.50 |
| Absolute Reset ile & ltc | 18.50 |
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| Enhance I or II Companion Disk | 19.50 |
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**CIRCLE 83 ON FREE INFORMATION CARD**

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1. Always do your layouts double sized (2X) on a blue grided Mylar sheet, available from any drafting supply house. Always work on a light box. Use only "real" printed circuit tape and dots. Bishop Graphics is one source.

2. Watch which side you tape from. Pin one of an Integrated circuit is at the lower left when viewed from the top as shown in the data book. Pin one will be at the lower right when etched from the bottom board foil.

3. Never cut your tape with an X-acto knife instead, lay the knife down flat and pull the free end of the tape back against the blade. Always firmly mash the tape in place after routing. A teaspoon is ideal for this.

4. Never do your own photography! A litho negative costs only $3 at a jiffy printer, ad agency, or lithographers. This is the only way to get the proper precision and density.

5. Never coat your own boards! Always use commercially precoated dry film boards, such as those from Kepro.

6. Always use dry film photoresist, rather than spray-on or liquid coated KPR types. Otherwise, pinholes, dust, and uniformity will eat you alive.

7. If you must coat your own board, incredible cleanliness is essential. Thoroughly scour the board with ultra fine steel wool and a chlorine activated (Comet) cleanser at least three times, spending not less than two minutes per square inch of board. Dry promptly and avoid all finger prints. If possible, follow up with a chemical copper cleaner. Then etch for a few seconds, rinse four times, dry, and use immediately.

8. Note that properly cleaned copper will allow an unbroken film of water to flow over it and that it will not be copper colored at all. Instead, it will be a uniform hot pink.

9. Never print through the negative basal! Always have the photo emulsion in direct contact with the dry film photoresist.

10. Always etch at an elevated temperature, around 120 degrees Fahrenheit. A warming plate from a yard sale is ideal for this. Agitate the etchant with a gentle sifting or bubbles from an aquarium pump.

11. Never etch with your foil side up! Support the board vertically, or else foil side down at least 1/2 inch above the bottom of the etchant tray. A mirror under a glass etchant tray lets you view etching progress. Use only plastic or glass in contact with your etchant.

**FIG. 2-SOME REALLY DUMB MISTAKES are often made by hackers who don’t their own photos.**

**PRINTED CIRCUIT RESOURCES**

**Advance Process Supply**
400 North Noble Street
Chicago, IL 60622
(312) 829-1400

**Bishop Graphics**
5210 Lewis Road
Aurora Hills, CA 91376
(818) 991-2600

**Black Lightning**
RR 1-87 Depot Road
Hartland, VT 05048
(802) 359-2790

**Circuits Manufacturing**
500 Howard Street
San Francisco, CA 94105
(415) 397-1881

**Datak**
3117 Paterson Plank Road
North Bergen, NJ 07047
(201) 863-7687

**DuPont Riston**
3945 Freedom Circle F4
Santa Clara, CA 95054
(408) 562-9300

**Electronic Manufacturing**
17730 W Peterson Road
Libertyville, IL 60048
(312) 362-8711

**Electronic Packaging**
1350 E Touhy Avenue
Des Plaines, IL 60018
(312) 635-8800

**Kepro Circuit Systems**
630 Axminster Drive
Fenton, MO 63026
(314) 343-1630

**Kodak**
343 State Street
Rochester, NY 14650
(716) 724-4000
sources as Dick Blick, Southern Sign Supply, and Advance Screen. Two trade journals that serve the field are Screen Printing and Signcraft magazines.

At one time, printed-circuit boards were etched using a ferric chloride solution. Today, ferric chloride is a very poor choice of etchant. A much better etchant choice is ammonium persulfate. It is much cleaner, faster, and easier to use. Being a light blue solution, ammonium persulfate also lets you view the board as it is being etched. Etching best takes place at an elevated temperature, typically 120 degrees Fahrenheit. You could easily heat that temperature with a modified aquarium heater, warming plate from a yard sale, or any of the strip heaters found on the surplus market.

Everything that comes in contact with the etchant must be glass or plastic. PVC is often usable. Ideally, your etchant should be sprayed on the vertically held boards. Other ways to keep the etchant moving would be a simple manual sloshing or injecting air from an aquarium pump.

One really dumb mistake that most hackers make when etching their first PC boards is to place their board face up in the etchant solution. All that does is redeposit sediments and any crud removed from the board back on itself, leading to all sorts of nasty problems.

