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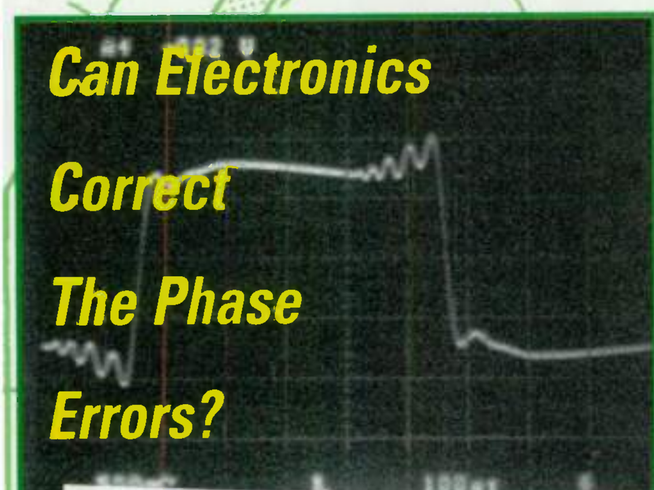

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Good News

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■ TAKE YOUR PICK

Harrison Laboratories introduces the FMod™ filter module. According to the manufacturer, this active crossover simulator features virtually no noise or distortion, 10V maximum RMS, and 12dB/octave. Also available from the company are attenuators, cables, and the SEMOD/Spectrum Analyzer and EQ Module. Harrison Laboratories, PO Box 1349, Parker, CO 80134.

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■ CUT THE NOISE

DCart, from Diamond Cut Productions, is a software program designed for the sound restoration of audio recordings. This Windows-based program removes ticks, pops, crackles, buzzes, and surface noise. It allows you to restore worn-out vinyl LPs and 78s to modern audio standards; preserves one-of-a-kind recordings; cleans up old optical and magnetic movie soundtracks; provides special audio effects and equalization for movie, radio, television, or stage use; and more. Diamond Cut Productions®, PO Box 305, Hibernia, NJ 07842-0305, FAX (201) 316-5098, E-mail dctools@aol.com, Website http://www.members.aol.com/dctools.

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⊃ "PRISM" SPEAKER

The DM305, from B&W Loudspeakers, is a floor-standing two-way model, incorporating the company's "PRISM" enclosure technology. The speaker includes a one-inch soft-dome tweeter rigidly mounted on its low-diffraction faceplate. An extended 6½-inch bass/midrange unit is mounted in a reinforced cast-steel chassis, utilizing an efficient long-throw "motor" and a dual front-slot/rear-port vented enclosure, for a clean, dynamic, and extended low-frequency response (–6dB at 45Hz). B&W Loudspeakers of America, 54 Concord St., N. Reading, MA 01864-2699, (508) 664-2870, (800) 370-3740, FAX (508) 664-4109.

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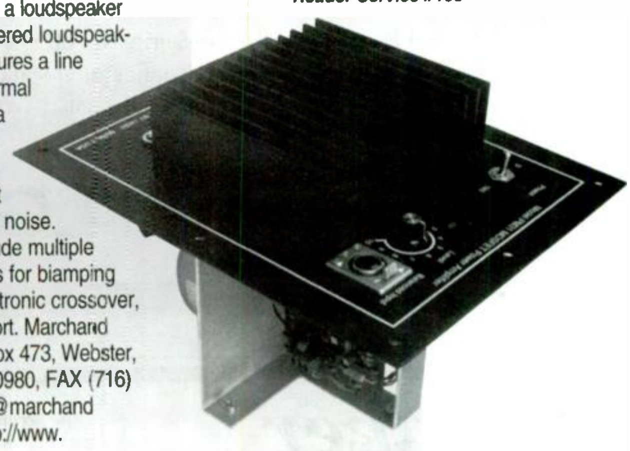
⊃ QUIET POWER AMP

The PM31 MOSFET power amplifier, from Marchand Electronics, is designed for direct-mounting into a loudspeaker cabinet, making a powered loudspeaker or subwoofer. It features a line circuit-breaker and thermal cutout protection, and a heavy-duty toroidal power transformer that provides compact power with no hum or noise. Available options include multiple power amplifier stages for biamping and multiamping, electronic crossover, and engineering support. Marchand Electronics Inc., PO Box 473, Webster, NY 14580, (716) 872-0980, FAX (716) 872-1960, E-mail info@marchandelec.com, Website http://www.marchandelec.com.



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⊃ GRAND OPENING

One of America's electronics giants is opening a division to serve electronics hobbyists and professionals, with a big mail-order catalog just out. TechAmerica is the name of this new 320-page mail-order compendium, offering a very broad line of electronic parts, test and pro equipment, plus books and kits. Tandy Corp. of Fort Worth, TX, the parent of TechAmerica, is also opening a series of giant superstores, the first already open in Denver, with Atlanta, Phoenix and Dallas to be open by year-end. The stores are modeled on the now familiar Home Depot or HQ megamarkets. TechAmerica's mail-order catalog requires no minimum amount and shipment is next day. To get a TechAmerica catalog call (800) 877-0072 or FAX your request to (800) 813-0087.

■ EQUIPMENT DISTRIBUTOR

MCM Electronics is now distributing a line of test and measurement equipment from Tektronix. Included in this line are handheld meters, scopes, power supplies, accessories, and more. MCM also announces the release of catalog #39, which includes an additional 9,000 items, for a total of 36,000 items stocked. MCM Electronics®, 650 Congress Park Dr., Centerville, OH 45459-4072, (937) 434-0031, (800) 543-4330, FAX (937) 434-6959.

Reader Service #104

■ FRENCH DEVELOPMENTS

Aaxis, located in France, specializes in speaker accessories, particularly inserts, spikes, and cones. It is also developing vibration-free cabinets and speakers, and other improvements for OEM standards. Its US agent is Orca Design & Manufacturing, 1531 Lookout Dr., Agoura, CA 91301, (818)707-1629, FAX (818)991-3072. Aaxis, c/o SCODIC, BP N° 27, 08001 Charleville, Mezieres, France.

← ***Reader Service #36***

About This Issue

If you're looking for a worthwhile and easy-to-follow construction project, then check out this issue's lead article. **Paul Kittinger**'s detailed instructions map the way to successfully building a three-way tower that includes an open-back mid-range and an Isobarik (constant pressure chamber) woofer section. The result is improved sound—at both low and high ends ("An Isobarik Tower," p. 10).

When it comes to enhancing stereo performance, **Peter Lehman** knows all the angles—especially those bouncing from the ceiling of the listening room. He uses this rather iconoclastic approach in his uniquely designed and positioned speaker system, which floods the listening position with audio output ("Enhancing Ambience with an Auxiliary Speaker," p. 22).

Some people are more troubled than others by the inevitable phase distortion in crossover networks. So, how you deal with this phenomenon is a personal choice. In simple terms, **Dick Crawford** explains how to significantly reduce phase distortion with a phase-equalization circuit ("The Phase Redeemer," p. 34).

Dick Campbell shows us another approach to equalization. His shelving-ladder filter (so-named because the response curve resembles a shelf) comes in handy when other, more traditional, filter topologies are infeasible ("Active Shelving Room Equalization," p. 28). The "professor" presents an interesting lesson in designing this filter, which is not adjustable by the user.

If you're lacking test equipment, you might consider **David Weems**'s review of the handy Woofer Tester, which combines the functions of several instruments ("Product Review," p. 44).

Then, the tables are turned on Mr. Weems, as we review the latest edition of his text on constructing your own loudspeaker system ("Book Report," p. 40).

Finally, in "Tools, Tips & Techniques" (p. 61), read how one author makes use of soothing white noise to ensure some domestic tranquillity.

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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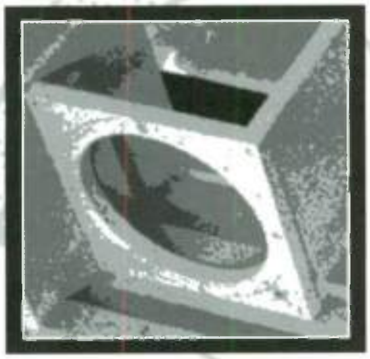
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SPECIFICATIONS			
Characteristics	Symbol	Value	Units
PRIMARY APPLICATION			
Nominal Impedance	Z	8	Ω
Resonance frequency	Fs	50	Hz
Nominal Power Handling	Pnom	120	W
Max Power Handling	Pmax	300	W
Sensitivity(1w/1m)		85	dB
VOICE COIL			
Diameter	ø	76	mm
DC Resistance	Re	6.3	Ω
Inductance	Lbm	0.75	mH
Length	H	15.5	mm
Former	Kapton®		
Layers	2		
MOTOR SYSTEM			
Magnet System	shielded symmetrical neodymium		
Force Factor	BL	7.66	N/A
Gap height	He	5	mm
Linear excursion	Xmax	5.25	mm
PARAMETERS			
Suspension Compliance	Cms	624	mMN
Mechanical Q	Qms	3.7	-
Electrical Q	Qes	0.53	-
Total Q	Qts	0.47	-
Moving mass	Mms	15.9	g
Effective Piston Area	Sd	0.0085	m^2
Equivalent Air Volume	Vas	6.4	L
Weight	M	1.5	kg

RECOMMENDED ACOUSTICAL ALIGNMENT			
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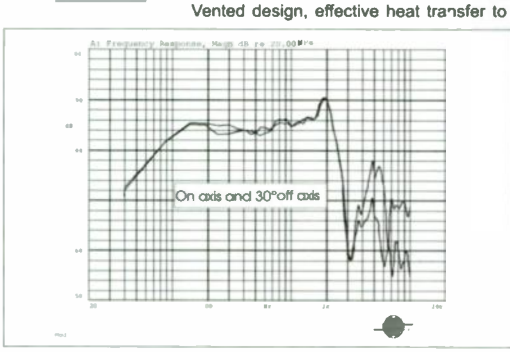

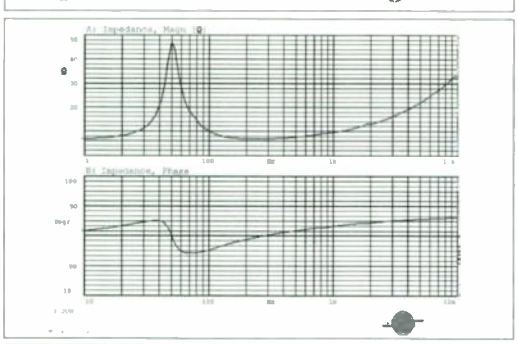

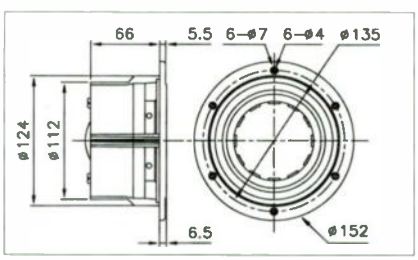

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Editorial

THE WHALE AND THE ELEPHANT

While listening to reproduced music may seem to be one environment, I suspect strongly that it is two. This isn't about room effects or concert-hall qualities, but about the mind.

Physician Lewis Thomas, writing about his father, who was also a physician, relates an interesting anecdote. The elder Thomas practiced medicine in Brooklyn in the 1920s and '30s. Medicine in those days was still largely homeopathic, with very little in the way of reliable, scientific information about the drugs available. This lack was a source of deep and continuing angst in his struggle with the patients' ailments. He noticed, however, that even though what he prescribed for the illnesses of some patients was little more than a placebo, with no proof of performance, the patients often got better and eventually recovered.

It is a truism that, in a basic sense, doctors do not heal people. The body heals the body, with assistance, to be sure, but it is primarily the mechanisms of the body itself that do most of the work. What I describe here is a very well-documented phenomenon: the placebo effect. Its effectiveness depends, apparently, on the patient's belief that the medicine will heal his ailment. Is the healing real? It depends on whom you ask.

Thomas senior was embarrassed by the result, even though gratified at the patient's condition. But he longed for a reliable, scientifically proven remedy which he could give with more certainty of the result, rather than relying on the patient's faith in him as the physician.

The engineering community's passion for accurate knowledge about the nature of the world's physical characteristics and behavior has given all of us amazing gifts—as well as some horrendous capabilities. No one would argue that experimental proof of how the physical world functions is not valuable, both as result and as a human enterprise. But there are limits to what we know.

If a music lover builds a preamp and states that a blend of solder makes a difference in how it sounds, then his experience of the difference is real—to him. It may be a physical fact, or it may be a mental one, but we do not know which.

There are those who believe that the placebo effect can be tested by double-blind methods. However, the double-blind test is not scientific in a strict sense. It does not account for the human variable of emotional response to the test itself and does not quantify what that variable might be. It does not, and cannot, determine how the test affects the participant. Perhaps someday someone will do the work of finding out what the effects of the double-blind process do to the feelings of the persons taking part in the test. Until they do, this variable is not controlled, which it must be in order for the single variable tested to be valid.

This long-standing debate between subjectivism and science is rather like a war between a whale and an elephant. The important thing about the participants is that they are both mammals, but they occupy different environments that are nearly mutually exclusive.

Is the person who buys a new cable or expensive capacitor or different solder and believes it makes his system sound better deluded? Any answer other than "we don't know" is speculative. In the absence of any proof, we are left with a proper agnosticism. Anything else is likely to be emotional and discourteous. No discipline is omniscient. Our reliable, repeatable knowledge is wonderful but minuscule compared to what we don't know about the world.

What we don't know about ourselves and how we function, particularly psychologically, is significantly large. If the subjectivist believes that he hears an improved version of the reproduced sound as a result of some change—however little measured evidence there may be of a scientific basis for that effect—the feeling and effect in that particular human being are nonetheless real. In some ways it is in the same category as our whole Blumlein-based stereo reproduction systems. Do we know how much is belief and how much is physical? Is what I hear in my listening room from the disk I am playing a physical replica of what I have heard at the recording site? How much do my mind and feelings add to the experience?

Everyone has, and enjoys, a belief system. We all need to be confident enough in the one we have chosen to work in it joyfully and positively without trying to make a weapon out of it to destroy or discredit those of others. The march of science in medicine has dramatically reduced the need for placebos. Perhaps the day will come when we know enough about the music reproductive process—and about how the human brain processes that result—to need fewer placebos and their effects.—E.T.D

← Reader Service #35

ISOBARIK TOWER

By Paul L. Kittinger

This article describes a three-way tower speaker system that incorporates an open-back mid-range with a constant-pressure (Isobarik) woofer section. The tweeter is a 1 1/8″-diameter fabric-dome type, the mid-range is a 6″ poly-type driver, and the woofers are 8″-diameter poly drivers.

This, my second system design, applies established principles to careful and thorough design to achieve a very good, if not superior, sound. The crossovers are second-order, with corners at 350Hz and 2.8kHz, and the system Q is nominally 0.7 with an f_3 of 35Hz.

The approximate cost is $1,000 per pair. The overall sound is open and spacious, as a result of the mid-range configuration; distortion at low frequencies is minimal, due to the woofer configuration; and imaging is very good. Also, floor-bounce is minimized because the woofers are located at the very bottom of the baffle. See *Photos 1, 2,* and *3* for three views of my finished system.

If you wish to design your own speaker systems, I strongly urge you to read Vance Dickason's *The Loudspeaker Design Cookbook* (Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458, 603-924-6526, FAX 603-924-9467). It contains everything you need and is presented in very clear fashion.

PERSONAL PREFERENCES

From my first efforts I learned that wood is cheap and it's a lot easier to design and build a sturdy, low-resonance cabinet from the beginning than to fix it later. I don't believe it is necessary to use costly materials, cabinet, or other components in order to have quite good sound; however, I do believe in using quality components and in following sound (no pun intended) engineering practices.

First of all, to compensate for the mid-range and tweeter sensitivities, I used adjustable L-pads instead of fixed-resistor networks. I did this so I could easily match these drivers' sensitivities to those of the woofers from the outside after the systems were built. Secondly, in the crossover I used some iron-core inductors and nonpolarized electrolytic capacitors, but I chose these carefully for this application to minimize any detrimental effects.

Finally, the internal wiring is 16-gauge stranded, crimped onto solderless terminals for connecting all the driver terminals to the crossover. Did these deviations and choices result in inferior sound? My ears say no.

SMALLER AND SEALED

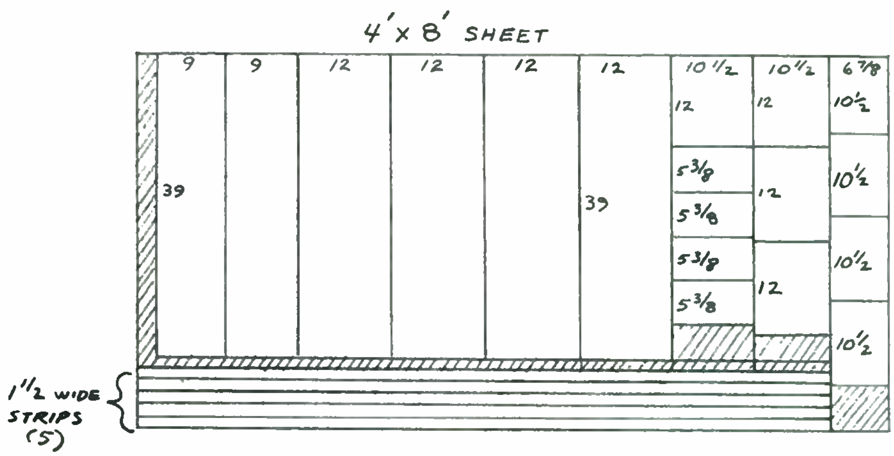
The system is a sealed, infinite-baffle design that benefits from the smaller required cabinet volume of the Isobarik configuration. I chose the sealed over a vented system not only to achieve the shallower rolloff below f_3 and good transient response at low frequencies, but also because it is a bit more forgiving of minor design and assembly errors. Nevertheless, the enclosure must be well-glued and well-sealed.

The mid-range enclosure is a 6 7/8 inch^2 tunnel (outside dimensions), open in the back and quite densely stuffed with 6 oz of Acousta Stuf® (polyester fiber). By the way, one speaker manufacturer uses two of the same mid-range drivers in a similar configuration that received a rave review in at least one magazine.

I chose second-order crossovers because they are not overly complex and their rolloffs are steep enough to minimize response overlaps between drivers. Based on the woofer's specified parameters and my desire to achieve an f_3 below 40Hz while keeping the overall size as small as possible, I calculated that Q_{tc} would be 0.725 without any stuffing.

I took into account all consumed volumes, series resistances from crossover inductors and wiring, and amplifier output impedance. To end up with an actual Q_{tc} close to 0.707, I estimated that the main enclosure would need 10 oz of Acousta Stuf (that worked out nicely—a 1 lb. bag takes care of one enclosure).

The entire enclosure should be made from ¾″ medium-density fiberboard (MDF), with the exception of the grille



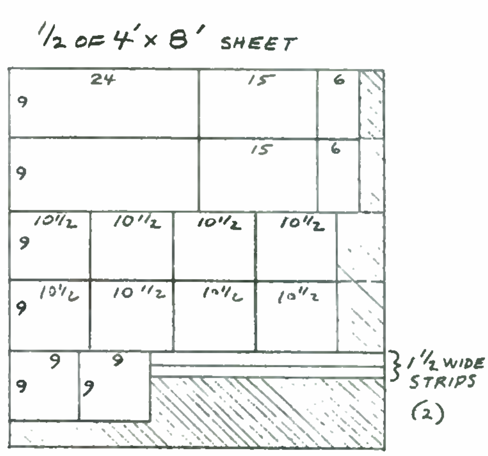


FIGURE 1: Cutting guide for MDF sheets.

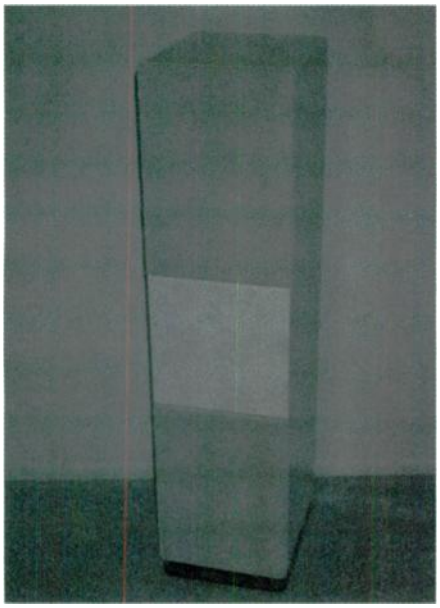


PHOTO 1: Finished system, front view, with grilles.

PHOTO 2: Finished system, front view, without grilles.

PHOTO 3: Finished system, rear view.

boards and the center portion on the front, which are of ½″-thick MDF or particleboard. It will require one and one-half 4′ × 8′ sheets of ¾″ MDF to make all of the necessary pieces for a pair of speakers. *Figure 1* is a layout/cutting guide for the MDF sheets. (As the accompanying photos reveal, I used some ¾″ particleboard because I already had some and was confident it would not cause any audible resonances in the extensively braced cabinet.)

Another unconventional design feature I used was not to recess the drivers; however, I attempted to compensate for this by chamfering the inside edges of the driver-perimeter cutouts in the grille boards at a 45° angle so the start of the chamfer is flush with the front surfaces of each driver. In other words, I intended to leave the grille assemblies on as an integral part of the design, hoping that any detrimental effects would be minimal (more on this later).

ADDING A BASE

I rounded off all edges of the enclosure, except the front, with a 3/8″-radius router bit, and used the same radius on the outer edges of the grille boards. I built a base from two ¾″ pieces of solid oak, rounding the corners and the top edges of the bottom oak piece to match those of the enclosure. I gave the oak a light stain and finished it with clear polyurethane.

You could choose a different base design,

TABLE 1

PARTS LIST (Quantities shown are for two systems; dimensions are in inches)

QTY	DIMENSIONS	DESCRIPTION
¾″ MDF		
4	10 ½ × 12	Top, bottom, (outside)
8	10 ½ × 9	Top, bottom (inside), shelf brace
2	6 × 9	Woofer subenclosure top
2	9 × 9	Rear woofer mounting panel
2	24 × 9	Rear panel
2	15 × 9	Access panel
4	12 × 39	Side panel
2	9 × 39	Front panel (baffle)
4	5 3/8 × 10 ½	Mid-range tunnel top/bottom
4	6 7/8 × 10 ½	Mid-range tunnel side
8	1 ½ × 13 ½	Brace
12	1 ½ × 7 ½	Brace
4	1 ½ × 6	Brace
8	1 ½ × 8 ¼	Brace
4	1 ½ × 15	Brace
4	1 ½ × 3 ½	Brace
6	1 ½ × 7	Brace
4	1 ½ × 10 ½	Brace (notched)
½″-thick MDF or particleboard		
2	10 ½ × 10 ½	Front panel dress plate
2	7 × 7	Crossover board
2	5 ½ × 7	Input connector/L-pad subpanel
4	10 ½ × 14 31/32	Grille board
Drivers		
4		Woofers: Peerless 831709, 8″, 8Ω
2		Mid-range: Morel MW-166, 6″, 8Ω
2		Tweeter: Morel MDT-33, 1 1/8″ dome, 8Ω
Crossover components		
2		L1-inductor, steel bobbin, 3.7mH (0.2Ω) 15 gauge wire
2		L2-inductor, ferrite bobbin, 7.5mH, 16 gauge wire
2		L3-inductor, air core, 0.70mH, (0.3Ω) 16 gauge wire
2		L4-inductor, air core, 1.0mH, 16 gauge wire
4		C1a, C3a-capacitor, polypropylene, 16µF, 100V
2		C1b-capacitor, non-polarized electrolytic, 40µF, 100V
2		C2-capacitor, non-polarized electrolytic, 65µF, 100V
2		C3b-capacitor, non-polarized electrolytic, 22µF, 100V
2		C4-capacitor, polypropylene, 3.3µF, 100V
2		C5-capacitor, polypropylene, 10µF, 100V
2		C6-capacitor, polypropylene, 6.8µF, 100V
2		C7-capacitor, polypropylene, 2.2µF, 100V
4		LPM, LPT L-pad, 8W, 100Ω
2		R1-power resistor, 15W, 3Ω
2		R2-power resistor, 15W, 8Ω
2		R3-power resistor, 15W, 6.5Ω
2		Barrier strip, 8-position
Miscellaneous		
30′		½″-wide, 1/8″-thick foam adhesive tape
4 pr.		Speaker input posts
2 lb.		Acousta Stuf®
16		Grille fasteners
1 yd.		Grille cloth
2		Felt tweeter diffraction ring (111mm diameter, 41mm hole)

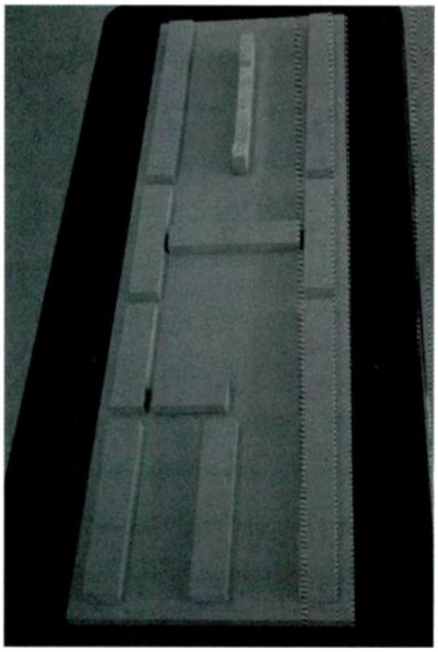


PHOTO 4: Assembled side panel.

or no base at all. I made this base 1½″ thick in order to locate the center of the tweeter at a height of 38″, which is about my ear level when I'm in my listening chair. The completed cabinet with base is 42″ tall, 10½″ wide, and 12″ deep, with a slight protrusion on the back from the input terminals.

