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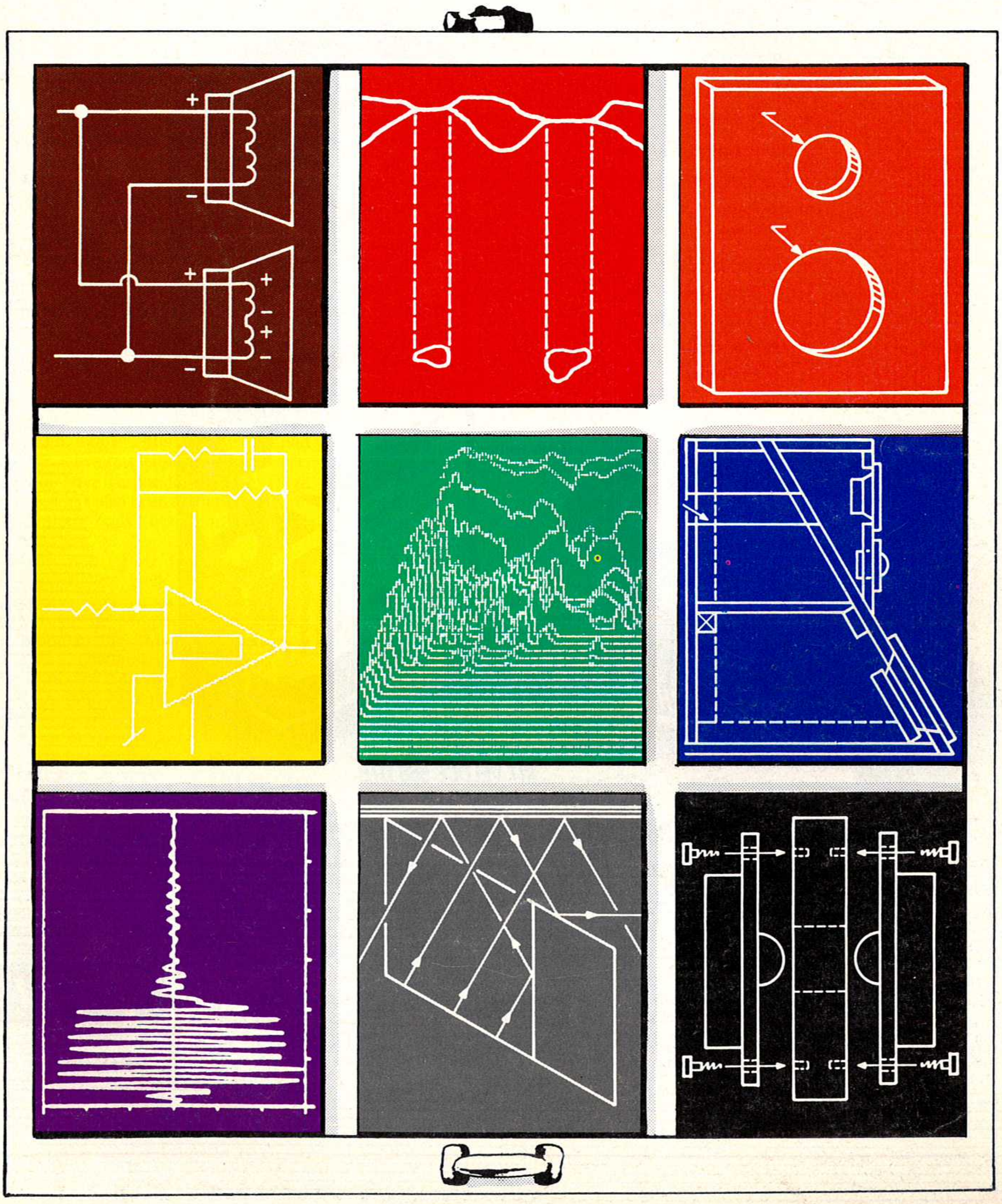

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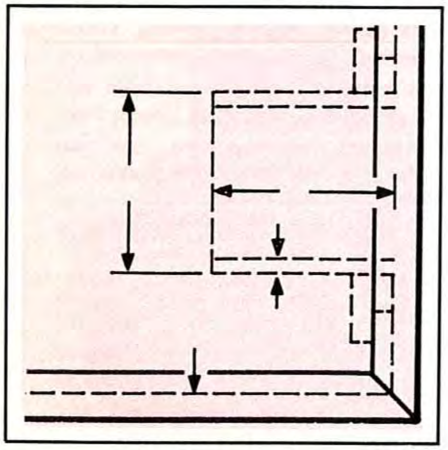
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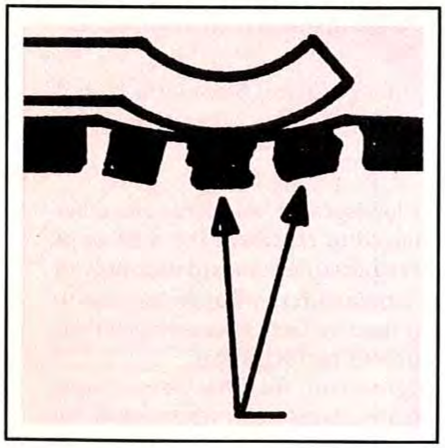
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FEATURES

DEPARTMENTS

Part III

A COMPACT INTEGRATED ELECTROSTATIC/ TRANSMISSION LINE

BY ROGER R. SANDERS

This transmission line (TL) has a strange shape and looks difficult to build but is no more difficult than other TLs, all of which are more complex than your basic box. I'm no carpenter, but I built these without much trouble. You need no special tools, as most of the cuts can be made with an ordinary circular saw and a long straightedge. Typical speaker enclosure construction is used, consisting of ¾" particle board screwed and glued together. I constructed mine in one weekend. Because I wanted them to be attractive, I had a carpenter apply Formica to the cabinets.

The TL is tapered both front to back and side to side for minimum resonance. Most TLs are a constant width, that produces one significant resonance. Probably the most unusual aspect of this TL is that it is a parallelogram rather than a rectangle in cross section. I did this for performance and aesthetics. A planar ESL is laser beam directional and must be aimed toward the listener. It must be angled inward at 15 to 30° for optimum soundstage presentation.

If you place the ESL at the front of a rectangular enclosure, you must angle the entire enclosure inward. Most people find this unacceptable. The problem could be solved by setting the ESL back from the front of a rectangular enclosure so it could be angled but hidden by a surrounding grille cloth. Then you could place the rectangular enclosure against the wall in the normal fashion, the woofer would fire perpendicular to the wall, and the ESL would be angled inward. The audible problem with this is the ESL would be out of the plane of the woofer and would not have free dipole radiation around the back of the TL. Aesthetically, it is unattractive because the surrounding grille cloth makes the speaker appear as a large box.

