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4/1980

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The Linkwitz Crossover/filter/delay network

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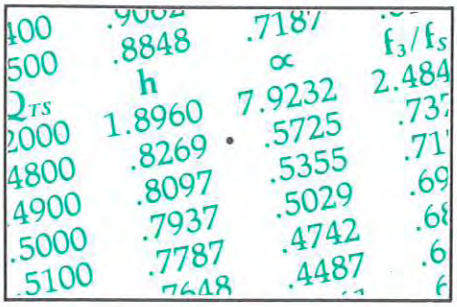
1980

SPEAKER BUILDER



400	.9002	.7187	
500	.8848	∝	f_3/f_s
Q_{ts}	h	7.9232	2.484
2000	1.8960	.5725	.737
4800	.8269	.5355	.71
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.5000	.7937	.4742	.6
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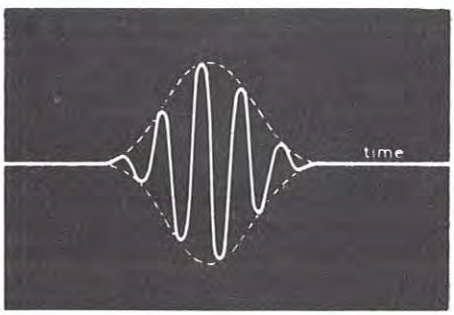


An Electrostatic Speaker System: Part III

by Roger R. Sanders

The woofer system is an important factor in the overall performance of the speaker system. Of the total sound energy radiated by the complete speaker system, probably 80% to 90% of the sound is radiated by the woofer. The ESL appears to make all the sound when you have a woofer system that is doing its job properly. In all the commercial ESL hybrid systems I have heard, woofer system problems usually destroy the system's coherence. The usual complaint is that two different types of drivers are obviously at work. The sound is not homogeneous.

In comparison to such a system, a full range ESL sounds considerably more coherent and detailed, even given its limitations. However, if you construct a transmission line speaker system to use with the ESL's the sound will be superior to a full range ESL. Electronic crossovers are a large factor in this superiority so do not attempt to operate the system without them or by using a single amplifier and a passive, high level crossover. A biamped system is absolutely necessary.

You may expect the following improvements with a T.L./ E.S.L. system: 1. greatly improved SPL's, 2. deep bass which is not available from the ESL's, 3. improved detail in the bass and midrange when compared to the full range ESL's, 4. the system will seem at ease.

T.L. construction is more complex than that of your average box. A number of designs for T.L.'s are available and I refer you to J. Theodore Jastak's articles on design and construction, particularly his first in *TAA* 1/73.

The transmission line's basic concept is to direct all the energy from the rear of the driver into a tube. The length of the tube essentially determines the low frequency cutoff of the speaker; the longer the tube, the deeper the response. Typically, 6' to 8' tubes are used, although this varies to some extent with the size of the woofer. I use a 10' tube in my design which is for 10" woofers. Some of the shorter lines can decouple from the woofer at lower frequencies so that the woofer flapping and fluttering becomes a problem. This does not occur in my design because of the 10' line. In fact, woofer excursions even at very high SPL's are amazingly small.

MULTI-RESONANT

A typical box enclosure has many resonant frequencies which markedly affect the sound. T.L.'s are generally free of resonances for two reasons: 1. The tube is tapered, which results in an infinite number of tiny resonances rather than a few large ones. 2. It is completely filled with damping material. Most T.L. designs do not use completely tapered tubes because of difficulties in construction, but have a number of steps in them to approximate a taper. My design tapers steadily along its entire length.

The tube terminates at a port. Most of the energy has been absorbed by the time the sound waves reach it. However, very low frequencies will escape the line there. I believe these frequencies have been slowed enough by the damping material to shift their phase by about 180 degrees by the time they escape the port. Therefore they come out in-phase with the woofer's front radiation and support the deep bass. However, I have no data to confirm this.

The general theory says the cross-sectional area of the line should be somewhat larger than the driven area of the woofer at the beginning and then taper to approximately the same size as the woofer area at the port. Several English engineers believe the line may be the same size as the woofer initially and taper to about 70% of woofer size at the port.

I chose to use larger areas and my enclosures are rather large. The drawings (*Figs. 17 and 18*) are for enclosures 3" narrower than mine. They will work adequately since they are still larger in cross-sectional area than the woofers and the cabinets will be more attractive.

