Win An Edgarhorn
See Sweepstakes, p. 53

HOW TO CHOOSE A GOOD CROSSOVER COIL

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Speaker Builder

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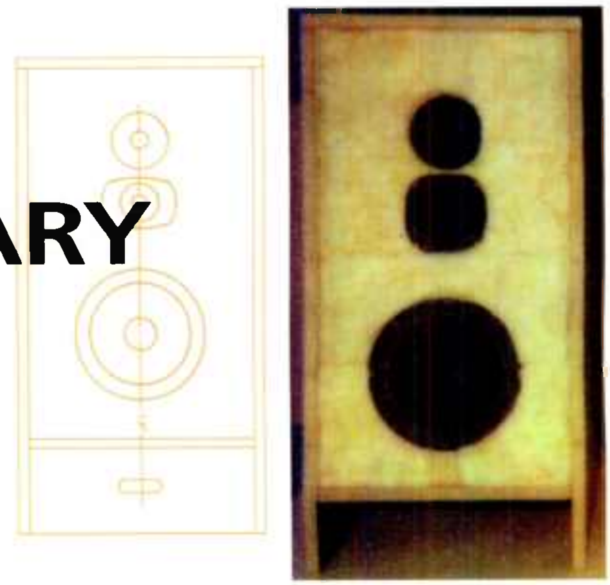

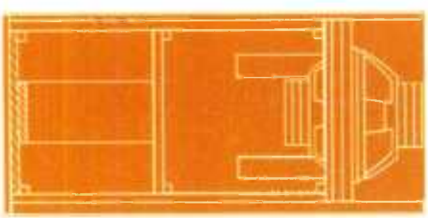

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New InfiniCap Signature

They said it couldn't be done, so we did it — InfiniCap's unique technology (pats pend) in a new film-and-foil design. This monster is the absolute ultimate in capacitor sound, when only the very best will do.

Critics Judge InfiniCap...

- A high end speaker system manufacturer:
  "**InfiniCap does amazing things for our speaker!** It's far better than all other capacitors. Compared to Hovland MusiCap, InfiniCap is more transparent, open, faster, and more dynamic, with better separation of instruments and their harmonics, better inner detail, better stereo imaging with a wider stage — and bass that's richer with more weight, yet also tighter, faster, and better defined."
- Another high end speaker system manufacturer:
  "SETI surpasses MultiCap RTX and Hovland MusiCap. It gives us the **most music**, with the blackest background."
- A leading high end mfr of tube and solid state electronics:
  "SETI gives us the **most realistic, natural music we've ever heard!** The difference compared to MultiCap is astounding, just amazing, night and day! SETI is the **biggest parts improvement we've ever heard!** It sounds so good that your reaction is emotional; we're giddy and swept away! SETI is fast and detailed but not hard, and it gets music's harmonic textures right. There's no sense of reproduced sound; it's just like hearing real live music."
- Another high end manufacturer of tube electronics:
  "The only other cap even close to SETI is the Audio Note Copper Foil in Oil, at 8 times the price!"
- Doug Blackburn, engineer, audio writer (his article in Stereophile satirized pseudo-physics in high end audio), and regular contributor to Positive Feedback and The Audiophile Network:
  "I found a great sounding new cap — unbelievable sounding actually. I used to think [a highly regarded multiple section film and foil cap] sounded pretty good, but these InfiniCaps are unreal."
  "I tried them in various locations in my equipment — power supply bypasses, in the audio signal path, etc. *Unreal* sound quality. These InfiniCaps make [the multiple section film and foil cap] sound ***broken!*** I'm **not kidding!** The difference is **very** large."
- Prominent audio retailer Peter Litwack, Music by Design:
  "In a high end preamp we replaced very expensive MultiCaps ($77) with an InfiniCap ($19). ***Ecstasy!*** This preamp came stock with MultiCap's best efforts, the deluxe film-and-foil PPFX-S and RTX series. To get good sonic results for the coupling cap, the preamp designer found it necessary to use an array of three MultiCaps: 5μF PPFX-S, externally bypassed by .47μF PPFX-S, bypassed by .01μF RTX. That's 30 deluxe MultiCap sections in parallel."
  "We replaced this whole $77 MultiCap array with a single 4μF InfiniCap ($19). No external bypasses on the InfiniCap. **This single InfiniCap, at 1/4 the price, thoroughly eclipsed the whole optimized array of MultiCaps!** Clearly, infinity is far better than 30."
  "InfiniCap took this preamp to a whole new level. Bass became deeper, more articulate, and much less soggy. The stereo space expanded dramatically, extending way beyond the room walls and wrapping around the room, almost like surround sound. Really wild! Also, musical instruments themselves became better articulated and more lifelike, with better resolution revealing their subtle resonances. The overall sound became cleaner and faster, even using InfiniCap's ruggedized version with no external bypasses. Wow! InfiniCap is a home run in every way!"
- Litwack's evaluation has since been independently confirmed — by the preamp manufacturer himself, who has now changed his product over to the new InfiniCap SETI.

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Reader Service #54

World Radio History

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Reader Service #16

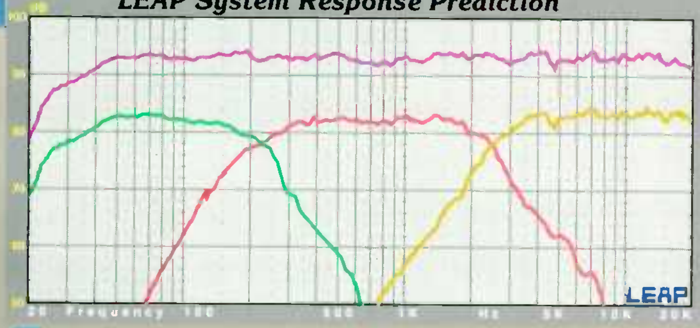
World Radio History

New! LEAP *Version 4.5*

LEAP

Precision Development Tools for Precision Loudspeaker Designs

LEAP System Response Prediction



Actual System Response Measurement

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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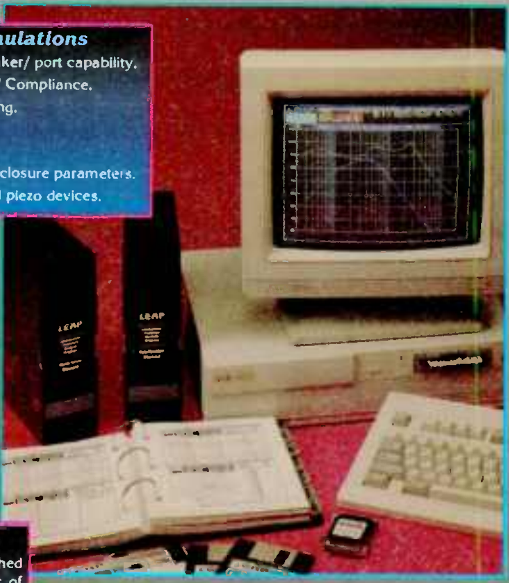
LEAP (Loudspeaker Enclosure Analysis Program) is a complete full range analysis package which provides virtually *all* of the tools necessary to develop precision loudspeaker systems, for today's demanding audio markets. Whether your applications are consumer audio, car stereo, professional audio, or custom esoteric marvels, LEAP provides the power, flexibility, and accuracy to investigate every possible design permutation. The open architecture and broad spectrum of features provided will dramatically reduce your development time, while improving the quality of the final result... and demonstrates why LEAP has become the #1 choice of professional loudspeaker designers world-wide!



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- ✔ 502 Page Reference Manual
- ✔ 436 Page Application Manual

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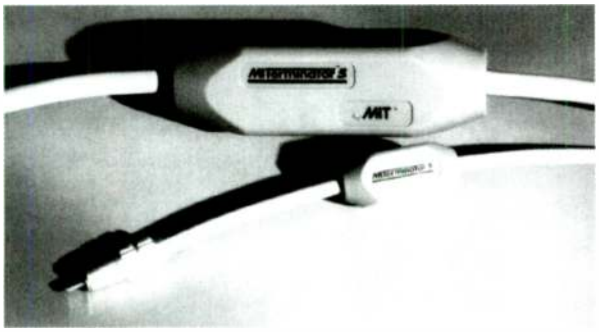
World Radio History

Good News

➲ MIGHTY CABLES



MIT's iconn™ Interchangeable Connector System eliminates the need to buy new cables or modify existing ones to new equipment. MIT cables, housed in gray jackets, feature a basic Pin Base connector at each end, accommodating spring-loaded and threaded terminals. Connectors available with the iconn system are gold-plated and include regular banana, economy spade, regular spade, and large spade. Music Interface Technologies, 13620 Lincoln Way, Ste. 320, Aubum, CA 95602, (916) 888-0394, FAX (916) 888-0783.

Reader Service #106

■ CD-ROM MAGAZINE

Elektor Electronics' CD-ROM, the *CD-Elektuur/Elektor 1995*, contains all articles—except news columns—published in the 1995 issues of the magazine. The CD-ROM offers an overview of 11 issues and allows you to view individual articles in a choice of four languages—English, Dutch, French, and German. Individual circuit diagrams, illustrations, and PCB layouts may be exported from the CD to other programs for adaptation and use. Elektor Electronics Publishing, PO Box 1414, Dorchester, UK DT2 8YH, (+44) 1305 250 995, FAX (+44) 1305 250 996.

Reader Service #103

■ TO SEAL AND PROTECT

Abilene Research & Development, makers of Texturelac leather finish for speakers, announces the relocation of its main office to Royal Oak, MI. The company has added three low-VOC clear topcoats to its product line, which includes satin, semi-gloss, and high-gloss non-yellowing finishes. Designed to protect and seal painted surfaces, these environmentally friendly glazes air dry within one hour. Abilene Research & Development, 803 N. Main St., Royal Oak, MI 48067, (810) 545-8042, FAX (810) 545-8833.

Reader Service #101

■ THE ULTIMATE CONNECTION

D.H. Labs, maker of interconnect and speaker cables, introduces the new Ultimate XLR connector. While the contact pins of conventional XLR connectors are made from brass, those of the Ultimate XLR are constructed of OFHC copper. Nickel-free gold-plating is laid over the base metal to prevent corrosion. D.H. Labs, PO Box 31598, Palm Beach Gardens, FL 33420-1598, phone/FAX (561) 625-8998.

Reader Service #104

■ CATCH THE SPIRIT

Absolute Zero, the latest addition to Soundcraft's line of Spirit console speakers, is a compact near-field monitor rated at 75W RMS. Absolute Zero utilizes a 30mm voice coil in its woofer, while the soft-dome tweeter is driven by a 25mm ferrofluid-cooled voice coil. The long-throw 170mm LF driver and vented cabinet with a large rear port extend LF response and allow unrestricted bass, even at high listening levels. Spirit by Soundcraft, Inc., 11820 Kemper Rd., Aubum, CA 95603, (916) 888-1488, FAX (916) 888-0480.

Reader Service #107

■ NEW SIMULATION VERSION

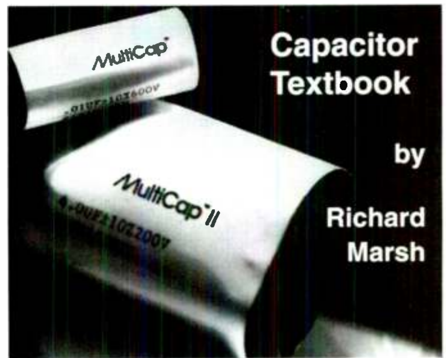
Interactive Image Technologies' Electronics Workbench Version 5.0 is SPICE-based software that simulates the behavior of analog, digital, and mixed circuits. Available in 10 different languages, Version 5.0 offers analyses for transient, AC sweep, DC operating point, Fourier, distortion and noise; schematic editing; graphical waveforms and autoscaling graphs; a library of analog components, device models, digital components, and ICs; and the import and export of standard SPICE netlists. Interactive Image Technologies Ltd., 111 Peter St., Ste. 801, Toronto, ON, Canada M5V 2H1, (416) 977-5550, FAX (416) 977-1818.

Reader Service #102

■ MONAD MINI

Probe Audio Labs' Monad two-way mini-monitor loudspeaker may be used in hi-fi and home-theater environments. The Monad boasts a frequency response of 50Hz–20kHz, 8Ω nominal impedance, and efficiency of 88dB/1W/1m. Available in black or natural oak-veneer finish, the monitor sports three drivers: a 6½″ magnetically shielded mid/bass, a 1″ silk dome tweeter, and one ¾″ rear-firing tweeter. Probe Audio Labs, 10223 NW 53rd St., Sunrise, FL 33351, (954) 749-7344.

Reader Service #109



Q: ***What is the difference between the Segmented Capacitor design and the patented MultiCap?***

A: ***Performance & Construction!***

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(2) Poor quality materials, not designed for audio use, invite shorts, increase ESR, greatly decrease both performance and life of the capacitor.

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Reader Service #69

← ***Reader Service #36***

World Radio History

Good News

SMALL BUT POWERFUL

Miller & Kreisel Sound designed its S-150THX® 5.1 multichannel discrete digital monitor for today's advanced home-theater Dolby Digital AC-3® systems. M&K's Phase-Focused crossover, featured in the S-150THX, combines analyses for time-domain, frequency-domain, and point-in-space (3-D, in-room response). Delivering musical sound quality in a small package, the enclosure measures 12½″ H × 10½″ W × 12″ D and incorporates front-baffle foam treatments and integral mounts on the back-baffle. Miller & Kreisel Sound Corp., 10391 Jefferson Blvd., Culver City, CA 90232, (310) 204-2854, FAX (310) 202-8782.

Reader Service #108

CC3 IN A PRISM

B & W Loudspeakers' CC3 is a sub-compact center-channel speaker housed in the company's PRISM enclosure system. PRISM slot-ported and magnetically shielded cabinets incorporate a fourth-order vented design with injection-molded front and rear baffles, an inner surface comprising dozens of tapered pyramids, and molded cross-braces. With a 1″ soft-dome tweeter and a pair of 4″ mid/bass drivers, the CC3 achieves an 8Ω nominal impedance, 60Hz–20kHz output at $\pm$3dB, and a sensitivity rating of 91dB/1W/1m. B & W Loudspeakers of America, 54 Concord St., North Reading, MA 01864-2699, (508) 664-2870, (800) 370-3740, FAX (508) 664-4109.

Reader Service #110

ALPHA EXPANSION

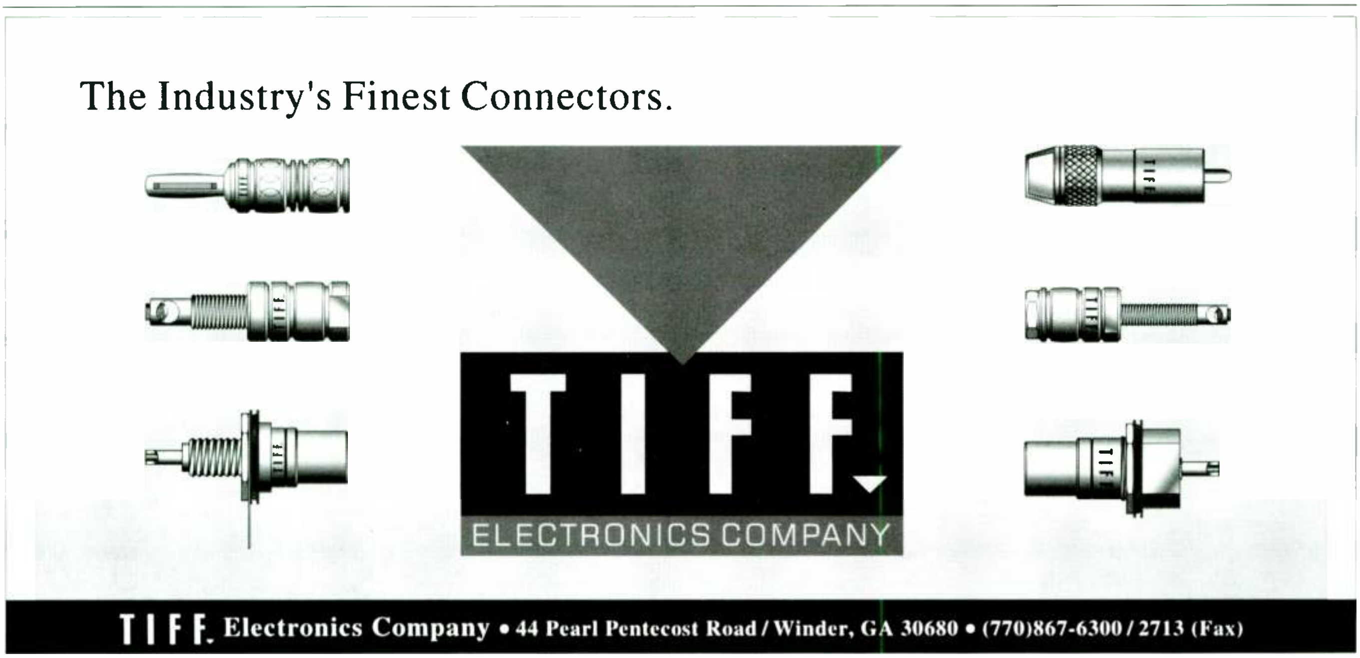
PSB Speakers' Alpha series of home-theater loudspeakers has expanded to include three new versions: the Alpha$^{A/V}$, Alpha Mini, and Alpha Mite. All three units employ a two-way bass-reflex design, 14mm (½″) polycarbonate dome tweeters, woofers with treated fiber cones, video and magnetic shielding, and a black or dark cherry enclosure with grille. Each design achieves 6Ω nominal impedance and runs at 60W RMS input power (program). PSB International Inc., 633 Granite Ct., Pickering, ON, Canada L1W 3K1, (800) 263-4641, FAX (905) 263-4633.

Reader Service #111

HOW SUITE IT IS

Liberty Instruments announces Version 2 of Liberty Audiosuite (LAUD), a DSP-card-based measurement system for loudspeakers and audio equipment. The PC-compatible package comprises both hardware and software to provide MLS- and sinewave-based transfer functions, impedance measurements, a dual-channel oscilloscope, FFT and RTA spectrum analyzer, and harmonic-distortion analyzer. This upgraded version further includes a script processor and real-time 1/3- and 1/6-octave analyzer, while performing pass/fail testing, automatic input-level adjustments, and display scaling. Liberty Instruments, Inc., PO Box 1454, West Chester, OH 45071, phone/FAX (513) 755-0252, Internet: www.libinst.com. Also available as #SOF-LAU from Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458, (603) 924-6371, FAX (603) 924-9467.

Reader Service #105



Reader Service #72

Reader Service #63 →

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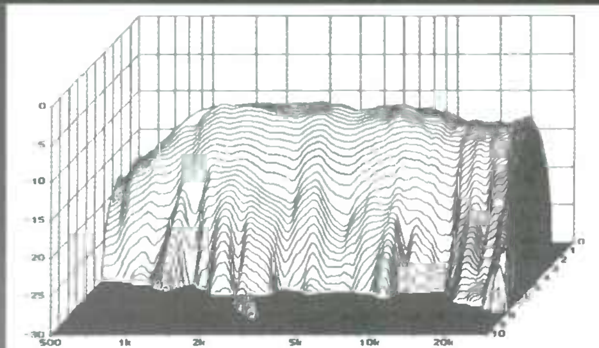
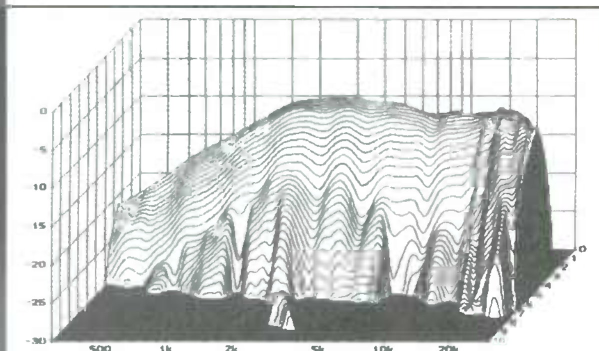


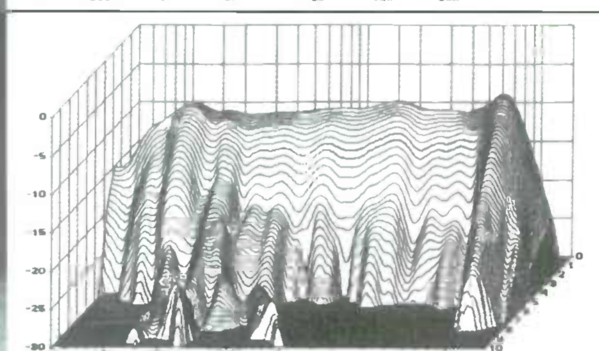
C2-12 Super tweeter US$ 180.00

Efficient (close to 90 dB) 1 in. concave dome high frequency unit. Liquid cooled. Very wide band (2.5 to 30 KHz). Low Fs (700 Hz). It can be used in 2 or 3-way designs with a large variety of crossovers. One of the very finest tweeters available today. This is where the super hard ceramic dome shines the most: the break up mode happens well above the audible range.



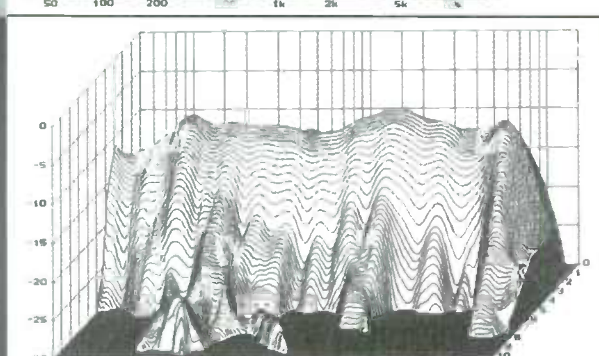
C2-23 Tweeter US$ 220.00

Efficient (close to 90 dB) 1-3/16 in. concave dome tweeter. Liquid cooled. Wide band (1.7 to 23 KHz). Very low Fs (350 Hz). The ideal tweeter for 2-way designs. The ceramic dome keeps the upper resonance still above the audible range, and at the same time the tweeter can meet just about any midrange or midbass unit where it best performs.



C2-79/6 Midrange US$ 260.00

Beautiful 3-1/2 in. concave dome midrange. Liquid dampened. Extremely wide band (200 to 6 KHz). Very low Fs (96 Hz). This outstanding unit covers perfectly the human voice (200 to 2000 Hz). Near perfect piston functioning warrants very low distortion and virtually no coloration over the whole spectrum. Designed to work well in a small tubular sub-enclosure.



C2-88 Midbass US$ 270.00

The first true midbass using a ceramic concave dome diaphragm. High-loss rubber surround. Wide band (40 Hz to 4 KHz). This 3-1/2 in. is an amazing bass unit and at the same time a remarkable midrange, working as a pure piston over its range. This will give the designer an extraordinary degree of freedom. Ideally suited for D'Appolito configurations.

World Radio History

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Reader Service #79

About This Issue

In the first of a three-part series, speaker experts **G.R. Koonce** and **R.O. Wright** document the development of their multidriver project ("A Modest-Cost Three-Way Speaker System, Part 1," p. 10). Not just another three-way design, this one is noteworthy for its low cost, simplicity and sound quality.

Not all woofers are designed to be downloaded; there are several factors you should consider first. **Andy Lewis** measures the effects of speaker orientation and answers the question, "Should You Download Your Woofer?" (p. 26).

In his appropriately-named Aftershock Subwoofer restoration project, **Philip Abbate** demonstrates how to turn some vintage drivers into a moving subsonic experience ("The Aftershock Subwoofer," p. 34).

How good are iron-core coils and how do they affect system performance? **Roger Russell**'s comprehensive coil-distortion tests take the guesswork out of choosing which ones to use in passive crossover networks ("Quality Issues in Iron-Core Coils," p. 44).

Tom Perazella offers an up-close-and-personal look at cone movement with some fascinating photos in "Low-Cost Stroboscopic Spider Analysis" (p. 54).

Finally, *Speaker Builder* invites you to participate in an experiment to test directionality. Does the amount of oxygen and alignment of crystals in the manufacture of wire make a difference? See "*SB* Mailbox," p. 60.

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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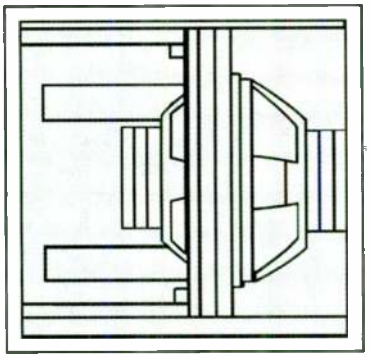

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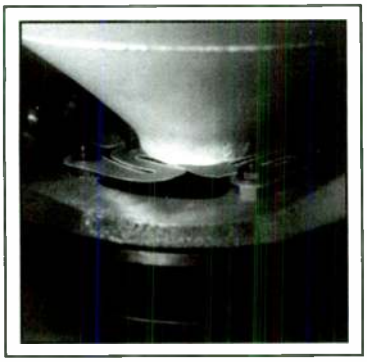

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A MODEST-COST THREE-WAY SPEAKER SYSTEM, PART 1

By G. R. Koonce and R. O. Wright

This three-part article will describe the rather serpentine path to the development of a moderately priced three-way system. In addition to creating a system that sounds good, your efforts can provide a learning experience. We will tell you how we developed the system and constructed the initial prototypes.

We designed the system to accept two different 1″ dome tweeters, so in just a few minutes you can change the tweeter and compare the sound of your favorite music as played by a hard (aluminum) or soft (fabric) dome. The project also has two physically interchangeable crossovers (COs), a first-order and a third-order. This is an ideal way to compare the differences in imaging that COs can make with no physical changes in the acoustic system.

The cost of the system is modest, as the drivers are all less than $40 each. The woofer is an 8″ unit produced by Eminence (DJ840/8). (The DJ840/8 designation is an Eminence in-house number that we will use throughout the article. This woofer is available from Madisound as the Eminence #8253, and we have tested samples of it to verify compatibility. The other drivers are available from Madisound and other companies—see Sources.) The midrange driver is a SEAS 4.5″ open-back (MCA11RC), and the two tweeters are the Audax TW025MO soft dome and the SEAS 25TAC/G hard dome.

TABLE 1

DJ840/8 WOOFER SPECIFICATIONS

Nominal impedance	8Ω			
Voice-coil diameter	2″			
Magnet weight	38 oz			
RMS electrical power	100W maximum (unverified)			
Measured data on two samples and catalog data:				
	Unit A	Unit B	Catalog	Units
f_s	35.1	33.5	32–35	H_z
Q_{es}	0.36	0.37	0.35	
Q_{ms}	8.08	7.65	6.97	
R_e	6.04	6.20	6.4	Ω
V_{as}	1.45	1.60	1.92	ft^3
SPL	88.9	88.4	90.1	dB/W/m

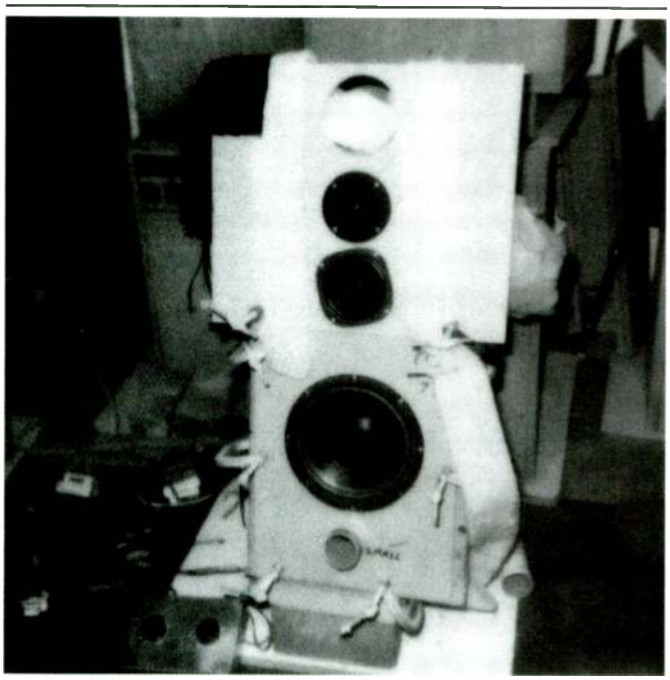

PHOTO 1: Three-way breadboard system.

IT ALL BEGAN...

This project started several years ago with a phone conversation between R.O. Wright (ROW) and myself (GRK) that went something like this:

GRK: "I wish there were more low Q drivers with a low resonance."

ROW: "I can get you all you need from the professional ranks."

GRK: "Yes, but the sensitivities are so high that they force you to use horns for the midrange and tweeter, or else go to biamping."

ROW: "That would not be a problem if one driver did the whole frequency range."

GRK: "If you can find such a driver, I will build the box and we will write it up for *Speaker Builder*!"

For over a year ROW sent me a variety of drivers. I rejected them all through tests or listening as not up to the job. I noted near the end that a little cheating was going on, as I opened one box and was greeted by a coaxial driver with built-in crossover. This, too, was rejected.

We finally agreed that a single driver would not do, and decided on a two-way system with a simple crossover. The basic goals were as follows:

1. −3dB response limits from about 40Hz–16kHz, the typical upper limit for a 1″ dome tweeter
2. A reasonably sized woofer box of, say, less than $2ft^3$
3. All drivers to be fairly low-priced and available to anyone
4. Drivers to be used as manufactured, with no home modifications
5. A simple crossover that others can duplicate without having complex measurement capability.

THE TWO-WAY SYSTEM

WOOFER RESULTS

To meet the 40Hz lower −3dB point with any reasonable power capability, we needed a driver of 8″ or more. The box requirement of less than $2ft^3$ indicated an 8″ woofer was the best bet. We investigated a variety of low-cost 8″ woofers and selected the DJ-840 as the best candidate. Tests of a pair showed they would meet our goal of −3dB at 40Hz

ABOUT THE AUTHORS

G.R. Koonce and R.O. Wright are both retired engineers—electrical and mechanical, respectively—who have long worked in the development of speaker systems. Mr. Koonce has built speakers as a home hobby for about 40 years, and Mr. Wright has spent about the same length of time working with speakers for the professional ranks.

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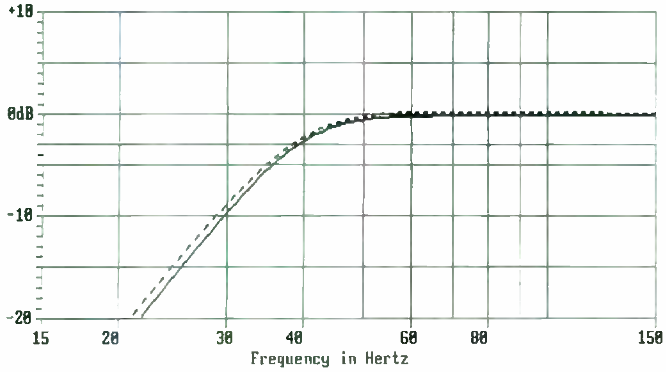

FIGURE 1: Small-model predicted woofer response in 1.1ft^3 vented box.

