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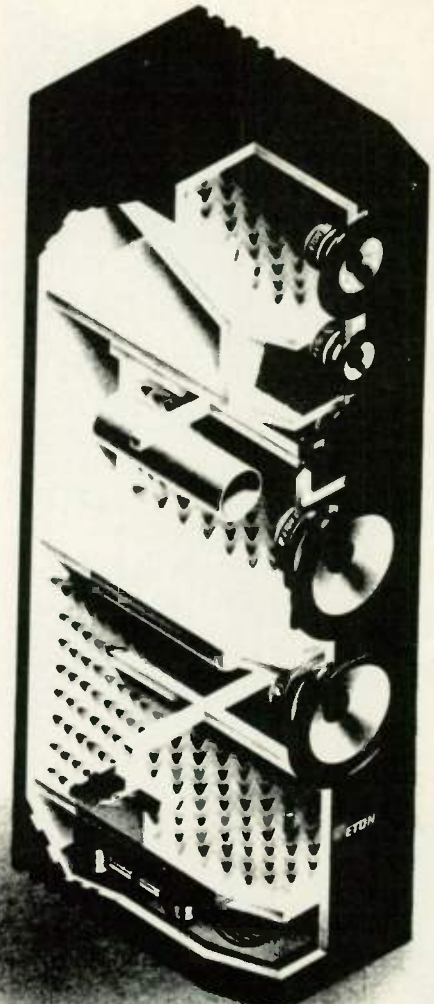

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ERRATA

I've found another error in my article, "A Dipole Subwoofer for Quads" (*SB* 6/89). Besides the error in *Table 1*, I noted earlier (C_H should be 0.033, 0.1, and 0.33 going across the top from left to right), there is an error in the parts list. R7, 107, 207, and 307 should be 100kΩ. Also, R4 and R104 can be increased to 1mΩ, if desired, to minimize loading on the preamp.

James Lin
New York, NY 10028

THROAT SLIPUP

Two of the *Fig. 7* labels in Bruce Edgar's article "Solving the Klipschorn Riddle," (*SB* 4/90, p. 34) were transposed. The corrected drawing appears below.

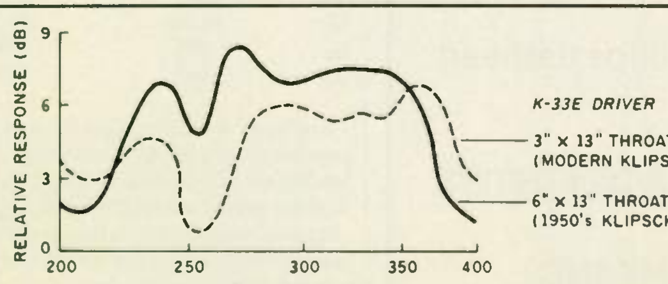

FIGURE 7. A comparison of the relative responses of a new and old Klipschorn models using the same driver.

VALID APPROACH?

I usually do my designs through simulations, using a SPICE-related program (*ECA 2*, Tatum Labs). The T/S models are specified using the DC resistance of the voice coil as R_E. However, this is lower than the speaker's minimum resistance, since it seems that when the model was developed only a crude voice coil model was used.

I've used a slightly modified value for R_E in which its value is taken from the speaker's minimum impedance (which I use when I don't have the full values for the voice coil supplied by the maker—at this time only KEF has supplied it to me).

The other components—L_{MS},C_{MS} and R_{MS}—are then calculated as usual from Q_M and Q_E, at F_S.

Is this a valid approach?

Jorge O. F. Oliveira
13083 Campinas SP Brazil

Joe D'Appolito replies:

The T/S model ignores voice coil inductance. When this inductance is in the equivalent circuit, the minimum impedance above the basic resonant frequency is always larger than R_E, the voice coil DC resistance. The proper way to model this effect is to include the voice coil inductance in your analysis. If you are interested only in low-frequency performance and voice coil inductance is not excessive, I would use R_E and not correct it for the measured minimum impedance.

IN MY OPINION

Regarding your recent article about Mr. Holman: It may indeed be of interest to your readers for someone to talk about his work for 18 pages or more, but when your subject begins bashing a leading competitor, such comments are better left out.

In my opinion, Mr. Holman's derogatory remarks about Paul Klipsch, Mr. Klipsch's products, as well as the quality and integrity of his work, were gratuitous and slanderous. That Mr. Holman should find it necessary to speak this way in order to promote himself is his business. However, whether through oversight or not, when a magazine actually publishes such remarks, no one benefits—least of all the magazine.

I respectfully suggest Mr. Klipsch is owed an apology.

John F. Allen
Newton Centre, MA 02159

Editor's note: Mr. Allen's company, High Performance Stereo uses Klipsch equipment in their professional installations.

HOLMAN VS. KLIPSCH

In reference to your recent article *Tom Holman, Skywalker and THX, Part I*, I would like to correct a statement by Mr. Holman. The study of Eleanor Powell's tap dancing occurred in 1935 and was elaborated upon in 1964 by John Hilliard.[1] Paul Klipsch published a paper[2] in 1972 that cited the Hilliard paper (among others) and *agreed* with Hilliard regarding audibility limits of delay.

J.R. Hunter
Klipsch Associates
Hope, AR 71801

REFERENCES

1. *IEEE Transactions on Audio*, Vol. AU-12, March-April, 1964, Number 2.
2. The *Journal* of the Audio Engineering Society, Vol. 20, Number 8, October 1972.

MISSING THE POINT?

Ralph Gonzalez' letter in *Tools, Tips & Techniques* (*SB* 2/90 p. 50) regarding "Woofer Alternatives" seems to miss the point by comparing modified woofers with unmodified ones. The unmodified woofers have F_S = 37Hz and Q_{TS} = 0.23. By doubling the cone mass, F_S drops to 26Hz and Q_{TS} rises to 0.32. The modified woofers have a significantly lower cutoff frequency at the expense of requiring a larger box. This is a common and well-known trade-off. However, there are two problems with his comparison.

First, he compares two woofers with different characteristics by their response in the same size box. The optimal box size (Q = 0.7) for the modified woofers is 19 liters (0.67 cubic feet). This results in a cutoff frequency (F3) of 57Hz. The optimal box size for the unmodified woofers in an Isobarik arrangement is only 2.2 liters, which is considerably smaller. The cutoff frequency is predictably higher at 113Hz. Comparing the two woofers by their response in a 28 liter box makes no sense.

Second, comparing the modified and unmodified woofers is really the same as comparing different woofers. The modified drivers require a box more than twice as large for any given arrangement. Let's compare the modified types using the Isobarik arrangement, and the one using both on the cabinet face. The cutoff frequency for both setups is still 57Hz, but the Isobarik design requires a box that is only one fourth the size. As Mr. Gonzalez correctly points out, higher SPLs and increased sensitivity are available from the larger box.

In conclusion, the Isobarik design serves best when a large box is out of the question. For the cost of two drivers, one can cut V_{AS} in half. When box size is not an issue, then for the cost of two drivers, one can double the radiating area.

Jack C. Rich
Weston, MA 02193

Ralph Gonzalez replies:

I apologize for seeming to imply the "Isobarik" (compound driver) arrangement is inferior to the alternate (both drivers on face of enclosure; cone mass of each doubled) approach I offered in my letter. My intent was to show that the compound driver approach should be applied with caution, since in some situations the alternative is better suited.

As John Cockroft pointed out to me, in a separate letter, the same can be said about the alternate approach. John considered a Peerless 8″ woofer with f_S = 29Hz, Q_{TS} = 0.32, V_{AS} = 104 liter, sensitivity = 90.4dB. In a 13.7 liter box this gives Q_{TC} = 0.7 and f_{CB} = 63.4Hz using the compound arrangement. In the same box the alternate arrangement gives Q_{TC} = 1.8 and f_{CB} = 82Hz—clearly bad results. (For a Butterworth response a sealed, 146 liter box is needed, producing f_3 = 32Hz.)

The reason I compared unmodified woofers to modified (mass-loaded) ones was so the compound arrangement and the alternate arrangement would have the same sensitivity. The alternate arrangement, however, still has twice the surface area, and thus greater low frequency power handling.

It occurred to me an equitable comparison between these two approaches should seek to eliminate this advantage. As you will see, a pair of woofers used in the compound configuration will give almost identical results to a pair of woofers used in the alternate configuration when we take care to match the total driver surface area, as well as sensitivity.

Compare two 6½″ SEAS P17RCYs in alternative configuration, versus two 8½″ SEAS P21REXs in compound configuration. This is fairer because now both approaches have the same total surface area, and therefore about the same LF air displacement capability, and both have about the same optimum box size.

Using a 28 liter box:

	Compound P21REX	Alternative P17RCY
F_S	33	26
Q_{TS}	0.37	0.32
V_{AS}	34.5 liter	72 liter
Sens	91dB	91dB
I_{MP}	4Ω	4Ω
V_B	28 liter	28 liter
F_{CB}	49Hz	49Hz
Q_{CB}	0.55	0.6

As you can see, they're about the same. Both approaches give roughly the same sensitivity, power handling,and bass extension using the same box size, provided larger-diameter drivers are used for the compound configuration. In this case, the only remaining differences are that the 8½″ drivers have a slightly higher thermal power rating and excursion capability, worse HF response (particularly) in compound configuration), and 25% higher cost.

Continued on page 78

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About This Issue

Those old *WHAT IFs*... finally got to **Bill Schwefel**. This particular experimental tangent occurred after he kept wondering what would happen if he arranged John Cockroft's Isobarik speakers in a symmetrical D'Appolito configuration. An exceptionally fine combination resulted—full-bodied voices, rich, and natural sounding. It's a good bet for anyone considering a small satellite system. Follow Schwefel's project on page 10.

If you're in that familiar situation of having designed and constructed your first system, only to feel some confusion over how to handle the crossover problem, this article is for you. Contributing Editor **G.R. Koonce** offers a proven approach, and one yielding an effective passive crossover. The article contains equations and theoretical considerations, but fear not, intrepid novice, your reading begins on page 26.

Want to achieve uncommon flexibility in a high-quality speaker system? Consider **Randy Parker's** method of designing a system that easily can be upgraded by using three modules as stand-alone elements covering different frequencies. The ingredient which makes this possible and practical: an electronic crossover. Read about Parker's triamplified modular system on page 46.

Tom Holman, the wunderkind of film sound technology, resumes his conversation with writer **Reid Woodbury, Jr.** Holman, director of Technical Operations at Lucasfilm, Ltd., discusses recent advances in theater speaker systems, and how THX is setting new standards. Part II begins on page 54.

SpeakerBuilder
THE LOUDSPEAKER JOURNAL

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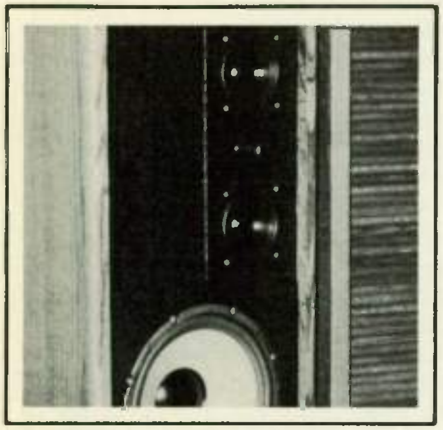

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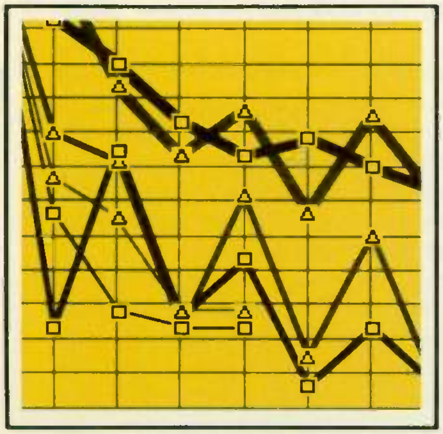

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FEATURES

DEPARTMENTS

On our cover: **Bill Schwefel's** Korean Wonder stands like a symmetrical isobarik sentinel on the shore of Lake Michigan, ready at any moment to emit its miraculous sounds across the water. Photo by the author.

Editorial

HAND AND HEAD

I receive a fair number of letters from worried would-be speaker builders who seem to want to get all their ducks in a neat row before beginning a project. They view the magazine as a fountain of accurate information where, if they can only connect with the right expert, the necessary enlightenment will be forthcoming in a brilliantly illuminating letter which will allow them to plunge into the speaker construction project they have dreamed of for many moons.

The anticipation is both pleasure and agony. They are usually worried that they will make a wrong decision about design, measurements, choosing drivers and the incorrect crossover. With that goes the real worry about wasting money on the wrong hardware, lumber, tools, or electronic parts.

Part of the dreaming usually consists of lots of reading about speaker theory. Finding out about how drivers work, who Thiele and Small are, and all the terminology and shorthand that goes with speaker design.

Among computer enthusiasts a bit of wisdom about understanding the machines is a great help to any beginner. Never try to understand your computer by reading the DOS manual. You won't understand the manual until you understand the machine. How do you learn about the machine? By yourself, by playing with it and wrestling your way through each application, making mistakes, having the machine bomb, losing data, enduring disasters, and generally living a miserable life until the light begins to dawn, tiny bit by bit.

Although the experience can be harrowing, somehow as time passes it becomes a pleasure. Beginners are always afraid they will wreck the machine, destroy something, or do some kind of irrevocable damage. It seldom happens. As time passes, you suddenly realize you are enjoying computing. Little by little you discover shortcuts, all manner of lights go on and your mastery of the monster becomes more and more evident. Then one day, you pick up the manual for DOS—preferably the one from Microsoft or Phoenix—and it all makes sense. At least a good deal of it does.

You can't begin with theory—at least most of us can't. Some bright wizards I know can do it, annoying as they are. But most of us learn by experience. The old bromide is true: "Experience is a great teacher, but she is very expensive." Unless you are willing to pay the emotional costs, you won't get very far with speaker building.

Begin with the data, not the theory. Build a speaker system. Start with a nice kit—or a project in the magazine. Listen a lot, critically. Don't let your amazement at yourself and your new prowess fog your critical faculties. Keep your mind on your goal and forget your need to be right, or correct, or defensible. Go for the best and always acknowledge it when you hear it, no matter who found it.

Share what you find. Expect to be mistaken, or deluded. And listen carefully to what your critics say, and be as careful with what your friends or loved ones say to be sure you are hearing truth and fact rather than cheerleading.

I believe you will be amazed at how much clearer Vance Dickason's *Loudspeaker Design Cookbook* will become after you have built your second or third system. Thiele and Small will begin to make sense. As for crossovers, Bullock and Koonce will be more exciting as you get into the actual making of the devices themselves.

One of my most important surprises in editing *Speaker Builder* was the discovery that our most competent authors and editors are all on a journey of discovery. Each begins in his or her own special place with some kind of knowledge and experience. But it is never encyclopedic and seldom comprehensive. Knowledge is evolutionary and its acquisition is speeded by direct experience, not manipulating formulas, but wood and metal and components. The formulas come later, shorthand and shortcuts.

Speaker building can become addictive as a hands-on activity, too. A time comes when all of us need to measure, review, and go back to the books again. We need to stop ignoring the nagging problem of why something doesn't quite turn out the way we expected it to. Those anomalies are gold. They are aggravating but are often the next step toward beauty.

Sometimes, for some, not enough reading has been going on. We get at least one letter each week asking us for a source for this or that product. A quick look at the advertising in the current issue reveals that the hardware the reader seeks is currently advertised, or that the vendor has an ad in *SB* with a list of suppliers who are eager to provide just the information the reader seeks.

We also get an occasional letter in which the reader really asks for design service. An author has presented a beautiful, well researched article using specific drivers and crossover elements, and invariably a reader will write with a list of bargain alternatives he or she purchased and hopes the author's design can somehow be adapted to fit those. This is very rarely possible and I hope you will think twice about asking an author to go back to the drawing board for what might be a week or two, so you can use bargain misfits in his design.

If you are a novice struggling to emerge from your chrysalis in order to become a dazzling speaker builder butterfly, be careful what sort of help you ask for. The misguided nature lover who observes the agony of a new creature struggling to emerge from a cocoon and tries to help, can destroy the butterfly. You need your own agony. Pointers can help and we all need them. But nothing can replace your journey of discovery.—E.T.D.

THE WONDER OF A SYMMETRICAL ISOBARIK

BY BILL SCHWEFEL

I nearly ordered the parts for a pair of SWAN IV™ satellites.[1] I even had my Madisound order blank filled out and ready for the mail.

I don't know exactly what happened, but the next thing I knew I was going off on another experimental tangent. I kept wondering, "What would happen if I arranged John Cockroft's Isobarik speakers[2] in a symmetrical D'Appolito configuration?"[3]

DRIVER SELECTION. I began by experimenting with the Radio Shack 40-1022A woofer. I built a small test box and removable tunnel system and proceeded to run several tests. I measured V_{AS}, Q_{TS}, and F_S in both the single and isobarik arrangements. The results of my test were published in *SB* Mailbox 1/90.

I noted a significant improvement in sound quality. The single woofer had a very hollow, boxy coloration. Voices sounded boomy and overblown. When I switched to the Isobarik arrangement, the bass became tight and clean. Voices sounded natural, non-resonant, and lifelike.

Impressed by this sound quality, I decided to splurge and mate the Isobariks with a matched pair of Morel MDT-33 tweeters. Wow, what a combination!

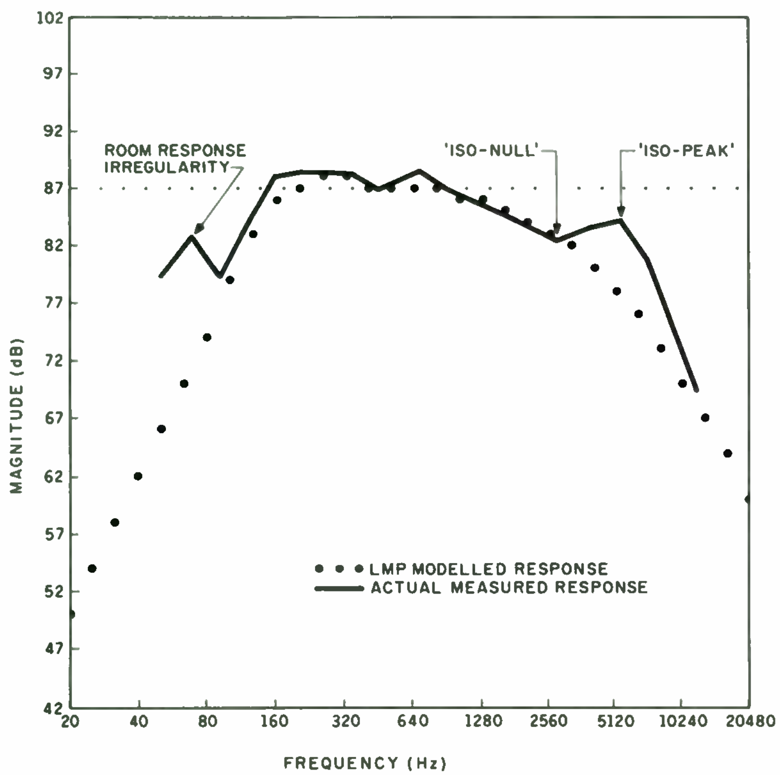

FIGURE 1: LMP model of Quad-Isobarik woofers mounted in the finished enclosures, without crossover.

CROSSOVER DESIGN. Before I began crossover design, I finished the boxes, mounted all drivers, installed the Acousta-Stuf™ damping material, and sealed the back panels in place. I brought a wire from each driver terminal through the rear panels and connected them to a 14-position barrier strip. In other words, I had completed my work on the speakers, except for the crossover.

I then proceeded to run frequency response plots, using my Radio Shack sound level meter and *Stereo Review* warble tone test record. For all tests, I placed the microphone 35″ from the floor on axis with the tweeter, at a distance of 39″. I positioned the speaker 20″ from the rear wall in my "great room" which is some 9,000 cubic feet, and has a sloped ceiling leading to an upper level loft. Side walls were approximately 15 feet from the speaker in either direction.

Figure 1 shows the frequency response plot for the "quad-Isobarik" woofers alone, without crossover. *Figure 2* shows the plot for the tweeter alone, without crossover. I developed LMP[4] models for these plots, and overlapped them on the same graphs.

The tweeter plot looks pretty much as it should, but the woofer plot needs a little explanation. You will notice that output falls off slowly beginning at around 700Hz and reaches a low point at 3kHz. I have labeled this point, the "Iso-null." Output then climbs again and peaks at roughly 6kHz. I have labeled this point the "Iso-peak."

Normally, a small woofer mounted on a small baffle should show a falling response below 1kHz due to diffraction loss. But my plot looks more like diffraction gain!

As I interpret it, this plot is easy to understand and does not require a test equipment upgrade (although that wouldn't be a bad idea). The plot is precisely as it should be for an Isobarik system.

I mounted the rear woofer 2¾" behind the forward facing woofer. This distance equates to one-half wavelength at approximately 2.5kHz. Thus the rear woofer is 180° out of phase with the front woofer, and causes a dip in the response. A perfect coupling of the two woofers would create a sharp null at 2.5kHz. The resilient air gap limits the result to a mild frequency response dip. (I decided to call it an "Iso-null" anyhow, even though it's only an "Iso-dip.")

Of course, the 180° out of phase condition is not the only one that causes cancellation. At all frequencies where the front and rear woofers are not in perfect phase (or 360° out of phase) there will be some cancellation. Response begins to fall off above 700Hz due to cancellation, as the rear woofer becomes progressively out of phase with the front woofer.

What about the "Iso-peak?" Well, the Radio Shack woofers have good response out to 6kHz. Response begins to climb again after the Iso-null as the two woofers begin to move toward phase alignment. Finally, response falls as the Radio Shack woofers begin to rolloff, due to voice coil inductance and cone mass.

This Iso-null and Iso-peak situation is dependent on woofer frequency response and the spacing distance between the inner and outer woofers. Closer woofer spacing moves the Iso-null higher in frequency. A greater spacing distance moves it lower in frequency. I think this

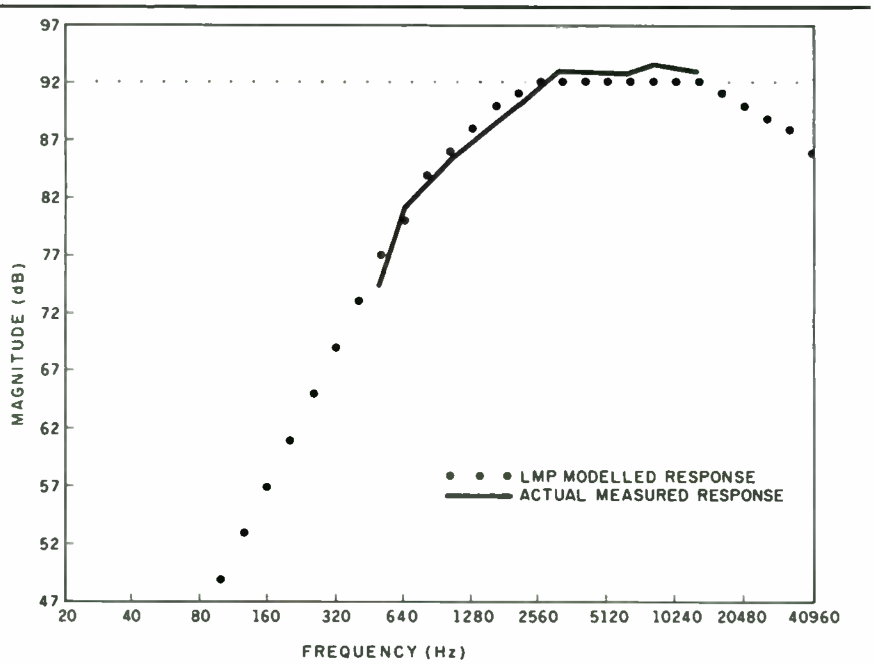

FIGURE 2: Actual versus LMP modeled response of the Morel MDT-33 tweeter, mounted in the finished enclosure, without crossover.

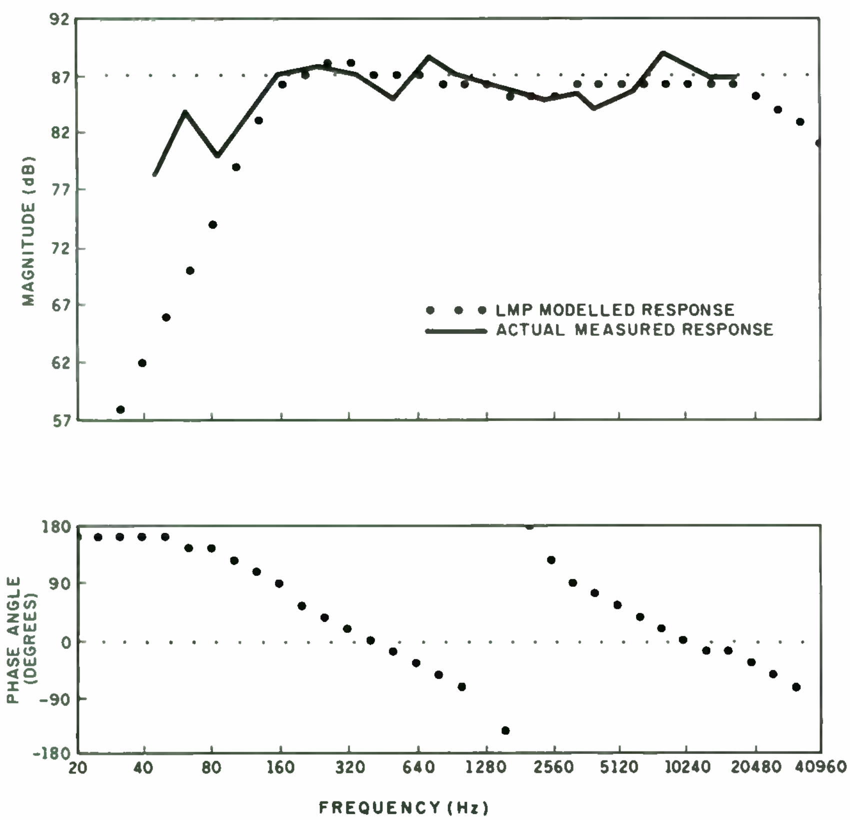

FIGURE 3: LMP model versus actual measured response of the finished speaker system, with crossover.

TABLE 1

LMP PARAMETER LISTING

DRIVER NUMBER 1

CORNER FREQ OF LOW FREQ ROLLOFF:	170
LOW FREQ ROLLOFF DAMPING RATIO:	.55
CORNER FREQ OF HIGH FREQ ROLLOFF:	4500
HIGH FREQ ROLLOFF DAMPING RATIO:	1.2
ORDER OF HIGH FREQUENCY ROLLOFF:	2
POLARITY INVERSION (YES OR NO):	N
SENSITIVITY OF DRIVER (DB):	87
DEPTH DISPLACEMENT (INCHES):	-.5
FREQUENCY OF RESPONSE STEP:	0
HEIGHT OF RESPONSE STEP:	0
IDENTIFICATION # OF CROSSOVER:	5
VALUE OF COMPONENT K0:	6.7
VALUE OF COMPONENT K1:	5E-6
VALUE OF COMPONENT K2:	7E-4
VALUE OF COMPONENT K3:	-1

DRIVER NUMBER 2

CORNER FREQ OF LOW FREQ ROLLOFF:	1200
LOW FREQ ROLLOFF DAMPING RATIO:	.85
CORNER FREQ OF HIGH FREQ ROLLOFF:	40000
HIGH FREQ ROLLOFF DAMPING RATIO:	1
ORDER OF HIGH FREQUENCY ROLLOFF:	2
POLARITY INVERSION (YES OR NO):	N
SENSITIVITY OF DRIVER (DB):	87
DEPTH DISPLACEMENT (INCHES):	0
FREQUENCY OF RESPONSE STEP:	0
HEIGHT OF RESPONSE STEP:	0
IDENTIFICATION # OF CROSSOVER:	6
VALUE OF COMPONENT K0:	6.7
VALUE OF COMPONENT K1:	1.25E-3
VALUE OF COMPONENT K2:	7E-6
VALUE OF COMPONENT K3:	-1

TABLE 2

CROSSOVER PARTS LIST—ONE CHANNEL

VALUE	DESCRIPTION
CAPACITORS:	
C1	5μF polypropylene
C2	22μF NP electrolytic
C3	7μF polypropylene
INDUCTORS:	
L1	.70μH air core (DCR .41)
L2	1.25μH air core (DCR .70)
RESISTORS:	
R1, R3	8Ω, 15W
R2	3Ω, 15W

Source: Madisound

is the reason reactions to this format have varied substantially.[5] The spacing distance is critical, and can have a significant impact on the sound.

In my design, I have attempted to work the effects of this cancellation into the crossover. I worked on LMP modeling for several weeks, trying various crossover configurations. I experimented with junk box crossover parts, listening to various first and second order electrical filters.

I finally stumbled across a good model. I took a standard 12dB/octave APC, developed using Robert Bullock's[6] equations, and moved the corner frequencies just a bit to produce an overlap at 2kHz. To prevent a large "suck-out" that was showing up on my LMP models, I connected the drivers in normal polarity. (12dB/octave APCs usually require a reverse polarity connection.) The result was a good sound, a flat magnitude response, and an acceptable looking phase plot (*Fig. 3* and *Table 1*). The final system measured −3, +2dB from 100Hz to 14kHz. *Table 2* and *Fig. 4* show the crossover parts list and schematic diagram.

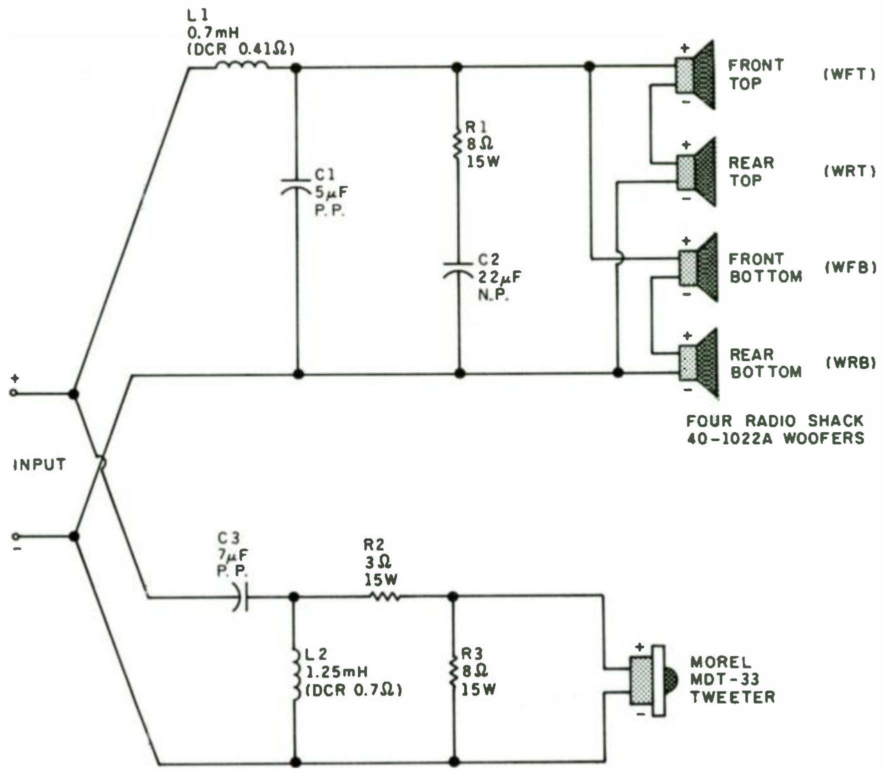

FIGURE 4: Crossover schematic diagram (one channel shown).

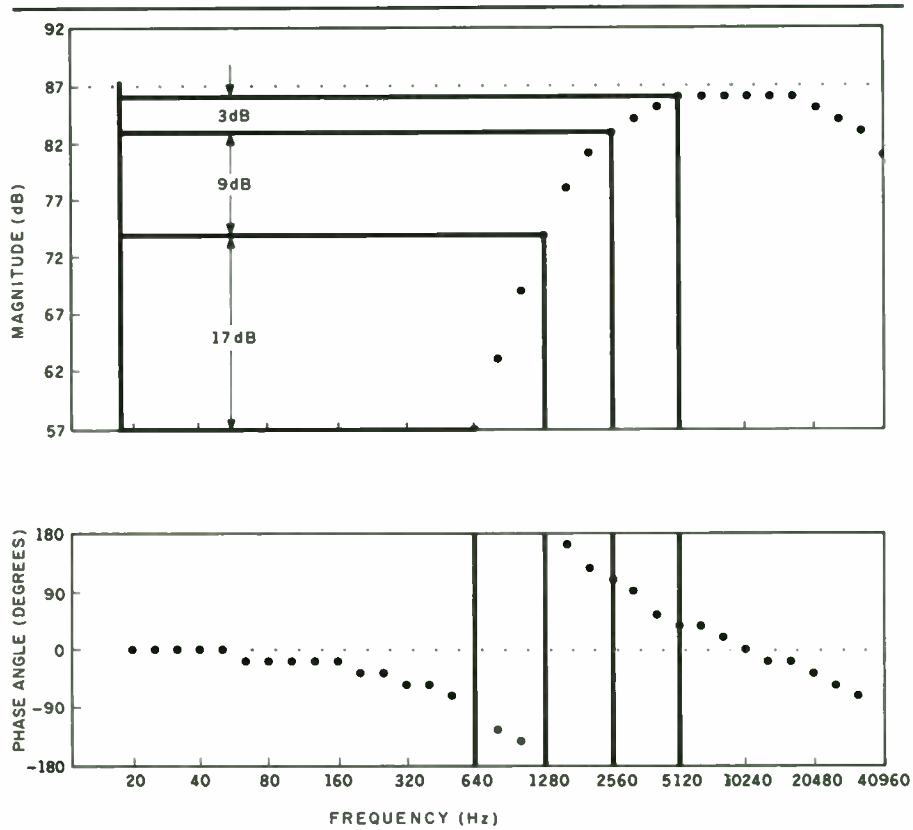

FIGURE 5: LMP model of the Morel MDT-33 tweeter mounted in the finished enclosure, with crossover.

POLAR TILT. An important part of the symmetrical 3/2 geometry is crossover slope (electrical plus driver rolloffs). An odd order slope is preferred to maintain a constant 90° relative phase difference throughout the crossover region. This 90° difference results in a 15° polar axis tilt, necessary to obtain the desired broad and uniform vertical polar response pattern.

A picture perfect odd order crossover will produce a constant 90° relative phase difference between the two drivers throughout the crossover region. (Assume infinite bandwidth drivers.) A picture perfect even order crossover will produce a constant 180° relative phase difference between the two drivers. Reversing the polarity of the second order network is therefore usually required to bring the drivers back into phase.

I do not have the test equipment to measure phase directly, so I pulled my phase data from LMP model plots. *Figures 5* and *6* show the response and phase angle of the tweeter and woofers. I ran the plots separately (specify Num-

TABLE 3			
WOOFER vs. TWEETER PHASE ANGLE			
FREQUENCY IN HERTZ	WOOFER PHASE ANGLE (DEGREES)	TWEETER PHASE ANGLE (DEGREES)	RELATIVE PHASE DIFFERENCE (DEGREES)
640	-17	-100	83
806	-33	-123	90
1016	-53	-140	87
1280	-73	-160	87
1612	-90	+160	110
2032	-127	+127	106
2560	-159	+107	94
3225	-180	+90	90
4064	+163	+57	106
5120	+147	+37	110

ber of Drivers = 1″ for LMP modeling purposes) for the tweeter and woofers, each with their respective crossover components in place.

Table 3 shows phase angle at several frequencies throughout the crossover region and the resulting relative phase difference at each. The relative phase difference is close to 90° with a high of 110° and a low of 83°. If this table is accurate, the polar axis should tilt at roughly 15°, perhaps somewhat less at certain frequencies.

LOW FREQUENCY RESPONSE. My system, if operated full range, will not put out a substantial amount of low frequency energy. The LMP models shown earlier suggest a low frequency rolloff a bit sooner than they should because I developed the models for a good match above 100Hz. For better accuracy, I changed to alternate software packages.

Table 4 shows BOXRESPONSE[7] output and *Fig. 7* Robert L. Caudle's[8] low-frequency response graph. They pretty much tell the story of what I heard below 100Hz.

There is an interesting anomaly here. With the completed speakers, I measured a Q_{TC} of 0.55 and an F_C of 82Hz. To approximate these figures on the Caudle program, I found it necessary to input the internal box volume as 5 liters. This is roughly double the net internal volume of my finished boxes (2.65 liters).

I can probably write off about 30 percent of the apparent increase in box size to the effects of stuffing material. This would bring the effective net internal volume up to 3.44 liters. I am at a loss to explain the remaining 1.54 liter discrepancy.

WOOFER MATCHING. Since I am using a series connection for each inter-

TABLE 4			
BOXRESPONSE OUTPUT			
FREQ. IN HZ	RELATIVE RESPONSE IN DB	MAXIMUM POWER INPUT IN WATTS	MAXIMUM INFINITE BAFFLE RESPONSE IN DB
5	-48.79	25	50.82
10	-36.79	25	62.83
15	-29.81	25	69.80
20	-24.91	25	74.70
25	-21.16	25	78.45
30	-18.16	25	81.46
35	-15.68	25	83.94
40	-13.60	25	86.02
50	-10.32	25	89.30
60	-07.91	25	91.71
80	-04.79	25	94.82
100	-03.06	25	96.55
150	-01.27	25	98.35
200	-00.67	25	98.94

```
PARAMETER LISTING AS FOLLOWS:

Driver FS: 53.5          Qes: .457          Qms: 2.487
Vas measured in cubic feet:                      0.247
Driver DC resistance:                            6.425
Driver power rating in watts:                   25.000
X-Max measured in inches:                        0.250
Piston diameter in inches:                       4.949
System Order:     2    (closed box design)
Alpha (Vas/Vb):                                  1.400
```

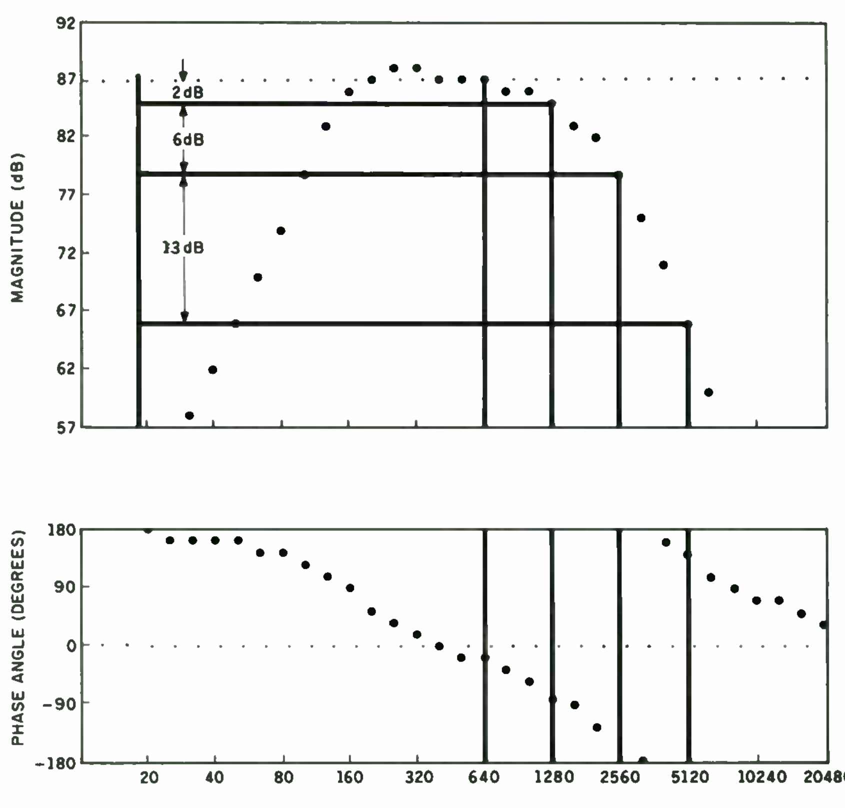

FIGURE 6: LMP model of Quad-Isobarik woofers mounted in the finished enclosure, with crossover.

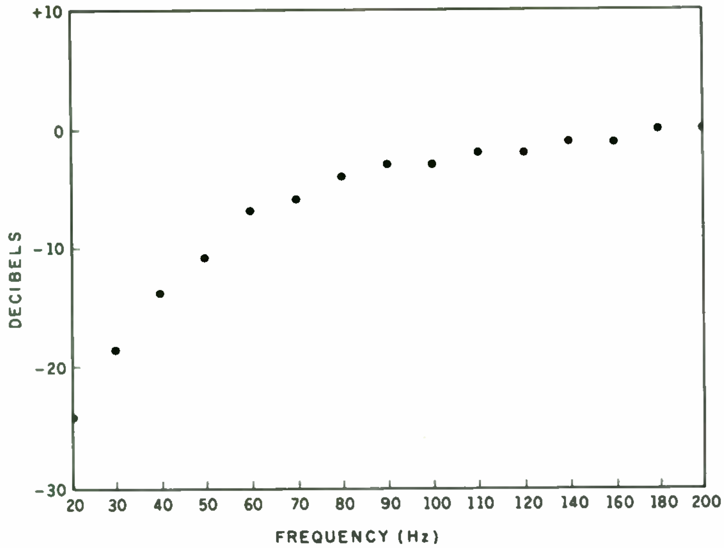

FIGURE 7: Caudle low frequency response graph. The −3dB point is reached at 100Hz.

nal/external woofer pair, it is important to match F_S parameters to ensure good power sharing. I grouped the woofers in pairs of two before mounting the drivers. I had a set of four that measured 55Hz, a pair that measured 50Hz, and a pair that measured 56Hz. I put the set of four 55Hz drivers in one cabinet and the 50/56Hz set in the other.

CONSTRUCTION. Begin by cutting the side, top, and bottom panels to size. Refer to *Fig. 8* for the cutting guide and *Table 5* for the list of materials. Try to hold a tolerance of 1/32" and keep the panels as square as possible.

Next, glue oak facing around the side panels, mitered 45° at each corner (*Photo 1* and *Fig. 9*). This process will take some time because the side panels are never perfectly square. To get the miters exact, purchase several extra one foot lengths of oak facing. Before making a cut run several tests on the extra facing to zero in on the correct angle.

Good miter joints are visually striking, and show the painstaking attention to detail that went into your project. Take your time and get the miter joints precise.

With the side panels done, glue a strip of oak facing to the front and back of the top and bottom panels (*Fig. 10*). Lay a straightedge across the panel and make sure it is perfectly flat. Check all edges with a straightedge to ensure proper alignment.

