a novice builds North Creek's Rhythm Revelator kit

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Speaker Builder®

THE LOUDSPEAKER JOURNAL

Building a **VIFA COMPACT TWO-WAY**

How transmission lines work: **FINALLY THE FULL STORY**

A simple, **HIGH-QUALITY SYSTEM** with stand

A review of **SPEAKER DESIGN FUNDAMENTALS**

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Binding Posts (crimp technique)

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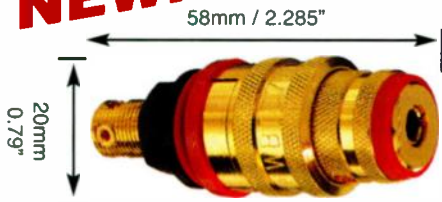
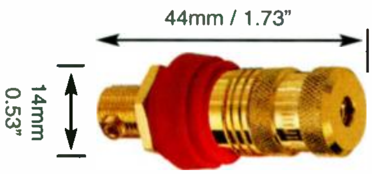


WBT-0701 Topline — each $50.00

WBT-0701-KIT 2 posts, 1 Torx™ key, boxed — kit $104.00

If you have this much room (20mm) for performance...buy it!

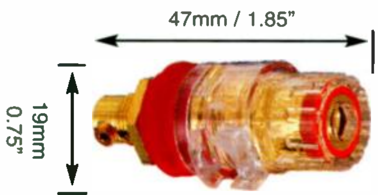
400 amperes continuous current. The ultimate pole terminal for demanding applications. Robust design with special elements and features. Patented clamping mechanism for high compression connection of spade connectors and crimped wire ends up to 16mm^2 (6AWG). Patented collet chucking device for banana plugs. New milled groove on both sides of compression plates for high-strength connection of spades. Includes built-in insulation. Color code: red or white. Can also be soldered.



WBT-0730 Topline — each $30.00

WBT-0730-KIT 4 posts, 2 spacer blocks, 1 Torx™ key, boxed — kit $126.00

200 amperes continuous current. Patented clamping mechanism for high compression connection of spade connectors and crimped wire ends up to 10mm^2 (8AWG). Accepts 4mm banana. Color code: red or white.



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WBT-0735 Topline — each $35.00

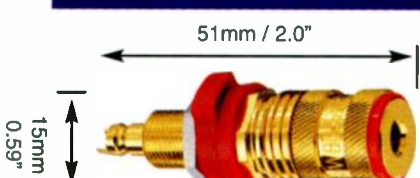
Highest performance, safety, quality. A bit more and worth it!

Fully insulated safety version of WBT-0730.

WBT Crimp sleeves	Conductor size mm²	AWG	each
WBT-0430	0.5	#20	$0.50
WBT-0431	0.75	#19	$0.50
WBT-0432	1.0	#17	$0.50
WBT-0433	1.5	#16	$0.50
WBT-0434	2.5	#14	$0.50
WBT-0435	4.0	#12	$0.75
WBT-0436	6.0	#10	$0.75
WBT-0437	10.0	#8	$0.75
WBT-0438	16.0	#6	$1.00

WBT Crimp sleeves with insulated collar	Conductor size mm²	AWG	each
WBT-0441	1.5	#16	$1.00
WBT-0442	2.5	#14	$1.00
WBT-0443	4.0	#12	$1.00
WBT-0444	6.0	#10	$1.50
WBT-0445	10.0	#8	$1.50
WBT-0446	16.0	#6	$2.00

Binding Posts (solder technique)



WBT-0744 Midline — each $17.50

Single pole terminal suitable for 200 amperes continuous current. Patented clamping mechanism, for high compression connection of spade connectors and crimped wire ends up to 6mm^2 (10AWG). Accepts 4mm banana plug. Color code: red, white or black

Safety Line

WBT-0745 Midline — each $20.00

Very popular for upgrades!

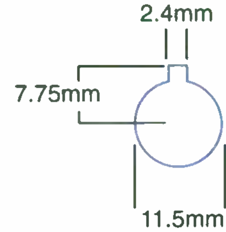
Fully insulated safety version of WBT-0744.

Part A Insulating shoulder washer, fits to the body of the binding post, and can be positioned at 90° increments. The "key", which is visible, fits in a corresponding keyed hole in the panel.

Part B Insulating lock washer is placed on the inside of the panel. The binding post nut tightens directly on this washer completing the assembly.

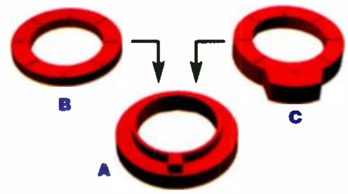
Part C Insulating cup washer is placed on the inside of the panel. This washer has a cavity that fits over the shoulder and "key" of part A. The binding post nut tightens directly on this washer completing the assembly.

Mounting hole dimensions



A + B for panel thickness from 2 - 6mm
A + C for panel thickness from 0.1 - 3mm

All binding posts are priced with washer set A + B.
Set A + C may be substituted for A + B at time of order.
May be deleted at time of order if not required.



Available in the colors white, red or black

WBT-0721 PCB adapter block

Fastens to circuit board with included bolt and lock washer. Mounts horizontally or vertically. Torx™ screw fastens jumper wire terminated with crimp sleeve. Other end of jumper wire connects to binding post.

WBT-0799 safety stick

Included with all **Safety Line** binding posts.

Specially shaped plastic peg, inserts in banana plug hole in binding post, required to accomplish CE safety conformity.

May be deleted at time of order if not required.

WBT-0716 thick panel mounting kit

Kit includes a gold-plated brass exterior bracket(1), and a plastic interior bracket(2).

30mm spacing

WBT spacer block (19mm spacing)

Fits all binding posts except WBT-0701.
3/4" plastic insulating spacer block.
Color code: red or white

WBT-0717 holding tool *(not illustrated)*

Use when mounting binding posts in the WBT-0716. Snaps into the two posts, holds them in alignment and prevents the posts from rotating while tightening the nuts.

WBT-0403 Crimping pliers

Crimping pliers with special multiple spike jaw. The only tool designed to crimp all WBT crimp sleeves. Gold-plating protects against corrosion. Comfortable, plastic-coated grip.

Associated parts

WBT-0488	Single Torx™ key (T6)	**$4.00**
WBT-0716	Thick panel mounting kit	**$16.00**
WBT-0717	Holding tool	**$12.00**
WBT-0721	PCB adapter block (works w/crimped cable ends)	**$8.00**
WBT-0799	Safety stick	**$0.50**
Part A + B	2-6mm panel	**$1.50**
Part A + C	0.1-3mm panel	**$1.50**
WBT - spacer block	two pole spacer block	**$2.00**
WBT-0403	Crimping pliers.	**$90.00**

WBT-0488 Torx™ key

T-6 size fits all WBT parts.

WBT silver solder

Highest quality solder with 4% fine silver content. The halogen-free flux is gentle on precious metal surfaces, the melting temperature (178/180°C) is extremely low.

WBT-0800	small spool	0.9mm Dia.	Weight 42 grams	**$14.00 each**
WBT-0820	medium spool	0.8mm Dia.	Weight 250 grams	**$41.00 each**
WBT-0840	large spool	1.2mm Dia.	Weight 500 grams	**$74.00 each**

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Reader Service #65

About This Issue

When the occasion calls for a small-sized speaker, it doesn't mean that the quality of the system should suffer. **Jim Moriyasu**'s compact design features Vifa drivers in a stepped-baffle arrangement. He provides plenty of construction details and measurements to demonstrate how good things can come in small packages ("A Vifa Compact 2-Way," p. 8).

Transmission-line fans will enjoy **A. Monk**'s series beginning in this issue, as he attempts to set the record straight regarding the performance of these labyrinthine designs. Part 1 explores the characteristics and history of the development of these low-resonant enclosure designs ("Transmission Lines: The Real Story," p. 20).

Do you sometimes have a tendency to complicate the art of speaker building? **Lester Mertz** shows you how to keep things simple without sacrificing the quality you desire ("High-Quality Two-Way Design," p. 30).

In the first of a three-part series, **Mark Wheeler** stresses some fundamental precepts that we often tend to overlook ("Navigating Speaker Design: Defining the Problem," p. 38).

Charles Hansen is a pro in the field of electrical engineering, but untried as a speaker builder. So it is with no small amount of pride that he relates his successful restoration of a pair of old Lafayette Radio Criterion two-way loudspeakers. He chooses the drivers and crossover offered from Madisound, and, in the process, establishes a new set of Criteria ("Reviving an Old Criterion," p. 42).

We are pleased to announce that **Charles Hansen** is also finishing up a book entitled *The Joy of Audio Electronics*. The critical role this book may play in our industry's future is discussed in the editorial on p. 7.

Readers should also be aware that noted *SB* author **Bill Fitzmaurice** has recently compiled his most popular speaker designs in a book entitled *Loudspeakers for Musicians*. It includes ten projects to help you get better sound from musical performances (see p. 40).

For the DIYer, North Creek Music Systems offers a speaker kit that promises high-end performance. **Daniel R. Smith** tackles this as his first speaker-kit project and finds the results with the Rhythm Revelator are well worth the effort ("Kit Review," p. 52).

Speaker Builder

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The peculiar evil of silencing the expression of an opinion is, that it is robbing the human race; posterity as well as the existing generation; those who dissent from the opinion, still more than those who hold it.
JOHN STUART MILL

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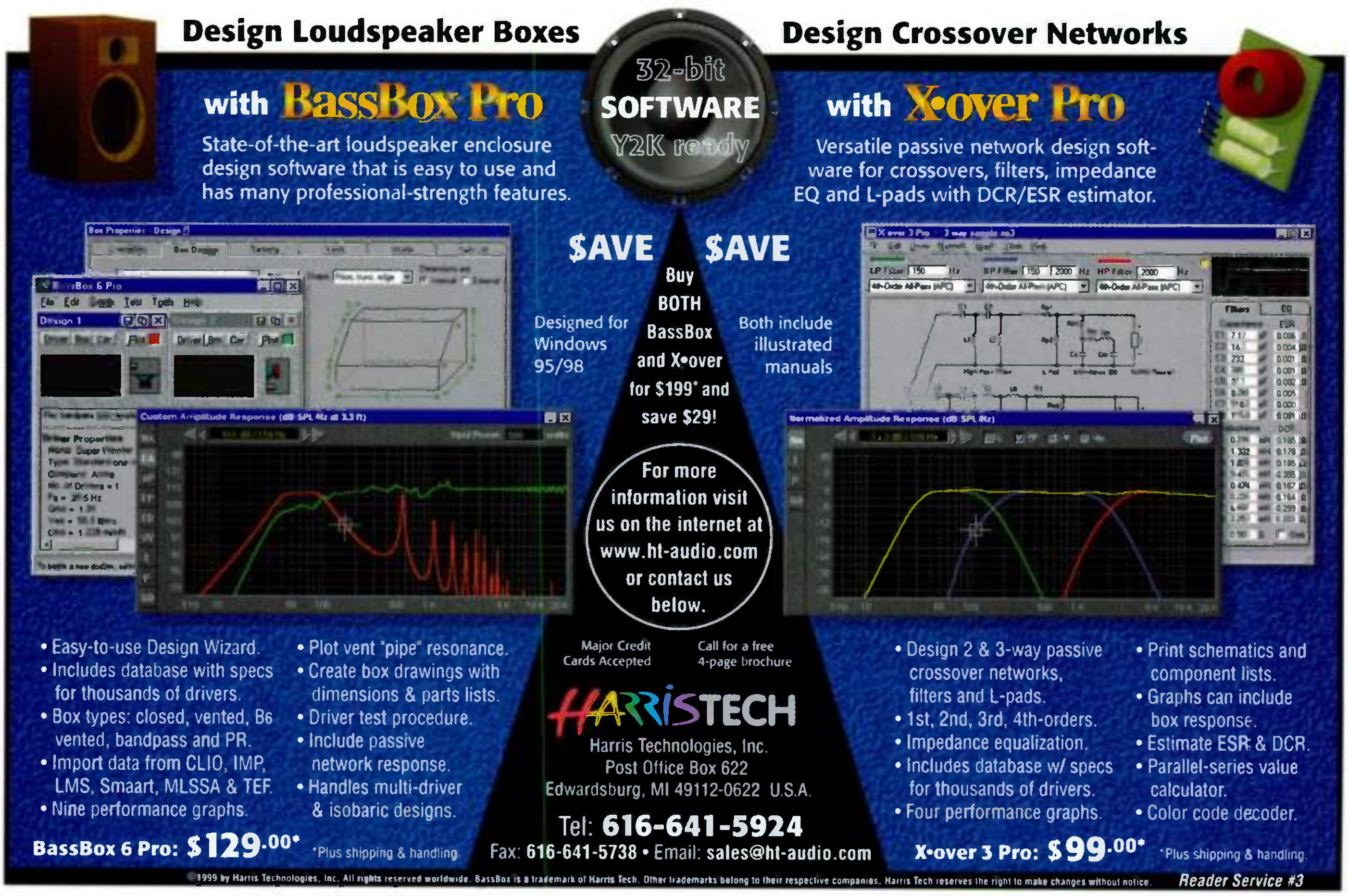

Good News

MIKE PREAMP

The MP-200 from AudioControl is a two-channel measurement microphone preamplifier that features switchable input gain, variable output pink-noise generator, 94dB acoustic SPL reference light for calibrating computer programs and other level meters, a calibrated microphone, and 3m mike cable. This compact (5″ × 6.75″ × 1.25″) preamp comes in a steel chassis for field reliability, and may be powered by a 9V-battery for over 12 hours or by an AC adapter. AudioControl Industrial, 22410 70th Avenue West, Mountlake Terrace, WA 98043, (425) 775-8461, FAX (425) 778-3166.

Reader Service #135

MAC SOFTWARE

True Audio released the latest version of its loudspeaker enclosure design software for the McIntosh computer. Version 3.5 has been completely rewritten, while at the same time retaining the user interface familiar to loudspeaker designers who have used the previous version. The program includes a library of over 1000 loudspeaker drivers from various manufacturers. You may choose any of these drivers and work with any of 18 different enclosure types to create a speaker system targeted for a specific application. True Audio, 387 Duncan Lane, Andersonville, TN 37705, (423) 494-3388, Website www.trueaudio.com.

Reader Service #136

MCFEELY CATALOG

McFeely's latest catalog includes an assortment of screwdrivers, drill bits, cabinet-making clamps, measuring and marking tools, saw blades, and more. McFeely's Square Drive Screws, 1620 Wythe Rd., PO Box 11169, Lynchburg, VA 24506-1169, (800) 443-7937, FAX (800) 847-7136.

SOUND-LEVEL METER FOR DUMMIES

Scantek, Inc. introduced the NA-26 from Rion. The device has a 100dB dynamic range and no range switch. Measure immediately after turn-on with only three keys operation. No skill required, and if you forget, instructions are included. With a 20-hour battery life, light weight, small size, and the ability to accept extension cables, the meter is perfect for general survey work, HVAC measurements, and more, according to the company. Scantek, Inc., 916 Gist Ave., Silver Spring, MD 20910, (301) 495-7738, FAX (301) 495-7739, E-mail scantek@erols.com, Website www.scantek.net.

Reader Service #138

SONANCE SPEAKERS

Sonance introduced the Mariner H_2O indoor/outdoor speaker. It features a weather-resistant cabinet and components to ensure long life, and includes two 5¼″ woofers made of magnetically-shielded polypropylene cones with rubber surrounds, which are placed between a 1″ magnetically-shielded cloth dome tweeter. It also includes an integral "C" bracket that provides flexible pole mounting capability so the speakers can be ideally positioned for dynamic sound reproduction. You may paint the system to color-match surroundings.

Also from the company is the MC center-channel speaker. It features two magnetically-shielded 5¼″ polypropylene woofers that reproduce the full impact of Dolby Digital™ and DTS soundtracks, handles 100W of power and has a 90dB efficiency. Sonance, 961 Calle Negocio, San Clemente, CA 92673, (714) 492-7777, FAX (714) 366-6468, Website www.sonance.com.

Reader Service #137

LINES FROM DYNAUDIO

Dynaudio's current line of loudspeakers fall into three separate ranges: Audience, Contour, and the "statement" line, consisting of the Confidence 3, Confidence 5, Consequence, and Evidence. Each Audience cabinet is constructed from rigidly-braced MDF, and features a 28mm soft-dome tweeter. This line's two subwoofers employ Dynaudio drivers with internal 90W amplifiers designed in conjunction with the drivers. All Contour speakers are housed in solidly-built MDF cabinets clad in matched-grain furniture-grade wood veneers. Inside the cabinets, each driver has its own separate enclosure, creating "boxes within the box." This line features the company's Magnaflux-cooled and damped soft-dome tweeter. The woofers feature double magnet systems, die-cast baskets, long-throw progressive spiders, aluminum voice coils, and five-duct cooling systems. The Confidence 3 and 5, Consequence, and Evidence were designed using Dynaudio's standard-setting Arbiter electronics. This line represents 20+ years of loudspeaker manufacturing experience. Dynaudio, Website www.dynaudiona.com.

MOUSER CATALOG

In Mouser®'s #599 catalog, you'll find an array of wire and cable, speakers, microphones, cabinets, tools, kits, and much more. Mouser Electronics, 958 No. Main, Mansfield, TX 76063-4827, (800) 346-6873, E-mail sales@mouser.com. Website www.mouser.com.


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FEATURES

DEPARTMENTS

IN EVERY ISSUE

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Editorial

A SMALL STEP FOR ENGINEERING

I HOPE YOU WILL INDULGE the publisher of this periodical if I interrupt the flow of useful material usually appearing in this space for a personal anecdote or two and an invitation. Having discovered the blandishments of classical music and at the same time being a nearly penniless student, I had to find ways to listen to FM broadcasts and play the few LPs I was able to afford through equipment which was better than the typical console or table top radio.

The kit offerings of Heath Co. were cheap and promised superior sound. My first foray into kit building was in 1952, assembling a 7W 6V6 push-pull integrated amp with volume, treble, and bass controls. Assembly took place on my landlady's kitchen table, on a board that could be put in the pantry during mealtimes.

Thanks to Heath's remarkable assembly manual, I was successful in my first brush with electronic assembly—knowing nothing whatever about volts, amperes, resistance, and certainly not Ohm's law. The sense of achievement and pleasure was, however, indelible. That pride of accomplishment, and the sense of beginning an unlimited adventure, was just the first incident in almost a half century of fascination with electronics, audio, and music.

As the years passed, I graduated to schematics, tools, instruments, measurements, and scratch building all manner of devices. But it all started with that initial excitement and the incomparable sense of achievement which comes from building with your two hands and having the device work as advertised.

That initial spark leading into a lifelong interest in electronics, and audio as a special flavor of it, is, I have discovered, one that I share with a very large group of engineers, technicians, and enthusiasts like myself. I have asked the question hundreds of times: "How did you get started in audio?" Almost invariably building some kind of kit project was the catalyst.

Dynaudio, that highly sophisticated Danish firm which manufactures some of the world's most impressive speakers, offers a series of six do-it-yourself speaker designs without ever making much, if any, money from them. When I asked why, the director of engineering explained that Dynaudio had discovered that its worldwide OEM customers had, almost without exception, entered the loudspeaker manufacturing business because of a childhood enthusiasm for building loudspeakers.

For a long time I have hoped to produce a guide for rank beginners like my younger self. I am glad to report that I have found the author for the task. We are in the final stages of preparing a remarkable introduction to hands-on audio electronics. The author has 27 years as a professional engineer for a very large U.S. electronics firm, AlliedSignal. Charles Hansen has been patient with me in writing *The Joy of Audio Electronics*. He was thinking of beginning the book with Georg Ohm's formula when I rudely intervened and turned his proposed outline on its head, as it were.

The book begins with a small, simple project of assembling a passive loudspeaker overload indicator. Chuck takes the reader through the project leaving nothing whatever to chance. In the second chapter, another more complex powered project is presented, and the reader learns how not only to build the gadget, but also to put it into a neat box.

The third chapter talks generally about electronics, how to test and measure projects, safety issues, and the kinds of tools and instruments the hobbyist will need. Chapter four is all about a place to work, from the simplest to the ideal shop. Chuck discusses construction, safety, and, best of all, how to keep good records and organize both the bench and the information.

Chapter five is a comprehensive directory of where to find everything the hobbyist might need to build almost anything electronic: tools, parts, instruments, and design information. It is full of web references, and will be regularly updated on this company's web site. Finally, in chapter six Chuck gets to talk about electronic and audio theory with a general outline pointing to further growth and development.

The Joy of Audio Electronics is a foolproof, fail-safe guide into the pleasures of hands-on electronic construction. We have high hopes for it in a time when the number of young people going into engineering is shrinking by 5% per year. The shortages throughout the industry are alarming.

I hope each one of you who reads this periodical will give some thought to finding a young acquaintance who might be mentored, with your help, toward the pleasures of discovering the exciting world of electronics. If those of us who know and love the joys of pursuing better sound are not the people to recruit our successors, then who is?

Audio is almost the ideal portal into electronics since it is not only often simple enough to be grasped easily, but it has the double reward of being an interesting craft as well as producing pleasurable music. It will be the rare young person who is not interested in some form of reproduced music. The idea of learning to make the means of producing it should have its own attraction, presented by an enthusiast like yourself.

Priced at $19.95 and including a circuit card, this book sets a gold standard for the art of electronic construction which I have never seen equaled and offers a source directory which will be valuable to any experimenter. I believe it will be the rare audio enthusiast who builds his or her own who will not learn something from Chuck Hansen's remarkable book.

I welcome your comments on and reactions to *The Joy of Audio Electronics* and about our cause. I believe the book is an important key to a solution for a serious problem, but also a gate for many lucky individuals to a lifetime of deep satisfactions. I hope you will consider it and the idea of using it to introduce a newcomer to audio electronics.—E.T.D.

This two-way speaker may be small, but it packs plenty of punch and features a Vifa mid-bass and tweeter in a stepped-baffle design.

A Vifa Compact 2-Way

By Jim Moriyasu

I designed these speakers for a friend from New Zealand, so they needed to be relatively small to be included as part of his luggage. Envisaging a compact system, I decided to go with the venerable Vifa P17WJ-08 6½″ poly-cone midbass and the Vifa D25AG35 1″ aluminum dome tweeter. While it was tempting to try the newer Vifa MW18 or the Peerless CSC drivers, their greater cost deterred me. I could have used other tweeters, but I happened to have a pair of the D25AG35s available from another project. I chose a Woodstyle WS802 cabinet, which has a volume of .41ft³, and ordered it from Madisound.

BASS ALIGNMENT SIMULATIONS

I used LinearX's Loudspeaker Enclosure Analysis Program (LEAP) for simulations and crossover design. LEAP simulations suggested that a box tuning at 50Hz would generate bass response down to 55Hz—pretty good considering the size of the cabinet. I considered box tunings at 45Hz and 55Hz, but they were less flat than the 50Hz tuning (*Fig. 1*).

Figure 2 shows the 50Hz tuned box at higher power levels of 4, 16, and 32W. *Figure 3* shows the simulated excursion with the driver's cone reaching its X_{max} of 4mm + 15%, or 4.6mm at 32W. So, based on the simulation, this box alignment and driver should be able to produce 99dB at 1m and have acceptable harmonic distortion[1] as long as there are no significant amounts of program material below 40Hz. At 4m, this corresponds to 87dB, and a pair would do another 6dB combined, or 93dB, which would be relatively loud in a modest-sized living room. *Figure 4* displays the impedance curve at the higher levels, showing that the 2″ port becomes less effective at 16 and 32W.

PHOTO 1: Finished JM-2/vf speaker with grille removed, showing stepped "top" baffle, felt ring around tweeter, and off-center driver positioning.

CONSTRUCTION DETAILS

The WS802 cabinets, 16″H × 10″W × 8″D, are made from ¾″ chipboard covered with oak veneer. You can order them with a clear or black finish. The cabinet corners are fitted with solid oak and have a ¾″ radius, as does the grille frame. Overall, the cabinets are attractive, well built, and nicely finished. Madisound sells them for $96 a pair, and even with shipping by air to Hawaii, the time they saved me

ABOUT THE AUTHOR

Jim Moriyasu has been an avid speaker enthusiast for over 20 years. Despite a BS in biochemistry, he has worked as a financial advisor (stockbroker) with Morgan Stanley Dean Witter for the past 21 years. He has been using LEAP and LMS for the past four years, and LAUD since last summer. He lives in Kula, Hawaii.

TABLE 1
PARTS LIST

2	Vifa P17WJ, midbass, Meniscus
2	Vifa D25AG35, tweeter, Meniscus
2	Woodstyle WS802, .41ft³ cabinet, clear finish, from Madisound
2	GB cup, input panel, Madisound
2	trim ring, 2″, Meniscus
2	tweeter felt ring, Meniscus
1	sheet of 1″ open-cell foam for damping, hardware store
1	2″ ID black ABS plumbing pipe (usually 8 feet long), hardware store
24	#6 × ¾″ black screws, Meniscus
1	roll of foam weatherstripping tape, Meniscus
1	8 feet of 16 gauge wire, red/black jacket, Parts Express
Crossover parts (from Meniscus)	
2	L1, 3.0mH, 16 ga., 21Ω, 500W, Quantum Super Ferrite
2	C1, 15µF, 250V, 5%, Solen
2	C2, 8.2µF, 250V, 5%, Solen
2	L2, .5mH, 16 ga., 23Ω, 500W, Air core
4	R1, 10Ω, 10W, 2%, Lynx
2	C3, 2.0µF, 250V, 5%, Solen
Measurement equipment and CAD software	
	LAUD—Liberty Audio Suite
	LEAP—Loudspeaker Enclosure Analysis Program
	LMS—Loudspeaker Measurement System
	Vermette Load Jockey 350

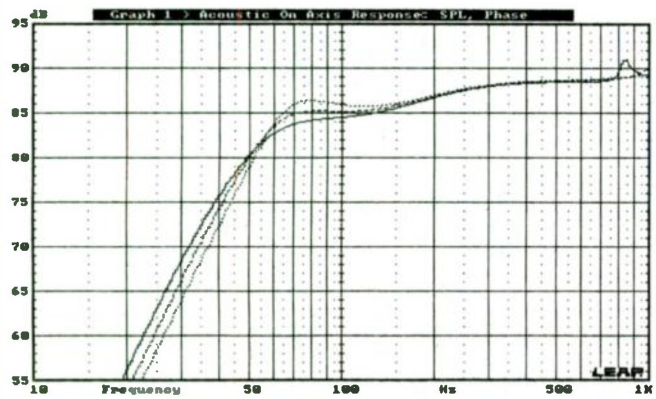

FIGURE 1: Low-frequency simulation of Vifa P17WJ at box-tuning frequencies of 45Hz, 50Hz, and 55Hz.

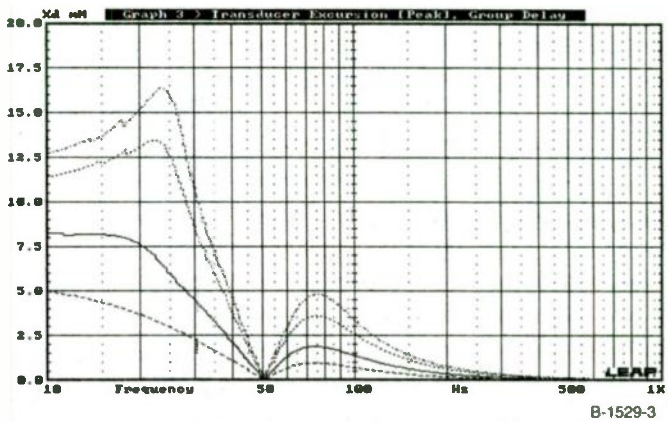

FIGURE 3: Simulation of driver-excursion curves for *Fig. 2*.

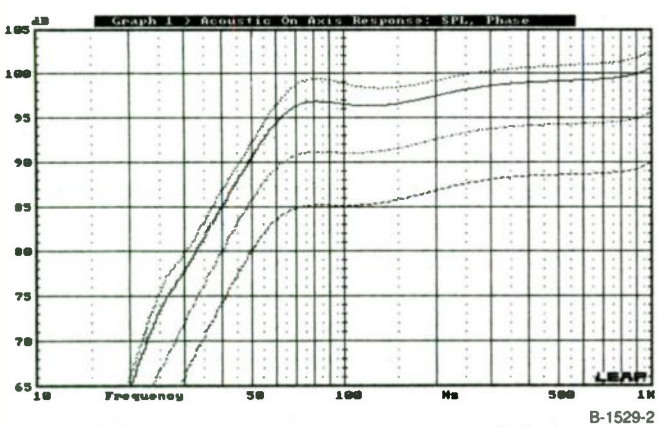

FIGURE 2: Low-frequency simulation of Vifa P17WJ with 50Hz box tuning at 1, 4, 16, and 32W.

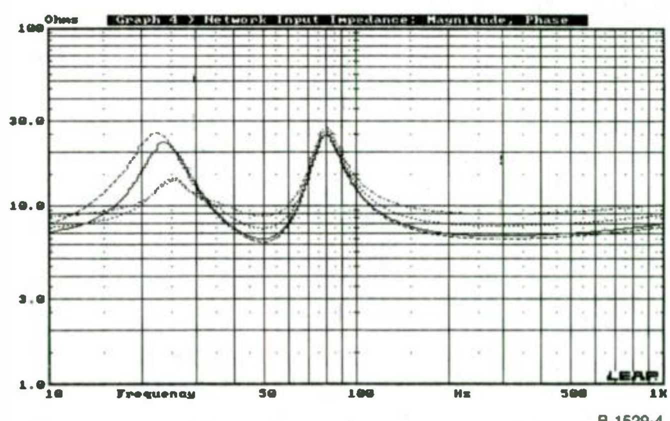

FIGURE 4: Simulation of impedance curves for *Fig. 2*.

was worth their cost. They come packed as a pair, and are double-boxed for safety. Although the front baffle is blank, the back of the cabinet is precut for a Madisound GB cup that you can order, and the latter comes with gold-plated five-way binding posts.

