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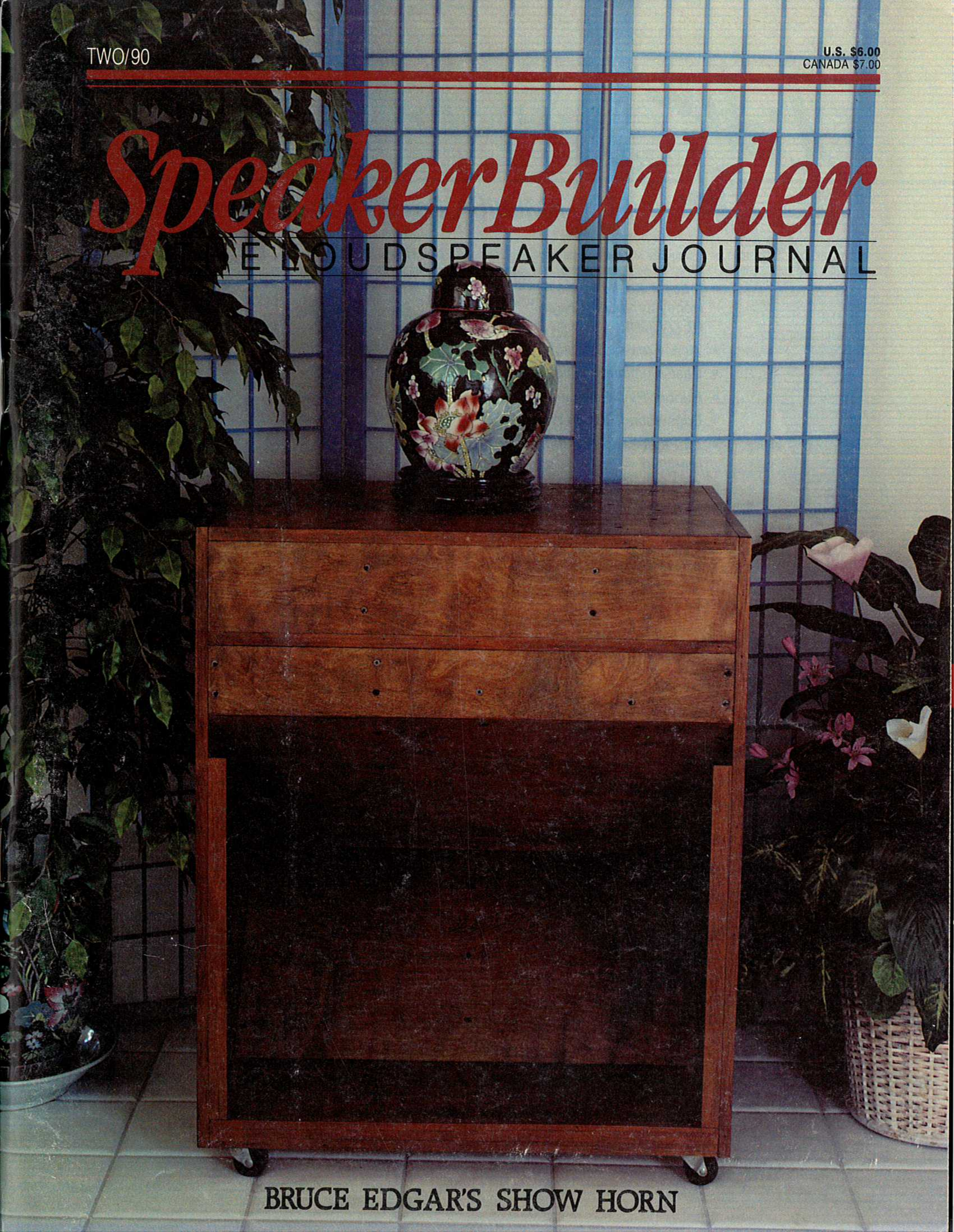

BRUCE EDGAR'S SHOW HORN

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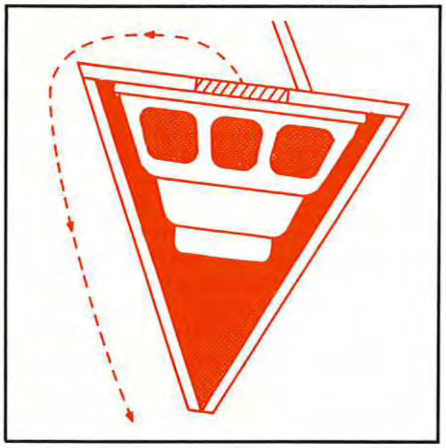

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FEATURES

DEPARTMENTS

On our cover: Contributing Editor **Bruce Edgar**'s Show Horn. Photo by Manfred Buechler.

Part II

A COMPACT INTEGRATED ELECTROSTATIC/ TRANSMISSION LINE

BY ROGER R. SANDERS

Perforated metal tends to be expensive. The ideal pattern would be $\frac{1}{16}$-inch perforations on $\frac{3}{32}$-inch staggered centers. Although a possibility, it is too costly for our use. Fortunately, a very good substitute in the form of decorative 2 by 3-foot Alcoa aluminum sheets is available from any Ace hardware store [and other stores stocking Alcoa]. The pattern you want is called Lincaine consisting of $\frac{1}{8}$-inch holes surrounded by $\frac{1}{16}$-inch holes. Although available in plain aluminum, I urge you to buy the gold anodized version. The plain type has an oily film difficult to clean. The gold type is spotless and costs only a few dollars more. The sheets are only 20 mils thick. The Ace order book lists this material as item number 1215.

