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Editorial

TWO DECADES WITH SPEAKER BUILDER

The onset of 1999 begins the final year of the second decade of this publication's life. *Speaker Builder* was born in the first months of 1980, and was our second publication, extracted from our flagship *Audio Amateur* (as it was then). Although we had been publishing articles about speakers with fair regularity in *AA*, the appearance of *SB* prompted a rush of new authors responding to this narrower editorial definition.

In many ways *Speaker Builder* is only one more example of a general trend in magazine publishing specifically and in communication generally: narrowed focus and specialization have been the rule since the early 1960s. Markets may still be called "mass," but the paths into those are more and more specialized.

In 1985 we collected the two dozen speaker articles which had appeared in *Audio Amateur* during the 1970-79 decade and published them as *Audio Amateur Loudspeaker Projects*. In those 40 issues of the magazine, we had published less than one per issue, and no more than 2.5 per year. We published more speaker articles in the first two years in *SB* than in the previous decade in *TAA*.

Quantity is not, however, the important news. Authors who had never previously published before made their debuts in these pages. The list was and is impressive: Siegfried Linkwitz, Bob Bullock, Bruce Edgar, and G.R. Koonce, to name only a few. Regulars from *Audio Amateur*—Nelson Pass, among others—offered articles on speaker topics. Bob Bullock reviewed a self-published copy of a spiral-bound booklet titled *The Loudspeaker Design Cookbook* by a very elusive author named Vance Dickason, the copy loaned to us by Gary Galo. Since that time Dickason has been awarded a citation by the Audio Engineering Society for his contributions to education in the loudspeaker field. His book, now in a fifth edition, and available in six languages (plus an unauthorized Chinese version), has become a world standard on the Thiele/Small speaker box theory as well as more recent additions on topics such as home theater and automobile systems.

Eight years later, Vance agreed to become editor of a monthly newsletter—*Voice Coil*—which has since become the primary business-to-business communication channel about loudspeaker manufacturing.

Speaking of authors, this issue carries an outstanding article by Robert C. Kral, beginning on page 40. I am delighted to acknowledge that author Kral graced the pages of the very first issue of this magazine with an equally excellent article on diffraction. Authors and readers who participate in the same enterprise for nearly two decades are rare and deeply appreciated.

Reader participation has been one of the prime foundations of *Speaker Builder*'s growth and maturity. The magazine was and has remained a conduit for reader-to-reader and reader-to-author interchange. I am sure the nearly 200 *SB* authors would join me in saying "we could not have done it without you." I am in no doubt that we might all express the same sentiments about *SB*'s advertisers, who have, in many cases, been outstandingly helpful to readers and authors. Their responsiveness to reader needs and their search for the best in products worldwide has enriched the avocation immeasurably.

The two-decade span of *SB*'s history has seen a breathtaking change in speaker technology, and even more impressive changes in what we have come to know about it. The most pervasive influence has been the computer, both in design, manufacturing, quality control, and measurement. I suspect the computer has had more to do with our ability to predict and to diagnose performance than any other development. In that same time span, the computer has given raw materials suppliers to the driver and box manufacturers insight into ways that make the parts used to assemble systems far better and more well-suited to the task than ever before.

Drivers are, on average, significantly smaller and more powerful than they were in the early eighties. Systems now come in a much wider variety of forms than ever. The appearance of flat-panel speakers looks to be a serious shift in how sound is delivered, especially in public spaces as well as in computers. Raw materials have changed in magnetic technologies, wire shapes, and quality, and cone materials have gone through a "plastic stage," which is now changing to stiffer types but also having growing competition by the return of paper cones, reinforced with fiber. The range of speaker-related goods is far wider than at any time in history.

During this period we have also seen a major change in the rise—and what now may be the beginnings of a decline—in what has been called "the high end." Economic troubles in Asia have had a major effect on "high end" sales, and this is reflected in losses in ad revenue in those periodicals which specialize in that genre.

The shift in source material from analog to digital has been a major influence on speakers in this time frame. Audio's recorded media issues right now seem to be at a central terminus with all sorts of choices of direction which have everyone vigorously arguing. Will home theater displace the traditional "hi-fi" stereo system? How will audio and visual media be delivered?

Amid all this uncertainty, I believe readers and authors together should be concentrating on two areas especially. First, computer system sound can be quite remarkably good, depending on the quality of the sound card. We need to look at powered speakers for this application, and I welcome all suggestions. Second, home theater is a challenge which ought to be a lot of fun finding answers for. We hope to explore subwoofer amps later this year in a comprehensive article. Tom Holman, writing about digital television issues in *Audio Media** in April of 1998, suggests that the speakers in a professional monitoring theater system should consist of five satellite systems which are good to a low of 80Hz, plus a subwoofer or two. This system will only work well, however, with "Bass Management," which extracts the low bass from all of the five main channels and delivers the result to the subwoofer. Although Tom is here talking about a professional monitoring system, the idea is certainly one we can experiment with for ourselves with profit.

Loudspeaker technology and theory are, if anything, more interesting and complex today than they were nearly 20 years ago when *Speaker Builder* began publication. Most types of systems have matured remarkably well. Components are better across the board whether we are talking about drivers, cabinet walls, crossover components, hardware, or damping fibers. I am confident that we, readers and authors, will continue to respond to the opportunities we have before us to make *Speaker Builder* the authoritative and exciting source for loudspeaker development.—**E.T.D.**

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Good News

■ **SAIL THE TITANIC ➲**

The Dayton Loudspeaker Company's Titanic subwoofer includes specifications of 16Hz F_S 14mm X_{MAX} (linear), 90dB SPL (2.83V), and 350W power handling. It utilizes a heavy cast-aluminum basket to control unwanted resonance, a talc-filled polypropylene cone to ensure stable, non-resonant operation, Santoprene® rubber surround for extended life and long excursion, an ultra-high-power voice-coil assembly with a high-temperature resistant Apical® former, and high-tech adhesives. Steel parts are coated with a black high-emis-sivity coating (originally developed for NASA), which improves heat dissipation and lowers distortion. Although designed primarily as a sealed-box woofer, it is also suitable for fourth-order bandpass enclosures. The Dayton Loudspeaker Co., 725 Pleasant Valley Dr., Springboro, OH 45066, (513) 743-3000, FAX (513) 743-1677, E-mail sales@parts-express.com.

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■ Use *The Car Stereo Cookbook: How to Design, Choose, and Install Car Stereo Speakers* as a guide to building your own system. The chapters feature projects for speakers, subwoofers, amplifiers, and equalizers. Other topics cover head unit projects, biamping and crossovers, CD changer projects, and accessories. McGraw-Hill, (212) 337-5945.

■ Website audiocafe.com features thousands of home-stereo records, computer-audio, and home-theater products. The site also offers daily reports of new products and developments in the world of audio, and a monthly summary of reviews and features from the international audio press.

■ **COMING TOGETHER**

Zoran Corporation has announced that Altec Lansing's ADA105 TV set-top home-theater surround system includes the company's digital audio ZR38600 IC. The ADA105 is the first Dolby Digital Surround and home-theater speaker system to use Altec Lansing's patented side-firing speaker technology. The system provides movie-theater sound from a single set-top speaker unit and a 40W subwoofer. Zoran Corp., (408) 919-4111, Website www.zoran.com.

Reader Service #136

About This Issue

With this issue, we kick off our 20th year of publishing *Speaker Builder*. We've incorporated a new look to the pages of this magazine, which we trust will help you better enjoy your favorite authors and appreciate the work of many new talented enthusiasts. Throughout the coming year, we'll be bringing you the best articles on speaker building–from hands-on practical projects for you to tackle to interesting theoretical discussions of speaker design. We trust you'll join us, and, as always, encourage your feedback.

When the speaker building bug bites, the effects can be long-lasting. Such is the case with **Paul Kittinger**. Within the last three years, he has completed one subwoofer and four full-range projects. In "Aperiodic Deuce" (p. 8), he shares with us his latest tower design effort.

In a humorous piece ("Walking the Thin Line," p. 22), **Philip Abbate** entertains us with his futile attempts to control his obsessive-compulsive behavior with regard to speakers.

In a more serious vein, **Mark Sanfilipo** guides us through a detailed look at PSpice, a PC-based program which makes building and analyzing even the most complex models a snap ("PSpice Probes a Loudspeaker's Evolution," p. 26).

Impedance measurement results can reveal much about your speaker design. Regular *SB* contributor **Bill Fitzmaurice** shows how you can build a device to quickly and easily test your speakers ("The Impedance Interface," p. 38).

Robert Kral, a veteran of the audio industry, presents a bandpass subwoofer design, which he describes as "an extreme subwoofer for extreme people"–maybe not the most aesthetically pleasing, but it works. In fact, with this woofer, be prepared for some bone-jarring listening entertainment ("Hybrid Single-Chamber Sub," p. 40).

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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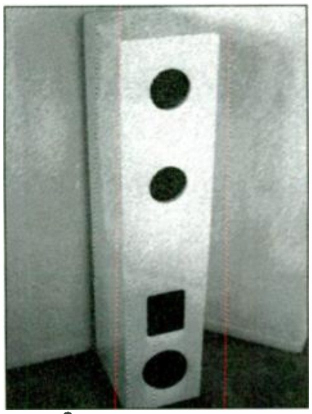

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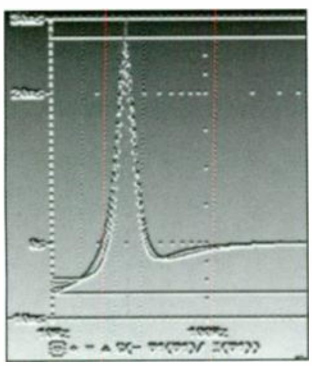

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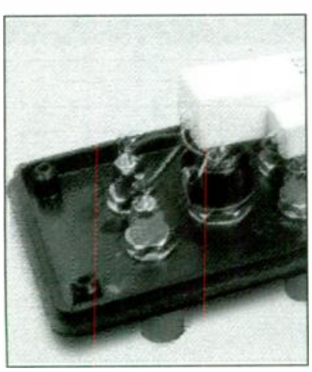

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DEPARTMENTS

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What, another speaker? If you've ever heard those words coming from your complaining partner, you can empathize with this author, who presents his latest (and perhaps last...for a while, anyway) design and construction project.

Aperiodic Deuce

By Paul L. Kittinger

This article describes the fourth speaker system I've designed and built during the last couple of years. According to my wife, it's the last speaker construction project I'll be doing for quite a while.

When I started this project, I had some "honey-do" jobs I'd been putting off. Did I really need to do another one? Well, I certainly didn't *need* another pair of speakers, but I believed it was possible to improve upon the previous systems. Besides, it's a lot of fun and keeps me out of trouble (unless I let the honey-do jobs linger undone too long).

COMBINING THE BEST

My first design was truly a novice's learning experience that included mistakes, redesign, and more than a few self-directed swear words. While I didn't describe my first design in an article, the second and third appeared in issues 5/97 ("An Isobarik Tower") and 2/98 ("An Isobarik Tower: The Sequel") of *Speaker Builder*.

All three met my expectations, but I wanted to combine the best characteristics of designs 2 and 3, at the same time eliminating, or at least minimizing, one problem all three shared to a greater or lesser degree. So, in the Aperiodic Deuce, for their smooth frequency response and good imaging, I used the same midranges and tweeter in a D'Appolito arrangement as in design 3. Then, to achieve the open and enveloping sound of design 2, I mounted the midranges in open-back, acoustically loaded tunnels instead of sealed or tuned cavities.

The problem I wished to mitigate is the effect of room boundaries on the frequencies below 100Hz. In my listening room, there are significant resonances in the 50–65Hz range that cause anywhere from 6–12dB of "room lift," not an unusual occurrence, but hardly desirable.

The absolute amount of lift depends on the speaker-system design, locations of speakers relative to walls and corners, and where I sit to listen. Since I couldn't move the walls or rearrange the furniture in my living room to cause a significant improvement (I tried), and adding tuning traps around the room wouldn't be cosmetically acceptable, I decided to attack this in two ways.

First, I designed for a higher f_3, around 50–60Hz. Second, I used a single 6½″ driver for the woofer. This woofer's smaller radiating area should result in less coupling to low-frequency room resonances. The advantage of a higher f_3 is that the woofer's natural rolloff in its en-

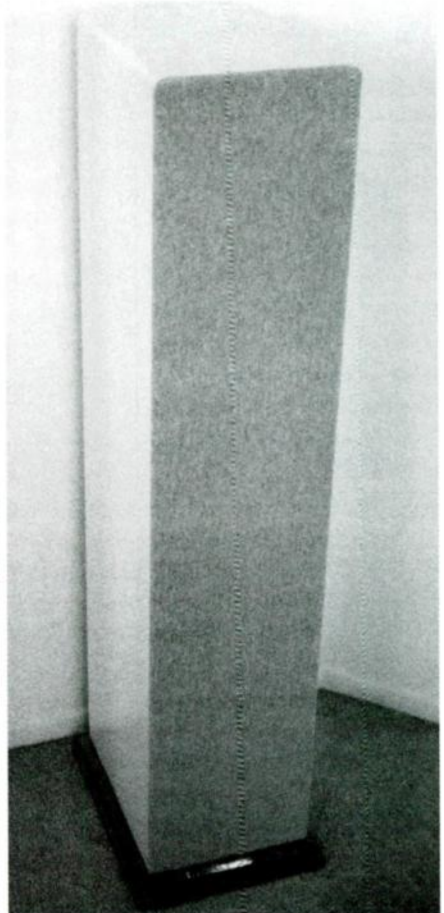


PHOTO 1: Finished system, front view with grille.

FIGURE 1: Frequency response measured outside.

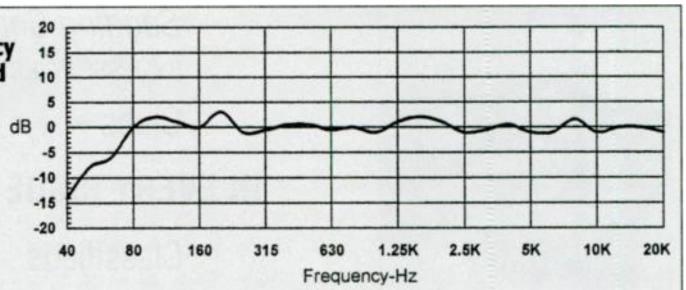
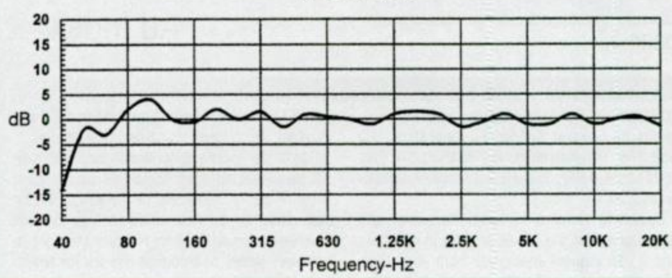


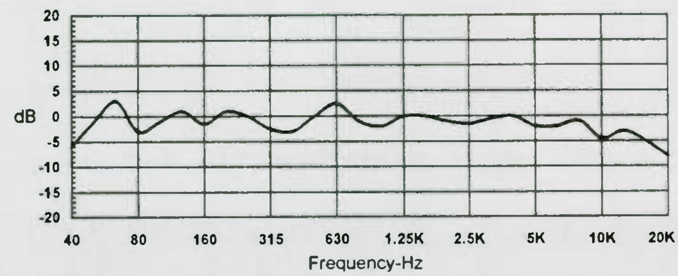
FIGURE 2: In-room frequency response (with minimal room effects).



ABOUT THE AUTHOR

Paul L. Kittinger has a BSEE degree with specialization in analog design, but his career path took a turn out of engineering about 20 years ago into the regulatory aspects of medical devices. About three years ago, a DIY bug bite resulted in his design and construction of a 200W per channel power amplifier, followed by a foray into speaker-system design. He has since completed a subwoofer and four full-range projects. (See also "An Isobarik Tower," *SB* 5/97.)

FIGURE 3: In-room frequency response (both systems together).



closure would also reduce its low-frequency output. But, you may ask, would this not limit the bass too much?

It certainly could in a resonance-free environment. I planned, however, to use the room lift to bring the low-frequency response back up, so that the speaker system would reproduce bass notes around 40Hz at an acceptable level. Another advantage of a smaller woofer is its ability to reproduce transients more accurately. A smaller mass simply accelerates and moves more quickly.

I prefer a sealed cabinet for its shallower rolloff below f_3, good transient response, and lack of subsonic artifacts. This sealed-cabinet design continues with my preference; however, I decided to use aperiodic loading for the woofer in order to minimize internal volume. A third advantage in using a small woofer is that the cabinet width can be fairly narrow, which further improves imaging and minimizes diffraction. Thus, the Aperiodic Deuce has a narrower cabinet than designs 2 and 3 and uses a Variovent® to create the aperiodic loading in an otherwise sealed woofer cavity of 20 ltr.

HIGHS AND LOWS

I built both cabinets up to a certain point, installing wiring, crossovers, and drivers only in one. Following preliminary frequency-response measurements, I experimented with different types and mixes of fill in the woofer cavity, as well as several different crossover configurations.

I made quite a few response measurements, interspersed with listening sessions, then completed both systems. *Photos 1–3* show three views of one system. The cabinet itself is 8½″ wide and 11⅜″ deep, including the grille-board assembly. The base is 10″ wide, 12⅞″ deep and 1½″ tall, making the cabinet height 42″.

I would love to have tested this speaker system in an anechoic chamber, but since I don't have one, I did the next best thing—I tested it outside, where resonances are nonexistent and reflections

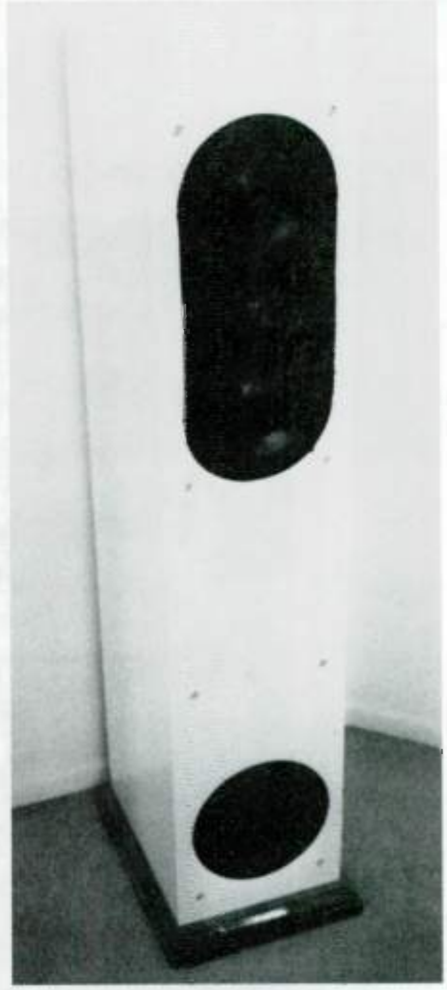


PHOTO 2: Finished system, front view without grille.

TABLE 1
PARTS LIST (QUANTITIES SHOWN ARE FOR TWO SYSTEMS; DIMENSIONS ARE IN INCHES)

DESCRIPTION	DIMENSIONS	QTY
¾″ MDF:		
Baffle, rear panel	7 × 39	4
Side panel	11 × 39	4
Cavity braces and inside of top and bottom	7 × 9½	12
Outside of top and bottom	8½ × 11	4
Runner	1½ × 7⅛	16
Runner	1½ × 7½	8
Runner	1½ × 6⅜	16
⅜″ PARTICLEBOARD:		
Grille board	8½ × 40 15/32	2
Tweeter crossover base	5 × 5½	2
Midrange attenuator base	2 × 5½	2
Woofer crossover base	4 × 5½	2
¾″ OAK:		
Base bottom	10 × 12⅞	2
Base top	9½ × 12⅜	2
MISCELLANEOUS:		
Foam adhesive-backed tape (Madisound)	⅛ × ½	12′
Adhesive-backed felt (Madisound)	⅛ × 32	1′
Terminal cup (Parts Express 260-304)		2
Grille fasteners (Parts Express 260-367)		2 pkg.
Acousta-Stuf®		2½ lb

DESCRIPTION	DIMENSIONS	QTY
Grille cloth	10 × 42	2
Dynaudio Variovent®		2
Wire or plastic screen (large mesh)	5 × 5	4
Nails, screws, glue, paint, bolts, T-nuts, silicone sealant, crimp-on connectors, wire, etc.		As needed
DRIVERS:		
Woofer	Dynaudio, 17W–75, 6½″, 8Ω	2
Midranges	Morel, MW-166, 6″, 8Ω	4
Tweeter	Morel, MDT-40, 1⅛, 8Ω	2
CROSSOVER COMPONENTS:		
L1	4.3mH, ferrite bobbin (Madisound Sidewinder)	2
L2	0.30mH, air core (Madisound Sidewinder)	2
C1A	140μF/100V, bipolar electrolytic	2
C1B, C5	1μF/100V, metallized polypropylene	4
C2	22μF/100V, bipolar electrolytic	2
C3	4.7μF/100V, metallized polypropylene	2
C4A	12μF/100V, metallized polypropylene	2
C4B	2.2μF/100V, metallized polypropylene	2
R1, R3	6.5Ω, 15W, wirewound	4
R2	3.0Ω, 25W, wirewound	2
Barrier strip		6

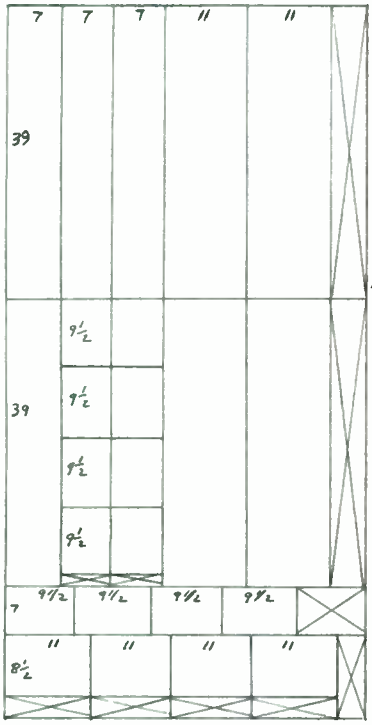


FIGURE 4: MDF cutting guide.

PHOTO 3: Finished system, rear view.

minimal. *Figure 1* shows the results of my outside testing. The response falls within a 4dB window from 80Hz–20kHz, falling off below 80Hz, as you'd expect, without any room lift.

For this test, my SPL (sound pressure level) meter was 50″ away at the same height as the tweeter's axis. Testing in my living room, with the speaker positioned to minimize room effects and the SPL meter 50″ away, gave the results shown in *Fig. 2*. As you can see, the differences between these first two graphs are primarily in the response below about 300Hz, with the response above 250Hz a smooth ±1½dB.

Finally, I tested both speakers playing simultaneously, with the cabinets positioned normally, two feet from the front wall, and with my SPL meter located where I sit to listen, about 9′ away. The results of this final test are depicted in *Fig. 3*. From 46Hz to just above 8kHz, the maximum variations are ±3dB, and the response is only 6dB down at 40Hz. The dropoff as frequencies climb above about 6kHz is typical of a tweeter's off-axis response.

ROOM EFFECTS

These three graphs amply illustrate the effects of a room on a speaker's response. Even if the speaker has a flat anechoic response, which these probably would not, the in-room response will not be flat. Still, the response shown in *Fig. 3* is very acceptable and shows how you can use a room to your advantage, or achieve good results in spite of a room's characteristics. I also measured the woofer's close-miked response from 20–800Hz, which showed an f_3 of 55Hz, a 15dB/octave rolloff below f_3, and a second-order rolloff above 200Hz.

I made two sets of measurements for all three tests, one with the grille on and one with it off. The grille caused insignificant detrimental effects, and the results shown were with the grille on. Keep in mind that my response tests were made at ⅓-octave intervals and so are not entirely complete as would be the case using more elaborate test equipment. The results are, however, reasonably representative of these speakers' overall performance.

I also made measurements to approximate their sensitivity, which came out around 88–89dB at 1m, based on 1W into 8Ω. The only other measurement I made was to compare both finished systems to determine how well they were matched. I measured both systems' overall responses at the same 28 frequency points—at ⅓-octave intervals—under identical conditions.

For 18 of those points, there were no differences. For eight, the SPL differences were ½dB (randomly positive and negative); one point had a 1dB difference; and another a 1½dB difference. The two systems, therefore, appear to be matched pretty well, at least within the resolution capability of my SPL meter.