Instead, always support your boards vertically in the etchant, or else use surface tension to float

A thermal transfer toner image is PostScript laser printed onto a treated polyester sheet as a 1:1 reversed positive.

Heat and pressure fuse the toner directly to a thoroughly cleaned printed circuit board.

The PC board then gets etched in ammonium persulfate in the usual manner.

FIG. 3—Our Brand New DIRECT TONER TRANSFER method can dramatically simplify and speed up making all of your hacker printed-circuits at a cost only of pennies per board. Here are the three key steps in this breakthrough process.
1. Create a PostScript printed circuit artwork image on disk, using your favorite word processor and the sample pages found in my PostScript Show and Tell, or some suitable third party printed circuit layout package.

2. Run a positive, reversed 1:1 proof on a PostScript speaking laser printer, such as an Apple LaserWriter IWT. Many copy shops offer this service. Low cost PostScript printers are available through Don Thompson.

3. Optional step: Take a polyester based, laser printable overhead transparency material and lightly coat one side with Miller-Stephenson type MS-135 heated mold release agent. Mark the coated side.

4. PostScript laser print a 1:1 positive reversed (black = foil; right = left) onto the coated side of the polyester sheet, using a special thermal transfer (T-shirt) toner from Black Lightning, Don Thompson, or Laser Products. Other graphic toners might also work; try them and see.

5. Sharpen and smooth the leading edge of an oversized piece of 1/16th inch printed circuit material with a file and steel wool, so that it can be sent through a Kroy Kolor machine without hurting the rollers. Use a 3/8 to 1/2 inch leading slope.

6. Thoroughly clean this oversized printed circuit board, scouring it three times with fine steel wool and Comet cleanser, followed by a chemical cleaner, followed by a brief etch. The board must be a uniform hot pink in color and must allow an unbroken stream of water to flow smoothly over it. Be sure to avoid any and all fingerprints.

7. Tape the leading edge of the polyester sheet toner side down to the copper side of the printed circuit board, using a suitable high temperature tape. Make sure the polyester sheet lies flat.

8. Run the board, image side up, through a preheated Kroy Kolor machine adjusted to a medium temperature. One source of these machines is Laser Products. See the November 88 Radio Electronics or my hardware Hacker II reprints for details on building your own machine.

9. Optional step: Chill the board suddenly in a freezer before lifting the polyester sheet. Allow to warm to room temperature, then bake for fifteen seconds at 300 degrees F in a kitchen oven.

10. Etch in the usual manner in ammonium persulfate etchant.

**FIG. 4**—THE STEP-BY-STEP "BASELINE" PROCESS for the new toner transfer PC method.

An ordinary iron can substituted for the Kroy Kolor machine, but the results may not be as good. Let us know your experiences here.
the board upside down on the surface of the etchant. Another ploy is to add nylon spacers to your PC board so the foil faces down in your etching solution. Or else throw some nylon hex nuts in the etchant and sit the board upside down on the nuts. Once again, never etch a PC board face up!

A second stupid mistake that lots of hackers make is failing to clean the boards properly. It is not possible to clean a circuit board at home without spending at least two minutes per square inch of board. Begin by using Comet or another chlorine-activated cleanser with a fine steel-wool pad or Scotchbrite pad. Rinse thoroughly and wipe on an inner fresh turn of a new roll of paper towels. Repeat that at least three times, avoiding any and all fingerprints.

Note that fairly clean copper will allow an unbroken stream of water to flow over it without any running or beading. Your key secret is that a genuinely and totally clean copper will not be copper-colored at all. Instead, it will be certainly a uniform hot pink. Commercial copper cleaners, such as CU3 from Kepro, are a great help, but are somewhat expensive.

The ultimate final cleanliness step is to place the copper in ammonium persulfate and etch it for ten to fifteen seconds or so. Then thoroughly rinse three times and air dry immediately. If you get a uniform hot pink result, then your copper is clean enough for immediate use.

The photographic methods get rather complicated, but they can be used for arbitrarily fine lines and for all of the precision you will ever need. In fact, the same tech-
niques are used to manufacture integrated circuits to a fraction of a micron accuracy. Note that there are 20 microns in a mil.

With the photo processes, a light-sensitive etch resist is placed on the thoroughly cleaned board. The resist is first contact-printed from a photographic negative and then developed. In the most popular negative-acting systems, those portions of the resist that receive light harden and remain; those that did not will dissolve out. Etching is done in the usual manner.

