the Audio Amateur

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EDITORIAL

JACOB RABINOW says the individual inventor is a dying species. Rabinow reports patents granted to individuals have dropped from 50% of the total in 1950 to 25% last year. Industry, as you might imagine, files 75% of the total these days.

Mr. Rabinow has good reason to know about such things. He's chief of the invention and innovation office of the National Bureau of Standards, as well as holding 200 patents himself, including the Rabco tonearm. Mr. Rabinow thinks it's a big mistake to let that situation continue. He believes the individual is being priced out of the market. A patent these days runs anywhere from a bare minimum of $6,000 or so and can cost up to $100,000. The Government, as we could have surmised, seems content to have the industrialists take over.

But inventions are starting to come in from other countries--which is no accident, evidently. Other countries, it seems, take an interest in the individual inventor. And they back it with cash. Japan gives loans ranging from $100,000 to $1 million. (Now we know why they're the third industrial power in the world.) In ratio of number of inventions to population, the U.S. trails Japan, Czechoslovakia, East Germany, Sweden, Switzerland and Luxembourg.

We'd go one step beyond Mr. Rabinow's reason of financial limitations, however. The style of the industrial and scientific establishment today tells the little guy he's too little to play.

But it's not enough to point out what the big guys are up to. Nor merely to bemoan it. We would do a lot more by taking to our work in audio with more systematic application. Do our work more thoroughly, test it more rigorously. We ought to be breaking more new ground--as I think some of our authors are doing. We ought to be sure of our facts, and prove them where we can.

The audio amateur has a doubly satisfying prospect before him. A genuinely satisfying hobby whose results might just be one more bit added to the scales on the side of human dignity.

Lack of money is not the only reason fewer individuals are taking out patents. Self-respect and confidence are even more basic fuels to creativity.

THIS ISSUE completes six years, twenty four issues, of *The Audio Amateur*. If your address label's top, or code,line ends in a 5 a renewal notice is in the mail to you as you read this. We hope you will want to rejoin the party. The signs of renewed interest in audio craftsmanship visibly multiply. The manuscripts we see in our new office advance steadily in quality.

In response to many requests we are now prepared, in this our jubilee year, to offer a Lifetime subscription to any who would like to invest $150 in our research fund. Annual income from the fund will pay for life subscriptions but anything the fund produces beyond those costs will go to purchase equipment for our growing test facility. Lifetime subscribers will not only receive the magazine for life but a suitable certificate as well.

The keel for the first issue of our seventh series is already laid, the articles are in type, and many are on page. If you read the fine print at the left you'll notice that prices for TAA have gone up: $9 per year, $25 for three. Prices for back issues will remain, for the moment, what they were when published: $5 per set for 1970 and 1971; $7 for 1972 through 1975. We hope to publish some larger issues during 1976. Your continued help and that of our advertisers could make it possible.

the Sanders ELECTROSTATIC SPEAKER

by ROGER R. SANDERS

IN OCTOBER 1974 I finally convinced my wife that the living room decor would be improved by my getting rid of my big speaker "boxes" and building some nice "thin" speakers. She agreed, and although she doesn't really have any better living room decor, I now have some superb speakers.

My interest had been smoldering ever since I read David Hermeyer's article on electrostatic loudspeakers (hereafter referred to as "ESL's") in Issues 3 and 4, 1972 series, of *The Audio Amateur.* The final straw was the last article's comment about building ESL's that would produce 120dB sound pressure levels (hereafter referred to as "SPL's") from 20Hz to 20kHz without crossovers.

I phoned David Hermeyer for help in building such speakers and, more importantly, in designing a suitable amplifier. Although he was rather amazed that I would try it, he promised help in the design problems. He had been working on some improved versions of the published speakers and had some very useful ideas.

I quickly learned that my original plans were indeed optimistic! However, the project has worked extremely well and surprised me with its performance. I have learned a tremendous amount. Specifically, it turns out that a huge direct coupled amp is not necessary and that if you are interested in building some ESL's but not interested in building an amplifier, you can be wonderfully happy with a standard amp and transformers.

ALTHOUGH author Sanders consulted David Hermeyer extensively about his design, nothing in this article or the second part of it to be published in TAA 1/76, should be taken to imply Hermeyer's approval of Sanders' designs or constructions. Hermeyer is continuing his own research into electrostatic speakers and amplifiers and hopes to have more articles for TAA's pages before too many more months have gone by.--Ed.

I also found that equalization is the only reasonable way to get bass from the ESL's unless you build them into a wall. And lastly, I found that it is just as good, and in many ways better, to use dynamic woofers. I also discovered that ESL's are not nearly as inefficient as I had been led to believe.

Right at the beginning I figured I would have to build large speakers, and I wasn't interested in building dozens of small cells and putting them together because of the difficulty of building suitable frames for them. So I built large cells, which are harder to make but turned out quite well.

The speakers in the pictures only have two cells per speaker and yet are two feet wide and eight feet tall. I intended to make them larger, but found this size was adequate. In fact, I think single cell speakers and dynamic woofers would be satisfactory for all but the most adamant fanatic. (I guess I'll have to include myself in that category.) *[Guess?--Ed.]*

Each cell is 20 inches wide and 36 inches long. Make a basic frame of plexiglas following Fig.1. The supporting insulators are spaced every six inches. They maintain the diaphragm to stator spacing which must not exceed the 100:1 ratio necessary for stability. The ratio refers to the distance between the supporting structures maintaining distance between diaphragm and stator. The stator is the stationary "electrode," "plate," or "grid," which the amplifier charges in order to attract or repel the diaphragm. As I am using readily available 1/16" plexiglas (approx. 0.063" thick) the maximum support distances are 6.3 inches.

Dave Hermeyer glued his frames together with epoxy. I find that plexiglas (which is acrylic plastic) can be *fused* together with acrylic cement. This liquid, when placed at the interface of two pieces of plexiglas, will run between the two pieces and *weld* them together in about 30 seconds. It is much stronger and faster than epoxy.

The plexiglas can be laid out and welded one section at a time and held by hand until solid. You will need a piece of ¼" plate glass that is cut *square* to the exact size of your finished cell. The outer perimeter of the plexiglas frame will exactly fit the plate glass. You should carefully mark the location of the center insulators. I found that a felt marker gradually wiped off--so I used ½" masking tape on

FIG. 1A: STEEL ROD STATOR ASSEMBLY SCALE 1:5; DIMENSIONS IN INCHES. ALL PLEXIGLAS 1/16".

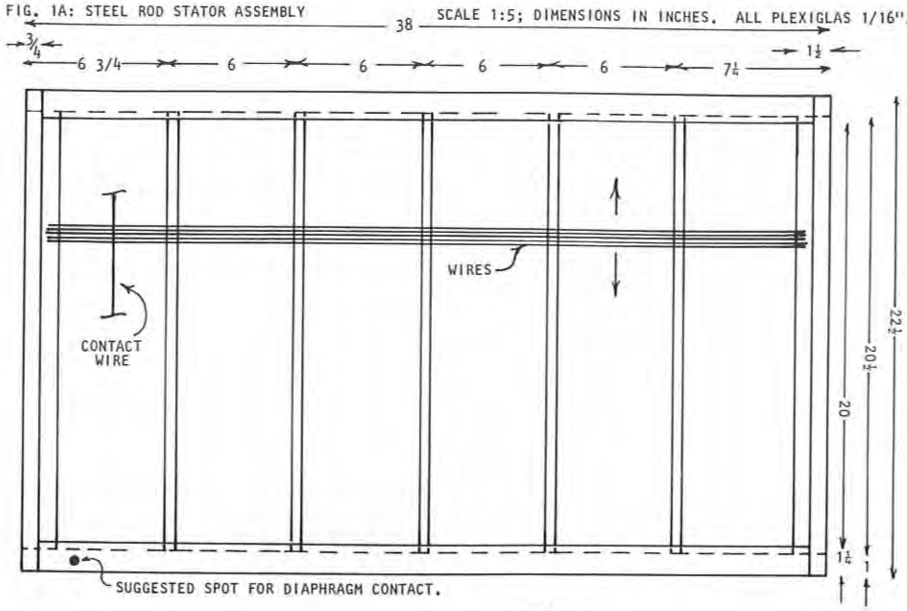


FIG. 1B: CORNER DETAIL OF WIRE STATOR CONSTRUCTION. FULL SCALE.