DESIGNS & MATERIALS

Ted Jastak demonstrates several types of construction techniques which should work well if you feel that my design is too difficult to build. I have not tried them, however. My design is a composite of ideas gleaned from Jastak,[1] I.M. Fried, Reg Williamson, and Bert Webb[2]. the basic design is the classical Bailey line[3] with modifications.

I used ¾" high density particle board in construction. Although there is no such thing as too much mass in a speaker enclosure, the ¾" sides of mine do not flutter at high SPL's, and the sound is clean and free of resonances when measured with a spectrum analyzer. If you want to use 1" particle board, or cast the enclosure in concrete, do so.

I did not insert the parts in grooves because I am not much of a wood worker. I just cut the parts accurately on a table saw and used wood screws about every eight inches along with plenty of "Tightbond" glue. A certain sequence should be followed during assembly. Take one side and attach the front, back, top, and bottom. Then add the internal partitions. These form a folded tube since a tube 10 feet long behind each woofer would be rather awkward. I wait to cut the port and woofer cutout until I have this basic box constructed because it is then a rather simple task using a sabre saw.

Run the speaker wires and jacks inside the box. Once you put the last side on the box, you will not be able to do this. Staple or otherwise firmly attach the loose end of the wire near the woofer cut-out so that is will not fall back when you turn the speaker upright.

Next lay a straight edge across the internal partitions, making marks on the edges of the box to show the locations of these partitions. When you put the last side in place, you will know where to drill the screw holes.

STUFFING GUIDE

You now must completely stuff the box with damping material. There is little question that natural long fibre wool is best for this. However, it is expensive and you must moth proof it. Other materials, such as polyester fluff, fibreglass, and open cell foam can be used, although they don't damp quite as well.

If you use wool, you will need to support it with nylon mesh or a dowel every eight inches so it will not gradually compress. Sprinkle it with moth crystals before putting the side on, and use a fine grille cloth over the port.

Determining the correct amount of damping material to use is at best a guess. Even if you know how much to use, determining the density in the enclosure would be impractical. Jastak suggests using about ½ pound of wool for every cubic foot of space. The material should be set up in a constant impedance mode, meaning that it should be packed tighter behind the woofer than at the port. I ended up putting in the wool very lightly at the port and pushing it gently to compress it a bit as I went up the line.

In my opinion it is better to overstuff rather than understuff. You need not stuff the area immediately behind the woofer at this point; you can do that after the box is completed and you are about to mount the woofer.

When you have completed the stuffing, attach the last side and finish the enclosures as you choose. I puttied the screw heads

Continued on page 28

SPEAKER SYSTEM PART III

Continued from page 26

(they were counter sunk during construction), sanded the edges and joints, and painted them with flat black latex paint. You may want to put a veneer on them or wrap them with some kind of cloth. If you use the cloth, it will probably be necessary to paint them black first so that the wood and silver screw heads do not show through. For cosmetic reasons I also added a 2" rim of wood on the bottom of my boxes recessed about 1" from the edges, to form a base.

HOOKUP & BALANCE

Now hook up the woofers and the ESL's and phase them. Place them in the position where you plan to listen and spend some time listening carefully. Reverse the leads and listen again with the idea of getting the best, most satisfying sound. One phase should sound fuller than the other; this is the in-phase condition.

Finally, adjust the woofer level to match the ESL level. You will undoubtedly find that your woofers will play louder than your ESL's so you must reduce the drive to the woofer amps to match the ESL's. Presumably you have level controls on your amplifier. If not you will have to mount attenuators in your crossover output on the low pass section. See *Fig. 19* for general attenuator design.

CRITICALLY IMPORTANT ADJUSTMENT

Virtually all constructors make a critical mistake in setting up their system: they adjust the woofer so that it is too loud! This is because most of us are used to hearing the sound of conventional woofer systems that are usually designed with a pronounced peak in the area somewhere between 60Hz and 120Hz. Most manufacturers have found that linear speakers do not fare well in the typical dealer's showroom in the conventional "A-B" listening test. To sell, a speaker must sound "bassy," even if it sounds unnatural. If you doubt this, notice that your dealer probably normally runs his showroom equipment with the bass jacked up and/or the "loudness" switch "on!"