Since this is an Isobarik configuration, I incorporated an access panel into the back to allow mounting of the rear woofer. I placed foam tape on the inside mounting strips and attached the panel tightly with 12 screws to ensure a good seal. The access panel also contains the input connectors and the L-pads, as well as providing an area for mounting the crossover assembly (built on a 7″ × 7″ board ½″ thick) below the connectors and L-pads and behind the rear woofer.

The two woofers face in opposite directions, which requires wiring them out of phase electrically so their cones will move in phase. In order not to reduce the sensitivity, I wired the woofers in parallel, thus compensating for the loss due to doubling the mass. Having the woofers arranged in this manner supposedly eliminates certain distortions resulting from cancellation of nonlinearities. While that may be true of drivers mounted above and below each other in opposite directions on the same surface, I'm not sure it applies to the Isobarik configuration; however, the bass sounds defined and clean.

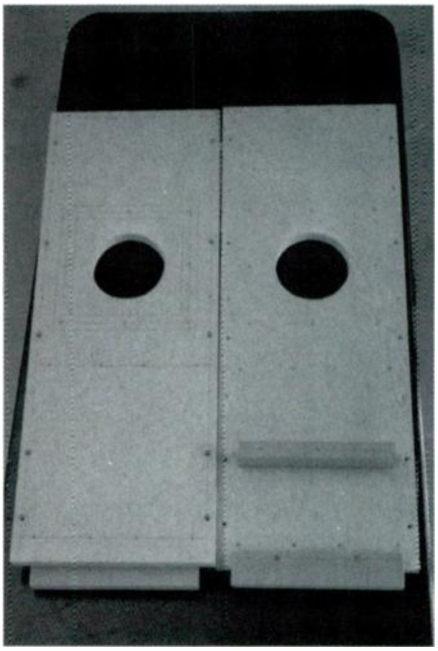


PHOTO 5: Assembled rear panel.

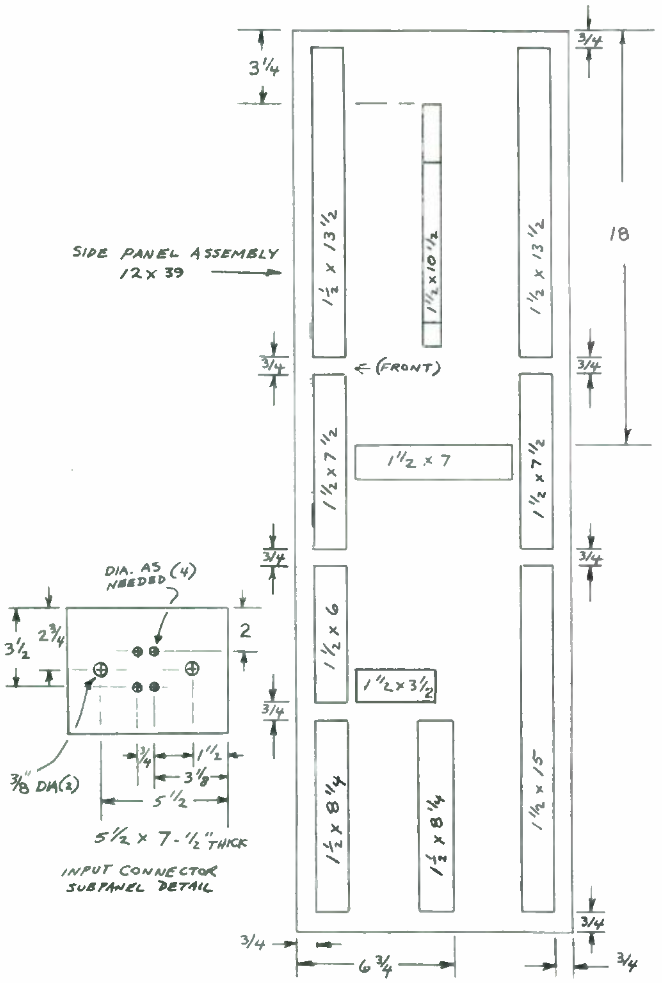


FIGURE 2: Side panel and input subpanel detail.

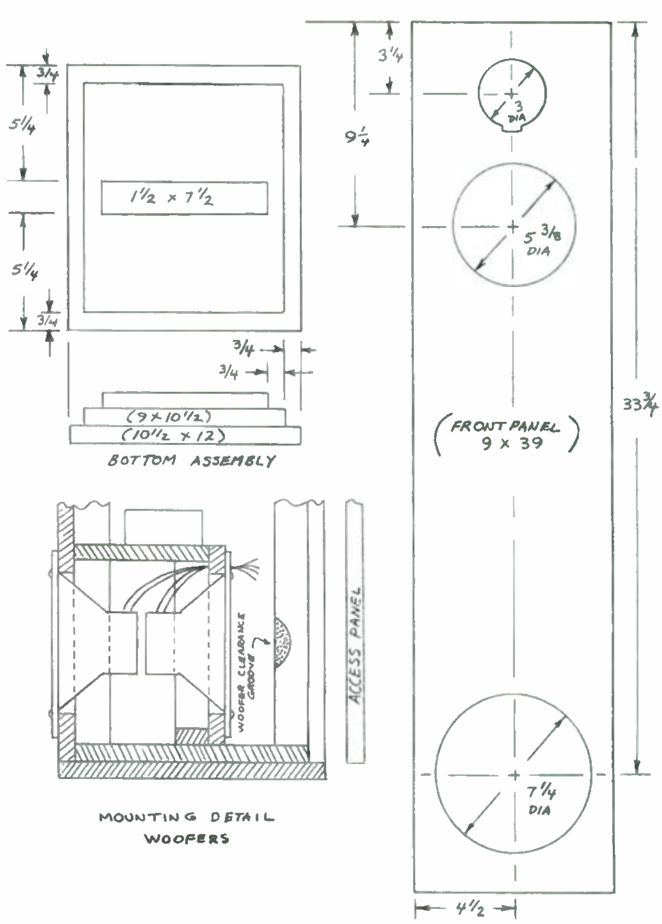


FIGURE 3: Front-panel layout, bottom assembly detail, and woofer-mounting detail.

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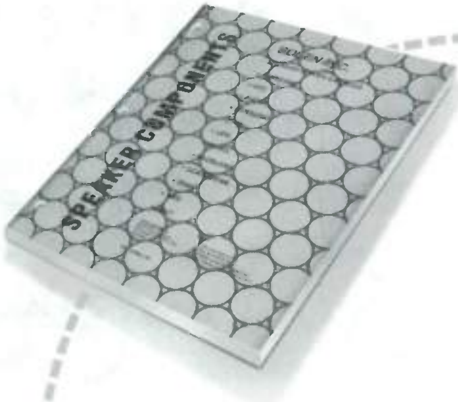

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Reader Service #24

Both the mid-range tunnel and woofer subenclosure have pass-through holes for leads to the drivers. I sealed these holes thoroughly with silicone sealant after the leads were in place so that the woofers would work as intended and their excursions would not affect the mid-range driver. Metal pass-through terminals with threaded fasteners on both sides of the panels would do instead.

BUILT-IN STURDINESS

I included several features to achieve a robust cabinet without audible resonances. Both tops and bottoms of the cabinet consist of two pieces of wood laminated together. The inside piece is exactly 1½″ less in both dimensions than the outside, to which it is attached, exactly centered. This forms a ¾″ notch into which the cabinet's sides, front, and back are attached. Of course, having a top and bottom this thick is structurally beneficial.

I used a similar technique on the side panels. Various lengths of 1½″-wide MDF are attached to the sides to form mounting edges for the front and rear panels, to create slots for two shelf braces and the top of the woofer subenclosure, and to increase the overall rigidity. These strips are attached exactly ¾″ inside the perimeter of the side panels, with ¾″ spacing between lengths for shelf braces and the top of the woofers' subenclosure.

The mid-range tunnel is attached to both front and rear panels and—more importantly for rigidity—to both side panels by screws that pull the side panels in. A 10½″-long vertical brace, notched to a 1 1/16″ width, is attached to each side panel to fill in the gap between the side panel and the outside of the mid-range tunnel. Two braces, 1½″ wide and 7″ long, are attached to the side panels between the shelf-brace slots, and a third, of the same size, is attached to the inside and just above the bottom of the rear panel.

CONSTRUCTION DETAILS

In order to ensure that the cabinet goes together properly, it is essential that you cut all of the rectangular pieces squarely and accurately on a table saw. Once you've done this, cut out the various holes with a jigsaw: holes for the drivers in the front panel and the rear woofer panel; the exit hole for the mid-range tunnel; the hole for the input terminal and L-pad subpanel in the access panel; the large holes in the two shelf braces; and the driver-clearance holes in the grille boards. Make sure you locate the driver mounting and clearance holes exactly in their respective panels and grille boards, or alignment will be off.

PHOTO 6: Cabinet assembly, showing parts locations.

To help align the various pieces during assembly, cut six 1″-wide strips of the ¾″ MDF—two 12″ long and four 6″ long. Clamp the 6″ strips onto the top (and later the bottom) outside piece as a frame for locating the smaller inside piece. In other words, clamp the four 6″ guide strips so that one edge of each ¾″-width strip is flush with the outer edge of the outside top piece. Apply glue liberally to the two pieces and nail them together with 1¼″-long brads from the inside surface.

Similarly, clamp the 6″ and 12″ guide strips to the various edges and in shelf spaces on the side panels to accurately locate the 1½″-wide braces. Fasten all the braces to the side panels with glue and 1¼″ nails.

To attach the side-panel braces, it is best to start at the top and work towards the center; then stop and work up from the bottom (*Fig. 2* and *Photo 4*). Attach both 13½″ and 7½″ braces. Move to the bottom and attach both 8¼″ braces, followed by the 15″ and 6″ braces. Finish the panel by attaching the 3½″ and 7″ horizontal braces, and finally the 10½″ notched vertical brace (use longer nails on the ends of the notched brace).

After the glued side-panel braces are dry, it may be necessary to ensure adequate clearance by filing or sanding the edges of the braces that form the slots for the two shelf braces and woofer subenclosure top

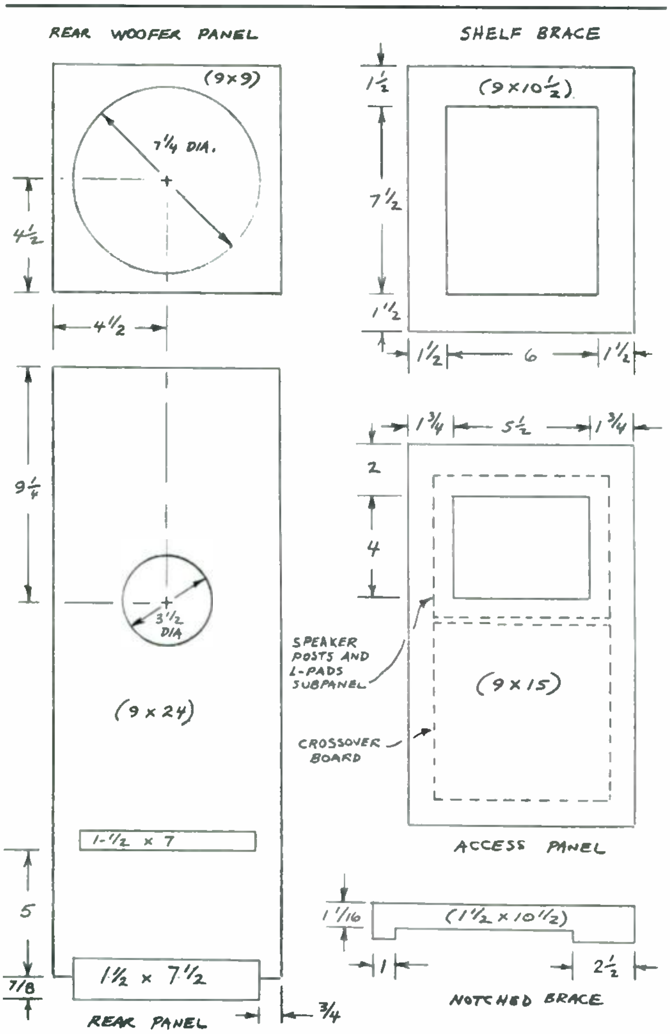

FIGURE 4: Cutting and assembly details for rear woofer panel, shelf braces, rear panel, access panel, and notched brace.

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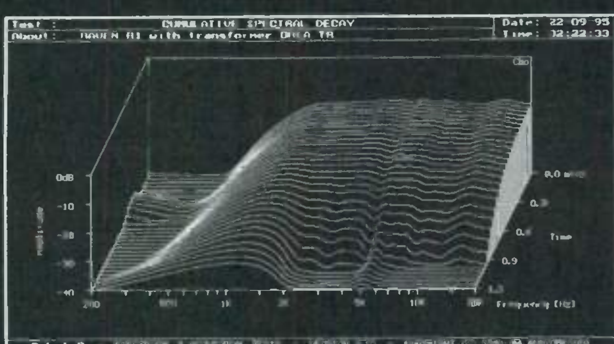
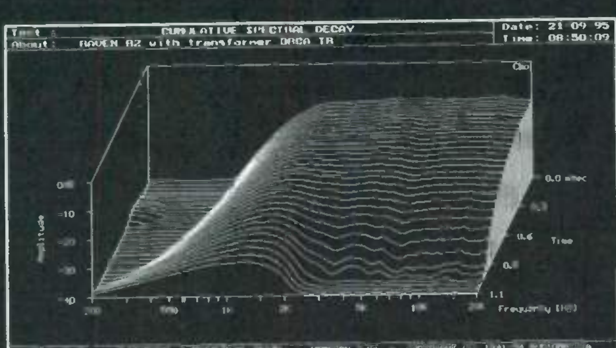
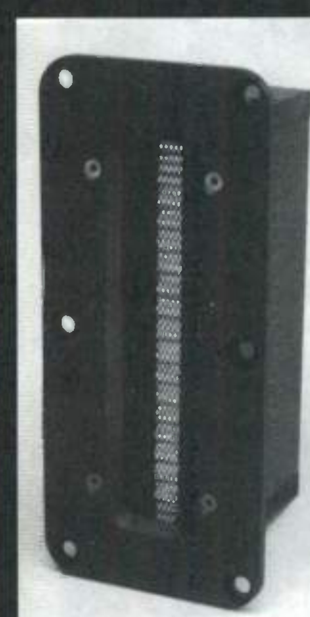


RAVEN R1
KGS 1.14
LBS 2.5
92 x 80 mm
3.63 x 3.15 in.
Moving mass:
0.0061 g
0.0002 oz.
dB/W/m 95
2 KHz to 40 KHz



RAVEN R2
KGS 2.22
LBS 4.9
166 x 76 mm
6.54 x 2.99 in.
Moving mass:
0.013 g
0.0005 oz.
dB/W/m 98
2 KHz to 40 KHz



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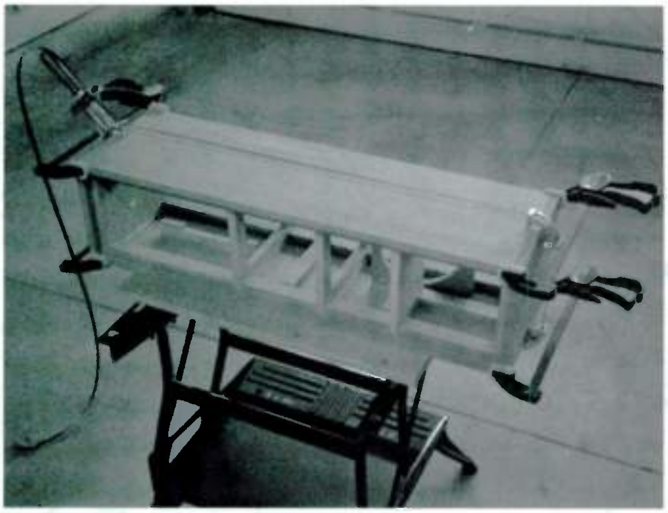


PHOTO 7: Clamped cabinet assembly, first stage.

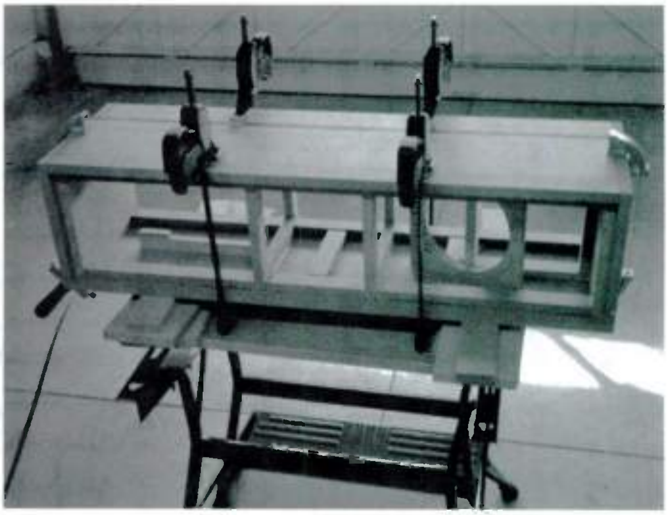


PHOTO 8: Clamped cabinet assembly, second stage.

panel. As you assemble the top/bottom pieces and side-panel braces, wipe off any excess glue that seeps out where other pieces will eventually attach. Also, when clamping guide strips, take care to avoid denting the outsides of the panels. Protect them with other pieces of wood (I used 12″ and 6″ lengths of ¼″ scrap wood). Note that the braces on the two side panels are assembled as mirror images.

COMPLETING PREASSEMBLY

Glue and nail the 7½″-long brace to the inside of the laminated bottom piece to form the bottom mounting brace for the rear-woofer mounting panel (*Fig. 3*). A 7″ brace is also glued and nailed to the upper rear panel below the tunnel exit hole, and a 7½″-long brace, laid on its side, is glued and screwed to the bottom of this panel, exactly centered left to right (*Fig. 4* and *Photo 5*). Once you drill the holes in the small subpanel for the L-pad bushings and input connectors (*Fig. 2*), glue and screw the subpanel to the inside of the access panel.

Predrill the rear-woofer mounting panel for mounting it inside the enclosure and for attaching the rear woofer to it. Use eight particleboard screws to attach this rear-woofer panel to the edges of the woofer subenclosure, one in each corner and one in the middle of each side. Assemble the mid-range tunnel by gluing and nailing the sides to its top and bottom.

With all preassembly completed, drill pilot holes for nails and countersunk screw holes in all of the pieces. Use 2″ 6D finishing nails to attach the side panels—with lots of glue—to the inside layers of the top and bottom pieces, the shelf braces, and the woofer subenclosure top panel.

Attach the front and rear panels with a mixture of the same nails and #9 particleboard screws—plus glue, of course. The screws and nails should be spaced 3–4 inches apart; their function is primarily to hold things together while the glue dries. (The glue provides the main strength.) In the following assembly steps, tighten screws and set nail heads below the surfaces before the glue has set.


PHOTO 9: Cabinet, front view, with front panel installed.


PHOTO 10: Cabinet, rear view, with front panel installed.


PHOTO 11: Cabinet, rear view, with rear panel installed.

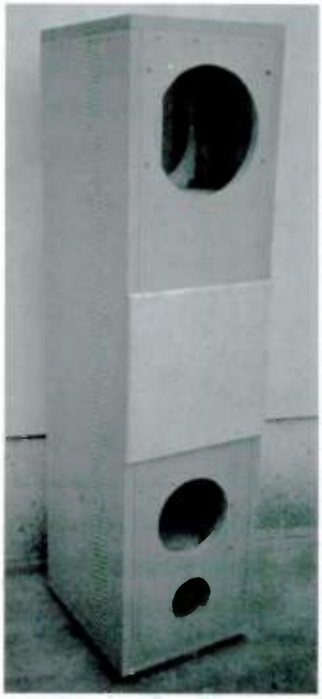


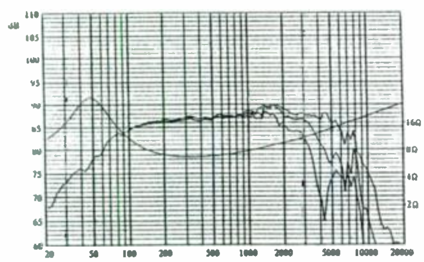
PHOTO 12: Cabinet, front view, with dress plate installed.

850108 5" CSX WOOFER $47.00

High quality 5" woofer with Peerless "Sandwich" cone and heavy magnet. This CSX woofer is supplied with a short circuiting ring in the magnet system to provide excellent linearity and low distortion. It is suitable for use as a high-end midrange or as a woofer in a small 2-way system or MTM design. With an f3 of 96Hz in a 4 liter sealed enclosure, it would perform well where a small satellite speaker is needed.

Peerless

Znom	8.0	ohm	Cms	1.09	mm/N
Zmin	6.6Ω @345Hz		Sd	91	cm^2
Re	6.1	ohm	BL	6.6	N/A
Le	0.9	mH	Vas	12.5	ltrs
fs (free air)	48.0	Hz	Xmax	4.5	mm peak
fs (baffled)	47.1	Hz	Sensitivity		
Qms (free air)	1.78		2.83V / 1m	87.5	dB
Qes (free air)	0.42		Longterm Max		
Qts (free air)	0.34		System Power	110	W
Mms (free air)	10.0	g	Magnet weight	0.4	kg

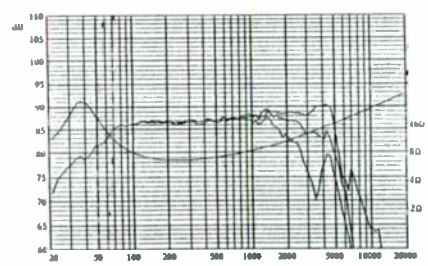


850122 6.5" CSX WOOFER $61.00

High quality 6.5" woofer with Peerless "Sandwich" cone and heavy magnet. This CSX woofer is supplied with a short circuiting ring in the magnet system to provide excellent linearity and low distortion. It is suitable for use as a satellite in a 1/2 ft^3 sealed box or as a stand alone system in a 2-way or MTM configuration. This woofer has a smooth response out to 3kHz and has the ability to get down to 40Hz in a vented enclosure.