Form the "shell" by gluing the top, bottom, and sides together. As shown in *Photo 2*, I used two picture frame clamps to set up a perfect 90° angle and

Continued on page 16

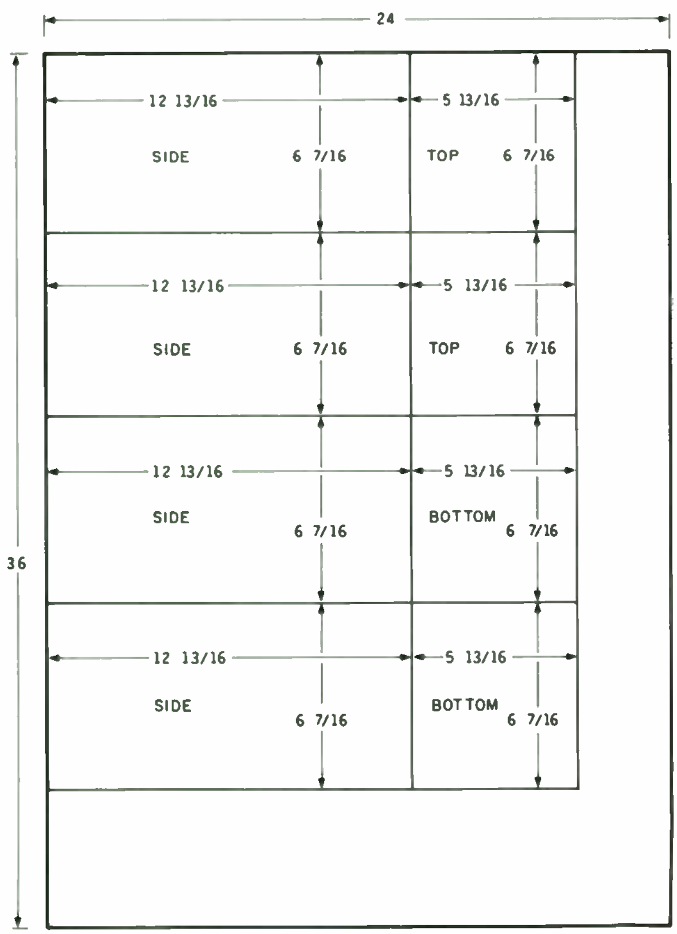

FIGURE 8: Cutting guide for 2 by 3' sheet of ¾" oak plywood. All dimensions in inches.

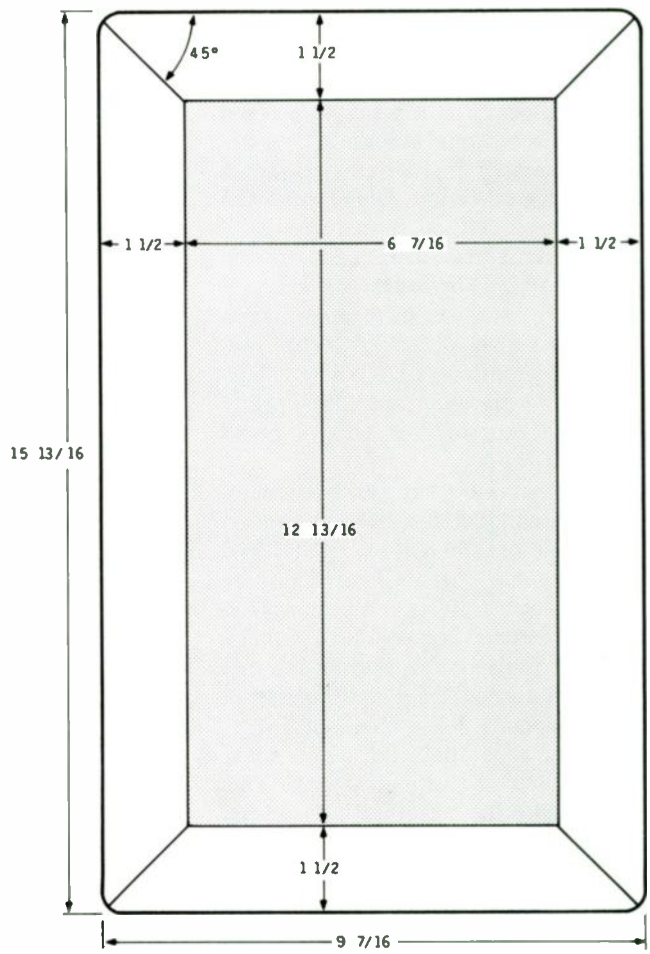

FIGURE 9: Side view—external.

Continued from page 14
clamped the assembly together with six bar clamps.

INTERNAL OPERATIONS. Next, glue strips of 1½ by ¾″ oak facing ⅝″ deep into the front of each cabinet (*Photo 3*). This facing follows the entire perimeter of the cabinet, and eventually becomes the Isobarik tunnel.

Glue four small 1½ by ¾″ right triangular pieces of oak facing into the corners of the tunnel (*Photo 3*). These pieces serve to fill the corners of the tunnels, increasing the strength of the corner joint. Do not make these pieces too large or they will interfere with the ¼″ felt lining that later goes into the tunnel.

To clamp the corner pieces in place, use a small block of wood with a 90° notch sliced into it. Place this on the exterior corner opposite the internal corner (*Photo 3*). This keeps the clamp securely in place at a 45° angle until the glue sets.

EXTERIOR BAFFLE. Cut the front (exterior) baffle board from high density ⅝″ particle board, according to the dimensions in *Fig. 11*. For the driver holes, use a router, (Black & Decker Deluxe Router, guide #76-234, or equivalent), a ¼″ carbide notching bit, and a circle cutting guide. Mark the center of each hole and then drill ⅛″ pilot holes for the guide. Using a piece of scrap, adjust the guide for a 3 13/16″ diameter hole. This hole must be precise, as the Radio Shack 40-1022A flange allows little room for error. Place the router guide pin in the ⅛″ pilot hole and, with circular motion, route about ⅛″ of material on the first pass (*Photo 4*). Continue to lower the depth, making about four passes to complete the cut.

This may seem like a great deal of work, but, after cutting several holes, I think it's worth the extra time. My Black & Decker router guide can cut a perfect circle, accurate to within 1/64th of an inch. The cut looks good too, with a sharp edge on the hole, instead of that chopped up looking mess I always get with my jigsaw.

For the tweeter hole, adjust the guide to a 4⅜″ diameter with a depth of precisely ⅛th inch. Make a test cut on scrap and then rout the baffle. Move the diameter setting to 4⅛″, and then rout the baffle again, at ⅛″ depth. These cuts serve to flush mount the tweeter. If you substitute the Dynaudio D-28 AF (flat flange), the depth setting should be adjusted to 3/32″ instead of ⅛″.

Next, set the guide to 3 7/32″ diameter and, with three or four circular passes, rout the hole for the tweeter. Set the Morel tweeter in the hole and mark the position of the solder terminals. After you rout a small notch to clear the terminals, the tweeter should drop perfectly in place.

Put one Radio Shack woofer in place, and trace the flange outline. Check both sides carefully, and line up the flange by placing a square across the mounting holes.

Rout the flange outline to a depth of 1/16″ on all four woofer holes. Flip the baffles over and rout the internal side of each woofer hole with a ⅜″ carbide round-over bit. This last step may not be all that important. I did it to ensure that the woofer basket area was smooth and free of any sharp edges.

With the external baffle machining complete, it is time to drop them in place. Coat all relevant surfaces with yellow carpenter's glue and slowly tap the baffle into each cabinet. They should fit snugly with no gaps in the sides, top, or bottom. Remember, the better the fit, the stronger the joint. I used 11 clamps (almost my entire stock) to hold them in place until the glue set (*Photo 5*).

TABLE 5

MATERIALS LIST FOR TWO SPEAKERS

QTY	DESCRIPTION
	Speakers:
8	Radio Shack #40-1022A Woofers
2	Morel MDT-33 tweeters (or Dynaudio D-28af)
	Lumber:
1	2x3' sheet of 3/4" oak plywood
12	3/4 by 1-1/2 by 17" oak facing
12	3/4 by 1-1/2 by 6" oak facing
8	3/4 by 1-1/2 by 10" oak facing
4	3/4 by 3-1/2 by 16" oak boards
4	3/4 by 3-1/2 by 6" oak boards
1	5/8 by 12 by 48" particle board
2	1-1/8 by 10-1/2 by 42" stair treads
1	8' pine 2x4 (speaker stands)
2	8' pine 2x6 (speaker stands)
	Miscellaneous:
1	Felt boot liner
1	Qt. of yellow carpenter's glue
1	Qt. of borosilicate ceramic coating
2	Oz. of Acousta-Stuf damping material
1	Spray can of flat black paint
4	Wooden drawer pulls
2	14 position barrier strips
1	Tube of 100% silicone sealer
1	18 gauge solid 3 pack (#278-1302)
1	Bag of 3/4 by 3/8" weather stripping
38	#6, 1/2" sheet metal screws
28	#8, 2-1/2" wood screws
1	Pint of fruitwood semi-clear oil stain
1	Pint of clear satin polyurethane
16	#10, 3" wood screws (speaker stands)

TUNNEL DIVIDERS. The next step requires patience. Glue in place two 1½″ by ½ by 4 5/16″ particle board partitions that serve to divide the woofer tunnels from the tweeter (*Fig. 12*). Place these two partitions flush with the tweeter hole, square them up, and then clamp them in place using yellow carpenter's glue and two short bar clamps.

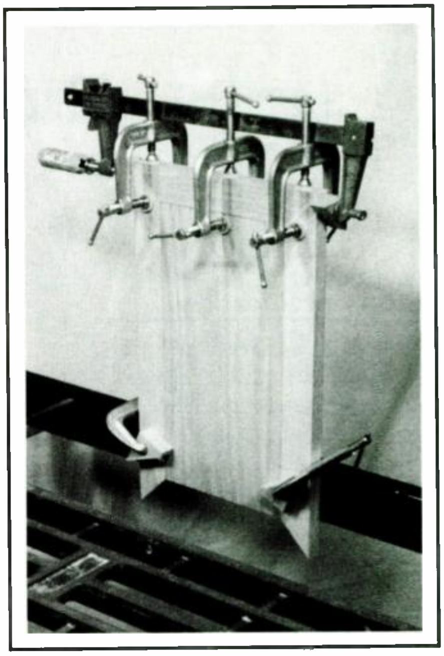

PHOTO 1: Miter that joint. Four clamps hold the facing firmly in position.

Be careful on this step. You must not allow these dividers to obstruct the tweeter basket and you must allow ¼″ clearance on the woofer side for felt lining the tunnel. Do not err in either direction.

Since the dividers form additional corners in the tunnel and tweeter basket areas, glue a few more small corner pieces in place. Leave one corner open on each driver to allow room for lead wires and holes.

INTERNAL BAFFLE. Cut the internal baffle to size, according to the dimensions in *Fig. 13*. I used 1⅛″ particle board stair tread material. I had initially planned to use high density ⅝″ material that I used for the exterior baffle, but changed to the stair treads after a table saw miscalculation.

Following the same procedure I used for the external baffles, mark each hole center point, drill ⅛″ pilot holes, and rout the baffles. Please note that the tweeter hole is not really a hole, but rather, is routed ⅝″ deep to allow clearance for the Morel MDT-33 basket. (If you substitute the Dynaudio D-28 AF (flat flange), skip this step. No extra clearance is needed).

Next, flip the baffle over, place the woofers on center over their holes, and

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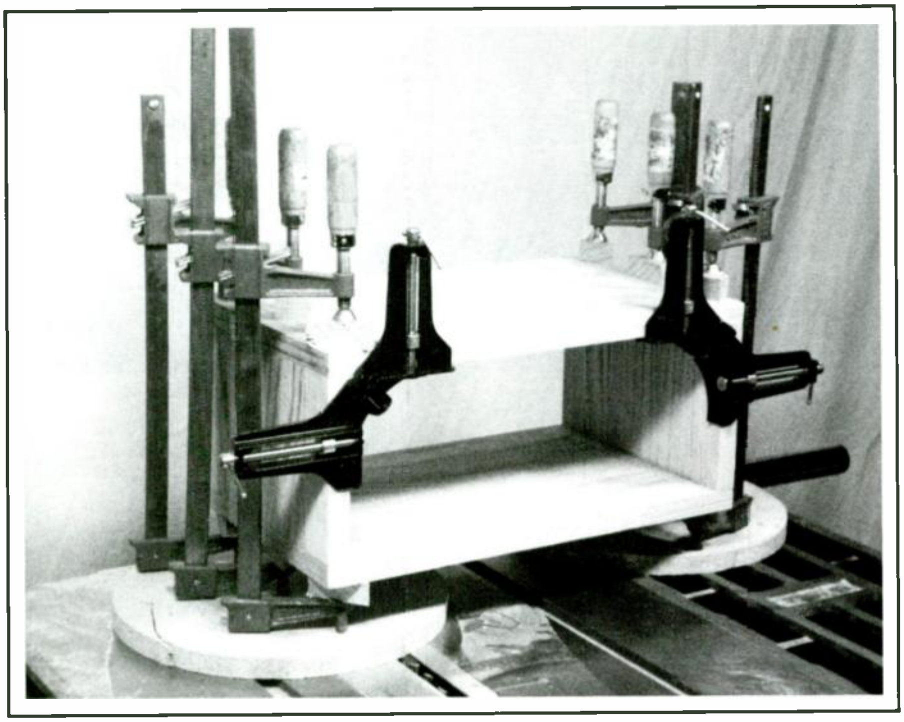

PHOTO 2: Forming the shell. Picture frame clamps help to keep things square.

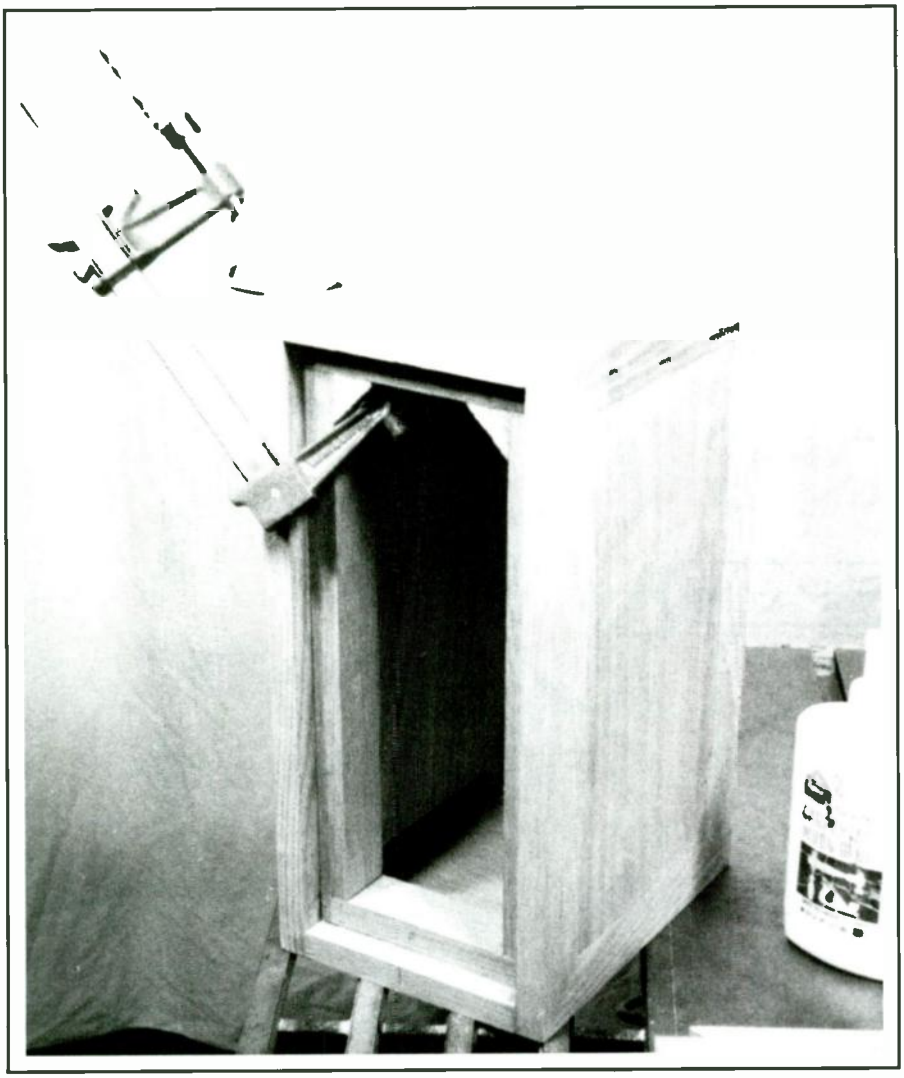

PHOTO 3: Tunnel construction. A bar clamp holds a small corner block in place as the glue sets.

Continued from page 16

trace the flanges. To make sure they are properly centered, check both sides carefully and line up each flange by placing a square across the mounting holes. Rout each flange ½″ deep by making several passes at different depth settings. This results in a 2¾″ offset of the front and rear woofers which, in turn, translates to an "Iso-null" of approximately 2.5kHz. Should you make changes to my plans (because of local material availability) try to keep the woofer offset at 2¾″. My crossover may not work well at different offset distances.

Before gluing the internal baffles in place, make some dry runs by dropping them into the enclosures from the rear side. If they do not fit easily at first, trim the length and width dimensions just a tad until they drop easily into place. Also, before gluing, mark and drill three ¼″ holes at the corners where the woofer and tweeter lead wires go through (*Photo 6*).

Warning: Be sure you glue this panel in place in the proper direction. The ½″ woofer flange routing must be toward the rear of the cabinets. The tweeter basket clearance routing (if you use the Morel MDT-33) *must* be toward the front of the cabinets.

REAR BATTENS. The rear battens extend from the internal baffle boards to the rear panels, and increase the cabinet thickness to 1½″. Use ¾ by 3½″ solid oak boards, or substitute ¾″ high density particle board. If you use oak, cut the boards a little shorter than the internal dimensions to allow for expansion and contraction. This is solid oak and it will want to move with the seasons.

Glue these boards to the inside walls. Use short blocks of wooden scrap, crisscrossed in various places to act as clamps. From top to bottom, bar clamp the panels through the woofer holes.

REAR PANEL. Cut the rear panels from another 1⅛″ particle board stair tread. External dimensions are the same as the baffle boards.

For the crossover wiring, silicone glue a 14-position barrier strip to the rear center of the panels. Then drill 10 holes through the panel for lead wires (refer to *Fig. 14*). To allow easy removal of the panel, bolt a wooden drawer pull above and below each barrier strip (*Photo 7*).

In case you are wondering why I chose to wire all crossover components into a barrier strip, it made sense from a design and testing standpoint. There

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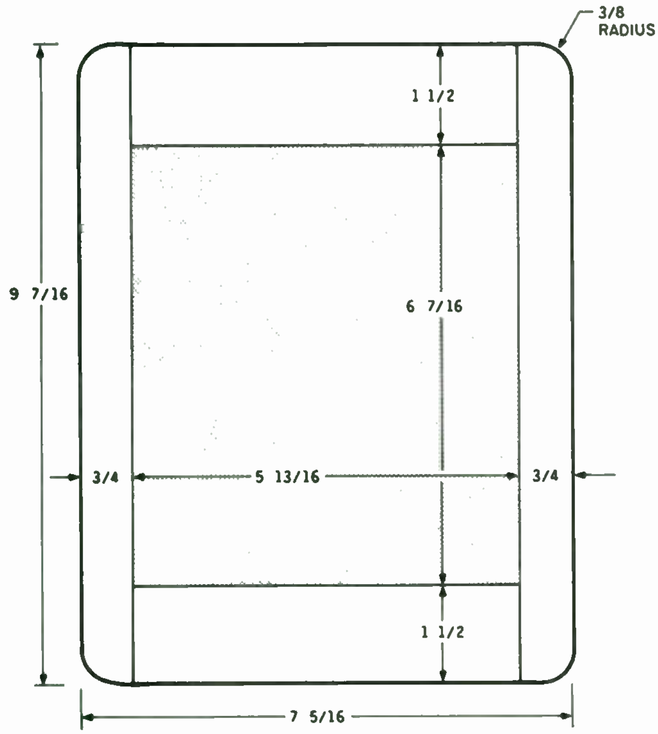

FIGURE 10: Top view.

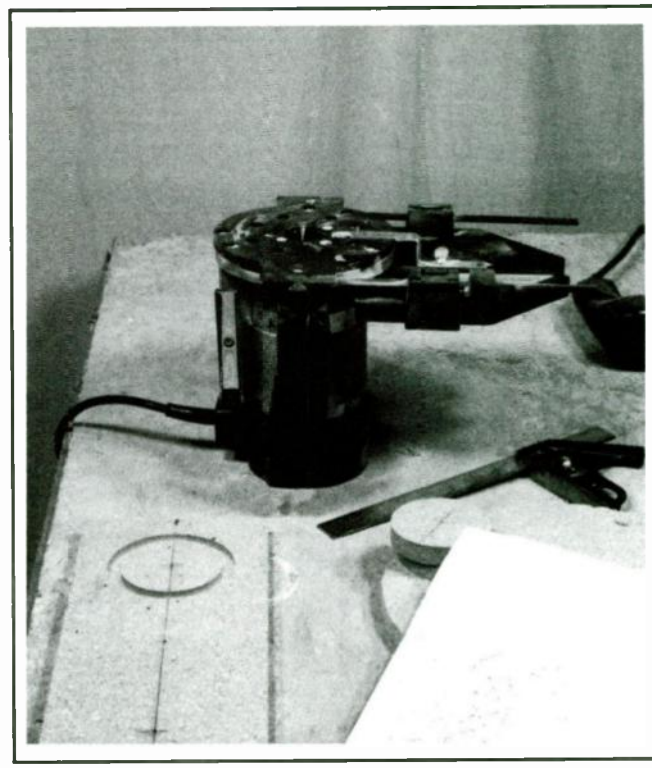

PHOTO 4: Cutting a woofer hole with the router guide. One-eighth inch of material was removed on the first pass.

Continued from page 18
has been much ado about amplifiers and speakers being "digital ready." Well, my speakers are "modification ready!"

THE BOROSILICATE TREATMENT. Coat all internal surfaces, including the tunnels, with seven coats of borosilicate ceramic coating. (Acoustical Magic™ available from Audio Concepts for $20 a quart.) Also coat the interior side of the rear panel with seven coats and give each woofer magnet seven coats as well. I considered using 11 coats, but in retrospect am glad I used seven because 11 coats would have required more than one quart.

GASKETS AND FELT. After the borosilicate dries, silicone glue ¼" felt in the woofer tunnels. Felt boot liners (available at sporting goods stores are ideal). Cut the felt into several 1½" lengths.

Install a 3/16" thick cork gasket on the rear woofer mounting holes with 100% silicone sealer. Then make a rear panel gasket from ¾ by ⅜" closed cell foam weather stripping.

FINISHING. Install temporary stands as shown in *Photo 8*. These hold the box about 1½ feet off the floor, and make the sanding and staining process easier.

Sand the cabinets smooth with #100

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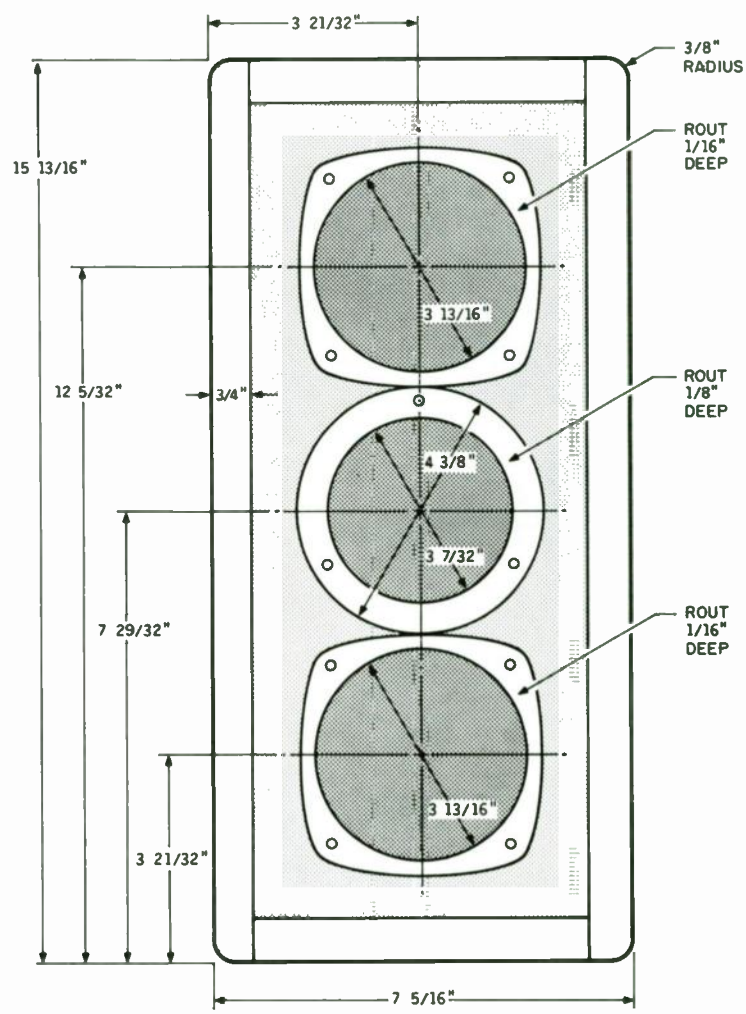
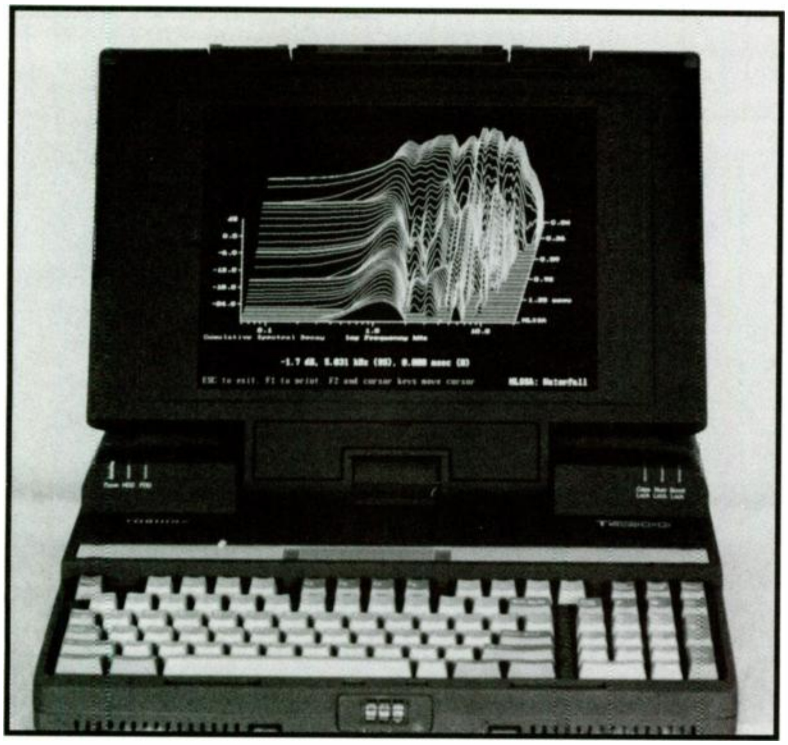


FIGURE 11: Front view.



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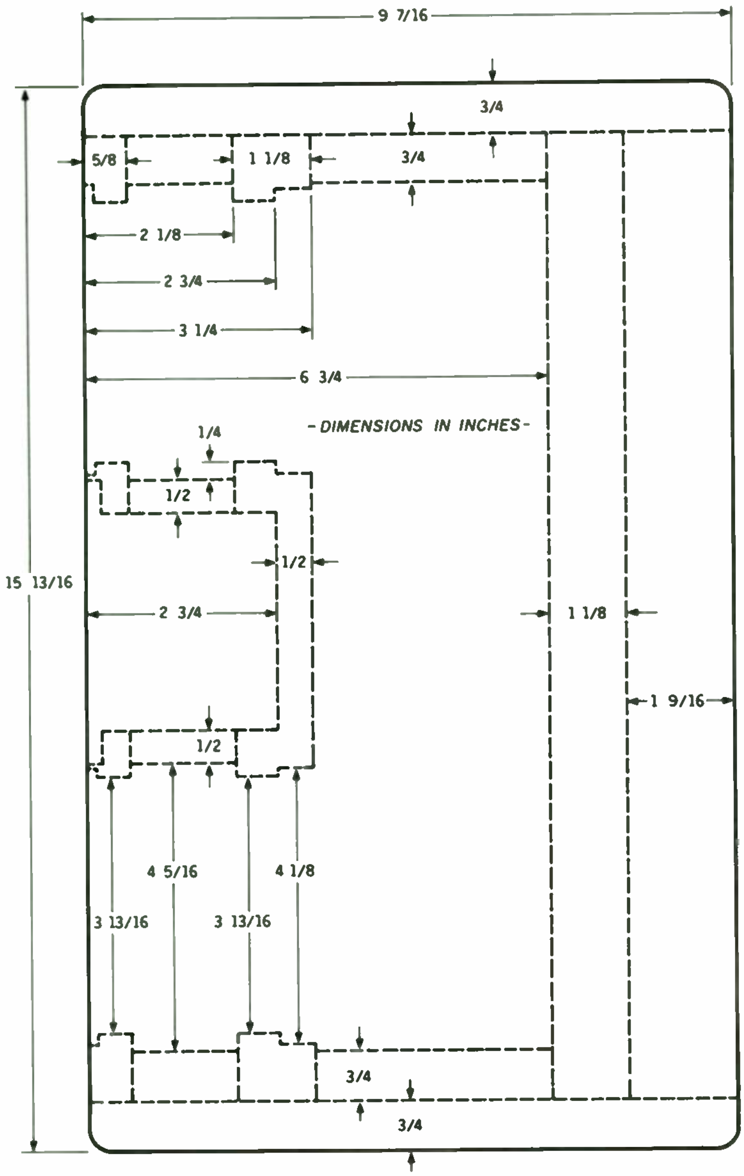

FIGURE 12: Side view—internal.

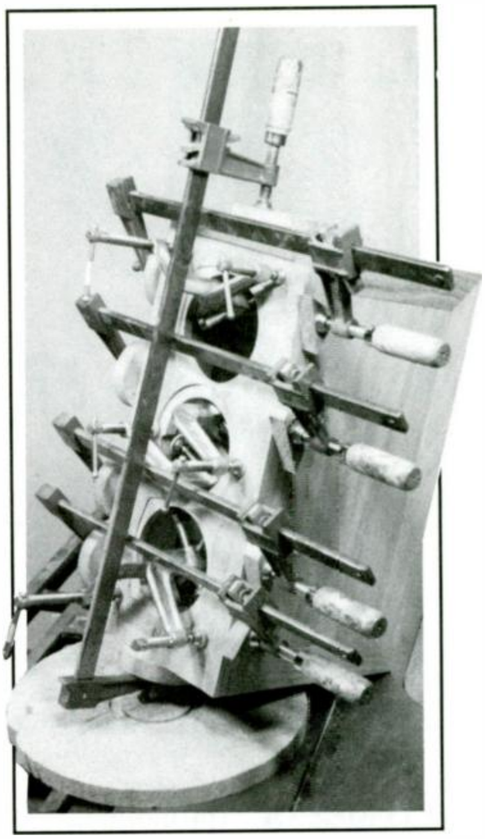

PHOTO 5: Eleven clamps hold the exterior baffle in place as the glue sets. Looks like something out of a science fiction movie!

grit and then round all corners with a 3/8″ carbide round-over bit (ball bearing guide). Sand all surfaces again with #150 grit and finish with #220.

After cleaning the surfaces thoroughly with a fresh tack cloth, stain the cabinets with a good quality oil stain (I used fruitwood). The temporary stands make this process easy. Wipe the stain with a dry, lint-free cloth to prevent streaking.

After the stain is dry, mask off the cabinets, including the tweeter and woofer flange areas, and spray paint the front baffles with five coats of flat black primer. When dry, remove the masking from the cabinets but leave the tweeter and woofer flange masking in place. Coat all external surfaces with a two part application of clear satin polyurethane. The finished speaker, with matching pine stands, is shown in *Photo 9*. (The stands are just something I whipped together for listening tests. My only alternative was to place the speakers on the floor.) The base is 11″ square, mitered 45° at each corner, cut from 2 × 6 construction lumber. The top is 7 by 9″, mitered at the corners, cut from construction grade 2 × 4s. The legs are 24″ lengths of the same 2 × 6 material. My total cost was $6 for both stands. While they are probably not the most attractive in the world, they provide a better support than many commercial stands costing much more.

WIRING & DRIVER MOUNTING. For the internal wiring, use a twisted pair of solid #18 copper for each leg. Hard solder this wire to the driver lugs, and use aluminum heatsinks to prevent damage to the driver terminals.

Mount the woofers and tweeters with #6, ½″ stainless steel sheet metal screws after pre-drilling with a very small drill bit. The internal woofers use a cork seal, (as previously described) and the external woofers use a small bead of mortite for a gasket. Before mounting, match F_S parameters of internal/external woofer pairs as closely as possible to ensure good power sharing.

Bring the wiring through the 10 rear panel holes (*Fig. 14*) and connect each wire at the nearest barrier strip position. Stuff each cabinet with approximately one ounce of Acousta-Stuf™ damping material, and screw the back panel in place with 14 evenly spaced #8, 2½″ wood screws.

Figure 14 shows the crossover wiring. A code listing showing driver terminal abbreviations is in *Table 6*. To secure the parts mechanically, place a small dab of silicone sealer under each component to keep them from stressing the wires or vibrating with the music.

THE SOUND. Voices are full-bodied, rich, and natural sounding, the way they ought to be. Most other small speakers sound thin and colored by comparison.

The speakers will not, when operated at full range, handle a great deal of power. I was able to play them comfort-

PHOTO 6: The internal baffle boards, completely machined and ready for installation. Note the position of the three ¼-inch lead wire holes on each baffle.

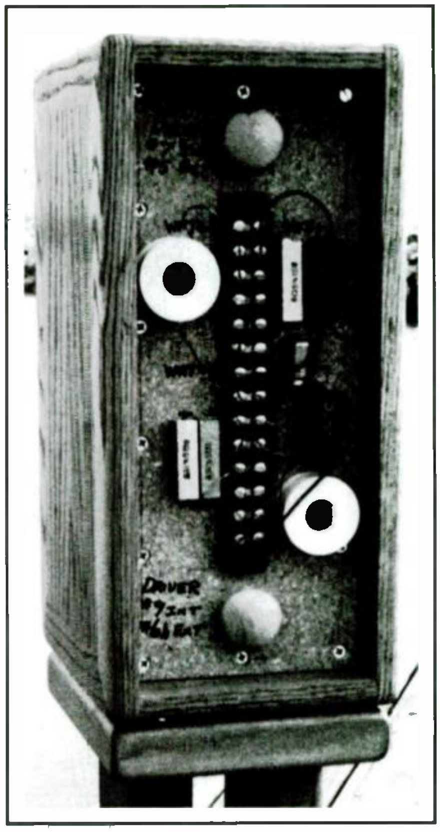

PHOTO 7: Rear view of the finished speaker, showing crossover layout. The deep rear panel recess keeps the parts hidden yet provides easy access for future modifications.

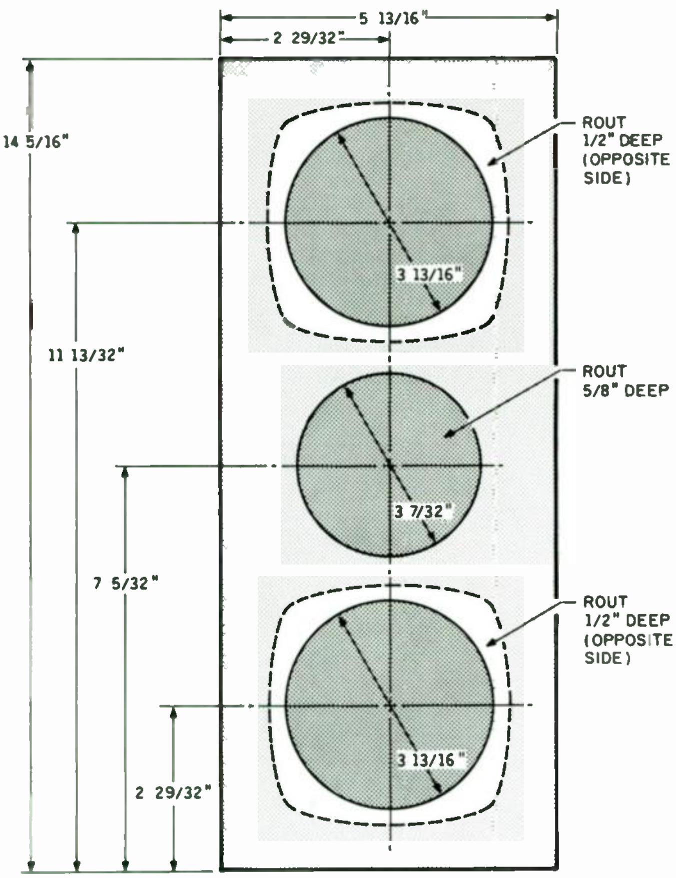

FIGURE 13: Internal baffle board.

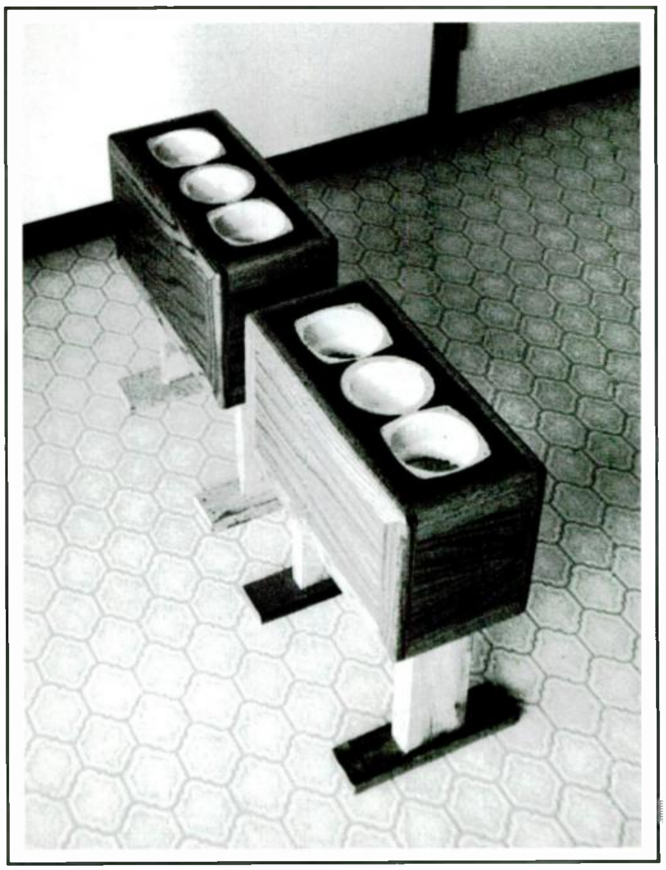

PHOTO 8: The finished boxes after staining, painting, and polyurethane finishing. Temporary stands, mounted from the underside, made the finishing process quick and easy.

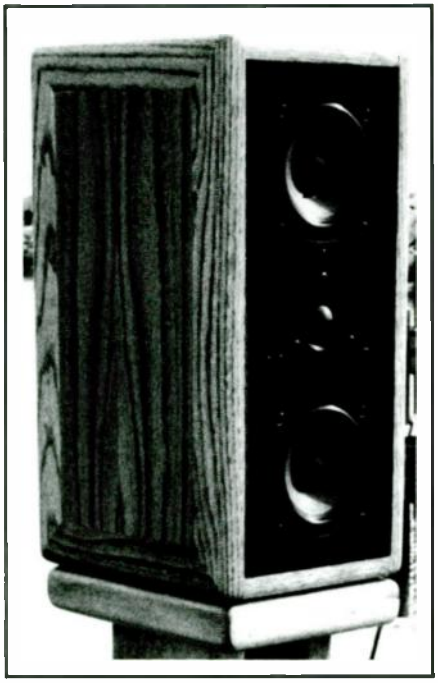

PHOTO 9: The finished speaker with matching pine stand.

ably, without strain or noticeable low frequency distortion, at an average level of 95dB when I had the speakers in a 2,100 cubic foot room. When I moved the speakers to a 9,000 cubic foot room the upper level dropped to about 90dB before noticeable low frequency distortion occurred.

The speakers tend to be bass shy. They will not produce much in the way of bass fundamentals below 60Hz. I should mention, however, that I intend to develop a subwoofer system for these speakers, which should help to solve both the power handling and low frequency extension problems.

On the positive side, these speakers image like crazy. With good recordings, they "lock on target" better than any system I have heard. Depth reproduction is also excellent, with a good sense of instrument placement along the stage.

In the midrange, I detect no strange anomalies due to the rear woofer "honking" into the front woofer. I listened intently for problems, but could hear no unusual sonic character or garbled noise in the upper midrange.

TABLE 6

CROSSOVER WIRING DIAGRAM CODE LISTING

CODE	DEFINITION
WFT+	Woofer front top positive
WFB+	Woofer front bottom positive
WRT+	Woofer rear top positive
WFT−	Woofer front top negative
WRB+	Woofer rear bottom positive
WFB−	Woofer front bottom negative
WRT−	Woofer rear top negative
WRB−	Woofer rear bottom negative
T−	Tweeter negative
T+	Tweeter positive

CONCLUSION. I highly recommend this speaker to anyone considering a small satellite system. The only drawback is possible F_S variation problems with the Radio Shack 40-1022As. Before you begin, buy a few woofers, run some tests, and see how it goes. If you run into trouble you can always scrap the whole project and build a pair of mini-speakers for your garage.

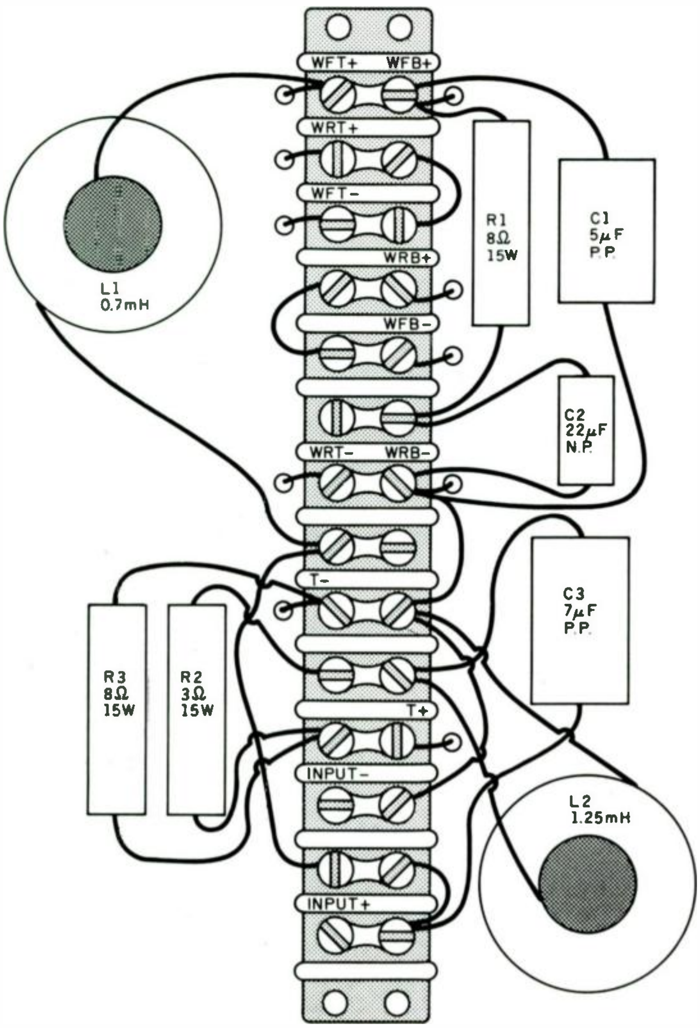

FIGURE 14: Crossover wiring detail. Note that inductor spacing is about six inches. Input connections are placed near the bottom.