This material is soft and thin and can be damaged easily in transit. Often a corner has been bent, but you can straighten that easily. Beware and reject those with a crease across the sheet. You will not be able to remove the crease. The sheets will have a modest bow or warp to them from the perforating process. This is normal and is not usually a problem.

You can cut a sheet in half with a pair of scissors, yielding two stators from one sheet. If you want a perfect cut, have a local sheet metal shop cut it on a sheet metal brake. Because the insulators are narrow to conserve space in this compact design, cut a notch in the metal so it clears the diaphragm contact (*Fig. 1*). Do this after you have drilled the insulating strips so you know exactly where to locate the notch.

The holes have rounded edges on one side and sharp ones on the other. During construction, face the round edged holes toward the diaphragm so you minimize corona problems. A corona is the tendency of a sharp, high-voltage surface to break down the dielectric strength of the air, causing arcing. Smooth, rounded surfaces suppress this. Glue the insulators on the side with the rounded holes.

INSULATORS. The insulators are made from either $\frac{1}{16}$-inch acrylic (one brand is Plexiglas) or 80-mil polycarbonate (one brand is Lexan). I have used both but prefer acrylic because it meets my specification for a 68-mil diaphragm-to-stator spacing and therefore produces the highest output. These materials are usually available from home improvement stores or glass shops. Glass shops can often cut the strips you need, but it is not difficult to cut them yourself and doing so will save quite a bit of money.

I have tried many different ways of cutting this stuff, but no method is perfect. Although it is possible to score and break off strips, it is very difficult to do so even with a jig. It is far more practical to saw the plastic into strips. The best tool for this job is a band saw with a very fine blade (a fine-tooth hacksaw blade works beautifully). Clamp some sort of rip fence to the saw and go to it. You can use a table saw, but there are problems. First, fine-tooth blades are not made for them, although you can do an acceptable job with a plywood blade. This will cause considerable chipping along the cut edge, however, which although unsightly, does not affect performance. You also will find the plastic sheet has a tendency to climb the saw blade. To prevent this, clamp a piece of wood on the side of the rip fence about a quarter inch above the table. Run the saw blade about a quarter inch up into the wood, which will prevent the plastic from climbing up the blade.

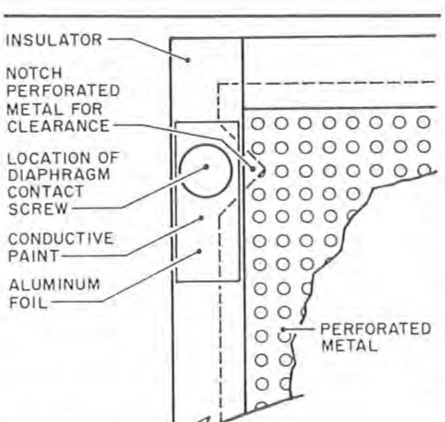

FIGURE 1: Diaphragm contact detail, front view.

Drill the diaphragm contact holes by first clamping two strips together (*Fig. 2*). Drill a $\frac{5}{32}$-inch hole (the size of a 6/32 bolt, which you will use for the diaphragm contact bolt) through both strips. Be careful: Conventional drill bits tend to shatter the plastic just as they exit the hole. One way to prevent this is to stop just as the drill point starts to exit, turn the stack over, and finish the hole by drilling in from the other side.

I like Barry's technique (see "The Waldron ESL Panel," opposite page) of using a solder tab for the diaphragm contact because it is simpler and more rugged than my method. It has the disadvantage of sticking out of the edge of the cell, which prevents slot mounting of the completed cell. If you use his design, skip to the next paragraph. If you use my design, separate the two strips and increase one of the holes to ½ inch, so the head of the screw and washer that make up the contact point can pass through one of the strips and make contact with the diaphragm.

CELL CONSTRUCTION. Use a piece of glass slightly bigger than your completed cell upon which to construct the cell. Draw the insulator pattern on the underside of the glass with a felt marking pen (*Fig. 3*). Alternatively, you may lay out the pattern with masking tape. All the stators must be identical so when you glue them together, the insulators match, particularly the center strip insulator, which is very narrow.

The diaphragm must be supported about every six inches for stability: thus, the center insulator. In theory, you have the option of replacing the strip insulator with insulating "dots" about every six inches. The dots allow more of the diaphragm to move and reduce stray capacitance, which should enhance speaker efficiency. I tried this initially, but it was unsatisfactory. The dots gave too little stability to the diaphragm to use high-polarizing voltages. Switching from dots to a strip increased the output by nearly 10dB. This is yet another case where practical experience proved theory wrong.

Obtain two types of adhesives from your local hobby shop. First, you will need a small amount of cyanoacrylate, or instant glue. The gap-filling type is preferable so your joints don't have to be perfect to make a good glue joint. Cyanoacrylates are not instant when used on plastic. You may want to get a "kicker" to make it work instantly. Second, you will need some 30-minute epoxy in a 9-ounce squeeze bottle. Devcon epoxy is preferable because it has the lowest viscosity, but other brands are acceptable. Those of us who build lots of cells use 5-minute epoxy exclusively, but you must use a syringe to apply it and work quickly. Thirty-minute is probably a better choice.

