BY DON LANCASTER

Magnetometer update, vacuum forming, and more

I CERTAINLY GET LOTS OF HELPLINE CALLS FROM INDIVIDUALS WHO ARE TRYING TO PROTECT ELECTRONIC DESIGNS WITH EPOXIES, PART-NUMBER GRIND-OFFS, AND SIMILAR STUPID PET TRICKS. WELL, ANY TIME YOU SEE A GLOPPED AND GROUND-UP project, you can pretty much rest assured that (A) All of the engineering is incompetent; and (B) The management suffers from acute recto-cranial inversion.

Besides being a monumental waste of time and energy that you should be spending improving your product and developing your design skills, those "protection" schemes simply do not work. In fact, they will have the exact opposite effect. All such "I've got a secret" stunts are red-flag invitations for people much smarter than you to spend lots of time and creative effort cracking your mystery. All you're doing is providing them with free entertainment.

Every town, no matter how small, includes a guild of highly capable epoxy-undoing specialists (for do-it-yourselfers, *Master Bond* sells a selection of epoxy-dissolving chemicals). These same folks have these neat-o X-ray machines that easily let you snoop into just about anything electronic or mechanical.

The moral? Just like that story about the fur-lined letter, the key protection secret is to always hide in plain sight. Far fewer people of far less competence will then be attracted to tracing your product. Chances are they will blow their quest anyway.

Always provide a complete, free, and detailed schematic with all of your products, and make your source code available at a fair price—one that is well under the cost of reverse engineering. Doing anything less is sheer insanity.

Magnetometer Update

Since last month's coverage, I've pinned down a bunch of new info and a few samples on magnetometers and fluxgates, so let's do an update. First off, Ripke's *Review of Fluxgate Magnetometers* in *Sensors and Actuators A*, volume 33, 1992, pages 129-141, is a real good technical starting point.

Figure 1 shows you the winding details on a classic fluxgate sensor. A softly saturating tape-wound toroidal core is normally used. The main or control winding gets driven by a low-distortion sinewave. That sinewave switches (or gates) the core in to or out of saturation.

Paired orthogonal sine and cosine sense windings tell the strength and direction of the external field as it is drawn in to and released from the core. For signal isolation, the sensing is normally carried out at the second harmonic of the drive frequency.

Although that fluxgate is a thoroughly tested and proven workhorse, it involves quite low-level, noisy, analog signals that are tricky to accurately interface to any micro. The multiple precision windings also add greatly to your final cost and complexity.

Additional details on the fluxgate support circuitry might be found in HACK14.PDF on www.tinaja.com and in the useful *Magnetic Measurements Handbook* from *Magnetic Research*. Magnetic Research also sells wound cores and working magnetometers.

Figure 2 shows us an improved circuit known as a resonant fluxgate. The op-amp operates open loop as a com-

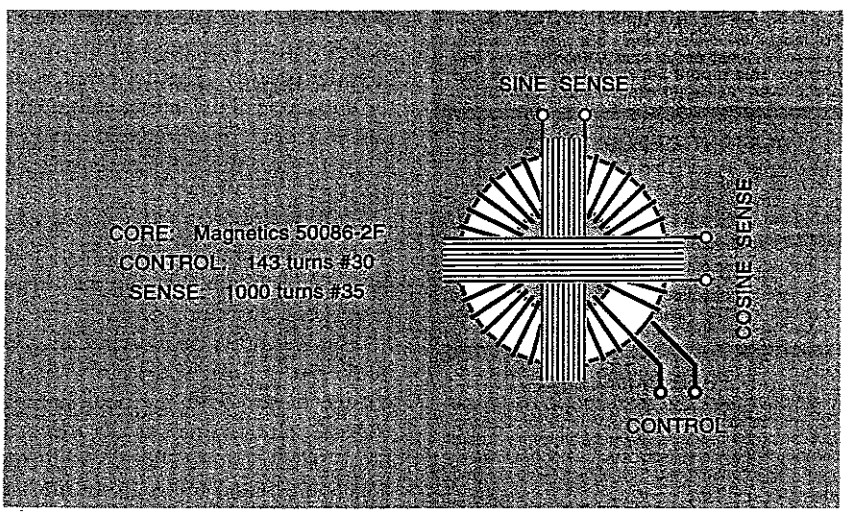

FIG. 1—CLASSIC ANALOG FLUXGATE MAGNETOMETER. An input audio drives sinewave the control input, switching (or "gating") the core in and out of saturation and drawing in or releasing an external magnetic field. Weak signals at the sense outputs end up proportional to field strength.

