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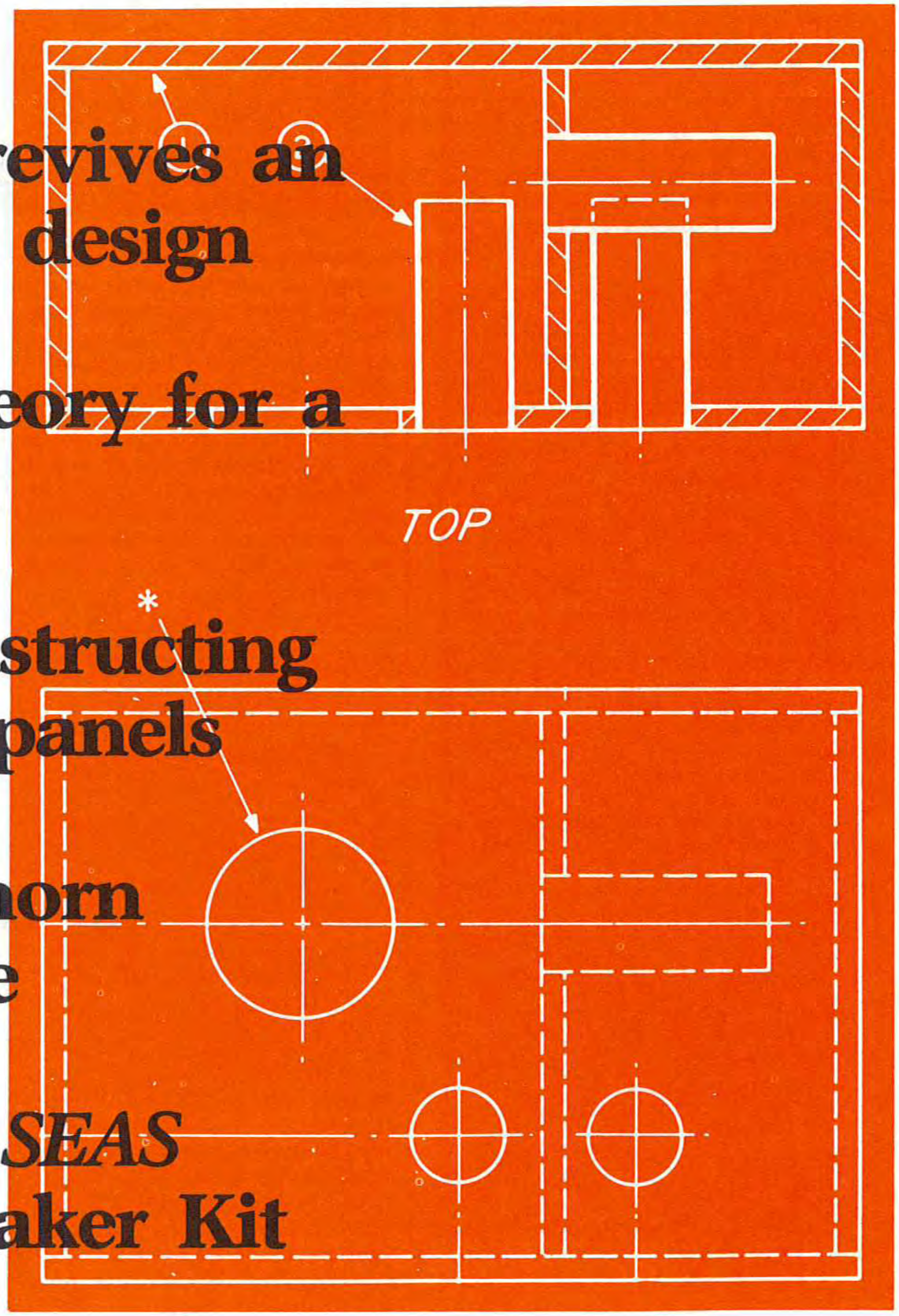

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Building the *SEAS* 603 Loudspeaker Kit

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SPEAKER BUILDER

An Electrostatic Speaker System

Part II

by Roger R. Sanders

ESL CELLS MAY BE constructed in many different ways. The method described below has several advantages: 1. low cost 2. quick, easy construction 3. readily available parts 4. excellent performance 5. light weight 6. true surface accuracy with a high degree of uniformity. The only disadvantage is an efficiency level down 3 to 6dB from the most efficient types that can be constructed. Since 3dB is barely audible, I believe this is not a problem.