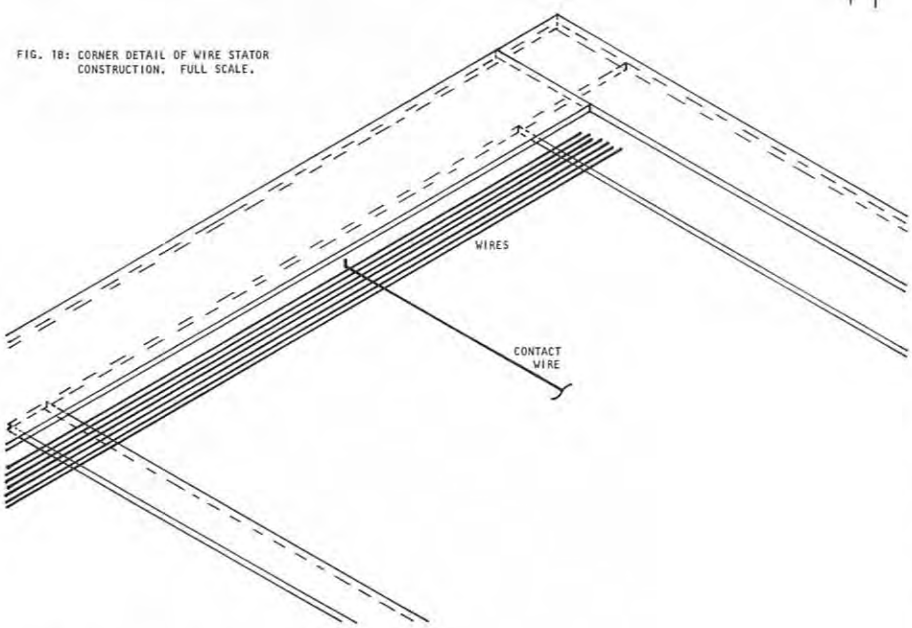
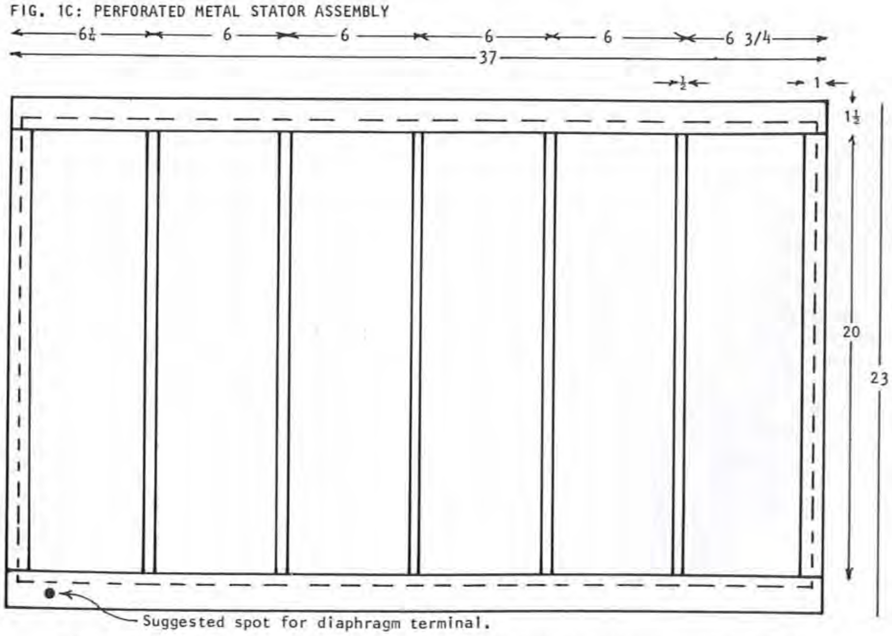


FIG. 1C: PERFORATED METAL STATOR ASSEMBLY



Note: Dashed line represents dimension and placement of perforated metal 36"x21". All plexiglas parts 1/16" thickness. Scale 1:5; dimensions in inches.

the underside of the glass.

A small syringe with a 27 gauge needle is a fine tool for running the cement onto the plexiglas. I can't think of any other way that would work so well. Place the needle right at the interface and quickly run it along the area you want to glue. I usually glue about 6-10 inches at one time, but I get a corner done first. Perhaps you can get a cooperative pharmacist or doctor or dentist to give you a disposable plastic syringe for this job. *[Pick one you know. Drug types have made doctors nervous about syringes. Most MD's and hospital rules now require destruction of used syringes.--Ed.]*

The acrylic cement will gradually destroy the syringe, so after you get through using it for the evening empty it out and leave it open to air and you'll have less trouble with it. If you get too much cement on the plexiglas and it runs between the plexiglas and the plate glass, just leave it. It will stick the plexiglas to the plate glass and it will roughen the plexiglas surface, but that is not serious.

You will need a sharpened putty knife for several parts of this project, to run between the glass and the plexiglas to get it unstuck without breaking it, to clean the glass, and to remove epoxy. I suggest you do not try to use a razor scraper for these purposes because the epoxy is so hard it will chip it. A putty knife works best if kept sharp.

The frame may be left stuck to the glass if you spilled. If you didn't spill over anywhere, use some tape to hold the thing in position. Now it is time to add the metal conductors. There are two ways of doing this. Perforated metal is easiest to use, but has several disadvantages. It does not lie flat, and it will produce a less efficient speaker. The warp can be overcome in final assembly so it is no real problem. The metal should be ordered with 1/8" holes on 3/16" centers, staggered (that is the information the salesman will want to know). The fact that the 1/8" holes have a relatively large open area and tend to produce corona effects decreases the efficiency.

For best results the metal should be etched to get the edges off the holes and reduce corona effects. You can use aluminum or steel sheet. Aluminum can be etched in sodium hydroxide. I suspect that plain old lye or "Drano" would probably work o.k. although I have not tried either.

Steel will have to be etched in acid. Nitric would work fine, but hydrochloric should also work o.k. You can purchase it for cleaning bricks in a form called "muriatic acid." I have not used any of these compounds. *[Follow ALL precautionary instructions for these fluids. --Ed.]* I built a couple of panels without etching them. You will find that one side of the metal has rather rounded holes while the other has sharp-edged holes. I placed the rounded holes toward the diaphragm and it worked o.k. Hermeyer advises that etching is best, however.

If you opt to use metal, get the thinnest possible. I believe that in aluminum you can get 36 mil, while in steel you can get 24 mil. You should not get thick stock or holes smaller than 1/8" because the holes will act more as "tunnels" with adverse effect on the sound. Aluminum won't rust and is lighter, but it is twice the cost of steel.