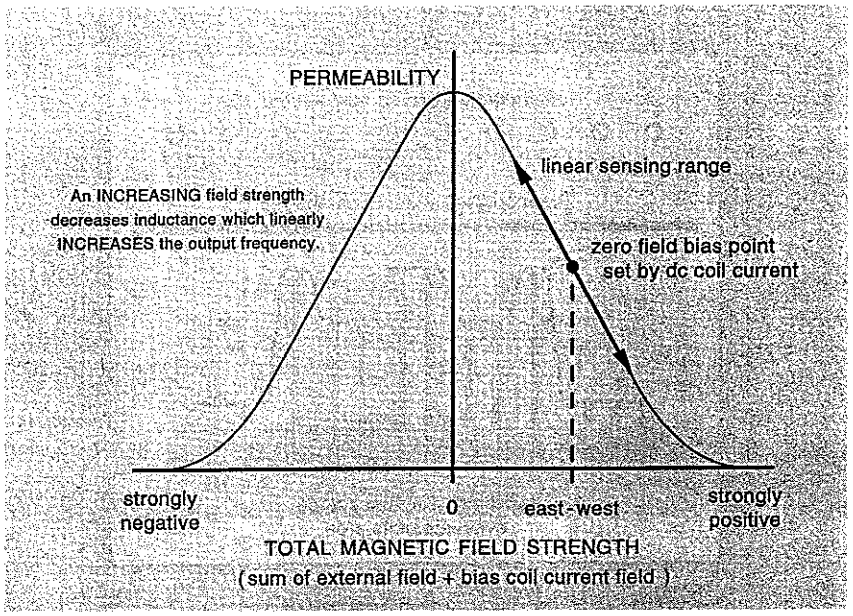

FIG. 3—SPECIAL ISOTROPIC MAGNETIC ALLOYS, whose permeability varies with field strength, are newly available. By biasing it as shown, a coil can be built so its inductance strongly varies with compass orientation.

netic materials manufactured by Allied Signal purposely goes out of its way to provide a variable permeability that changes with the applied field strength or bias current.

As Fig. 3 shows us, that new material has a high permeability with low applied fields and a much lower permeability with high fields. Note particularly the fairly linear permeability shift with applied field above and below the bias point I've shown. You can bias to that point by running some DC current through an overwound sensing coil. The earth's magnetic field (or some other magnetic source) will add to or remove from that magnetic bias level, raising or lowering the coil's inductance!

You therefore end up with a plain old coil whose inductance varies with the applied field strength. Put that in any suitable oscillator circuitry, and your output frequency should follow the strength and direction of the earth's applied field. With proper design, as much as a 2:1 frequency change can be caused when you rotate the sensor through the compass points.

What is really interesting here is that a single, ultra-cheap solenoid winding over an ordinary core bar or rod acts both as a field sensor and the control bias setter. The sensing gets done by measuring the inductance, and the biasing by inputting a DC current.

Note that this is not a fluxgate, and that your core material never really gets into hard saturation. Instead, you have a variable permeability sensor that progressively saturates.

The rest is easy. Place the coil in a relaxation oscillator, add some DC bias, and shove the variable-frequency output into your microcontroller.

Figure 4 shows us one possible circuit. Unlike fluxgates, one simple winding over the core material is all you'll need. To calibrate your sensor, rotate it through 360 degrees or else drive around the block.

Though we have not said so explicitly thus far, we are working with the falling slope of the magnetic field. The falling slope is chosen for the following reason: An increasing magnetic field will decrease the permeability. Which in turn decreases inductance, and the decreasing inductance will increase frequency in most oscillator circuits. Thus, your output frequency should linearly track your input field strength on the falling slope.

Note also that an op-amp or comparator can give you better accuracy than the simple CMOS Schmitt trigger I have shown here. Your oscillator circuit must be voltage and temperature stable if you are to get useful results. Two or three axis operation could get picked up by use of two or three sensors, and then positioning them in quadrature to each other.

Precision Magnetics offers a wide variety of sensor solutions suitable for digital compasses, robotics, and for vehicle navigation applications. The coils themselves measure about 3/16-inch in diameter by 3/4-inch long. Their typical dual-axis compass magnetometer measures a tad over an inch square, draws a few milliamps, and sells for $80 or so.