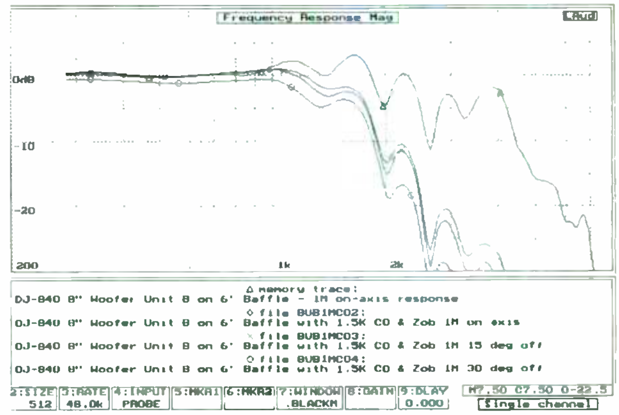

FIGURE 2: Woofer acoustic response on- and off-axis with 1.5kHz crossover.

in a vented box slightly over 1ft^3 (*Fig. 1*).

We also evaluated the woofers to establish their upper-end frequency performance. *Figure 2* shows the performance of the DJ-840 woofer. It starts to show ripples at about 1kHz, and we deemed it usable to about 1.5kHz in a two-way system. Also shown in *Fig. 2* is the performance with a third-order 1.5kHz low-pass (LP) crossover; note that the performance holds up well off-axis to at least 30°.

We listened to the woofer in a breadboard vented box of slightly under 1ft^3 with a small two-way system doing the rest of the audio band. Since we found the sound quality good, we adopted the DJ-840 as our woofer. Now our problem was to find a tweeter to go with it. *Table 1* shows the DJ-840 data.

TWEETER RESULTS

The catalogs listed some new low-resonance 1″ dome tweeters that might be usable down to 1kHz. We purchased three tweeters in pairs for study (*Table 2*). *Figure 3* shows the frequency response for these in the 6′ baffle (see sidebar, Testing Approach). None were really usable to 1kHz; the summary catalog pages had misled us in this regard. From reading the detailed data sheets, it became clear that a lower frequency limit of about 2.5kHz was what the manufacturers had in mind.

The Audax TW025V2 tweeter does go below 1kHz, but has a nasty dip in the 1.5kHz region that made its use questionable. Since it was clearly no better than the Audax TW025MO unit, had a lower sensitivity, and was 4Ω, we dropped it from further consideration. We listened to the Audax TW025MO unit (hereafter simply called the Audax tweeter) and the SEAS tweeter in a system and found them acceptable, although they sounded different, as one has a soft dome and the other hard. We decided that since they had similar impedances and close to the same sensitivity, we would use both for the two-way system.

FRONT-PANEL DEVELOPMENT

One major problem when you design a multidriver system is the effect of driver offset (drivers not located similarly in height and in depth on the front panel) on the performance of the system in the region of the crossover frequency. To investigate this effect, you must determine the driver spacing on the cabinet's front panel.

I insist on putting a brace above the woofer to stiffen the front panel. Thus the two drivers cannot be mounted so they nearly touch. I arrived at a minimum spacing of 7.5″ center-to-center for the two drivers and made a test insert for the 6′ baffle that provided this spacing. I mounted the woofer and tweeter in line vertically, with the tweeter at the top.

BAFFLE TESTS AND CO-DEVELOPMENT—TWO-WAY SYSTEM

It was clear that we were going to be pushing both drivers in terms of their frequency-response capabilities, so we decided to use a third-order electrical CO. We set the initial CO frequency point at 1.5kHz. Tests indicated that the driver responses were causing the acoustic responses to deviate from the electrical CO responses.

To get a reasonable total response for the driver pair, it was necessary to modify the CO component values from the design values to correct for the driver responses and impedances. We did this and measured the

TABLE 2

1″ DOME TWEETER TYPES

Type #	1	2	3
Maker	Audax	SEAS	Audax
Model	TW025MO	TAC25/G (H400)	TW025V2
Measured f_s	930–950	600–610	720–740
Manufacturer's ratings:			
f_s	900	660	600
SPL dB/W/m	92	91	87
Dome material	textile	aluminum	textile
Nominal Z_{in}	8	6	4

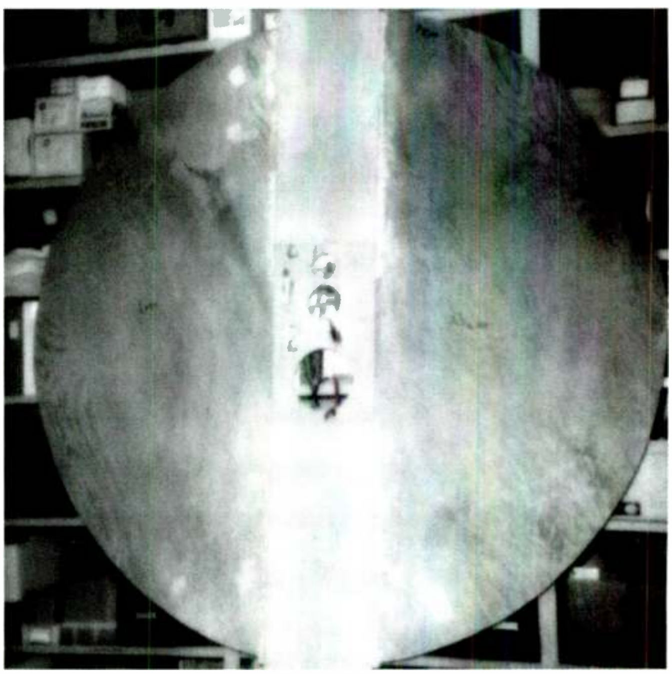

PHOTO 2: Six-foot test baffle with three-way system insert.

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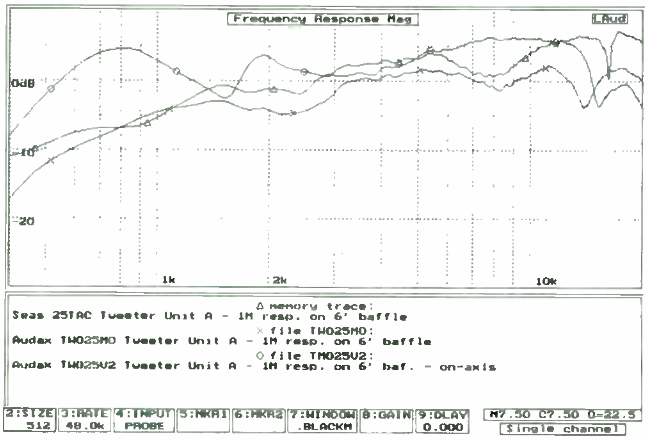

FIGURE 3: Acoustic responses for three tweeter types measured at 1m.

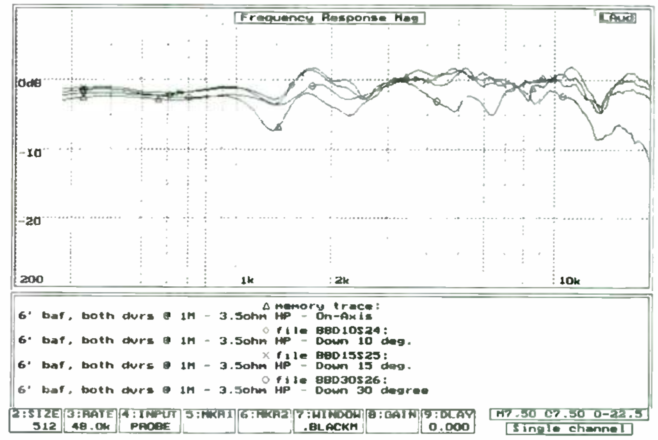

FIGURE 4: Summation response for two-way system at various angles.

resulting performance at various vertical angles off the tweeter axis with the Audax tweeter (*Fig. 4*).

Note that "up" refers to an angle above the tweeter (away from the woofer) and "down" refers to moving toward the woofer. This measured response was quite good, and the system was breadboarded and sounded good when listened to on an axis of about 10° down. While a lot of testing and listening effort was spent on the two-way system, we decided not to build it because:

1. The modifications to the CO to flatten the summed response caused the system input impedance to dip to about 2.4Ω in the 2kHz range. The removal of this dip resulted in inferior performance.
2. We were really pushing the tweeters too far in terms of their low-frequency power-handling capability.
3. We were factoring the driver responses and impedances into the CO design, and we doubted that others building the system would get the same summation response.
4. Victor Staggs informed us that his design, which factored in the tweeter performance, had changed with tweeter aging.

THE THREE-WAY SYSTEM

We now had tested lots of drivers, yet had no practical system. I was not sure the world needed another low-cost, moderate-performance three-way system, but ROW pointed out that we had low-resonance tweeters, and that if we could get a midrange driver with low resonance and wide frequency response, perhaps we could develop a three-way system with a first-order CO.

This was a worthwhile goal, so we began searching for an acceptable midrange. With our present woofer and tweeters, we thought that to make a first-order CO possible, the CO frequencies would have to be about 600Hz and 4kHz. The midrange would then have to cover more than this span, with acceptable impedance and frequency response.

It turned out that good-sounding, wideband, low-cost midrange drivers are rather scarce. We evaluated four midrange drivers for this project (*Table 3*). *Figure 5* shows the acoustic responses of types 1–3. Initially, we selected the drum midrange, type 2, but I thought we could do better. Brian Kane of Madisound suggested using the SEAS MCA11RC, and while I was a bit worried that it was short on sensitivity, testing and listening showed it to be a great match with our other drivers, so it became the midrange for this project. Its sensitivity is such that it runs with the woofer without padding.

FRONT-PANEL DEVELOPMENT

The SEAS midrange is open-backed, so it needs a chamber behind it. SEAS offers a low-cost plastic chamber, but it is so small that it would raise the resonance too high for this project, so we rejected it. The front-panel design must therefore allow not only a brace above the woofer, but also a midrange enclosure. *Figure 6* shows the minimum front-panel spacings we arrived at. We built a test insert with these spacings (*Photo 1*). You can use either the SEAS or the Audax tweeter with this insert.

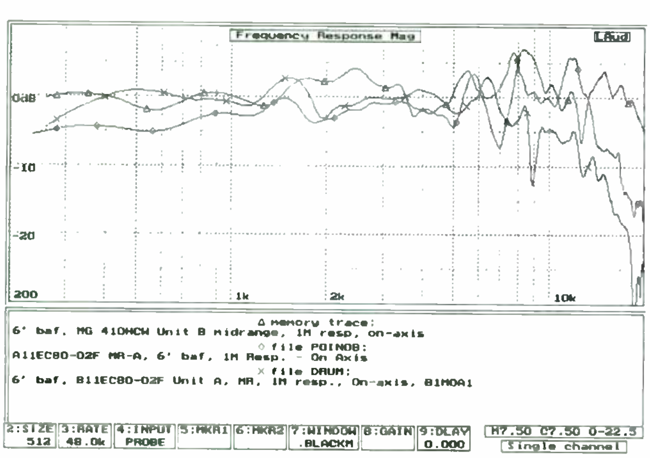

FIGURE 5: Response of midrange types 1–3 at 1m.

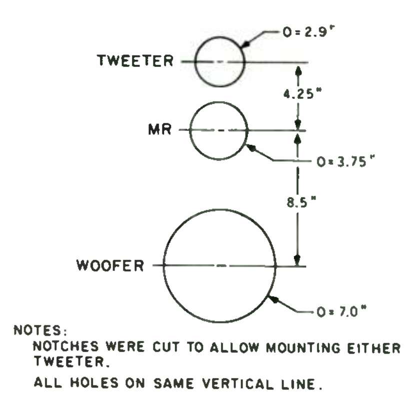

FIGURE 6: Driver spacings for three-way test front panel.

BAFFLE TESTS AND CO-DEVELOPMENT—THREE-WAY SYSTEM

The idea of a first-order CO was interesting, but it was doubtful our drivers would support first-order acoustic CO responses. We therefore decided to develop and test both a first-order and third-order CO. Since they both had to support two tweeter types with

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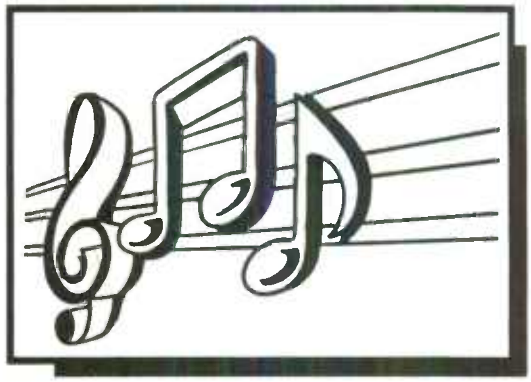

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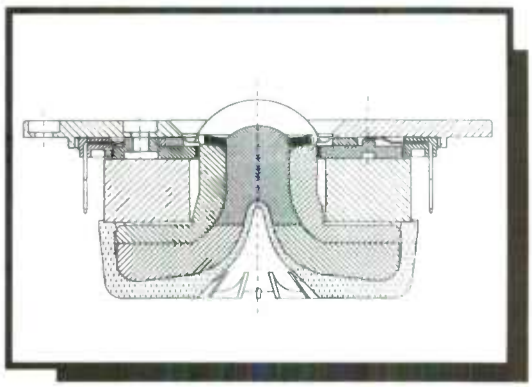

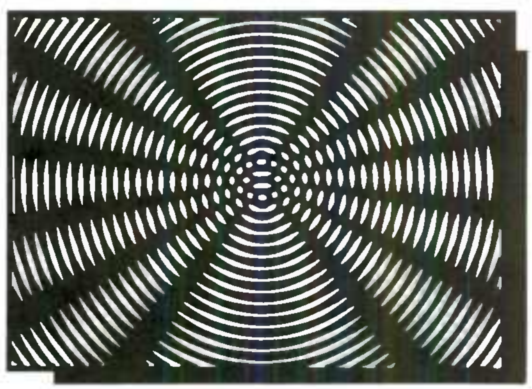

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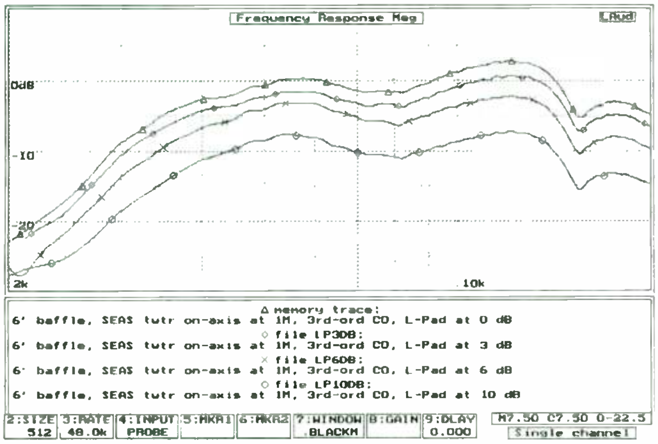

FIGURE 7: Response of SEAS tweeter with various L-pad settings—third-order crossover.

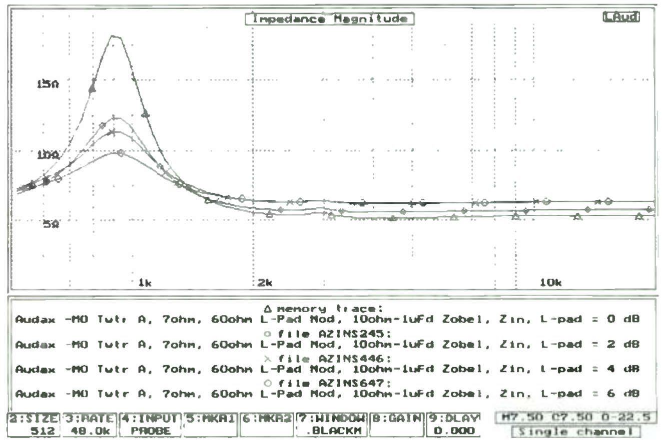

FIGURE 8: Z_{in} to Audax tweeter with Zobel versus L-pad setting.

differing sensitivities, we had to apply some tricks to the design.

We easily handled the difference in tweeter sensitivities by including an L-pad on the tweeter. I normally will not use L-pads, as they are very dangerous to the health of the tweeter. ROW feared that a low-cost L-pad might add sufficient inductance to the tweeter circuit to cause a significant loss of high-frequency response. *Figure 7* shows the acoustic response of the SEAS tweeter (without Zobel) with various L-pad settings and a third-order high-pass (HP) filter. There is no indication that the presence of the L-pad harms the tweeter response.

TWEETER IMPEDANCES

We investigated the impedances of both tweeter types and developed a compromise Zobel that worked for both. This resulted in impedances of about 6Ω for each type. Using an 8Ω L-pad directly would result in a CO load on the HP section that changed too much with L-pad setting.

It is possible to correct an 8Ω L-pad to 6Ω at a single padding value (see L-pad sidebar for equations), and we did this for a padding value of 3dB. Note that all padding values used in this work refer to the L-pad working with an 8Ω load. They were read off the calibrated scale for the L-pads (*SB* 3/81, p. 30).

Figures 8 and *9* show the input impedance to the two tweeter types for various L-pad settings, with the L-pad corrected to 6Ω at 3dB padding, and with the compromise Zobel. We considered the results satisfactory for use with a 6Ω HP CO design. The midrange driver does not need padding, but the first-order CO requires the tweeter and midrange to have the same impedance, so we Zobeled and shunt-padded the midrange to give 6Ω.

TABLE 3

FOUR MIDRANGE DRIVERS

Type #	1	2	3	4
Maker	Pioneer	Pioneer	MG	SEAS
Model	A11EC80-02F	B11EC80-02F	410HCW	MCA11RC (H143)
Type	Open back	Drum	Open back	Open back
Measured f_s	105	340	170	120
Manufacturers' ratings:				
f_s	70	320	/	140
Nominal size	4.5″	4.5″	4″	4.5″
Nominal Z_{in}	8Ω	8Ω	8Ω	8Ω
SPL dB/W/M	90	94	91	89
Usable frequency range (Hz)	70–15k	320–6k	120–19k	400–5k

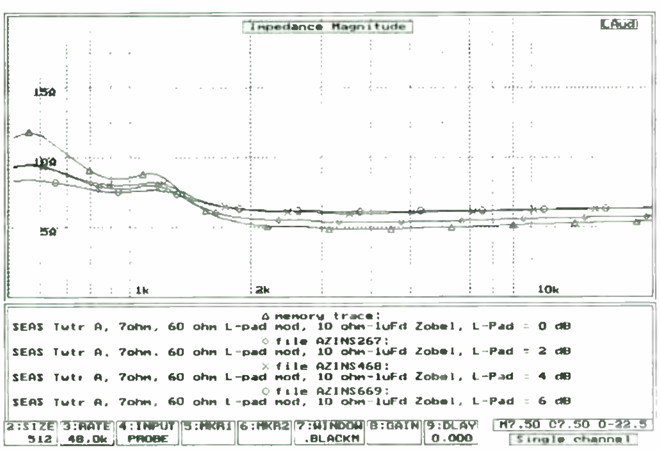

FIGURE 9: Z_{in} to SEAS tweeter with Zobel versus L-pad setting.

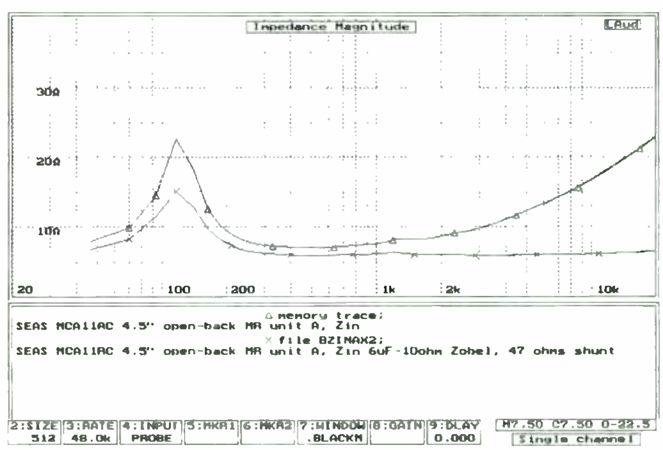

FIGURE 10: SEAS midrange Z_{in} bare and with Zobel and padding.

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Resonance	37Hz
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SPL 1/W/1/M	88DB
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Magnet	14.6 oz.

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Frequency Range	1.5–35KHz
SPL 1/W/1/M	89DB
Power Handling	100W
Voice Coil	25mm
Magnet	8.5 oz.

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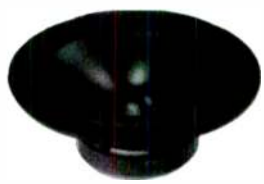
P21WO-20-08 8″

- Magnesium Basket
- Mineral Filled Polycone
- High Temp Voice Coil
- Very Smooth Response

Specifications

Impedance	8Ω
Resonance	28Hz
Frequency Range	25–4000Hz
SPL 1/W/1/M	91DB
Power handling	150W
Qts	0.33
Vas	113 LTR
Voice Coil	40mm
Magnet	24.6 oz.



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- High Damping Surround
- Paper Cone

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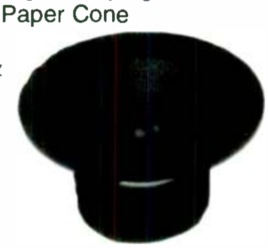
Qts	0.35
Vas	12 LTR
Voice Coil	25mm
Magnet	12.1 oz.



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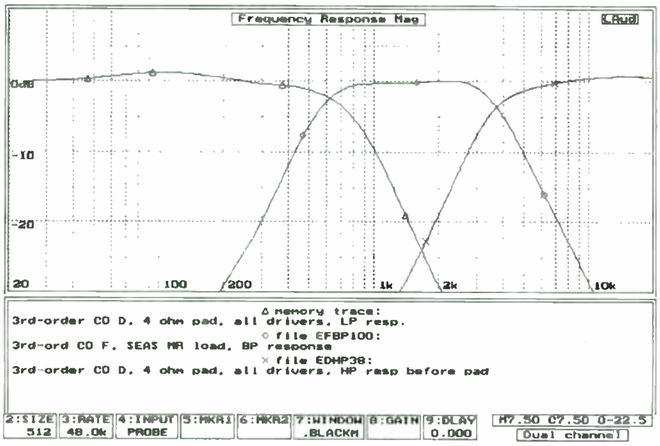

FIGURE 11: Electrical responses of LP, BP, and HP sections with third-order crossover and actual driver loads.

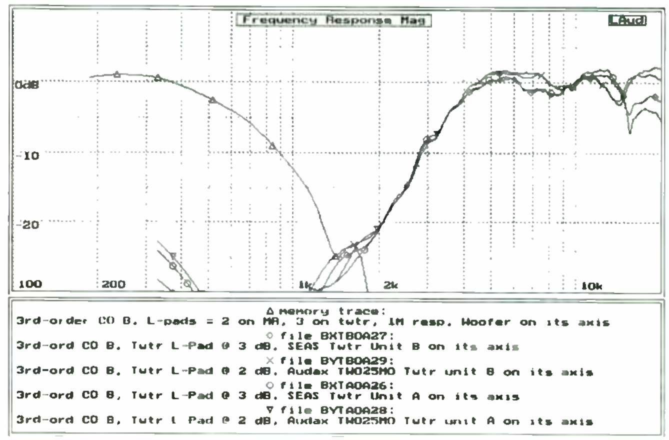

FIGURE 12: Acoustic responses for woofer and four tweeter samples with third-order crossover.

Figure 10 shows the basic midrange driver input impedance and the resultant impedance with the Zobel and shunt resistor. The result is nearly a 6Ω load for the CO bandpass (BP) output down to about 300Hz. The third-order CO we used is the Bullock positive-polarity bandpass all-pass design with transposed midrange topology (*SB* 2/85, p. 26). This all-pass CO has slight rises in the total power response, with corresponding slight dips in input impedance at the two CO frequencies.

The transposed BP topology has a voltage gain of unity. Using the cascaded BP topology would have resulted in about a 2dB rise in available midrange sensitivity, but the cascaded topology causes a dip in input impedance throughout the midrange band, and I have always thought the transposed topology sounded better.

TESTING APPROACH

We generated the test data presented in this article via Liberty Audiosuite. We mounted the drivers near the center of a 6′-diameter wooden baffle (*Photo 2*) that allowed anechoic measurements solid down to below 400Hz and usable to at least 200Hz. We kept the measurement distance greater than three times the span of the drivers to ensure a valid far-field measurement.

The measurement microphone was a 33″-long unit, flat within ±0.5dB over the range 200Hz–20kHz. (Note that data acquired before 7/10/95 was taken with an uncorrected microphone that showed a peak less than 2dB in the 8k–15kHz frequency range.)

Every attempt was made to ensure anechoic measurements. We applied no smoothing to any of the acoustic test results in this work; they show all the nasties that existed. Note that "up" refers to measurements made off-axis above the reference axis, and "down" to those below the reference axis. For a single driver, the reference axis was the driver center line; for the two-way system, it was the tweeter center line; and for the three-way system, it was the midrange driver center line.

A minimum of acoustic data is provided on the finished systems, since my test room simply does not support echo-free testing of a structure the size of the finished enclosure. Impedance data for the finished systems is provided.

ELECTRICAL OUTPUTS

Figure 11 shows the measured electrical LP, BP, and HP outputs from the third-order CO with the driver loads, including Zobels and the paddings described above. These are really quite good, almost matching the performance with resistive loads because of the low midrange and tweeter resonant frequen-

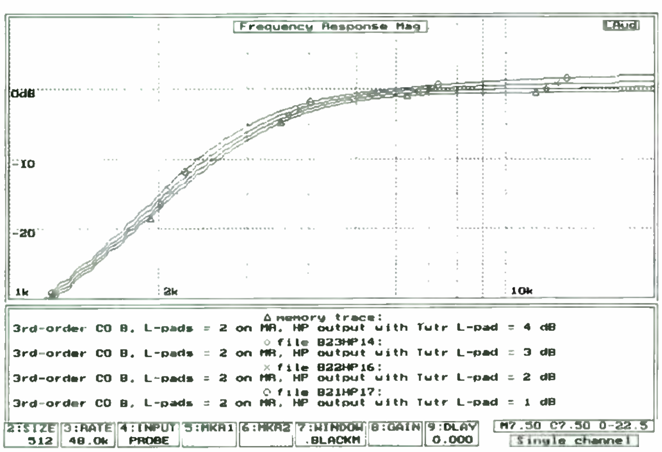

FIGURE 13: Electrical HP output driving SEAS tweeter versus L-pad setting with third-order crossover.

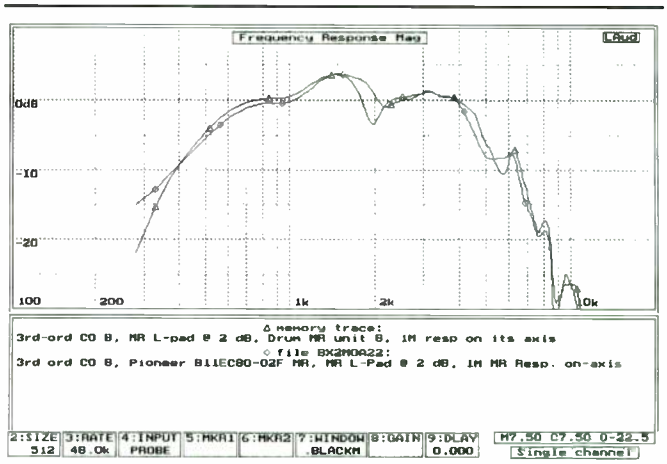

FIGURE 14: Response of both type 2 drum midranges with third-order crossover.