Drill a 5/32-inch hole in one corner of the aluminum sheet for the 6/32 brass nut and bolt used for electrical connection to your amplifier. Carefully remove the burr left by the drill by manually twisting a much larger drill bit or a countersink in the hole. Bend this corner at right angles to the diaphragm *after* the cell is completed and then install the bolt through the hole to attach your electrical connection. The tab needs to be only about a half inch. If you prefer to have all the connections in the same corner of the speaker, remember that the stators will be mirror images of each other.

GLASS CARE. Remove all grit from your plate glass, aluminum, and insulators with a vacuum cleaner. Protect your glass from glue by coating it with car wax or covering it with plastic wrap. Wax paper is porous to epoxy, avoid it. Lay out the insulators and tack them together with cyanoacrylate. When all eight are done, lightly sand the glued areas to remove any high glue spots. Lay one of the insulator frames on the glass and spread a thick film of epoxy where the perforated metal will fit. Omit epoxy in the tab contact area so you can bend it up later. Lay the metal on the insulator frame, remembering to keep the rounded holes toward the insulators, and cover it with plastic wrap.

Place flat weights on this assembly until the glue cures. It is important to have a flat stator, so make sure the weights are flat. If you are using books, select them carefully for flatness. It is a little more expensive, but well worth the cost, to place a second piece of glass or a steel sheet on top and then put books on it. This will ensure a truly flat assembly. Note that when the assembly is lifted from the glass after the epoxy has cured, it will still be warped. Don't worry; it will be flat after it is sandwiched to the other sheet in the final assembly.

Now you need some conductive paint. I use the stuff LocTite sells for repairing rear window defrosters in cars, but any type will do. Take the stator with the large hole and paint a line ¼ inch wide and about six inches long from the hole to the inside edge of the insulator. Go in whatever direction necessary to avoid

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Alternative Method:

THE WALDRON ESL PANEL

BY BARRY WALDRON

This electrostatic panel's architectural design is the result of a similar though wider configuration conceived a few years ago. When Roger asked me to construct the prototype, we discussed the pros and cons of various stator designs. My role was to construct a set of panels to satisfy Roger's overall goals. Since the prototypes were to be offered for sale, it became important to offer a panel which would provide the best possible results.

Roger introduced me to the ESL in 1976. With my first design, I subdivided the original Sanders panel (*TAA* 4/75, p. 18), making the individual sections free standing. The problem with this is the rods are horizontal across the stator, requiring them to be cut, a difficult and time-consuming task.

While building and testing these panels, I found they were structurally unsound, flexing in various places. This caused the diaphragm to become attracted to a stator, and the immediate area then would not emit sound. To correct this, I fashioned and attached Plexiglas longerons to each side of each stator.

After completing the above project (Showcase, *TAA* 4/79), I tried many topologies. I wanted to construct a panel using uncut rods. I made a long, narrow panel with longerons, and added external ribs to support the rods. These give us three advantages: First, more of the diaphragm is usable; second, stray capacitance is reduced, and third, the structural integrity of the frame is enhanced. These are slightly more difficult to construct than the Sanders type.

In the next configuration, I widened the panel and changed the mounts from top and bottom tabs to a peripheral flange. To maintain the 100:1 diaphragm support structure, I strategically placed insulated pads in the first prototype, as shown in David Hermeyer's second design (*SB* 2/77, p. 4). They also have less stray capacitance and more usable diaphragm area. I used a single electrical termination point in each variation.

Roger's initial tests showed that while the pads worked, they failed to adequately support the diaphragm; the panels would only allow 1,800V to be applied, resulting in SPLs of 97dB. Although this is fine for many, we are seeking the best so we eliminated the spot insulator pads and returned to the strip insulator. While stray capacitance is still a valid issue the gain possible by using the strip insulator outweighs the stray capacitance. These panels accept 3,000V and deliver a whopping 106dB.

By following Sanders' articles in *TAA* (4/75) and *SB* (3/80) in addition to the following text, you should have no trouble constructing a suitable set

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ABOUT THE AUTHOR

Barry Waldron, 47, has been tinkering with electronics since the mid '50s and with audio since the early '60s. Another hobby is still-life photography. In addition, Barry holds a commercial pilots license and is an avid ballroom dancer and instructor.

THE WALDRON PANEL

Set the remaining jigs (13–18) in place between the ribs of the top stator, then position the glass on top of the assembly and weight it down. Remove the awls and insert metal screws as above.

FINAL VENTURE. With weights and jigs removed, trim and clean the panel edges using an X-acto knife or single-edged razor blade.

Remove the metal screw if you haven't already and prepare to replace it with one of nylon. Before inserting the electrical hardware, determine which of the panels will be left, right, top and bottom. Pair up left and right and orient them so the contact holes of each set will be one above the other. This done, insert the screws, washers and any additional solder connectors to the front and rear portions of each panel and tighten down with a nut.

Note: Even though the metal screw keeps the contact hole open and provides more accurate alignment when mating the two stators, I found it necessary to clean the contact holes by running a drill bit through them prior to inserting the nylon screw.