Construction uses a sheet of perforated aluminum and insulating spacers to make one stator. Two stators comprise each cell. The diaphragm is 0.00025" (¼ mil) thick polyester film (brand name Mylar® by DuPont) coated with powdered graphite to make it slightly conductive. Epoxy glues bond together the film and acrylic sheet (brand name Plexiglas®) or polycarbonate sheet (Lexan®) for the insulating spacers. You will need some special tools including a piece of ¼" plate glass as a building base and a special steel bar frame to stretch the diaphragm to tension when you mount it.

The ideal stator material for the perforated metal sheets is about 20 mil aluminum sheet punched with IPA (Industrial Perforators Association) Standard Hole Pattern No. 105 or No. 107. These two patterns have holes approximately ⅟₁₆" in diameter with an open area ratio of about 40%, which gives the highest efficiency. However, you can successfully use metal sheet that has larger holes and different amounts of open area. Different patterns, have absolutely no effect on the sound other than loudness. The ESL's total size determines the frequency response, and only grille cloth and/or associated electronics affect sonic detail.

Acceptable cells can be made from Lincane® pattern, decorative aluminum sheet by Alcoa that is sold in hardware stores or in home improvement centers. It comes in plain or gold anodized finish; both work equally well. The price is about $4 per 2x3' sheet.

This is an excellent size for the metal stators, and if necessary, you can carefully cut it to size with scissors or with a metal shear at your local sheet metal shop. Notice that the holes have sharp edges on one side and smoother ones on the other side. It is extremely important that the *rounded* side of the holes *face* the diaphragm. If the perforated metal is to be shipped to you, specify that it must be packaged to prevent creasing. I advise that, if possible you pick it up in person.

INSULATORS

The insulators can be cut from ⅟₁₆" acrylic or from 80 mil polycarbonate sheet, often sold as single strength unbreakable windows. The acrylic (Plexiglas®) is nearly twice as expensive as the polycarbonate (Lexan®) and is not as uniform in thickness. These materials can be found in glass shops or home improvement centers.

The plastic can be cut with a fine blade, using a table, radial arm or band saw. To prevent the plastic from riding up and over the blade of the table saw, clamp a piece of wood above the blade just high enough to allow the plastic to slide under, and raise the blade until it cuts into the wood. No blade can cut the plastic without chipping its edge; just take some medium grit sandpaper and smooth any sharp edges.

The strips can also be broken off after scoring, as one would do with true glass. However, this is difficult to do with a long strip unless you use a slotted tool to snap the entire length at one time. You can usually get a glass shop to cut the strips for you, but it can be expensive.

DIAPHRAGMS

The diaphragm must be made from clear polyester film. Quarter mil is best because its small mass will not affect the sound until the frequency reaches about 32kHz. Therefore, for audio purposes, you have a massless speaker. Strength is a problem with thinner films. Thicker films can be used, but then the mass starts to roll off the sound in the audible range. Film is most easily available in 36" width.

This material can be obtained from large plastics houses. However, there is usually a $50 minimum order. Purchase about four times the amount you think you will need to allow for errors. Readers have found that 40 feet is adequate. Because of the problem in obtaining small amounts, I will supply readers with small quantities for 25¢/running foot in 36" widths.