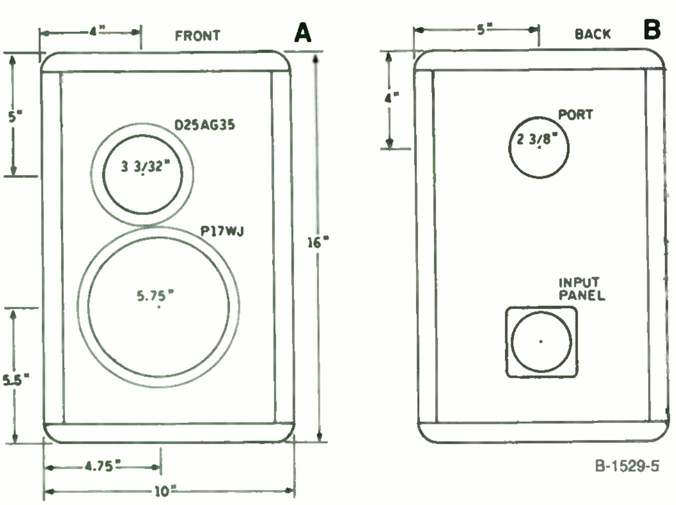

FIGURE 5: Driver and port placement details.

They also come fitted with a grille that attaches with male/female connectors. This is made from ¾″ medium-density fiberboard (MDF), so it can cause quite a problem with diffraction. To eliminate this, I decided to add a ¾″ MDF piece to the front baffle that would sit just inside the grille frame and be flush with the grille fabric. Mounting the drivers flush with this "top" baffle minimized if not eliminated diffraction from the grilles.

The grilles are cut from a single piece, forming a 1–1½″ frame that remains after you make a cutout. The hole, however, is not rectangular, but has rounded corners, and there is a bulge for the woofer, so determining the correct baffle size is a problem. My solution was to lay the grille with its fabric side down on top of aluminum foil and trace the outline of the inside of the grille frame on the foil with the rounded edge of a paper clip.

Using paper glue, I then attached the foil to a piece of cardboard, and bandsawed away the excess. I then used the foil/cardboard template to draw an outline of the inside of the grille on a piece of ¾″ MDF and cut it out on a bandsaw. I used a sanding block and file to smooth out the "top" baffle, and then test-fitted it to make sure the grille would fit around it.

I determined the driver locations by positioning them around the front baffle so that they were not equidistant from any edges. The tweeter is located 5″ from the top of the cabinet, 4″ from one side, and 6″ from the other. The woofer, because its size afforded less "wiggle" room, is 5½″ from the bottom, 4¾″ from one edge, and 5¼″ from the other. Since the driver locations are asymmetrical, I positioned them so that one speaker has the drivers to the left of center and the other has them to the right (*Fig. 5A*).

When you start laying out the holes for cutting, make sure you orient the speaker properly, meaning that the output hole is toward the bottom of the speaker. That's because you will install the port in the top part of the rear panel.

PHOTO 2: JM-2/vf speaker on Load Jockey 350, a 7′-high manual forklift.

CUTTING THE HOLES

Since the top baffle overlies the front one, I first cut holes in the front baffle. I cut a 3″ hole for the tweeter, which is very close in size to the tweeter can. However, so as to avoid "loading" the woofer, I cut a 6¼″ hole, which is larger than the woofer hole, in the top baffle. I also cut a 2⅜″ hole for the port in the back panel of the speaker, 4″ from the top of the cabinet and equidistant from the sides. I did all this cutting with a fly cutter on a 16″ drill press (*Fig. 5B*).

Before attaching the top baffle, I laid it down over the front baffle and positioned holes for six 1½″ × 8″ wood screws. I countersank the holes so the screw heads would sit flush. It's a good idea to position the drivers so that these screw holes are not too close to them. Glue the top baffle into place first; then use screws to secure it.

I roughed up the gluing area on the front baffle with some 125-grit sandpaper, then applied a layer of glue. I positioned the top baffle, and then placed the grille frame into its fasteners to make sure the baffle was properly aligned. Since the glue doesn't provide the holding power in this situation, but is used simply to align the two baffles, you need only a small amount. Use enough so that air can't escape from around the driver holes, but make sure the glue doesn't slop over the side onto the grille frames. After the glue dries, secure the top baffle with the six wood screws.

I drilled a 5¾″ hole for the woofer and a 3³⁄₃₂″ hole for the tweeter in the top baffle. Then, since the drivers must sit flush or just below the grille cloth, I rabbeted out ½″ wide ledges with a hand-held router fitted with a ½″ rabbeting bit. Determining the proper depth, however, took some figuring, since the woofer has a ³⁄₁₆″-thick surround that protrudes above the frame.

To measure the surround with the woofer cone fully extended, I hooked up the woofer to a couple of AA batteries. It has a 4mm X_{max}, and allowing for an extra couple of millimeters, I assumed that ¼″, which is close to 6mm, would be adequate clearance. Because the driver frame is ¼″ thick, I routed a ⁷⁄₁₆″-deep rabbet for the woofer. The tweeter also has a ³⁄₁₆″ faceplate that protrudes ⅛″, so I routed out a ⁵⁄₁₆″ rabbet. To finish off the woofer, I took a ⅛″ rounding bit to give the hole a nicer look, although I don't think it has much impact on diffraction.

PHOTO 3: JM-2/vf speaker "walks the plank."

Finally, I masked off the front and top baffle with newspaper and duct tape and spray-painted them with flat black paint. Make sure you press the tape tight; otherwise, paint will leak onto the cabinet sides.

PORT INSTALLATION

The ports are made of 2″ ABS pipe, commonly used for drain pipes in plumbing applications, and usually available in hardware stores. I prefer it to PVC because it is black. I cut the ports to 5³⁄₁₆″ in length, which should tune the box to 50Hz. After cutting the ports, I cleaned up the ends with some 120-grit sandpaper lying flat on the shop table. To smooth the inside rims, I used a sanding drum on a drill press to put a very slight bevel on the side that meets the exterior of the cabinet. I radiused the inside rim as best as I could. I used a wooden mallet to pound the ports into the cabinet, and then added trim rings, ordered from Meniscus, for a finishing touch, secured with a little Super glue.

Finally, I damped the inside of the cabinet by installing 1″ open-cell foam, which is available at hardware stores. I purchased mine from Eagle for about $12 for a 3′ × 12′ piece.

INSTALLING THE DRIVERS

I prepared the tweeter by trimming the felt rings to fit the flange. They are just a little larger in diameter than the driver's flange. Since the felt has a self-adhesive backing, I attached it after installing the driver, and I placed ³⁄₁₆″ × ⅜″ open-cell vinyl weather-stripping tape along the inside of the back of the tweeter's mounting plate. I then checked the tweeter's terminals with a AA battery to make sure I had the right polarity. If the driver moves outward when connected to the positive end of the battery, then you have the positive terminal for the driver.

To the tweeter, I soldered 16-gauge wire that has red and black plastic jacketing. Then, after drilling pilot holes with a ⁵⁄₆₄″ bit, I installed the tweeter with four 6 × ¾″ screws. When the tweeter was in place, I attached the felt ring. I confirmed the positive terminal of the woofer, soldered 16-gauge wire to the correct terminals, and then attached the woofer with four 6 × ¾″ screws. I waited to weather-strip the woofer until I had installed the crossover. *Photo 1* shows the finished speaker.

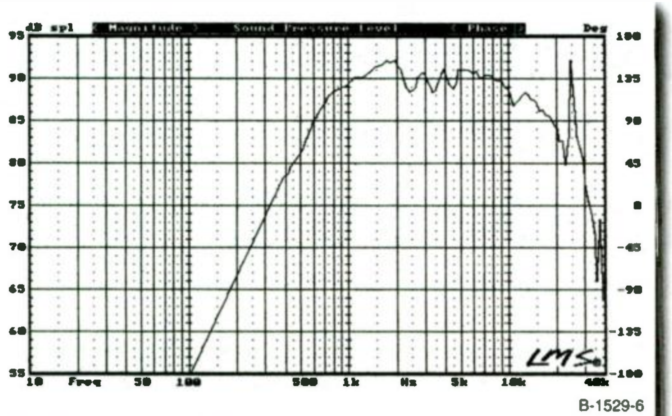

FIGURE 6: Vifa D25AG35 tweeter measured SPL on-axis at 2 meters with 4W; gated and ground-plane measurement.

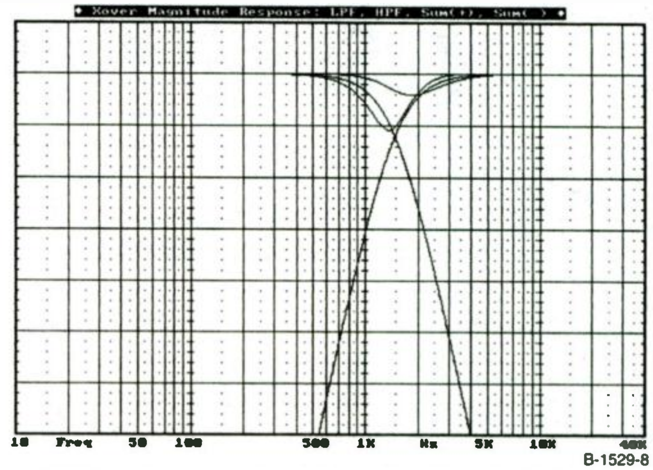

FIGURE 8: Crossover simulation of fourth-order Linkwitz-Riley with woofer and tweeter crossover at 1.5kHz with 125µs delay of woofer.

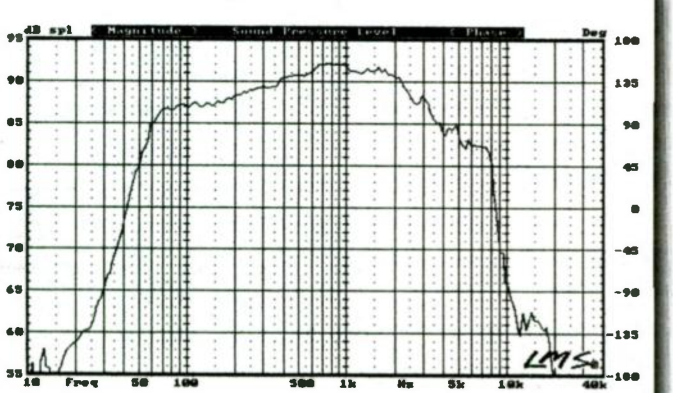

FIGURE 7: Vifa P17WJ woofer measured SPL on-axis at 2 meters with 4W; gated and ground-plane measurement.

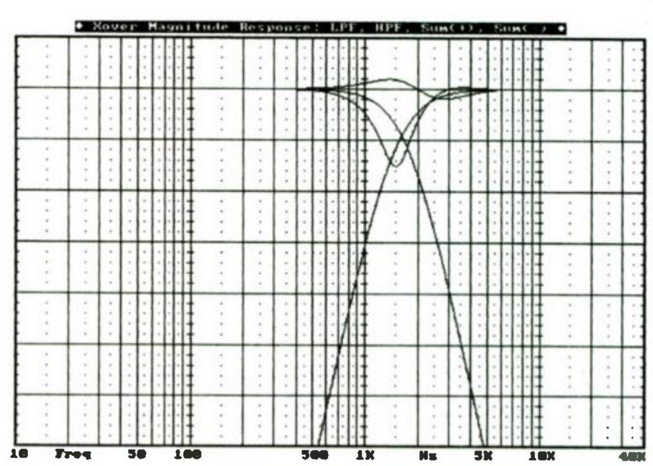

FIGURE 9: Same as *Fig. 8*, except with woofer crossover at 1.8kHz.

SPEAKER TESTING

Since the drivers are mounted on a vertical flat baffle, and the sound impulse starts at the center of the voice coil, the impulse from the woofer is delayed or behind the tweeter impulse. Since it is important to know the amount of delay for proper crossover modeling, this was the first measurement I made.

To measure interdriver time delay, I loaded up Liberty AudioSuite and clamped the loudspeaker to my shop bench. Then I measured impulses from both the tweeter and the woofer from about 3m on axis with the tweeter. The difference in the locations of the impulse peaks was 125µs, which corresponds to about 1⅝″, the distance from the front of the woofer frame to the top plate that sits atop the magnet.

Then, using LinearX's Loudspeaker Measurement System (LMS) in the gated mode, I measured the sound-pressure-level (SPL) response of each driver, eight feet above the ground on a crank-up stand, with 4W and from 2m away, and with the microphone on axis with the tweeter. This produced a quasianechoic measurement down to 250Hz.

Photo 2 shows the speaker on my Load Jockey 350, a manual forklift commonly used by air-conditioner installers. It has a 350 pound capacity and a lift range of 3″ to 7′. The microphone is mounted at the end of a ½″ × 30″ aluminum tube fixed to the end of a homemade stand made from a telescoping extension pole. My mike stand can extend from 6′ to 12′ in height. *Photo 3* shows the speaker on a little "plank" to extend it away from the over-wide forks.

I then took a ground-plane measurement of the woofer from 10Hz to 1kHz. In this case, I placed both the speaker and the microphone on the ground and measured from 2m with 4W. Since the ground-plane measurement was 6dB higher than the gated/quasianechoic measurement, I scaled it down to the level of the gated measurement and spliced it at 552Hz. These tasks I easily accomplished in LMS's process and utilities menu.

DROOPING RESPONSE

Figure 6 is the Vifa D25AG35's SPL response taken at 2m with the grilles on. The D25 response droops a bit, due in part to the felt ring and the grille fabric, which I had found in previous measurements to lower the output by 1-2dB in the 8-12kHz region. Between 1kHz and 5kHz, edge-diffraction dips of about 2dB are evident, caused by the grille-frame edges.

As pointed out by Joe D'Appolito,[2] for rounded edges to be effective in reducing edge diffraction, the edge radius must be comparable to a wavelength. For a ¾″ radius, this corresponds to a frequency of 18kHz. So the "ripple" in the 1kHz-5kHz region is due to the location of the tweeter, which is 5″ from the top edge, 11″ from the bottom, 4″ from the

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Great news from Swans!

New beautifully cabinets for Swans M1 kits are available in three finishes: piano black, solid walnut and rosewood veneer. Totally irresistible!

The Swans M1 speaker system is a two-way bass-reflex design. The front baffle is very narrow with rounded edges to reduce cabinet diffraction for better clarity and imaging. The internal panel and corner reinforcement substantially reduce unwanted cabinet vibrations. A flared port is mounted on the rear baffle for smooth transition from the port to cabinet boundaries. This provides linear bass performance and absence of port noise. The heavy-duty gold plated binding posts are mounted directly on the rear panel to enable easy cable connection.

The 5-inch paper/Kevlar cone woofer has a rubber surround, cast aluminum frame and a magnetically shielded motor system. This driver utilizes a central phase plug to avoid air compression, improving frequency response and dispersion. These key features greatly contribute to the M1's clear transparent sound and effortless dynamic performance.

The tweeter is a high-tech planar isodynamic design that employs Neodymium magnets and extremely light Kapton® film, with flat aluminum conductors.

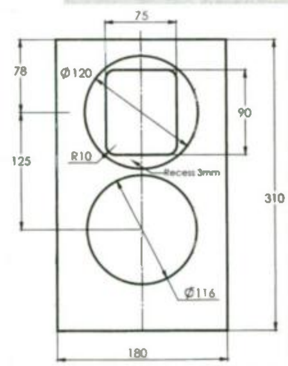
This unit provides an immediate and precise response to any transients in original signal, and gives the M1 an exceptional ability to reveal the true dynamics of instruments with a complex high frequency spectrum.

The crossover is a second order Linkwitz-Riley type resulting in an in-phase connection of the drive units. The crossover frequency between the two drivers is 3.3 kHz and only high quality polypropylene capacitors are used. Each filter has it's own dedicated board mounted on a special rubber interface to reduce vibrations and microphonic phenomenon. The filter boards are spaced inside the loudspeaker with the inductors positioned at right angles to minimize the interaction.

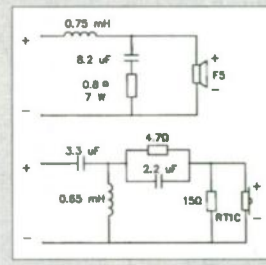
Swans M1 kit includes:
- 2x F5 paper/Kevlar bass-midrange drivers,
- 2x RT1C isodynamic tweeters with sealing gaskets,
- 2x dedicated tweeter crossovers,
- 2x dedicated bass-midrange crossovers,
- two flared ports,
- two pairs of heavy duty gold plated terminals.

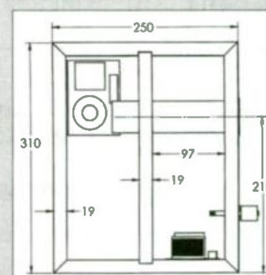
The drawings of the cabinet shown here represent general dimensions required for optimum bass performance. Rounded corners are advisable as they improve imaging and clarity. Actual finish and appearance is a matter of personal taste.

Price: $410 delivered without cabinets;
$660 delivered with cabinets.
Warranty 3 years. We accept VISA.

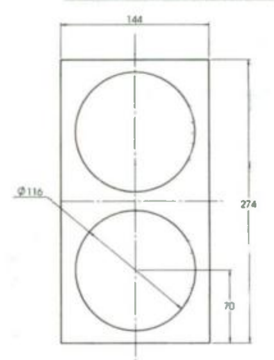


Front view

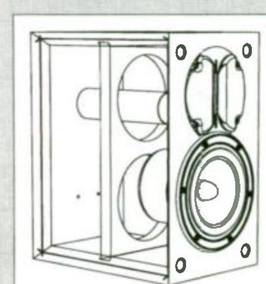




Right view of the cabinet with accessories(right side panel removed)



Internal panel



SPECIFICATIONS

Frequency response (1m,half space)	60Hz-35kHz,±2dB 55Hz-40kHz,-3dB
Sensitivity,1W/1m (100Hz-8kHz averaged)	86 dB
Nominal impedance (7.2 ohms minimum at 250 Hz)	8 ohms
Power handling	50W nominal, 90W music
Dimensions,HxWxD	310x180x250 mm

Amplifier requirements:
30W recommended minimum.

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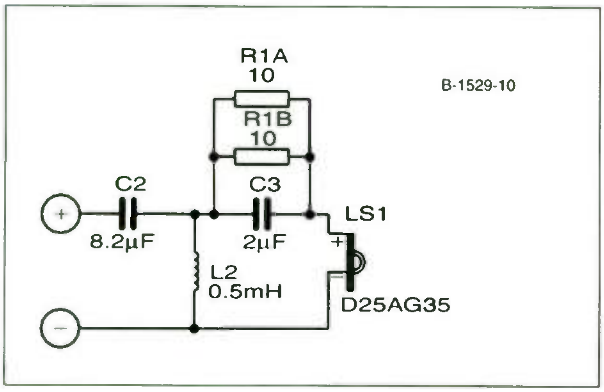

FIGURE 10: Crossover schematic for Vifa D25AG35 tweeter.

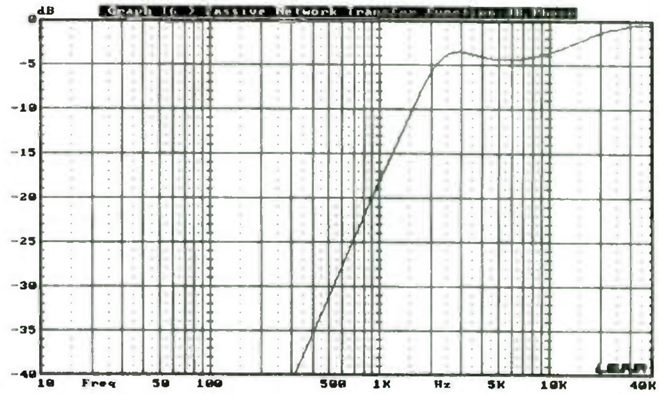

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FIGURE 13: Simulated tweeter crossover passive-network transfer function.

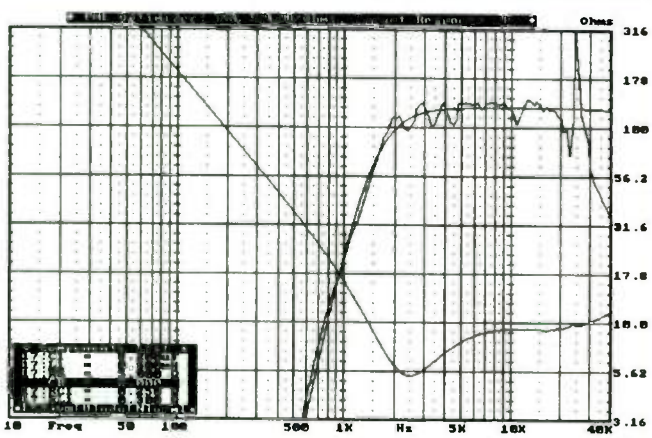

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FIGURE 11: Simulated tweeter SPL and impedance response with crossover optimized to fourth-order Linkwitz-Riley target.

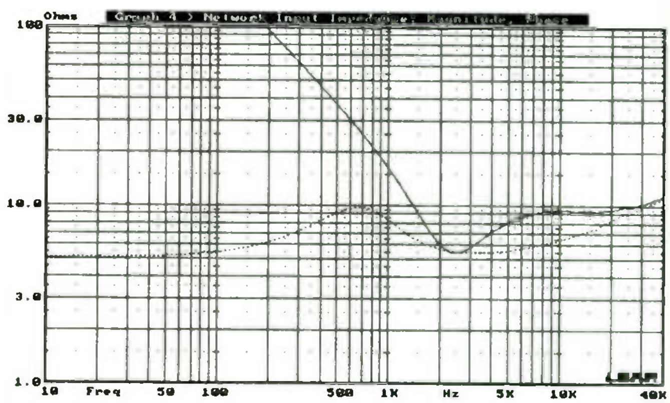

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FIGURE 14: Simulated tweeter impedance with and without crossover network.

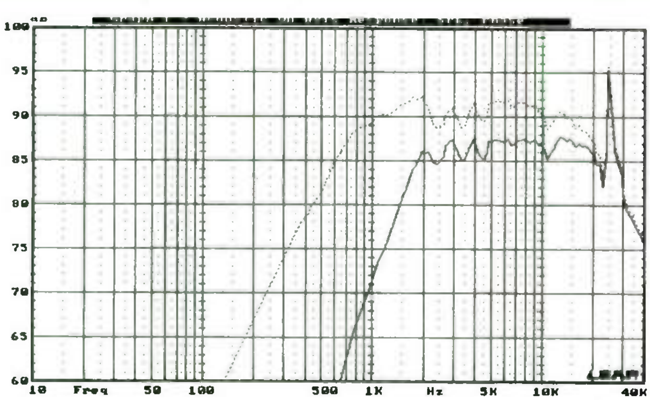

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FIGURE 12: Simulated tweeter SPL response with and without crossover network.

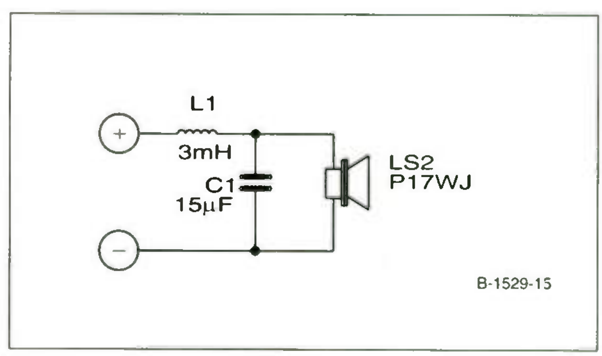

FIGURE 15: Crossover schematic for Vifa P17WJ woofer.

left edge, and 6″ from the right. Also, some of the diffraction is caused by the woofer, since the cone creates a cavity. The tweeter's response below 450Hz was "tail corrected" with an LMS utility to 12dB/octave to remove the jagged response of the gating measurement as the signal falls into the background noise.

Figure 7 is the P17 woofer's full-range response. As I mentioned previously, the gated measurement was spliced to a ground-plane measurement at 552Hz. It shows the overall response and shape of the measurement to be close to the simulation; however, the response is about 2dB higher than simulated. Above 2kHz the woofer's response falls off a little faster than expected, which may be due to the slight recessing of the driver or a change in driver parameters. The P17 measured in *Loudspeaker Recipes 1*[3] has a more extended response—out to 7kHz.

Finally, I measured the driver's impedance with LinearX's VI box at a 4W level

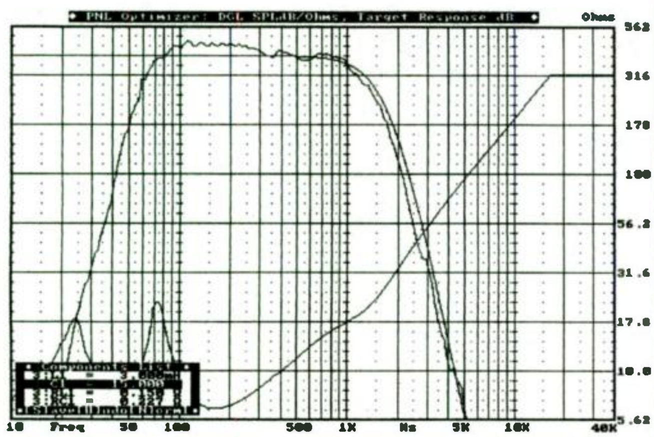

FIGURE 16: Simulated woofer SPL and impedance response with crossover optimized to fourth-order Linkwitz-Riley target.

FIGURE 18: Simulated woofer crossover passive-network transfer function.

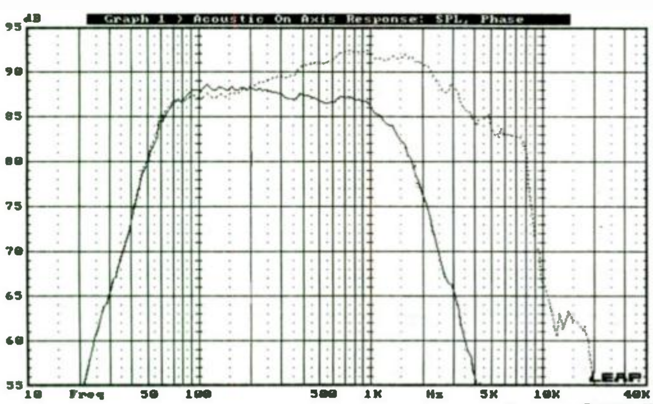

FIGURE 17: Simulated woofer SPL response with and without crossover network.

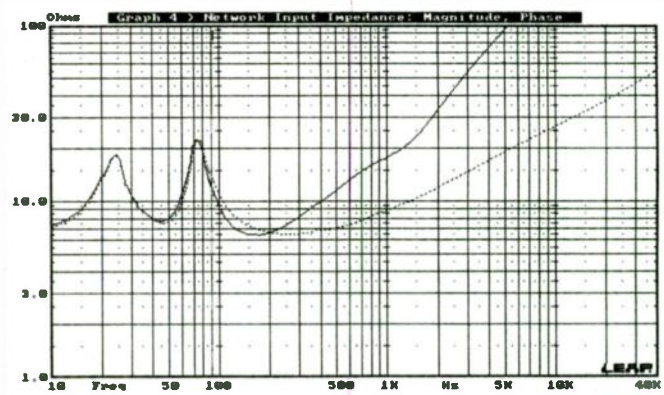

FIGURE 19: Simulated woofer impedance with and without crossover network.

via the constant-current method. I believe it's important to measure the drivers at levels that are close to the power levels at which they will eventually be played. In that way, the SPL and impedance measurements will correspond to "real" situations. I have found that below 150Hz, impedance measurements done at lower power levels with the constant-voltage method can vary by several ohms compared to the constant-current method.

Prior to my importing the measurements into LEAP, some additional processing of the data was necessary. I made tail corrections to both the woofer and the tweeter measurements at the extreme ends of the spectrum to remove noise that occurs as the signal drops to a very low level. For the tweeter, I made the correction at 30kHz and 450Hz; for the woofer, at 25Hz and 12kHz. Finally, phase for the response is generated using the Hilbert transform. All of these processes are available in LMS.

CROSSOVER DESIGN

I imported the impedance measurements and the SPL data into LEAP, where I designed and evaluated several crossovers. I usually choose fourth-order Linkwitz-Riley crossover slopes for all of their positive attributes.[4] I chose a 2kHz crossover point since it is about two octaves above the tweeter's 670Hz resonance. Because the tweeter's voice coil is damped with ferrofluid, tweeter excursion was not a concern. Also, the P17's response starts to narrow above 2kHz[3], so a crossover at that point would improve the system's dispersion. And since the woofer has 87dB of output at 100Hz, and the tweeter starts to fall below 87dB above 15kHz, I chose 87dB as the target sensitivity for the crossover optimizations.

My initial tweeter crossover was a third-order design. (In case you are confused, a third-order electrical filter combined with the tweeter's second-order rolloff can be made to optimize to a fourth- or fifth-order rolloff target.) However, since I wished to minimize crossover parts, I tried a 1.5kHz crossover point, and found I could achieve it with a second-order crossover.

A quick check of LEAP's crossover utility showed that due to the woofer's 125µs delay, a 2dB dip develops at the crossover point if both the woofer and tweeter have a 1.5kHz crossover (*Fig. 8*). However, by "overlapping" crossover frequencies, you can lessen the dip with the tradeoff of having a peak. By raising the woofer crossover point to 1.8kHz and leaving the tweeter at 1.5kHz, a 1dB hump in the response is followed by a 1dB dip (*Fig. 9*).

