Refurbishing the Quad ESL

(or How to Cure Audio Burnout)

By Sheldon D. Stokes

Have you changed interconnects more than you changed underwear last month? Have you been listening to some bizarre audio-yucca test disk (track 7) over and over because you think it's the most revealing piece for checking your system out? Have you banished some of your music because it's "unlistenable" on a high resolution system? It's time to take a deep breath, and a step back. I suspect that 95% of all High-End audio enthusiasts are music lovers. That's is what got me interested in audio in the first place. But how many "audiophiles" can forget about the sound of their systems, and just sit back and enjoy the music? I used to be constantly "aware" of my system; even when I was trying to just sit back and enjoy the music. It becomes an obsession. Herb Reichert described it the best when he said, "Get the tweak monkey off your back" (positive Feedback, issue 9). If you haven't read his article, you should, he's dead on...

I cured my audio burnout with a new set of speakers (a fix for the addict). But these are no ordinary speakers, they are finicky, bass limited, no top end, dynamically challenged, beamy, unreliable, terrible to drive monsters; at least that's what non-owners say. I'm talking about Quads; the original Quad ESL's; Walker's wonders. I'm not going to go into the Quad ESL 63, as I don't have enough experience with them to write yet. Much has been printed about these classics, so I'll just touch on some of the major points.

The Quads convey the human voice with a sense of naturalness that no other speaker I've heard has even come close to. The Quads do not sound limited in the treble region. The treble is so natural, and free of harshness (those of you with dome tweeters will be amazed), but it's not recessed at all. The bass the Quads produce (down to about 50 Hz) is very clean and fast. If you use them in a small room, the bass response is as close to perfect as I've heard. The individual features don't do the speaker justice, you have to just sit and listen. The people who have heard a properly set-up Quad system know exactly what I'm talking about, you don't think about the stereo anymore, you are lost in the music. It's like you have always been outside listening to music through a window, and now, your inside in your comfy chair. But I'm not here to get you to buy Quads, because then there will be less of them out there for me. I'm here to tell you how to re-furbish the Quads you already have, or are running out to buy right now.

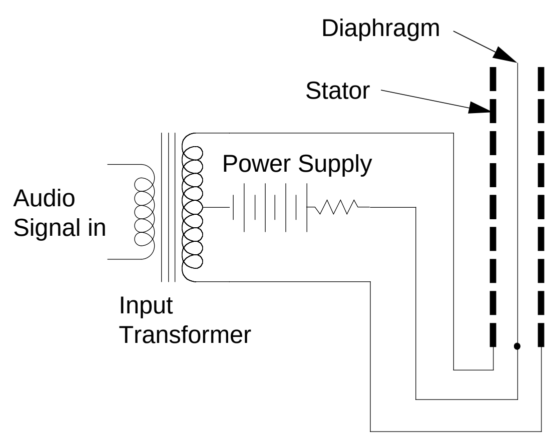

Figure 1: ESL electrical diagram

Electrostatic Speakers are conceptually very simple devices, an electrical diagram is shown above. The heart if the speaker is a stretched thin film diaphragm that is suspended between perforated conductive stator panels. The distance between the stators and the diaphragm is typically small, on the order of 1/16th to 1/8th of an inch. The diaphragm is coated with a slightly electrically conductive coating. The coating should only be slightly conductive. The diaphragm is charged via the power supply. Typically the diaphragm is sitting several thousand volts above the stator panels. There is no current flow however because the diaphragm is insulated from the stators. The audio signal drives a step-up transformer that increases the voltage of the signal typically 50 or so times. The output of the transformer is connected to the stator panels. Potential difference across the stators causes an electrical field (a linear filed too) between the stators and this causes the diaphragm to be pushed and pulled toward one the stators by electrostatic force.

The advantages to this system is that the diaphragm is very light, so it is capable of reproducing the entire spectrum of audio. The diaphragm is also uniformly driven, so it moves in a very controlled linear fashion. The diaphragm is also very light, and it's spring constant is high, so the diaphragm couples very well to the air it's driving, so it's also well damped. Some of the disadvantages are that you are running your audio signal through a transformer. And due to cancellation effects that plague all dipoles, they must be physically large to produce any bass at all. Many modern ESL's are heavily equalized to get decent bass response, and that tends to make them less efficient than dynamic drivers. For a more complete discussion of ESL's I recommend Roger Sander's ESL book. It's a wealth of information on the technical aspects of building your own electrostatic loudspeakers, or just understanding the principals of them more thoroughly.