Hair dryers do not heat Mylar enough to tension the diaphragm. Heat guns are better for the shrinking and final tensioning. Industrial varieties are available, but hobby shops market more reasonably priced machines.

Final tension the diaphragm by placing the panel on a chair, stool or other suitable surface and holding it upright with light reflecting off the Mylar. Run the gun from side to side directing the air downward or upward toward the Mylar. Applying the heat straight on does not work well. It takes only six seconds, or about two inches per second, to cover the span. As you do this, you will see wrinkles disappear.

You also will see the diaphragm tighten up as you move toward the bottom using slightly overlapping passes. Dallying in any one area will burn a hole in the Mylar. Several quick passes are better than one slow pass. Once the gun has covered the entire surface, set this panel aside and do the others. Note: Two or three separate sessions will probably be required for each panel. Touch up any wrinkles.

The ESLs are now ready for testing and mounting to the bass enclosure.

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the joint in the insulators at the corner. I discovered the hard way that the joint usually has a void into which the conductive paint can run and touch the stator, resulting in a shorted cell. Keep close to the inside edge of the insulator, but be extremely careful not to get any paint on the edge of the insulator or drip onto the metal stator. Be particularly careful that the paint does not run down inside the hole. Put no paint near the outside edge of the insulator because you will need that area for gluing things together. If paint drips or runs, clean it off with a cotton swab soaked in acetone or paint thinner, or sand it off with sandpaper after it dries.

CONTACT TESTING. When the paint is dry, take an ohmmeter reading between the stator and the paint using the meter's megohms position. Any meter movement represents a short, which is easier to fix now than after you have assembled the cells. You can test the contact by connecting one side of your polarizing supply to the paint and the other to the stator. If it arcs, you will know exactly where the short is.

Your stators are now finished. Most builders believe they need to insulate them, since all the books on the subject recommend it, but I have found this neither effective nor necessary. Specifically, I have found no spray-on insulation that cannot be arced when I use very high polarizing and drive voltages, particularly when there are foreign objects such as insects in the speakers. I have found that uninsulated cells work beautifully and arcing does not damage them any more than it does insulated cells. Neither will be damaged by an occasional arc or a collapsed diaphragm, but both will develop a hole in the diaphragm if arced persistently by a foreign object. Fortunately, a few holes do not affect the sound. Insulation reduces cell efficiency, is expensive and troublesome to apply, so why bother? If you want to insulate your cells anyway, consult Barry's instructions.

For cosmetic reasons, you may wish to paint the outside of the stators flat black so they are essentially invisible behind a moderately sheer grille cloth. On the other hand, some gold showing through a black grille cloth is attractive.

DIAPHRAGM FABRICATION. Only Mylar, made by DuPont, is acceptable for the diaphragm. Imported imitations do not hold a high diaphragm tension and therefore do not allow a high polarizing voltage, which grossly reduces output. Mylar comes in many forms, but the ultrathin films we use (either ¼ mil or ½ mil) come only in types S and C. I have used type S with splendid results, but DuPont advises me that type C has the same characteristics. Type C is made to tight dimensional tolerances for use in capacitors, but this is unimportant for our use. Although Mylar is rather inexpensive, in recent years it has become nearly impossible to obtain in small quantities.

Mylar film is an insulator and therefore must be made slightly conductive for our use. The diaphragm must be slightly conductive so we can get an electrostatic charge on it. In theory, charge migration is a problem with low-impedance diaphragms. This means the electrostatic charge on the diaphragm will tend to move toward the area where the stator is closest to the diaphragm. This problem is worse at bass frequencies, since charge has more time to migrate and the diaphragm is driven closer to the stators.

Ideally, the conductive coating should be highly resistive (several thousand to

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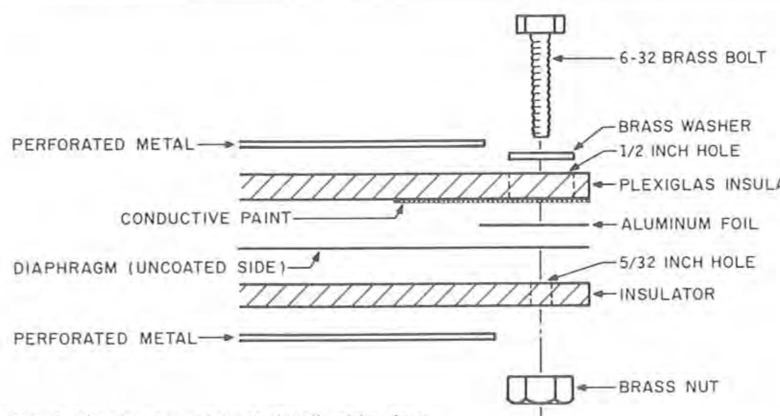

FIGURE 2: Diaphragm contact detail, side view.

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several million ohms depending on the lowest frequency of interest) to prevent this. Peter Walker (designer of the QUAD ESLs) refers to this as constant-charge operation.

Although this has been accepted as gospel in the past, it has become somewhat controversial recently because aluminum coated diaphragms also can work very well, and they are very low impedance as demonstrated by the Beveredge ESL. However, I do not recommend aluminum coated diaphragms because they are too massive and may burst into flames if they arc. This is not a problem with high impedance diaphragms.