So I then designed several second-order circuits for the tweeter, and optimized their responses to 1.5kHz with fourth-order Linkwitz-Riley slopes. Similarly, I tested several woofer circuits and optimized them with a fourth-order Linkwitz-Riley slope at a cutoff frequen-

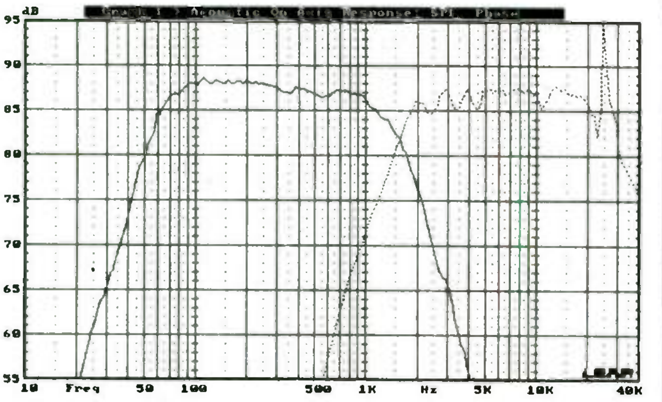

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FIGURE 20: Simulated individual SPL response of tweeter and woofer, showing crossover point.

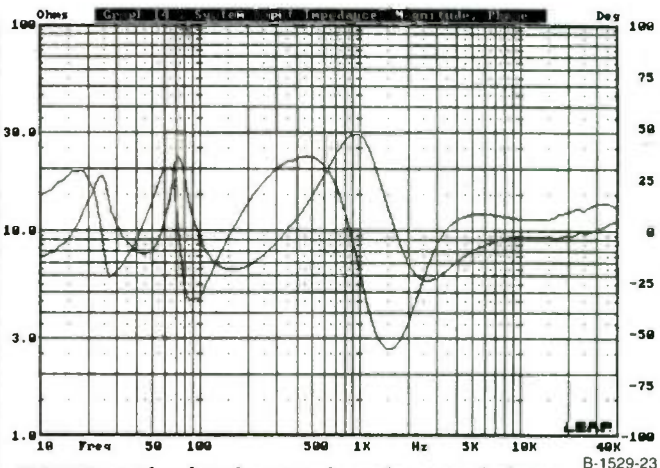

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FIGURE 23: Simulated system impedance and phase.

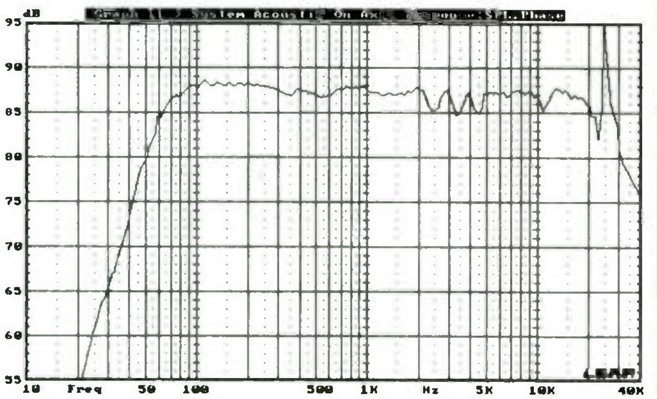

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FIGURE 21: Simulated system SPL response of tweeter and woofer.

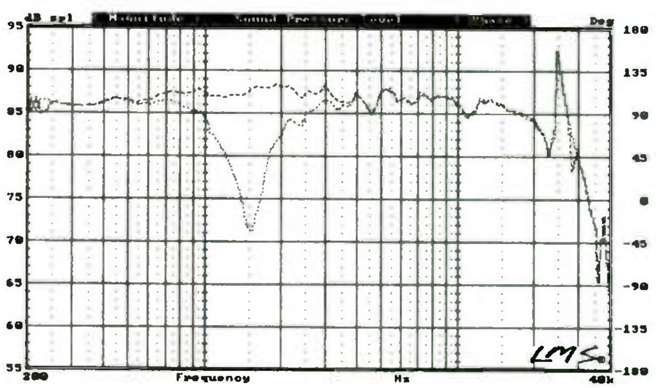

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FIGURE 24: Measured system SPL response and reverse-polarity SPL response on-axis at 2 meters with 4W; gated measurement.

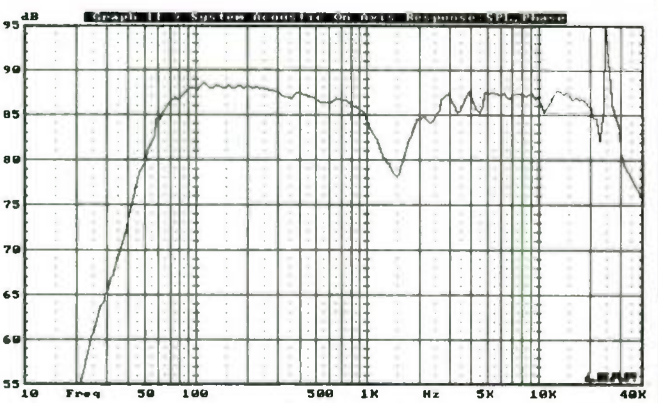

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FIGURE 22: Simulated system SPL response of tweeter and woofer with electrical polarity to one driver reversed.

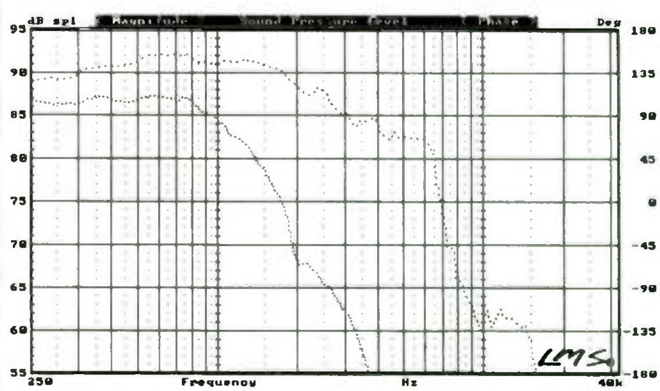

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FIGURE 25: Measured woofer SPL response with and without crossover.

cy of 1.8kHz.

Figure 10 is the best and final tweeter circuit. C2 and L2 form the high-pass network. R1 attenuates the response, while C3 shorts R1 at higher frequencies to boost the tweeter's drooping response. I found no Zobel or series RLC networks necessary. *Figure 11* shows how the optimized response fits the target; it also shows the impedance of the driver and the circuit. By the way, R1 uses two resistors to increase power handling.

TWEETER RESPONSES

Figure 12 shows the response of the tweeter with and without the crossover. *Figure 13* is the network's transfer function; it shows the crossover has a .5dB peak at the "knee," and has less attenuation above 8kHz due to the boost capacitor C2. Also note that the signal to the tweeter is down some 26dB at the tweeter's 670Hz resonance. *Figure 14* shows the crossover-network impedance compared to the tweeter's impedance curve.

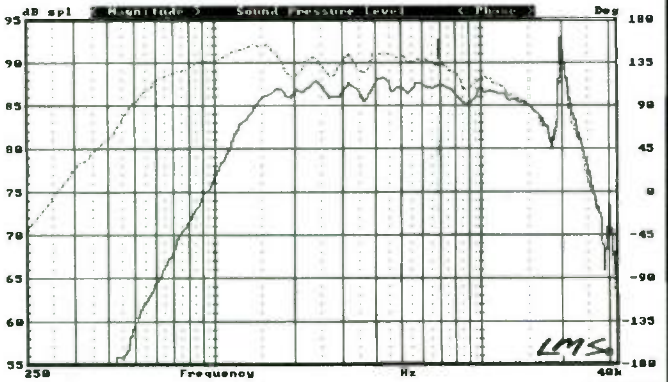

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FIGURE 26: Measured tweeter SPL response with and without crossover.

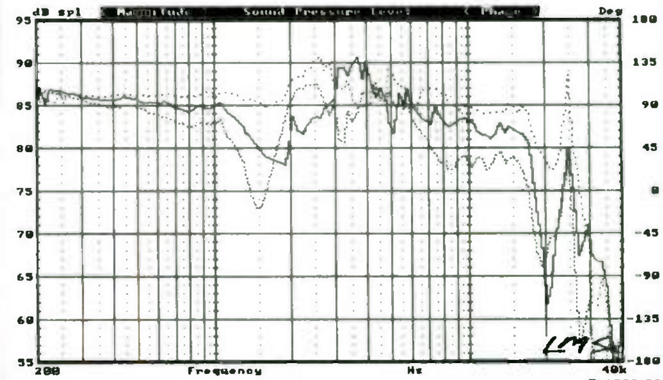

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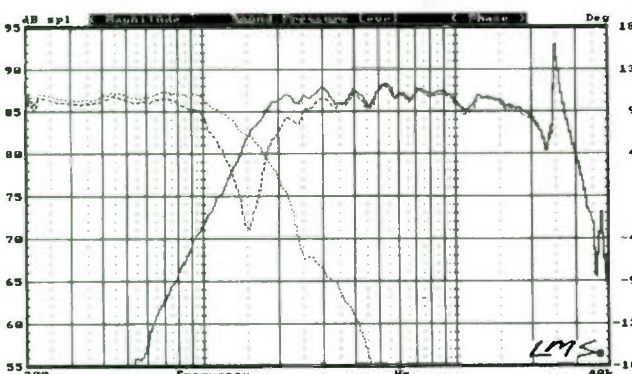
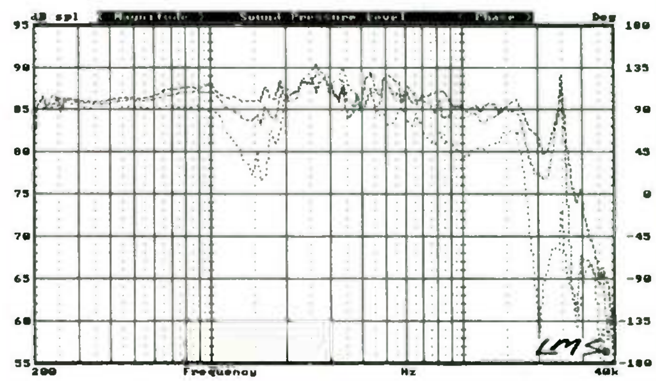
FIGURE 29: Measured system SPL response at 15, 30, and 45 degrees below tweeter axis.



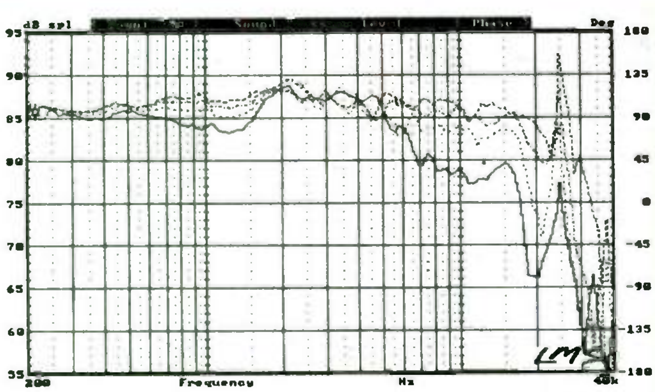
B-1529-27

FIGURE 27: Measured reverse-polarity SPL response plus woofer and tweeter SPL response.



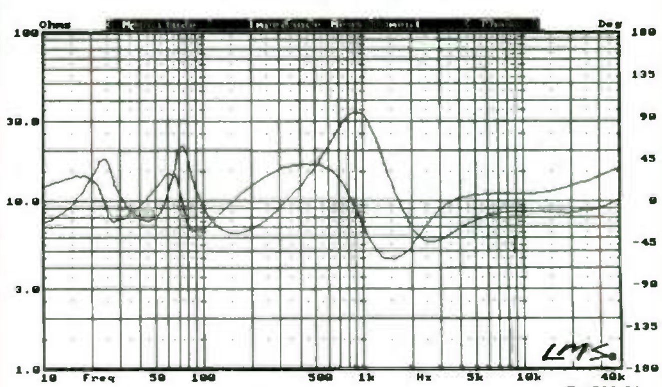
B-1529-30

FIGURE 30: Measured system SPL response at 15, 30, and 45 degrees above tweeter axis.



B-1529-28

FIGURE 28: Measured horizontal system SPL response at 0, 15, 30, and 45 degrees off tweeter axis.



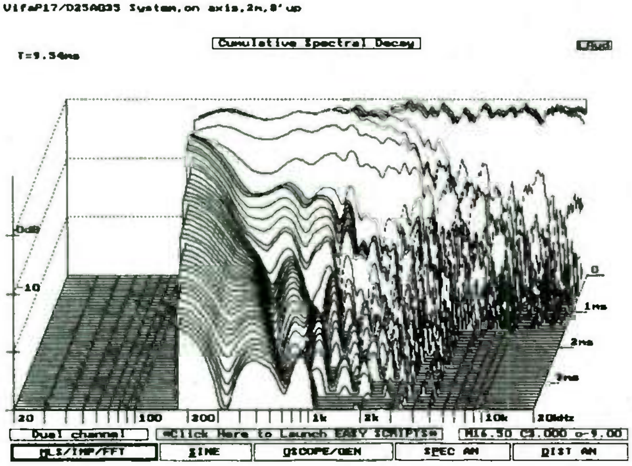
B-1529-31

FIGURE 31: Measured system impedance and phase.

Figure 15 is the woofer circuit. L1 and C1 form the low-pass network. No zobel or series RLC networks are necessary. *Figure 16* shows how the optimized response fits the target; it also shows the impedance of the driver and the circuit. *Figure 17* shows the woofer with and without the network. *Figure 18* shows the network transfer function, and *Fig. 19* its impedance with and without the crossover.

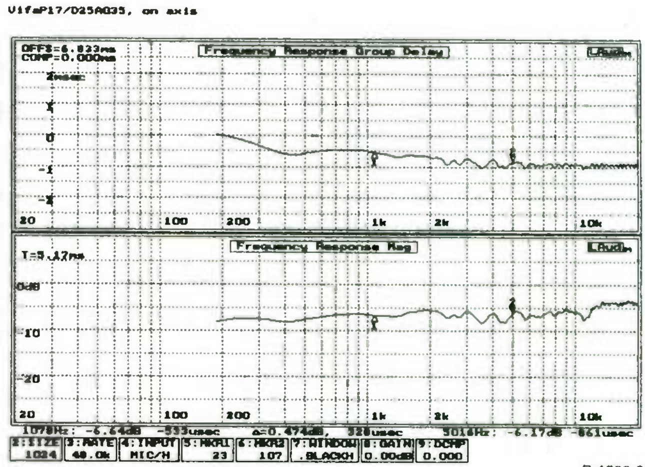
As you can see in these curves, the interaction of the woofer's impedance peak and L1 forms a 1dB boost between 80 and 180Hz. This could have been corrected with a series RLC, but I ignored this because the peak was relatively small, which meant it would add a little bass without causing too much of a drop in the impedance. Also, it would mean three fewer parts in the crossover.

Figure 18 shows that a theoretical second-order transfer function would not optimize the woofer, since the actual transfer function has a "knee" at 200Hz to compensate for the fall in the woofer's response due to "spreading



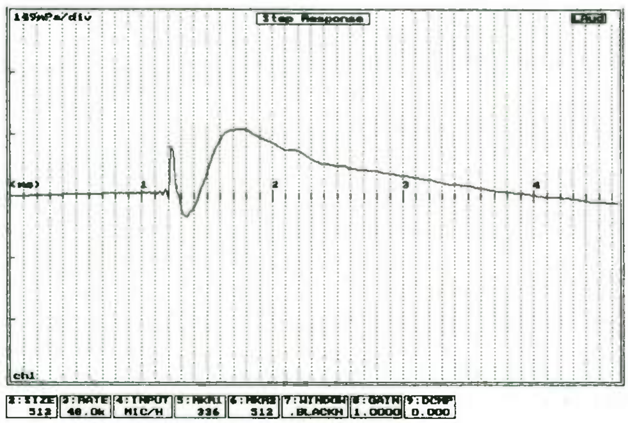
B-1529-32

FIGURE 32: Measured cumulative spectral decay for driver resonances.



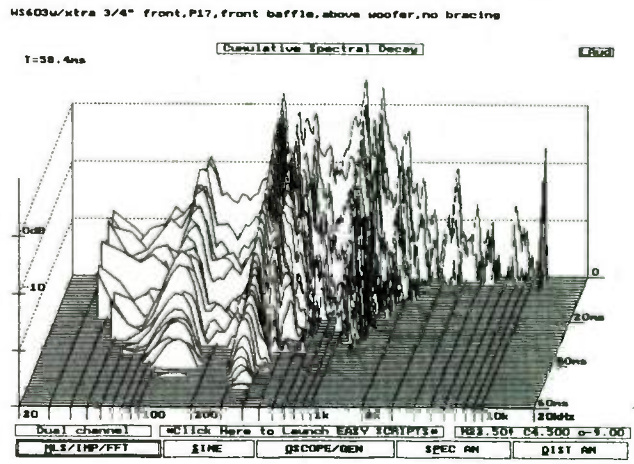
B-1529-34

FIGURE 34: Measured system group delay on tweeter axis.



B-1529-33

FIGURE 33: Measured system step response on tweeter axis.



B-1529-35

FIGURE 35: Measured cumulative spectral decay for front-baffle resonances.

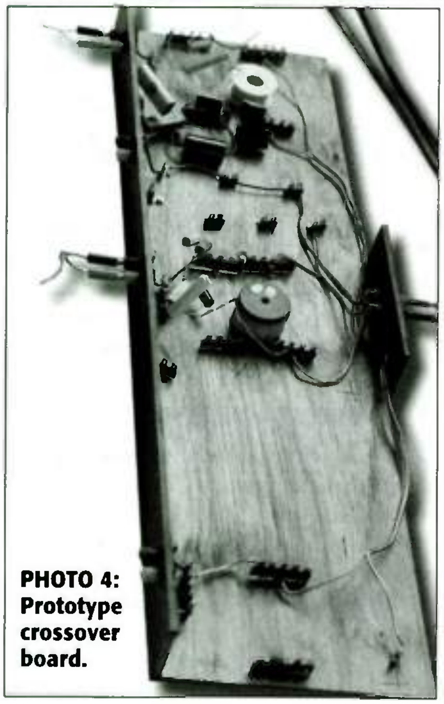


PHOTO 4: Prototype crossover board.

loss,"[5] which is related to the longer wavelengths at the lower frequencies wrapping around the speaker cabinet. At around 1.25kHz, a second "knee" develops, followed by a steeper rolloff than in the 200Hz to 1kHz region.

Figure 20 shows the tweeter and woofer with their crossovers and a crossover point at 1.6kHz. *Figure 21* is the full-range response predicted by LEAP. *Figure 22* is with the tweeter polarity reversed, showing a 9dB "dip" or cancellation, indicating the crossover is "in phase." *Figure 23* shows the combined or system impedances of the drivers and their crossovers. While impedance stays above 5.5Ω, phase does drop to –62° at 1.5kHz.

PROTOTYPE CROSSOVER CONSTRUCTION

To test the crossover before installing it in the speaker I placed the crossover components on a prototype board, which is simply a ¾″ plywood board with a 2″-tall, ¼″ masonite front and a back in which I have installed banana plugs for the left and right channels. The crossover parts are attached to terminal strips. I replaced the speakers' normal cup with a plate having multiple pairs of banana plugs. The drivers are wired to each pair of plugs. *Photo 4* shows a crossover board for three-ways.

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1. Dickason, V., *The Loudspeaker Design Cookbook*, Fifth Edition, 1995, Audio Amateur Press, p. 19.
2. D'Appolito, J., *Testing Loudspeakers*, First Edition, 1998, Audio Amateur Press, p. 59.
3. Dickason, V., *Loudspeaker Recipes 1*, First Edition, 1994, Audio Amateur Press, p. 9.
4. Dickason, V., *The Loudspeaker Design Cookbook*, p. 108.
5. D'Appolito, J., *ibid*, p. 58.

MEASURED PERFORMANCE

LEAP is very effective in designing and optimizing crossovers. *Figure 24* shows the system response measured at 2m/4W, gated at eight feet up from the ground. The response is quite close to the simulated one, although the reverse-polarity measurement shows a 16dB dip deeper than predicted. Also, above 15kHz there is a 2dB droop that is greater than the simulation. *Figures 25* and *26* show the drivers with and without their crossovers. *Figure 27* shows how the drivers cross over, and how that compares to the out-of-phase connection.

Off-axis measurements are shown in *Figs. 28, 29*, and *30*. Horizontally, because of the relatively low 1.5kHz crossover point, dispersion is very good out to 45° at 4kHz, where the tweeter starts to beam. At the crossover point, the 45° measurement is only down by 4dB. In *Fig. 29*, as you move more than 15° below the speaker, an 8–13dB suckout develops in the crossover region. This is probably partly caused by the woofer cone acting as a cavity. However, in *Fig. 30* you can see that even at 30° up there is only a 3dB dip in the response at the crossover point. That is one advantage of a 1.5kHz crossover point versus a higher point. By the way, *Figs. 29* and *30* do not include the on-axis measurement, but only the 15°, 30°, and 45° off-axis measurement. System impedance (*Fig. 31*) closely tracks the simulation.

Switching to Liberty AudioSuite for time-based measurements shows the systems to be relatively clean of resonance. *Figure 32* shows there are no major resonances in the response above 100Hz. Of course, if Liberty AudioSuite could measure out to 40kHz the aluminum dome resonance would show up as a ridge at 25kHz. The step response (*Fig. 33*) shows the tweeter and woofer to be wired normally, with both drivers moving forward with the signal. And, since the drivers are not time-adjusted—there being a 125μs time delay between the woofer and the tweeter, as well as the use of higher-order networks—it is clear that the woofer is about 400μs, or .4ms behind the tweeter. This is also borne out in *Fig. 34*, which shows that the group delay below 2kHz is about .4ms, thus reflecting the woofer's response.

Since this project was meant to be relatively low budget, I made no effort to damp the cabinet resonances, but out of curiosity I attached an AMP accelerometer to the cabinet front and side, and the results are shown in *Figs. 35* and *36*. Some strong modes are evident at around 130Hz and 300Hz. In previous testing I've found that front-to-back and side-to-side bracing will lower the peaks by 10–15dB.

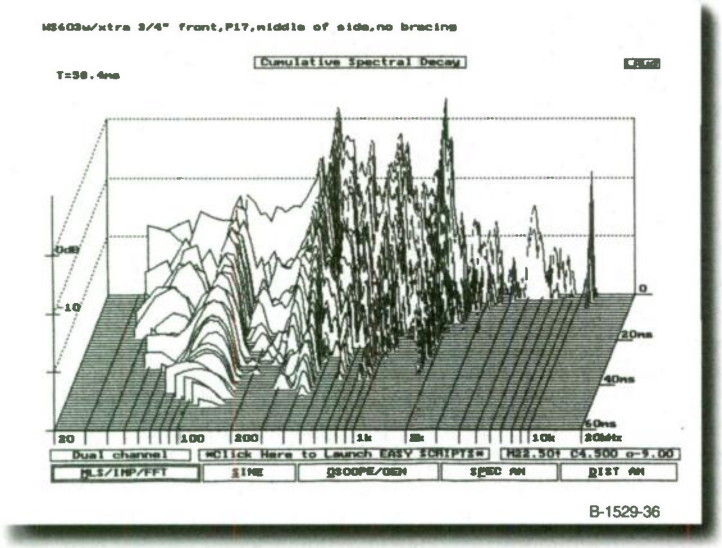

FIGURE 36: Measured cumulative spectral decay for side-panel resonances.

SUBJECTIVE TESTING

Once hooked up to my system, which is composed of a Van Alstine Transcendence Series Two preamp, a Van Alstine MOSFET 120D power amp, and a Van Alstine FET 3 CD player, the speakers were surprisingly musical and enjoyable. Although they have limited bass extension (my current system has a biamped Vifa M22WR with an F_3 of 32Hz), they did well on most popular music. Highs were very clear and crisp, vocals were clear with no signs of resonances, and bass impact was very good. They also imaged well. My friend thought they sounded wonderful, and he was very pleased.

FINAL CROSSOVER CONSTRUCTION AND INSTALLATION

I assembled the crossover parts on a 5″ × 6½″ piece of ½″ plywood, soldering them to terminal strips attached to the plywood with ½″ screws. I tied the inductors into place with some copper magnet wire, for I've found that plastic ties fail after a few years. I also secured the capacitors and resistors with hot-melt glue to minimize vibration effects.

The crossover boards are located in the bottom of the speaker, held in place with two wood screws. I drilled two 3⁄16″ holes in the board between the parts. Since the speakers are too small for a hand drill, I used a hand awl to provide holes for the screws. I then placed the foam that goes in the bottom on top of the crossover board, and installed the woofer after affixing foam weather stripping.

I welcome comments or questions on the design; you can reach me at jimbo@maui.net.

ACKNOWLEDGMENTS

Many thanks to Vance Dickason, whose books and advice I much appreciate. Also, I wish to thank Glenn Phillips of The Speaker Clinic, as well as Chris Strahn and Mike Frost at LinearX, for their patience and assistance.

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This is the first of a three-part series that takes a close look at transmission-line design. You'll discover what types of speakers are considered TLs and how they work.

Part 1

Transmission Lines: The Real Story

By A. Monk

The designation "transmission line" (TL) in speaker design is used very imprecisely by amateurs. To define a TL, first you must understand how a TL works. But before that, you need a short definition: a TL is what A.R. Bailey built (*Fig. 1*).

What is *not* a TL is a Voigt pipe, a labyrinth, a reflex box and the vented box from which it evolved, or even a TL design that does not meet the performance criteria that Bailey defined. Thus, paradoxically, a ¼λ line that is not optimally stuffed is not a TL, though in a limiting case it is a TL's predecessor, and it should be referred to as a Helmholtz resonator. If these distinctions are confusing, I hope to clarify them in this series.

BAILEY'S TL MODEL

In October 1965, the British magazine *Wireless World* [now *Electronics World*—Ed.] published an analysis of A.R. Bailey's investigations of a long line stuffed with long-hair wool in the suppression of a driver's back wave. This paper formed the basis of the transmission-line concept. Previous to this analysis, the majority of loudspeakers were of a "bass reflex" design, characterized as a box with a port; neither the box volume nor the port dimensions were well defined or related to the driver characteristics. This produced a sound characterized as a "boom box," with the cabinet acting as a Helmholtz resonator for the lowest frequency produced and adding coloration to the LF output.

The signal that Bailey used for the TL and the bass reflex was a pulse having a flat spectral response, obtained from an exploding wire. The bass reflex exhibited a ringing output well past the 5ms mark, while the TL showed an impulse that was critically damped within the first millisecond. This was probably the first instrumentation of a speaker's transient response. He also identified the bandwidth slope characteristics (*Fig. 2*): "The effect of the abrupt change in the slope of the amplitude/frequency characteristics is to give ringing, at the frequency where the slope change takes place. This effect is unavoidable and the necessary price to pay for the extension of bandwidth by the use of resonance effects."

This definition, applicable for the bass reflex, is true for even the vented box, which was developed once the T/S parameters were understood. This is currently characterized as group delay. The experiments were made with a folded pipe of about 8′ and packed "loosely, about one pound to every two to three cubic feet." This would result in a D_T ~0.5. There does not seem to be any record of the systematic investigation of the D_T value for other TL line lengths (*Fig. 3*).

MISCONCEPTIONS

The imprecision of the stuffing density has proven a major cause of misunderstandings in modern TL design methodology, since the majority of practitioners have adopted this D_T value regardless of the TL column length. Bailey characterized the effects of the driver's parameters on the TL response: "As the acoustic loading of the pipe is, therefore, dominat-

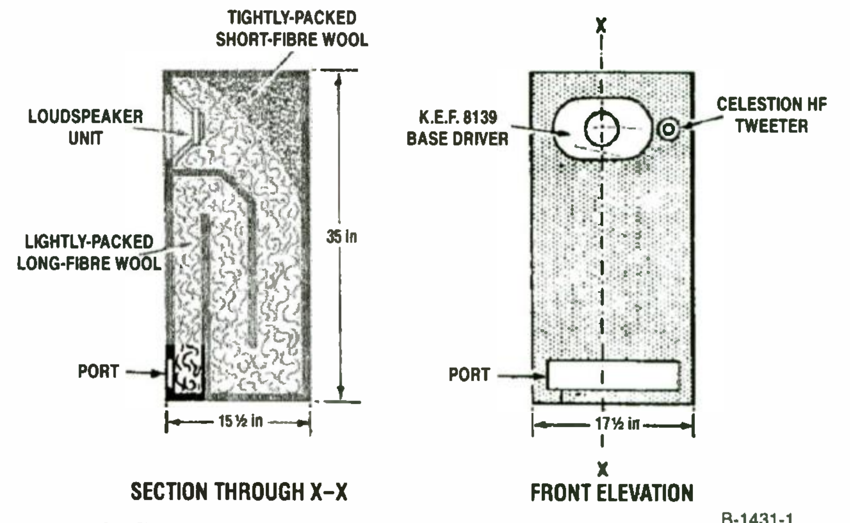

FIGURE 1: The first TL.

ABOUT THE AUTHOR

A. Monk is a retired and retiring amateur, who has devoted the last three years to TL study and research. His effort, like that of the medieval monks, is a translation of what others had done and has unfortunately been misinterpreted.

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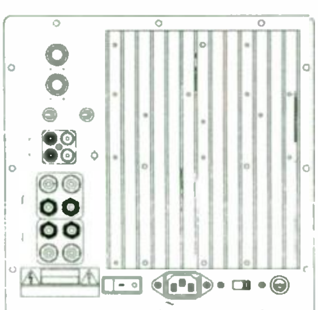

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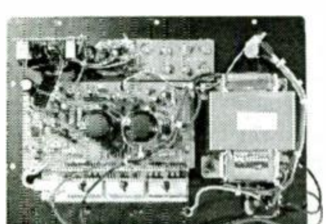

Rear view of KG-5150

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Peerless 831727	10"	2.25	V	10"	26.7	220
Peerless 850146	10"	3.1	V	8.1"	23.8	220
Peerless 831857	12"	6	V	7"	23	220
Peerless 831857	12"	3	S	-	28	220
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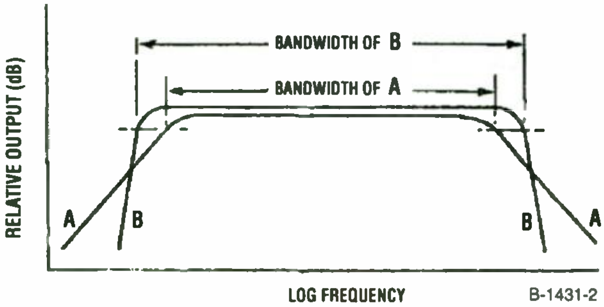


FIGURE 2: Bandwidth comparison.