SOURCES

Madisound Speaker Components
8608 University Green
Box 4283
Madison, WI 53711

Radio Shack
275 W. Wisconsin Ave.
Milwaukee, WI 53203

Audio Concepts, Inc.
901 S. 4th St.
PO Box 212
La Crosse, WI 54601

Mahogany Sound
2480 Schillingers Rd., #488
Mobile, AL 36695

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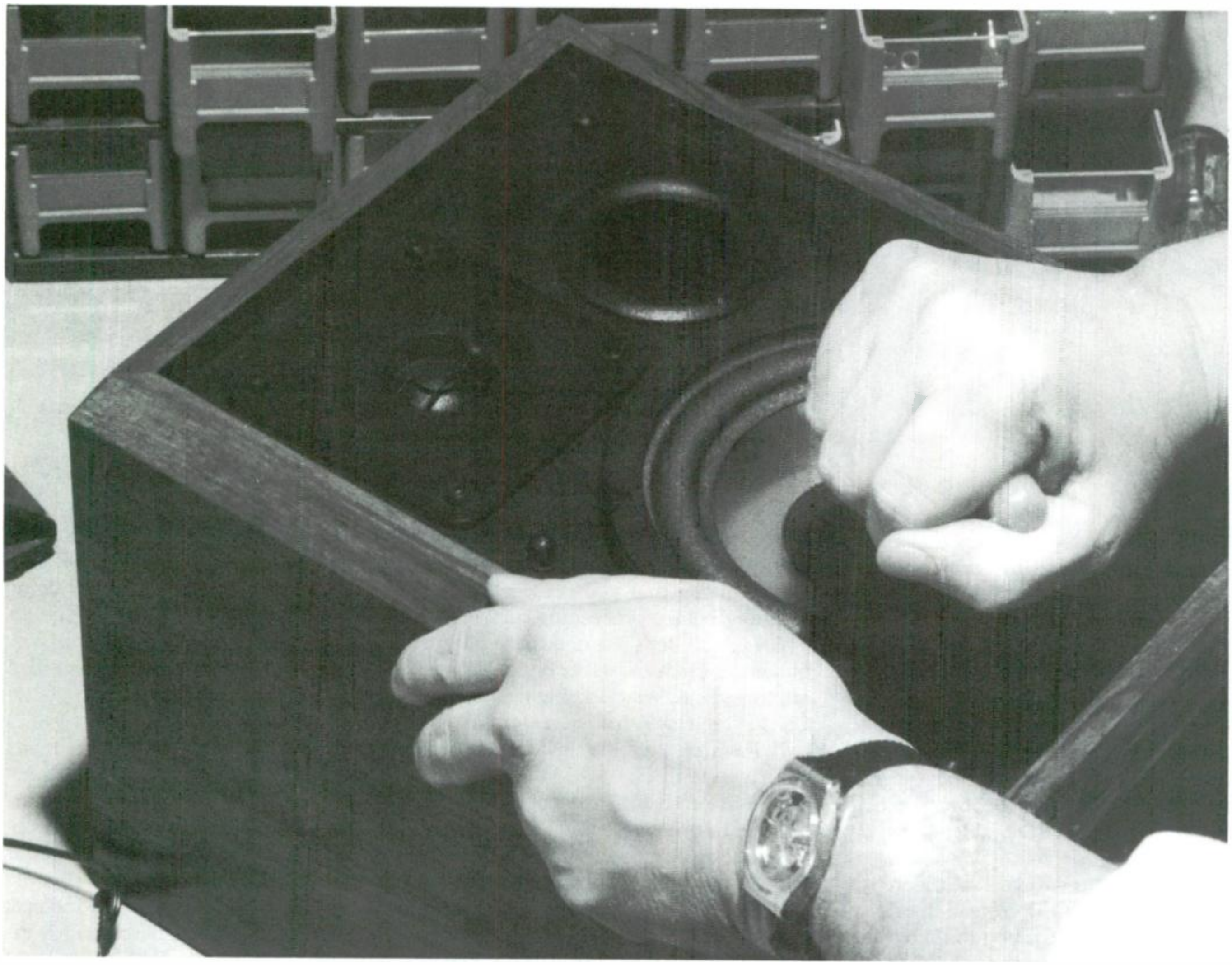

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CROSSOVERS FOR THE NOVICE

BY G. R. KOONCE
Contributing Editor

If you have detailed impedance and response data on the drivers in the system you are building and access to crossover (CO) optimization software, this article is not for you. Similarly, if you have built numerous systems, the material presented here is probably not of great interest. However, if you are in, or about to be in, the situation of having designed and constructed your first system and felt some confusion over how to handle the CO problem, read on: this article is for you.

It will not give you a theoretical development of COs; instead, it offers a proven approach for you to follow that will yield an effective passive CO. While I understand the advantages of using active COs, here we will assume that you have decided to use a passive CO approach. It is very easy for a novice builder to get overly involved in the many aspects associated with the CO and lose interest in the whole project, so little or no aid will be offered here on things such as the frequency response limits for each driver and driver placement interaction with the CO. The first time out, I recommend that you go with a vertical driver alignment, with the lowest-frequency driver on the bottom and highest-frequency driver on the top.

You will find that this article contains equations and theoretical considerations, since they are needed to understand certain principles, but an effort has been made to simplify and minimize such material. It's just about impossible to design COs without some equations and some test equipment. There are terms associated with CO work that you must understand in order to follow the procedure described here. To simplify things, I have marked such terms with an asterisk when I first introduce them, but I provide no definition there. You can find very simple definitions for these terms in the Glossary elsewhere in this article; I recommend that you read it through carefully before proceeding further.

That done, let's assume that you are building a unique speaker design. There are three basic ways to obtain a passive CO for your system:

1) Purchase it off the shelf from a local store.

2) Perform a logical design of a CO specific to your system.

3) Use a design optimization program based on detailed knowledge of your drivers' impedance* and response curves.*

Approach #1 is doomed. The sound will be terrible. What's more, in many cases I have seen high-frequency drivers destroyed at low power by such COs. The problem is that the vendor does not know your specific drivers. He has designed for some nominal impedance values, omitted impedance correctors* (Zobels*) and selected arbitrary CO frequencies and response slopes.* Furthermore, the designer has probably assumed that all your drivers have the same sensitivity.* And, for the final touch, these COs are usually constructed with components of poor quality. The chances of getting good sound with such an approach are so few that you can never justify the cost. Such COs can be fixed, but the procedure is the same as designing the CO in the first place. If you have already purchased COs, you may be able to use some of their components in your own CO design.

We have already said that this article is not aimed at anyone with access to optimization software and the detailed driver data required to use it, so approach #3 is out. We are thus left with approach #2, the logical design of a specific CO for your system. I will introduce you to an approach I have used successfully on many systems over more years than I care to admit. Every experienced builder has his own way of doing things, so I expect some might take exception to certain aspects of my method. My intent is simply to provide a unified approach—one known to work.

CROSSOVER TYPES. There are many classes of CO: all-pass,* constant-power,* constant-voltage,* and so on. Studying the various advantages and disadvantages of each is beyond the scope of this piece, but *Speaker Builder* has covered them in the past. (See the Mini-Index at the end of this article.) Based on my experience, I would say that if you want your system to image* properly, you would want to use a CO of the all-pass class (constant-voltage COs are all-pass). Two-way systems, in which things are fairly clean, can accommodate the popular Butterworth CO which can be all-pass in nature. A two-way system requires one low-pass* (LP) CO section for the woofer and one high-pass* (HP) CO section for the tweeter. With three-way systems, things are a little more complex and CO selection more of a problem. The three-way CO is composed of one woofer LP section, one tweeter HP section and a band-pass* (BP) section for the midrange. I have done no work with four-way or even more complex systems (and I hope you're not starting at this level of complexity).

COs also have an order,* relating to the slope of the response curves. My feelings, not shared by some others, are as follows:

1) *First-order* (slopes are ±6dB/octave) COs use a minimum parts count and are theoretically near-ideal, but they are dangerous and require extreme driver overlap.* I have not found drivers in which the necessary overlap in flat impedance

and acceptable response (without funny sounds) was available. Also, upper-frequency drivers receive too much power and show large displacement at low frequency while having no useful output. They are thus subject to destruction. You want at least second-order HP on any high-frequency driver in order to prevent this low-frequency displacement problem.

2) *Second-order* (slopes are ±12dB/octave) COs normally requires one driver to be inverted* in order to provide an all-pass response. I have never found the sound to be acceptable with this approach, but I concede that many others build with it successfully. You can build acceptable systems without the driver inversion by creating a slight overlap or hole in the CO response (HP and LP frequencies not quite the same), but the performance is very sensitive to component values and the CO function is ob-

Continued on page 28

Crossover Glossary

This section presents simple definitions of terms introduced in the article and marked with an asterisk (*). Understanding the meaning of these terms is vital to understanding the concepts presented here. Please note that the definitions are aimed specifically at CO concepts as presented in this article and may not be general in nature.

All-pass CO. On the major axis, the system acoustic output level (with ideal drivers) is the same at all frequencies.

Bi-wire. A method in which a single amplifier output is tied to the speaker system via two cables, one for the woofer and the other for all other drivers.

Band-pass. A CO section in which only a band of frequencies is passed on to the driver, and both the high and low frequencies are blocked.

Constant-power CO. Puts the same acoustic power (over all radiating space) into a room at all frequencies (with ideal drivers). These COs tend to exhibit a constant input impedance.

Constant-voltage CO. Acoustically reconstructs the electrical input exactly (with ideal drivers), but delays it in time. This is the "ideal" CO.

CO Order. The ranking of a CO function based on the exponential index in an equation related to the function. For CO work the order defines the number of reactive components (Ls and Cs) and the response slope as follows:

CO Type	Reactive Components Inductors and Capacitors	Response Slope dB/Octave
LP	1 times Order	−6 times Order
HP	1 times Order	+6 times Order
BP	2 times Order	±6 times Order

Driver Resonant Frequency. *See* **Resonant Frequency**.

High-pass. A CO section in which only the high frequencies are passed on to the driver, the low frequencies being blocked.

Image. The multidimensioned acoustic "picture" created by a good two speaker system in which the sound source cannot be identified as the speakers.

Impedance. The opposition to flow of current in an AC circuit (*i.e.*, the AC equivalent of resistance) seen looking into a driver or a CO. This is a vector quantity composed of orthogonal resistance-reactance components and thus having a magnitude and phase angle.[16] Resistance with capacitive reactance yields a negative phase angle and resistance with inductive reactance a positive phase angle.

Impedance Corrector. A network put across the driver terminals to attempt to make the driver impedance appear as a fixed resistance. Also called a Zobel.

Inverted Driver. A situation in which the electrical input to the driver is inverted relative to the other drivers in the system.

L-pad. A two-resistor padding network, fixed or adjustable, that ideally maintains a constant input impedance as the padding (attenuation) is changed.

Low-pass. A CO section in which only the low frequencies are passed on to the driver, the high frequencies being blocked.

Octave. A two-to-one frequency spread. Given a higher frequency F_H and a lower frequency F_L, they are spread by Z octaves where Z = $[\mathrm{Log}(F_H/F_L)]/\mathrm{Log}(2)$; conversely, where F_H is above F_L by Z octaves, they are related as follows: $F_H/F_L = (2)^Z$.

Order. *See* **CO Order**.

Overlap. The frequency spread in the region of your CO frequency where both drivers have acceptable response curves and acceptably constant, nearly resistive, impedance curves. For passive CO development, at least two octaves of overlap are needed, the CO frequency selected to yield a one-octave overlap on each side.

Padding. An attenuation network that is placed between the CO output and the driver–Zobel combination in order to reduce the driver's output level relative to the other drivers. (*Fig. 3*)

Peaking. In a CO section, a situation in which the output voltage exceeds the input voltage, or the CO is showing voltage gain. When this occurs, the CO section input impedance must dip below the load impedance, since a passive CO cannot provide power gain.

Phase or Phase Angle. *See* **Impedance**.

Resonant Frequency (Driver). A frequency at which the driver's mechanical structure will give a large displacement for a small input. It appears as a sharp rise in the driver input impedance. Certain driver construction techniques (*e.g.*, ferrofluid-filled voice-coil gap) will greatly reduce or eliminate any resonant rise in impedance.

Response Curve (Driver). A plot, usually dB on a vertical scale versus frequency on a logarithmic horizontal scale, which indicates the driver's acoustic output versus voltage input (normally on an axis perpendicular to the driver's). This helps to establish the usable frequency range of the driver.

Response Slope (CO). The ultimate attenuation rate (plus or minus) obtained by a CO section, varying with the CO order. *See* **CO Order**.

Sensitivity. The acoustic level out of the driver relative to the voltage applied to the driver. You really want the same output from all drivers when driven by the same voltage, independent of their impedance.

Series Padding. Padding a driver with a simple series resistor. The padding amount may vary with the frequency. (*Fig. 3*)

Zobel. *See* **Impedance Corrector**.

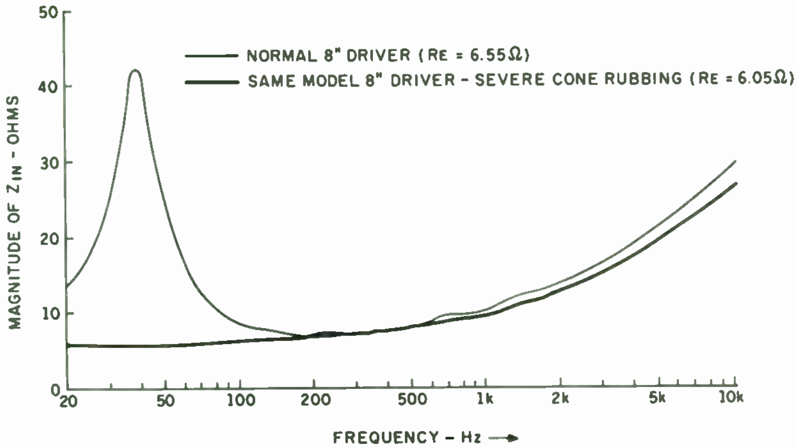

FIGURE 1: Magnitude of input impedance to 8" woofers.

viously not all-pass. This is not the best approach for a novice.

3) *Third-order* (slopes are ±18dB/octave) COs have a parts count that gets rather high, but I find that they work the best right "out of the box," with the least playing needed. Since a novice may not have the spare parts on hand to be able to play with component values, I recommend the third-order CO as the one to start with.

4) *Fourth-order* (slopes are ±24dB/octave) COs have a parts count so high that I have never even tried them. They might be acceptable in a two-way system, but I have no experience with this.

5) *Asymmetrical* COs (slopes not the same on LP and HP) are also outside my experience. I have not used them, and design equations for them may be difficult to locate.

When you get to three-way systems in which the midrange CO is a BP, you can implement it in different topologies (i.e., configurations of the parts). Their two topologies are the cascaded and the transposed.[1,2] Both these groups of parts implement the same BP CO function and there is no change in the LP or HP used with them, but they do have some differences:

1) *Cascaded topology* (the combination of a high-pass and a low-pass, cascaded in either order) shows peaking* in the response which tends to increase as the two CO frequencies get closer together. This means that the input impedance seen by the amplifier can dip throughout the midrange region. However, if you are a little shy on midrange sensitivity, then this peaking can be used to aid the situation. This is the most common topology and the one shown in most design references.

2) *Transposed topology* (a true BP filter design) does not peak and thus provides a better impedance load to the amplifier. It may, however, require the midrange to have a slightly higher sensitivity than the woofer. I prefer this topology if the peaking is not needed. I have tried both topologies on a couple of systems and the transposed topology sounded better for reasons I cannot explain.

One additional consideration is whether you want to build with a parallel or a series CO. The parallel CO is conventional and has all the CO sections in parallel driven by the amplifier. The series CO stacks the CO sections and drivers in series across the amplifier. Some theoretical claims exist for the advantage of the series CO (first-order), but I recommend that you avoid them. The major problem is that if you have to change one component, you have to change them all. An impedance change on one driver due to padding,* for example, means a total CO redesign, rather than a redesign of just one section as would be needed with the parallel CO.

In summary, my recommendations to the novice crossover builder are as follows:

1) With a *two-way system*, use the third-order Butterworth. It is all-pass and constant-power with no driver inversion. Build it with parallel sections.

2) With a *three-way system*, use the Bullock positive band-pass third-order all-pass.[1,3] This all-pass CO requires no midrange inversion, but you should be sure that the upper CO frequency is at least three times the lower CO frequency. Build it with parallel sections, and if you do not need the peaking for the midrange, use the transposed topology.

DRIVER INFORMATION. There is certain information you must know about each driver in order to allow for

Continued on page 30

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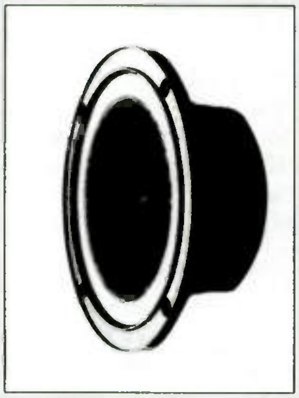

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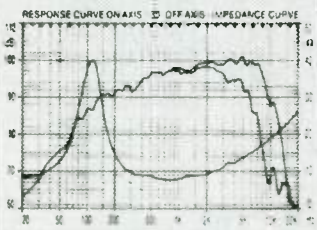
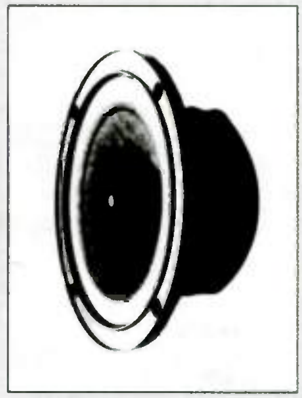
Optimized Flat Surround Diaphragm





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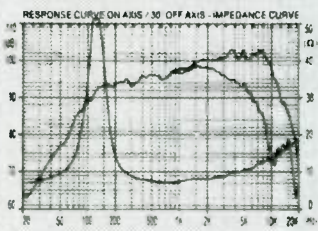
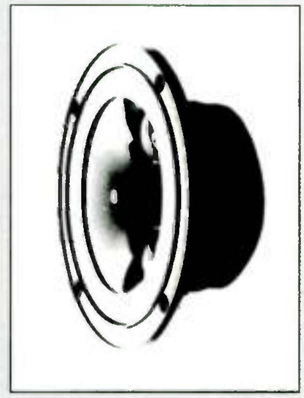
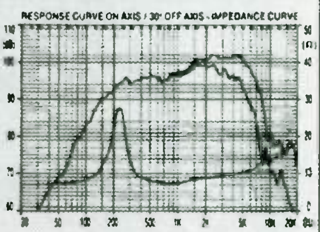
Flat Edge Wound Coil on Kapton





PR 17 TX 100

6 1/2 " Midrange with TPX Cone
101 dB Sensitivity
Flat Edge Wound Coil on Kapton



SPECIFICATIONS:

	PR 17 HR 70		PR 17 HR 100		PR 17 TX 100	
Nominal Impedance	*Z (Ohms)*	8	*Z (Ohms)*	8	*Z (Ohms)*	8
DC Resistance	*Rscc (Ohms)*	6.7	*Rscc (Ohms)*	6.0	*Rscc (Ohms)*	6.0
Voice Coil Inductance	*Lbm (uH)*	520	*Lbm (uH)*	270	*Lbm (uH)*	270
Resonant Frequency	*fs (Hz)*	110	*fs (Hz)*	125	*fs (Hz)*	210
Moving Mass	*Mmd (kg)*	0.00910	*Mmd (kg)*	0.00700	*Mmd (kg)*	0.00774
Effective Piston Area	*Sd (m2)*	0.01430	*Sd (m2)*	0.01430	*Sd (m2)*	0.01430
Equivalent Cas Air Load	*Vas (m3)*	0.0066	*Vas (m3)*	0.0066	*Vas (m3)*	0.0021
Mechanical Q Factor	*Qms (-)*	1.7	*Qms (-)*	1.94	*Qms (-)*	3.90
Electrical Q Factor	*Qes (-)*	0.34	*Qes (-)*	0.55	*Qes (-)*	1.02
Total Q Factor	*Qts (-)*	0.28	*Qts (-)*	0.43	*Qts (-)*	0.81
Voice Coil Diameter	*d (mm)*	38.0	*d (mm)*	38.0	*d (mm)*	38.0
Voice Coil Length	*h (mm)*	7.0	*h (mm)*	7.0	*h (mm)*	7.0
Height of Gap	*He (mm)*	6.0	*He (mm)*	6.0	*He (mm)*	6.0
Linear Excursion	*Xmax (mm)*	0.5	*Xmax (mm)*	0.5	*Xmax (mm)*	0.5
Magnet Weight	*Wt (kg)*	0.876	*Wt (kg)*	0.876	*Wt (kg)*	0.876
Characteristic Efficiency	*E (dB SPL)*	99	*E (dB SPL)*	101	*E (dB SPL)*	101
Nominal Power Handling	*P (W)*	70	*P (W)*	100	*P (W)*	100

T E C H N O L O G Y and I N N O V A T I O N

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Continued from page 28
the proper design of a passive CO. Remember that you are really trying to obtain a given acoustic CO function. If the driver does not have a flat response past the frequency of the electrical CO, you will not have the anticipated CO function. The driver's response range must be established by tests or by known specifications. I recommend testing because I have learned not to trust any published data as being truly representative of my own particular drivers.

It is imperative that you implement some approach to measure driver input impedance. Having phase* along with amplitude is nice but not necessary. (The listings in the Mini-Index can serve as sources for guidance here.) The drivers are each tested to establish the resonant frequency* and the input impedance versus frequency. *Figure 1* shows the input impedance magnitude versus frequency for two 8″ woofers of the same type mounted on a baffle in free air. Fortunately for this article (but not the systems I was trying to build!), one of these units has the voice coil off center and is jammed. The good unit shows a resonance at about 38Hz, which is absent in the jammed unit and clearly indicates that the driver impedance reflects the cone motion. Note, however, that both drivers show a rising impedance magnitude at high frequency that is not a function of cone motion. This is the impedance rise that causes problems with the CO response and must thus be corrected. To accomplish this, we develop an impedance correction network (Zobel) for each driver requiring impedance correction in the upper end of its frequency range. (We will cover developing the Zobel in the next section.) The midrange driver is the most difficult for which to develop the Zobel, since it will have a CO point at each end of its response. I have had cases in which I had to design the lower CO frequency at one impedance value and the upper one at a different one, thus making the BP CO section a very difficult design problem. I surely hope you are not presented with this problem the first time out.

Reviewing the response range of each driver, along with knowing the location of its resonance, will allow you to establish your needed CO points. There is a tendency in many people to have preconceived ideas of where the CO frequencies should be. This is fine, providing that tests show that the drivers can support these frequencies. Keep in mind that with typical music, not using equalization or tone controls, one half of the input power is below (approximately) 800Hz and the remainder above.[4] Pushing the CO frequency too low can put severe power requirements on the midrange or tweeter in a two-way system. I recommend letting the drivers tell you the proper CO frequency point(s) the first time through. If your tests tell you that the drivers will not overlap sufficiently to provide good CO performance, you should consider changing one or more of the drivers. You must obtain an absolute minimum of a one-octave overlap on each side of the CO frequency in order to have any chance of success with passive COs.

IMPEDANCE CORRECTION. We have seen that the woofer does not offer a constant and resistive input impedance. Other drivers will also display this same problem. The approach I use to handle this is to add Zobels on the drivers that require correction. In general, you have to get the impedance reasonably flat over the driver's region on the CO slope, which varies with the CO order and in theory can be as wide as three octaves* each way from the CO frequency. I recommend staying with second-order or higher COs. In practice,

Continued on page 34

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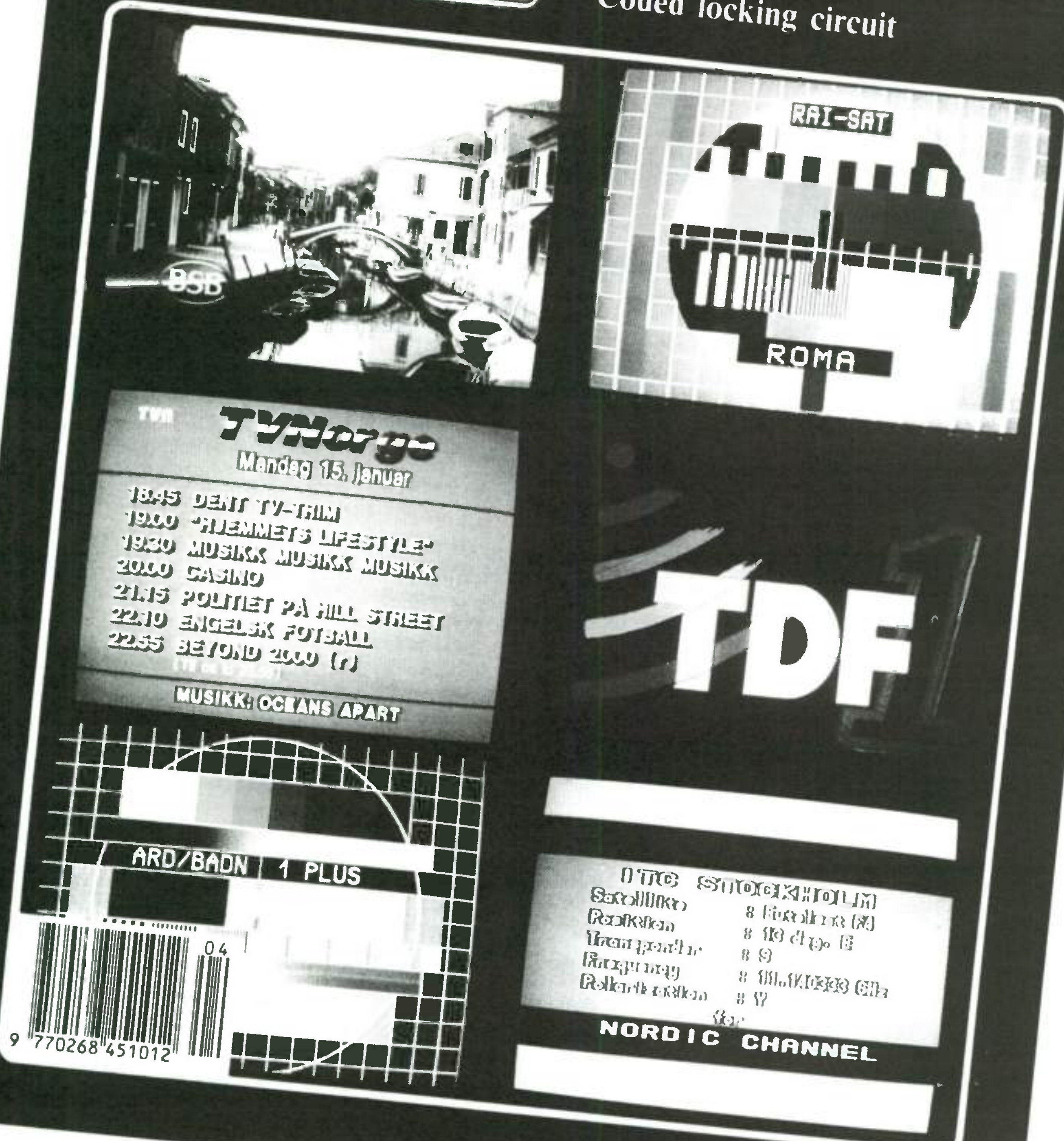

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good sounding systems can be built by using passive COs that allow only one octave between the CO frequency and impedance anomalies. More separation is certainly better, but it's not always possible. You can find examples of these effects later in this article.

My basic approach is not to attempt to correct the driver resonance impedance anomaly. However, it *is* possible to do so.[5,6] I do not recommend that you try this, but instead that you stay at least one octave above resonance for your CO point. For example, with a two-way system crossing over at 2kHz, the woofer impedance should be smoothed to better than 4kHz and the tweeter resonance should be below 1kHz. Generally, when you smooth the upper frequency impedance of a driver with a Zobel you can smooth it for many octaves.

You can find in numerous references equations for computing the series resistor-capacitor (RC) Zobel needed for driver impedance correction. Unfortunately, they don't work. They are based on the assumption that the driver looks like a series resistance-inductance (RL) at high frequency. I found out early that this did not work out properly, based on the following:

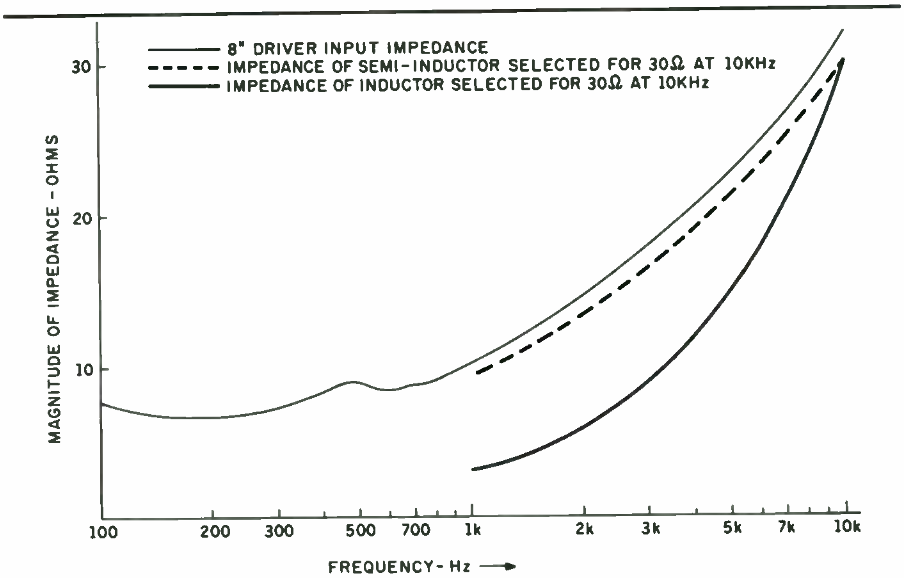

FIGURE 2: Impedance comparison of driver with inductor and semi-inductor.

1) A series RL would have an impedance angle approaching 90° at high frequency. When I tested drivers, they would go to the mid 40° range and stay there.

2) If I measured the driver impedance (magnitude and phase) and computed the needed Zobel at various frequencies, I got different R and C values at each frequency.

It was obvious that something was wrong with the basic assumption that the driver looks like a series RL. The problem was clarified when I saw Vanderkooy's 1989 article.[7] The driver at high frequency looks like the series combination of a resistance and, as Vanderkooy defines it, a semi-inductance. While an ideal inductor has an impedance magnitude proportional to the product of in-

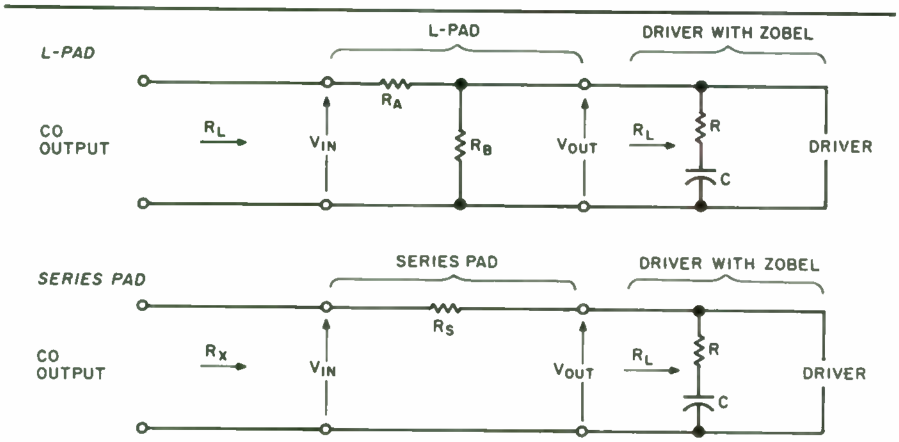

FIGURE 3: Pads—location in driver wiring, schematic, and design. *L- pad*: driver and Zobel = fixed resistance = R_L; CO load = input impedance to L-pad, also = R_L; A = attenuation of L-pad in dB (positive number); voltage ratio (VR) = V_{IN}/V_{OUT} = $(1.12202)^A$; R_A = $[(VR-1) R_L]/VR$; R_B = $[R_L (R_L - R_A)]/R_A$. *Series pad*; driver and Zobel = fixed resistance = R_L; CO load = input impedance to series pad = R_X = $R_S + R_L$; A = attenuation of series pad in dB (positive number); voltage ratio (VR) = V_{IN}/V_{OUT} = $(1.12202)^A$; R_S = $(VR-1) R_L$. If no Zobel is used, load on pad = Z_L, a complex load. R_S = $(VR-1)|Z_L|$, where $|Z_L|$ is the magnitude of Z_L computed at the frequency where you want attenuation A. CO load = input impedance to series pad = Z_X = $R_S + Z_L$. Attenuation and CO load will both vary with frequency.

ductance times the frequency, an ideal semi-inductor has an impedance magnitude proportional to the square root of the product of the semi-inductance times the frequency.

Figure 2 demonstrates this for the 8″ woofer we have already discussed. Added to the driver measured impedance are two curves selected to give 30Ω at 10kHz, one curve an ideal inductor and the other an ideal semi-inductor. It's clear that the driver impedance matches the shape of the semi-inductor curve and not that of the true inductor. This means that it is impossible to truly correct the driver impedance with a single RC Zobel and that all the equations for Zobel design assuming an LC driver impedance are incorrect.

I have tried, unsuccessfully so far, to develop Zobel design equations based on a semi-inductor model; perhaps someday that will come. Does this mean that the Zobel concept is dead? No way. It just means that you must design the Zobel by trial and error as I have always done in the past. With playing, you can do a pretty good job of flattening the impedance magnitude curve and keeping the impedance angle under 10° with a single RC Zobel network. This works out in practice to be sufficient to yield acceptible CO performance. Examples of the improvement that Zobels make in impedance magnitude and phase correction will be shown later.

My basic approach is to hook a "Corrector Box"[8] across the driver terminals. This box has switchable series R and C values. I start with R near the driver nominal impedance value and with a C value guessed at by using the size of the driver voice coil. I then continue to play with the values until the impedance is sufficiently flat above the anticipated CO frequency. With just a little experience, you learn what to change to correct various effects.

This is not an elegant engineering approach and for production would be unsatisfactory, but for the home builder it does the job. You should apply it to the woofer for sure, to the midrange on a three-way system, and possibly to the tweeter if the upper CO frequency was quite high. I have found improved imaging on some three-way systems when a tweeter Zobel was added. Without a Zobel, the tweeter response with a passive CO tends to peak above 0dB by a dB or two. If you are a little shy on tweeter sensitivity, this latter effect can be advantageous; you must consider it when doing the tweeter padding.

Remember that the Zobel network always stays right across the driver input terminals. If you need padding on a midrange or tweeter (you don't pad the woofer without a complete enclosure redesign), the padding network goes between the CO output and the driver-Zobel combination.

CROSSOVER DESIGN. At this point, I will assume that you have been able to select a CO type along with the CO frequencies. You have the impedance of the Zobelled drivers (assumed as a pure resistance for design purposes) and are ready to start your design. Keep in mind that it is extremely likely that all the drivers but the woofer will require padding to the proper level. See *Fig. 3* for the location of the padding and the schematic for the series* and L-pads.*

If you plan to experiment with adjustable L-pads, please note that they can change the driver impedance reflected to the CO. If your driver is near 8Ω, then you can use common 8Ω adjustable pads, but be sure to note that the impedance will become closer to 8Ω as more attenuation is added with the pad.[9] For drivers of other than 8Ω impedance, you will have to design the pads, changing them each time you need a different attenuation. Series padding is very simple, but it has the problem of changing the load on the CO with each change, and thus should be avoided or used carefully. Series padding used without a Zobel can push the response of inexpensive tweeters, but CO and padding design become difficult.[10]

At this point, you have the CO frequencies, you've refined the load impedances for the selected CO, and now you want to establish the CO component values. There are numerous references with design charts and equations for this purpose. I would recommend Bob Bullock's excellent series in *Speaker Builder*[2,3,6,11,12] and his work in the AES *Journal*.[13,14] Also, you may wish to know that my SOF-CRS185 crossover-design disk for the IBM compatible computer (available from Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458; (603) 924-6371, $12.50) will allow the design of two-way and three-way COs of the first through third orders including my own recommended CO types.

Although it's not really within the basic scope of this article, let me at this point offer some brief comments on components for CO construction:

1) *Resistors*. I use Squareohm power resistors (although other high-quality brands can work just as well). They are inexpensive, reasonably accurate, and easy to RTV down for construction. My tests show that they stay resistive throughout the audio band in the values normally used in speaker work. Make sure they are big enough to take more power than the driver when used in pads. I normally size the Zobel resistor at about one half the power to the driver.

2) *Capacitors*. I can hear nonpolar electrolytics, so I don't use them if I can avoid it. I never use them with a midrange or tweeter. For the woofer CO and Zobel on inexpensive systems, I will use

Continued on page 38

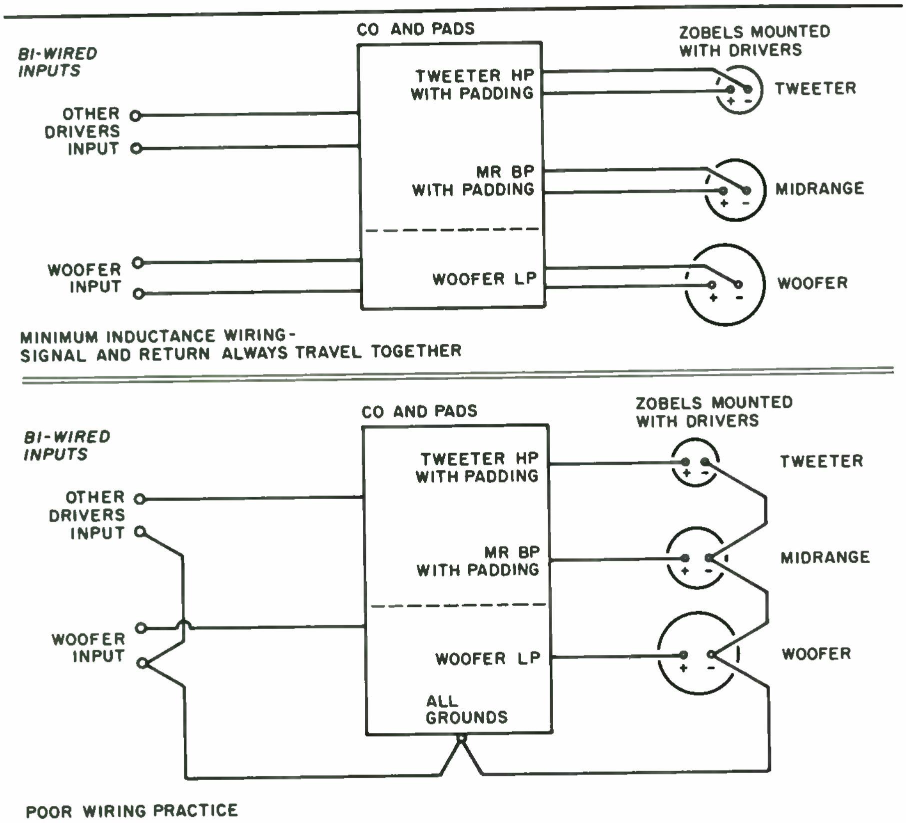

FIGURE 4:Minimum inductance wiring is good practice.

Continued from page 36

electrolytics for about 65 percent of the capacity bypassed and film capacitors for the other 35 percent. You don't have to buy expensive capacitors: Mylar or any other film, oil-filled, and paper and mica (for small trim capacitors) all work well.

3) *Inductors.* This is the real problem. Avoid iron-core and solenoid-wound ferrite-rod-core inductors.[4,15] Use air-core or ferrite-bobbin-core coils. I prefer the ferrite-bobbin ones because they keep the DC resistance low and are physically smaller. They are now difficult to find; R & B Enterprises (PO Box 1016, Manchester, CT 06040, (203) 647-1654) is the only source that I presently know. They wind good coils and are willing to work with you to make what you want. Select a core the right size to handle the current for the intended application and remember to mount the coils far apart (with a minimum of 2" between the edges). Keep them away from ferrous metal, and RTV them down or mount them with brass hardware.

4) *L-pads.* If you purchase commercial units, be sure to get them with a high enough power rating. The low-cost, low-power units generally available do not hold 8Ω too well, but they have caused me no trouble.

5) *Connections.* I recommend soldered connections only.

6) *Wiring.* I recommend initially that you bring all the driver connections out of the enclosure and develop the CO externally. If the CO eventually goes internal, you must have left volume for it in the enclosure design. More and more, I mount the Zobels and CO components external to the sealed portion of the enclosure. You should try to use two sets of input terminals in order to allow bi-wiring* for the final hookup. I don't see a need for expensive wire, but you *should* use minimum-inductance wiring

Continued on page 41

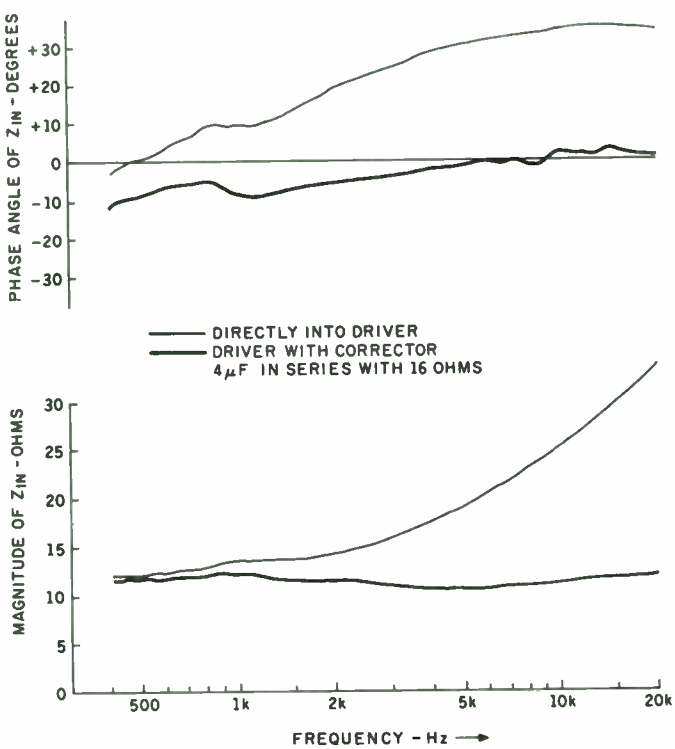

FIGURE 5: Impedance of small woofer with and without Zobel.

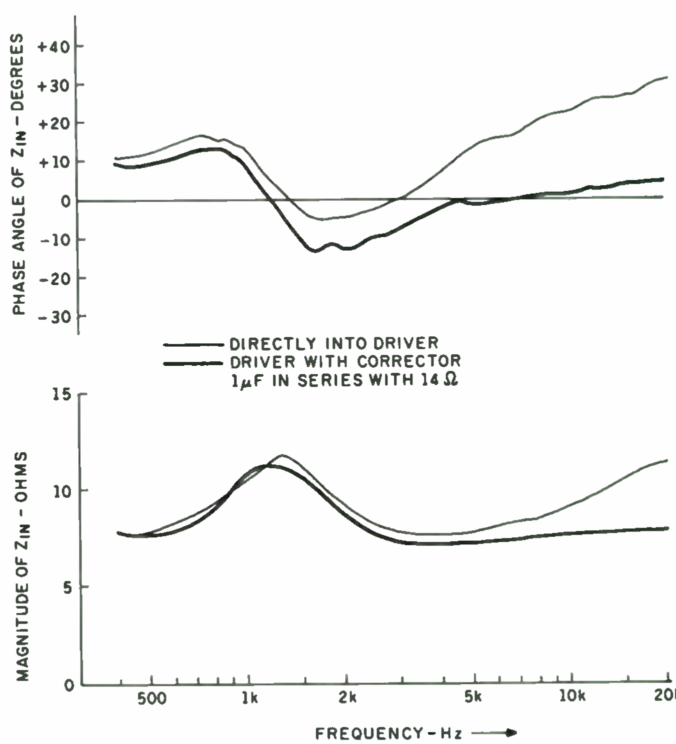

FIGURE 6: Impedance of dome tweeter with and without Zobel.