Peerless

Znom	8.0	ohm	Cms	0.99	mm/N
Zmin	6.5Ω @230Hz		Sd	143	cm^2
Re	6.1	ohm	BL	7.0	N/A
Le	1.3	mH	Vas	27.7	ltrs
fs (free air)	38.0	Hz	Xmax	5.5	mm peak
fs (baffled)	36.8	Hz	Sensitivity		
Qms (free air)	2.22		2.83V / 1m	86.5	dB
Qes (free air)	0.53		Longterm Max		
Qts (free air)	0.43		System Power	150	W
Mms (free air)	17.8	g	Magnet weight	0.54	kg

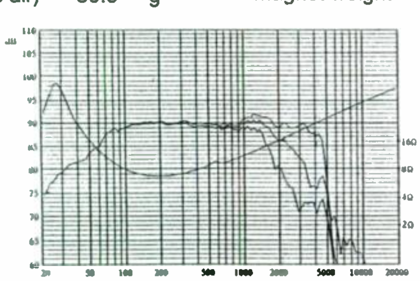


850136 8" CSX WOOFER $70.00

High quality 8" woofer with Peerless "Sandwich" cone and heavy magnet. This CSX woofer is supplied with a short circuiting ring in the magnet system to provide excellent linearity and low distortion. The smooth extended response makes this driver ideal for 2-way systems with good bass response to 45Hz.

Peerless

Znom	8.0	ohm	Cms	1.04	mm/N
Zmin	6.6Ω @188Hz		Sd	235	cm^2
Re	5.9	ohm	BL	10.4	N/A
Le	2.6	mH	Vas	79.7	ltrs
fs (free air)	28.2	Hz	Xmax	4.0	mm peak
fs (baffled)	27.4	Hz	Sensitivity		
Qms (free air)	3.50		2.83V / 1m	89.5	dB
Qes (free air)	0.29		Longterm Max		
Qts (free air)	0.27		System Power	150	W
Mms (free air)	30.5	g	Magnet weight	0.68	kg

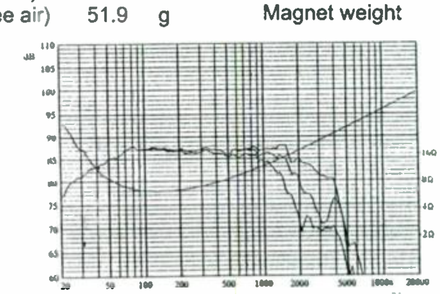


850146 10" CSX WOOFER $98.00

High quality 10" woofer with Peerless "Sandwich" cone and heavy magnet. This CSX woofer is supplied with a short circuiting ring in the magnet system to provide excellent linearity and low distortion. This woofer is suitable for use in either sealed or vented enclosures. In a 3 ft^3 vented enclosure, you can have a flat bass response down to 30Hz. The 9mm X-max will a assure a tight and controlled bass in the lower frequencies.

Peerless

Znom	8.0	ohm	Cms	0.96	mm/N
Zmin	6.2Ω @130Hz		Sd	330	cm^2
Re	5.5	ohm	BL	10.0	N/A
Le	2.9	mH	Vas	144.4	ltrs
fs (free air)	22.6	Hz	Xmax	9.0	mm peak
fs (baffled)	21.9	Hz	Sensitivity		
Qms (free air)	2.56		2.83V / 1m	88.2	dB
Qes (free air)	0.40		Longterm Max		
Qts (free air)	0.35		System Power	200	W
Mms (free air)	51.9	g	Magnet weight	0.87	kg



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BEGINNING ASSEMBLY

Start by laying one side panel, outside down, on your work surface. Apply glue where the shelf braces and woofer subenclosure top panel go, then set in and center those three pieces in the slots. (You will need another pair of hands to continue.) Apply glue to the top and bottom inside edges of the side panel.

Set the rear-woofer mounting panel in the general vicinity of its ultimate location, but do not apply any glue to it. Set the top and bottom assemblies onto their respective ends of the side panel and have your helper hold them in place (*Photo 6*).

Now apply glue to the five edges that will attach to the other side panel. Place the other side panel onto the mating edges and squeeze it all together. At this point, you need to attach clamps to pull everything together squarely. I used picture-frame strapping clamps around the centers of both side panels and top and bottom pieces, plus clamps with 12″-wide jaws at each of the four corners, back to front (*Photo 7*).

Once everything is squared up with the clamps, drive some of the nails through the upper side panel into the edges of the five pieces. Then, turn the assembly over and drive all the necessary nails through the other side panel. Turn the assembly over once more and drive the remaining nails through the first side panel. Before driving any nails, make sure everything is square and the shelf braces and woofer subenclosure top panel are correctly located.

If necessary, you can move the four corner clamps to pull the side panels in near the shelf braces (*Photo 8*). I suggest that you leave the clamps in place for a couple of hours and allow the glue to dry for 24 hours before doing any more work on the assembly.

ATTACHING THE PANELS

After a day for drying, glue and screw the rear-woofer mounting panel to the back edges of the subenclosure now formed. Now attach the front panel (baffle) with glue, nails, and screws to the top and bottom pieces, shelf braces, subwoofer-enclosure top panel, and side strips (*Photo 9*).

After allowing the glue to dry on the parts assembled so far, apply silicone sealant liberally to all seams inside the main enclosure and inside and outside the woofer subenclosure (*Photo 10*). Next, attach the preassembled mid-range tunnel to the back of the front panel with glue and nail it from the front panel. The notches in the vertical braces on the side panels help center the tunnel around the mid-range driver cutout in the front panel.

Finally, attach the upper rear panel to the enclosure and tunnel with glue, nails, and screws (*Photo 11*). It will not be possible to apply silicone sealant to the inside seams of the rear panel, so use lots of glue to ensure an airtight seal. Pull the side panels tightly to the walls of the tunnel with single, 2½″ screws from each side, driving them through the vertical braces to the vertical center of the tunnel.

You do not need to drive any nails or screws through the side panels into front-panel or rear-panel edges. After rounding all four front edges of the 10½ inch² dress plate with a 3/8″-radius router bit, you attach it, exactly centered and parallel to the sides, to the front panel with glue and nails (*Photo 12*).

PHOTO 13: Grille boards, shaped and primed.

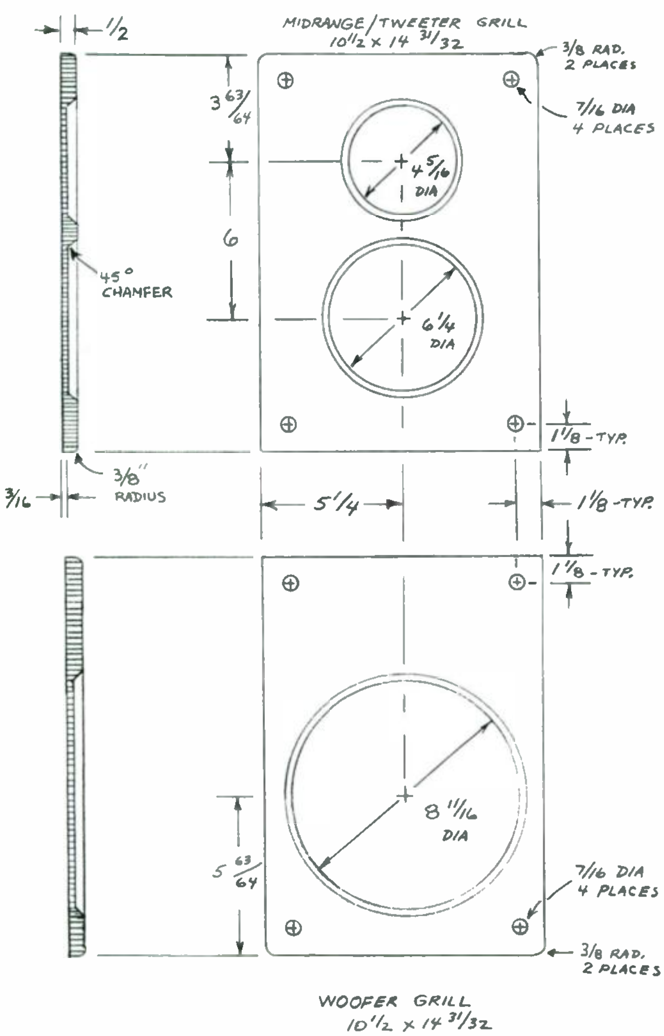


FIGURE 5: Grille boards, cutting/shaping detail.

PREPARE TO MOUNT

If all your cutting and preassembly was accurate and square, the enclosure should go together with relative ease. Fill all nail and screw-head holes with wood filler, sand down, then round the cabinet edges with the 3/8″-radius router bit.

To mount the tweeter, you must file a groove approximately 1″ wide and ¼″ high at the bottom of the tweeter hole in the baffle to clear the tweeter's terminals (*Fig. 3*). Also, shape the inside and outside edges of the ½″-thick grille boards with a router (*Fig. 5* and *Photo 13*).

Clamp the grille boards onto the front panel so they are exactly centered on the driver-mounting holes. Set in the drivers to make sure the grille-board cutouts clear them, and then mark the locations of the mounting holes for each driver on the front panel. Remove the drivers.

Now drill 7/16″-diameter holes all the way through the grille boards into the cabinet's front panel to a depth of ½″ for the four plastic fasteners ("mushroom" type) that will hold each of the grille assemblies. Then, and only then, remove the clamps and the grille boards.

In order to install the rear woofer, you must file down part of the inside edge of one of the vertical side braces used to attach the access panel so that it clears the woofer's edge (*Fig. 3*). When installing the woofer, angle the edge opposite the filed-down brace all the way through the access-panel opening, then lower the other edge of the woofer past the filed area until you can lay the woofer flat on its mounting panel for installing. The textbooks say the inside walls of the woofer subenclosure should be lined with ¼″ felt, but I used 5/8″ acoustical foam, instead.

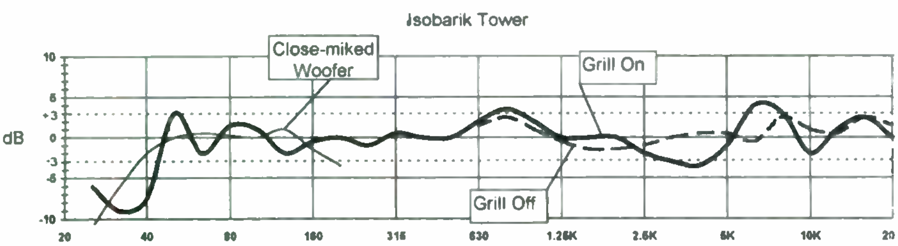
FINISHING

You can now do the final finishing. A textured finish will hide minor imperfections, but if you use a smooth finish—whether flat, semi-gloss, or gloss—the surfaces must be essentially free of all blemishes, including seams and filled nail and screw holes. Don't rush the finishing process. You'll be much happier if your speakers' appearance matches their good sound.

I painted my enclosures white with a textured finish. After two coats of primer, I sanded lightly and applied a coat of the finish color, followed again by light sanding. (Be sure to vacuum thoroughly after sanding, and wipe with a tack cloth to remove the dust before applying the next coat of paint.)

I next gave the upper and lower baffle areas covered by the grille assemblies a second coat of finish color. On the remainder of the enclosure (sides, top, back, and the ½″ plate on the front between the grille assemblies), I applied three coats of finish color (semi-gloss acrylic) with a stippling roller to achieve the textured finish.

The grille boards, shaped and sanded, received one coat of primer and another of flat black spray paint before I affixed the grille cloth. I found that contact cement applied to the backs of the grille boards is better for attaching the grille cloth than using staples.



SPL Meter at 50" distance on tweeter axis height
(SPL meter readings corrected above 2Khz)

FIGURE 6: Frequency-response graphs of finished system.

WIRING AND INSTALLING DRIVERS

With the cabinet finished, install the wiring for all drivers to the crossover, use silicone sealant (allowing it to set before stressing the wiring) in the driver-wiring pass-through holes, and drill pilot holes for the screws needed to mount the drivers. You can use 1″ #8 pan-head screws for the woofers and mid-range, and ¾″ #6 pan-head screws for the tweeters.

Before mounting the drivers, install four grille fasteners for each grille assembly and lay down a ½″-wide strip of foam tape where the mounting flanges of the drivers will go in order to prevent any leaks there. You'll need to install a wire screen in the back of the mid-range tunnel to keep the

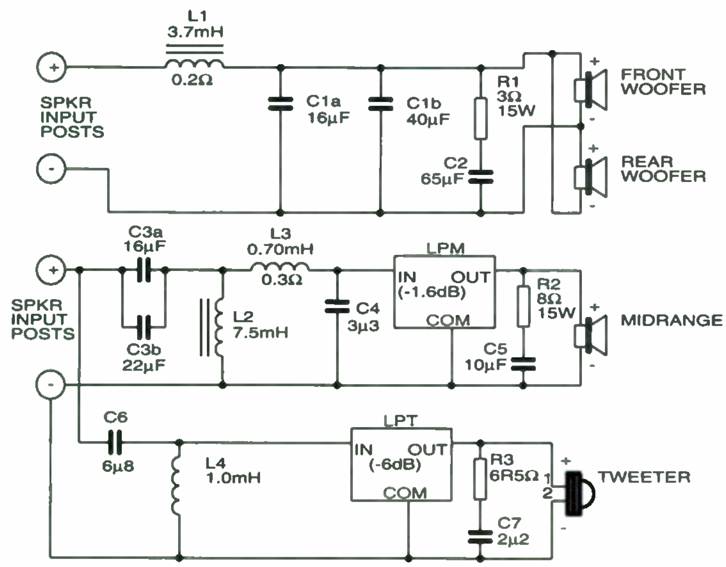


FIGURE 7: Crossover schematic.

Acousta Stuf from falling out. This screen should have a fairly large mesh—¼″ or larger squares.

Mount the rear woofer first and connect its wiring. Then, in sequence, connect each driver's wiring and mount it. After fluffing up the remaining 10 oz of Acousta Stuf, place it in the cavity of the main cabinet between the two shelf braces. To complete the assembly, attach a self-sticking felt pad, 4″ in diameter and 1/8″ thick, on the front plate of the tweeter to minimize diffractions.

MEASURING RESPONSE

What about those grille boards? As stated earlier, I had hoped that chamfering the inside edges of the driver-clearance cutouts would avoid any significant detrimental effects on the sound and its measurements. Unfortunately, the finished grille assemblies were hardly transparent, causing 4dB dips and peaks above 2kHz.

With the mid-range/tweeter grille removed, I measured maximum deviations from a flat response of ±3dB from 44Hz to 20kHz (most were within ±2dB or less) in an acoustical environment as free-field as I could create. (When I measure the response in an off-axis, normal listening position, the high-frequency response smooths out even more.)

Close-miked measurements of the woofer response below 200Hz showed an f_3 of 35 to 36Hz, a flat response above 50Hz (indicating a Q_{tc} of 0.7), and a 12dB per octave rolloff below f_3 (*Fig. 6*). In my normal listening configuration, the combined response of both speakers measured 3dB down at 32Hz. Other acoustical environments may have different results due to different resonances, reflections, and absorption.

With the exception of the grille effects, performance was reasonably close to what I expected. Regarding these measurements, I do not have elaborate test equipment such as that used by audio magazines. I achieved the above results by using the *Stereophile* Test CD 2, tracks 16–18, and my Radio Shack sound-pressure meter. Therefore, my tests should not be considered as accurate or thorough as those in *Audio* or *Stereophile*; yet they are reasonably representative of the speakers' performance.

I also measured the approximate sensitivity of the finished system. Using a pink-noise signal and setting the input voltage to the speaker terminals to 2.8V RMS, I measured a sound-pressure level of 87–88dB at 1m. I drive these speakers with a solid-state amplifier (also of my own design) having 200 watts per candle (wpc). Since their sensitivity is reasonably good, 50 clean wpc should be adequate, but more is better, and all of these drivers are rated to handle significant power levels.

Speaking of sensitivities, those of the tweeter and mid-range can be matched to the woofers by using *Stereophile*'s Test CD 2 frequency-response tracks (16–18) and a sound-pressure meter. Adjust the mid-range and tweeter L-pads until you get the most even response across the frequency spectrum.

CROSSOVER DESIGN

The textbooks also say this crossover design requires you to wire the mid-range driver out of phase with the woofer and tweeter. I found, however, that an in-phase hookup achieved a much smoother transition and integration between woofer and mid-range. Furthermore, essentially no difference existed between the two hookups for the transition between the mid-range and tweeter, so I wired the mid-range in phase (*Fig. 7*).

Before you whip out a calculator or run a computer program to check my calculations for crossover-component values, let me say that I ended up using a larger value for C6

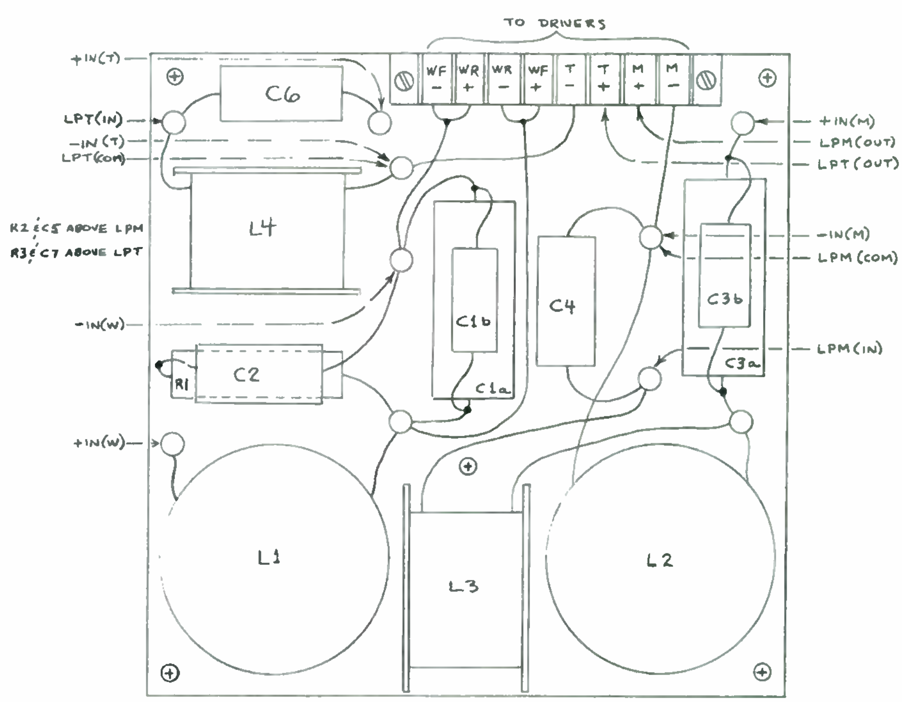


FIGURE 8: Crossover assembly layout.

than that calculated from the equations. Obviously, this lowered the crossover frequency for the tweeter, but I made this change to minimize a broad dip in the frequency response between 2kHz and 5kHz.

I attached all the crossover components, except the Zobel networks for mid-range and tweeter (series resistor and capacitor in parallel with each driver), to the 7″ × 7″ board with silicone sealant (note that the inductors were oriented to minimize mutual coupling). I then attached the completed crossover board to the inside of the access panel with five #8 pan-head screws.

On the crossover board, I used an eight-position barrier strip that accepts solderless terminals for connections to the drivers. A screw-type barrier strip will work as well. I attached the Zobel networks for the mid-range and tweeter with silicone sealant just above the two L-pads.

After everything was mounted to the access panel, I completed the interconnections between the crossover board, the input connectors, and the L-pads (*Fig. 8* and *Photo 14*). Note: You would be wise to prevent leaks by adding a bit of sealant in the holes for the L-pad bushings and input connectors when mounting those components.

To adjust the L-pads close to what is needed, set the one for the tweeter to approximately 50% of its mechanical rotation, and that for the mid-range to approximately 80% of full clockwise. Capacitors used in the crossover should have at least 100V ratings and a tolerance no worse than ±10%, with ±5% preferred. Inductor tolerances should be at least as good as ±5%, but many with ±1 or 2% are available at reasonable cost.

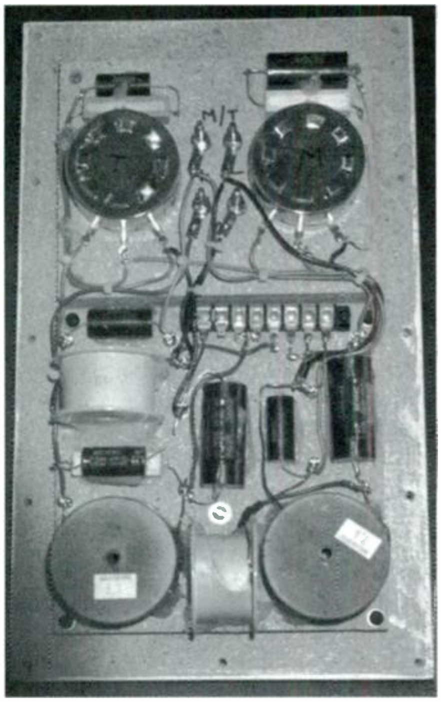


PHOTO 14: Completed crossover mounted and wired onto the access panel.

BI-WIRING

I configured my system for bi-wiring, which is the way I run it, and I wired the crossover with three "star" grounds, one for each section of the crossover. The common pair of input terminals for mid-range and tweeter has two separate wires, for positive and negative, running from each terminal to each of the two crossover sections.

If you can't or don't wish to bi-wire, you can use a single pair of input terminals for all three driver sections. Just be sure to run separate wires with both polarities for each of the driver crossover sections to avoid ground loops, drops, and unwanted interactions. Each pair of wires connecting the crossovers to the drivers should be twisted together.

The subpanel that I used for mounting the input-terminal pairs and L-pads was ¾″ thick. Since the bushings of the L-pads were too short to pass through this and allow me to mount the pads, I had to counter-bore the outside of the subpanel with a 1″-diameter bit. To avoid this extra step, you should use a ½″-thick panel instead.

THE SOUND

Describing the sound of a speaker system is a challenge. Each person has different tastes in music, not to mention different experiences and expectations. Nevertheless, I was very impressed with the sound these systems produced. In addition to a substantial low end and a sparkling high end, I'm hearing subtle parts of the music, such as a gently plucked string or a lightly brushed cymbal, that were previously masked by more prominent aspects. I attribute this to the mid-range configuration.

My wife couldn't understand why I wanted to build these, since the first ones I designed and built sounded so good and so much better than the two commercial systems I previously had. But she, who is an accomplished musician with a good ear, agreed, after some critical listening, that these were even better, especially the imaging and the critical mid-range. I'm reasonably confident that if you build these as described, you will also be very pleased. Have fun, and good luck!

ENHANCING AMBIENCE WITH AN AUXILIARY SPEAKER

By Peter Lehmann

If you are an adventurous type of reader with an inclination for experimenting with unorthodox design, and aren't afraid to build an unusual, perhaps even somewhat bizarre, speaker system, then this article will appeal to you. It contains a complete construction sequence that is relatively short and simple, and should you decide to take the plunge, an additional incentive is that your wallet will not be the worse for wear. If, on the other hand, you are an audiophile of the purist strain, that is, one who insists on the literal meaning of the word *reproduction*, then for you what follows is sheer heresy, and you need not read further.

In this arrangement, two auxiliary speakers complement conventional stereophonic reproduction to improve the illusion that you are present at a live performance. The stereophonic reproduction is conventional in that it results from a pair of stereo speaker systems with a flat amplitude-versus-frequency characteristic positioned in front of the listening area, with all the acoustic output of each system directed towards the interior of the area.

Each auxiliary speaker consists of a full-range 4″ loudspeaker mounted at the radial center of a circular flat baffle with an 18″ diameter. The input terminals of the left- and right-channel auxiliary speakers connect to the speaker-output terminals of the corresponding channels of the power amplifier that is a component of the conventional system.

Each auxiliary speaker is positioned directly above the main speaker system of its corresponding channel, and each is mounted so that its acoustic output is reflected from the ceiling, with maximum intensity directed towards the sweet spot of the listening room (*Fig. 1*). This arrangement enhances the listener's sense of resonance—the apparent depth and "solidity" of the sound—and intimacy with the reproduced performance.

PREVIOUS RESEARCH

Essential features of the design of the auxiliary reflector and its integration with a conventional stereophonic reproduction system, as described here, are in the US Patent (#4,256,992) granted to Rudolph Görike on March 17, 1981. In this patent, entitled "Stereophonic Effect Speaker System," Görike describes one embodiment of his invention that includes the following.