Reader Service #1→

World Radio History

MADISOUND'S WITCHES' BREW OF WICKED SPEAKER SAVINGS

QTY	Description	Price
1,000	**Sreco 10 ohm 25 watt Resistor**, sand cast wire wound, 10%, 12mm x 13mm x 64mm	10/ $3.00
6,000	**Mallory 1.33µfd Mylar capacitor**, 250V, 10%, 25mm L x 11mm Ø, Axial 43mm leads	10/ $2.00
500	**IC 2.0µfd Mylar capacitor**, 250V, 10%, 32mm L x 11mm Ø, Axial 41mm leads	10/ $2.00
1,000	**Siemens 2.2µfd Mylar capacitor**, 250V, 5%, 20mm x 10mm x 31mm, PC mount	10/ $3.00
1,500	**Wima 3.3µfd Polypropylene cap.**, 160V, 10%, 31mm L x 16mm W x 34mm T, PC mount	$1.00 each
2,000	**Hitachi 4.7µfd Mylar cap.**, 100V, 10%, 30mm L x 7mm W x 13mm T, Axial 13mm leads	10/ $4.00
19,000	**Elpac 5.0µfd Mylar capacitor**, 50V, 10%, 30mm x 10mm x 7mm, Axial 53mm leads	10/ $4.00
1,700	**Roederstein 6.8µfd Polycarbonate cap.**, 63V, 10%, 30mm x 10mm Ø, Axial 41mm leads	$0.90 each
300	**T.I. 1300µfd Electrolytic capacitor**, 100V, 5%, 71mm x 30mm Ø, Axial 42mm leads	$4.00 each
60	**Sledgehammer 2.7mH Steel Bobbin Inductor**, 15 awg, .166 DCR, 64mm Ø x 44mm T	$8.00 each

QTY	Description	Price
700	**Audax DW50M 4 ohm tweeter**, 94dB, Fs 2050, 45 Watt, 14mm direct drive poly dome with diffuser, 50mm round flange with no mounting holes, mounting ring and wedge mount available separately. We recommend a 12dB crossover of 6.8µfd & 0.15mH coil	$5.50 each
2 pair	**Audax TP1X2P0 1" x 2" HD-3P dome tweeter**, Gold ion deposited piezo electric polymer film direct-radiating dome, includes 6dB 6K x-over with Solen cap and transformer	$300 / pair $130+ below cost
90	**Seas 25TA/D H533 1" aluminum dome tweeter** with diffuser, 6 ohm, Fs 1000 Hz, 91dB, 60 watts, 4" Ø flange, 3" cut out. Great for frequencies above 3K, smooth to 20K	$15.00 each
370	**Phenolic Ring tweeter**, 4.25" Ø flange with metal grill & 10oz magnet	$5.00 each
160	**Seas 25TAFN/QG 1" aluminum dome tweeter** with metal grill and neodymium magnet, 6 ohm, Fs 1800 Hz, 89dB, 100 watt, 64mm square flange, fits in Audax wedges	$19.00 each
180	**LPG 26TSP 1" titanium dome tweeter** with cropped flange, chambered back, metal mesh grill, 8 ohm, Fs 730 Hz, 90dB, 100 watt. Very smooth to 25kHz.	$18.00 each

QTY	Description	Price
100	**Peerless 821214 2" dome midrange**, textile dome, chambered back, Fs 298, 89dB, 200W @1kHz, 134mm flange with a 106mm cutout, smooth response to 5kHz	$28.00 each
136	**Vifa C11WG-09-08 4.5" woofer**, coated paper cone, rubber surround, vented pole piece, 8 ohm, Fs 72Hz, 85dB, 30 watt, Vas 4.2 liters, Qts .40, frequency response from 100Hz to 10kHz. Nice for small Sat.	$15.00 each
95	**Seas P11RC H454 4.5" woofer**, Poly cone, rubber surround, cast frame, 8 ohm, Fs 55 Hz, 84.5dB, 60 watt, Vas 5.3 liters, Qts .34, frequency response from 75Hz to 7kHz. Great as woofer or midrange.	$25.00 each
48	**Peerless 1667 5.25" Paper cone woofer**, cast frame, rubber surround, 8 ohm, Fs 58 Hz, 88dB, 80 watt, Vas 12.4 liters, Qts .425, F3 of 65Hz in .3 cf vented(1.5"Ø x 3.7"L) or 100Hz in .25 cf sealed. Like the KO40	$23.00 each
150	**Vifa C17WG-07-04 6.5" 4 ohm woofer**, coated paper cone, foam surround, vented pole piece, Fs 51Hz, Qts .54, Vas 26 liters, 50 watt, 88dB, 3mm x-max, F3 of 75Hz in 10 liters sealed. ***OKAY!*** So you wouldn't take them at $14 each, so we made a mistake and bought something you're not all excited about. I hope you can find uses for them at this price and help to restore our confidence in making these large purchases of surplus items.	WOW only $10
104	**Peerless 2622 8" Poly cone woofer**, foam surround, 8 ohm, Fs 26 Hz, 90dB, 100 watt, Vas 168 liters, Qts .37, F3 of 50 Hz in 1 cubic foot sealed and stuffed enclosure, nice choice for a small 2-way	$25.00 each
150	**Famous maker 8" woofer**, paper cone, foam surround, 8 ohm, 90dB, Fs 41 Hz, Qts .37, Vas 36 liters, 50 watt, F3 of 47Hz in .9 cubic foot with 2" Ø port by 3.6" long	$14.00 each
80	**Eminence T1040 10" Paper cone woofer**, cloth accordian surround, 40oz magnet, 2" VC, 92dB, 150 watt, Fs 24Hz, Vas 240 liters, Qts .34, F3 of 52 Hz in 2 cf sealed or F3 of 38 Hz in 3 cf vented (3"Ø x 5"L)	$30.00 each
85	**Stanford Acoustics 12" Paper cone woofer**, treated paper cone, rubber surround, 2" voice coil, 90dB, Fs 14 Hz, Vas 695 liters, Qts .24, F3 of 40Hz in 3 cubic feet sealed or 30Hz in 4 cf vented, 3" Ø x 7" L	$39.00 each

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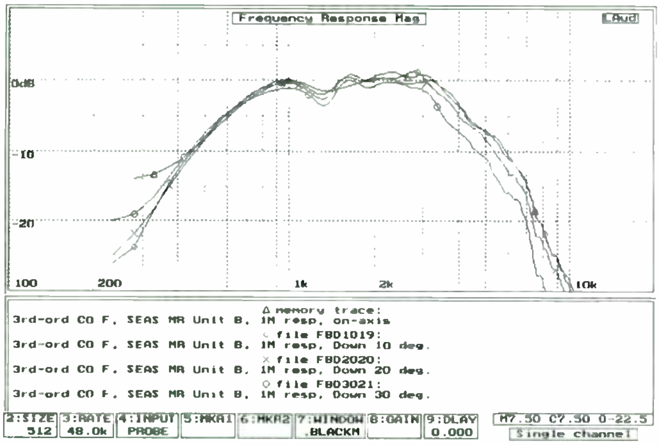

FIGURE 15: Acoustic response of SEAS midrange versus angle with third-order crossover.

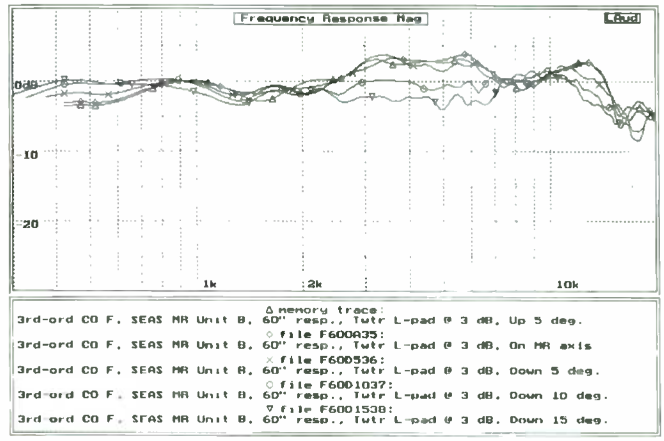

FIGURE 16: Summed response with third-order crossover from up 5° to down 15°.

cies. Note that while the CO frequencies are 600Hz and 4kHz, the BP response narrows to about 600–3.5kHz, which I will explain shortly.

Figure 12 shows the acoustic LP response for the woofer and the acoustic HP responses for two each of the SEAS and Audax tweeters, indicating the CO does work for both tweeter types and that the tested pairs match quite well. *Figure 13* shows that the HP response (SEAS tweeter load) tracks well with L-pad settings over the expected range (about 3–4dB padding).

The mismatches and wiggles in the acoustic BP response for the two drum midranges (midrange type 2) prodded us to search for a new midrange (*Fig. 14*). Note that the electrical BP response was from 600–4kHz. Similar tests with the SEAS midranges indicted that the acoustic BP response was wider than the electrical BP on the upper end. The BP section was redesigned only to cover 600–3.5kHz to correct for this effect. *Figure 15* shows how well the resultant acoustic response of the SEAS midrange holds up over a considerable listening angle.

COMBINED PERFORMANCE

The total span of the three drivers in the 6′ baffle is about 19″ from the bottom of the woofer to the top of the tweeter. Since any acoustic measurements of combined performance must be done from a distance exceeding three times this span, we selected a value of 60″. At this test distance, my room will not support anechoic tests even down to 400Hz at certain listening angles, so in some of the following curves you will note that the low end of the response is truncated.

For the three-way system, the listening-angle reference is the midrange axis, up again meaning toward the tweeter, and down meaning toward the woofer. *Figure 16* shows the measured acoustic response of the three-way system (SEAS tweeter) for every 5° of listening angle from up 5° to down 15°. I think the performance over this range is quite good. The woofer-to-midrange CO is not even detectable, while the midrange-to-tweeter CO is bounded by a tight box.

Remember that there is no smoothing applied to these curves; they show all ill effects. It was doubtful that we could match this performance with the enclosure added. *Figure 17* shows the acoustic response for every 10° from on-axis to down 20°; it is clear that we start getting into trouble by down 20°. The box will be designed for a listening angle of about down 5°.

I became very worried about the tweeter protection with a first-order CO, so we used a slightly modified CO configuration, called the cascaded two-way first-order CO, which offers some added tweeter protection (*Fig. 18*). This consists simply of two first-order two-way COs put in cascade. L1 and C1 split the signal at 600Hz, then C2 and L2 split the first HP output at 4kHz for the true BP and HP output. The advantage is that below 600Hz the tweeter goes to a second-order HP response for increased protection.

This CO does require the tweeter and midrange to have the same impedance, which explains why we did this. We will henceforth refer to the cascaded two-way first-order CO simply as the first-order CO. In *Fig. 19*, which shows the measured performance of this CO with dummy loads, note how the tweeter HP goes to second-order at low frequency. *Figure 20* shows the electrical LP, BP, and HP out-

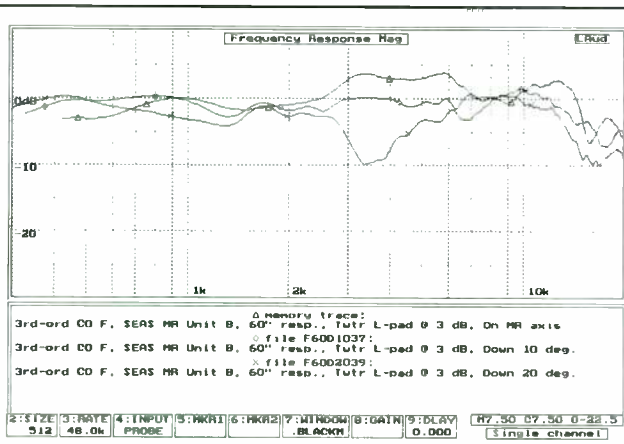

FIGURE 17: Summed response with third-order crossover from on-axis to down 20°.

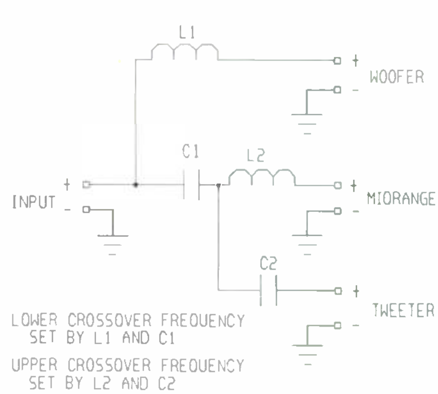

FIGURE 18: Schematic for basic cascaded two-way first-order crossover.

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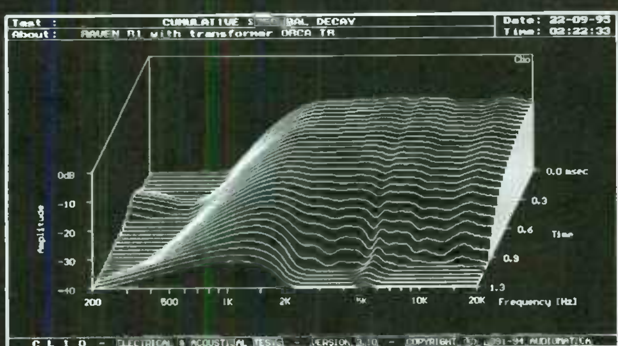

RAVEN R1
KGS 1.14
LBS 2.5
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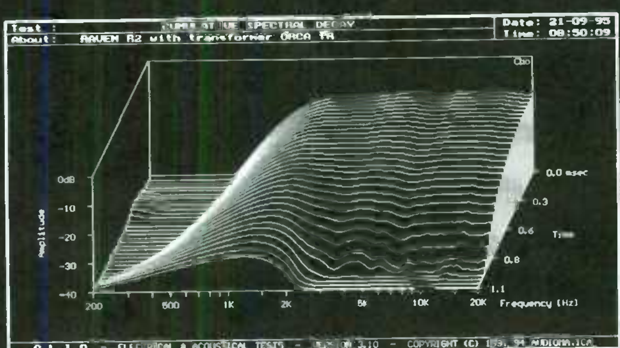
3.63 x 3.15 in.
Moving mass:
0.0061 g
0.0002 oz.
dB/W/m 95
2 KHz to 40 KHz



RAVEN R2
KGS 2.22
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0.0005 oz.
dB/W/m 98
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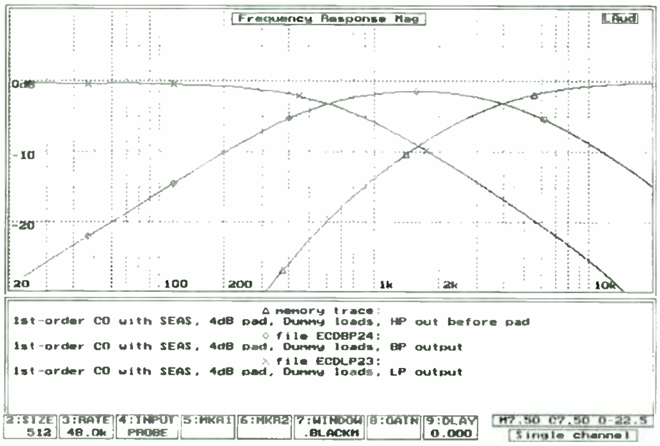

FIGURE 19: Performance of cascaded two-way first-order crossover with dummy loads.

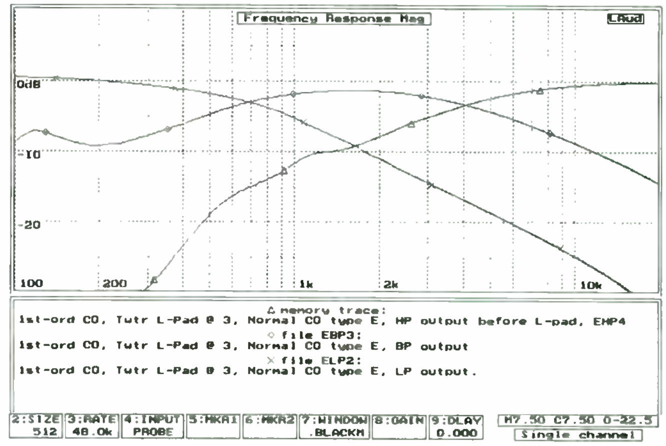

FIGURE 20: Electrical responses of LP, BP, and HP sections with first-order crossover and actual driver loads.

puts with the drivers as loads. It is clear that the first-order CO is bothered much more by driver-impedance variations than was the third-order CO.

Figure 21 shows the acoustic responses for the first-order CO with drivers on their own axis. We were definitely not getting an accurate acoustic first-order CO with these drivers. I believe a major improvement could be made here by using complex Zobels (see *SB* 5/94, p. 28, and 4/95, p. 24) to limit the destructive effects of the midrange driver and tweeter resonant impedance rises. Such Zobels must be designed for the individual drivers (with the midrange in its final enclosure) and so were outside the goals of this project.

DRIVER-OFFSET EFFECTS

In his clever approach to effects of driver offset on various two-way CO types, Bruno Carlsson (see *SB* 1/95, p. 26 and 2/95, p. 26) shows that the first-order CO with drivers having the same polarity is very sensitive, while performance with one driver inverted is much better. Testing certainly verified this result. *Figure 22* shows the total acoustic response of the three drivers (SEAS tweeter) hooked up at normal polarity at various listening angles. Listening tests verified that the performance is terrible.

If the midrange is connected with inverted polarity (*Fig. 23*), then each CO pair has one driver inverted, and the offset effects are greatly reduced. I played with the first-order CO component values with no major improvement. I also tried a straight first-order all-pass CO, and it was even worse. Since the first-order CO requires only four components, we carried it on this project, but it is nowhere nearly as accurate as the third-order CO. The first-order CO is wired with inverted midrange polarity. Again, the optimum listening angle is in the down 5°–10° range.

Breadboard tests (*Photo 1*) in monaural using a down 5–10° seated listening angle indicated the third-order CO to be very smooth and accurate. I judged sound quality to be consistent between seated and standing listening and over a wide angle from side to side. The first-order CO with the midrange inverted sounded musical, but showed some change between seated and standing listening. The first-order CO with normal midrange polarity was terrible, with the lower midrange sound missing at most vertical listening angles. Note that the breadboard system did not match the design front-panel driver spacings.

In general, the listening tests agreed well with the baffle-measured data; however, the first-order CO with inverted midrange sounded better than I had expected from the tests. The data showed that the third-order CO performance was to a great extent free from effects of the impedance or driver response. This means that others building the system should get almost the same performance we did. The first-order CO is not well isolated from driver effects, but should be tolerant of mild variations.

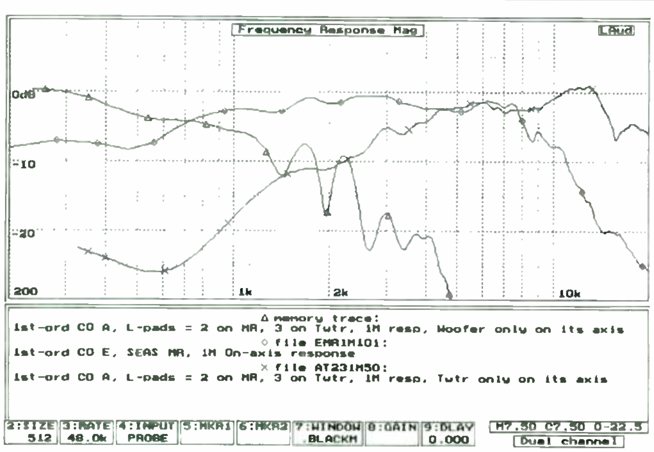

FIGURE 21: On-axis acoustic responses for drivers with first-order crossover at 1m.

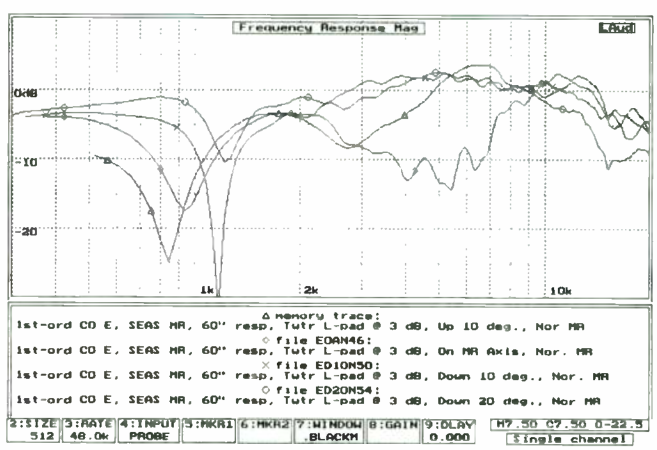

FIGURE 22: Summed responses for first-order crossover—normal midrange polarity.

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ZALYTRON

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FOCAL is pretty secretive about whom they supply with their famous drive units (and Klmon Bellas the FOCAL importer sounds like a locked bank vault when you ask him about it), but if you visit any high-end show, you see an awful lot of FOCAL drive units by many very respected speaker manufacturers. Well these high end OEMs, like any manufacturer on earth need to change models and change drivers. Sometimes only the paint of the frame changes, sometimes a little stiffer spider ... That is how you create very attractive obsolete product. When the French woke up form their traditional August siesta, we made an offer to FOCAL: ZALYTRON would take all these brand new OEM drives (with the usual warranty) they had on their shelves if they would sell it to us ... at an appropriate price. We would be hard pressed to print here that we made a killing, just see for yourself in the ZALYTRON tradition, we pass the benefit of our good deals directly to our customers. If this reads like the D.I.Y. dream list it simply is. If only these OEMs could keep changing models...

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7CZLT	300	45.00
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BOX DESIGN REQUIREMENTS

The problem is now to develop a box for the system that does not distort the performance too much from what the baffle tests and breadboard listening showed was available. The requirements for the box are as follows:

Front Panel

Maintain the driver spacings used in the testing and provide a seated listening angle of around down 5°. To maintain the same sound quality as heard in the breadboard tests, you should keep the woofer relatively low in the box and maintain the overall box width near the breadboard value of 13.5″.

Woofer

Woofer design shows that you need a net volume of 1.1ft^3. Based on an estimate for volume lost to the woofer and the port duct, and allowing a 5% overvolume for bracing, you need a design gross volume of about 1.2ft^3.

Midrange

To give the first-order CO a chance, you want to keep the midrange resonance as low as possible; hence, you need a relatively big midrange chamber.

Tweeter

Many tweeters are heavy masses with thin mounting plates. I believe that they will move slightly if exposed to acoustic pressure, and with the short wavelengths and slight tweeter diaphragm motions involved, this hurts the tweeter clarity. Therefore I place the tweeter outside the woofer and midrange boxes.

Port

I am a firm believer in the diffuser port (*SB* 2/81, p. 16, and 2/91, p. 45), which lowers the air velocity at the front of the port and puts it outside the area covered by the grille cloth. I also think the bass sounds better than with a conventional port. Generally, the diffuser port allows you to use a larger-diameter port duct, something we both think is important.

Crossover

It has to go somewhere, and I prefer to have it external to the acoustic portions of the box so it does not affect box volumes, is not subject to acoustic pressures, and can be easily modified. With this project, there are two CO designs you must make interchangeable for comparison purposes. You should also make the L-pad on the tweeter easily accessible.

Bracing

As noted above, I insisted on a front-panel brace that is just above the woofer. Cutting holes in the front panel and then bolting large masses into them makes the panel the most likely to give trouble and therefore the area in need of the most attention. My engineering training won't let me mount the woofer compliantly; I want it tied tightly to the front panel and the panel made rigid around the woofer.

Resorting to thick material for the front panel is an approach I don't like. I believe part of what results in "slow" bass is energy stored in the woofer box. The more mass you put into the walls, the more energy they can store. I prefer reasonable wall thickness with the braces necessary to create a stiff structure.

I also do not like to set the drivers flush into the front panel, as I believe it weakens it at this critical juncture. I handle the fact that the drivers are not flush-mounted in another way, which I'll describe later.

For this project, all panels are ¾″ particleboard. The most important braces you can provide in an enclosure are those tying the opposite walls together so that the box cannot "balloon" with acoustic pressure. The best way to lose all bass punch (i.e., make slow bass) is to fail to tie the two sides or the front and back of the woofer box together.

The simplest way to do this is to tie the opposite surfaces together with wooden dowels that terminate near the stiffening braces for those walls. For this project, I included dowels from the front panel to the back wall and between the side walls. I would also like to have a dowel between the top and bottom, but the diffuser port and driver depth make this nearly impossible, so you should keep the top and bottom of the woofer chamber relatively small.

Building Limits

There is no sense designing a box you can't build. My building skills are fairly limited, so I build in a way that is tolerant of cutting mistakes. I would rather have no parallel walls in the woofer box, but I can't cope with cutting the angles required to build a pyramid-shaped box. I try to minimize the number of parallel walls while limiting the box to simple angle cuts; i.e., all cuts that are not on a rectilinear X-Y grid on the board's surface are vertical cuts, and all cuts at an angle other than 90° are on the X-Y grid. This makes cutting the boards much easier with a table or radial-arm saw.

Grille Frame

One of my construction limitations is that I can't build grille frames. Thus I make them part of the basic box structure by setting the front panel back a little from the front of the box. I can then simply staple the grille cloth right on the front of the box and cover it with some form of trim strips.

If you want to use another approach, you will have to modify my box design. Based on physical measurements of the drivers, I thought it best to set the front panel back ¾″ so as to have the grille cloth as close as possible to the panel, yet still protect the drivers.

ACTUAL BOX DESIGN

I wrote a BASIC program to design the enclosure. The back of the box is vertical and the top horizontal (*Fig. 24*). The front panel and bottom board are also at right angles to one another, but tipped to provide for the diffuser at the bottom and to slant the front panel for the proper listening angle. A 2 × 2 board is mounted on the back of the front panel just above the woofer.

The midrange enclosure has a horizontal top mating with the front panel between the midrange driver and tweeter, and a midrange bottom runs from the back of the 2 × 2 front-panel brace to the top of the midrange box at the

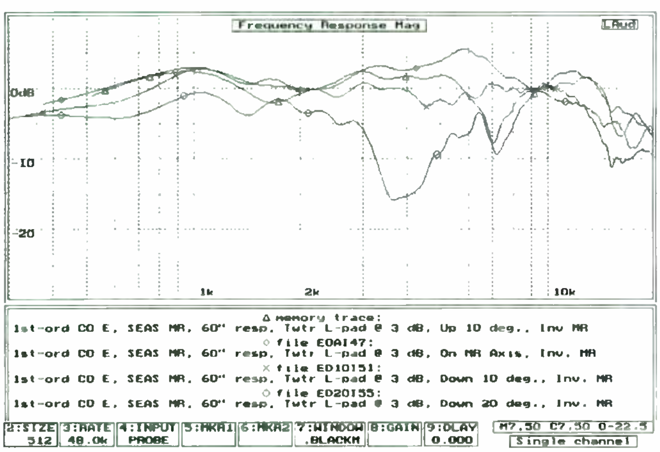

FIGURE 23: Summed responses for first-order crossover—inverted midrange polarity.

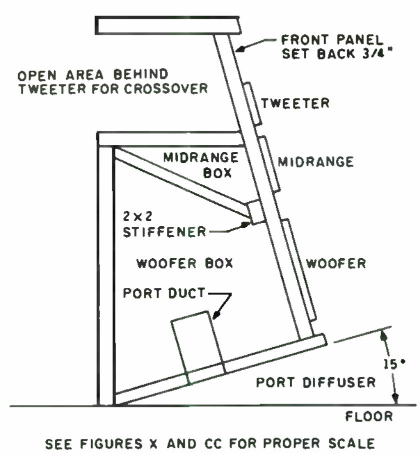

FIGURE 24: Basic internal configuration of box to be used.

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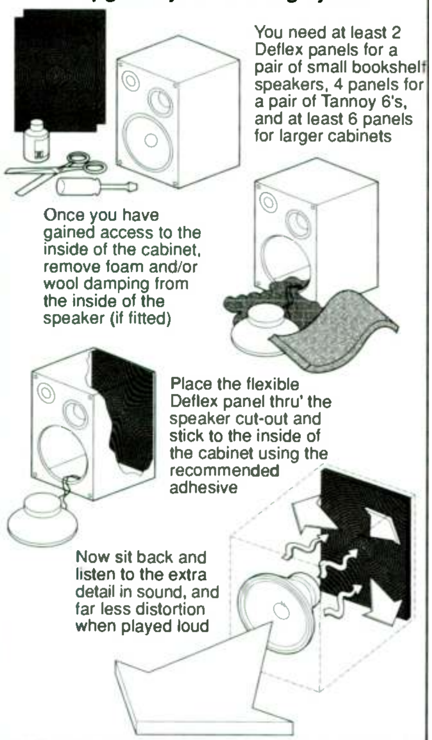

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back. All this results in the woofer box having only its sides parallel, and makes the midrange chamber a triangular box with small parallel ends. Thus the midrange box is a very stiff structure supporting the front panel.

Early results from the computer program indicated the slant needed for the front panel was greater than I had initially estimated, requiring more height on the panel. I therefore had to increase the driver spacings from those I had used in testing: the woofer to midrange center-to-center up from 8.5″ to 8.625″, and the midrange to tweeter up from 4.25″ to 4.3125″. Even with these increases, tolerances for attaching things to the front panel were tight.

Two options were available for locating the CO, which consists of two parts. One portion (called the Zobel board) contains the L-pad, Zobels, and padding resistors, and is used with either CO. The second part (called the CO board) is the first-order or third-order CO. One option is to put a portion of the CO in a pedestal below the port diffuser, but I settled on a configuration that extends the height behind the tweeter and puts both CO portions in this area. (Part 2 of this article will deal further with the crossover boards and components.)

8Ω L-PAD MOD

Over a small range of padding, the modified L-pad will be quite accurate in both attenuation and resistance. You must first establish the actual load resistance (R_L and less than 8Ω) and the nominal padding value (PdB) that you will use. You then place a resistance (R1) across the 8Ω L-pad from input to output and a resistance (R2) in shunt with the load. Refer to *Fig. 25.*

PdB = nominal padding value in positive dB
$K = E_{out}/E_{in}$ ratio for PdB padding
R_s = series resistance of L-pad at PdB padding
R_p = parallel resistance of L-pad at PdB padding
R_L = actual load resistance used
R_{in} = input resistance to modified network = R_L at PdB padding
R1 = resistance added input to output on L-pad
R2 = resistance added shunting load
$K = 10^{PdB/20}$
$R_p = 8 \times K/(1-K)$
$R_s = 8 \times (1-K)$
$R1 = R_s \times R_L/(8-R_L)$
$R2 = R_p \times R_L/(8-R_L)$
An example of using an 8Ω L-pad with a 6Ω load in the area of 3dB padding:
PdB = 3dB and $R_L = 6\Omega$
$K = 10^{3/20} = 0.7079$
$R_p = 8 \times 0.7079/(1-0.7079) = 19.392\Omega$
$R_s = 8 \times (1-0.7079) = 2.336\Omega$
$R1 = 2.336 \times 6/(8-6) = 7.009\Omega$
$R2 = 29.392 \times 6/(8-6) = 58.177\Omega$
When the L-pad is set to 3dB, the actual padding is 3dB and $R_{in} = 6\Omega$.

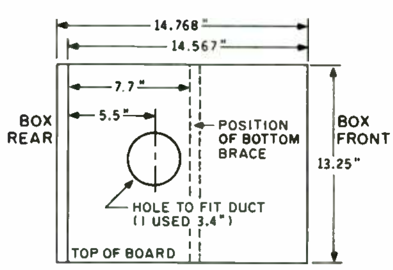

FIGURE 25: Schematic for L-pad modification.

INPUT AND OUTPUT

The input to the design program includes the front-panel dimensions, the woofer and midrange positions, the desired woofer volume, the actual 2 × 2 brace size and its location on the front panel, and the front-panel height in the tweeter area. The program output the size of the various boards, the midrange box volume, the various box dimensions, and the listening angle, which was based on an ear height of 42″ back 10′ from the midrange driver.

I judged that a vertical height of 6.9″ was needed to package the CO. We ran the design program with input data to provide this distance. The resulting design used for this project showed the final listening angle to be down 3.9°. After sketching the box, I concluded I could use a duct up to about 8″ long, and that an inside diameter up to about 3.0″ was safe.

Part 2 will describe the details of the project's construction.

SOURCES

Liberty Instruments, Inc.
PO Box 1454, West Chester, OH 45071
513-755-0252

Kim Girardin
Homer Rd., Winona, MN 55987

Madisound Speaker Components
University Green, Madison, WI 53744-4283
608-831-3433

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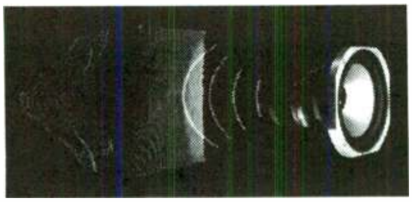

DEFLEX
ACOUSTIC PANEL TECHNOLOGY

TECHNICAL SPECIFICATION

	Standard Panel	*Sub-woofer Panel*
Material........................	Advanced polymer	Advanced polymer
Colour..........................	Charcoal grey	Charcoal grey
Surface emulation........	Spherical concave	Spherical concave
Defined radius - nominal.	200 mm	300 mm
Focal point - nominal.....	100 mm	150 mm
Thickness at centre.......	5 mm (maximum)	12 mm (maximum)
Max. edge thickness.....	12 mm	12 mm
Overall dimensions......	280mm x 210mm	340 mm Diameter
Density / hardness.......	1.36 / < 15º A	1.36 / < 15º A
Rebound resilience......	< 15%	< 15%

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SHOULD YOU DOWNLOAD YOUR WOOFER?

By Andy Lewis

Some audio systems include a woofer pointing toward the floor. This technique is sometimes referred to as *downloading* or *downfiring* the speaker. Listeners describe the sound of these systems in glowing terms, as if there were an inherent advantage to mounting a woofer in this way. They fail to specify, however, what this advantage is.

After considering this subject, I realized that I had many questions:

- Can this design technique offer better bass with a given woofer?
- Is a downfiring woofer really a selling point?
- What are its disadvantages?
- How far above the floor should I raise the bottom of the enclosure?
- Will a carpeted surface have an effect on its performance?

I decided to perform some simple tests to answer these questions.