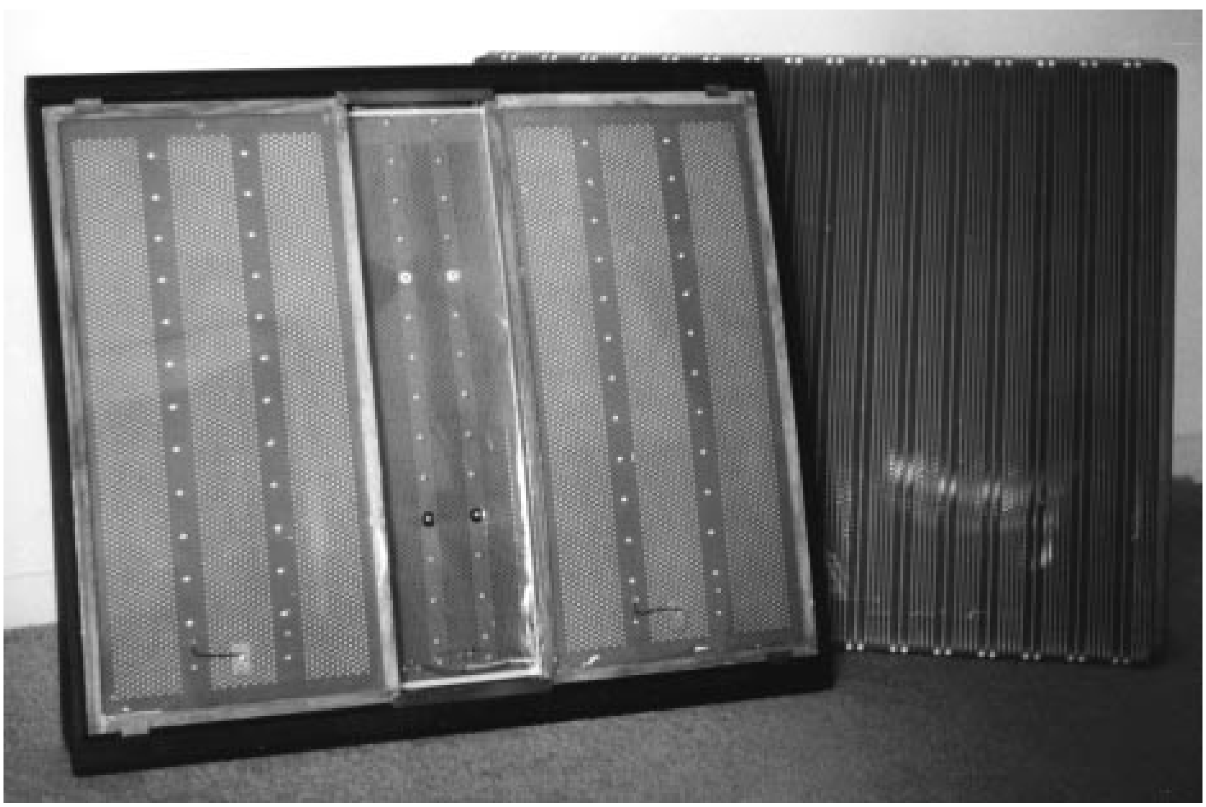

Figure 2: Original Quad ESL's

Due to limitations at the time of design, the Quad ESL is made up of three panels. Using a sectionalized approach allows the speaker to be more efficient (this speaker was designed back when 15 watts was a lot of power), and the treble to be more dispersive. The Quad ESL with it's front grille off can be seen in **Figure 2**. The two bass panels and single center treble panel can be clearly seen. The Quad ESL's are now between 15 and 40 years old, and probably could use a good cleaning and checking over even if they seem to be working fine. The dust covers need to be intact in order for them to stay working. So the first step is to unplug them and wait an hour or so for them to discharge. If you are worried, you could wait overnight. The high voltage power supply is wimpy and discharges quickly. But I don't want to be responsible for any deaths.

Disassembly:

Shown below is the schematic for the Quad ESL, it is included here as a reference for disassembly and servicing.

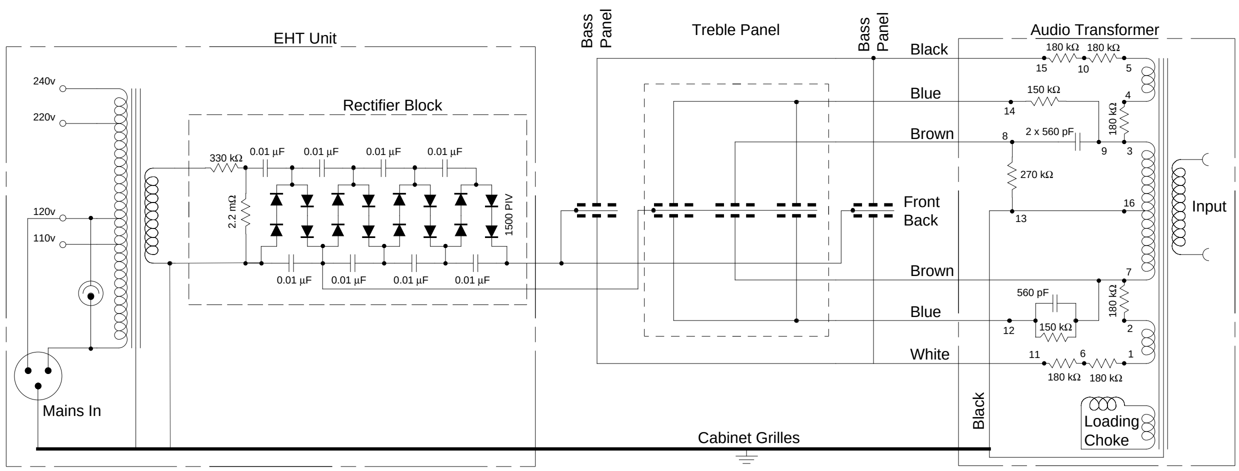

Figure 3: Quad ESL Schematic Diagram

The first step is to unscrew the wooden end panels. After these are removed, the staples for the front grille should be carefully removed with a screwdriver. After all the fasteners are removed, you should be able to carefully peel the front grille off it's frame. The back grille should just screw in place with about 20 screws. Now you should be looking at a dusty and interesting looking set of "guts". Examine the dust covers on all the panels for rips, tears or any sort of breaks. You might have to remove or pull back some wooly covers from the back of the speaker (more on those later). The dust covers are a clear heat-shrink Mylar, and are there to keep the dust out of the "works". Dust is attracted to the diaphragm just like the diaphragm is to the stators, so dust will get pulled into the inner workings of the speaker and short out the whole mess without the dust covers. So you need to have dust covers with no holes. If your covers look fine, just dust them with a vacuum, or carefully wipe them down with some soap and water. I used Windex on my old ones. If you find any small tears, you can patch it with a little tape. But that is only a stop-gap measure. Chances are the dust covers are getting brittle and will fracture in other places. It's time to bite the bullet and replace them.

Replacing dust covers:

Replacing the dust covers is time consuming and a pain, but it's not that hard. The bass panels use heat shrink window insulating film for dust covers. 3M makes a nice kit that contains all the film and double sided tape you'll need. The tweeter uses a 1/4 mil mylar for recovering. I haven't seen a tweeter that needed to be recovered that wasn't fried. So your probably safe in not recovering those.

The bass panels can be removed from the speakers by carefully removing the brackets on the front of the speaker in front of the tweeter panel at the top and bottom. After removing the four screws that hold the two brackets, turn the speaker around and unsolder the wires that attach to the terminal boards at the bottom of each of the bass panels. Note where each wire goes. IT's a good idea to cover the area around the terminal board with a towel or rags because if a bit of solder drops onto the dust cover is will go right through the dust cover and quite possibly through the diaphragm as well. After unsoldering, the bass panels can be removed from the speaker. From the front of the speaker carefully push one of the panels toward the center of the speaker, it will pop off the ledge on the vertical side of the speaker and should slide outward as it moves toward the middle of the speaker. The other panel is similarly removed.   If your tweeters are in need of work (arced of bad dust covers), you'll have to unbolt the audio transformer box and flip it over and unsolder the four wires from it's underside. Note the position of each wire. You'll also have to unsolder the power lead from the power supply.