CABINET DESIGN

In the Isobarik Tower, I developed a cabinet design that allowed me to build a square and sturdy assembly relatively easily, yet without complicated joints requiring a full-blown woodworking shop. The

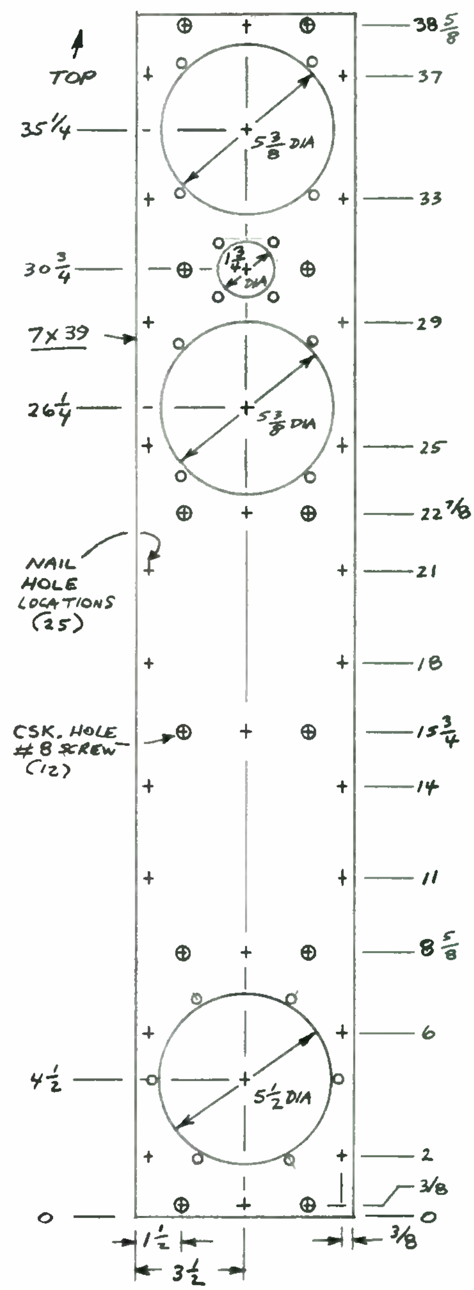


FIGURE 5: Baffle.

Aperiodic Deuce cabinet utilizes the same concept: butt joints, glue and nail attachment, and full-height vertical runners attached to all four inside corners of the cabinet. *Table 1* is the parts list. These runners increase rigidity, form attachment rails for the baffle and rear panel, create "slots" for braces and shelves, and allow the use of ¾″ MDF (medium density fiberboard) throughout.

Even with my limited tools and woodworking abilities, I'm able to build a fairly decent cabinet. Also, because I'm not skilled (or "tooled") in making those complicated joints, I don't use wood veneered materials. So I paint the cabinet with a textured finish, which also hides minor imperfections.

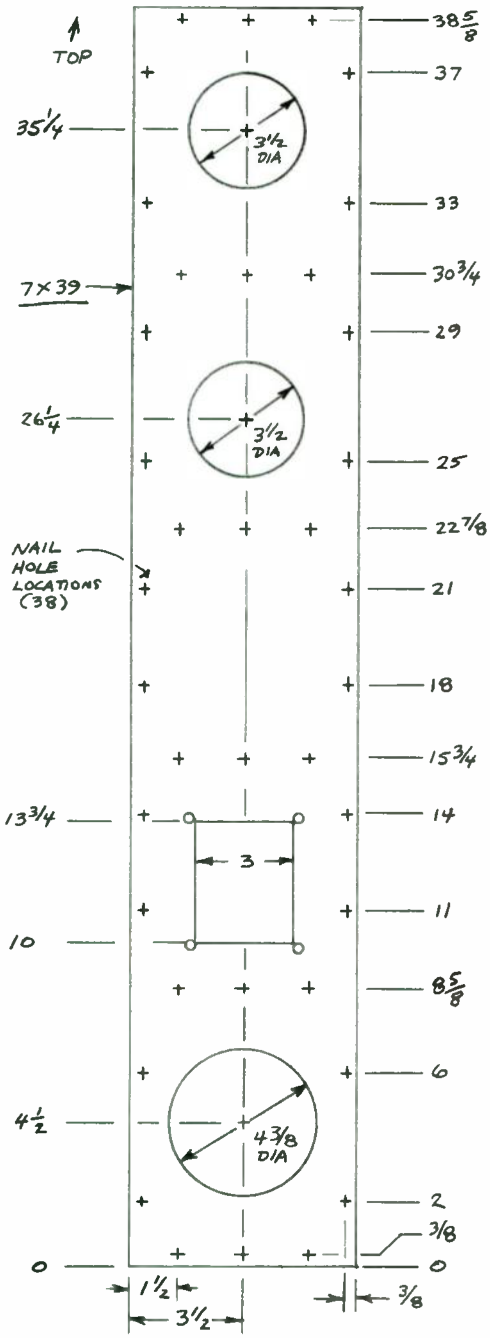


FIGURE 6: Rear panel.

In my first two articles, I described the construction process in great detail. The text of this article is shorter, but I've included enough photos and detailed drawings to provide adequate information for anyone to successfully build duplicates. It would benefit you, though, to read one or both of my first two articles and appropriately apply their hints, suggestions, and directions to this project. Where necessary, I'm specific to avoid any confusion.

START YOUR SAWS!

Except for crossover bases and grille boards, which I cut from ⅜″ particleboard, I used ¾″ MDF, and you can cut all the pieces for a pair of speaker systems from one 4′ × 8′ sheet (a nice benefit is that a sheet of MDF is actually 49″ × 97″). Don't give in to the temptation to substitute particleboard for the MDF to save a few bucks, for it is less dense and less strong, is harder to work with, and doesn't hold nails or screws as well.

Besides, the cost of the MDF is almost nil compared to all the other costs. Incidentally, it costs $900–1000 to build a pair of these speaker systems. As to the ⅜″ particleboard, most large hardware or lumber stores carry precut 2′ × 4′ pieces, more than enough for this project. If you already have some ⅜″ MDF, however, it is preferable for the grille boards.

For assembly to go smoothly and the resulting cabinet to be square, it is important that you cut out the pieces accurately and squarely. Locate and size carefully the holes in the panels for the drivers. This is especially true for aligning the grille-board cutouts around the drivers' perimeters and drilling mounting holes through the grille boards into the baffle for the grille fasteners.

Basically, construction should proceed as follows:

1. Cut out all of the pieces from the MDF (*Fig. 4*) and particleboard on a table saw. After cutting out the major pieces from the MDF sheet, cut the leftover pieces into 1½″-wide strips, then cut the runners from these strips.

2. With a jigsaw, cut out all the driver holes, terminal-cup hole, shelf slot behind the tweeter, holes in the two woofer-cavity braces, midrange tunnel-exit holes, and the Variovent® hole. Drill pass-through holes for wiring (see *Figs. 5–9*).

3. Predrill pilot holes for nails (2″ 6d) through the side panels, baffle, and rear panel (see *Figs. 5, 6,* and *10*).

4. Drill countersunk holes in the baffle for 12 particleboard screws, 1¼″ #8 (see *Fig. 5*).

5. Attach vertical runners to the side panels with glue and 1¼″ 3d nails (see *Fig. 10* and *Photo 4*). Use two nails across the runners' width, spaced about every 2″ or 3″. After attaching them, you may need to file or sand the ends of the runners at the shelf slots to ensure the shelves will fit into the slots without being too tight.

6. Seal the inside seams of the runners with silicone sealant.

7. Make the double-thick top and bottom assemblies by attaching the 7″ × 9½″ pieces squarely to the centers of the 8½″ × 11″ pieces with glue and 1¼″ 3d nails or particleboard screws. This leaves a ¾″ "notch" around all four sides for side panels, back, and baffle.

8. Drill pilot holes for #8 ¾″ or 1″ particleboard screws in the midrange-cavity brace, midrange-cavity bottom, and cabi-

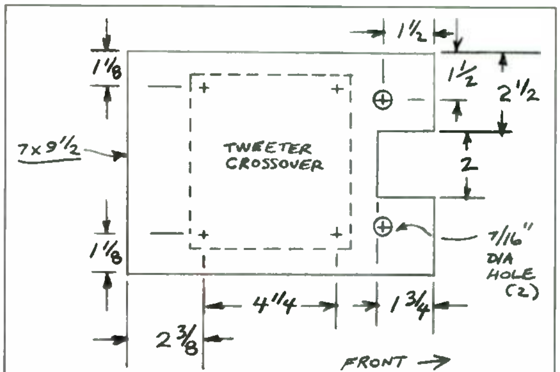


FIGURE 7: Midrange-cavity brace.

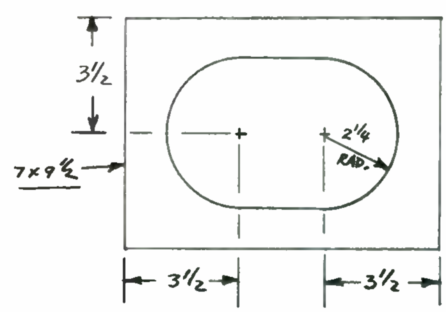


FIGURE 8: Woofer-cavity braces.

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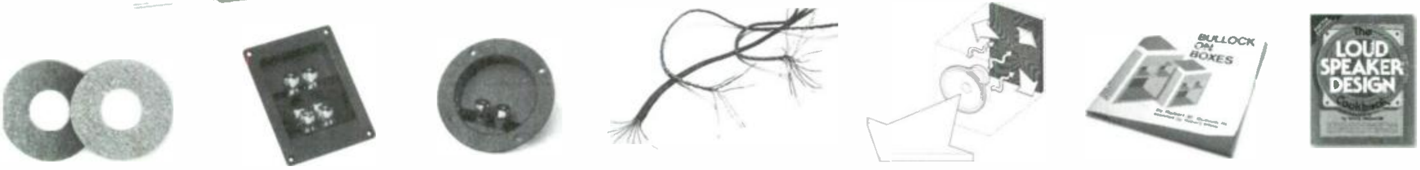

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net-bottom assembly to mount the three crossovers (see *Figs. 7, 11,* and *12*).

9. Attach the side panels to the four horizontal pieces and to the top and bottom assemblies with glue and 2″ 6d nails. You'll need to clamp this all together and make sure it all squares up before nailing; then leave it clamped for an hour or so. Recess the nails with a nail set as you hammer along (see *Photos* 5 and 6 and *Fig. 13*).

10. After the glue has dried for 24 hours, attach the rear panel with glue and 6d nails (see *Photo 7*).

11. After *that* glue has dried for 24 hours, seal all of the inside joints with silicone sealant.

12. Attach the baffle to the cabinet with 6d nails, particleboard screws, and glue, and allow it to dry for 24 hours (see *Photo 8*). By reaching in through the various cutouts, seal the baffle's inside seams with silicone sealant.

13. Drill mounting holes for the grille fasteners (see *Fig. 9*):
a. Center all four drivers into their baffle cutouts.
b. Lay the grille board around the drivers on the baffle.
c. Clamp the grille board squarely on the cabinet, centered around the drivers and within the outside edges of the baffle.
d. Mark the location of mounting holes for all four drivers, then remove the drivers.
e. Drill eight 7/16″-diameter holes through the grille board and to a ½″ depth into the baffle.
f. Remove the grille board, and on its front side, round the outside edges and the edges inside the driver cutouts with a ¼″-radius router bit.

14. Finish the cabinet:
a. Fill all nail-head holes, screw-head holes, and seams with wood filler, then sand flush with the MDF surface.
b. Round the top edges of the cabinet (front to back) with a ½″-radius router bit.
c. Sand, prime (two coats), sand again, and paint the cabinet. Paint the baffle with a brush (two coats) and the rest of the cabinet with a stippling roller (three coats). The grille board needs only one primer coat, followed by spraying with black paint.

15. Drill holes for mounting drivers (with T-nuts) and terminal cup. Install T-nuts using 8-32 for the woofer and midranges, 6-32 for the tweeter. Note that the woofer has six mounting holes (see *Fig. 5*). Because the cabinet is narrow, the two holes at the sides of the cabinet have runners behind them and T-nuts won't fit there. You'll need to use 8-32 wood screws for these two mounting holes.

16. Install screens inside at the back of each midrange tunnel over the 3½″ holes in the rear panel (silicone sealant works well for this).

17. Install crossovers, wiring and Variovent. For the vent, if you cut its mounting hole the correct diameter, you can mount the vent by force-fitting with the vent's barbed flanges. Instead, I intentionally cut the mounting hole slightly larger and used silicone sealant on the lip of the vent.

18. Place 6 oz of Acousta-Stuf® into each midrange tunnel and 8 oz into the two upper chambers of the woofer cavity. Don't allow any of the Acousta-Stuf to block the pathway between the woofer and the Variovent.

19. Lay down adhesive-backed foam tape around the tweeter, each mid-

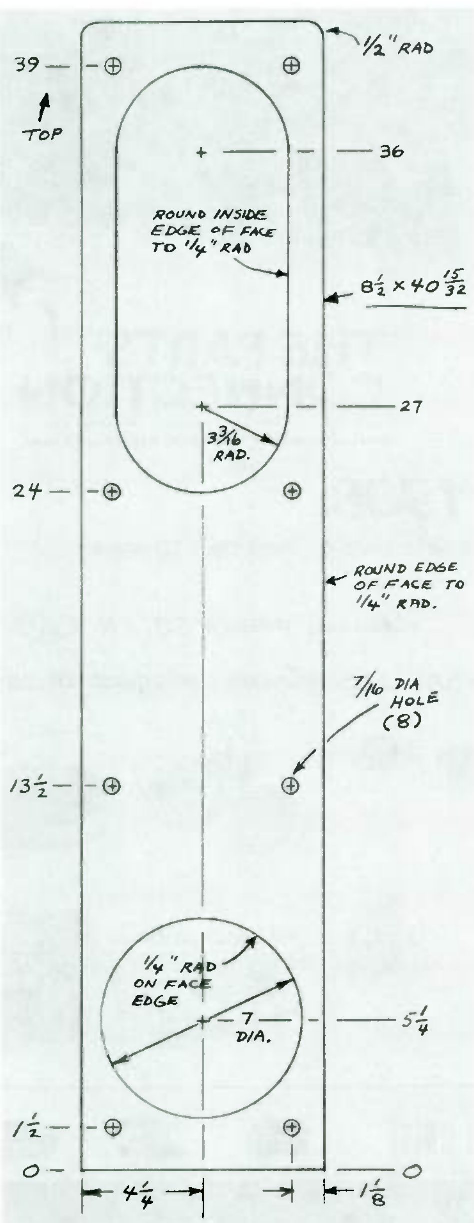


FIGURE 9: Grille board.

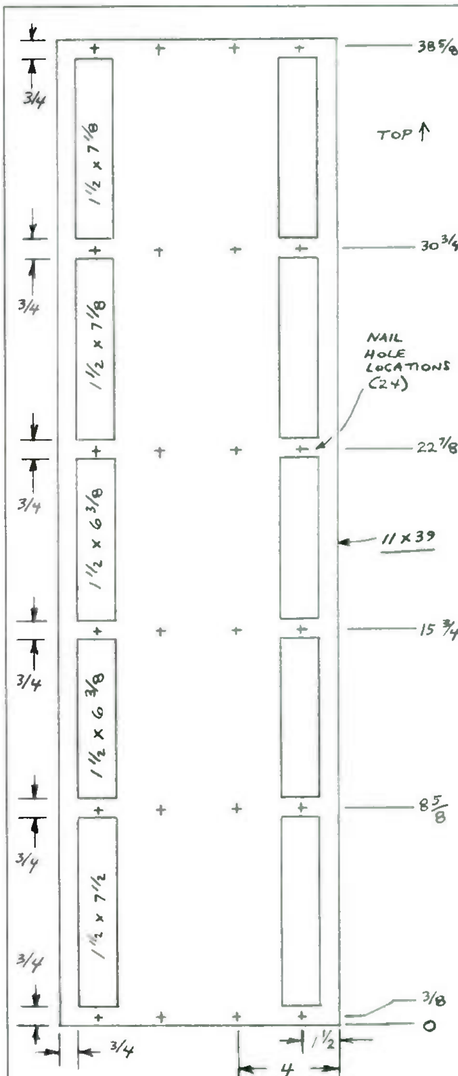


FIGURE 10: Side-panel assembly.

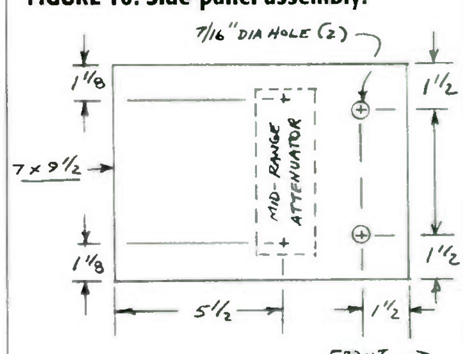


FIGURE 11: Midrange-cavity bottom.

PEERLESS

830411 8" Sealed Box Woofer for $29.00

Thiele Small Parameters

Nominal Impedance	Zn	Ω	8
Minimum Impedance	Zmin	Ω	6.2
Maximum Impedance	Zo	Ω	24.8
Dc Resistance	Re	Ω	5.5
Voice Coil Inductance	Le	mH	2.4
Resonance Frequency	fs	Hz	35.4
Mechanical Q Factor	Qms		2.47
Electrical Q Factor	Qes		0.70
Total Q Factor	Qts		0.55
Equivalent Volume	Vas	liters	57.8
F (Ratio fs/Qts)	F	Hz	65
Mechanical Resistance	Rms	Kg/s	2.41
Moving Mass	Mms	g	26.7
Suspension Compliance	Cms	mm/N	0.76
Effective Cone Diameter	D	cm	17.3
Effective Piston Area	Sd	cm^2	235
Force Factor	Bl	N/A	6.8
Reference Sensitivity @141Hz	dB	2.83V@1m	88.3

Magnet and Voice Coil Parameters

Voice Coil Diameter	d	mm	33
Voice Coil Length	h	mm	17
Voice Coil Layers	n		4
Flux Density in Gap	B	T	0.94
Height of the Gap	hg	mm	6
Linear Excursion		mm	±5.5
Diameter of Magnet	dm	mm	72
Height of Magnet	hm	mm	15
Weight of Magnet		kg	0.23

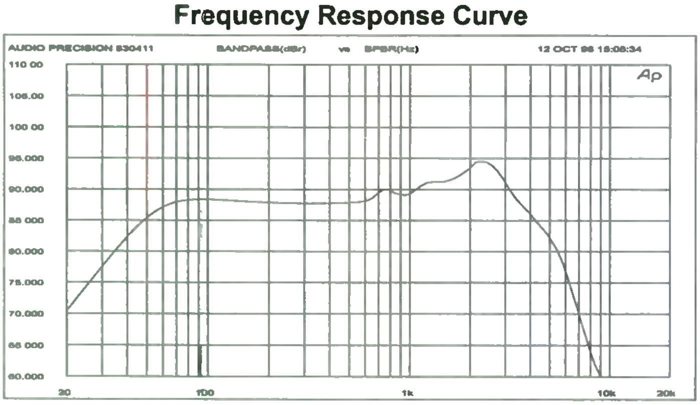
Speaker Physical Properties

Cone material	Black Polypropylene
Frame	Stamped steel
Surround	Rubber
VC Former	Aluminum
Dust Cap	Soft Poly

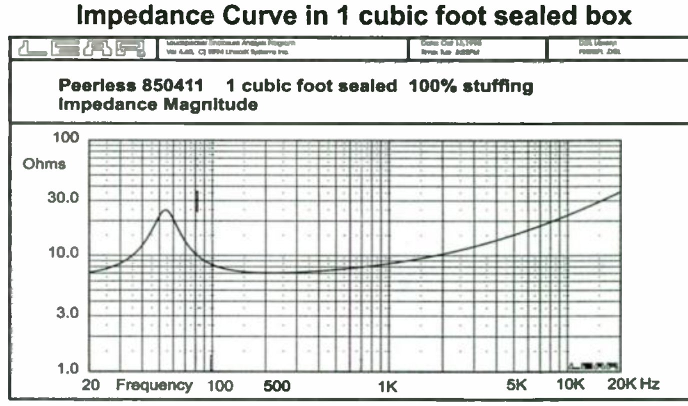
Speaker Physical Dimensions

Outside Frame Diameter	mm	220.5
Cut Out Diameter (hole size)	mm	184
Depth from Back of Flange	mm	89
Thickness of Flange	mm	5

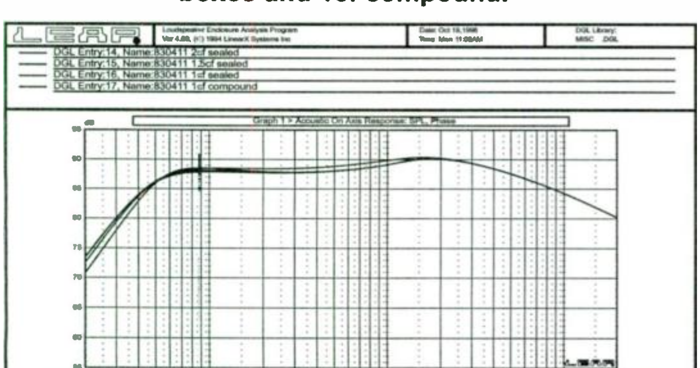
Frequency Response Curve



Impedance Curve in 1 cubic foot sealed box



Simulated box responses in 1cf, 1.5cf, 2cf sealed boxes and 1cf compound.



The 830411 seems to have a similar response in any any box size from 1 cubic foot to 2 cubic feet. It also has the same response when used in a compound loaded isobaric enclosure. The 5.5mm X-max in one direction will insure accurate bass response. There is no dips in the response to cause any x-over problems.

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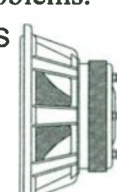

range, and the terminal-cup cutouts (the woofers come with rubber sealing gaskets).

20. Solder wires to the terminal cup and attach the cup with 6-32 wood screws. Attach wires from the crossovers to the drivers and mount all four drivers.

21. Cut out and install two layers of ⅛″-thick, adhesive-backed felt, one on top of the other, around the tweeter and between the midranges on the baffle within the grille-board cutout.

22. Cut about 1/16″ off the back of the eight grille fasteners and install them in the back of the grille board. Wrap and stretch the grille cloth around the grille board and attach it to the back with contact cement. Snap the grille-board assembly onto the baffle. If you've used particleboard for the grille board, be careful, since there isn't much material around the driver cutouts, and you can easily break the grille board when installing or removing it.

BASE ASSEMBLY

The cabinets don't absolutely need bases, but I made some to raise the tweeter axis a bit, to make the cabinet more stable, and to add a little glamour. I constructed my bases from two pieces of solid, ¾″ thick oak, with the top edges of the upper piece partially chamfered at 45° (*Fig. 14*). I finished them with a light stain and two coats of polyurethane.

The two pieces of oak are attached to each other with six #8 1¼″ wood screws and glue, and the base is attached to the bottom of the cabinet with four #9 1¾″ particleboard screws and glue. Note that the base assembly is mounted to the cabinet off center towards the back. With the grille attached, however, the cabinet is centered on the base, and about 1/16″ of the top of the base assembly shows around all four sides of the cabinet.

Build and finish the cabinets and bases separately and attach them afterwards. If you don't wish to build the bases (the oak costs more than all of the rest of the wood combined), I recommend rounding the bottom edges of the cabinet and the bottom corners of the grille board similarly to their tops for the sake of appearance. You can put spikes or feet directly into the bottom of the cabinet, or you can design your own base.

CROSSOVER DESIGN AND ASSEMBLY

After determining the amount and type of fill to use in the woofer cavity, I experi-

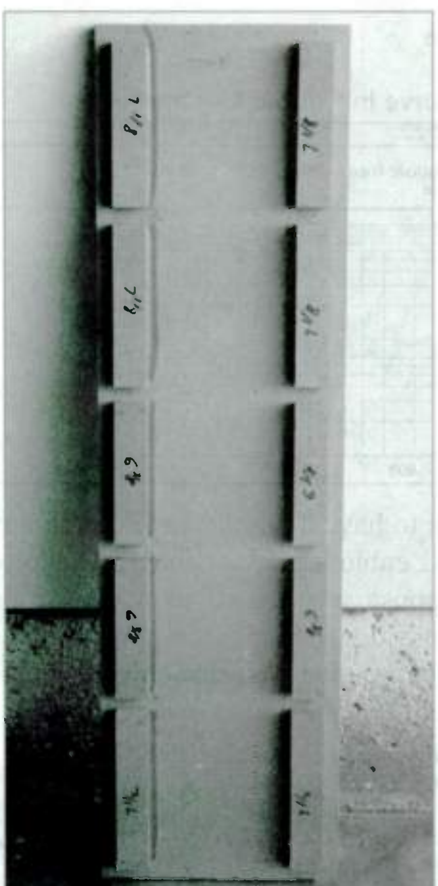

PHOTO 4: Side panel assembly.