I decided to leave the enclosure sides perpendicular to the wall and angle the entire face of the speaker. Not only does this make an attractive enclosure, but it is the key to the rear-wave beam splitter. By picking the right width to depth ratio on the vertical part of the TL and putting the ESL inside, the TL will intersect about two-thirds of the rear beam. Different surfaces of the TL are then used to reflect parts of the rear wave in directions not usually covered by conventional dipoles, which produces the casual dispersion desired.

You may want to consider a curved ESL. Although this would have the disadvantage of wide dispersion, it would allow a rectangular enclosure with part of the ESL facing the listener and the basic enclosure perpendicular to the wall.

The drawings are somewhat difficult to visualize because of the angles (*Figs. 1–3*). To make them easier to interpret, the front and side views are drawn as though the enclosure were a rectangle rather than a parallelogram. The dimensions are essentially the same in either case. Just make the cuts at the required angle rather than the normal 90° angle, and you will automatically end up with a parallelogram when you assemble it.

IMAGING CONSIDERATIONS. Unlike magnetic speakers, ESLs sound the same no matter how close you are to them. This makes it possible to have different stage presentations based on the percentage of room acoustics in the image. If you sit far away, the performers will sound as though they are in your room. If you sit very close, you will think you are in the concert hall where the recording took place. Close seating has other advantages as well, including higher SPLs, improved detail resolution, more precise instrument location and greater intimacy with the performance. The effect is much like listening to good headphones but without their bizarre imaging.

Another consideration is image width. Since planar ESLs have such excellent imaging ability they may be more widely spaced than wide-dispersion magnetic speakers without developing a hole in the middle of the image. I have found they can present perfectly an image 60° wide. Thus, you can set them up to form an equilateral triangle with your listening location. I have set up a very small equilateral triangle only 5 feet on a side. The resulting image is astounding, but your eyes can play tricks on you until you get used to this position. Initially, visual clues tend to contradict and override what your ears are telling you, suggesting a compressed image. If you close your eyes, the image opens out into the concert hall.

After deciding your preferred listening distance, determine the angle required to have the speakers face your seat. This may be up to 30° for each speaker. Note that angles less than this will reduce not only the soundstage width but also the effectiveness of the rear beam splitter (*Fig. 3*). For optimum performance, your seating position should not be against a wall or the sound will be smeared by wall reflections immediately behind you. If you must sit near the wall, put some sound-absorbing material on it.

If you don't want a chair in the middle of your room, consider my solution. I have two tiny marks on the carpet for the front legs of my listening chair, which is normally near the wall. I place the chair on the marks for serious listening, but the rest of the time it is out of the way.

CONSTRUCTION. Remember to make

PARTS LIST

TL

2	Particle board 0.75″ × 4′ × 8′
2	Driver, Dynaudio 24W75
1	Grille cloth, Mellotone flameproof 30″ × 8′
Misc.	Screws, glue, paint, Formica, connectors, wire, aluminum bracing, wool or polyester damping material

ELECTRONICS

2	Transformers, audio, Triad S-142A
2	Electronic crossover, assembled module, Biamp 650Hz 18dB/octave, DeCoursey #9078
2	Gain/equalizer, assembled module, DeCoursey #871
1	Power supply, 3kV, 0.01mA
Misc.	Chassis, switches, jacks, connecting cables, plugs

mirror-image parts for the left and right cabinets. All these angles make for some interesting cuts, but if you pay attention, it is not difficult. To make the long vertical cuts at the required angle, clamp an 8′ straightedge (aluminum bar stock 1½″ by ¼″) to the wood with C clamps along the required cut. Adjust the foot plate of the circular saw to the required angle. Run the saw along the straightedge to make the cut. Your saw's foot plate will probably not tilt the other way to make the mirror image cuts, so run the saw from the other direction. You cannot run the circular saw completely to the right-angle corner on one side of each front and rear piece without cutting into the face of the enclosure. Just get close to the corner and finish the cut with a handsaw. The power saw's kerf makes a good guide.

If you are careful, you can get the screws in at the appropriate angle freehand. I found it easier to drill one screw hole at each end of the enclosure and assemble the two parts temporarily using only those two screws. Be careful not to tear out the screws while you finish drilling a string of screw holes down the joint. I put screws about every 6 inches. An assistant is essential during this process. After the holes are drilled, disassemble the two parts, apply the glue and reassemble them using all the screws. With all the screws in place, the parts are stable, and you can use the same process on the next part.

Perfect joints are nearly impossible because the wood tends to slide, but this is not critical. Use a belt sander or plane to trim the overhangs after the glue is dry. Don't forget to insert the damping material before you put the last piece in place.

Note that the woofer goes on the tapered side of the enclosure. This helps balance the front-heavy speaker and aims the ESLs slightly upward so you are not listening at the joint between the two panels.