DOWNLOADED SYSTEM

Figure 1 shows a traditional, or standard, system with the woofer oriented vertically and affixed to a panel. *Figure 2* shows a woofer mounted facing down, or downloaded, and the enclosure supported by nonspecific "feet," separating it from the floor. *Figure 3* shows the same downloaded system on a carpeted surface, to see what effect this might have on a system's performance.

In these illustrations, the enclosure is a simple sealed box, but in practice, the horizontal orientation is used in sealed, vented, and other systems. Although the measurements presented here are outside the discussion of primary loading methods (sealed versus ported, for example), we will see that positioning a woofer downward can affect your choice of enclosure type.

Three effects of downloading a woofer are: (1) an apparent change in the moving mass of the cone assembly, (2) a change in the damping characteristics (Q) of the driver, and (3) displacement of the cone assembly due to the force of gravity on the cone mass. While there may be other changes in performance, these three effects lend themselves to easy analysis.

MASS AND DAMPING

When a woofer "fires" into a restricted air space, as in the throat of a horn or in a downloaded system, the result is what horn theorists refer to as a "high pressure-low velocity" situation. This is a fancy way of saying that the air in the vicinity of the cone is moving (wind), instead of merely acting as a medium for traveling waves (sound). As a pressure front travels the length of a horn, of course, it undergoes a gradual transformation to a high velocity-low pressure condition, or sound wave.

In a downloaded system, no provision exists for this gradual transformation from moving air to sound wave. Instead, it is abrupt and unpredictable. We do know, however, that air has mass, which, when moving in conjunction with the speaker's cone, could have the effect of increasing the apparent moving mass of the driver. Horn designers, in fact, often calculate the volume of the air chamber behind their diaphragm expressly to compensate for the added air mass being "dragged" by the cone.[1] In a simple downloaded system, I had expected the result of this added mass to be insignificant, but this was not the case.

Also, as the speaker pushes air back and forth between the bottom of the downloaded system and the floor, energy is lost to friction. Frictional energy losses (damping) in the driver are expressed as Q_{MS}, and Q_{ES} for electrical damping. You would expect this new loss, when added to the soup, to cause a lowered Q_{MS}, which would in turn lower Q_{TS}. A carpeted surface under the speaker might tend to increase this loss and lower Q_{MS} still further.

SETUP

I figured that information about changes in mass and damping would be easy to express in numbers. I chose to measure the effects on the driver itself, and once I quantified and expressed the effects as a change in the parameters of the driver, then extending them to a finished downloaded system would become no more difficult than in a vertically oriented system. You could simply use these

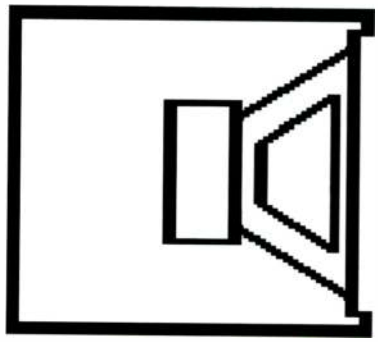

FIGURE 1: Standard vertical configuration.

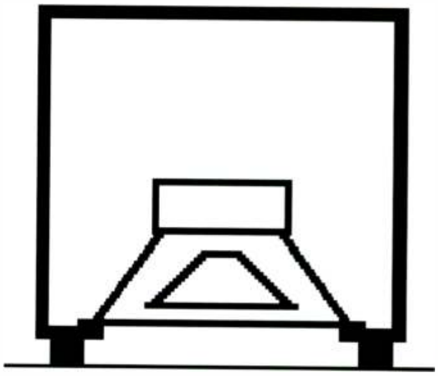

FIGURE 2: Downloaded (horizontal) system.

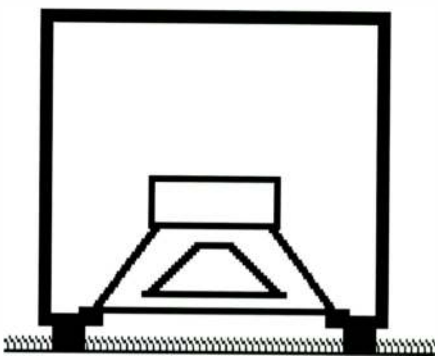

FIGURE 3: Downloaded system over carpeted surface.

ABOUT THE AUTHOR

Andy Lewis lives in Englewood, CO, with his wife Lori and two sons, Corey and Collin. He learned some physics at Hastings College, plays drums professionally in the Denver area, and has a consequent interest in bass guitar speakers. He can be reached by E-mail at Dadbag@aol.com.

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amended driver parameters and proceed with a design in the usual way.

Since each design has its own problems, the changes in effective driver parameters would provide an easy way to extend the results into your finished system. Consequently, I chose to measure without an enclosure. I simply mounted a speaker to a baffle, oriented the baffle in different ways, and performed measurements in each position.

I chose an old Electro-Voice 12″ woofer I had pulled from an ancient Knight 3-way system. It has a fairly low-moving mass (41gm) and a fairly high Q_{TS} (in excess of .5). These characteristics would make any changes in damping and effective mass more apparent as I made my measurements, as the effects of downloading the speaker would have a larger effect relative to the speaker's inherent mass and damping. A woofer with high-moving mass or a very low Q_{TS} would be less affected on a relative basis than this somewhat underdamped woofer with its low moving mass.

I mounted the woofer in the center of a piece of ¾″ particleboard scrap, about 20″ × 30″ (*Photo 1*). I soldered a length of zip cord to the terminals, so I could then make my measurements at the end of the zip cord, rather than at the speaker terminals themselves. This would allow me to move the speaker/baffle assembly to different positions as I made the different measurements without adding any wire. Any measurements of Q made with my fixed length of zip cord would reflect the presence of this wire in the circuit, but the results would be reliable for purposes of comparison.

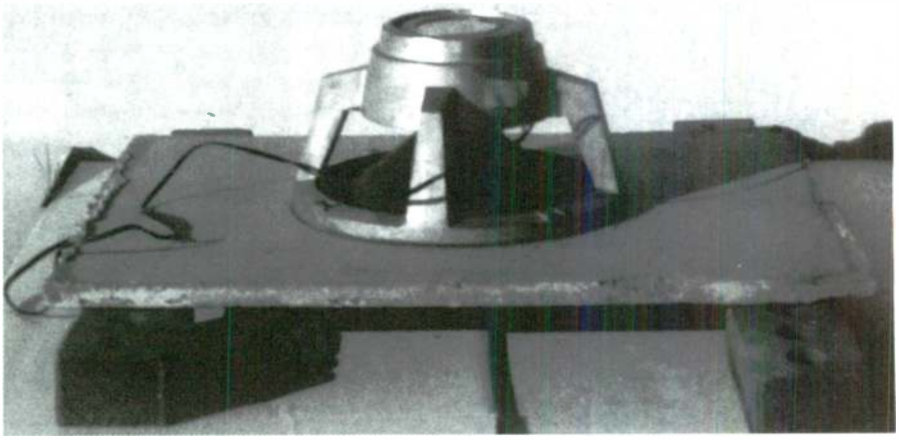
PHOTO 2: Test setup using bricks.

I could then orient this speaker/baffle assembly in different ways to measure the effects of downloading the woofer. With the speaker placed in different positions, I could isolate the effects of downloading the speaker as I measured the Q and resonance of the woofer.

TESTS

I performed tests with the speaker/baffle assembly in six different positions:

1. With the baffle standing vertically, as in a standard system (*Photo 1*). This would be the control, against which I would compare other scenarios.
2. With the baffle suspended woofer-down on bricks placed on their sides, one at each corner, with the baffle about 3½″ above a concrete surface. This is the first downloaded scenario.
3. With the baffle suspended woofer-down on bricks lying flat, one at each corner, with the baffle about 2¼″ above a concrete surface (*Photo 2*). This is the second downloaded scenario.
4. With the baffle suspended woofer-down on 2″ × 2″ blocks, one at each corner, with the baffle about 1½″ above a concrete surface (*Photo 3*). This is a more extreme downloaded scenario.
5. With the baffle suspended woofer-down on 2″ × 2″ blocks, one at each corner, with the baffle about 1½″ above a ½″ thick carpeted surface (*Photo 4*).
6. With the speaker oriented vertically, but with a mass of modeling clay added to the cone's moving mass, to simulate a mass of moving air, and as a consequence remove frictional loss. This is explained in greater detail below.

These first four positions measure the increasing effects as the baffle is lowered toward the floor. As the tests were run, I hoped a pattern might emerge that would provide a "feel" for what to expect from the downloading technique.

In each of the six positions, I connected a standard impedance-measuring setup and measured the damping (Qs) and resonance frequencies (f_S). The resonant frequency, of course, is the frequency of maximum impedance in the bass region. Q_{MS}, Q_{ES}, and Q_{TS} figures are derived from impedances measured at several frequencies. I use the standard derivation found in most popular texts.

While these tests give us a generalized


PHOTO 1: Vertical speaker baffle.

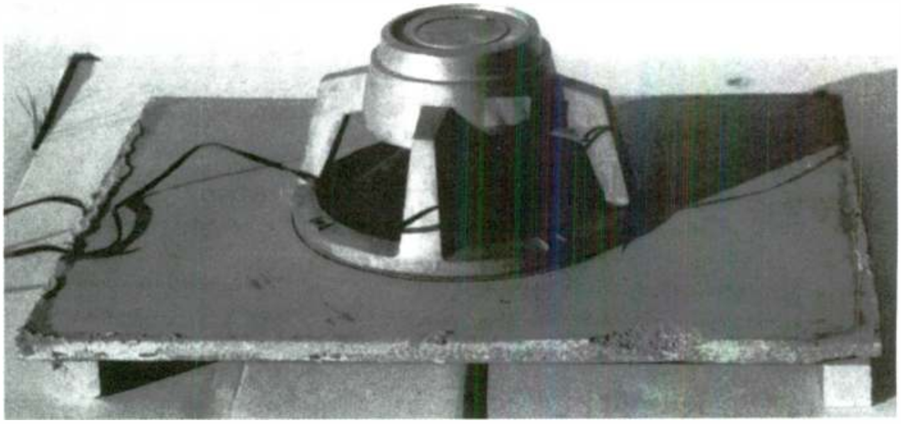
PHOTO 3: Lowering the baffle on blocks.

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idea of the effects of downloading, it is important to realize that they should be performed with a setup that more closely approximates the finished system (with a more realistic baffle size and an enclosure). Otherwise, unpredictable results could occur.

RESULTS AND INTERPRETATION

Table 1 shows the measurement results. Please note that column 8, "EBP," lists the calculated "Efficiency Bandwidth Product," which is simply the ratio of f_S to Q_{ES}, for the speaker in each position. This refers to the popular, and very concise, method for evaluating whether a speaker is better-suited for a sealed or vented enclosure.[2] A rule of thumb states that an EBP around 50 indicates the driver will probably be better-suited to a sealed enclosure, while a value of 100 places the speaker in a vented system.

Interestingly, the change in resonance as the baffle is lowered toward the floor is dramatic. For example, going from 38.3Hz to 33.2Hz represents a change of about 13%! We know that the compliance of the woofer's suspension is unchanged, so the change in resonance must be due to the mass of the air in the vicinity of the cone, as it moves with the cone. We can, in turn, calculate the mass of this air for each test scenario.

An accepted test exists for determining the compliance and moving mass of a driver. When a known mass (such as a lump of modeling clay) is artificially added to a speaker's cone, the resonance is obviously lowered. The amount by which the frequency of resonance changes reveals the speaker's inherent moving mass. If we already know the cone's actual mass, however, we can determine the mass added to the cone.

ADDED MASS

A woofer's moving mass, the change in resonance, the speaker's original resonance, and the known mass of the clay (or air, in this case) are related by the following equation[3]:

$$M_{MD} = M' / [(f_S / f_S')^2] - 1 \qquad (1)$$

where:

M_{MD} = the woofer's moving mass
M' = added test mass of clay (air)
f_S = speaker's natural resonance
f_S' = lowered resonance with test mass added.

If we know the speaker's true moving mass, we can determine the mass of the moving air:

$$M' = M_{MD} \times [((f_S / f_S')^2) - 1] \qquad (2)$$

where:

M' = the effective mass of air moving with the cone.

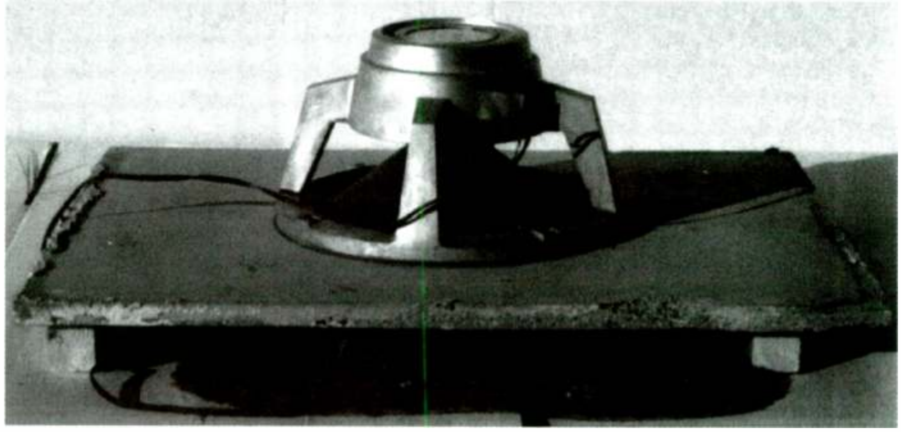

PHOTO 4: Testing the effects of a carpeted surface.

I made these calculations for each of the downloaded test scenarios, using an M_{MD} of 41gm and the relevant quantities in *Table 1*, and entered in column 7 the apparent mass that has been added to the cone in each case. As the enclosure is lowered toward the floor, the amount of air under the baffle decreases, but the amount of air which apparently moves with the cone increases! I was surprised by the amount the speaker's resonance changed in these tests.

When referring to masses of air, I find it interesting to consider the actual physical volume of the air in question. How much air represents a gram of mass? A typical figure for the density of air at sea level is 1.29×10^{-3}gm/cm^3. The volume of a gram of air, then, would be the inverse of this figure, or 775. A gram of air occupies about 775cm^3 of space, or about three quarters of a liter![3]

Within the context of this downloaded setup, this allows us to calculate, more or less, the volume of air under the speaker actually moving with the speaker's cone. If we multiply the mass of the air moving with the cone (6.99gm, column 7, 2¼″ bricks) by the volume per mass (775cm^3/gm), we get a figure of 5417cm^3, effectively about 5.4 liters of moving air.

Q AND DAMPING

With regard to damping (Qs), I expected to see a clear decrease in the figures for Q_{MS} as the woofer was lowered. The extra friction should tend to lower the Q_{MS} of the driver as the air is pushed and pulled through the restricted air space. As a general rule, when friction goes up, Q goes down! As Q_{MS} decreases, Q_{TS} decreases as well.

The test results, however, seem to contradict my expectations. Column 4 shows that unless carpet is added under the system to increase friction, the relationship between downloading and Q_{MS} is unclear at best. In fact, the Q_{MS} figures in the vertically oriented system and the very low (1½″) example change only from 5.70 to 5.71. The interim examples seem to gyrate somewhat, and no clear pattern occurs.

As friction is increased with the addition of a carpeted surface, Q_{MS} decreases when compared to scenario 4. From earlier experiments, I noticed that adding mass to a speaker's cone generally has the effect of raising both the Q_{MS} and Q_{ES} of a driver. Could it be that the Q_{MS}-lowering tendency of the air friction was being overwhelmed by the Q_{MS}-raising effect of the additional moving mass of the air?

TABLE 1

MASS AND Q TEST DATA

TEST #	ORIENTATION	F_S (Hz)	Q_{MS}	Q_{ES}	Q_{TS}	G_{MS} AIR	EBP
1	Vertical	38.3	5.70	0.651	0.584	N/A	58.8
2	On 3½″ bricks	37.3	5.90	0.676	0.607	2.23	55.2
3	On 2¼″ bricks	35.4	5.77	0.683	0.611	6.99	51.8
4	On 1½″ blocks	34.5	5.71	0.738	0.653	9.53	46.7
5	1½″ blocks, carpet	33.2	5.11	0.749	0.654	13.56	44.3
6	Added mass vertical	34.4	6.09	0.753	0.670	N/A	45.7

TABLE 2

AIR LOADING VS. ADDED MASS

TEST #	ORIENTATION	F_S (Hz)	Q_{MS}	Q_{ES}	Q_{TS}	G_{MS} AIR	EBP
4	On 1½″ blocks	34.5	5.71	0.738	0.653	9.53	46.7
6	Added mass vertical	34.4	6.09	0.753	0.670	N/A	45.7

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ANOTHER TEST

This apparent conflict between two opposing consequences of downloading the woofer suggested the last test scenario, in which the woofer is oriented vertically, but with extra mass added to the cone to simulate a mass of moving air. By artificially lowering the effective f_S to the point of resonance in the downloaded example, you can effectively remove the frictional loss and measure the effects of added mass independently of the air friction.

Because the speaker is not firing into a restricted air space in this added-mass test, the friction of creating wind under the baffle is removed. Additionally, if you used a test mass similar to one of the previous downloaded examples, this added-mass test could isolate any Q_{MS}-decreasing effect of air friction associated with the woofer's downloading itself. I chose the third downloaded setup (#4) to simulate in this fashion. I simply added the modeling clay to the cone to decrease the resonant frequency to the desired point and to simulate the mass of the added air in the equivalent downloaded setup.

With the speaker oriented vertically and the correct mass added to the cone, I performed the (#6) test (*Table 2*). The #4 and #6 figures for f_S don't quite match, due to the limitations of the accuracy of my work and equipment. A difference between 34.4Hz and 34.5Hz is probably less than my measurement error itself, and I chose to ignore it.

But, when you compare the results of these two tests, the frictional loss in test #4 does appear to lower Q_{MS} substantially. When the frictional loss is removed, as in test #6, Q_{MS} is increased from 5.71 to 6.09. In the downloaded system, with the loss in place, Q_{TS} is decreased from .670 in test #6 to .653 in test #4. I characterize this change as substantial. Apparently, the frictional loss associated with downloading itself is significant; however, it tends to be obscured by the more influential effect of an increase in effective moving mass, resulting in a general increase in Q_{TS} when a woofer is downloaded.

EFFECT OF DISPLACEMENT

A woofer in its position of equilibrium, or zero excursion, in a standard vertical orientation (*Fig. 4*) normally is manufactured with its voice coil centered in the magnetic gap (note the position of the voice coil as indicated by the arrow). One effect of mounting the speaker face-down (or face-up) is that the earth's gravitational field exerts a force on the moving system of the unit, which tends to pull the voice coil out of its centered position. *Figure 5* shows a driver face-down, with the inset showing the voice coil slightly displaced from center (arrow).

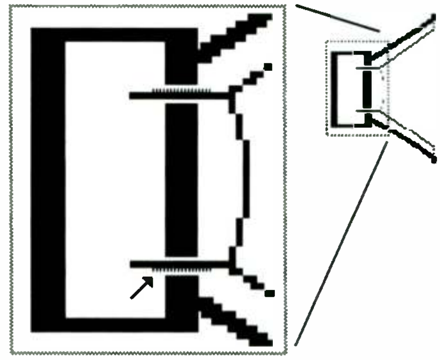

FIGURE 4: Voice coil centered in gap in vertically oriented mounting.

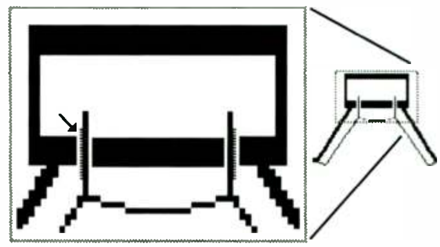

FIGURE 5: Voice coil pulled from center position when mounted horizontally.

The magnetic field of the speaker's magnet is concentrated in the magnetic gap. The turns of wire that make up the voice coil are immersed in this field. As electrical current passes through the voice coil, the magnetic field exerts a force on each turn of wire. The equation describing the force on a conductor in a magnetic field is:

$$F = Bli \quad (3)$$

where:

F = force on the conductor
B = magnetic field strength
l = length of the conductor immersed in the magnetic field
i = electrical current in the conductor

You can see from this equation that when Bl remains constant, force is proportional to current. The length of the conductor in the field, in the special case of a loudspeaker, is equal to the length of each turn of wire times the number of turns in the gap. As long as the number of turns remains constant, the "Bl product" will be a constant as well, and the speaker will work as it should, with force on the voice coil in direct proportion to current through the wire voice coil.

In extreme situations, when a speaker is required to reproduce signals with long woofer excursions, a voice coil will sometimes move far enough to exceed the length of the windings. This over-excursion causes

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the number of turns of wire in the gap to be reduced from that when the driver is in its equilibrium position (*Fig. 5*). When this happens, the Bl product is reduced, because as the number of actual turns decreases when excursion is long, the effective length of wire in the field decreases.

As the Bl product decreases, the force on the voice coil is no longer in direct proportion to input current, and the performance of the motor is nonlinear, i.e., distortion or breakup occurs. The X_{MAX} parameter describes one-way linear excursion limit.

Small and others[4] have described "displacement-limited power handling" in terms of the volume of air displaced at maximum linear excursion:

$$P_{AR} = f_3^4 \times V_D^2 / (3 \times 10^8) \qquad (4)$$

where:

P_{AR} = displacement-limited power handling
V_D = volume of air displaced at maximum linear excursion
f_3 = 3dB down point

In turn,

$$V_D = X_{MAX} \times S_{SD} \qquad (5)$$

where:

X_{MAX} = maximum linear excursion
S_{SD} = cone area

Consequently,

$$P_{AR} = f_3^4 \times (X_{MAX} \times S_{SD})^2 / (3 \times 10^8) \qquad (6)$$

Actual displacement-limited power handling is proportional to the square of X_{MAX}, so any reduction in X_{MAX} will have a disproportionate effect on actual system power handling. As gravity exerts a force on the speaker's moving assembly, and the voice coil is in turn displaced from its centered position, power handling can be reduced.

POWER-HANDLING REDUCTION

Gravity's force on a speaker's moving assembly is equal to the mass of the moving system times the acceleration due to the earth's gravitational field:

$$F_{MD} = M_{MD} \times g \qquad (7)$$

where:

F_{MD} = force on the moving system in dynes
M_{MD} = the speaker's moving mass in grams
g = acceleration due to the earth's gravity
$= 9.80\ m/s^2 = 9.80 \times 10^2$ dyn/gm

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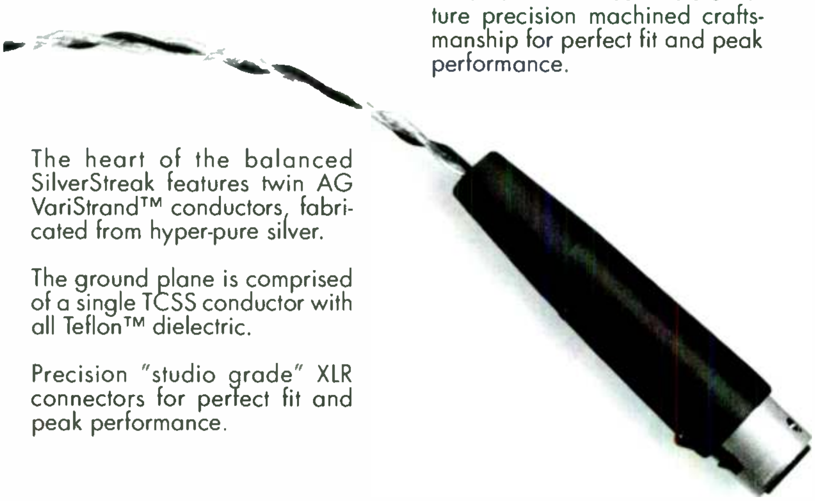

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Displacement due to gravity then will be equal to the downward force on the cone times the compliance of the speaker's suspension:

$$D_G = F_{MD} \times C_{MS} \qquad (8)$$

where:
D_G = displacement due to gravity in cm
C_{MS} = speaker compliance in cm/dyn

Amended X_{MAX} would then be equal to the original linear excursion minus displacement due to gravity.

$$X_{MAX}' = X_{MAX} - D_G \qquad (9)$$

where:
X_{MAX}' = amended linear excursion limit

Since displacement-limited power handling is proportional to the square of X_{MAX}, the factor relating vertical and downloaded power-handling figures will be equal to the square of the ratio of the two:

$$P_{AR}' / P_{AR} = (X_{MAX}' / X_{MAX})^2 \qquad (10)$$

where:
P_{AR}' = amended displacement-limited power handling.

TABLE 3

POWER-HANDLING REDUCTION IN SEVERAL DRIVERS

DRIVER	M_{MD} (gm)	F_{MD} (dyn)	C_{MS} (m/N)	C_{MS} (cm/dyn)	DISP (cm)	X_{MAX} (cm)	X_{MAX}' (cm)	P_{AR}'/P_{AR}
Audax HM100XO	3.23	3165.4	0.00225	0.00000225	0.0071	0.23	0.2229	0.939
Peerless 1599	12.2	11956	0.00015	0.00000015	0.0018	0.3	0.2982	0.988
Eton 11-580	23	22540	0.000094	0.000000094	0.0021	0.4	0.3979	0.989
Audax PR300MO	33	32340	0.000264	0.000000264	0.0085	0.44	0.4315	0.962
Dynaudio 30 W-100	35.2	34496	0.000121	0.000000121	0.0042	0.8	0.7958	0.990
Madisound 12204	106	103880		0.00000048	0.0499	0.6	0.5501	0.841
Audax PR380MO	115	112700	0.000062	0.000000062	0.0070	0.38	0.3730	0.964
Madisound 15254	160	156800		0.00000048	0.0753	0.55	0.4747	0.745

Using these equations, along with a speaker's mass and compliance data, you can then see what effect gravity can have on power handling in a downloaded system. Without linear-excursion data (X_{MAX}) for my old Electro-Voice, I used the manufacturer's data for several drivers to calculate the anticipated loss in linear excursion and displacement-limited power handling (*Table 3*).

In the event you need to determine your own figures, here is the simple mathematical relationship between mass, compliance, and resonant frequency:

$$f_S = 1 / [2 \times \pi \times (M_{MD} \times C_{MS})^{1/2}] \qquad (11)$$

You can derive compliance from figures provided for resonance and moving mass:

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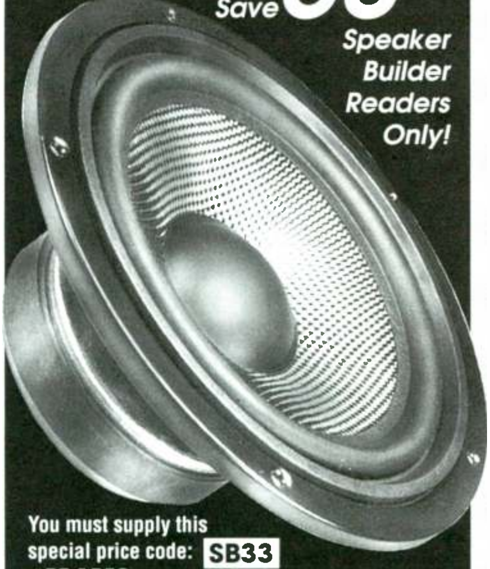
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$$C_{MS} = 1 / [(2 \times \pi \times f_S)^2 \times M_{MD}] \quad (12)$$

Make sure you use consistent units. For example, in *Table 3* I converted m/N in column 4 to cm/dyn in column 5. This information indicates that the effects of gravity on voice-coil centering range from significant to inconsequential. The two woofers most affected (the two Madisound models) both exhibit high-moving masses and high compliances, as you'd expect.

Keep in mind that these calculations are parameter related, and indicate nothing about the relative quality of any of the units listed. They may, however, provide an insight into their relative usefulness for downloading.

As a rule of thumb, when evaluating a woofer's suitability for downloading, high mass and compliance are your enemies, if high power handling is a consideration. A high figure for a speaker's X_{MAX} is your friend, as gravitational displacement will be smaller compared with the original X_{MAX}.

CONCLUSIONS

These tests demonstrate that downloading a woofer can change a woofer's apparent parameters. As a system is oriented horizontally and lowered toward the floor, the driver's frequency of resonance decreases due to an apparent increase in moving mass, as air in the cone's vicinity moves with the cone itself. This added mass results in an increase in driver Q_{TS}, which the frictional loss associated with the movement of this air somewhat mitigates.

As the speaker designer, you can anticipate a moderate increase in effective Q_{TS} and a decrease in apparent f_S when you download a woofer. The best conditions involve a woofer with a somewhat low Q_{TS} or one with a somewhat high inherent f_S. In practice, this would suggest a speaker with an EBP that needs to be decreased, or that might become more useful through a reduction in EBP. In addition, using such a system over a carpeted or other "lossy" surface can significantly affect damping, and can lower Q_{TS}, or at least reduce the increase in Q_{TS}.

From this look at the effects on mass and damping, it is clear that to proceed with a design of this type without some careful consideration could produce a system that does not operate as intended. If you capriciously apply this technique to a woofer without accounting for its effects, you'll be working with design goals that could be vague, and achieve an unpredictable result. When carefully used, however, downloading can change effective driver parameters in special cases, i.e., when the driver could be helped by a lower f_S, higher Q_{TS}, or lower EBP.

Another effect of downloading is that the force of gravity tends to pull the voice coil from its centered position, resulting in a decrease in maximum linear excursion for the driver and a decrease in displacement-limited power handling. This effect will vary in importance from woofer to woofer, and will be most harmful in drivers exhibiting high compliance, large moving mass, and short inherent linear-excursion capability. Be sure to evaluate the effect gravity will have on the woofer before choosing your driver.

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2. Vance Dickason, *Loudspeaker Design Cookbook*, Marshall Jones Co., Third Edition, 1987, p. 5. Attribution to Small.

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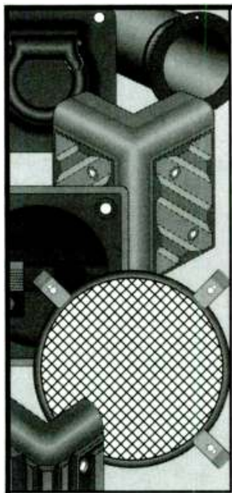
4. Richard Small, and Margolis, "Personal Calculator Programs," JAES, June 1981, p. 422.



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Reader Service #48

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THE AFTERSHOCK SUBWOOFER

By Philip E. Abbate

One night I was screening the *True Lies* laserdisc at theater-reference volume. This means that the *va-rooom* during the THX logo at the beginning of the disc peaks at 105dB. During a very loud passage, I could swear I felt the house move. I replayed the passage and was convinced that what I felt was in the movie. I mentally noted the time.

I found out the next day that there had been a 2.7 aftershock on the Northridge fault at that moment. Using this information to calibrate the sensation, I predict that my subwoofer (*Photo 1*) could mask a 2.0 Richter-Scale quake at the epicenter—thus the name Aftershock.