PHOTO 5: Side panel, with internal braces shown.

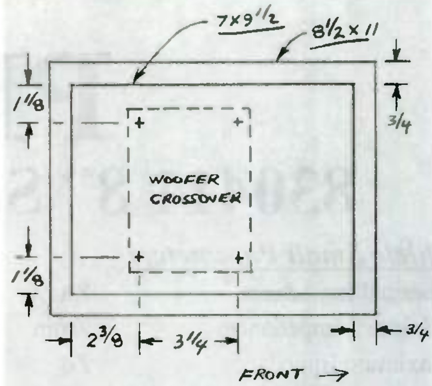

FIGURE 12: Bottom assembly.

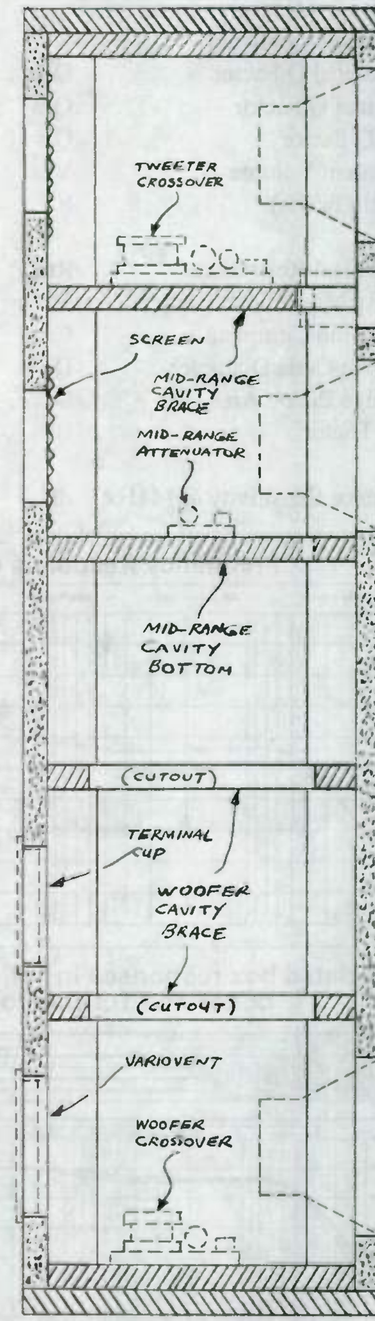

FIGURE 13: Cutaway side view of cabinet.

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MOREL. ANOTHER WAY OF SAYING DRIVE UNIT QUALITY

mented with crossovers for all three driver sections. Rather than describing the results of the various configurations, I'll just outline the final versions.

The woofer crossover is a nonstandard, second-order with a corner frequency of 200Hz, while the tweeter's is a third-order Butterworth at 3kHz. I ended up using no crossover at all for the midranges, allowing their natural rolloffs at both ends to blend with the other drivers.

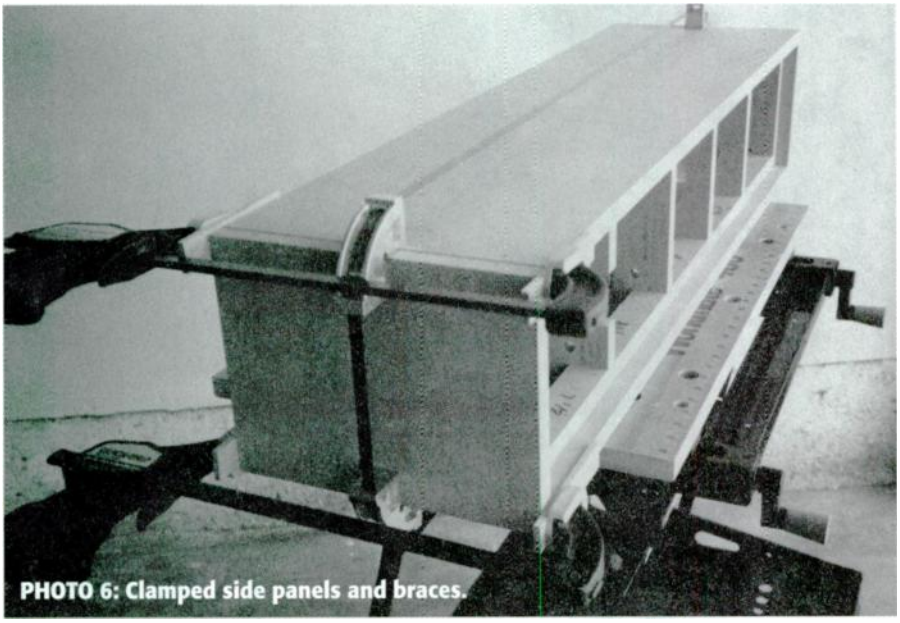
PHOTO 6: Clamped side panels and braces.

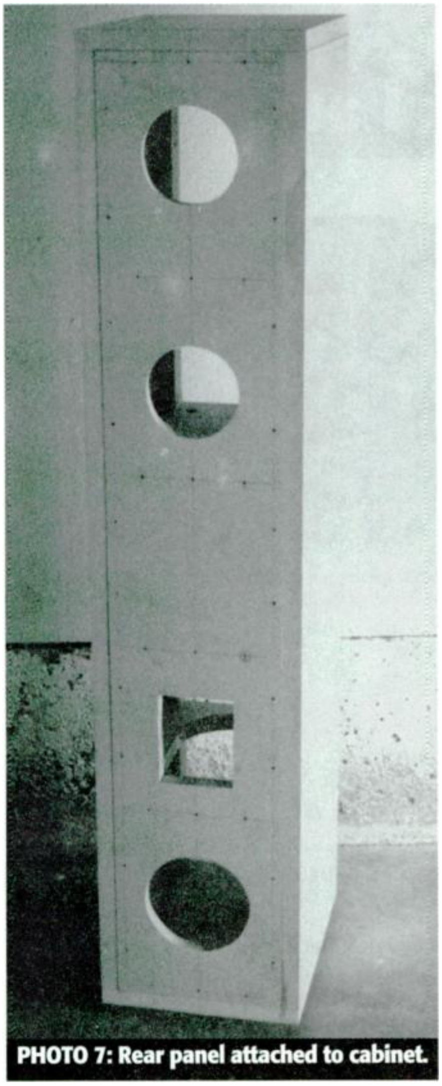
PHOTO 7: Rear panel attached to cabinet.

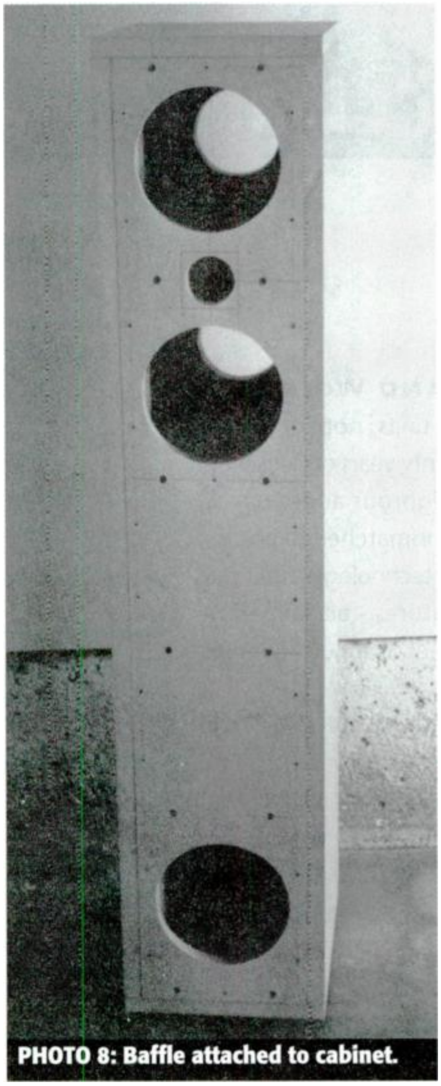
PHOTO 8: Baffle attached to cabinet.

In order for this to work properly, the choice of midrange drivers is critical. They must have a fairly wide response range and, more importantly, the rolloff at each end of their response range must be very smooth. The Morel MW-166 meets these requirements very nicely and has a first-order rolloff below its f_3 of about 110Hz.

For sensitivity-matching to the other drivers, I wired a 3Ω resistor in series with the paralleled midrange drivers. So the midrange "crossover" is actually just a 5dB attenuator assembly. This overall crossover configuration is somewhat unusual, but measurements and listening validate its effectiveness.

I used silicone sealant to attach crossover components to the ⅜" particleboard bases. Again, as in designs 2 and 3, I attached 8-place barrier strips to the bases with wood screws for input/output connections. These have two rectangular blades at each position that accept slip-on connectors. I used one blade of each pair for soldering to the crossover components and the other for the input/output slip-on connectors (see *Figs. 15–18*). The paralleled midrange drivers are wired out of phase at their attenuator's output from both woofer and tweeter.

WIRING

Internal wiring is normal stranded wire, and I used a biwired arrangement as in designs 2 and 3. From the two pairs of binding posts I ran 14-gauge wire to crossover inputs, connecting the bottom pair of posts to the woofer crossover input, and the top pair of posts (with two pairs of wires) to the inputs of midrange and tweeter crossovers. I used 16-gauge wire for connections between the three crossovers and the drivers.

I soldered the connections to the input binding posts, but made all other connections with crimp-type, slip-on connectors (you may instead prefer not to use the barrier strips or crimp-type connections, and directly solder all the connections). The wires in each pair were twisted together.

As viewed from the front of the cabinet, one pair of 14-gauge wires from the upper pair of binding posts passes up and through the left 7⁄16" hole in the midrange-cavity bottom for connection to the midrange attenuator input. The other pair of wires from the upper posts is routed up and through the right 7⁄16" hole in

Swans M1 kit

The Swans M1 minimonitors open a new line of affordable high-end loudspeakers featuring several technological achievements and sound quality distinctions.

The 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 drivers used in the M1 represent a new high performance design from Hi-Vi Research. 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. The extremely rigid cone is hand coated with a special dampening compound to further maximize its performance. The cone is then coupled to a selected grade rubber surround that provides break-up free operation and very low distortion even at high power levels. 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.

The vibrating element of the tweeter is almost weightless in comparison to a conventional dome driver. 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.

M1 provide very even acoustic power dispersion. The important horizontal early reflections that create spatial impression and add to the overall presentation have the same even spectral balance as the direct sound, these are crucial features of a good loudspeaker.

On the contrary, the M1's vertical dispersion is well controlled in the high frequency domain in a 15' arc symmetrically to the reference axis. While 15° create adequate room for adjusting a listening position, the floor and ceiling reflections are well down in amplitude. This feature greatly contributes to the clarity of sound and imaging of the M1.

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 and two swans logos,
- two pairs of heavy duty gold plated terminals.

Cabinets are not included.

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.

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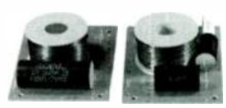
SWANS SPEAKER SYSTEMS

The step beyond the limits

RT1C Tweeter

F5 Bass-midrange



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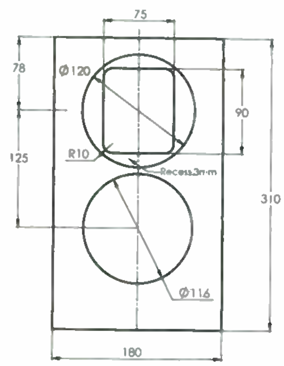
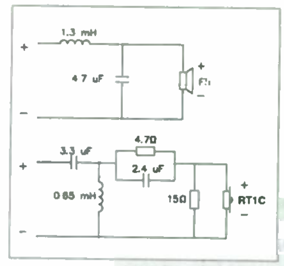
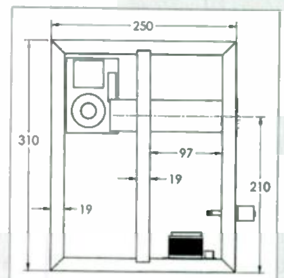
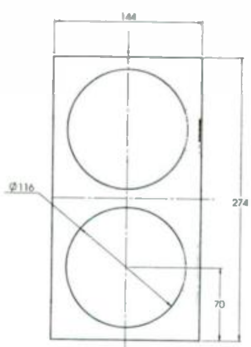


Front view

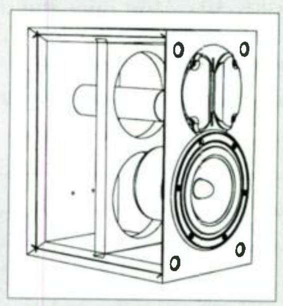




Right view of the cabinet with accessories(right side panel removed)



Internal panel



SPECIFICATIONS

Frequency response (1m,half space)	53Hz-40kHz,±2dB
Sensitivity,1W/1m (100Hz-8kHz averaged)	85 dB
Nominal impedance (7.2 ohms minimum at 250 Hz)	8 ohms
Harmonic distortion At 90dB SPL, 100Hz-10kHz, 1m	THD less than 1%
Power handling	50W nominal, 90W music
Dimensions,HxWxD	310x180x250 mm

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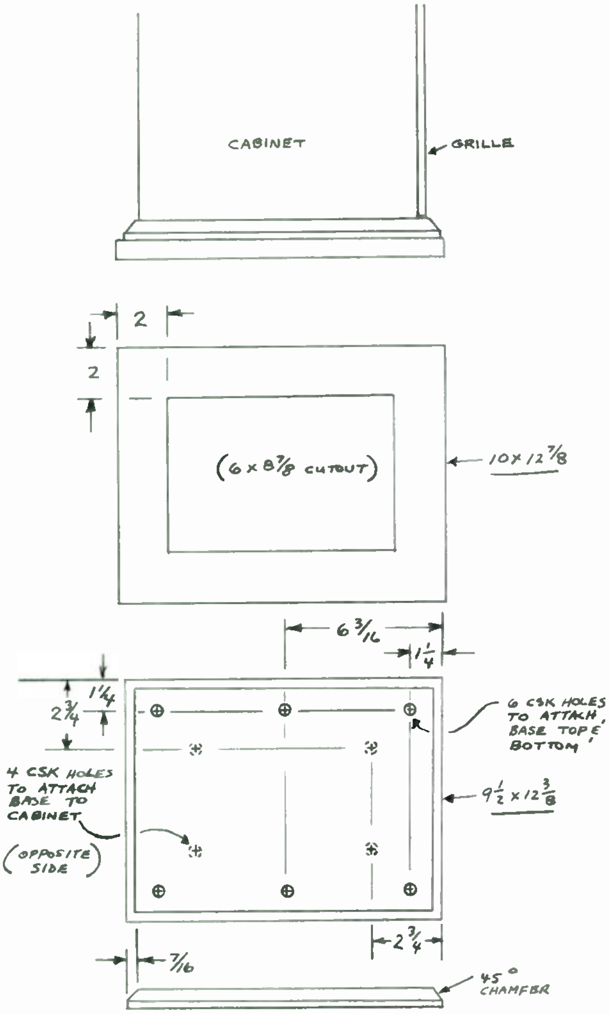

FIGURE 14: Base assembly.

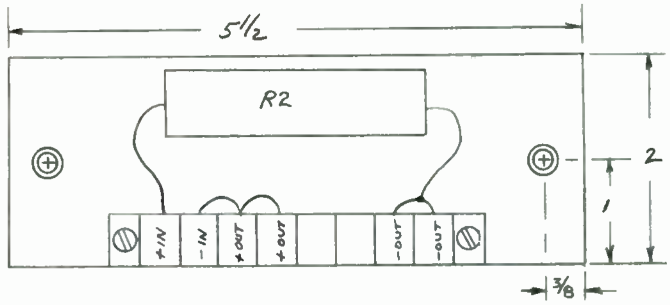

FIGURE 16: Midrange-attenuator layout.

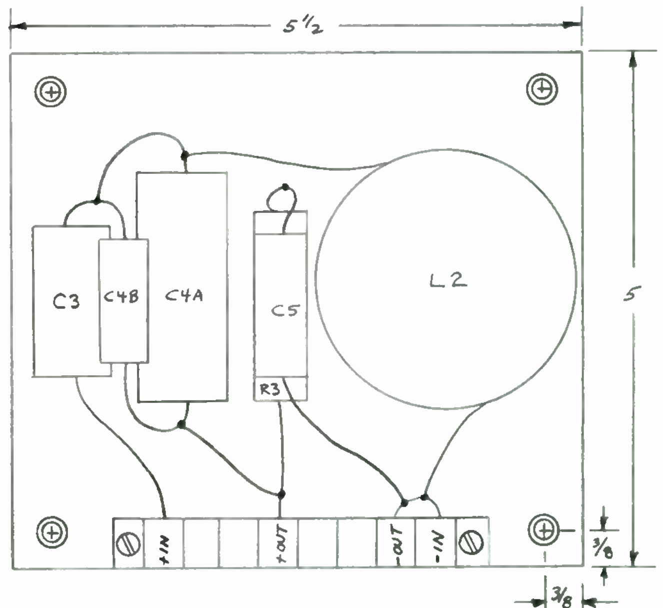

FIGURE 17: Tweeter-crossover layout.

this bottom shelf, then through the hole in the shelf directly above for connection to the tweeter crossover input. You need to seal both holes in this cavity *bottom* with silicone sealant once the wires are in place.

From the midrange attenuator, one output pair of wires is routed up through the left-side hole in the midrange-cavity brace above for connection to the upper midrange driver. I believe it is good practice to keep leads to and from crossovers and drivers separated as much as possible to minimize mutual coupling between the three driver sections.

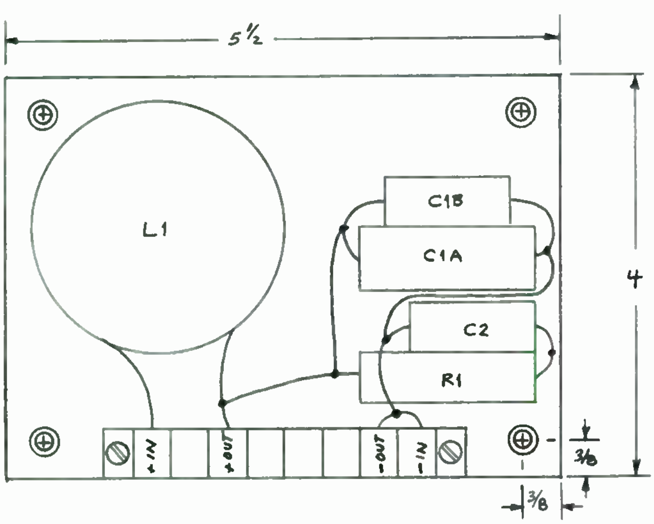

FIGURE 15: Woofer-crossover layout.

SHOULD YOU BUILD A PAIR?

The Aperiodic Deuce is, to some extent, my solution to a specific problem. Due to the small size of the woofer and low-frequency characteristics, these systems may not be suitable for home-theater sound tracks that contain loud, very low-frequency special effects, unless augmented by a subwoofer. I listen mostly to classical music, with a little jazz thrown in, and these speakers work well for my musical tastes.

Their main advantages are in the imaging, an overall smooth response, and delightfully involving midrange (the kind of sound that draws you into the music and excites your emotions). The midrange sounds so good, I be-

SOURCES

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Madisound Speaker Components
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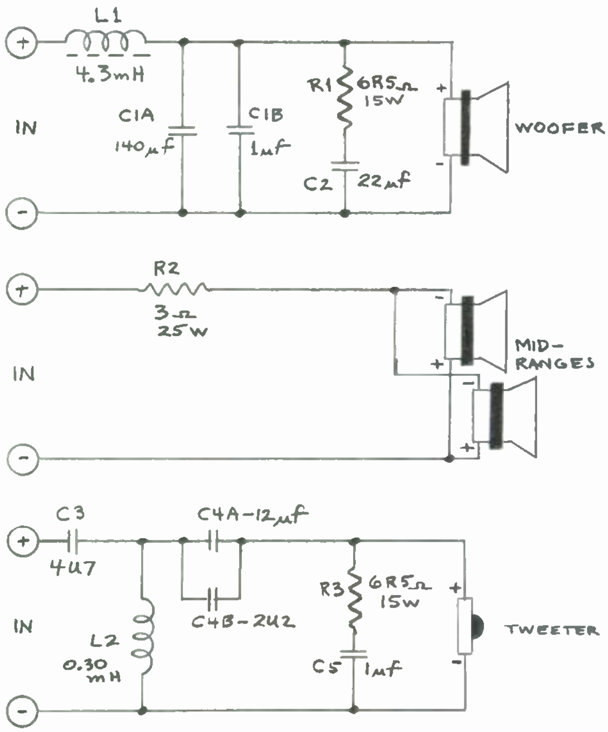

FIGURE 18: Crossover schematic.

lieve, because the open-back tunnels can't cause a "boxy" or hollow sound, and, without a crossover, there are no crossover-induced anomalies, such as response peaks and dips or phase shifts. There's an effortless, unrestrained quality to the midrange's sound. Since most of music's content is in the midrange, the Aperiodic Deuce's accurate reproduction in this area is highly satisfying.

For me, these attributes more than make up for any losses in the bottom octave; however, I haven't noticed any lack of low-end response in the music I play. My wife's comments after she did her critical listening were, "they sound really good, and the flutes and piccolos were incredible." If your musical tastes and needs parallel mine and your listening environment is similar, the Aperiodic Deuce might be just what you need.

Read how one man's unsuccessful attempts to kick the speaker-building habit have plunged him headlong into the depths of lonely late-night tinkering sessions searching for the perfect highs and lows of home-theater sound.

Walking the Thin Line

By Philip Abbate

I am a recovering speaker builder. I was cured for a while, but I relapsed when I received a complimentary copy of this magazine. I've resisted the cravings for sawdust, fiberglass, and speaker-adhesive fumes since 1978. Before then I could be found in Cal Poly's computer lab late at night rearranging and resubmitting box-volume and tuning-frequency keypunch cards to the FORTRAN compiler over and over, time and time again. I am a little more in control of myself now that I have matured. I can walk the thin line between occasional and obsessive speaker building.

I sometimes catch myself reminiscing about the good old days, when I would allow my obsession to drive me to make large multidriver sound-reinforcement speakers or folded bass horns one or two dozen at a time. Suddenly I'll wipe the sweat from my forehead, and get a grip by reminding myself of the consequences: the sore back from loading and unloading a truck; waking up in a rock-and-roll tour bus, without a clue to what city I was in; and the ringing in my ears that lingers the morning after.

NEVER AGAIN

"OK, OK, I won't become like that again," I said to myself, "I'll just replace the piezo tweeter and el cheapo stamped-frame paper-cone woofer in these old left and right stereo speakers with some of the new drivers advertised in the catalogs I got from the *Speaker Builder* advertisers. That should clean up the stereo sound when I listen to music on the theater system for a fraction of the cost of new, high-end speakers. After this one project, I will be satisfied.

My hand shaking, I removed the polymer money substitute from my wallet and ordered a pair of Focal T90ti tweeters and Focal 8V01 woofers, along with a copy of Vance Dickason's *Loudspeaker Design Cookbook* from my paisano Elliot (516-747-3515) at Zalytron. When I heard the phone on the other end click, I was struck with buyer's remorse. I swore once more "after this project I'll never build another speaker."

When I fired up my creation, I could not contain myself, and yelled to my wife, Monica, "Wow! This stuff's gotten better since 1978." As I enjoyed the music, the dilapidated excuse for a center-channel speaker that was collecting dust on top of my TV caught my eye. My hands started to twitch as I thought, "I promised my family I would never build another speaker again." At that moment, Monica noticed that faraway look in my eye and knew I was a goner.

Then it struck me. I'll go to Speaker City in Burbank (www.speakercity.com) to check out what prefab speakers I can buy. I walked in the door, browsed around, and in an obscure corner of the store, a driverless oak-tower speaker cabinet that looked like someone designed it to fit on top of my TV set called out to me. What a coincidence!

A DEAL I COULDN'T REFUSE

Shortly after I pulled into the driveway, Monica saw me unloading this oak box from the car and asked me, "Never again, huh?"

"But honey," I apologetically exclaimed, "it was used, and

PHOTO 1: "Bet ya can't build just one."

ABOUT THE AUTHOR

When he's not obsessing about building speakers, Phil Abbate is a registered professional engineer. He shared his 15" subwoofer design with *SB* readers in the 6/96 issue.