An exploded view of a Quad ESL Bass panel is shown above. Note the dust cover frames. The dust cover film is either taped or glued to the outside surface of those frames. The diaphragm is riveted between both stator panels and comes apart as a single unit. Both dust covers are taped to the stator assemblies around the perimeter. Removing the tape around the parameter frees the front dust cover and the back is then only held in place by the wires going to the stator assembly which are soldered to the terminal board bolted to the frame of the back dust cover. Carefully unsolder the terminal board being extremely careful not to let any solder fly into the stator assemblies. Also note where the wires were soldered. The back dust cover should now be free.

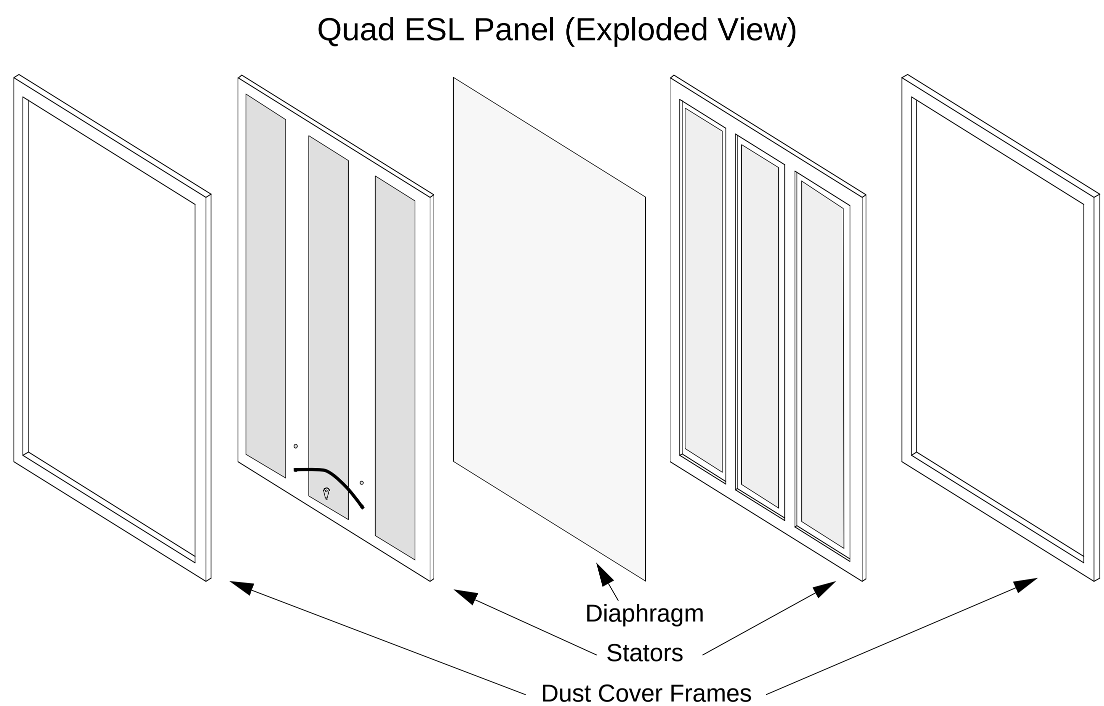

Figure 4: Quad ESL Panel (exploded view)

Clean the old dust cover film and as much glue and dirt off the dust cover frame as possible. Then cut a piece of window weatherizing shrink film about two inches wider and taller than the dust cover frame. Place this film on a table and pull it tight using masking tape at the corners of the film. Take the double sided tape and apply it to the front surface of the frame all the way around. Remove the tape backing and press the tape into the film. push down hard and rub back and forth a little bit to insure it's stuck there. You can now remove the masking tape and life the frame and film up. rub the film into the tape to insure it's contacting the tape fully. You can then cut off the excess film. You can also glue the film in place if you don't want to use the double sided tape. Be sure to stack a weight on top of the frame to make sure it's contacting the film as the glue is drying. Unbolt the terminal board and repeat the procedure for the back frame.

Now bolt the terminal board back to the back frame. With your soldering iron, burn the three holes for the wires. If you cut the holes instead of burning them, the film will tear very easily like a candy bar wrapper. You are ready to solder the wires back onto the terminal board and to tape the whole thing together. Of you want, you can blow any accumulated dust out of the panel with canned air (available at most photo stores). Carefully tape the panel together, being very neat and careful with the corners. Any open spots will let dust into your panel. After the panel is taped together, take a hair dryer and shrink both dust covers. The covers will draw tight and all the wrinkles will come out. They will look very nice and professional if you do a careful job.

Rebuilding Power Supply EHT Blocks:

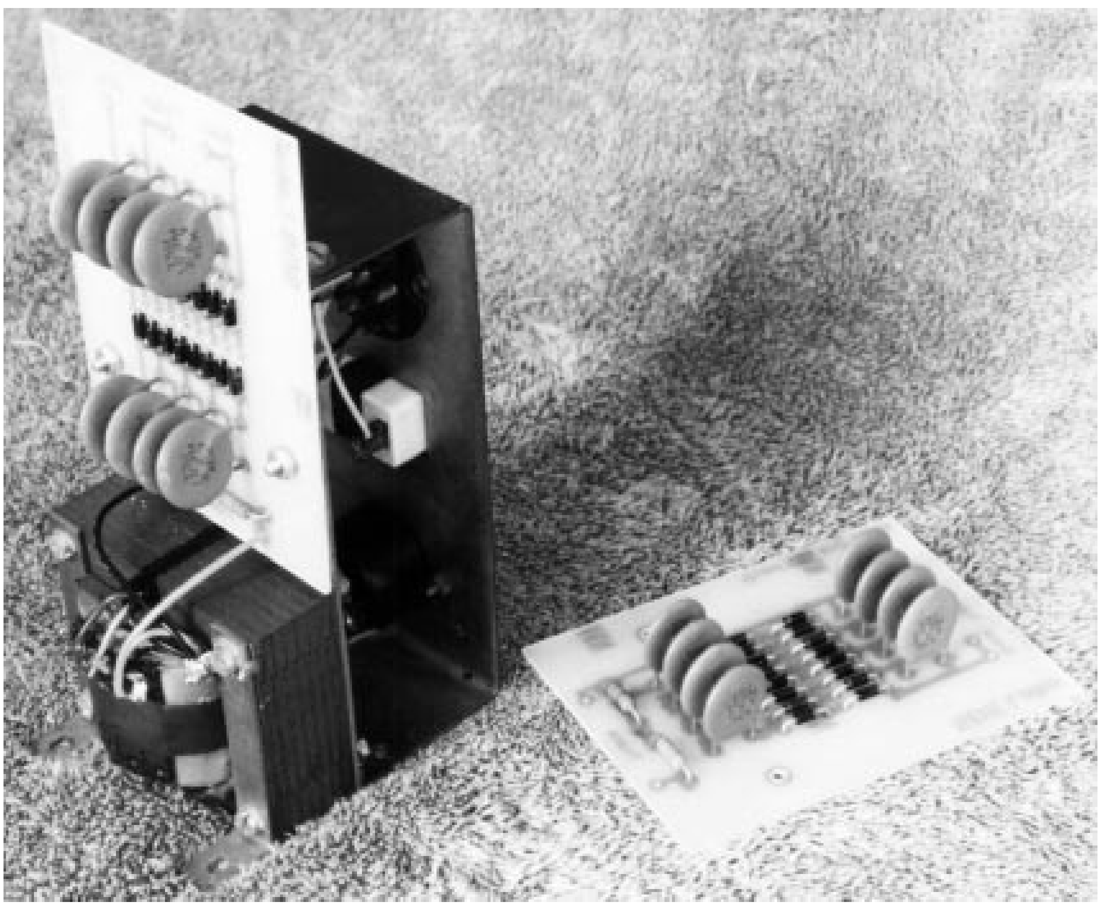

Figure 5: Quad ESL Power supplies (new circuit cards)

The newest of the Quad ESL's are now 16 years old, and the oldest are 40. The diodes Quad used in the power supplies are most likely getting pretty tired and leaky. If you are experiencing a loss of efficiency in one or both of your speakers, or your bass isn't as extended as it used to be. Then you ar probably in need of an EHT tune-up. The Quad ESL's have two different types of rectifier blocks. The early ones used a non-serviceable epoxy block. So you'll have to built my circuit boards. The newer rectifier blocks were either wooden or plastic boxes with a circuit board sticking vertically out of the top of them. The box is then filled with bees wax as a primitive corona dope (corona is the ionization of the air due to very high electric field gradients, that actually make the air conductive and glow. this discharge is a leakage path that will prevent your power supply from fully charging). Quad changed to these new block with serial numbers 16000 (or so) and higher. If you have the new blocks, you're in luck, they are fairly easily overhauled. Unscrew the power supply modules from the base board of the Quad. Carefully pull it away from the bass panel, and cover the bass panel with a towel. Unsolder the wires going to the speaker, and note where they go. You can now unsolder the wires to the rectifier block, and unbolt the block from the transformer frame. The EHT blocks should then be put in a brownie pan or something similar, and placed into the oven set to 300 degrees. The wax filling the boxes will then melt out and you can remove the circuit boards and solder new diodes into each board. There is sixteen diodes in each block. I have been using 1N4007 diodes for several years now with good

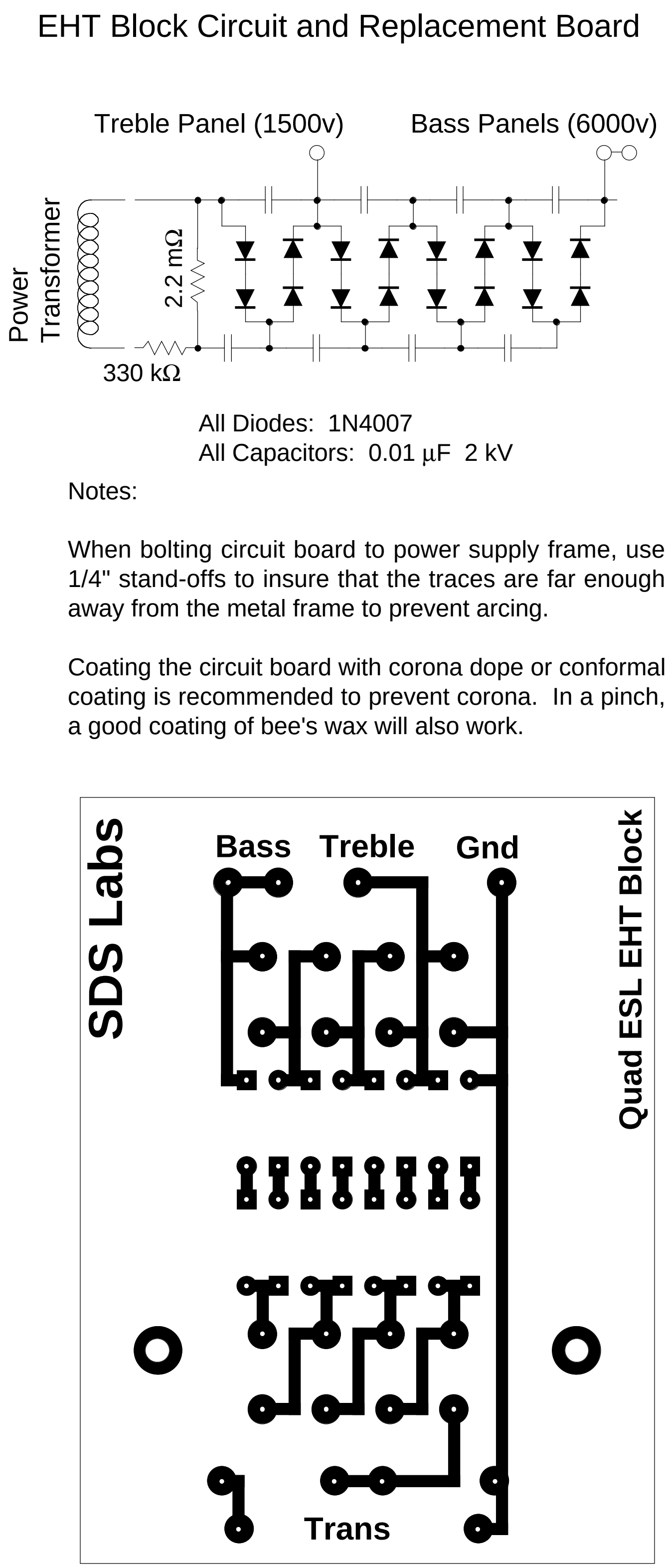

Figure 6: Replacement Rectifier Block Design

results. The capacitors are ceramic units and should be good for life. If you want to you can replace those as well, although I never have. You then can pour the melted wax back into the boxes after placing the circuit boards back into the boxes. You can cover the holes in the side of the boxes with tape so the melted wax doesn't run out.

If you have one of the original epoxy rectifier blocks, you can use the circuit board shown below to make new rectifier boards. I covered the boards with a conformal coating I got from an electronics store. If you can't find any conformal coating or corona dope, you can use a liberal coating of bees wax. After soldering the transformer wire back to the circuit board, you are ready to mount the power supplies back onto the speaker base boards.