To use the perforated metal, clean it in solvent (especially the steel) since it will be painted later and because epoxy won't stick to oil. You can cut the metal to size without deforming it with a good pair of "duck bill" snips. But *do* handle it carefully because if you crease it you can never get it straight and flat again.

Use a 1 oz. tube of 24-hour epoxy to assemble each stator (do not use 5 minute epoxy for this part, it will set too fast and is not nearly as strong as the 24 hour). You'll also need waxed paper and lots of heavy books. Loosen the frame with your putty knife and place the plate glass on a solid surface.

Completely cover the plate glass with waxed paper. Put the frame back on the plate glass on top of the waxed paper. Mix your epoxy and apply it to the plexiglas where the metal will contact it. A 10 CC syringe without a needle is super for this, and mixing it in a medicine cup (disposable types) is convenient. Place the metal in position and cover it with waxed paper. Now weight it down evenly with books so it lies flat. Leave it overnight.

Take it up the next evening and make the next stator. When you get them all made you will need to solder one inch of a two inch piece of #20 copper wire to one corner of the metal. It doesn't really matter where you solder it but it looks nicer if the contacts all come out at the same corner on both sides of the cell. These will connect your stators to your amplifier later.

Buy some Red GLPT High Voltage Insulating Varnish from GC Electronics (Rockford, IL 61101) or from one of their distributors. You will probably have to order it and you might as well order a gallon for $15 rather than buy a bunch of little cans. You can thin it for spraying with lacquer thinner. You

FIG. 2A: STRETCHER

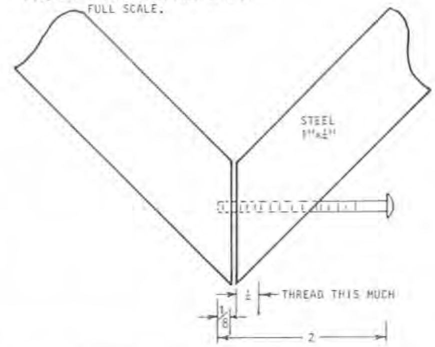
only need to thin it about 10% to spray it. Mask the surfaces of the plexiglas that will contact the diaphragm (that will be all the surfaces that contacted the plate glass when you built them). Then spray both sides of the stators with the insulation and let them dry (they dry fast).

You may prefer to build the stators of wire. They have several advantages over perforated metal. First, since they are round there are no corona effects. They can be laid close together so the field is more uniform and powerful. They also lie flat. Ideally, there should be about 37% open space in the stator (according to Dave Hermeyer). Moreover, there should be no greater gap in the field than the space between the stator and the diaphragm. My wires are placed 83 mils (center to center) apart, with 33 mil gaps. That gives me an open percentage of 39%. Ideally the wires should be placed no further apart than 63 mils (center to center), but that was impractical since smaller wire would tend to sag. These figures work out to 12 wires per inch.

To build wire stators you will need 240 pieces of hardened steel "music" wire, 50 mils in diameter and 36 inches long for each stator. Order it by asking for "straight and cut music wire, 50 thousandths in diameter". Order about 10% more than you need, because although the salesman will tell you it is straight as an arrow and some of it is...much of it isn't!

I test each piece by trying to roll it on the plate glass. If it rolls it's OK, if not, I discard it. The price is about 5¢ each in large quantities. The wires must be cleaned of all oil. This is a tough job. I soak them in solvent

FIG. 2B: STRETCHER CORNER DETAIL FULL SCALE.



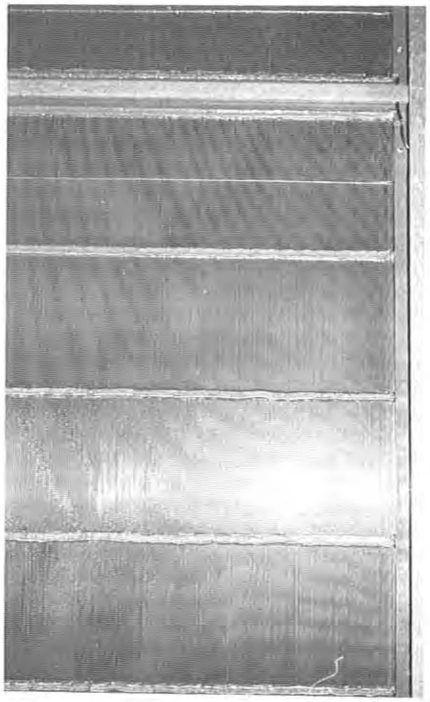
and wipe each one with a rag. To make a tub for them I used a piece of rain gutter, placed a big rock at each end, and lined the thing with a plastic sheet.

To assemble the wires lay out a bunch of them and roll an old 12-tooth per inch clock gear along one end. Cellophane tape one end to the plexiglas frame, and fold it back out of the way. Now as you work the gear along, you tape in place the wires you have already spaced. When you get to the end you stick the tape to the other side of the plexiglas frame. Now check carefully to see whether you have crossed any of the wires, then go to the other end and do the same.

It will take some practice to learn to use the gear evenly enough to keep all the wires parallel. Sight down the rows of wires frequently to see that you are keeping them even. If you don't, you will end up with too many wires bunched up at one end and too few at the other--then you have to pull the tape up and start again. Once the two ends are in place, run the gear along each center support. Do not place the tape right over the center support because you will have to glue there. Lay the tape to one side.

Once you have all the wires laid out and taped, mix up some epoxy and run it down between the wires where it contacts the plexiglas. Again, a syringe is the best tool. You'd better use disposable ones because you'll never use them twice.

After finishing all the stators you must connect them together electrically. I tried Mr. Hermeyer's conductive epoxy suggestion which unfortunately works very poorly and is extremely expensive. Soldering them is not difficult. Take a left-over piece of music wire and lay it across a sanded segment of the wires, use a good acid flux and a heavy duty soldering iron such as the Weller controlled heat type. Once you have used one you'll never be without it. They are small, but extremely powerful and do tough jobs like this with great ease. If you use plenty of flux and plenty of heat you will find that you can solder the wires to each cross wire in about 10 minutes. You should attach a piece of copper wire to the cross piece to make later connections. Now mask the plexiglas and paint.



After you have removed the masking tape when the stators are dry, and thoroughly cleaned your plate glass you are ready to install the diaphragms. Dave Hermeyer has developed a method of making much better diaphragms than the Saran wrap types he used earlier. Much higher diaphragm tensions are possible by using 1/4 mil mylar film, but it must be stretched with a strong, rigid, heavy mechanical stretcher to high tension across the plate glass.

I found that 1" wide by 1/4" thick steel bars work satisfactorily. You will need 12 feet of the steel. Cut it with a hack saw to the dimensions shown in Fig. 2. Drill and tap both ends of the short side. Drill just about 1/8 inch into the other bar so that it will accept the bolt. Sand the steel down to the bare metal.

Get some double sided sticky tape and lay strips of it along each piece of the bare steel. Place a 1" piece of single sided sticky tape on the ends so they won't come loose when you take the mylar off the tape.

Photo two, at left, is a closeup of two panels of the piano wire type installed in oak frames and wires attached. A friend of the author's, below, rubs in some graphite on a stretched mylar diaphragm.

The mylar film is not terribly expensive, but it is difficult to find and when you do find it you will be faced with a minimum charge of $25 or so. Each roll is 48 inches wide. I have a couple of hundred extra feet which I will sell for 20¢/running foot. Minimum order $1 postage paid.