PHOTO 2: Center-channel speaker.

there was only one of them, so Frank made me a deal I could not refuse ... and ... and I can order a Focal T90ti-B shielded version of the tweeter our left and right speakers use, and a Focal 7K011 DBL-B shielded 7″ speaker that is the same brand of woofer as in our left and right speakers. If I voice the crossovers just right, the sounds moving across the room will be very coherent."

"How much?" she interrupted with her familiar smile. "If it makes you happy, OK; those other speakers you worked on sound quite good, but..." Oh-oh, not a condition! I conjured up visions of shopping sprees at the mall, weekends at a bed and breakfast in the Valley of the Moon. But she continued, "What are shields?"

The engineer in me contrasted magnetic and electric fields. I waxed eloquent, illustrating in lay-person terms how the CRT in the TV shot streams of electrons through a magnetic-deflection circuit called a yoke. I elucidated how those electrons illuminated one of three phosphors to create a red, green, or blue dot on the TV screen.

We observed the TV screen and beheld the individual dots blending to form a picture on the screen. I described the detrimental effects that the "stray magnetism" in the center channel's unshielded drivers would have on the picture.

To demonstrate her comprehension, Monica pointed to the junker on top of the TV and asked "why doesn't that one do it?"

"It's because the magnet in that speaker doesn't have enough magnetism to pick up a pin, let alone create a stray magnetic field," I explained. I demonstrated the consequences of stray magnetism by holding the magnet from an old woofer right next to the TV picture tube. The intense rainbow effect convinced my wife that we needed magnetic shielding in our new center-channel speaker.

PERSISTENT RAINBOWS

Satisfied that I had made my point, I recycled the power on the TV to engage the automatic degaussing circuitry and remove the rainbow pattern. "Are you sure you showed up to your electronics classes?" Monica interrogated, as I frantically turned the TV on and off, only to see the rainbows disappear and reappear.

PHOTO 3: Cute surround speakers.

Eventually, the degaussing circuitry did its job, but since it is only designed to degauss low-level fields, such as those created by a speaker several inches away, it took a couple of days for the TV to return to normal.

I knew I had created another success when we auditioned the new center-channel speaker, and Monica exclaimed, "The voices are so clear!"

I had to take advantage of the situation to point out the value of speaker building. I gloated, "Yeah, and the entire left-center-right system only cost $500. If we had bought comparable equipment at a retail store, we would have spent $2,000."

What happened next made me think I was dreaming. We talked about why we needed those ugly, 24″-tall, two-way speakers I bought when I was in high school blocking the doorway, when I could make some of those cute surround speakers that hang out of the way on the wall. We imagined how realistic movies would sound with a subwoofer, and how the left and right speakers could look a little better, and how it was OK for me to buy a radial-arm saw for Christmas. "Why are you pinching yourself?" Monica asked with a puzzled look on her face.

SATISFACTION

It's three years later now, and Monica and I are quite satisfied with the sound and looks of the system. There is something schizophrenic about the system, however. Some of the time it thinks it is a high-end audiophile-quality stereo, and at other times it thinks it is a kick-butt home theater. The common elements of both the system's personalities are the left and right three-way stacks that work in conjunction with Aftershock, my subwoofer that appeared in *SB* 6/96.

[We are pleased to report that, since he wrote this article, Mr. Abbate appears well on the road to recovery, effectively suppressing his impulses to tweak and/or modify every speaker system he encounters. For a closer look at his work, *SB* readers are encouraged to revisit his "Seismic Stack System" (*SB* 5/98, p. 18). –Eds]

The Process of Design.

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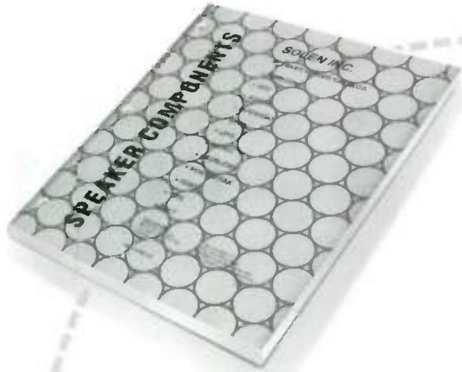
CUSTOM COMPUTER AIDED CROSSOVER AND CABINET DESIGN

HOW TO BOOKS



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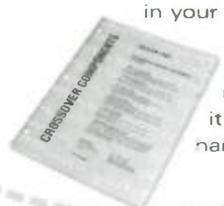

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Reader Service #24

Powerful, fast, and easy to use—discover why PSpice has become a favorite for analytical design work.

PSpice Probes A Loudspeaker's Evolution

By Mark Sanfilipo

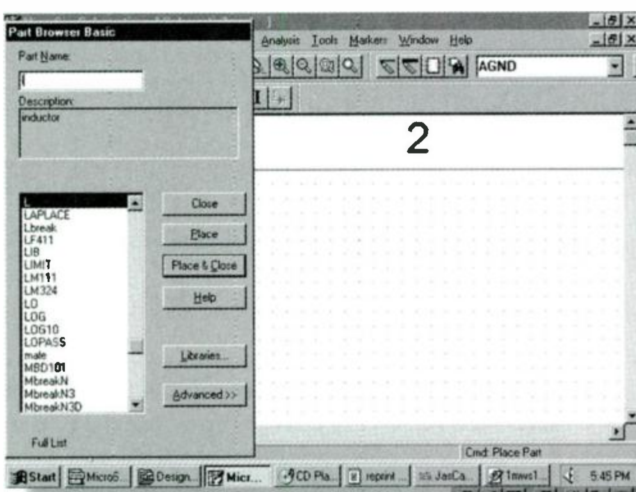
Speaker builders are now fortunate in having at their disposal many powerful CAD programs that not only assist them in searching for solutions, but also significantly shorten the time needed to bring concepts to fruition. This article examines the application of one such program, PSpice®, to various developmental stages of an electrodynamic loudspeaker model, including the latest versions featuring frequency- and temperature-dependent components.

POPULAR AND POWERFUL

One of the most popular CAD programs now inhabiting the engineering workplace, PSpice began life as a doctoral thesis and was further developed in the late 1960s at the University of California-Berkeley as a mainframe application to assist in the development of ICs. It has since evolved into a powerful desktop application with surprising and far-reaching capabilities.

Even the demo is powerful! Indeed, I did all the work illustrated here using the evaluation version of PSpice 7.1. If you'd like a free copy, call MicroSim at (800) 245-3022 or E-mail the company at sales@microsim.com and ask for the DesignLab (of which PSpice is a part) evaluation disk set. It's available both on floppy disks and in CD-ROM format. DOS versions of PSpice also exist.

Alternatively, if you have access to the Internet, you can download the program from http://www.microsim.com/. If you choose this route, be prepared for a lengthy download period—the complete DesignLab file is over 13.3MB in size. It's also worthwhile to do an occasional Net search, since there are many sites where the application (particularly older versions) and support resources are available. You'll also find on the Internet many circuit and schematic files developed for PSpice.



S-783-1

FIGURE 1: The parts library.

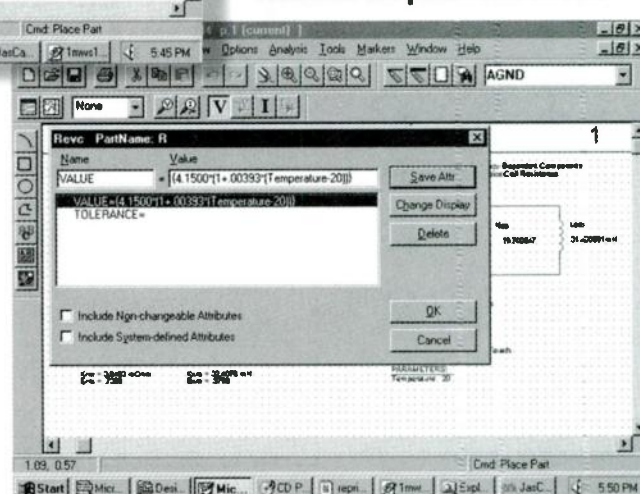
Speaker Builder's readers have encountered PSpice before.[1] Here, I'll use PSpice 7.1 for Windows '95 to take a look at the evolution of a moving-coil loudspeaker model. Although PSpice easily calculates the dB-SPL curves of a driver, I will restrict this examination to the impedance curves and associated components.

HARDWARE BASICS

To run this version of PSpice, you'll need an 80486 or Pentium machine, a math coprocessor, 16MB or more of RAM, a mouse, and, of course, Windows '95. Setup is quite straightforward and the demo comes with ample help files.

When you first fire up PSpice, you're presented with the main workspace.

FIGURE 2: The parts value screen.



S-783-2

If you are new to the program (or perhaps experienced only with a DOS version), it's worth taking the time now to become thoroughly familiar with the Windows version, since this will save lots of time later on when you start putting the application through its paces with larger projects. Not too large, though; the demo version, although possessing the functionality of the full program, has some limitations: for example, you're allowed only 50 symbols per schematic.

BUILDING THE CIRCUIT MODEL

Once you've explored a bit and examined the sample circuits provided, the process of building your circuit model is not very complex. First, pick parts from the parts library (*Fig. 1*) (Draw\Get New Part\) and drag them onto the workspace. Then connect them with wires (Draw\Wire) and ground (Draw\Get New Part\) the circuit. PSpice absolutely will not let your design go anywhere without a grounded circuit.

Once you've got all the parts in place, wired correctly and grounded, assign values to each part. Double-clicking on each part calls up the screen to do this (*Fig. 2*).

When you've completed a circuit, it's a good idea to use the Redraw (View\Redraw) utility to neaten things up a bit. If you've missed any connections, they'll then become obvious, and you can take corrective action. You can also use the Fit (View\Fit) utility when it's appropriate to have the circuit cover the whole screen.

If you're accustomed to working with earlier DOS versions (as I am), I think you'll agree that Windows' drag-and-drop capabilities represent a tremendous advance in terms of efficiency and ease of use. When you have your circuit built, you can bring PSpice's real strengths to bear.

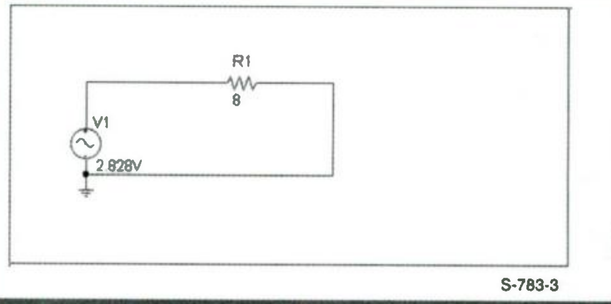


FIGURE 3: Model 1; driver as 8Ω resistor.

FROM 8Ω TO FREQUENCY DEPENDENCE

The first model to look at (*Fig. 3*) considers the driver's impedance as a simple 8Ω resistive load. I found this early version of the electrodynamic speaker model referred to in a design-your-own crossover chart tucked away in a 1950's edition of a popular radio-electronics handbook. Paradoxically, while the reactive nature of the driver's load was already well understood by the 1930s,[2] many contemporary charts implied a pure resistance and persisted for decades.

In those days, it appears that all the home hobbyist had to do was decide whether the driver at hand was the equivalent of an 8Ω or 16Ω creation and what the crossover frequency ought to

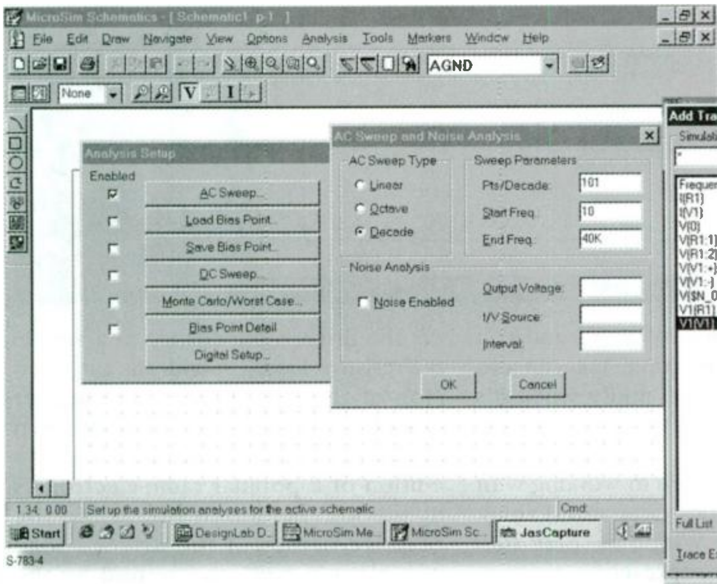


FIGURE 4: The setup selection screen.

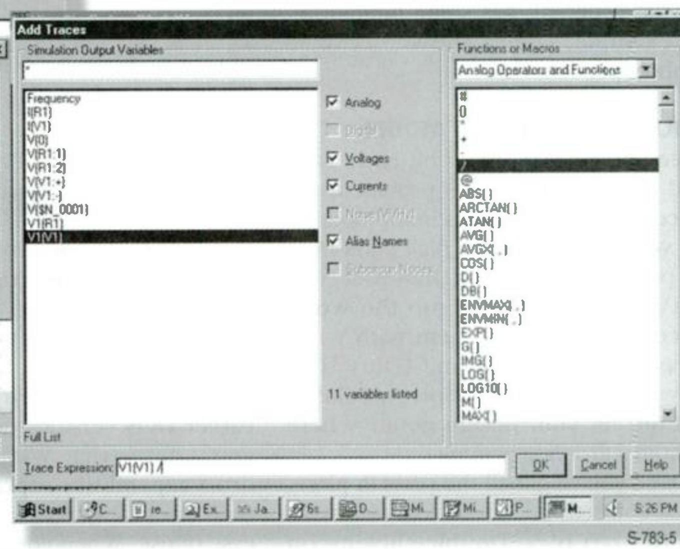


FIGURE 5: The add-trace screen.

be. Then, all he or she needed to do was look up the appropriate inductor or capacitor values in the charts. How many crossovers were built in those days using an "equivalent" resistor as the driver's load? I suppose "high-fidelity" was a relative, flexible descriptor back then. [Back then?! —Ed.]

I'll now apply PSpice's analytical abilities to this rather simple model. Since no intelligent speaker builder would *ever* model the raw driver as a simple 8Ω load, it might seem a trivial pursuit to probe it. However, the very simplicity of the model commends it as an ideal starter example.

First, click on Analysis, and then on the first item in the drop-down box, Electrical Rule Check. Once PSpice has completed its electrical rules check, click on Create Netlist.

PSpice is able to point out mistakes you've made, and the Create Netlist utility is usually the first point in the analysis that this will happen—if indeed you have done anything incorrectly. I always use this utility when working on a new circuit or making any significant changes to an older one, even if I have no immediate plans to do a simulation.

READY TO SIMULATE

PSpice then generates the netlist that you'll find familiar if you've used DOS versions of the program:

```
*SCHEMATICS NETLIST*
*MODEL 1: DRIVER AS OHM RESISTOR*
V_V1   $N_0001 0 DC 0V AC 2.828V
R_R1   $N_0001 0 8
```

You can look at it by clicking on Examine Netlist, and once it has been generated, you're ready to do a simulation.

If you've made any mistakes that slipped by the Create Netlist utility, they'll likely be caught when you run a simulation. If it detects any errors, PSpice automatically stops and displays the output, with the location of the error clearly indicated. Also, if you haven't saved your circuit by now, PSpice stops and asks you to save it as a file. Once you've done so, the simulation continues.

You begin the simulation by clicking on Setup (still in the Analysis drop-down box), where you set the simulation parameters (*Fig. 4*). Enable AC Sweep by clicking its button, and set the appropriate sweep numbers. The values I typically use are:

- AC sweep type: decade
- Pts./decade: leave at default of 101 (or choose whatever you consider appropriate)
- Start frequency: 10Hz
- End frequency: 40kHz

Click on OK to save the values and close out the Analysis Setup box. You're now ready to commence the simulation. Click on Run Probe, and you're on your way. A screen will pop up that indicates the progress of the simulation.

After the simulation is run, and if PSpice has found absolutely no errors, you'll see the graph screen, where you can build the curves you wish to look at. Click on Plot and set the X- and Y-axis parameters.

Since this first graph will show impedance, you'll need to use a log-log plot, so set both axes accordingly. With the graph screen all set up, you're ready to do some real analysis.

Click on Trace, and click on Add in the drop-down box. This brings you to the screen where you specify the kind of analysis (and subsequent curves) you wish to look at (*Fig. 5*).

CURVES, CURVES, AND MORE CURVES

To generate an impedance curve—which, in the case of a simple, ideal resistor, is actually a pure resistance—set up the following in the Trace Command line: V1(V1)/I(V1). Click on OK, and you have your first curve.

Here's a list of commands to generate other curves:

1. Impedance: V1(V1)/I(V1)

2. Impedance phase: P(-V1(V1)/I(V1))
3. Impedance (real part): R(-V1(V1)/I(V1))
4. Impedance (imaginary part): IMG(-V1(V1)/I(V1))
5. Impedance (group delay): G(-V1(V1)/I(V1))
6. Nyquist plots: Set X and Y axes to linear, set X axis = V1(V1)/I(V1), and then graph P(-V1(V1)/I(V1))

Note the minus sign preceding the (V1) in items 2 through 6. It's not a typo; it's required. As you work with more complex circuits, you'll see that the resulting curves more closely match reality. Looking at the figures for other models, all the components and their designations are (with the exception of R_{em} and L_{em}) commonly found in the literature.[3,4,5] *Figures 6–11* show a sample of Models 2 and 3. *Table 1* shows the impedance values found at eight different frequencies as generated by Models 2 and 3, compared with actual measured values.

To aid in comparison, I've provided the actual impedance curve and group-delay curve of the driver I used as the test subject (*Figs. 12* and *13*). And for reference, the values for the test driver are shown in *Table 2*.

Now take a closer look at the components featured to see how they contribute to the impedance characteristics of the models.

To begin with, look at the impedance rise found to the right of the Z-peak (*Fig. 7*). For the sake of clarity, remove the Z-peak by removing C_{mes}, L_{ces}, and R_{es}. Also remove the voice-coil DC resistance, R_{evc}. The resulting curve is that of the motor impedance (*Fig. 14*). The actual reconstruction of the circuit and the generation of the impedance magnitude and phase curves I leave as an exercise for the reader.

EASY MODIFICATION

You can easily make this modification with PSpice, since all you need do is remove selected components from the circuit, rewire as appropriate, and generate the new curves. Looking at the resulting two curves, you can begin drawing the mathematical basis for the frequency-dependent components, R_{em} and L_{em}. If you've done any curve-fitting work, you'll recognize that both curves can be generated by the equation:

$$y = k\omega^x \qquad (1)$$

where, in this case:

- y = resultant curve value
- k = a constant that scales the location of the curve up or down
- $\omega = 2\pi \times$ frequency
- x = an exponent that determines the behavior of the curve's slope.

The general equation for the motor's impedance is[6]:

$$Z = K_r\omega^{Xr} + jK_i\omega^{Xi} \qquad (2a)$$

or, written using more commonly known variable names[7]:

$$Z = K_{rm}\omega^{Erm} + jK_{xm}\omega^{Exm} \qquad (2b)$$

where:

- Z = resultant impedance, in ohms
- K_{rm} = a constant that scales the resistance curve up or down
- $\omega = 2\pi \times$ frequency
- E_{rm} = an exponent constant that controls the slope of the resistance curve.

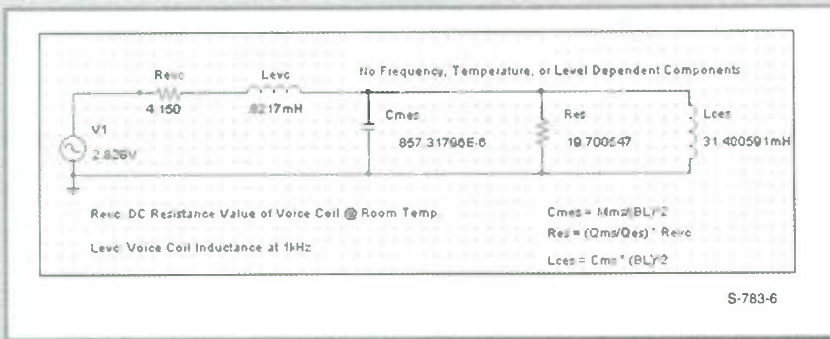


FIGURE 6: Model 2; classic driver circuit with no frequency, temperature, or level-dependent components.

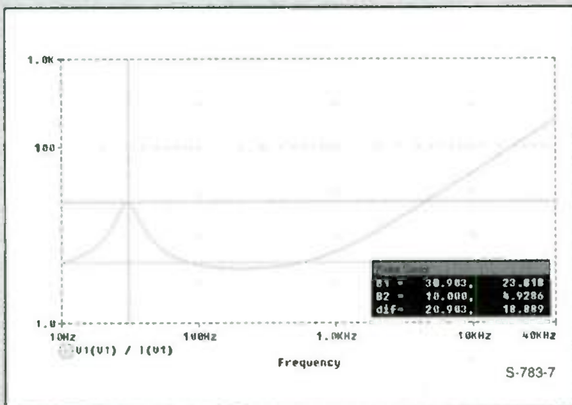


FIGURE 7: Model 3; classic circuit with two frequency-dependent components (magnitude of impedance).

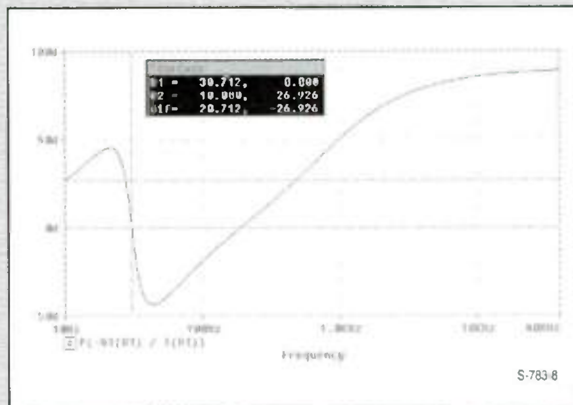
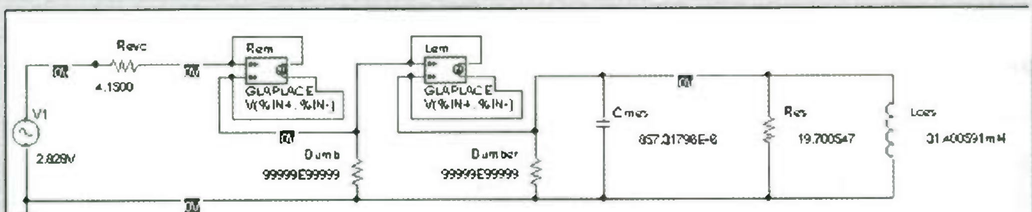


FIGURE 8: Model 3; classic circuit with two frequency-dependent components (phase).



Revc = 4.150 Ohms (DC Resistance of Voice Coil)

Rem XForm: 1/(.0036483*pwr(abs(s),(.7358)))
Lem Xform: 1/(s*.0324076*pwr(abs(s),(-.4202)))
Rem = 3.6483mOhms * (2 * Pi * Frequency)^(.7358)
Lem = 32.4076mH * (2 * Pi * Frequency)^(-.4202)

Krm = 3.6483 mOhm   Kxm = 32.4076 mH
Erm = .7358   Exm = .5798

V1= 2.828 Vac

Res = (Qms/Qes) * Revc
Res = 19.70054688643 Ohms

Lces = Cms * (BL)^2
Lces = 31.4005907302

Cmes = Mms/(BL)^2
Cmes = 857.317959868E-6

Dumb, Dumber = 99999E99999 Ohms

S-783-9

FIGURE 9: Model 3; classic circuit with two frequency-dependent components.

TABLE 1
COMPARISON OF IMPEDANCE VALUES FROM TWO MODELS

FREQUENCY (HZ)	MODEL 2 (Ω)	MODEL 3 (Ω)	ACTUAL MEASURED VALUES (Ω)
10.126	4.95099	5.16623	5.070
20.153	8.96412	9.3627	9.330
30.079	23.6469	23.8811	23.670
123.706	4.38324	4.76795	4.820
1012.593	6.53332	8.16838	8.140
10040	51.9829	25.6943	25.700
20041	103.543	38.4159	38.430
40004	206.573	58.3148	58.32

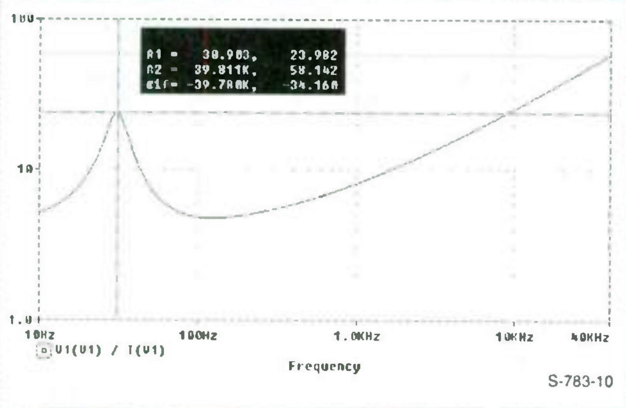


FIGURE 10: Model 2; classic circuit (magnitude of impedance).