Remember that any accurate compass measurement must be dead level. To cure that problem, Precision Navigation has introduced a Vector 2XT gimbaled electronic compass module. Introductory pricing is $100 for that self-leveling unit. By making use of that exciting new isotropic technology, there's no real reason why any consumer compass, navigation device, or robotics sensor that costs less than a dollar per axis cannot be built in large quantities.

Let's have your thoughts on this. It would seem that there are all sorts of exciting new possibilities here—and a lot of tech venture opportunities.

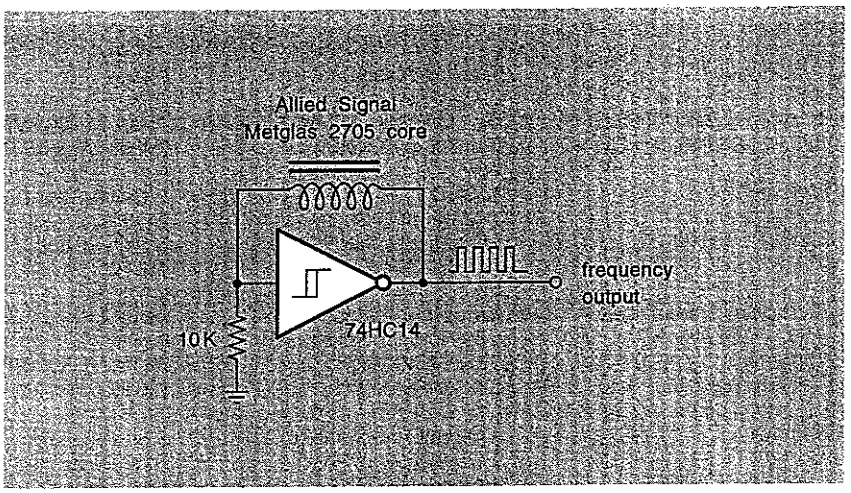

FIG. 4—THIS ELEGANTLY SIMPLE earth's field detector uses a special variable permeability cored coil. The output frequency varies with orientation.

parator, generating a squarewave output. That squarewave is converted to a current source by the 56,000-ohm resistor. The current waveform excites the control winding, driving the core in to and out of saturation.

The high-turns secondary winding is made resonant by the 0.1-µF capacitor, producing a sinewave. The resonant sinewave then gets strongly amplified and converted back to the output squarewave.

The operating frequency is determined by your drive current, the inductance, and the time that is required for the core material to unsaturate. Any external magnetic field should bias your core material, causing the positive cycle to get longer and your negative cycle to get shorter, or vice versa with a field of opposite polarity. The net result is that the duty cycle of the output ends up proportional to the single-axis external magnetic field that you are sensing with the coil.

The amorphous ribbon core is made from an alloy of iron, cobalt, silicon, and boron. Chromium sometimes is thrown in for good measure.

For low noise, it is important your alloy has a low *magnetostriction*, or change in size with the field strength. Any core motion dramatically affects the level of the noise floor. Additional details are found in "A Resonant-Type Amorphous Ribbon Magnetometer That Is Driven By An Operational Amplifier" by Takeuchi and Harada, *IEEE Transactions on Magnetics*, MAG-20, Sept. 84, pp 1723-1725. As we've seen a time or two before, *UMI* is a great reprint source for these.

Finally, note that the circuit has both digital and analog outputs. The digital output might be interfaced with an appropriately programmed PIC or other microcontroller that will then handle the measurement function. Alternately, as shown, a simple resistor/capacitor low-pass duty-cycle integrator can create a bipolar, analog, output voltage (available at the circuit's analog output) that tracks the input field strength for you. Additional details on duty-cycle integration circuits and techniques are available in my *CMOS Cookbook*.