A loudspeaker system situated at the front of a listening room has first and second drivers. The angles of the axes of radiation of these drivers relative to a horizontal plane are such that the path of the first driver's acoustic output to the listening area is direct, while that of the second is by way of reflection from the ceiling.

The reflection of the second driver's output results in a psychoacoustic phenomenon that Görike describes as "a mirror or phantom sound image," with an apparent location at a distance above the ceiling equal to the distance of the second driver below the ceiling. That is, the laws governing the reflection of sound waves are in some respects identical to those governing the reflection of light waves. The orientation of each auxiliary reflector relative to that of its corresponding main speaker produces the same sort of effect.

The text of Görike's patent document includes the statement, "Through experience with the invention, it has been found that substantial differences in frequency response between the frontal loudspeakers and the lateral radiators are needed to obtain a wide base effect for the acoustic event."

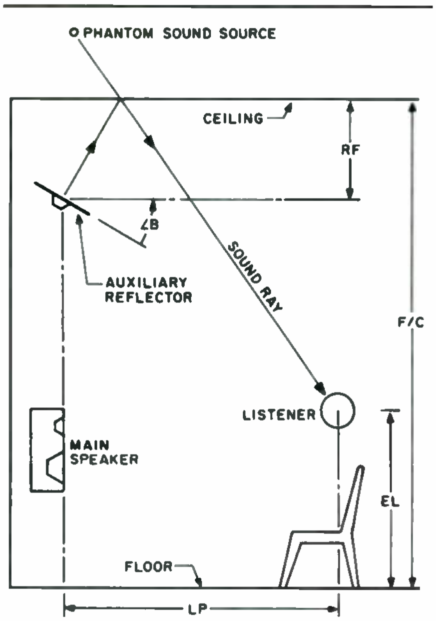


FIGURE 1: Diagram of a setup for reproduction with enhancing ambience.

In the light of this statement, it is not unreasonable to assume that the frequency-response characteristics of the frontal speaker and of the auxiliary reflective speaker, as described above, must also be substantially different for sound-field expansion to occur. That Görike's patent speaks of the "lateral" sound field, or reflection from a side wall should not mean that the same kind of effect does not occur through reflection from the ceiling.

APPLYING THE FLAT BAFFLE

Ideally, the amplitude-versus-frequency characteristic of a conventional stereophonic reproduction system is very nearly a flat response within the operational frequency range. As a result of the alternating cancellation or reinforcement interference of frontal and backward acoustic output, the amplitude-versus-frequency characteristic of a speaker mounted on a flat baffle exhibits alternating maxima and minima.

The radiation axis of the loudspeaker and the radial center of the auxiliary reflector's flat baffle are coincident to maximize overall interference of frontal and rearward radiation. This design aspect of the reflector is a simple yet effective means of creating the needed difference of frequency-response characteristic between the frontal speaker and the auxiliary reflector.

Sound waves generated at opposite faces of a loudspeaker's cone are 180° out of phase. A sound wave of period T_A radiated from the back to the front face of the auxiliary reflector's speaker travels a distance equal to twice the radius, r, of the baffle on which the loudspeaker is mounted.

Where N is a natural number, v is the speed of sound, and $2r/v/T_A = 1, 2, 3, \ldots N$, then destructive interference occurs, since the sound wave from the rear face of the cone and that generated at the front face are 180° out of phase. Where $2r/v/T_A = 0.5, 1.5, 2.5, \ldots N–0.5$, then the interference is constructive because the sound waves from the back and front faces of the cone are in phase.

PERFORMANCE SIMULATION

It seems reasonable to conclude that the uneven response characteristic of an auxiliary reflector, complementing that of the main speaker, would impart an unnatural quality to the sound. However, an analysis of directionality of radiation from musical instruments shows that the intensity of sound produced with respect to the angle of radiation varies greatly according to the type of musical instrument and the frequency of the tone it produces.

Therefore, at a concert-hall performance of primarily (unamplified) acoustic instruments, the relative intensity of a first reflection and the corresponding direct sound also varies greatly according to the type of instrument and the note(s) it plays.

The reproduction system with a pair of auxiliary reflectors described above produces a variation in relative intensity of the reflector's and main speaker's output of each channel that is a function of the electrical signal's frequency. The first arrival of the reflector's output at the sweet spot follows the reflection from the ceiling, while the first arrival of the main speaker's output occurs directly. Therefore, when the intensity of the first reflection of the reflector's output is substantially greater than that of any other first reflections occurring, the concert-hall experience is simulated.

RESPONSE-SHAPING NETWORK

A simple network for shaping the characteristics of average output level and frequency-response range of the reflector is shown in *Fig. 2*. Resistor R_S, connected between the negative terminals of the speaker-input terminal strip and the speaker, reduces the average output level of the reflector by approximately 6dB, thereby muting its output level relative to that of the main speaker. This simulates the reduced level of a first reflection relative to the level of its associated direct sound (as a function of the difference in distance travelled) as heard by those attending a live concert-hall performance.

The high-frequency choke, L_S, shown in *Fig. 2* connected between the positive terminals of the speaker and the speaker-input terminal strip, effects a balanced frequency-response range. An audio-engineering rule of thumb is that the product of low- and high-frequency limits of a speaker system should equal 640kHz. The reflector's low cut-off frequency, f_l, is that at which $f_l \times 2r/v = 0.5$, which is the case where f_l = 377Hz. The reflector's high cut-off frequency, f_h, is that where $f_h \times f_l$ = 640,000, which is the case when f_h = 1.69kHz.

The selected inductance value of L_S—1.7MH—is the required value for a first-order low-pass filter where f_h = 1.69kHz and the load impedance = 18Ω. A broader frequency-response range than that selected would probably help in enhancing ambience, but I considered a flat baffle of radius 9″ to be the maximum allowable, considering spatial practicality.

Another reason to limit the reflector's high-frequency response is that, as the frequency of the sound wave radiated by a loudspeaker mounted on a flat baffle increases, the frequency-response characteristic of the loudspeaker and baffle becomes progressively more even. This happens because the angular distribution of intensity of sound produced by a direct radiator-loudspeaker is concentrated in a narrow band relative to the axis of radiation of the speaker, to an extent that is directly proportional to the frequency of the output.

Therefore, interference of radiation from the front with that from the rear of the speaker is reduced as the output frequency increases. If the reflector's design did not limit the high-frequency response, then the apparent sound-field expansion would be reduced, since it depends on a high degree of variation in the response of the reflector and main speaker.

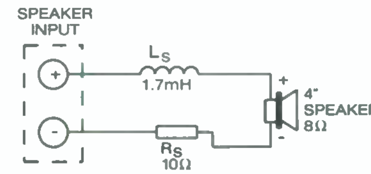


FIGURE 2: Network for shaping response of auxiliary reflector.

CONSTRUCTING THE REFLECTOR

Cut the baffle and front and rear grille boards from 1/8″-thick hardboard, and rivet both grille boards flush to the baffle board. Stretch the fabric of the rear grille over the frame of the speaker and the coil of the shaping network to conceal those components.

The wiring that connects the speaker-input terminal strip to the response-shaping network runs along the front surface of the baffle and is concealed under the fabric of the front grille. Feed this wiring to the rear surface of the baffle by way of a hole located in the baffle beneath the rear-grille fabric. (In the following sections, OL = X″ means that the distance from the radial center of the

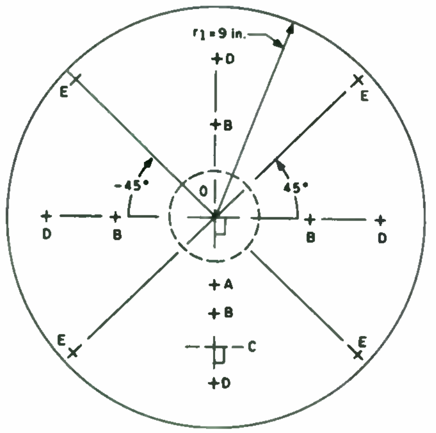


FIGURE 3: Plan for baffle board, front view.

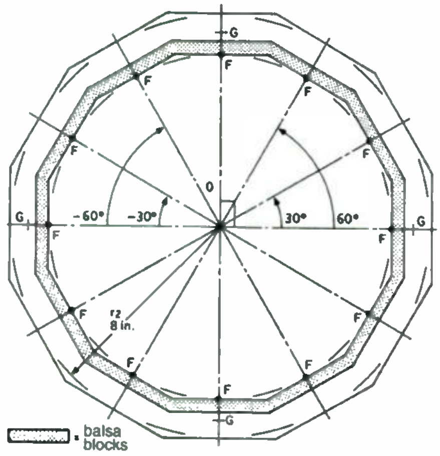


FIGURE 4A: Plan for front grille board, front view.

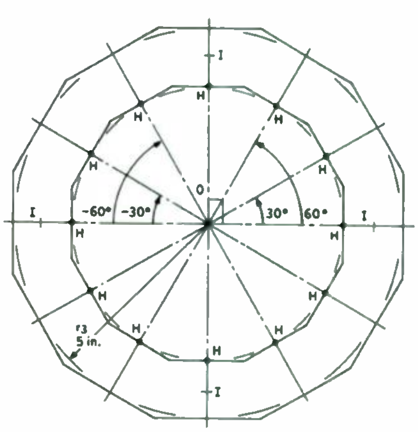


FIGURE 4B: Plan for rear grille board, front view.

part under discussion to a point defined by the letter "L" equals X".)

CUTTING AND DRILLING THE BOARDS

Figure 3 shows the baffle-board plan, indicating the locations of numerous drill holes and the radius (r_1 = 9") of the exterior edge of the baffle. Dimensions not given in *Fig. 3* are the radius of a cut-out for the speaker, the speaker mounting holes, a cut-out for the speaker-input terminal strip, mounting holes for the strip, and mounting holes for inductor L_S of *Fig. 2*, all of which will depend on the particular speaker, terminal strip, and coil that you install.

You should mount the speaker with its frame flush with the front of the baffle. Its diameter cannot much exceed 4", since space is limited for installing the shaping circuit's coil between the speaker's frame and the interior edge of the rear grille. If you don't have access to a large circle cutter, you can cut the exterior edge of the baffle according to the directions for cutting the grille boards, as explained in the following section. Dimensions of *Fig. 3* are as follows:

A = 1/8" drill hole for wiring feedthrough; OA = 3";
B = 1/8" drill hole for mounting rear grille; OB = 4¼";
OC (distance to center line of mounting holes of speaker-input terminal strip) = 5¾";
D = 1/8" drill hole for mounting front grille; OD = 7¼";
E = 1/16" feedthrough hole for picture-hanging wire;
OE = 8½".

To ensure the smooth attachment of the grille fabric to the board, you must cut the exterior edges of the front and rear grille boards as follows. Draw circles of radius r_2 = 8" (*Fig. 4A*) and r_3 = 5" (*Fig. 4B*) for cutting the exterior edges of the front and rear boards, respectively. Draw radii at 30° intervals from the center O of both boards. At all the points of intersection of the radii and circumferences of both circles, draw perpendiculars to the radii. These intersecting perpendiculars define the exterior edges of the boards.

CUTTING THE EDGES

Cutting the interior edges of the grille boards with a circle cutter involves little work. If you have no such cutter available, then draw additional lines perpendicular to the radii through points F (*Fig. 4A*) for the front baffle, and points H (*Fig. 4B*) for the rear baffle. Drill access holes for a sabre-saw blade at all those points F and H, and make straight cuts from hole to hole along the perpendiculars. The relevant points and dimensions for *Figs. 4A* and *4B* are as follows:.

F = access hole for blade of a sabre saw (*Fig. 4A*);
OF = 6½";
G = 1/8" drill hole for riveting grille to baffle;
OG = 7¼";
H = access hole for blade of the sabre saw (*Fig. 4B*);
OH = 3½";
I = 1/8" drill hole for riveting grille to baffle;
OI = 4¼".

You must build up the interior edge of the front grille board (*Fig. 4A*) so that the grille fabric clears the solder lugs of the speaker-input terminal strip and the rivets attaching the grille to the baffle. You do this with 12 small blocks cut from ¼" balsa-wood stock (*Fig. 5*). Apply white glue to the front surface of the grille board, adjacent to the interior edge of the board. Press the sections of balsa wood firmly into position end to end and flush to the interior edge of the grille board as shown in *Fig. 4A*. Clamping is not required.

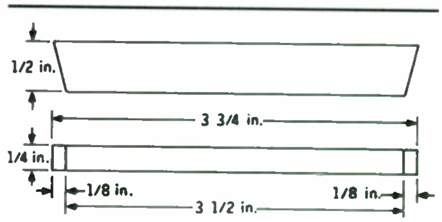


FIGURE 5: Dimensions of balsa blocks for front grille.

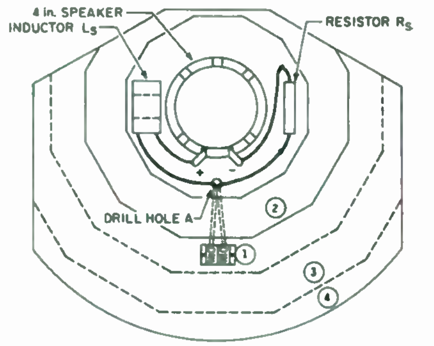
ATTACHING GRILLE FABRIC

Place each of the two grille boards front side down on a square section of grille fabric large enough so that you can lap it over the board and pin it to the fabric underneath. Lap and pin the fabric along one radius at the midpoint between two corners of the exterior edge of the board. In the same way, stretch, lap, and pin the fabric along the radius on the opposite side of the board. Repeat this process until the fabric is lapped over and pinned along each of the twelve sides. When pinning the fabric of the rear grille, do not stretch it too tightly, since it must be stretched over the frame of the speaker mounted on the baffle board to which the rear grille will be riveted.

After you have completed the pinning, apply a band of white glue through the fabric lapped over the board. Make this band ½" wide, starting at the exterior edge of the board. Bunch the excess fabric at the corners. When the glue has dried, remove any unfastened fabric with an X-acto knife.

CIRCUITRY AND FINAL ASSEMBLY

Figure 6 shows the layout and wiring of the speaker, input-terminal strip, and the coil



(1) SPEAKER INPUT TERMINALS
(2) REAR GRILLE BOARD
(3) FRONT GRILLE BOARD
(4) BAFFLE BOARD

FIGURE 6: Sectional rear view of assembled auxiliary reflector (minus rear grille fabric), including layout and wiring of circuitry.

and power resistor of the response-shaping network of *Fig. 2*. Mount the speaker and input-terminal strip to the baffle board with round-head machine screws and hex nuts.

Mount the input-terminal strip with the terminals on the rear side of the baffle board. The power resistor (R_S) and the high-frequency choke (L_S) are mounted on opposite sides of the speaker. Fasten R_S to the baffle board with cyanoacrylate adhesive (super glue).

Mount L_S with its windings perpendicular to the surface of the baffle board, and fasten it to the board with a small cable tie passing through the core of the coil and two holes in the board. The wire connections from the input-terminal strip to the response-shaping network are initially beneath the front surface of the baffle board, then above the rear surface of the board after passing through drill hole A.

Hold the rear grille flush against the back surface of the baffle board while aligning mounting holes B and I of the baffle board (*Fig. 3*) and the rear grille board (*Fig. 4B*), respectively. Insert 1/8″-diameter pop rivets into the aligned mounting holes from the front side of the baffle board, and rivet the rear grille to the board. Hold the front grille flush against the front surface of the baffle board while aligning mounting holes D and G of the baffle board (*Fig. 3*) and the front grille board (*Fig. 4A*), respectively. From the rear side of the baffle board, insert pop rivets into the aligned mounting holes and rivet the front grille to the baffle board.

MOUNTING THE REFLECTOR

Screw a hook into the ceiling of your listening room directly above each speaker of your system. Pass lengths of picture wire through pairs of drill holes E of the baffle board (*Fig. 3*), so that when you hold the reflector vertically, one hole of each pair is above the other, and the input-terminal strip is at the bottom. Twist the ends of each length of wire together, and hang the loops over the ceiling hook.

Adjust the angle of the baffle board of each reflector, relative to a horizontal plane, so it is approximately equal to angle B (*Fig. 1*), which you calculate as follows:

$$\text{Angle B} = \tan^{-1}\frac{RF + F/C - EL}{LP} - 90°, \text{ where}$$

RF = distance from the ceiling to auxiliary speaker
F/C = ceiling height
EL = distance to ear level from the floor
LP = horizontal distance from listener to mounting location of reflector

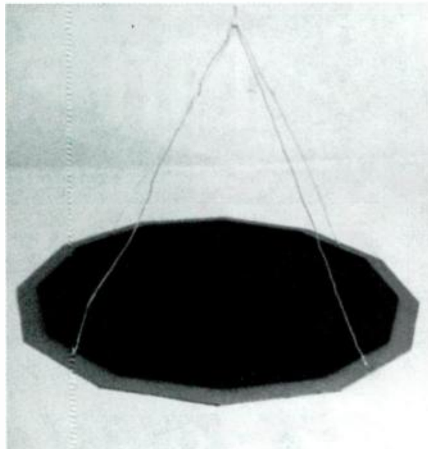


PHOTO 1: Frontal view of an auxiliary reflector suspended by picture wire looped through a ceiling hook.

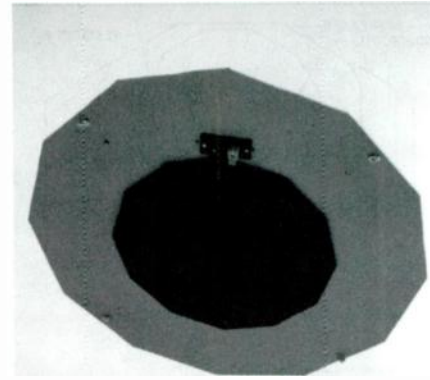


PHOTO 2: View looking toward the ceiling from directly below the reflector of *Photo 1*.

The distance (RF) of the reflector from the ceiling should be as great as possible while avoiding direct radiation from the reflector to the listener. If the listener hears substantial direct radiation from the reflector, then the variation of the amplitude of direct and reflected sound—with frequency of tones reproduced—is diluted. Interference of sound waves radiated from the front and back of the reflector occurs along its sides, as well as in front of it.

Maximizing the distance RF also maximizes the apparent distance above the ceiling of the listening room of the phantom sound source, which is beneficial for effecting sound-field expansion. An unnatural expansion of the sound field might occur if the distance RF exceeds some limiting value; therefore, it is probably good to experiment with different values of RF.

Photos 1 and *2* show a reflector positioned by hanging from a ceiling hook, as previously described. This isn't the mounting method for best appearance, but it is probably the easiest. You might try this approach to see whether you wish to include a pair of such reflectors as components of your system on a permanent basis.

If your listening room has a shelf on the front wall a short distance below the ceiling, an alternative mounting method would be to attach the flat baffle of each reflector to an open-frame stand supported by the shelf. Another method might be to use open frames supporting each reflector and attached directly to the front wall or ceiling.

AΞON

AX-ON (Greek axon, axis): that part of a nerve cell through which impulses travel away from the cell body.

AXON capacitors are offered by ORCA to discriminating audio amateurs and professionals, that is to say people capable of appreciating a special product for its excellence. For ORCA, elegance in design and manufacturing means offering truly outstanding products at a price well below what you have been accustomed to pay for this level of performance. For example, we use heavy gauge film so that the automatic Swiss-made machines on which all our caps are made can be dialed to a high winding tension, thus considerably minimizing the undesirable microphonic effects. We also encapsulate and oven cure to better internal dampening. Music is what we have in mind.

AXON NOVA 1200 VDC New technology metalized film. True 5% precision centered on nominal value. Standard value: 20 μF (special values upon request). Extremely compact (dia: 36 mm x L: 59 mm). Integral encapsulation with polyurethane resin and heat shrunk PVC tubing. Pure copper solid lead wire with PVC insulating sleeve. Oven cured and stabilized.

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ACTIVE SHELVING ROOM EQUALIZATION

By Dick Campbell

A colleague who designs and installs very expensive home-theater systems came to me with a graph and a request. The graph displayed the settings of a third-octave EQ, the irregular serpentine curve shown in *Fig. 1*, which made the installed system sound "just right." The request was for me to construct a two-channel active EQ box, duplicating the settings as closely as possible, as a replacement for the adjustable third-octave EQ. Obviously, my friend did not want the owner to "diddle" with the settings.

This posed a dilemma, because nearly any response shape is possible with a multiband EQ. *Figure 1* has an interesting feature that emerged as I studied it more closely. I can overlay a couple of straight lines, as seen in *Fig. 1*, that intersect at 500Hz where there is a dip in the desired response. In addition, a broad low-frequency (LF) peak exists around 100Hz, and a somewhat narrow high-frequency (HF) peak around 10kHz.

One straight line has a slope of about −7dB/octave and the other has a slope of +2dB/octave. The latter must be maintained over several octaves. Clearly, I could not synthesize this slope with conventional multipole R-C filter topologies, such as Sallen-Key, that have some multiple of 6dB/octave in their limit.

One solution was to use a shelving-ladder filter that you can design for any slope between 0 and 6dB/octave and over any desired bandwidth. In this article, I will show you how to design such filters using a simplified approach.

A SIMPLE LP SHELF

Figure 2 shows a low-pass shelving-filter circuit rendered in a simulation software package called Electronics Workbench (Interactive Image Technologies Ltd., 908 Niagara Falls Blvd. #068, North Tonawanda, NY 14120, 416-361-0333, FAX 416-977-1818). At high frequencies where the capacitor is a short circuit, the filter output is merely that of the voltage divider R2/(R1+R2). At low frequencies where the capacitor is out of the circuit, the "gain" is unity, assuming a high impedance load. If R1=R2, the gain (loss) at high frequencies is ½, or −6dB. So this filter's insertion loss goes from 0dB in the LF region to −6dB in the HF region. Obviously, it must be −3dB exactly in the middle.

I am not in the mood to be excessively mathematical here, so can I learn enough through keen observation of this simple example to establish a design guideline?

The output of the circuit of *Fig. 2* is −1dB at 300Hz and −5dB at 1.6kHz. These are the two frequency points where the capacitive reactance is either just showing itself or is a short circuit. I also observe that the −2dB point is at 500Hz and the −4dB point is at 1kHz. Between these points the curve has a nearly straight section of −2dB per octave.

In terms of audibility, the deviation from a straight line is not enough to worry about over the previously mentioned frequency band: 300Hz to 1.6kHz, or nearly three octaves. The frequency in the center of the curve is the geometric mean [$\sqrt{(f1 \times f2)}$] of the two corner frequencies, 1kHz and 500Hz, which computes to 707Hz.

A CASCADE OF SHELVES

To get a handle on computing the slopes and the errors, I have set up an experiment where the resistor has a constant total value of 20kΩ in series with a 0.016µF capacitor. *Figure 3* shows a family of shelf responses based upon adjusting the resistor ratio from 0% to 100% attenuation, or, as I call it, "pot rotation." Clearly, the 100% position gives a simple and familiar one-pole RC response.

Figure 4 is the same graph zoomed in to

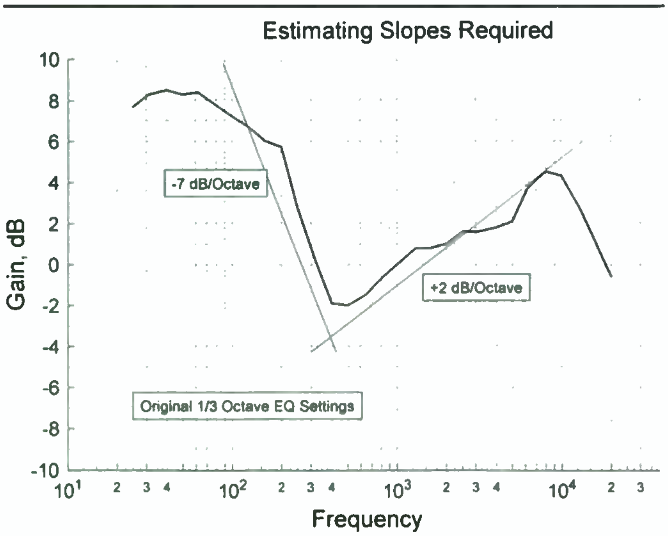

FIGURE 1: Original 1/3-octave EQ settings and two straight-line slope estimates.