Epoxy adhesives are the only type to use. (I find the Devcon brand to be the most consistent.) Five-minute epoxies work well and you can glue an entire set of cells in one evening. However, unless you have access to suitable applicators, such as medical syringes, the material "goes off" too quickly to give adequate time to work with it. The best adhesive is the "2 Ton," epoxy by Devcon which takes about 6 hours to go off. Heat shortens curing time considerably and if you work in a hot garage in the summer, for example, you can probably get adequate bonding in under three hours. It is better to lay up one stator per night and let the epoxy cure well than to push the project and have broken glue bonds later.

FLAT GLASS

Your base of ¼" plate glass on which you will assemble the units must equal the size of your cell. Have the glass shop sand the edges or do that yourself with some 100 grit aluminum oxide sandpaper and a sanding block so there are no sharp edges to cut the mylar. The usual method of taping the edges is not suitable for our purposes since the diaphragm is stretched across the edges and we want it to lay flat.

You will need a tube of fine powdered graphite of the sort commonly used to lubricate locks which costs about $1 per

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tube. I buy mine from Western Auto stores, but most hardware stores should have it. Some single edge razor blades and a sharpened putty knife about 1" wide will be useful, as will cotton or rayon balls for rubbing on the graphite.

Begin the stator construction by gluing the insulators to the aluminum. (*See Figs. 14A and 14B.*) These strips are necessary because the diaphragm must be supported about every 6 inches for adequate stability. (The rule of thumb is that the unsupported distance must not be more than 100 times the diaphragm-to-stator distance.) It is better if the strips are glued to each other first, and then the assembled "grid" glued to the aluminum and weighted with books until the epoxy goes off. A quick and easy way of gluing the strips to each other is to use one of the cyanoacrylate adhesives such as "Crazy Glue," "Zap," or "Hot Stuff." You can find these in hardware stores and hobby shops.

Place a sheet of waxed paper over the plate glass along each side where the joints will be in the grid. Lay out the insulators in their approximate position, hold each joint closely together and put a single drop of glue on it. It will run into the joint and fuse the plastic in about 20 seconds. This type of glue does not fill gaps. If your joints do not fit well, use a bit of baking soda to fill the gap and then place the glue on the soda. The soda will become like concrete. The joint does not have to be a good one since we are only trying to "tack" the pieces into position so that we may place the aluminum on top of the strips that are inside the perimeter. They must mate with strips on the other stator when the two are sandwiched onto the diaphragm, requiring accurate placement. You may find that putting masking tape on the reverse side of the glass to mark the exact locations of the insulators will make it easier to properly position them for gluing, and aid in having the stators match up.

After you have tacked the grid together, sand the glazed surface of the insulators so that the glue will adhere. 180 grit aluminum oxide sandpaper works well for this. Sand the glue joints well, since we want the aluminum to lay flat.

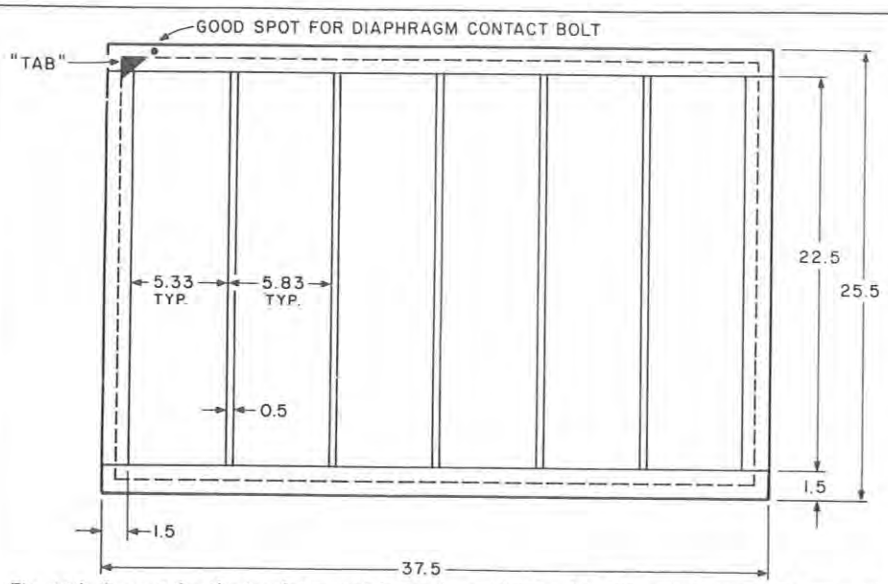

Fig. 14A. Layout for the insulator grid for each panel. The dotted line indicates the border of the perforated aluminum panel.