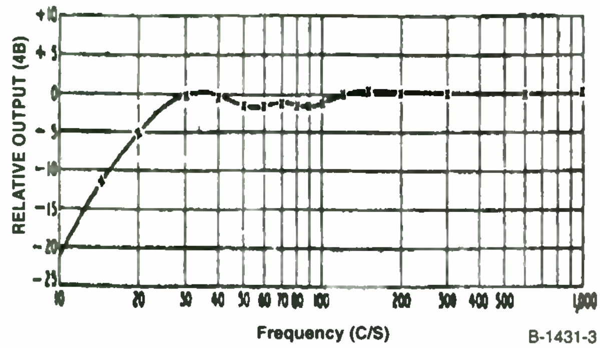


FIGURE 3: Bailey's TL's frequency response.

FIGURE 4: Flared woodwind instrument.

ing the speaker unit, the low frequency wave form will be better as the non-linearity in the loudspeaker unit will be swamped by the linear acoustic loading." This distinction has not been understood, since many use the example of the box response of the driver's response as equivalent to the line's response.

Bailey apparently also investigated the closed acoustic labyrinth cabinet: "Acoustic labyrinths have been used in the past in an attempt to 'lose' the sound down multiple paths—but the size needed is excessive. Unless there is adequate internal lagging, then these cabinets will also possess pronounced energy storage and consequently lack sound clarity." This warning is apparently misunderstood by a currently well-regarded constructor of the TL.

Overall, his was a remarkable achievement, which unfortunately was not extended by modern instrumentation and analysis unavailable to him. Misinterpreting the D_T value has caused controversy and resulted in attempts to link speaker parameters to TL length, producing aberrations in design methodology. These cannot be attributed to Bailey's pioneering work, but to the abandonment of the principle of experimentation based on measurements that Bailey employed.

A more insidious misunderstanding has been perpetuated from the comparison of the TL to the bass reflex: that the vented box, the successor to the bass reflex, is related to the transmission line. This is insidious, in my opinion, because it has stymied the development of an adequate mathematical model of the TL. Bailey clearly differentiated the acoustic principles of the two designs. However, they can be summarized as:

- Vented box is designed as $Q_C = 1.00$, with the port tuned to the resonant frequency of V_B. The design impedance has the characteristic of a double peak, and the group-delay curve reflects this resonance notch and has a much higher value below the notch. This results in a high group delay and a poor transient response.
- The TL has a $Q_{TC} < 0.5$; that is, it is critically damped and the terminus response is acoustically vector summed with the speaker response and can be analyzed as independent of the driver characteristics. The impedance curve is quite flat and the group delay is also good, bettered only by the sealed box. The critically damped TL has a good LF transient response and a low harmonic distortion.

MUSICAL INSTRUMENT ANALOGY

In its simplest form, a TL is a straight pipe with a woofer at one end and bears a superficial resemblance to the organ pipe. Therefore, it is similar to the musical instruments of the woodwind family. This analogy may help us to understand the characteristics of the TL's resonance and will permit me to define some terms that I'll use later.

For our purpose we can divide the woodwind family into two categories:

First, the straight bore terminates in a bell at the terminus, as with the clarinet (*Fig. 4*). The fundamental note has a wavelength that is four times the length of the bore and a harmonic series of odd-numbered fractions (⅓, ⅕, ⅐, and so on).

The second group is a cylindrical bore open at one end, such as the flute and organ pipes (*Fig. 5*). The lowest, or fundamental, frequency of resonance has a wavelength 2× the length of the bore. It will also resonate in a harmonic series of integral fractions of the fundamental (such as ½, ⅓, ¼, and so on). From this we can surmise that the bell of the clarinet-type woodwind changes the impedance at the open end and produces a distinct resonance pattern.

The basics of a TL (*Fig. 6*) consist of:

1. A line length that defines the system's

FIGURE 5: Flute type woodwind.

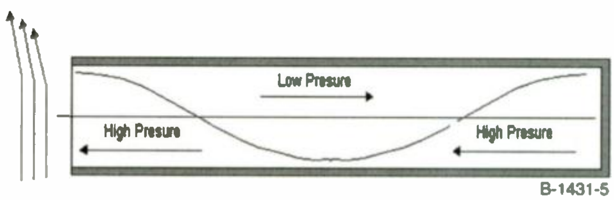
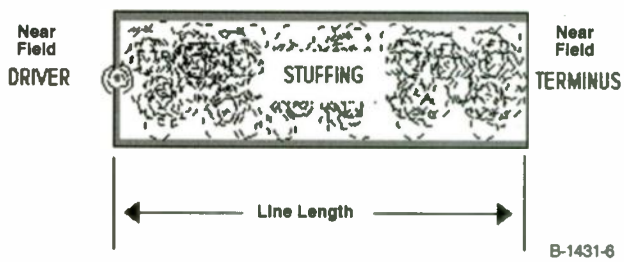


FIGURE 6: The basic TL speaker.



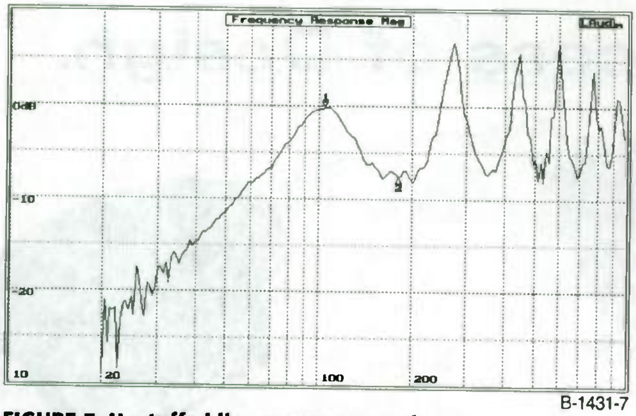


FIGURE 7: Unstuffed line response graph.

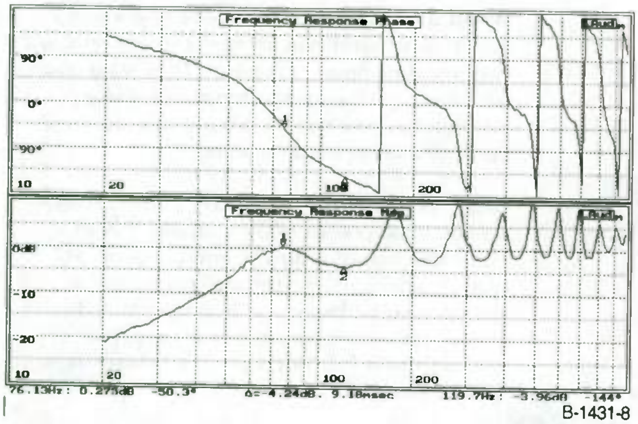


FIGURE 8: Magnitude and phase data (TL = 1.56m, Dtr = 1 terminus response).

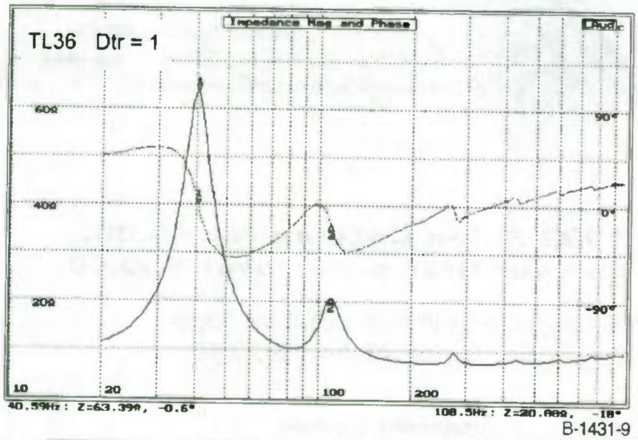


FIGURE 9: TL response (0.9144 meter line)—unstuffed line.

TABLE 1
MEASURED VS. CALCULATED RESPONSES

FREQUENCY	CALC.	MEASURED	SHIFT	
F_R fundamental	94.2Hz	104.3Hz	+12.1Hz	+8.6%
First harmonic null	188.3	180.8	–7.5Hz	–4.0%
Second harmonic peak	282.5	273.2	–9.3Hz	–3.3%
Third harmonic null	376.7	352.8	–23.9Hz	–6.3%
Fourth harmonic peak	470.9	446.6	–24.3Hz	–5.2%
Fifth harmonic null	565.0	533.1	–31.9Hz	–5.7%
Sixth harmonic peak	659.2	599.8	–59.4Hz	–9.0%

For a TL line = 0.9144m

resonance and the low-end frequency response.

2. A woofer at one end that defines the mid-frequency response.
3. The terminus, the open end of the pipe.
4. The fiber mass in the line shaping the low-end response.

Since the TL's response is defined by the combined response of the driver and the terminus, it is useful to separate the combined response (system response @ 1m) from the individual components, which are usually referred to as near field (microphone no more than ¼" from the source), the woofer and terminus responses. The fiber mass in a line is defined as

$$D_T = \frac{\text{fiber weight}}{\text{line volume}}$$

When normalized, this fiber density equation is expressed as

$$D_{TR} = \frac{P}{P_a}$$

where $P = D_T$, the fiber density and Pa = nominal air density = 1.18kg/m^3 Thus, $D_{TR} = 1$ is the definition of an unstuffed line.

While resembling the organ pipe, the TL has different resonance characteristics. Unlike the organ pipe, which has the energy source at the open end, the TL has the source at the closed end. Thus the TL produces an absorption and compression response. The harmonic series is the same as that of the flute but the fundamental frequency is defined as one-quarter the line length. It is interesting to note that if the TL line is passive, its absorption resonance is the same as that of the flute; that is, wavelength = 2× line length.

Figure 7 illustrates the harmonic series of peaks and nulls related to line length. The unstuffed line = 0.9144m; Mk 1 defines the Fr frequency; Mk 2 defines the first harmonic; the second peak = second harmonic; and the second null = third harmonic.

Table 1 shows the divergence of measured versus calculated data due to the progressive phase shift of air density with frequency.

The resonance phenomenon, which is documented in the J. Backman study and mentioned briefly in the following design section, has an interesting bearing on the question of line taper for the TL.

EVOLUTION OF A MATHEMATICAL TL MODEL

Bullock's T-matrix model. Bailey's original work lacked a mathematical analysis of the TL. His empirical investigation was extended by Bullock and Hillman.[1] This attempt at mathematically modeling the TL was a T-matrix representation, in which the primary radiation impedance function had a feedback defined by the acoustic parameters of the pipe and its radiation impedance function. It treated the propagation of sound in a fiber-filled tube as a simple fiber model.

Bullock writes: "Although the model is not refined enough for precise quantitative predictions, it does appear reliable enough for some qualitative comparisons." The model reproduces some of the absorption effects of a fiber-stuffed pipe; however, the low-frequency re-

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sponse at F_R diverges badly from measured data. A serious shortcoming is that fiber-density-related effects are very cursorily documented.

Bullock/Hillman states that: "There are three obvious possible causes for the low frequency deviation between model and data. First, it is possible that the model should account for the fold in the experimental line....Second, the model does not account for the fact that the driver end of the pipe has a larger area than the driver cone....Third, the experimental line clearly tapers toward the undriven end. The stuff of a tapered line model is now in progress." Unfortunately, the data in this paper was never updated with the indicated study.

The T-matrix model was translated into PC simulation software–Bullock's TLBox Model. Unfortunately, the simulation does not accurately reflect the measured data and is of very little help in analyzing a TL design. However, this study did document that the impedance plot for a line with a single fold versus a straight open pipe shows minimum gain differences. This implies that, compared to a straight line design, a single fold line should have minimal losses.

J. Backman's Equation CPU Simulation model. The most comprehensive mathematical description of the TL is the work of Juha Backman[2] in 1992. The simulation is truly impressive and educational. However for the amateur, the paper suffers from overwhelming detail and the lack of a concise design methodology.

As in the Bullock paper, the phase effects of the fiber-modified speed of sound in the stuffed line are not clearly analyzed. In the concluding paragraph, Backman says, "The most important field for further work is, however, the experimental verification of the model presented here...." This is a shortcoming difficult to comprehend–that a magnificent mathematical model was not verified by experimental data and, consequently, some of the simulation results that are at variance with empirical results were never corrected.

Numerous sources–*LDC* among them–have hinted at the existence of a PC program that was the result of the seminal paper. Obviously, the original work was a computer simulation, but whether for a PC or mainframe is unknown, and it cannot be determined whether a PC version existed. Apparently this was an academic challenge for Backman, who has since moved into management, so attempts at communication about the paper are fruitless.

There appear to be references to a TL model in some of the more expensive modeling programs from Europe, but they seem to fall into the category of mirages. The present status of TL modeling seems to be the breadboard and poorly documented construction examples.

PRESENT STATUS OF SIMULATION MODELS

The Bullock and Backman TL models attempted to define the TL from fundamental acoustic concepts. Such a theoretical approach is very inviting, in that the multiplicity of variables associated with the TL could be analyzed. The questions of line gain versus the cross-sectional area or line taper (that is, terminus impedance) could be studied in isolation. Unfortunately, both models have not bridged the gap between a theoretical formulation and empirical data that can be applied to constructing a specific TL.

A much more modest approach to a TL model is to build it on empirical data

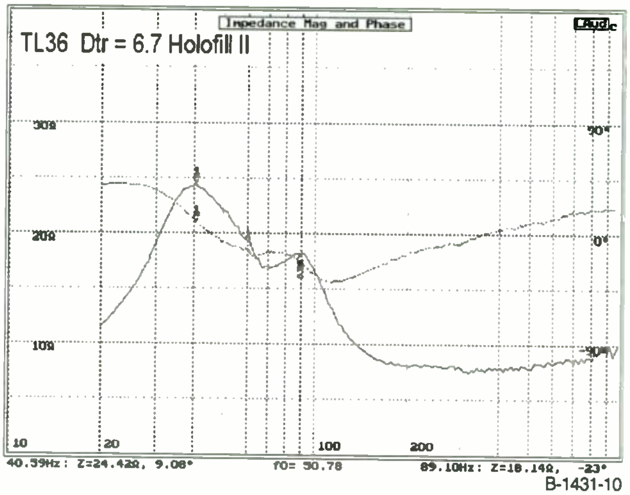


FIGURE 10: TL response–understuffed line.

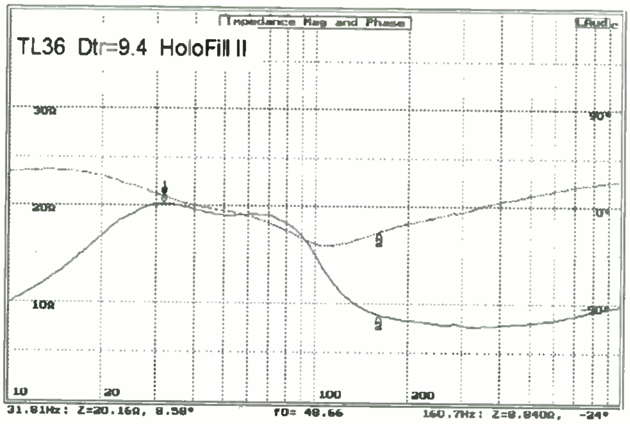


FIGURE 11: TL response–optimally stuffed line.

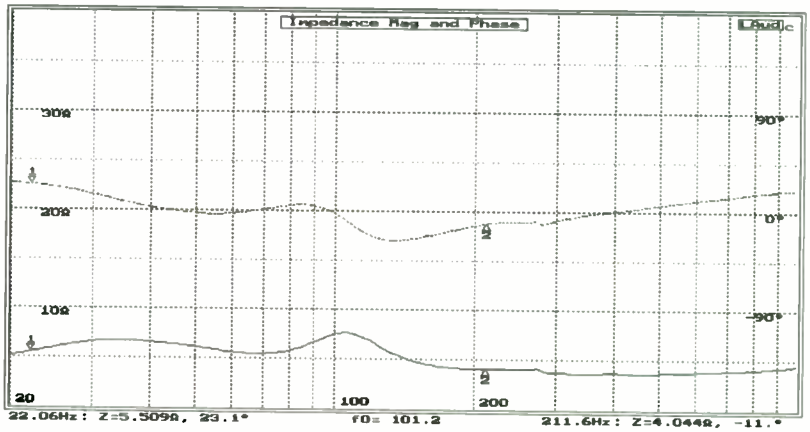


FIGURE 12: Dual woofer impedance data.

results. Such a model has the advantage that each step is self-checking, since it must agree with measured data. The empirical TL model could not answer such questions as posed previously, but it could simulate the response of a specific driver in a line of given length and of varied fiber density. Since the accuracy of the model could be calibrated for a first-order set of variables, it would be possible to extend the model to second-order effects associated with fiber characteristics and perhaps eventually to incorporate equations to define the impedance characteristics for the terminus, and thus compute the actual line gain for the basic set of TL variables.

To attempt such an empirical TL model, a comprehensive understanding of the various responses of the TL is necessary. I hope to provide this in the following sections.

COMPONENTS OF A TL DESIGN

Line response characterization. The woodwind resonance characterization, in conjunction with the empirical data of *Fig. 4* for a line length = 0.914m and *Fig. 8* for a line = 1.56m, gives sufficient data to define the TL line equation:

$$F_R = \frac{c}{4 * \text{line length}}$$

where F_R is the line resonant frequency where the −18dB slope commences, c is the nominal speed of sound = 344.4 m/s, line length is in meters.

Figure 8 shows the magnitude and phase response for a 1.56m line. This introduces the phase response as the associated component of any measured signal. In TL design the question of phase will be very important when we try to define the TL's system response and need to use a vector summation to add the woofer's and the terminus response components.

PARAMETERS

Impedance. To understand the characteristics of the TL's F_R shift with fiber variation in the line, it is helpful to examine the nominal TL's impedance characteristics. The graphs in *Figs. 9–12* show the change in impedance from an unstuffed line toward an optimum stuffed line. Phase data is overlaid with the impedance magnitude.

For Dtr = 1, unstuffed line (the fiber type is Dacron HoloFill II for stuffed lines), several interesting results are shown in *Fig. 9*:

1. Primary peak is driver F_S related.
2. Secondary peak is F_R related.
3. The harmonics are prominent in the magnitude as well as in phase plots.
4. The very steep phase change at F_S indicates the poor transient response of the unstuffed line.

The density and the impedance variation is specific to this line length and should not be generalized. As the line fiber density is increased, the impedance plot changes dramatically.

The primary peak defined by driver type drops in amplitude (*Fig. 10*). This is the effect of the fiber's attenuation characteristics. The more interesting effect is the frequency shift of the secondary peak lower in frequency, due to the change of speed of sound in the line. Thus we have the first indications of the dual effects of the fiber mass in the line: the fiber type will have an attenuation as well as a speed of sound change that will be type-, as well as density-, frequency-dependent.

As the fiber density approaches the optimum Dtr value, the secondary peak shift to about 70Hz and the magnitude of the primary and secondary merge into the flat-topped region (*Fig. 11*). Note that

BACKMAN EXCERPT

With very small ports the behavior of the line changes entirely, as the quarter-wave resonance that is used in the line cannot be excited due to boundary conditions at the end terminated with a port much smaller than the area of the line. If the attenuation in the line is small (as in transmission line systems designed for narrowband subwoofer applications, *Fig. A*), then as the output from the line is larger, also the effect of the port is more significant.

Figure A also shows that the frequencies of the resonances decrease as the port area is reduced, which increases the acoustical inductance of the port.

If the length of the output port is increased, then the high-frequency output of the port and thus the passband irregularities of the system are decreased due to the increased acoustical inductance. Also the frequency of the line resonance shift to lower frequencies. Examples of the effects of the length of the port are shown in *Fig. B*. As the examples show, the port has an effect also on rather low frequencies. Thus if maximum low-frequency output is attempted, then there should be no separate tube at the line port and the area of the port should be as large as possible, preferably equal to that of the port. *(Extracted from Backman paper, "A Computational Model of Transmission Line Loudspeakers," pp. 30–2.)*

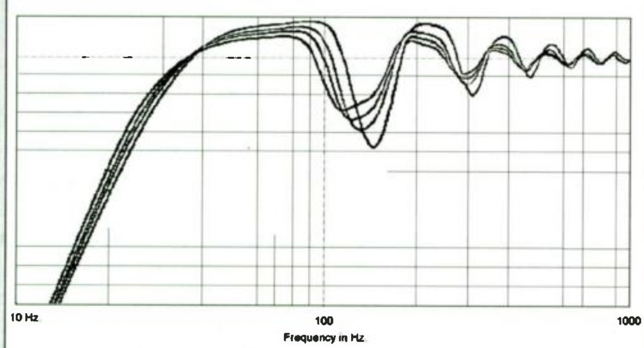


FIGURE A: The effect of port area on the response of a transmission line loudspeaker with small attenuation in the line. Driver parameters: transmission line length 2m, transmission line area 0.1m², V1 = V2 = 0, L_p = 0, absorber density 5kg/m³, port area (from top to bottom) 0.1m², 0.05m², 0.025m², and 0.0125m². Vertical scale 2dB/div.

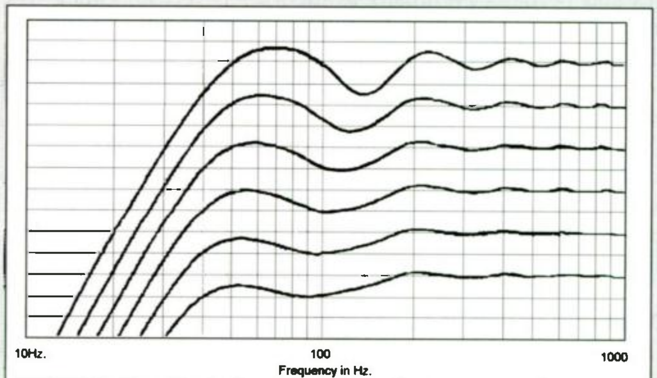


FIGURE B: The effect of port length on the response of a transmission line loudspeaker with large absorption in the line. Driver parameters are the same as in Fig. A, transmission line length = 1.6m, line area = 0.05m², port radius = 0.05m (⇒port area = 0.00785m², port length (from top to bottom) 0cm, 5cm, 10cm, 20cm, and 25cm. Constituent density 1000kg/m³, absorbent density 20kg/m³, fiber diameter 0.02mm.

the phase curve has flattened out as well. The primary peak has been reduced by about 70%. This specific combination of driver's T/S parameters, line length, and fiber type and density resulted in the impedance curve as shown in *Fig. 12*.

However, if the woofer's F_S was lower and the Q_{TC} = 0.5 response required less gain from the terminus, the Dtr value could be increased and then the impedance curve would not look as symmetrical. Thus the shape of the impedance curve should not be regarded as an indication of optimum tuning in itself. The optimum Dtr value is a dynamic process of design tradeoffs.

As an example of the possible variation in the impedance response, *Fig. 12* shows data for a dual woofer loading that results in a flat impedance curve and translates into an outstanding transient low-frequency response.

LINE AREA AND TAPER QUESTION

There seems to be much confusion about the desirability of tapering the TL line, with various ratios recommended. For instance, *LDC*, while somewhat hedging, states that the ratio can vary from about 1.25–2.5 times the SD. "This defines a taper ratio, beginning area/SD which will have a direct effect on the subjective quality of the bass and mid-bass of the TL. Low ratios generally give the 'lean' and 'tight' sound quality associated with TLs. As the ratio increases past 1.4–1.5, the emphasis is placed more on the low bass area, and better sounding mid-bass." The original of this included: "ratios approaching 2.5 to 1 will sound fuller and richer. Ratios much above will sound tubby."

What an astonishing statement to make! I wonder from what witches' cauldron this description was extracted. I guess that the LMS/Leap version used to define this did not include the calibration for "fuller and richer," and "tubby" must have been a real problem.

The problem here, as with all word-of-mouth recommendations, is the complete lack of data to back up the question of taper. However, there is some data to refute it. The material given in the sidebar is somewhat academic jargon and difficult to read, but I did not wish to change J. Backman's wording.

The data extract is from the "Computational Model of Transmission Line Loudspeakers" and, as the title states, is a CPU simulation. This data identifies the effects on system response of the variables that would define line taper. The conclusion is that line taper will shift the F_R frequency higher and increase the passband ripple. These results are in line with my own measurements on a single sample of a tapered line. What is interesting is that it is congruent with the examination of the musical instrument of the woodwind family, of the straight and the bell-shaped termination on resonance frequency. The TL taper is analogous to the bell-shaped termination in that it moves the fundamental resonance from ¼λ to ½λ, thus the F_R frequency would move higher. This is what the CPU simulation shows.

In summary TL line taper is counterproductive, and the terminus area should be as large as possible to avoid low-frequency gain loss.

In Part 2, I will examine the frequency response of the TL, the transient response, from several viewpoints. Part 3 will explore the heart of the TL, the fiber characteristics, and their limitations.

REFERENCES

1. "A Transmission-line Woofer Model," by Robert M. Bullock, 1986, JAES preprint 2384(D-6).
2. "A Computational Model of Transmission Line Loudspeakers," by Juha Backman, 1992, JAES 2TD1 preprint #3326.

Speaker builders often prefer the simplicity of a two-way design. This one, with high-quality Scan-Speak drivers and a LEAP crossover, proves that simpler is better.

High-Quality Two-Way Design

By Lester J. Mertz

Many articles on two-way speakers have appeared, and here is another! Last year an article describing a Dutch-designed, two-way speaker was published in *SB* 2/98 ("Reference Monitor," p. 32). The approach was very straightforward, using high-quality, Scan-Speak units in a thick enclosure. I read the article with great interest, since I had been toying with a similar idea for my own design, and, of course, reading every article I could find on the subject.

Some controversy on that *SB* article has erupted, with several letters questioning various aspects of the design, particularly the crossover and resultant phase relationships. I read the responses with interest, but moved forward with my plans, as I will detail here. I am certainly not the expert to answer the questions as presented in those letters, but here is my design.

SOUND DESIGNS

Neither of these designs will be the last word on two-ways, which are the most prevalent of all current speaker designs. I believe this is true for good reasons: very high-quality sound, great imaging, and fine performance in general.

I simply believe that if you can purchase two pairs of high-caliber drive units that will do the job of quality stereo reproduction, why spend an equal sum for a three- or four-way design with units of lesser quality? It strikes me that two drivers are all that is needed. Why add more?

It has been said the three-way-design speakers are more than twice, or even four times as difficult to get right as the two-ways, so use the old KISS principle (keep it simple, stupid)—simpler is better than more complicated, so why not try this in addressing the design? Use two drivers! For me, the answer is easy: I crave better sound, and I enjoy making my own speakers.

TWEETER

I used different Scan-Speak tweeter and mid-bass drivers than the units selected in the Dutch-design article. The Dutch design used the most expensive tweeter that Scan-Speak makes, the Revelator, which some experts and reviewers claim is as good as it can get. If you think the more expensive unit is worth the money, go for it, but realize that you must reengineer the crossover to accommodate this major change.

Most noticeable is the difference in moving mass in the smaller-diameter unit; it is about half the mass of the larger 28mm domes. I believe that the lower mass is beneficial in low-level detail retrieval.

Experimenting with this Scan-Speak tweeter—the 19mm (or ¾") soft-dome D2010/8513—for several months, I fell in love with this gem. When coupled with a simple crossover capacitor, a MusiCap 2μF, with an L-pad to balance the levels, and placed on top of my existing speakers, its sound was wonderful. It had detail, nuance, and a three-dimensional quality that my own tweeters lacked. I was very impressed. I wished to try it with one of the newer midbass units. And best of all, I already owned it.

MIDBASS

A single driver that covers almost all of the fundamental frequency range of the musical instruments cannot really be called a woofer. So I use the term midbass, meaning midrange and bass.

PHOTO 1: Completed speaker and steel pipe stand.

I thought, why risk problems within the main sonic envelope by using multiple drivers and crossovers in this critical region? The crossover in this region has undone many designs, so I let the single midbass carry the major portion of the music. The unit would need to reproduce up to 3kHz to do this, and the 6–7" units come close to carrying this off before the beam width begins to narrow appreciably at the upper end.

I needed to make a choice, or some might say a compromise: try for a smaller driver, maybe a 5", which would easily cover the range while sacrificing some bass and power, or select a larger 8" unit for bass power and settle for less midrange dispersion.

I must confess, I looked long and hard for an 8" unit with good upper-end dispersion. This was what I have been listening to for almost 20 years in two Spendor models, the BC-1s, and then SP-1s. No matter how many different speakers I lis-

ABOUT THE AUTHOR

Lester Mertz, a licensed environmental-project manager, was recently relocated to the Phoenix, AZ, area from the East Coast, but is currently unemployed, since his company ran into problems. His past work experience has included commercial photography, restaurant managing, and research electronics in microwave-band interferometers. But his most satisfying experiences have involved all aspects of building his own audio systems and enjoying the resulting great music.

tened to, or built, I always went back to them after my initial infatuation with the latest, but not necessarily the greatest, driver technology wore thin. The sweet-sounding midrange of this English manufacturer and its wonderful 8″ mid-bass always satisfied me with its relaxing musical presentation.

Acknowledging this preference, the 6–7″ units are the modern-day unit of choice, and that is where I concentrated my search. The 18cm unit's frequency response and dispersion is good enough to provide a coherent, seamless transition, especially at the listening seat or sweet spot.