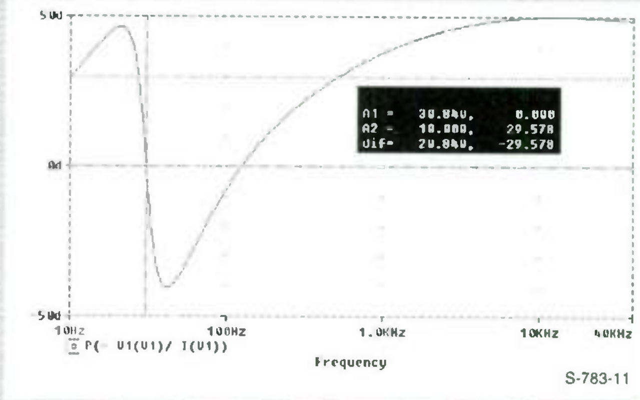


FIGURE 11: Model 2; classic driver circuit (phase).

K_{xm} = a constant that scales the reactance curve up or down

E_{xm} = an exponent constant that controls the slope of the reactance curve

Now measure the electrical impedance at two points along the flat portion of the impedance rise, and characterizing these values as:

$$Z1 = K_{rm}\omega 1^{Erm} + jK_{xm}\omega 1^{Exm} \quad (3)$$

and

$$Z2 = K_{rm}\omega 2^{Erm} + jK_{xm}\omega 2^{Exm} \quad (4)$$

(You must determine individually the exact points for measuring these Z values. In the case of this driver, 10kHz and 20kHz would be good places to measure. The key here is simply to find a couple of points sufficiently distanced in frequency in the relatively flat, positive-slope portion of the impedance curve.)

Then, by solving equations 3 and 4 simultaneously, you derive the expressions for E_{rm} and E_{xm}:

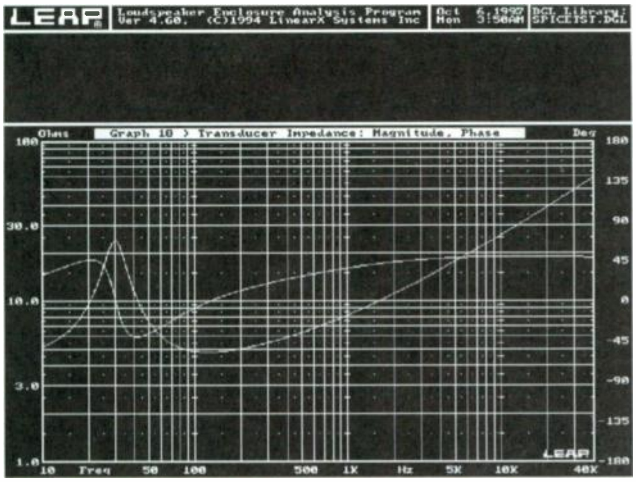


FIGURE 12: 12″ Kevlar cone driver.

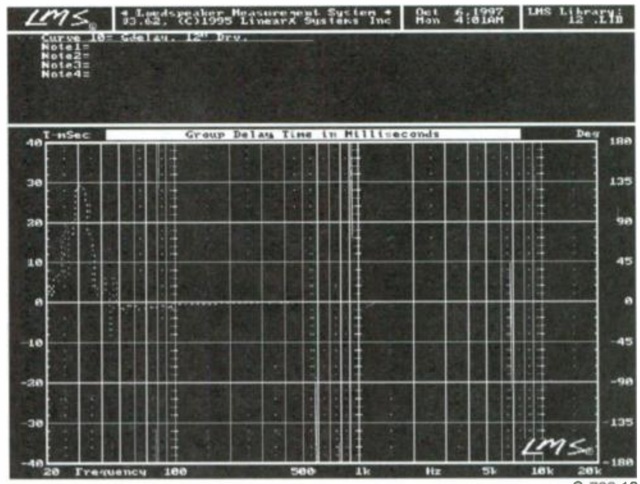


FIGURE 13: Group delay time in milliseconds.

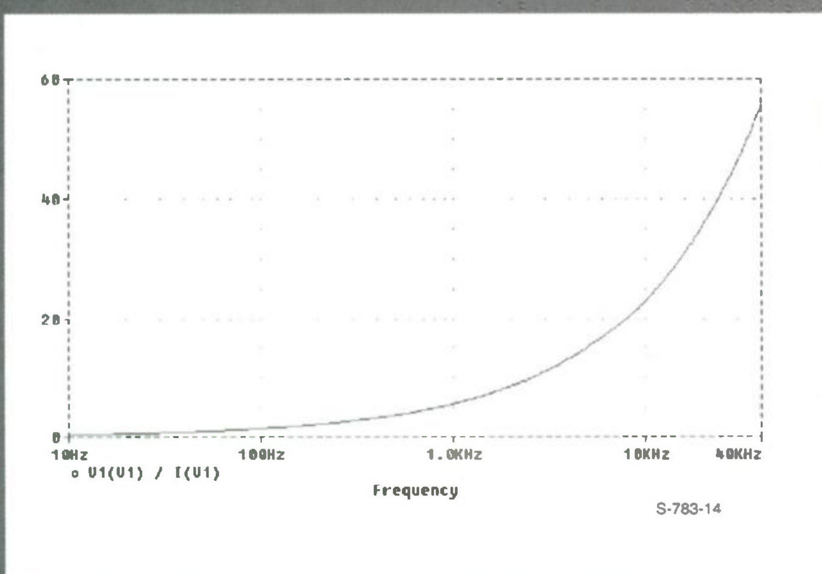


FIGURE 14: Model 3 motor impedance.

$$E_{rm}=Log(Real(Z2)/Real(Z1))/Log(\omega 2/\omega 1) \quad (5)$$

$$E_{xm}=Log(Img(Z2)/Img(Z1))/Log(\omega 2/\omega 1) \quad (6)$$

and for K_{rm} and K_{xm}:

$$K_{rm} = Real(Z1)/\omega 1^{Erm} \quad (7)$$

$$K_{xm} = I_{mg}(Z1)/\omega 1^{Exm} \quad (8)$$

Finally, from these equations you derive the formulas for R_{em} and L_{em}:

$$R_{em} = K_{rm}\omega^{Erm} \text{ (ohms)} \quad (9)$$

$$L_{em} = K_{xm}\omega^{(Exm-1)} \text{ (henrys)} \quad (10)$$

FIXED-VALUE COMPONENTS

An interesting feature of both these equations (which represent frequency-dependent components) is that you can easily use them to represent fixed-value components as well. In the case of R_{em}, setting the value of E_{rm} to zero accomplishes this. For L_{em}, setting E_{xm} to 1 will do likewise. L_{em} then becomes L_{evc}. As an example, referring to the curves for the motor-impedance model, here are the measured and derived values:

Calculating E_{rm} and E_{xm} first, using equations 5 and 6,

Z1	Z2
Freq. = 5029.7Hz	Freq. = 20137Hz
Mag. = 15.138Ω	Mag. = 35.995Ω
Phas. = 60.457°	Phas. = 54.866°
Real = 7.4641Ω	Real = 20.7147Ω
Img. = 13.1698Ω	Img. = 29.437Ω

$$E_{rm} = .7358, \text{ and } E_{xm} = .5798$$

Calculating K_{rm} and K_{xm}, using equations 7 and 8,

$$K_{rm} = 3.648E\text{-}3, \text{ and } K_{xm} = 32.407E\text{-}3$$

If you're trying to pull E_{rm}, E_{xm}, K_{rm}, and K_{xm} directly from actual impedance plots as opposed to a motor impedance plot, equation 5 becomes

$$E_{rm} = log((Real(Z2) - R_{evc})/(Real(Z1) - R_{evc}))/log(\omega 2/\omega 1)$$

and equation 7 becomes

$$K_{rm} = (Real(Z1) - R_{evc})/\omega 1^{Erm}$$

In this case, E_{rm} is generated by the above version of the E_{rm} formula. The formulae for E_{xm} and K_{xm} remain the same.

Once you've derived the values of K_{rm}, E_{rm}, K_{xm}, and E_{xm}, you can construct the frequency-dependent components R_{em} and L_{em}. Using the GLAPLACE device, insert two of them into the circuit and label them R_{em} and L_{em}. Wire them *exactly* as they appear in the schematics for either Model 3 or Model 4 (*Figs. 15–20*) For each component, set the XFORM attribute as follows:

For R_{em}:

$$XFORM = 1/(K_{rm} \times pwr(abs(s),(E_{rm}))) \quad (11)$$

Inserting the values of K_{rm} and E_{rm} for this particular driver, XFORM becomes:

$$XFORM = 1/(.0036783 \times pwr(abs(s),(.7358))) \quad (12)$$

For L_{em}:

$$XFORM = 1/(s \times K_{xm} \times pwr(abs(s),(E_{xm}-1))) \quad (13)$$

Inserting the values of K_{xm} and E_{rm} for this driver, XFORM becomes:

$$XFORM = 1/(s \times .0324076 \times pwr(abs(s),(.5798 - 1))) \quad (14)$$

Don't forget to click the Save Attr button once you've made these entries. That's all there is to it.

TABLE 2
TEST-DRIVER SPECIFICATIONS

Z_{nom}: 8.000Ω	S_d: 0.0460M²	F_i: 29.477Hz	H_{vc}: 14.5000mM
R_{evc}: 4.1500Ω	B_L: 8.9337Tm	F_0: 30.675Hz	H_{ag}: 6.0000mM
K_{rm}: 3.6483mΩ	V_{as}: 118.2194 ltr	Q_{ms}: 3.2551	X_{mx}: 4.2500mM
K_{xm}: 32.4076mH	C_{ms}: 393.4369μM/N	Q_{es}: 0.6857	C_{mx}: 4.2500mM
E_{rm}: 0.7358	M_{ms}: 68.4234 Gram	Q_{ts}: .5664	C_{mo}: 1.000
E_{xm}: 0.5798	M_{md}: 62.7505 Gram	P_{mx}: 150W RMS	θVC: 1.667C/W

DUMB RESISTORS

You'll note in the schematics for Models 3 and 4 two resistors labeled "Dumb" and "Dumber" and tagged with some ridiculously high values. These are required when you gang up GLAPLACE devices. I set them as high as I did to guarantee they would not load the circuit. As a side note, if the data you have in hand is in table form, you can still model your frequency-dependent components using the GFREQ component. It is purposely designed to accept data in table form.

Now take a closer look at the Z-peak residing in the left half of Model 3's impedance graph. It is produced by the C_{mes}-R_{es}-L_{ces} parallel tank circuit, where:

$$C_{mes} = M_{ms}/BL^2 \quad (15)$$

$$R_{es} = (Q_{ms}/Q_{es}) \times R_{evc} \quad (16)$$

$$L_{ces} = C_{ms} \times BL^2 \quad (17)$$

In terms of energy dissipation, three mechanisms are at work: electrical, mechanical, and acoustical. Here, I'll concentrate on the first two. Frictional loss in the driver's suspension is a good example of mechanical dissipation. Electrical dissipation occurs as a result of R_{evc} and the output resistance of the amplifier. The mechanical Q (Q_{ms}) and the electrical Q(Q_{es}) are both determined

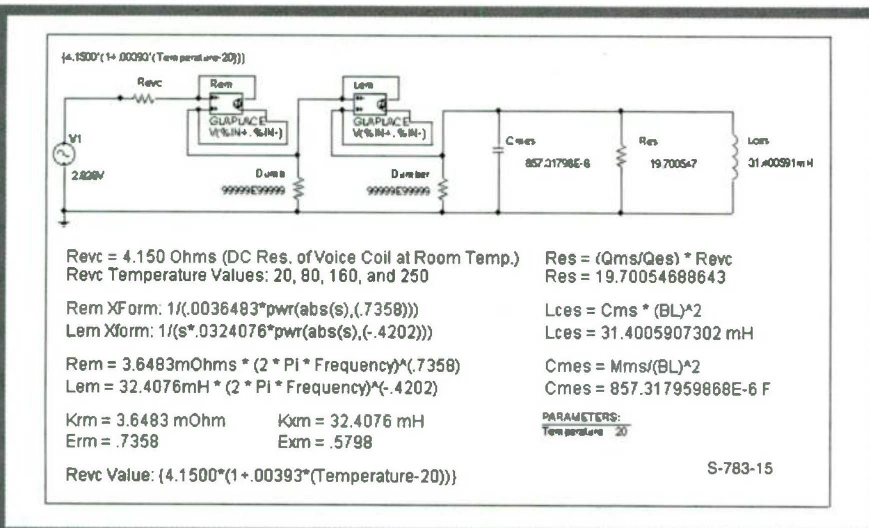


FIGURE 15: Model 4; classic circuit with two frequency-dependent components and temperature-dependent voice-coil resistance.

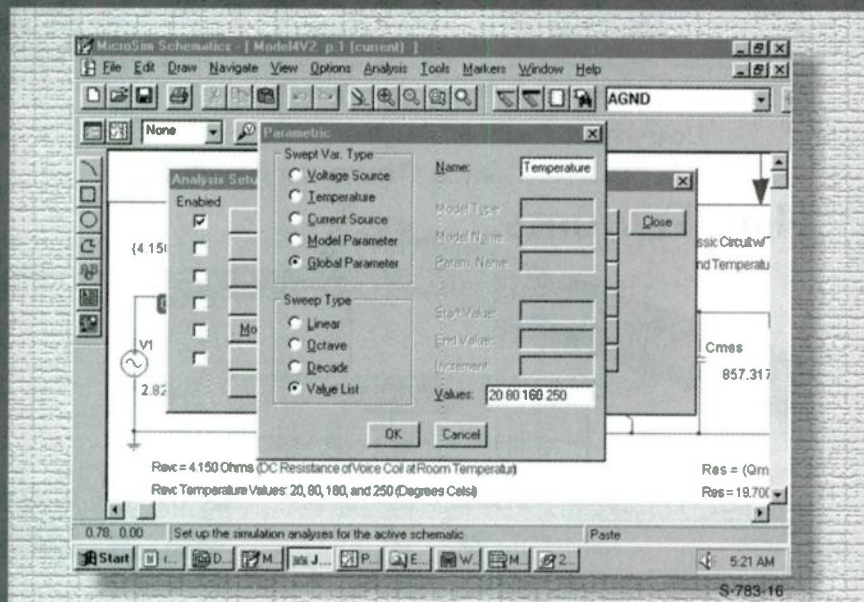


FIGURE 16: Temperature-dependent component parameter setup.

by these dissipative mechanisms. In the tank circuit, C_{mes} is the capacitive equivalent of the driver's mass, R_{es} is the equivalent of the suspension loss, and L_{ces} is an inductive equivalent of the driver's suspension compliance.

At resonance, which in this case occurs at:

$$fs = 1/(2\pi\sqrt{(L_{ces} \times C_{mes})})\ (Hz) \qquad (18)$$

energy is exchanged back and forth by the C_{mes} and L_{ces} components and is dissipated by R_{es} and, of course, R_{evc}. The ratio of the energy stored by the reactive components to the energy dissipated by the resistive components is the actual Q of the driver.

TEMPERATURE-DEPENDENT RESISTANCE

The majority of power dissipated by your driver amp is dissipated in the form of heat.[8,9,10] The voice coil is, of course, at the heart of the process, and as it heats up, the DC resistance of the coil increases. This in turn affects the driver's overall impedance. PSpice can easily model this effect. The following formula is useful in determining the DC resistance of the coil at various temperatures.

$$R_{evc} = R_{evc}@\text{Room Temp.} \times (1 + .00393 \times (\text{Temperature of Voice Coil} - 20)) \qquad (19)$$

R_{evc} at room temperature is determined simply by measuring the DC resistance of a voice coil at room temperature, assumed in this case to be 20°C.[11] (.00393 is the temperature coefficient of copper at 20°C.)

To get the R_{evc} component to behave as a temperature-dependent resistor is fairly straightforward. First place the PARAM device at any convenient spot on the schematic. (I chose the bottom right-hand corner for Model 4.)

Next, set the NAME1 attribute to Temperature and the value to 20. Then go to the Analysis Setup form, disable Temperature, and enable Parametric. When you click on Parametric, you'll see the screen shown in *Fig. 16*.

The four numbers appearing in the Value box are the temperatures at which I wished to model the circuit. Once all the appropriate parameters have been set, click OK, close the Analysis Setup box, and then analyze and simulate as before.

CONCLUSION

Now that you've seen how to model temperature- and frequency-dependent com-

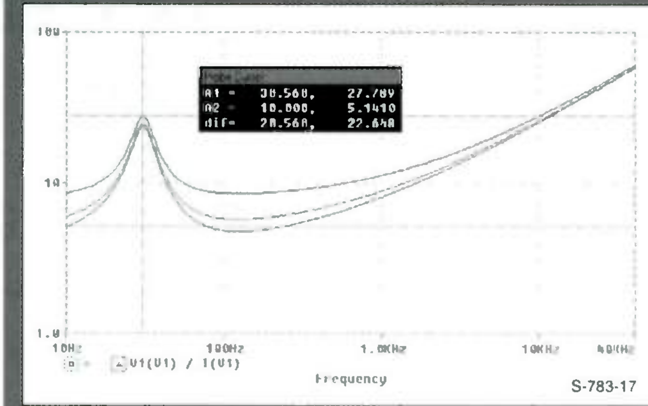


FIGURE 17: Model 4; classic circuit with two frequency-dependent components and temperature-dependent R_{evc}.

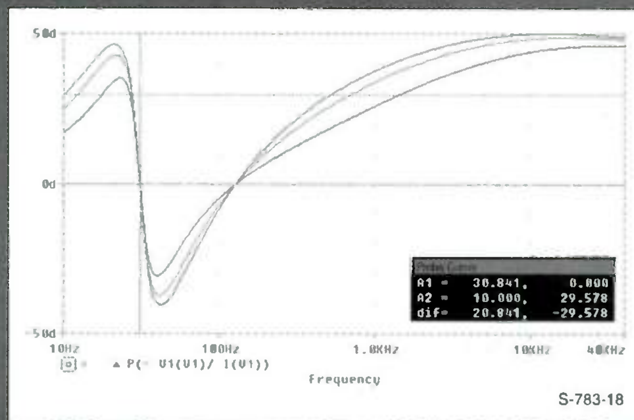


FIGURE 18: Model 4; classic circuit with two frequency-dependent components and temperature-dependent R_{evc} (phase).

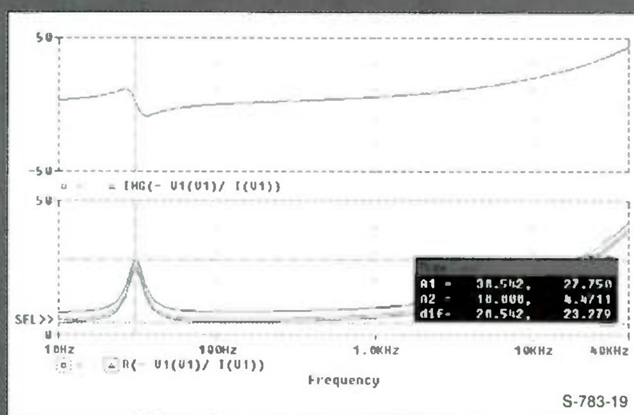


FIGURE 19: Model 4; classic circuit with two frequency-dependent components and temperature-dependent R_{evc} (real and imaginary parts of impedance).

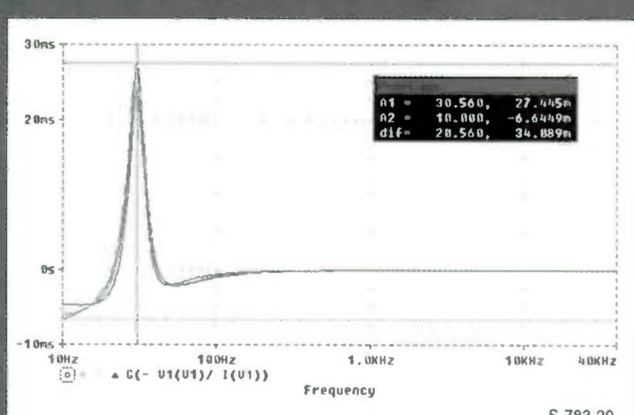


FIGURE 20: Model 4; classic circuit with two frequency-dependent components and temperature-dependent R_{evc} (group delay).

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ponents using PSpice, with a little practice you'll find the program makes it a snap to build and analyze even the most complex models.[12,13,14,15] In closing, I wish to thank those who provided important technical insights that would later prove invaluable in writing this article: Brian Hirasuna at MicroSim Corporation for his schematics expertise; Chris Strahm at LinearX, who greatly helped me to understand the latest versions of the models used in LEAP; and Dr. Jonathan Scott at the University of Sydney, Australia, who, helpful above and beyond the call of duty, is truly an educator in the very best sense of the word.

Your home workshop is incomplete without this handy tool to measure impedance. And, best of all, you can build it yourself—quickly and inexpensively.

The Impedance Interface

By Bill Fitzmaurice

A few tools are indispensable if you wish to design and test your own speaker cabinets. Of prime importance is a tone generator, which at about $200 requires a fair amount of dedication to the art before you'll shell out to buy one.

More affordable at about $50 is a sound-level meter, and for some $20 and up, a digital volt-ohmmeter (VOM) is an item most hobbyists have around the shop.

But for quickly and easily testing speaker impedances, I'm unaware of any off-the-shelf apparatus. For years now I've cobbled together the necessary resistors and wires whenever I needed to test a cabinet, always promising myself that I'd fashion a logical means to test impedance "the next time." Recently I finally got around to taking the 15 minutes and $10 worth of parts necessary to construct the logical impedance-testing device I describe here.

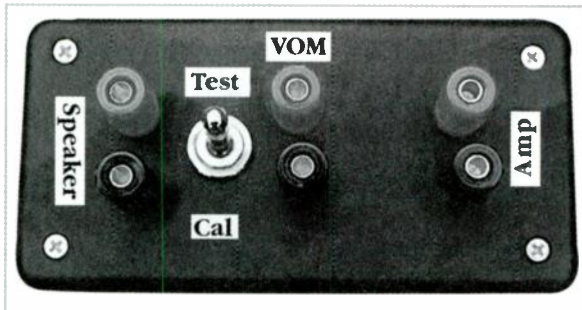


PHOTO 1: Banana jacks and switch on the box cover.

INTERFACE CONSTRUCTION

The parts are available from just about any mail-order electronics house, as well as your local Radio Shack. You'll need a project box, three pairs of banana jacks, both a 100Ω and an 8Ω wirewound resistor, an SPDT switch, and a few inches of hook-up wire. A plastic project box is better than metal, being easier to drill and immune to chassis short circuits. You can use the banana jacks as binding posts with bare wire, or to accept banana plugs in a more sophisticated arrangement.

Construction is very simple. Mount the three pairs of banana jacks and the switch on the box cover as shown in *Photo 1*, and wire the components as shown in the schematic (*Fig. 1*) and *Photo 2*. The jack pairs are labeled "Amp," "VOM," and "Speaker," and the two switch positions "Test" and "Cal" (for calibrate). To test the circuit for proper labeling of the switch, connect a

PHOTO 2: Component wiring.

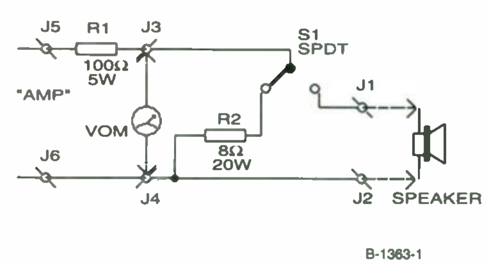


FIGURE 1: The interface schematic.

VOM to the proper terminals, and set it for "Ohms." In the Test position there should be no reading, while in the Cal position, the VOM should read 8Ω.

Hooking up the interface is easy. Connect a signal generator to an amplifier, with the amp output wired to the Amp terminals on the interface. Hook up the VOM to the VOM posts, with the meter set for AC Volts, and the speaker you're testing wired to the Speaker posts. To test, start with the generator set at 100Hz, and both the generator and amp volumes turned off. Set the switch at Cal, and gradually bring up the volumes of the generator and amp until the meter reads 0.8V.