Traditionally, the spray-on photosist was used, such as a KPR product from Kodak. These days, though, it is far simpler and far better to use a dry-film photosist, such as the Resisto materials by Dupont, or any of the Laminar AX products from Thokol. Those dry films develop in trisodium phosphate, the garage-floor cleaner found at your local hardware store. They are quite resistant to pinholes, eliminate dust and drying problems, have highly visible images, and are always at the right thickness. Once sensitized, the boards must be kept dry, cool, and in total darkness. They also have a one-year shelf life.

The third most stupid mistake that hackers make is trying to use KPR instead of the new and infinitely better dry films. Mistake number four, of course, is trying to coat their own boards instead of using pre-coated ones. Excellent dry-film pre-coated boards are stocked by Kepro.

The cost of the dry-film resist by itself is around a dollar per square foot. Unfortunately, a fancy laminate is needed to bond the resist to the board. I have a hunch that a Kryo Kolor machine or one of its imitators can be substituted here. The required temperature is 234 degrees Fahrenheit. Let me know if you pick up any experience along those lines.

Double-sided plate-through boards often use a combination of processes. Typically, you start with a double-sided board. The holes are first drilled, and then they are plated through by additive techniques. The holes get chemically activated and then seeded with an ultra-thin palladium plating. Electroless copper is then built up on the conductive palladium to a medium thickness, followed by a heavy copper plating up to the final wall thickness needed. The rest of the board is then processed through the usual double-sided photographic steps. Key hacker printed-circuit mistakes are summarized for you in Fig. 2.

Printed-circuit resources
I've gathered some of the major PC-board resources into our first sidebar, as we've done in previous columns for other topics. Most of the products we have mentioned are available directly through those sources.

The best trade journal for printed circuits is Circuits Manufacturing. A few others are Electronic Packaging and Production, Surface Mount Technology, and their sister publication, Electronic Manufacturing. Be sure to let me know if there are other resources that you think should be added to the list.

The direct-toner method
There's a new process on the block for hacker printed-circuits which is ridiculously simpler, faster, and far cheaper than any of the above. All you really need is a word processor and an iron. This new scheme is known as the direct-toner method. And it is new and undeveloped enough so that you might play a major role in making it work and shaping its future.

Very simply, copier or laser-printer toner is outstanding as an etch resist. Two decades ago, Xerox even had a product that directly printed on your copper PC boards from a 2:1 artwork original. A ways back, a new hacker product known as Meadowlake did attempt an iron-on toner system. Early versions of the product didn't turn out reliable enough and lacked stability.

But there is a brand new type of thermal-transfer toner now carried by several laser-printer supply houses. While the toner is intended for making iron-on T-shirt images, it transfers to copper beautifully and smudge-free, and is thus a key secret to the direct-toner process. Three sources of a thermal-transfer toner are Black Lightning, Lazer Products, and Don Thompson. Black Lightning does offer a free sample. Cost of the toner ranges from $90 to $180 per cartridge, which translates to a dime per board. Several of the other new graphics toners should also work well. Your help is needed in pinning down which ones are acceptable and which are not.

Figure 3 summarizes the key toner-transfer steps; that is followed by some detailed instructions in Fig. 4.

The best way I've found to create initial artwork is by using a PostScript speaking laser printer and my word processor. In fact, I have a complete package that does just that for Apple, Mac, and IBM.
users. Note that the original image must be a 1:1 reversed positive. That means that left is where right belongs and black is where you want your foil to remain. Naturally, since your image is disk-based, it is easy to change, and super easy to build up from a library of suitable Post-Script dictionary routines.

The image gets printed, again as a 1:1 reversed positive, ontostet than a laser-printable Mylar or polyester overhead projection sheet. Just for luck, I’ll previously apply a very thin coating of MS-136 Heated Mold Release Agent from Miller-Stephenson. That may or may not help, but it sure seems like a good idea, at least for now. It also may be a good idea to anneal or remelt the toner for a few seconds in an oven, after the image is transferred.

Too much reheating, of course, would lower the resolution. Although ten-mil lines on twenty-mil centers should be possible, I’d stick with double that as an initial lower limit.

In theory, you could still iron the toner directly onto a previously super-cleaned PC board. Instead, I modify the board by sharpening its leading edge, and run it through one of the imitation Kroy Kolor machines we looked at in Radio-Electronics, November, 1988. By the way, an improved and economical do-it-yourself version of that beast is in the works here at Radio-Electronics.