Since low impedance diaphragms work very nicely (another case in which practical experience supersedes theory), we need not worry about exactly what diaphragm resistance we get. Graphite-coated diaphragms, as outlined below, typically have impedances between 10 and 100kΩ per inch and work beautifully. Thus I believe you can safely ignore everything you may have heard about trying to achieve some particular resistance.

GRAPHITE COATINGS. Diaphragms may be coated with many materials. Almost anything works—for a while. Most of the spray-on antistatic coatings work very well initially, but the adhesive eventually evaporates, vibration causes the coating to come off, and the cell dies. Experiment if you wish, but if you want to use a coating that has withstood the test of time, use graphite. Fine powdered graphite is available for a dollar or so from any hardware store, commonly used to lubricate locks. Pencil lead rubbed against fine sandpaper also is an excellent source of powdered graphite. Rather than relying on some type of adhesive (very few of which adequately bond to Mylar), you can grind graphite into the Mylar surface so you know it will not come off. Despite the fact that many builders seem intimidated by this process and prefer to use some type of liquid or spray coating, making graphite-coated diaphragms is a simple task. The following directions are very detailed because of all the calls and questions I have received in the past about diaphragm coating.

The main hazard to graphite rubbing is tearing the film on grit between the glass and the Mylar. Both materials must be very clean. If you clean the glass and the Mylar with acetone on a paper towel, you should have no problems. Acetone is the only acceptable cleaning agent because it cuts grease, will not dissolve Mylar, evaporates without a trace, is an effective epoxy solvent, and is nontoxic in small quantities. This is particularly important because you will be working indoors. Acetone is also inexpensive and available from any hardware or paint store. I cannot stress too strongly that *acetone is extremely flammable*. Treat it accordingly.

The only other solvent I might recommend is distilled water. It is not as good as acetone because it is slow to evaporate and does not cut grease or epoxy. However, it is nontoxic, will not burn, and doesn't stink.

Keep windows closed and fans off during cleaning so you don't stir up dust. It is also a good idea to damp-mop the floor and the work area to pick up as much dust and grit as possible before starting. Vacuum cleaners are forbidden, as they only blow dust around.

HANDS OFF. Cut a piece of Mylar a little larger than your glass. Fingerprints do not accept graphite very well, so keep your hands off the surface you will be making conductive. Dave Lang (*SB* 6/88, pp.18–25) recommends cotton or thin latex gloves to solve this problem. You can always wipe fingerprints off the Mylar with acetone if necessary. Wipe the glass with a paper towel wetted with acetone. If you feel any lumps of epoxy or anything else on the glass, scrape them off with a single-edge razor blade and wipe again with acetone.

Lay the Mylar over the glass. Unless the glass is much larger than the cell, give yourself a couple of inches of Mylar border. With a dry paper towel, gently rub the Mylar with about one pound of pressure from the center to the edges of the glass while gently pulling on the edge of the Mylar with your other hand. The object is to smooth it out, get rid of the major wrinkles, get it to stick to the glass, and find the grit.

When the wrinkles are out, wipe with about five pounds of pressure. Using a strong light will reveal little "tents" in the Mylar caused by grit trapped between the Mylar and the glass. Lift the edge of the Mylar and wipe away any grit that forms a tent larger than about ⅛ inch across. Smaller ones are okay unless they are very sharp or pointed. Incidentally, you may notice creases in the Mylar that appear as fine lines. Ignore these; heat shrinking will remove them.

Tape down the Mylar every four to six inches all the way around. Tape the corners first, then put tape halfway between the corners, then tape halfway between that, then halfway between that until you have a piece of tape about every six inches. Now there should be no wrinkles in the Mylar. It is easy to pull the diaphragm quite tight as you tape it down. You need not get it perfectly smooth at this stage because the heat shrinking will do this for you later. It takes me less than five minutes to lay out the Mylar, smooth it, remove the grit, and tape it down.

Sprinkle a little graphite on the Mylar and rub it in gently with a clean, dry paper towel. A light-colored tablecloth or white paper under the glass will make it easier to see the graphite on the diaphragm.

ELBOW GREASE. Now it is simply a matter of rubbing hard to grind the graphite into the Mylar. It is not as difficult as Barry makes it sound. I just use a paper towel and the heel of one hand placed beneath the other and rub hard back and forth, making sure I cover the entire area. The key is to rub hard. I lean on my hands with virtually all my weight. Unlike Barry, I don't worry about slate buildup, and I don't care what resistance the diaphragm has. I don't even bother to measure it anymore. If the diaphragm looks gray and I've rubbed hard, I know it will work perfectly and indefinitely.

Remove the excess graphite with a clean, dry paper towel. Don't be afraid to rub hard. You won't be able to rub off all the coating. If you can, you didn't rub it in hard enough to begin with. Wipe a couple more times with clean paper towels until no more graphite comes off. If you don't clean off the excess, the cell will hiss when first placed in operation until the excess graphite burns off.

Cut a piece of aluminum foil about ¾ inch by two inches. This will be placed under the diaphragm contact screw.