Unroll the mylar across the plate glass. Be sure the plate glass is on top of something light colored so you can see what is going on when you begin your coating. Position it so you have a good 6" extra on all sides before trimming. Now, take a few pieces of cellophane tape [*Masking tape may be easier to remove.--Ed.*] and fasten the edges down. Start with the corners and add a couple of pieces along each edge. The object is to get the majority of wrinkles out and have it under light tension. Then place the steel stretchers (one piece at a time please) sticky tape side down on the mylar. I start with a long piece first, then add the short sides and finally the last long side.

If you have the bolts protruding about 1/4" you will be able to hold one end of a piece of steel up in the air, engage the other end in the steel that is already lying on the mylar and then 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. The frame will expand and you will have a tight, wrinkle free diaphragm.

Although there are certain guidelines for diaphragm tensions (the tighter the higher your fundamental resonance), in this case you simply want the diaphragm as tight as possible. The limiting factor will be double sided tape's tack which will start to arc, pop, and "cave in" long before the other areas limiting your efficiency because you will be forced to use a lower voltage with the polarizing supply.

Coat the diaphragm with fine powdered graphite. David Hermeyer's original techniques were satisfactory--simply spread the graphite around and rub it in with a ball of rayon. Keep your fingers off the mylar as you work with it because the graphite doesn't seem to want to stick to finger prints nor does it seem possible to clean them off either. They don't appear to affect performance, but they can't help.

The graphite must be rubbed in hard. I had trouble with my speakers at first because I didn't rub it in vigorously enough. Then, they would play a while, the graphite would come off and the cell would die. So, rub it in hard.

David Hermeyer talks about the proper resistance being 10 to 100 million Ohms per inch. In theory this is true. I have found it does not matter. I don't even bother to test with an Ohmmeter anymore. I just rub it in hard so I know it will stay put. I usually get resistance between 100 and 500 thousand Ohms per inch. Nor does it matter whether you put a super low resistance border around the perimeter as Hermeyer suggested. It works with or without a border.

You will find that the mylar has a charge on it that attracts dirt and you will always have some between the mylar and the glass. Little pieces you can ignore for now, but the larger pieces tend to cut the mylar as you rub and can tear the film. I find that I can lift the side of the stretcher and have another person gently wipe the dirt off with a soft rag without disrupting the diaphragm.

When you get the diaphragm properly coated you should take a vacuum cleaner with a soft brush and clean off as much graphite as possible. Then take a paper towel or soft rag and wipe off as much more as you can. If you don't do this the cells will make a tremendous amount of hissing noise for the first few hours of operation until the excess is burned off.

Check the stators you are going to use to sandwich a particular diaphragm to see that they match reasonably well before proceeding further. As you will have made several stators you can place different ones together until you get the closest matches possible. With the stators lightly clumped together face to face you must drill the hole through the plexiglas at one of the corners for the bolt that will make contact with the diaphragm.

Drill very carefully. Plexiglas will tend to crack and break just as the drill finishes the hole unless a special bit is used. A regular bit is OK, but go slowly. Alternatively drill almost through, and then turn the panel over and drill the hole completely through from the other side. Decide which way you want the bolt to stick out. You'll want your bolts mounted the same way so you can make electrical connections easily. You must enlarge the hole in the stator that has the *head* of the bolt against it so that the head of the bolt can pass completely through it. The bolt will actually bolt the mylar film to one stator and will not contact the other stator at all.

Continued on page 24

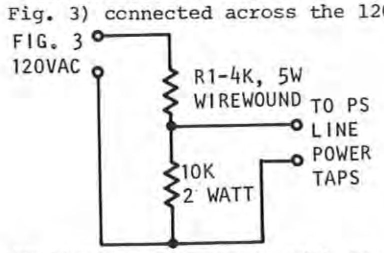
THE POLARIZING SUPPLY

THE SPEAKER DIAPHRAGMS must be charged, of course, and if they are not operated with an amplifier that develops a constant voltage on the stators (such as Mr. Hermeyer's amplifier) you will need about three thousand volts to do the job. The power supply does not need to deliver much current--certainly 1/10 milliamp is adequate. Such a power supply can be made up with surplus parts, but numerous ready--built photostatic copier supplies are available from surplus houses. The power supply I use and find to be ideal is in a semi-chassis (two sides open), is brand new, supplies both 5kV and 10kV, and only costs $9.50 from Electro-Science Mart, 119 Foster Street, Peabody, Mass. 01960. Include about $1.50 for shipping and handling. Ask for stock #1106.

This particular unit uses two tubes. This is not as bad as it sounds as the tubes turn on instantly, do not have glowing filaments, run cold, and apparently will last a long time. Furthermore you may remove the 10kV rectifier tube along with its resistors and capacitors. Save the tube for a spare if you ever need it. Connect the extra capacitor to the 5kV tap for added capacitance.

The power supply will now develop 5kV which you can reduce through a fixed resistor voltage divider (see Fig. 3) connected across the 120 V

FIG. 3

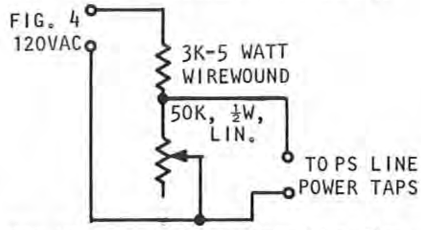


AC line input. If you wish to adjust to the voltage, one fixed resistor and a small carbon pot works very well and will fit the chassis. The ½ watt pot does not get hot or even warm. If you use fixed resistors you may have to experiment with R1 to get optimum results related to the tension you manage to get on your diaphragms. The higher the tension the more voltage you can use. See Fig. 4.

Connect the power supply appropriately as necessary for either transformer coupled or direct coupled amplifiers and adjust the voltage until it causes the diaphragm(s) to start "popping". This popping will occur at a rate of about one pop per ½ to 10 seconds. If you watch where the popping comes from you can see the diaphragm move closer to the stator until it arcs with a small spark.

The voltage will thus be reduced and the diaphragm will return to center. The cycle will continue until the voltage is turned down. I have never noticed any damage from this happening, but Dave Hermeyer tells me that extended over voltage operation will gradually burn off the conductive coating.

FIG. 4



You will want to operate the diaphragms at the highest voltage possible for maximum efficiency.

Another interesting thing happens as you turn the voltage up. Because my speakers are operated without grille cloth or dust covers I theorize that dust is constantly being attracted to the diaphragms. I believe when it gets between the stator and the diaphragm it gets "fried" with a weak snap. These snaps go on constantly while the voltage is on if it is turned up to just below the point where the diaphragms become unstable. The noise from this happening is very weak, but it can be heard.

If the power supply is turned off for several hours, at turn-on a great deal of this noise occurs but then diminishes after a few minutes to a barely audible noise. I suspect that dust gets on the diaphragms while the power supply is off (it always keeps some charge on it to attract dust), and when it is first turned on again it must "fry" all this accumulated dust. It then settles down. I have never had to clean any dust from my speakers, but I believe that if I ran the voltage lower where the noise was absent that I might have to clean dust out of the speakers occasionally. As it is they are self cleaning. [*Sounds like a great cure for mosquitoes.--Ed.*]

Because of the additional turn-on noise if the speakers are left off for a while I leave the power supply on. You may prefer to keep it off, but it draws less than 1 watt so is inexpensive to operate continuously and seems to be a bit more stable as well.

The input/output voltage ratio is high and if you run it right on the "ragged edge" just below the diaphragm's unstable point you may find that small house voltage changes will make your diaphragms unstable, so keep it reasonably conservative.