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Continued from page 38

techniques. Use some parallel wire cable (Zip/lamp cord is handy) and take the two wires to each driver (don't loop a single ground to all drivers). Such looping can put excessive inductance in series with the tweeter, cause crosstalk between drivers, and increase pickup feedback to the amplifier. See *Fig. 4* for a comparison of minimum inductance wiring and "poor" wiring.

7) *Input terminals.* I'm not fussy here. I dislike some of the commercial plastic fixtures that mount in the enclosure wall because they are not stiff enough, not because I object to them electrically. Normally I use barrier terminal strips mounted on the outside of the enclosure and bring the wires through holes sealed with RTV throughout the wall thickness.

SOME EXAMPLES. Let's take a look at some examples of a two-way-system CO design. The drivers are a small 12Ω woofer, picked because of its odd impedance, and a common dome tweeter. *Figure 5* shows the input impedance to the woofer with and without a Zobel. The improvements in impedance amplitude flatness and in minimizing phase shift are evident. *Figure 6* shows the same

Continued on page 43

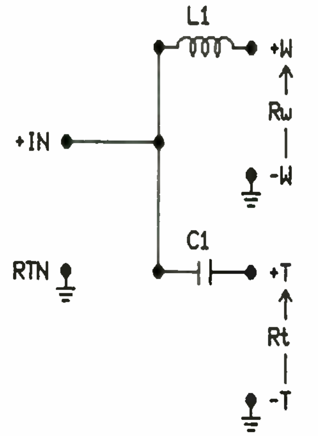

FIGURE 7: First-order Butterworth crossover (6dB/octave, two-way).

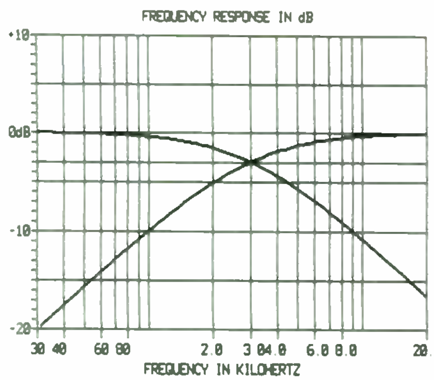

FIGURE 8: Ideal amplitude response of first-order Butterworth crossover. R_W = 12Ω. R_T = 8Ω. L_1 = 0.64mH. C_1 = 6.63μF.

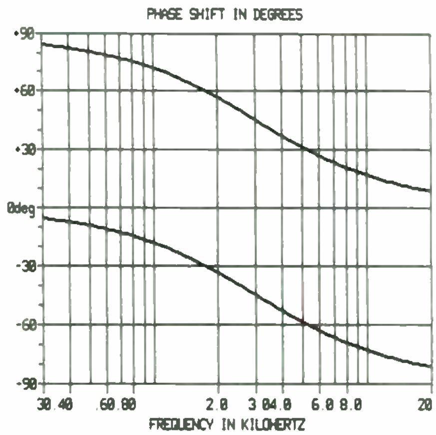

FIGURE 9: Ideal phase response of first-order Butterworth crossover. R_W = 12Ω. R_T = 8Ω. L_1 = 0.64mH. C_1 = 6.63μF.

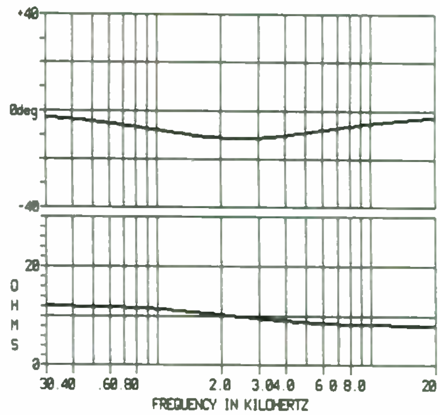

FIGURE 10: Input impedance to first-order Butterworth crossover with ideal loads. R_W = 12Ω. R_T = 8Ω. L_1 = 0.64mH. C_1 = 6.63μF.

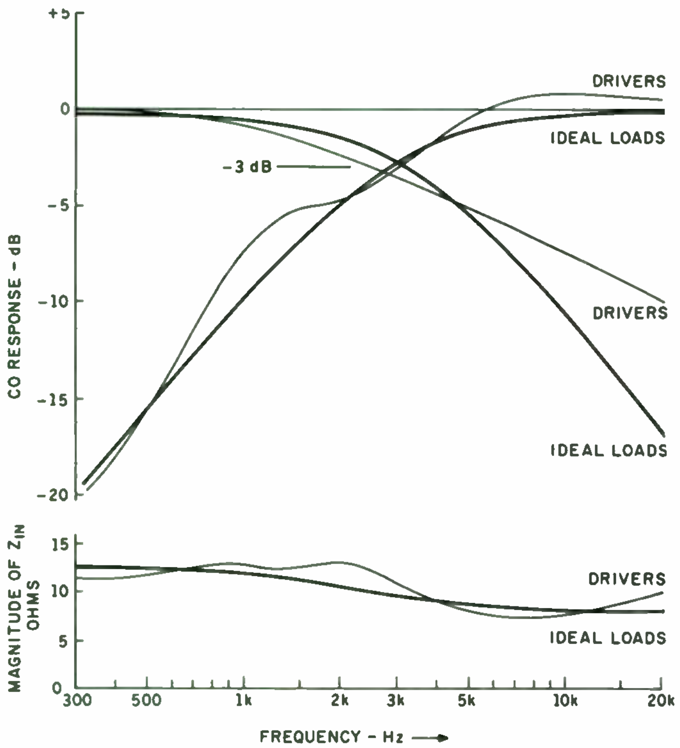

FIGURE 11: Test results for first-order Butterworth crossover with no Zobels.

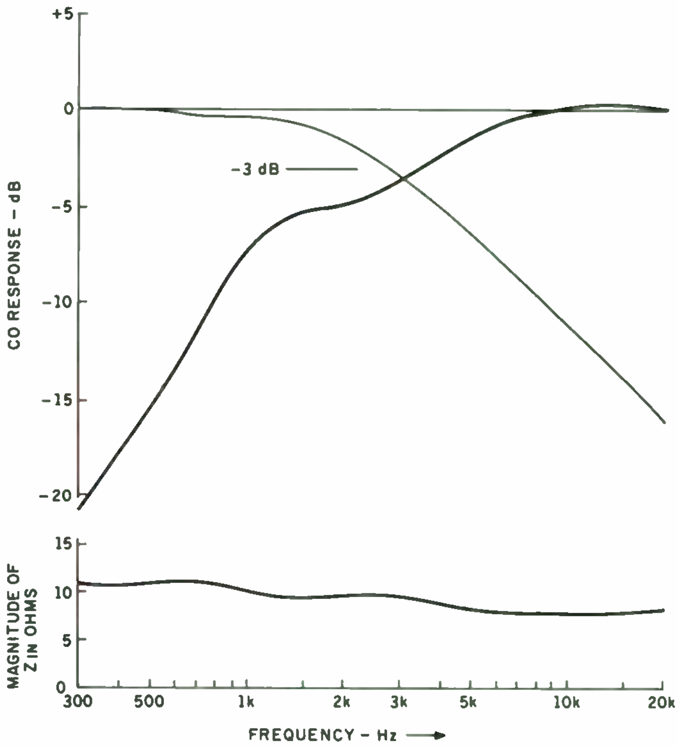

FIGURE 12: Test results for first-order Butterworth crossover with Zobels.

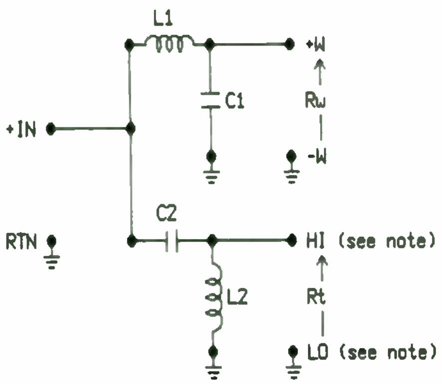

FIGURE 13: Second-order all-pass crossover (6dB/octave, two-way). For some 12dB crossovers, many recommend inverting the tweeter (HI = −T) to correct the phase.

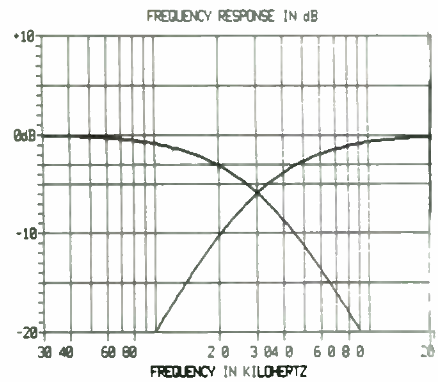

FIGURE 14: Ideal amplitude response of second-order all-pass crossover. R_W = 12Ω. R_T = 8Ω. L_1 = 1.26mH. C_1 = 2.21μF. L_2 = 0.85mH. C_2 = 3.32μF.

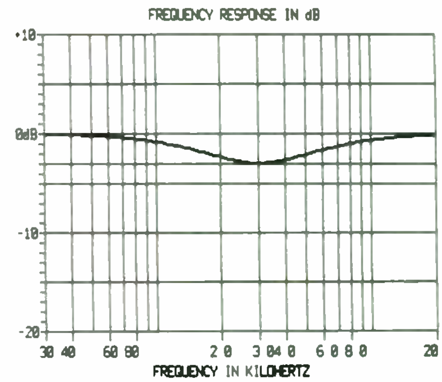

FIGURE 15: Ideal total power response of second-order all-pass crossover. R_W = 12Ω. R_T = 8Ω. L_1 = 1.26mH. C_1 = 2.21μF. L_2 = 0.85mH. C_2 = 3.32μF.

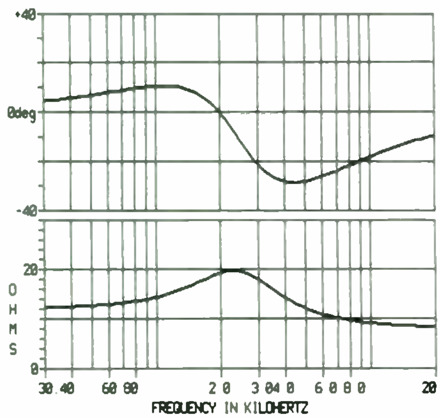

FIGURE 16: Input impedance to second-order all-pass crossover with ideal loads. R_W = 12Ω. R_T = 8Ω. L_1 = 1.26mH. C_1 = 2.21μF. L_2 = 0.85mF. C_2 = 3.32mH.

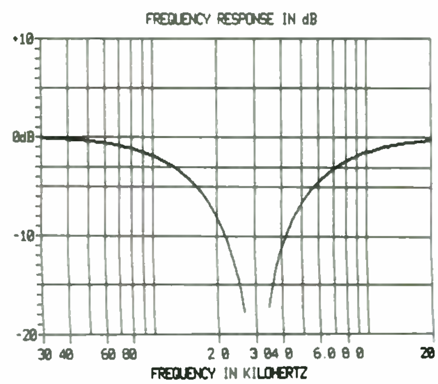

FIGURE 17: Ideal on-axis response of second-order all-pass crossover (normal tweeter). R_W = 12Ω. R_T = 8Ω. L_1 = 1.26mH. C_1 = 2.21μF. L_2 = 0.85mH. C_2 = 3.32μF.

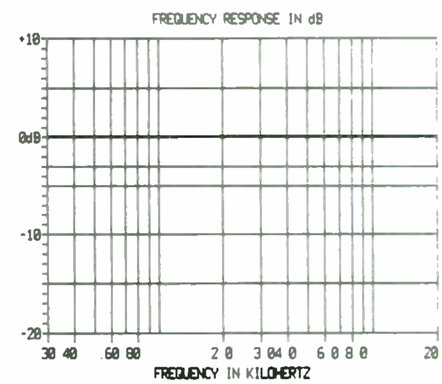

FIGURE 18: Ideal on-axis response of second-order all-pass crossover (inverted tweeter). R_W = 12Ω. R_T = 8Ω. L_1 = 1.26mH. C_1 = 2.21μF. L_2 = 0.85mH. C_2 = 3.32μF.

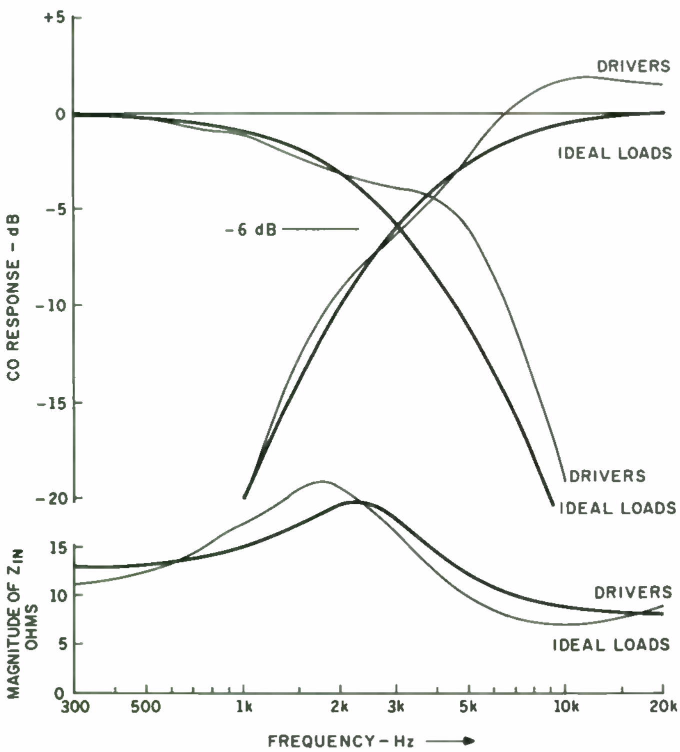

FIGURE 19: Test results for second-order all-pass crossover with no Zobels.

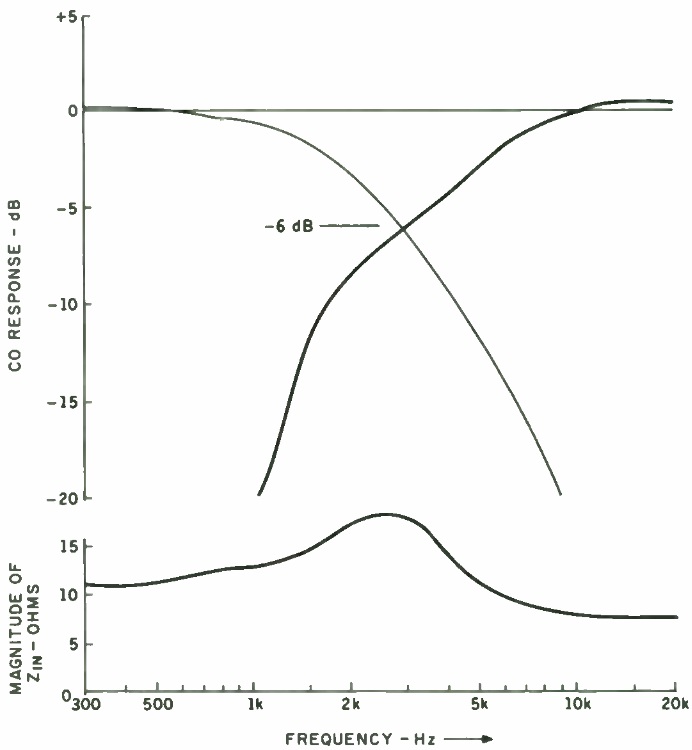

FIGURE 20: Test results for second-order all-pass crossover with Zobels.

Continued from page 41
data for the tweeter. Note the clearly defined tweeter resonance around 1.3kHz. It's questionable whether the tweeter needs a Zobel for the intended two-way application, but in these examples we will use one.

I have selected a CO frequency of 3kHz. Note that this is only 1.2 octaves above the tweeter resonance, but about as high as the woofer response will allow. It's common in two-way systems to have the drivers squeeze the allowable CO frequency into a narrow zone, so be prepared for this. I'm providing you with plots for first-, second- and third-order all-pass COs designed with and without Zobels. The schematic and ideal CO response is shown for each CO, as well as the measured response with the actual CO components and various loads. Note that the CO design for no Zobel used part values based on the driver nominal impedances; it's not the same CO as the one with Zobels. All the COs were built with ferrite-bobbin-core coils and film capacitors.

Figures 7–10 show the schematic, ideal amplitude and phase responses, and input impedance for a first-order Butterworth CO. In a two-way configuration, this is a constant-voltage and constant-power CO. Although a constant-power CO should display constant input impedance, this CO does not because the two loads don't have the same resistance. Notice that the CO input impedance (*Fig. 10*) develops a maximum phase angle of about 12° with ideal resistive loads. You may not realize this, but the constant-power CO delivers a fixed resistive input impedance only if all the sections are designed for termination in the same resistance.

Figure 11 shows the measured response of the non-Zobel design with ideal resistor loads and with the actual driver loads. The CO works as predicted with ideal loads, but it's clear that with the uncorrected drivers, the CO does not behave as designed. The woofer re-

Continued on page 45

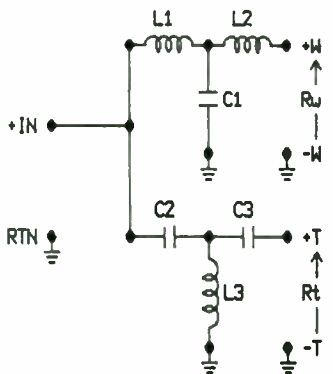

FIGURE 21: Third-order Butterworth crossover (18dB/octave, two-way).

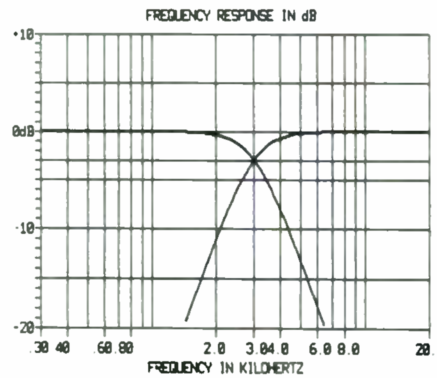

FIGURE 22: Ideal amplitude response for third-order Butterworth crossover. R_W = 12Ω. R_T = 8Ω. L_1 = 0.95mH. C_1 = 5.89μF. L_2 = 0.32mH. C_2 = 4.42μF. L_3 = 0.32mH. C_3 = 13.25μF.

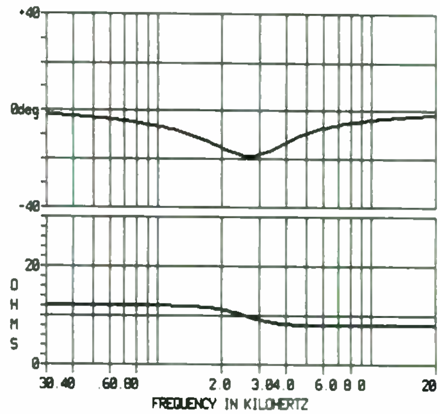

FIGURE 23: Input impedance to third-order Butterworth crossover with ideal loads. R_W = 12Ω. R_T = 8Ω. L_1 = 0.95mH. C_1 = 5.89μF. L_2 = 0.32mH. C_2 = 4.42μF. L_3 = 0.32mH. C_3 = 13.25μF.

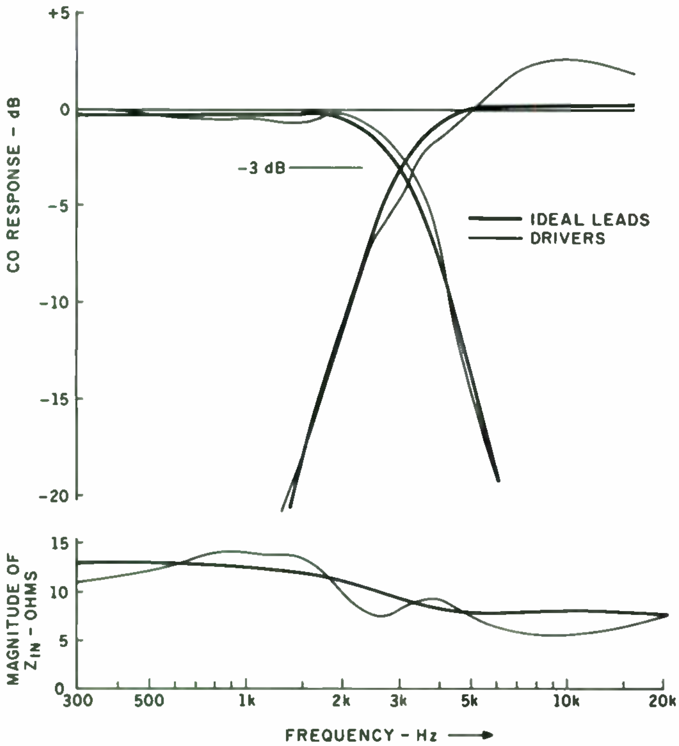

FIGURE 24: Test results for third-order Butterworth crossover with no Zobels.

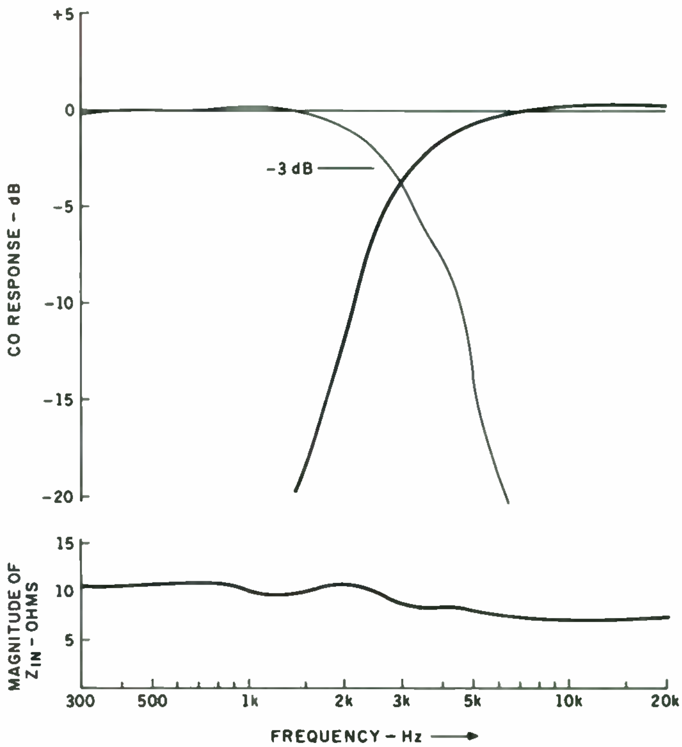

FIGURE 25: Test results for third-order Butterworth crossover with Zobels.

Crossover Readings

This Mini-Index covers material on the subject of COs in past issues of *Speaker Builder*. Listed under the various topic headings are the type of material, magazine issue, page number, and author.

(Back issues, sold in complete-year sets only, are available from Audio Amateur Publications. Please refer to the "Advertising Index" in the classified section of this issue in order to locate correct price information.)

AR = Article
CO = Correction
CR = Craftsman's Corner
KT = Kit
KR = Kit Report
LE = Letters
LI = Literature
RE = Reply
SO = Software
TP = Tip(s)

Type	Date	Page	Author
Active CO design			
AR	3/80	9	Linkwitz
AR	4/80	14	Linkwitz
CR	3/81	26	Levreault
AR	2/82	12	Pass
AR	3/82	14	Ballard
AR	3/82	22	The Editor
AR	4/82	26	Ballard
TP	2/83	26	Rauen
LE	2/83	33	Dunning
CO	2/83	34	Ballard
LE	4/83	34	D'Appolito/ Ballard
TP	2/84	30	Berg
CO	4/84	38	Berg
AR	1/85	20	Dell
AR	4/87	15	Graham
AR	4/88	35	Viesca/ Perez
KT	5/88	46	Bullock
SO	5/88	52	Galo
AR	2/89	33	Gonzalez
AR	6/89	11	Lin
AR	6/89	33	Hillman
LE/RE	2/90	3	Thompson/ D'Appolito
SO	2/90	49	Bullock
CO Books and References			
LI	3/80	28	Kevil
LI	1/81	22	Kevil
LI	2/81	26	Kevil
LI	4/81	26	Kevil
CO Components (also Testing/Winding)			
LE	3/80	39	Spangler
AR	3/82	20	Coyle
LE	1/83	41	Harms
LE	1/83	43	Ellis
LE	4/83	39	Coyle
TP	1/84	34	Ellis
TP	3/85	44	Meraner
AR	3/86	14	Koonce
LE/RE	3/86	52	Miller/ Coyle
AR	4/86	32	Koonce
AR	1/87	25	Edgar
TP	4/87	47	Mulkins
AR	1/88	23	Viesca
AR	6/88	43	Koonce
LE	3/90	77	Meraner/ Koonce
CO Discussion			
CR	3/81	36	Levreault
LE	1/84	39	Cabaniss
LE	1/84	40	Vermette
LE/RE	2/84	36	Linkwitz/ D'Appolito
KR	1/85	36	Bullock
LE/RE	3/85	47	Babrauskas/ Bullock
LE/RE	3/85	48	Gonzalez/ Bullock
AR	3/86	14	Koonce
LE	4/86	52	Ballard
AR	2/88	29	Buschmann
AR	3/88	34	Gonzalez
AR	4/88	9	D'Appolito/ Bock
LE/RE	4/88	65	Barber/ D'Appolito
LE/RE	5/88	61	Stompler/ D'Appolito
LE/RE	5/88	73	Weems/ Coyle
LE/RE	1/89	57	Meraner/ D'Appolito
AR	5/89	40	Oliveira
LE/RE	5/89	71	Readinger/ Levreault
LE/RE	6/89	69	Kern/ Millikan
LE/RE	3/90	3	Meyers/ Koonce
AR	3/90	10	Schwefel
LE/RE	3/90	85	Bryson/ Bullock
LE/RE	3/90	88	Hatch/ D'Appolito
AR	4/90	10	Woodbury
AR	4/90	36	Ricart
CO Packaging			
TP	1/82	34	Koonce
AR	3/82	22	The Editor
AR	3/85	14	Bullock
AR	3/85	20	Dell
TP	1/86	37	Conner
TP	2/86	41	Meraner
CO Wiring			
AR	2/86	30	Hupp
Impedance Correction (Zobel)			
AR	4/82	14	Harms
AR	1/83	11	Knittel
AR	1/85	19	Bullock
TP	1/85	33	Ball
AR	3/87	31	Meraner
LE	4/87	50	Meraner
LE/RE	6/88	69	Duverger/ Bullock
LE/RE	6/88	69	Rivera/ Graham
AR	6/89	27	Cox
TP	2/90	50	Rumreich
LE/RE	3/90	4	Koonce/ Cox
Impedance Measurement (also Concept)			
AR	3/80	13	Linkwitz
AR	1/81	7	Saffran
AR	1/81	12	Bullock
TP	1/82	31	Mastel
AR	3/84	16	Koonce
TP	3/84	32	Meraner
AR	4/84	21	Koonce
AR	2/88	15	Dickason
LE/RE	2/88	54	Light/ D'Appolito
AR	4/89	37	Crawford
Notch Filters and Other Compensators			
AR	2/86	24	Weems
LE/RE	4/86	46	Gonzalez/ Weems
TP	3/87	44	Gonzalez
AR	3/88	15	Rumreich (time delay)
Passive CO Design			
TP	1/82	32	Welsh
AR	2/82	18	Harms
AR	3/82	12	Harms
LE	2/83	35	Norris
AR	4/84	10	D'Appolito
AR	1/85	13	Bullock, Part I
AR	2/85	26	Bullock, Part II
CO	2/85	46	Meraner
AR	3/85	14	Bullock, Part III
LE/RE	4/85	52	Flippin/ Bullock
AR	1/86	20	Bullock, Part IV
TP	2/86	40	Gonzalez
KT	1/87	42	Davenport
AR	2/87	42	Gonzalez
AR	4/87	9	Bullock, Part V
LE/RE	1/88	53	Saraceno/ Bullock
SO	5/88	49	Koonce
LE/RE	1/90	61	Irason/ Oliveira
Padding			
AR	1/80	23	Stamler
TP	3/81	20	Koonce
AR	2/82	26	Galo
AR	2/83	20	Phillips
TP	1/84	34	Clarke
LE	2/84	39	Knittel
AR	1/85	20	Knittel
TP	6/89	56	Klockeman
Series Padding			
TP	3/81	28	Koonce
TP	1/82	30	Koonce
Vertical Polar Pattern (Driver Alignment)			
AR	3/80	10	Linkwitz
AR	4/84	9	D'Appolito
AR	1/85	16	Bullock
AR	2/85	35	Bullock
LE/RE	2/85	46	Meraner/ D'Appolito
LE/RE	3/85	45	Miller/ Bullock
LE	4/85	48	D'Appolito
AR	2/89	26	Rauer
LE/RE	5/89	55	Habrle/ Rumreich
LE/RE	2/90	4	Kocian/ D'Appolito

Continued from page 43

sponse does not fall above 3kHz as you would want, the tweeter response peaks above 0dB, and its resonance falls in an area where the response is only 5dB down. This system would not sound as intended.

Figure 12 shows the measured performance of the first-order CO with Zobels. Curves follow the "ideal" much better, but the tweeter resonance is still causing a bad problem. The CO frequency is about 2.3 times the tweeter resonant frequency (1.2 octave above resonance), but this is not enough with first-order COs.

Figures 13–18 show the schematic and the ideal performance of a second-order all-pass CO. Note that the tweeter must be inverted to obtain an all-pass response, and that the CO point is 6dB down (*Fig. 14*), not 3dB as with the Butterworth. This results in a 3dB dip in the power response (*Fig. 15*) and a notable rise in input impedance around the CO frequency (*Fig. 16*). The LP plus HP response (*Fig. 17*) shows a big notch (this is normal tweeter connection) while the LP minus HP response (*Fig. 18*) shows that the CO is all-pass (this is inverted tweeter connection) with 0dB response on-axis at all frequencies.

Figure 19 shows the measured response of the non-Zobel CO design with ideal loads and with the actual driver loads. Again, performance with the actual driver loads does not follow the ideal performance, showing severe distortion of the woofer LP response and great peaking of the tweeter HP response. Please note, however, that the tweeter resonance has far less effect on the second-order CO than it did on the first-order. *Figure 20* shows the performance of the Zobelled second-order CO to be much closer to the predicted curve, but we can see that the tweeter HP response is distorted by impedance variations.

Figures 21–23 show the schematic and the ideal performance of a third-order Butterworth CO. This CO is constant-power and all-pass in a two-way configuration. Please note once again that the ideal input impedance (*Fig. 23*) shows a phase shift of about 20° near the CO frequency due to the unequal driver resistances. *Figure 24* shows the measured performance of the non-Zobel design with ideal and actual driver loads. Even when we use a third-order CO, the performance without Zobels is pretty bad. Observe, though, the tweeter resonance is hardly observable in the HP response. *Figure 25* shows the Zobelled design's performance. Both responses differ somewhat from the ideal, but tweeter resonance is not indicated and the basic shapes are as intended. This CO would probably sound fine as shown with no "playing" needed for proper frequency response and proper imaging.

Hopefully, these examples have clearly demonstrated that first-, second- and third-order COs all require impedance correction (Zobels) on the drivers for proper performance. We have shown, too, the clear advantage of the higher-order COs in masking a driver resonance.

CONCLUSION. I hope you have learned here why the purchase of an off-the-shelf CO is unacceptable. Although we have had to skip over much of the necessary driver evaluation and the deeper aspects of CO theory, the approach presented here can be one which you, as a novice builder, might find helpful in developing passive COs. We've looked at the problems of driver resonance and impedance variation with increasing frequency, as well as the failure of classical Zobel design equations, and

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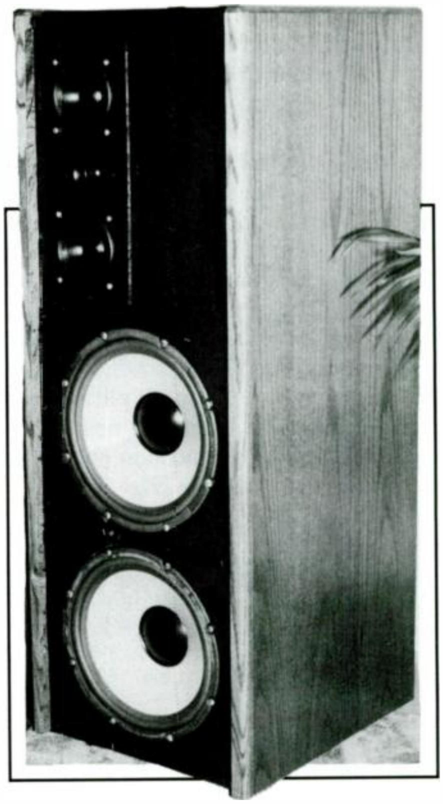
A TRIAMPLIFIED MODULAR SYSTEM

BY RANDY PARKER



This high-quality speaker system is designed so that it can be upgraded easily when new drivers and technologies become available or if I want to try something different. I achieved this flexibility by using three optimized modules as independent stand-alone elements covering different frequencies, which allows one module to be modified, upgraded or replaced without disrupting the integrity of the others.

The ingredient that makes this approach practical is an electronic crossover. In my application, it is used at two frequencies (45Hz and 200Hz) in a triamplified system. An electronic crossover makes it easy to match the levels of modules with different sensitivities and simplifies changes in crossover frequencies and slopes.

My system combines a number of design ideas published in *Speaker Builder* with a unique space-saving subwoofer concept used by several members of the Southeastern Michigan Woofer and Tweeter Marching Society (SMWTMS) audio club.[1] These ideas range from the routine to the semioutrageous (18″ JBL woofers mounted in the floor). My design also benefits from lessons I learned while working on other speaker projects.

BACKGROUND. My latest system evolved out of several speaker projects. I began with the satellite/woofer system described in *Speaker Builder* 2/84 (p. 7), installing KEF B110 and T27 drivers in the satellite enclosures and B139 woofers in vented fourth-order aligned 2.6-ft³ bass enclosures. Subsequently, I biamped the system, lowered the crossover point from 400Hz to 250Hz, added sixth-order alignment equalization, and the bass enclosures accordingly. I modified one speaker and compared the original version to the biamped, sixth-order version.

The original system was very good, but the modified system had improved low-frequency extension and punch. The bass also seemed tighter. This might be attributed to the low-frequency high-pass filter intrinsic in the sixth-order alignment, which greatly reduced woofer cone flutter at high-volume playback of LP records. However, I wanted to be able to play the system at even higher sound levels without strain or fear of speaker damage and to improve the system's ability to handle the wide dynamic range required of compact discs.

Therefore, I designed a new system that would retain the sonic virtues of the KEF system but add greater capabilities. By now I had become an advocate of biamplification and sixth-order aligned woofer systems. Several *Speaker Builder* articles and letters[2-6] appeared at that time describing the advantages of multiple woofers for achieving high output levels and low distortion. I used a pair of 12-inch Peerless/Precision TA 305F woofers in a sixth-order aligned 6.6 ft³ pyramid-shaped enclosure. The Thiele parameters of the TA305Fs (available again, thankfully, as the Swan 305) are very similar to those of the KEF B139 drivers, but the TA305Fs offer greater power handling and sensitivity at a much lower cost.

The woofer system was electronically crossed over at 100Hz to a Dynaudio 21W54 8½-inch mid-woofer, which was passively crossed over at 800Hz to a Dynaudio D-52 AF 2-inch upper-midrange dome driver and at 2.5kHz to a Dynaudio D-28 AF 1-inch dome tweeter. The passive crossover used the 6dB/octave slope recommended by Dynaudio. The 21W54 crossover was actually approximately 500Hz and the D-52 is 800Hz. This combined for a relatively flat response from 500-800Hz, but produced a pronounced dip at 1kHz. (The Dynaudio drivers and their crossover were purchased as a "parts only" version of a kit package.) The use of multiple woofers and high-power handling/high-output midrange and tweeter drivers resulted in good bass extension and high sound level capability at all frequencies. However, the large floor-standing system produced a very narrow vertical response pattern, which was annoying. Small changes in the listening position height resulted in significant shifts in the sound balance. The system tended to become strident at certain frequencies and listening positions.

I investigated fixes for these acoustical problems, and SMWTMS friend David

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Clark measured the Dynaudio drivers as installed in their enclosure with his Techron TEF 10 analyzer. (Others using these drivers might be interested to know that the acoustical centers of the three drivers are aligned when the front of the D-28 AF flange is 0.125″ behind the front of the D-52 AF flange and the center of the 21W54's dust cap is 0.0235 inch behind the front of the D-52 AF flange.) The resulting time and energy response curves indicated that electronic crossovers with variable-rate crossover slopes between the mid-bass and mid-dome drivers were best suited to this system. Achieving this would require tri-amplification.

I concluded that starting over with a new system was justified and that a modular design would provide the greatest long-term satisfaction. A description of the resulting system follows.

Midrange/tweeter module. D'Appolito type using a Dynaudio D-28 1-inch horn loaded tweeter, two Focal 5N412 5¼-inch single-voice-coil midranges in a 10-liter sealed enclosure, an 18dB/octave passive high-pass and low-pass crossover at 2kHz, and a 24dB/octave Linkwitz-Riley electronic high-pass crossover at 200Hz.

Woofer module. Two Audio Concepts AC12 12-inch polypropylene woofers in a 4¾ ft³ sealed enclosure [Q_{TC} = 0.8 (measured), F_C = 34.5Hz (measured), F_3 = 30.9Hz], a 24dB/octave Linkwitz-Riley electronic crossover, a low-pass filter at 200Hz and a 12dB/octave high-pass filter at 45Hz.

Subwoofer module. Two JBL 2245H 18-inch woofers floor mounted in an infinite baffle enclosure, a 24dB/octave Linkwitz-Riley electronic low-pass crossover at 45Hz, and summed mono bass.

MIDRANGE/TWEETER MODULE.

The midrange/tweeter module covers the frequency range from 200Hz to 20kHz. This range is critical because of the large percentage of the music spectrum present and the fact that the ear is highly sensitive to these frequencies. Also, the horizontal and vertical dispersion patterns of the system are determined at these frequencies. Objectives for this module included improving the sound quality of the earlier KEF system and achieving a higher output capability and a better vertical dispersion pattern.

I met each of these objectives by using the D'Appolito 3/2 design geometry for tweeter and midrange drivers combined with more sensitive drivers. D'Appolito's article, "A High-Power Satellite Speaker" (*SB* 4/84, p. 14) and his subsequent "Mailbox" contributions detail the design concept and attributes. The series on the Swan IV speaker system, beginning with *Speaker Builder* 3/88, describes this design concept further.

I built this module following the original D'Appolito construction project using the Dynaudio D-28 horn-loaded tweeter but including the Focal midrange driver update (*SB* 4/85, p. 46), substituting a new high-power, single-voice-coil, cast-frame Focal driver (5N412) that became available in the spring of 1987.

When the Swan IV speaker system appeared, it affirmed my selection of the 3/2 driver geometry for the midrange/tweeter module and the use of the new cast-frame Focal drivers. The designs of that system, however, used the dual-voice-coil version of the 5N412 (the 5N412DB). The primary reason for using dual-voice-coil drivers is to provide a convenient means of achieving diffraction loss equalization. The boost is necessary because the small baffle area of the satellite enclosure results in a falling off of the low-frequency response.

D'Appolito originally offered two options for diffraction loss equalization. The first uses passive components connected to the second voice coil of dual-voice-coil drivers. The second uses standard single-voice-coil drivers and active equalization in the electronic crossover. Because of D'Appolito's original preference for the second option, I used the single-voice-coil 5N412 (*SB* 4/85, p. 48: "First the op amp compensator is easily modified to get just the right amount of correction. Also most satellite systems users are already bi-amping, making addition of the extra op amp to their existing electronic crossover relatively easy. Second, the 2.8Ω minimum impedance of the *parallel connected* dual-voice-coil 5N402DB drivers is still too low for many amps.") The dual-voice-coil 5N412DB driver in the Swan IV system allows passive equalization and, being *series connected*, avoids the problem of low minimum impedance.

I provided switchable diffraction loss equalization in the electronic crossover, which is easily modified and permits A-B comparisons of the circuit. Advantages of the 5N412 over the 5N412DB driver include 36% greater power handling, 22% greater cone excursion and a 40mm-diameter Kapton voice-coil former with edge-wound flat wire compared to the more widely used 25.5mm-diameter Nomex voice-coil former with four-layer copper wire. Use of the single-voice-coil version also retains the benefits of parallel connection of the drivers, which includes improved load sharing[7] between drivers, a 3dB increase in voltage sensitivity,[8] and a 4Ω impedance, which maximizes the amplifier power that is available.

Examination of the low-frequency re-

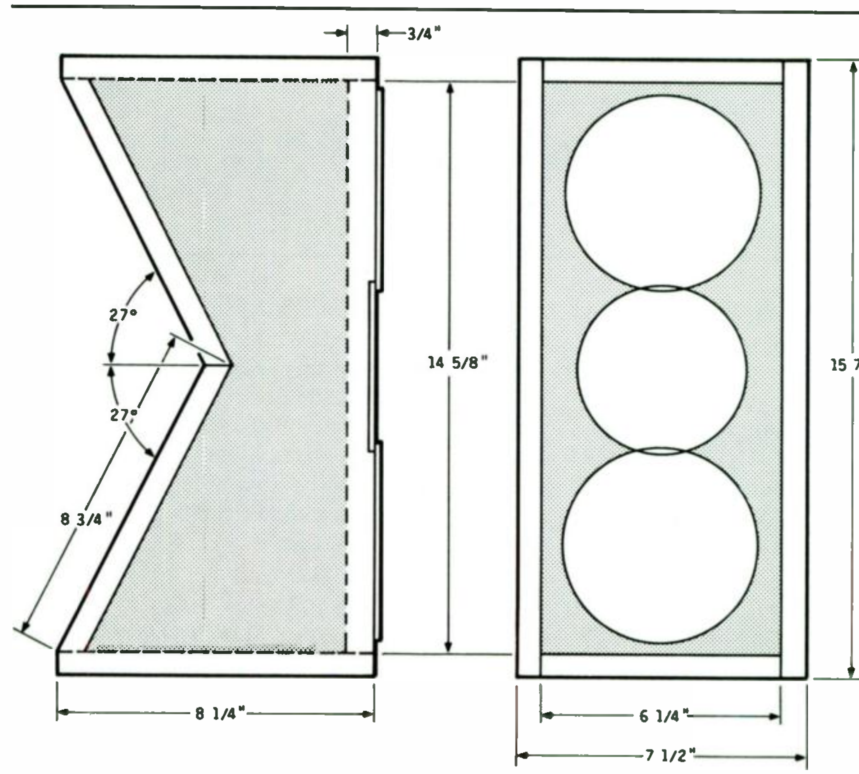

FIGURE 1: Side view and front view of midrange and tweeter module.