The idea that the speakers will provide an excellent stereo image anywhere in the room is not relevant for me—and maybe not a good thing if the reflections cause problems by interfering with the direct line-of-sight music presentation. Near-field monitors allow you to sit close. Just look at the sheer number of absorbent pads, panels, and sound-control tubes that are available to suppress these unwanted reflections. Maybe wide-dispersion design isn't all it's cracked up to be?

The Scan-Speak midbass units are very popular, especially with certain very high-end (read expensive) manufacturers. I researched all the catalogs I had on hand, and have virtually memorized Madisound's comprehensive descriptions. The account of the 18W 8546 Kevlar cone, a die-cast frame unit, had a line that stopped me in my tracks—"The best we have to offer." If a respected maker like Scan-Speak says that, why look further? I ordered two.

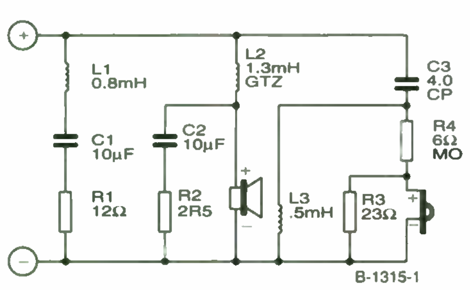


FIGURE 1: Crossover schematic.

CROSSOVER/FILTER

Crossovers for loudspeakers are tricky compromises at best, with much rationalization about the driver's beam width, the 3dB response points off-axis, power handling, and all sorts of other optimistic and pessimistic banter. Regular readers are familiar with all these complex issues and their proposed solutions. It's enough to drive you crazy, and no wonder the computers are doing it all. I called Madisound, and paid for the LEAP design—a mere $25 for a two-way design; what a bargain (*Fig. 1*)!

My only requirement for this design was consideration for the 19mm tweeter; it needed to be rolled off below the 3kHz point. The 12dB-slope crossover minimizes risk of damage to the unit, and provides relatively good phase coincidence. A 3dB crossover, a simple capacitor often found in the majority of two-ways, will not provide any protection at this low frequency. The odd-order crossovers, 6 and 18dB, can give phase problems and listening-axis shifts, depending on the design.

Also, the steeper 18dB slope needs additional components, which may negate the simpler-is-better approach. The odd-order designs seem better suited to three-driver designs. Avoiding the phase shifts and matching problems in the middle of your music is a complex and next to impossible problem. Let the computer do it.

A simple 12dB crossover to the 18W midbass is all that is used in this design and in the Dutch design, which also omitted the LCR network on the midbass.

I also must question the notion of spending $175 each for the tweeters, while not spending another twenty bucks or so for a couple of state-of-the-art capacitors, MIT or MusiCaps? One of the aforementioned *SB* letters also questioned this choice, and the response was that the selected components *are* state-of-the-art. My own experience is that the capacitors make a considerable improvement in sound quality for a low investment. Not having heard the finished Dutch design, I may need to eat those words. So I put out a challenge: if someone is willing to A-B these speakers with me, give me a call (602-981-5695).

LCR NETWORK

This LEAP-modeled design uses an LCR network to tailor the input impedance and frequency response before the actual crossover components. This is a major difference in design; the Dutch designer thought it wasn't needed. I am a tube-amplifier enthusiast; I think the network and its ability to even out the humps is an important step to smooth sonic performance. While this circuit may introduce some phase shift, and maybe some other compromises, the resulting graphs (*Figs. 3–6*), as supplied by Madisound, look good to me. And the finished speakers sound very smooth.

The tweeter gets a premium Hovland MusiCap (film and foil) capacitor, a metal oxide resistor in series with it, and its own board. The MusiCap boasts low ESR (electrical series resistance), improved detail and resolution, and a sense of spaciousness and imaging. All of these qualities were exhibited in my own earlier experiments, as well as a very comfortable and nonfatiguing performance.

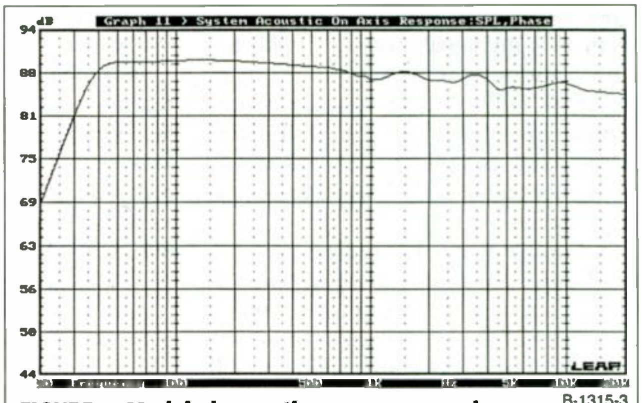


FIGURE 3: Modeled acoustic response on axis. B-1315-3

The Goertz air-core copper-foil inductor is in series with the 18W midbass speaker and measures very low resistance, several tenths of an ohm—a good thing. The value was specified in the LEAP design, and it was shipped directly from Goertz. (Madisound handled the payments and billed me accordingly.)

Other components are Madisound's Sidewinder and standard, air-core inductors, GE high-voltage polypropylene caps, and high-wattage resistors. I placed everything on heavy-duty board with point-to-point wiring. The boards are simple Masonite, laid out to be compact, with the components tie-rapped in place. All the coils have rubber-damping pads under them.

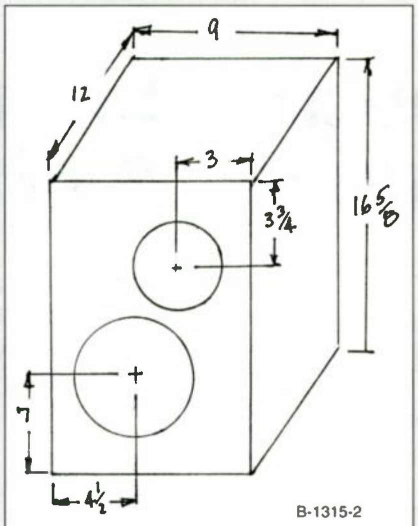
You must take extra care in drilling through the Goertz foil leads. I used backing pieces of Masonite on both sides, and then slowly drilled through for a clean hole. The copper foil leads are long enough so you can practice first. Cut off the excess and errors. Just lay the foil over the bolts as a mechanical connection, and then solder everything up later.

Recheck what you have put together by confirming proper layout against the schematic. The midbass board uses all copper bolts and nuts as binding posts. The copper pieces are somewhat hard to find; try looking for copper ground straps. Those I found had ¼-20 hardware.

If you are not comfortable with the crossover step, Madisound will supply it complete and ready to use. This will save you several hours of time, and allow you to avoid the labor involved in the hot soldering work.

TABLE 1
PARTS LIST

2	Scan-Speak 18W/8546 midbass
2	Scan-Speak D2010/8513 (no fluid) tweeters
1	LEAP crossover, modeled in Audio-Precision measurement system (AP)
2	Goertz air-core foil inductors: 1.30mH; 14 AWG copper foil (special order shipped direct from Alpha Core, Inc., Bridgeport, CT)
2	Sidewinder, 0.8mH; AWG #16
2	Air core, 0.5mH, std.
2	Hovland MusiCaps 4µF, 100V, speaker
4	GE 1040L400; 10µF, 40L polypropylene caps
2	25R 12 12Ω, 25W, resistors
2	15R 2.5 2.5Ω, 15W
2	15R 23 23Ω, 15W
2	6E Eagle 6Ω
4	Madisound's BG posts, extra long 1¼″ for terminals
4	Deflex panels, 280mm × 210mm
4	Masonite boards cut to size for crossovers
1	Foam sheets, 1″
2	PVC pipe, 2″ inner diameter × 150mm (5.9″)
1	Driveway Medic, roll
1	Weld Bond, all-purpose glue
1	GE silicone sealant
2	30″ × 96″ counter top, 1″ thick
1	12″ × 36″ MDF panel, ¾″ thick
Miscellaneous:	
	Router (plunge type) will be necessary for precise driver flush-mounting and laminate trimming, and an extra-long 2.5 × ½″ router bit for plunging through front panel
1	¾ roundover bit, optional
1	Constantly elastic speaker-mounting compound, optional spray paint, semigloss black (or your choice)
1	Stapler, with ½″ staples for foam and bituminous materials
20	Brass wood screws, #4 × ¾″ for the speakers
8	Small rubber grommets or rubber tape to level tweeters flush with front panel
6	Copper bolts and nuts for midbass crossover boards
6	Small metal bolts and nuts for tweeter boards
	Coarse-thread (self-tapping) drywall screws for mounting crossovers and thick front panels



B-1315-2

FIGURE 2: Simple isometric draft; measurements in inches.

ENCLOSURE

Small, stiff, solidly constructed, and well damped, the basic box is made from 1″-thick material, but has a 1¾″ front panel. Both drivers are flush mounted, with extensive router work a major part of front-panel preparation (*Photo 1*).

After selecting the midbass unit, I made some quick calculations and determined that it needed a vented box. The ideal volume calculation comes to 0.865ft³, or approximately 1,500in³. This leads to a vent length of 3.9″. This seems in opposition to the Reference Monitor's smaller volume of 0.6ft³ and its 150mm vent length. The Madisound crossover design also specified the 0.6ft³ volume, so I acquiesced. I never bothered to go back and look for my error, but instead moved on with my plans (*Fig. 2*).

My own calculations for a 0.6ft^3-box vent length worked out to 7.6". Was I wrong again, since both designs stipulated a nearly 6" (150mm) vent length? I was confused, but that's nothing new. Please refer to "Flaring Concerns" in Ask *SB* (*SB* 3/97, p. 50), where G.R. Koonce discusses vent length and flaring. His response ends with a comment that classical port-length equations generally do not produce accurate results.

The port is made from PVC pipe, schedule 80, the gray stuff, strong and slightly thicker than the usual plumbing pipe (*Photo 2*). It is placed on the rear of the box, inset ⅜" and then flared out with a round-over router bit. The length is slightly greater if measured from the back surface—almost 6.25"—but then rounded over on the back with a ¾" router bit.

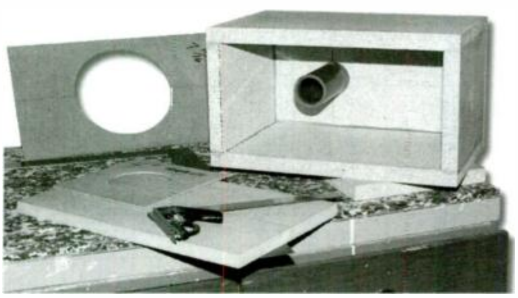


PHOTO 2: Masonite templates and partially completed enclosure.

The tweeter is fully enclosed to isolate it from the midbass speaker. Whether this effectively isolates a closed-back tweeter is open to discussion, but I believe the tweeters sound better when unmodulated by the sound field inside the cabinet.

Two Deflex panels line the interiors of each enclosure, along with a homemade combination of bituminous and foam sheets covering everything else inside. The exterior is black laminate on all sides and bottom. The back is painted, and the front rounded over with a ¾" router bit. You may prefer to omit the laminating step, and spray-paint the cabinet after some filling and sanding.

All-in-all, it turned out to be a nice, professional-looking box.

CONSTRUCTION

Measure as much as you need in order to feel comfortable, then cut. Follow the straightforward basic plan, unless you wish to make your own design. I used a gap-filling wood glue, Weather Tite, with lots of good wood clamps. The panels are so small that I omitted the nails and screws, and just clamped it (*Photo 3*). It is essential to wait at least 24 hours for the glue to dry before removing the clamps and taking the next step. Glue only as many pieces together as you have clamps for; don't try to skimp on this part, and take your time.

First, I routed the port's inside diameter into the back panel, then the pipe's inset and fitted hole—⅝" deep in the 1"-thick stock—making sure the pipe fit tightly. Glue the PVC pipe in place with Weld Bond, which adheres well to the plastic; give it 24 hours to dry.

Glue the sides onto the top and bottom, and add the back the next day. Hold off on the front panel until you've finished securing the damping pads and installing the crossovers.

STUCK WITH NO-STICK

The Deflex polymer panels deserve special mention—they are weird, as though they're wet or soggy. I must say they constituted the most frustrating step in the entire building process. It took three dif-

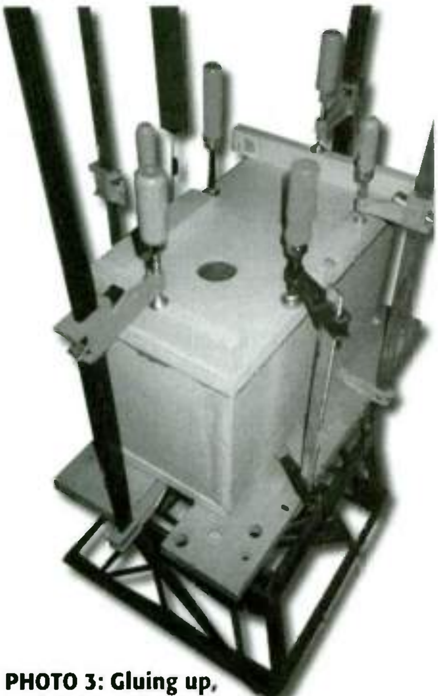


PHOTO 3: Gluing up, with lots of clamps.

ferent adhesives to make them stay where I wanted them. They have a clear film on the back, which led me to believe they had an adhesive backing. Not so! I put them in place, but then gravity took over and they fell off. Next, I tried contact cement, but gravity won again after about 24 hours. Then I applied silicone adhesive; almost, but gravity prevailed yet again. I started using staples, but the panels were still sagging.

Frustrated, I called Madisound. "Oh yeah, they need a special rubber adhesive, but it was so expensive no one would buy it," said Jason. "But we found that Weld Bond is just as good." "Gee, thanks, certainly am glad I called! I was just about to go back to fiberglass," I mumbled to myself as I hung up.

Well, I think I've won the war with gravity on the Deflex panels, but I'm not sure. The Deflex ads say that two panels are all you should use in a small enclosure. I placed one centered on the back, and cut the other in half and fixed the pieces on each side, toward the rear and butting against the back panel. But only half the interior wall surface was covered at that point.

Then I found a product called Driveway Medic, a small roll of bituminous driveway-patching material. I cut pieces off the roll of this soft, pliable stuff, and then contact-cemented and stapled them to the rest of the cabinet interior not covered by the Deflex. Later, I applied foam to the areas not covered by the crossovers, which need to be screwed in place over the bituminous layer that prevents the panels from rattling.

Once the interior is complete, drill the holes for the connection posts, and mount them carefully, for they just make it through the thick panel. Wire in the crossovers and carefully attach them inside, with the tweeter (*Photo 4*) separate on the inside top of the box, and the midbass (*Photo 5*) inside the bottom (*Photo 6*).

Remember that the box is too narrow for a screwdriver, so plan accordingly. Cover the panels with foam or Dacron wedged in place. Check everything by hooking up with alligator clips to a sound source, and be certain the crossovers and speakers are correct before sealing the front panel. If something is not right, it is much easier to solder on the table than inside the box.

PHOTO 4: Tweeter crossover/filter section, to be mounted separately.

RAPPING TEST

The knuckle-rap test on the outside surfaces was becoming much better—more of a thud. Then I picked up a heat gun, to relieve some of the curl on the driveway patch, and while using it, I rested it briefly on the cabinet, which immediately caused a loud resonance. What was wrong?

Damned resonant ported enclosures, I thought to myself. I pulled down some older boxes (all infinite baffle) and tried resting the heat gun on them: similar sounds, but not nearly as loud. The different panel thicknesses and the mounting seals changed the sound. Good old wool felt seemed to be the quietest. The MDF front panel was not yet glued in place, so I set it on top of the new design. Presto—almost no motor sound from the heat gun. The open-ended box was reinforcing the sound of the heat-gun fan motor, but when I just rested the front panel on the box, the sound quieted down.

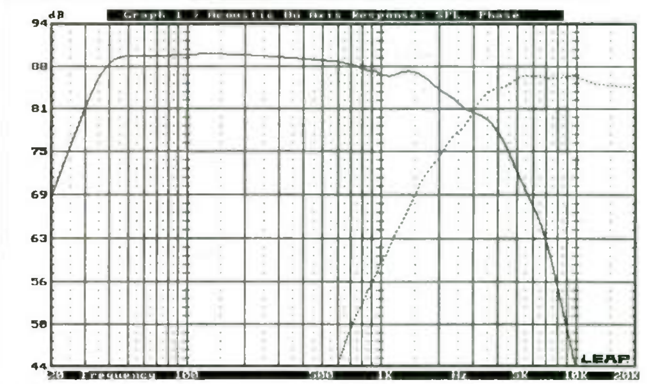


FIGURE 4: Acoustic response; solid line—midbass; dotted line—tweeter. B-1315-4

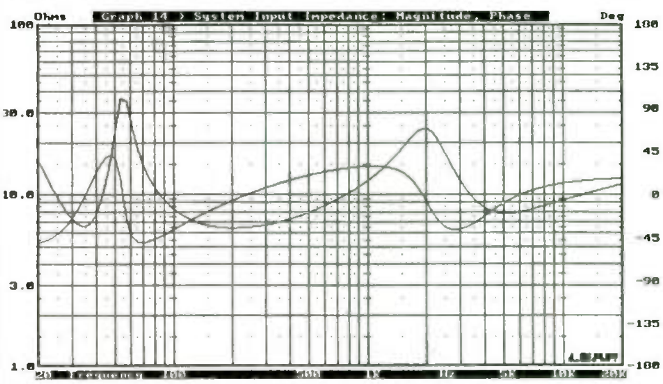


FIGURE 5: Input impedance: magnitude, phase. B-1315-5

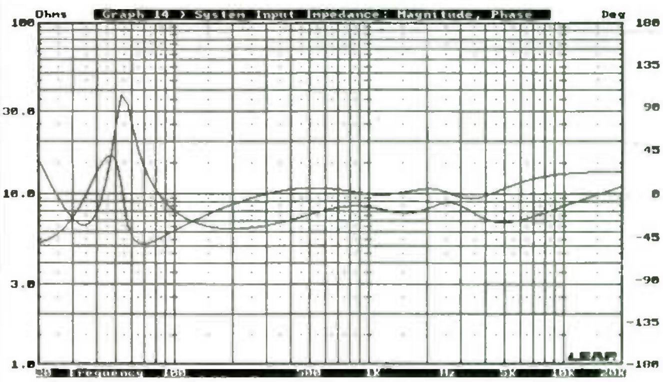


FIGURE 6: System input impedance: magnitude, phase. B-1315-6

FRONT PANEL

The front panel is made of two materials—1″ particleboard counter top, and ¾″ MDF (*Photo 7*). At first, the two pieces are held together only by long drywall screws, which allows you to register perfectly all the driver mounting-hole machining. Take note that with the front panel this thick, my regular 1″-long router bit would not drill all the way through. I purchased a much longer 2.5″ bit and changed to the longer one midway through the work.

A word of caution here: make sure the router bit has stopped completely before pulling it out of the cut. If this long bit is spinning, it will shock and surprise you by catching, and then destroying your pristine panel work.

The tweeter mounting holes needed small, time-saving templates from Masonite. I used a fly cutter on a drill press, then carefully checked the fit with routed test holes on a piece of scrap wood. The templates must be oversized by the space between the bit and the pattern collet that fits your router. The recessed faceplate is made in mirror pairs, making left and right speakers.

When I noticed that the closed-back unit extended only another eighth of an inch beyond the baffle, I decided that another piece of MDF thickness would completely seal the tweeter from the midbass, providing the isolation from the back waves. I routed into another small section, about 4″ × 4″ of scrap MDF, ⅜″ deep, and glued it in place after carefully aligning it away from where the side wall would intercept the front panel. Complete isolation!

I also recessed and flush-mounted to a millimeter fit the midbass driver. Then I treated the rear opening by rounding it over with a ¾″ bit. The rear of the speaker sees a flared-out opening and not a straight tunnel, which might affect the sound and loading. I centered the rear-panel Deflex sheet on the midbass opening.

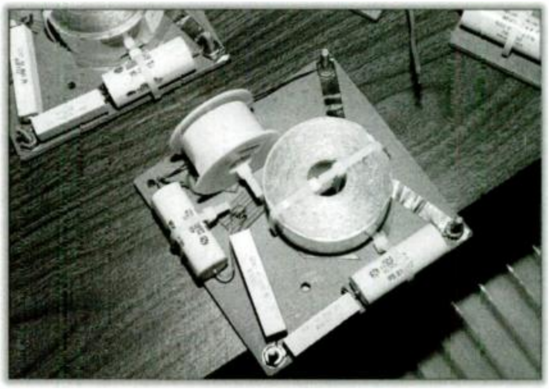


PHOTO 5: Midbass crossover/filter section.

Glue and clamp the 1″ front panel to the existing box. Once it is dry, protect the openings by taping covers over them before doing any trimming or sanding. This will prevent dust from getting into the cabinets and crossovers.

Smooth all the box joints by sanding, and then wipe off the dust before applying the adhesive. Apply the laminate all around in separate steps, except the front and back. Flush-trim the top, bottom, and side laminates to the faces of the front and back panels.

Then, and only then, rescrew the ¾″ front panel in alignment, and carefully round over the edges using the ¾″ bit. Determine and set the depth of cut with some test stock before plunging into the face panel. Carefully make a dry run with your router; be sure there aren't any glitches or bumps in the road. Carefully feel the entire surface with your hand, and then glide the router base (not running) over it. It must be free of bumps and nicks that might ruin a smooth finish cut. This additional step will produce a perfectly fitted and rounded-over front panel.

PERFECT MATCHING

The seemingly redundant steps of screwing the ¾″ panel on and off again allows you to match the MDF front panel perfectly to each laminated box. The routing in place compensates for little imperfections in dimensions, or the slight bowing in of the sides from too much clamp pressure. Trying to match things up separately is next to impossible. The extra step produces exact alignment.

If you mess up at this point, it's time to practice your spackling or auto-body-repair skills. Don't get me wrong here; I made these types of repairs on this project. On the back panel, which I spray-painted with gray sandable primer, the router pulled the "grain" of the particleboard around the port and left pockmarks. This sort of thing will show up after painting when the surface is a uniform color.

I used Magic Putty and Sealer, available from any auto-parts store. It comes in a tube, and you apply it in one step to the painted surface. Just wipe it on with a rag. After it has hardened for an hour, sand lightly and repaint. Repeat this as many times as needed, until the imperfections don't bother you. You can take it to a very smooth, uniform finish. If you don't wish to laminate, this will make a beautiful painted finish. Apply primer first, make it smooth with the putty, then spray on the finish coat. Buy one of those trigger handles if you are using spray cans; it makes it very easy to achieve a professional paint job.

Buy enough spray paint to complete the entire job, and use only the same brand; different brands may not be compatible with each other, and you may find the surface becoming covered with little balls of paint, as the second brand refuses to adhere to the first. I made this mistake, and it was a mess; I was forced to sand off the second coat on the back panel.

I added a small inset or relief detail with the router bit, and before gluing the front panel in place, I added a silver finish to the laminated front edge, allowing the rounded front to stand out. You may omit this relief detail, if you wish, but I liked it.

Afterward, remove the screwed-on front panel to paint it (flat black), finish it with varnish, or treat it in the manner it deserves. Once finished to your heart's desire, rescrew, glue, and clamp it for the final time.

WIRING

The speakers are wired internally, using the latest flat-ribbon type (*Photo 6*). This stuff is stiff and hard to form and fit inside the enclosure. The tweeters are wired using Teflon®-insulated, silver-coated, solid-core copper. I intended to mount them using Norsorex gaskets, but it seems they're no longer available, which is a shame. As alternatives, try rubber, foam, or silicone gaskets.

The midbass is held in place with small brass screws. This cast-frame unit has six very small mounting holes, much smaller than I am used to seeing on such expensive drivers. By providing such little holes and associated screws, perhaps the manufacturer is trying to send a message not to torque it down so much.

FIRST LISTEN

I hooked up the units to the amplifier and played some female vocal selections I know well. Some of these albums have very well-recorded imaging, providing a quick read of the overall timbre of the female voice; it was very good. The bass was tight, even without any treatment of the port or special positioning in the room. By the end of the second album, the bass had improved even more. The vocalist sounded fantastic, better than ever, with an almost creamy texture to her presentation.

I switched to something completely different on the third selection—some modern electronic mix. These little babies had my foot tapping with bass that really surprised me! By the end of this CD, I knew I would need to rebalance the subwoofer's cutoff frequency, since the bass was now really too much. I took the subwoofer out of the system.

I played with the new unit's height, and tipped back the angle somewhat, which was a little better. I also increased the height, which was an improvement. After several weeks of experimentation with the height, I decided on stands just over 2′ high.

Bear in mind that positioning of this rear-firing design has a very pronounced effect on the bass and the imaging, so be prepared to move these speakers around for the first few weeks or so. Bass response varies depending on room placement and the distance from the rear port to the wall. If they seem too boomy, pull them out into the room. If you find an interested listener to help you with the positioning, it will go much faster. These speakers are really very good!

I continued to play different disks. Listening was a revelation, with each album a new experience, as though I hadn't heard it before. There were details, nuances, depth of image, and punch. The music took on the alive excitement of the real thing, especially the classical albums. Orchestral music was beautiful, and it did not wear you out after a few cuts, like some other speaker designs I've listened to.

Don't misunderstand me—not every album sounded sweet and dreamy. The bad albums sounded much worse, but the really good sound mixes stood out as magnificent. The so-so ones seemed more disappointing than ever, but no disk was unlistenable or glaring, and the highs remained sweet.

I think the Spendors tended to sweeten up everything, and the early CDs needed all of that and then some. Now that the

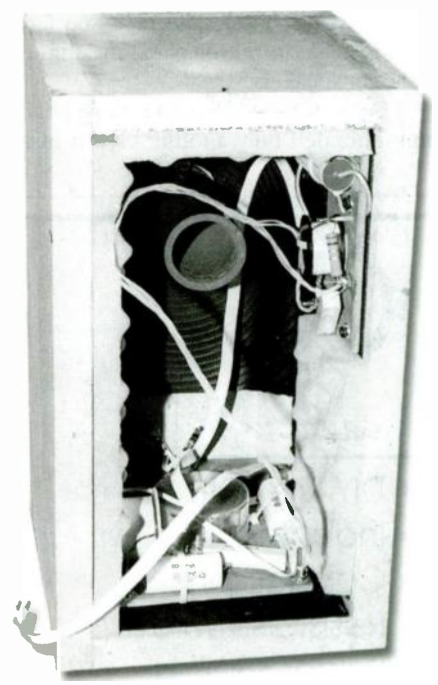


PHOTO 6: Inside of cabinet, ready for front panel.

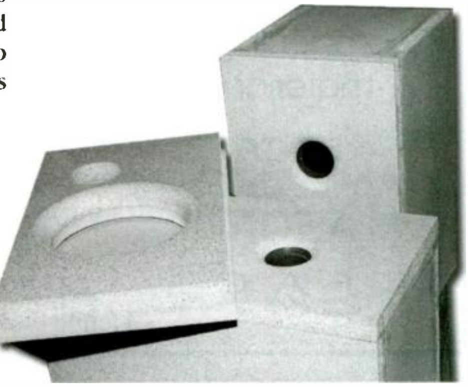


PHOTO 7: The outside back, showing inset plastic pipe and ¾″ flair, and the inside front panel.

PHOTO 8: "The mortars"—steel pipe 6″ in diameter with welded top plate matching cabinet base dimensions. ⅜″ "all-thread" is bolted tight top to bottom. Aluminum channel is inverted under 1¾″ bottom and torqued down. Note: sand weights are freezer bags taped closed to prevent sand from spilling in the event of poor assembly.

CD playback systems are much better and much less irritating, these far more revealing speakers can really make you happy with lots of detail and nuance.

CONCLUSION

Please refer to earlier issues of *SB* for all the methods of setting up your speakers in your room and system. There are lots of good suggestions that really work and will bring things to life, making your listening time more pleasant. And moving your system around is very inexpensive compared to many other options for improving the sound.

One thing I have found to work well is placing the tweeters at or near the listening level when you're in your favorite chair. So consider this height when seeking or making your own stands. I call mine the Mortars, two-foot sections of steel pipe with a 6″ diameter and steel welded plates. They're heavy as hell without any sand filling, and I'm still moving quite a bit (*Photo 8*)!

I also prefer to toe in, or aim the speakers slightly toward my seat While you're adjusting speaker placement, get your measuring tape and make certain that they're both equidistant from each other and from the back of the room. Then measure an equal distance from the sidewalls on the left and right sides. Mine are placed about 8′ apart, about 8′ away from my listening position. This measuring and balancing of the distances will improve the stereo imaging significantly. I also like the deep image you get with the speakers placed well out from the back wall. I sit approximately 8′ away on a large couch, which is also well removed from any side or rear walls.

Give your new speakers a couple of weeks of break-in time, and then retest the setup again. I use a test CD and a sound-pressure-level meter. Move the speakers around again and retest everything. (A note of caution: tube amplifiers do not take kindly to repeated extremely low-frequency test tones from the *Stereophile* Test CD; my output tubes were glowing cherry red!)

Perhaps you may wish to change back to those old interconnects and speaker wires, the ones you liked before you bought those super high-tech and expensive "magazine top-rated" trendy jobs. I'll bet the old ones sound much better now, and I recommend that you never throw the old stuff away—it may be just what you want now. I use these interconnects and speaker wires like tone controls, shaping the sound to what I like.

Place tiptoes, cones, and spikes under the stands, under the speakers, over the speakers—whatever! Maybe with those cone points up, the system will be able to gather knowledge of the heavens and the universe, just like Merlin's pointed hat!

The author takes us on an intriguing three-part journey to explore speaker-system design and construction. In the process, we learn a little about what makes us tick as listeners.

Part 1

Navigating Speaker Design: Defining the Problem

By Mark Wheeler

The intention of this three-part article is to take another look at some loudspeaker-design concepts often taken for granted. The keynote of Part 1 is a simple reminder of the most important fundamental of loudspeaker design and construction: that *loudspeakers exist to convert, accurately, electrical energy into sound energy*; nothing more and nothing less.