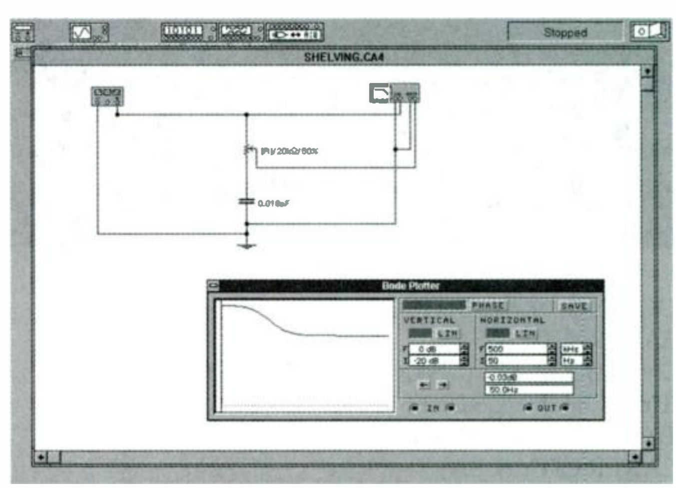

FIGURE 2: Circuit simulated with Electronics Workbench for studying slopes in a low-pass shelving equalizer.

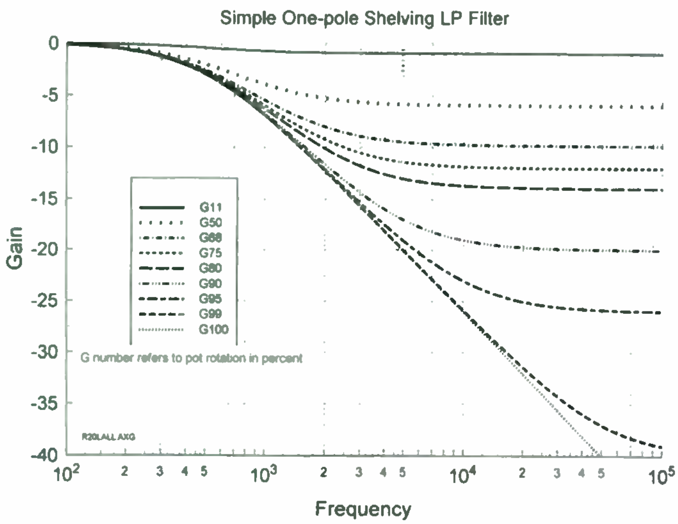

FIGURE 3: Slopes and shelf attenuation for the circuit of *Fig. 2* for pot rotations from 11 to 100%.

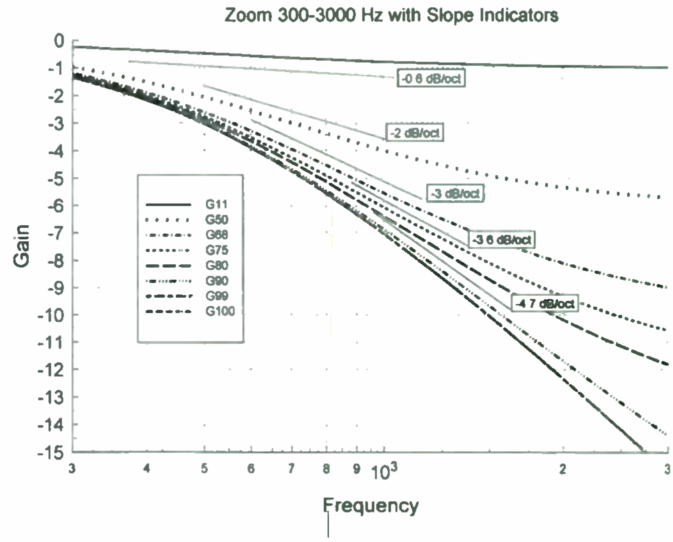

FIGURE 4: Detail of *Fig. 3*, showing slopes in the mid-shelf region.

the LF region, where the slope becomes established. It is obvious that the maximum slope can be anything from zero to −5dB/octave depending upon the pot rotation. If a method can be found to cascade a number of these shelves, each tuned to the appropriate frequency, then it seems possible to propagate the slope over a very wide band.

It is revealing to look at the deviation from the maximum slope to each side of it as a function of frequency. *Figure 5* is a plot of the same family, but with the slopes computed by dividing delta-loss in dB by delta-frequency for each plotting point. Following this, they are normalized by dividing by the maximum slope. Therefore, the maximum slope is shown as unity for each pot-rotation setting.

It is now possible to observe the bandwidth for a 10%, 20%, and 50% deviation from the maximum slope as indicated by the arrows. The example shown uses the 90% rotation setting (about −5dB/octave) and illustrates that the slope changes by a factor of two for a bandwidth of 5.76kHz and a 1.652kHz frequency of maximum slope.

This point of 50% slope change is of par-

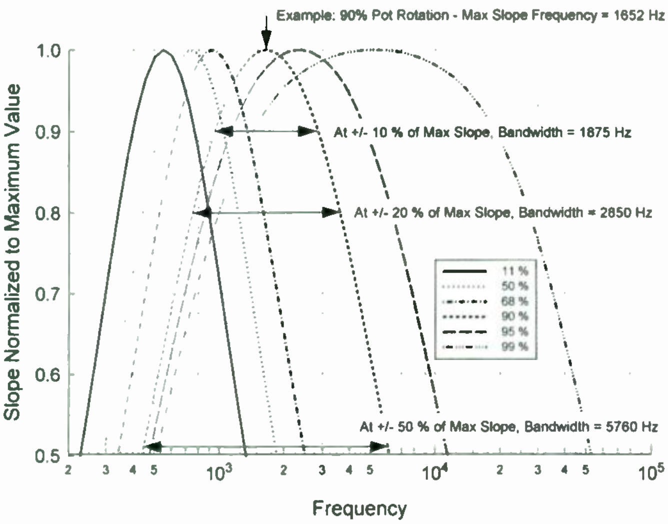

FIGURE 5: Slopes for the circuit of *Fig. 2* with pot rotations from 11 to 99%, normalized to the maximum slope for each rotation.

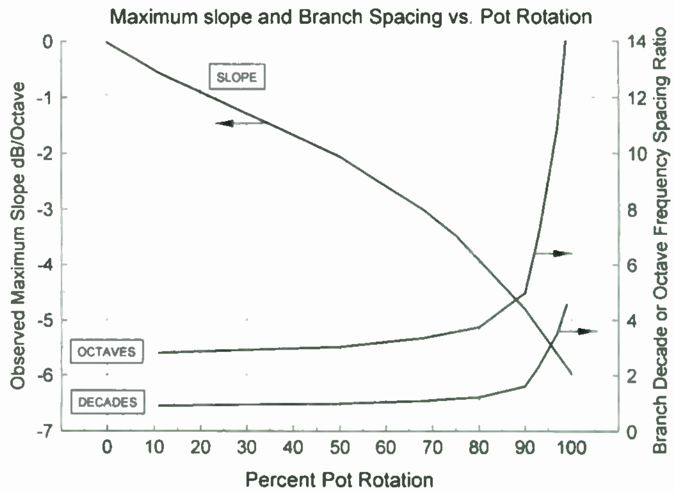

FIGURE 6: Design guide for selecting pot rotation and branch frequency spacing for any desired slope from −1dB to −5dB per octave.

of two for a bandwidth of 5.76kHz and a 1.652kHz frequency of maximum slope.

This point of 50% slope change is of particular interest because the cascading process is one of handing off from one ladder section to the next as frequency increases. Since the initial and final curvature of the shelf is symmetric, a suitable spot to join the succeeding sections may be at the 0.5-slope point.

THE MASTER GUIDE

Figure 6 is a kind of master guide for the required design calculations, because it summarizes the pot rotation and useful bandwidth ratio for any desired slope. For example, notice that the −2dB/octave point shows 50% pot rotation and about a one-decade spacing between ladder sections.

Figure 7 represents an expectation of success when cascading three ladder sections to form a −2dB/octave filter over the considerable frequency range of 2.5 decades.

Figure 8 likewise illustrates a −3dB/octave filter that can span three decades using only three ladder sections. Three decades is all you need for the entire audio band, but a ladder filter really requires four decade branches so that you can be certain the design slope is well established at each end of the passband.

THE PINK-NOISE FILTER

I will now walk you through the design of a pink-noise filter for the band 20Hz–20kHz. This filter falls at 3dB/octave (−10dB per decade).

Step 1 is to consult *Fig. 6* and pull off 68% of pot rotation and one decade of spacing between ladder sections. The first ladder section will have a top resistor that is 0.68 times the total resistance. If I assume the circuit is being driven by a low-impedance source, then I can be somewhat arbitrary about selecting the resistor value. The value of the capacitor for ca. 20Hz is also a consideration, because it should not be an electrolytic.

Step 2 is to consider the first ladder section, the leftmost shunt branch in *Fig. 9*. The slope should be well entered at 20Hz, indicating that the corner frequency for the first ladder must be lower than that. If I select 100k for the total resistance and 0.1μF for the capacitor, then the corner frequency would be 16Hz. No matter what else happens, the next ladder section will have a cor-

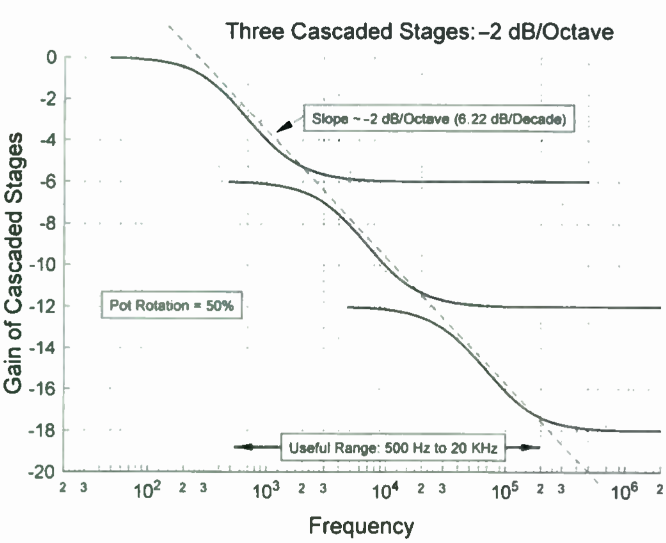

FIGURE 7: Development of a wideband −2dB-per-octave slope using three cascaded branches.

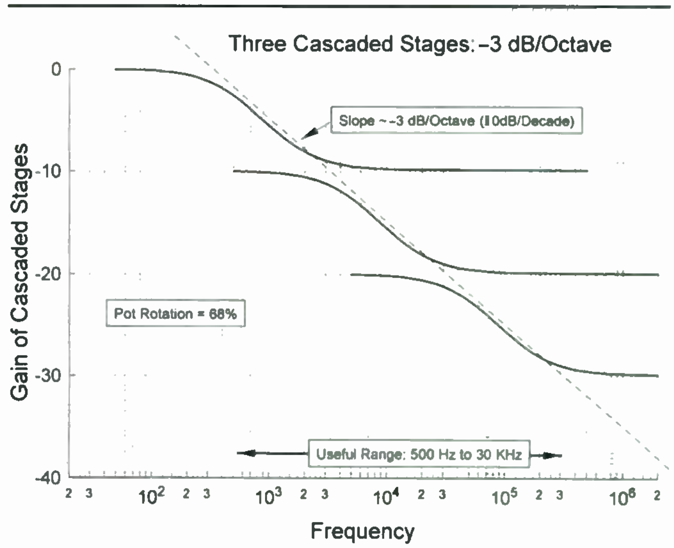

FIGURE 8: Development of a wideband −3dB-per-octave slope (pink-noise filter) using three cascaded branches.

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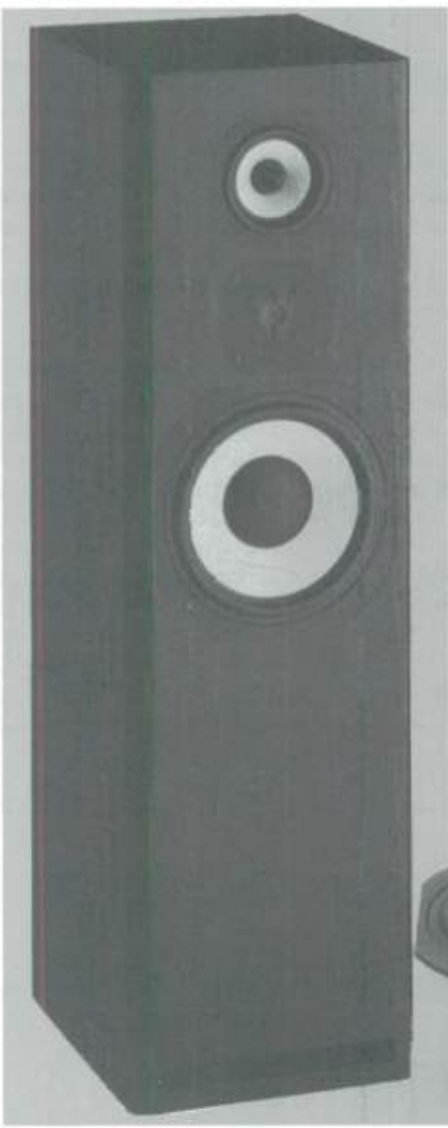

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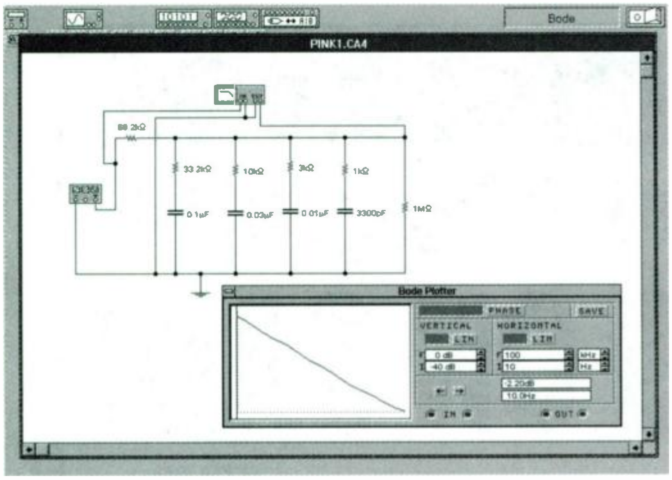

FIGURE 9: Electronics Workbench circuit simulation for the pink-noise filter of *Fig. 8*.

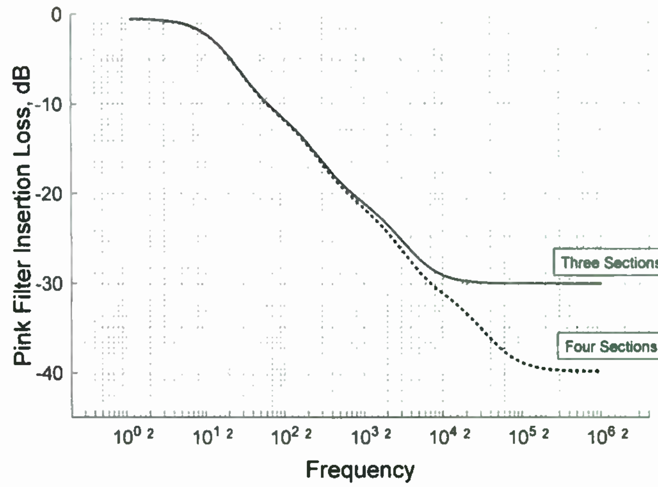

FIGURE 10: Insertion loss of the pink-noise filter showing both three and four cascaded branches.

ner frequency of 160Hz, the next 1.6kHz, and the next (if necessary) 16kHz.

The final choice for the first ladder section, then, is two resistors, 68k and 32k, and a 0.1µF capacitor. The two closest 1% values would be 66.6k and 33.2k.

I now have a new problem and a critical question to answer. Whereas the source impedance driving the series circuit of 33.2k and 0.1µF is known to be 66.6k, what is the source impedance driving the second ladder section?

THE ANSWER

The quick answer (remember, engineering is the art of compromise) is to use an approximation. At the frequency where I want the second section to take hold, the first section is about done, meaning it has entered the essentially flat portion of its response curve.

Under these circumstances, you can assume that the capacitor is nearly a short circuit. You can therefore approximate the source (or Thevenin) resistance driving the second ladder section as the parallel combination of 66.6k and 33.2k or 22.1k. Take care to note that this value of 22.1k is 0.68 of the total resistance of the second ladder section.

Step 3 is to complete the second ladder section. I know the top part (the 0.68 part) of the resistor string is 22.1k, and that the total must be 22.1/0.68 or 32.5k. Therefore, the bottom resistor must be 10.4k, which I can round off to 10k with little error. The remaining question is what capacitor do I use to get a corner frequency of 160Hz, based upon the total resistor string of 32.2k? The answer is close to 0.032µF.

Step 4 is to compute the third ladder section. The approximate source resistance will be 10k in parallel with 22.1k, or 6.9k. Remember, this is the 0.68 value, so the total resistor string will be 6.9/0.68, which is about 10k. The correct capacitor for a corner frequency of 1.6kHz and 10k is about 0.01µF. The resistor in series with the capacitor is 10–6.9, or about 3k.

I pause here to have a look at my work. The solid line in *Fig. 10* shows the three-section response, which does not quite reach over the audio band, so a fourth section is required. It will be driven by 3k in parallel with 6.9k, which is about 2k. Dividing by 0.68 gives a total string resistance of 2.9k and a resistor in series with the capacitor of about 1k. The capacitor value for a 16kHz corner frequency is about 3300pF. The dashed line in *Fig. 10* shows the four-section filter, which does meet the requirements. The small bumps and grinds just discernible in the curve are minuscule and inaudible.

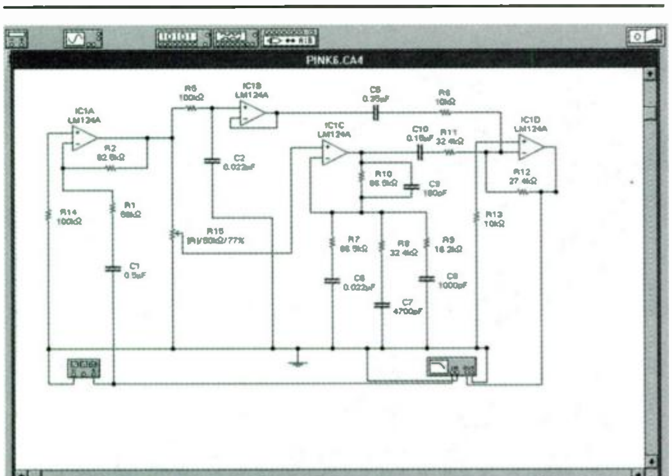

FIGURE 11: Final circuit of an active EQ that includes a three-section cascaded shelving-ladder filter (R7–R10 and C6–C8) in a feedback loop to provide a +2dB-per-octave slope.

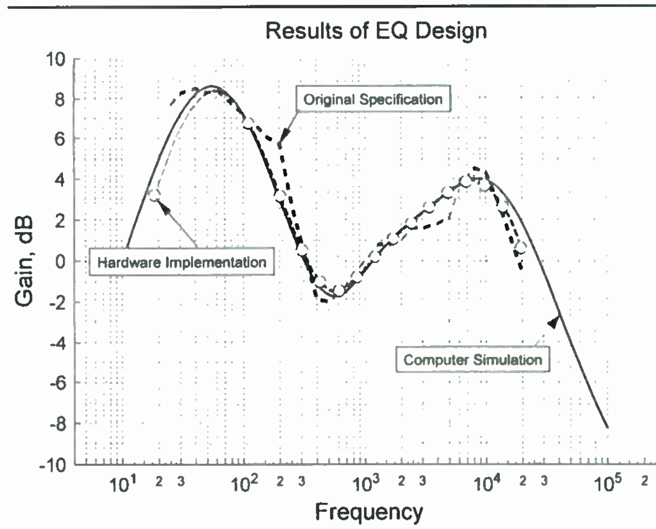

FIGURE 12: Comparison of original specification, computer simulation, and actual filter response.

A REAL EQ SOLUTION

The solution to the loudspeaker EQ problem presented at the beginning of this article is taking shape. I will need two parallel signal paths that mix at the output: an LF feature having a bump in the response at around 60Hz, and an HF feature with a +2dB/octave rising response rolling off sharply above 10kHz. The frequency at which their gains are equal must be close to 500Hz.

The LF path could be created with a simple single-pole −6dB/octave, plus a −1dB/octave shelving ladder. In addition, the LF path should drop off below 30Hz. You can realize the HF path by putting a −2dB/octave shelving ladder in the feedback loop of an op amp, coupled with a rolloff above 10kHz. The circuit glue includes buffering and a summing amplifier at the output stage to add the two parallel paths.

The schematic diagram in *Fig. 11* shows the resulting implementation. For the LF path, I decided to create the bump using a simple one-pole high-pass input section coupled with a simple one-pole low-pass output section. I thought the cost of adding a −1dB/octave shelving ladder to provide the required total of −7dB/octave really needed to be shown as necessary. Keep it simple.

The LP input pole is formed with R5 and C2 at 65Hz, and the HP output pole is formed with C5 and R6 at 48Hz. R6 is the summing resistor for the LF section.

The output of the first inverting buffer amplifier also drives a potentiometer, R15, which you can use to adjust the HF path gain. The HF path amplifier has a three-section, −2dB/octave shelving ladder in its negative feedback loop, and the resulting circuit-gain rise terminates at about 10kHz with the feedback capacitor C9.

COMBINING PATHS

The LF and HF paths are combined in a summing amplifier where the HF path sums with about five times less gain than the LF path. Adjusting the potentiometer R15 to 60% attenuation causes the paths to have equal gain at 500Hz at the output of the mixer. In accordance with the customer's wishes, no phase reversal exists in this EQ design.

The shelving ladder used in the feedback loop is a real quickie to design, because the slope is −2dB/octave; hence, the resistance ratio is 0.5. Since I chose 66.5k for the op-amp feedback resistor, the ladder sections will have 66.5k, 32.4k, and 16.2k, while the capacitors are chosen to tune the branches to 50, 500, and 5kHz, respectively.

Figure 12 shows the simulated response of this filter using *Electronics Workbench*. The deviation from the customer's requirement is not more than about 2dB over the audio band. The slope of +2dB/octave from 600Hz to 8kHz is clearly shown.

Figure 12 also shows the actual response of the prototype EQ as built. It is important to keep track of headroom in the HF path, since padding outside of an amplifying stage may shield you from the true signal peak at the amplifier terminals.

CONCLUSION

The hardware-filter implementation closely follows the customer's desires based upon a set of 1/3-octave gain settings. The client has reported that he can hear no difference between the third-octave EQ and the hardware implementation provided by the author. The implementation would not be possible without the use of shelving-ladder topology to achieve the wide-band, constant-slope feature of +2dB/octave from 600 to 8kHz.

Shelving-ladder filters have been widely used in telephony. In fact, the required frequency response of an operator's headset microphone transmit amplifier can be met only over some of the speech band using this filter topology.

If you decide that an "oddball" filter slope is what you need to fix a response problem, you now have the tools to design it.

THE PHASE REDEEMER

By Dick Crawford

Phase distortion occurs in most loudspeaker crossover networks. Its nature is that the sounds from the tweeter reach the ear before those from the woofer, and this is true even if the drivers are precisely aligned.[1] Its audibility is open to question, but for those who believe that phase distortion is a problem, this article describes a way of significantly reducing it.

The method I use is phase equalization.[1,2,3] My implementation involves active networks (op amps and the like), and thus is well suited for use with active crossovers. But phase equalization has its own problems, and it may be that the cure I've devised is worse than the disease.

THE PROBLEM

Dennis P. Colin's article, "Waveform Phase Distortion" (*SB* 1/97), describes the problem. Any crossover that has a flat frequency response belongs to a family of networks called all-pass. The simplest 6dB/octave all-pass can result in a crossover with no phase distortion. Most other crossovers, including the popular Linkwitz-Riley (L-R) designs, do exhibit phase distortion.