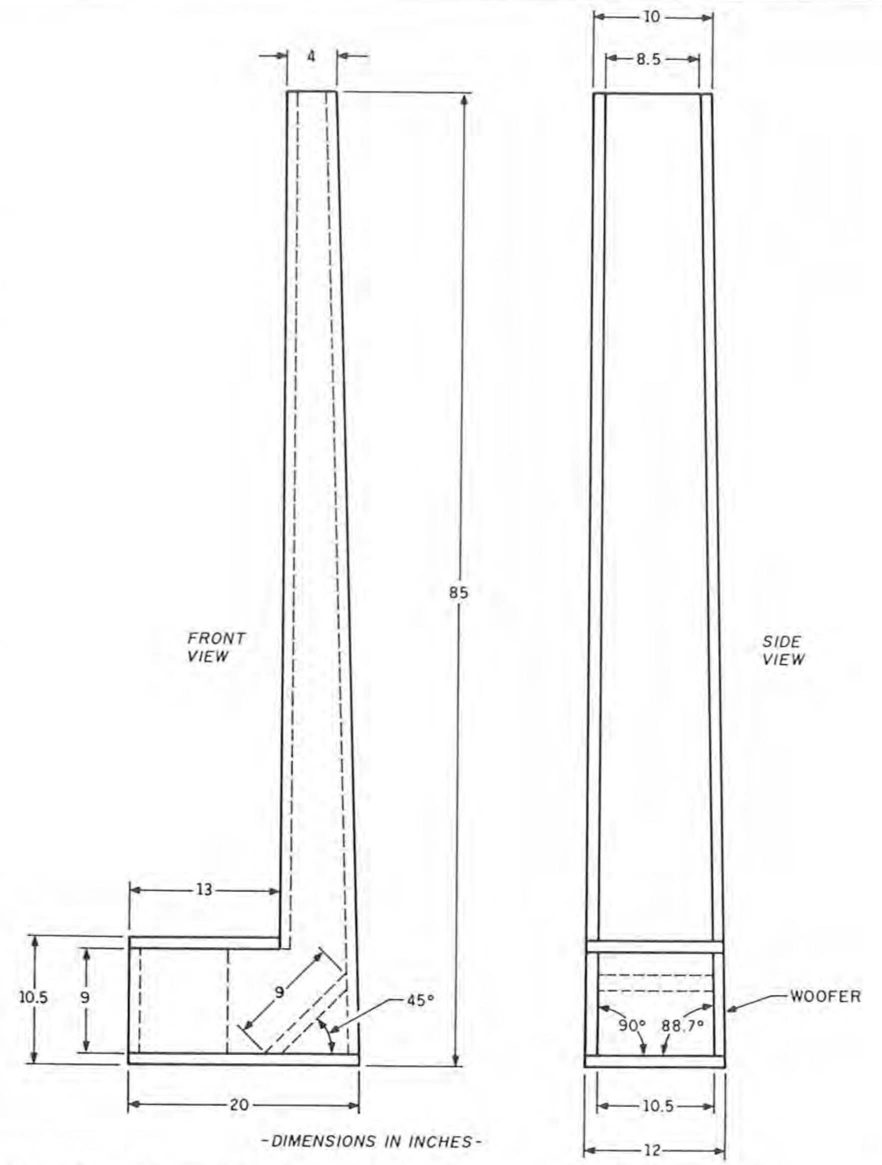

FIGURE 1: Front and side views of enclosure.

Virtually all woofer systems reflect the rear wave off the back wall of the enclosure and radiate through the woofer cone into the listening area. You can solve this problem by placing a 45° baffle directly behind the woofer to direct the sound waves down the line rather than allowing them to reflect back through the cone. Place a 45° baffle at the 90° turn in the line to direct the sound up the line rather than reflecting it back into the woofer. You can make these baffles out of scrap particle board.

DAMPING MATERIAL. This design has very tight dimensions, and you must be careful not to overstuff it. Too much damping material will wipe out the deep bass.

Natural long-fiber wool is the best damping material, but it is costly, hard to get, and must be mothproofed and supported. Expect to use about ¼ pound or a little less per cubic foot. I prefer constant-impedance stuffing, which must be packed more tightly near the woofer than at the port. Staple some nylon webbing into the line about every foot to support the wool and keep it from settling. Sprinkle moth crystals in with it and be sure to use a grille cloth over the port to prevent moth entry.

There is little audible difference between wool and synthetic materials, so polyester fluff is commonly used. If you have a choice, use fine rather than coarse polyester. Polyester is cheap and readily available, moths hate it, and it does not need support. Under a microscope, the fibers are smoother than wool.

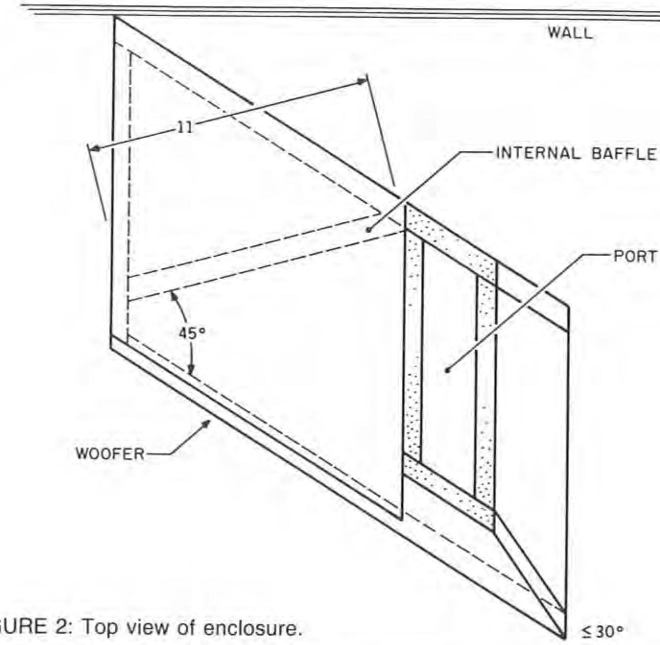

FIGURE 2: Top view of enclosure.

Hence it is not as good for impeding sound, so stuff it a little more tightly than you would wool.

Fill the line loosely; but put in a little extra near the woofer. Too little stuffing is better than too much. Do the finish work before you stuff the area behind around and install the woofer itself. It is easy to finish stuffing through the woofer opening. The wiring can also wait until the last minute.

DRIVERS. Which driver is best in a TL? Unlike ESLs, magnetic drivers are extremely complex and unpredictable. How do you pick a good one? I use a combination of logic and luck, which has served me well. My philosophy is simple: 1) use the largest driver possible consistent with design limitations; 2) buy the best quality, most advanced drivers available; and 3) spend whatever money it takes to achieve numbers 1 and 2. Drivers are inexpensive, so don't cut corners here.

The Dynaudio 24W75 best meets my criteria for this design. I originally planned to use an 8″ woofer, but this 9″ unit offers high quality with hexagonal voice coil wire, a plastic cone, a very large spider, superb frequency response, and excellent power-handling capacity. It also has a very shallow cone, which minimizes phase alignment problems. I did not test any others in this design, but I would be surprised if you can improve on this one. I expected clarity and linearity from this compact TL system, and I was not disappointed. But I was not prepared for the degree of deep bass extension and power handling that these speakers exhibit.

TL TESTS. I was concerned I had made so many compromises in the interest of compactness that performance would be unacceptable. With considerable anxiety I substituted them for the woofers in my big system, that uses the excellent 12″ Dynaudio 30W54 in a large cross-section 10′ TL stuffed with wool. Its performance is truly outstanding. To expect a compact system to approach this level of performance seemed unreasonable.