A PRACTICAL DIRECT COUPLED AMP

IT IS ALSO QUITE simple to drive your speakers with a direct coupled tube amplifier. Take output from the plates of the O/P tubes rather than from the secondary of the output transofrmer. The amplifier is not modified in any other way; however, certain unusual precautions must be taken. First you must load the secondary of the output transformer in order to stabilize the amp and reduce ringing. In practice this means placing a loading resistor across the terminals that matches the impedance recommended by the manufacturer. Connect an 8 to 12 Ohm wirewound resistor of approximately the same wattage as your amplifier across the 8 Ohm taps of the amp instead of the usual speaker.

For connections to the tube plates I suggest drilling the chassis and mounting well insulated banana plug jacks. Connect the plates to these jacks (color code them so you will have them in--phase). Even without a schematic diagram you will find that it is not difficult to locate the proper tube pins that represent the plates. Find the wires that connect to the primary winding of the output transformer, usually the five or three that do NOT connect to the output jack. The center tap wire will be the one that does not connect to any tube pin.

Now attach one Ohmmeter lead to the center tap. Connect the other at one of the output tube socket pins with a transformer connected to it. The one with the highest resistance (the tube's plate), is the one you want. You may find it necessary to lift the center tap lead from its connection to get a clear meter reading. Measure the other tube and connect the plates to the jacks in the chassis wall with high voltage test probe wire. Your modification is now complete.

To hook up the amp to the speakers it is only necessary to connect the stators to the jacks and connect one side of your polarizing supply to the amplifier chassis.

Those of you who have a good deal of electrical engineering skill (I don't) may want to adjust the amplifier's feedback network to reduce ringing. This direct from the tube plates drive method offers tremendous improvements in the square wave performance over the amplifier/step-up transformer system. Virtually perfect square waves are possible in the middle frequencies with this system with ringing beginning to seriously alter the wave only at very high frequencies. In comparison my step-up transformer produces lousy square waves in the middle ranges and nothing remotely resembling a square wave at the higher frequencies.

Your choice of amplifier is up to you. I think its most important characteristic is operating B+ voltage level. You will get at least double the normal operating voltage when you measure between the plates. I find about 1kV on the stators is enough to produce ear-shattering levels from my speakers. The Dyna MK III operates on 480 volts (960V plate-to-plate) so you can see it would work very well. On the other hand I have used an amp with a 250 volt power supply and found it was adequate for all but ear shattering levels. A 35 to 60 watt amplifier will deliver all the current you need so there is no problem here. Those of you who like to tinker may want to modify an amp to operate on higher voltage.

One interesting note concerning this arrangement: I have found that the polarizing supply voltage varies (depending on its polarity) when the amp is turned on and off. This is caused by the tube's voltage potentials. It seems to have no effect on performance. I mention this because if you leave your power supply on at all times and then turn on the amp you may find that your diaphragms "cave in"; or conversely, lose efficiency. The moral: adjust your diaphragm voltages with the amplifier on.

If you have an audio generator that will produce square waves (a sine wave generator won't show enough distortion to be of any use) I would recommend testing your setup. Simply feed in a wave and read the output on an oscilloscope at the speaker terminals. You may want to change the load resistor to see whether you can get better wave forms. I found that my amp would oscillate at low input levels unless I used a 12 Ohm resistor or lower. Interestingly this oscillation would disappear when the level was turned up a bit. You will be interested in noting how the speaker affects the wave. Alternately connect and disconnect one speaker lead while observing the wave. *[Square waves above 10kHz at high levels for sustained periods may weaken or destroy output semiconductors.--Ed.]*

I was surprised to find that the tube type amplifiers I tested would not produce good square waves at high frequencies even without the speaker load. I was also surprised to find that the transformer/transistor amp would not produce good square waves even when not loaded by the speaker. All I can say is that I am happy that the sound isn't as bad as the square wave test would have you believe.

Figure 5 details the proper connection for a "typical" system. I have not tested all available amplifiers with this modification, of course, so cannot be positive that all will work satisfactorily this way. The amplifier I tested was an Ampex monitor amplifier, and a friend of mine has made a similar modification to the Dyna MkIII.

It would obviously be best to not have to load the secondary of the output transformer because that is inefficient. We are working on a method of getting around that, but at the present a load is all I can offer.

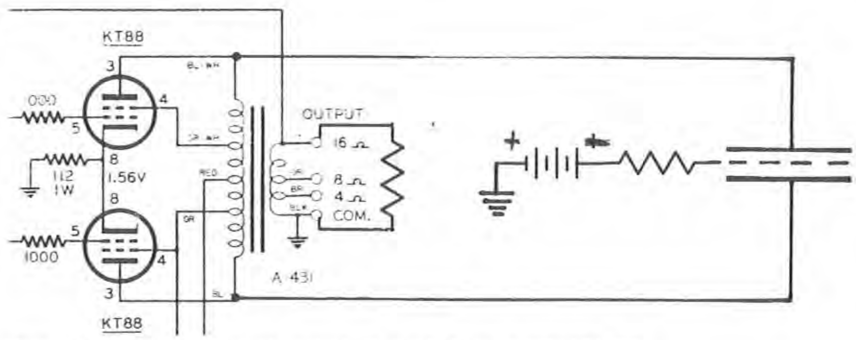


Fig. 5. Typical direct coupled amplifier connections.

Continued from page 22
Drill the hole in the other stator so the bolt can be installed later. Sand and tin one end of the bolt in order to solder to it later but do not fill the threads.

After completing the drilling operation you are ready to mount the diaphragm. First cut a piece of aluminum foil about one inch square. This will make a solid contact against the diaphragm. Now, vacuum the stator with the *larger* hole in it so that there are no chips of anything on it, as debris will be almost impossible to remove after the cells are completed.

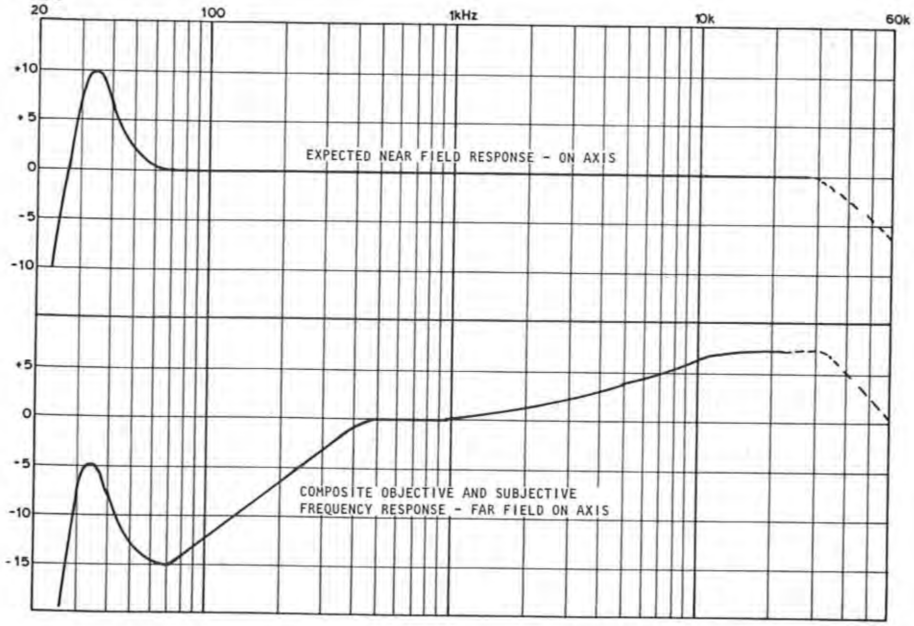
Epoxy is about the only adhesive that will adhere to graphite coated mylar. I use 5 minute epoxy for this operation but you must work fast and to apply it you will *have* to use a syringe. Alternatively you may use 24 hour epoxy and wait a full day before proceeding. If your panels are made with perforated metal they will be warped requiring a pile of books close by to weight it down while the epoxy cures. If you have built a wire stator the books will not be necessary as it will be flat.