My Aftershock subwoofer uses two re-coned, 15″ Altec Lansing 421-8H bass speakers in a 111-ltr vented Isobarik cabinet. The Woofer Wizard Subwoofer Crossover (*SB* 6/92, p. 16, Old Colony PN KF-7A) sums left, right, and preamp outputs into a mono feed that rolls off the highs starting at 60Hz, and the lows starting at 18Hz. A vintage Yamaha M4 power amplifier delivers 120W to each driver's 8Ω load. The Wizard's underdamped 20Hz high-pass filter adds 9dB of gain at 20Hz to effect a sixth-order system that cranks out a full 108dB at 20Hz in my living room when placed appropriately in a corner.

A BLAST FROM THE PAST

My circa 1970 Altec woofers (*Photo 2*) are typical of many models from past years and some that are currently manufactured for the professional stage. When a friend dusted them off and showed them to me, I fell in love with them. When he gave them to me, I almost fainted. He knew I would somehow make these beauties sing again.

Everything about the speakers is heavy

PHOTO 1: Aftershock complete.

duty. They weigh 26 lbs each; I can flick the dust cap with my finger without phasing it. Comparing these drivers with today's typical hi-fi models would be like comparing a 1970 Coupe de Ville to a Ford Festiva.

The 421's heavy cast-aluminum frame minimizes energy transfer to the enclosure, and the 1″ lip facilitates mating of the two drivers in a face-to-face Isobarik configuration—outside of the enclosure! The driver uses a massive aluminum nickel cobalt (alnico) magnet. The force field this magnet develops, in conjunction with the underhung 3″ edgewound aluminum voice coil, makes this a very efficient driver.

The large top plate assures that the voice coil stays in the gap throughout the X_{MAX} excursion, providing superior linearity and low distortion because the coil is always driven by a constant magnetic field. Also, since the coil is totally enclosed by a large amount of steel and the speaker has a rear-vented pole piece, the driver unit has good thermal stability, high power handling (200W all day long), and dynamic capability. The fabric surround keeps the system aligned despite the force the motor can exert, and it should last longer than the generations of Star Trek.

COLLECTING THE FACTS

Initial tests revealed an open voice coil in one of the 421s. I decided to attempt to design an enclosure with one speaker and then repair the second if necessary. I located Altec Lansing in Oklahoma (of all places) and found out that ElectroVoice had absorbed its pro-audio division. Steven Upchurch, an original Altec employee from California, was kind enough to provide me with the specifications for the 421-8H and its near twin, the 421-LF. He told me that if I wasn't satisfied with the 421-8H, I could re-cone the blown speaker with 421-LF parts, which would fit the 421-8H frame.

I measured my working 421-8H's Thiele/Small parameters using the constant-current method as described in *Bullock on Boxes* (from Old Colony, PO Box 243, Peterborough, NH 03458, 603-924-6371, FAX 603-924-9467, #BKAA8). The factory specifications, my measurements, and the averages I used for input into the modeling programs appear in *Table 1*.

PRELIMINARY DESIGN HOMEWORK

To design a box of appropriate size, I used my 421-8H's f_S and Q measurements with

PHOTO 2: Altec 421 drivers.

ABOUT THE AUTHOR

Phil Abbate, a registered professional electrical engineer, was inspired to build his first speaker cabinet in 1969 when his uncle introduced him to John Karlson, designer of the Karlson enclosure. Phil Abbate's Karlson cabinets were the first in a long line of folded and straight horn speakers built for live-music production and reinforcement. Having taken a break from audio to raise two children and earn B.S. and M.S. degrees, he refound his first love when he discovered *Speaker Builder* three years ago.

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TABLE 1

SPEAKER PARAMETERS

REF:	1	2	3	4	5	6
f_S	31.5	27.5	44.23	34.4	34.7	34.5
V_{AS} (1)	361	569	258	139	181	80*
Q_{TS}	0.25	0.25	0.4341	0.47	0.524	0.497
Q_{ES}	0.27	0.28	0.534	0.548	0.61	0.579
Q_{MS}	2.6	2.75	2.323	3.29	3.71	3.5
X_{MAX} (mm)	13.	13.	13.	13.	13.	13.
SD (cc)	858	858	858	858	858	858
R_E (Ω)	5.5	5.5	5.3	5.1	5.1	5.1

1 = Factory, 421-8H
2 = Factory, 421-LF
3 = My 421-8H
4 = First 421-LF recone
5 = Second 421-LF recone
6 = Values plugged into BoxModel

* Average/2 used as Isobarik V_{AS}

the 361-ltr V_{AS} supplied by the factory as input to Ralph Gonzalez's LMP box program (shareware downloaded from the Madisound BBS). LMP determined that the size of an optimal SBB4 aligned ported box was 303 ltr for an f_C of 71Hz and an f_3 of 72Hz.

LMP also suggested larger, refrigerator-size boxes for other ported alignments, which in my estimation would yield equally disappointing bass. LMP predicted that a 204-ltr closed box would have a poor f_C of 44.2. Looking at the massive driver and doubting LMP's prediction, I confirmed LMP with Boxmodel V2.1 (Old Colony SOF-MOD3B5G) and concluded that the 421-8H would not produce sufficient quantities of bass under 30Hz to satisfy my subwoofer requirements.

What bothered me most was that my f_S and Q measurements were significantly different from Altec's specs, which made me also suspect its V_{AS} specification. I thought the drivers' Thiele/Small (T/S) parameters might have changed in use or in its ten-year hibernation three miles from a Southern California beach. I just couldn't believe that this beautiful massive driver was unable to produce more low bass than the 8″ Focal drivers currently in my system.

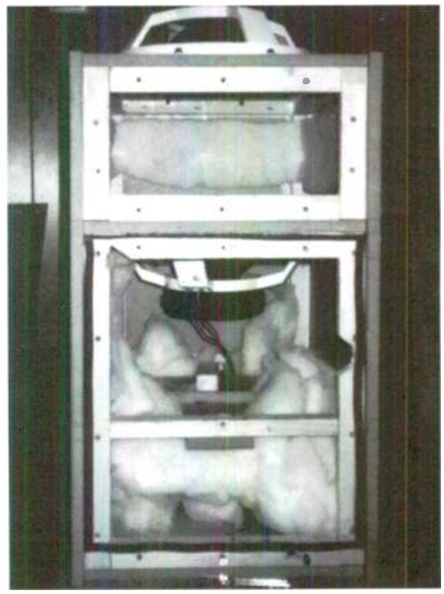

PHOTO 3: Prototype design.

At this point, I decided that since I had not yet invested any money, I could afford to buy a 4′ × 8′ piece of MDF, build the largest box possible from it, measure V_{AS}, and listen to this driver. The prototype box (*Photo 3*) would be 166 ltr and measure 18″ × 24″ × 33″.

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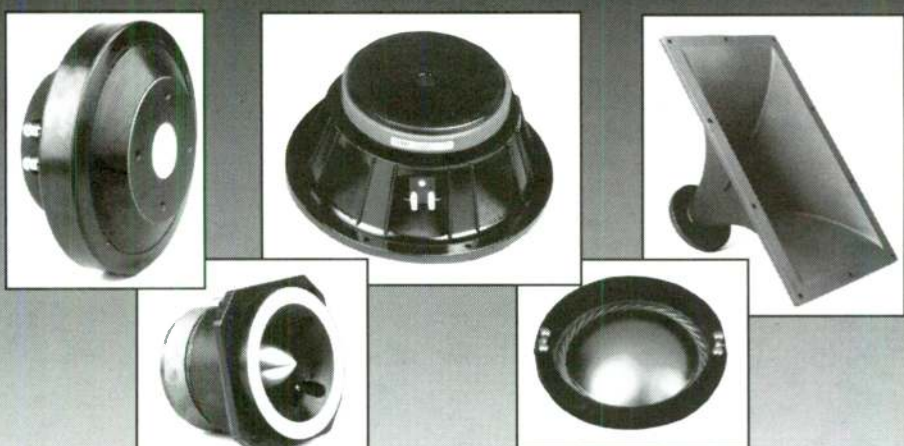

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I continued to wonder what would happen to my design by plugging the factory specs for the 421-LF into Boxmodel using a constant 166-ltr volume and evaluating closed-box and various ported and Isobarik alignments. My Isobarik evaluation assumed I would compound-load the two drivers face to face, and that V_{AS} for the pair would be half the average of the two V_{AS} figures.

At this point, I must admit, I had not realized what a sixth-order alignment could do for me, so the best I could do was synthesize a couple of Isobarik ported alignments with the 166-ltr box that extended to 20Hz. The output level was attenuated about 9dB at 60Hz and falling rapidly. I reasoned that, since I would cross over the subwoofer below 60Hz and the Altecs' efficiency was relatively high, I would be able to realize a believable 20Hz sound-pressure level out of a 166-ltr box.

At the time I was designing my 166-ltr prototype box, I was intrigued by Matt Federoff's birdhouse ("The Birdhouse: A Sound Reinforcement Subwoofer," *SB* 2/94, p. 36). Matt's Carvin driver was similar to my Altec. Augspurger's recommendation that bass enthusiasts interpolate the designs in his article ("More About The Birdhouse Bandpass," *SB* 4/94) influenced me to make a modular prototype box approximately the same size as Federoff's. What's more, the modular design of my box would be suitable for measuring V_{AS}.

PROTOTYPE ENCLOSURE

With Aftershock's modular enclosure, I could experiment with the Altecs in a variety of configurations. The enclosure had a 55-ltr chamber and a 111-ltr chamber with removable side covers, and a baffle board with a hole in the center to fit an Altec, dividing the enclosure into two sections. The outside end of the 55-ltr section eventually evolved into a second baffle, with a hole cut to fit an Altec.

The test enclosure enabled me to measure V_{AS}, which appears in *Table 1*. My experimental configurations are listed below.

- Fifth-order bandpass with a sealed 55-ltr box firing into a 111-ltr ported enclosure, and a sealed 111-ltr enclosure firing into a 55-ltr ported enclosure.
- Sixth-order bandpass with both the 55 and 111-ltr ends ported.
- Sealed 55, 111, and 166-ltr enclosures.
- Ported 111, 55, and 166-ltr enclosures.
- Ported Isobarik with 111-ltr volume and the 55-ltr volume acting as a compression chamber.

Since Aftershock was going to a cutoff below 70Hz, I figured that configurations with the rear of the Altec firing out into the room or into an uncovered chamber would not sound much different than the typical subwoofer configuration with the front of a driver firing into a wall or the floor.

CONSTRUCTION

I used the butt-joint, screw, glue, and batten construction technique to build the prototype (*Photo 3*). I ripped kiln-dried 2″ × 4″ studs into three equal strips on the radial-arm saw and used them for the battens. All the sides were anchored to the battens with screws piercing the ¾″ medium-density fiberboard (MDF).

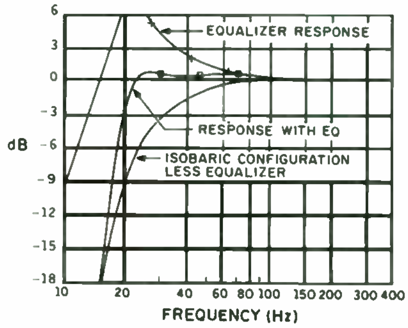

FIGURE 1: Sixth-order design.

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I cut the panels for the box with a 7.25″ circular saw because the wood was too large to control on the radial-arm saw table.

To assemble the prototype, I laid the two largest pieces (32″ × 18″) across the sawhorses and clamped glue-coated battens to the sides, ¾″ from the four edges. Once I'd set a batten with clamps, I flipped over the MDF sheet and screwed it to the batten with 2″ drywall screws. I also installed a batten for attaching the parting baffle.

Next I cut the three 24″ × 18″ pieces. I selected one as the parting baffle, cut the speaker hole in it with a jig saw, and installed T-nuts so I could easily remove and replace the driver. I installed two battens ¾″ from the edges of all three of these pieces on the 24″ sides. I then glued and screwed the two 18″ × 24″ sides and the 18″ × 24″ parting baffle to the two 32″ × 18″ pieces. I glued and screwed the 24″ × 32″ back to the framework of battens, which completed the box except for the side covers. All the screws pierced the MDF, anchoring it to the battens.

I attached the removable side covers with T-nuts, laying the covers into the cabinet and drilling slightly undersized pilot holes through the covers into the battens to be sure the holes registered with the T-nuts. Removing the covers, I held each T-nut behind the batten and threaded an oiled ¼″ cap-head screw with a washer on the cap side into the T-nut. I tightened the cap-head screw with an allen wrench, pulling the T-nut into the undersized pilot hole and thus seating it into the batten. When all the T-nuts were seated, I attached a ½″ strip of adhesive-backed, open-cell weather strip to the batten to seal the cabinet when I installed the side covers. Finally, I sealed all of the internal batten joints with 100% silicon sealant.

INITIAL TESTS

I installed the original 421-8H in the center baffle and sealed the side cover of the 111-ltr chamber. I then measured the original 421-8H's T/S parameters in the sealed box so I could calculate V_{AS} using the closed-box method described in paragraph 8.70 of Vance Dickason's *The Loudspeaker Design Cookbook*.

Before taking serious measurements, I swept the cabinet with sine waves from 15Hz to 1kHz to check the test box for rattling or buzzing noises. I also checked for air leaks using a 30Hz tone to excite the cabinet, and running the flame of a lighter along all the joints. Since the flame was not disturbed, I was sure there were no air leaks. I found f_C with the box sealed, remeasured the Qs in the box, and calculated V_{AS}.

TABLE 2

BOXMODEL INPUT PARAMETERS

F_S	35.4Hz	V_B	111
V_{AS}	80.0 ltr	F_B	25.5
Q_{ES}	0.579	Filter order	second
Q_{MS}	3.500	Cnr	20Hz
R_E	5.1Ω	Dmp	0.4587
S_D	858	Vent diameter	10.6cm
P_E	200W	Vent length	29.9cm
X_{MAX}	7.1mm		
Q_{AS}	28		
Q_{LS}	14		
Q_{PS}	28		

I couldn't wait to listen to the speaker, so I rigged up a 12dB/octave LP crossover using a handy 13mH choke and 75µF capacitor, and connected the sealed cabinet and crossover across the left-channel output from my amplifier. The sub's output was 3dB more efficient than the pair of Focal 8V01/4 and T90Ti 91dB+ satellites, but subjectively no bass extension was added to the soundstage.

I decided to port the enclosure to squeeze some low bass out of the subwoofer and measure V_{AS} with the vented-box method to

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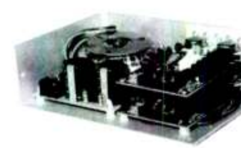

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World Radio History

confirm my closed-box method measurements. To port the enclosure, I removed the side cover and used my radial-arm saw to cut a hole $^{1}/_{16}''$ smaller than the 3″ diameter shipping tube I intended to use as the port.

I used a razor to scribe a line around the shipping tube ¾″ from the end, and peeled off layers of cardboard until the end of the tube would fit into the hole in the baffle. The uncut end butted up against the baffle, sealing the hole. My initial experiments had the tube on the outside of the cabinet to facilitate rapid adjustments and A/B testing. I used a pair of 5″-long 3″-diameter tubes to measure F_H, F_M, and Fl, and calculated V_{AS} using the vented-box method. As I suspected, the average measured vented/closed box results for V_{AS} (*Table 1*, ref 3) were very different—fortunately for the better—from those specified by the manufacturer.

I used my new V_{AS} value and Boxmodel to calculate suitable vent lengths, and tried various arrangements of bandpass designs, but was not satisfied with the sound. Using the signal generator, I could generate 110dB SPL at 25Hz in a standing wave peak, but while this sub was connected to the same amp that was driving my satellite, there was no apparent extension to the sub bass—just an increase in volume of the mid bass, which was completely rolled off at around 40Hz.

NEW LIFE

I called Eddie's Re-Coning Service (840 Cypress Ave., Los Angeles, CA 90065, 213-221-3714) and talked with Chico, who had been re-coning speakers at Eddie's since the business opened. He listened to what I wanted to do to the speaker and said, "Trust me—you will like it when I'm done!" He re-coned the blown 421 with the cone/surround (Waldom pn w5758) and spider kit for the 421-LF, as both the 421 and 421-LF use the same voice coil.

The cone on the 421-LF is heavier than that of the 421-8H's, and the suspension is not as stiff. A popular misconception these days is that a very light cone is necessary to attain adequate speaker speed. In general, this is true, but the transient response of woofers with heavy cones, coupled with very large and powerful magnets, can attain the same speed as lighter cones coupled with less powerful magnets.

I broke in my new re-coned speaker by running 20Hz through it for a day. It measured as far from the factory 421-LF specifications as the 421-8H did (*Table 1*, ref. 4). Some Boxmodel plots I ran with the measured parameters looked much more promising than the previous plots.

I used Boxmodel to align the enclosure with the 421-LF. The new speaker and alignment were much better, but it still was not what I wanted.

BIAMPING AND EQUALIZATION

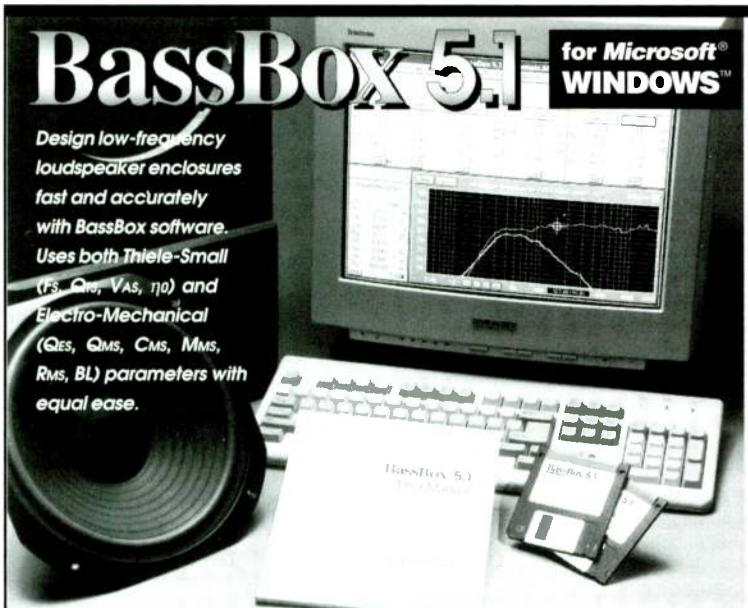
I decided that I needed to biamp the system to achieve my goal. I removed a 90W amplifier from a powered subwoofer and used it on the 421-LF in the 111-ltr ported prototype cabinet. The powered subwoofer amplifier allowed me to sum left and right channels and adequately roll off the highs. It also let me compensate for the efficiency differences between the sub and the satellites.

I liked the resulting big, powerful bass and listened to it for weeks. Eventually becoming critical of the sound, I felt the extreme low registers were lingering longer than the signal was present at the source. This was especially evident on TKO, track 8 on Dave Grusin's *Migration* CD (GRD-9592). I suspected that something other than the low-pass filter, L/R summing, and gain control was responsible for the improvements I heard. I decided to measure the transfer function of the powered subwoofer amplifier.

The input-to-output measurements revealed some serious (+14dB @24Hz) shelving EQ was being applied below 70Hz. There was no apparent rolloff other than the amplifier's inability to work to DC. Now that I knew equalization was responsible for my success, I noticed in *Stereophile* articles that top-of-the-line Infinity, B&W, and Genesis speakers used active bass equalization, and that with Boxmodel I could design systems using B6 alignments.

I synthesized the design shown in *Figure*

PHOTO 4: Aftershock in position.



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1 by entering the parameters in *Table* 2 into Boxmodel. Rather than build an electronic crossover, I bought Dan Ferguson's Subwoofer Wizard, tuned it by injecting a 20Hz signal (you can use the signal from any of the test CDs if you don't have a signal generator) and adjusted the frequency pot until the output peaked. I then adjusted the damping pot for the maximum (9dB) gain.

I connected the output to one channel of a Yamaha M4 power amp and auditioned the system. The sound was much more extended and controlled than with the shelving equalizer from my commercial subwoofer amplifier. I could now hear the individual plucks on TKO. I attribute the improvement to the high-pass action of the B6 alignment and the application of the EQ to only the lowest frequencies. The Subwoofer Wizard also had a steeper rolloff on the high end, which made it much more difficult to hear the placement of the subwoofer's location in the room.

To complete the biamping, I installed capacitors in series, with the input to the power amplifier driving the left and right satellite speakers. I determined the capacitor value using the reciprocal of $(2\pi) \times$ (crossover frequency) $\times$ (amp input Z), assuming the specified input impedance of the amplifier was accurate. I fine-tuned the value by measuring the amplifier output and noting the -3dB power point at 70Hz. I matched the 70Hz -6dB filter by adjusting the LP control on the Subwoofer Wizard to 50Hz with a test tone and finding the -3dB point.

I then fine-tuned the crossover by ear. I tweaked the filters until I could turn up the volume without the 8″ Focal 8V01/4 woofers bottoming out and the subwoofer putting out incredible bass. A great test for low bass is the title track of Bela Fleck's "Flight of the Cosmic Hippo" (Warner Bros. 9-26562-2). At this point I was satisfied, and over the next couple of months I listened to my CD collection, caught up on my laserdisc movie watching, and found the perfect location for the subwoofer.

IN SEARCH OF THE SWEET SPOT

My criteria for locating the subwoofer in my listening room were:

- to minimize perceptual localization of the sub-bass emanations;
- to maximize the excitation of all room modes so as to have as many standing wave peaks at as many frequencies in as many places as possible;
- to find a location my family could live with.

I read Tom Nousaine's "Subwoofer Secrets" article (*Stereo Review* 1/95, p. 97) and decided I would place my sub in my two favorite listening positions and then walk around the room, determine the hottest spots, and try the subwoofer there. Nousaine's theory is that the generation of standing waves would reciprocate as the listening position and the subwoofer were exchanged, and exciting my room this way seemed to work.

Using a bass warble-tone CD track, I found the best spot in the room was in front of the main entrance to my house. When my wife came home and saw this, her patience evaporated and she said, "Either your subwoofer goes, or I go!" (I'm gonna miss her.)

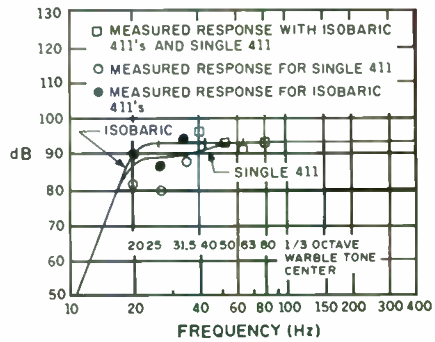
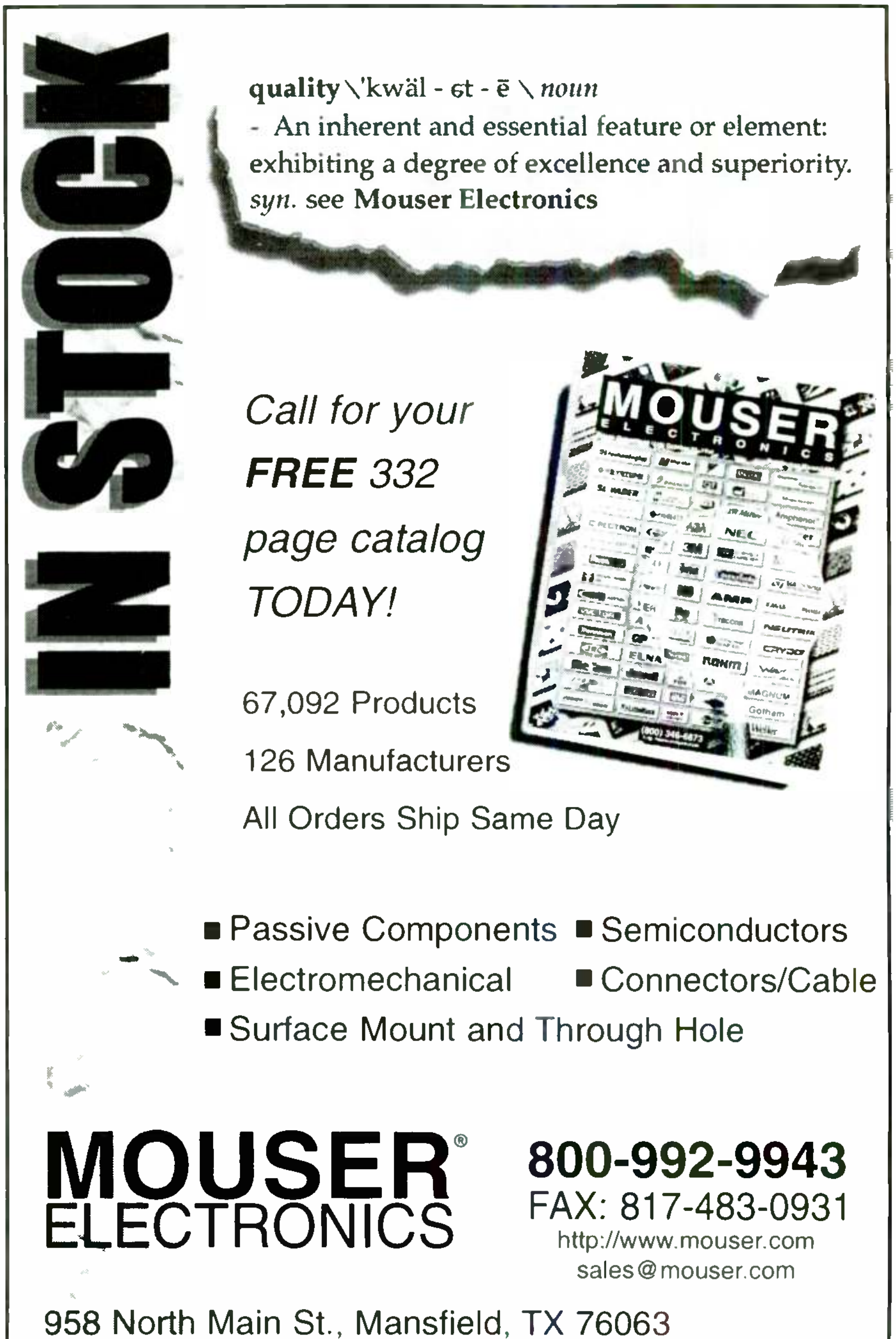


FIGURE 2: SPL predictions and measurements.



Reader Service #30

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I tried a corner at the rear of the room, and for a while I thought I could tell the sound was coming from the corner. However, after surprising several people who listened to the system without knowledge of the subwoofer or its location, I was convinced there was no problem (*Photo 4*).

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Reader Service #42

ISOBARIK

I returned to the re-coning shop and left the working Altec 421-8H also to be re-coned as a 421-LF. I installed the second 421-LF in the end of the 55-ltr chamber (*Photo 2*). This resulted in one Altec's rear, loaded by the 111-ltr ported enclosure, firing into the 55-ltr chamber, and the second Altec's front firing into the dacron-lined 55-ltr chamber, with its rear facing outward. The 55-ltr chamber was sealed to form an Isobarik or constant-pressure zone between the two speakers that were driven out of phase. I used Boxmodel again, with the values shown in *Table 1*, reference 6, to design new porting for the Isobarik box (*Fig. 2*).

I tested the response with the *Stereophile* test-CD warble tones and a Radio Shack SPL meter, and the measured results were as good as Boxmodel's prediction (*Fig. 2*). The Isobarik implementation notably increased the dynamic response as well as the bass extension, which was probably due to halving the V_{AS}. This let me align the system at a lower frequency, and the dynamic increase was probably due to the doubling of the power, since I was now running two 120W amplifiers into two 8Ω voice coils.

With Aftershock in the corner, my Radio Shack meter registers 108dB at the listening position with the 20Hz warbles from the test CD before my M4 amp begins to clip. I was so pleased that I moved the ports inside the box, stuffed it with dacron, and listened to this configuration for several months.

REMODELING

I decided to remodel the prototype to improve its look. I needed to eliminate the second chamber, make a baffle strong enough to mount both the Altecs face-to-face, thicken the box to reduce cabinet reso-

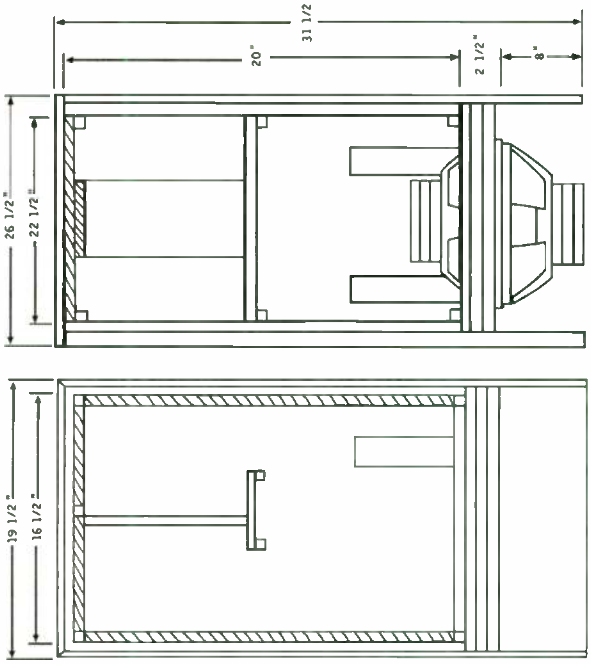
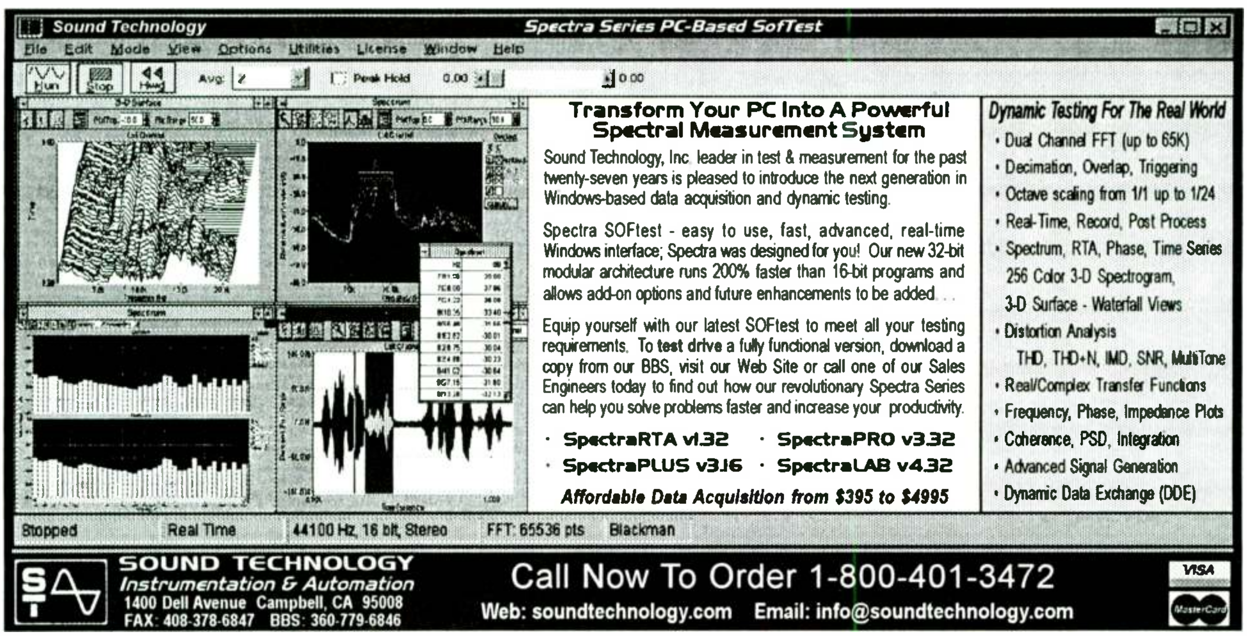


FIGURE 3: Adding more MDF.