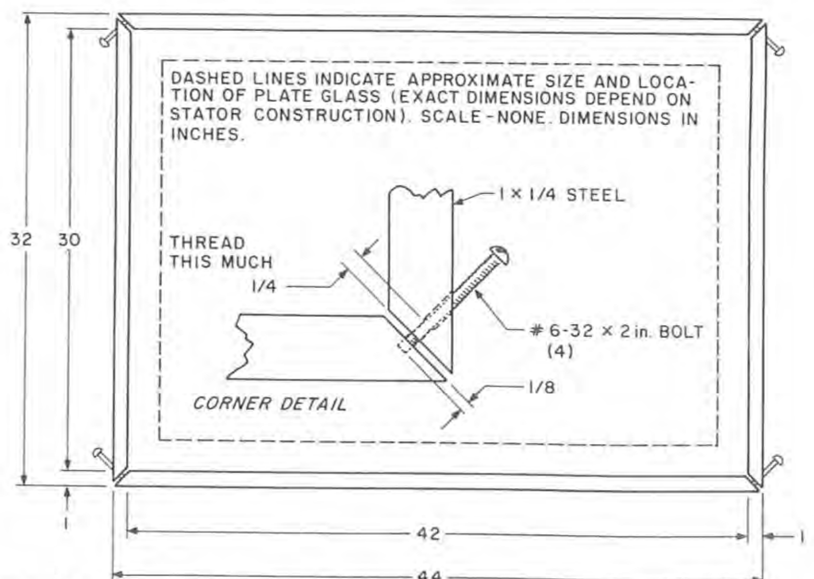

Fig. 14B. The steel stretcher frame for flattening the diaphragms and mounting them on the plexiglas frames.

DRILLING & CLEANING

Take the aluminum sheets and drill a small hole in one of the corners. Carefully remove the burr left by the drill by manually twisting a much larger drill bit or a countersink in the hole. This corner will be bent at right angles to the cell after the cell is completed, and a bolt will be placed through the hole for attaching your electrical connection.

The tab need only be about ½ 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.

Remove all grit from your plate glass, aluminum, and insulator grid with a vacuum cleaner. Lay the grid on the plate glass and place a small thread of epoxy along the insulators, making sure it is continuous because unglued spaces may rattle later. Do not put epoxy on the area where your tab will be because you will want to be able to bend it. You do not need much on the insulators to get a solid bond with the aluminum.

Position the aluminum, remembering that the rounded sides of the holes go down facing the glass. Place the waxed paper over the aluminum and then carefully weight it flat with a large number of books or similar weights. Be sure to have the books spanning at least two insulators so that the pressure exerted by the books is distributed over the insulators and does not deform the aluminum.

Allow the epoxy to cure well and then remove the stator from the glass and do the next one. Note that the stator will still be bowed and warped just as the aluminum was before you glued the insulators to it. Do not be concerned about this since it will be flat when you are done.

INSULATING PAINT

Now paint the stators with insulation. Before painting, take some masking tape and mask off the insulators so that you can glue to a bare surface later. Also put a bit of tape over the hole in the stator tab.

A variety of materials will serve for insulation. I have always used red GLPT insulating varnish, which has a lacquer base and is quick drying. It is distributed by GC electronics. Unfortunately it only comes in ½ pint cans, which are expensive, or gallons (about $20/gal). Some readers recommend a green Epoxy Insulating Varnish which comes in a 12 oz. spray can, distributed by Dayton Electric Mfg. Co.,

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Chicago IL 60648. It should work fine and would eliminate the need for a spray rig.