Apply the epoxy to the unpainted plexiglas surfaces and remember to place the aluminum foil over the smaller hole you drilled. Avoid spreading epoxy in the hole. Now simply pick up the stator and place it face down on the mylar. Press it firmly in place around its perimeter and across the center strips. The stator will tend to "creep" across the mylar as you press the epoxy around so check the edges as you go. Be quick if you are using 5 minute epoxy.

After the epoxy cures take a *sharp* razor blade and cut the diaphragm free of the stretcher. It is difficult to trim the mylar close to the stator at this time so just leave a 1 to 2 inch margin all around. Lift up the stator carefully by one side so the air can run under the diaphragm. You will be amazed by your good results.

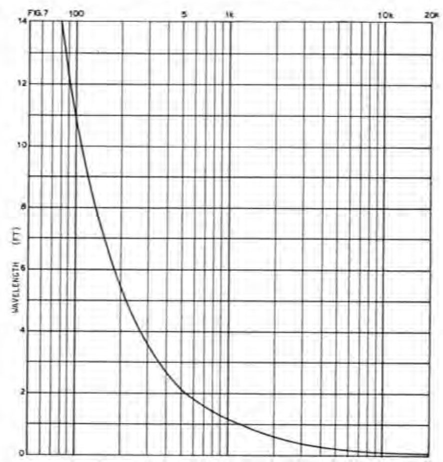
The diaphragm will be perfectly wrinkle free and tight as a drum. The very small creases in the mylar that were there when you got it will be visible, but no serious

FIG 6



wrinkles. Now wipe the mylar with a soft cloth to remove any tiny bits of dirt that may be clinging to it. Turn the other stator upside down on the plate glass. Position the stator and diaphragm assembly on the other stator so the cell is in its finished form. Gently poke a sharp pencil into the hole until you puncture the aluminum foil and the mylar film over the hole in the lower (unglued) stator. Now place the bolt in the hole to be sure everything 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.

Remove the bolt after you are sure it fits, and remove the upper stator. Apply a layer of epoxy to the stator on the glass. Carefully position the stator diaphragm unit on the one with the fresh glue. It is easiest to align two corners and then lay the whole thing down. Try to avoid smearing the mylar with epoxy except where the glue joints are against the plexiglas.



As soon as the stator is in place, insert the bolt to be sure the corner is exactly aligned.

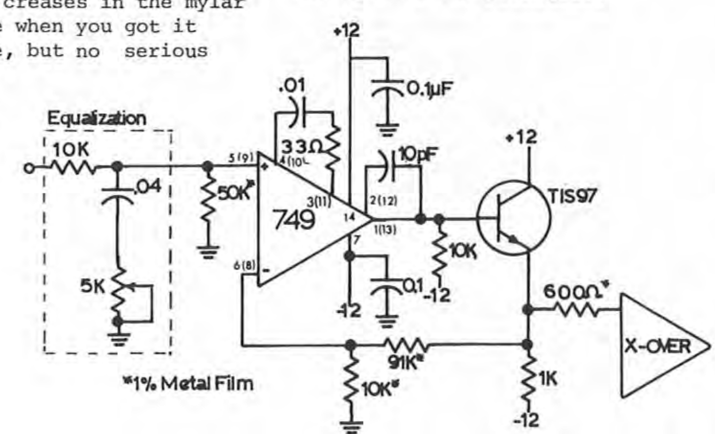
Then press the stators together gently. Watch for "creeping". Again, apply books to the sandwich if you are using perforated metal.

When the epoxy has cured thread the nut on the bolt and prevent it from turning with a screwdriver while carefully turning the nut with a socket wrench (or a pair of pliers if that is the best you can do). Trim the excess mylar around the edges with a sharp razor. Your cell is finished!

Another word of caution: The cells are heavy--mine weigh 14 pounds each. If they are flexed across their short dimension tremendous stress is exerted on the glue bond. The bond is not strong because nothing sticks to graphite coated mylar very well. This bond is extremely rigid (it holds the perforated metal very flat!) and therefore it may not be abused. Be very careful to always hold and store the panels on end for safety.

Being a realist, I know you will

FIG.9



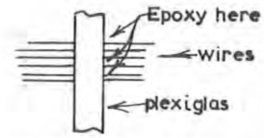
probably have to replace a diaphragm or two for one of the following reasons: 1. You tear it. 2. You have insufficient tension on one diaphragm relative to the others and you want to increase efficiency. 3. The graphite burns off because you didn't put it on hard enough. 4. You damaged the diaphragm contact. 5. You break something.

Fear not! The diaphragms are easily replaced. Position the cell flat on the plate glass. Take your sharp putty knife and run it along the bond between the stators in order to break it. The bond across the center strips will probably break itself loose if you just gently lift the stators apart to stress the bond. If you are too chicken to do this, you can gently lift the stators and run a sharpened yardstick on one end along the center strips. A metal yardstick works best. Or you could just get a thin strip of aluminum about three feet long at the hardware store and sharpen the end of that.

Once the stators are separated, scrape the epoxy off the plexiglas with the putty knife. Take care not to scratch the high voltage insulation. A Q-tip dipped in fresh varnish can repair any damage. Vacuum liberally as you work, then repeat the diaphragm process outlined.

Amplifier connections will be made at the copper wire on each stator, the high voltage polarizing supply will be attached to the bolt on the diaphragm.

If you have made the wire stator version make sure they don't rattle before you paint them. Probably they won't, but if they do turn the stator over (diaphragm side up) and run a bead of epoxy glue along the interface of the wires and the plexiglas as shown in the little drawing above, right.



Place waxed paper on the plate glass for this operation since the epoxy may drip through. The cells have no resonances if there are no rattles as you tap the edges.

The number of cells you use and the way you mount them is up to you. A single cell for each channel is adequate. Each cell if made of wire will have approximately 1200pF of capacity. My speakers have 2400pF each and David Hermeyer's amplifier drives them with no difficulty even though in *theory* the full power bandwidth will not extend above 3kHz. Regardless of construction, all ESL cells will sound exactly the same if they are the same dimensions.

My "enclosures" are made of $1\frac{1}{2}$" square oak bars. The frames are dado cut so the ESL cells fit into them. An additional cut in one side is just wide enough and deep enough to accept the three contact wires. The bottom is cut away $\frac{1}{4}$" deep to fit a $\frac{1}{4}$" plate of plexiglas holding three banana plugs for the connections made with high voltage test probe wire. The tops have regular room divider spring loaded legs braced against the ceiling to hold them upright.

I do not use grillecloth on the speakers because it has been very effectively demonstrated that it audibly degrades the sound. Foam grilles do not affect the frequency response in the same way that ordinary grille cloth does, but it destroys the transient response of the speakers.

You can cut your own plexiglas parts and save money. You will need a good table saw and a fine--toothed plastic cutting blade. The thin plexiglas tends to ride up the blade and make it difficult to cut, so clamp a block of wood to the rip fence about 1/8" above the work table. The block should be thick enough to extend over the blade and the blade should be raised until it just cuts into the wood. Now the plexiglas can be cut and it cannot ride up the blade.