The new rectifier diodes and dust covers (If needed) will most likely get your ESL's working like new again. It's amazing what an improvement a new power supply can make to an aging set of Quads. The next topic I'll cover is what to do if you have panel damage.

Panel Damage:

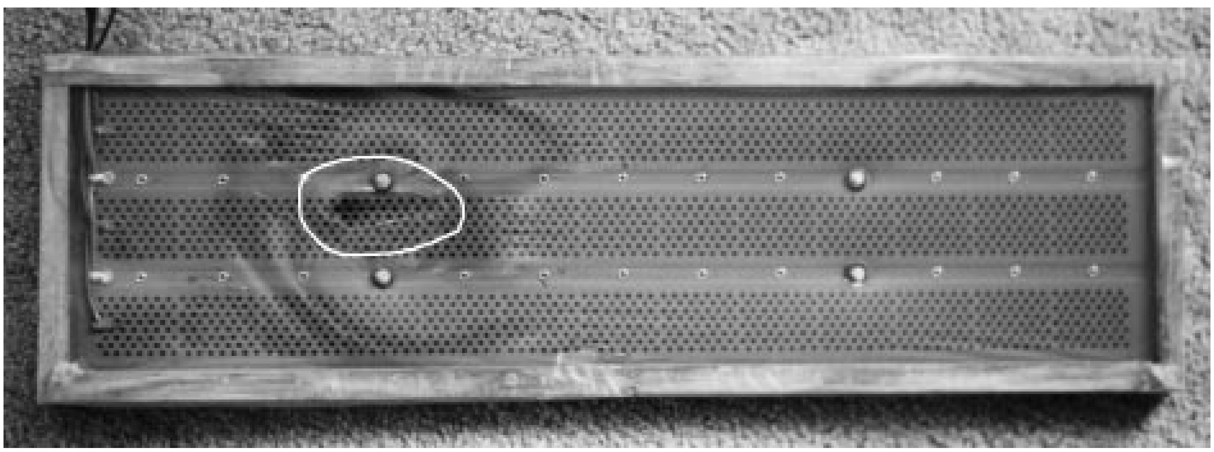

Figure 7: Arced Tweeter Panel

The most common failure of Quad ESL's other than power supply problems is arcing the tweeter panels. The Quad ESL's were designed in a time when 15 watts was a lot of power. I doubt if Peter Walker could foresee 200 watt transistor amps being plugged into his little fragile speakers. The owners manual warns against using an amplifier that can produce more than 35 volts at the speaker terminals, or you risk arcing the tweeter panel. Arcing the tweeter panel means exactly what it sounds like. You drive the tweeter membrane so hard that it touches the stator panel and the charge on the diaphragm discharges through the audio transformer and the resulting arc burns a hole in the diaphragm. If it's a small arc, you might be all right. But I've seen arcs so bad that they melted a bit of the plastic stator panel. Many time the arc won't be strong enough to melt the 1/4 mil mylar, but it will be strong enough to burn away the conductive coating where the power supply meets the diaphragm. This prevents the diaphragm from charging up, and you get no music. This didn't used to be a big problem, as you could buy a new tweeter panel for about $100. But they are no longer available, in fact I bought the last original tweeter panel in the US for $475. But all is not lost if you have a fried tweeter (or bass) panel because I have figured out how to rebuild them, and I'm being nice enough to share my knowledge with you.

Let's take a close look at the exploded panel diagram shown earlier. Notice the center three elements. There are two stators and a mylar diaphragm. The coated mylar diaphragm is stretched and glued to one stator, and the other is sandwiched to the first and the whole thing is held together by about 60 rivets. Both the tweeter and bass panels have the same kind of construction. The dimensions are just different. The stators are flat on the outside, but have three rectangular cavities on the inside that allows the mylar diaphragm to move. There are three cavities instead of one large cavity because the diaphragm must be supported every so often so it doesn't get sucked into a stator (see Sanders' book for more info). So what had to be done was figure out a good coating to use to make the mylar just slightly conductive, and a method to stretch the mylar on the stator panel.

Some of you might think that because we want an electrically conductive diaphragm, metallized mylar would be a good choice, but that's too conductive. The first reason is that if the panel arcs the charge is too free to move and create a very powerful arc that can actually set the mylar on fire. Second is the issue of charge migration when the diaphragm is moving. The diaphragm is attracted to a stator because of the electrical charge on it's surface. As the diaphragm starts to move, one point will be closer to the stator than another, and if the charge is very free to move (read: low impedance), then the charge on the diaphragm will migrate to that spot and the motion will be non-linear. Ideally you want the charge fixed to the diaphragm permanently. But it's sufficient to make the time constant of the charge migration to be longer than the period of the lowest desired frequency (audio frequency). Sanders has a very good discussion of this in his book, I'll recommend it again. So what is needed is a coating that has a very high but finite resistance.

The original Quad ESL diaphragms used a white paint-like substance that was very sloppily applied. This coating has a very very high resistance, so high that it can take hours to charge the diaphragm up. This is ideal from a charge migration standpoint, but not good from a arc resistance and aging standpoint. If you arc the panel slightly and burn a little bit of the coating off (near where the power supply attaches) many times the diaphragm is just too resistive and the humidity in the air discharges the diaphragm faster than the power supply can charge it. This was the failure mode that happened to my tweeter panel. The second problem with this approach is that it seems that this paint coating evaporates over the years. Because the resistance is already so high any higher and your running into the same problems are slightly arcing the panel. I had a bass panel that had only half of it's diaphragm being driven because the coating had evaporated and only the bottom half of the diaphragm could charge up.

So the ideal coating would be very stable over time, and have a high enough resistance to keep the charge stationary, but not so high that the panel stops working if it's arced. If a hole is burned in the mylar, the ragged edges can touch the stator and discharge the diaphragm. This is the common failure mode with severe arcing.

I use a graphite rubbing technique like many home-brew ESL builders. You can't get much more inert than carbon. But my technique is slightly different. If you rub graphite onto a mylar surface, you will get a surface conductivity reading of 50K-200K ohms per square. This is pretty low by Quad standards. So I added another step. I liberally rub the graphite into the mylar, and check to see that the diaphragm is conductive everywhere, I then take a paper towel wetted with 91% isopropyl alcohol (not rubbing alcohol), and rub as much of the graphite off as I can. IF you rubbed it in hard, you won't be able to remove all of it. And you'll get a very high resistance reading (it's higher than 100 meg ohms per square, where my meter reads to). This is the trick to making ESL panels that compare to the Quad original ESL panels. IF you wanted to spend a lot of money, you can call a mylar coating company and get them to coat some 1/2 mil mylar with Indium Oxide. That is the coating that commercial ESL makers like Martin Logan and Soundlab use for their diaphragms. You don't expect the ML folks to be rubbing their fingers off with little cotton balls full of graphite do you?