Curve B of *Fig. 1* shows the phase distortion of a 12dB/octave L-R crossover, assuming drivers that are aligned. Notice that the high frequencies arrive at the ear some 57µs before the low frequencies. Moving the tweeter back about 5/8″ would add more delay to the tweeter and thus help the phase distortion problem; but then the tweeter would not be correctly aligned, probably resulting in a frequency response with dips and peaks near the crossover frequency.

Phase distortion and time distortion are related by the equation: phase distortion = (time distortion) × (frequency) × (360).

Phase distortion is difficult to hear. Most experiments conclude that the phase distortion for orchestral music can reach several milliseconds before it is audible. For transient sounds (such as tap dancing), phase distortion of about 100µs has been reported as audible. Mr. Colin claims to hear phase distortion of about 57µs. My goal is to use phase equalization to reduce phase distortion to 6µs, or 10 times less than what may be audible.

Mr. Colin says this cannot be done. He claims that "all-pass responses are nonminimum-phase, and cannot be compensated by any real-world circuit, since a positive exponential (endlessly growing) response would be needed in the compensator."

Mr. Colin has logic on his side, but I've designed a "real-world" circuit that does equalize for the phase distortion of a 12dB/octave (L-R) crossover, reducing it from about 57µs to about 18µs. I chose a 3.1kHz crossover, since this is a common crossover frequency for two-way systems. This requires three dual op amps per channel for the phase equalization.

Reducing the phase distortion to below 18µs would require more op amps, as would going to a lower-frequency. Going to a higher-order (say 24dB/octave) crossover would also require more op amps, or would create greater phase distortion (more than 18µs). So there are definite limitations on the degree (pun intended) of phase equalization that is practical—as Mr. Colin suggests.

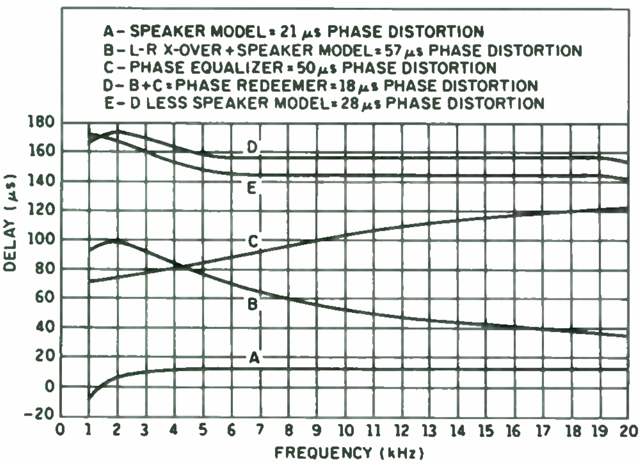

FIGURE 1: Phase distortion.

CROSSOVER PROBLEM

A problem of most crossovers is that the high frequencies arrive before the low ones. I equalize for this by adding circuits that delay the high frequencies more than the low. Doing this for *very* high frequencies would require many op amps, but if I limit my equalization to 20kHz, I need only six.

The outcome is an electronic delay line that results in a nearly constant delay for all audio frequencies. This is the same as waiting a fraction of a second longer before starting your CD player. The delay, as long as it is nearly constant for all frequencies, is inaudible.

The results are shown in *Fig. 1*. Curve A is the delay of the loudspeaker, with 21µs of phase distortion. Curve B is the delay of the L-R crossover plus the delay of the loudspeaker, giving 57µs of distortion. Curve C is the delay of the delay equalizer, with a compensating phase distortion of 50µs.

Curve D is the delay of B + C, with a resulting distortion of 18µs. Curve D shows a significant reduction in phase distortion compared to curve B; that is, the phase has

TABLE 1

EQUATIONS AND PROCEDURE TO ACCOMPANY FIG. 2

Equations:

1. $$Q = \sqrt{\frac{R4}{R3}} = \frac{1}{2}\sqrt{\frac{R2}{R1}}$$

therefore, $R4 = Q^2 R3$ and $R2 = 4Q^2 R1 = (4R1)\left(\frac{R4}{R3}\right)$

2. Gain = R4/(R4 + R3) = $Q^2/(Q^2 + 1)$

3. $$\text{Frequency} = \frac{1}{2\pi}\sqrt{R1R2C1C2} = \frac{1}{4\pi R1C1Q}$$

Procedure:

1. Somehow determine the desired Q and frequency for each section,
2. Choose R4 and R3 to give the desired Q,
3. Calculate gain = R4/(R4 + R3),
4. Choose R1 and C1 to give the desired frequency,
5. Determine R2 = (4R1)(R4/R3).

Important: Usually the Q and frequency can vary by up to 10% without a problem, but R2 must be within 2% of procedure step 5, or the frequency response will not be flat. I often use two resistors in series to achieve the right resistance for R2 (*Fig. 3*).

been redeemed. Finally, curve E shows curve D, but with the delay of the loudspeaker not included, and a resulting phase distortion of 28μs. Curve E shows that the phase equalizer can partially correct for the phase distortion of the loudspeaker.

CASCADING NETWORKS

The design of an electronic delay line is well known. Basically, it is a set of all-pass networks with Bessel coefficients. One way to do this is to cascade first- and second-order all-pass networks, each succeeding one having the Q and resonant frequency set by the Bessel coefficients.[1,2] The all-pass networks

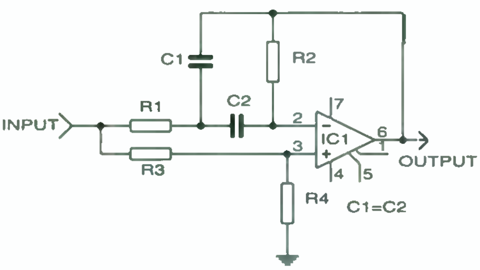

FIGURE 2: Phase-equalizer section.

I used are shown in *Fig. 2*. (Accompanying equations and procedures are in *Table 1*.)

Doing this requires a single op amp for each second-order all-pass network, so I found I would need a lot of op amps to do the Bessel delay line. However, the line has a uniform delay, and it is possible to reduce the number of op amps needed by accepting a certain amount of imperfection (ripple) in the delay. I then looked at a "linear phase with equiripple error of 0.5 degrees" type of design, but found that this also resulted in many op amps.

The problem was that I wanted a "linear phase with equiripple error of 0.1 delay" design, which is not in any of my books. So I designed it on my little computer, using an archaic simulation program. I am certain a better design is possible, and if any reader knows of one, please write me in care of this magazine.

I added 12dB/octave L-R active crossovers and an input buffer with gain. I call the combination of an L-R crossover and phase equalizer the Phase Redeemer; the schematic is shown in *Fig. 3*.

The all-pass networks had some loss in each stage, so I needed to add gain to make the overall gain equal to unity. I placed some of this gain in the input buffer (IC1a), since this gives the best signal to noise. I could not put too much gain at the input without risking overload of the input buffer, so I placed a 6dB gain stage at IC2a. IC2a also contributes to the phase equalization, as well as being a filter to reduce interference from radio transmitters.

IC1b, IC2b, IC3a, and IC3b are the phase equalizers. IC4a is the high-pass 12dB L-R active crossover, the output of which goes to the tweeter amplifier. IC4b is the low-pass crossover, with its output going to the woofer amplifier. Remember that for proper operation of a 12dB L-R crossover, you must connect the drivers in opposite phase.

TABLE 2

PERFORMANCE

1. Gain: Measured 0.998 (= –0.02dB) at 1kHz.
2. Frequency response: –0.1dB at 20Hz, plus 0.08dB at 20kHz (this does not include the loudspeaker simulation).
3. Total harmonic distortion (THD):
   at 1V RMS, and at 1kHz, with 30kHz bandwidth: 0.0039%
   at 1V RMS, less than 0.005% from 20Hz to 20kHz (using an 80kHz bandwidth limit on the distortion analyzer).
4. Noise:
   at phase equalizer output = 11μV = 99dB below 1V
   at woofer output = 10μV = 100dB below 1V
   at tweeter output = 12μV = 98dB below 1V
5. DC offset (using 5532s):
   Phase equalizer output:
   Calculated worst case = –45mV
   Measured = –1.9mV
   Woofer output:
   Calculated worst case = –62mV
   Measured = –2.9mV
   Tweeter output:
   Calculated worst case = –8.8mV
   Measured = –2.7mV
6. Power-supply requirements: ±15V at 50mA per channel, or 100mA for stereo.

I prefer active crossovers, but if you choose to use a speaker with passive crossovers, then the output of the phase equalizer would go to the power amplifier. This design is intended for phase equalization of a 12dB L-R filter at 3.1kHz, so it will not properly phase-equalize other designs. It will improve the phase distortion of most loudspeakers with crossovers in the 3–5kHz region, but the improvement may not be noticeable.

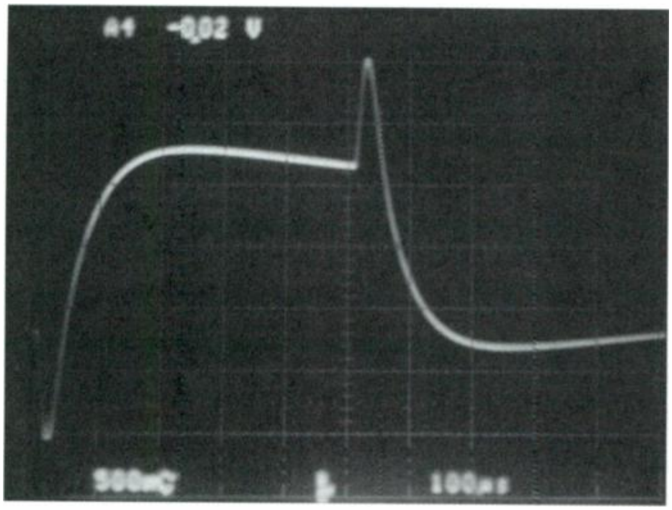

PHOTO 1: Square-wave response: L-R crossover plus loudspeaker simulation.

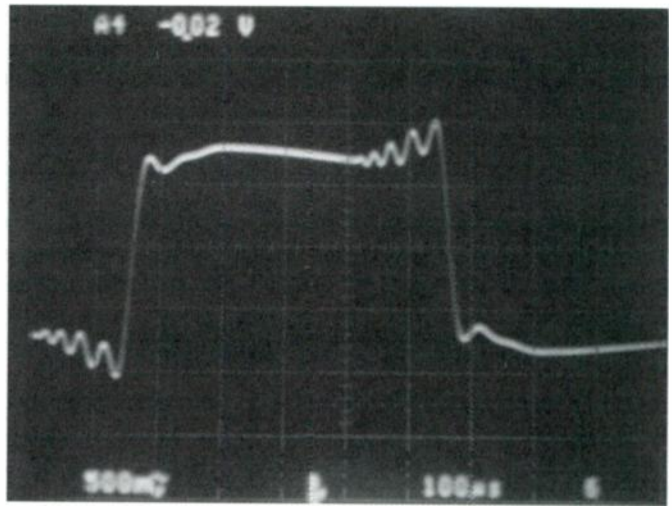

PHOTO 2: Phase Redeemer square-wave response.

MEASURING RESULTS

Figure 4 shows the test circuit I used to measure the results of the Phase Redeemer. I should emphasize that the circuit of *Fig. 4* is not needed for phase equalization, but is a test circuit used to evaluate the Phase Redeemer. Notice that I modeled the loudspeaker by using a bandpass Butterworth filter with 3dB bandwidths of 80Hz and 20kHz. I did this because the loudspeakers themselves contribute some phase distortion, and I wanted to include this effect in my design.

The major phase distortion of the loudspeaker model I used occurs at 1kHz and

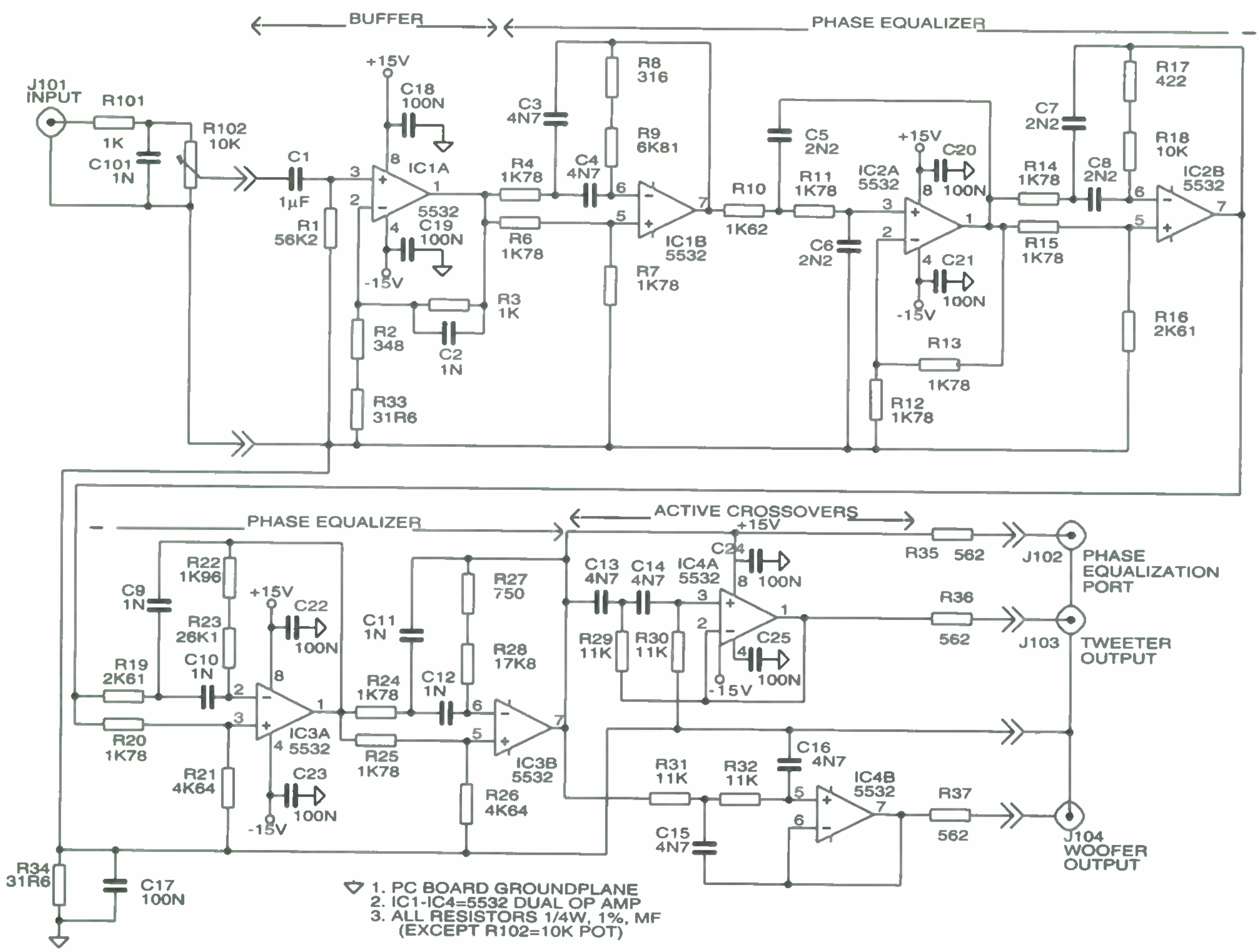

FIGURE 3: Phase Redeemer schematic.

TABLE 3

PARTS LIST

Prices and quantity are for two channels (stereo). In some cases, a minimum quantity order is necessary, so you may need to pay for some parts that you won't need to use.

CAPACITORS				
C1	1μF/50V film	Digi-Key P4676-ND	2@	$6.78
C5–C8	2.2ηF ±2% polypropylene film	Digi-Key P3222-ND	8@ $0.53	$4.24
C3, C4, C13–C16	4.7ηF ±2% polypropylene film	Digi-Key P3472-ND	12@ $0.52	$6.24
C2, C9–C12, C101	1ηF ±2 polypropylene film	Digi-Key P3102-ND	12@ $0.52	$6.24
C17–C33	100ηF/50V film	Digi-Key P4525-ND	2×(10@ $1.65)	$3.30
CONNECTORS				
J101–J104	Phono jack, RCA	Digi-Key 576K-ND	8@ $1.09	$8.72
J105	50-pin ribbon cable header	Digi-Key MHB 50K-ND	1@ $2.72	$2.72
Ca101	50-pin flat ribbon cable	Digi-Key M1AXA 5036R-ND	1@	$10.39
SEMICONDUCTORS				
IC1–IC4, IC5a, IC5b, and IC6a	5532	Mouser NJM5532D	7@ $0.56	$3.92
RESISTORS				
R1	56.2kΩ, ¼W, 1%, MF	Digi-Key 56.2KXBK-ND	1× (5@ 0.54)	$0.54
R2	348Ω, ¼W, 1%, MF	Digi-Key 348XBK-ND	1× (5@ 0.54)	$0.54
R3, R101	1kΩ, ¼W, 1%, MF	Digi-Key 1KXBK-ND	1× (5@ 0.54)	$0.54
R4, R6, R7, R11–R15, R20, R24	1.78kΩ, ¼W, 1%, MF	Digi-Key 1.78KXBK-ND	5× (5@ 0.54)	$2.70
R8	316Ω, ¼W, 1%, MF	Digi-Key 316XBK-ND	1× (5@ 0.54)	$0.54
R9	6.81kΩ, ¼W, 1%, MF	Digi-Key 6.81KXBK-ND	1× (5@ 0.54)	$0.54
R10	1.62kΩ, ¼W, 1%, MF	Digi-Key 1.62KXBK-ND	1× (5@ 0.54)	$0.54
R16, R19	2.61kΩ, ¼W, 1%, MF	Digi-Key 2.61KXBK-ND	1× (5@ 0.54)	$0.54
R17	422Ω, ¼W, 1%, MF	Digi-Key 422XBK-ND	1× (5@ 0.54)	$0.54
R18	10kΩ, ¼W, 1%, MF	Digi-Key 10KXBK-ND	1× (5@ 0.54)	$0.54
R21, R26	4.64kΩ, ¼W, 1%, MF	Digi-Key 4.64KXBK-ND	1× (5@ 0.54)	$0.54
R22	1.96kΩ, ¼W, 1%, MF	Digi-Key 1.96KXBK-ND	1× (5@ 0.54)	$0.54
R23	26.1kΩ, ¼W, 1%, MF	Digi-Key 26.1KXBK-ND	1× (5@ 0.54)	$0.54
R27	750Ω, ¼W, 1%, MF	Digi-Key 750XBK-ND	1× (5@ 0.54)	$0.54
R28	17.8kΩ, ¼W, 1%, MF	Digi-Key 17.8KXBK-ND	1× (5@ 0.54)	$0.54
R29–R32	11kΩ, ¼W, 1%, MF	Digi-Key 11KXBK-ND	2× (5@ 0.54)	$1.08
R33, R34	31.6Ω, ¼W, 1%, MF	Digi-Key 3.16XBK-ND	1× (5@ 0.54)	$0.54
R102	10kΩ potentiometer, linear taper	Mouser 31VW401	1@ $2.35	$2.35
R35–R37	562Ω, ¼W, 1%, MF	Digi-Key 562XBK-ND	2× (5@ 0.54)	$1.08
SOCKETS				
SIC1–SIC4	8 pin DIP	Digi-Key A9308-ND	1× (10@ 0.80)	$0.80
				TOTAL
				$68.66

MISSION POSSIBLE

I stand corrected—I said all-pass responses are impossible to compensate. That's true with infinite bandwidth (without using an infinite number of op amps, and so on), but you can achieve any degree (sorry!) of compensation within a finite bandwidth, say 20kHz, as Mr. Crawford has nicely shown.

Also, I'm not sure I heard phase distortion in the A/D/S 6 versus 12dB/ octave crossover test I described in my article. I may have heard amplitude flatness differences, or more spatial driver separation due to the steeper crossover rolloffs, or perhaps the magnetic permeability of my air-core inductors was being modulated by cometary/ solar flux quantum interactions.

I'm only sure of consistently hearing around 1.6ms, not the 57μs of the A/D/S crossover. So I tend to accept the 100μs threshold that Mr. Crawford quoted. At any rate, on most 12dB/ octave or higher crossover systems, I believe I'm hearing a quick but noticeable separation of frequency components—on cymbal bells, for example, which when heard live are in such a coherent phase as to form a precise tonal transient and perfectly solid image.

Audio reproduction is less than perfect because of the net result of many distortion mechanisms. It's reasonable that the combined effect can be audible because of the sheer number of degradations, even if each separate mechanism is below threshold.

I'm affirming the value of reducing a distortion, even if its audibility is questionable. On the variability of threshold, I certainly agree with Mr. Crawford—it's a matter of degree! —**Dennis P. Colin** lower, where the distortion of the 80Hz rolloff becomes significant (*Fig. 1*). Notice that the distortion of the Phase Redeemer, including the loudspeaker, is 18µs, whereas without the loudspeaker it is about 28µs. In order to be really accurate, you should measure and model the phase distortion of the loudspeakers, but the circuit of *Fig. 4* is a good start.

This simulates the drivers, and assumes that their sound will add in the same way that currents in the resistors do—that is, almost perfectly, at least in the vicinity of the crossover. The phase equalization will do little to correct for poor driver/crossover design. At best, it can offer a better electrical signal as input to a well-designed loudspeaker.

The loudspeaker model I used is based on a good two-way system, with −3dB frequencies of 80Hz and 20kHz. If you use a subwoofer, the frequency response will extend below 80Hz, but the phase distortion will probably not change much. This is because the crossovers used in subwoofers contribute a phase distortion close to that of Curve A in *Fig. 1*.

A GOOD PERFORMER

Measurements of the amplitude response, noise level, and THD show good performance for the Phase Redeemer (*Table 2*). My goals were an amplitude response of better than 0.1dB over the audio range of 20Hz–20kHz, a signal-to-noise ratio of 100dB at 1V RMS input, and a THD of less than 0.1% at all frequencies with 1V RMS input.

I achieved all of these with the exception of the signal-to-noise, which is about 98dB. Much of the noise is due to hum pickup from the transformer in the power supply I used. A signal-to-noise of 98dB is still very good, and I cannot hear the noise with my ear to the loudspeaker. The Phase Redeemer is designed to have a nominal gain of unity, that is, 1V output for 1V input. Input levels up to 2.8V RMS are fine, resulting in a slightly better signal-to-noise.

I achieved comparable noise and distortion numbers when using the Linear Technology LT1124 dual op amps in place of the 5532s. I like the LT1124 because of its tighter specifications, but in this application the 5532 wins because of its lower cost.

The measurements seem better than the oscilloscope traces of a 1kHz square-wave output (*Photo 1*). The rise and fall times look OK, but there is a slight waviness at the tops of the square wave. These occur about 100µs before the rise and fall times, and they are due to the imperfections in delay that occur in the phase equalizer at frequencies above 20kHz. If you find it hard to believe that these are due to phase imperfections, look at *Photo 2*, which shows the square-wave output of the L-R crossover and all of the initial peak that is due to phase imperfections. The difference between *Photos 1* and *2* is due to the phase equalization.

THE SOUND

So how does it sound? First, you should not ask the designer, as his latest efforts always sound great. Second, I think that the only valid sound comparisons are double blind, and I haven't done those. Third, my hearing is poor. Beyond that, I have tested the Phase Redeemer on a number of drivers, including a Scan Speak 5″ (13W/8636), Vifa 5″ (13WH-00), Scan Speak 6.5″ (18W/8543), Focal 5.25″ (5N313), Dynaudio 28mm dome (D260), and Scan Speak 3/4″ dome (D2010/8513).