I was amazed when the little system matched the big one in almost every way. There were two differences. First, as expected, the small system was not as efficient, requiring that I turn up the bass amplifier to match the output of the ESL. This presented no problem, however, as I could not drive it into obvious distortion even though I was seeing in excess of 105dB on my SPL meter. The other difference was in the deep bass response, which was not quite as extended as in the big system. This I also expected, but the difference was remarkably small. Good woofer systems literally make the floor move without sounding strained. You feel the bass rather then hear it. This is the first woofer system under 10 inches that I have heard do this, and it does it with ease and authority.

MOUNTING THE ESLs. The method of mounting the ESLs to the TLs may vary depending on the ESLs you build. I attached some wood strips along the TL to form a slot for the ESLs. The opposite edge and unsupported top edge are braced with aluminum strips similar to those used for the cutting guide. I used 1 by ⅛″ aluminum, which is easy to bend without cracking and can be cut with wood tools. I also used 8/32 nylon bolts to maintain insulation.

Physical phase alignment between the ESL and TL is not critical in this design because the relatively low frequency crossover is below the region where the ear is sensitive to phase abnormalities, low-frequency wavelengths are long so errors are minimized, and the woofer cone is shallow. This is fortunate because there was no alternative but to drop the woofer from ear level to the floor, which results in a longer sound path for the woofer than for the ESL. A good rule of thumb is to place the ESL diaphragm in a plane about one-third the way down the woofer cone. In this design, that means the ESL diaphragm should be recessed only ¼ inch from the front of the TL cabinet. I don't think this speaker can be optimized for phase unless it is angled severely backward so the ESL and woofer are equidistant from your ears. Obviously, this would be aesthetically unacceptable. I suggest you place the ESLs reasonably close to the front edge of the TL and don't worry about phase alignment. Listening tests have not revealed any serious phase problems.

GRILLE CLOTH. Grille cloth impairs sound quality. Close-weave fuzzy cloths and thick foam are the worst. The best are the open-weave smooth plastic cloths made by Mellotone. Flameproof Mellotone cloth is not cheap but is difficult to detect sonically. Other than cost, the only disadvantage is its sheerness, so you must paint your cells black lest they show. I do not use grille cloth, but omitting it is aesthetically unsatisfactory. Like reduced SPLs and deep bass extension, grille cloth is part of the compromise of an aesthetically pleasing speaker.

To test grille cloth, mount it on some type of frame and have someone alternately put it in front of the speaker and then take it away while you are listening to a wideband complex source. Use blind testing, otherwise you will be convinced the sound has changed just because you see an obstruction. You should readily and reliably be able to tell when the grille cloth is on.

ELECTRONICS. Audiophiles get all worked up over trivial differences in their sound systems while overlooking major areas of improvement. A good example is the listener who spends thousands of dollars repeatedly trading one amplifier for another while continuing to operate

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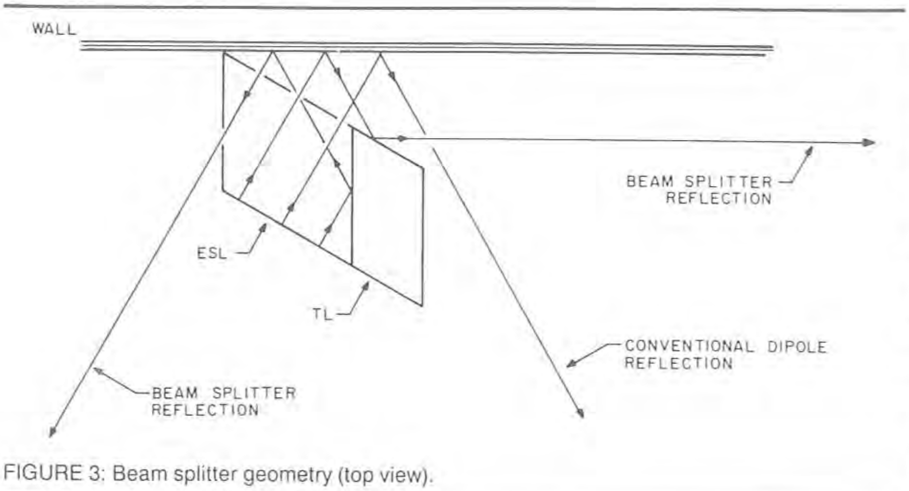

FIGURE 3: Beam splitter geometry (top view).

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his speakers with passive high-level crossovers. The superior sound quality of low-level active (electronic) crossovers used with multiple amplifiers is obvious, but amplifier differences are subtle at best. All my speaker systems have electronic crossovers and multiple amplifiers. I consider this essential (*Fig. 10*).

Since no electronic component is as pure as one that isn't there, it doesn't make sense to have a preamp. We use preamps for RIAA equalization in analog disk systems, which I believe are obsolete. Digital audio's flaws are fewer than those of commercial analog systems. Analog tape has always been superior to analog disks, but manufacturers have not used tape to its full potential.

If you still have an analog disk system, I recommend you copy any music of interest to a quality tape system; discard your turntable, preamp and disks; and use a passive attenuator and switching network to adjust gain and select sources. Similarly, tone controls are unnecessary with a top quality speaker system. If you feel tone controls are essential, you need at least a 10-band equalizer, not tone controls on a preamp. If your attenuator tracks well, you don't need balance controls either. In short, there is no longer any need for a preamplifier.

It is easy to build a passive attenuator/switching unit. You can customize it to your specific needs; then incorporate it into your gain/equalization/crossover electronics, which I will describe shortly. I use the AR Remote Control because it offers power, gain, balance, muting and selection of two sources without any detectable influence on sound quality. It is cheap, convenient and has perfect gain tracking between channels. The AR has two shortcomings: its power switching is limited to 600W (a problem shared by virtually all preamps as well), and it switches between only two sources. You can solve the power problem by using the unit to turn on a large power relay that switches on the rest of the system. I have a switch in my gain/equalization chassis that allows me to select one of several other sources.

CROSSOVERS. I chose Butterworth filters because they are maximally flat in the passband and in odd-order designs they afford constant voltage and power levels through the crossover regions.

First-order Butterworth filters are low in phase shift and have constant output through the crossover point, but they roll off at only 6dB/octave, which requires a two-octave spread beyond the crossover point for the drivers. For example, for a 550Hz crossover, the woofers should be linear up to at least 2,200Hz and the ESLs should be linear down to at least 136Hz. This is not practical.

Second-order filters have 12dB/octave slopes, which are steep enough for most speakers and widely used in passive high-level crossovers. Unfortunately, there is a definite, audible discontinuity at the crossover point. You can make this "hole" less noticeable by reversing one speaker, but there is still an audible imperfection.