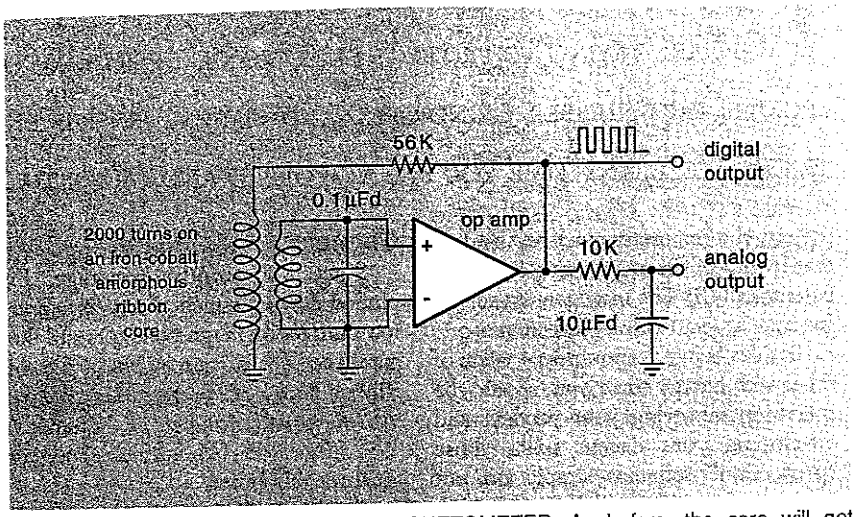

FIG. 2—A RESONANT FLUXGATE MAGNETOMETER. As before, the core will get switched in and out of saturation. The output duty cycle varies in proportion to the single axis field strength and direction. The high level output square wave is easy to interface to a PIC or other microcontroller.

The Variable Permeability Method

A brand new isotropic approach to earth's field sensing has been championed by Precision Navigation. Surprisingly-full tech details appear in their patent (#4,851,775).

The inductance of any winding is proportional to the permeability of its core. Normally, you will want your permeability to be a constant, and one that is independent of the applied field or bias currents. Fail to do that in an audio transformer and you will get mild to severe distortion.

One location where a variable or nonlinear permeability has been used for years is as a swinging inductor in DC power-supply filters. In those, a partial air gap is used to produce additional inductance (and more filtering) at low currents, and faster response at higher currents.

A unique new class of *MetGlas* mag-

NAMES AND NUMBERS

AlliedSignal
1090 S Milpitas Blvd.
Milpitas, CA 95035
Tel: 408-946-2411

Elantec
1996 Tarob Ct.
Milpitas, CA 95035
Tel: 408-945-1323

Epoxyworks
PO Box 908
Bay City, MI 48707
Tel: 517-684-7286

Fujitsu
3545 N First St.
San Jose, CA 95134
Tel: 800-642-7616

IEEE Transactions
445 Hoes Ln.
Piscataway, NJ 08855
Tel: 908-981-0060

Integrated Circuit Systems
PO Box 968
Valley Forge, PA 19482
Tel: 610-630-5300

Magnetic Research
122 Bellevue Ave.
Butler, NJ 07405
Tel: 201-838-6348

Master Bond
154 Hobart St.
Hackensack, NJ 07601
Tel: 201-343-8983

Phaedra Enterprises
PO Box 1241
San Bruno, CA 94066
Tel: 415-359-0432

Precision Navigation
1235 Pear Ave., Ste. 111
Mountain View, CA 94043
Tel: 415-962-8777

Science First
95 Botsford Pl.
Buffalo, NY 14216
Tel: 716-874-0133

Society of Mfg. Engineers
One SME Dr.
Box 930
Dearborn, MI 48121
Tel: 800-733-4763

Synergetics
Box 809
Thatcher, AZ 85552
Tel: 520-428-4073

System Three Resins
PO Box 70436
Seattle, WA 98107
Tel: 206-782-7976

Tiare Publications
PO Box 493
Lake Geneva, WI 53147
Tel: 800-420-0579

West System
PO Box 908
Bay City, MI 48707
Tel: 517-684-7286

yes, anyone can buy from those low-cost sources—they just happen to advertise mostly to the school shop market, making them hard-to-find if you don't know about them.

Two common plastics suitable for vacuum work are Styrene and Vivak. The latter is sometimes used for clear helicopter canopies. Rigid vinyl and acrylic also work fairly well. Actually, almost any thermoplastic will do just fine as long as it has a reasonable softening temperature.

Friendly plastic suppliers include both United States Plastics and AIN Plastics. Also check out the folks at Southern Sign Supply. Useful magazines to check out include *School Shop*, *Signcraft*, *Sign Business*, *POP & Sign Design*, and *Cinefex*. A lot more content on amateur vacuum forming in general appears in Steve Hansen's *Bell Jar*.

On the internet, all your usual Net-search engines will give you dozens of effective hits on vacuum forming—including a not-quite-so-useful hit on something that I've always suspected: "vacuum-formed fruitcake." I've got hot links to those sites on my www.tinaja.com. More on plastics in general can be located in my file RESBN50.PDF on the new *Resource Bin* library shelf.