I wired up the Phase Redeemer so that I could switch the phase equalizer portion in or out, and then I hooked up various combinations of the above drivers, using the active L-R crossovers and biamping. My favorite combination was the Vifa 5″ with the

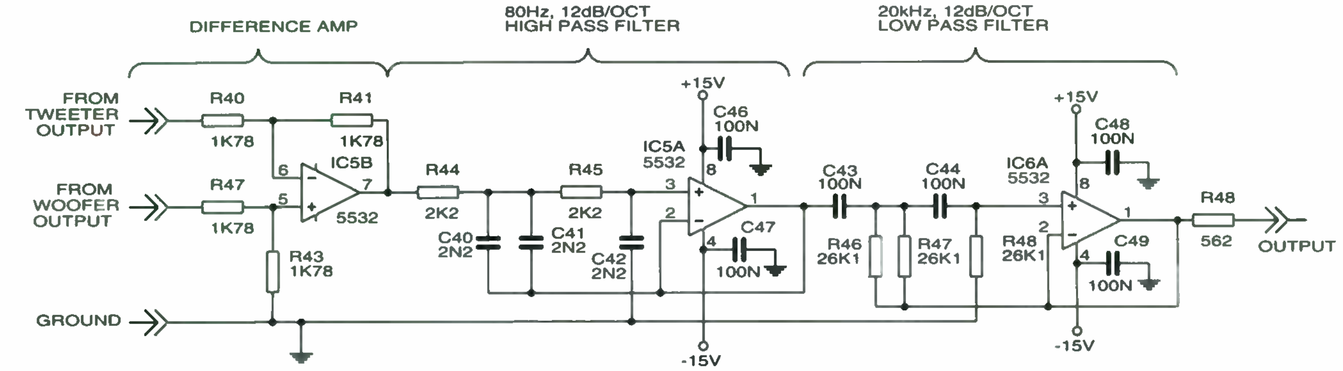

FIGURE 4: Test circuit with simulated loudspeaker.

Dynaudio 28mm, but the Scan Speak 6.5″ with the Dynaudio 28mm was very good, had better bass, and could play louder. I was careful to match levels to within 0.1dB.

I heard very little difference on any combinations when I switched the phase equalizer in or out. The only time I detected a small difference was in the anvil strikes in the anvil chorus of Verdi's opera, *Il Trovatore*. Does this mean that the phase equalizer is useless? No, because other listeners might hear differences more clearly. Furthermore, I often reduce distortions to below audibility, since this seems to me the meaning of high fidelity.

What are the drawbacks of the Phase Redeemer? It costs about $70 in parts (*Table 3*). This includes the active crossover, but not the power supply or a printed circuit board. It adds six op amps in series with the L-R active crossovers, and these op amps add noise and THD, albeit not much. You probably will not hear much improvement on orchestral music, but you might on synthesized music.

In summary, I've shown a design that reduces the phase distortion of a two-way L-R crossover from about 57µs to about 18µs. This should reduce the phase distortion to at least three times below what is audible. I would prefer to reduce the delay distortion to ten times below audibility, which to me is a goal for all hi-fi electronics, but this is the best I can do at this time.

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2. *Reference Data for Radio Engineers*, Howard W. Sams, 6th Edition, 1975, pp. 10–19 through 10–21.

3. Williams and Taylor, *Electronic Filter Design Handbook*, McGraw-Hill, 2nd Edition, 1988, chapter 7, pp. 7-1 through 7-28.

Book Report

DESIGNING, BUILDING, AND TESTING YOUR OWN SPEAKER SYSTEMS

Reviewed by Hilary and Hitch Paprocki

Designing, Building, and Testing Your Own Speaker Systems, David Weems, fourth edition. Available as BKT12 from Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458, (603) 924-6371, FAX (603) 924-9467, for $19.95 plus s/h.

When Ed Dell, Publisher of *Speaker Builder*, asked me to whip up a review of the book, *Designing, Building, and Testing Your Own Speaker Systems*, by David Weems, I didn't feel very qualified. But my brother, Hitch, builds many speakers, so I thought he could guide me in my critique of this book. So here's some quasi-academic blather from me and some feet-on-the-street comments from Hitch.

HILARY'S VIEW

A couple of years ago I threw out my copy of *Designing, Building, and Testing Your Own Speaker Systems*. The book was basic and outdated, and frankly, I didn't like the cheap paper and stiff binding. There is a certain level of cheapness that crosses the line into "insulting," and this book was almost there. Now there is a fourth edition with a glossy cover, large, wide pages of nice paper, and a flexible, reader-friendly spine.

The new edition tackles modern issues such as imaging, which for me is very important, since almost half of what I listen to is in stereo. It is strong in explaining audio concepts to the average reader who owns saws and hammers and would prefer the fun of hacking boxes together rather than pay for them.

THE BASICS

Chapter One, for instance, is entitled, "How a Speaker Works." The issue of transient response comes up quickly—on page three, in fact. V_{as} appears on page five, three pages before "polarity" (phase). I can imagine you might be tempted to skip over this stuff, but the explanations are clear and expertly simplified.

Next, sensible explanations abound concerning enclosure types; for example, Weems observes that the heavy cones that are appropriate for closed-box enclosures tend to require either small woofers or separate midrange drivers if you want any midrange response at all. He points out that reflex (ported) design is complex, and at this point, he might have suggested avenues (software, for instance) that simplify the process for the dabbler. Do not worry, though; discussions of the software appear later on in the book.

Chapter Three dives into construction tips and techniques, and once again, there is plenty of good advice. Reading this chapter is an adequate substitute for a few years of experience. I humbly disagree on just one point: Weems recommends the use of a simple cross-brace to help stiffen the panels on the opposite sides of the box. This method was shown by Iverson (*JAES* Vol. 21, No. 3, 1973) to be practically useless (*Fig. 1*).

Surprisingly, the most effective brace is a rib glued along the panel's long dimension. After this is done, you can use sheet or liquid damping material to arrest higher-frequency panel resonances, and fluffy stuffing smooths out the resonances of the enclosed air. This is a separate issue from the stuffing usually discussed and used in the bass tuning! Weems calls the enclosed-air resonance "sounding loud at low volumes," which is a fairly good way to describe it to a "newbie." He goes on to further describe what he's getting at, which is an admirable bit of extra effort towards clarity.

Q LEVELS

At this point Weems plunges into a discussion of closed-box systems, doing you a favor by suggesting what levels of system Q you might prefer based on musical tastes and expectations. He pulls you through a simple equation or two, takes you to a graph, and there you have your box size.

For ported systems, there is a simplified procedure using printed graphs, a scary-looking (but better than going it alone) procedure using flowcharts and a calculator.

A third method uses a basic PC program that you type in (isn't *that* retro!) or buy for $15 in DOS using a coupon in the book. Unfortunately, the calculator method gives you only an "optimum" enclosure. But the PC program lets you fool around with box sizes and optimum dimensions, crossovers, stands, bandpass boxes, double-chamber boxes, filters, and so on. It is a screaming good deal for the price.

There is also a Windows version for the computer-pampered. But, I didn't see any-

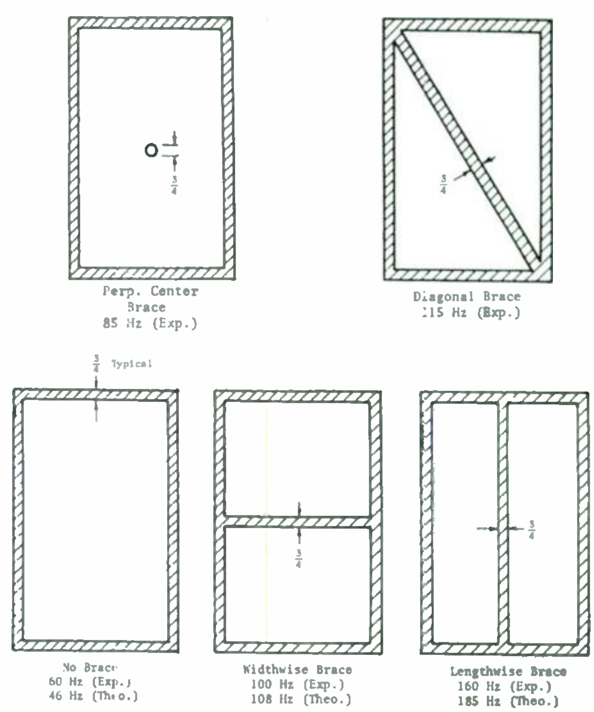

FIGURE 1: Effect of bracing on fundamental resonance frequency of 12×18×0.02″ steel panel with clamped edges. (Reprinted from *JAES* Vol. 21, No. 3, 1973.)

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thing in the program listings for system Q, and wanted to tell it to "give me a .6 system," for example.

As the book continues, it provides surprisingly comprehensive crossover design notes, notch filters, directivity computations, impedance equalizers (Zobel networks, which I consider mandatory, and that notably cleaned up my AR2ax project speakers), and so forth. There are simple procedures for establishing component values, and a loudspeaker user's guide addressing wire, amplifiers, and placement.

Also included is a useful chapter on testing and measuring both the drivers—for design purposes—and the finished system to see what you really have wrought. Finally, a chapter describes four mini-speaker projects, and a few appendices are full of peripheral data, sympathetically presented.

So, is this a good book? Yes, emphatically. It is very understandable and ideal for the non-audio-nut do-it-yourselfer, as well as for the audio nut who seeks understanding and a self-contained reference book that stops short of esoterica. The book itself is beautifully made, in sharp contrast to the lousy trade paperbacks we had ten years ago. With all this, it would be a wonderful gift for anyone (or for yourself) who can use a practical set of fundamentals in the craft of homemade speaker building. It contains many of the kinks, knacks, and senses that we usually rely on expensive experience to provide.

HITCH'S VIEW

I was of two minds when Hilary asked me to add my two bits in a review of *Designing, Building, and Testing Your Own Speaker Systems.* I also had an earlier version of David Weems' book, and really liked it.

Over the years I have built several excellent speaker systems: a few Dynaudio kits, a couple of Audax, and some store kits. An experienced builder, for sure, but a builder of someone else's designs. Busted! I'd rather spend idle hours gazing vacantly at various wood grains than crunch numbers in designing crossovers, box volumes, and so on.

The fourth edition, while similar to my previous version, is much better. The information is up-to-date and complete. The book contains information for the beginning and seasoned builder.

However, Chapter 6 (crossovers) doesn't sing out to me. The information is complete, but difficult to understand. Plainer explanations may seem condescending to a hobbyist with a scientific mind, but not to me.

A crossover diagram could be explained as "...this capacitor does this to the tweeter, and changing the value would have this effect...." Or, "The reason there is a capacitor in series before and after an inductor is...." Or, "Changing the value of the first capacitor will do this:...." This would help me in fine-tuning my designs. The "Fun with Computers" chapter is an open door for me to get into crossover design.

The speaker projects use some of my favorite drivers, and they are worth doing! In my experience, only a few tools are required to build top-notch cabinets. We can drool over table saws, planers, joiners, and so on, but a circular saw with good blades, a router with bits, and an orbital sander takes you far. Ingenuity comes with practice! How about building a transmission-line cabinet? Every builder has to try it once!

A beginner can't go wrong with this book. There is enough information to keep you busy for years. Owners of earlier versions will likely find enough new information in the fourth edition to be delighted.

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Product Review

THE WOOFER TESTER

Reviewed by David Weems

The Woofer Tester, version 4.4, Peak Instruments, 340 E. First St., Dayton, OH 45402-1257, (800) 338-0531, $249.

The Woofer Tester (WT), an updated version of an instrument reviewed earlier by Vance Dickason,[1] is a digital oscillator, a digital frequency counter, and a digital voltmeter, all rolled into one. The system is compatible with any PC that has EGA graphics, or better. The current model uses a DOS program, although the inventor, Brian Smith, is now developing a new model for Windows 95.

The instrument is housed in a 5¼″ × 5¼″ × 2″ metal box. The front panel has a power switch and four jacks, two of which receive banana plugs for test leads to the driver under test. The extra two jacks are RCA types. One, labeled "out," supplies test signals at three frequencies to an outboard amplifier for woofer break-in. The other is a line-input jack for future accessory use.

The back panel has a 9-pin serial port for connection to a PC, and a 9V AC 2.1 × 5.5mm input jack from the AC adapter (included). The WT comes with an RS-232 serial-port cable having a 9-pin connector. A 25- to 9-pin adapter is also supplied so that you can use either a 9-pin or a 25-pin RS-232 port.

When I saw the WT in a Parts Express catalog, I was immediately tempted. My test equipment has never been very exotic. For many years, my standby was the Heathkit IG-18, as modified by Reginald Williamson,[2] my only complaint being that with its switch-operated frequency controls, it was a bit slow to use. When I later got an audio generator with a dial frequency control for each range, I needed to add a frequency counter to achieve accuracy comparable to the Heathkit. Would the Woofer Tester, in its tiny box, replace my four pieces of separates? I decided to try it.

FIRST IMPRESSIONS

For a typical WT installation, you create a directory for the tester and, to facilitate getting into the directory and accessing the menu, write a batch file, such as W.BAT. Later you will see the need for quick access to the program.

The WT, powered by the AC wall adaptor, must be switched on before you can access the program. At the C:> prompt, type W1 or W2, depending on whether you are using COM1 or COM2 for connection to the PC.

After plugging the unit into my PC and powering the system, I found that the menu (*Table 1*) includes a calibration procedure. A double banana plug, with a ½W, 1%, 10Ω resistor wired across it, is included in the equipment. I plugged in the resistor and chose Calibrate System. During the calibration process, the WT checks the impedance of the resistor at various frequencies and stores the data for a future reference standard.

When I ran my first test, taking the DC resistance of a resistor previously measured on a wheatstone bridge at 5.123Ω, the WT read it at 5.5788. Checking the leads, I found that the cross-split banana plugs didn't fit the jacks very well. It would have been easy to spread the plugs for a tighter fit, but I had an extra set of

TABLE 1

WOOFER TESTER MENU

Main Menu
Plot impedance, f_s, Q_{ts}
Measure V_{as}
Inspect Results
Measure Vented Box
Calibrate System
Arbitrary Impedance Plot
Plot Nominal/Minimum/Max
Measure DC Resistance
Q-Loss Calculation
Woofer Break-In
Measure Inductor
Quit

leads with expansion plugs, so I used them instead and made another test. This one came out at 5.3665, still a bit high. I suspected the calibration resistor, but my LCR meter measured it at 10.0Ω.

It then occurred to me that I should have clipped the banana-plug resistor at the end of the test leads to calibrate the system. After I did that, the WT gave a reading of 5.26Ω (rounded off), or about 2.7% high. Perhaps it would be better for the calibration resistor to be supplied as a bare resistor, so that no one would be tempted to use the double banana plug as I did.

MEASURING DRIVERS

I then got out some drivers that I had measured on a bridge and checked them. For a typical driver with an R_e of 5 to 6Ω, the results with the WT were consistently about 0.1Ω greater than the bridge measurements. Because the WT measures DC resistance at 1Hz, it isn't perfectly accurate for checking voice-coil R_e.

Just how important is this error? Apparently it is of little consequence when computing the value for Q_{TS}. It also reads Z_{MAX} a bit high, so the value for R_O is not much skewed, and is even less so when you take the square root of R_O for Q calculations.

For example, in *Table 2* the greatest variation in R_e values is for the Siare 190SPCM. For that driver, I compared the square roots of the R_Os obtained by the WT and by my shop test setup. The WT gave a value of 2.36, the shop, 2.37. As an alternative, if you have a highly accurate ohmmeter, the software permits you to manually enter the value for R_e. Whether that would improve accuracy in obtaining Q values is debatable.

Next, I tried measuring some inductors obtained from G.R. Koonce that he had mea-

TABLE 2

WT AND SHOP-EQUIPMENT COMPARISONS

	R_e	f_s	Q_{ms}	Q_{es}	Q_{ts}	V_{as} Liters	Keele Optimum Alignment V_B Liters	f_B Hz	f_3 Hz
Audax-HM170GO									
WT	6.62	38.8	6.71	0.34	0.32	45.3	26	45	50
SHOP	6.5	40.5	8.22	0.36	0.34	43.1	29.2	45	48
MFR.	6.6	42	7.83	0.38	0.36	32.5	26	44	46
MCM 55-1545									
WT	6.03	35.5	6.12	0.44	0.41	24.1	28	33.3	32.2
SHOP	5.9	35	6.46	0.44	0.41	25.7	29.8	32.8	31.7
MFR.	NA	32	NA	NA	0.39	32.3	32.5	31.4	31.1
							Closed Box Q_{tc} = 1 V_B Liters	f_c Hz	f_3 Hz
Siare 190SPCM									
WT	6.75	58	3.8	0.85	.7	21.1	20	83	65
SHOP	6.6	59	4.25	0.85	0.71	21	21	83	65
MFR.	NA	45	NA	1.05	0.8	20	36	56	44
Radio Shack									
WT	6.86	38	5.68	0.72	21.1	43.6	30.2	59.4	46.7
SHOP	6.8	38	5.72	0.73	21	43.7	32	58.5	46
MFR.	6.2	35	3.9	0.551	20	59.4	18.1	72.5	7

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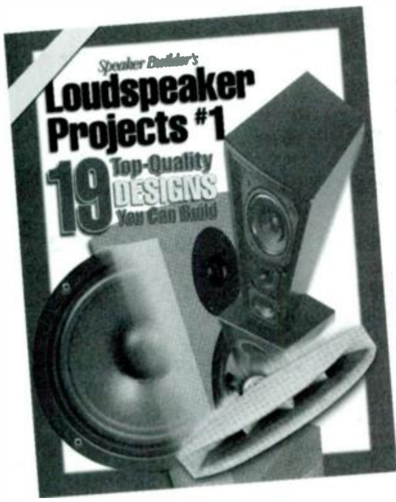

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sured with a B&K 875A LCR meter. My meter, the Testmate 195, gave a fairly close reading, but the WT values were significantly lower (*Table 3*).

I called Karl Keys at Parts Express to ask about this problem and some others, and he told me that my version of the software, 4.3, caused the tester to sample inductance at several frequencies—1kHz, 2kHz, and 4kHz—and then average the readings. Version 4.4 takes one reading, at 1kHz. Most loudspeaker manufacturers measure voice-coil inductance at 1kHz. If you have an earlier version of the software, call Parts Express and ask for an update.

Version 4.4 gave less accurate readings on inductors of very low value, but was more accurate on values above 0.5 mH (*Table 3*). The 0.5mH area appears to be the dividing point. Above that, you can expect a 5 or 6% error on the low side, but below that point, the magnitude of the error is inversely proportional to the value of inductance. Obviously, you can use the WT only as a rough guide for low-value inductances.

TESTING DRIVERS

So much for reading DC resistance and inductance. The real purpose of the Woofer Tester is to check the parameters of woofers. The first line in the menu, Plot Impedance, f_S, Q_{TS}, is the logical first step in testing a driver. This procedure takes the most time (about two and a half minutes) of any function, with the possible exception of Measure Vented Box. About 30 seconds is required to check R_e, and the rest of the time to plot impedance and compute Qs.

You can watch the plotting as the graph of the impedance curve develops from 5Hz out to a peak at resonance. It then reverses itself as the tester probes back to locate the f_1 frequency below f_S. Finally, it goes on beyond f_S to locate f_2 and calculate Q_{MS}, Q_{ES}, and Q_{TS}. The impedance graph remains on the screen (*Fig. 1*) until you strike a key, get the menu and choose Inspect Results (*Table 4*). Note that on this function, the WT extends the curve only far enough to find f_2 and compute Q values.

The results are not rounded off, but reported to four decimal places (*Table 4*), with the exception of one report of the value for V_{AS} by the vented box method. If you plan V_{AS} tests, it's best to do them before testing another driver, although you can enter data manually if you come back to it later. You cannot save data with the current version, so it's convenient to do all your tests on one driver then go on to another.

If you test another driver without quitting the program, it will retain data for any tests not duplicated with the new driver. This could be a source of confusion, so it's best to quit the program after each driver to clear the data—then go back into the program. This is easy to do. Just go to the menu, press Q and then W, or whatever letter or name you chose for your batch file to access the program.

You can use "Plot Impedance, f_S, Q_{TS}" to test a closed-box system, but the results will be reported as f_S, Q_{MS}, Q_{ES}, and Q_{TS}, instead of f_C, Q_{MCT}, Q_{ECT}, and Q_{TC}.

CROSS-CHECKING

I tested four small woofers with the WT and then ran a cross-check with my traditional test equipment, which I label Shop in *Table 2*. I have duplications of some instruments, so while making the tests reported here, I used various combinations of the following: Heath IG-18 audio generator, Tenma 72-455 audio generator, Tenma 72-450 AC millivoltmeter, Radio Shack 22-168A digital multimeter and frequency counter, Fluke 77 multimeter, and Testmate LCR 195. I also used a B&K model 1472B oscilloscope to monitor my shop tests for f_S.

The four drivers I tested were the Audax HM17OGO, the MCM 55-1545, the Siare 190SPCM and the Radio Shack 40-1024. The first three are 6½″ woofers, and the Radio Shack model is an 8″ driver. For the first two, I used Keele's program[3] for optimum vented-box alignment, comparing the manufacturers' parameters with the results obtained with the WT and my shop tests. The Siare and Radio Shack drivers had Qs that were too high for vented-

TABLE 3

WT INDUCTOR-TEST COMPARISONS

Test Sample	B&K 875A	B&K 878	T-MATE	WT-4.3 LCR 195	WT-4.4
Values of inductance shown in milliHenries (mH)					
#1			0.099	0.071	0.063
#2	0.237		0.227	0.186	0.163
#3			0.501	0.453	0.431
#4	0.981	0.967	0.961	0.906	0.919
#5	1.021		1.001	0.937	0.945
#6	1.674		1.646	1.563	1.576

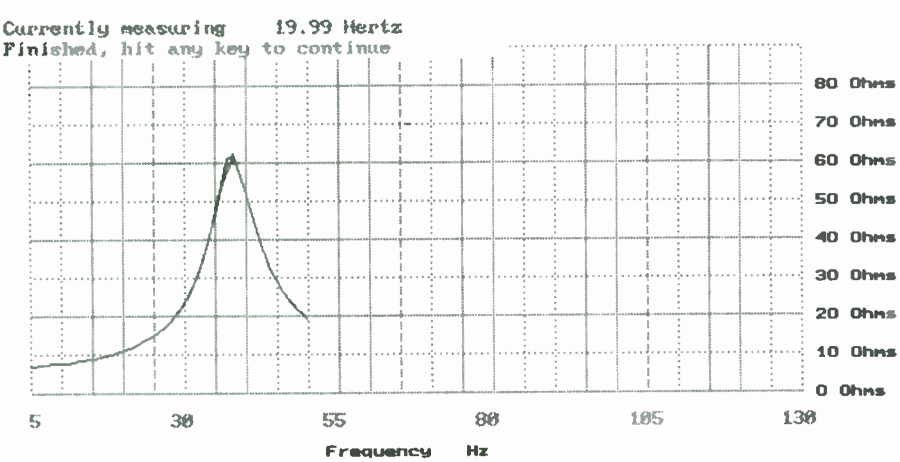


FIGURE 1: The screen for "Plot impedance, f_s, Q_{ts}."

box design or even a classic Q_{TC} of 0.7. For them, I chose to compute the predicted box volume and system resonance frequency for a planned Q_{TC} of 1.

Table 2 shows a pattern of the WT giving slightly higher readings for R_e and slightly lower for Q_{TS}. For V_{AS}, there is no distinct pattern; in fact, considering the spread you often get for V_{AS}, I was pleasantly surprised that the values obtained by the WT were relatively close to those of my shop tests. It should be noted that these are simply delta mass tests. Delta compliance tests might give somewhat different values for V_{AS}.

Figure 2 shows a double plot of the predicted performance if my shop parameters are considered correct, but the values obtained by the WT were used to design a vented-box enclosure. First, I fed the WT parameters into the Koonce file (VBPLOT2)[4] and the program developed an optimum QB3 alignment based on that data. This is somewhat different from the Keele QB4 alignment shown in *Table 2*, with a volume of 0.676 ft³ and an f_B of 48Hz.

Then I assumed that two different drivers, one with the parameters reported by the WT, and the other with those reported by the shop data, were installed in identical enclosures. As you can see, the two curves appear almost identical, showing that the differences in measurement by the two methods were negligible or self-compensating.

By either Keele's calculator program or the Koonce file, the ideal tuning frequencies for the vented-box and system-resonance frequencies for the closed-box speakers were amazingly close, with the exception of values based on manufacturers' specifications for the closed-box speakers. When I finished the tests for f_S and V_{AS}, I decided I could trust the Woofer Tester as much as my shop equipment.

The second choice in the menu is Measure V_{AS}. Finding V_{AS} accurately can be a challenge with any kind of test equipment.