It is too easy to forget this simple reason for the existence of loudspeakers while juggling sensitivity versus bass extension, polar response, diffraction, and domestically acceptable styling. The only reason for having these wooden behemoths at home is that they make some agreeable noise out of the electricity fed into them.

THE POINT IS MUSIC

Having spent a good slice of income on the equipment that produces a tiny electrical signal at the loudspeaker terminals, it is imperative to make an acceptable job of converting this signal into something worth hearing. For most audio enthusiasts, this means music or movie soundtracks. I am aware that some folks like to listen to other stuff, such as steam locomotives or whale squeaks, but in this article I'll consider only music, from Tommaso Albinoni to Frank Zappa.

The complex web of variables juggled when you design a loudspeaker system all connect either to the fundamental tenet I stated in the first paragraph, or to that other fundamental design criterion, cost. However, I will ignore financial cost, which tends to vary over time, location, and circumstance. I will scrutinize some of the issues raised by that bald definition of the function of any loudspeaker design. The question that arises with any loudspeaker will always tend to boil down to, "How effectively does it convert electrical energy, delivered to its terminals, into music delivered to my ears?"

The word "effectively" should be distinguished from the word "efficiently." I am asking "how well?" rather than "how much?" Anton Ehrenzweig, in his book *The Hidden Order of Art*, coined the term "inarticulate form" for the unconscious formative processes that are a part of a musical experience that allows you to recognize a breathtaking performance that moves you to tears.

This inarticulate form is not the overt "form" that can be described precisely, such as "12 bar blues" or "sonata form." This inarticulate form is the *raison d'être* of creative activity, almost impossible to describe, but experienced profoundly. The fact that it is nearly impossible to describe in words is precisely the reason art and music are necessary. So if that is what is needed from music, how does this affect the building of loudspeakers?

This article will examine the more inarticulate aspects of loudspeaker design. These are not the number-crunching decisions about cone mass or port size. These are the decisions about materials and construction and their contributions to the design goals. Such decisions need not be haphazard, and they make bigger contributions to design success than are sometimes credited. My aim is to give designers a worthwhile framework in which to make informed decisions about every aspect of loudspeaker design and construction, and a means of correlating their vast empirical experience into a more considered form than vague intuition.

INTUITION AND KNOWLEDGE

Intuition is a good thing, often allowing you to know immediately whether an idea will work in a particular application. To know that a particular form of construction sounded great in a certain project is very worthwhile, but to understand *why* it sounded great will be more useful for the next project.

Now take a fresh look at aspects of loudspeaker-system design, from the choice of drive unit itself to the more esoteric aspects of cabinet and stand design. The idea of "the system" will be paramount, remembering at all times what its primary function is all about. It is always useful to know what each design or constructional element may contribute to a particular parameter, but the mutual interaction of every element of design and construction will have even more bearing on the final effectiveness of the project.

Systemic analysis considers not only the actual function of any particular aspect or detail but also its contribution to the whole system, including how it interacts with every other element therein. Tug a spider's web at any point, and every other part of it may change in several respects.

At the design stage, some audiophiles seem to express little interest in what does what beyond bass alignment and cone material. As the builder, you must be motivated by a passion for loudspeaker construction; otherwise you could

ABOUT THE AUTHOR

Mark Wheeler's fascination with loudspeakers goes back 25 years to his first attempts at speaker building as a 14-year-old. During early adulthood he was involved in designing and building PA systems, reggae sound systems, and studio control-room systems. He is currently engaged in a master's-degree program examining the relationship between personal psychology and experience of art and music.

buy serviceable ready-made products for less money and much less hassle. If you are motivated by a desire to address performance aspects of particular concern, you obviously have much more choice about many design elements than the retail purchaser of ready-made boxes. How do these choices become informed?

OVERLOOKING THE PURPOSE

Perhaps because of an obsession with actually building loudspeakers, you may sometimes tend to address the finer details of construction and electrical performance without considering how these aspects affect the ability of the complete speaker system to carry out its original purpose. In Britain, in the late 1970s and early '80s, there was a subspecies of the genus audiophile known derogatively as the "Flat Earth" fraternity. The title Flat Earth did not refer to any esoteric electrical hookup (the term "earth" is the British equivalent of "ground"), but to the medieval belief that the earth was flat.

These tortured souls of the Flat Earth persuasion placed certain aspects of audio performance above all others. Indeed, they refused to discuss audio performance in "audio-speak" terms, insisting on using the language of music criticism—particularly in their favorite journal, *The Flat Response*. Their constant reminder was that audio systems are usually bought to experience music. Their articles also were intended to connect some design aspects to the musical outcomes thereof, although the Flat Earthers perhaps went a little too far in their attempts to compensate for the perceived shortcomings of the mainstream audio press.

The Flat Earthers placed pace, rhythm, and pitch reproduction at the head of their musical hierarchy, which superficially seems sensible enough for music reproduction. Sadly for speaker builders, the Flat Earthers regarded the loudspeaker as the least important component in the audio chain, resulting in weird systems starting with a $2000+ turntable (always the Linn Sondek LP12/Linn Ittok/Linn Asak) and terminating at a pair of $150 speakers. The Flat Earthers believed that any budget pruning should be at the speaker end of the system. In this respect they were horribly wrong, as you shall see. I'll demonstrate that loudspeakers are absolutely crucial to the basic foundations of reproduced music, as well as why and how they are so.

RHYTHM AND PITCH

In a music system, the loudspeaker can

have as negative an effect on the musical qualities as the source component. This may seem like stating the obvious, but it should be paramount when designing loudspeakers. A poor bass alignment can render the **rhythm** turgid and slow.

It seems odd that a speaker can affect the perceived pace of a piece of music—this would seem to be more the preserve of the source component—but experiments with a KEF Kube bass-alignment processor bear this out. The "Kube" is an active equalizer, inserted between preamp and poweramp to modify electrically the bass alignments of the KEF Reference Series. It allows you to vary Q and extension electronically. It's a very instructive experience, so check one out if you get the opportunity.

Bass alignments affect perceived rhythm and pace dramatically. I became aware of this phenomenon when working on reggae sound systems about 20 years ago when I noticed that attempts to get a fuller low-bass sound by non-textbook bass alignments often resulted in a loss of rhythm so noticeable that fewer people were dancing! The group delay of different alignments can vary dramatically, and at low frequencies these phase shifts have a greater effect in the time domain. Thus the timing of different elements of the music is affected differently, and rhythm is about timing.

The pitch and timbre of reproduced instruments are also fundamentally dictated by the loudspeaker. Constructional integrity of the speaker driver and enclosure has a fundamental influence on these and related areas. Neutrality is also at the heart of this, but designers often sacrifice musical ability in the quest for more theoretical neutrality.

The classic BBC monitor designs (for example, the wonderful little LS3/5a) managed to achieve neutrality without sacrificing musical ability by specifying top-quality cabinet construction and materials and paying attention to panel behavior at the design stage. They were very expensive to build, but, most importantly, they were fit for their intended purpose.

Unfortunately, many designs (which I shall not name) aimed at low coloration and neutrality to the exclusion of all else—indeed, even of music itself. Some approaches to eliminating coloration sadly eliminate music, too; a silent system has no coloration. Unfortunately, some of these single-minded efforts failed to make convincing music, which led to "neutrality" falling out of favor in much of the British hi-fi press and marketplace. So I'll examine what a loudspeaker must achieve to make a half-decent job of reproducing music that sends shivers down your spine and sets your toes to tapping.

CRITERIA AND DESIGN AREAS TO CONSIDER

The "why" of construction often demands as much careful analysis as the "how." Centuries of experience in cabinetry have contributed to the extremely fine art it has become. The knowledge is well established to make boxes that don't fall apart, but you need to know the audible effects of different material choices and construction techniques. The theoretical decisions about materials and constructional details pay great dividends for the thoughtful designer/builder.

Perhaps the paucity of information about the importance of various factors to the actual musical effect inhibits designers from committing themselves to theorizing in print. A lack of previous references to a specific design application—and its relevance to music—makes it difficult to convert the wisdom of experience to words. A writer cannot cite references that don't exist. But this should not prevent writers from making statements of opinion based on experience and intuition, if they are acknowledged as such.

The experiments described in this article were prompted by my own lack of knowledge. It is fine to discuss the measurable effects of various modifications and principles, but what do these measurements sound like? This is not to advocate the abandonment of objectivity (or at least measurability), but to advise well-applied engineering. The most complicated measuring device in audio is the human ear, but ears do not have non-volatile memories and chart printers, and many ears have been poorly calibrated and badly maintained.

The answer seemed to lie in conducting listening tests of loudspeaker-design aspects using a variety of ears. The "listening panel" has a respectable history in the more intellectually rigorous hi-fi press, and it is worthwhile to borrow the better features of the best of them. The reactions of these test ears would be recorded immediately to reduce memory problems. Recording of results would use the rawest of raw data, rather than answering "closed questions." The approach would be hypothesis-generating, or "heuristic."

This has a great advantage over hypothesis-testing approaches to experimentation, in that it allows new ideas to be generated rather than merely confirming or rejecting existing ideas. The broadest range of data would be assembled to allow the broadest opportunity for patterns to emerge. Therefore I tried heuristic research into the audibility of design and construction decisions.

RELIANCE ON CLICHÉS

Cabinet materials and construction provide a wide scope for diversity, but most amateur builders fall back on a limited selection of formulaic clichés. Unfortunately, the space and time required to conduct useful experiments in these areas are usually beyond the resources of the home builder. This seems to lead to the adoption of practices from the mass producers, but their solutions are based on a different set of criteria from those of the amateur builder.

High on a commercial producer's list of priorities are ease of economic manufacture and repeatability between samples. The box must not only look and sound the same from sample to sample, but must be available to the consumer at a price that represents good value. The manufacturer of an inconsistent or overpriced product will not remain in business for long. The home constructor has the opportunity to produce a hand-built, individually tuned masterpiece regardless of labor input.

This article will seek to enable you to exercise a wider and more informed choice of design and construction judged by performance. If you elect to build a kit or a published design, of which there are many excellent examples in the pages of *Speaker Builder*, the influence of their particular constructional decisions will have a dramatic effect of the ultimate sound of the completed project. I will examine the effects that each constructional parameter may have on sound quality.

Each part of this article takes a look at aspects of what happens to some of the electrical energy delivered to the loudspeaker terminals. Some of this expensive amplifier energy is converted into something other than music. Bizarrely, audiophiles and designers often refer to this as "unwanted energy."

Part 2 will help you determine fact from fancy when looking at advertised driver specifications.

With some know-how, a little patience, and a modest expense, you, too, can bring new life to old speakers.

Reviving An Old Criterion

By Charles Hansen

I have a pair of Lafayette Criterion 50A two-way speakers that I purchased for about $70 in the early '70s, along with a Lafayette receiver. (I noticed that Dennis Colin used a similar receiver as a noise break-in device in his "Swan M1 Kit Review" in *SB* 3/99, pp. 36–54. My wife still uses my LR-5000 as her receiver, so the Criterions are now her *de facto* speakers.) These speakers are rated for "30W Music Power."

Photo 1 shows one of the Criterion 50As. The cabinet is ½″ birch plywood, with the corners perfectly mitered. There are a few minor dings, but a coat of Liquid Gold brings back the finish very nicely. In fact, they are much nicer as furniture than they are as music reproducers. These speakers lack bass response, the midrange seems designed to optimize the male speaking voice, and the high frequencies are shrill. My plan was to replace the tired old drivers with modern devices, producing, so to speak, a new set of Criteria.

Let me say at the outset that I have no speaker-building experience whatsoever. I decided to write this article from the viewpoint of a total woodworking, speaker-building amateur. I once replaced the stock drivers in my 1978 TransAm with Jensen's latest 6 × 9 triaxials, but other than that, my only contact with speakers has been as a purchaser.

While I have worked with MDF, plywood, and particleboard, those projects have been strictly utilitarian, such as closet shelves or a garage storage rack. My woodworking power tools are limited to a circular saw, a saber saw, and a router that I once used to make the cabinet described in my article, "Electrolytic Capacitor Reforming Unit" (*Glass Audio* 6/97, pp. 22–27).

ABOUT THE AUTHOR
Charles Hansen is an Engineering Consultant and holds five patents in his field of electrical engineering. He began building vacuum-tube audio equipment in college. He plays jazz guitar and enjoys modifying guitar amplifiers and effects to reduce noise and distortion, as well as building and restoring audio test equipment. He also has 40 magazine articles to his credit.

EXISTING SPEAKERS

First I took one of the Criterion units apart to ascertain its structural suitability. The basic box has external dimensions of 19″H × 11″W × 8.625″D, and a gross internal volume of 18″ × 9.75″ × 7″. *Photo 2* shows the speaker with its ½″ particleboard back panel removed. The front baffle and rear-panel mounting sup-

PHOTO 1: Criterion 50A loudspeaker prior to upgrade.

PHOTO 2: The Criterion box showing unmounted speakers and back panel removed.

ports fit into dados in the top, bottom, and sides. All mating surfaces are reinforced with ¾″ triangular corner braces, and all miter joints with full-length rectangular splines. Structurally, it looks quite promising.

All the internal walls except the ½″ front baffle have ½″-thick acoustic padding. The 8″ woofer and 3″ cone tweeter are mounted from the inside with captive screws and nuts. The sealed-back tweeter is mounted in a shallow ¹⁄₁₆″ routed circle. There is also a 3″ID × 4.75″L cardboard vent tube just below the centrally mounted woofer.

Both drivers are marked "8Ω," and the crossover is a single 3.3μF nonpolar cap. There was evidence of dried electrolyte leakage at the seal at one end of the capacitor. The tweeter had a date code of 7220D, presumably the 20th week of 1972. The grille cloth is glued to ⅛″ luan, with speaker cutouts corresponding to those in the front baffle. Eight thin wire brads hold the grille board in place, and it was also lightly glued to the baffle, as you can see in *Photo 3*.

After spending a couple of weeks poring over catalogs full of drivers and speaker accessories, I decided to contact Madisound for its assistance in choosing new drivers for the existing Criterion enclosures. They recommended the drivers and crossover from the Madisound Cygnet two-way speaker kit.

The full 19″H × 12″W × 10.5″D Cygnet kit is $415 per pair. The kit without cabinets costs $235, and consists of two Peerless 831709 8″ polypropylene woofers, two Peerless 812687 1″ fabric-dome tweeters, two crossover networks, two input terminal cups, foam sheets, wool, mounting hardware, foam tape, hookup wire, and solder. The parts for one speaker are shown in *Photo 4*. Two pages of instructions show you how to mount the drivers, crossovers, and terminal cups, and how to wire the speakers.

I did a quick CAD layout, dimensioned in mm, to make sure the new drivers would fit in the existing cabinets without major rework or interference (see *Fig. 1*). It looked as though the woofer would drop right into the existing cutout, but the new tweeter was larger than the original, and, if mounted on the existing centerline, would hit the woofer frame. I would need to enlarge the tweeter opening and move its centerline upward about 3mm. The existing vent tube is 3″ID × 4.75″L, while the Cygnet's is 2″ID × 6″L, so I didn't know what effect that might have on the sound. I selected the crossover mounting location to accommodate either one.

DISADVANTAGES OF THE EXISTING BOX

The rear-mounted drivers are not sealed into their openings, so there is some air leakage at the flanges. The back of the cabinet is held in place with only ten #5 × ⅞″ flat-head wood screws, so there is probably leakage there also. Moreover, the cardboard vent tube is held in place by only two staples, and I could see daylight between the tube and its cutout. I could also see daylight through the rear terminal strip—more air leakage.

The central location for the woofer is probably not ideal, and the tweeter is offset 8mm from the centerline. These

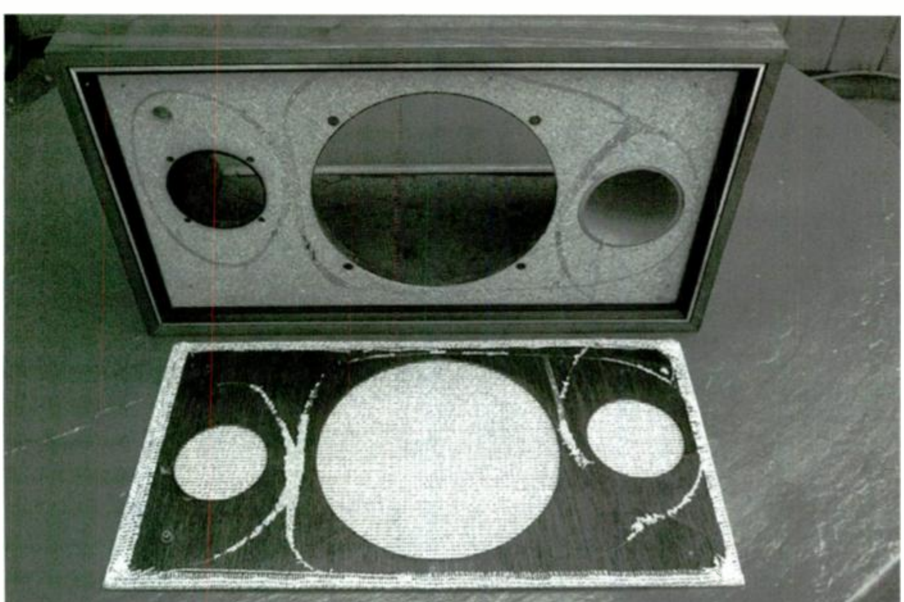


PHOTO 3: Grille cloth and drivers removed.

speakers were originally "bookshelf" types, probably intended for placement with the long dimension horizontal, since the terminal strip and rear nameplate are oriented this way.

I would think there is a lot of uncontrolled diffraction from the speaker cutouts, the grille board, and the frame of the box where it extends forward past the baffle surface. The trend also seems to be toward boxes that are deeper than they are wide, although the Cygnet's proportions are more like those of the Criterion.

Finally, the Criterion's volume is only about three-quarters that of the Cygnet ($1230in^3$ versus $1654in^3$ gross interior volume). I didn't know what effect that would have on the vent-tube design.

AUDIO MEASUREMENTS

I decided to run some audio measurements on the other Criterion 50A as a performance baseline. First I measured the impedance versus frequency, using my low-impedance sine-wave generator. I recorded the voltage across the input terminals and measured the speaker current as a voltage drop across a series 0R1Ω 1% resistor.

Next I borrowed a friend's Radio Shack model 33-2050 sound-level meter. I set up the speaker on a 24" stand on my back patio, and mounted the meter on my camera tripod (the meter has a handy ¼" threaded socket). I placed the microphone one meter from the speaker grille in line with the tweeter, and set the sound-level meter to C weighting and slow response. I connected the sine-wave generator to one channel of my power amplifier, and adjusted the signal for 2.83V RMS at the speaker terminal strip at 1kHz.

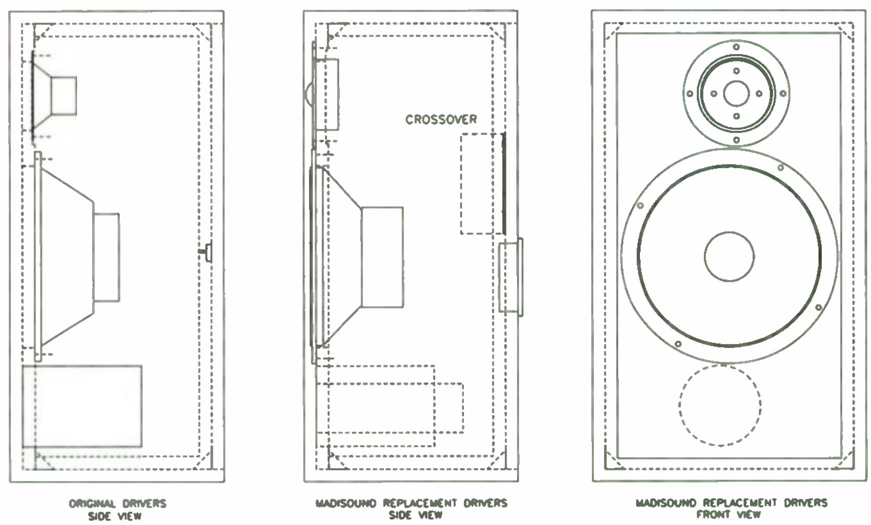


FIGURE 1: Criterion 50A CAD layout.

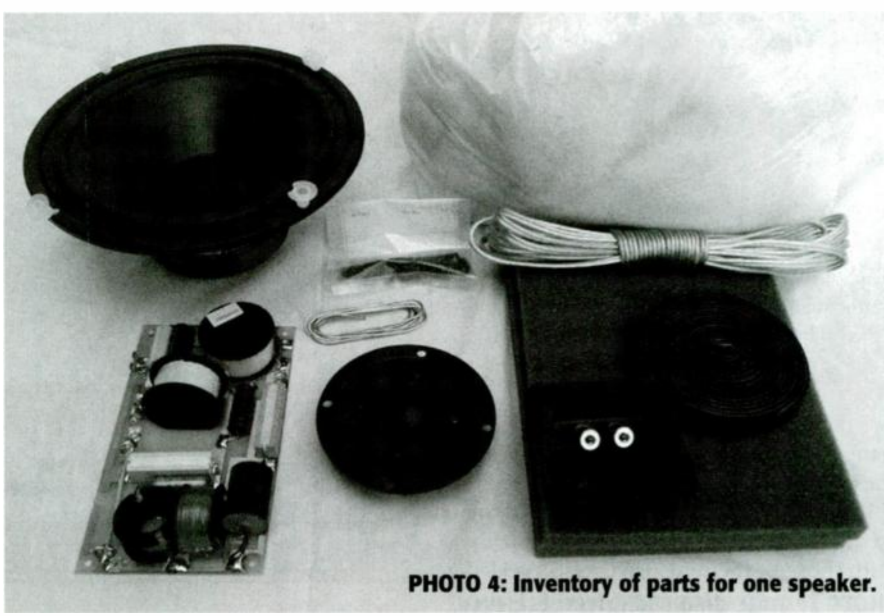


PHOTO 4: Inventory of parts for one speaker.

The sound-level meter read 91dB. Even with ear plugs, the sound was deafening, and I certainly wouldn't want to be close enough to take meter readings at that volume. I reduced the voltage level to 1V RMS, which was at least bearable at 82dB. Besides, I didn't want to beach any dolphins.

During the tests, the cabinet began to rattle and buzz at 70Hz. I took off the back, tightened the eight driver-mounting nuts, and reassembled the speaker. This cured the mechanical-resonance problem, but the woofer still sounded distressed at these levels.

I also took measurements of one of the NHT SuperOne speakers I use in my own system. Its specified sensitivity at 1kHz is 86dB/2.83V/1m, which fell to 80dB at 1V RMS. After modifying the first Criterion 50A, I will take its measurements.

While I had measured amplifiers and preamps in the course of product reviews for *Audio Electronics* and *Glass Audio*, I had never before made any speaker measurements. I used modest test equipment and methods that were convenient and that I considered practical. If you plan to write the magazine pointing out that my measurements are lacking, allow me to agree with you ahead of time. This is simply comparative data between one known and two unknown speakers. I leave the interpretation of the data—if indeed there is any valid conclusion to be reached—to those well versed in the field of loudspeaker design.

CONSTRUCTION

Before beginning construction, I read all the *Speaker Builder* kit reviews I had on hand, seeking construction tips and pitfalls. The first order of business was enlarging the tweeter opening. I suppose a router is the proper tool for this, but the baffle surface was recessed ½″ below the plywood edges of the cabinet, so I would have had to make a special jig to guide the router bit. I decided to use a coping saw and manual labor. For the same reason, I did not rout around the driver cutouts so the drivers could be flush mounted. Besides, with only ½″ baffle walls, I did not dare to remove any more material. In addition to moving the tweeter up 3mm, I moved it as far as possible toward the centerline.

I drilled ten additional holes for rear-panel mounting screws, and increased the size of the screws from #5 × ⅞″ to #6 × 1″, for a total of 20 screws. None of the existing driver-mounting holes lined up with those of the new drivers, so I sealed all the holes with plastic wood. I also sealed the eight holes made by the brads that secured the grille board. Finally, I scraped off the old glue from the front of the baffle.

Next I soldered the 16-gauge wire provided by Madisound to both driver voice-coil terminals. The tweeter is connected out of phase, so the positive wire goes to the negative terminal.

After the sealer dried, I sanded the baffle board front and back, and drilled new 9⁄32″ driver-mounting holes. I also rotated the tweeter 45° from its original mounting position so I could drill into solid wood. I rotated the woofer only 30°, so the lower mounting screw would not be near the vent tube in case I needed to make modifications later. Then I cleaned and masked the cabinet and gave the front of the baffle a coat of flat black paint (*Photo 5*).

The vent tube on the Cygnet is 2″ID × 6″L, so since the Criterion cabinet is only 7″ deep, I would probably need to use a 1.5″ID vent tube, especially with the reduced internal volume. I cut a few 3.25″OD wood plugs from ½″ particleboard to hold the new vent tube.

When the paint was dry, I mounted the woofers into the baffle without the foam tape, and measured their resonant frequency and impedance, which was 28Hz at 36Ω. I ran the two woofers without the cabinet backs for 15 hours at 6V RMS (about 1W) and 28Hz.

While the woofers were running in, I turned my attention to the rear panel. I removed the existing padding and terminal strip, then cut the 2¾″ hole for the new terminal cup and drilled mounting holes.

In contrast to the single capacitor used in the Criterion 50A, each Madisound 18dB/12dB crossover has four capacitors, three resistors, and four air-core inductors mounted on a glass-epoxy PCB. The crossover has four mounting holes, and is designed for mounting in the bottom of the Cygnet cabinet. Since the vent tube is at the bottom of the Criterion cabinet, I mounted the crossover just above the terminal cup. There was a large open spot in the middle of the crossover PCB, so I drilled another mounting hole and secured it with five screws. I used flat washers as spacers under the PCB to keep the solder joints

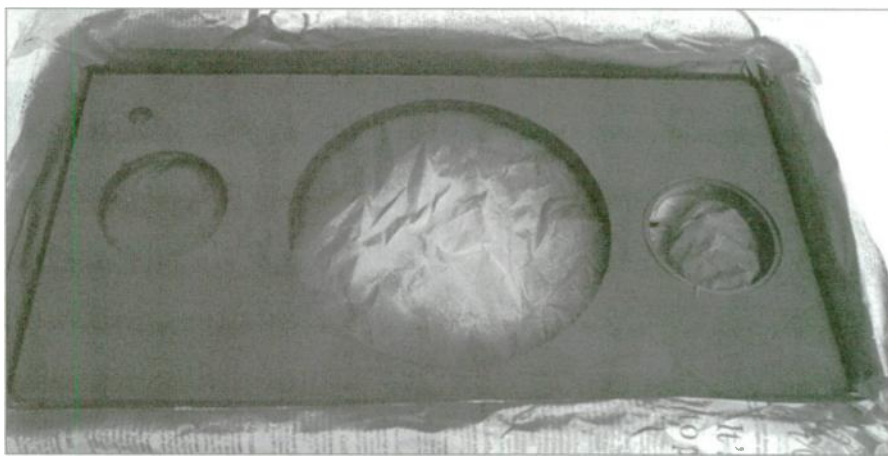


PHOTO 5: Baffle board sealed and painted.

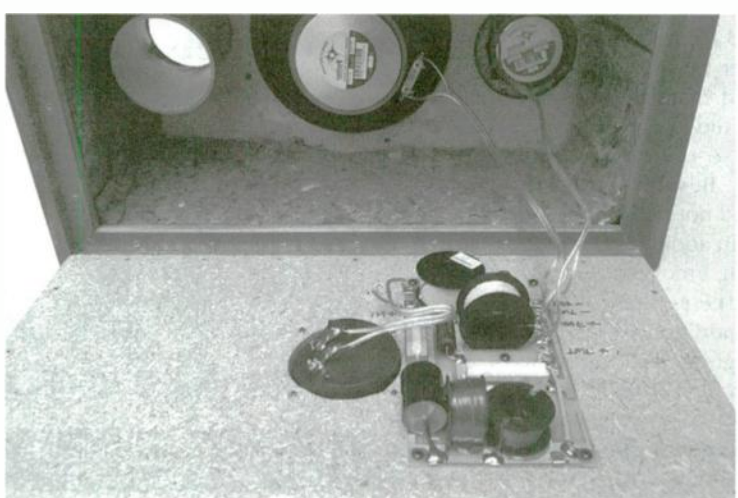


PHOTO 6: Rear panel with new terminal cup and crossover.

from hitting the rear panel surface and putting stress on the PCB.

At the end of the run-in period, the woofer resonance had shifted down to 24Hz at 34Ω. I removed the woofers and applied foam tape to the rims of all the drivers. I vacuumed out the cabinets and installed the drivers. Then I connected the wires to the crossover board. *Photo 6* shows the revised rear panel wired to the new drivers.

Before mounting the rear panel, I installed the original ½″ padding, cut for clearance around the crossover and terminal cup. Then I covered the crossover with foam and filled the cabinet with wool in accordance with the Madisound instructions. In order to seal the rear panel, I applied sealing caulk around its mounting surface. *Photo 7* shows the modified speaker with the sound-absorbing materials installed, just before attaching the rear panel.

INITIAL MEASUREMENTS

I connected the speaker to my signal generator and measured the resonant frequency (f_B) of the speaker—18Hz! Clearly the existing vent tube would not work. I decided to try the other extreme, and plugged the vent with the polyethylene container that the plastic wood came in, wrapping a few turns of electrical tape around it for a good seal. Now the f_B was just over 50Hz.

I removed the temporary vent plug and installed the speakers in my system. They had poorly defined bass, all one-note like a '60's juke box, and the mids were hollow and lifeless, without any accurate imaging. The highs were just overpowered by the exaggerated bass.