TAKING READINGS

Now the VOM is calibrated, with the 0.8V reading equaling an impedance of 8Ω. Flip the switch to Test, and the reading will then show the speaker's impedance at 100Hz. A reading of 0.8V equals 8Ω; 0.4V equals 4Ω, 1.2V equals 12Ω, and so forth. Now reset the signal generator to the next frequency you wish to measure, recalibrate the meter, and take the impedance measurement.

It is important to recalibrate at every frequency, since variations in the circuitry of both the signal generator and amplifier (especially if the amp has tone controls) could give varying output levels at different frequencies. Recalibrating at every frequency also helps eliminate the possibility of errors, and it's easy—accomplished just by the flip of the switch.

When I first started designing cabinets, I was intimidated by measuring impedance, and relied solely on SPL measurements for testing. It was not until I invented the ducted-throat folded horn (the Snail) that I realized how much information impedance testing can provide the cabinet designer. With such a simple device as this for impedance testing, you need no longer relegate this critical process to the laboratory, but keep it where most speaker-design breakthroughs occur—in the home workshop.

This article describes the design, construction, and testing of a low-frequency bandpass speaker. The author also reveals some secrets about driver power handling and distortion.

Hybrid Single-Chamber Sub

By Robert C. Kral

It may not look pretty, but it works and it's a conversation piece (*Photo 1*). The testing and design techniques are simple but sufficient, the test instrumentation is affordable, and I think you'll find the design elegant.

SEISMIC BASS

This subwoofer isn't what you would call a relationship builder. Once it's fired up, it's intrusive. No person or creature is safe behind closed doors or drywall, even if they're deaf. It doesn't add to your *listening* enjoyment per se. As best I can describe it, it adds to the ambiance, producing vibration rather than sound, rattling china cabinets 20 feet away. Loose flooring adds to the effect. I would call this an extreme subwoofer for extreme people.

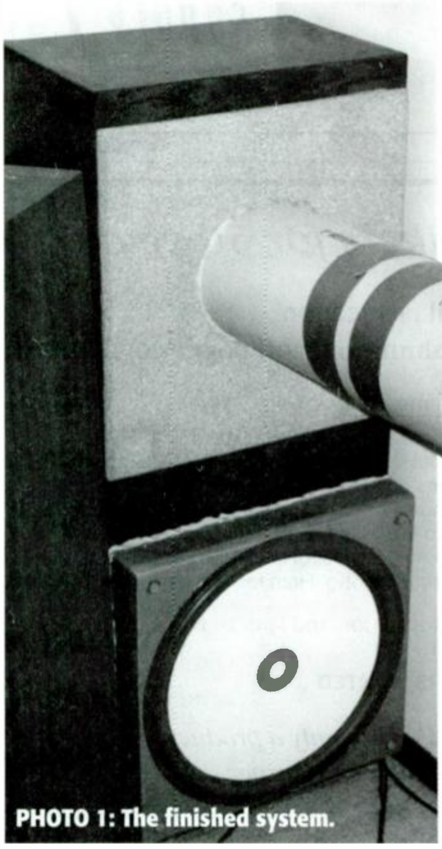


PHOTO 1: The finished system.

During the 1970s I had been bewitched by subwoofers and unconventional enclosures. I believe the spell was cast during a visit with Gene Czerwinski at Cerwin-Vega, the outfit that builds "Sensurround" woofers for movie theaters. Slot loading (*Fig. 1*) intrigued me, so I started experimenting in my first job.

The "slot" in the bottom of the enclosure traps a mass of air which is coupled directly to the woofer diaphragm. There is very little compliance associated with this air; the woofer pushes and pulls it in and out of the slot. The trapped air adds mass to the diaphragm, lowering the resonant frequency. It also acts like an inductance, rolling off the high end of the woofer and creating a bandpass response characteristic. In a way, the slot behaves like a bad Helmholz resonator.

Postulating that I could tune the two port outputs to reinforce each other if both sides of the woofer faced into ported enclosures, I built a prototype cabinet using a 5″ woofer. I could tune it to provide output 6dB higher than the piston band at the same lower 3dB point, or an output about an octave lower at the piston-band level. Then, having a coffin-sized enclosure built with adjustable baffles, I designed a system with flat output to 20Hz, using a 10″ woofer that could barely reach 50Hz in a sealed box.

I was excited about it, but to my dismay no one else at the company shared my enthusiasm, except for one of the other engineers who liked it so much he decided to make one for his mobile home by taking a saw to his TV cabinet (the truth, I swear; we speaker builders are an extreme bunch). "Can't sell subwoofers," I was told flatly.

One day at the summer CES, I eavesdropped as my boss asked a friend from Bose what was new. The man described a new subwoofer for commercial applications that mirrored my design to the last detail. Bose had independently followed the same design path, developed

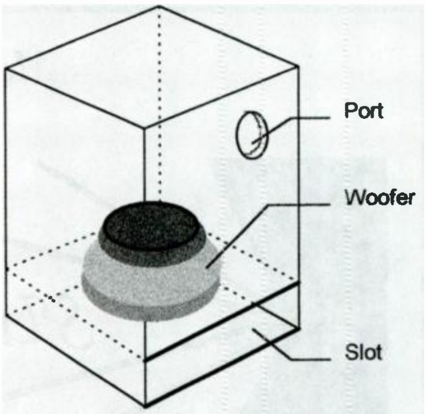
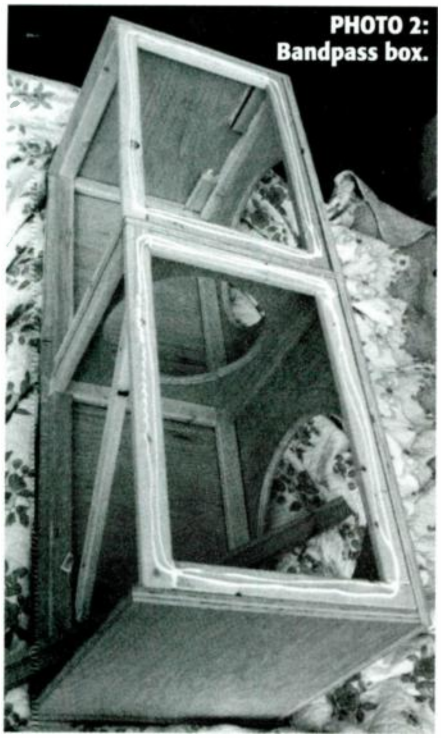


FIGURE 1: Slot-loaded subwoofer.

ABOUT THE AUTHOR

Bob Kral has a BSEE from BYU and an MBA from Dominican University. He spent ten years as an acoustical engineer at CBS and Jensen before becoming product manager for B&K Test Instruments. He is now project manager for Reltec Corporation.



it into a product, and protected it with a patent. After I quit my job, I heard that my company had contested Bose's patent, but to no avail. Although my research predated Bose's, the challenge was dismissed because my employer was not interested in pursuing the concept into a product at the time it was discovered.

That marked my exodus from engineering and consumer electronics into the friendlier and calmer (or so I thought) waters of industrial and commercial product marketing. For a while, the sight of subwoofers made me sick. It wasn't until recently that I got back into speakers as a hobby. I started thinking. That subwoofer...that was good...that was fun...I think I can improve it...!

THEORY

Building a bandpass subwoofer enclosure is quite intricate. Since manufacturers are well aware of this, there isn't an excess of bandpass boxes in the stores. At the onset of my subwoofer project, I made a bandpass box with two ported cavities that produces deep, powerful bass; but look at *Photo 2*. The enclosure is enormous, and it weighs a ton.

The two isobaric woofers (mounted face-to-face) must be secured to a baffle inside the enclosure, and the back must be removable to allow access. It's not very simple. There is no advantage to reducing the volume of one cavity, because the smaller cavity provides the controlling compliance. Practically speaking, the two cavities should be roughly equal.

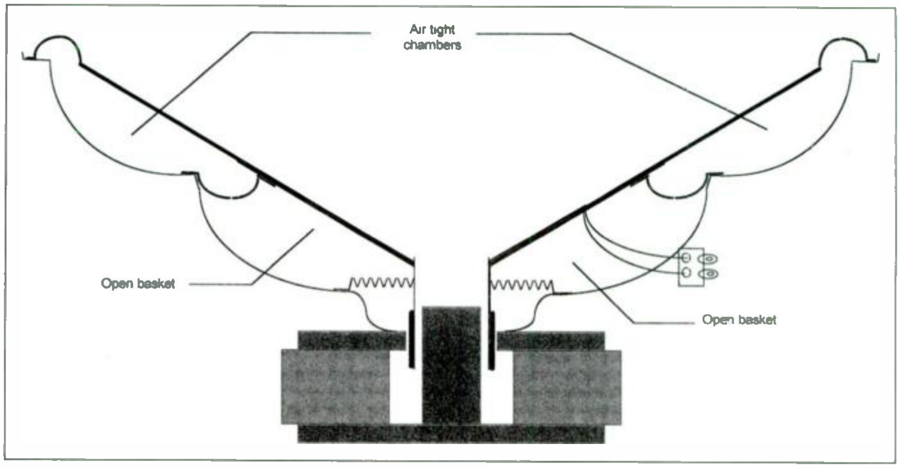


FIGURE 2: The author's dream. It probably will not work, because as the cone moves inward, the airtight chambers must remain at a constant volume to avoid compression.

After this first subwoofer was completed and the smell of success was still fresh, I had wood, ideas, and motivation left over for making another subwoofer.

If I could eliminate one cavity, the enclosure would be just a simple box, half the size and easier and cheaper to make. I considered replacing a tuned cavity with a slot, but scrapped the idea because it would complicate the carpentry. I contemplated simplifying the slot by mounting the woofer on the bottom of the enclosure and facing it into the floor about an inch away, but dismissed that because it created design confusion. How would performance vary if the speaker faced into soft carpet? Linoleum? Tile? How would I equalize microphones for near-field measurements? What is the effective radiating area for the slot?

My solution to the dilemma was to mount a passive radiator in front of the woofer diaphragm, thus fixing the radiating area and providing some control over mass and compliance. If I reduced the volume of the air trapped between the woofer and passive diaphragms to the point where it could be considered infinitely stiff, it would no longer act as a compliance, but instead would directly couple the two diaphragms at low frequencies. At higher frequencies, the passive diaphragm would decouple from the woofer and add acoustic isolation, which I could enhance by the choice of diaphragm material. The added mass would also roll off the woofer's high end.

The passive also acts as a transformer of sorts. While the inside of the box sees an 8.5"-diameter piston, the outside air sees a piston with a diameter 5 inches greater. Small woofers tend to produce the lowest possible bass in small enclosures. All things being equal, larger woofers require larger enclosures for the same lower cutoff point. Unfortunately, the small woofer's advantage is

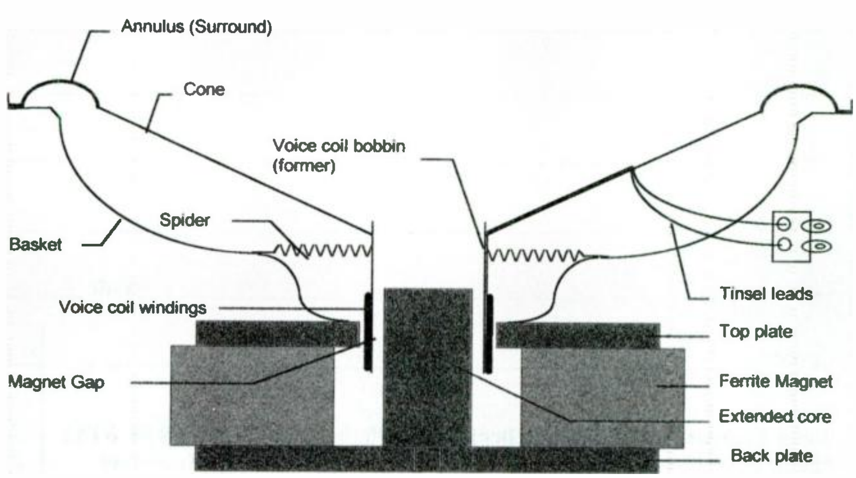


FIGURE 3: Woofer cross section showing flat spider, core extension, and overhung voice coil.

counterbalanced by lower power-handling capacity; that is, to reproduce bass at the same loudness as a larger woofer, the smaller one must move farther. Because of the limitations of materials, this puts a crimp in bass performance.

My subwoofer design takes advantage of the smaller woofer's superiority in a small box, and cheats on excursion demands by having the woofer modulate a much larger diaphragm. To be sure, some efficiency is lost due to imperfect (air) coupling of the diaphragms. However, it may be possible to attach a cone of larger diameter to a smaller woofer, and mount it using a radical basket or trim-ring design (*Fig. 2*). This gives me a bandpass subwoofer in half the volume with only a simple box enclosure. Does it work? You bet!

DRIVER CONSIDERATIONS

I settled on a Pyle 10″ dual-voice-coil woofer from MCM after returning a couple of other woofers because of hard bottoming, which is totally unacceptable. That's not MCM's fault, but they took them back without a hitch. Nothing distracts from your musical enjoyment like loud *clack-clack-clacks* as the spider/cone junction smacks the top plate or the voice coil slams into the back plate. The suspension should always limit the movement; that is, the spider and surround should limit travel.

The only way to check that is to connect an oscillator or sine-wave generator to an amplifier, sweep the woofer in free air to find resonance, and then turn up the volume until something hits. If you hear a noise that sounds like metal on metal, get rid of the driver. For the excursions under consideration, I guarantee the woofer will be stressed to its limits.

Although paying careful attention to the design of the woofer could satisfy this application, you unfortunately have to deal with what you can get from the store, and most manufacturers haven't designed for this type of insanity. They are more focused on reproducing loud 60Hz woofs from car trunks rather than 20–40Hz subsonic blasts in the home.

You owe it to yourself to be particular. The type of construction details I'm talking about can make or break a subwoofer project, but they don't appear on any specification sheet. Keep in mind that the driver must make longer excursions as you lower the frequency, increase the maximum power output, and reduce the woofer's diameter.

For example, suppose you use two identical motor assemblies (voice coils, magnets, steel parts, and spiders), but attach a 10″ cone to one, and a 15″ cone to the other. The 15″ woofer in a sealed box might be able to reproduce 30Hz at the same power-output level at which the 10″ reproduces 50Hz. The only difference between the two is cone diameter.

MOTOR-ASSEMBLY DESIGN

In *Fig. 3*, I've identified the various parts of a motor assembly, including the voice coil, top plate, core, ferrite magnet, and back plate. The voice coil is cemented to the apex of the cone, and its leads are soldered to flexible cloth/metal tinsel leads, connected in turn to terminals on the basket.

The spider and foam annulus work to-

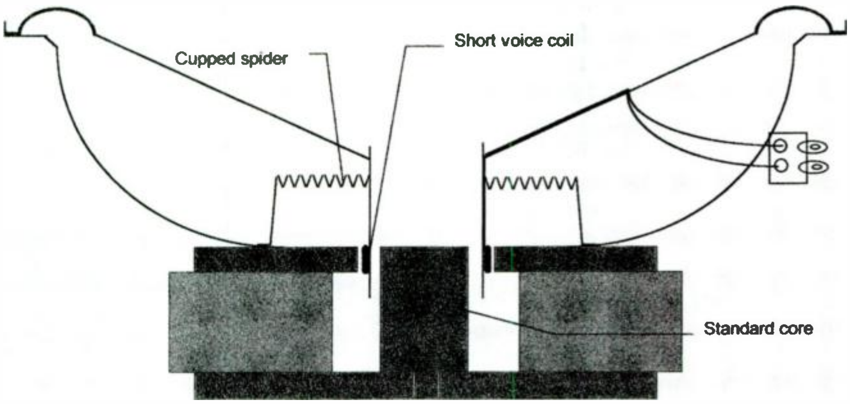


FIGURE 4: Woofer cross section showing cupped spider, standard core, and short voice coil.

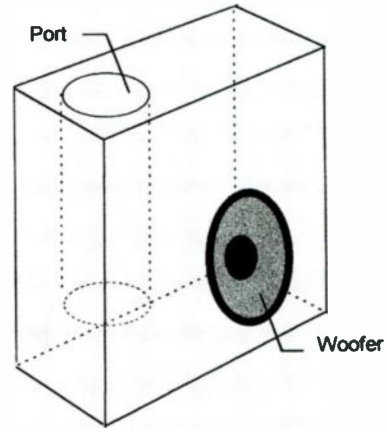


FIGURE 6: Improved cabinet design.

gether mechanically to limit cone movement, although most of the burden falls on the spider. The force required to displace the spider increases the farther the cone moves, as is proper. However, the force required to move the cone outward during long excursions is not necessarily equal to that needed to move the cone inward. Such a discrepancy causes distortion. The best spiders in this regard are flat ones that mount to a step in the basket (*Fig. 3*). The worst offenders are those with deep cups (*Fig. 4*).

The spider may allow greater travel than the speaker can negotiate with low distortion. In *Fig. 3*, you'll notice that the voice coil overhangs the top plate equally above and below it. If the top plate is ¼″ thick, then the coil extends ¼″ above it and ¼″ below. The gap between the core and the top plate is an area of concentrated magnetic flux. By designing the voice coil for a ¼″ overhang, the voice coil can move forward or backward ¼″ with the same number of turns of wire immersed in the field gap. The end result is long travel with low distortion.

Some manufacturers, intending their speakers to be loud and efficient, are less concerned about bass response or distortion. They then make a voice coil equal to the thickness of the top plate—in my example, about ¼″, with little or no overhang (*Fig. 4*). In that way, all of the turns are immersed in the field in the gap, but small movements result in the coil leaving the gap, producing distortion.

Assume you decide to design for ¼″ travel, using a voice coil with a ¼″ overhang. The lines of flux (magnetic field) are not wholly contained in the gap. Rather, flux fringes the gap, as shown in *Fig. 5a*, and you see that the fringing is not symmetrical. Hence, the speaker encounters one magnetic field when it moves outward, and a different one when it moves inward, thus producing distortion.

The motor design in *Fig. 5b* is superior. Because of the longer core, gap fringing is symmetric, minimizing distortion. The longer core also has an added benefit—it conducts heat out of the upper windings. Without the longer core, the top windings would retain the most heat, char first, and fail first. Undercutting the core is another possible solution for symmetric gap fringing (*Fig. 5c*).

VOICE-COIL SIGNIFICANCE

The voice coil itself can be critical to the design. I have seen wonderfully perfect voice coils come from the loving hands of an engineer in a sample lab, only to undergo a disturbing metamorphosis in production. Variations occur because of the manner in which the coil is wound, or the method by which it is cured.

If wire is put under tension, it stretches, and its diameter shrinks. I have seen wire put under such excessive tension

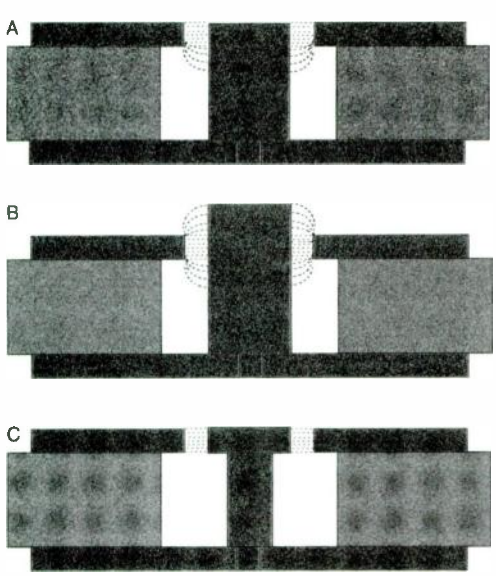


FIGURE 5: Effect of motor geometry on gap fringing: a) Typical gap fringing; b) Symmetric gap fringing utilizing an extended core; c) Symmetric gap fringing utilizing an undercut core.

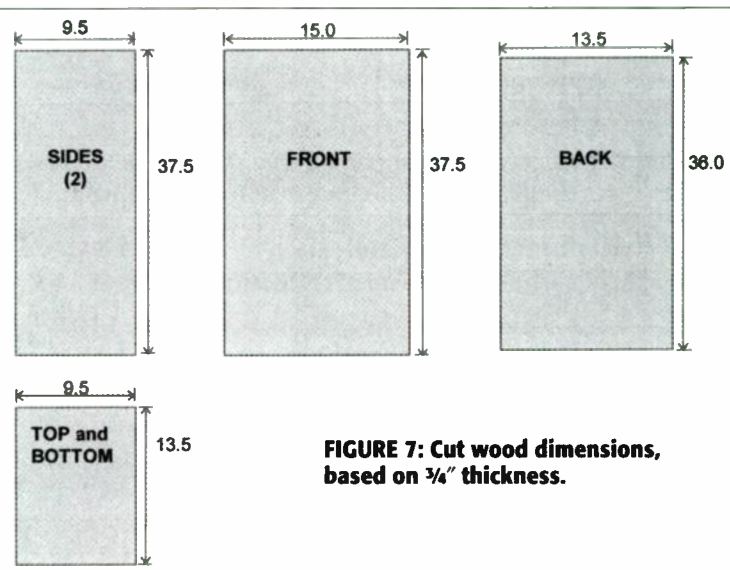


FIGURE 7: Cut wood dimensions, based on ¾″ thickness.

during winding that it shrinks one full gauge. To get an optimal BL product, the coil must be wound tightly, with no daylight between turns. Since curing utilizes heat to bond the wire, coils are often baked slowly in an oven. This takes time, but the windings remain sound.

To save time, voice coils are sometimes cured using different processes at higher temperatures. As a result of heating, the windings expand, and then contract as they cool. Although the coils do become cured, the wire may not settle back into its original position, and the coil becomes uneven, with gaps developing between turns.

If you pay attention to these details, you can optimize the enclosure/driver system, maximize low-frequency power handling, and minimize distortion. Because many of these design details are unknown to us, the speaker builders, and are out of our control, we cannot hope for perfection. However, we can still build an acceptably good subwoofer that neighbors and police will marvel at, even as complaints are filed and warrants served.

ENCLOSURE DESIGN

Making the box is simple. It's just a wooden box with two holes, one for the speaker and one for the port. I used 6″ diameter plastic pipe for the port. I had hoped to use smaller-diameter plumbing, but the volume velocity is so great at low frequencies that smaller tubing generates horrible wind noise. I didn't plan for the length of pipe needed, so as a result the pipe hangs out of the enclosure. If I were to do it again, I would adjust enclosure size to accommodate the pipe inside the box, porting it through the top (*Fig. 6*).

The accompanying photographs show the step-by-step assembly of the box. I had Builder's Square cut the plywood to size (*Fig. 7*). Then I set the baffles in position, gluing them in place with carpenter's glue and clamping the boards together (*Photo 3*). If the pieces are cut squarely, they'll butt up against each other nicely for gluing.

Then I added rectangular wood moldings along the seams, fixing each in place with construction adhesive and screws (*Photo 4*). Construction adhesive is indispensable for sealing cabinet edges and making the cabinet rigid. It dries rock-hard, and when you screw through it, the threads pull adhesive down through the wood, locking the screws into position.

Notice that the moldings go up the edges within ¾″ of the back (*Photo 5*). I

PHOTO 3: Sides and front glued and clamped.

PHOTO 6: More moldings glued and screwed in place to accept the back.

PHOTO 4: Moldings glued using construction adhesive.

added a molding on top of this to form a shelf on which to drop the rear baffle (*Photo 6*), which I then glued in place with construction adhesive and secured with screws (*Photo 7*). The rear baffle should receive a heavy dose of glue (*Photo 8*). It will simply press in snugly (*Photo 9*).

All that remained was to drill holes for the terminals, solder in wires, and line the enclosure with foam to damp cabinet vibrations. (You fill sealed cabinets to lower box resonance, but damp vibrations in ported cabinets by lining the enclosure (*Photo 10*).

The passive radiator at the top of the finished enclosure in *Photo 11* is a sad testament to my original ambition. I wanted to use a passive instead of a port. I reversed my decision later when the passive cone didn't pass a high-voltage/low-frequency sweep and my budget did not allow the purchase of a good 15″ passive or 15″ woofer.

I used screw terminals for electrical connections. You can use any type of terminal you wish, but remember that you'll need four if you use a dual-voice-coil woofer as I did.

THE PASSIVE DIAPHRAGM

Next, I needed to make the passive diaphragm. I did this on my own, but I would suggest you buy ready-made passives, or buy a 15″ woofer and knock off the magnet (pry the cone/basket assembly from the top plate). The crucial thing for the passive is linear motion with no rocking. Keep in mind that you'll be synthesizing vibration more than sound, so the ability of the driver cone to travel long distances without making foul noises is paramount.