Third-order, or 18dB/octave, filters correct these problems. In addition to a maximally flat passband, they maintain a constant sound level through the crossover point. Driver cutoff is sharp, minimizing extended frequency response requirements. The smooth, gradual phase shift across the band is not objectionable.

You can use steeper sloped filters, but phase shift becomes a problem and it is difficult to obtain parts precise enough for proper performance. Therefore, I decided to use 18dB/octave slopes.

Select the crossover frequency carefully. The advantages of a low crossover frequency (less magnetic driver energy in the midrange, flatter frequency response, less critical phase performance and better driver blending) must be balanced against high output. I have chosen a 550Hz effective crossover point for optimum results. If you demand a lower crossover point, more equalization will be required, the ESL will have to produce more bass, voltage requirements will be higher, and driver excursion will be greater. All these conspire to reduce output. The ESL can be operated down to 150Hz, but the TL is so good that the subjective difference between a crossover at 150Hz and one at 550Hz is nil, while the difference in output is dramatic.

You can obtain crossovers from several sources, as well as build them yourself. *[Several kits are available from Old Colony, PO Box 243, Peterborough, NH 03458.]* You need precision components, however, and these can be difficult to obtain. Complete circuit boards are often cheaper than building your own. I use units built by DeCoursey Engineering Laboratories. They come in both hardwired and plug-in versions, are about 2″ square and are glass epoxy with quality components. They cost about $50 per channel. The part number for the plug-in version is 9078. The crossover point should be specified at 650Hz, which yields a 550Hz crossover point when mated with the necessary gain/equalization stage.

EQUALIZERS. As I mentioned, the speakers use a modest amount of equalization to compensate for phase cancellation. You can accomplish this equalization passively but with an insertion loss of around 18dB. Most systems don't have much extra gain, particularly when driving high-powered amps, which typ-

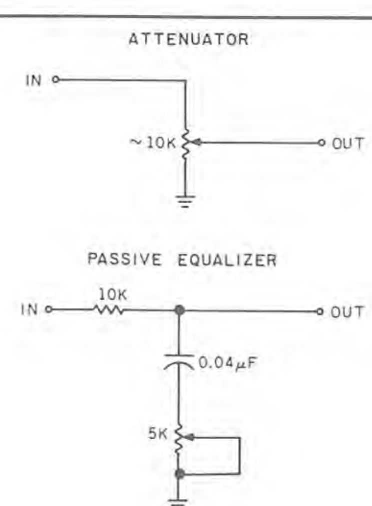

FIGURE 4: Passive and active circuits.

ically need high drive voltage. For this reason, I use an active circuit with a small amount of gain. Both passive and active circuits are shown (*Fig. 4*).

If you use the passive circuit, measure its response with an audio generator and voltmeter to adjust the response to match the curve (*Fig. 5*). Because it is influenced by your amp's input impedance, you must tailor the components to the amp. Be sure the amp is connected to the circuit when making adjustments. The active unit is buffered from the amplifier, so the components are precise and no measurements are required.

You can build the equalizers yourself, but DeCoursey offers them for about $50 per channel (part #871). The units are slightly smaller than their crossover boards, use the same power supply, plug into the same type of sockets and will fit into the same chassis.

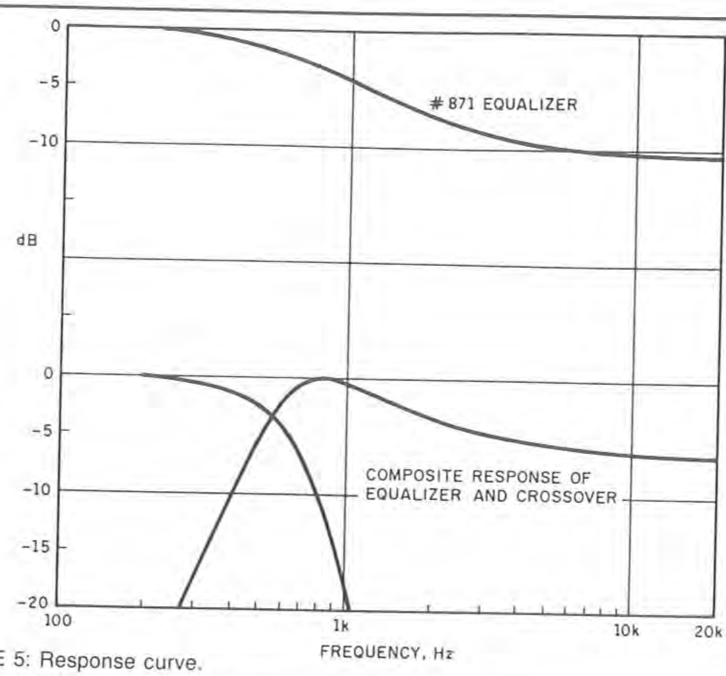

FIGURE 5: Response curve.

ELECTRONICS ASSEMBLY. Assemble the equalizers and crossovers in the same chassis with a common power supply. If you wish, add an attenuator (*Fig. 6*) to control overall system gain, a rotary selector switch for choosing different sources and a few RCA jacks on the back panel to provide a complete control center/gain/equalization/crossover unit in one small chassis. DeCoursey also sells the chassis with everything installed and ready to use.

VOLTAGE SURGES. Voltage surges occur when the unit is turned on or off. To avoid amplifier and speaker damage, these must be suppressed. Most amplifiers are AC coupled and will tolerate surges when first turned on, but DC-coupled amps may blow woofer cones right out of the cabinet. Leaving your electronic circuits on at all times prevent turn-on problems. They use practically no electricity and will probably last longer this way. If you must switch them on and off, use a delay relay in the output to protect your amps.

DC OFFSET VOLTAGES. Most low-level electronics have a trace of DC offset in their output. Most amplifiers are AC coupled, which blocks this DC voltage. Some modern amplifiers are DC coupled, however, and will amplify DC voltage. With these, there must be no DC component to the input signal. If there is, the DC will be amplified and the transformers or woofers can overheat or have their operating parameters reduced by the steady current. You can solve this problem by turning your DC amp into an AC amp by putting a capacitor between the crossover and the amplifier.

In double-blind A/B comparison tests, I found the effect of a good DC-blocking capacitor audibly undetectable. If you think otherwise, obtain the IC application notes used in your particular crossovers and build a DC offset adjust circuit to null the output. The same holds true if you use a differential tube or discrete transistor circuit. In that case, you must also use regulated power supplies, leave the electronics on all the time for stability and check the output for DC occasionally, particularly when the unit is new. Your ESL amplifier should run almost as cold as it would if it were not driving any speakers. With matching transformers, they should run cold. If your amp or transformers get hot, look for DC problems or supersonic oscillation.