You may be used to hearing this midbass peak and you will miss it immediately in T.L.'s. Notice that speakers with this midbass peak do not sound as if they have deep bass because the bass is attenuated compared to the peak. The T.L.'s will have a lot

FIG. 17

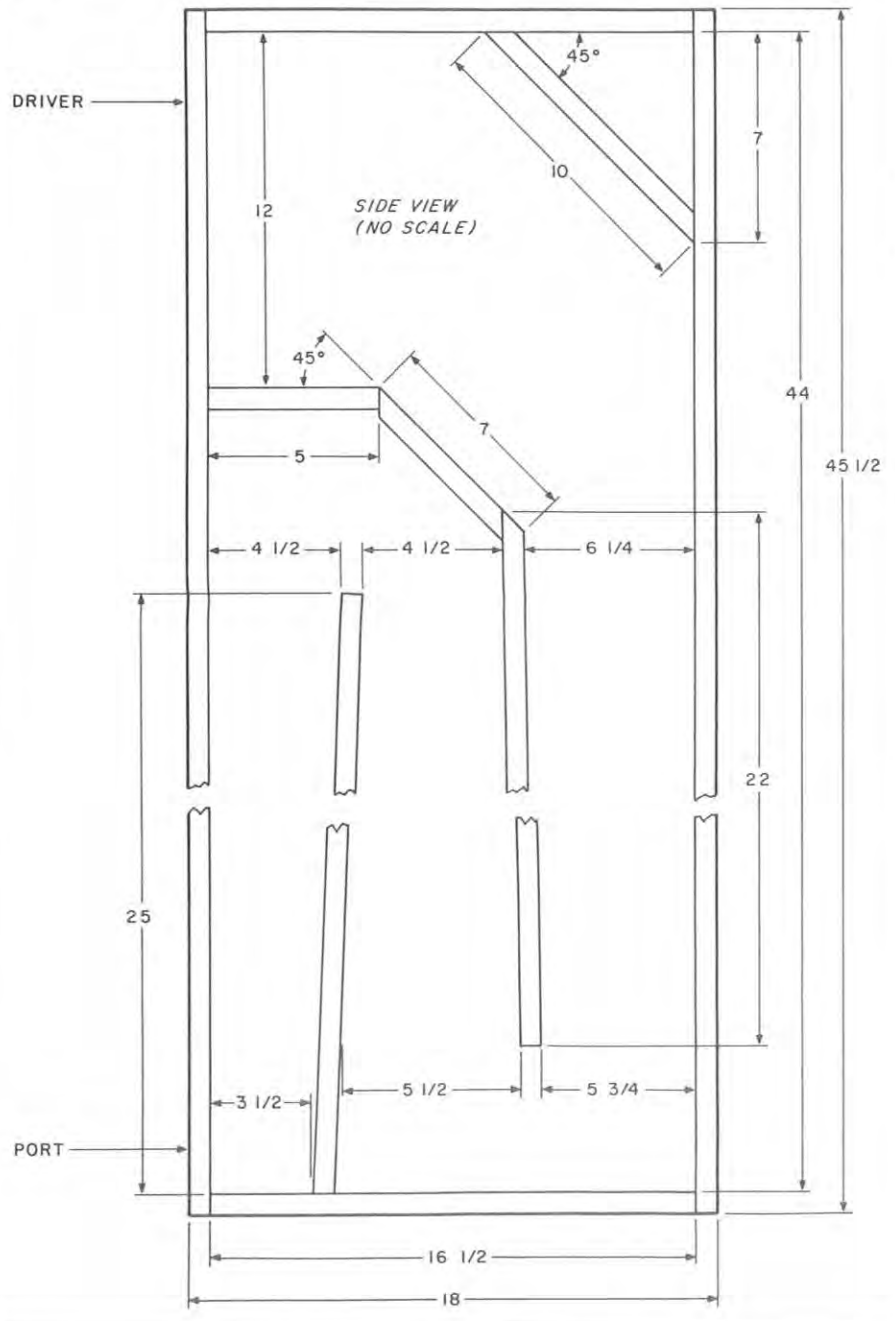
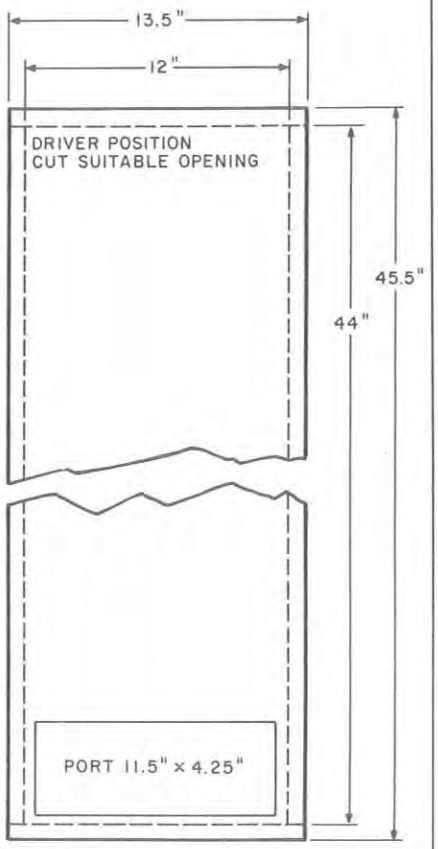
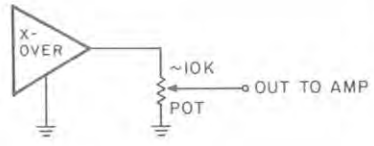