Epoxy is easiest to mix in a one-ounce plastic medicine cup obtained from a doctor's office or a hospital. Some hobby shops also carry them. If you can't find any, use a small plastic cup or the top of a spray-paint can. Do not mix epoxy in a waxed paper cup, as the wax often comes off and contaminates the epoxy, resulting in a loss of bond strength. Use a small Popsicle stick for mixing. Mix about 10cc and stir for at least one minute. A heat gun can reduce the epoxy viscosity if you wish, but this will increase the reaction rate and reduce the pot life, so work rapidly if you use heat.

EPOXY. If possible, use a 10cc dispos-

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able syringe without a needle to suck up the epoxy. Squirt a small bead (about ⅛ inch wide) down the center of each insulator on one of the stators that has the large diaphragm contact hole with conductive paint. When you get to the diaphragm contact area, move the bead of epoxy to the outside edge so that the paint is free to contact the diaphragm rather than being coated with an insulating film of epoxy. Avoid the tendency to use a lot of epoxy because it will form a thick film and tend to run down the edges of the insulators. I mix about 10cc, am able to suck up about 6cc in the syringe, and actually use about 5cc per stator.

After you have applied the epoxy, put the aluminum foil over the diaphragm contact hole. It should cover the width of the insulator and it will lie on the bead of epoxy. Do *not* allow the foil to extend past the inside edge of the insulator, or it might short the cell. Carefully flip the stator over and set it on the diaphragm. Press hard on the insulators all the way around and up the middle. The object is to squeeze the epoxy into a thin film. Be careful that you do not slide the stator around and smear the epoxy. Put the glass or steel sheet on top, weight it, and let the epoxy catalyze.

The epoxy cures much faster in the cup or syringe than it does in a thin film, so be sure it has cured well before removing the assembly from the glass. To free the Mylar from the glass so you can lift the assembly, cut it along the perimeter of the glass with a razor blade. Then carefully lift one end of the assembly to allow air to enter; otherwise, the assembly will tend to stick to the glass. Even though the Mylar was free from wrinkles when you glued the stator to it, you will probably find that it now has a few small wrinkles. Don't sweat it; you're in good shape.

With your thumb, gently press on the Mylar at the diaphragm contact hole. This will clearly outline the hole. The next step is critical. Use a sharp pencil, awl, or other sharp object to gently puncture the aluminum foil at the diaphragm contact. Puncture from the diaphragm towards the insulator so you don't tear the diaphragm away from the insulator. Remember that you did not put epoxy between the Mylar and the aluminum foil, so this area is vulnerable to disruption if you are not careful. The hole you make should be only as large as the shank of your diaphragm contact screw. It must be centered in the hole in the stator. Be careful to keep it small. If you make it as big as the hole in the stator, you will have no place to contact the diaphragm after the cell is assembled, and you will have to put in a new diaphragm.

HEAT SHRINKING. A heat gun will shrink the diaphragm so it is tight and wrinkle-free. Guns are available from a hobby shop or hardware store for about $20, or if you ask around, you can probably borrow one. Do not substitute a hair dryer, as they simply don't get hot enough. Heat guns vary in power and heat. The common hobby type is rated at 900W and has little vents on the back that can sometimes be adjusted to control the heat output.

Test your gun by having someone stretch a scrap of Mylar between their hands while you heat it with the gun. The object is to determine how much heat you can apply without melting the Mylar. Effective heat shrinking requires that you almost, but not quite, melt the Mylar. I generally find that leaving the vents wide open while holding the gun one to two inches from the film is about right. You have it right when you can hold the gun stationary and the Mylar will not melt. By adjusting the distance from the film and the vent openings, you can easily determine the safe zone.

Hold your stator/diaphragm assembly vertically while passing hot air from the heat gun over the diaphragm in a slow, uniform motion. I move the gun at about four inches per second and cover about a two-inch path with each pass down the cell. This is really very easy to do and takes less than a minute. One pass will do the job unless you have huge wrinkles in it. Feel free to heat and shrink repeatedly until you get the diaphragm smooth and tight. There is a limit, as the Mylar will shrink only about 10% maximum. This is plenty for all but the sloppiest construction. Forget anything you might have heard about exactly how much tension you should have on the diaphragm. You can't get it too tight, but you sure can get it too loose! Get it as tight as you can, since more tension allows you to use higher bias voltages, which gives you more output.