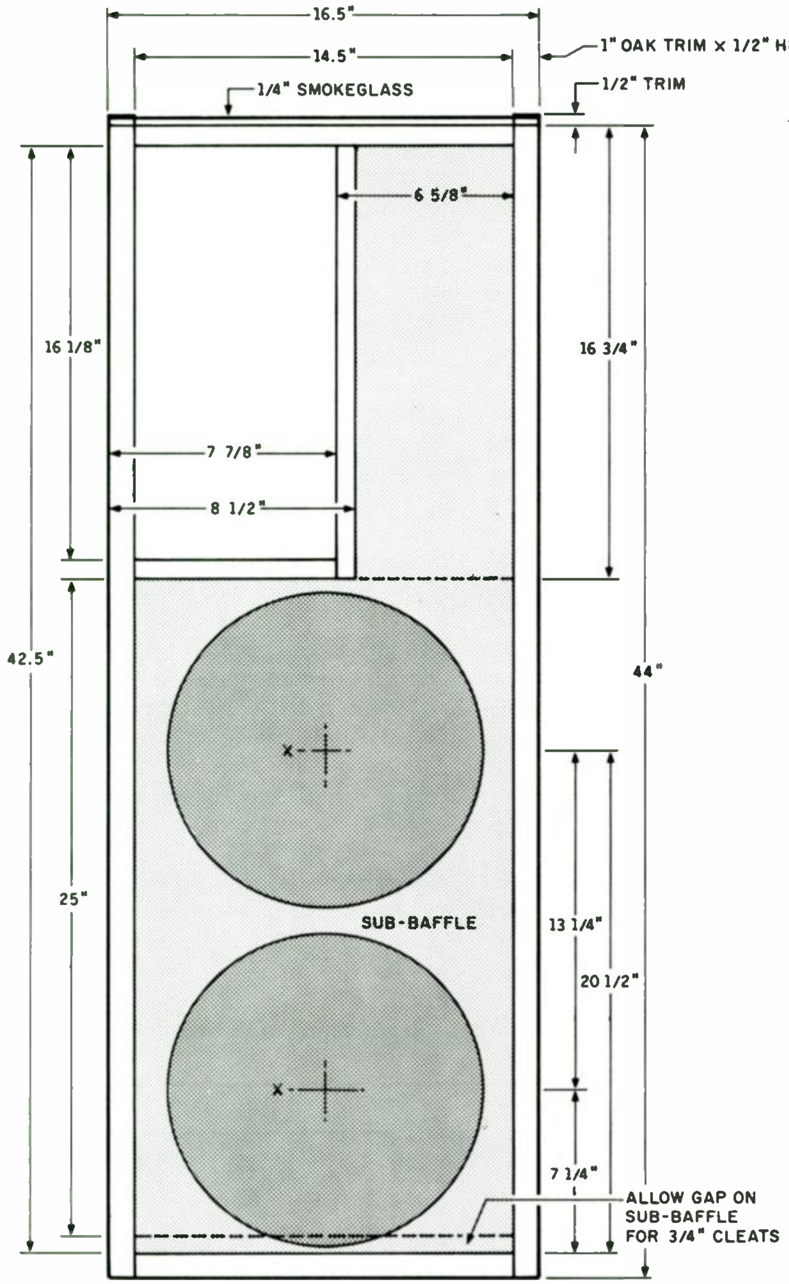

FIGURE 2: Front view of woofer module.

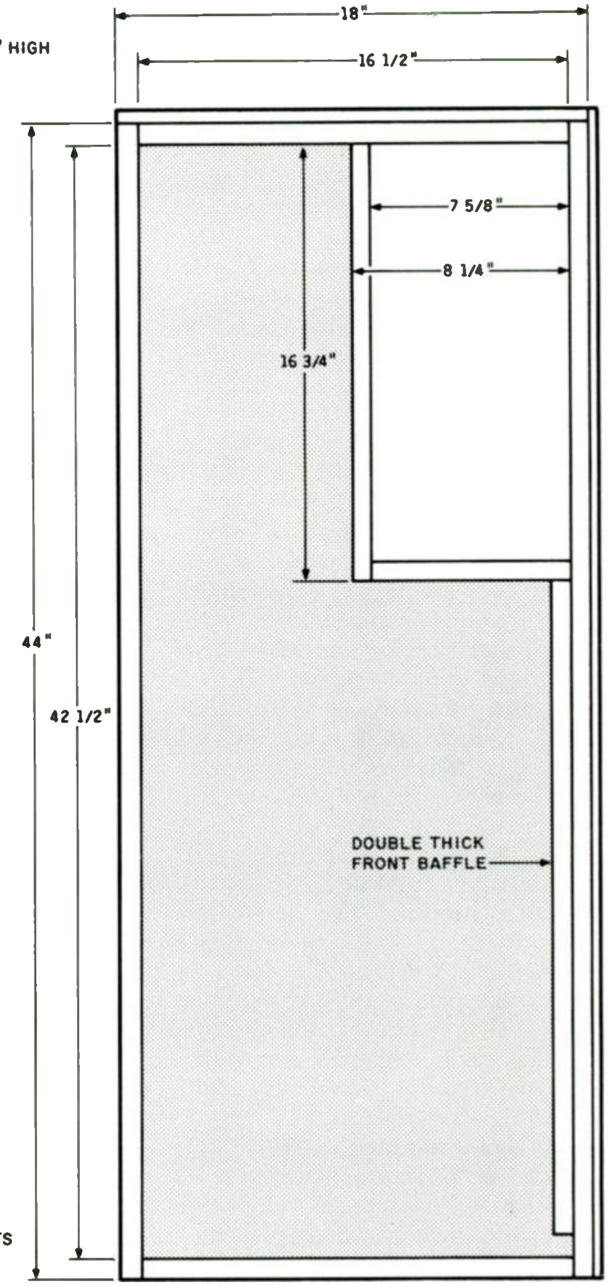

FIGURE 3: Side view of woofer module.

sponse of this driver in a sealed enclosure showed that reducing the enclosure volume of approximately 20 liters for the original D'Appolito enclosure to 10 liters for the two drivers results in increasing Q_{TC} from 0.31 (very damped) to 0.39. This provides a more properly damped resonance, which prevents lower frequency output from rolling off too early. The predicted box resonance is 81.7Hz with this enclosure; I measured 79Hz.

Internal standing waves and rearwave reflections were suppressed with a V shaped back, as illustrated in *Figs. 1* and *2*. I also lined the rear of the enclosure with acoustic foam and loosely filled it with Dacron fiber.

In my system, the tweeter and midrange drivers are mounted in this small satellite enclosure, but the enclosure is installed in a cavity in the larger woofer module enclosure (*Figs. 3* and *4* and *Photos 1* and *2*). This placement scheme significantly increases the effective baffle area of the driver, because the speakers are placed on either side of a six-foot-wide entertainment center and the front of the speakers is only two feet from the rear wall. I have found that the most satisfactory sound balance is with the diffraction loss equalization switched off.

The passive crossover between the midrange drivers and the tweeter is identical to that in the Focal 5N401 driver update. This is possible because the sensitivity of the Focal 5N412 is the same as that of the 5N401. Matched sets of 5N412 drivers, D-28 tweeters and all crossover components, including the circuit card on which they are mounted, are from Madisound.

The success of this module was apparent immediately. The sound is quite natural and unstrained and lacks the stridency of my previous system. Both vertical and horizontal dispersion patterns behave as predicted, providing a relatively broad and tall listening area with angled-in speaker placement. Furthermore, the satellites are capable of great dynamic range with 325W/channel of amplifier power available into the 4Ω load. As mentioned earlier, an electronic crossover is used at 200Hz. In addition

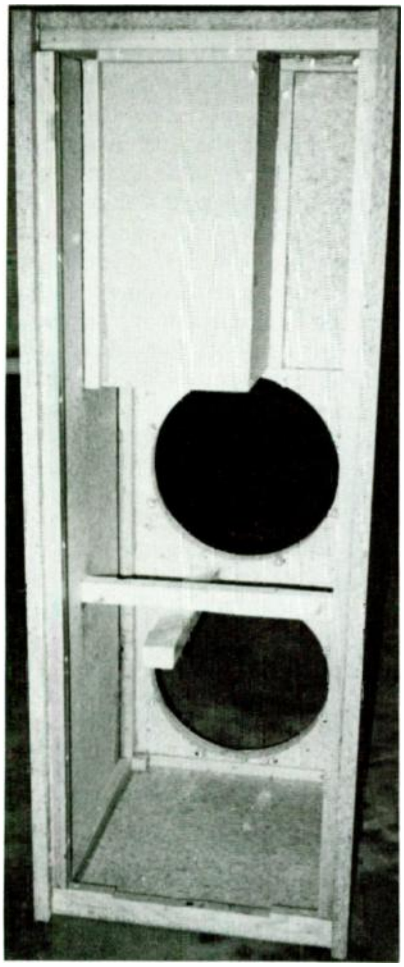

PHOTO 1: Rear view of partially assembled left channel woofer module. The subenclosure into which the satellite midrange/tweeter module is inserted is visible in the upper left corner.

to the switchable diffraction loss equalization, it includes switchable high-frequency equalization (*SB* 4/85, p. 47) to compensate for the D-28s' falling response at the highest frequencies. I leave the high-frequency equalization on all the time, and its effect is very subtle.

I recently helped a friend with the construction of a properly built Swan IV system. The crossover design for the satellite in his system is more highly refined, and I highly recommend the smooth, detailed, effortless sound of this system.

Having lived with many different looking speaker enclosures over the years, I settled on the conventional appearance of a single tall, narrow enclosure. I compromised optimum acoustics somewhat in favor of aesthetics by integrating the midrange/tweeter enclosure into the larger woofer module enclosure. The woofer enclosure was oversized by the amount necessary to include a sealed cavity in the front to accommodate the midrange/tweeter module. The passive crossover is mounted externally inside the recessed back of the midrange/tweeter module for easy access. The outside of the midrange/tweeter enclosure is lined with felt for vibration isolation from the woofer enclosure, and its close fit within the subenclosure ensures that the enclosure wall sound output is suppressed.

WOOFER ENCLOSURE. I believe that it is easier to build something closer to a "no compromise" system for the frequency range 45Hz to 200Hz than it is to build a woofer system that must reproduce frequencies below 45Hz. I find many different drivers and woofers that could meet my objectives for flat response, high output and power handling, system resonance below 45Hz (out of the pass-band) and reasonable enclosure size. When the woofer system is relieved of the requirement to provide high sound levels at the two lowest octaves, it will have reduced modulation and harmonic distortion, improved power handling and flatter frequency response within its operating range. A 200Hz upper crossover frequency is low enough to permit the use of large-diameter woofers.

I considered a number of woofer systems. I was pleased with the sound and capabilities of the dual 12-inch Peerless/

Precision TA305F drivers in an earlier sixth-order aligned vented enclosure, but the relatively large volume and sixth-order alignment were unnecessary for my cracyurrent application. In fact, one of my objectives was to decrease the size of the woofer enclosure as much as possible while retaining high output capabilities. I continued to investigate multiple-driver systems because high-output capabilities require not only high power-handling capability but also sufficient volume displacement. In addition to the 12-inch Peerless/Precision drivers, I considered using four 8-inch Peerless/Precision woofers in a vented enclosure or a pair of 12-inch Audio Concepts woofers optimized for sealed enclosure use.

Exploring the theoretical attributes of a sealed system versus those of a vented system, I concluded that a sealed system using a pair of 12-inch drivers would best meet my needs. The need for only a 45Hz response facilitated this decision. For instance, the slow roll-off of the sealed system versus the faster roll-off of the vented system is relevant only when frequencies below 45Hz are being reproduced. The question of port damping on system resonance also was irrelevant.

I chose a sealed system for the following reasons: (1) the frequently stated preference for the transient response and accuracy, presuming an appropriate system Q_{TC}; (2) a sealed-system resonance is theoretically more predictable given normal driver parameter variances; (3) sealed systems can be designed to be free from the resonant peaks often found in vented systems; (4) tuning is less critical and can be modified through the addition or removal of damping material to achieve a different system response; and (5) the sealed system would require the smallest enclosure volume given the drivers and output level I was considering. Having built only transmission line and vented woofer systems in the past, I wanted to experiment with the sound of a sealed system.

Audio Concepts woofers have varied over time, both in origin of manufacture and published Thiele parameters. The version I used was first available from a new supplier during the summer of 1987 and is different from the current (September 1989) Audio Concepts' drivers. (I

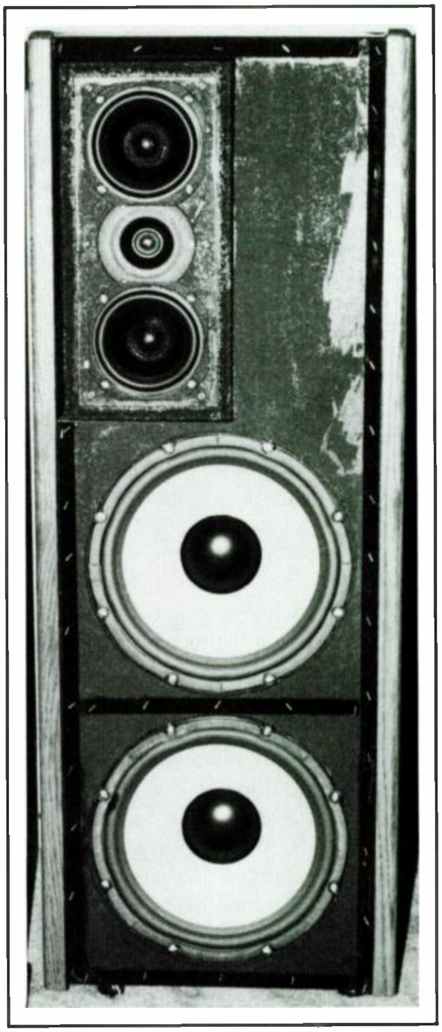

PHOTO 2: Completed woofer module with the midrange/tweeter module set in place.

have seen but not heard the current AC12 driver. I believe it is manufactured by Carbonneau, and it appears to be of better construction than my drivers, including a vented pole piece magnet structure.) My drivers also are different from those listed in the catalog at the time I designed the enclosure. The volume of the enclosure was based on achieving a target Q_{TC} 0.7 to 0.8, which would produce the transient response and frequency response I desired. The drivers I received, however, had a larger V_{AS} and a higher Q_T, which would produce a theoretical Q_{TC} of 1.2 installed in my 4.75 ft³ enclosure.

I explored various alternatives to correct this problem. Both Weems[9] and Dickason[10] suggest using damping material to increase apparent box volume and lower Q_{TC}. I stuffed the enclosure by lining the interior walls with 2-inch-thick acoustic foam, tightly compressed 10-inch-thick fiberglass insulation into the open volume and filled the remaining volume immediately behind the woofers with five feet of 27-inch wide by 2-inch thick bonded Dacron. The tightly packed stuffing was intended to provide as much volumetric increase as possible.

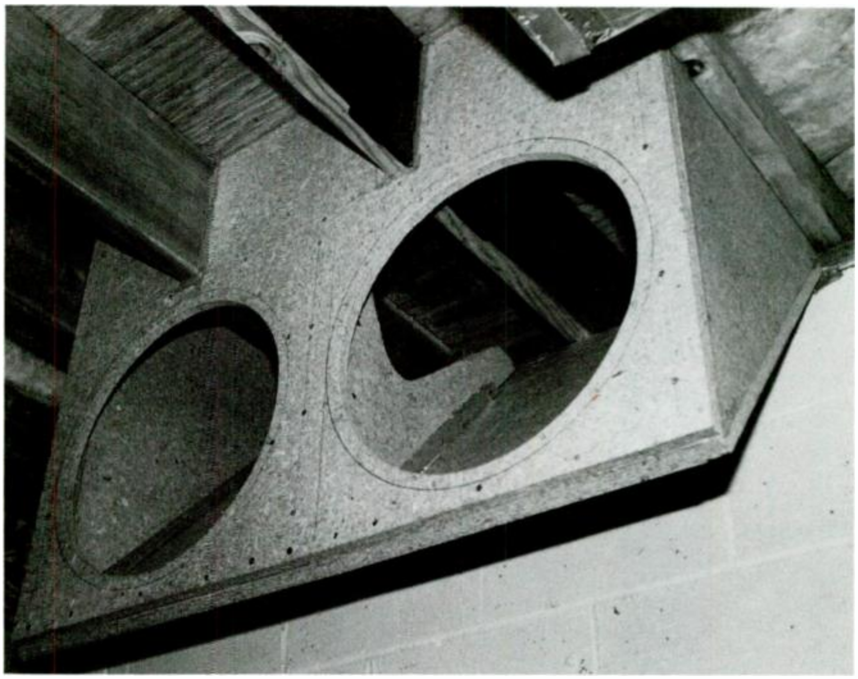

PHOTO 3: Subwoofer duct attached to basement ceiling. The floor opening had not yet been cut when this photo was taken.

Tightly packing bonded (not fluff) Dacron around the back of the woofer basket was intended to lower the driver Q_{TS} (per Weems). My Q_{TC} measurement demonstrated the value of these techniques. On my first stuffing attempt, the measured Q_{TC} of the left module was 0.77 and that of the right module was 0.81. This was great news and a great relief.

The sound of this sealed woofer system is different from that of my former vented dual Peerless/Precision system. Setting aside the reproduction of the very lowest frequencies, which would be an unfair comparison by design, the sealed system has less heaviness and is also less "peaky" when sweeping a signal generator through its frequency range. The sealed system is very smooth, detailed, and accurate sounding, but it doesn't have the punch on rock music bass. This may be a result of my former system's greater bass extension, but I don't believe that is the case because most rock music is above 45Hz. The sealed system definitely conveys a sense of "tightness" and at times sounds as though it has less bass than my former system. When well-recorded compact discs are played, however, the bass sounds effortless and detailed.

SUBWOOFER MODULE. The band of frequencies below 45Hz contains only the lowest fundamental frequencies. The reproduction of these frequencies with a uniform response at adequate volume levels and with low distortion is a much sought after, but difficult to obtain, objective. A driver system dedicated to reproducing only these frequencies is a subwoofer in the true meaning of the word. The size of most speaker systems is dictated by the large enclosure volume necessary to achieve the desired response at these frequencies, regardless of the acoustical loading technique chosen. One of my goals was to reduce the size of the speaker enclosure in the listening room.

The woofer module I chose enabled a 2 ft³ reduction in enclosure size. The primary factor in this reduction was the decision to use a separate subwoofer with an "enclosure" outside the listening room. Such an enclosure may be a basement below the listening room or a garage either behind or below the room. A closet or an adjacent room also works well. Thomas Clarke described a similar approach in his "Free Volume Subwoofer Systems" (*SB* 2/86, p. 20). This technique permits using the entire basement or garage as an infinite baffle enclosure or constructing a sealed, vented, or other type enclosure in the basement or garage.

You can use the basement or garage as an infinite baffle enclosure by cutting an appropriate size hole in the floor or wall. This hole is not necessarily used for mounting the driver itself but is an opening with an area equivalent to that of the woofer cone(s). None of the installations I have seen have the driver(s) mounted directly in the wall or floor opening. Instead, a "duct" is constructed to enclose the opening. One side of this duct serves as the mounting baffle for the driver(s). I chose a right-triangle-shaped duct with a vertical mounting board for the woofers (*Fig. 7*). A rectangular duct also may be used. Vertical mounting of the drivers helps prevent the large, heavy woofer cones from sagging out of their centered positions, as may occur with angled or horizontal mounting positions. Aiming the subwoofers directly into the listening room is not important. I have been told that the duct actually serves as a pressure transfer device, and at these low frequencies, only this pressure transfer into the listening room is relevant.

I used the basement below my listening room as an infinite baffle enclosure. To improve the energy transfer into the room, the first-floor opening is located in a corner of the room on the same wall as the main speakers. (One system I listened to has the floor opening in a corner behind the listening position, which produces good results.) Crossing over at 45Hz, using a 24dB/octave slope and not aiming the driver at the listener all help eliminate any high-frequency directional clues to the specific location of the subwoofer. Based on the applications with which I am familiar, I opted to try a summed-mono subwoofer format, and have been satisfied with the results.

Mounting the drivers outside the listening room permits the use of any size driver. In this application, a 30-inch Electro-Voice driver has been used satisfactorily. The most popular choice is a pair of JBL 18-inch 2245H woofers, which is what I am using. The best system I have heard uses four of these woofers in a single duct similar to mine. I've heard it ripples the water in the bathtub on the second floor, and I observed objects dancing across the dining table in an adjacent room. The JBL drivers are expensive, but these beautifully and massively constructed cast-frame units have great power handling and cone excursion capabilities. They have been used in other construction projects[11] in vented enclosures of eight to twelve ft³ Obviously, this project conserves a considerable amount of space in the listening room. A pair of these drivers are recommended because of the significant losses of energy in this fre-

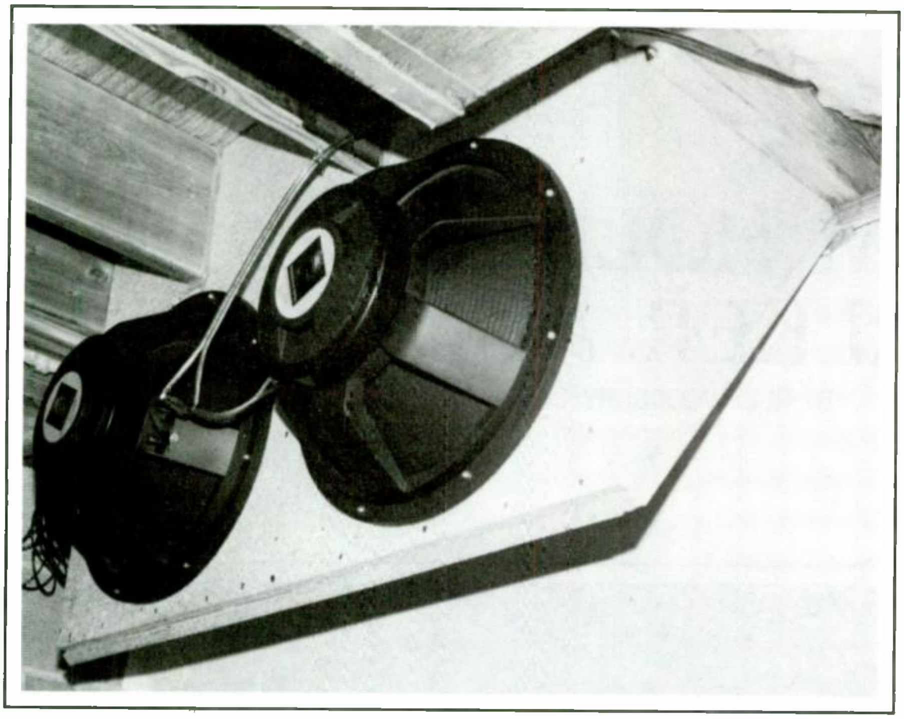

PHOTO 4: Completed subwoofer installation.

Photos 3 and 4 and Figs. 5 and 6 illustrate my scheme for attaching the duct and woofers to the basement ceiling. You should use the dimensions in the drawing only as a general guide. The spacing and size of the floor joists determined the position of the cutouts on the baffle board. I used cleats on all corners

Continued on page 92

quency range, due to the flexing of walls, floors, and windows in most homes.

The duct opening must be custom designed. I found the construction to be surprisingly easy when mounting the woofers in the floor. I wanted the woofer opening to be located on the same wall as the main speakers and as close as possible to them. Because the main speakers are placed on either side of the entertainment center, the floor opening had to be located to the outside of the left main speaker to achieve corner placement. I had to be careful that there were no obstructions, such as heating ducts or plumbing, below the floor. Location of the floor joists helped me determine the final position of the floor opening. For that I suggest that you not cut the opening through the carpet and floorboard until after you have installed the duct.

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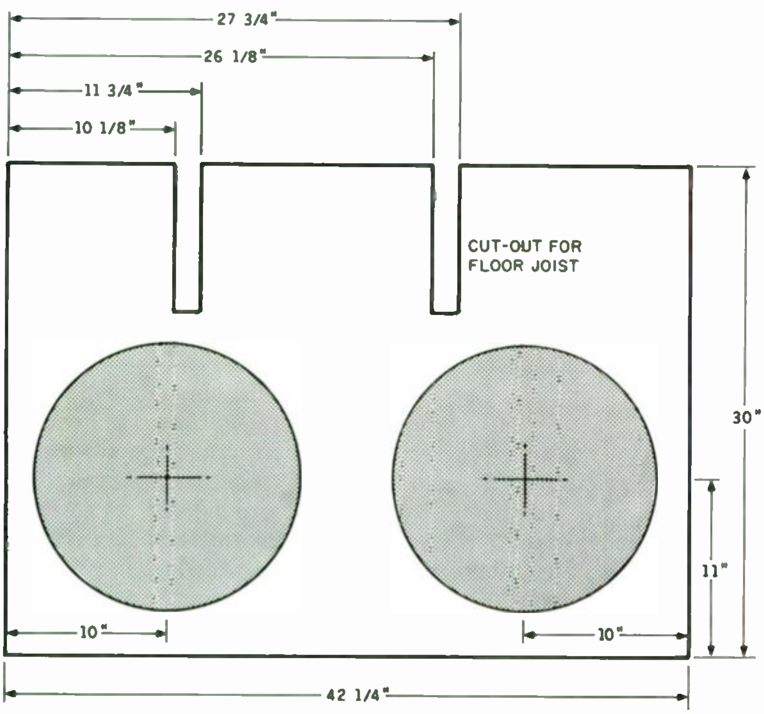


FIGURE 4: Subwoofer baffle board.

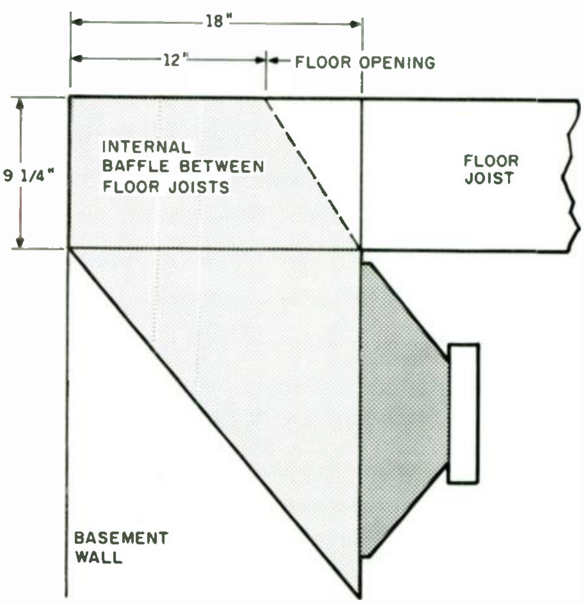


FIGURE 5: Side view of subwoofer duct.

Part II

TOM HOLMAN, SKYWALKER AND THX

BY REID WOODBURY, JR.

In Part I of Reid Woodbury's interview with Tom Holman, *SB* 4/90, the master sound technician discussed what is going on at Skywalker Ranch in technological innovations, and also in THX. In this issue, Holman continues his dialogue on the leading edge of sound theory and technology.

PHOTO 1: Tomlinson Holman, Director of Technical Operations, Lucasfilm, Ltd.

TH. We've talked about the time displacement. We did that for a good practical relationship between the woofer and the horns. Hang the screen in front of it. Then the next thing you notice is if you stick your head between the screen and the horn, suddenly you realize where all the highs are. They're all bouncing back and forth between the screen and wall, causing nasty comb filtering—many delayed reflections, many hits because it's very bright, even at the bottom of the wall. It's obviously done many round trips between the wall and the screen. So the trick is to cover the wall with absorptive material for high frequencies, where the screen is reflective, which doesn't absorb lows, so it provides the 2 pi boundary. You can see the loudspeakers are built in, flush mounted. The absorption on the face of the wall is rather thin, only about an inch.

If you made the wall fully absorptive you would be putting the loudspeaker in a 4 pi environment, and we don't want that. We want it in a 2 pi environment. We want the fuzz on the face of the wall not to absorb lows. On the other hand, we are launching quite a lot of high frequency energy at the screen, progressively above 5kHz. Anything returned from the screen to the wall we want absorbed. The idea is, the wall works in an acoustical crossover mode where it reinforces low frequencies and absorbs high frequencies.

What is the screen made of?
TH: PVC or some other plastics. Maybe vinyl.

It's perforated?
TH: Oh, it must be perforated. It's usually 50 thousand perfs on a little diamond grid. It's seven percent open, but the percentage open area isn't the most important thing. They're all about the same open area, but it's the thickness and the hole size. We later participated in an experiment to get an equation for the transmission loss. One says if you have many finer holes you'd be in better shape—smaller for the same open area.

It does affect the horn's radiation pattern somewhat, but it has a tendency to square up the pattern. It actually makes the -3,-6,-9 contours come closer together —an interesting thing. In other words, you get less transmission loss off axis than on axis. The sheet, when you think about it, is more transparent. You're looking at more open area, if you look at it at an angle than if you look at it dead on. Transparency goes up at off angles.

FINAL TESTING. So, you get all this

together and set it up and play it. The first thing you learn is you're smack on the curve, the X curve. You're very carefully tuned to it, because you employ third-octave equalization, spatial averaging, and time averaging. A trick commonly done in this industry, until recently, was using quarter-inch B&K microphones so that you have no diffraction effects to worry about with the microphones. You take a many point average for many seconds each point—very tedious. This takes 40 hours to tune five channels, first time out, because of the equipment and such.

There are a number of interesting findings. One is, the room acoustics dominate the uniformity of coverage up to between 300 and 400Hz, in a 70,000 cubic foot room. The nodal pattern dominates the uniformity of distribution. It's not the loudspeaker. Above there, the loudspeaker's the most important ingredient in sound field uniformity (*Fig. 6*). That's one finding.

Also, to prove the loudspeaker system's constant directivity, you measure tone bursts from the screen, and open up a gate as that tone burst passes the microphone. You see the early arrival sound, and that early arrival tone burst is around 10mS long. So that 10mS includes reflections between the horn and the screen, and includes local reflections off the console, because that's rather close to the microphone.

We're trying to do it where people are listening. You get comb filtering because of these reflections at either end. You also find the average response falls off at high frequencies in exactly the same way the pink noise does. They track very well. There is no begging the question, which sound field, direct or reverberant, is more important. With the power response, they are the same. No need to tune it or equalize it. You've done it, period.

The reason for a house curve in large auditoriums is we're measuring long-term pink noise, and what we really should be measuring is the first arrival sound. And since we're using non-constant directivity horns, and the horn directivity is collapsing, plus we're measuring in a reverberant far field, we're seeing a rolloff. If we measured the first arrival, it would be flat. That's why we want an overall rolloff.

Well, fortunately that didn't turn out to be the real reason. In the last few years, the real reason for the house curve has more to do with diffraction about the head, and all these things acoustically going on. They're actually there, but the fact is that we're evaluating with ears instead of a microphone.

If you play CDs on this system it's a great shock—it sounds like hi-fi.

And you say, this doesn't sound like a movie at all. What's wrong with this sound system?

It doesn't honk at you?

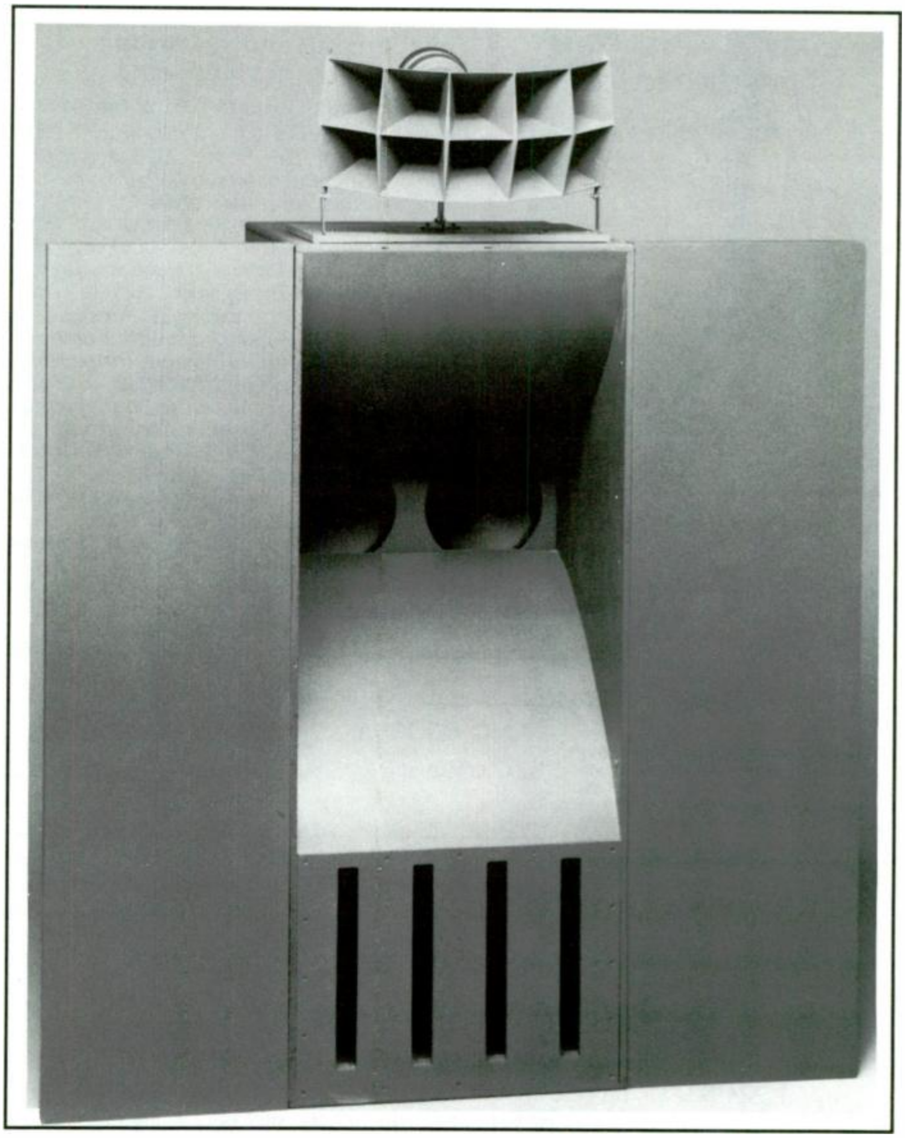
TH: It doesn't honk! Well, that was a bit difficult for people to get used to. The combination of all these things we've talked about has the effect of lowering the bass corner by about an octave, and of raising the treble corner by more than an octave. So suddenly there are two octaves you never had before. It's much more uniform around the room.

SUBWOOFER. So that happens. The corner of the system is 40Hz, and since we really do want to go down to 25, or so, we use a subwoofer just for that octave. The really low stuff.

Is there any thought of going lower?

TH: Not really. The trouble with lower ones would be that you're down at frequencies where the room nodes are so strong you can't get it covered uniformly. Small changes in level have a lot more change in the loudness, and the room acoustics are against you. There are a couple of things wrong with theater subwoofer design. First they were one-note bass design—everything sounded exactly the same. Second, at high drive levels they would clatter. We bottom out the drivers. The design we picked does neither of those things. It's smooth and it can't clatter because of special electronic limiters. In different Dolby systems there is a sub-woofer output for its lowest octave.

The low end of THX is down 1dB at



K. Tredwell

PHOTO 2: The classic "A4" found in most "other" theaters.

40, and it's two poles below that, so there's a rather rapid rolloff below 40. The subwoofer goes down to about 25. The system really stays on the X curve, which we've talked about before, from 25Hz to 16kHz. We're within ±1dB of the X curve here. The screening room subwoofer at the ranch has two 15s: a powered Kintek subwoofer with a 500W amplifier. You can set it differently for two purposes. One is a bandwidth extension down to 25Hz from the main channel's low end of 40Hz. The other is simulated baby boom channels. The dubbing stage doesn't have the baby boom channel, no left extra or right extra so the subwoofer is set at 250Hz to simulate them.

MIXING AND THEATERS. My colleagues in Hollywood say you only want a dubbing stage to be like an average theater. If so, I believe you never know what your program material is. So what you want, I think, is a dubbing stage which is a laboratory. You need a lot of electronic degrading facilities to make it more nearly like the theaters, so the mixers can tell what the compromises are. We measured all sorts of theaters for frequency response. At first, we put in an average bass filter. Later on, we got more sophisticated and modeled specific systems, like with and without EQ, with and without Dolby.

Dolby was an amazing improvement.
TH: Oh, yeah, because they did it without equalization. They Band-Aided a lot of the system problems, in effect. It's nice they did it, but it was a Band-Aid.

They could go into an existing theater with a few pieces of equipment.
TH: They did everything they could with a piece of electronics in the booth, that's right, and THX tries to do everything else. We brought in people, first from Hollywood, then the exhibitors, to see what this sounded like, and they were amazed. The sound was so different from what they were used to in a movie. Some of the Hollywood dubbing stages and some of the theaters wanted to put it in the theaters in time for *Return of the Jedi*. We installed four of them. Then we had this battle of what the noise should be, what should the reverb time be, what should this be, what should that be. I had to write the manual and establish what the standards were going to be for the system. That's why it's very different from Dolby selling a piece of equipment, because it's licensed to meet a certain level of performance.

Dolby has a license?
TH: Well, they may have one with respect to the use of their logos, but it's not on the theater. It's no performance standard, unfortunately. They're the first ones to say that.

I have been in so many misaligned theaters. The one in which I saw Amadeus *had the surrounds so loud I couldn't hear the music over the reverberation. At another theater, you were hit as hard with the bass as with the characters on the screen.*
TH: I teach that very strongly in my classes. That has to do with the difference between "production" and "reproduction." People in the theater business are supposed to be in the reproduction business. They are not supposed to be the producers of the movie. They're remixing the movie, and causing lots of problems.

We've started something else at Lucasfilm called TAP, the Theatre Alignment Program, to tune up theaters before the release of films. That's less known than THX, but it's a very important ingredient. It tunes up THX and many other kinds of theaters to the best level possible, and gets the levels set right. Sets the subwoofer level right and gets the screen brightness right, and all these factors. That's an important part of it, too.

So THX became a commercial enterprise. After that first four and our dubbing stage we've built, oh, gosh, how many, I don't know. There's about 12 rooms at Lucasfilm with THX sound systems and projection in them.

What's the smallest room size?

TH: The smallest practical room size in which the whole system fits is about 20 by 30 feet or so. Any smaller than that the source size gets to be an important factor. You don't want a discrepancy between treble and bass, a vertical discrepancy. Then you go to smaller systems.

Then it's not THX?

TH: No. We tried to match them as best we can. One of the main things I've studied the last few years, is how to make the loudness and the tambour match across the different room volumes.

People wanted to be in on the program and we had to certify products, so we were doing product testing. The first surround loudspeaker was done by taking a Boston A70 and hanging it up in the dubbing stage and saying, OK, it measures like this, and we want it to measure like this. Can you change the network to do that? And they did. They made a new model, the A70-T which has the X curve built in for the average theater. The trouble is, the Dolby equalizers are prohibitively expensive for surrounds because you have to buy an accessory rack and the equalizer card. So surrounds are not routinely equalized. We

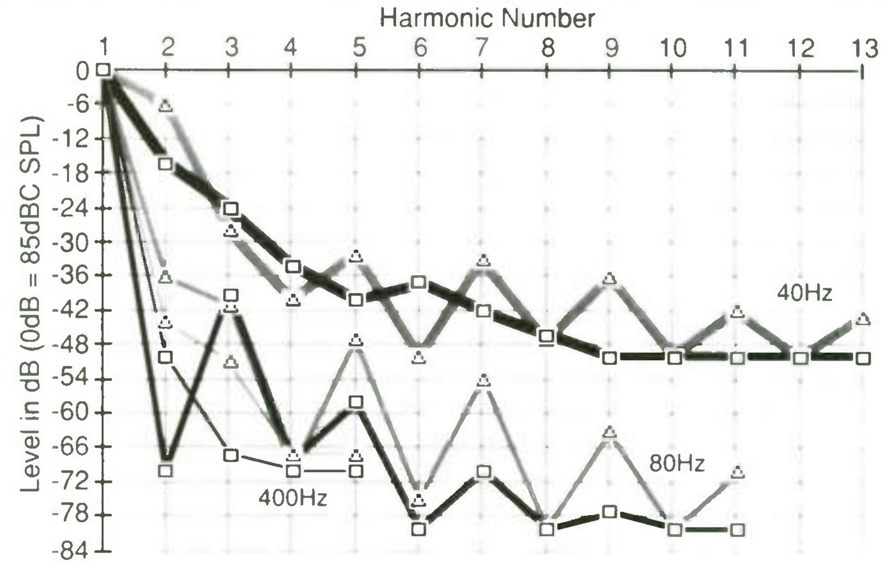


FIGURE 1: Harmonic distortion of horn loaded (triangle with gray line) vs. vented box (square with black line) at three frequencies: 40Hz, 80Hz, and 400Hz.

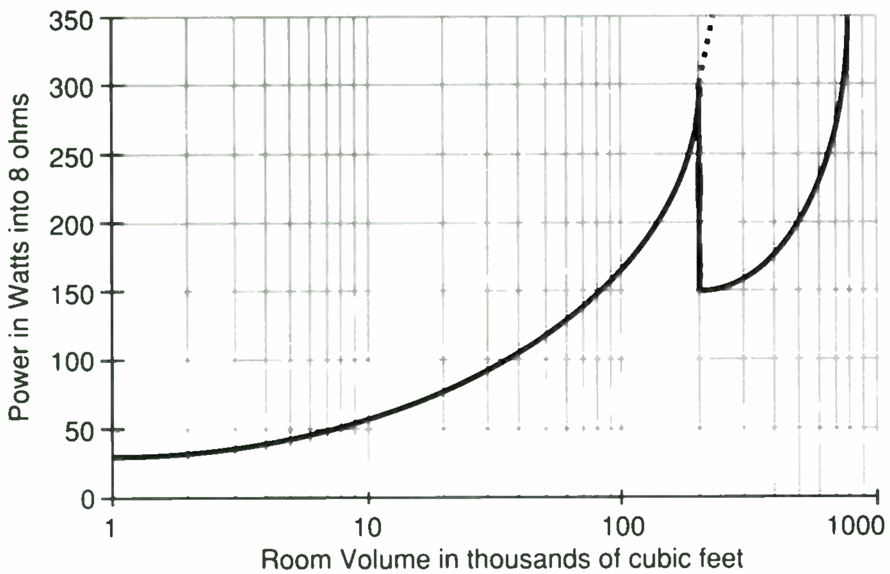


FIGURE 2: Amplifier power requirements vs. room volume. Redrawn by author from THX Sound System Program instruction manual.

designed a loudspeaker that, at least on average, will be on the curve.

SYSTEM LOUDNESS. We had to do studies on the loudness range of movies to see how loud it should play without distortion. (*Opens own unpublished book*) Here's a quiet movie, *The Verdict*. This is a statistical sound analysis, 16 minutes long, where the L50 in the 31.5Hz band is 50dB. That means that half the time it's greater than that, half the time it's less than 50dB. The average is 51. One's the median and the other's the mean. In *Raiders of the Lost Ark*, the rolling boulder scene, it goes to a hundred and five at 63Hz [maximum]. For at least one percent of the time it's hitting 105dB. You find this sort of thing, hitting 105, 106 at low frequencies, 1% of the time, and very low background noise levels. You see this is NC 15, which is a very quiet studio. The levels are actually below there. I had to use an exceedingly quiet room to do this, to capture this whole dynamic range. It rolls off at high frequencies, but this is because this is a one-eighth second time constant. So transients are not very well handled by this system. Every eighth second this is valid. Basically you'd like the rooms quite quiet.

I know I said before that we got the rooms down to very low background noise level, NC 12, and what happened then is interesting, because we took the movie, played it at the Northpoint Theatre about a month before *Jedi* came out. There's a scene, at the beginning of reel five, where Luke and Leia are on the bridge and the nature of their relationship comes out, the fact that they're brother and sister, and it's a very quiet dialogue scene. It's very intense. There's a little string, cello, music in underneath that scene. And we took it to this theater and it was gone. Totally, utterly, gone.