FIG. 18



Note: Entire enclosure stuffed with wool or dacron fluff. Pack loosely at port, moderately tight behind driver. Design suitable for 10" drivers, KEF B139 recommended, all wood ¾" particle board (hi density) or ply.

FIG. 19



Attenuator

of deep bass because it will not be masked by a midbass peak. Your tendency will be to turn up the level of the T.L.'s until you are satisfied that there enough bass is present. This will probably be too much woofer level. The deep bass will be exaggerated with rumble and other garbage, and more importantly, the midrange will sound muddy.

I thought I would be able to tell when the adjustment was correct, but I couldn't seem to get the midrange straightened out. I was cursing the woofers until I used a spectrum analyzer. It was then clear where the problem was. I turned the woofers down and as usual, the sound wasn't bassy enough. But after a few hours of listening, particularly to master tapes, it was obvious that this was the correct level. We get used to errors in the sound and then we can't recognize the problem.

Since few of you will have a spectrum analyzer, the rule of thumb is to listen to the midrange. If it is not absolutely clean, your woofer level is too high. Another good technique is to turn down the woofers to where you are sure they are too low. Listen to that level for several hours and then turn them up a little at a time, and listen again for a full, but clean midrange.

THE SOUND

It is difficult to describe the system's sound because nothing about it is impressive . The problems that plague other speakers, such as poor resolving power, poor imaging, boxiness, poor frequency response, edginess, distortion, etc., are absent in this system. Nor does it have the typical "electrostatic sound," caused by the rising high end and falling midrange, which makes most ESL's sound bright and thin. Yet the legendary electrostatic detail is there.

The speaker has extended highs with good detail. It does not sound edgy and does not exaggerate hiss and noise. I attribute this to lack of tweeter resonances. Hiss seems to be suppressed, yet the highs are obviously present and the system never sounds dull.

Another unique feature is that the speaker system is easy to listen to at low levels. It has been my experience that conventional dynamic speakers must be driven at loud levels in order to "bloom" and sound reasonably good. With this system, you will no longer keep turning up the level to hear the sound well. You will be listening at lower levels and enjoying it more.

The image the speaker produces is unique and must be experienced. It is three dimensional and stable. For the first time you will clearly hear the hall sound and ambience as it was recorded (although this is totally dependent on the source material). The directional design virtually eliminates room acoustics at all but the bass frequencies.

The speaker sounds as natural with hard rock as it does with classical chamber music. Many of the better dynamic speakers make good source material sound well, but make marginal material sound

Continued on page 30

THREE-ENCLOSURE LOUDSPEAKER DESIGN

Continued from page 24

til today. If a driver could be represented by a resistor then exact network values are easily calculated,[20] *Fig. 28(a)*. Real drivers have complex terminal impedances, *Fig. 18*. This not only affects the component values of the theoretical network but also the topology as can be seen by comparing the two networks of *Fig. 28*. Here a prototype design is shown for a 1.6kHz crossover between the Son-Audax tweeter and a 110mm woofer/mid-range similar to the B110 in the plywood enclosure of *Fig. 4*. Even the computer-optimized network of *Fig. 28(b)* has the desired acoustic amplitude and phase characteristic only for about one octave either side of the crossover frequency. Additional electrical equalization is required to correct for the diffraction effects below 1kHz and to extend the low frequency response to 50Hz.

The active network in contrast to a passive one can be exact because the voltage source at the driver terminals is able to impose any desired acoustic frequency response on the driver, without interaction between the source's frequency response and the driver impedance. □

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THIELE, SMALL, and VENTED LOUDSPEAKER DESIGN

Continued from page 13

Parameters obtained in this way are subject to typical production spreads of up to 20 percent. You will obtain the most accurate design by measuring the parameters of the actual driver you will use. A good, but brief description of how to find these parameters can be found in the catalog offered by EMS, Inc., who provide good reasonably priced drivers and crossovers. If you cannot do the measurement yourself, a competent audio repairman should be able to do it for you.