New Tech Lit

From Integrated Circuit Systems comes a superb data book on a mind-blowing collection of music-synthesizer chips, video and audio circuits, multimedia, battery chargers, timers, and bunches more. A *New Products Supplement* on fast video and communications chips is now available from Elantec. From Fujitsu comes their *Wireless Communications Products* and *Power Management* data book.

There's a new book and video catalog on Santa Claus machines, on CAD/ CAM, and even on ingenious mechanisms from the Society of Manufacturing Engineers. *Outer Space Frequency Directory* is mostly a detailed listing of NASA and the other satellite related communications channels; it's from Tiare Publications.

And speaking of outer space, the fourth edition of the *International UFO Directory* by David Blevins is now available for $12.50 from Phadera Enterprises. That text is sort of a combined *Michelin Guide* and *Thomas Registry* to a wild assortment of hundreds of organizations world wide. The quality and the annotation detail is a tad down from earlier editions, but the price is certainly right.

I really enjoy watching the UFO industry move from one happening to the next. The big trouble is that they never seem to build on anything, and hard evidence sure seems to be elusive.

Science First has a new catalog on Van De Graaf generators and similar low-priced science demos. But the product that impresses me the most is their #40-500 Roman Arch Kit—a puzzle made of lightweight wooden kiddy blocks. Put them together just right without any glue or support and you can actually stand on it.

For those looking for additional fiberglass info, from EpoxyWorks comes a West Systems booklet on building, restoring, and repairing with epoxy. System Three Resins offers a similar full-resin products line, as well as support info.

For the fundamentals of starting up your own technical venture, be sure to check my *Incredible Secret Money Machine II* book, available per my nearby Synergetics ad. I've also still got lots of surplus test-equipment bargains. Those include Tek 1230 logic analyzers, a like-new TG-501 time-mark generator, and bunches of bargain-priced Heathkit test items. You can view that catalog online as SURPCAT01.PDF.

As usual, most of the mentioned resources appear in the Vacuum Forming or the Names & Numbers sidebars. Be sure to check there first before using my US tech helpline or visiting www.tinaja.com. EN

NEED HELP?

Phone or write all your US Tech Musings questions to:

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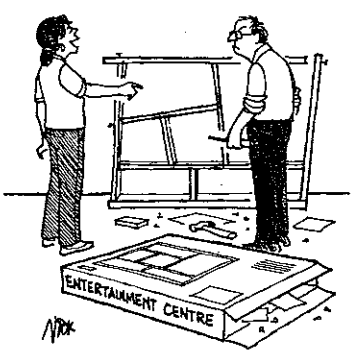
Web page: http://www.tinaja.com



Vacuum Forming

I just received some intriguing new vacuum forming information, so I thought this might make a useful discussion. As Fig. 5 shows, vacuum forming is the process of bending a plastic sheet. The sheet is first heated to a carefully controlled temperature above its softening point. It is then draped over a male mold.

The mold could be made of wood or plaster or most anything rigid and capable of withstanding medium-hot temperatures. The mold has zillions of tiny holes in it that are routed to a vacuum source.

A vacuum then gets applied that sucks the sheet down to conform with the mold shape. Two stages of vacuum will sometimes be applied. One is high volume to get rid of most of the trapped air, and the other is high pressure to force an exact match to the mold. Finally, the part is cooled and taken out of the mold.

Important vacuum-forming uses are signs, packaging materials, and theater props, but there should be all sorts of custom electronic-enclosure possibilities as well. The process can be cheap and low tech, especially when compared against an injection molding set up. For example, you can easily build your own machines.

Vacuum forming obviously works best when there are no undercuts and when a whole lot of stretching is not needed. As the sheet stretches, it gets thinner, so you can only go so far. However, there is no real upper limit to vacuum-forming sizes. Full four by eight plastic sheets can be formed if you need big results.