If you use a regular driver, the spider keeps the cone movement linear because it provides support at the apex of the cone. In addition, you can minimize rocking by choosing the largest-diameter diaphragm you can get your hands on. The larger the diameter, the less it must move for a given SPL. In this type of application, an 18″ or 24″ passive is not excessive, but good luck trying to find one.

A passive diaphragm rocks for two reasons. In an enclosure, cone movement at low frequencies creates lots of air turbulence, and the effect is accentuated when the wind pushes on the angled surface of the cone. To minimize the problem, it would make sense to reduce turbulence by paying careful attention to the shape of the space between the passive and the woofer, and to reduce the passive's reaction to turbulence by making the passive diaphragm perfectly flat.

I first cut a piece of wood to fit around the face of the woofer on the enclosure's front baffle (*Photo 12*). Then I cut an additional square of wood the same size and glued on 1″ × 2″ moldings to form a frame (*Photos 13a* and *13b*). Once it was dry, I cut a hole large enough to accept the 15″ passive diaphragm, inverted the subassembly, and

PHOTO 5: Moldings extend to within about ¾″ of the back.

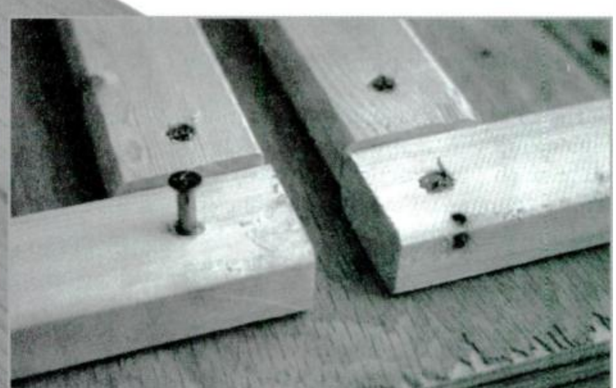


PHOTO 7: Screws hold down moldings.

glued it to the board that was positioned around the woofer (*Photo 14*). I then used plastic foam filler to fill the frame (*Photo 15*) and sculpted the foam to create smooth, contoured walls (*Photo 16*). Finally, I filled, sealed, and painted the cavity (*Photo 17*).

I obtained a 15″ cone from RDM's Phil Williams, a venerable and long-time behind-the-scenes specialist in the loudspeaker industry. I carefully cut a 15″ circle from foam poster board and beveled the edges so it would fit perfectly just inside the surround (*Photo 18*). Then I glued it in place (*Photo 19*) and cut away the cone (*Photo 20*).

When it was dry, I glued this flat diaphragm in place on the frame (*Photo 21*), screwed the frame to the enclosure using carriage bolts, and caulked it to make it airtight. Of course, if you use a 15″ factory-made passive or a 15″ woofer with the motor structure lopped off, you would invert the face of the passive over the face of the woofer and screw and seal it securely in place.

TESTING AND TUNING

This is the heart of the project. You will need a two-channel, two-trace oscilloscope, a function generator, two good microphones, an audio amplifier, and a computer with a graphing spreadsheet program. You'll be doing near-field measurements, preferably outdoors, so you'll also need pleasant weather and patience.

You can buy a good function genera-

PHOTO 8: Rear baffle receives heavy dose of glue.

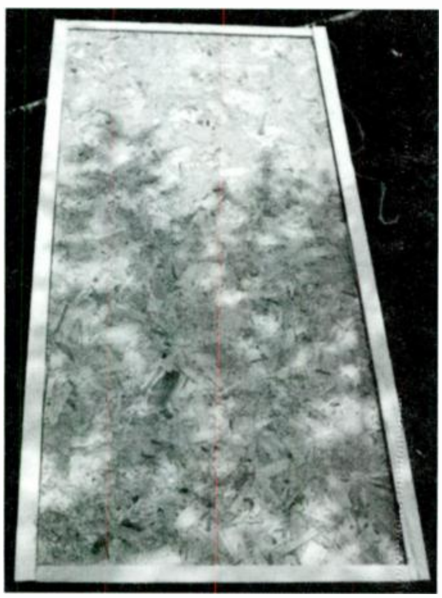


PHOTO 9: Rear baffle drops in.

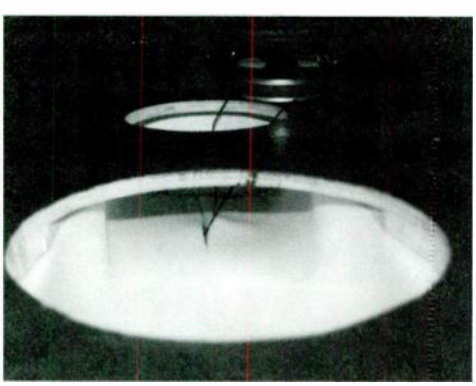


PHOTO 10: Cabinet lined with foam, and woofer ready to be mounted.

PHOTO 11: Finished enclosure showing a passive instead of a port.

PHOTO 12: Plywood cut to fit around the woofer.

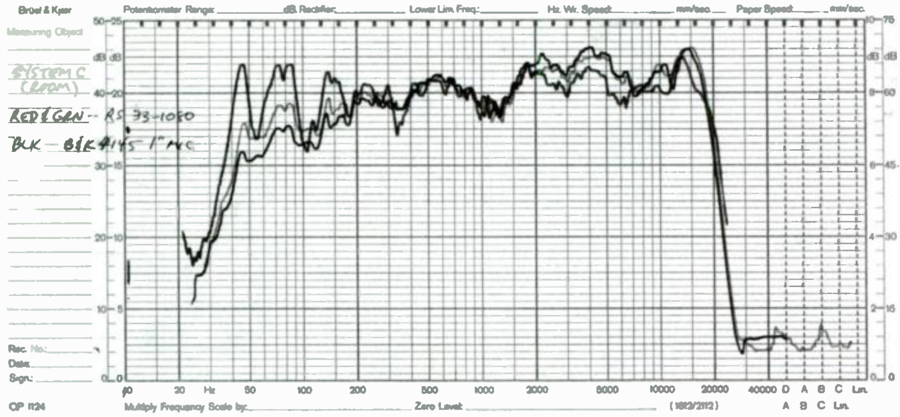


FIGURE 8: Comparison of author's mikes with the response of a B&K model 4145 lab mike.

tor cheaply. I used a B+K 3011B, which has now been replaced by a Model 4011. The great thing about the B+K generator is its fine frequency adjustment. For a speaker designer, a function generator, along with the built-in counter, is indispensable.

I used some moderately priced recording microphones, which I had on hand. Not trusting the response curves in the instruction sheet, I compared their measurement of a Jensen System C's frequency response to that of a Bruel and Kjaer Model 4145 lab mike (*Fig. 8*), producing a reference curve of sorts. If you look at the response below 100Hz, you'll notice that my mikes are both usable but attenuated in comparison to the flat lab mike. The response plots I will show have *not* been corrected for the mikes' response.

Connect your equipment as shown in *Fig. 9*. I performed the testing outdoors as a matter of convenience. My microphone stands are wooden 1″ × 2″ stakes taped to the microphones, which allows easy adjustment of mike positions. Just drive them into the ground wherever you wish.

You should not test at a very loud level. To start, place both mikes close together and aligned evenly with the outer edge of the port (*Photo 22*). Make sure both scope and amplifier channels are set up to be equal. Be certain to manually sweep the frequency range of interest, and equalize the microphones across this bandwidth by fine-tuning the scope's level adjustment.

Now you must compensate for the sizes of the port and passive. It turned out that my passive's diameter was twice that of the port, so 2^2 is 4, and I needed to adjust the passive mike to have a level four times greater than that of the port

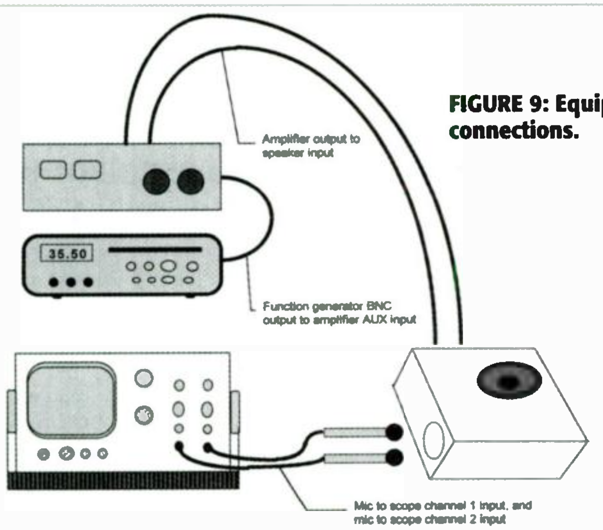


FIGURE 9: Equipment connections.

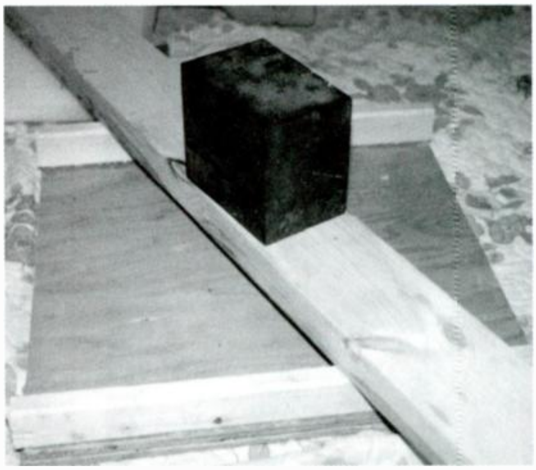


PHOTO 13a: 1 × 2s glued in place.

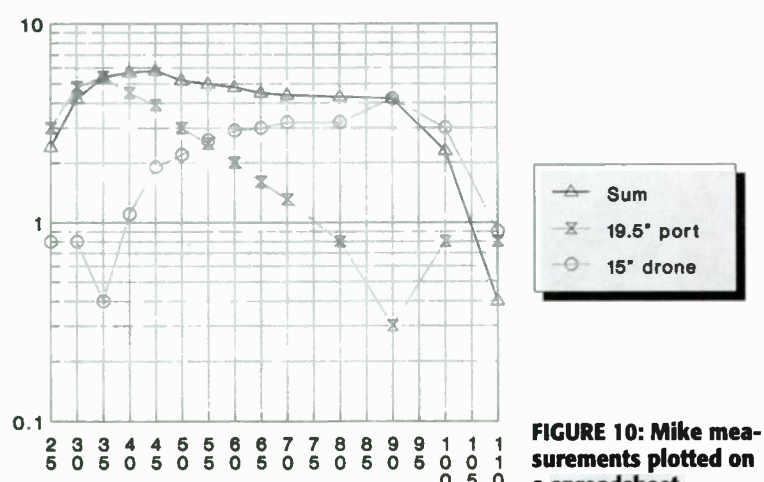


FIGURE 10: Mike measurements plotted on a spreadsheet.

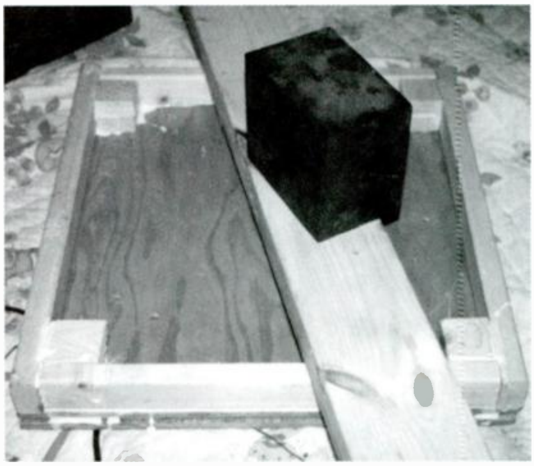


PHOTO 13b: 1 × 2s and corner blocks glued in place to form a frame.

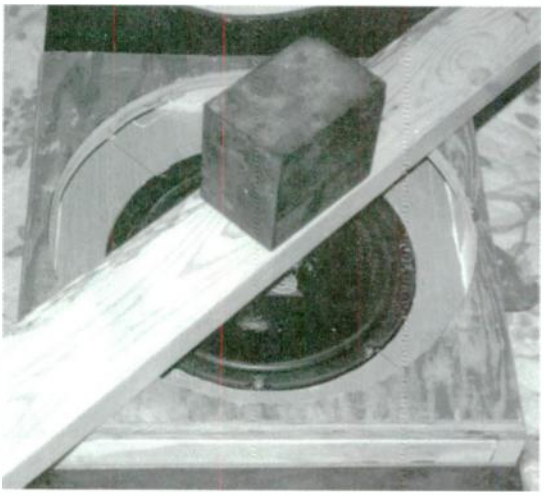


PHOTO 14: Plywood top is glued onto frame.

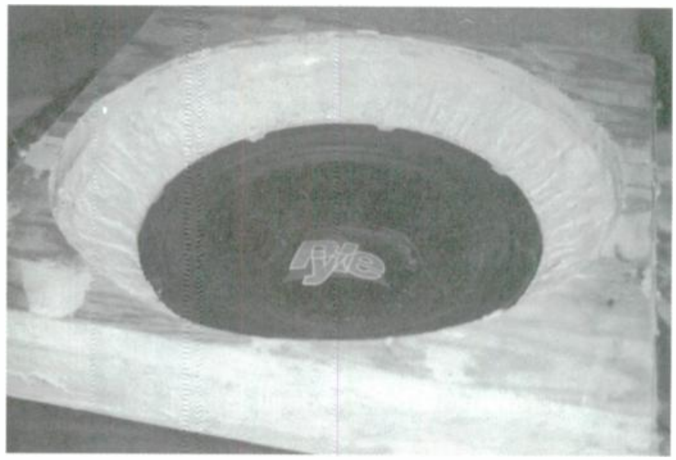


PHOTO 16: The foam is cut, smoothed, and contoured.

mike. Of course, I did this using the scope's level-adjustment knobs.

Now you can move the passive mike into position in front of the passive. Remember that the amplifier need not be turned up high. You should place the mike as close as possible to the passive surface without touching it, even during the diaphragm's maximum excursion. A sweep from, say, 20–100Hz will confirm this.

LABORIOUS PROCEDURE

When you measure the waveforms on the scope, you are just counting screen divisions. You don't care about voltage readings. The procedure is laborious, but it works. Start at 20Hz. Look at channel 1 (port output) only, and write down the number of vertical divisions the sine wave occupies peak to peak. You can adjust the vertical and horizontal trace positions to line up the trace to the graticules and make measurement easy. Then do the same with channel 2 (passive output). Finally hit "sum" or "add" on the scope and see how the waveforms add. Record each of these readings on a sheet of paper. Adjust the generator up to 25Hz and repeat the procedure. Keep doing this every 5Hz.

Now plug the numbers into a spreadsheet program and produce a graph. If you choose a vertical log scale, the result will be in the familiar dB format, although it will not be calibrated in any way. To find your 3dB points, just identify where the number of divisions drops to 0.71 (71%) of the midband level.

In other words, if you measure six divisions peak-to-peak on the oscilloscope at 45–50Hz, then your 3dB points will occur where the voltage drops to 4.25 screen divisions. The 3dB points on my system are at roughly 27 and 95Hz (*Fig. 10*), based directly on my measurements. I infer from my microphone's attenuation that the lower half of the response is actually more elevated, and the 3dB point is somewhat lower.

You will need to vary the mass of the passive and the length of the port. Whatever you do, do not change more than one variable at a time. To adjust port length, I added incremental sections of port using the handyman's secret weapon, duct tape. To adjust the mass of the passive, I glued on metal washers of varying diameters and thicknesses using the handyman's other secret weapon, hot-melt glue. You'll need to plot out graphs to make useful analyses. You'll notice the effects of port length and mass, and you'll begin to formulate new strategies to optimize bandwidth. For me, the procedure took several days.

PHOTO 17: The cavity filled, sealed, and painted.

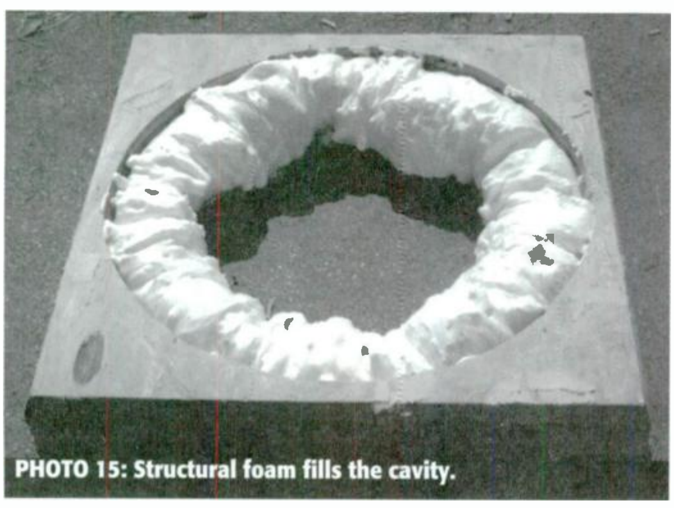


PHOTO 15: Structural foam fills the cavity.

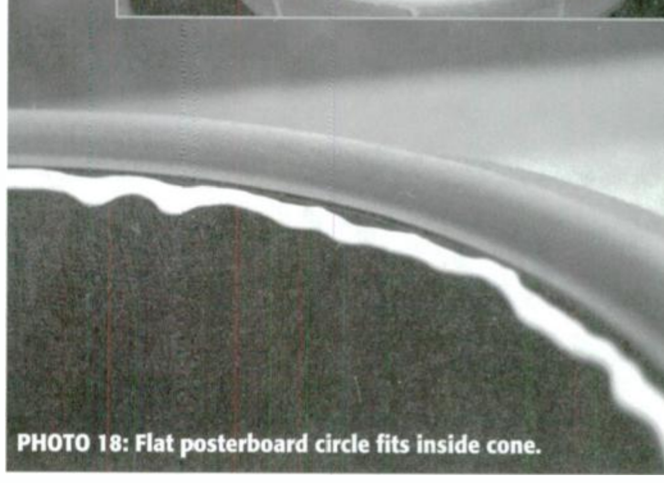


PHOTO 18: Flat posterboard circle fits inside cone.

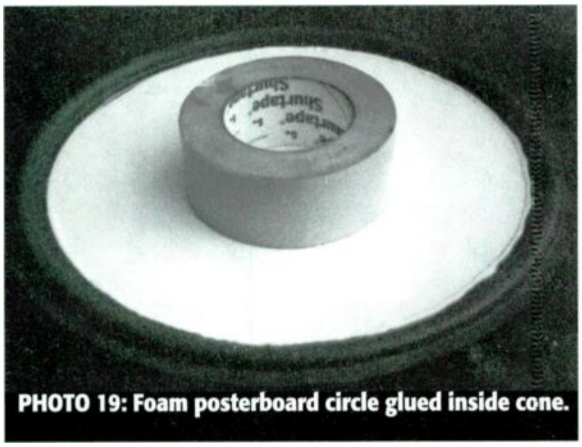


PHOTO 19: Foam posterboard circle glued inside cone.

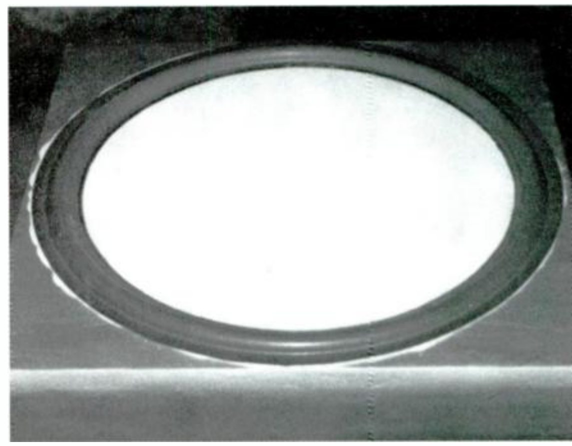


PHOTO 21: Flat passive diaphragm is glued to frame.

INTEGRATION INTO THE SYSTEM

Because of the bandpass nature of the subwoofer, all you actually need is a couple of inductors on the speaker's input to filter out midrange radiation that invariably escapes through the passive and the port. However, that arrangement provides no flexibility to tweak the subwoofer's output other than experimenting with speaker placement.

I opted instead to use a Furman X324 24dB/octave electronic crossover with a crossover point adjusted to around 35Hz and a Linkwitz-Riley characteristic feeding a separate 120W-per-channel amplifier. In addition to providing the ultimate in flexibility, this also eases the load on the primary channel's amplifier by removing the very lowest frequencies.

Then there is the issue of actually having program content at low frequencies. While some newer CDs have content below 40Hz, the signals at these frequencies are usually attenuated. To compensate for this, I added a dbx 1BX-DS dynamic-range expander and 120X-DS subharmonic synthesizer. Although these items are currently out of production, you can still get them from Raymond's Electronics Services, 5462 Buchana Place, Fremont, CA, 94538 (510-490-1622).

LISTENING TESTS

My most awesome bass experience had been listening to a Jensen Serenata reproduce the kickdrum on "Limehouse Blues," from Sheffield's *Lincoln Mayorga, Volume II*. Sitting on the listening room couch, it seemed as though invisible fingers were running through my hair. Way cool!

Not knowing what to expect, I fired up my subwoofer, having invited a friend over as an objective witness. We agreed that if the Serenata's bass was like fingers running through your hair, the effect of this subwoofer is more like a punch in the face. Victory!

The effect is breathtaking on the *Rocketeer* score by James (Braveheart) Horner, which I first heard played at the synchronized "dancing" fountains at the Epcot Center. The power of the second track, "The Circus," was done an injustice in the movie. Another recording that shows off the system is *Tricycle*, by Flim and the BBs.

Aesthetically, some people may find my speaker objectionable. Nevertheless, it's there in our parlor, now and forever, and it doesn't clash with the furnishings, although our house is decorated in Early American Good Will, so that may have something to do with it.

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PHOTO 20: Cone is cut away from flat diaphragm.

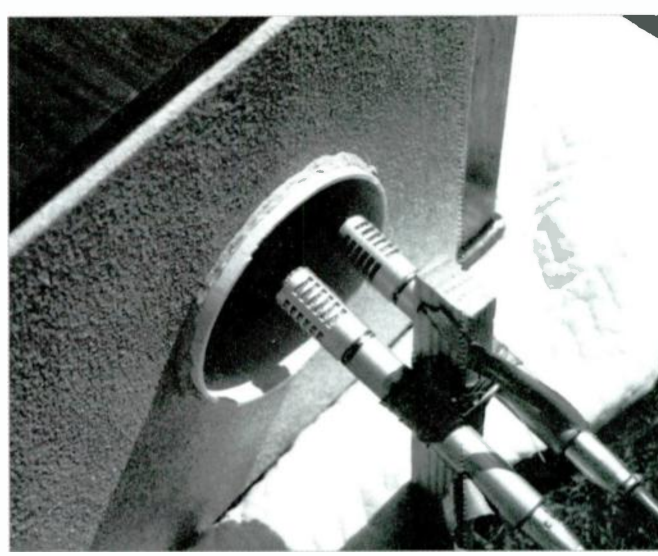

PHOTO 22: Mike is in position to be equalized.

HOW TO START A FIRE

Robust design for low distortion and long excursions goes a long way to bolster power handling and safety. You may have heard of fires started by speakers. I heard of one instance where a manufacturer was being sued by a consumer whose apartment was set ablaze. Under questioning, the audiophile intimated that his speakers were "not playing very loudly—the volume control was only three-quarters of the way up." Asked where his speakers were located at the time they torched the drapes, he answered, "In the window." Questioned where he was at the time, he clarified, "Down the block at the laundromat."

Consider that the amplifier was being driven into hard clipping. Harmonics are therefore dissipated in the driver's voice coil as heat. The heat chars the enamel wire insulation, creating conductive paths through the insulation and lowering resistance. Increased current flow heats the coil further, and as the wire expands, the insulation cracks, exposing bare wire and shorting turns. Resistance drops further, drawing more current from the amplifier.

Because the voice-coil wire is copper and the former or bobbin is aluminum or Nomex®, the materials expand at different rates as they heat. Soon they separate, which may cause the coil to jam inside the gap. Because no movement is possible, all the power from the amplifier is dissipated in the voice coil as heat, lowering the resistance further and drawing more current.

Different amplifiers react in different ways. Sometimes overload protection will shut down the output. Sometimes the fragrance of burning silicon will waft to your nostrils as the output transistors barbecue. And sometimes the output transistors are so wonderfully robust that they welcome the 0Ω load and proceed to dump large amounts of current into it.

When that happens, the voice coil becomes a toaster. If the coil uses heavy-gauge wire, its fusing current is high, and as a result it conducts the current without opening. The tinsel leads glow bright red from the current flow, and they begin to droop. When they touch the spider, it burns, which ignites the cone, vaporizing the trim ring.