Reader Service #20

World Radio History

nance, permanently close up the side covers, and beautify the cabinet with red-oak veneer and trim strips.

I decided to have the second layer of MDF overlap the baffle enough to cover the protruding Altecs. The driver end was open, facing the wall in the corner. The design would also support standing Aftershock on end, with the speaker pointing downward on an added 2″ × 4″ frame stand.

Working on a sheet of scrap carpet to prevent damaging the cabinet, I cut the 55-ltr chamber and the parting baffle out of the prototype using a jig saw. I flattened the MDF and batten surface where the parting baffle had been with a belt sander using 36-grit paper. I cut three new 18″ × 24″ MDF sheets, cut the holes for the speaker and ports in each, and recessed the inside piece to accommodate the binding posts for the inside speaker. I floated each baffle onto the prototype box with the technique described in the next section. When the new baffles were glued up, I installed T-nuts and glued and caulked the port tubes.

MDF FLOATERS

I bonded the three baffle boards and a second layer of ¾″ MDF onto the prototype using Franklin Titebond Aliphatic Resin as the primary agent. In a variation of the method described by Spear and Thornhill ("A Prize-Winning Three-Way TL," *SB* 1/93, p. 44) to attach the ¾″ MDF, I used screws rather than clamps to hold the second layer in place while the glue dried.

I smoothed all uneven protrusions and enhanced the bonding surface by belt-sanding the test cabinet. To ensure continuous bonding of the two layers of MDF, I coated both of them with resin. To prevent the two sheets of MDF from floating while I installed the first screws, I drilled pilot holes in the outside layer and cleaned off all chips from the inside surface prior to applying the resin. These holes located the second sheet on the test box and also prevented the additional drywall screws—installed without the aid of pilot holes—from pulling the second layer of MDF away from the first.

All of the 3½″ drywall screws used to attach the second layer of MDF pierced both layers and pulled them into the battens. After securing the edges of the new MDF panels to the battens, I installed several 1¼″ screws in the centers of the panels to pull the layers together while the glue dried (*Fig. 3*).

FINISHING TOUCHES

Veneering: Considering veneer and formica too expensive, I decided to cover Aftershock with a $14 sheet of 1/8″ red-oak plywood. I needed to veneer only the top, front, and two sides of the cabinet. I ignored waste in favor of aesthetics when deciding how to cut up the 4′ × 8′ oak sheet (*Fig. 4*). The sheet consisted of six laminated strips that made three similar patterns along the 8′ length. I wanted one of the patterns to run through the center of Aftershock's top and then continue down the front piece. Each side would also contain the same pattern, facing in the same direction as the top. I marked the areas to be cut with 1″ overlap on each dimension, and ripped them out with a jig saw. After cutting each piece, I marked its orientation on the inside to aid me when laminating it. On the bottom, I used a scrap of 1/8″ mahogany door skin.

I sanded the sides lightly, vacuumed them clean, and did the same for the veneer pieces. I coated the veneer and cabinet surfaces with Elmer's Latex Contact Cement.

Using three scrap MDF strips as standoffs along the width of the cabinet, I registered the veneer panel on the strips so there was even overlap at each edge of the cabinet. Then I removed one of the end standoffs and pushed the veneer into the cabinet with a piece of carpet fastened to a ¾″ MDF scrap. I removed the other standoff strips and pressed the sheet until it was completely laminated to Aftershock. To ensure that the edges of the veneer were

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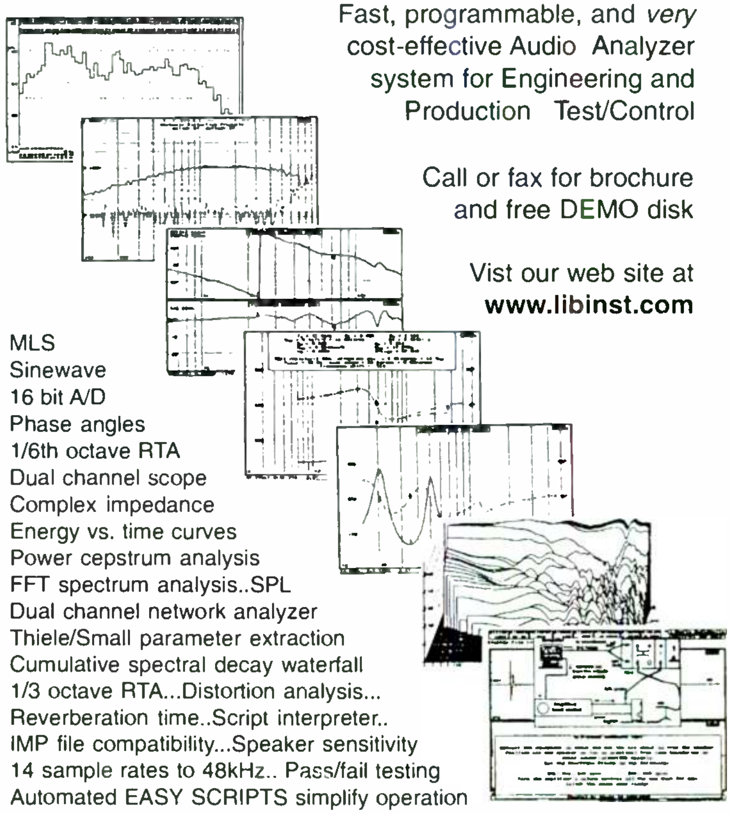

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bonded to Aftershock, I hammered the carpet-covered MDF around the edge.

After laminating each panel, I used my router with a roller-bearing edging-trimmer bit to make the veneer flush with Aftershock's edge. To avoid splintering the veneer, I moved the router along the surface from right to left. When all four edges were done, I sanded with 100-grit paper from the center of the cabinet outward to smooth the edge. This was important, since rough edges could catch in the carpet when I worked on the other side.

Trimmings: If I had to start over, I would follow Spear's and Thornhill's advice and align the second layer of MDF so I could use sections of 1″ hardwood board for the trim strip. Instead, I butted the corners of the ¾″ MDF where the trim strip was to be installed (*Fig. 5*). Once the 1/8″ panel was glued into place, this required a $^{7}/_{8}$″ trim strip. Unfortunately, that meant I had to find a $^{15}/_{16}$″ red-oak board instead of a standard 1″ board (which measures exactly ¾″) to cut the trim strips from. I sanded a slight chamfer on the inside edge of the trim strips so they would center themselves flush to the two side edges.

Finishing: Before installing the veneer, I painted the baffle flat black. With the veneer and trim completed, I sanded and then stained Aftershock with two coats of MinWax #245 Golden Pecan wood finish, applied four hours apart. Twenty-four hours later I applied three coats of MinWax fast-drying clear-satin polyurethane. I waited four hours between applications to sand, vacuum, and recoat.

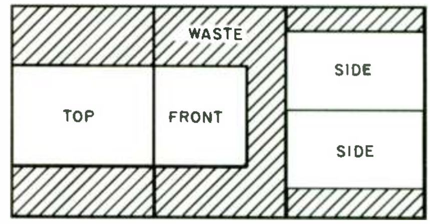

FIGURE 4: Getting the wood pattern right.

BACK IN BUSINESS

When the finishes were dry, I installed a piece of closed-cell foam rubber on the rear of the enclosure, opposite the baffle, and fastened a sheet of AC foam to the brace to prevent reflections from bouncing out of the cabinet through the cones. I lined the entire box except for the baffle with 1″ of Dacron blanket batting and loosely stuffed the cabinet with about 2 lbs of AC Stuff. I installed one Altec magnet in and the other out and secured them with eight 3½″ cap-head machine bolts.

The inside speaker connects to the amplifier's speaker cables through 2-inch-long banana jacks in the baffle, with the connections to the banana plugs supplied by 12-AWG monster cable. The outside speaker is connected directly to the amplifier's 12-AWG speaker cable. I checked the seal between the two drivers with my lighter, driving both speakers with a 30Hz in-phase tone. There were no air leaks.

I reversed the leads on the outward facing speaker, and Aftershock was in service again. I could not detect any significant difference in sound through changing the

to page 65

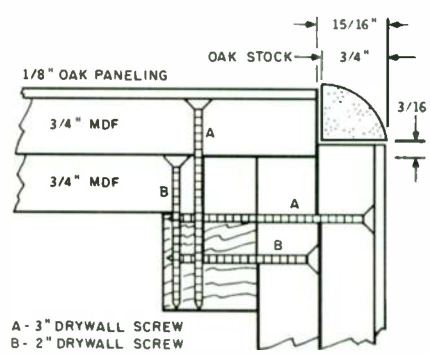

FIGURE 5: Joint section.

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QUALITY ISSUES IN IRON-CORE COILS

By Roger Russell

If you plan to use iron-core coils in a passive crossover network, the quality of those coils can make or break the sound of your speaker system. This article describes a method you can use to measure coil distortion as well as conduct an effective listening test. Then it's easy to tell which ones to use.

I selected various types of coils from well-known suppliers to see how they would perform. Some iron-core coils are surprisingly good up to very high power, while others are very good up to moderate power. A few are not acceptable at all.

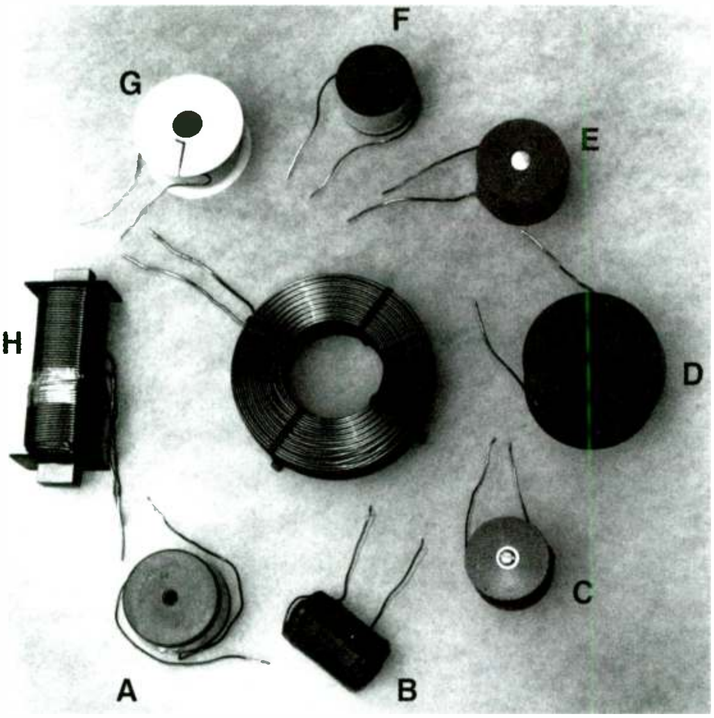

PHOTO 1: The group of coils used for the tests (identified in Table 2).

EXPENSIVE COPPER

Why even consider using iron-core coils when there are air-core coils and even active crossovers that don't have a core distortion problem? First, there's the problem of cost. Active crossovers are expensive, and they also require one or two extra power amplifiers to drive the remainder of the system.

Air-core coils are also costly because copper wire is expensive, and they require more turns of heavier wire to give the same inductance and DC resistance (DCR) as comparable iron-core coils. Large-inductance air-core coils can also be very big and heavy. Moreover, if you use a third- or fourth-order network for the woofer, you need two series coils, requiring even lower DCR for each one. Adding a simple, low-cost iron core can reduce the amount of expensive copper wire needed. *Figure 1* shows how you can reduce the number of turns of wire for the same inductance by inserting an iron core in the center of an air-core coil. At 3mH, for example, you can reduce 425 turns to 280. *Figure* 2 shows that the corresponding weight of the wire is reduced from 0.575lb to 0.33lb. A further benefit of adding the iron core is that at 3mH it reduces the DC resistance from 1.38Ω to 0.87Ω, as shown in *Fig. 3*.

Iron cores come in a variety of sizes, shapes, and materials. There are plain cylindrical "slugs" and I-shaped (bobbin) cores, usually made by the sintering process, which squeezes iron powder or granules under high pressure into a desired shape. There are also laminated cores made with layers of thin iron strips. Finally, there are toroid cores.

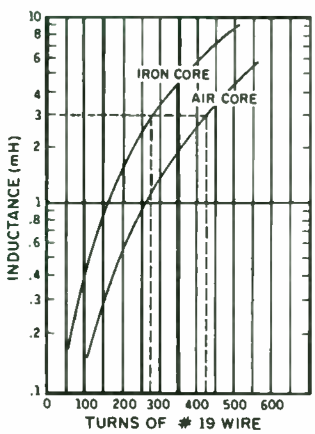

FIGURE 1: Graph of inductance versus turns of wire. Adding an iron core reduces the number of turns from 425 to 280 for a 3mH coil.

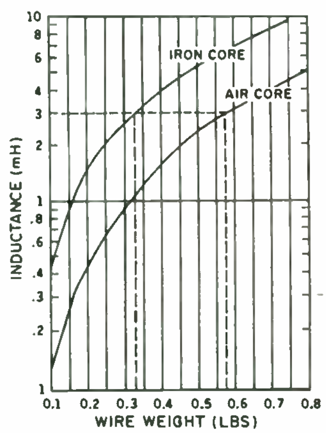

FIGURE 2: Graph of inductance versus wire weight. Adding an iron core reduces the wire weight from 0.575 to 0.33 lbs for a 3mH coil.

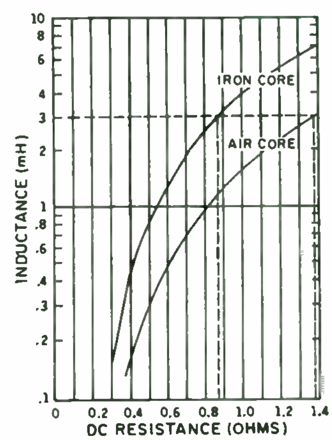

FIGURE 3: Graph of inductance versus coil DCR. Adding an iron core reduces the DCR from 1.38 to 0.87Ω for a 3mH coil.

World Radio History

The disadvantage of iron-core coils is that the material used can become saturated. As the core approaches saturation, distortion increases more rapidly. The type of core material, its shape, and the current levels that pass through the coil determine how soon the saturation will occur.

THE TEST SETUP

You can measure coil distortion using the test setup shown in *Fig. 4*. An oscillator drives a low-distortion power amplifier. Although it isn't mandatory, you can use a frequency counter for accurate and repeatable settings of the oscillator. A high-wattage load resistor replaces a speaker, and you connect the coil you're testing in series with the resistor. A distortion analyzer connected across the resistor then measures the coil distortion.

The power amplifier you use for the coil test should be the one you plan to use to drive the finished speaker system. Be sure your amplifier can deliver the necessary sustained sine-wave power for the time it takes to make each distortion test. It's a good idea to check with the manufacturer first. You can check for clipping in case the power amplifier is overdriven by connecting an oscilloscope across the power-amplifier output.

Be certain to use heavy hookup wire between the coil, load resistor, and amplifier. I used about ten feet of #12 speaker wire. The value of the load resistor you select should be the same as the nominal impedance of the system in which you plan to use the coil. I use an 8Ω, 100W resistor, placed in a container of water to keep it cool.

You can make a form (*Table 1*) to select the powers and voltages you plan to use. The measurements you make should start at 1W and proceed in convenient steps up to the maxi-

TABLE 1

SAMPLE FORM

COIL ____________ DATE ____________
INDUCTANCE ____mH TYPE ____________
DCR ________ OHMS WIRE SIZE ________

PWATTS	V1	%-20Hz	%-100Hz	%-250Hz
1.13	3			
3.13	5			
7.03	7.5			
12.5	10			
28.1	15			
50	20			
113	30			
200	40			
313	50			
450	60			
613	70			

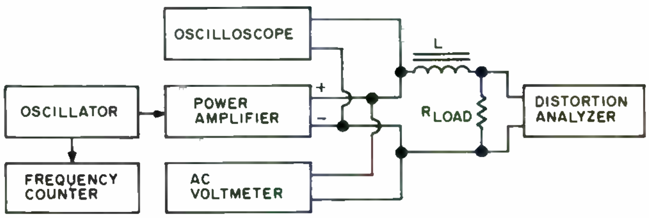

FIGURE 4: Block diagram for the distortion-test setup. L is the coil to be tested.

ABOUT THE AUTHOR

Roger Russell has a degree in electrical engineering from Rensselaer Polytechnic Institute. He has written several articles about loudspeaker design, testing, and other audio devices. Several patents have been awarded for some of his designs. He is a member of the Audio Engineering Society and the International Society for General Semantics. His interests range from stereo sound to photography, new-age music, computers, and science fiction.

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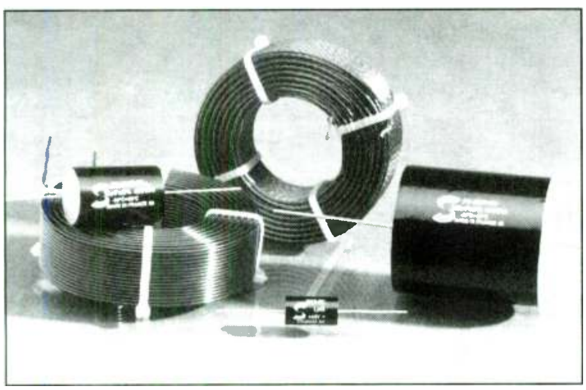

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mum power safely available from your amplifier. *Figure 5* shows the relationship of voltage and power for four different values of load resistance. This is derived from the formula V=√(PR), where V is the voltage at the power-amplifier output terminals, P is the power in watts, and R is the load resistance in ohms.

You can then use the AC voltmeter to indicate the corresponding power level you need when running the test. Since I own a McIntosh MC7300 that I can connect for 600W in mono operation, I was curious to see what the coils would do, both at "normal" and extra high power.

The coils I chose all had about the same value of inductance, which allows a better comparison of the various types of core and construction. When making the test, be careful not to place the coil on a metal surface, which could affect the test results. I placed mine on a wooden test bench.

Coil distortion doesn't remain the same at all frequencies. You can use several test frequencies, starting at 20Hz for the lower limit. *Figure 6* shows the upper test-frequency limit for four different values of load resistance. This comes from the formula L = R/(2πf) × 1000, where L is the inductance in millihenries (mH), f is the frequency in hertz, and R is the load resistance in ohms.

For example, the upper limit for a 5mH coil and an 8Ω load is 250Hz, the actual crossover frequency for these component values in a first-order network. I selected 100Hz as an intermediate frequency. You can choose other test frequencies if you so desire.

TEST RESULTS

Figures 7–15 show the distortion curves for each of the nine coils at the three different test frequencies. The solid line is 20Hz, the dashed line is 100Hz, and the dotted line is 250Hz. Coils A – E have the highest distortion. The curves for coil F are noticeably different.

The horizontal portion, up to 50W, is not due to the coil, but is the lower limit of my test equipment. Below 50W, this coil's dis-

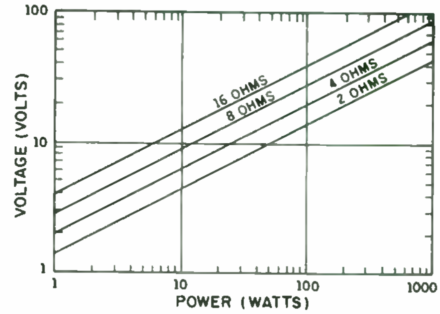

FIGURE 5: Voltage and power conversion chart for 16, 8, 4, and 2Ω load resistors.

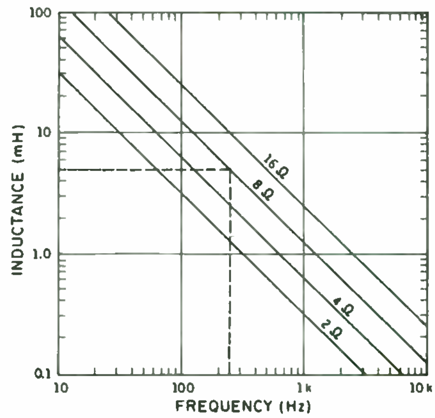

FIGURE 6: Inductance versus upper-frequency test limit for 2, 4, 8, and 16Ω load resistors.

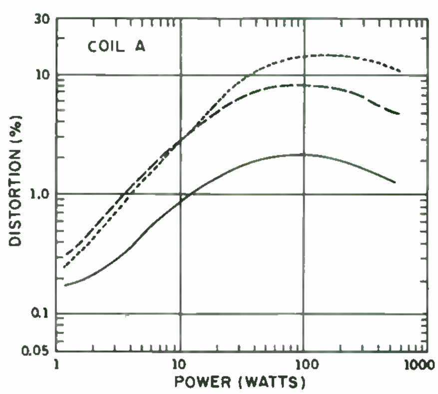

FIGURE 7: Coil A. This graph (and those in Figs. 8-15) measure distortion versus power at three test equipment frequencies. The solid line is 20Hz, the dashed line is 100Hz, and the dotted line is 250Hz.

TABLE 2

RAW DC TEST SUPPLY PARTS LIST

COIL	IND	DCR	WIRE	TYPE	COST	NAME	SOURCES
A	5.0	0.37	18	iron bobbin	$10.50	AMS	MCM 50-690
B	5.0	0.42	18	iron slug	8.69	AMS	MCM 50-395
C	5.0	0.37	18	iron bobbin	8.89	Feron	MCM 50-1025
D	5.0	0.27	16*	iron bobbin	11.70	Sledgehammer	Madisound SHS
E	4.7	0.241	16*	iron bobbin	8.92	Feron (low dist)	Zalytron
F	5.0	0.39*	18	iron bobbin	6.50	Super ferrite	Meniscus(custom)
G	5.0	0.80	18	iron slug	6.65	MHL	Madisound MHL
H	5.0	0.242	15	laminated bar	12.00	Sledgehammer	Madisound SLS
I	4.7	0.56	14	air core	20.76	Perfect Lay	Zalytron

*measured

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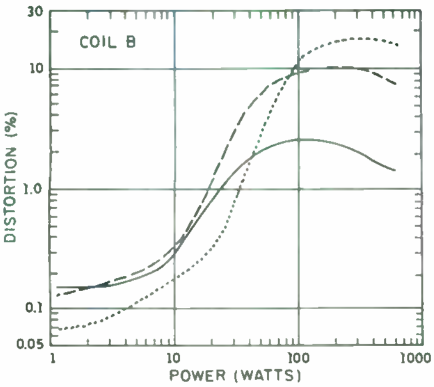


FIGURE 8: Coil B.

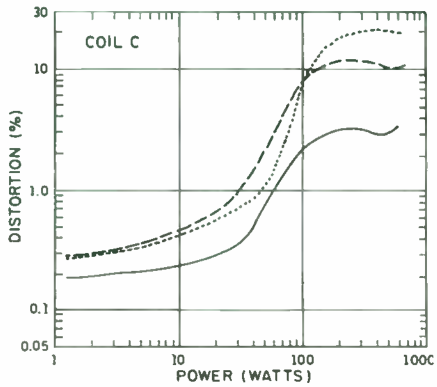


FIGURE 9: Coil C.

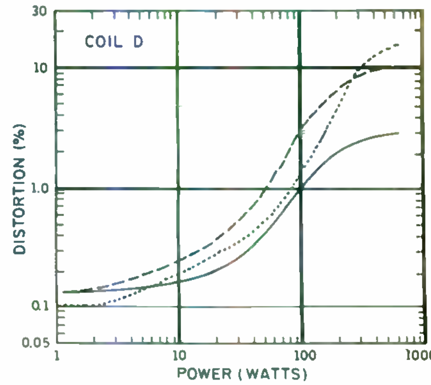


FIGURE 10: Coil D.

tortion could be far below that of coils A through E, and even G. F's distortion rises more rapidly, however, compared to the others, and is just as high as coils A through E at very high power.

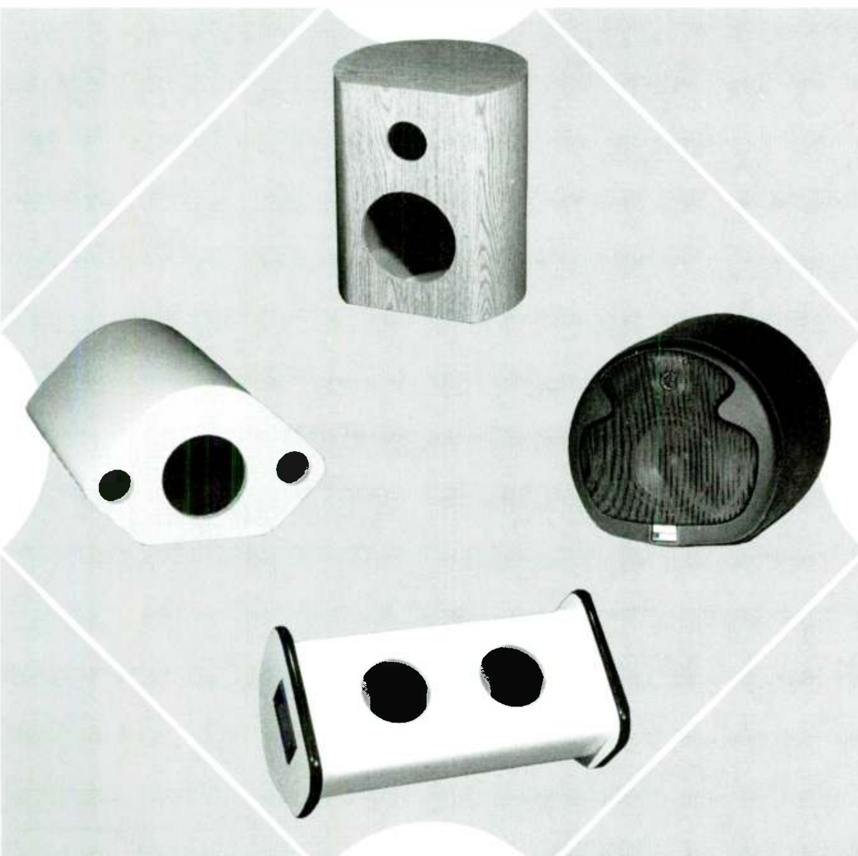
Coil G's distortion remains relatively low, even at high power. Coils F and G have the lowest price in the group, and H, with the lowest distortion of all the iron-core coils, is the most expensive—except for I, an air-core coil that has no measurable distortion. The curves for coil I show the limit for my test equipment through the whole power range. I included it for comparison and in case anyone has doubts about distortion in air-core coils! The fact that distortion in coils A, B, and C increases to a maximum and then decreases slightly is caused by the initial permeability of the core material increasing and then decreasing.

Figure 16 shows a typical spectrum of distortion components measured on a 1/10-octave analyzer. This one is for coil C at 260Hz, driven with 100W. The distortion products are all odd harmonics, indicating top and bottom waveform symmetry. The total harmonic distortion is 8%. This coil is advertised as having a 300W power rating and being "virtually free of distortion."

Table 2 shows the specifications as advertised by the suppliers, with the coils listed in the order of overall decreasing distortion.

LISTENING FOR DISTORTION

How much distortion can you actually hear? Although much emphasis is currently placed on electronics having .01% or .001% distortion, the plain truth is that such low distortion is completely inaudible. Several sources[1,2,3,4] indicate that under ideal conditions with pure tones, a threshold as low as 0.1% to 0.25% can be detected. With



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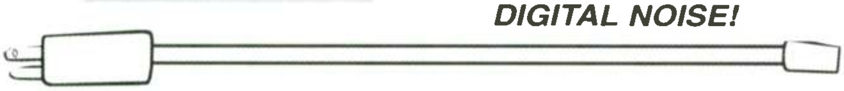

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music, the threshold can be as low as 1%.

Perhaps the best way to decide is to do your own listening comparison with the coils you have chosen. You perform the test using a sine-wave oscillator, AC voltmeter, power amplifier, and oscilloscope. There are two ways to proceed.

You can connect a switch into the speaker line, as shown in *Fig. 17.* This will give you an instant comparison between the coil you intend to use in series with the driver versus a direct connection to the driver. There may be some slight listening differences, because the response will change with and without the coil, but this normally will be minor compared to the sound of the core distortion.

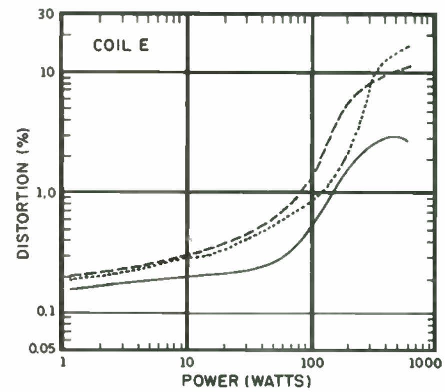

FIGURE 11: Coil E.

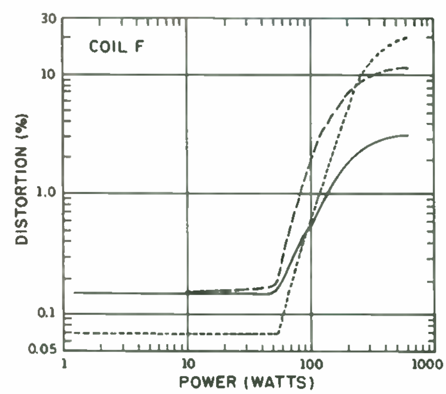

FIGURE 12: Coil F.

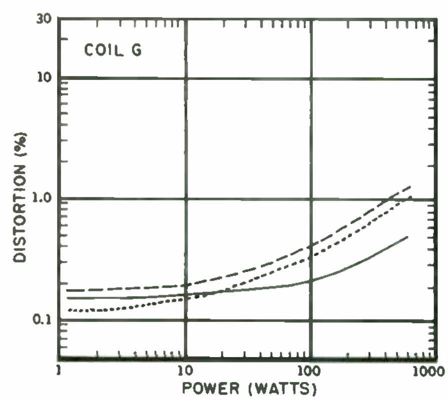

FIGURE 13: Coil G.

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As an alternative, you could do the listening test as shown in *Fig. 18*. This will give you a little more control by switching between the test coil and an air-core coil of similar value. Having no distortion, the latter can keep the frequency response of the woofers about the same as it would be with the iron-core coils, so the amplitude of the harmonics relative to the fundamental will stay about the same.