Well, we didn't punch in. We must have been playing the track but we didn't record it. OK, we go back and listen to it. No, it *is* on the track. The Dolbys must be mistracking. Let's go measure the Dolbys. We measure the Dolbys. Dolbys are fine.

I got the bright idea to measure the background noise level of the theater. It was NC 45! We recorded it in an NC 12 room. They had put that cello right in that region between NC 12 and NC 45, and it was thoroughly masked in the theater. The cello overtones didn't go up very far, and were gone.

So we came back. I'd already done these filters, because we knew we had to limit the frequency range. Since then we've added this background noise, like an average theater, and a clipper to show optic clash like an average theater. So you give them X amount of power, but you punch in buttons that show them what it's going to do when you finally get it to an average movie theater.

Does the background noise include people, air conditioning and traffic?
TH: No. That was all air conditioning noise. I consider air conditioning noise to be the insidious one, because it's the one that's constant. People say that audiences sitting still make NC 25. And I say true, on the average, but they can all hold their breath for that dramatic moment. It's not a good reason to make an NC 25 concert hall, just because the audience can make NC 25 noise on the average.

SURROUNDS. *What is the Dolby specified frequency response of the surrounds?*
TH: The Dolby matrix encoder has a 70Hz high-pass and a 7kHz low-pass. And the theater system has a 7kHz low-pass. I don't think there is a high-pass in the theater playback system.

The rule is the matrix requires as much power in the sum of the surround channels as in one screen channel, so smaller speakers can be used. Or you can split surrounds, and you can say each of them should handle as much frequency response.

I'd read somewhere that the lowest frequency in the surrounds is 300 to 500Hz.
TH: No. A split surround format was used on very few films, on *Apocolypse Now*, *Top Gun*, a few others. You see you've got the first stripes (*he picks up clear plastic block imbedded with one 70 mm frame of* Return of the Jedi), and the outside stripes are wider so they contain two tracks and these two contain one track each, so there are six tracks. In the old format they went: left, left-center, center, right-center, right, surround. When Steve Katz worked on this for *Star Wars* in 1977 the format was L, C, R, S. The other two channels LE and RE [left-extra and right-extra], intermediate channels, were used only below 200Hz for extra bass power handling, called the "baby boom" format. Most films made in baby boom format have a level stager between channels so that the flux on the film is lower on the LE-RE channels. It's turned back up in the theater. It helps the headroom both on the film and in the theater because you've got more speakers going.

Now for these few films the split surround format was invented and that may be where the 300Hz crossover is. In split surround you get the bass for the surrounds off the surround channel, and you get left and right high frequencies off the LE and RE channels. There's a crossover in the LE and RE and that's probably at 200 or so, because the bass information still goes to Le and Re. The high frequency information becomes left surround and right surround. So it's probably that split surround format you're thinking of.

When I toured Twentieth Century's sound department, they had only three surround

speakers in their mixing/screening theater. Other theaters seem to have many.
TH: Oh, definitely.

Is there a THX standard for that?
TH: Yes, there is, with THX. The theaters that have two or three are based on the 1950s idea of the "effects channel," as it used to be called. When I saw *Ben Hur* at the McVickers Theatre in Chicago, about 1957 or so, they had two A7s in the back corners to play the effects channel.

Now, there are several problems with that. First, it's a point source— everybody can localize it. Second, people who are close to it get creamed in level. People who are farther away don't. So there's no way to set the level. Third, an artistic use of surrounds problem exists in those early films that went like this: In *Ben Hur* there's a kind of subjective camera shot with the camera overhead on a moving dolly walking behind him as he walks through a bazaar. The bazaar is all across the screen and comes around you into the effects channel. Well, at one point a cow moos in the effects channel. And me, at age seven, turned around and looked at the loudspeaker and said, "What is that cow doing loose in the auditorium?"

This has to do with the whole effects nature of the movie. Today, it's much more of a surround nature. Surrounds have two kinds of artistic use. One is the low level ambiences without specific hits to put you in the same space. And one of the best of those is in *Apocolypse Now*, where they get off the boat and go into the jungle to get mangoes. The sound of the jungle is sneakily crept up behind you so you don't even know you've been pulled into the scene. And then a tiger jumps out! It's like you've been made a part of the action. That use of surround is a very, very good one. The other current one is the fly-over, when something "flies off" the screen or onto the screen.

You feel it go over.
TH: That's right. Those pans really work. So those are more discrete effects, but they usually lack transients.

They can come from all sides.
TH: Yes. Usually they won't be ticky, talky things, they'll be whooshes. They come from an indeterminate place and they wind up on the screen. The whole point is that the screen contains the sound of the images, whereas the auditorium contains the enveloping, sounds as though you were there. It has to do both with the sound system and artistic use.

We completed the THX system in 1982, and fired it up and it sounded wonderful. Pretty soon people are playing more old films and they're saying, "Wow, this is really what movies sound like!" For me, the problem early on was that we made these auditoriums dead, so we had a lot of direct sound. Yet, that's exactly the opposite of what we would want for an enveloping sound field. You would want it to be non-directional, non-localizable. So what do you do about that?

Add many small loudspeakers as opposed to two or three large loudspeakers.
TH: So the reason behind using many small loudspeakers was so that you would not localize as much. Now you sit in the center of the dubbing stage, on the center line, and what you get is this left, center, right, very discrete impression, plus this middle of the head, earphone like, impression of the surrounds, because they're not spatialized. If you move two feet to the left side of the console the surrounds are all left, because the Haas effect is so predominant. You

Continued on page 61

Continued from page 59
move to the right, it's all right. I don't know how many times over the years we've answered the problem, "Man, the surrounds are left heavy. Well, move to the middle."

We need many surround channels to promote spatialization. Or we need electronic surround scrambling, which is something I've been working on for a while (and trying to get patented), to yield non-correlated signals having the same program material. A number of ways have been tried in the past: comb filtering, phase shift networks, what have you. Those all cause problems, and I think we've found a better way that doesn't.

Is SR actually getting into the consumer theaters?

TH: Oh, yes. They expect to be into, oh, I don't know how many, a hundred maybe for big releases.

Is the level set for each movie?

TH: No, all the movies are mixed for the same standardized sound pressure level. So now movies are much better than recording or broadcasting other things, because at least we've all agreed on the target: a certain sound pressure level. It's 85dBC for 50% modulation of the optical with one channel playing—50% pink noise. The C curve is practically flat. It's just ignoring the very ends.

I've read how some films have their dynamic range packaged to go into the home. This was before hi-fi video came out.

TH: There is a difference between the dynamic range of a 70 mix and a 35 mix. The 70 mixes are too wide for home, I think. The 35, Dolby A, mix works just fine. It goes straight across. Absolutely perfect copy if you can get it. Clone copy it on the digital laser disk, then you can have a crack at decoding it as well as the theater can. That's what I've been working on the last couple of years, but I can't talk about it yet.

I understand that Dolby reworked the Sansui QS.

TH: There's been a lot of work done since the early QS. Initially they actually used QS boards. But then Dolby did their own proprietary boards for the second generation. Now they've done a third. The latest stuff is actually easier to understand than the older stuff, because there are left-right and front-back detectors. And those detectors go into the VCAs and the VCAs add up these voltages that come Lt and Rt to make L,C,R, and S.

That's one of the issues on THX. Two years ago one of the first ones was going over to CBS and hearing people overdo these crazy *over*-matrixed, *over*-dematrixed signals; where they try to take left and right and ship it off to left and right surrounds, to make it *bigger* than ever. But the picture, if anything, is *smaller* than it ever was! It makes no sense at all to have the footsteps coming at you from the left surround when you see the guy on the left side of the screen. It makes no sense at all.

AMP/DRIVER INTERFACE. *Speaker Builder is just starting to address the issue of amplifier interaction with the speaker. You've touched on it with the crossover. What have you done with that?*

TH: Well, I did quite a bit of work on it. I published a paper in the AES *Journal* about it[4] when I designed the Apt preamp and power amp. I went out and got a whole pile of loudspeakers to find out what they did at different frequencies. I published the photographs of the excursions caused by various loudspeakers.

I showed that some loudspeakers have very strange behaviors like, pushing the

J. Hannon

PHOTO 3: THX crossover boards and monitor control panel. Shown is a five-channel system in a rack that allows monitoring each channel's crossover and amplifier output.

voice coil out of the gap, then at the end of the travel the impedance changes dramatically. Or an input autoformer, to change impedances, saturating, so you'd go to five amperes very smoothly, but when you add one more dB of drive, you're suddenly at 30 amperes. We jerk from five amps to 30 amps, because the amp went from seeing a six ohm load to seeing a tenth of an ohm load, because the transformer saturated.

It makes designing a power amplifier a very difficult chore, because every power amplifier is designed with some kind of economic performance in mind. We'd like to produce the most number of watts for the least dollars. Yet, you have to be able to drive, what I call, elbow room, which is to be able to drive the severity of excursions caused by the phase angles of the load.

I was in an amateur loudspeaker listening test recently at Just Speakers in San Fransisco where seven hobbyists had loudspeakers built for a contest. One of those loudspeakers shut down these very expensive Boulder power amplifiers, made them snap like crazy—very, very bad sound. So we eliminated that pair from competition, and when we measured later, they dropped to half an ohm 140Hz. Half an ohm! That wasn't even a phase angle problem. That was just a pure and simple resistance problem.

In THX, by the way, we have qualified the front channel loudspeakers to be a certain impedance curve, and we test every amplifier into that curve. We put up tone bursts versus frequency, as loud as possible, up to clipping, and make sure they make no protection circuitry to speak of, so we know the amp will drive those loads. If an amplifier appears in our list (*Table 1*) it doesn't say that it will drive all loudspeakers. It will, however, drive the loudspeakers we certify, because we know that the interaction is acceptable.

THX specifies loudspeakers and amplifiers, matched to each other?

TH: Yes, except for power level. You must pick the right power for the room size. A power graph in the manual tells you how to pick the power.

SPEAKER CABLES. *What about interconnect cable?*

TH: We designed the cable for frequency response variations. Wire gauge is most important. In theaters where we have very long runs, up to 150 to 250 feet, we have to get down to 12- and 10-gauge cable, respectively. I set our standard as plus/minus one eighth of a dB ripple, due to impedance variations. That's probably inaudible. The only thing I believe about cable is wire gauge, and wire gauge with strange impedances can matter, because we can get frequency response differences of even half a dB over an octave or more. Then they become audible. That's where it becomes important.

It's nothing mystical if you can measure it.

TH: Yes.

Like resistance, capacitance, and inductance.

TH: Well, capacitance and inductance are not that important because, after all, it's not a transmission line. But, they will become problems if they have peculiar characteristics which cause problems for the amplifier. If the cable is built to be low inductance, and therefore high capacitance, it can be a capacitive load to the amplifier which moves the poles around in the amp's transfer function. When incorrectly connected this causes trouble. It may cause oscillation.

Shorting at high frequencies...

TH: Shorting it at high frequencies, right. Such problems are certainly possible. We generally use limp, many stranded 10-gauge wire so you can pull it and get good connections. That's the main reason.

REFERENCE LEVEL. The speakers, by the way, can't be in physical contact with the wall. They sit on vibration absorbers, and are gasketed into the wall, air-tight, with about a half inch rubber gasket between box and wall so they do not transmit to the structure.

So, you don't have a structural radiation factor as part of the equation?

TH: That's right.

What's the reference fluxivity level for 70mm films?

TH: The reference level is 185 nanoWebers per meter, the standard.

And that gives you 85dB SPL?

TH: And that makes 85dB, right. The headroom is about 21dB to the MOL, but we use 16 of that. In *Willow*, there's a limiter, a slow band limiter operating at +16dB over 185. So, that's about 3% distortion. The reason for the limiter is to make the 70 mix more like the 35 final resolve. So, when you make the two of them you don't have to spend all your time pulling the 70 mix down into the realm that 35 can handle.

Is the 70 mixed first and then kind of compromised for the 35?

TH: Yes. Usually we make the 70 print masters first. Also, because it takes longer to make the 70 prints.

Those are usually made one at a time and not just one in a batch.

TH: One of the jobs TAP does is the reel check-outs. Somebody will have to sit there and watch the same reel as many as 200 times, over, and over, and over, to make sure there aren't any blotches or drop outs or clicks.

I heard a problem when I saw Willow, *and I don't remember whether it was a THX theater or not. The recorder (flute, not reel-to-reel) was playing the main theme.*
TH: Yes, it was real Ocarina, or something...

It was a breathy, swishy sound as though the film was skating across the tape head.
TH: That's probably a head contact problem. You saw the 70, probably. That's certainly one of the things that should be checked out. In fact, that's what the 10kHz tone is for: to set azimuth and check level.

SYSTEM COST. *How much does it cost a 500-seat theater to upgrade to THX? Assume they already have a good sound system installed.*
TH: That's a complete unknown because of the acoustic requirements. If the place meets the acoustic requirements it's pretty straightforward. If it's new construction they can design it in from the beginning. The difference in cost is minimal. But, if it's an older theater with rattly air conditioning and high reverb time for a 70mm house then it gets to be a lot of money. So it's a huge range. The basic system Dolby included, with MPU's, Dolby CP-200, our electronic crossover, eight (to 12) power amps, surround speakers...

Surrounds are bi-amped, also?
TH: No, they're just usually wired split-surround. Wired in groups of some kind. The entire cost will be around $50,000 to $60,000, something in that range. Home hi-fi's are that much (*laughs*).

How much further is film sound going to improve?
TH: I think it's a distribution period for the available technology. The next revolutionary step will be digital film sound. But whether that makes sense, and when it makes sense, is still in question.

Could DAT recording squeeze enough information on the existing tracks?
TH: The linear speed is high enough. You don't need a rotary head. You could replace the mag stripes with optical bits on the film from a negative or directly written by a laser or something. There's enough space to do it. It's a simple matter of hardware.

What about reading it off?
TH: That's not even so hard with CDs. It can all be done, today. It would be a multi-million dollar development effort. But who's going to pay? It would mean the upper end of the market would get a little better. It wouldn't be widely or quickly disseminated.

It's still the speaker.
TH: It's the theater acoustics, actually.

That's right, you've taken care of the speakers!
TH: Yes. Actually, I'd say the A4, *even* the A4, is not the limit in most theaters. It's mostly room acoustics. So THX is as much concentrated on room acoustics as it is on loudspeakers, and background noise levels. We were in a theater recently that had an [a noise level of] NC 47. What that usually specifies is high school gyms, or light industrial manufacturing spaces. Not exactly motion picture theaters.

REFERENCE

4. Holman, Tomlinson, *THX™ Sound System Instruction Manual: Architect's and Engineer's Edition*, Fourth Edition, Theatre Operations, a division of Lucasfilm Ltd., October 1987, p.15.

MAGNETIC CROSSTALK IN PASSIVE CROSSOVERS

BY MIKE CHIN

During the past three years, I have performed numerous modifications to allow for bi-wiring on a variety of speaker systems manufactured by such respected companies as Linn, Rega Camber, Genesis, AR, and Rogers. Among audio enthusiasts in Vancouver, bi-wiring has become very popular, often providing dramatic but relatively inexpensive improvement. (See *Figs. 1* and *2* for graphic illustrations of conventional and bi-wired speakers.)

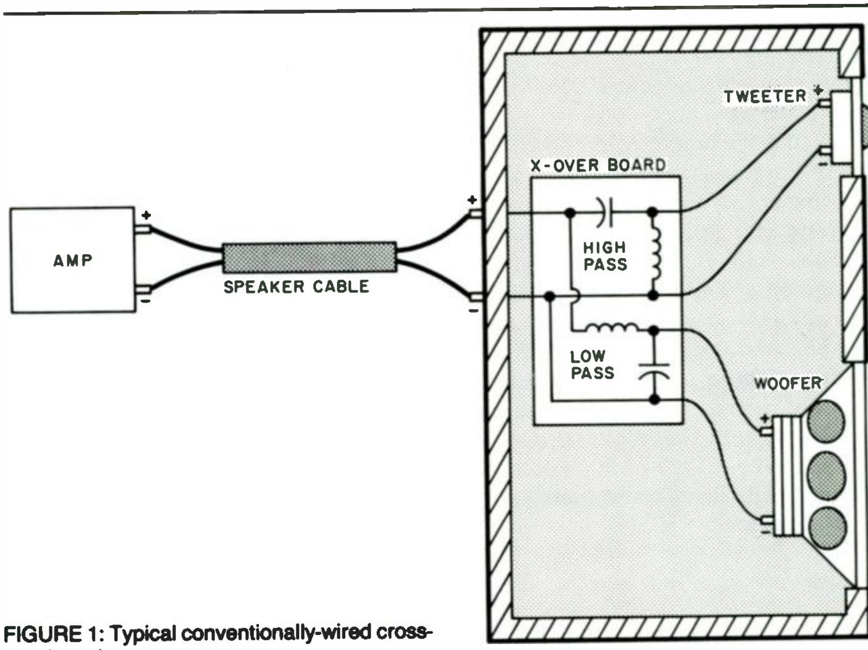


FIGURE 1: Typical conventionally-wired crossover/speaker.

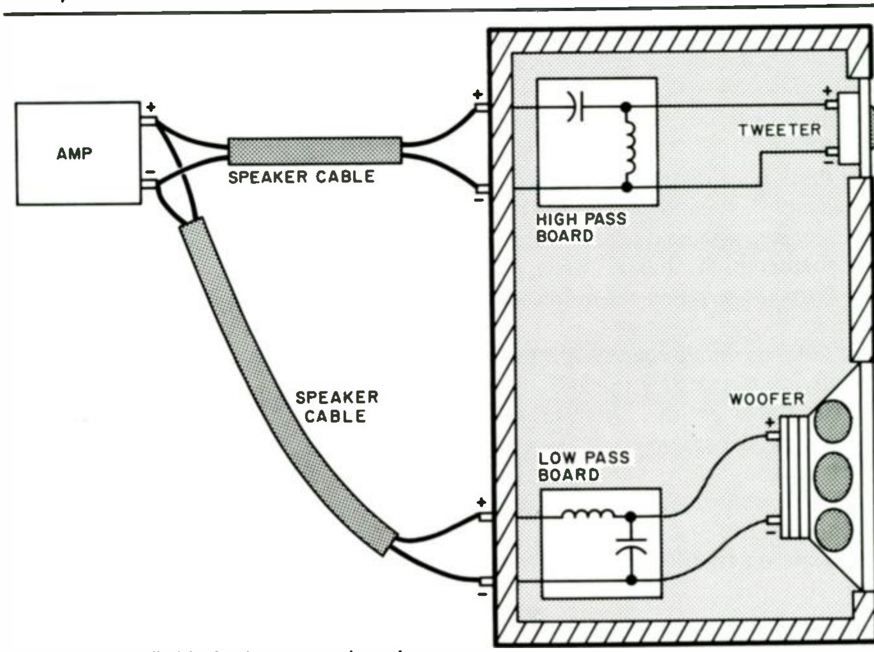


FIGURE 2: Ideally bi-wired crossover/speaker.

BASICS. The typical bi-wiring mod consists of the following:

1) Carefully removing the woofer to gain access to the crossover (CO), usually mounted on the inside of the back panel of the enclosure.

2) Examining the CO circuit to separate electrically the high- and low-pass sections (for typical two-way systems) there is always a common ground).

3) Installing a second set of input jacks for the high-pass section (usually), using the original input jacks for the low-pass one.

4) Reinstalling the woofer, after checking the wiring, and sealing the enclosure as before.

As an aside, I might mention that invariably the attitude of the speaker owner is that if he is performing such major surgery on the speakers, he might as well do everything possible to improve their performance. So, before sealing up the box, you might also do any number of the following mods: replac-

ABOUT THE AUTHOR

Formerly an audio store owner/operator in Vancouver, BC, Mike Chin has been involved with audio for twenty-five years. He enjoys writing fiction and nonfiction, and designing/building speaker systems and house-husbanding/fathering—not necessarily in that order.

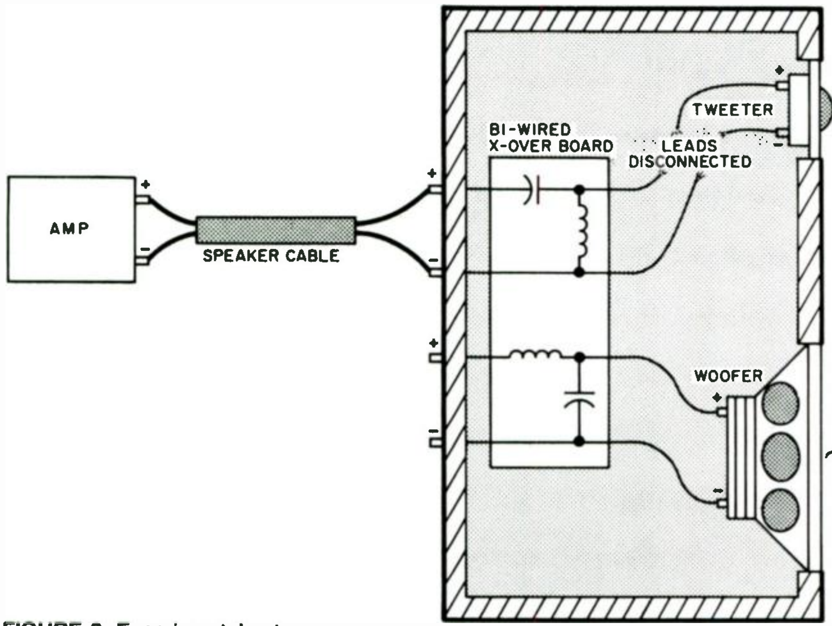


FIGURE 3: Experimental setup.

ing stock wire with high-grade speaker cable; replacing capacitors, inductors, resistors, and/or input terminals with higher quality items; removing, bypassing or replacing L-pads, fuses, and other non-essentials in the signal path; damping the driver baskets with hot glue or tar; adding internal braces or wall damping material to improve cabinet strength/rigidity; (occasionally) redesigning the CO, replacing the drivers, and/or removing the CO to an external box.

Bi-wiring almost always provides some improvement over conventional wiring. The degree of improvement depends on the quality of the speaker system (the higher it is, the greater the improvement) and that of the audio components used to drive it (again, the better the driving system, the more audible the improvements). Some enthusiasts also experiment with using one type of speaker cable on the high-pass section and another on the low-pass (something I have not tried). You can easily upgrade bi-wireable speakers to passive bi-amping (*Fig. 4*) simply by adding another amp. This procedure provides some improvement over bi-wiring, but it is usually not as significant as that achieved when you use bi-wiring instead of conventional single wiring.

I have heard and read many explanations of how/why bi-wiring improves speaker performance. These reasons appear to be widely accepted:

1) It reduces the unwanted modulation of the tweeter by the back EMF of the woofer.

2) It improves the electrical separation of the high- and low-pass sections.

3) It improves the amplifier/speaker interface through the use of two sets of speaker cables.

EXPERIMENTING. Not long ago, curiosity led me to do some experiments with a speaker I was modifying for bi-wiring. This particular model was a compact solidly-built, sealed two-way system using a KEF B200 (8″) variant, a Japanese dome tweeter, and a crossover with high-quality parts mounted on a high-quality circuit board located 4–5″ behind the woofer. It was a good-sounding little speaker and, in short, an excellent candidate for bi-wiring.

After modifying one speaker, I hooked it up into my system in bi-wired form on one channel. I hooked up the unmodified one to the other channel for a brief preliminary listen in mono, switching between the speakers with the balance control—a standard procedure to ascertain that the bi-wiring mod did, in fact, improve the sound. And it had: the modified speaker sounded clearer, had greater weight, and generally was more pleasing. I decided out of curiosity to give the tweeter, which I'd never encountered before, a listen by itself. So I disconnected the unmodified speaker as well as the cable to the bass section of the modified one and listened to just the tweeter at medium volume. Naturally, it sounded shrill and bright, especially with the crossover rolling off the sound at 18dB/octave below 3kHz. In the middle of this, something compelled me to go right to the speaker and put my ear up to the woofer. Lo and behold, sound was emanating from it.

Perplexed, and wondering if there was some kind of wiring error, I opened up the enclosure and double-checked everything: all was as it should be, the tweeter and woofer on completely separate circuits. On a hunch, I disconnected the tweeter from the CO, left the speaker wire hooked up just to the high-pass section, and played the music through the system again, at what would be a

Continued on page 67

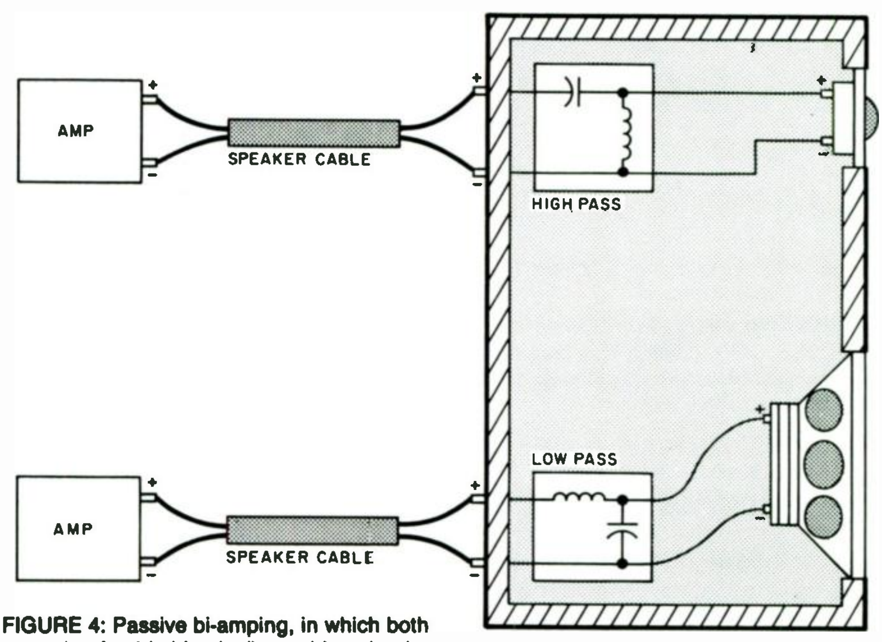


FIGURE 4: Passive bi-amping, in which both amps (preferably identical) are driven by the same signal.

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SPEAKER SAVER, FILTER

KH-2: SPEAKER SAVER AND OUTPUT FAULT DETECTOR. [3:77] This basic two-channel kit includes board and all board-mounted components for control circuitry and power supply. It features turn-on and -off protection and fast optocoupler circuitry that prevents transients from damaging your system. The output fault detector has additional board-mounted components for speaker protection in case of amplifier failure. **$65**

KF-6: 30Hz RUMBLE FILTER. [4:75] This kit implements a 1975 design for a low frequency garbage filter. The filter knee is set to 30Hz. Roll-off below that knee is the 18dB/octave characteristic of its three pole design. Gain for the filter is unity (0dB) but can be simply adjusted for up to 12dB of gain. The reprint of the article explores the use of the filter with other components in crossovers (see kits SBK-C1A, C1B). It shows how to obtain slopes of 6, 12 or 18dB in high and low pass filters. The kit contains all parts for building a two channel HPF including a board (3" × 3"), quad op amp IC, precision resistors and capacitors. Requires a bipolar supply of ± 15V—the KE-5 is suitable. **$30**

AIDS & TEST EQUIPMENT

KK-3: THE WARBLER OSCILLATOR. [1:79] This unit will produce a swept signal covering any ⅓-octave between 16Hz and 20kHz. The total harmonic distortion at the output is less than 1.5%. The output voltage is adjustable from 0 to 1V. When used with a microphone it is as effective as a pink noise source in evaluating speaker system performance. It also reveals the listening environment's effect on sound through reflection and absorption. The sweep rate is set at about 5Hz. The kit includes 3¼" x 3⅞" circuit board, transformer, all parts and article reprint. **$70**

KH-7: GLOECKLER PRECISION 101dB ATTENUATOR. [4:77] All switches, 1% metal film and 5% carbon film resistors to build prototype. Chassis, input/output jacks are not included. **$65**

KC-5: GLOECKLER 23-POSITION LEVEL CONTROL. [2:72] All metal film resistors, shorting rotary switch and two boards for a two-channel, 2dB per step attenuator. Choose 10k or 250kΩ. **$48**

KL-6: MASTEL TIMERLESS TONE BURST GENERATOR. [2:80] All parts with circuit board. No power supply. **$24**

KP-2: TWO TONE INTERMODULATION TEST FILTER. [1:82] This filter is designed to isolate the two high frequency tones at an amplifier's input from low frequency intermodulation products present at the output. The high pass filter corners at 2kHz and rolls off at 24dB/octave. A 5kHz signal at the low pass input will be down at the output by 80dB. An article reprint detailing design and use is included with the kit. All parts are supplied, including quad op amp IC, circuit board and precision resistors and capacitors. **$26**

SBK-D2: WITTENBREDER AUDIO PULSE GENERATOR. [SB 2:83] All parts, board, pots, power cord, switches and power supply included. **$80**

SBK-E4: MULLER PINK NOISE GENERATOR. [SB 4:84] All parts, board, 1% MF resistors, capacitors, ICs, toggle switches included. No battery or enclosure. **$35**

CROSSOVERS

KC-4A: ELECTRONIC CROSSOVER, KIT A. [2:72] Single channel, two-way. All parts including C-4 board and LF351 ICs. Choose frequency of 60, 120, 240, 480, 960, 1920, 5k or 10k. KE-5 or KF-3 supplies are suitable. **$14**

KC-4B: ELECTRONIC CROSSOVER, KIT B. [2:72] Single channel, three-way. All parts including C-4 board & LF351 ICs. Choose two frequencies of 60, 120, 240, 480, 960, 1920, 5k or 10k. **$18**

KK-6L: WALDRON TUBE CROSSOVER LOW PASS. Single channel, 18dB/octave, Butterworth [3:79], includes three-gang pot. Choose 1: 19-210; 43-465; 88-960; 190-2100; 430-4650; 880-9600; 1900-21,000 hertz. **$60**

KK-6H: WALDRON TUBE CROSSOVER HIGH PASS: Single channel, 18dB/octave, Butterworth [3:79], includes three-gang pot. Please specify 1 of the frequencies in KK-6L. No other can be supplied. **$62**

KK-7: WALDRON TUBE CROSSOVER POWER SUPPLY. [3:79] Includes board, transformer, fuse, semiconductors, line cord, capacitors to power four tube crossover boards (8 tubes), 1 stereo bi-amped circuit. **$110**

SBK-A1: LINKWITZ CROSSOVER/FILTER. [SB 4:80] Three-way crossover/filter/delay. 24dB/octave at 100Hz and 1.5kHz and 12dB/octave below 30Hz, with delayed woofer turn-on. Use the Sulzer supply KL-4A with KL-4B or KL-4C.
Per channel **$75** Two channels **$140** SBK board only **$25.50**

SBK-C1A: ELECTRONIC TWO-WAY CROSSOVER. [SB 3:82] 30Hz filter with WJ-3 board & 4136 IC adapted as one channel crossover. Can be 6, 12 or 18dB/octave. Choose frequency of 60, 120, 250, 500, 1k, 2k, 5k or 10k. The KL-4A/KL-4B or KW-3 are suitable supplies. **$32**

SBK-C1B: THREE-WAY, SINGLE CHANNEL CROSSOVER. [SB 3:82] Contains 2 each SBK-C1A. Choose high & low frequency. **$60**

SYSTEM ACCESSORIES

CDDA. Reusable soft vinyl Disc Ade CD damper from Apature. **$18.95**

HDTT. Mod Squad Tiptoes decouple system components from surface beneath, providing greater sound resolution. Special alloy cones, ½" high, 1½" in diam., are placed point down under speakers, CD players, turntables, to optimize stabilization. 3 per component recommended. **$6 ea. 3/$17**

KW-3: BORBELY IMPROVED POWER SUPPLY. [1:87] This single channel, low impedance supply was designed for the exacting requirements of Erno Borbely's moving-coil preamp [2:86, 1:87]. The design utilizes polypropylene caps and 1% metal film resistors. LM317/337s are used in the preregulator and Signetics NE5534 in the op amp regulator. The kit includes a low profile 24V toroidal transformer, 4¼" × 5½" circuit board and all board-mounted components. Chassis and heatsink are not included. **$135** Two or more, **$128**

KE-5: OLD COLONY POWER SUPPLY. Unregulated, ± 18V @ 55mA. **$20**

KF-3: GATELY REGULATED SUPPLY. ± 18V or ± 15V @ 100mA. **$52**

KL-4A: SULZER POWER SUPPLY REGULATOR. **$40**

KL-4B: SULZER DC RAW SUPPLY. ± 20V @ 300mA. **$60**

KL-4C: SULZER DC SUPPLY w/ toroidal transformer. **$85**

KH-8: MORREY SUPER BUFFER. [4:77] All parts, 1% metal film resistors, NE531 ICs, and PC board for two-channel output buffer. **$22**

SBK-E2: NEWCOMB NEW PEAK POWER INDICATOR. [SB 2:84] All parts & board, new multicolor bar graph display; red, green & yellow LEDs for one channel. No power supply needed. **$14** Two for **$22**

KL-2: WHITE DYNAMIC RANGE & CLIPPING INDICATOR. [1:80] One channel, including board, with 12 indicators for preamp or crossover output indicators. Requires ± 15V power supply @ 63 mils.
Single channel **$58** Two channels **$110** Four channels **$198**

KW-1: MAGNAVOX CD PLAYER MODIFICATION. Improves frequency response. Includes two Signetics NE5535s, two Panasonic HF series 330µF capacitors and four 3.92k, 1% metal film resistors. **$12**

KW-2: MAGNAVOX CD PLAYER MODIFICATION. As above, but with two AD-712 op amps in addition to the NE5535s. **$16**

KX-1A: DISC STABILIZER. Set of 3 Sorbothane feet, 3 Tiptoes and Mod Squad's Disc Damper with 15 centering rings. **$70**

KY-1: BEERS' BUDGET CD MOD. [1:89] Kit provides POOGE-4 improvements without additional wiring or circuit boards. Complete parts for assembling amplifier modules and replacing DAC components. Article reprint included. Soldering skills required: not recommended for beginners. **$95**

What's Included? Kits include all the parts needed to make a functioning circuit, such as circuit boards, semiconductors, resistors and capacitors. Power supplies are not included in most cases. Unlike kits by Heath, Dyna and others, the enclosure, faceplate, knobs, hookup wire, line cord, patch cords and similar parts are not included. Step-by-step instructions usually are not included, but the articles in *TAA* and *SB* are helpful guides. Article reprints are included with the kits. Our aim is to get you started with the basic parts—some of which are often difficult to find—and let you have the satisfaction and pride of finishing your unit in your own way.

Continued from page 65
medium to loud volume. (See *Fig. 3*, the experimental setup.) The sound that emerged from the woofer was loud enough to be heard clearly from 12 feet away; the music was even recognizable.

I took the speaker apart again, and this time pulled out all the components—the tweeter, the woofer, and the crossover. Keeping the wiring connections as above (tweeter disconnected, high-pass section hooked up), I played the system again, this time holding the CO and moving it around. The sound from the woofer became louder as I moved the CO closer to it; it diminished slightly when the CO was moved farther away, but the woofer never stopped playing. In a drastic move, I cut the CO circuit board into two parts: one with the high-pass section on it, the other with the low-pass.

Again, with the wiring hookup as before, I turned on the source. This time, with the high- and low-pass components separated by three feet, there was no sound at all. I brought the high- and low-pass sections of the CO closer together; when they were 10″ apart, the woofer began emitting just barely audible sound (with the volume control of the preamp at full). By the time they were six inches apart, the woofer was playing quite audibly. At three inches apart, it was almost as loud as when the CO was in one piece. Moving any part of the high-pass section—wires, jacks—close to any part of the low-pass section (including the woofer) increased crosstalk to some degree, but putting the CO sections close together had the greatest effect.

SOLUTION. In the end, I mounted the two CO sections in this speaker as far apart as possible, while at the same time keeping them as far away from the drivers as possible (*Fig. 2*). When tested, they displayed no crosstalk whatsoever, but I could not tell whether there had been any improvement as a result. All bi-wiring mods I perform now include a high-/low-pass crosstalk test that virtually no conventional speaker CO passes. Physical separation of the crossover is almost always necessary. One solution I have found is to remove the CO from the enclosure and mount it externally on the back of the speaker; in a box that is laid on the floor near, behind, or under the speaker; or integrated into the speaker stand. The terminals on the enclosure now run directly to the drivers. This arrangement allows the speakers to be bi- or tri-amped without any modification. The only difficulty I have sometimes encountered comes in fitting the CO components in a box unobtrusive (small) enough to maintain enough distance between the high- and low-pass sections to avoid crosstalk.

Later, I modified four identical speakers used in a quad setup. I bi-wired both pairs, one with the high- and low-pass sections apart, and the other with the crossovers not separated. Over the course of several nights, a variety of experienced and inexperienced listeners came to the general consensus that the speakers with the separated CO sounded better. To them, the sound was clearer, with individual musical lines or instruments better defined, with less background fizz—as if the music were projected onto a brightly lit foreground against a darker, velvety background.

CONCLUSIONS. I have drawn several conclusions from my experiences and experimenting with crosstalk that might be of interest and benefit to you:

1) Conventionally designed, laid out, and built passive crossovers suffer from

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Kit Report

Upgrading the Seifert Maxim III to IIIH

By James T. Frane

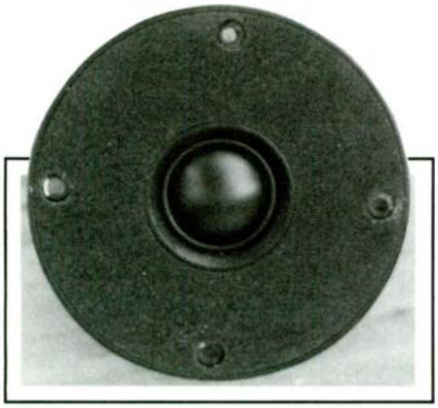


PHOTO 1: The original tweeter with foam rubber covering.

I ordered my Seifert Maxim III speakers by mail order directly from the factory in late 1985, spurred on by J. Gordon Holt's review in *Stereophile*, and the fact that Siefert allowed 30-day trial listening. I have learned over the past few years that Holt and I agree on a number of speaker performance priorities, so I had few reservations about trying these speakers.

I was not disappointed, and except for their low bass performance, I found the Sieferts superior to the speakers I had been using. Despite their very respectable – 3dB down point of 46Hz, they don't fill in the lowest octave. I eventually augmented the Sieferts with the smaller VMPS subwoofers, which cured any low bass shortcomings.

Reviews of modified Siefert Maxim III, called the Maxim IIIH, appeared in 1987, stating this version was an improvement over the IIIs. The IIIH replaces the III's soft dome tweeter with a metal dome tweeter, and uses a different crossover, a six-element providing 18dB/octave to restrict the overlap between tweeter and woofer near the crossover frequency of 3.5kHz. The original crossover was a first-order 6dB/octave configuration. The rated frequency response of the III is 46Hz–22kHz ±3, while the IIIH is rated at 48Hz–24kHz ±1½–a significant improvement. The III is a two-way speaker, reflex-loaded by two equal diameter tubed ports. It has a 1" polyamide soft dome ferrofluid damped tweeter, and a 6½" damped polypropylene woofer. The cabinets are 13" by 9" by 11", weigh 18 pounds each, and are internally cross-braced.

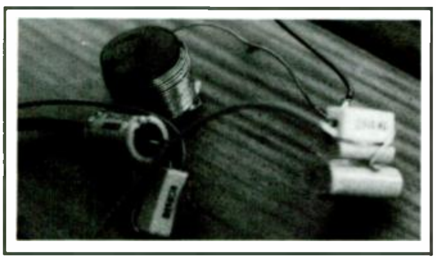


PHOTO 3: The original crossover.

Shudder, Shudder

Siefert wrote early in 1988 saying they would upgrade my Maxim IIIs for $114. I was happy with the performance of the III/VMPS combination, and a little worried the modification might degrade performance. I was curious though. I like to experiment with reversible modifications in hopes of improving music reproduction. If I sent my speakers to the factory, the changes would be irreversible. I called Ed Miller, Siefert vice president and told him about my background in building and modifying electronic components and speakers, and my wish to convert the Maxim IIIs myself.

He agreed to send the parts, and provided some over-the-phone instructions, such as using hot melt glue to hold the crossover in place, and connecting the leads to the new tweeter opposite the connections on the original to maintain proper phasing. A few days later, the new tweeters and crossovers arrived, without instructions. The modification was straightforward, however, since I had the information about reversing the connections to the new tweeter.

Both tweeters are manufactured by SEAS of Norway. The original tweeter (*Photo 1*) has a foam rubber covering on the faceplate, from the outside diameter of the dome to the outside diameter of the faceplate. It isn't clear whether the foam is intended to attenuate sound waves travelling across the face of the driver. The new unit (*Photo 2*) doesn't have foam covering, but a wire mesh screen covering the dome. The dome is recessed about ⅛" behind the screen.

The Modification

Four screws hold the woofer to the baffle. Once these and the screws that hold the tweeter to the baffle are unscrewed, the tweeter can be removed by pushing gently from behind. All the connections are push-on spade lugs, so disconnecting the drivers from the crossover is easy. Pulling the fiberglass batting from under the woofer cutout gives access to the crossover.

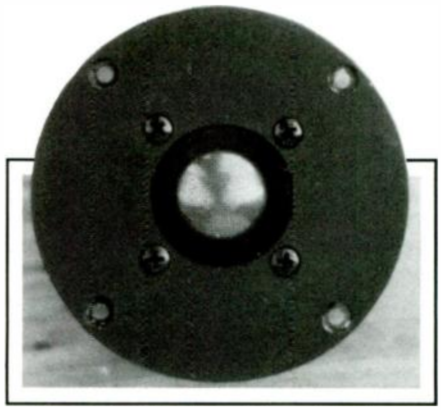


PHOTO 2: The new unit with wire mesh screen covering the dome.

The crossover components are bonded to a piece of masonite-type material, which is bonded to the inside of the rear baffle. There isn't enough leverage in the tight working quarters to break the bond between the crossover mounting board and the baffle, so I pried the components loose, and disconnected the leads from the crossover to the enclosure terminals. *Photo 3* shows the original crossover, and the new one in *Photo 4*. I used hot melt glue to bond the new crossover board to the original. Other adhesives would bond as well, but take longer to set.

Terminally Speaking

The original tweeter had one terminal on each side, and the baffle cutout was milled for this configuration. The new tweeter has both terminals on one side, so I enlarged the baffle cutout on one side to accommodate them (*Photo 5*). Miller recommended using a rotary rasp but a saber saw worked very well. The new tweeter was a very snug fit in the recess, milled in the baffle enabling the driver faceplate to fit flush with the baffle. I drilled new $^1/_{16}$" screw

Continued on page 71

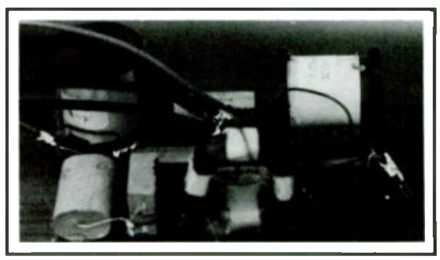


PHOTO 4: The new crossover.

TABLE 1

CUT	HERTZ	MID-POINT	SYSTEM B SLM Readings Before Siefert Modification	SYSTEM C SLM Readings After Siefert Modification
1	14.7–20k	17,350		
2	10.3–14.0	12,500		
3	7.36–10	8,830	69.5	67
4	5.2–7.3	6,280	69.5	65
5	3.7–5.2	4,450	69.5	64
6	2.6–3.7	3,150	66	68
7	1840–26	2,220	66	70
8	1300–18	1,570	65	68
9	920–13	1,110	66	66
10	650–92	785	72	70.5
11	460–65	555	68	67.5
12	325–46	392.5	70.5	71
13	230–32	277.5	68	71
14	160–23	195	64	65
15	115–16	137.5	68.5	69
16	80–11	97.5	71.5	72.5
17	40–80	60	72	71
18	20–40	30	62	67

Continued from page 69
holes since the terminals limited driver rotation, and the original screw holes were covered.