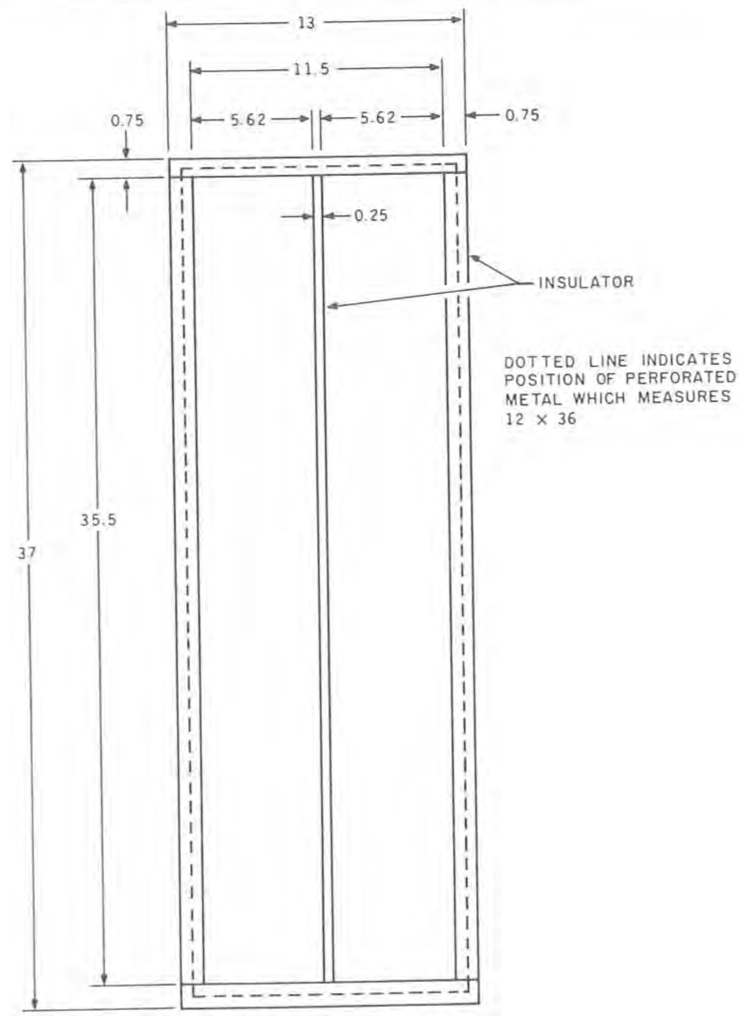

FIGURE 3: Insulator pattern and dimensions.

REHEATING. The diaphragm may relax a little after the first application of heat. It is a good idea to reheat it about a day later, after which it will stay tight. Some builders use mechanical stretching devices to tension the diaphragms. These work, but generally you cannot get the diaphragm as tight as with heat shrinking and the diaphragm will still tend to relax, although to a lesser degree.

You can always touch up the diaphragm in the future by heating it when the cells are mounted, although this is not normally necessary. Once the diaphragm is thoroughly shrunk, it will remain so. Problems occur if the cell is stressed during shipment or by accident, causing the diaphragm to go slack. It is wonderful to be able to retension the diaphragm rather than having to replace it.

If you are using steel wire stators, simply heat the diaphragm on one side as though there were no stator present. If you are using perforated aluminum stators, the aluminum will expand from the heat, which will cause the cell to bow and break glue bonds. The ideal way to handle this is to use two heat guns, one on each side opposite each other. It is possible to use one heat gun by briefly heating one side, then quickly switching to the other side, and then back again. Both these techniques will result in fairly even expansion of the aluminum and prevent broken glue bonds.

When you are satisfied with the diaphragm, put epoxy on the other stator in the matched pair and set it on top of the diaphragm. Look *very* carefully at the diaphragm contact hole. The puncture you made in the Mylar must be centered under the hole in the second stator so that you can put the diaphragm contact screw through it. Again, put the glass over the assembly and weight it. Before leaving, double-check the alignment of the diaphragm contact to be absolutely sure that the two holes are centered on each other.

TRIMMING. When the epoxy has cured, gently lift the assembly. Nothing sticks to graphite-coated Mylar very well, not even epoxy. The glue joints are adequate, but they can be broken if abused. The assembly will be amazingly rigid and flat and will have no give, so if you force the assembly into a curve, the glue bond will fracture. Use a sharp new single-edge razor blade to trim the Mylar. The Mylar will quickly dull the blade, so you should throw it away after trimming one cell. Use a new blade for each cell. You can remove the last fragments of diaphragm from the edges by rubbing a medium-grit sandpaper along the edge, but this is not usually necessary.

Bend up the stator contact tabs and insert 6/32 brass contact bolts. Using a small washer under the head of the diaphragm contact bolt, carefully push it through the diaphragm hole. This goes through the large hole first so that the head and washer contact the aluminum foil. Add the nut and gently tighten. When connecting wires to these contact bolts, avoid excessive tightening or rotating of the bolts, which could damage the contacts on the diaphragm or stators. Your cells are now complete.

When you first fire them up, they will make a faint hissing sound. I believe this hiss is caused by excess graphite on the diaphragm and it is temporary. If you test them with music alone, without equalization, woofers, and the baffling effects of the TL cabinet, you will be disappointed in the SPLs and frequency response. Hang in there; there is nothing wrong. This is a *system*, and when all the parts are working together, the sound will be splendid.

TROUBLESHOOTING. The foregoing instructions have 17 years of mistakes behind them. I have tried to advise you of all the pitfalls involved in constructing your cells, and it is unlikely that the cells will not work if you follow the directions closely. Writing a troubleshooting section suggests that the speakers are going to be difficult to build and operate and you are going to have problems. Actually, the cells are quite reliable and easy to construct, but I know how frustrating it is to have something not work and not have the slightest idea of what the problem is or how to fix it.

If the cell does not work, only three things can be wrong. First, make sure you have polarizing and drive voltages at the connections to the cell. If you do, there are only two possible problems with the cells themselves. The most common is that you have a short between the diaphragm and one of the stators. This is usually a foreign object and can usually be removed by vacuuming the cell with a soft brush or blowing out the cell with compressed air. Possibly conductive paint ran down the edge of the stator insulator or into the hole. If you painted the stators with insulation, it is possible that you have some conductive object embedded in the paint.