For the diaphragms, I use 1/2 mil Dupont Mylar that I bought from Roger Sanders for all the panels. You can also buy if direct from Dupont, but you are going to have to buy about 20 lbs. of it, which will be about a mile of mylar, and cost you about $250. Make sure you are getting genuine Dupont mylar, Roger warns against imitations, apparently he's had bad luck with others. The original Quad tweeter panels used 1/4 mil mylar, but it was tensilized. Nobody seems to make tensilized mylar anymore, it seems that the things they needed tensilized mylar for are now being done with another type of film. Without tensilizing, the 1/4 mil mylar is just not strong enough to stay tensioned, and after some time the diaphragm sags and gets stuck to a stator. The 1/2 mil is still much much lighter than the air it's driving, so it still works very well. (I can't hear a difference). Quad used a weird saran type of membrane for their bass panels. I think they did this for ease of manufacture, but I'm not sure. I use the 1/2 mil mylar, and they work great (arguably better than my stock bass panels).

The factors you have to be concerned with are diaphragm tension, and surface conductivity. The tension of the diaphragm counteracts the attractive pull of the mylar toward the nearer stator panel due the diaphragm charge. The higher the tension the higher the force keeping the diaphragm in the center of the gap between the stators. It's not something that you should worry about, if your tension is too low the panel won't work, if it's high enough, it will. I use a technique that is different than Sanders, you can pick which you want to try. He uses a hot air gun to heat shrink the mylar after it's epoxied to one of the stators (mylar will shrink about 10% with heat). The problem with this technique is that it takes a bit of finesse, if you are not careful you'll burn a hole in the mylar. It's a good thing to try if you have your diaphragm epoxied to one stator already and got the panel assembled and realized that the tension is too low. You just increase the tension with a hot air gun. A hair dryer doesn't work, it doesn't get hot enough.

I use a mylar stretching jig, a diagram of it is included here. I cut and firmly tape the mylar to the perimeter of the jig. First I tape the mylar in place with masking tape, pulling it tight and as smooth as possible. I go around the edges of the mylar and jig twice with clear packing tape. The first ring of tape goes on the mylar and wood about 1/3 mylar 2/3's wood. I then put another ring of tape that's 1/3 first tape and 2/3s wood. This will curve around three sides of the wood, and will very firmly hold the mylar to the jig without gluing it. If in doubt epoxy it there. I slightly tension the mylar. I tighten each of the wing nuts on the frame, and tap around on the mylar like I was tuning a drum. I get a nice but not too tight tension. I then go clean off my dining room table top with Windex and then distilled water. You want a surface that is very clean. Ideally you would use a cleaned piece of glass (Sanders' recommendation), but I found my smooth table top to be adequate. I set the jig on the table top with the mylar touching the surface (actually it floats about 1/8 inch above it. I lift up one half of the jig and slide a stator assembly underneath. Be careful not to push down on the mylar at the corners of the stator assembly. I then take 1" wide masking tape and mask off a rectangle in the center of the mylar that is about 1/2 an inch smaller than the stators all the way round, I use the stator itself as a guide. You want to mask off the area around the perimeter of the stator so the edges of the diaphragm don't get charged where it sticks out of the sides of the stator assembly. This will prevent one possible discharge path for the diaphragm and could make your fixed panels last longer. After you masked off the area, remove the stator assembly and you are ready to graphite. This is total drudgery. You can get powdered graphite in tubes that are sold as lock lubricant.

Put a little bit on a cotton ball and start rubbing *hard*. You'll be surprised at how little graphite it takes to cover the diaphragm. Rub right up and onto the masking tape. You'll know if you're rubbing hard enough if you look closely and can see a graphite glaze. If the mylar is wanting to wrinkle up, the tension isn't high enough, increase it. Take your multimeter and a couple of pennies, and put the pennies about 6 inches apart on the diaphragm. Place your multimeter in the high kilo-ohm setting or the mega-ohm setting and start measuring the resistance between the pennies. You should get reading everywhere on the diaphragm with no discontinuities. If you have any discontinuities, rub them out with the graphite. After you are convinced that your panel is continuously coated, take a paper towel and wet it with 91% isopropyl alcohol and rub as much graphite off as you can. You'll see the coating lighten up and also become more uniform. If it's not totally uniform, don't worry about it, it will work just fine, remember it's a static charge. Rub for a little bit, but don't rub for a long time of you will risk making discontinuities. I have tried to rub the graphite totally away, but it doesn't seem possible, so you don't have much to worry about. After you are done with this step, it's time to take the making tape off. Carefully peal it away from the mylar.