The new crossover is connected to the enclosure and driver terminals using Tweek to ensure good contacts. The green wire from the original crossover is connected to the tweeter's positive terminal. Miller's instructions were to reverse this for the new tweeter, so the green wire is connected to negative, and the black to positive.

Besides the do-it-yourself fun, it only took a short time, about two hours, and I have the old crossovers and tweeters to use for future experiments.

Modification Results

I use the Sieferts with the smaller VMPS subwoofers, and all measurements and comments are based on this combination. The modification resulted in a number of subtle, but definite, improvements in speaker performance. The *Table* shows a before and after frequency response comparison. Measurements were taken with an ADC sound level meter, Model SLM-2, mounted midway between the top and bottom of the Siefert/VMPS combination, with one meter in front of the speakers on the axis of the right speaker.

I used the *Stereo Review* Test Record Model 211, which generates a series of warble tones. The differences in frequency response aren't great, but the measured responses don't tell the whole story. There are a number of speaker performance indications no one knows how to measure. *Listening* is always the best, and final, sound quality indicator.

The first difference I noticed, perhaps because it seemed the most prominent, is the change in the bass, which became taut and well-defined, particularly in reproducing sounds such as a kickdrum. The plucking of bass strings is also more distinct and realistic. Bass improvements are probably solely attributable to the new crossover network, a pleasant benefit I wasn't expecting. The overall effect is similar to a planar type speaker, with no loss of the lowest fundamentals.

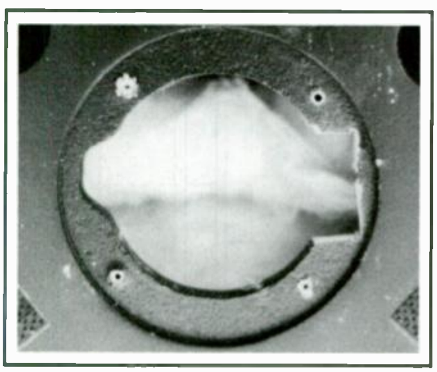


PHOTO 5: The baffle cutout was enlarged to accommodate both terminals.

Sounds Great

Highs gained clarity and precision, an increased sense of openness, real, and distinct, without overemphasis in the midrange. The upper octaves have more detail and a bit of increased ambience.

Imaging is more stable with a wider soundstage, often beyond the boundaries of the speakers, but dependent on the source material. Soundstage depth also is improved. Overall, the sound is smoother than before the modification.

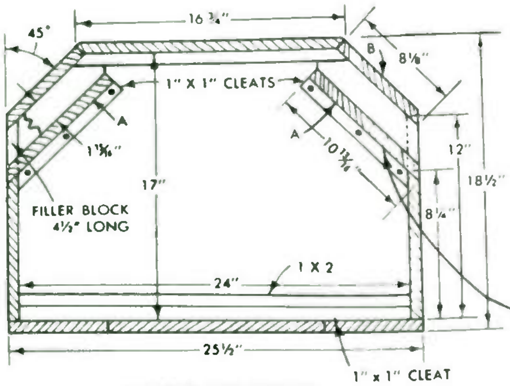
I believe this modification is definitely worthwhile. It improved speakers that were already very good.

Ed Miller comments:

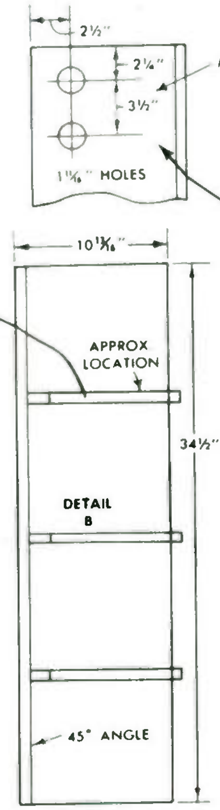
Siefert will offer the SEAS aluminum, dome tweeter and 18dB/octave crossover components for the Siefert Maxim III upgrade at $49.50, plus $4 shipping, in the continental US. Siefert Research is located at 31212 Bailard Road, Malibu, CA 90265.

Vintage Designs

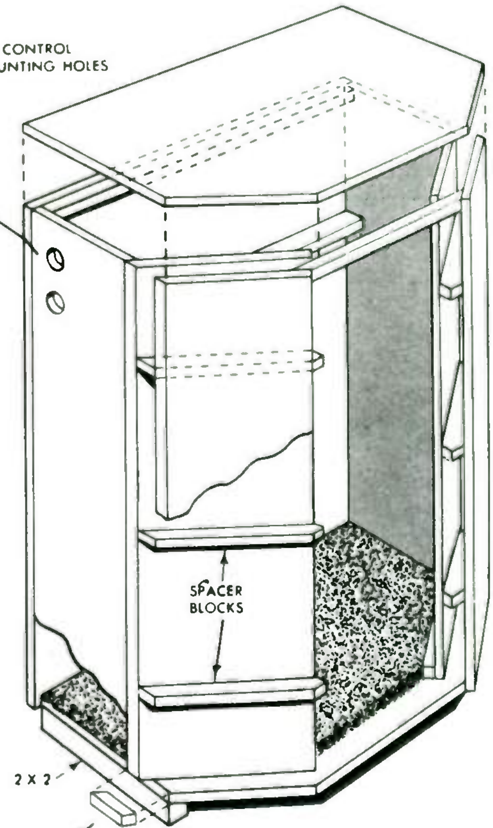
A Bass Ultraflex Enclosure

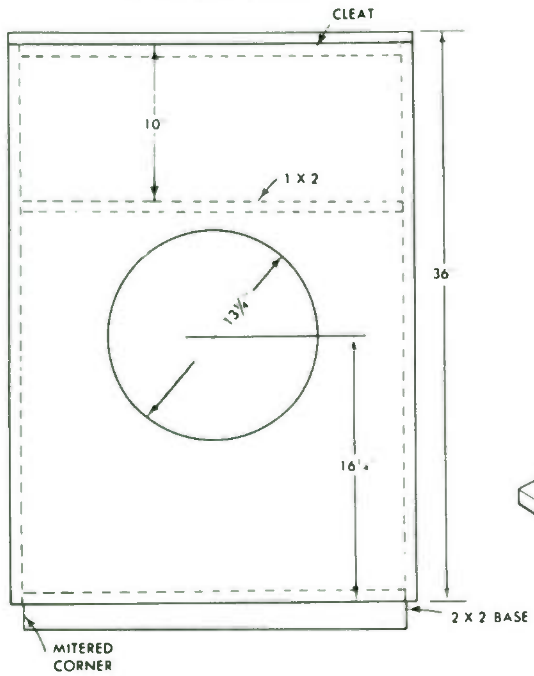


TOP VIEW—TOP REMOVED

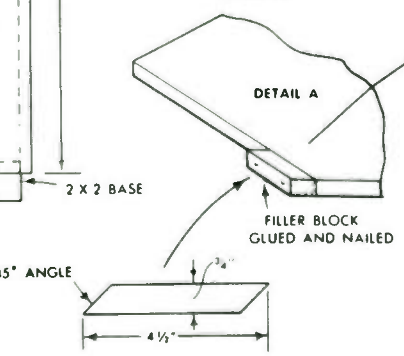


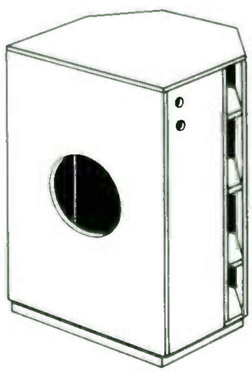
PANEL A





FRONT VIEW





MATERIAL LIST

BASS ULTRAFLEX-15 ENCLOSURE

FREE STANDING TYPE
FOR CORNER OR SIDEWALL

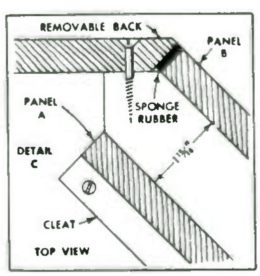
3/4-in. Plywood

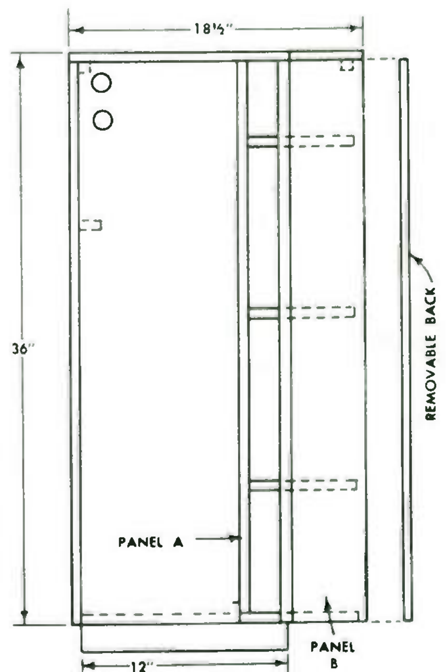
1	25-1/2 x 35-1/4	Front
1	17 x 24	Bottom
1	18-1/2 x 25-1/2	Top
2	8-1/4 x 35-1/4	Sides
2	10-13/16 x 34-1/2	Panels A
2	8-1/8 x 35-1/4	Panels B
1	16-3/4 x 35-1/4	Back

Lumber

1	1-5/8 x 1-5/8 x 48	Base
1	1 x 1 x 66	Cleats
1	1 x 2 x 96	Cleats

All dimensions in inches.





SIDE VIEW

J. GORDON HOLT

The original guru of
subjective hi-fi journalism

Thanks

OLD COLONY SOUND LAB
PO Box 243
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J. GORDON HOLT

If you had to invent a new language, where would you begin?

Back when high quality sound reproduction was a new idea and **J. Gordon Holt** was a staffer at *High Fidelity* magazine, manufacturers and journalists alike depended on the simple technical quality tests which everyone accepted as the yardsticks for performance. As the industry grew, equipment got better, competition fiercer, and technical reviewing became more crucial to sales managers. Before long, **J. Gordon** began to realize that reviewing was becoming more and more accommodating, and where the reviewers continued to rely on the standard tests, the measurement data began to look more and more alike.

Finally, in frustration, **Holt** left Great Barrington and headed for home in Pennsylvania where he founded *Stereophile* magazine in the spare room of his mother's house. He became convinced that although equipment tests and measurements were important, they no longer accounted for the differences he could hear. Two devices could easily measure the same and yet sound quite different.

Holt abhorred the tendency of the larger magazines to depend almost entirely on measurements, which he saw as a safe way to review without disturbing the manufacturer with any bad news. Not only that, he realized that not one of the US audio publications was publishing reviews that were critical of equipment. In fact, in some cases they were ignoring some flaws.

However, if the reviewer wishes to review how equipment sounds, he faces a severe problem. Our sense of hearing has the smallest vocabulary of any of our five senses. Thus, **Gordon** faced the difficulty of describing sound differences with all too few words with which to do it. He not only had to invent the techniques and disciplines of what has become known as "subjective reviewing" but also the language with which to do it.

Today, the magazine he founded has become a major force in audio quality judgments around the world. And almost all the vocabulary definitions are his work.

Seldom will you have the opportunity to purchase a reference work backed by so much primary research and experience. Few reviewers have spent more time and energy in an honest search for a defined, factual account of what matters in good sound reproduction techniques. In audio equipment reviewing, **J. Gordon Holt** is not only a pioneer but a master.

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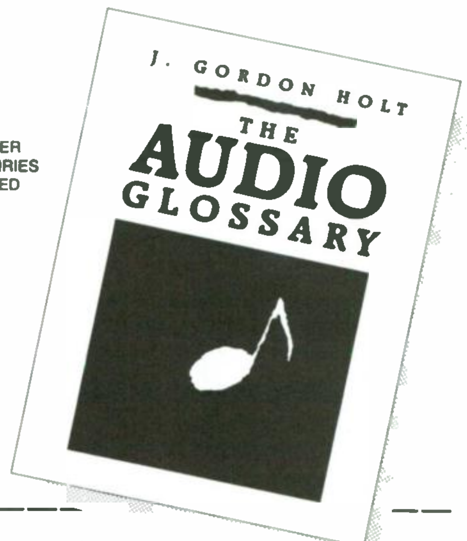

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2 FOLD BOTTOM UP

Tools, Tips & Techniques

BATTENING BASKETS

Like many *SB* readers, I have sometimes sought out drivers for projects that must be low cost, but still sound good. There are many modestly priced speakers with good cone/motor system behavior. One of their common compromises is a less rigid, more resonant frame or basket. You can actually feel the difference in vibration levels between those with strong cast frames and flimsier ones simply by holding them with a test signal applied. Higher basket resonances and vibrations naturally tend to affect sonic performance. Many high-end speaker systems incorporate some form of basket damping.

I tried the compliant driver mounting technique wherein rubber grommets surrounding the mounting bolts decouple the driver from the cabinet. In A/B comparisons with firm mounting, however, I noted a loss of detail and dynamics. For me compliant mounting is not the ideal solution. I use several techniques:

1. Damp the basket. I have successfully used hot glue, 100% clear silicone glue, and various combinations of petroleum-based products (roofing tar, for example, emulsion or automobile undercoating) mixed with sand and cement. Liberally coat all basket surfaces except the mounting flange. You'll find the damping really cuts down on vibration—just try tapping the basket before and after.

2. Use silicone to mount the driver in the cabinet. When compressed by the mounting screw or bolts, the silicone spreads out to form a thin but slightly compliant gasket which also effectively seals any gaps between driver and front panel. It is much harder to achieve the same results with a putty-type sealer such as Mortite.

3. Be careful not to over-tighten the mounting screws or bolts, as it can cause the driver frame to bend or twist. This is especially true if you are using bolts and T-nuts because so much more torque can be applied. Even a small amount of basket twisting adversely affects the linearity of all parts of the moving system.

4. Position an internal bracing panel in the enclosure so the back of the magnetic structure makes firm contact with it when the driver is installed. (This requires real precision in your carpentry. See measure for a less demanding method.) The bracing panel should be less than one square foot. Larger ones will resonate too much. It should be made of the same strong material as the rest of the cabinet and connect three enclosure panels firmly, the sides and back or the top, bottom and back. (I use grooves and glue.) Any basket vibration will be dissipated in the high mass of the enclosure.

5. A final measure is to make the bracing panel slightly shorter and mount a rubber gasket between it and the driver. A thick stiff piece of neoprene rubber tubing, perhaps ½" to ¾" in diameter works well. Check with a rubber company in your area. The gasket should be compressed when the driver is installed and act as a shock absorber.

All of these measures in combination can effectively reduce driver vibrations.

Mike Chin
Vancouver, BC, Canada V5W 2V7

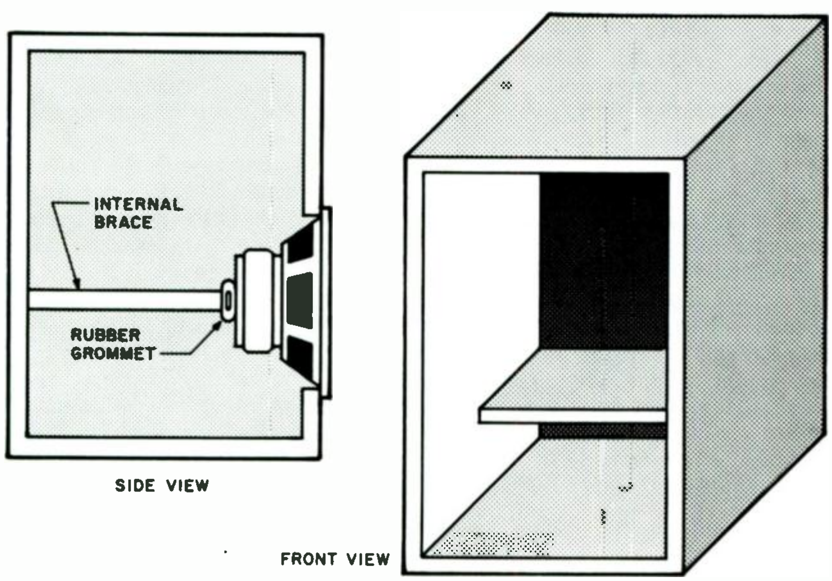


FIGURE 1: Side view, and front view without speaker baffle.

WHY TIPTOE?

For the past few years, reviewers have raved about the merits of tiptoes, cones of machined aluminum designed to mass-couple components to the surfaces on which they sit. Speaker tiptoes are 1½" high, and 1½" in base diameter. When I purchased a pair of VMPS Smaller Subwoofers, they recommended tiptoes to improve reproduction.

Tiptoes are installed point downward, concentrating the weight of the object they support onto these points. Generally, three tiptoes per enclosure work well. Tiptoes are particularly effective for speakers that sit on carpet, since they penetrate it and couple the speakers directly to the floor beneath. The theory behind mass-coupling speakers is that, given the law of physics that for every action, there is an equal and opposite reaction, when a voice coil moves the cone (or other driven speaker element), the magnet and basket or frame tries to move in the opposite direction.

Losses prevent the actual reaction from being equal to the initial action, but some force is transmitted. Cone speaker forces are transmitted to the enclosure, and then to the surface on which it sits. If the enclosure flexes, or moves, the motive force transmitted to the driven element will be reduced, and the bass may be

Continued on page 93

Mailbox

continued from page 4

In conclusion, you don't need to use the compound configuration to get deep bass from a small box. You can, instead, use two smaller, mass-loaded drivers mounted in conventional fashion. On the other hand, if you've already purchased your drivers, you have the choice between using the compound arrangement for much smaller box size, or the alternate arrangement for deeper bass and greater low-frequency power handling.

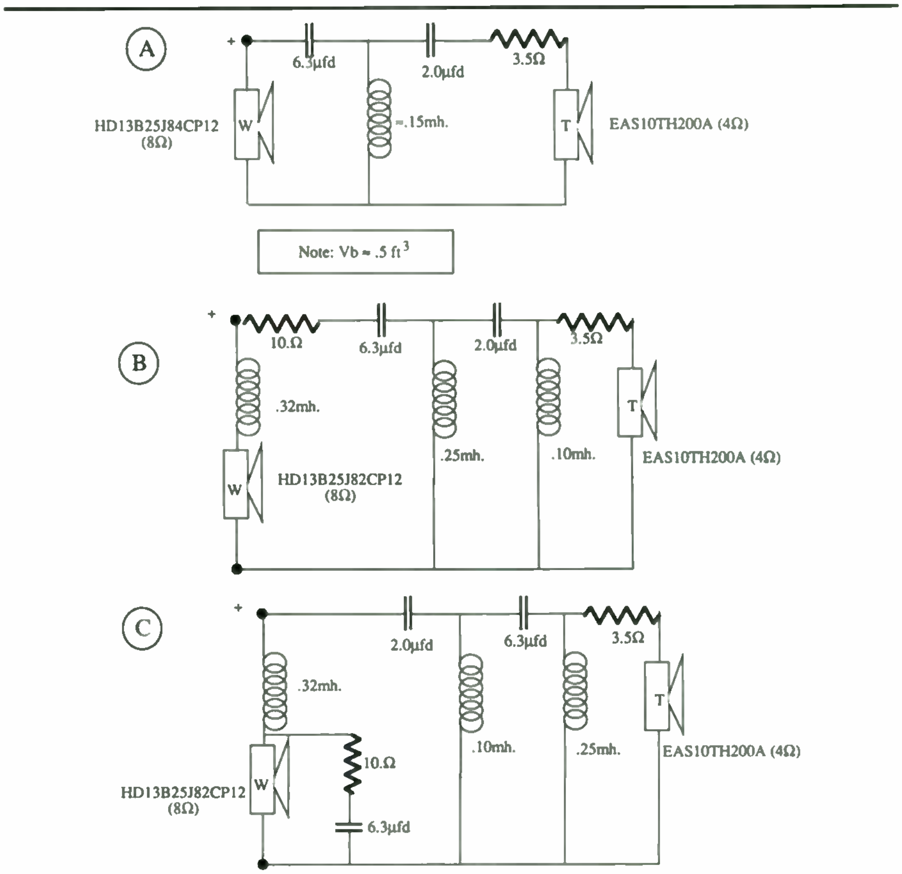


FIGURE 1: The three crossover designs from Bradley's system.

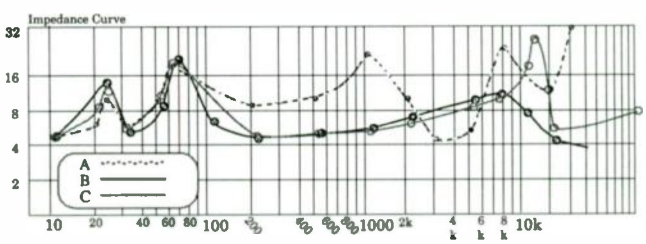


FIGURE 2: The curves are superimposed upon each other to illustrate curve variations relative to each crossover variation.

MORE, MORE, MORE

I found Randall Bradley's article "Practical Considerations for Passive Radiators" (*SB* 4/89, p. 41) quite interesting. I would like to know if you have any information regarding *Photo 2* on page 44, the 8" by 14" cylindrical cabinet, with Polydax and Matsushita parts. I would greatly appreciate any specs or additional information you might have regarding this unit.

Frank Anzalone
Oceanside, NY 11572

Randall Bradley replies:

Scratching my head for some time, I tried to picture what additional information I could make available beyond what was covered in the article. Everything required to make the cylindrical 8" × 14" speakers was included by naming the drivers and providing a picture.

So, to get a hint of what needs to be explained, I called Mr. Anzalone. Here are the answers based upon our conversation:

Use any shape cabinet, an 8" (i.d.) × 14" rectangular box will work fine. D'Appolito's satellite cabinets are of similar size and construction. Just change the holes and the driver placement to use his design. Remember, the driver on the bottom is an 8" diameter passive radiator. Leave room for it. The actual volume of this cabinet was 0.465 cubic feet, not counting the jog for the mounting baffle or the volume of the drivers, or passive radiator.

Cylindrical cabinets look exciting, but are very difficult to build. I would not suggest you try a cylindrical cabinet, unless your skills are strong. I would not build cylindrical cabinets today. The units in the photos were built in 1980.

If you must try a cylindrical cabinet, I used "Sonotube," a wood fibre (cardboard) tube. These are commonly used for pouring concrete footings in the construction industry, and are available from many industrial supply houses. Yes, you could experiment with PVC or other materials. Cutting a straight line across the length of a cylinder is no fun.

Line your cabinet, do not stuff it. Half-inch felt is quite good, or heavy foam carpet underlayment will work as well. Other absorptive treatments can be used. The aim is to attenuate mid- and high-frequency rear radiation.

OK, so you've decided on a cabinet, now you need a passive. The passive should have a full suspension. This means it is a regular speaker, minus the magnet and voice coil. Yes, you can make a passive out of those blown 8" drivers in the closet. (Remove the magnet and VC assembly.) Do not attempt to use those low cost *flat* passives, that have no suspension other than a surround. These simple units will not behave well under the excursions this system will demand.

The passive radiator is a mass loaded system. This means you need to add weight to the cone to tune the passive. You tune the passive to the desired frequency, f_P, to yield the desired box resonance, f_B. In fact, you can tune the passive just about anywhere in the band below 100Hz. Practically speaking, you will need to be at the driver's resonant frequency, f_S, or up to ½-octave below. Measure your impedance curve to find f_P. It shows up as the lower hump.

I prefer the passive to be mounted on an adjacent wall to the driver. I do not prefer the passive on the same wall as the driver, or the opposite wall. If you mount the driver down, you will have to solve certain problems due to the effect of gravity on the suspension. To avoid inventing a solution to this problem, mount the passive vertically on an adjacent wall.

The main driver should be the 4cp12 four layer voice coil, not the 2cp12 two layer version. The 4cp12 has exceptional bass response compared with the 2cp12, which is OK. Whatever driver you choose it should have a low Q_T, less than 0.3, and a low f_S, below 35Hz. Small, low f_S, low Q_T drivers are hard to find. If you find one other than this Polydax, let me know.

A Zobel will dramatically improve the midrange response of this driver, so use one. Adjust the Zobel values to tweek your midrange presence.

Caution! Use only one driver per passive, not two. Two drivers will resonate at different frequencies and cause all sorts of havoc. To use two drivers, you can split the cabinet in half and use two passives.

The tweeter was an EAS10TH200A—probably no longer available. If there is significant interest, I may be able to locate a small supply of these EAS10TH200As. The JVC Dyna flat tweeter is an acceptable substitute.

Today, you might choose one of the better dome tweeters, since some will simplify the crossover issues. Some of the domes will permit use of a highly desirable 6dB/octave crossover, given that you still crossover reasonably high in frequency.

The crossover is all that remains. To make the job of building and trimming the crossover easy, and to avoid pulling drivers in and out of the cabinet to make changes, I usually put terminals for each driver on the cabinet. In this way you can place the crossover outboard for testing and adjustment. Later, you can place the final version in the cabinet.

Enclosed are three crossover designs, (*Fig. 1*) which evolved in my system. Version C is actually quite good to listen to. The other versions look fine on paper but are not quite right. Notice the variations in impedance, in versions (A) and (B).

Essentially, the woofer rolled off at 6dB/octave above 4.5kHz, and the tweeter rolls in at 24dB/octave. The high slope is required to protect the tweeter from low frequencies, 12dB/octave is not sufficient for the EAS10TH200A. Also the tweeter is a 4Ω device, so the resistors match efficiently and produce an 8Ω load to the crossover.

This system's design is problematical. For a design of this type to work, many components must be made to operate at or near certain limits. For example, this tweeter likes to operate above 4kΩ, so this precludes nice and easy 6 or 12dB/octave solutions. This also forces use of the main driver up to 4kΩ, at which point its polar response is not terribly "happy." Also, for any cone running from 20Hz to 4kHz, at very high levels IM and Doppler distortion can become a problem. So, tweeking this system's parameters can make a big difference in the way it will sound.

In small rooms, this design will impress any listener. Should you find yourself out of headroom with these speakers, or wanting to run them in a larger room, you can do what I did. I have had excellent results stacking one or more pairs.

If you decide to build one like my design, I would like to hear from you. Photos of systems would be appreciated.

Good building!

ABOUT MOD IDEAS?

I'm a new subscriber to *Speaker Builder*, and I think I'm really hooked. I realized this late one night when I looked up from the 2/90 issue and it was 2 a.m.! This might not have seemed so unusual if it had just arrived in the mail, but this was the third time I had read the same issue.

I've been looking for a new speaker system to replace my 1979 large Advents, (the ones with the orange tweeters). When I went to my local high-end shop, I couldn't believe the prices: The pair I really liked went for $2,995. This was way out of my budget, so I took a different tack. It was love at first sight when I read the article for D'Appolito and Bock's Swan IV System. I'm currently gathering all the parts and look forward to starting.

Has anyone any ideas for modifying the Large Advent system, particularly updating the drivers? I've improved the sound somewhat by stiffening the cabinets, using better wire between the crossovers and drivers, and stapling roofing felt to the inside walls.

I'm also interested in building several small plate systems using a 6½″ driver with a 1″ tweeter to mount inside a wall. Has anyone done this before? Any suggestions? From what I understand in *The Loudspeaker Design Cookbook*, the speakers would see an infinite baffle. Do I need to build a small enclosure and then mount the whole thing in the wall or just mount the plate with the speakers attached, to the wall? How exactly would the enclosure be constructed inside the wall, if that's the case, to get good sound out of it? Many of these systems are coming onto the market, but most are really expensive. Again, I want to try the do-it-yourself approach.

Thanks for a great magazine.

Mark Florian
Austin, TX 78746

Wall mounted devices only require a mounting plate, with any necessary isolating cups for mid or tweeter drivers. No baffle other than the wall cavity is usually needed—unless mice inhabit your wall. One of our authors has been considering a Large Advent modification. Stay tuned.—Ed.

A MINOR MATTER

I have a minor correction to make to Roger Sander's electrostatic article in *SB* 1/90. He claims with moving-coil loudspeakers "the unavoidable result is overshoot and ringing." In fact, the transient response of a moving-coil driver in a sealed enclosure can be characterized by its damping, or QCB. If QCB is less than or equal to 0.5 and if a second-order Linkwitz-Riley ($Q = 0.5$) or first-order low-pass crossover is used there will be *no ringing* in the woofer's response after the input signal is cut off. The same is true for moving-coil midranges and tweeters whose high- and low-frequency cutoffs or crossovers are second-order with $Q = 0.5$ or first-order and which are being used in their frequency range of pistonic motion —admittedly a difficult proposition.

Ralph Gonzalez
Wilmington, DE 19803

Roger Sanders replies:

Whenever I have objectively tested magnetic speakers, I have found them plagued with overshoot and ringing. While I have not measured *every* speaker made, I have tested most of the highly respected ones. Many of these claimed to be free of overshoot and ringing, but testing proved otherwise.

Ringing and overshoot are well-recognized and common flaws with speakers. My tests supported these general observations. My opinion continues to be that magnetic loudspeakers have problems in these areas.

Testing speakers for overshoot and ringing is not difficult. You must have some test equipment consisting of a good condenser microphone, tone burst and square wave generator, and dual trace triggered sweep oscilloscope. Ideally, you should test in an anechoic chamber, but a quiet, windless, outdoor location works OK.

Begin your setup by connecting the tone generator output to both the amplifier input and one channel of the oscilloscope. Adjust levels as necessary for reasonable speaker output and 'scope tracings.

Mount the microphone within a few inches of the driver being tested. Be sure to remove any grille cloth before testing. Feed the microphone output to the other channel of the 'scope and adjust levels, as necessary, to match those of the first trace.

Test by providing sine wave tone bursts and square waves at various frequencies and comparing the two traces. It is desirable, but not essential, to photograph the traces for later analysis.

The representative drawings of oscilloscope tracings that follow are not specific for any particular driver. They are intended to give an idea of the types of flaws you will see.

When testing with square waves keep in mind the square wave requires bandwidth about 10 times the testing frequency for valid results. In other words, if your woofer must reproduce 1kHz, don't test it with a square wave at that frequency, because it must have response to 10kHz to accurately reproduce the wave. Instead, use a maximum of 100Hz.

It is likely you will see many flaws on square waves. This is a very difficult test for speakers. The most common is that the leading edge of the square wave does not rise at the same rate as the tone generator. Also, it usually overshoots the wave form's top. The top does not remain flat, and the drop-off is not as crisp as the input wave form. The trace continues past the baseline then gradually settles over a few small oscillations.

On sine wave tone bursts, flaws often include a gradual build-up to full output followed by a leisurely fall, rather than an instant stop at cut-off. This widely varies among magnetic drivers, but the trend is always there in my experience.

In comparison, ESLs usually only exhibit a slight overshoot at the rise of a square wave, because their

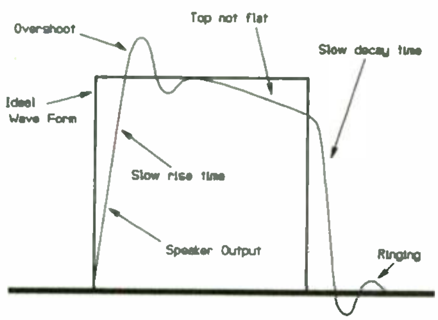


FIGURE 1: Square wave patterns.

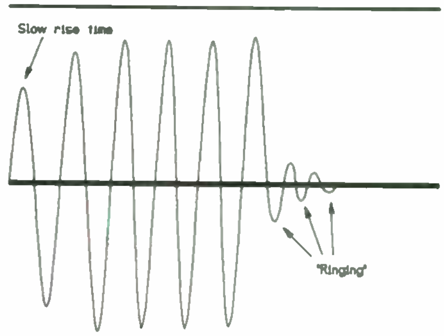


FIGURE 2: Tone burst pattern.

transformers have a high frequency resonance. Their performance otherwise is exemplary. When driven by direct coupled high voltage amplifiers, even the slight overshoot disappears.

It is important to test at various output levels. Often a magnetic speaker will perform reasonably well at very low levels, but will deteriorate rapidly at higher levels. I have been consistently impressed at how far off magnetic speakers are when driven at high levels with this type of testing.

You can make some interesting comparisons between ESLs and magnetic speakers by photographing the traces from both types at various frequencies, and overlaying the resulting negatives. The differences between the two will be startling. It is little wonder the two types of speakers sound so dissimilar.

This testing produces some interesting results when you introduce grille cloth into the picture. Some, particularly acoustic foam, seriously degrade performance. All grille cloths I have tested impair performance a little. The best grille cloth in these tests had a very open weave and was made with smooth plastic fibers.

Also, it's worth keeping in mind square wave and sine wave bursts are very crude and simple tests compared to music. If a speaker can't even do well on these tests, is it any wonder it does poorly on music?

Mr. Gonzalez does not address the issue of overshoot in magnetic speakers. He only mentions ringing. Even so, I wonder if he has actually *measured* a speaker system that did not ring. If so, and he has found one that does not ring, I would like to know about it. I would love to have a woofer system that performs as well as an ESL in these areas.

If he has *not* measured it, then I suggest he does. I think he will be disappointed. Theory and mathematical modeling are only speculation until objective testing proves otherwise.

ISOBARIK SPECS

As a relatively new entrant into the world of amateur speaker building, I was wondering if I could get some recommendations on a project I wish to undertake. I am interested in building a pair of subwoofers using a vented Isobarik configuration. I purchased four Eminence 15″ woofers with paper cone, foam surround, f_S = 23.5Hz, Q_{MS} 9.86, Q_{ES} 0.34, Q_{TS} 0.33, V_{AS} 17.9 ft³, which I believe will work in this configuration.

My problem is my limited resources, both financially and practically. I don't own a PC nor do I have software (e.g., BOXRESPONSE) to guide me. Could somebody give me suggestions as to cabinet size, port diameter, and port length? In an Isobarik configuration, I'd like to keep the volume between 4 to 6 ft³ I think this should be feasible.

While I'm writing, I would like to thank Mr. Cockroft for his informative articles on both Isobariks and transmission lines. I have enjoyed these articles and am currently working on a Shortline using a Peerless TX205F/8. (According to Madisound, this is equivalent to the KP825WFXPP you recommended as a substitute for the RS 40-1021. I do hope it is.) I'm looking forward to completing this, my first project, and hearing a transmission line for the first time.

My second question is, what if transmission lines were Isobarik-loaded (or would an Isobarik-loaded pair of speakers be installed in a transmission line, well you get the point)? This question came to me and I immediately assumed that there would be no reason to try this. But the more I thought about the question, the more I realized I lacked the practical experience to make that decision.

My last question is, what is a Zobel circuit used for and how do you calculate the proper values? Thank you for your time.

Troy E. Guise
Titusville, FL 32780

Contributing Editor John Cockroft replies:

Thank you for the very kind remarks regarding my articles. They fell upon receptive ears. It's funny, on the morning of the day I received your letter, I was looking in a Parts Express catalog and I think I was looking at the very woofer you discuss in your letter. (At least the specs were identical to the ones you quote.)

You are not the only one without a PC and software. My cupboard is bare in that department, too. Ye publisher makes annual attempts to prod me into such enlightenment, but I guess I'm just too old fashioned. (I *did* have a ouija board when I was a kid.)

Designing systems using only published specs of the drivers isn't the very best way to go, as individual drivers will vary somewhat (or more than somewhat). But, as they say, any port in a storm. To come up with a box for you I relied upon Hoge's version of Keele's approximate box method, as presented in my *SB* 2/87 article ("The Demonstrator"), among other places. (Since I am again discussing this article, I would like to again mention that there are errors in equations 4, 5, and 6. They all have the same error of form: instead of $(V_{AS})^{1/2}/V_B$, in the case of equation 4, it should be $(V_{AS}/V_B)^{1/2}$. The other equations are the same, but with different exponents. Equations 1, 2 and 3, which I am using here, are presented correctly.

In order to work out your box for an Isobarik, or compound speaker (Isobarik is actually a proprietary trademark of Linn), V_{AS} must be halved from 17.9 ft³ to 8.95 ft³ This makes net V_B 5.57 ft³ This doesn't include the volume of the driver (as I recall, about 150 in³ is about right for a 15" speaker), the Isobarik tunnel (if used), the volume of the duct and the bracing. I'm envisioning the two woofers facing each other, perhaps mounted together on a ring of, say, ⅜" particle board. The sides of the box would extend down below the bottom to at least the depth of the external woofer and a bottom plate could be screwed in place. The woofer would fire out of the "slot" created by the open front and rear of this extension.

The inner woofer must be wired out of phase so both speakers move in the same direction with a given signal, even though the inner one is moving "backwards." Some people believe this configuration reduces harmonic distortion. This is true in the case of a regular "push-pull" system where both drivers fire into the room. I'm not sure that this is also true for the compound situation, since only one radiates into the room.

I don't seem to have all that much luck with equations for determining ducts. (I usually end up going trial and error.) Sometimes, using a factor of about 0.7 on the original answer comes close. I have done that here. I came up with about 2¼" long for a 3" ID duct, or 6 ⅛" long for a 4" ID duct. (Maybe a rug tube would have that ID.)

In my senility, I forgot to list F_3 and F_B. Sorry. They are 28.8Hz (F_3) and 26.8Hz (F_B0). Getting back to the duct, I recommend you make it easily replaceable so you can try other lengths, for example, ½" longer or shorter. I doubt that at 26Hz you will be able to tell anything meaningful by ear. By the same token, if you can't tell the difference, will it matter much?

Since this is a subwoofer, a case could be made for leaving out the acoustic padding, but I recommend a 1" layer of fiberglass (Radio Shack 42-1082) on the back, top and one side. If you put the duct on the back, just cut a hole an inch or so larger than the duct in the fiberglass so it can protrude. I recommend this because even with low cutoffs and sharp filters the midrange can bounce around in the box and muddy things up. I would use heavy construction and bracing. In view of this, please don't throw the thing at me if it doesn't work well.

Regarding the Peerless TX205F/8 woofer for the Shortline, that's the number I'm praying will be the one to replace the KP825WFXPP. (I published a crossover for the latter in *SB* 2/89.) Please note that I currently recommend not reversing the tweeter polarity as shown in the drawing. The big question is, of course, will the woofer work with the crossover? I hope you'll be able to tell me something about that when you try it. Incidentally, the TX205F/8 is a good example of the confusion Peerless creates. This is also the number of an older Peerless (Precision) woofer, made in the US. It is an entirely different driver. Manufacturers seem to have no conception of the trouble they cause with these little things they create.

I can't think of any compelling reason to mount a compound speaker in a transmission line (other than just for fun). The main reason for using a compound speaker is to allow the use of a smaller enclosure. This isn't a problem with TLs. On the other hand, I do sense a different quality from compound speakers. But that may be due to other considerations, such as the way an enclosure is constructed, as Mr. Linkwitz once suggested, so I don't want to be totally negative about it. The lower frequency of compound speaker bothers some, but not me.

A Zobel is an ancillary circuit which interfaces a crossover to a driver. It is intended to compensate for the fact that a speaker isn't a resistor (and most crossovers are designed for resistive loads). It is a "sort of" crossover designed to bump voltage that won't go through the woofer because of inductive reactance at higher frequencies so the real crossover can do its thing. (Perhaps this is an oversimplification.) The circuit is simply a resistor and capacitor in series paralleled across the speaker terminals, or at the downstream end of the crossover. The Peerless catalog advises an 8Ω resistor with an 11μF capacitor for the TX205F/8. I suggest you use the one in the Shortline wiring diagram first, as the whole crossover is based on the impedance that results from using that Zobel.

Bob Bullock, in one of his articles on crossovers, states that R_{Zobel} (the resistor) = R_E (the DC resistance of the speaker voice coil) in ohms. C_{Zobel} (the capacitor) = L_E/R_E^2 in farads (0.000001 = 1μF), L_E is the voice coil inductance in Henries (0.001 = 1mH). Mr. Bullock says he often determines a satisfactory value for L_E by: $L_E = (M^2 - R_E^2)^{1/2}/2\ \text{pi}\ F_M$. Let F_M = 10kHz. Let M = speaker impedance at F_M. He also states that R_{Zobel} can often be juggled in value about 20% to find a more nearly flat impedance. I've had good results using the above equations. (See Mr. Koonce's letter in *SB* 3/90 for times when they may be contradicted.)

Regarding the Shortline again. I eventually used an additional 10 grams of weight on the cone of the Peerless woofer. (See my answer to Mr. Vergis' letter in *SB* 3/90.)

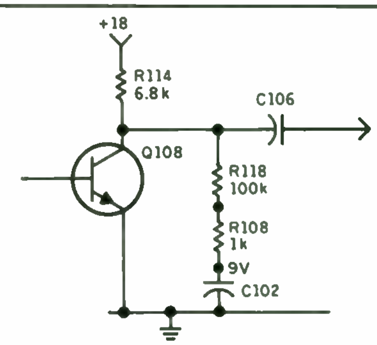


FIGURE 1: The output stage and feedback network with nominal DC voltages.

ADVENT MOD ANYONE?

Does anyone have experience in modifying the Advent MPR-1 mike preamp to reduce its gain by about 10 to 15dB? I don't want to use external attenuators, because they do not reduce the MPR's noise floor, therefore degrading the S/N.

A friend recently ran the following failed experiment on the MPR-1: placing a 5k resistor in parallel with R118, whose value is 100k, caused the original 40dB gain to become 32dB gain. The maximum input signal, however, only increased by 3dB before overload occurred.

This modification also caused the original 60dB gain setting to become 34dB gain, with the maximum input signal increased by only 2dB. I would like the mod to provide about 28dB of gain on what is now the 60dB setting, thus providing 28 and 40dB of gain.

My friend hypothesized the "hot" input is limited by the input transistor drive stage, and was unsure how to increase its ability to handle 10 to 15dB hotter input signals than the original design was intended for.

Any solutions to this problem are welcome. Also, what is the maximum SPL of of high school orchestras as heard by the conductor? I estimate 115dB.

Ron Freeman
Freehold, NJ 07728

Fred Gloeckler replies:

You wish to modify an Advent MPR-1 to have switchable gains of 28 and 40dB. I assume you have the original Advent unit and not my modified version,[1] and that you want to make minimal changes rather than a major redesign.

Shunting R118 with 5Ω loaded down the output stage and reduced its drive capability in your experiment. The MPR-1 is load sensitive, as indicated by the difference in output level and distortion between no load and a 10kΩ load in *Figs. 10* and *11* of my article. Reading between the lines, I surmise you want to record an orchestra using high output microphones. If this is the case, you might want to try a more modern design with lower input noise and higher drive capability than the MPR-1.

Let's take a quick look at the MPR-1 output stage. *Figure 1* is a simplified schematic showing the output stage and feedback network with nominal DC voltages. The article contains the complete schematic. C102 has a low impedance at audio frequencies. Essentially, this single ended, common emitter circuit is a voltage divider comprised of R114 in series with the shunt combination of Q108 and R118 + R108. Even with Q108 turned off, there will be a voltage drop across R114. With the original R118 value of 100kΩ this drop is only 0.6V. However, when R118 is changed to 5kΩ, the drop is 4.8V, which limits the peak positive output voltage to 4.2V. This is a reduction of 6dB in output on positive peaks.

Now that we know what the problem is, how can we fix it? Choices include improving the drive capability of the output stage and/or reducing the load of the output stage. Output drive can be increased by lowering the value of R114 or replacing R114 with an active stage. A lower R114 will increase current consumption. This isn't desirable for battery operation. A new stage is added complexity. Therefore, we will modify the feedback network to reduce the load. Changing R108 to 4.7kΩ, R118 to 47kΩ, and R120 to 16kΩ will give you the desired gains. Raising R108 may increase the output noise a little, but I don't think it will be objectionable.