You can avert this sort of disaster by using an extended core to conduct heat from the top windings, by using smaller-gauge wire with a lower fusing current, by fusing the speaker, or by avoiding trips to the laundromat while your system is running.—**Robert C. Kral**

SB Mailbox

SUPER CROSSOVER UPDATE

In response to John Cockroft's comments to Gordon Burkhart-Schultz ("*SB* Mailbox," *SB* 1/98), the unusual high-pass filter shown in Fig. 1 intrigued me so much that I made some tests and performed some calculations whose results I will detail later in this letter. But first, I object to your apparent belief that series-connected filter elements (that convey the modified input signal directly to the driver) are more important than shunt-connected filter elements (that convey the modified input signal directly to ground "in silent bliss"), and that, therefore, the shunt elements need not be of comparable quality.

A filter is, after all, a system in which each element must perform as expected if the filter's expected behavior is to be realized. In fact, you recognized this in your discussion of selecting the inductor element of your filter. (Yes, the series resistor is also a filter element in your filter—it's not there merely to attenuate the tweeter's output.)

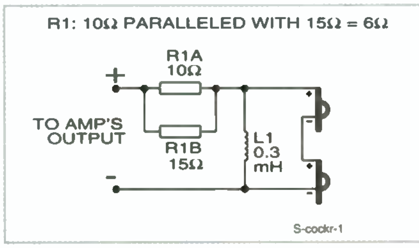

FIGURE 1: Tentative high-pass circuit for alternative series-connected dual speaker Super Simpline.

I assembled your filter with an 8Ω, 1" dome tweeter, and measured input voltage and voltage across the tweeter over a range of frequencies. The filter produces a passband attenuation of about 3dB; the response is down by another 3dB at about 2500Hz, which would then be the crossover frequency. At lower frequencies, the filter gradually assumes a 6dB/octave slope. I could not measure phase behavior, so I did a circuit analysis at 2500Hz. Response was down 6dB (that is, –3dB from the reference level), and the phase angle was just about 45°.

In all of these respects, then, this filter behaves very much like a conventional first-order filter. I found, however, that there are two performance areas where it makes radical departures from conventional behavior. The first is its impedance function, where it exhibits a falling characteristic from its high-frequency end: 10Ω at 20kHz, 5Ω at 3000Hz, and 3.3Ω at 500Hz. When the woofer section is added to the system, the impedance will be driven to even lower values, which may "try" the average amplifier.

The other difference is a more welcome one: the tweeter I used has resonance frequency of 1350Hz, at which its impedance has risen to 15Ω. Your filter wasn't much bothered by this, however, and rode through this difficult region without problems. On the other hand, when I used a conventional filter, the output hovered around –2 to –4dB, all the way down to 1000Hz, where it finally made a normal descent. To make this filter perform as required, I needed to put a series R/L/C across the tweeter terminals. Your filter, therefore, offers parts-expense savings.

One last comment about your filter: the series resistor not only produces tweeter output attenuation, but is also essential to the proper operation of the filter. Imagine, for example, that you require no attenuation: the resistor must therefore be eliminated, but then the full value of the input voltage will appear across the tweeter over the entire range of frequencies, and no filtering will take place.

Finally, as to those suggestions for using ultraexpensive filter components, I admire your common-sense advice to keep the relative cost of speaker-system parts in a reasonable balance.

David J. Meraner
Scotia, NY

Contributor John Cockroft responds:

Thanks for taking the time and the effort to share your experiences with the new crossover for my Super Simpline. Your objections are obviously well taken. Perhaps if I had held my mistaken beliefs "in silent bliss," things would have been better. On the other hand, thanks to you, I have a more realistic grasp on the situation.

This reminds me of the days around the end of 1985, when I was attempting to explain to the world my inept thoughts on the workings of the Isobarik (compound) speaker. I recall that one man attempted to sell me a bridge, and there was a lot of talk about a "no free lunch" alignment. I found out then that crow has almost as much protein as pheasant. After a few months of joviality and what Publisher Ed Dell told me was the largest influx of letters to reach *SB* up to that time, we all knew pretty much what was going on with compound speakers. This "sorting out the wheat from the chaff" has been one of the finer points of *SB* in the past, and I'm quite pleased that this function still remains with us.

Consistent with my other foibles, I did not realize the ultimate importance of the series resistance in this circuit. I'm mighty glad that most tweeters are more efficient than most woofers.

Regarding your remarks about finding two radical departures from conventional behavior, I had already learned about the unfortunate impedance characteristics from another reader. The second departure, as you stated, is indeed more welcome. The ability of the circuit to "hold its own" in the lower treble area helps to explain some of the smoothness and naturalness that Gordon Burkhart-Schultz and I have experienced.

It seems that you're correct when you state that the low-pass section also requires a series resistor to perform its function as a filter. I disconnected the capacitor on one of my Super Simplines. On the basis of a short listening session with some very familiar CDs, my old ears hear the same things with either version. You have convinced me. The parallel capacitor in the low-pass circuit is officially exorcised.

Most of these circuits I have devised have been high-pass filters only, as the woofers I have used (the 6½″ and 8″ woven carbon-fiber cone woofers from MCM) have well-behaved high-end rolloffs requiring no external assistance. The Super Simpline uses a "full range" speaker (admittedly modified, with polyvinyl acetate damping and with the added mass of lead weights). I arbitrarily added the capacitor in an attempt to reduce what I considered might be an extended area of speaker overlap. Apparently the act was in the nature of an elegant failure. As you showed, it was an act that was not required. I sometimes wonder, in idle moments, whether somehow I'm not a distant relative of Don Quixote. Tilting at windmills is definitely a part of my life.

The warning about the very low impedance values generated by this circuit should be heeded by those with amplifiers not designed to work into low impedance values and difficult loads. The woofer should have a well-behaved rolloff at its upper end, in a range that will comfortably complement the low-end rolloff of the tweeter. The tweeter should have a sensitivity at least several dB higher than that of the woofer. The quality of the filter components should be of as high a grade as reasonable (commensurate with the intended purpose and cost of the designed system).

An alternative might be a design using dual speakers in a series connection to raise all impedances by a factor of two. This would also raise the input power rating by the same factor. My Bottle Baby system (*GA* 1/98) would suit the situation exactly. Merely cut the woofer holes to fit the Simpline woofers, wire them in series, and perhaps start out with the crossover of *Fig. 1*. This should probably get you in the ball park, and if I were really lucky, it might be closer than that. The original Bottle Baby used the carcass and stuffing of a dual version of the Super Simpline, so I know it will work.

Your letters of a year ago regarding the Simpline, Super Simpline, and SS Phoenix were my introduction to speaker building. The results, thanks to the clearly written articles about your singular speaker design, have been overwhelming and have changed my perspective on audio sound. These speakers represent the best audio value I have seen or heard. I have now modified the Phoenix as you described in *SB* 1/98 and am pleased with the results. I plan to add the B-line and the Bottle Baby this summer.

You mentioned a 6½″ woofer and Vifa tweeter in a larger system. Do you plan to publish details for this? I would be interested, since my listening room is fairly large.

John R. Pope
Ft. Smith, AR

John Cockroft responds:

I'm glad you've been pleased with the Simpline clan. I'm also happy that you have been able to use the latest published Super Simpline crossover without difficulty–that is, without high-frequency oscillation or thermal shutdown of the amplifier, due to the low impedances incurred when using this crossover. (See preceding letter regarding these potential problems.–Eds.)

As Mr. Meraner correctly points out, the capacitor shunted across the woofer terminals serves no earthly purpose and lowers the woofer impedance even further. This capacitor should be excised like an infected appendix. I have listened to the Super Simpline without the capacitor for three weeks, and I can hear no loss of sound quality.

The B-Line article was written over two and one-half years ago. Since then I've discovered another woofer to substitute for the 6½″ Parts Express one. It is the 8″ MCM woven carbon-fiber cone woofer, #55-1550 @ $34.95. Build the enclosure as specified in the article with the exception of the woofer mounting hole, which should fit the 8″ woofer. Position the latter so the bottom of the 8″ woofer flange is the same distance from the base as the 6½″ speaker flange would have been.

I've had excellent results with this system when used with my Super Simplines and the line-level passive crossover I used with my Simpline Sidewinder woofer (*SB* 4/95). Set the B-Line between the Super Simplines, and set the levels using the Sidewinder article as a guide. The 0.1μF capacitors used in the crossover in the article give a crossover frequency of about 160Hz and work very well with the centered B-Line.

The system worked best for me with the Super Simplines wired with the absolute polarity reversed relative to the B-Line. I suggest you try both normal and reversed polarities. It's possible my main and woofer amplifiers are putting out different polarities; they are different brands. You will know when it's right. There's no mistake.

In my room the very best situation occurred when I set the B-Line into a corner on the same wall as the Super Simplines. I had good results with the woofer facing to the side as designed, and also with it facing to the rear. This worked best with a lower crossover frequency. Substitute 0.157μF for the 0.1μF capacitors in the published crossover (0.1μF, 0.047μF, and 0.01μF wired in parallel give 0.157μF). This gives a crossover frequency of about 101Hz.

With this frequency and the correct level settings, the bass seemed to emanate from the Super Simplines. It was the most natural-sounding system I've ever had in this apartment. It passed my "Who's kicking the rear fence now?" test in spades. I was always looking outside for sounds coming from the speakers. Nothing sounded like "bass." The instruments merely played through their full registers, and the ambient sounds were there.

HELP WANTED

I have Beveridge III speakers, which are tall electrostatic towers with foam grilles. The grilles, approximately 72″ long and 10″ wide, have deteriorated (disintegrated). Do you know of any source that can supply me with a pair of grilles or the foam strips?

Lionel Alan Marks, Esq.
61 Broadway, Ste. 3000
New York, NY 10006

For some time now, I've been looking for a kit or circuit diagram (w/parts list) for a home speaker switch box capable of routing audio to at least eight speaker pairs and maintaining a constant 8Ω load on the amplifier no matter which combination of speakers is selected. Are any readers familiar with such a circuit?

Bill Newcomb
<Bill_Newcomb@amrcorp.com>

I would like to replace all the drivers in my pair of AR-3a speakers. The cost of replacement from AR is $580, plus shipping and handling. I prefer drivers that are more modern, with different magnets, cone material, surround, and so on. Driver design has improved so much that I am reluctant to use ones manufactured this far back, but for super sound it's sometimes necessary to try different brands.

What speaker models could I use without excessive modifications of the enclosures, which are superb?

Paul Lapinsky
5878 110th St.
Jacksonville, FL 32244

Readers with information on these topics are encouraged to respond directly to the letter writers at the addresses provided.–Eds.

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Book Report

INTRODUCTION TO LOUDSPEAKER DESIGN

Reviewed by Dennis Colin

Introduction to Loudspeaker Design, by John L. Murphy. Available as part #BKTA1, for $24.95 plus s/h from Old Colony Sound Lab, PO Box 876, Peterborough, NH 03458, (603) 924-6371, FAX (603) 924-9467, E-mail custserv@audioXpress.com. Published by True Audio. 166 pp.

I highly recommend this book to anyone entering the difficult, but rewarding, area of speaker design. I found it a pleasure to read. With a lively writing style, Mr. Murphy accurately presents the necessary physics fundamentals (he is a physicist), while requiring no more than basic math understanding on the part of the reader.

But the book is mostly about the practical considerations and tradeoffs involved in designing multi-way dynamic driver systems. Although neither a design cookbook, electroacoustics text, nor musical perception treatise, it nicely covers the basics of these areas needed for a good intuitive feel for the various phenomena taking place in loudspeaker systems. The book is well illustrated with diagrams, graphs, and handy charts, and contains many practical test procedures.

CHAPTER SUMMARIES

Chapter 1, Audio Basics—includes a brief history of audio and speakers; the basics of the audible frequency range, SPL, and so on; pitch perception; and an introduction to the frequency-range division of multi-way speakers.

Chapter 2, Loudspeaker Basics—covers speaker system components and theory of enclosure types, including the dipole, sealed box, vented box, isobaric, and bandpass systems. Although the author presents some mathematical relationships, his emphasis is on the significant variables (box volume, resonance frequency, Q) and their effect—pro and con—on each enclosure type. He also describes frequency-response rolloffs, excursion response, volume velocity, phase/transient/group delay, impedance, and power handling (thermal and mechanical), and discusses proper damping. The chapter concludes with accurate and understandable definitions of the Thiele/Small parameters, along with an explanation of the tradeoffs between efficiency, box size, and low-frequency extension.

Chapter 3, Advanced Loudspeaker Topics—contains nicely illustrated explanations of spatial loading; cabinet diffraction loss; cavity effect (room and car cabin gain); point, line, and plane sources; and enclosure losses; as well as an interesting description of the use of a stethoscope to hear very sensitive spurious noises such as leaks, buzzes, resonances, port noise, and so forth. The chapter also includes Olson's classic diffraction responses of various-shaped baffles, and basic circuits to compensate the typical 6dB response step.

Chapter 4, Enclosure Design and Construction—covers the basics of good material selection and construction techniques (sealing and bracing, for example), and includes charts relating the three box dimensions, based on suggested "golden ratio" proportions

$$\left(\frac{1}{2}\left[\sqrt{5}\pm 1\right]\right),$$

to box volume.

Chapter 5, Crossover Design—contains a comprehensive description of the types of crossovers widely used (Butterworth, Linkwitz-Riley, first-order parallel, quasi-first-order series) and their relative pros and cons. The chapter also describes impedance compensators—both the Zobel (driver inductance compensation) and resonance compensation. Also included is a table of recommended upper frequency limits versus driver diameter, attenuators for (usually) tweeters, and crossover component recommendations regarding quality. Driver/crossover interactions such as non-flat impedance and inter-driver phase effects are also mentioned.

As I mentioned, this is not a cookbook; formulas for crossover components are not given, nor are they necessary. Many references, such as Vance Dickason's excellent works, already cover this.

I would like to comment on one area: Mr. Murphy mentions the lack of perfect amplitude response summing of some standard crossover types, for example, the 3dB summed peak of (even an ideal) second-order Butterworth crossover (with drivers in opposite polarity, necessary to avoid a deep notch). I would like to have seen a mention of how "tweaking" crossover elements, either real-time or with simulation, can often flatten these aberrations by adding some experimentally optimized phase shift, and so forth. I realize that this is really nit-picking, but reviewers are supposed to do that! Actually, this chapter (as well as the whole book) very well suits the purpose of introducing the reader to these very intricate topics.

Chapter 6, Driver Parameter Measurement—shows how to measure Fs, Qts, Qms, Qes, and Vas using a signal generator, 10kΩ 1% resistor, AC voltmeter, and a sealed test box.

Chapter 7, Frequently Asked Questions—includes very practical questions,

ABOUT THE AUTHOR
John L. Murphy, B.S., M.S., AES, IEEE, ASA, is a physicist with over 20 years experience in the design of recording consoles, electronics for guitars and electric bass, and loudspeakers for pro audio, hi-fi, musical instruments, and autosound. As an Air Force captain, he served as a space systems software analyst. In the audio industry he is probably best known for his recent WinSpeakerz and MacSpeakerz application software.

on topics such as vented-box port variables, driver placement, impedance compensation, driver protection, phase response, and musical instrument and sound reinforcement considerations.

APPENDICES

In addition to 12 technical references and a list of physical constants, conversion factors, and loudspeaker system relationships, the appendices include a section called "Box Types." Each of the 18 types shown includes drawings, a list of box variables, and a basic graph showing rolloff slope(s). The box types range from "2nd Order Closed Box Highpass" to "6th Order Symmetric Bandpass Triple Chamber Isobarik" (whew!)

Overall, I found the book easy and interesting to read, with its emphasis on real-world practical situations. The subject matter is treated sometimes with humor. For example, when the author mentions the present impossibility of a $0.25ft^3$ speaker with 100dB 1W/1m SPL at 20Hz. Or, in response to a question: "What? You say you're having trouble getting 20Hz out of your piccolo? Just smack the bass player with it on the down beat! It's an acoustic jungle out there! Speaker designers, beware!"

APPLICATIONS

I think that the more experienced readers and authors of *Speaker Builder* probably know most of the subject matter covered in this book. But probably not all of it, especially some tradeoff aspects of crossover interactions. But even for the experienced designer, the book contains many useful and handy tables, charts, and other data.

However, for those interested in learning about the fundamentals of speaker design and operation, this book provides an excellent introduction. And even though the emphasis is not on detailed design methods, those covered are accurately patterned after Thiele's and Small's comprehensive work. Even if you don't know a woofer from a tweeter, but can solder, cut wood, and do basic arithmetic, this book will give you sufficient knowledge and intuitive grasp to select the type of system you need, and, with some software and/or experience, successfully design a complete speaker system.

In conclusion, I cannot imagine a better "Introduction to Loudspeaker Design" than this book. And the low price of $24.95 represents only a small fraction of the cost of one serious audio mistake, which this book should help prevent.

Tips, Tools, & Techniques

SAGGING CONE ALERT

By Jesse W. Knight

The following adventure illustrates a principle I have followed for many years: In audio, what on the surface appears to be an esoteric problem requiring an expensive solution is often a gross component failure or a serious circuit design flaw that reveals itself only under certain circumstances. Once found, the problem will often seem stupid and very obvious. Good scientific methods can save money.

INTERMITTENT VAGUE SOUNDS

An interesting problem surfaced with my "Musician's Speaker" (*SB* 8/96) when using old Peerless KO 40 MRF midranges (#821385). For several years I have sensed that I was hearing intermittent noise modulation at midrange frequencies. The subtle nature of this distortion made it impossible for me to pin it down. At first I blamed my hearing, as I have multiple allergies, but the noise continued to persist.

I never could find the noise with headphones either at the CD player output or at the power amp output (properly attenuated). High-quality headphones (such as AKG K240) are excellent for checking your signal path and recording quality for harsh sounds. These tests eliminated everything except the crossover and drivers. Cheap "off the rack" phones are useless, however.

I decided to build two pieces of test gear. First I built a blind tester (on a breadboard with parts from the junk box) that allows for ABX testing without an assistant. This device uses a multi-position selector switch with unmarked wires connected at random to a relay switching unit. I trace the wires to determine which switch positions correspond to test A or test B, only after the test is complete. This allows for the elimination of experimenter bias when testing components. Switching artifacts are concealed with a muting circuit common to both test A and B, and I rescramble the wiring before the next test.

I also built a meter to measure DC resistance of midrange and tweeter voice coils while they are operating. This costs about $30 to build and allows voice-coil temperature to be estimated under dynamic conditions.

Voice-coil heating with classical music turned out to be a non problem at my listening level. The blind tester ruled out the crossover. It also demonstrates how difficult it is to hear some circuit changes.

Finally, I removed the KO 40 midrange from one cabinet and took it to my test bench. While it was reproducing a 400Hz sine wave, I poked the cone and rotated the speaker on axis. It was easy to make the noise come and go at will. Finally I had the answer! The voice coil had sagged.

AUTOPSY TIME

Dissecting the unit revealed that the spider was so supple that it couldn't maintain a centered voice coil for more than one decade. After 20 years all units display some distortion.

Most shocking, however, was the very subtle distortion in light of a serious failure. When a driver is fed through a 600Hz second-order high-pass filter, cone motion at moderate levels is not sufficient to create that scraping sound so familiar in a dead woofer. Years ago I dropped a speaker and decentered the tweeter magnet. I did not hear it right away either, despite the fact the voice coil was pinned at one point.

In defense of Peerless, let me point out that no other chambered midrange has the low resonance of the KO 40, possible only by the use of a very compliant spider. This gives it a wide flat response without the work of building a midrange enclosure. Many people will find a ten-year life span (without rotation) acceptable considering the pace of speaker development.

My conclusion is that any driver with a soft spider should be rotated periodically. Mount the driver with a non-drying caulk such as wax from the wax ring used to mount a toilet and rotate the midrange every four to five years. With care, you should be able to reinsert wood screws into the same holes several times.

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AD INDEX

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Speaker Builder

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SUBMITTING COPY: A word is any collection of letters or numbers with a space (*a slash (/) is counted as a space*) on either side. All hand written ads must be block printed and submitted on our classified order form (please call us at 800-524-9464 to obtain a form). Please circle or underline all words to appear in bold. Illegible ads will be discarded. Submit copy by mail, fax, E-mail or on diskette (Quark XPress, Wordperfect, Microsoft Word 2.0 or 6.0, or Word for DOS). If submitting by disc, include a list of fonts and graphics used and a printout of your ad.

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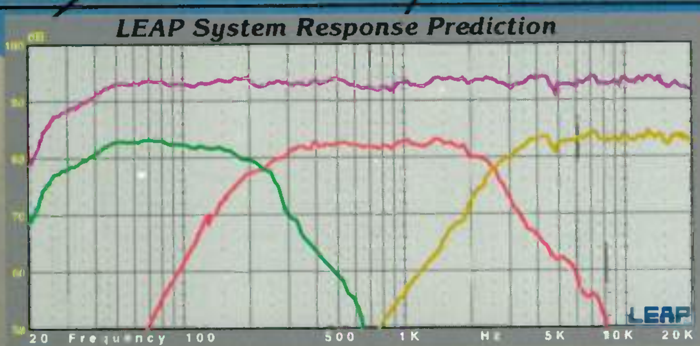
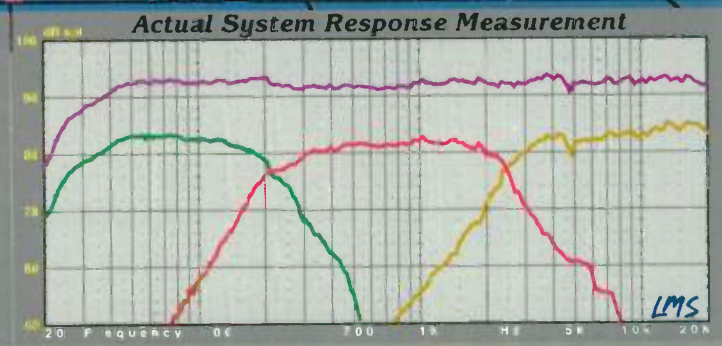
New! LEAP
Version 4.5

LEAP

Precision Development Tools for Precision Loudspeaker Designs





The Art and Science... of loudspeaker system development today has become more complex than ever before. Competition is tough, and to compete each design must perform to the best of its ability, and make the most out of every dollar's worth of transducer cost. The simple approach of choosing a combination of seemingly appropriate transducers coupled with ordinary networks and filters, has given way to a painstaking process of meticulously blending selected transducers in combination with carefully devised and matched crossover designs.

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- ✔ Sealed, Vented, Bandpass, PR Simulations with multiple speaker/ port capability.
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- ✔ Use simulation or imported actual measured SPL/Z data.
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Reader Service #36

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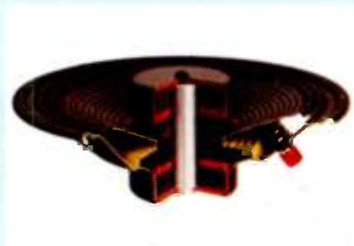
The 1978 C.E.S. in Chicago was the very first time that Morel Acoustics USA, Inc. presented their product to the public. It became clear, early on, that the loudspeaker industry was in need of high quality speaker drivers. Shortly thereafter we introduced several drivers and established the MDT-28/30 as one of the most popular and highly demanded tweeters on the market.

Through the course of the years Morel brought many unique and innovative products to the speaker industry. The introduction of the 3″ voice coil in a 5″ basket, using hexagonal shaped aluminum wire, utilizing a double magnet system and ducted design woofers and mid-basses are a few examples of the company's breakthroughs. Also introduced were the Integra concept (single motor system for both the tweeter and woofer) and the Push-Pull 8″ and 10″ subwoofers (dual motor system, dual voice coils with a single cone).

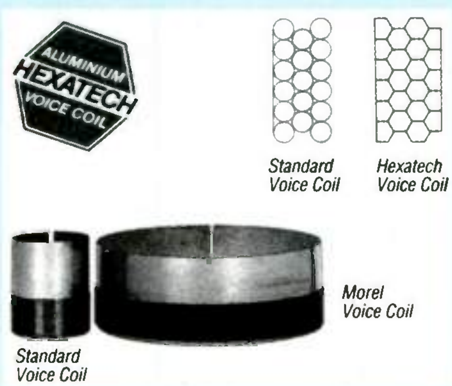
Integra



Push-Pull

Double Magnet

Morel Acoustics USA, Inc. has come a long way since 1978. Currently, the company has a diverse line of exciting products which includes over 40 models of tweeters, midranges, mid-basses, woofers and subwoofers. Being a leader in the field of speaker design, for our 20th year anniversary we are scheduled to launch several new products that are sure to attract attention.



Typical double magnet ducted woofer.

Double magnet tweeter

For further information please contact:

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