In order to retune the vent tube, I referred to the only speaker-design book I own: *Bullock On Boxes* (available from Old Colony Sound Lab, PO Box 876, Peterborough, NH 03458, 1-888-924-9465, Fax 603-924-9467, E-mail custserv@audioXpress.com). I concentrated on the sections describing vent-tube design, pages 8, 20, and 21. Using the formulas provided, I found a 3″-diameter vent tube would need to be 33″ long, and a 2″ tube 14″ long. Even a 1.5″ tube would be longer than the box was deep, at 7.8″. Can you put a 90° elbow in a vent tube, making it a "bent vent"?

I also did not know how much the wool filler had decreased my estimated net volume, thus requiring a longer vent tube than I had calculated. There were also indications that the velocity of the air in the smaller-diameter vent tube might be audible.

I sent another e-mail to Madisound for some advice, which was that the Criterion box was probably too small for a vent, and they suggested I try a sealed box. I removed the cardboard vent tubes from the two speakers and made up a set

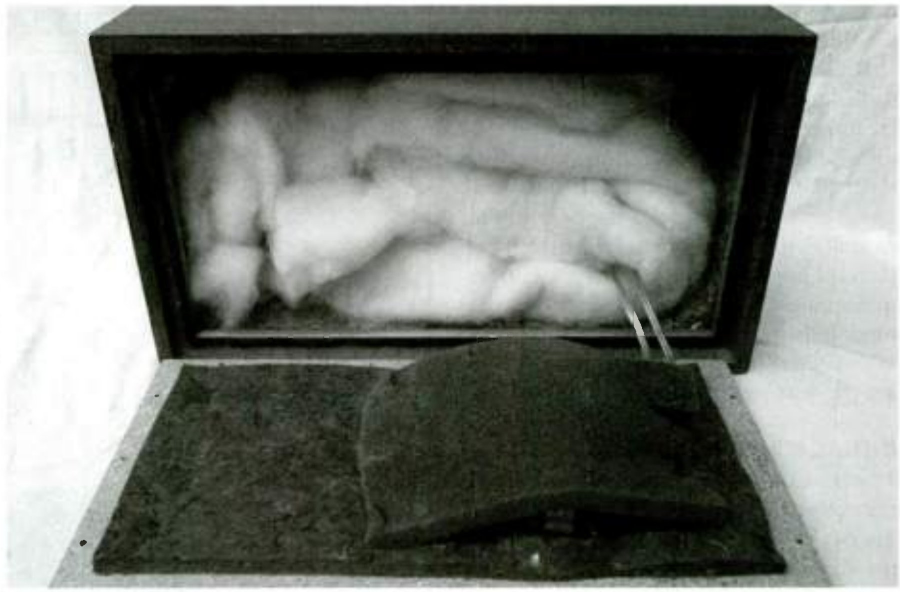


PHOTO 7: Sound-absorbing material installed.

of square blocks and cleats from ⅝″ particleboard. With the cleat inside and the block outside, I used a long screw to close each vent hole. A sheet of neoprene on the inside surface of the blocks made the box airtight.

Installing the sealed boxes in my system, I tried the speakers on 24″ stands, 16″ stands, flat on the floor, and on the floor tilted up toward the listening position, with and without toe-in.

FINAL LISTENING RESULTS

I achieved the best results with the speakers flat on the floor and toed in. I made a set of tight-fitting permanent vent plugs from particleboard, epoxied them into the vent openings, and masked and painted the plugs. These plugs also reinforced a weak spot in the front baffle—there was only ¾″ between the openings for the woofer and vent.

With the now-sealed speakers back in my system, the bass was under control, with good extension and definition. The midrange was spacious and more natural, with nice imaging. The upper midrange and lower highs were a bit darker than the NHTs, which I really like for their detail and transparency. The high frequencies, however, were nice and bright, which made the laid-back midrange even more obvious.

I would guess that it is not easy to blend a large 8″ woofer with a small tweeter in the crossover frequency (the NHT woofer is 6½″). I would think each is being extended slightly beyond its most effective range in the overlap. Perhaps the sound will brighten with time as the drivers break in. At higher volumes, the speakers held up very well, without any change to their basic sound.

The sound was well balanced when I used the warble tones on the *Stereophile* Test CD 3 (available from Old Colony Sound Lab). I played the low-frequency warbles very loudly, and did not detect any cabinet noise. I suspect a closed box puts more stress on the enclosure than a vented box, but even with the ½″ walls, there were no extraneous creaks or groans.

GRILLE BOARD

The finished units are shown (front and rear) in *Photo 8*. At this point I still had not completed the speaker grilles.

Parts Express has grille cloth, guides, and frames so you can build nice custom grilles for your speakers. I decided to stay with the existing grille cloth. Since I could not glue it back onto the baffle with the front-mounted drivers, I used grille guides to make the grille removable and also provide clearance for the drivers, especially the fragile tweeter dome. I also considered strip magnets and Velcro™ before settling on the grille guides.

TEST RESULTS

With the speakers finished, and after several days of listening, I ran the same tests as on the NHT and the original Criterion. The impedance graphs for the NHT SuperOne, the Criterion 50A, and the Madisound-modified speaker are shown in *Fig. 2*. The peak impedance for the new Criteria is at 53Hz, which is fairly close to that in the Cygnet graphs, about 57Hz.

Next, I went back out to the patio for tests with the Radio Shack dB meter. The frequency-response graphs are in *Fig. 3*. The Criterion 50 and the NHT had their grilles installed, while the Madisound-modified Criterion had no grille.

The sensitivity of the new Criterion was 88dB/2.83V/meter at 1kHz. I reduced the voltage at the speaker terminals to 1V RMS, the same level I used for the earlier measurements. The 0dB refer-

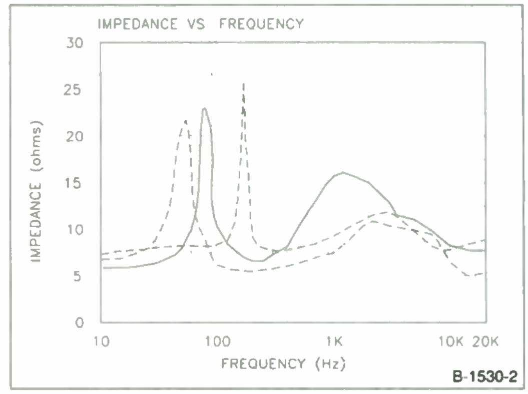


FIGURE 2: Impedance versus frequency for each speaker.

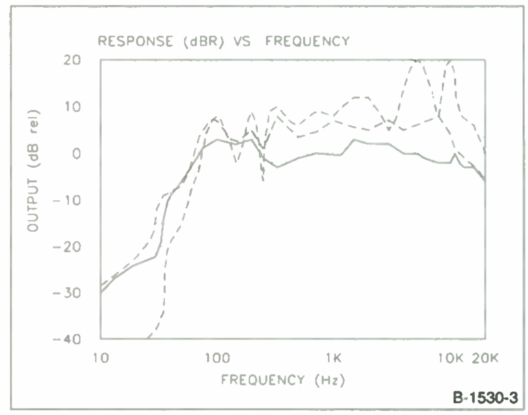


FIGURE 3: Frequency response for each speaker.

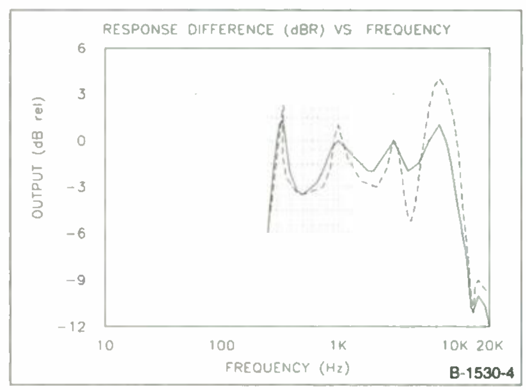


FIGURE 4: System response with grille installed.

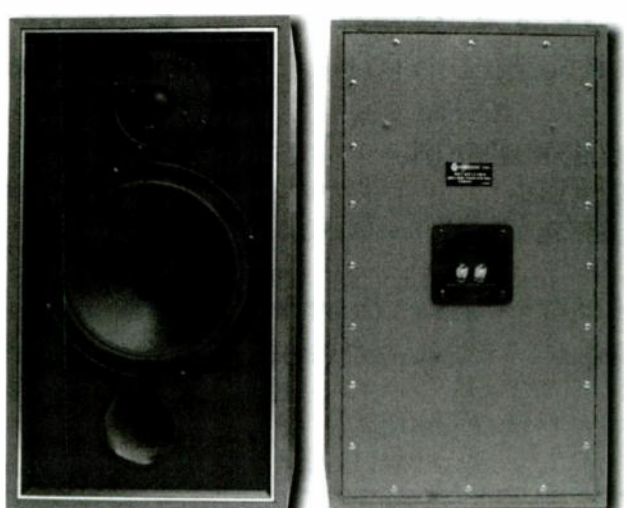


PHOTO 8: Finished speakers, front and rear view.

ence point is 80dB, which is the level I measured for the NHT SuperOne at 1kHz and 1V/meter. All other measurements are relative to this level. The rolloff above 15kHz may be inherent in the Radio Shack dB meter, since the NHT is fairly flat to 20kHz and isn't down 3dB until 25kHz.

One thing that leaps out from the graph is that the peaks and dips in response with the new drivers occur at the same frequencies–between 100Hz and 1kHz–as with the old drivers. I don't have the expertise to know, but I wonder whether this is a characteristic response caused by the Criterion enclosure? The smooth curves of both dome tweeters are in contrast to the wild HF peaks of the original 3″ paper-cone tweeter.

Figure 4 shows a comparison of the response with the grille board installed. The data is the same as in *Fig. 3*, expanded, with the "no-grille" 1kHz response as the 0dB reference. The grille exaggerates the level changes between 1kHz and 14kHz. I will use the grilles for protection while the system is off, and remove them for listening.

CONCLUSION

I wonder how many older loudspeakers like the Criterion are out there, with decent cabinets but poor audio performance. Companies like Allied Electronics, Lafayette Radio, Radio Shack, and Heathkit sold thousands of these speakers with a receiver and record changer as part of a prepackaged audio system. Many were two-way vented systems with 8–10″ woofers and 3″ cone tweeters.

I derived a lot of satisfaction from this project, and ended up with a nice set of speakers in the bargain. Madisound was very helpful, and I developed a new appreciation of the reason speaker designers use computers.

My total parts cost for replacing the drivers and modifying the speakers was about $260 with shipping. *Table 1* is the parts list, with prices.

TABLE 1
CRITERION 50A DRIVER UPGRADE PARTS LIST:

From Madisound, 608-831-3433 (info@madisound.com)
Cygnet two-way speaker kit without cabinets, $250
From Parts Express, 1-800-338-0531 (www.parts-express.com)
3 36″ speaker-sealing caulk, p/n 269-300 $2.25
1 Heavy-duty grille guides, p/n 260-367 12 pr., $2.40
I also ordered two Gold dual banana plugs (p/n 091-334, $4.80 each) and some 12-gauge speaker cable to complete the upgrade. This replaced the 16-gauge lamp cord I had been using with the Criterions since the 1970s.

Kit Review

THE RHYTHM REVELATOR KIT

Reviewed by Daniel R. Smith

The Rhythm Revelator Kit, North Creek Music Systems, PO Box 1120, Old Forge, NY 13420, (315) 369-2500, www. northcreekmusic.com.

In my search for affordable high-end speakers, I came across those of North Creek Music Systems (NCMS), which offers speaker kits as well as ready-made systems. This was a challenge. Why pay double the price for a speaker when I could build it myself? As a die-hard do-it-yourselfer, I'm accustomed to building things myself, rather than paying what I consider high prices. But I was willing to trust my gut feeling on this one.

I chose the Rhythm Revelator Project kit (*Photo 1*). North Creek seems to have done its homework in that the reasoning behind the speaker design was quite straightforward. I was impressed with the detail in which the company developed its strategy for a better musical mousetrap. For example, it researched and developed its own custom capacitors and inductor coils. North Creek is owned and operated by George Short, who answers the phone directly when you have a question and need technical support—customer service *par excellence*.

HOMEMADE PARTS

NCMS makes its own inductor coils from military-grade high-purity copper. They are domestically manufactured low-tension wound coils. According to NCMS, low-tension winding preserves the crystal structure of copper and enhances the low-end performance of the

PHOTO 1: Finished Revelator.

crossover. The average woofer inductor requires over 100′ of wire; therefore, the quality and gauge of the inductor wire could make a noticeable difference in woofer and midrange performance.

The tweeter and woofer crossover both use #10 AWG air inductors. The sound quality of 10-gauge coils is apparently refined and delicate, but as an amateur hobbyist, I cannot make expert comparisons of all electronic components and their possibilities of sound reproduction. With that said, I'll move on to a further description of the kit.

Next are the custom-made capacitors, which I thought a novel and bold attempt by NCMS to develop its own unique sound. It came up with two designs, the Zen and the Crescendo. The former is claimed to have midrange and high frequencies that are natural, smooth, soft, and delicate. NCMS says it is "remarkable in resolving fine detail without grain or harshness." I am not an expert on capacitors, and so hesitate to offer an opinion, but they do sound very sweet to my ears.

As for the Crescendo, NCMS claims it is smooth and liquid, and harmonically correct in the midrange. The pulse capability of the 1.0μF is 500V/μs. This produces a high end with lightning transient speed and a sound stage that is dead silent. The film-foil construction forms a thick conductor that transmits a purer signal.

For resistors, NCMS uses Ohmite 1%-tolerance wirewounds, claimed to be "completely transparent." NCMS says that the gritty sound and texture of sand-cast resistors is eliminated by using wirewound units, adding dynamics, detail, and clarity to the crossover circuit. By using matched 1% pairs, as opposed to the more common ±10% tolerance, the sound stage is brought into sharp focus.

KIT CONTENTS

The kit comes with cabinet diagrams, assembly manuals, and a cabinet and wiring handbook. It includes drivers, all crossover components and boards, binding posts, internal wiring, silver solder, connectors, grille fasteners, hardware, port tubes, and glue—basically everything you need. North Creek recommends as a prerequisite soldering and electrical-assembly skills and the ability to read schematics. You have the option of cutting your own panels for the cabinets, or getting precut, prerouted, predrilled boards with grille frames as a cabinet kit.

The Rhythm uses a QB3 box, a 43-ltr volume yielding a tuning frequency of 39.5Hz and an F_3 of 47.2Hz. The rear panel is 1.5″ MDF composite, and the front is 2.5″ MDF Baltic birch composite, as is the internal bracing. The shell is ¾″ MDF, with coated and damped internal surfaces. This is a very rigid, solid cabinet, weighing 67 lb without any electronics mounted. Assembled and mounted, each unit weighs about 100 lb (*Fig. 1*).

The driver arrangement is midrange-tweeter-midrange. The drivers of choice are the Danish Scan-Speak Revelator D2905/9300 for the tweeter (*Fig. 2*) and the Scan-Speak 18W/8545 for the woofer-midrange (*Fig. 3*). The interesting thing about the Revelator

TABLE 1
ASSOCIATED EQUIPMENT

Digital source: Adcom GCD 700 CD transport; Sonic Frontiers' Assemblage, DA-2 20-bit HCDC processor; Monarch DIP anti-jitter.
Preamplifier: Sound Valves' VTP-101 tube.
Amplifier: Sound Valves' M60 monoblocks 30-60W tube.
Cables: Tara Labs' 8′ biwired prime; Kimber Kable TGDL .5m digital; Kimber Kable .5m KCAG analog.
Other: Power Wedge 116 power conditioner.

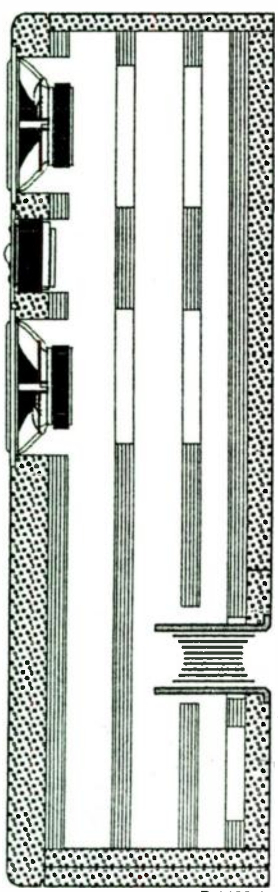


FIGURE 1: Cutaway view of cabinet.

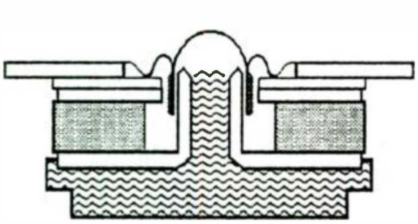


FIGURE 2: Scan-Speak tweeter design.

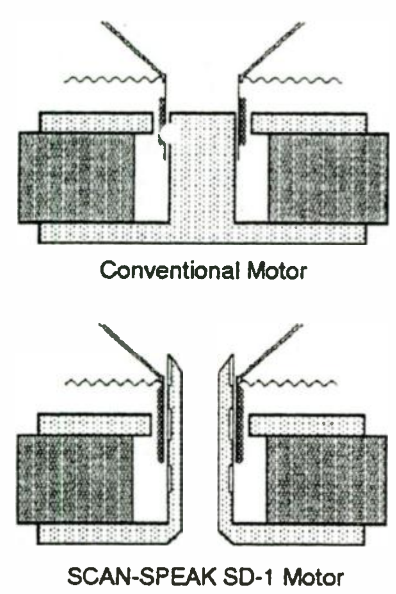


FIGURE 3: Motor structure of woofer.

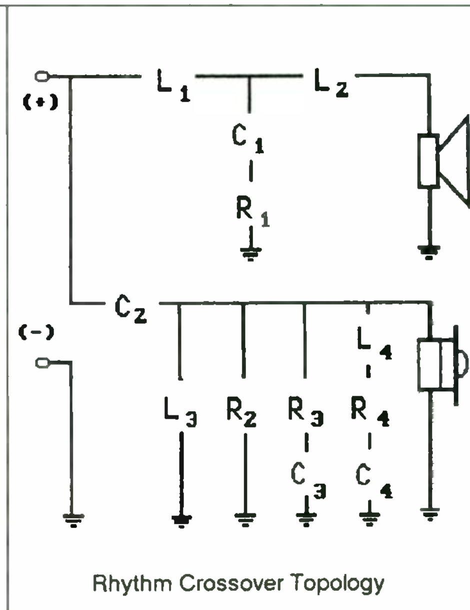


FIGURE 4: Crossover design.

tweeter is that it is constructed with a long-coil, short-gap geometry, like a woofer. The excursion is a full 1.0mm pk-pk, double that of conventional tweeters. While normal woofer excursion is 6mm, the Scan-Speak's is an amazing 13mm. The sensitivity rating for the Revelator speaker is 90dB, biwired.

Since I had never before attempted to assemble a speaker kit, I needed to study everything in great detail and organize my tools, parts, and supplies. Just as in planning a long journey, it was necessary to think through everything from start to finish in as much detail as I could. My goal was to match or surpass the standards and quality of large manufacturing companies, and since I had everything needed to accomplish this goal, I embarked on this task with great anticipation.

CONSTRUCTION STEPS

Beginning with cabinet construction and crossover assembly, I then veneered the cabinets and fascia. I wired and mounted the crossovers, then the drivers. For the cabinets, you can use any good wood glue such as Elmers or Tite Bond. For veneering, I utilized the services of the Constantine Wood Center. Picking out the right veneer, and then applying, sanding, and finishing it was a project unto itself, but well worth the effort. As an alternative, I believe you can obtain panels for cabinet construction already veneered from NCMS if you so choose.

My approach to cabinet construction is the drill/screw method. Carefully mark off your sites to be glued and drilled, apply your glue, position the panels, and clamp them, which can be tricky and must be precise for a well-approximated edge (*Photo 2*). You need a drill bit to drill the holes, and a screwdriver bit to drive the drywall screws, forming a tight fit between the panels.

Once the panels are set, remove the clamps and screws. Fill the holes with wood filler and sand off the excess. You

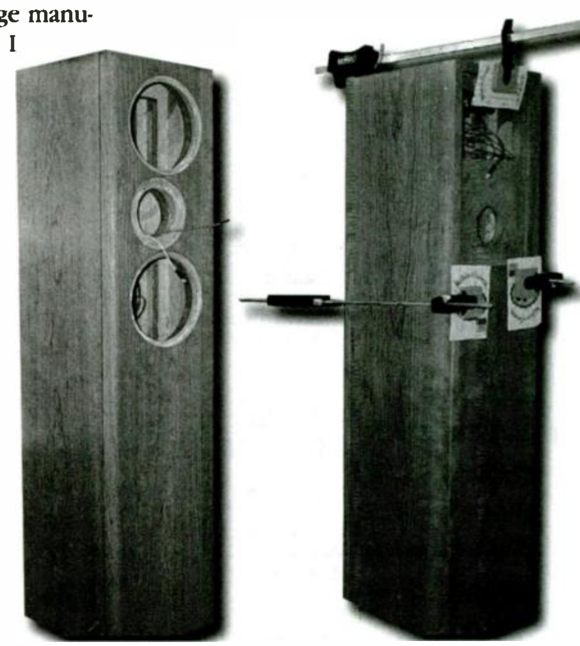


PHOTO 2: Gluing and screwing the panels.

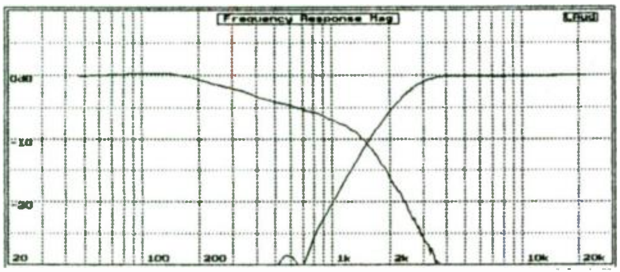


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FIGURE 5: Filter transfer functions.

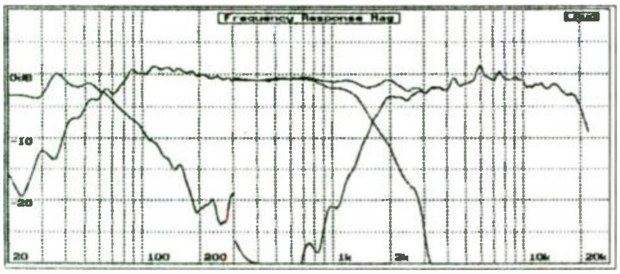

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FIGURE 6: Combined frequency response.

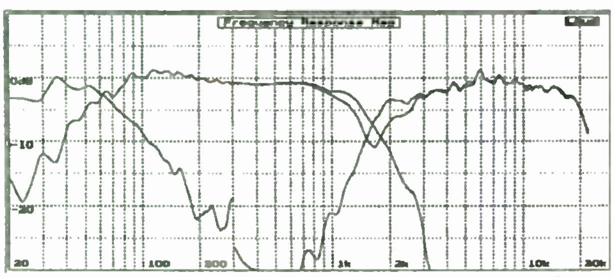

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FIGURE 7: Antiphase response.

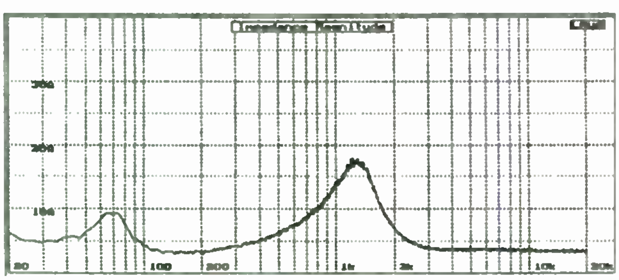

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FIGURE 8: System input impedance.

need a glass-smooth surface for applying the veneer. This method was quite efficient and brought me excellent results. You next apply the damping compound, which is a mixture of gypsum and specialized glue from NCMS. This ensures that the cabinets are dead solid to prevent unwanted vibration.

Crossover assembly is an adventure (*Fig. 4*). NCMS supplies you with silver-content solder for high-conductive contact. You achieve the best connections with cold welding, supplemented with silver solder. To attain the best performance from the crossover, you must take care with every detail. As an example, I had failed to grind the side of a woofer inductor lead to provide greater contact surface area with the bus wire. Consequently, I needed to desolder this whole assembly step and begin again so that it was done correctly (*Figs. 5–8*).

Capacitor bundles are bonded with silicone, and the crossovers are mounted to the inner cabinet wall with Liquid Nails®. You may prefer to wrap the crossovers with bubblewrap for added insulation from vibration and emf/RF. All internal wiring is Vampire high-purity copper, including the gold-plated binding posts. Take your time in double-checking that all points of contact are cold-welded and soldered well (*Photos 3* and *4*).

PAPER-BACKED VENEER

Turning again to the cabinet, the ports at the removable back panel (*Photo 5*) are tuneable, and the cabinets are mechanically grounded with huge isolation spikes. Good mechanical grounding produces a tighter, more detailed baseline, and a more stable soundstage. When it came to veneering the front panel, I was confronted with a challenge that required a creative solution. I desired an attractive wood finish on the whole cabinet, not just the compromise of painting the front panel black. The problem was that the panel had rounded corners, and to apply the veneer there would be difficult.

I took a chance and decided to experiment with a paper-backed veneer (*Photo 6*). The thickness of the wood is less with the paper-backed veneer, and makes sanding a more delicate activity. However, the trade-off was that it also had the high level of flexibility needed to make those tight 90° corners. Well, my theory paid off, and with the help of

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Classifieds

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AD INDEX

Yard Sale

FOR SALE

AudioControl Richter scale crossover, $275; Son of Ampzilla, $150; Sony outboard Dolby, $50; Denon DP30L turntable with Grace F-9E cartridge, $100. Jim, (253) 862-8140.

Sonic Frontiers SFT1 CD transport; Stereophile Class A, $850; Counterpoint SA-20 amp, $800, with SA-20 upgrade, $1050; JBL 2150 15″ coaxial drivers with crossovers, $325/pr; Ashly MFA-6000 power amp (550/900W/p/c), $795; QSC 1300 power amp (400/650/1000W/p/c), $600. David, (914) 688-5024.

Two Eton 11-580 subwoofers—each in a QB3 aligned cabinet, $270 each plus shipping. Marc McCalmont, (603) 860-3085.

Adcom ACE-515 AC enhancer, $100; Adcom GFA-535 stereo amplifier, $175. Both excellent. Classical CDs & misc items—send stamp or E-mail for list. Darroch, 1807 Elm Crest Dr., Arlington, TX 76012, darrochrd@juno.com.

New Vifa drivers: P13WH, $20; M22WR, $50. Used SEAS P21REX $20; new JBL HLS610, $175/pair; new NHT SuperOne XU, $260/pair; Motorola KSN1086 drivers with 4″ × 10″ horns, $25/pair. Fred, (610) 693-6167, E-mail audioarts@enter.net.

18″ Pyle DVC subwoofer, #S18C800-11A, new, in box, $100; 12″ Madisound DVC subwoofer, #1252DVC, almost new, $25; Madisound 12″ DVC subwoofer, #12204DVC, used, $25; pair vintage JBL 12″ woofers, #123A, cast frame, excellent condition, $100/pr. Will consider trade for ribbon tweeters. Jeff Bagby, (765) 457-4260.

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Two JBL 375 drivers and oval-shaped horns out of Paragon's new aluminum diaphragms, excellent condition, $1,250/pr. JBL Century L-100, three sets include Alnico midrange and woofer, mint, $500/set. Two Sansui 9090 receivers, 120W/channel RMS, mint, $175 each. Alan Feinstein, 5743 Yellowrose Ct., Columbia, MD 21045.

WANTED

HSU sub: 12V, 12Va or 1220, with crossover and amp. Cabinet may be in any condition. Roger, (512) 257-7800, M–F 7–11 CST or weekends.

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12. Noncompliance with any of these guidelines will result in your free personal-ad submission being refused for publication.

Kit Review

Continued from page 55

my wife I was able to mount the paper-backed veneer around those corners with no difficulty.

I used standard veneer for the rest of the cabinet, including the back panels. A Dremel drill was invaluable during all phases of this project. I used cherry veneer, which I stained with wood oil, and then applied a gel finish. Remember that judicious sanding is required on your veneer to get that glass-smooth finish. The grilles are optional, and I believe you achieve a better sound without them.

LISTENING TESTS

So how convincing are these speakers in reproducing original musical events? I heard soundstage, focus, presence, dynamics, detail, naturalness, and musicality. Of course, your experience would vary depending on the source recording, but when this is good, you will hear exciting sound reproduction.

The break-in period is very important to consider when evaluating this system. Don't expect everything at once, since it takes time for these speakers to bloom. But once they do, they are everything you'd expect from a wide-range dynamic speaker system.

I used a wide variety of test discs and analog sources to evaluate the Revelator. A good start is Alan Parson's and Stephen Court's "Sound Check," Mobile Fidelity SPCD-15. Try track 85—Chieftain Tank. If you are looking for dynamics and speed, prepare to have your hair raised. The best way to test soundstaging and naturalness is to use recordings of voice and acoustic instruments. Try Patricia Barber's "Modern Cool," Premonition Records PREM-741-2. The acoustic stand-up bass will shake your walls with defined musical notes. The soundstaging is breathtaking.

These speakers have a full-spectrum soundstaging that faithfully reproduces live music. Put on Mickey Hart's "Planet Drum," Rykodisc Au20 RCD 10206, for incredible dynamics and soundstaging.

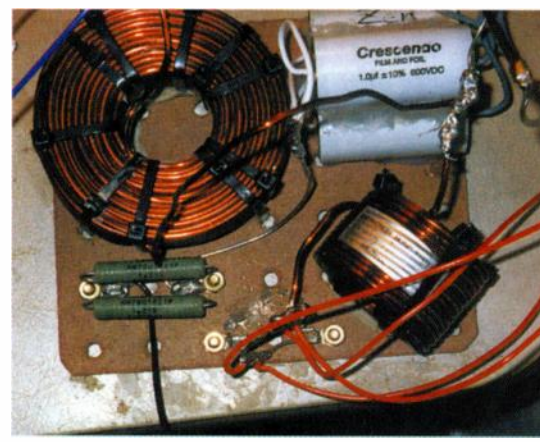

PHOTO 3: A close-up of the woofer crossover.