The benefits of the new way are obvious. You go from artwork to PC prototype amazingly fast. No cameras, chemistry, screens, or fancy equipment is needed. Without any fuss or bother. Just print and etch. And products such as GoScript and Freedom of the Press even let you fake PostScript on a dot-matrix printer, so “no printer” is no excuse.

The technique could also revolutionize running hacker PC projects. You show the PostScript code in the magazine and offer it downloadable off your BBS. Now, every hacker can end up with a precisely accurate original, rather than a third-generation copy.

Figure 5 shows some sample PostScript code from my PC layout stuff, while Fig. 6 shows a simple

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**CIRCLE 75 ON FREE INFORMATION CARD**
actual layout that you can use to test out your own version of the direct-toner board method.

As I said before, this is a brand new technique that needs some further experimentation to perfect. So, for our first contest this month, just tell me anything you find out on your own about making a direct-toner PC board. There'll be the usual dozen or so Incredible Secret Money Machine books for best entries, along with an all-expense-paid (FOB Thatcher, AZ) Simon Quest for the very best of all. Let's hear from you on this hot new topic.

New tech literature

The hacker buy of the month has to be the new $3.75 speech synthesizer available as stock number 1030CA from All Electronics. It even includes a load-power sensing detector. There is one very tiny gotcha, though—the synthesizer has to say is “Your ice cream is ready.” Oh, well.

PROPERTY GUARD

continued from page 40

The EG&G Reticon folks have three brand new data books out. They are their Image Sensing Products, Solid State Cameras, and the Analog Signal Processing Integrated Circuits. The latter covers analog delay lines, switched-capacitor filters, and some very useful appendices.

The BU291 is an interesting new melody chip from Rohm. It provides a pair of folk songs and six different chimes and siren sound effects. Uses? How about some clocks, doorbells, or alarms? Miniature fluorescent lamps from JKL are offered in various colors at very low prices; they also carry EEPROM erasing lamps.

The SPIE folks have great bunches of reprints involving nearly everything optical, and covering laser scanning, CD ROM, holography, fiber optics, and 1-R detection. Get their list number 6.

Turning to mechanical stuff, free molded-gear samples are obtainable from Winzeler. And Robert A. Main has a unique catalog of Hooks, Points, and Teeth. A sharp outfit for sure. Tellyawhut. Their catalog number twelve is so unusual, that we'll make us a second contest out of it. Just come up with some off-the-wall use for any of the hooks, points, or teeth shown.

If you want to explore our new direct-toner hacker PC contest further, or want to draw your own first-quality electronic schematic diagrams, isometric drawings, or architectural perspective sketches (including all lettering!) using nothing but your favorite word processor, check into my PostScript Show and Tell, that has scads of working code and detailed examples in it. Available for Apple, Mac, or IBM, it does need a PostScript speaking laser printer (or a software emulator).

As always, this is your column and you can get technical help and off-the-wall networking per the Need Help? box. The best calling times are weekdays 8-5, M.S.T. R.E.

![Frequency Response](image_url)

**Fig. 7—Frequency Response of the piezoelectric transducers.**

should be such that they direct their energy to the points of intrusion or access. They can be all directed to any target area, or be individually placed for multiple effect.

The transducers used in this system are piezoelectric and are many times more efficient than the electromagnetic-type speaker. Their frequency response is shown in Fig. 7.

**Ultrasonics**

Ultrasonic is a gray area in many respects when the application involves the control of animals or as an intruder deterrent. It is always best to consult with local municipal and state laws before using this device to protect home or property.

Do not operate at continuous high output at frequencies below 20 kHz. Daily sound pressure exposures in excess of one hour at 105 dB may lead to hearing impairment. When properly used, this device provides a limited liability deterrent. It should not cause permanent damage or trauma.

There have been numerous requests for information on the effect of these devices on people. First of all, an ultrasonic device should not be used unnecessarily on humans, because of the possibility of acoustically sensitive people being highly irritated.

Remember that the Property Guard cannot stop a person with the same effect as a gun, club, or more conventional weapon. It will, however, produce an extremely uncomfortable, irritating, and sometimes painful effect in most people. Although not everyone will experience the effect the same degree. Younger women are much more affected than older men, due to being more acoustically sensitive. The range depends on many variables, but is normally somewhere between 10 and 100 feet. R.E.