LEVEL MATCHING. You will undoubtedly discover that the various amplifiers and drivers will not match in loudness. The woofer will be louder than the ESL. Therefore, you must put an attenuator in the woofer circuit to bring its level down to that of the ESL. Many basic amplifiers have input level controls that do this. If yours does not, you may add them or incorporate level controls in your equalization/crossover electronics. A suitable schematic is shown (*Fig. 6*).

AMPLIFIER CHOICES. You will need a very powerful amplifier for the ESLs and a modest one for the TLs. It may seem crazy to use a 500W stereo amp to drive tweeters, but that's what it takes to do it well. ESLs are extremely efficient (power dissipated vs. acoustic power generated), and they dissipate an insignificant amount of power, so at least you don't have to be concerned about burning them up. The TLs are reasonably efficient; an honest 60W amplifier should be adequate. The woofer amp quality standards are much more relaxed than those for the midrange amp. To save money, you might want to build a kit. I now use a Hafler 500 on the ESLs and a Hafler 220 on the woofers, but for years I was happy with a Williamson Twin 20 on my big woofers. *[The Twin 20 is no longer available from Old Colony. The 40-40 is being closed out.—Ed.]*

Direct drive amps capable of the outputs I consider adequate are not, in my view, practical. If you wish to design and use one, see my article, "The Sanders Electrostatic Amplifier," (*TAA* 1/76) or David Hermeyer's "An Electrostatic Speaker System," (*TAA* 4/72). *Audio Amateur Loudspeaker Projects*, available from Old Colony, also offers plans for two direct drive amps.

One possibility for a new type of amplifier is one with a power supply or bias circuit that can vary voltages in response to the musical demands. Or perhaps a dual amp with a high-voltage/low-current section for the lower frequencies and a low-voltage/high-current section for the higher frequencies might work. This should greatly reduce the power requirements. I would be interested in hearing from anyone who develops a satisfactory direct drive design.

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ESL MATCHING TRANSFORMERS. As discussed earlier, when using conventional amplifiers, you must raise their output voltage drastically to drive the ESLs. This requires special transformers which, although available and reasonably priced, are difficult to find. Look for audio output transformers designed for small, high-quality tube amps. The transformer must have the following characteristics:

1) A high turns ratio (at least 40:1). The turns ratio is the square root of the secondary impedance divided by the square root of the primary impedance.

2) Adequate power handling. A conventional 15W audio transformer designed for wide bandwidth and good bass response is adequate for even the largest amplifiers when operated above 300Hz.

3) Flat frequency response when driving a capacitor of around 1,600pF.

4) Adequate insulation to handle the voltages developed. 1,500V RMS seems to be all that is readily available. Keep in mind, however, that we are working with peak voltages and 1.5kV RMS converts to 2.1kV peak-to-peak. These ratings must be very conservative because such transformers don't arc even when putting out more than 7kV. Transformers are normally used to drive essentially resistive loads, and are therefore tested into resistive loads. You cannot trust the manufacturer's specifications. When driving a 1,500 to 2,000pF capacitive load, a transformer's high-frequency response will be only about one-third of what the manufacturer specifies.

You must make a few compromises when evaluating transformers. First, to obtain an extended high-frequency response, you must compromise other parameters such as the turns ratio. The higher the turns ratio, the poorer the high-frequency response. Second, you must make a similar compromise with power handling in that large transformers tend to have a lower frequency response than small ones. Conveniently, large transformers are needed for bass performance, but we are not using our ESLs as woofers.

TRANSFORMER TESTING. Unless you buy transformers known to operate ESLs satisfactorily, test your potential selection. The engineering data and mathematics available will not accurately predict the behavior of a transformer driving a capacitor. All information I have found indicates the transformer will roll off at some high frequency, which is true. What isn't mentioned is the resonant peak somewhere below that.

Testing requires a sine-wave audio generator and vacuum-tube voltmeter (VTVM) or FET volt-ohmmeter (VOM) suitable for measuring audio frequencies. Connect your generator-driven amplifier to the low-impedance side of your transformer. You will probably have a choice of various input taps, typically 4, 8 and 16Ω. The lowest impedance taps will produce the highest turns ratio, and you will want to use the 0-4Ω taps.

A knowledgeable reader pointed out that you obtain the highest turns ratio by connecting between the 4 and 8Ω taps, which produces an 8dB increase in output over the 0-4Ω taps. However, my transformer's frequency response was not satisfactory at this higher turns ratio. Test the transformer at all the taps to determine the best compromise between frequency response and turns ratio. Your choice of secondary taps is simple: always choose the highest impedance ones to connect to your load. You may use your speakers for the load, but it is usually more convenient to use a small capacitor of equal value. Connect your meter across the load for measurements. Do not exceed about 300V at the output of the transformer, or you may arc the meter.

Sweep the frequency range of interest (400Hz to 15kHz) looking for a resonant peak. A rapid rolloff will follow the peak. You will almost certainly discover a resonant peak of 3-6dB somewhere between 4kHz for a poor transformer and more than 20kHz for a superb one. I have encountered transformers with no resonant peak, but they also rolled off well below 10kHz.

I have tested nearly a hundred transformers over the years and have found only three suitable. One set came out of an old Williamson 10W tube amp, and the others were designed as small high quality tube output transformers. One of these is made in the US, and the other is Japanese. The American one is still manufactured by Triad Corporation (part number S-142A) and is rated at 15W from 7Hz-50kHz. Using their 0-4Ω input taps, it has a 45:1 turns ratio, is flat to 10kHz, +2dB at 15kHz, +4dB at 20kHz, and +6dB at 24kHz, its resonant peak. They cost about $50 each and can be ordered from any Triad dealer.

When Triad transformers are used with a Hafler 500, the combination can produce the maximum voltages that these speakers can withstand. I have occasionally seen arcing on master tapes playing extremely loud passages with tremendous amounts of timpani and French horn. If you manage to obtain a higher voltage drive, you should increase the diaphragm-to-stator spacing of your cells by using 80-mil polycarbonate insulators and increase the polarizing voltage. Otherwise, the additional voltage will not be usable.

This combination performs as well as a high-voltage amplifier. You cannot audibly detect a smooth rise of 2dB between 10 and 15kHz, and even if you could, virtually all source material is deficient in this range and can benefit from the slight boost. While the Triad transformers are satisfactory, if anyone knows of a source of better performing transformers, I would appreciate knowing about them.