The foregoing design procedures take into account the actual amplifier-speaker cable to be used. Except for some integrated systems, commercial manufacturers obviously cannot do this. They probably design assuming the speaker cable resistance and R_g are both zero. If you wish to simplify the procedure you can do this too. However, response variations can easily reach several decibels, depending on the amplifier and speaker cables. Even ignoring these effects, modify Q in the presence of a crossover. Failure to do this will cause even more variation, so you might just as well include all effects. In this aspect of design, you could achieve better sound than the manufacturer.

I would also like to emphasize that these procedures apply *only* to a driver in its piston range. In other words, it is implicit in the procedure that the driver be crossed over within its piston range. If it must operate above this range, as is commonly the case in two-way systems, then the voice coil inductance and the altered mode of diaphragm vibration for example, may have a significant influence on response and you must take them into account.

In order to hone your design skills, given in the Design Box are a number of examples. The first one is in detail; the others contain only the results so you can do the calculations. The drivers in the examples are actual units I have used, and I measured the parameters. My bass amplifier is the ST 150 for which I measured R_g. The Pass A40 was built by a friend and is an impressive sounding amplifier with a most awesome damping factor of 500. Using it you could surely ignore R_g.

Thiele-Small alignments provide an accurate, predictable design method for the home builder, with a potential for sound superior to any commercial system using raw materials of equal quality. I encourage you to build a vented system using these procedures and prove it to yourself. □

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AN ELECTROSTATIC SPEAKER SYSTEM PART III

Continued from page 29

awful. This design corresponds well with everything. It is able to extract as much detail as is available from the source material without exaggerating any of the distortions or edginess present in so much of our corrupted source material.

SUMMING UP

I hope this series of articles has been useful to the home constructor. I am confident that those who build the system will be awed by their accomplishment, particularly when they hear the results. I wish to again thank David P. Hermeyer for his invaluable assistance several years ago, when the idea of my ESL was still a dream. Many of the techniques described here were developed by him and he generously allowed me to publish them. Thanks also to Bob Unterbrink for all his work and experimentation on practical methods of building the curved ESL's.

As always, I stand behind my work and remain willing to answer questions and assist readers who may be having problems. I would appreciate a S.A.S.E. if you write, particularly from foreign correspondents. I can also be reached evenings at 209-358-1427 California time. □

SOURCES

The Audio Amateur, P.O. Box 576, Peterborough, NH 03458. ESL and electronic articles.
DeCoursey Engineering Laboratory, 11828 Jefferson Blvd., Culver City, CA 90230. Precision 18dB/octave electronic crossovers.
Old Colony Sound Laboratory, P.O. Box 243, Peterborough, NH 03458. Electronic kits nd parts, Williamson amplifiers 12dB/octave crossovers.
B&F Enterprises, 119 Foster St., Peabody, MA 01960. Surplus electronics & power supplies, catalog available.
Roger R. Sanders, 1578 Austin Street, Atwater, CA 95301. ESL matching transformers ($35 each, $40 foreigners) Polyester film 36" width, (25¢ running foot).

PARTS LIST

8 Perforated metal 24" x 36", 20 to 36 mil thick
40 Insulators (1/16" acrylic sheet or 80 mil polycarbonate sheet) 0.5" x 22.5"
16 Insulators 1.5" x 22.5"
16 Insulators 1.5" x 37.5"
1 Polyester film ¼ mil clear, minimum 20 feet, 40 recommended, 36" wide
1 Tube of tine powdered graphite
1 Epoxy adhesive, 32 oz.
12 4-40 x ¾" brass, round head nuts and bolts for electrical connections.
1 Steel bar stock 12 feet long, 1' x 0.25"
4 Bolts, steel 6-32, 2 inches long
1 Roll "Scotch" double sided tape
1 Roll masking tape, ½" wide
1 Roll plain cellophane tape
4 Aluminum foil 1" x 0.5"
1 Plate glass, ¼" thick, 38 x 26
1 Package rayon or cotton balls
2 10" dynamic drivers (see text)
2 Sheets 4' x 8' x ¾" particle board
1 Woofer damping material, approximately eight pounds long fibre wool or synthetic material (see text).
200 Long wood screws
1 Pint "Tightbond" glue

Misc: Electronics as required for ESL drive. Frames as desired for ESL cells. Hook up wire, suggest high voltage test prod wire for ESL's. Finish trim and grille cloth as desired.