The other problem may be caused by something conductive on the outside. Keep in mind that even though you trimmed off the diaphragm, it is easy to make electrical contact with the diaphragm anywhere along the edge. Look closely for something touching the edge of the cell that is also touching a stator. That something may be quite insignificant and still cause problems. Usually the short is fairly easy to find and correct, but if it isn't, you must tear down the cell and put in a new diaphragm.

SHORTED DIAPHRAGM. It is rather easy to determine which stator has the short. Connect only the two stator connections (you need not play music, but it doesn't hurt to do so during testing). With the polarizing voltage on, bring the diaphragm contact wire slowly up to the diaphragm contact. Almost, but not quite, touch the diaphragm contact with the wire. In a properly operating cell, there will be a slight momentary arc as the current charges the diaphragm. In a shorted cell, the arc will be much larger and will persist. You will usually hear a pronounced pop from the speaker when it is first connected as well.

You can tell which stator is shorted by removing one of the stator connections and again bringing the polarizing voltage wire slowly to the diaphragm contact. Alternately connect and disconnect one stator at a time. The shorted stator will cause persistent arcing. You can usually tell by connecting an ohmmeter between the diaphragm contact and the stator contact. Keep in mind that the short may be several megohms and still render the cell inoperable. Ohmmeters don't always identify the problem, as the foreign material may not actually be making contact between the diaphragm and stator. The meter, which measures at low voltage, will see an open circuit. But when a high voltage is applied, it will arc and prevent the use of the necessary high voltages.

It is also possible that you have a stator in which the aluminum is not flat or a wire stator in which one or more wires are bent or detached from the support structure. You can prevent warping by

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ESL PARTS LIST

Qty.	Description
16	1/16″ acrylic insulators, 0.75 × 35.5″
16	1/16″ acrylic insulators, 13″
8	1/16″ acrylic insulators, 0.25 × 35.5″
4	Lincaine perforated aluminum sheets, 24 × 36″
1	Mylar film, 0.5 or 0.25 mil, 48″ × 20′
1	Epoxy, 5 or 30 minute, 9 oz. bottles
12	Bolt, washer, nut, brass, 6-32 × 1/2″
1	Conductive paint, LocTite "Quick Grid"

the techniques described in references 1 and 9.

REFERENCES

1. Vance Dickason, "The Loudspeaker Design Cookbook," 3rd ed., The Marshall Jones Company, Francestown, NH, 1987.
2. Jean Margerand, "The Third Dimension: Symmetrically Loaded," *SB* 6/88.
3. Jean Margerand, "The Third Dimension: Symmetrically Loaded Delta," *SB* 1/89.
4. Richard Pierce, "Rapid Loudspeaker Design Using Spreadsheets," *SB* 3/87.
5. Marc Bacon, "The Beauty Of Spreadsheets," *SB* 4/89.
6. A product of Funk Software, Inc.
7. A product of Borland International, Inc.
8. A product of Lotus Development Corp.
9. Richard Bush, "Tuning Bass Reflex Speaker Systems," *SB* 3/87.

COMPACT ESL/TL

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using glass on the top and bottom when building the stators. Either of these problems will appear as persistent arcing whenever the polarizing voltage is applied. The aluminum sheet can be bent away from the diaphragm by inserting a small punch or nail in the ⅛-inch holes along one edge and prying gently. If you used wire, you can figure out what has to be done.

OPEN DIAPHRAGM. A failed diaphragm contact or diaphragm conductivity is easy to identify by bringing the polarizing voltage wire slowly up to the diaphragm contact, as described in the previous section. There will be no arc, pop, or noise—nothing. It is also possible to have the basic cell work but have dead spots in it. This problem is caused by areas of the diaphragm that have no graphite (highly unlikely) or by a coating that has started to come off. This is unlikely to occur with graphite unless you didn't rub it in hard, but it is very common with many other types of coating.

DIAPHRAGM REPLACEMENT. Replacing a diaphragm is not difficult. It requires a sharp putty knife and a metal yardstick (or other long, thin metal object) with the end sharpened. After removing any bolts in the cell, use the putty knife to separate the insulators around the perimeter. Slide the yardstick down the center insulator while lifting one end of the top stator. With the stators now separated, run the putty knife under the epoxy on the insulators. Generally it comes off quite easily. Be sure everything is clean and any problem you might have had is corrected. Now you are ready to install a new diaphragm.

There is an interesting problem with ESLs that I have yet to understand. I have never seen any reference to it in the literature, and I have never heard any mention of it. But I have noticed that as the diaphragms age, they develop holes that gradually get bigger. After 10 to 15 years new diaphragms seem to be in order. The sound quality remains the same, but I don't like looking at holes. It is almost as though the diaphragm material evaporates. I have searched for an explanation but have not found one. Initially I assumed that arcing must have caused them, but this is doubtful because I have looked very carefully at locations on the diaphragm that have arced, and macroscopically I cannot detect any damage. Possibly some type of microscopic damage occurs that eventually results in a larger hole, but this is only a guess. Persistent arcing caused by insects occasionally creates a pinhole, but as near as I can tell, this does not get bigger. If any reader has any factual insight on this phenomenon, please contact me.

The next installment of this article will cover transmission line design and construction, as well as electronics and crossovers.