The insulation must be sprayed on since it tends to pull away from the edges of the holes and brushing it on will not give even coverage at the edges. Spray the insulation at a 45 degree angle, going first to the left, then to the right, then up and then down. Go over lightly this way several times to get good insulation build up at the hole edges. The insulation should be reasonably thick; you should not be able to see any trace of metal through it. Avoid runs, however. The GLPT dries so quickly that by the time you have sprayed all 8 stators, you can reapply it without causing runs.

Do both sides of the stators. The outside is not important except to keep you from getting shocked on bare metal, so you need not use the 45° angle technique there and it does not have to be thickly applied. Note that even with a good coating of insulation you will still get arcing through it. The prime purpose of insulation is to prevent the voltage breakdown of the air gap between the stators.

When the stators are dry, put them in matched pairs. You may find that by careful selection you can get the insulators to match closely when the stators are placed together, and you want the tabs to be in the same corner on each side. Mark the stators so that you will be able to identify the pairs at any time.

CONNECTIONS

Next drill a suitable hole for a 4-40 bolt through both stators near the corner where your tabs are located. Be careful if you use standard metal and wood bits, since the bit grabs and shatters the plastic at the completion of the hole. There are several solutions to this problem: You can drill part way through the plastic and then turn it over and drill the rest of the way from the other side, or you can drill most of the way through and then turn the drill backwards while you gently force it the rest of the way, you can use a drill press at high speed and go through slowly, or you can use special plastic drill bits that do not grab and shatter plastics. Do not drill closer than ¼ inch from the edge of the aluminum to avoid arcing from the bolt to the aluminum. These holes must line up perfectly at final assembly, so be careful to put them in the identical place on both stators. It is a good idea to leave the masking tape in place until after the holes are drilled as this helps to prevent shattering and chipping. Take one of the stators in each pair and enlarge the hole. One quarter inch is generally a good size. The object is to make the hole large enough to allow the head of the diaphragm contact bolt to pass through it. The bolt must make direct contact with the diaphragm for solid electrical connection.

Strip the masking tape off the insulators. Do not bend the tabs yet. Your stators are done.

STRETCHER STRUCTURE

Making the diaphragm is the next procedure. First, you must make a stretcher. I used steel bar stock 1"x¼" thick and consider it marginal but adequate. You will need 12 feet of steel. Cut the steel with a hack saw to the dimensions shown in *Fig. 14B*. Tap both ends of the short sides. Drill about ⅛" into the other bar so that it will accept the bolt for stability.

You will have to sand the bars to the bare metal on one side, using 100 grit aluminum oxide sandpaper. Place a strip of Scotch brand double sided tape on the bars on this side. Take some regular tape or masking tape and wrap it around the bars about 1 or 2 inches from the corners to prevent the double sided tape from pulling off at the corners, where the tensions will be highest.

It is important to remove every trace of grit for the next step, so vacuum carefully. Your plate glass should be lying on the table with a light colored surface under it so you can see the graphite on your diaphragm as you work with it.

Lay the mylar for the diaphragm over the glass, and cut it, leaving a large enough margin to attach the stretcher. Take some pieces of masking tape and tape down the mylar edges to eliminate most of the wrinkles. Now place the steel stretcher, one piece at a time, sticky tape side down, on the mylar. I start with a long piece, then add the short side pieces and finally the last long side. If you have the bolts protruding about ¼" you will be able to hold one end of a piece of steel up while engaging the other end in the piece laying on the mylar. With its end stabilized, you will be able to position the rest of the steel easily.

Once all your pieces are in place, screw in the bolts evenly all the way around; maximum tension is not necessary yet. The frame will expand and you will have a tight, wrinkle-free diaphragm. Do not be alarmed if you have a few tiny wrinkles in the corners of the diaphragm, but these wrinkles should not extend over the plate glass.