In these tests that use a sine-wave oscillator, there is some risk of damaging the driver you plan to use, since some driver power ratings are for music and not sine wave. Check with the driver manufacturer before applying too much sine-wave power.

You can hear the distortion products more easily by standing at a point in the room where the fundamental of the test frequency cancels due to room reflections. This may not be the way controlled hearing tests are done in a research lab, but it certainly is appropriate and typical for us in home listening environments. The listening position in typical living rooms has nulls at several low frequencies, allowing you to hear distortion products more easily.

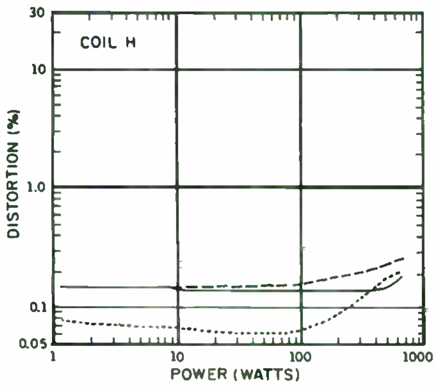

FIGURE 14: Coil H.

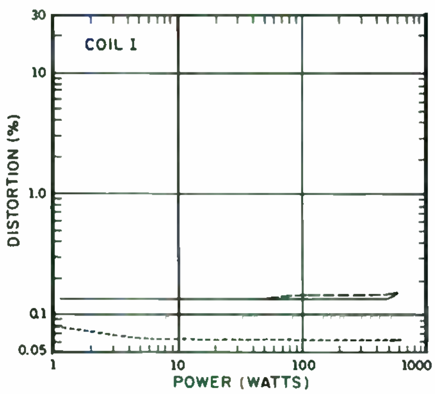

FIGURE 15: Coil I.

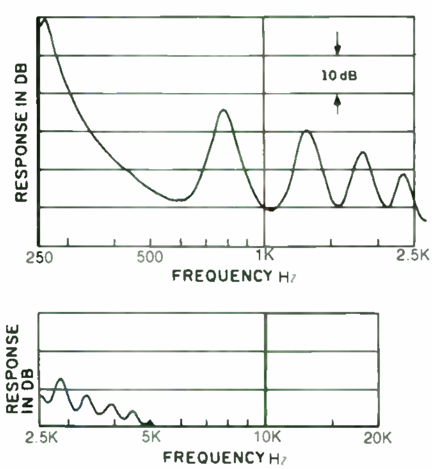

FIGURE 16: Distortion spectrum of coil C at 100W. Total harmonic distortion is 8%. The manufacturer rates this coil for 300W of power.

DETECTING DIFFERENCES

You can choose several different frequencies for the listening test. I selected 100Hz. Start at 5 or 10W. If you can hear a difference from one switch position to the other, reduce the power until you can still just hear it clearly. This, then, will be the maximum acceptable power for that coil. If you can't hear a difference, increase to 15W, then 20W, and so on, until you can clearly hear a difference. Be careful not to exceed the maximum

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power for your driver, as the coil you are testing may not have audible distortion for the power you have available. At higher power levels, coil-distortion measurements can be much safer than listening tests.

Coil A's distortion was clearly audible at only 2W. Coil B was clearly audible at 15W, C at 20–25W, and D at 30–35W. At 50W, all four coils sounded very distorted. Coil E became clearly audible at 60W, and F at 80–90W. Although F's distortion is exceptionally low at low power, there may be no audible benefit, for reasons I'll discuss shortly. Coil G became audible at 500–600W, and H was not audible at 600W.

You shouldn't take this listening test to mean that the speaker system you use has no distortion. It simply means that any increase in distortion could or could not be heard using the driver you have selected. Because I wanted to listen at high power, I used the woofer section of my McIntosh XR290 speaker system, which has four low-distortion 12″ drivers mounted in a 10ft³ sealed box. At the highest powers, even the four woofers had significant distortion. However, if I had used a single 12″ driver, the extremely high distortion would have interfered with the test. The voice coil might even have bottomed or burned out.

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DISTORTION LIMITS

Certainly, the coil distortion should not be audible compared to the driver distortion. References to other sources,[1,2,3,4] the distortion measurements, and the listening tests suggest that a distortion between 0.5 and 1.0% is the maximum allowable. Then, your choice depends on either the maximum power available from the power amplifier, or the power rating of the drivers you use, whichever is lower.

If, for example, your woofer or midrange driver is rated at 100W, then coils E and F are marginal and G and H are the best choices. However, if the amplifier you use with these drivers is rated at only 50W, then coils E and F would be acceptable as well.

COIL DC RESISTANCE

DC resistance is another concern for a crossover coil. How high or low should it be? If DCR for woofers is too high, it can result in significant loss of power delivered to the woofer. As a point of practical reference, the crossover-coil DCR should normally be less than 1/10 of the nominal speaker impedance. This would be a maximum of 0.8Ω for an 8Ω driver, and 0.4Ω for a 4Ω driver. Using coils with lower DCRs is conservative and certainly won't hurt, but the cost can be higher and the improvement is questionable.

To make a comparison, coil G, at about half the price of coil H, has a DCR of 0.8Ω, the highest in the group, as well as reason-

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Hewlett-Packard 200CD oscillator
Instek OS-622 dual trace oscilloscope
McIntosh MC7300 power amplifier (connected for 600W mono)
McIntosh XR290 speaker system (woofer section with no crossover)

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2. P. Milner, "How Much Distortion Can You Hear," *Stereo Review*, (June 1977): 64–68.

3. P. Fryer, "The Audibility of Distortion in Loudspeakers," *Stereo Review*, (Aug. 1977): 68–71.

4. J. Moir, "Just Detectable Distortion Levels," *Wireless World*, (Feb. 1981): 32–38.

5. H. Fletcher, *Speech and Hearing*, D. Van Nostrand Company, Princeton, NJ (1929).

6. G. Augspurger, "The Damping Factor Debate," *Electronics World*, (Jan. 1967).

7. F. Toole, "Damping, Damping Factor, and Damn Nonsense," *Audio Scene*, (Feb. 1975): 16–17.

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ably low distortion at both low and high power. Coil H has a DCR of 0.24Ω, one of the lowest in the group, and has even lower distortion. The difference in DCR between the two coils is 0.56Ω. *Figure 19* shows the response of an 8Ω woofer in a sealed enclosure, first with coil H in series (upper curve) and then with coil G in series (lower curve). The change in response is 1/2dB or less. The reason for this small difference, of course, is that most of the DC resistance in a speaker system is in the woofer voice coil.

Typically, an 8Ω woofer has a DCR of 7.2Ω and a 4Ω woofer has a DCR of 3.2Ω. The greatest response difference between the two curves is in the areas of 20Hz and 100Hz. This is where the impedance of the woofer, shown in *Fig. 20*, is near its lowest value, and where the crossover-coil DCR could be a significant part of the system impedance.

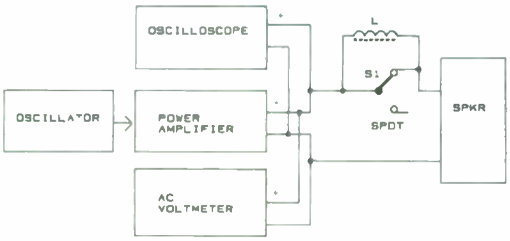

FIGURE 17: Block diagram for listening test. At each power level, you can instantly switch from the iron-core coil to a direct connection to the woofer. The speaker response will not remain the same.

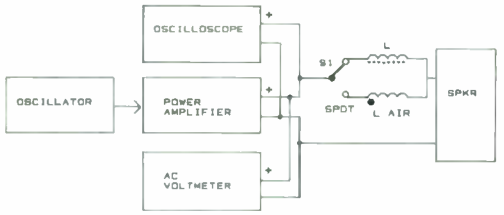

FIGURE 18: Block diagram for listening test. At each power level, you can instantly switch from the iron-core coil to a no-distortion air-core coil of the same inductance. The speaker response will remain the same.

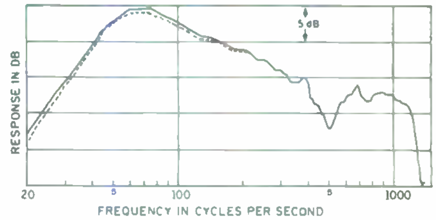

FIGURE 19: Response of coil H, having 0.24Ω DCR (upper curve), and coil G, having 0.8Ω DCR (lower curve).

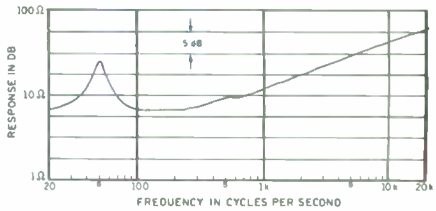

FIGURE 20: Impedance curve of the 8Ω woofer in a sealed enclosure used for the response curves in Fig. 19.

SPEAKER-LOCATION EFFECT

How significant is this small change in response? To put it in perspective, look at the response measured at the listening position in a listening room. Locating a speaker on the floor in a corner of the room gives a maximum low-frequency output.

Moving it from the corner against the wall on the floor reduces the bass by 3dB. Sliding the speaker up the wall reduces the bass by another 3dB. Moving it out away from all reflecting surfaces reduces bass output by still another 3dB. In addition, low-frequency response can change by as much as 10–15dB due to room reflections that cause low-frequency reinforcement and cancellation.

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Stereophile, *May 1996.*
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Fletcher[5] suggests the minimum perceptible change in intensity level for a pure tone at 100Hz is 0.6dB at higher levels, and greater than 5dB at low levels. Again, a listening test might help. Select a low-DCR coil similar to coil E or H. You could connect a ½Ω resistor in series with the woofer and switch it in and out to see if you can hear the difference. Use the setup in *Fig. 21*. Again, be certain to use heavy speaker wire, making the connections very tight or soldering them.

You can try the listening test at normal and high listening levels, using pink noise or program material as well as pure tones. This time, you could have a friend do the switching for you without telling you whether the resistor is in or out, but just saying it's position A or position B. Then see if you can hear the difference. I could hear no difference with either ½ or ¾Ω in series. The small change in DCR for the two different coils does not significantly affect the damping factor of the system.[6,7]

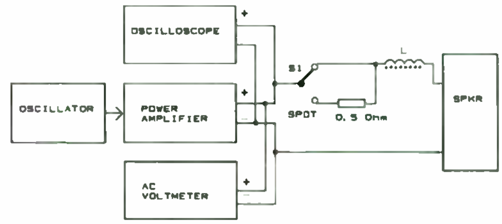

FIGURE 21: Block diagram for the series DCR listening test. You can instantly switch to compare any listening difference with and without a ½Ω resistor in series with a low DCR coil. A normal or high listening level can be used.

SOURCES FOR IRON CORE COILS

Madisound Speaker Components
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Zalytron Industries Corp.
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SMALLER-VALUE COILS

The cost of iron-core crossover coils with smaller inductance values may not be as significant compared to air-core coils. The transition area can be in the vicinity of 1mH or so, depending on the manufacturer's pricing. You can then use smaller-value air-core coils economically, unless there is a particular need for very low DCR.

In mid-range and tweeter circuits, a resistor is often used in series with a crossover coil to reduce the Q of the circuit or attenuate the output of the speaker. You may not need a low-resistance coil at all. A neat trick is to wind the coil with wire of smaller diameter so the series resistance is included in the coil DCR. This eliminates a part in the crossover and also cuts down on the coil size and weight. You can use wire as small as #28 and still handle up to 3A of current.

SUMMARY

By using the procedures described in this article and knowing the test results for a sample group of coils, you can see the value of testing the coils you plan to use with your favorite speaker system. All iron-core coils are not the same. Some can offer both very good performance and considerable savings, even at high power. Others can provide excellent value depending on the power levels you plan to use. A few should be avoided completely. Without making these tests, you might blame distortion on the drivers, the amplifier, the cabinet design, or even the cabinet construction, without becoming aware that the cause may lie in the coils.

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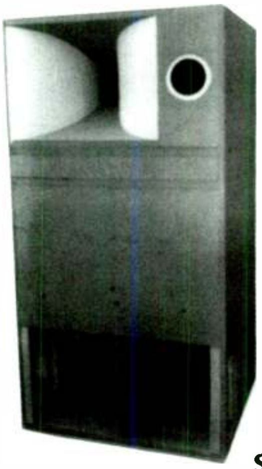

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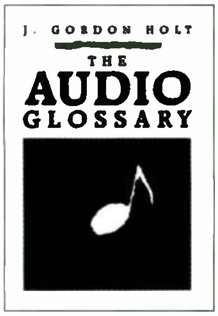

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LOW COST STROBOSCOPIC SPIDER ANALYSIS

By Tom Perazella

Since the early days of experimentation with electronic flash, one of the most interesting applications has been stop-motion or "stroboscopic" analysis. Dr. Harold Edgerton has been called the father of electronic flash, and he received popular recognition by photographing subjects such as milk droplets striking a pool of milk and bullets penetrating apples.

However, as entertaining as these subjects might have been, the greatest benefit is that it allows researchers to visualize repetitive motions otherwise imperceptible because of their high speeds. Compared to some of the other techniques for analyzing speaker components, the relatively inexpensive stroboscope provides a surprisingly good overall view of what is happening to a spider. Before covering the specifics of this technique for driver analysis, a review of the principles involved may be helpful.

EYE RESPONSE

One basic limitation of human vision is that you cannot discern the details of motion that occurs at frequencies higher than 30Hz. At higher frequencies, the eye integrates the motion into a "blur" of a certain visual density. The higher the frequency, the more uniform that density, and its value is a function of the density and size of the moving object in relation to the background.

For example, if you rapidly spin a white disk with small radial slits in front of a dark background, the slits will appear almost as light as the white segments of the disk. If the slits are then enlarged to the point where only narrow white segments remain between them, the spinning disk will appear dark. The density, or conversely, the apparent brightness at any point of the disk is a function of the time integral of light reflected from the disk at that point. The eye continuously integrates light from all points, resulting in the blurring effect.

STOP MOTION

To prevent this blurring, you can limit the time that light strikes a moving object while in a specific position. The electronic flash is an ideal device to accomplish this lighting control. Instead of a constant production of light, the flash device stores electrical energy and then discharges it very rapidly through a gas-filled tube, resulting in a very bright flash of light in a short time period.

If the duration of the flash is sufficiently short, the amount of the object's movement is inconsequential. If its movement is periodic, you can arrange to fire the flash at the same point in each period, with the visual result of "freezing" the motion. This can be especially valuable in observing a distortion of the object at a point of high stress in the period.

SLOW MOTION

As valuable as observing a particular point in the period can be, it is sometimes useful to observe the complete range of movement or distortions that can occur in an object during the whole period. By adjusting the time between firings of the strobe to be longer or shorter by some fixed amount in relation to the period of the object, the illumination will occur at a different point in the period with each flash. The result is that the object appears to be moving in slow motion. The closer the period of the flash to the period of the object, the slower the motion appears.

THE STROBOSCOPE

The stroboscope is an electronic flash optimized for stop-action work in several key areas as follows:

- The duration of the flash is very short, much shorter than a typical photographic flash. Special circuitry and flash tubes make this short duration possible.
- Stroboscopes generally have a narrow angle of illumination. This is necessary to concentrate the lower light levels produced at short flash durations onto a specific area of interest.
- In addition to an external sync, there is an internal time base to trigger the flash in a stable, repetitive manner.

USING A STROBOSCOPE

To get the best results from a stroboscope, you must take account of several factors:

1. The reflectance of the subject relative

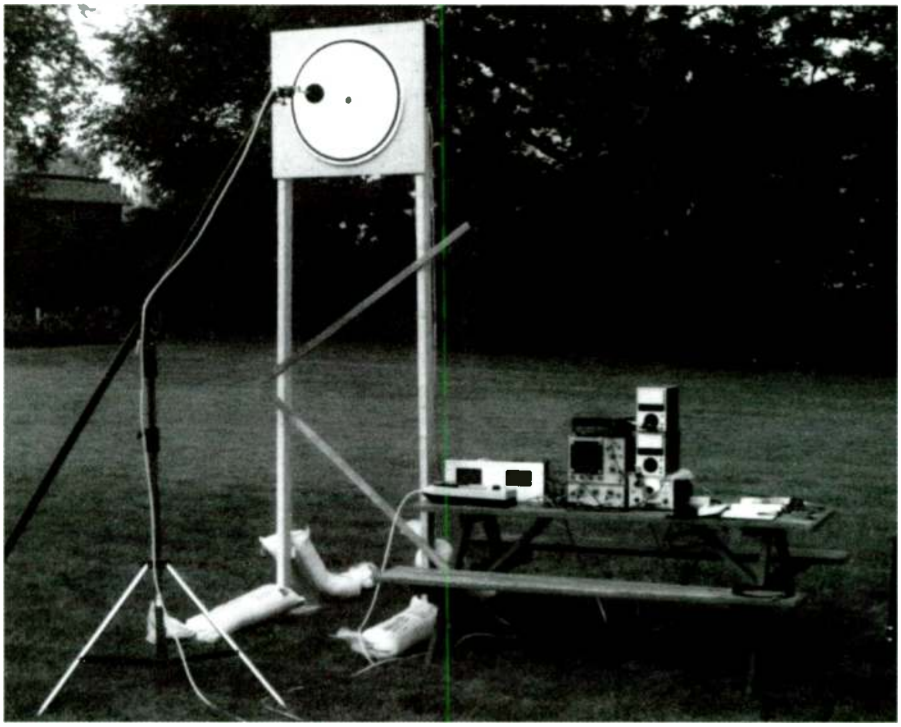

PHOTO 1: Test setup for 24″ woofer.

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The book deals with the specific problems of various vehicle formats from small pickups to large sedans to hatchbacks. A wealth of information about specific problems is scattered throughout the book as well as solid advice on what the novice modifier should and should not do in upgrading certain vehicles. Dan suggests various paths to achieve success as well as sources for all the supplies, parts, drivers and even replacement door panels.

Best of all, the book is anything but dry theory. The information is solidly backed by hands-on experience in hundreds of vehicles of a very wide variety. The sources listed put you in touch with vendors the author has found reliable and who offer the best buys on what you need for better sound. There are also phone numbers for hand-holding support should you need it.

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PHOTO 2: Microphone position used for testing.

PHOTO 4: "S"-shaped spider construction.

to the background. The greater the difference, the more visible the motion. If you're viewing a light object, use a dark background, and vice versa. The basic product-photography trick of outlining the edges of dark objects with chalk can help in differentiating the object from the background.

2. Use appropriate lighting levels. Visual observation is not too critical, since the eye has a very broad range of light acceptance. However, if the contrast ratio between the object and background is too great, the eye will have difficulty. This ratio is even more important when using photographic or video capture, as these media are more limited in accepting ranges of brightness.

3. Adjust the viewing or photographing angle to best show the motions in question. The eye and camera are most sensitive to movements perpendicular to the axis of vision. Conversely, motions along the viewing axis are the most difficult to discern. If motions occur in multiple planes, try to view them from various angles.

4. Position the light to take maximum advantage of surface textures and contours. The more oblique the lighting in relation to surfaces, the more prominent textures and contours become. The changes of lighting on these surfaces help the brain process visual changes into the perception of motion.

5. There is an optimum range of perceived speed. You should adjust the stroboscope so that the viewed motion is slow enough to see details, yet not so slow that the overall motion is not readily apparent.

ABOUT THE AUTHOR

Mr. Perazella is the Director of Information Systems for a national retailer of professional photographic equipment headquartered in the midwest. Prior experience includes work as a criminalist in the San Diego and Long Beach (CA) crime labs and director of marketing for a photographic wholesale distributor. In addition to speakers, Mr. Perazella has designed commercial high-powered electronic flash equipment as well as numerous pieces of audio electronics for his own use.

A CASE STUDY

The versatility of the stroboscope is illustrated by an analysis of an audible anomaly that appeared while I was testing a 24″ woofer. The manufacturer of this driver claimed an f_S of 13Hz, but MLSSA analysis indicated it was 27Hz. The manufacturer was skeptical of MLSSA analysis and asked for testing of the driver in an open environment. To satisfy the manufacturer's objections, I conducted tests the old-fashioned way, i.e., making point-by-point measurements in an open field. *Photo 1* shows my test setup.

I measured using a Bruel & Kjaer type 2209 sound-level meter feeding a digital voltmeter, two analog voltmeters, and an oscilloscope. *Photo 2* shows the mike position in relationship to the driver. Test results were within experimental tolerances of those achieved with MLSSA. During the tests, however, when drive levels exceeded 2V RMS at 27Hz, I noticed a howling at higher frequencies. The scope trace confirmed a higher frequency component on top of the base frequency. *Photo 3* shows the resultant waveform from an input of 5V at 27Hz.

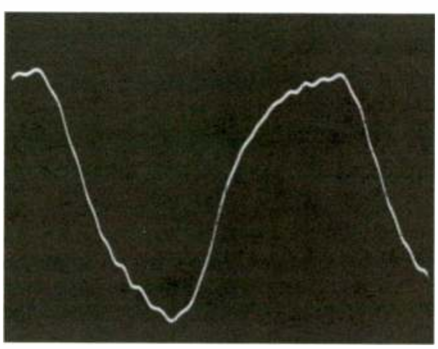

PHOTO 3: Waveform at a 5V level at 27Hz. Note the high-frequency component.

I measured relative acoustic outputs at 31.5Hz and 500Hz using the Bruel & Kjaer 1613 octave filter set attached to the 2209 sound-level meter. Relative levels at a 12″ mike-to-driver distance and a 6V drive at 27Hz were 111dB at 31.5Hz center frequency, and 82dB at 500Hz center frequency.

A study done by Eric Busch of DLC Design states that the sensitivity of the ear at 27Hz is approximately 50dB below that at 200Hz. Unfortunately, data for the 500Hz center frequency was not available in that study, but extrapolating from other studies, the difference would be even greater at the higher frequency. The measured 29dB difference, when compared to the greater than 50dB sensitivity of the ear at 500Hz, confirms the degree of audibility of the higher frequency component.

At first, I suspected cone breakup. To see if this was the case, I used a stroboscope to view the cone motion with the same drive conditions. No breakup was apparent.

SPIDER SCRUTINY

The spider was the next area I examined. This particular driver had a spider style popular years ago. It appeared to be machined from a sheet of glass/epoxy material in such a way that four S-shaped fingers connected the base of the cone to the basket. *Photo 4* shows that construction.

To view the spider in motion, I positioned a stroboscope so that part of the light struck the spider itself and part was reflected from the white cone material, resulting in partial direct and partial backlighting. I observed the spider's motion while applying signals at 27Hz at various voltages, adjusting the stroboscope to yield an optimum perceived motion as described above.

Since I had not worked with this type of

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PHOTO 5: The driver at rest before the test.

PHOTO 6: The cone in a rearward portion of its stroke with the tip of the spider also rearward.

PHOTO 7: The cone moving outward with the tip of the spider actually leading the cone movement.

PHOTO 8: The cone continuing its outward movement with the spider still leading.

PHOTO 9: The cone continuing to move outward with the tip of the spider slowing down.

PHOTO 10: The cone further outward with the tip of the spider moving backward.

PHOTO 11: The cone moving significantly inward with the tip of the spider staying outward.

PHOTO 12: The cone moving again toward the front with the tip of the spider moving backward.

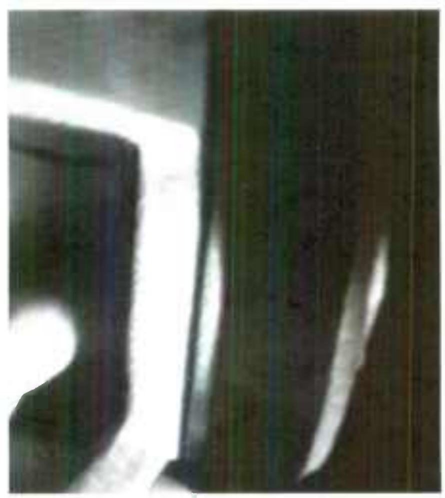

PHOTO 13: Using a finger to damp the oscillations of the spider.

spider construction before, the results were quite surprising. As the spider traveled through the center part of its range of movement, the tip of the "S" portion fluttered back and forth at a frequency higher than the fundamental. In addition to this flutter, I noted a torsional vibration in the spider sections, also at a higher frequency.

RECORDING THE EVIDENCE

The next step was to record this motion on video so the results could be sent to the man-

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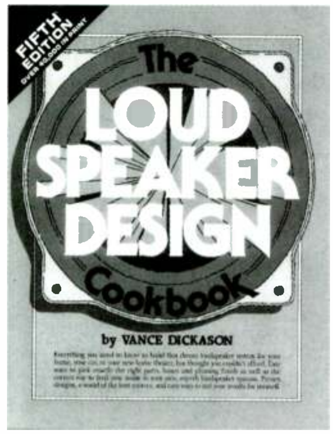
Book Report

THE LOUDSPEAKER DESIGN COOKBOOK, FIFTH EDITION

Reviewed by Robert Bullock, Contributing Editor



The Loudspeaker Design Cookbook, Fifth Edition, by Vance Dickason, published by Audio Amateur Press, $34.95, available from Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458-0243, (603) 924-6371, FAX (603) 924-9467.

Since *The Loudspeaker Design Cookbook* (*LDC*) was first reviewed in *Speaker Builder* in 1987, four subsequent editions have appeared, as well as translations into German and Portuguese. Such widespread interest justifies this review of the latest edition.

The first sentence of *LDC* states that it "aims to describe the operation, application, and measurement of electrodynamic loudspeakers and their associated enclosures and crossover networks." That this is an accurate thumbnail description of the book's scope explains why I consider it to be the best available loudspeaker-design reference. Speaker-building novices should not take any steps without a copy to refer to. Because Vance Dickason has done such a fine job, this review will be mainly a description of the contents of *LDC*. The following chapter headings give a good indication of the coverage of the work.

1. HOW LOUDSPEAKERS WORK
2. CLOSED-BOX LOW-FREQUENCY SYSTEMS
3. VENTED-BOX LOW-FREQUENCY SYSTEMS
4. PASSIVE-RADIATOR LOW-FREQUENCY SYSTEMS
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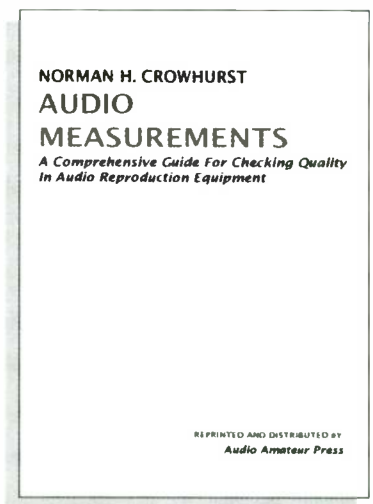
7. MID- AND HIGH-FREQUENCY DRIVERS: APPLICATION AND ENCLOSURES
8. PASSIVE AND ACTIVE CROSS-OVER NETWORKS

First published in 1958, Audio Measurements by Norman Crowhurst is a complete compendium of measurement and testing techniques for audio reproduction equipment with discussions of all the instruments needed to use them. Not surprisingly, it has a simplicity and clarity which are the hallmark of Crowhurst's writing.

After clearly explaining how to measure and detailing all the equipment needed to do so, he leads the reader step by step through all the types of audio reproduction equipment a reader is likely to have, including amplifiers, transformers, preamps, turntables and changers, tonearms and cartridges, tape recorders, and microphones. Crowhurst's Audio Measurements belongs in every audio hobbyist's library—and most especially so if the hobbyist is a tube enthusiast.



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12. CAR AUDIO LOUDSPEAKERS

The first chapter is a thorough discussion of the anatomy of an electrodynamic loudspeaker driver and how it acts to produce sound. It also briefly discusses acoustic power requirements in typical listening rooms and how they affect driver selection.

The next four chapters are devoted to the design and performance of the low-frequency portion of a system, each one starting with a bit of history on the particular design covered in that chapter. The first of these—on closed boxes—discusses not only the basic design methods but also box filling, multiple-driver configurations, thermal behavior, equalized alignments, bandpass systems, and variovents. Of particular interest is an empirical discussion of box filling—something I have seen nowhere else.

The chapter on vented boxes contains a thorough discussion of various alignment types and includes extensive design tables for them. With sufficient study, this material should enable anyone to make an informed design choice. The chapter has a good discussion on accounting for box losses, and it also covers vent behavior and tuning, vent-driver interaction, box stuffing, equalized vented boxes, and vented-box bandpass systems.

The chapters on passive radiators, transmission lines, and cabinet construction are somewhat shorter, but they still contain complete design information and cover additional topics such as the augmented passive radiator and alternative transmission-line design procedures. I am glad to see that *LDC* stresses that desirable passive-radiator responses usually require a PR that is substantially more compliant than the system driver. This is readily verified from models, but is rarely mentioned when the subject of passive-radiator design arises.

Chapter 6 discusses the important considerations in mounting midrange and high-frequency drivers. Included are such matters as midrange enclosures, driver spacing, and effective baffle design.

Chapter 7 on crossover networks is among the longest in the book. The treatment of passive crossovers is quite thorough as far as the standard networks are concerned, and quite a few design formulas are included for various types of two- and three-way networks. This chapter also discusses elementary impedance and response equalization networks. Active crossover networks are justifiably deemed beyond the scope of *LDC*, but it supplies several useful references. Overall, the chapter is an excellent introduction to crossovers and contains an extensive list of references for those who care to pursue the subject in greater depth.

Next is a chapter on loudspeaker testing. It covers not only the basic topic of determining Thiele/Small driver parameters, but also frequency-response measurements, phase measurements, enclosure-vibration measurements, and measurement microphones.

Chapter 9 consists of descriptions of the many loudspeaker design and analysis software programs available.

The book culminates in two chapters on topics that are currently of widespread interest: home theater and car audio. The material on home theater discusses the audio requirements of such systems and describes the THX and Dolby systems. The chapter on car audio concentrates on contrasting speaker performance in a lossy closed field (auto passenger compartment)—as opposed to a free field (large listening space)—and designing a system with good center-channel imaging.

In summary, I believe this book is of great value for anyone involved in designing and building loudspeaker systems. Its broad and thorough coverage of the basic concepts makes it an ideal reference for both the beginner and the experienced designer, and its extensive list of references should make it useful to even the most expert designer.

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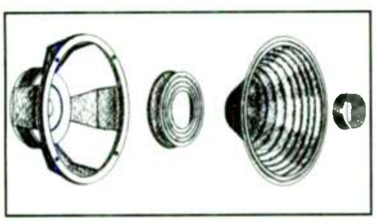

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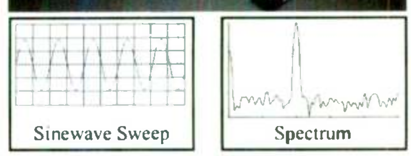

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VOLUNTEERS WANTED

Belden has been making professional audio cable for almost 100 years. As part of our determination to learn as much as we can about audio cables, we are interested in investigating the quality of performance of audio cables called "directionality."