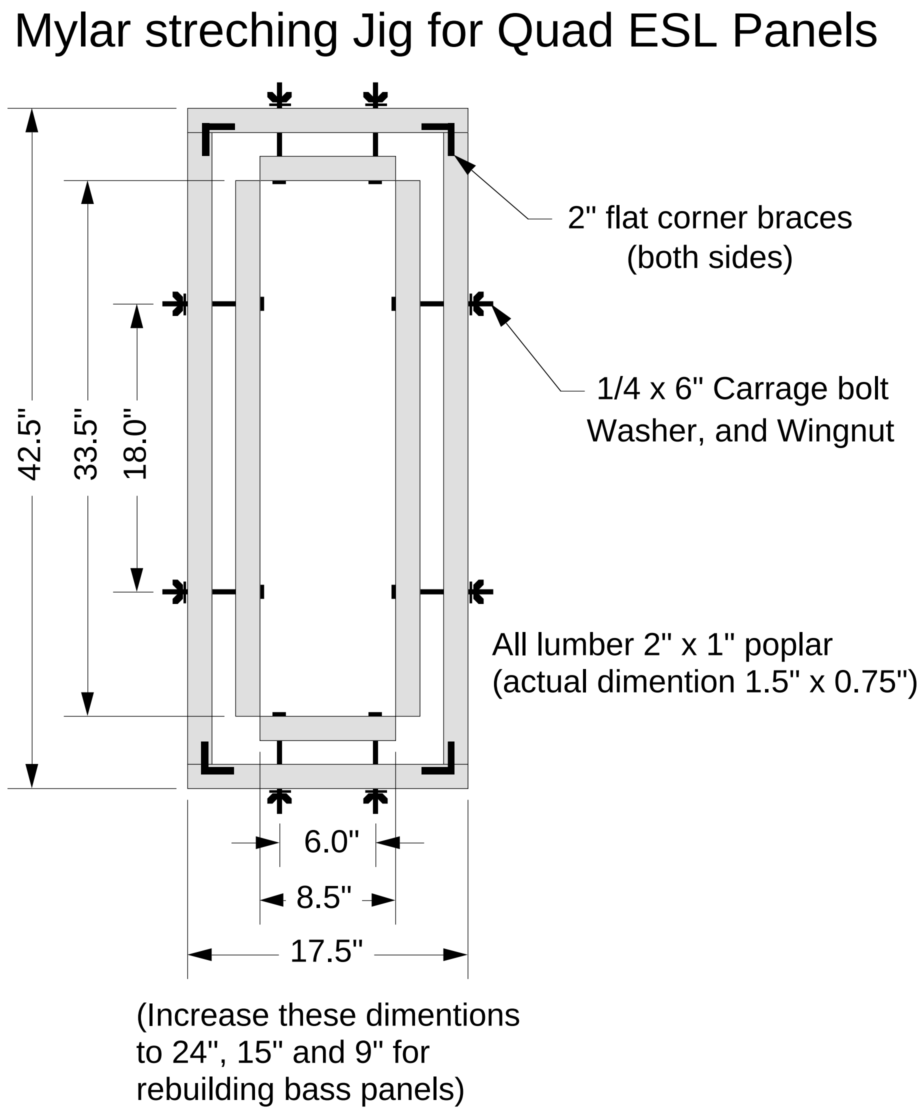

Figure 8: Mylar Stretching Jig

Now you're ready to crack open your stator panels. You need to remove all the rivets. This is also total drudgery. Before you can remove the perimeter rivets, you'll have to remove the tape around the perimeter. This tape is insulation to protect the diaphragm charge from leaking through the wood speaker frame (now do you see why we masked off the edge of the diaphragm?). You'll get sticky and dirty removing the tape. After the tape is gone, you can remove the residue with the 91% alcohol if you want to. It makes it nicer to work with the panel, but it's not necessary. I crimp the bottoms of each rivet with the tips of a small pair of diagonal cutters. I squeeze once in one direction and then again at 90 degrees, so there are four crimps. The rivet then will push out. You have to develop your own system for removing the rivets. You can grind them off with a Dremel moto tool, but that tends to melt the plastic stators. After you have removed all the rivets, you can pull the stators apart. The diaphragm will be stuck to one of them. You'll notice how poorly the conductive coating was applied. And you'll probably see some dirt. As the dust covers aren't totally effective. Check out what went wrong with the diaphragm, and remove it. Inspect the stator panels for any signs of burning or melting. If the panel was arced badly, you might have to sand the area lightly and give is a coating with corona dope to insulate it. Be very careful sanding the tweeter stators, as the conductive material is a paint under the grey insulating overpaint. If you got an arc right over the rivets where the center (brown) wires hook onto the panel, you may have to replace the conductive paint as well. Electronics stores or catalogs sell special paints that are designed to fix circuit boards. These work really well to repair the conductive paint coating. After applying the conductive paint, cover your repair with corona dope. When the stators are repaired (if necessary) and dry. Vacuum off both stators and both sides of the mylar. You want to get all the graphite dust off. If you get a bit of that in the panel, you're lost for sure, as it's very conductive. Now pick the worst of the two stators if they were repaired, this is going to be epoxied to the non conductive side of the diaphragm. Lift the jig off the table and tension it more. You want a nice tensioned feeling like the head of a large drum, but don't overtighten it, you should feel where the mylar starts to resist more tightening. Now mix up a bit of two part epoxy. Use the clear stuff with no fillers. (you don't want anything conductive in there). I mix up a circle about 1.5 inches around and 1/8" high for a panel. But you should mix up a bit more until you get the hang of how much you need. Better to throw a little away than to have to mix again. I don't use the 5 minute epoxy, because I like a little bit more working time. The stuff that curse in an hour or two should be fine. If you get the process down it can be done in much less than 5 minutes (but that brings up the issue that you are blowing way too many panels). After you mix up the epoxy spread a thin bead of it around the perimeter of the stator panel, all the way around. Lift up the corner of the jig and carefully slip the epoxied stator panel under it. Now after you have slipped the stator panel under the jig, pick up the other side and carefully position the conductive rectangle in the mylar so it's centered on the stator, with a uniform amount of non-conductive area on each side. Now lower the mylar onto the stator, and pile stack of books on top of the mylar and stator. Before I add the books I run my finger around the edge to push the epoxy fully onto the mylar. Let the epoxy dry fully, a thin film takes longer to dry than what's left on your mixing card.

After the epoxy has cured, unstack the books, and pick the jig up, the stator should be tightly clinging to it. Now take your soldering iron and burn the holes in the diaphragm where each rivet hole is. If you cut them, the mylar will split like a candy bar wrapper. Now it's time to improve the diaphragm contact scheme tremendously (this is the main reason that the tweeter panels fail so easily in my opinion). Take a little bit of copper foil (I suppose aluminum foil will work, although I haven't tried it) and cut two little strips about 1/16th of an inch wide by about 1 inch long. Note where the power comes in to the diaphragm on the other stator (the one that isn't epoxied to the diaphragm), it will be two rivet areas down where all the wires connect. The rivets will be on the support strips. Take the foil strip and put about 5/8th of an inch on the support strip and push the rest through the rivet hole and to the outside of the stator, then push it down so it's lying against the outside of the stator. You just increased the diaphragm contact area for the high voltage by a couple orders of magnitude. The next step is optional, I've found it nessesary in some cases; take some 1/4" wide masking tape (or you can cut it that wide), and run a strip of it down both support strips on this stator. But stop it where the foil is located, and restart it after the foil. This actually increases the spacing of the stators a little bit, but don't worry, when you're done with the panel you'll squeeze that tape pretty flat (Because you are going to be using little 4-40 nut and bolt assemblies instead of rivets.). Without this tape, some panels can become unstable and arc. I believe this may have been because there was too little diaphragm tension, the newest panels I've made don't need this extra tape. Now after that it done, place the foiled stator on top of the diaphragm and line the holes up. This next step is easiest if you suspend the jig between a set of chairs. You'll need a bunch of 4-40 x 1/2" bolts (I use pan head), flat washers and nuts. put a flat washer on the bolt and feed it from the free stator through to the epoxied stator and put another flat washer and a nut on it. I put the bolt head on what will be the front because it stick out less. After you put all the bolts in and the nuts are finger tight, go back and snug them down. You want them snug, but not really really tight. After they are all tight, you can cut the panel out of the mylar on the jig. You want the graphite side to be the front, because when you bend the panel slightly, you want the diaphragm to curve away from the coated side, it's less likely to arc that way.