GRAPHITE DRUDGERY

Coat the diaphragm with a small amount of fine powdered graphite and rub it in with a cotton or rayon ball. Begin rubbing lightly and gradually increase the pressure until you are rubbing quite hard. Examine the mylar closely for grit, between it and the glass because if the chunks of grit are large you will tear the mylar as you rub. Remove any grit with a dry, lint free cloth or cotton ball, and rub over the area again.

The only failures I had in my original speakers occurred because I did not rub in the graphite hard enough. You must get a conductive coating all over the diaphragm to avoid "dead spots" which will produce no sound. The border must be conductive to help distribute the electrostatic charge over the entire surface.

After you have finished rubbing, vacuum up all excess graphite. Then take a paper towel or more cotton balls and rub off as much graphite as you can. Any loose graphite left on the diaphragm will eventually be burned off, but the speakers will hiss for anywhere from several hours to seveal months in doing so. Take on ohmmeter and touch its leads a few inches apart over several areas of the diaphragm. You should get anywhere between 50k and one megohm resistance at all test points, which indicate evenly distributed graphite.

Lift one edge of the stretcher to get a little air between the glass and the diaphragm. Tighten the stretcher as much as possible. It should start to bow and bend slightly. The limiting factor will be the double sided tape's tack, which will start to arc, pop, and pull loose from the corners. You can expect to deform the mylar at the corners.

Cut four pieces of aluminum foil, about ½"x1". These will be used to make contact to the diaphragm. Place some epoxy on the insulators of the stator of each matched pair that has the large hole for the diaphragm contact bolt. Put the aluminum foil over the hole making sure no epoxy oozes into the bolt hole. There should be a little epoxy under the foil to adhere to the insulator; however, there should be none on the other side of the foil because it must make clean contact with the graphite on the diaphragm.

Now, lay the stator, insulators down on the stretched mylar. Press firmly to squeeze the epoxy to a uniformly thin film. Weight the assembly with books and let it set up solidly.

FINAL FIXES

When the epoxy has gone off, cut the diaphragm away from the stretcher with a razor blade, and disassemble the stretcher. Leave the mylar pieces attached to the tape to keep the dust off it so that it can be used for the next diaphragm. You will probably be able to use the same tape for the entire project.

Gently lift one corner of the stator to work a little air under the diaphragm and lift the assembly from the glass. The diaphragm should be smooth. But, the stator will be bowed and warped because the diaphragm is pulling on it. If you let it bend it wrinkles the diaphragm. That is all right if there are no big wrinkles in the diaphragm when the stator is laid flat on the glass. Diaphragm tension should be high enough so that it will take three or four quarters to push it across the $\frac{1}{16}$" gap to the stator, maybe even more. Little creases are of no importance.

Take the other stator from the matched pair and hold it in place on the assembly, if everything fits as expected, lay this stator on the plate glass with its insulators pointed up. Position the stator and diaphragm assembly on it so the cell is in its finished form.

Gently poke a sharp pencil into the hole for the diaphragm bolt until you puncture the aluminum foil and the mylar film. Now place the bolt in the hole to be sure it fits. A word of caution: The bolt head will rest against the aluminum foil and mylar, which is very fragile. Never allow the bolt to turn when it is in contact with the aluminum foil or you will destroy the contact. Also, avoid moving the stators around with the bolt in place as this puts stress on the foil and the holes.

Remove the bolt and the stator, and diaphragm assembly. Apply a layer of epoxy to the insulators of the stator resting on the glass, after you have carefully vacuumed everything. Carefully position the stator/diaphragm unit on the stator. It is easiest to align two corners and then lay the assembly down. Try to avoid smearing the mylar with epoxy. When the stator is in place, and the corner is exactly aligned, insert the diaphragm contact bolt. Press the stators carefully and firmly together. Weight with books and allow to cure.