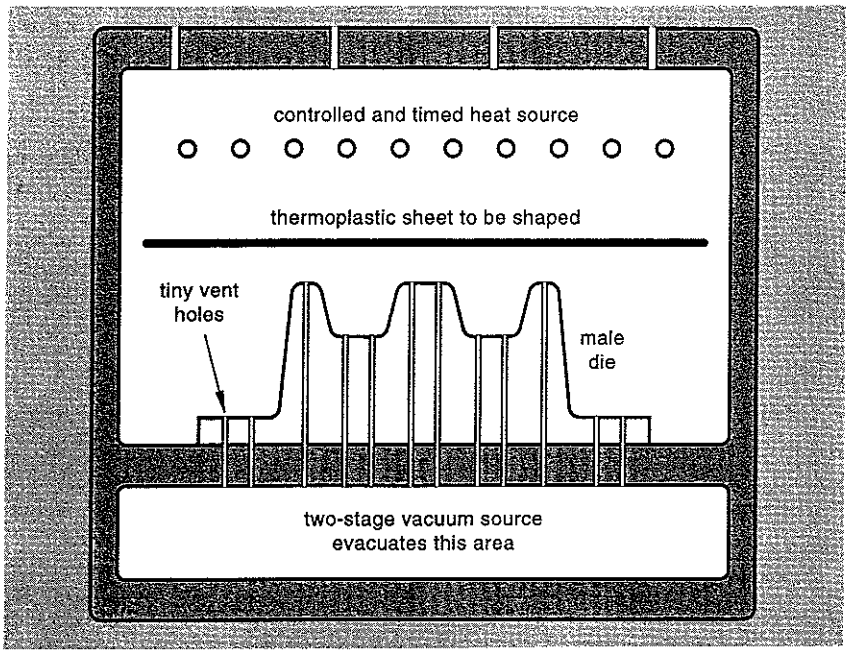


FIG. 5—VACUUM FORMING is a process that first heats a plastic sheet and then draws it against a form. This low-to mid-quantity process is fairly cheap and low tech. Custom electronic enclosures are one app.

So how do you find out more? Let us start off with *The Molding and Casting Handbook* by Thurston James. That book is mostly on theatric props but includes an outstanding chapter on how to build your own vacuum-forming machine and then use it. It is available from Betterway Books. Other books on vacuum forming are sold by Lindsay Publications.

A company calls, of all things, Vacuum Form views themselves as the leaders in low-cost vacuum forming. Prices on their Hobby-Vac series start at $99. They do cheat a little on that budget model, requiring your kitchen oven to presoften the plastic and your shop vac for first stage vacuum. A small hand pump is provided for the final forming drawdown. Even so, the unit does sheets up to 6 X 9 inches and, amazingly, can handle up to a 3/16-inch thickness. Prices on their fancier commercial machines, which include heaters and pumps, start at $458. They also retail books and precut plastic sheets (though you can save a lot by cutting your own from full sized sheets).

Other sources of low-end hobby and school vacuum formers include Pitsco, Delvies, and IASCO. Those are outfits that specialize in the school markets and they also offer reasonably priced injection-molding and blow-molding machines, molds, and materials. And,

VACUUM FORMING RESOURCES

AIN Plastics
249 E Sandford Blvd
Mt. Vernon, NY 10550
Tel: 914-668-6800

Bell Jar
35 Windsor Dr.
Amherst, NH 03031
Tel: 603-429-0948

Betterway Books
1507 Dana Ave.
Cincinnati, OH 45207
Tel: 800-289-0963

Cinefex
Box 20027
Riverside, CA 92516
Tel: 909-781-1917

Delvies Plastics
133 W Haven Ave.
Salt Lake City, UT 84165
Tel: 800-533-5843

IASCO
5724 W 36th St.
Minneapolis, MN 55416
Tel: 612-920-7393

Industrial Education
1895 Crooks Rd. #135
Troy, MI 48084
Tel: 313-649-4900

Lindsay Publications
PO Box 538
Bradley, IL 60915
Tel: 815-935-5353

Pitsco
1004 E Adams
Pittsburg, KS 66762
Tel: 800-835-0686

P-O-P & Sign Design
7400 Skokie Blvd.
Skokie, IL 60077
Tel: 708-675-7400

School Shop
Box 8623
Ann Arbor, MI 48107
Tel: 313-769-1211

Sign Business
1008 Depot Hill Office Pk.
Broomfield, CO 80020
Tel: 303-469-0424

SignCraft
PO Box 06031
Ft. Myers, FL 33906
Tel: 813-939-4644

Southern Sign Supply
127 Roesler Rd.
Glen Burnie, MD 21060
Tel: 310-768-8600

US Plastics
1390 Neubrecht Rd.
Lima, OH 45801
Tel: 800-537-9724

Vacuum Form
272 Morganhill Dr.
Lake Orion, MI 48360
Tel: 810-391-2974