To flatten the transformer's high frequency peak, you'll need to shunt R118 with a capacitor and replace C108; 39pF and 120pF, respectively, are good starting values for the Advent transformers. They should be about twice as large for the Sescom MI-64 transformers used in the modified version. As noted in my article, changing the value of C102 permits a trade-off between low-frequency response

REFERENCES

1. Gloeckler, Fred M., "The Advent Mike Preamp Updated," *TAA* 3/82, pp. 24-29, 44.

and noise. Try something in the range of 2 to 5 microfarads with the new feedback resistor values.

I haven't tried these modifications. You will need to perform some tests to check them out and optimize component values. If you do try them, please share your results.

TRACTRIX HORN UPDATE

I recently came across some useful information in a book concerning graphics programming which I applied to a program found in *SB* 4/86. The program is by Brian D. Smith, and will calculate the various dimensions for a tractrix horn. The program is straightforward and easy to implement, but tends to run rather slowly when confronted with a prospective horn that has a very low cutoff frequency. Of course, compared to doing the calculations by hand it is an immense improvement.

The changes being made to the program are for optimization of the numerical calculations to allow faster processing of information. In assembly language programming, multiplication is much faster than division, and multiplying a number by itself is more efficient than using exponentiation to square it. This carries over to compilers that include popular BASIC and C languages.

Only a few changes have been made to the program listed in *SB* 4/86 to allow easier conversion to your specific application, and programs you have developed around it. They are as follows:

```
150 B = SQR(PI * (A * A))
290 (A * A) * PI
310 ((A * A) * PI) / 8
440 YONE = SQR((R * R) * PI) * .5
470 YTWO = SQR((R * R) * PI) * .5
490 PRODUCT = SQR((A * A)—(R * R))
530 DIST = SQR(((XONE - XTWO) *
  (XONE - XTWO)) + ((YONE - YTWO) *
  (YONE - YTWO/)))
590 AREA = (R * R) * PI
```

(PI references = 3.14159)

You may wonder why some of the division calculations have not been changed to multiplication. I felt it was unnecessary to change, at this time, the calculations that do not occur in the loop, since they are calculated only once.

The difference made by just these few changes is astounding, and certainly seems to make a case for optimizing code to increase performance. The other possible changes would be to convert single and double precision values to integers (possibly using an assembly language subroutine) for processing, and then convert them back for output to the printer or screen.

I have included some performance

times of horn calculations with and without the stated changes. I hope this will be of use to people using Brian Smith's program to further increase productivity.

Performance Comparison

F_C	100Hz	20Hz	5Hz
Original	1′ 20″	7′ 35″	31′ 17″
Optimized	0′ 20″	1′ 54″	7′ 54″

Gregg S. Irwin
Whittier, CA 90601

Readers interested in obtaining a copy of the source code for reader Irwin's update of the Smith code, please send a #10 self-addressed envelope with first class postage (International Postage Coupons overseas) to Speaker Builder. *If you'd like disk copy of the code, send an IBM formatted 360k or 720k disk with an addressed, stamped disk shipping envelope and correct US postage. Please mark your envelope: Tractrix Program.*

BUILDING THE SHORTLINE

After reading "The Shortline" (*SB* 1/88) and subsequent designs by John Cockroft, I have decided to build them. I am, however, having difficulty selecting the components to complete a pair as close as possible to Mr. Cockroft's project. His responses to various letters still has some confusion with driver parameters. Specifically:

1. The bass driver: The original Radio Shack 40-1021 had f = 30Hz, Q_{TS} = 0.51.

If the Peerless KP825WFXPP is the same as the Peerless TX20F/8 (a supplier said it was) which has f_O = 29Hz and Q_{TS}—0.32, how could this have been successfully substituted as in *SB* 2/89, p. 65 with a Q_{TS} this low?

Would not the new Peerless CC line model 220WR/8 with f_S = 25Hz and Q_{TS} = 0.38 be better?

I wondered if the damping quantity was changed in the article, to allow the driver change. Would you alter the cabinet dimensions to better suit the different drivers? Do you suggest the same Zobel values as those Peerless use?

2. The tweeter MCD25: The manufacturer's specification sheet suggests crossover frequency of 2.8kHz for maximum power handling of 100W.

A crossover of 2,017Hz (calculated) and a 12dB slope means modest attenuation at the resonating frequency of 990Hz. David Weems used a RPF in his pipes (*SB* 2/87, p. 28) with the MB tweeters for the resonant peaks. Is there something in the modified Shortline I've missed?

3. The Crossover: Can the capacitor types be substituted for polypropylene types like WonderCap, Solen, and so forth, as hinted in replies (*SB* 6/88, p. 71)?

Because of the cost of importing components, it's good to know the right ones to order. Thank you for bringing these projects to us in *Speaker Builder*.

P. S. Friis
Taradale Napier, New Zealand

John Cockroft replies:

I'm sorry for the continued confusion regarding the Shortline and my articles. I realize the Radio Shack 40-1021 had a published specification of Q_{TS} = 0.41. However, the unit I used had a measured Q_{TS} of 0.529. Those things happen. It was a unit I originally used in my Isobarik "Project 2."

The Peerless KP825WFXPP is not the *same* as the TX205F/8, but is similar. I am hoping it will be close enough to use with the same crossover. I have no way of knowing it until someone tries it. As I mentioned in an earlier letter, my Shortline was stolen, so I can't do any more playing with it. One reader bought a TX205F/8 and plans to install it in a Shortline, so perhaps we will find out something from him. Of course, he hasn't heard the original for comparison, but at least we will know what he thinks of it. All the woofers readers have mentioned in connection with the Shortline, would probably work quite well, but they might necessitate changes in the crossover. My main concern has been to find a replacement woofer that won't require changes. I have already gone through 19 or 20 changes to the Shortline crossover, and I've lost enthusiasm for continuing.

Asking how the Peerless, with its low Q_{TS} could have been successfully substituted for the higher Q_{TS} Radio Shack woofer is like asking how the Allison 1, with its Q_{TC} of 1.0 could sound well when the AR-3 also sounded well with a Q_{TS} of 0.707. They don't sound like one another, but they both do sound well. The Peerless had a different sound than the Radio Shack woofer. I enjoyed them both, as did the reader for whom I redesigned the Shortline. As I mentioned in a recent letter, I eventually added 10 grams of solder wire to the cone of the Peerless woofer. This brought the Q_{TS} up from 0.30 to about 0.42, or so, and lowered F_S to about 21Hz. I preferred the sound of the modified woofer, but someone else may have preferred the unmodified one. In my letter to Mr. Vergis (*SB* 3/90, p. 81,) I have attempted to clear up any confusion.

The CC line Peerless 220WR/8 might possibly be useable. It costs $10 more and has a sizeable peak starting at 2,000Hz. Actually the curve for the TX205F shows a peak on axis, although it isn't as abrupt. A second look at the curves shows that both are mostly on the axis. This probably isn't as bad as it looks, as the axis of the Shortline points to the ceiling, rather than at the listener. However, the DC resistance of the CC line woofer is 5Ω while the other one is 6Ω. Looking back at my notes I find the woofer for which I designed the crossover was 6.1Ω with wires. It would seem that about an ohm of series resistance would have to be added for the CC woofer. Actually that wouldn't be bad. It would raise Q_{TS} to 0.456 or so, at a cost of about 1.6dB. It would have to be about 50W or more.

I wouldn't alter the dimensions of the Shortline. It shouldn't be necessary. I think you should use the Zobel I have designed, since the whole network was designed with it in mind. Peerless doesn't give the effective impedance with their Zobel in place. I doubt if it is the impedance listed in the catalog.

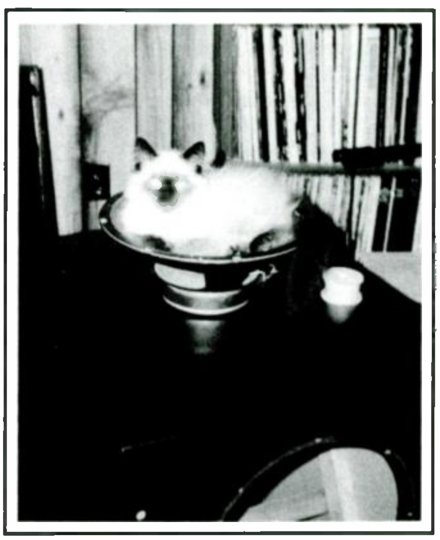
The MCD-25 tweeter worked very well, when used in the manner I described in my letter in *SB* 2/89. I recall no problems with the 990Hz impedance peak. (It is an impedance peak, not a SPL response peak.) If you find a problem in this area, I suppose you could design a compensating filter to solve it. It would have different values than the one Mr. Weems used, as he used a different model tweeter. I was happy with the sound that came from the way I set things up. I don't think you've missed anything in the modified Shortline. It's just that there is more than one way to skin a cat. Incidently, I now prefer the tweeter and the woofer to be in the same phase, rather than in the opposite phase, as shown in the figure.

I seemed to notice an improvement in the sound of my Octaline when I substitued Solen polypropylene capacitors for the original Mylar ones. Perhaps a similar substitution with the Shortline capacitors would have a similar improvement. At least it wouldn't hurt anything. By the way, I have now changed the Octaline capacitor from 4μF to 3.3μF. The difference is subtle, but I like it better.

I know I haven't been as helpful about a woofer substitution as you would have liked. I just don't know. It looks promising, but it may entail a bit of tweaking. If you come up with any other questions, please write. I'll try to help. Good luck with your Shortline.

EGG-CRATING IT

Your recent series on ESLs in *Speaker Builder* has me interested in trying my



Dux is living the life of Riley in a speaker built for one at Greg Cahill's home in Cullowhee, NC. He says Madisound woofers are purrfect. Just look out, Dux, when your owner plays the *1812 Overture*!

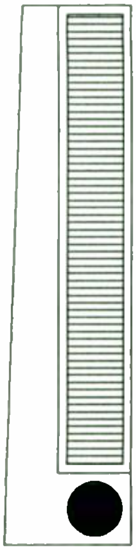


FIGURE 1: The "egg crate."

hand at a pair. Luck prevailing, I will tend to the project this summer. In all likelihood I will use "egg-crate" with either your recommended perforated aluminum sheets or window screen for sensors. The egg-crate seems a bit more structural than perforated aluminum alone, thus reducing the chances of warping a cell. The construction I have in mind will make it easier to remove the diaphragm for repair.

My first question concerns panel equalization. In your series you indicate your curve takes into account the cancellation effects of the panel and the added baffling of the beam. For reasons of simplicity, I do not plan to build the TL woofers. I would also like to build the ESL panels a little wider than your's to increase the width of the listening window. I suspect with these changes your equalization curves will not work. Can I calculate the compensation mathematically, or must it be derived empirically?

My second question concerns using tube amps and electrostatics. I have a Dynaco ST-70 in fairly good shape which could be used to drive the panels. It seems silly to me that if one wants to use a tube amp on ESLs that the signal go through two transformers, each providing relatively inverse functions. How difficult is it to bypass one of these transformers?

Third: I am interested in using ESLs or ribbons in reverse, i.e. as high quality microphones. Do you have any experience in this usage?

Mithat Konar
Circle Pines, MI 55014

Roger Sanders replies:

Thank you for your letter of concerning electrostatic loudspeakers. Your plan to attach perforated metal to "egg-crate" should work beautifully. Let me assure you, however, that it is not *essential* to support perforated metal in this manner. Perforated metal will lay flat if built with care as described in my article.

You can operate the ESLs full-range, but you must accept a massive loss of output, and give up deep bass compared to a hybrid system. I appreciate your desire for simplicity and if all else were equal, I'd go for simplicity also. But all else is not equal and the extra parts dramatically improve performance. I strongly encourage you to reconsider your decision.

Widening the panels will not increase the size of the listening "window." This window is defined by psychoacoustics, and has nothing to do with the width of the panels.

For example, when listening to a *single* two-foot-wide ESL, you will find the proper image is present anywhere within the two-foot-wide beam. Take two of these speakers and aim them to cross beams, as we do in a stereo system. You will find the image is ideal only where the beams cross at the "focal point." The proper image is no longer present across a two-foot-wide area, but shrinks to an infinitely small point.

There are good reasons to make the panels wider, such as higher output, better bass response, and reduced equalization requirements. Increasing the image width is not one of them.

The equalization specified will be correct with or without woofers for 12″ to 18″ wide panels, as it compensates for phase cancellation losses down to the crossover point. Below that you must add much more equalization, and add a notch filter to suppress the fundamental resonance. If you wish to go to 24-inch-wide panels, the feedback capacitor should be increased to 8,500pF to shift the equalization curve to a lower frequency.

The additional equalization needed below 500Hz, and at what frequencies, is difficult to predict because it depends greatly on the magnitude and frequency of the fundamental resonance. So many variables are involved that even mathematically modeling is inadequate to the task because their values aren't known.

The subject of bass frequency response in ESLs is complex and beyond the scope of this letter. It takes an entire chapter in my upcoming book *The Electrostatic Design Cookbook*. I have enclosed a draft copy of that chapter to help you understand the problems you face. I apologize for not including the drawings to go with the chapter, but they are not yet completed. I think you can manage without them. If you still have questions, please feel free to phone me.

I agree with you that it seems silly to run the signal through two transformers. The Dyna ST-70 amplifier can drive ESLs directly. Simply connect the stators to the plates of the output tubes. The amplifier will be unstable when you do this. You will need to connect a 50Ω resistor across the 0-8Ω output taps to control oscillation. Check with a scope to be sure you have stabilized it. You may need to reduce the resistance further for complete stability under dynamic conditions.

Regrettably, this amplifier only has a 440V B+ power supply (if memory serves me correctly). This is just not enough to give adequate output. You really need an absolute *minimum* of 2kV and I strongly feel you need at least 6kV for acceptable performance.

This drive voltage problem is bad enough in a hybrid system. It would be completely unacceptable in a full-range system—after all, what good is an ESL if you can barely hear it?

I do not recommend the ST-70. It is just not powerful enough. If you plan to use it anyway, then you can get much higher output by using an ESL step-up transformer with it, though this means running the signal through two transformers. You can maximize the step-up ratio by connecting the 4Ω taps of the step-up transformer to the 16Ω output taps on the ST-70.

I have not built an electrostatic microphone, because I was in the envious position of having worked with a manufacturer of fine condenser mikes. I custom modified a pair to my standards. It is possible to build your own, but you will not find it an easy task, particularly if you want cardioid performance. Omnidirectional types are much easier but you still *must* have professional frequency response measuring equipment to have good results.

Reg Williamson built such microphones and published them in *Audio*, July 1963, p. 122. The tubed electronics for these were later replaced by a solid state amplifier designed and published by Robert B. Schulein in *Audio*, October 1966, p. 104.

CROSSOVERS

continued from page 45

a technique for Zobel component-value determination. We've seen, too, that the ability to measure driver impedance magnitude is as necessary for CO development as it is for driver T/S parameter determination. Finally, I've offered you some tips about what CO type to use, some component selections, and even some aspects of system wiring. It's important to remember that although some people might disagree with various aspects of my approach, I know that it provides a unified working method for passive CO design. I, and many other speaker builders with whom I've worked have found it to be a good approach—and you will, too.

TRIAMP SYSTEM

continued from page 53

and at attachment points on the floor joists. I also internally braced the duct and used a liberal amount of construction adhesive for both structural strength and airtight joints.

After the duct was securely attached, I pounded nails from the inside corners of the duct up through the floor to mark the exact location of the cutout. The floor opening is 36 inches long by 12 inches wide. I carefully cut through the carpet and pad with a very sharp razor to produce a neat cut. Doing so will ensure that the carpet section can be replaced if you move or wish to return the floor to its original condition. I carefully cut through the floorboard with a saber saw, (a handsaw works best to make the cut against the wall), being careful not to fray the edge of the carpet or scrape the wall.

I installed a heavy expanded metal grate over the hole for the safety of both people and the drivers below. Finally, I cut a 1-inch thick piece of foam grille material to the size of the opening, and spray painted it a color to match the carpet. It isn't a perfect match, but it is relatively inconspicuous. A grille frame also could be constructed with an appropriate colored grille cloth.

My listening room is the family room, which opens into the entire first floor of our two-story home. When a high-quality recording containing the lowest possible bass is played, the low frequencies are reproduced with great authority. It's hard to resist setting the level on the subwoofer slightly higher than natural because it's fun to hear and feel the lowest notes. Once you've heard those really deep notes reproduced so effortlessly, you will be spoiled for any other system that can't do the same.

ELECTRONIC CROSSOVER. The selection of an appropriate electronic crossover depends on whether you want to build or buy one. Several very good electronic crossovers are available in finished form at a reasonable cost. An alternative is to build your own using the *Audio Amateur* and *Speaker Builder* construction projects as a guide. I chose a crossover from Alpha Electronics,[12] which offers crossovers in everything from two-way to six-way designs, with just about any combination of frequencies and slopes you could ask for. This crossover, with the addition of an available gain stage, could even become the heart of a very good preamp. The boards are designed with a building block approach in mind, as they can incorporate differential input buffer stages, equalization, all-pass phase delay networks and even output buffer stages. The quality of the circuit boards, active and passive elements, and circuit design are all first-rate. The flexibility of the design, and the ease with which it may be expanded or modified, made this a very good investment.

CONCLUSION. The application of these ideas and the combination of equipment have resulted in a very satisfying and successful system. The modular approach has left the possibility of future improvements and modifications. My desire to improve the system will never end. Now it's just easier to make those changes.

MAGNETIC CROSSTALK

continued from page 67

considerable magnetic and electrical crosstalk between their high- and low-pass sections that results in an audible deterioration of sound, and amounts to a hefty monkey wrench thrown into the original CO design. Most theory doesn't take into consideration such crosstalk. Rudimentary measurements with a multimeter suggest that magnetic crosstalk alone can cause signal transfer at a level that is some 20dB below the original. The implications for such designs as the now-popular 24dB/octave Linkwitz-Riley crossover are ominous: in actual operation, with electrical and magnetic crosstalk such passive filters may never even reach the −24dB point at any frequency.

2) Bi-wiring helps to minimize the electrical crosstalk, but unless your high- and low-pass components are physically separated, magnetic crosstalk alone can cause significant, audible degradation.

3) Careful orientation of passive crossover components—to ensure that the magnetic field of each is at 90° angles to others for minimum magnetic crosstalk—should be integrated into all crossover layouts. (The Swan IV satellite crossover shown in *Photo 1* on page 10

of *SB* 4/88 shows the correct right-angle alignment of the inductors, but I wonder how much the speakers would improve with bi-wiring and the electrical and physical separation of the high- and low-pass sections . . . .)

I confess to being a pragmatic enthusiast with little training in electronics, but I think my findings were worth passing along. I encourage you to experiment with your own speakers and report the results. I'm sure that a more detailed, in-depth, systematic, and scientific investigation into this little-known phenomenon would interest all *SB* readers. Any takers?

Tools, Tips & Techniques

continued from page 77

smeared. I once was treated to an unintentional illustration of this effect. A now-defunct stereo dealership had suspended Bose 901 speakers from the ceiling on chains. The cannon shots on the *1812 Overture* compact disc set the speakers to swaying. Obviously, this was energy that should have gone into reproducing sound. When speakers are placed on carpeting, a similar situation occurs, although to a lesser degree. The thicker the carpet, the more pronounced the effect.

My subwoofers sit on pieces of low nap carpet on the raised hearth of a corner fireplace. The satellite speakers are perched on the subwoofer tops. I installed the tiptoes point down, two at the front and one at the rear center of each subwoofer enclosure. Improvements in the bass were subtle, but evident. The bass became tighter and more definite. Transient response also seemed to be improved, more nearly matching that of the satellite speakers. The system became just a little more musical. I *like* the improvements.

Why not simply remove the pieces of carpet? The carpet covers the uneven hearth bricks and improves stability. Also, it permits repositioning the subwoofers a little for fine tuning. The tiptoes concentrate the speakers' weight, firmly coupling them to the surface.

I wanted to know how much mass-coupling I might be achieving, so I performed some calculations. My subwoofers weigh 55 lbs. each, and the satellites 18 lbs. each, for a combined weight of 73 lbs.

The formula for the surface area of a cone is: one-half the perimeter of the base of the cone times the cones's slant height.

I took the slant height as 1/16″, or 0.0625″, and the diameter of the base of the cone (at the floor surface, assuming the cone's point penetrates the floor to a slant height of $1/16''$) as 0.0625.

The perimeter is then pi times the diameter, or 3.1416 × 0.625″ = 0.196″. 0.196″ / 2 = 0.098″ (one-half the perimeter).

0.098″ × 0.0625″ (slant height) = 0.0061 sq. in. of bearing area per tiptoe.

0.0061 sq. in. × 3 (tiptoes) = 0.018 sq. in. of bearing area per speaker.

73 lbs. (per speaker)/0.018 sq.in. = 4055.56 lbs. per sq. in. (rounded off) of force each speaker transmits to the floor through the tiptoes' points.

This should be enough to prevent a lot of movement between the speakers and the surface on which they sit. It helps to explain why using a conical device, such as tiptoes, improves speaker performance under certain conditions. Some benefit may be derived from using such devices on any type of surface.

James T. Frane
Orinda, CA 94563

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B&K Pro-10MC preamp, mint condition, was $648, must sell, $498, original box; Syrink Le-Profile tonearm with SME silver Litz leads, $350; Vandersteen 2C, mint with stands, $950, original boxes. Ask for Jeff or Cliff, (707) 963-0789, 9–12 a.m., 5:30–7:30 p.m. PST, evenings and weekends.

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Old Klipsch catalogs, components; *Audio Engineering* volumes 1-5; diaphragm for international Projector LU-1000 high frequency driver; Army manual TM 11-690; early Poloroid polarizing film ads, literature; book, The Throne of Merlin, by R.C. Schaller; *High Fidelity* volumes 1-5. D.R. Schaller, 6704 Schroeder Rd., Suite 6, Madison, WI 53711.

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Help! Has anyone done a *mod* on the old Bozak's? Would like advice on B-4000! This speaker contains 2-12" woofers, 1-6" mid and 8-2" cone tweeters. Can Rudy Bozak's speakers be improved? Dewitt Davidson, 214 Cedar Dr., Grand Prairie, TX 75052, (214) 262-7820.

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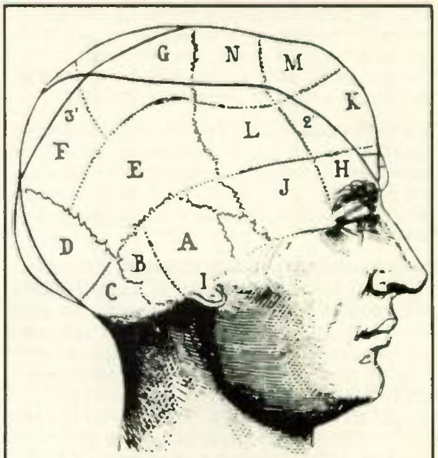

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THE COLORADO AUDIO SOCIETY is a group of audio enthusiasts dedicated to the pursuit of music and audiophile arts in the Rocky Mountain region. We offer a comprehensive annual journal, five bimonthly newsletters, plus participation in meetings and lectures. For more information, send SASE to: CAS, 4506 Osceola St., Denver, CO 80212, or call Art Tedeschi, (303) 477-5223.

AUDIO SOCIETY OF MINNESOTA. Audiophiles, music lovers, scratch builders, record collectors, tube freaks, digital freaks — we've got 'em all! Monthly meeting, tours, audiophile concerts, special guests, etc. Now in our 12th consecutive year! Write ASM, PO Box 32293, Fridley, MN 55432.

CONNECTICUT AUDIO SOCIETY is an active and growing club with activities covering many facets of audio — including construction, subjective testing, and tours of local manufacturers. New members are always welcome. For a copy of our current newsletter and an invitation to our next meeting, write to: Richard Thompson, 129 Newgate Rd., E. Granby, CT 06026, (203) 653-7873.

ELECTROSTATIC LOUDSPEAKER USERS GROUP is now a world-wide network for those interested in sharing valuable theory, design, construction, and parts source information. If you are interested in building, or have built, your own SOTA ESL we invite you to join our loose-knit organization. For information, send an SASE to: Barry Waldron, 1847 Country Club Dr., Placerville, CA 95667.

THE HI-FI CLUB of Cape Town in South Africa sends a monthly newsletter to its members and world-wide subscribers. To receive an evaluation copy of our current newsletter, write to: PO Box 18262, Wynberg 7824, South Africa. We'll be very pleased to hear from you.

THE INLAND EMPIRE AUDIO SOCIETY our former name, has now been changed to the**SOUTHERN CALIFORNIA AUDIO SOCIETY** (SCAS). Our effort is now inviting musiclovers, audiophiles, hobbyists and other interested parties throughout the southland to join us in our pursuit for that elusive sonic perfection and truth at our meetings and seminars and through our official speaker, *The Reference* newsletter. For information write or call: Frank Manrique, President, 1219 Fulbright Ave., Redlands, CA 92373, (714) 793-9209.

MEMPHIS AREA AUDIO SOCIETY being formed. Serious audiophiles contact J.J. McBride, 8181 Wind Valley Cove, Memphis, TN 38125, (901) 756-6831.

NEW JERSEY AUDIO SOCIETY meets monthly. Emphasis is on construction and modification of electronics and speakers. Dues includes monthly newsletter with high-end news, construction articles, analysis of commercial circuits, etc. Meetings are devoted to listening to records and CDs, comparing and A-B-ing equipment. New members welcome. Contact Bill Donnally, (201) 334-9412 or Bob Young, 116 Cleveland Ave., Colonia, NJ 07067, (201) 381-6269.

ORGAN MUSIC ENTHUSIASTS: If live recordings of fine Theatre Organ Music are your thing, SFORZANDO has room for a few new members. We lend you the music on cassettes. All operation is via the mail. SFORZANDO, c/o E.A. Rawlings, 5411 Bocage St., Montreal, Canada H4J 1A2.

PACIFIC NORTHWEST AUDIO SOCIETY (PAS) consists of 60 audio enthusiasts meeting monthly, second Wednesdays, 7:30 to 9:30 p.m. at 4545 Island Crest Way, Mercer Island, Washington. Be our guest, write Box 435, Mercer Island, WA 98040 or call Bob McDonald, (206) 232-8130.

PIEDMONT AUDIO SOCIETY. Starting an audio club in the Raleigh-Durham-Chapel Hill area of North Carolina. Interested in designing, building, and modifying speakers and electronics (solid state and tube). Beginners and old hands both welcome. Kevin Carter, 9009 Langwood Drive, Raleigh, NC 27612, (919) 870-5528.

SOUTHEASTERN MICHIGAN WOOFER AND TWEETER MARCHING SOCIETY (SMWTMS). Detroit area audio construction club. Meetings every two months featuring serious lectures, design analyses, digital audio, A B listening tests, equipment clinics, recording studio visits, and audio fun. The club journal is *LC, The SMWTMS Network*. Corresponding member's subscription available. Call (313) 477-6502 (days) or write David Carlstrom, SMWTMS, PO Box 721464, Berkley, MI 48072-0464.

THOSE INTERESTED IN AUDIO and speaker building in the Knoxville-East Tennessee area please contact Bob Wright, 7344 Toxaway Dr., Knoxville, TN 37909-2452, (615) 691-1668 after 6 p.m.

TUBE AUDIO ENTHUSIASTS. Northern California club meets every other month. For next meeting announcement send a self-addressed, stamped #10 envelope to Tim Eding, PO Box 611662, San Jose, CA 95161.

WANT TO START OR JOIN CLUB IN CENTRAL ILLINOIS (Peoria, Bloomington, Champaign, Kankakee area). Speaker building and audio in general. Trade info and parts. (815) 657-8488 evenings or weekends.

WASHINGTON AREA AUDIO SOCIETY (N. VA, MD and DC) is looking for sincere audiophiles who are eager to devote their time and get involved with the direction of the society and the publication of a monthly newsletter. Please contact: Horacio J. Vignale, 3730 Gunston Rd., Alexandria, VA 22302.

THE WESTERN NEW YORK Audio Society (WNY Audio Society) is an active and growing audio club located in the Buffalo area. We issue a quarterly newsletter and hold meetings the first Tuesday of every month. Our meetings have attracted many local and distant manufacturers of audio related equipment. We are involved in all facets of audio—from building to purchasing at discount prices. For a copy of our current newsletter and information regarding our society, please write to M.A. Monaco, WNY Audio Society, PO Box 312, N. Tonawanda, NY 14120.

THE BOSTON AUDIO SOCIETY invites you to join and receive the bimonthly *B.A.S. SPEAKER* with reviews, debates, scientific analyses, and summaries of lectures by major engineers. Read about Apogee, Nytal, Conrad-Johnson, dbx digital, Snell, music criticism and other topics. Rates on request. PO Box 211, Boston, MA 02126.

THE ATLANTA AUDIO SOCIETY is dedicated to furnish pleasure and education for people with a common interest in fine music and audio equipment. Monthly meetings often feature guest speakers from the audio manufacturing and recording industry. Members receive a monthly newsletter. Call: Chuck Bruce, (404) 876-5659, or Denny Meeker, (404) 872-0428, or write: PO Box 361, Marietta, GA 30061.

CHICAGO AREA ENTHUSIASTS WANTED for audio construction club. Call Tom, (312) 558-3377 or (708) 516-0170 evenings for details.

THE OREGON TRIODE SOCIETY is seeking men and women who are interested in good sound reproduction and the music it recreates. We are 80+ members strong and meet bi-monthly in various locations in the Portland area. Our bi-monthly newsletter is *Positive Feedback*, a vital forum on audio and a host of related subjects. For information on our next meeting and newsletter, contact Richard Eggerston, 3623 S.E. Hawthorne, Portland, OR 97214, (503) 238-1957 or Ian Joel (503) 233-1079.

Advertising Index

Good News

RAPID SYSTEMS has released the R3 software, a universal FFT spectrum analysis and digital oscilloscope software for their line of high performance FFT spectrum analyzers and PC peripherals. R3 has real-time split screen display of frequency and time waveforms. Up to 1,024 acquired spectrums on as many as four simultaneous channels can be achieved. Choice of instruments: 1, 2 or 4 independent channels, frequency response from DC to 10MHz, frequency resolution to 0.03Hz, data buffers to 128k per channel, and 8 or 12 bits of A/D resolution, digital and analog triggering.

Features include "Zoom" and cross correlation of frequency spectrum, FFT sizes of 1024 or 2048 points, phase plot of data, log or linear scaling on amplitude and frequency axis, auto save spectrums to hard disk, EGA/VGA software with mouse or keyboard.

Rapid Systems, Inc., 433 N. 34th St., Seattle, WA 98103, (206) 547-8311.

Fast Reply #JE948

The **B&K-PRECISION** division of Maxtec International Corp. has introduced a 2MHz function generator featuring a four-digit display. The Model 3011B Function Generator provides a full range of capabilities, including variable duty cycle, to fill the need for an accurate signal source for sine, triangle and square waveforms, plus TTL and CMOS pulse signals.

The Model 3011B covers from 0.2Hz to 2MHz in seven ranges. Special features include coarse- and fine-frequency controls, a separate TTL and CMOS pulse output and external sweep/source capability. Duty cycle is continuously variable from 1:1 to 10:1, and when inverted from 1:1 to 1:10.

The built-in frequency counter with 10 ppm time base permits precision frequency settings never before achievable without external test equipment. The bright LED display gives four digit resolution and the fine frequency control enhances setting ability.

For engineering applications, a switchable variable DC-offset introduces a DC signal on the generator output. This capability is useful for matching the DC voltage at the signal input point to prevent changes when the test signal is applied, and for evaluating the effects of DC bias on AC circuits and shifted operated points of a DC coupled amplifier, as well as other tests.

Sinewave distortion is less than 1 percent, with square wave symmetry of better than 98 percent at 100kHz and triangle wave linearity at 98 percent. Output level is continuously adjustable from zero to −20dB. A 20dB step attenuator extends the range from zero to −40dB.

For additional information, contact B&K-Precision, Division of Maxtec International Corp., 6470 W. Cortland St., Chicago, IL 60635.

Fast Reply #JE7

ACOUSTIC RESEARCH has announced that the 1MS 660 is now available in the U.S. The 1MS 660 had been previously offered only in Europe, but will now be sold by AR dealers worldwide.

The 1MS system uses the same subwoofer enclosure as AR's STC 660 Subwoofer System, which recently received a U.S. patent. The subwoofer is a series tuned cavity which contains dual 6″ woofers in a push-pull configuration. The first cavity works both to increase efficiency in the lower bass frequencies and to minimize distortion; the second acts as a filter to remove unwanted higher frequencies from the drivers that would otherwise allow the ear to pinpoint the position of the subwoofer. Its power handling is 75W to 180W.

For more information contact Acoustic Research, 330 Turnpike St., Canton, MA 02021.

Fast Reply #JE324

POLYDAX SPEAKER CORP., a subsidiary of Audax Industries in France, has introduced the MDA 100 4″ midrange. It is the first available model in the Prestige line of ultra high-end loudspeaker components.

The MDA 100 uses a proprietary cone material made of an advanced formulation polymer plastic (TPX). The TPX material exhibits superior stiffness and damping qualities. Further developments, such as Supra magnet technology, a Norsorex surround, and a pure Titanium former all create an extremely smooth response in the mid-frequencies. Characterized with high sensitivity (92.5dB 1W/1m) and excellent power handling (60 watts RMS), the MDA 100 delivers a balanced tonality with perfect equilibrium.

For further information, contact Polydax Speaker Corp., 10 Upton Dr., Wilmington, MA 01887, or call (508) 658-0700.

Fast Reply #61

Continued on page 101

EVERYTHING YOU EVER WANTED TO ASK ABOUT YOUR CD PLAYER BUT WERE AFRAID TO KNOW!

After 18 months of painstaking research and several trial pressings, here is the most complete and functional test package ever available on the market. Created in the studios of Pierre Verany, with the collaboration of French audiophile magazine Compact, *the final product was submitted to the creators of the CD concept and its standard - the Philips laboratories in Eindhoven, Holland. Their verdict: 'a beautiful piece of work!'*

The compact discs in this copiously documented set are unique. For the first time, they offer the consumer a tool for verifying the qualities and defects of a given CD player, with no required measuring equipment or in-depth technical knowledge. However, they have been shown to yield startling performance demonstrations even under the strictest of laboratory conditions.

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Continued from page 99

McCAULEY SOUND of Puyallup, WA has begun exportation of loudspeaker parts and design expertise to the Soviet Union. McCauley has launched its initial marketing and production phase for the new 15" extended low-end speaker, which will ultimately be assembled in Russia.

Ultimately, McCauley plans to manufacture moderately priced, high quality loudspeakers in Russia for distribution throughout Europe. President Tom McCauley said, "It's not only a marketing adventure, but a cultural and technological exchange as well."

Fast Reply #JE278

OLSSON ENGINEERING has announced the availability of the Automated Active Filter Design Kit. The filter kit consists of a circuit board and an active filter design program that has been optimized for the state variable circuit configuration. The circuit board implements six general purpose second-order filter stages, and can support all of the common circuit configurations (low-pass, high-pass, band-stop, all-pass). The kit provides the user with fast turnaround time for custom filter configurations. Most common filter types are supplied in the filter parameter library. The circuit board measures 2 × 6 inches and supports ¼W resistors and capacitors of variable size. Each second-order stage can be cascaded or implemented separately for desired filter complexity. Additional circuit boards are available.

Available from Olsson Engineering, 561 Pine St., Edmonds, WA 98020.

Fast Reply #JE6

Two enterprising readers have compiled indexes of ***SPEAKER BUILDER*** from its first 1980 issue. David G. Baldwin uses the famous Macintosh Hypercard stack facility for producing his version on a single 3½" disk. He asks $15 for the disk and promises upgrades for $2 with SASE and a blank disk. His address is 1118 Foster Ave., Lake Bluff IL 60044.

Russell Schoof works in the IBM format and has chosen to produce his index using the famous shareware data base management program PC-FileB by Dick Button, compatible with dBASE files. His disk is available for $15 on a 5¼" 360K disk in compressed form, or on a 720K 3½" disk in uncompressed form. The compressed disk downloads easily on the author's clear instructions either to a hard disk, two 360Ks or any of the three other IBM disk formats. Schoof's address is 17777 S. Ramsby Rd., Molalla OR 97038.

Pox Humana

Who was that strange little man, anyway?

by Dick Pierce

While not strictly audiophilish in its content, I have always found this event in my life most enlightening and amusing.

Back in the days when I was involved selling hi-fi, I had numerous occasions to be involved with well-known studios and artists. On one such occasion, a friend of mine at WGBH in Boston asked if I would mind lending myself and what I considered a good pair of speakers suitable for recording studio monitoring. They had several different types already, JBL L-100s, Braun (pre-ADS) 800s, Klipsches and the like, and found them all severely wanting. The Brauns were probably the least offensive of the bunch, but quite fragile by comparison.

Well, I hopped into a cab with a pair of Celestion Ditton-66's, and away I go to GBH. Upon arriving, we set up the speakers and do some preliminary tests. They seemed to do just fine. My friend, Tom, asks me if I want to hang around for the recording session. It seems that Leonard Bernstein was about to conduct the Harvard Glee Club in a special rendition of parts of Stravinsky's *Oedipus Rex*, to use as a demonstration in the Norton lectures he was giving, "The Unanswered Question." Sure, I would.

Now, at this time, I was still in my classical/romantic period. Beethoven, Schubert, Brahms, *et al*, with a liberal sprinkling of Tchaikovsky and such thrown in for good measure. Be in the same CITY as Maestro (his Exalted Batonship) Bernstein? You betcha!

So I sit in the control room, visually isolated from the studio itself, listening to His Wonderfulness admonish the singers for obviously failing to achieve the musical nirvana that Mr. Bernstein surely inspires them towards. I sit in front of the console, helping mix, thinking about my joyous pre-pubescence, watching Mr. Bernstein tower as the giant he was over the New York Philharmonic during one of his many Young People's Concerts. What a titan, I used to think. A veritable Einstein of Classical Music.

The recording session was finished, and everyone seemed to be satisfied. Tom asks me, "Do you want to go over and meet Lenny?" Lenny?, I say, who's Lenny? Tom smiles knowingly and says, "Let's go and meet Mr. Bernstein."

I must say that this was one time in my life that I entered a situation completely unprepared. Looking for this giant, imposing, tall, musical hero-type veritably bursting at the seams with the essence of the Muses, I was confronted by a short, pot-bellied, elfish, chain-smoking little creature that looked like he belonged on a park bench somewhere. Here was my musical hero, hacking his lungs inside-out from smoking four packs of cigarettes a day, dressed in torn oversized basketball sneaks, dingy, smelly, ripped gray sweat pants, a green sweatshirt that had "BEAT HARVARD" emblazoned on the back, and, capping, but barely confining, his tangled mat of greasy-white hair, a red "YALE" baseball hat. Ladies and gentlemen, Maestro Leonard Bernstein, gettin' down.

Lenny was amazing. He picked up two Scheops condenser microphones, finds the appropriate coupler, hooks them end-to-end, and procedes to start batting microphone wind screens about like wiffle balls. Seeing the staff cringe at the thought of two $700 microphones being trashed, he says, "Don't worry, I'll buy you guys a new station."

After cleaning up the studio, he decides he's hungry. "Who wants pizza?" he yells. Well everybody does, so 30 of us head over to the Allston House of Pizza at 11:30 at night, where Lenny buys us all pizza.

Oh, by the way, I can't remember whether WGBH liked the speakers or not. It seemed unimportant compared to the other event of the evening.

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The MDM 85 is a mid range 75mm soft dome unit of extremely high standard, both from a design and technical viewpoint.

It incorporates the renowned Morel double magnet and Hexatech voice coil techniques, and results in a unit of above average sensitivity with extremely low distortion and high power handling capability.

With an output level of 96dB distortion in the area of 400-800Hz is slightly over 1% falling to 0.015% from 1Khz.

There are two different types available, one with a rear enclosure and one without (MDM 85NE). The type with the rear enclosure can be fitted into a cabinet as an integral unit.

The MDM 85NE without the rear enclosure can only be fitted into a system having a separate housing to enclose the unit. A volume of 0.7 litre is recommended for this housing, which is essential to prevent inter-reaction with the bass unit compressions and expansions. This housing must be filled full with damping material, such as fibreglass or rock wool.

The Thiele small parameters are given for both types under specifications. The contribution of this unit to a suitably designed system will be evident in the clarity and detail given in the 500-5000Hz region.

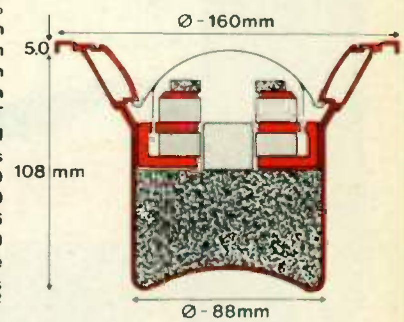
Specification

MDM 85 (with enclosure)

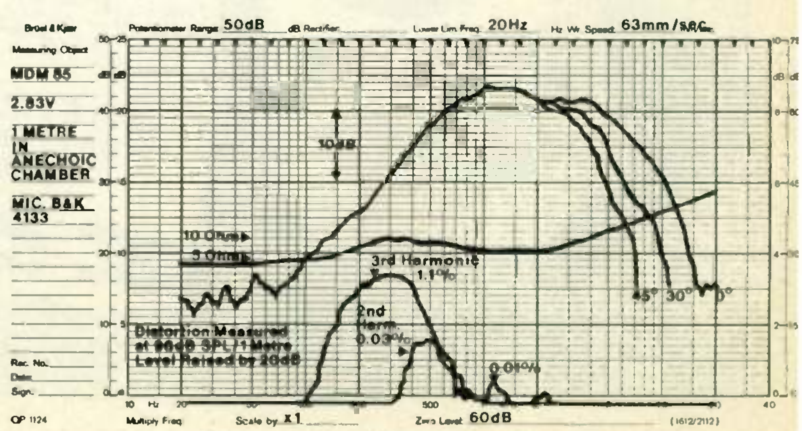
Overall Dimensions	Ø - 160mm x 113mm
Nominal Power Handling Din	300W
Transient Power 10ms	1500W
Voice Coil Diameter	75mm (3")
	Hexatech Aluminium
Voice Coil Former	Aluminium
Frequency Response	300-5000 Hz
Resonant Frequency	250 Hz
Sensitivity	92 dB (1W/1M)
Nominal Impedance	8 ohms
Harmonic Distortion for 96 dB SPL	<1%
Intermodulation Distortion for 96 dB SPL	<0.25%
Voice Coil Inductance @ 1 Khz	0.2mh
Air Gap Width	1.05mm
Air Gap Height	3.0mm
Voice Coil Height	6.0mm
Flux Density	1.0T
Force Factor (BXL)	4.6 WB/M
Rdc	5.2 ohms
Rmec	37.90
Qms	0.29
Qes	2.66
Q/T	0.20
Vas	0.33 litre
Moving Mass including Air Load	7.0 grams
Effective Dome Area	63.50 cm^2
Dome Material	Chemically Treated Fabric
Nett Weight	1.25 kg

Variations to specification for MDM 85NE (without enclosure)

Overall Dimensions	Ø - 160mm x 60mm
Frequency Response	250-5000 Hz
Resonant Frequency	170 Hz
Rmec	39.33
Qms	0.19
Qes	1.81
Q/T	0.17
Vas	0.7 litre
Nett Weight	1.05 kg



Specifications given are as after 24 hours of running.



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