COMPLETED CELLS

When the epoxy has cured, the cell may be gently lifted. It will be rigid with the stators absolutely flat. Nothing can bend unless the glue joints are broken, which can easily happen since nothing adheres to graphite coated mylar very well. It is particularly important to avoid holding the cell in a horizontal position like it is on the plate glass. There is much less stress on it if it is suspended vertically from the upper corners when you are carrying it.

Thread the nut on the diaphragm contact bolt, preventing the bolt from twisting by holding a screwdriver on the head and turning the nut only. Finally, bend the tabs on the aluminum upward, insert the bolts, and tighten. Trim off any excess diaphragm material with a razor blade or with sandpaper. Repeat this process for the other cells.

You will probably have to replace a diaphragm for various reasons. It can be done easily. Position the cell flat on the plate glass. Take a sharp putty knife and run it along the bond between the stators to break it around the perimeter. The bond across the center insulators will probably break loose if you just gently lift the stators apart. If this doesn't work, take a sharpened end of a metal yardstick and slide it between the insulators.

You must clean all the old epoxy off the insulators with the putty knife before you can repeat the diaphragm process. Be careful not to damage the stator insulation. If you do, varnish applied with a Q tip will touch it up.

Frames are up to you. I used 2"x2" oak in which I cut a slot to accept the edge of the cells. Remember that wood is not a good insulator when dealing with high voltages, so do not allow the aluminum to touch the frames.

When the speakers are first turned on, they will hiss, but with time this will cease. Adjust the polarizing voltage until the diaphragms "cave in" or start a low frequency popping noise (you will see an arc with each pop if you look closely), then back off about 25%. If you get to full voltage and they play fine and there is no sign of arcing or instability, don't worry about getting higher voltages.

DISPERSION ISSUES

If dispersion is desired, make strip cells about 5" wide and 36" long. No cross insulators will be needed because the maximum unsupported distance is 5". Five or six of these cells should be arranged around the surface of a cylinder. The angle between each strip should be less than eight degrees for minimum "venetian blind effect." Sand the edges carefully to remove all traces of stray diaphragm material; if you don't, you will get arcing from one cell to the next.

Keep the long border insulators very narrow (under ½" if possible) so the diaphragms are as close to each other as possible. Run some tape or use foam between the cells so there are no significant air leaks between them. The group of cells should act as one. You probably will not use a stacked set of cells if you make them wide dispersion. Since you will have poor vertical dispersion, make your enclosure so that it leans back to aim the beams upward.

The cells can have stators made from wire, which is the most efficient, but there are several disadvantages. First, they are quite expensive. Second, 50 mil music wire is hard to find. Third, the wires are not straight and you can get better uniformity with perforated metal. Finally, they are very heavy. Several readers have turned instead to 1/16" plain copper welding rod. These are spaced 10/inch rather than 12/inch as they are in my earlier design with music wire. For those of you who wish to build wire cells anyway, please refer to my article in *TAA* 4/75.

SETTING UP

The planar speakers must be set up properly, accurately placed an equal distance from your listening location, and pointed directly at you. They should be vertical and not twisted. If any of these conditions are not met, you will find that the speakers do not sound balanced and that possibly the frequency response is down in one channel.

To set them up, take a tape measure and hook it to a pin that you have stuck in your listening chair at your body midline. Set one speaker where you want it and measure on the floor to he inside edge of that speaker. Place the other speaker with its inside edge at the same distance. If you change the direction of one speaker, always move the other as well.

If your speakers are set up as room dividers with spring feet at the top as mine are, you will need a level to position the speaker vertically as well. When seated, you should be able to see your reflection centered in the speaker diaphragms. Rotate them to achieve this.

Woofers should be set up so that they are also the same distance from you as the ESL's. KEF B-139 drivers are flat and it is easy to measure from the ESL diaphragm and then duplicate that measurement to the woofer surface. If you use a cone woofer, I cannot say for sure where the effective "surface" of the driver is, but guessing from the recent designs that use "phased" arrays of drivers, I would place the woofer ⅓ of its cone depth closer to the listening location than the ESL.