Keep the blade *sharp*. Even if it is razor sharp it will still chip the edges somewhat. This chipping is not serious, but edges should be lightly sanded to remove any burrs before assembly. Some plexiglas shops will cut large pieces of plexiglas by scoring and bending them until they break. This can't be done on the long skinny strips, so you must saw them. Most shops will cut them for you, but you will pay for it. Sanding the surfaces of the plexiglas to which you will

DRIVING THE LOUDSPEAKERS

THE SPEAKERS CAN be driven with a direct coupled amp, or a regular amp or receiver with step up transformers. Both offer superb results. I have tested both methods with ear and instruments. The most severe test is square waves fed to the amp with an oscilloscope on the speaker's stator terminals. The amps and transformers don't like that.

My critical listening testing shows that while there is a tremendous difference in the ability of various systems to drive the speakers on the square wave tests, the differences aurally are subtle. Anyone contemplating building some ESL's should not feel that it is necessary to build an amplifier in order to obtain adequate results.

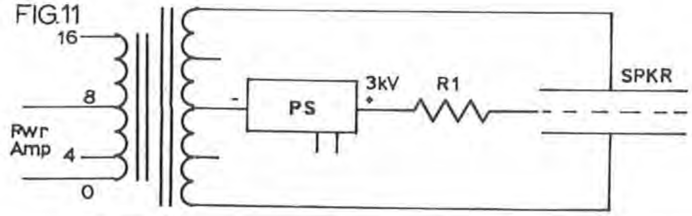
David Hermeyer brought his magnificent Class A direct coupled amp over to my home for some direct sonic comparison testing with two other critical individuals present. For comparison we hooked up a Williamson Twin 20 driving a pair of moderate quality 20 watt output transformers connected in reverse. All present agreed that the direct coupled amp was superior. It had slightly greater resolving power and a softer sound quality.

Hermeyer has tested his unit and states that it does not ring on square waves. I tested the transformers and found that they rang badly, even to the point that a 20kHz square wave was turned into a sine wave. I am *amazed* that they sound as good as they do, but the fact is that they do sound superb and that most anybody could live with them happily. In fact, I find that even though I realize that a subtle improvement is available by using a direct coupled amp, the sound is so good that I do not feel in any rush to scrap the transformer system. *[Williamson's amp has a built in roll-off around 50kHz which accounts for a 20kHz square wave turning rounded. The 10-octave content of a 20K wave is a very stringent test for any audio device.--Ed.]*

Unfortunately Hermeyer's amplifier is just too monstrous for my taste, and it certainly will run up the electric bill. I presently use Williamson's 20-20 amplifier and step-up transformers. The combination is extremely efficient and sonically excellent. See Fig. 11.

T1 audio output transformer 20 to 60 watts is adequate.
R1 22 meg ohms, $\frac{1}{2}$ to 1 watt.
PS High voltage polarizing supply at about 3KV at 1/10ma. polarity may be either way if connected to transformer.

FIG.11



glue will help the epoxy to stick better.

OPERATION

LET ME SAY IMMEDIATELY that the frequency response of my speakers is not flat. They have a rising high end and a falling low end. Figure 6 represents a composite frequency response that is both measurable and audible. The low frequency roll-off begins when the wavelength of the sound approaches the minimum dimension of the speaker. Figure 7 shows graphically the wavelength of sound at various frequencies and you can get some idea of the size of the dipole radiator speaker you would have to build to get flat response to 20Hz.

Bass response may be balanced with the rest of the range in several ways: 1. Equalize the bass of the ESL flat. 2. Mount the ESL's in some kind of an enclosure (such as a false wall) to isolate the front from the back so there simply is no cancellation. 3. Used dynamic woofers.

Building the ESL's into enclosures can be tricky--and they must be big. I have not tried it. I have tried equalization and dynamic woofers and made quite a lot of A-B comparisons between the two. I am consistently impressed by the fact that there is virtually no audible difference between the two methods. Each has its merits.

The ESL running full range is really simple. No crossovers, woofers, or enclosures and only one amplifier. The sound is going to be as close to perfection as possible. There are two disadvantages however. First, even though equalization produces tremendous excursions, it doesn't produce deep bass. Subjectively flat response can be obtained to about 50 - 60Hz. The tremendous excursions reduce your maximum sound level as the diaphragms will hit the stators on heavy bass passages. A *very* important note here is that the 34Hz fundamental resonance must be suppressed if you are to get high SPL's.

The resonance will cause tremendous excursions of the diaphragms. It is wild to watch a light being reflected in the diaphragms as heavy bass is played but they will not add much to the bass because of the severe cancellation at the deep frequencies. However, the excessive excursion will reduce your maximum SPL on passages with deep bass by about 10dB. The moral: Douse that resonance with a rumble filter or an equalizer. It would be even more important to control the resonance if you built the speakers into a wall.

Separate dynamic woofers allow

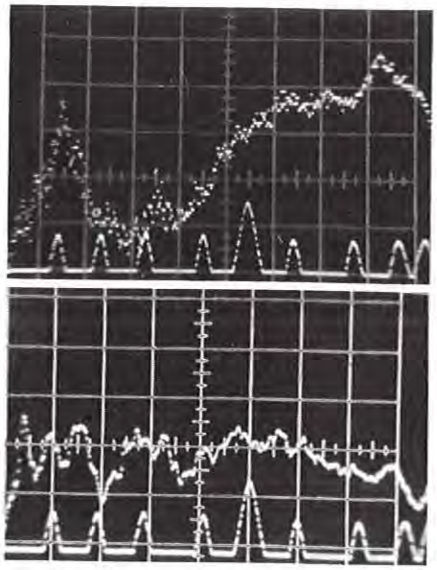


Photo 4, above, a storage 'scope trace of 1/3 octave pink noise into a real time analyzer measuring the unequalized response of Sanders' ESL taken in the room at 5 meters. Photo 5, below, is the same set of panels equalized below 1kHz, with a crossover at 120Hz, measured at 4 meters. The large "blip" in both photos is 1kHz, 5dB between horizontal lines.

you to have much higher SPL's and deep bass. You pay a penalty in complexity and cost. But I am now firmly convinced that there is no sonic loss of detail or linearity if a good woofer is used and the crossover point is kept no higher than 500Hz. The choice of woofer is up to you.

The photographs show a pair of 24" Hartley woofers, but I presently am using KEF B 139 MkII woofers in 10 foot transmission line enclosures. The KEF's are placed next to the ESL's in the same plane as the diaphragms which produces better phase characteristics around crossover than do the Hartleys which are a couple of feet behind the ESL's.

Another possibility: use the Hartley 24" woofers in a transmission line and cross them over at 100Hz. Equalize the ESL's to 100Hz and use the Hartley's below. However, we all aren't that rich or have that much room. I'll not go into the design and construction of woofer enclosures which is covered very well by Theodore Jastak (TAA 1, 1973 and 4, 1973). He discusses both the transmission line Hartley and KEF in these articles. You might be interested to know I have a switch which removes my crossover network and woofers, equalizes the bass of the ESL's and runs them full range. I use this mode for moderately loud to background music levels, and switch in the woofers only when I want to shake the rafters. It also makes it easy to A-B the system.

You have a choice of crossovers. (See TAA, issue 2, 1972). At present I am using the crossover and equalization network in Fig. 9.