Directionality is an attribute that pertains to the direction of flow of audio information in the cable. Some people believe that the sound quality of audio differs depending on the direction of signal flow through the cable, that one direction yields sound quality that is preferable to the other, and that this is related to the way the cable is created in the manufacturing process.

As the Technology Development Manager at Belden, I felt we should investigate this attribute. In discussions with our engineering staff we came up with a simple double-blind experiment that should satisfy most of the concerns of critical musical listeners. The goal of the experiment is to determine whether or not there is a correlation between "direction" in which the cable is manufactured and the quality of audio information flow in the cable.

We would like to invite readers to participate in this experiment. Those interested must send a card, letter, or fax volunteering to participate in this experiment by the end of the November to:

Belden Wire & Cable
Stephen H. Lampen
Technology Development Manager
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FAX (317) 983-5825 or (317) 983-5294.

Be sure to clearly mention my name, Stephen Lampen, and that you want to be part of the Audio Directionality Test.

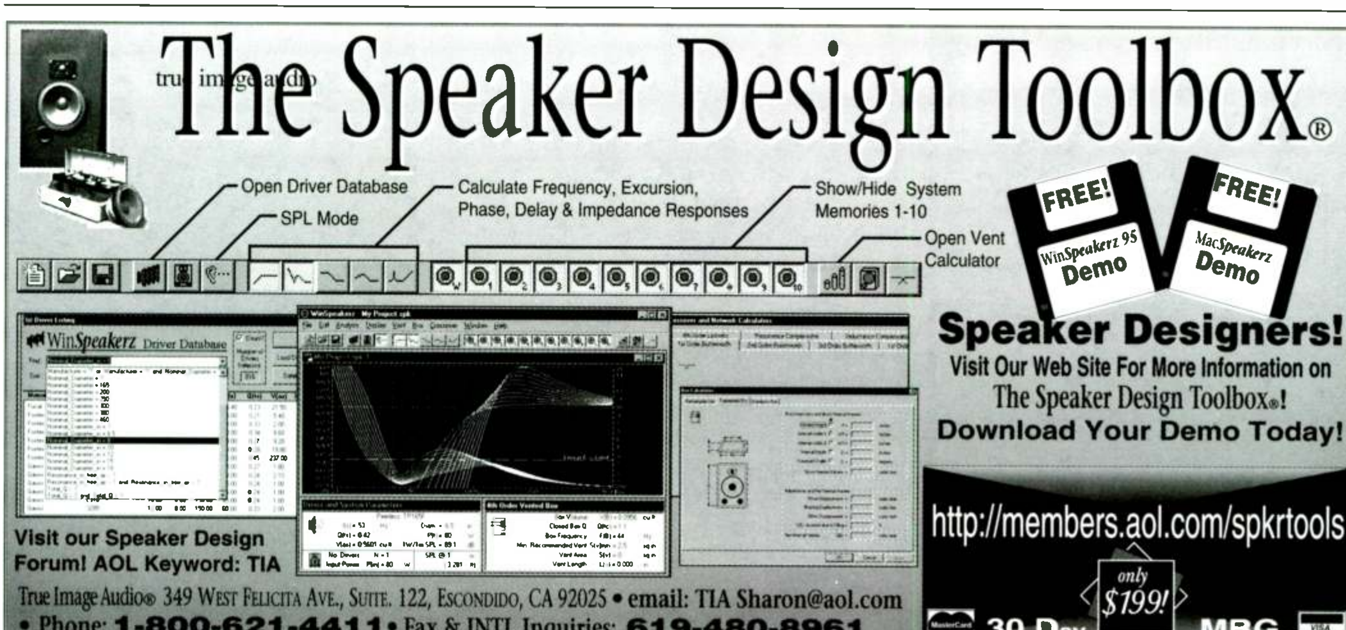
We are seeking 100 volunt*ears*, each of whom will receive ten pieces of single-conductor polyethylene-jacketed wire approximately 5′ long. The wire ends will be tagged with numbers chosen at random. Belden will maintain a master log of the "direction" each wire was drawn during manufacture, copies of which will be furnished to David Moulton, of David Moulton Professional Services, who has volunteered to be the third-party judge of the results.

The experimental task for each participant will be to audition the ten pieces, substituting the test piece for the positive lead from your amplifier to the positive connection for one speaker. This may be done at your convenience, and according to your preference, over a period of two months. During this time, you will try to determine in each piece of wire which "direction" you prefer.

Each participant should complete the answer sheet provided with the test wires and mail it in its post-paid envelope to David Moulton Professional Services, Groton, MA, for tabulation and statistical analysis. This should be completed within 60 days (two months) after receipt of the test wires. The wires do not need to be returned.

David Moulton Professional Services provides neutral testing services devoted to the audio field. Mr. Moulton has no professional opinion regarding cable directionality nor any vested interest in such a question. Mr. Moulton will tabulate the received answer sheets and correlate them with Belden's master log. He has no previous connection with Belden and was nominated for this position by Ed Dell, editor of *Speaker Builder*. Using normal statistical techniques, he will prepare an analysis of the correlation between preference and directionality, which in turn will be presented to Belden Wire & Cable, which will conduct its own statistical analysis of the results. All results will be made public to interested parties.

Speaker Builder will publish the test results in a future issue. Belden reserves the right to present these results at some appropriate convention or trade show. Should there be a significant group of testers whose perception of direction correlates positively, we expect to continue the investigation with these individuals. Our goal for such research is to develop a positive correlation between measured physical qualities and directionality.



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Thank you in advance for your help with this experiment.

Stephen H. Lampen
Technology Development Manager
Belden Wire & Cable

Speaker Builder *is pleased to be involved in this unique experiment and encourages reader participation. We wish that those readers who decide to take part in the directionality test will commit to it seriously, keep an open mind, and respond in a timely manner. We consider it a credit to both the magazine and its dedicated, knowledgeable readers to be approached to participate in this test, which attempts to address the question of directionality without bias.—Eds.*

TUBULAR EXPANSION

I couldn't find the values for the capacitor used as a crossover in Richard Carlson's article, "Tubular Speakers" (*SB* 4/96). I also cannot locate the placement of the sound port or the tweeter. A small diagram with values, placement, and assembly would have taken little space and clarified much. I am anxious to build two pairs of these for my office and workshop.

Carlos Alvarez
Winder, GA

Dick Carlson responds:

My sincere apologies for excluding tweeter and crossover information from my article. I cannot imagine why I overlooked such an important aspect of the system, other than pure haste.

To the point, each of the tubes employed an Audax TW010F1 10mm polymer-dome tweeter. The manufacturer recommends a first-order crossover frequency at 6kHz; yet, since I did not intend for the system to be played at extreme levels, I opted for a 5kHz crossover frequency. All loudspeaker components have an impedance of 8Ω, so I used a Mylar 10% polyester film capacitor rated at 3.9μF based on the calculations of X-over 2.0 (Fig. 1). *Should you decide on a different tweeter, the values will be affected. Although I did not employ a coil for the woofer,* Fig. 1 *shows 0.25mH coil would have worked nicely.*

Concerning the placement of the tweeter, I used a ½″-thick strip of plywood as a tweeter baffle. It is cut to the length of the tube, less baffle thickness at each end, and glued flush with each baffle. Before doing this, I cut a hole at the approximate center of the strip for the tweeter. After mounting the drivers, I routed the wires to the drivers and, using electrical tape, secured the wires to the tube for appearance and to prevent vibrations.

You will really enjoy the full-bodied sound of these loudspeakers, as I did for many months. Beware, you will receive numerous comments on the speakers, so be prepared to tell your story over and over again.

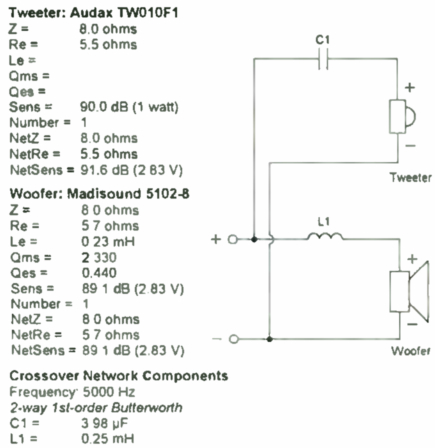

FIGURE 1: Passive-crossover design for tubular speakers.

APERIODIC MYSTERY

I am interested in building an aperiodic enclosure. I have found only bits and pieces of information in various magazines and books, which mainly talk in generalities and offer no concrete information.

I understand that a purely resistive membrane allows air to escape the enclosure. What is meant by "purely?" Is the box just large enough to enclose the speaker? What about tuning? Are there any mathematical equations involved in this design? Can a response be predicted or is it all trial and error?

What is the membrane made of and how much do you compress it? Does the compression thickness affect the tuning or the response? Is there a formula for surface area to the membrane?

John Rose
Saugus, CA

Although there are vendors who sell a type of cover for an aperiodic opening in the rear of closed boxes, very little in the way of formal investigative work has been done on this interesting format.

In the 1960s, Dynaco imported many hundreds of thousands of their A2 aperiodic speakers made for them by SEAS, but Dynaco's production manager confessed years later that the design was totally empirical, without any proven scientific theory as to why or how it works. The speaker was highly popular and many still survive.—E.T.D.

WAVEGUIDE ALTERNATIVES

Thanks very much for sharing your waveguide enclosure configuration in your three-part "The Waveguide Path to Deep Bass" (*SB* 6, 7, 8/95). I was also struck by the synchronicity of finding the letter from J. David Keener on the page opposite the end of your article. Reading your waveguide article, I kept wondering, "Why didn't he try PVC pipe?"; then, Mr. Keener's letter prompted me to suggest the idea.

Four-inch sewer pipe is a perfect match for the 4″ RS-1022 speakers from Radio Shack and 6″ pipe works nicely with 6½″ drivers. Hot-melt glue is great for attaching the drivers to the PVC, allowing you to glue pipe to the front and back of a driver, putting it directly in the waveguide. Using elbows and tees, as Mr. Keener mentions, you can easily create configurations and change them in a matter of minutes.

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I have been playing with transmission-line enclosures for a few years. Using PVC pipe convinced me that you can get truly great bass from a transmission-line enclosure. In fact, after trying plastic pipe, which is easy to work with and should be suitable for waveguides as well, I swore to never build another wooden cabinet.

TLs are woefully inefficient: the driver's back wave adds nothing to the sound, as with closed-box or vented enclosures. TLs can reproduce really low notes, but not with real authority. The best results seem to come from using drivers with higher sensitivities; otherwise, you cannot fully appreciate what these wonderful enclosures can do for your music. Given the waveguide articles and audio-testing software now available, useful empirical data on how TLs behave in real life when varying drivers, lengths, types and density of stuffing, and configurations is plentiful.

Doug Jones
72614.3525@compuserve.com

Contributing Editor G.R. Koonce responds:

Most readers who responded to the waveguide article recommended construction via round piping. At the time of my experimental double-ended waveguide investigation, I wanted a structure that had adjacent location of the two output ports and could handle one or two drivers of various size and mounting-hole arrangement. The only way I could see to accomplish this was with particleboard construction.

Certainly, if you know the final dimensions for what you want to build, the round pipe would offer simplified construction, greater wall stiffness, and less risk of air leakage. In waveguide work, the required pipe diameter is not set by the driver's nominal diameter, but by a combination of the driver's physical and electrical characteristics.

The transmission-line (TL) structures that Mr. Jones is experimenting with are, indeed, single-ended waveguides when used with little or no stuffing. I believe testing would show that the unloaded side of the driver cone makes a contribution to the total system output, which must be considered. In many TL applications, the woofer is used to a frequency above the range controlled by TL effects. For a flat response, the whole structure must be designed for a sensitivity that matches the driver's reference efficiency; i.e.,

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1994 Sanctuary Sonics • Modular Active Crossovers • A Full-Range Open-Baffle System • An Evolving Magnepan MG-1 • Low-Frequency AC-To-DC Converter • A Compact Bass Guitar Speaker • Measuring Speaker Impedance Without a Bridge • The Dynapleat • The Danielle II • The Birdhouse: A Sound-Reinforcement Subwoofer • The Linear-Array Sound System • A Revised Two-Way Minimonitor • Exploring the BUF 124 with Pspice • Signet's SL280B/U • Time Response of Crossover Filters • Converting Radio Shack's SLM To Millivolt Use • Acoustic Distortion and Balanced Speakers • Microphone Response Correction with IMP • More About the Birdhouse Bandpass • A 16Hz Subwoofer • D.H. Labs Silver Sonic Cables • The System III Loudspeaker • Exploring Loudspeaker Impedance • IMPcycling • The Linear-Array Chronicles • Book Report: Loudspeaker Recipes, Book One • The Woofer Test • A Large Ribbon You Can Build • Loudspeakers, A Short History, Pt 1-2 • Absolute SPL Sensitivity Measuring with IMP • The Damping Factor: One More Time • Cliffnotes for Loudspeaker University • Software Report: The Listening Room for Macintosh • Book Report: The Theory and Design of Loudspeaker Enclosures • A 15" Transmission Line Woofer • Inductor Coil Cross Talk • Quick Home Theater on a Budget • Silk Purses: A Two-Way Salvage Design • Audio Phase Inductor •

1995 The T-Rex Minisubwoofer • High Quality Use of Motorola's Piezo Driver, Pt 1 • The Achilles: A Two-Way Automotive Transmission Line • Driver-Offset-Related Phase Shifts in Crossover Design, Pt 1-2 • The Linear-Array Chronicles, Pt 3 • From Sad to Sparkle: A SAAB Story, Pt 1-2 • A Compact Two-Way PA, Pt 1-2 • The Baekgaard Crossover Technique • Rebuilding the KLH-9 Power Supply • KIT REPORT: Audax of America A652 • Satellites For a New System • Box Models: Benson Versus Small • PRODUCT REVIEW: Sapphire III Reference Monitor • The Simpline Sidewinder Woofer • Focused Arrays: Minimizing Room Effects • A Flexible Four-Way System • Extending IMP: A Program Set • CD REVIEW: *My Disc* From Sheffield Lab • The Freeline: An Open-Pipe Transmission Line • Computer-Aided Bass Horn Design • A Mike/Probe Preamp For Sound-Card Measurements • Four-Poster Speaker Stands • Mining For Gold On the Madisound BBS • SOFTWARE REVIEW: CLIO Test System • The Waveguide Path to Deep Bass, Pt 1-3 • Stereo Bass: True or False? • A Morning Glory Midrange Horn • Testing a Simple Focused Array • PRODUCT REVIEW: LinearX's pcRTA • A Self-Powered Subwoofer for Audio/Video • Your Car's (and Living Room's) Bass Boost • Driver Temp and T/S • SOFTWARE REPORT: SoundBlaster 16 • A Push-Pull Planer Speaker Quest • PC Sound Overview • Design a Three-Way TL with PC AudioLab, Pt 1 • PRODUCT REVIEW: Audio Control C-101 • SOFTWARE REVIEW: Electronics Workbench •

World Radio History

the same situation as for a vented or closed box. If the woofer is only used above the frequency range where resonant effects dominate, it is possible to obtain increased sensitivity over the bare driver. I encourage Mr. Jones to write up configurations he has found to perform well for the benefit of all readers.

AD INDEX

AS I WAS SAYING...

To continue my response to Thomas H. Eberhard's letter (*SB* 5/96, p. 54), the latest version (1.1.0) of Mac SLM© lets you save the measurement as a text file, enabling its importation into a spreadsheet, analysis, or graphics program. I sent Mr. Eberhard an upgrade version and user's manual. As it turns out, he had not received the printed manual with his order, which is necessary to experience the program's full potential.

Along the same vein, I give H. Donn Hooker (*SB* 5/96, p. 58) some sympathy regarding MathCad.© I use version 3.1 for consulting and personal projects, such as designing the DSP filters in Mac SLM. You should first read the book and then practice using the program. Quite powerful in some ways, MathCad is weak in optimization and in the facilities provided by the Maple© subset.

Beware that some impedance measurements are normalized by the impedance of free air, which radically changes the system of units.

Dr. Victor Staggs
Orange, CA

Aftershock Subwoofer

from page 42

phase. Removing the 55-ltr chamber and thickening the walls made Aftershock sound a little more solid; however, the response measured the same as it did before the overhaul.

SUMMARY

If you can get your hands on some old professional bass-instrument or sound-reinforcement speakers, take a little time to restore them, analyze what you have, and use the knowledge available in *Speaker Builder*, you may surprise yourself with incredible results and save yourself a ton of money. Warning: if you live in Southern California, watch one of those PBS specials on earthquake-proofing your house and take the precautions before putting your Aftershock into service, or you may hear some crashes that were not in the original soundtrack!

Spider Analysis

from page 57

ufacturer. I used a Sony MVC5000 video camera for this session, utilizing the composite video output available to drive both a monitor for real-time viewing and a VCR for recording. I used several different levels and recorded the results. Frame grabs from the video showing representative results are shown in *Photos 5–13*.

As you can see from the photos, there were significant motions at frequencies higher than the fundamental. These vibrations, coupled to the air both directly and through the base of the cone, were quite audible.

To confirm this spider motion as the source of the errant sounds, I conducted another basic test using the stroboscope to visualize the results. I again fed the test signal to the driver, and, while watching the vibration of the spider under the stroboscope, I placed my index finger on a point of one leg where it was attached to the basket. I then moved my finger up the spider until the strobe showed that the vibrations were damped, all the while listening for changes (*Photo 13*). The reduction in the high-frequency anomalies was consistent with the reduction of vibration I noted. Since I subjected only one of the four legs to this test, the anomalies were not totally removed, but the effect was clear.

In summary, a stroboscope can show motions in drivers that you cannot see with the naked eye. Additional advantages include its moderate cost, its portability, and the fact that you can use it with a wide range of objects. A little care in basic lighting techniques greatly enhances visual results, extending the range of objects that can benefit from this technique.

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Tools, Tips & Techniques

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In recent years, controversy has raged about the presence of audible differences in speaker cables, interconnects, and even amplifiers. A major factor influencing cable performance is total resistance, which reduces the damping of the amplifier/speaker combination, causing frequency-response variations. Less resistance has less of an effect. A larger wire diameter has less resistance for a given length than a smaller one. The greater the length of wire, the greater the resistance.

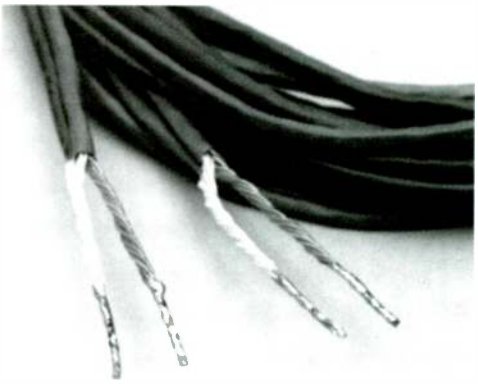

PHOTO 1: Multiple twisted pair of speaker cables.

WIRE FEATURES

Skin effect is a diameter- and frequency-dependent property of the wire, which adds an inductive-type roll-off to the high frequencies. You should minimize this effect within the audio band by using small-gauge, individually-insulated Litz wire. The geometric layout of these small wires affects mutual inductance and self-inductance. Long parallel runs of closely-grouped small wires exhibit high inductance, whereas a tightly-twisted pair has both low inductance and high capacitance.

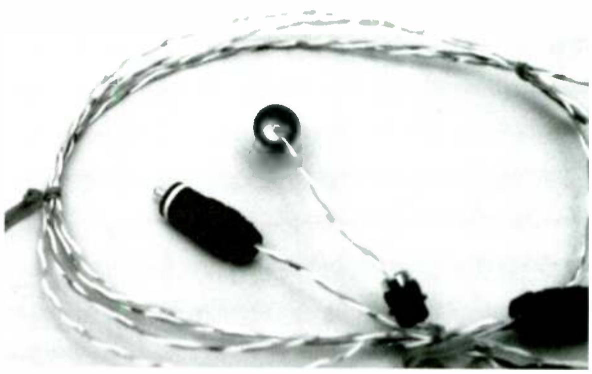

PHOTO 2: Interconnects.

Insulation forms the dielectric of a capacitor, while the two wires alternately form positive and negative plates. When the potential across this capacitor crosses zero, the capacitor will discharge back into the signal path. A slow discharge is audibly more disruptive than a rapid one, since the longer discharge duration represents a lower spectrum in the frequency domain.

Even just a little storage of the musical peaks can wreak havoc on the low-level detail when discharged back into the signal path, even at a minute fraction of the original amplitude. A Teflon® dielectric, which discharges more rapidly than any other, can keep this zero-crossing energy release to such a short duration that its frequency is inaudibly high, thus avoiding noticeable degradation of the signal.

Characteristic impedance is calculated as the square root of cable inductance divided by cable capacitance, and expressed in ohms. A cable with a characteristic impedance of 8Ω will most efficiently serve an 8Ω speaker load. Ideally, this match should be within 20% for best power transfer and minimal reflectance of the signal to the source. When the source and load are mismatched with the transmission line, the line can support resonances that are comparable to the standing-wave pattern of multiple echoes between parallel walls.

Most speaker wire does not match well to an 8Ω load and even less so to the 0.1Ω output impedance of a typical power amplifier. This mismatch at source and load can cause an unfavorable situation in which electrical reflections are set up in the line.

World Radio History

DREAM CABLE

With all of this in mind, an optimal speaker cable that minimizes foreseeable pitfalls and matches characteristic impedance to the 8Ω load of most loudspeakers is conceivable. The model could then be easily transposed for 4Ω, 6Ω, and 16Ω speakers. Speakers with a constant impedance would benefit the most from line matching, but other design considerations should reap like benefits. An equivalent gauge of AWG 14–16 should give an adequately low total resistance for most applications.

Multiple twisted pairs of small-gauge Teflon-insulated, high-purity copper wire, calculated to provide the desired 8Ω characteristic impedance and minimal skin effect, would be such a multipurpose cable (*Photo 1*). This dream cable would require specialized production facilities and, thereby, would be expensive to make—perhaps costing over $50 per foot. The only way to reduce the cost would be to mass-produce the cable on an industrial scale, as is done with the digital trunk line for computer installations.

Incidentally, the digital trunk line for computer networks is rated to 110MHz and consists of four twisted pairs of 24-gauge high-purity, Teflon-insulated copper wire. How many runs of this cable would you need for a workable equivalent gauge? Eight twisted pairs would equal a 15-gauge pair, with a characteristic impedance of 9Ω.

So, you would need a double run of category 5 Plenum-rated digital trunk line to get eight twisted pairs. For the double run, the cost would be a dollar a foot, which is as much as Radio Shack's knock-off of Monster cable. On the other hand, a 1,000′ spool costs only $240*. Obviously, I stacked the deck on this one. The point is that good speaker wire is available at low cost.

Ideally, sound is extremely detailed, spacious, dynamic, and free of grain. It is somewhat dependent upon the impedance curve of speakers with which it is mated. Speakers with a very high impedance across the midrange and high-end, such as a two-way design incorporating a series resistor on the tweeter for level matching, may sound better with a single run of twisted pairs with a 19Ω characteristic impedance.

In this case, the equivalent gauge is 18, so keep the runs under 8′. By the same token, four runs can be compiled for an equivalent gauge of 12 and a characteristic impedance of 4.75Ω.

PREPARING THE WIRE

The important factor here is "sweat equity," or the amount of work required. Four runs of four twisted pairs of 24-gauge wire per channel gives 128 little wire ends to strip, segregate, and solder for one pair of 12-gauge cables. If even one of the ends is mistakenly bunched with the opposite polarity bundle, the amplifier will immediately short out and die, unless the protection circuit works really well. Testing with an ohmmeter first is a very good idea.

Twisted pairs are color-coded, and the positive of each is easily distinguishable from its negative mate. Remove kinks in the runs of wire before twisting and soldering. "Electrician's scissors" are good for stripping the wire ends, but have the salesperson at your local electrical-supply store show you how. There is a touch and a technique to the procedure.

I should mention that a single twisted pair can be extracted from a length of cable to make an exceptionally clean, detailed, transparent interconnect (*Photo 2*). With a characteristic impedance of 75Ω, it can also serve as digital interconnect. As such, it should be terminated with good-quality RCA plugs. Shop around for gold-plated and Teflon-insulated plugs.

John Day, MD
Austin, TX

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MINI SUBWOOFER

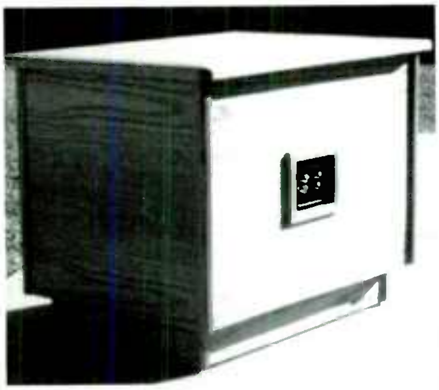

PHOTO 1: The author's subwoofer enclosure includes a ¾" oak top and ¼" plywood sides. It is powered by a 65W individual amp and features 6½" Madisound 8Ω speakers.

My neighbor, Burr Coffelt, and I constructed two mini T-Rex subwoofers ("The T-Rex Minisubwoofer," *SB* 1/95, p. 10), because he very much liked the sound of my subwoofer, which has a single 12" woofer. Also, I wanted a smaller one.

We contacted Madisound Speakers for their evaluation of a change from the 4Ω speaker in the original T-Rex to 8Ω, in order to be compatible with their house speakers. We were then able to use the 6½" mid-bass drivers, as in the original T-Rex design, and simply constructed two each from medium-density particleboard, using the Madisound connection blocks. We discussed crossovers, amplification, and other design considerations at great length, but knowing the sound would be similar to my existing 12" speaker subwoofer, we chose to loop the sound through a separate amplifier and a separate equalizer to control both volume and bass response. The resulting sound is magnificent.

PHOTO 2: This attractive speaker unit also makes a perfect end-table.

HOME IMPROVEMENT

Burr, who happens to be a master carpenter, designed the end-table concept. Using ¾" red oak for tops and ¼" oak plywood surfacing on all sides, he constructed each unit to the height of our respective homes' furniture. The box is a nice addition to the livingroom and a source of an incredibly mellow bass sound.

We discovered, however, that if your room is carpeted, you might encounter difficulty running wires to the speaker unless it is situated close to the amplifier.

Gerald H. Jones
Yuma, AZ

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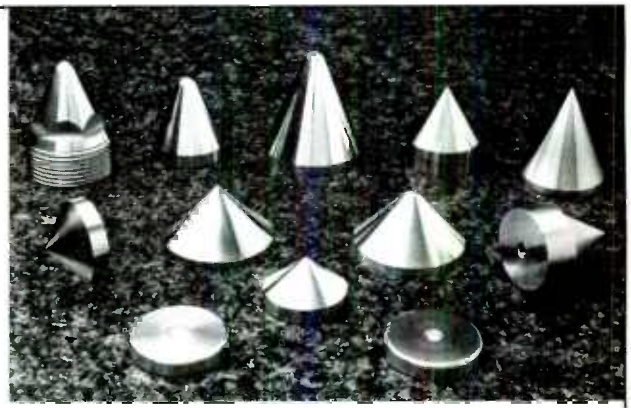

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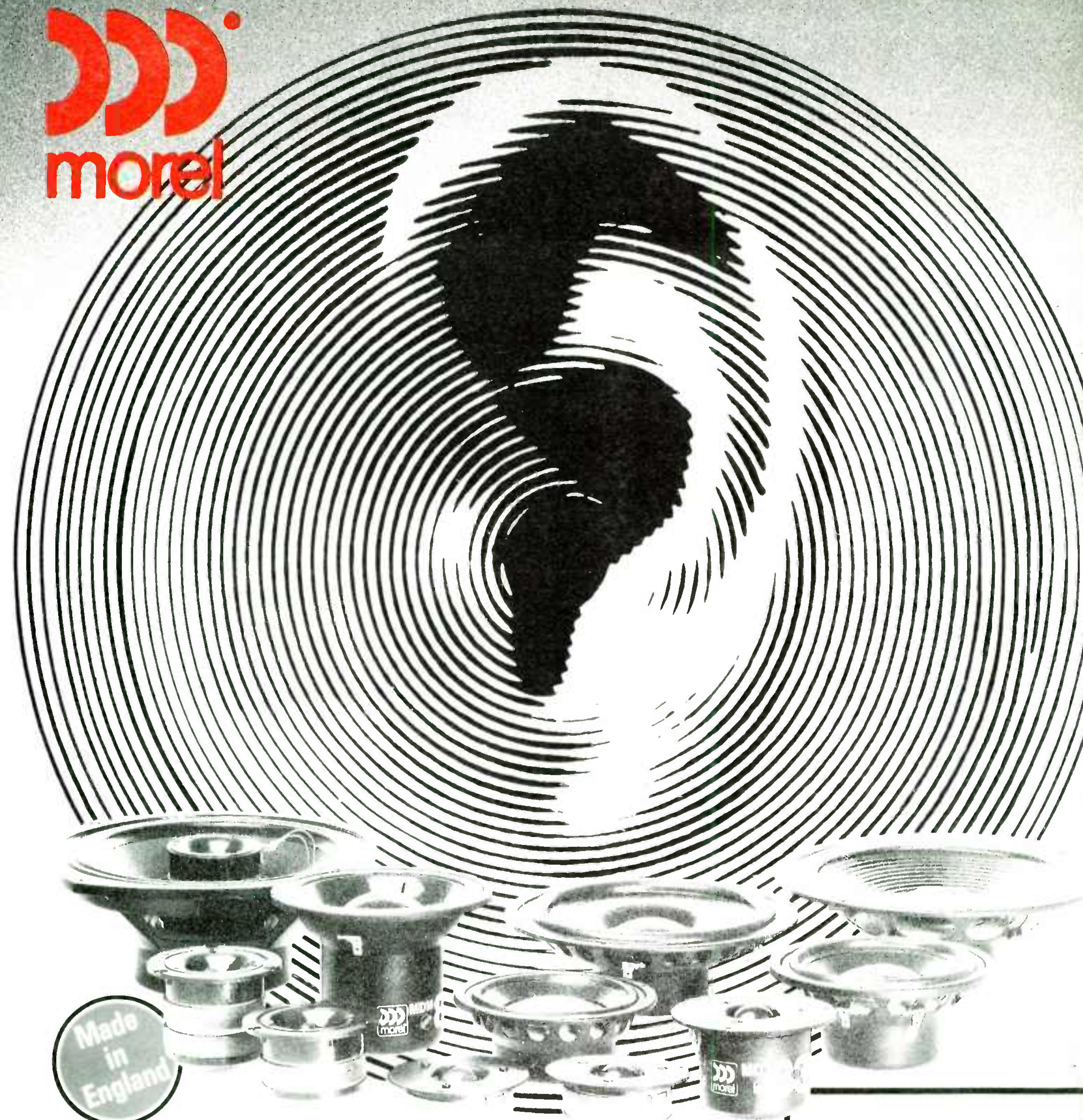

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