CURVED CELLS

Curved ESL's provide completely uniform dispersion. Several attempts have been made in the past to accomplish this, but in my opinion, none have been successful, even though there are several patents outstanding. The problem with curving ESL's is that when you bend the cell, the diaphragm is pulled into the inner stator. The usual solution has been to use various types of supporting structures to keep the diaphragm spaced evenly from the inner stator. The result is either many flat cells whose supporting structures break up the smooth curve of the diaphragm, or, if a continuous support is used (such as a sheet of foam), you do not have linear motion and/or a push/pull speaker. These techniques ruin efficiency and make high SPL's impossible.

I have proposed a solution to this problem, and Bob Unterbrink has spent countless hours perfecting the fabrication techniques. A patent has been granted to us covering both the concept and the construction techniques, which I will present here. This speaker design will be marketed by us under the company name Sanders Systems. Although full patent protection covers the design, individuals who wish to attempt construction for their own personal use and not for commercial sale may do so.

The design allows for a fully push/pull speaker, high SPL's, perfectly uniform dispersion, low distortion, and a totally free diaphragm. The disadvantage is that it is nearly impossible to build.

Study into the causes for the diaphragm collapsing into the inner stator reveals that there is tension on the diaphragm in all directions. Horizontal tension on the surface of the cylindrical shape pulls the diaphragm straight so it cannot follow the curve of the stator. It will tend to form a straight line between the support points of the diaphragm and will be pulled into the inner stator.

The solution is to have only vertical tension on the diaphragm. If you can imagine the diaphragm as an infinite series of straight lines running vertically across the curved insulators, you can see that there should be no tendency to bow towards the inner stator.

The curved cell is constructed in the same manner as a flat cell, with an insulating grid glued to the aluminum stators. However, the gluing must be done on a curved surface, known as a jig. The curve should be greater than what your finished shape will

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be because the composite tends to spring back when cured.

The diaphragm is stretched vertically over the curved surface and coated with graphite. Then the stator is glued in place. This assembly is removed, the remaining stator is placed with insulators up, and the diaphragm/stator assembly is glued onto it. The laminations hold the assembly in an arc that is determined by the amount of curve built into the jig. 20 degrees of curve are sufficient but you may put in as much as you wish.

IMPOSSIBLE DREAM

This construction sounds simple, but it is nearly impossible to do.

To begin with you need a building jig, a table whose surface is very smooth and has an appropriate amount of arc. At each end of the table is a curved steel bar with tape on it to attach to the diaphragm. A lever is attached to the bars, and they can pivot as directed by a turnbuckle to tension the diaphragm. The various parts of the cell are held in place by nylon or leather straps and cinching buckles while the epoxy cures.

Some other problems are that you will still need a slight bit of horizontal tension to get the wrinkles out of the mylar, it is hard to get the grids to match on both stators, the glue joints are highly stressed and tend to pop loose, and the diaphragm tends to move more easily towards the inner stator under dynamic conditions.

Some of the solutions are thinner insulators on the outer stator for more even movement, nylon bolts through the insulators to help hold the glue bonds, careful mounting of the cell in a supporting frame, and a more highly curved surface for easier construction, so that the tendency for spring back brings the cell to the desired curve rather than past it, thus requiring the glue bond to hold the shape.

Our operational cells of this type are four feet tall and two feet wide and one per channel is used in conjunction with a pair of KEF transmission line woofer systems. The sound is exactly as expected: perfectly uniform dispersion throughout the listening area with absolutely no "venetian blind effect." Such a cell still needs all the electronics and equalization of a planar cell, so do not omit the equalizer.

I strongly advise you not to attempt to build such a cell, since you are very unlikely to succeed. If anybody can figure out an easy way to make this type of cell, I will buy the rights to use it. Even better, I will purchase completed cells from him/her for our commercial use. □

Part three, next time, will include details on building the woofer enclosures.—ED.