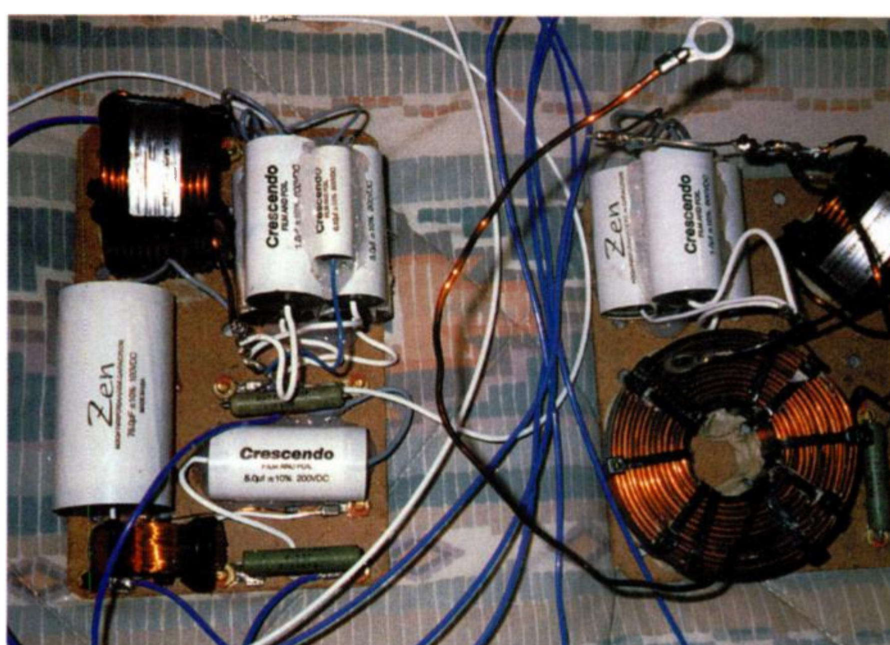

PHOTO 4: Left—tweeter crossover, giving a clear view of the Zen and Crescendo capacitors; right—woofer crossover, with a good look at the inductor coil.

These babies also have a very delicate finesse for micro detail in sound.

Try Yes' "Fragile," Atlantic Gold CD 825224-2. When Steve Howe hits those opening notes, you can hear all the beautiful subharmonics clear as a bell. They just float up in the air and spread out into a flowering soundstage, almost physically concrete. The Revelator delivers well for a wide range of recordings, faithfully reproducing anything.

The Revelator kit delivers performance beyond expectation. It is an easy kit to deal with if you are patient. For the more seasoned builder, it is a good challenge to undertake.

The speakers are rated at 100W. I have a 60W monoblock amp system, and still achieved great results. Remember to give them a little break-in period. Like wine, they just keep getting better with listening.

PHOTO 5: Front and back of finished speakers. Note the access panel with bass port and biwiring posts.

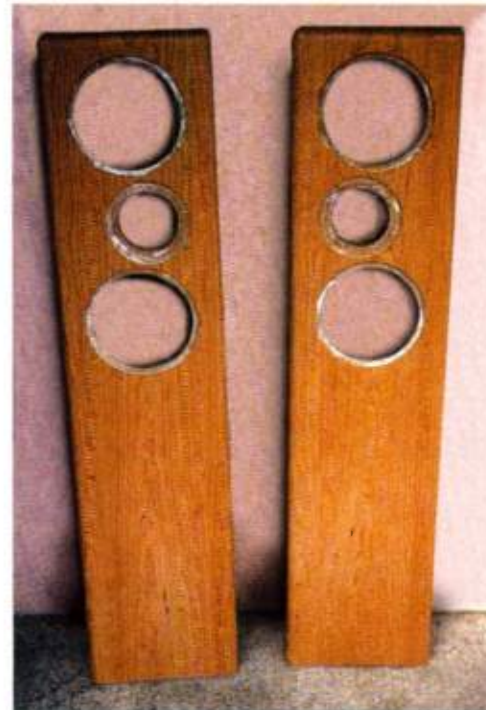

PHOTO 6: Using paper-backed veneer.

SB Mailbox

AFTERBURNER ERRATA

I should have proofread the re-drawn "Afterburner for Aftershock" (*SB* 3/99, p. 26) schematic with my eyeglasses on before I gave the okay to print. I missed an error in the power supply that would make the Afterburner "flame-out." The rectifier diodes connected to the transformer and power supply are reversed. The correction is shown in *Fig. 1*.

Philip E. Abbate
Duluth, GA

TESTING FOR WHAT IT'S WORTH

I had been following Tom Yeago's work on the AR-3*a* speakers with only mild interest until reading the report in *SB* 4/99 ("Test Drive," p. 42). Tom may have produced a speaker that reproduces classical music well but tests poorly. He needs to get opinions from listeners who spend large amounts of time listening to live unamplified music to get the whole story.

First some history. Three decades ago there were no T/S parameters. Almost everything was intuitive cut and try, much like wooden boat building. With no way to accurately measure speakers, it only makes sense to do whatever is required to arrive at a sound that imitates live acoustic music. Back then, serious listeners were skeptical of using close-miked popular vocals to assess speakers.

I know a musician who worked for a defense contractor that had a small audio division which encouraged its employees to attend symphony concerts on company time. This was to assure that they knew what real unamplified music sounded like.

My father started singing major oratorios as a boy soprano, later learning the alto, tenor, and bass parts of the same music as his voice matured. He could tell you almost every note that was missing on a recording of the Bach B minor mass and sing those notes as the record played. He liked large speakers and was not impressed by mini speakers.

To make a long story short, this gave me an idea. Why not make speakers that allow you to hear the most inner musical parts at one time? This can be done with less reference to live music, an advantage to those often unable to attend live concerts. Experience has shown that flat response does not accomplish this, so, over a long period of time, you need to try almost endless networks to get the best results. All my speakers would test very poorly as a result.

So where does all this lead? I would recommend replacing the tweeters with either Dynaudio D-21 or the low-cost Peerless wide-angle dome 811815 to get rid of the peak at 8kHz.

Now you need some top-notch choral recordings of high performance and recording quality. For starters, let me recommend Handel's *Messiah* with John Eliot Gardiner conducting (Phillips 411041-2). Next, you will need the vocal score—or better, a full score to follow the music. I pick the *Messiah* because almost every choral singer is familiar with it and many churches and libraries have the musical score. If you don't read music, see if someone from a local church or choral society would like to keep score on your speakers as you make changes to the crossover.

This would be more in keeping with the design tradition at AR at the time the AR-3 was born. Finally, I strongly believe that the best speaker critics are listeners who spend half their time performing and the other half listening to others performing the same music in a wide variety of unamplified venues. My overall objective is to obtain a sound that is perceived as similar to that heard in a live performance.

Advanced readers will not find the *Messiah* sufficiently complex to challenge the best speakers. For this, I recommend Brahms' German *Requiem*, a work so complex no single performance, let alone recording, can capture it all.

Jesse W. Knight
Woburn, MA

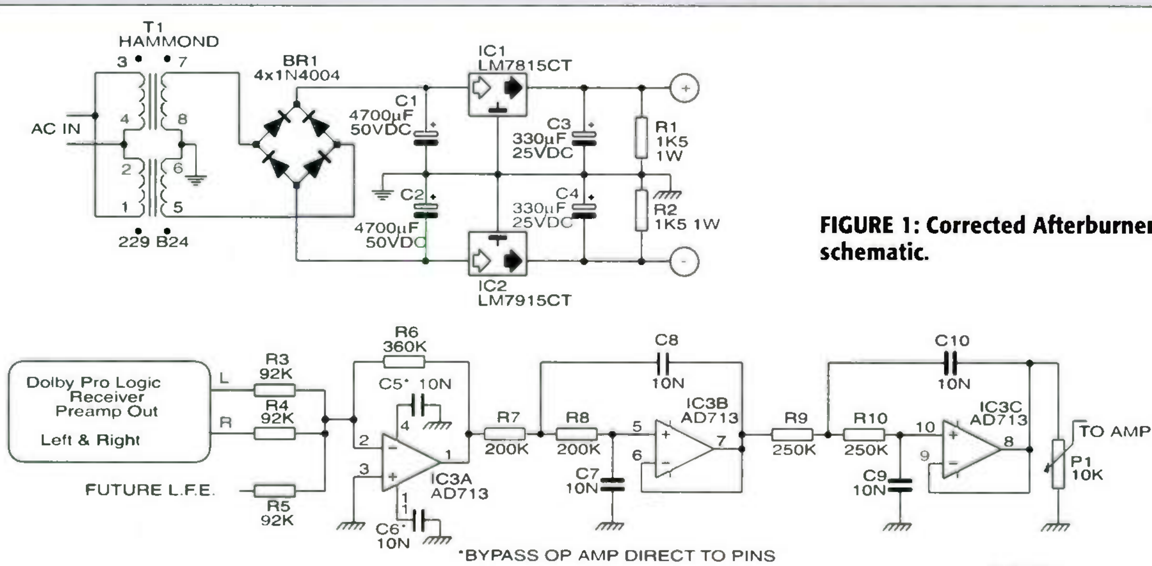

FIGURE 1: Corrected Afterburner schematic.

Tom Yeago responds:

This interesting letter manages to touch on a whole raft of topics. I'll start off on a disagreeable note with a quibble over the characterization of my project AR-*3as* as speakers that test poorly. The tweeters were something of a shambles, it is true. Worse, even, than those Focal units which are unaccountably popular in lots of high-dollar designs. Go figure.

But I am confident—for several reasons I won't bore readers with here—that those woeful distortion figures were caused by saturation in the two cored inductors, thanks to not enough iron. Anemic. One in the low-pass, one in the high-pass. It probably goes without saying that the offending coils have been replaced.

Bass performance worked out very close to targets. Figures 2 and 4 (p. 43) indicate a successful crossover, particularly if the ripples in the mid-dome's response are due to box diffraction. The spectral decay (Fig. 3) is especially good for the bass and midrange drivers. And yes, Dynaudio D-21 units have been acquired, but not yet installed owing to sloth.

The letter's second paragraph brings up a point to be made for the benefit of less experienced readers. Thiele/Small parameters codify a system's performance at the low-frequency end of its response. The midband and high-frequency end of a driver's response have nothing to do with T/S parameters. And it was vented box response that T/S revolutionized. Closed-box design was already being done with great confidence, but the T/S analysis put the closed-box proposition in such simple terms that you can work out a solution in your head. Honest. And while getting good data was expensive and time-consuming, it could be done if a firm had the intestinal fortitude and determination. Cheap computing has simply made the traditional testing much cheaper, and has provided a new set of tests unthought-of without cheap digital processing. I think spectral decay plots are fabulous, revealing far more about a loudspeaker's sins than anything else.

But before these tools became available, designers were far from clueless. If you drive a rigid piston with a linear motor, and don't try to use it too far into the treble (where physics conspire to make the depth of the cone, for example, and how it flexes of critical importance), the driver will behave in a predictable and salutary fashion. This is the line I took with my project, and I'm prepared to declare the woofer and mid-dome units a success.

Readers may recall having seen tales of Rudy Bozak's and Henry Kloss' experimentation with bizarre paper pulp formulae for cones. This was an effort to stretch the performance of a cone at the treble end, seeking high-frequency response which "must be sustained by focusing of high frequencies along the axis or by juggling cone 'break-up'" (Peter Walker's apt description). A quick little calculation shows that this sort of thing is still going on, the juggling, that is.

As for using a close-miked vocal as an evaluation tool, I've never heard any objections to this before. The point of close-miking is to minimize the acoustics of the studio or room, minimizing the uncertainties caused by the "2nd venue problem." I would point out that's exactly what AR was after when they recorded that string quartet in an open meadow (i.e. anechoic environment) for later playback in competition with and comparison to the real thing in their famous AR-3 "live versus recorded" demos.

The point about a performer being intimately familiar with a work and what a loudspeaker should be producing is well taken. That's what I was up to when I farmed out a pair of my project loudspeakers to Bruce Shull and his household (*SB*, 3/98, pp. 35 & 39).

The whole business of a loudspeaker keeping its composure during involved orchestral and choral works is likewise well taken. It seems to me that for the device to successfully convey the inner voices and nuances without muddle is a question of power-handling and freedom from resonances. I can think of no better test than spectral decay plots.

But how the ear-brain tandem works is far from well understood. I read that the nerve cells can't fire in intervals shorter than about 1mS. Does this mean that transients needn't decay much faster than this?

I also see (one of those cable channels) that melody, pitch, and rhythm stimulate three distinctly separate locations on the cortex. What can that mean? Until we are more enlightened, designing for flat on-axis and (where possible) power response is sensible. It may not be right, but it's probably not far wrong.

ON THE ROAD

Why have I never seen a pair of coaxial/triaxial car speakers used in any home designs? It would seem easy to cook up a crossover, mount them in a floor-standing tower, and have a pretty simple assembly. The two (or three) drivers are presumably already matched. Are the T/S parameters way out of line for home use or is there some other reason?

Ed Schweiger
schweige@funtv.com

Coaxials and triaxials save space in cars. All of them have some compromises in diffraction effects. Coaxials are rarely used in home environments since space constraints are not a problem. There are a few coaxial units in use in home speakers which have been very successful. All are horn types and include Tannoy, Altec's 604 series, and Lowther.—Eds.

continued on next page

Tools, Tips, & Techniques

EXTERNALLY MOUNTED CROSSOVERS

By Darcy E. Staggs

Only one serious disadvantage has arisen from building my own loudspeakers—accessibility (or lack thereof) of the crossover for adjustment, modification, and measurement. After removing the loudspeaker front panels too many times to mention, I finally joined the ranks of those who install crossovers on the back of their speaker cabinets. This turned out to be a big success, helped by some useful features of the crossovers and their mounting.

Photo 1 shows an external crossover. A sub-panel holds the input connections; the inductors and L-pads are bonded with caulking compound, and the solder terminals are actually copper nails—1½″ long × 0.110″ diameter, in this case. Jumpers are solid copper magnet wire (also used to wind the inductors), which finally lead in pairs, through tight-fitting holes, to the drivers in the cabinet. The leads of the capacitors and resistors are soldered to the nails, suitably spaced for the purpose.

DESIGN SIMPLICITY

Figure 1 is a cross-section summarizing the mechanical features of the external crossover design. Mount the crossover board by screwing pairs of fairly long wood screws into each end of the board, then sawing off their heads. The resulting studs are simply passed through mating grommeted holes in extruded aluminum L-brackets, which are fastened to the cabinet backs with wood screws. This mounting effectively isolates the crossovers from cabinet vibrations.

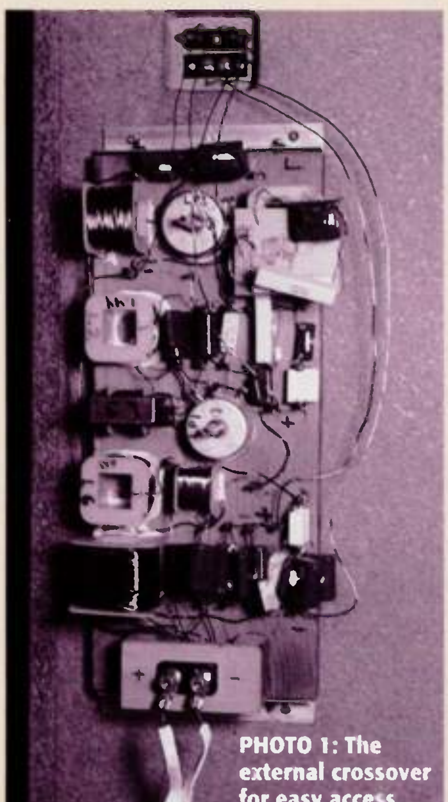

PHOTO 1: The external crossover for easy access.

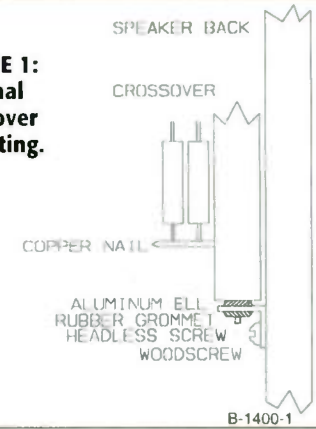

FIGURE 1: External crossover mounting.

To begin an application, lay out your crossover components fairly accurately on a piece of paper. Verify that all nodes are spaced to fit all components. In my case, some nodes consume several nails jumpered together. This eliminates crowding of components and eases the soldering task.

Indicate all jumpers and speaker connections, and double-check these. Now you know your required board dimensions, so turn out a pair of boards from suitable wood of ¾″ measured thickness.

You can transfer the nail locations to the (¾″ thick) boards by taping the layout paper over the board and punching each location with an awl, sharp nail, or similar point. Then through-drill a pilot hole for each nail. As an option, you can drill a shallow countersink or counterbore for each head into the back of the board. Drive the nails, then double-check against the artwork and add any missing nails.

WIRING

Following your paper pattern, install the inductors and L-pads. Jumper all nails which combine to form a node, keeping the wire about ¼″ above the board. Simply mount the resistors and capacitors by winding their leads a couple of turns around the nails. Soldering requires a 45–50W iron and rosin-core solder.

Heat the joint quickly and use plenty of solder—this avoids cooking the nail and burning the wood surrounding it, which loosens the nail. Mount the crossovers as shown, then add speaker wires. Now you can experiment with total accessibility.

Given the thickness of the board and the length of the nails, their points are usually lower than the heights of the coils, L-pads, and other components. If you anticipate a problem, flatten the nail points with a grinder before driving, or use a cover plate over the whole crossover (clear plastic looks very good here).

SB Mailbox

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VALUE SYSTEMS

In some crossover designs I have seen some strange-looking component value designations for capacitors and resistors. Things like 4Ω7 for resistor values, and 3μ9 for capacitors. Are these to be read as 4.7Ω and 3.9μF, respectively? If this is the case, why would those designations be used? They aren't really any shorter than the conventional designation. Is this a European convention?

Ed Schweiger
schweige@funtv.com

The Greek mu is a standard mathematical representation for millionths. The Greek omega is the standard symbol for units of resistance, the ohm. The "O" would normally be used, honoring Georg Ohm for his formulation of Ohm's law, but the O would always be confused with the mathematical zero symbol. These Greek symbols sometimes are used to replace the decimal point in component values since the point is easily lost or disappears in the copying process. Those who use both the Greek designators and the decimal point are either being conventional, cautious, or inconsistent.—ETD

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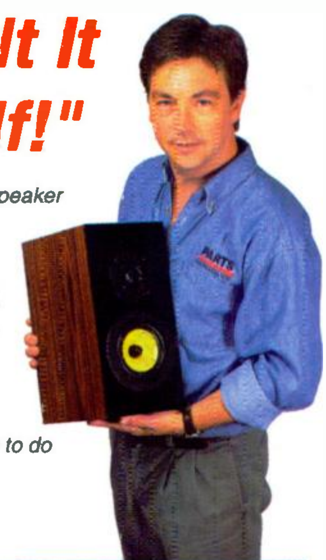
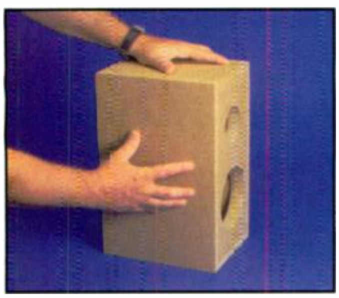
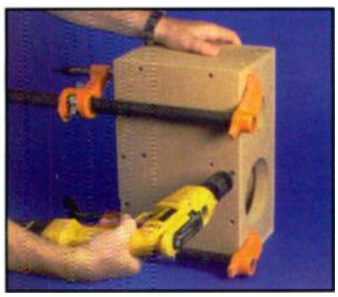


By using technology previously only available to high end speaker manufacturers, we are able to offer audiophile speaker cabinets at reasonable prices. Now you can build an audiophile quality speaker system without expensive woodworking tools or hours of labor. We have developed a series of cabinets designed by audiophiles and computer manufactured. The cabinets are made of 1" MDF (medium density fiberboard) to reduce cabinet resonance and coloration. They are precision milled with a CNC router to incredible exacting tolerances. Dado and slot joinery are used throughout to provide incredible strength. Internal braces reduce unwanted cabinet resonances. All you have to do is assemble, glue, and finish to your liking.

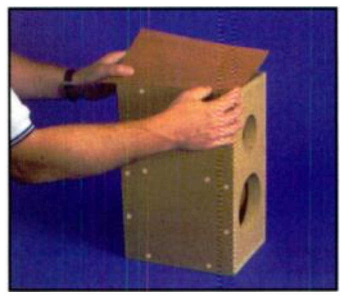
Blank Baffles: The cabinets come with pre-cut baffles for standard drivers. Blank baffles are available for you to rout yourself for flush mounting or custom drivers.



Step 1
Assemble cabinet on your workbench and pre-drill and countersink screw holes. Modifiy driver holes if necessary at this time.



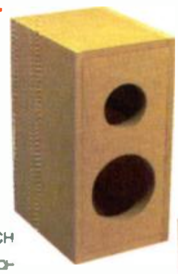
Step 2
Brush Polyurethane glue (available at most home centers) on both sides of all joints. Assemble cabinet (clamp if possible) and install screws.



Step 3
Fill screw holes with putty let dry and sand. Apply your veneer or laminate.

Step 4
Varnish or paint cabinet to your liking. Install crossover, rear terminals and drivers.

.25 Cu. Ft. Bookshelf Cabinet



Reminiscent of the classic British mini-monitor, this cabinet is well suited as a compact 2-way audiophile system or home theatre setup. .25 cu. ft. internal volume. Includes 1" Dado brace. 1" Front Baffle is pre- cut to accept most 5 - 6 in. mid/woofs and tweeters. 100% 1" MDF Construction. Internal dimensions: 5" W x 12-3/4" H x 7" D ◆External: 7" W x 13-3/4" H x 9" D ◆Woofer hole: 4-5/8" ◆Tweeter hole: 3" ◆Net weight: 12 lbs.

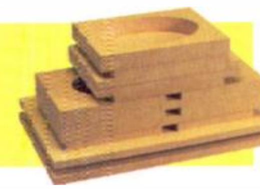
#300-704 .... $34.50 EACH
#300-703 (Blank Baffle, 1" MDF) .... **$3.95** EACH

.55 Cu. Ft. Cabinet

This is the perfect cabinet for any single 6-1/2" woofer and 5-1/4" single or dual woofer arrangement. .55 cu. ft. internal volume including 1" MDF Dado brace. 1" front baffle pre-cut to accept 6-1/2" woofer and tweeter. Internal dimensions: 6-1/4" W x 15-1/2" H x 10" D ◆External dimensions: 8-1/4" W x 17-1/2" H x 12" D ◆Woofer hole: 5-5/8" ◆Tweeter hole: 3" ◆Net weight: 20 lbs.

#300-708 .... $46.80 EACH
#300-707 (Blank Baffle, 1" MDF) .... **$5.95** EACH

Note: All of our MDF cabinets are shipped "knocked down" ready to assemble. They include detailed assembly instructions and finishing recommendations.



.75 Cu. Ft. Dual Woofer Cabinet

Build the popular D'Appolito style dual woofer speaker system. The front baffle is pre-cut to accept two 5-6" mid/woofs and one tweeter. Popular tall European style cabinet with two internal braces to help eliminate unwanted panel resonance. .75 cu. ft. internal volume including 1" braces. Internal dimensions: 6-1/4" W x 21-3/4" H x 10" D ◆External dimensions: 8-1/4" W x 23-3/4" H x 12" D ◆Woofer holes: 4-5/8" ◆Tweeter hole: 3" ◆Net weight: 26 lbs.

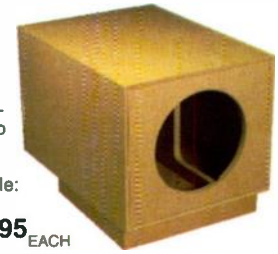
#300-714 .... $59.80 EACH
#300-713 (Blank Baffle, 1" MDF) .... **$7.95** EACH

1 Cu. Ft. Esoteric Speaker Cabinet

When completed, this cabinet will rival audiophile systems costing thousands! Designed to accept dual 6-1/2" mid/woofs and a center tweeter in a D'Appolito configuration, or buy the optional blank front baffle to design your own system. Two internal braces to help eliminate unwanted cabinet resonance. Internal dimensions: 6-1/4" W x 21-3/4" H x 13-3/4" D ◆External dimensions: 8-1/4" W x 23-3/4" H x 15-3/4" D ◆Woofer holes: 5-5/8" ◆Tweeter holes: 3" ◆Net weight: 31 lbs.

#300-718 .... $69.50 EACH
#300-713 (Blank Baffle, 1" MDF) .... **$7.95** EACH

3 Cu. Ft. Subwoofer Cabinet



Finally, a high quality, high performance MDF subwoofer cabinet at an affordable price. This cabinet utilizes 3/4" MDF (medium density fiberboard) not particle board. MDF has far superior sound deadening characteristics than particle board, plywood, or OSB. 3 cu. ft. cabinet is perfect for 10"-15" subwoofers. Internal Dado brace to reduce cabinet resonance. Inside dimensions: 16-1/2" W x 14-1/4" H x 22-1/2" D ◆Outside dimensions: 18" W x 15-3/4" H x 24" D ◆Woofer hole: 11-1/8" ◆Net weight: 43 lbs.

#300-728 .... $89.95 EACH

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TITANIC 1200

Titanic 1200 Subwoofer

The Dayton Loudspeaker Company assembled a team of the best speaker designers in the industry with one thought in mind ... to build the finest A/V subwoofer on the market! These engineers were chosen because of their expertise and pioneering designs of long excursion, high output subwoofers. A dozen prototypes were built and rigorously tested before we were satisfied with the final design parameters. With specifications like 16Hz Fs, 14mm Xmax (linear), 90dB SPL (2.83V) and 350W power handling, we're sure you will agree that this subwoofer is truly, Titanic!

Only the finest components are utilized: a heavy cast aluminum basket, a talc-filled polypropylene cone, SantopreneR rubber surround, an ultra high power voice coil assembly with a high temperature resistant ApicalR former, and quality, high tech adhesives to hold it all together. All of these components cost more, but are worth it!

ONLY $149[80] ASK FOR #295-400

Lets talk Performance!

The 12" Titanic was designed primarily as a sealed box woofer. One possible design is a 3 cubic foot sealed box with 50% fill. This design produces deep, accurate bass to 25Hz. You will be overwhelmed by the incredibly realistic low frequency that this driver will produce. Go ahead, put the T/S parameters into your favorite box design program and see for yourself what the Titanic 1200 can do!

Try It for 30 days ... If you don't feel this is the best A/V subwoofer you've ever heard, we'll refund your money! The Titanic 1200 is covered by our 5 year warranty.

Thiel-Small Parameters

◆Power handling: 350 watts RMS/ 450 watts max. ◆Voice coil diameter: 2" ◆Voice coil inductance: 1.96 mH ◆Nominal impedance: 4 ohms ◆DC resistance: 3.66 ohms ◆Frequency response: 16-400 Hz ◆Magnet weight: 84 oz. ◆Fs: 16 Hz ◆SPL:90dB 2.83V/1m ◆Vas: 9.894 cu. ft. ◆Qms: 8.22 ◆Qes: .42 ◆Qts: .407 ◆Xmax: 14.2 mm ◆Net weight: 14.6 lbs. ◆Dimensions: A: 12-1/8", B: 11-1/8", C: 6-9/16", D: 6", E: 2-3/4"

TITANIC Subwoofer Cabinet

ONLY $119[80] ASK FOR #300-729

This cabinet was designed to make the Titanic woofer "Sing." 3 cu. ft. cabinet with a substantial 1" MDF braces to couple all cabinet sides and help eliminate unwanted panel resonance. One inch thick MDF (medium density fiberboard) is acoustically superior to particle board, plywood, and OSB. Dado and Slot joinery coupled with screws and polyurethane glue (not included) make this cabinet virtually "Dead." The MDF exterior is easily painted or veneered to your liking. (Finishing Instructions Included Free). Inside dimensions: 17-3/4" cubed ◆Exterior dimensions: 19-3/4" cubed ◆Woofer hole: 11-1/8" ◆Net weight: 50 lbs. ◆Shipping knocked down.

250 Watt Class D Subwoofer Amplifier

- Perfect mate for Titanic Subwoofer
- High efficiency amplifier
- Made in the U.S.A.
- Advanced Class-D Topology
- Reliable/stable operation
- Low distortion
- High pass filter for satellite speakers

ONLY $249[80] ASK FOR #300-795

All subwoofer amps are not created equal! Today you have many choices when it comes to an amplifier for your next subwoofer project. In our quest, we have seen them all and tested many. The heart of any subwoofer system is the amplifier; do you really want to trust your "Audiophile grade" subwoofer system to an amplifier made in China? This American made, **TRUE 250 WATT** amp produces earth shaking bass, especially when mated with our 12" Titanic subwoofer. Class D amps are nearly 95% efficient creating less heat making them more reliable and stable while producing less distortion. This amp features both high and low level inputs, phase reversal switch, level control, auto on/off (activated by input signal), and a second order (12dB) electronic low pass filter that is continuously variable from 40 to 160 Hz. It also features a 6dB high pass filter (90Hz @ 8ohm) output for satellite speakers. The amp has overload and fuse protection for years of reliable use. The highly efficient amplifier sums the right and left stereo inputs to a mono output, so that only one amp is required per system. Rated power output: 250 watts into 4 ohms @ 0.1% THD. Signal to noise ratio: 100dB (A-weighted). Dimensions: 10" W x 10" H x 2-1/2" D. Net weight: 4 lbs.

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