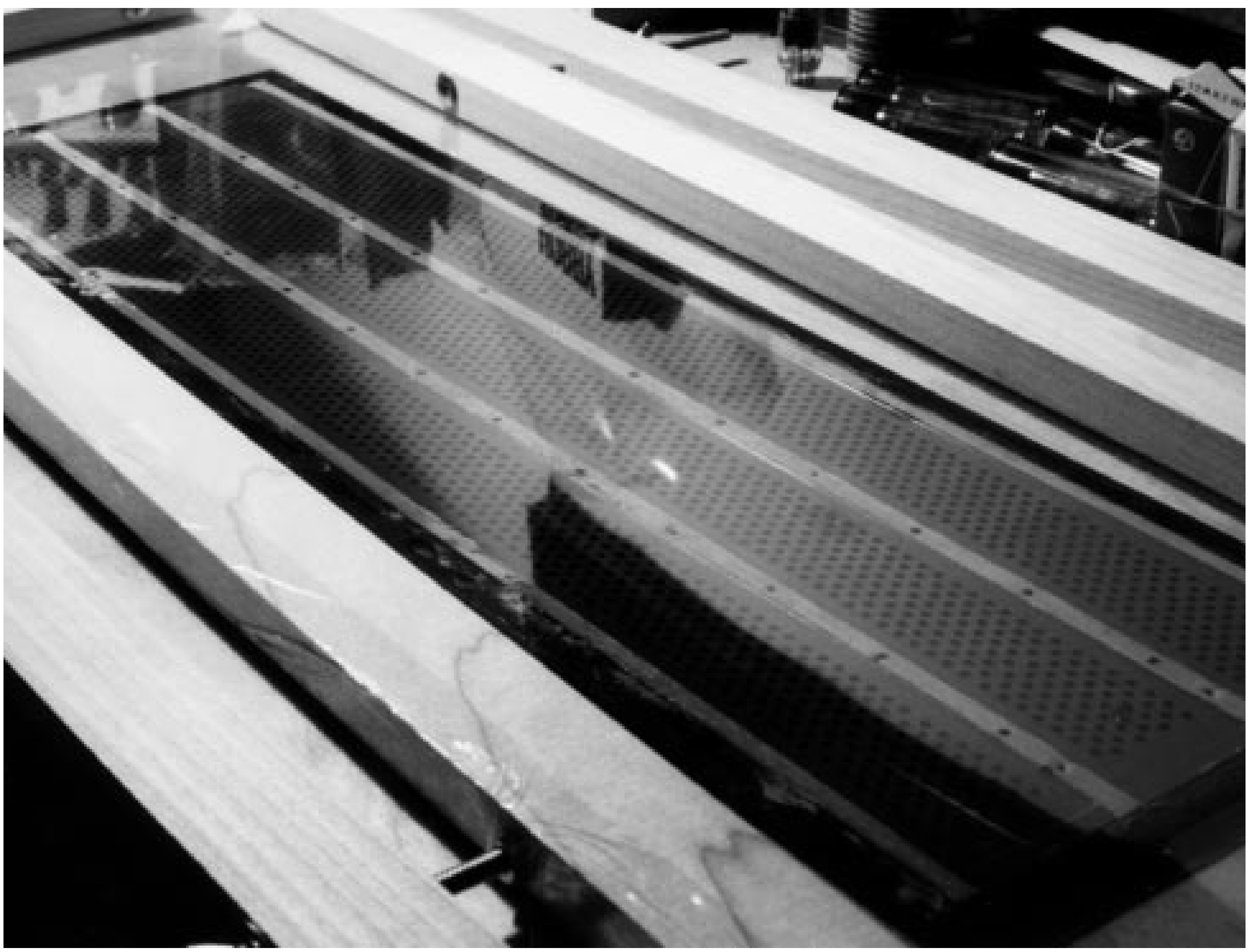

Figure 9: Tweeter Panel Stator Epoxied To Diaphragm in Stretching Jig

Now you can replace the dust cover, and the bolts and felt washers that keep the tweeter dust cover from rattling. It's a good time to replace the mylar on the treble panel dust cover as well. It's done similarly to the bass panel, except you don't heat shrink it, and you ise the 1/2 mil mylar. Also you don't have a terminal board to deal with.

Replacing the diaphragms in a bass panel is very similar, except the conductive coating on the stators is on the outside, so you never have to worry about fixing it. The power being supplied to the bass panels also much better, so you won't have to deal with the little foil strips.

Conclusions:

After rebuilding all six panels and both power supplies in a set of Quads, I auditioned them against a mint condition pair that I use as my reference speakers. I did near field listening with the same signal being fed to both. I put my refurbished speaker next to an original one and I would move back in forth trying to distinguish any differences. I can't hear any difference, and neither can any of my faithful listening folks that I always recruit. I thought there would be some sort of differences, after all I've done some pretty radical surgery. But from a geometry and an electrical operation standpoint, they are essentially unchanged. Actually I think the new bass panels put out a bit more bass, I think this is due to my original woofer's coating starting to go. But I can't really tell because an ESL performance is effected by the parameters of the room it's placed (the damping is a function of room dimensions and placement position in that room), so I'm not going to commit on that one.

I hope you can keep you magical Quad ESL's running for a long time to come. I would like to hear any comments or suggestions you have about rebuilding the Quads. I am in the process of starting a small business to rebuild Quad ESL panels, so if you are unsure if you can perform the repairs or don't feel like the hassle of doing it yourself, I can do it for you. I will rebuild a bass panel (complete with a new dust cover) for $250, and a treble panel for $225. I will also rebuild your EHT units for $85 a pair for the wax varieties, and $100 a pair for the new circuit cards for the epoxy varieties. I can be reached at the following e-mail address: stokes@exis.net. I also have an audio web site where you can get my DAC schematics, or other designs (headphone amp, phono stage etc) and I have a Quad ESL refurbishing page where you can learn more. Here's the URL: http://www.clarkson.edu/~stokessd. I can also be reached at the following address:

Sheldon D. Stokes
103 Windy Cove Apt I
Hampton VA 23666