HV POWER SUPPLY. You must give the diaphragm an electrostatic charge of about 3kV. But for a small amount of leakage, we would have to charge them only once and would not need a power supply. The power supply need deliver only a tiny amount of current; 0.1mA is plenty. Power supply ripple will not cause hum in this application, so quality standards are very low. No filtration,

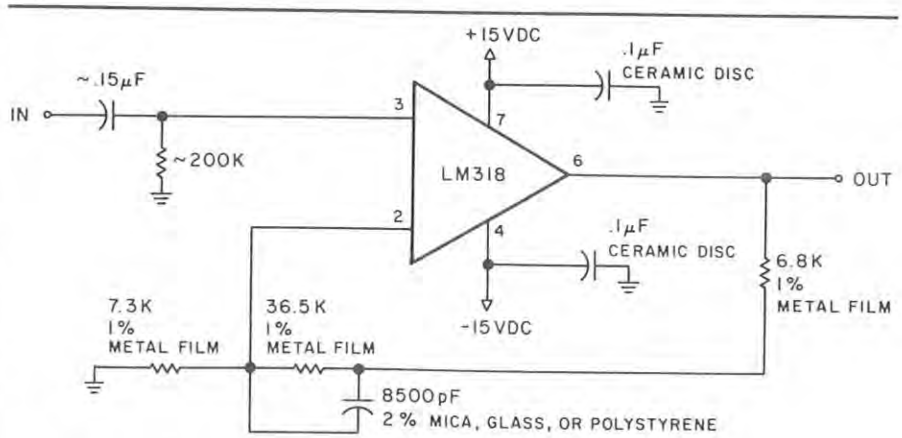

FIGURE 6: Schematic for one channel of an equalizer with gain for the electrostatic panels.

storage or full-wave diode bridges are required. Since a high polarizing voltage is critical to high SPLs, and because diaphragm tensions and building accuracy vary, you need some adjustability in this supply.

Unfortunately, there is no ready source for such supplies. Copy machine power supplies are commonly available from surplus electronics outlets for about $10. They usually develop around 7kV and will need to have their voltage reduced. You can accomplish this easily with a voltage divider at the input. Frequently you can simply add series resistance to reduce the output. Of course, the ultimate control would be a variable autotransformer, but resistance is much cheaper and more compact.

If you have some electronics background, it is easy to make a transformer/diode power supply. The catch is getting a small, high-voltage transformer rated at about 2,100V RMS, which when rectified will be in the required 3kV range. You can gang several smaller transformers, use voltage doubler, tripler, or quadrupler circuits, or use a combination of these to get the required voltage.

A well built set of cells will tolerate about 3kV of bias voltage. Cells with warped stators or a low or uneven diaphragm tension will handle only about half that. If you turn up the voltage excessively, the diaphragm will usually move over to the stator and stick there while hissing and possibly arcing. Sometimes it will move over to the stator, arc and pop back to its neutral position. It will repeat this indefinitely until the voltage is reduced. A few such arcs don't seem to harm anything, but arcing should not be allowed to persist.

If you have a bad spot, the problem will be either poor diaphragm tension, a warped stator, or a foreign object between the stator and diaphragm. Check the stator by laying a straightedge over the area. Adjust the bias voltage so the cells are always stable, but don't push it to the ragged edge, as the slight gain in output isn't worth the frustration of arcing or unstable cells.

You can mount the ESL transformers in a separate chassis along with the high-voltage power supply and keep them with your amplifiers, or you can mount them in each TL in the unused space behind the woofer baffle. The latter has the disadvantage of requiring two high-voltage power supplies, one in each speaker. You also will have to run rather large speaker wire from the amps to the transformers, and an AC power cord to a wall socket to energize the power supply. The advantage is that you will have one less chassis.

The advantages of having a separate chassis are that you need only one power supply, the wires running from the transformer to the ESL may be very small, you will not have AC power cords running all over the place, and the chassis may be specifically designed for high-voltage parts. I prefer the separate chassis. I built mine from ¼″ Plexiglas so I could mount high-voltage parts directly without having to worry about arcing to a metal chassis. Remember, when you deal with high-voltage parts, plenty of space between parts is the best insulation.

SET UP. Because of the parallelogram shape, you can place these speakers directly against a wall without compromising dipole radiation. With the exception of corner horn designs, however, it is always better to keep the speaker some distance away from the wall. To guarantee holographic quality images, you must be geometrically precise about speaker position relative to your seating location.

Begin by removing the grille cloth and squaring the speaker sides with the wall. Sit in your listening chair and look for the reflection of your face in the speakers. This is usually easy to see, but a flashlight just above your head will make it more obvious. Move your chair until your reflection is centered between the vertical borders of both ESLs, in the same location vertically on both speakers, and is centered between them left to right. If necessary, you can shim under the speakers or install adjustable feet.

Now measure from the center of the back of your chair to the reflection points. This must be the same distance for both speakers. If it isn't, then rotate at least one of the speakers so the distance is the same.

The front of the enclosure is angled slightly upward so that when you are seated, the junction of the upper and lower cells is not at ear level. You may need to shim or use a different height chair to get your reflection off this area. Failure to do so will compromise high-frequency performance and imaging.

Improper setup will prevent the speakers from fulfilling their potential. When set up correctly, the phasing/imaging is so good that moving your head to the left will not shift the image to the left as with conventional speakers, but rather to the right. In other words, your brain prefers phasing precision over loudness when determining source position.

For optimum beam splitter performance, you must have a hard surface behind the speakers. A bare wall or window is best. Heavy drapes, cork walls, or other sound-absorbing materials will reduce rear-wave output and hence dispersion. While the sound at the focal point (your listening chair) is always best, the speakers will produce adequate sound anywhere in the room because of the beam splitter.

ESL hookup wire must be able to handle high voltages, but the current requirements are very low. Therefore, the wire can be quite small. Test probe wire works well but is expensive and bulky, particularly since you need three wires to each ESL. A better choice is Teflon-coated wire, which typically uses silver-coated copper conductors. AC signals are carried on the surface of the wire, and silver is more conductive than copper. Teflon insulation is quite thin but effective. I have found 22-gauge wire adequate, and have never had arcing problems as long as the insulation has been intact, even when driving more than 7kV through the speakers.