A word about SPL's is in order here. When I heard David Hermeyer's speaker/amp system at his home he had on hand a precision B&K sound pressure level meter. On heavy classical material his amplifier clips at about 92dB. Driving my ESLs his amplifier does not clip at any tolerable listening level.

I am currently using a Williamson 20-20 amplifier and driving the speakers through two small (20 watt) audio output transformers. Tests show that even this small amount of power is enough to drive the system to ear breakup levels. This is equivalent to fourth row concert levels. I would judge that my full range ESLs driven by the Williamson amplifier produce levels equivalent to those of Dave Hermeyer's speakers. Considerably higher levels are produced if the ESLs are supplemented by a woofer.

Why does the high end rise? The diaphragm motion is essentially linear above fundamental resonance. Hermeyer advises that the highs roll off at about 30kHz (finally) due to the mass of the diaphragms. Well, it turns out that the diaphragm motion *is* linear, but that the far field response rises because of the beaming qualities of the speaker. The high frequency energy is concentrated into a tight beam on-axis while the middle frequencies are allowed to spread out a bit. The result is that you have a subjectively rising high end on-axis at far field.

Hermeyer points out that the wider a speaker disperses sound (highs) the less this phenomenon affects the sound. I agree. However it would appear that unless your speaker radiates 180° that this rise will take place. Note that several designs attempt to spread the sound about by using small panels angled outwards. While this increases dispersion, remember that the highs are still only tightly concentrated in the on-axis beam so that if the angle of the panels is 10 or 20 degrees then the dispersion is only 10 or 20 degrees and you will still have a rising high end. I believe the panels must be angled an entire 180 degrees to achieve a flat high end.

I chose *not* to have a wide dispersion speaker. There are several reasons why a narrow dispersion speaker is superior to a wide dispersion one: 1. Room acoustics are minimized. 2. The stereo image is more precise. 3. Subjective SPLs are higher. 4. The wavefront is coherent.

The usual complaint about the narrow dispersion speaker is that it must be listened to on-axis and that there is only one ideal listening location. This is true, but I would argue that all speakers produce only one ideal listening location because sound time arrival must be equal from both speakers to produce a coherent wave front. Moreover, any speaker with more than one driver will have its various drivers out-of-phase at all but one precise point.

I believe in a narrow dispersion speaker, and sonically its superiority is borne out to my ears. I will agree that there is only one person who can listen critically to it and that is the person who is on the "spot". My speakers are so directional that I align them to my listening location by watching my reflection in the diaphragms and centering the speakers so that my reflection is in the center of the speakers. *[Indulging more than one vice at a time may be harmful to your psyche.--Ed.]*

To equalize and cross over my speakers I use a special network feeding a 20dB stage of gain (2MHz bandwidth) before the active electronic crossover itself. (See Fig. 9) The electrostatic panels need a low frequency corner at about 400Hz with a 3dB per octave fall off below that. The series 10k resistor (R1) of the filter is well below the 50k input impedance of the gain stage.

The capacitor in the filter is determined by the formula $F = \frac{1}{2}\pi RC$ where R is the series resistance in Ohms, C is in Farads ($1x10^6$ microfarads). Thus C is .000000039 or roughly .04µF for 400 Hz. Choose the high frequency corner with the same formula but shifted to find a shunt resistance (R2) or $R = \frac{1}{2}\pi FC$. If R2 equals about 2k, your high corner will be just below 2kHz. If R2 is a 5k variable pot your range will be 795 Hz. to somewhere above the hearing range.

Room acoustics and source material will affect where you set this control--from dull to very bright. The frequency and the resistance are inversely related--the higher the resistance, the lower the corner frequency. Also, the slopes are gentle and the 3dB corner does not mean that the response is flat from that point on. It continues to fall slowly, and becomes flat finally at around 20kHz.

THE SOUND

NO DISCUSSION OF A PROJECT of this magnitude would be complete without telling you what to expect from the sound. Obviously anyone who attempts this project will do so because he is determined to improve upon present equipment that is available commercially. To this end I can recommend this system without reservation. The sound is not particularly impressive at first listen--it is just terribly natural. The problems that plague other speakers and tell you that you are listening to a speaker; like poor resolving power, poor imaging, boxiness, poor frequency response, edginess, etc., are simply absent in this system. The speaker does not have the typical "electrostatic sound" caused by the rising high end previously mentioned which makes them sound bright and thin. On the other hand, the legendary electrostatic detail is there.

The highs I found surprising. For the first time I was hearing a speaker that had extended highs with good detail that did not sound edgy and exaggerate hiss and noise. The high end is so smooth that there is just no listening fatigue. I attribute this to the lack of tweeter resonances. Hiss actually seems to be supressed. Yet, the frequency response is right as proved by listening to master tapes of live orchestras.

Imaging is amazing. It is three dimensional and rock stable. For the first time I can clearly hear the hall sound and ambience as it was recorded. The sound is not ruined by room acoustics.

I wish to publicly thank Mr. David Hermeyer for all his assistance, without which the project would undoubtedly have been less successful. I will be pleased to assist anyone with this project and would enjoy hearing of your experiences.

Write or call Roger R. Sanders, 1578 Austin St., Atwater, CA 95301 (209) 358-1427.

NEXT TIME we will publish author Sanders' modification of the Hermeyer electrostatic amplifier, a smaller, lower powered version.

MYSTERY CODE?

Your address label has a "code line" above your name, as below:

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The first five numerals are your ZIP code (six for Canadians) a space follows and then the first two letters of your last name (so we can sort within ZIP codes). Another space is followed by a zone number which we need for our report to the Postal Service. This is followed by another space and dots and some numerals. Those last numerals are your "expire" code.

In our example above "567" mean this subscriber has a three year subscription for 1975, 1976 and 1977. The dots indicate years of TAA he doesn't have--so far as we know. Those whose expire code reads 01234567 have it all--through 1977. Those whose last number is a "5" expire after issue #4, 1975 series. If you have earlier issues not listed in your code line, don't worry about it. If you order them separately we don't add them to your code (lazy us).

PARTS LIST
(for 2 complete cells)

All dimensions in inches

WIRE STATORS:
1/16" Plexiglas
8 pcs. 38 x 1
8 " 20½ x 1½
8 " 22½ x 3/4
8 " 36½ x 1¼
20 " 20½ x ½
1056 pcs. Straight & Cut Wire, 0.050 x 36

PERFORATED METAL STATORS:
1/16" Plexiglas
8 pcs. 37 x 1½
8 " 20 x 1
20 " 20 x ½
4 " Perforated aluminum or steel .024" 1/8 holes on 3/16 centers, staggered 21 x 36

BOTH TYPES OF CONSTRUCTION REQUIRE THE FOLLOWING PARTS:
2 - ¼ mil mylar film 48 x 36 (double quantity for safety)
1 tube Fine powdered graphite
8 oz. Epoxy
2 - 4-40 bolts ½" long with nuts
2 - steel 1 x ¼ x 44
2 - steel 1 x ¼ x 29
4 - 6-32 bolts 2" long with tape
12 ft. Double sided sticky tape
Plain cellophane tape
Aluminum foil
Roll ½" Masking tape
Qt. RED GLPT high voltage insulating varnish
10" Copper wire (bare 20 ga.)
1 - Plate glass ¼" thick to fit panel
1 - Package of rayon balls

Speaker frames, connectors, etc. as desired

OLD COLONY will consider offering a kit of parts for two cells with sheet aluminum stators and cut plexiglas parts if enough readers express interest. Estimated price, complete, is expected to be $150. delivered.