If the wires are close together, they can become capacitively and inductively in

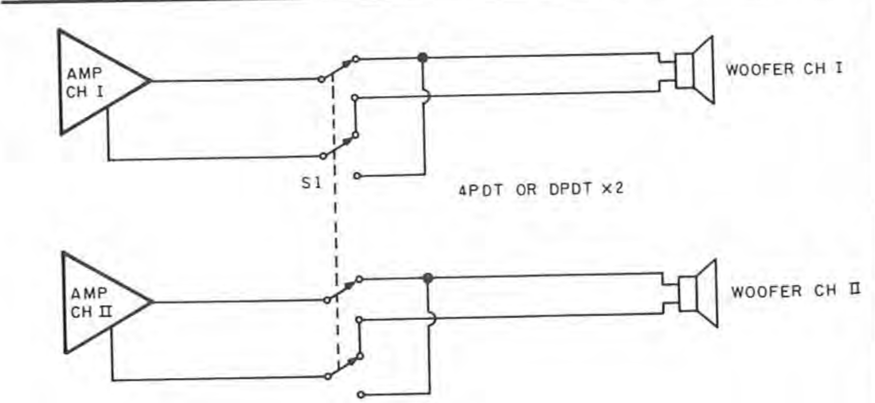

FIGURE 7: Woofer-to-ESL phase test circuit.

teractive, which results in increased stray capacitance and impedance. This is not a big problem, but you can avoid it by keeping the wires separated by ¼ inch or so.

The best high-voltage connectors I have found are plain old banana plugs. They are better insulated than other connectors, are very easy to use and have been completely reliable in my system.

Make sure the phasing between the two channels is correct. Determining the correct phasing between each ESL and its respective woofer is more difficult. You must do this by ear after the system is fully operational. The effect of ESL/woofer phasing is subtle, but generally you can detect a slight increase in fullness in the upper bass/lower midrange when the drivers are in phase. This is audible only if you have used high-quality odd-order Butterworth filters in the crossovers. It is somewhat difficult to evaluate this if there is a significant delay while you reverse the leads to your woofers. It is helpful to make an instant A-B tester (*Fig. 7*).

CRITICAL ADJUSTMENT. Matching the woofer level to the ESL level will make or break your system. I cannot overemphasize the importance of this adjustment. Without sophisticated instrumentation, you must achieve the correct frequency balance subjectively. I can offer some suggestions to help guide you.

Unlike most ESLs, these do not sound bright and thin; nor is the TL bassy and thin. Optimally, the system should have the full, rich sound of the best magnetic speakers, but with electrostatic detail, imaging and delicacy.

Adjust the bass level while listening to the midrange, which should be full but completely clean. A lack of definition in the midrange indicates the woofer level is too high. If the midrange is thin, the woofer level is too low.

All this assumes you have first-class source material. Be particularly careful if you are using a male voice as a reference. Good recordings of the male voice are rare because cardioid microphones exhibit a proximity effect when used at close range. This produces exaggerated bass and is largely responsible for the unnatural quality of male voices and guitars typically noted on commercial source material. I also assume you are using the crossover point and equalization I have specified. If not, you are on your own.

If the deep bass response is inadequate, either your source material lacks deep bass information or the damping material in your line is packed too tightly. Room acoustics also might affect the woofers, although the ESLs are immune to this problem. To determine if acoustics are a problem, try the speakers in different locations in the same room and in different rooms.

THE SOUND. It would be foolish to believe what an obviously biased designer has to say about his latest creation, so I will simply review the system's design parameters and point out what they are known to accomplish.

First, this system is electrostatic. Therefore, it has the detail, smoothness, transient response and delicacy inherent in that operating principle.

Second, I have carefully attended to linear frequency response, as demonstrated by the selection of crossover types and frequencies, equalization, rear-wave delay paths, woofer systems and driver balance. This system does not have the thin, bright, anemic character typical of electrostatics. Rather, it has a full, rich, powerful sound similar to that of the best magnetic speakers.

Third, at the outset it was clear that the biggest problem was going to be obtaining high output. I have extensively outlined the methods for accomplishing this. As a result, the system will reproduce commercial source material at levels well above those any reasonable human being can tolerate. It is even capable of reproducing "Row A" concert hall levels with clarity and ease.

Fourth, I have discussed imaging and dispersion and the unavoidable compromises associated with both. With the introduction of beam-splitter technology, I have largely resolved this very difficult issue. The focal point image has a degree of three-dimensionality and spatial definition you must experience to appreciate. The soundstage is reproduced between the speakers much as a visual image is produced by a laser holograph. At the same time, casual listening is not compromised.

Finally, distracting qualities such as edginess, exaggeration of noise, boxiness, strain and listening fatigue are absent. The speakers are neutral and able to extract full detail from all types of music. You also will not find it necessary to turn the volume way up to get the speakers to "bloom." The details can be heard at low levels.

FURTHER RESEARCH. Much work remains to be done to gain a better understanding of membrane speaker operation. The most pressing need is achieving larger excursions so smaller radiating areas may be used. The most promising approach is stacked (sandwiched) cells operated at higher voltages. These will require better transformers or acceptable direct drive amplifier designs. The cells also need to be more rugged. We need to understand why diaphragms "evaporate" as they age. Finally, the beam-splitter concept is new and needs refinement.

While these physical parameters are important, I find psychoacoustics intriguing. I have made several observations that have no clear-cut scientific answers and would like to know more about the issues. First, a single planar speaker has a tweeter beam as wide as the speaker, but when crossed during stereo listening, the beams subjectively become infinitely narrow. Second, planar ESLs sound subjectively louder than wide-dispersion ones, even though they radiate identical energies. Third, why are phase relationships so different between planar cells, curved planes, and domes/cones? I encourage anyone who has done, or is interested in doing, research in these areas to contact me with results or advice.

As always, I remain available to answer questions and assist with problems. Letters should include an SASE, and phone calls are best late in the evening (9 to 11 p.m. Pacific time). My address is Roger R. Sanders, Route 1, Box 125, Halfway, OR 97834, (503) 742-5023.

SOURCES

B & F Enterprises
119 Foster St.
Peabody, MA 01960
Various high voltage power supplies and associated parts

DeCoursey Engineering Laboratory
11828 Jefferson Blvd.
Culver City, CA 90230
Precision 18dB/octave crossovers and custom built equalizers

H & R Corporation
401 E. Erie Ave.
Philadelphia, PA 19134-1187
High voltage power supplies and transformers

Old Colony Sound Lab
PO Box 243
Peterborough, NH 03458-0243
12dB/octave crossovers and amplifier kits

Roger R. Sanders
PO Box 125
Halfway, OR 97834
Genuine ½-mil Mylar film, 4 feet wide, $1 per running foot