PROBING V_{AS}

The Woofer Tester allows for three ways to test V_{AS}: delta compliance/vented box; delta compliance/closed box; and delta mass. Version 4.4 of the software requires you to enter the effective diameter of the driver's piston area for each of these choices, and the program computes driver compliance as well as V_{AS}. Earlier versions of the software computed compliance only when using the mass method of V_{AS} measurement.

Each of these methods carries its own hazards. I decided to compare the WT's measure of V_{AS} by the delta-mass method, but before using the data to design a box, I would prefer to confirm it by either or both of the other two methods.

There are two requirements for delta mass: a known value of mass to add to the driver's cone, and an accurate measure of effective piston diameter. The WT program asks you to enter the number of grams of added mass, but the instructions suggest using nickels, a nickel for each five grams you wish to add.

They also suggest using an "overkill" for mass on the first run, such as 40 grams for a 6½" woofer, and so on. Then, after reading the mass of the cone's moving system (M_m) from Inspect Results on the menu, you are supposed to make the final reading by adding 75% of M_m to the cone. Following these instructions would necessitate a lot of nickels for a large woofer—28 for the first run on an 18" size.

NICKELS AND DIMES

In 1958 J.L. Smith used coins in testing speakers, setting the mass of a nickel at 5.05 grams.[5] Although Krause and Mishler[6] state the mass of a nickel to be 5 grams, they show clad-composition dimes at 2.27 grams, suggesting that the dime is more precisely controlled.

I tried the nickel system, but then abandoned it in favor of either OHaus® brass weights or carefully measured blobs of modeling clay pressed on firmly enough to adhere to the cone. One problem with modeling clay is that it usually leaves some residue on the cone after you remove it. This suggests that some mass is lost each time you run a test. You should periodically check the mass of the clay.

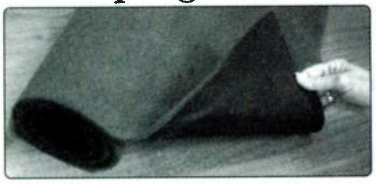
Vance Dickason[1] was critical of the use of nickels because of the lack of precision and possible vibration. The WT is designed to measure f_S and f_S' at such low drive voltage that vibration doesn't affect the result. In fact, the manual suggests that you may not hear any sound from the driver during a test. If you listen carefully, you will hear pulses, and at frequencies near resonance when using a standard closed box, or at the upper frequency peak in a vented box, you will certainly hear the WT probing for the peak frequency.

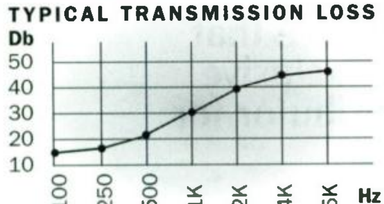
In using nickels for the added mass, I found vibration a noticeable problem with only one driver—a woofer with a large magnet and low Q. But I did find some variation in the mass of randomly selected nickels. Long use may change the mass of a nickel slightly, but I found some that looked brand new, yet proved to have slightly less mass than others that appeared older. Obviously, if you have no access to dependable weights or a good balance, using nickels is an option that will provide a fairly accurate mass.

DRIVER DIAMETER

A potentially greater problem, I believe, is the estimate of driver diameter. The formula for V_{AS} is: $V_{AS} = C_{MS}dc^2A^2$, where C_{MS} is driver compliance, d is the density of air (ρ is often used as the symbol), c is the speed of sound in air, and A is the driver's effective piston area.

Note that not only is A squared, but you





must square the radius to get A, so any error in measuring the diameter is compounded by the calculations. How much of the suspension, if any, contributes to piston area is questionable. The WT instructions suggest measuring from the center of the suspension on one side to the center of the suspension on the other side. I find it easier to include the suspension on one side only, rather than try to locate the center point in the suspension.

Also, I find it easier to measure in centimeters, reading the value to the nearest millimeter. The WT asks for the diameter in inches, but it is a simple matter to make the conversion. This method of determining cone diameter might be called the rule-of-thumb (R.O.T.) method. It is probably more accurate for narrow suspensions than for wider ones.

I decided to test the R.O.T. method using small woofers, where the chance for serious error is greatest. The test I used was to estimate the diameter to the nearest millimeter and compare the result with the figure published by the manufacturer for either diameter (d) or area (S_D). For this I assumed that the manufacturer had made an accurate estimate of S_D.

After assigning the two values of diameter to each woofer, I did some quick runs with the WT, feeding the data in twice—once using the manufacturer's diameter, and once using the estimated data. The results are shown in *Table 5*.

STARTLING ERROR

After seeing the tremendous error on the Siare 190, which would result in a 50% error for V_{AS}, I ran a quick check on another Siare driver, the 230 PPR. Siare sets the diameter on that driver at 14.7cm, but I had estimated it as 16.5, a whopping 12% error. Obviously Siare drivers don't conform to the R.O.T., making you wonder if Siare uses a different method of deriving S_D. Following that, I tried various small woofers and found that in most cases the errors for the R.O.T. method were 2% or less, assuming that the manufacturers' figures were correct.

Obviously, you can also produce erratic results by careless use of the delta compliance methods. If you press the driver down over a hole in a standard box, the net volume will be somewhat greater than the calculated box volume, because of the air under the driver's cone. This usually does not cause a significant error, often no more than 3%.

In earlier times, drivers had gaskets on the

TABLE 4

THE SCREEN FOR "INSPECT RESULTS"

Raw-driver or closed-box results		
F_s is 63.6197Hz	Q_{ts} is 0.3712	
cone area is 0.0085m^2	Q_{es} is 0.4255	
V_{as} is 0.4212 ft^3	Q_{ms} is 3.0956	
V_{as} is 11.9324 ltr		
R_e is 7.2347Ω	R_m is 60.3737Ω	R_1 is 20.9442Ω
Voice-coil inductance L_e is 0.2994mH		
Efficiency is 90.28dB 1W/1m B_L is 6.07 Tesla-meters		
C_m is 1182.486 microns/Newton		M_m is 5.4328 grams
R_m (mechanical) is 0.695 mechanical ohms (Ns/m)		
Vented-box measurement results		
F_{sb} is 66.61H	alpha is 1.212	h_a is 0.961
F_1 is 38.22	F_m is 64.04	F_h is 111.61
Q loss is 6.18	R_m (vented) is 9.42	
Nominal-impedance measurement results		
R min is 8.17	R max is 59.59	R average is 16.55
Press Shift-PrintScreen to print results		

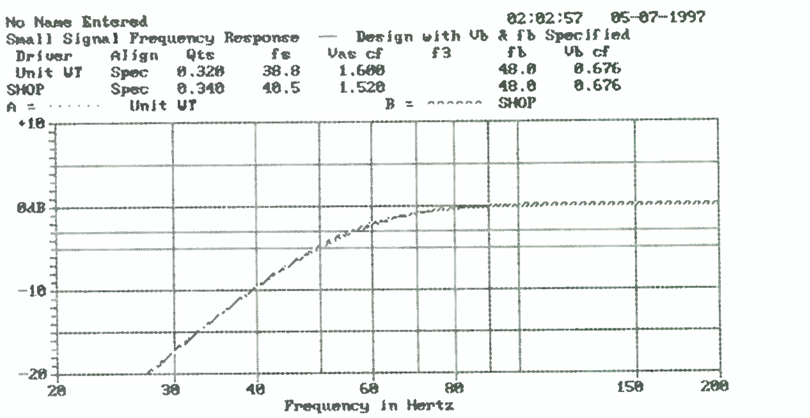


FIGURE 2: Koonce file (V8PLOT2) performance predictions for Audax 170GO (see text).

front of the frame, but now many do not, so you cannot easily test them by the press-down method. For these, you can test the driver in the box, but this can cause an error with large magnet drivers unless you subtract the volume of the driver from the net volume of the box.

VENTED-BOX MEASUREMENTS

There are two items on the menu that apply to completed vented-box speakers: Measure Vented System and Q-Loss Calculation. You can use either independently, but a measurement of the vented system would logically precede the Q-Loss procedure. As you can see in *Table 4*, this measure quickly shows f_{sb}, alpha, and h_s.

For the tests shown in *Table 4*, I used a Radio Shack 5¼″ driver, (model 40-1354) purely because I happened to have an empty 8.5 ltr vented box with a cut-out to fit that size of driver. I made no attempt to match the box to the driver. The value for alpha suggests that the WT "sees" the box larger than you would expect in comparison to V_{AS}, probably because of damping material in the box.

After running the vented-box test, you can go to Q-Loss Calculation, where you are asked to enter raw driver f_S, Q_{ES}, and Q_{MS}. Apparently, the current version of the software does not allow the Q-loss function to access the data obtained from the initial run for impedance and Q measurement. For the vented system reported in *Table 4*, I ran a shop test for Q and got the almost identical value of 6.16.

THE FIVE-SECOND ZOBEL TEST

This Arbitrary Impedance Plot allows you to choose any frequency range you wish and run an impedance plot over that range. Not only do you choose the range, but you can also specify the number of steps for the sweep. To explore a range in detail, you would choose many steps, particularly if you were searching for a maximum or minimum impedance by this method.

The first time you use this, you may wonder why it is included, but it is a jewel for quick Zobel design. For a typical woofer, you can set the range at 200–10kHz in ten steps. When you hit the Enter key, there is a three- or four-second pause, then a one-second plot, so that in five seconds you have a rough impedance plot.

You can substitute various combinations of R and C across the woofer terminals and rerun the plot until the curve looks flat. After that, you can switch to Plot Nominal/Minimum/Maximum to get a detailed impedance plot with the Zobel installed. The reason for limiting the arbitrary plot to 10kHz as the high point is that the impedance plot is not very accurate above that point, as you can see in *Fig. 3*. After all, as Karl Keys told me, this is a tester for woofers, not tweeters.

The WT uses Print Screen plus the shift key to make a hard copy of Inspect Results, but it does not print graphs. The graphs for the figures were made with NeopaintR 3.2, a DOS screen-capture program.

If you wish to explore impedance values in detail, you can quit the program, which leaves you in the directory, and access the IMPEDANC.WOO file to get a printout of every fre-

TABLE 5

R.O.T. vs. MANUFACTURER'S PISTON DIAMETERS

Driver	Mfr. Diam.	R.O.T.	% Error	V_{as} A	V_{as} B	% Error
Audax HM170GO	13.3	13	–2.3	45.3	41.3	–8.8
Siare 190SPCM	12	13.2	10	21.1	31.8	50
Radio Shack 40-102	16.2	16.5	12	43.6	47	8

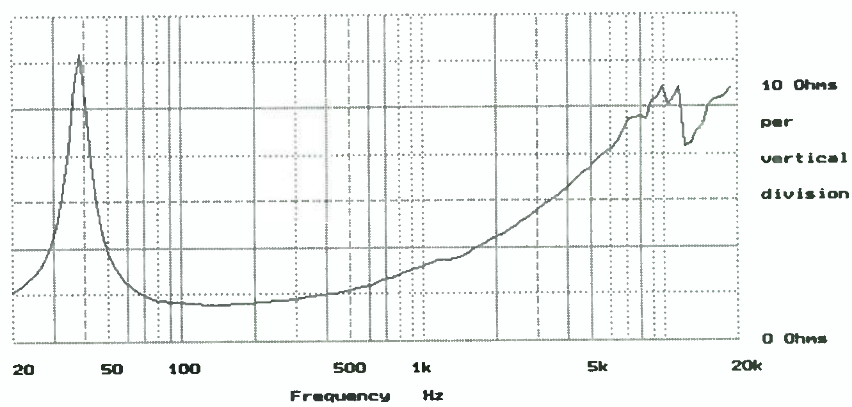


FIGURE 3: Impedance plot; note anomaly above 18kHz.

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quency tested, with the impedance and phase angle for each. You can do the same for VENTED.WOO and ARBITRAR.WOO files.

That's about it, except for Woofer Break-In. The Woofer Tester provides a choice of three low-frequency signals to exercise your woofer prior to testing: 15, 20, and 25Hz. There is a line-output RCA jack on the front panel for connecting to the input of an external amplifier. Obviously, you must use such low frequencies with care on small woofers. It would be wise to check the value of X_{MAX} for your drivers and adjust the volume control on the amplifier to prevent cone movement from exceeding safe limits.

CONCLUSIONS

The Woofer Tester is not perfect. It gives a slight error in measuring DC resistance and a significant error for low-value inductors. It doesn't save files for future use, although you can use shift-plus-print-screen to print out the tabular results of any test. You must quit the program to clear data from memory, but that can be almost instantaneous if you set up your computer with a "W.BAT" or other such command.

I have no plans to junk my old equipment; there will always be uses for separates. But I find myself choosing the Woofer Tester more and more to get a "quick fix" on a driver.

As I mentioned at the outset, I have always considered the Heathkit IG-18 (at $67.50 in 1970) to be the buy of the century. However, it was only an audio generator, so in order to test drivers, you needed to add the cost of at least two other basic items—an AC millivoltmeter and an accurate ohmmeter; also, if possible, a frequency counter.

Before I became too nostalgic about the prices of equipment in 1970, I remembered that you could buy a new Buick Century then for about $3000. Considering the current value of the dollar and what the Woofer Tester will do, I suggest that if you have a PC, it is really the buy of this or any other century.

References

1. Vance Dickason, "The Woofer Tester," *SB* 5/94.

2. Reginald Williamson, "The Greening of the IG-18," *Audio Amateur*, 1/71.

3. D. B. Weems, *Designing, Building and Testing Your Own Speaker System*, 4th edition, McGraw-Hill, 1997, p. 171.

4. G. R. Koonce, "The Private Files of G. R. Koonce," (#SOF-KPF; available from Old Colony Sound Lab, PO Box 576, Peterborough, NH 03458, (603) 924-6371, FAX (603) 924-9467).

5. J.L. Smith, "Testing the Properties of Loudspeakers," *Radio & TV News*, August, 1958, p. 39.

6. Chester L. Krause and Clifford Mishler, *1996 Standard Catalog of World Coins*, Krause Publications, Iola, WI, p. 2127.

SB *Mailbox*

CORRECTION

In Figure 7 of Matthew Lattis' article, "An Insulated Diaphragm Electrostatic" (*SB* 4/97), the input voltage to the bias supply should be 12V DC, rather than the 2V DC noted.

FREELINE FINE POINTS

I noted a slight bit of confusion in my reply to Mike Bengfort's letter (*SB* 2/97). I meant to say that the stuffing density of the lower line section of the Freeline (*SB* 5/95) was originally 0.9 lb./ft^3. I raised the density to a current 1.375 lb./ft^3 by adding an additional 2.4 oz to the original 5½ oz of stuffing, making a total of 7.9 oz of stuffing in the lower (longer) line section. Sorry about that.

As long as I'm here, I'll mention that the 0.022µF capacitor I refer to is identical to the 22n capacitor in Fig. 1 (*SB* 2/97, p. 54).

John Cockroft
Sunnyvale, CA

RETRO DESIGN

As an additional note to my article ("The Classic Altec 604 Reborn," *SB* 1/97, p. 32), I should have been more explicit in stating that the 604 is a coax design with the horn mounted in the center of the woofer (a design that people are again finding interesting). This makes the task of constructing the full system easier: you just build the box as if for the woofer, and everything else takes care of itself.

An Altec crossover comes with the unit, along with a treble adjustment. I mounted the crossover inside and worked the adjustment through the port after the box was closed to achieve the desired balance. Except for my compulsive overkill on the box, this is really a great project. Also, remember that some of the great recordings such as Fine's and Mercury's were mastered with Altecs as the reference speakers.

Otto Doering
W. Lafayette, IN

RECAP

I want to thank those involved in the lengthy debate on capacitors for the vast amount of knowledge I have gained about these wonderful devices. I believe that I have a marvelous solution that will satisfy all of you. If you can hear the difference between a three-dollar capacitor and a fifteen-dollar capacitor, and you will be placing them into your own personal speakers, buy the fifteen-dollar ones and be done with it! If you cannot hear the difference, or if the person who will be using the speakers cannot, for goodness sake, buy the three-dollar ones.

Thousands of people are purchasing dual 3″ cube boxes for surround-sound and are then calling their system a high-tech, transparent, completely flat-response acoustical environment. This sad fact alone should make it obvious that most of the general public cannot hear the minute differences between the capacitors you all are discussing.

By the way, as a rule of thumb, if it takes an oscilloscope to find the acoustical problem, your friends would most likely never hear the difference.

Chuck Swindoll
President, Lucid Audio
Brentwood, TN

HYPERSONIC HISTORY

Has anyone experimented with the "Hypersonic Sound" principle that American Technology Corp. (Poway, CA) has announced? This "technology" mixes two ultrasonic (approx. 200kHz) frequencies to produce a lower sideband of sound in the audible range. On the surface, it seems that this overcomes some of the basic limitations of today's speaker technology: box volume vs. cutoff frequency, directivity vs. frequency, and so on.

Kevin Kersey
San Diego, CA
kkersey@cts.com

Vance Dickason previewed this process in Voice Coil *(February 1997):*

"This latest invention, HSS, is really an interesting new application of a technology which dates back to the 1930s. It all began with the observation that when two separate frequency tones are combined, they produce a sum and difference tone. The observation of this effect is attributed to Giuseppe Tartini, an 18th-century Italian composer, and is often referred to as the Tartini Effect....

Past efforts by others include a patent idea from 1930 intending the transducer to be used with loudspeakers in art galleries. Since the device was known to be highly directional (much like a flashlight), this applicaton would allow gallery visitors to hear a description of each painting they encountered, without being disturbed by the adjacent loudspeakers emitting their individual stories.

Various articles about similar devices, using the sum/difference effect with ultrasonic transducers, have been described in the Journal *of the Acoustical Society as early as 1957, but most concern hydrosonics. Matsushita presented a practical application at the Japan World Fair in the 1985 Tsukuba Science Exposition. Matsushita engineers exhibited a talking billboard that was sonically perceptible only when you were standing directly in front of it. It could not be heard on either side of the display, showing the extremely high directivity of this technology. This device operated in the 40kHz region, but produced no practical application.*

A previous incarnation of this sound-producing technology used two ultrasonic piezoelectric devices which, when fired into the air, produced sound waves at the beam-intersection point. What differentiates the American device is that it mixes the modulated ultrasonic signal with the carrier signal at the feed, to form a single ultrasonic piezo transducer. The actual creation of soundwaves takes place in the air, directly in front of the transducer; the distance is a function of the wavelength being reproduced....

Carver Corporation in Seattle is working with American Technology Corporation to produce a workable prototype appropriate for the home-audio market. At this time, American Technology has shown Carver a proof-of-concept prototype using a single non-ideal piezo transducer operating in the 40kHz range, configured as a dipole. Audible sound was produced, but lacked low frequency (for the same reason any dipole lacks low-frequency content). While the prototype was functional, it was not really ready to displace any product currently on the market.

The companies plan to fabricate a transducer configured as a monopole which operates at the more ideal 200kHz range. The 200kHz range produces much greater dynamic and bandwidth than a 40kHz ultrasonic range. It is expected to be up and running sometime in January. If this proves to be successful, the Carver/American Technology *product could reach the market in the third or fourth quarter of 1997. It is unknown as yet if the device will produce the low-frequency sonic impact characteristic of conventional cone-type subwoofers."*

DRIVER IMPEDANCE DISAGREEMENT

Referencing Don Jenkins' "Dynamic Characteristics of Driver Impedance" (*SB* 1/97), it turns out that my interpretation of his voltage and current waveforms was correct. Don really did have a zero source impedance while the test pulse was on, and an infinite source impedance after the test pulse was turned off. This test did not involve the use of an amplifier hooked to the speakers.

We both agree upon the nature of a time-varying impedance due to some input waveform, the fact that it is a real quantity in the time domain, and that it is complex in the frequency domain.

Our one point of disagreement is how to treat measured impedances, averaged over the measurement period, that are larger than the DC resistance of a device. Don wants to assume that the part that makes it larger is in quadrature to the DC component. This assumption that the extra impedance is in quadrature, after being averaged over a measurement period, has no meaning in the technical literature of which I am aware.

The fact is, most speakers are purely resistive at more frequencies than just DC. They are also purely resistive at the peak in their fundamental resonance, and at the trough formed by the interaction of the voice-coil inductance with the mechanical mass. Since any switched DC pulse test will contain all of these frequencies, you can't assume that the measurement is composed of just the DC resistance and some other reactance in quadrature.

I am not opposed to inventing creative waveform tests to check the behavior of a loudspeaker driver. Mattei Ottala and others invented cruel voltage waveforms that produced huge currents in the output stages of amplifiers. This showed that loudspeaker loads sometimes behave as much smaller resistors than their DC resistance. This led to some appreciation of high-current capability among high-end amplifier designers.

My recommendation is that when an author presents data, he also should describe the experimental setup sufficiently so that any reader can duplicate the measurements. Then you can be sure everyone will know what the measurements mean.

Dr. Victor Staggs
Orange, CA

Don Jenkins responds:

Dr. Staggs still seems to have trouble with using a DC pulse to calculate driver impedance. Perhaps the following test data will help illuminate this problem.

I connected the same driver that was used in the original article, as follows. RMS averaging meters (Fluke 45s) were placed in the circuit from an amplifier to the driver. Using a square-wave frequency of 16Hz (the original pulse was 30ms) the following data was recorded.

Voice-coil resistance
7.1Ω
Square-wave input @ 16Hz:
RMS voltage across voice coil 0.388
RMS current to driver—amps 0.0496
Calculated impedance magnitude
0.388/0.0496 = 7.82Ω
Calculated impedance
7.1 + j3.28Ω

*These voltage and current values were averaged over thousands of cycles. Would the measurements have been any different if the average was over only 100 cycles, 10 cycles, or, as in the case of the reference pulse, ½ cycle? I suggest the answer will be the same. As mentioned in the original article and my response to Dr. Staggs' letter (*SB *4/97), the reactance calculated by the described procedure is correctly interpreted.*

Reactance—either capacitive, inductive, or mechanical*—has the same property of storing and returning energy to the circuit. Relative to this common property, each effect can be implemented correctly in circuit analysis using classical definitions, notations, and mathematical procedures.*

In steady-state circuit analysis, the storage and return of energy from the reactive components becomes a constant quantity over repeated power cycles, and the calculated value of impedance magnitude appears constant when using slow-response RMS-averaging meters. If the instantaneous values of the quotient of the applied voltage and input current are plotted over a power cycle, the resulting curve will be the changing value of impedance magnitude during the measuring period.

The average value of the integration of this function will be the value of the "steady-state" impedance magnitude. Resolution of the impedance magnitude into the complex impedance is made by solving the impedance triangle. The resolved RMS impedance *is noted as resistance magnitude plus or minus the reactance magnitude (in ohms). The so-called "quadrature" reactance is a notation used to*

to page 60

Classifieds

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Reader Service #7

Stevens FR120, $180; pair Wharfdale 12", $70; pair 16 Pyle 8" full-range, $60; 64+ 3" tweeters, $60; University Type 200 Diffusicone, $75; pair Realistic 8" coaxials, $40; pair Altec high-frequency diaphragms, $65 each. Bob, (916) 273-9679.

GAS Grandson 40W amp, rebuilt by Gasworks; Son of 80W; excellent amps in great condition, $225 each. Doug, (509) 921-6067 days or (509) 922-2441.

Dynaudio: four 17W75 woofers, two D260 Esotec tweeters, excellent condition, $325 or best offer, cannot separate. Karl, (702) 884-3963.

Pair Altec 515E, $425; pair 288K, $425 (as recommended in *Sound Practices*/Stronczer article); pair 515B, $600; pair 288B, $500; pair Altec N501-8B crossovers, $200; pair JBL 2410 (pro version of LE-175), $225; pair JBL HL92 horn/lens, $175. Kent Elliott, phone/FAX (913) 677-1824, before 9 p.m. (CST), or E-mail Kentelltt@aol.com.

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Two pair Infinity ERS-820 in-wall speakers, new in boxes, $300 per pair; two pair Infinity ERS-800 in-wall speakers, used, excellent, $175/pair; two Nakamichi 670-ZX rack-mount cassette decks, black, excellent; Altec 511, 811 horns; 806, 291 drivers. JBL 1" Alnico drivers; Pioneer Spec I preamp; Spec 4 amps. David, (914) 688-5024.

AD INDEX

Toroid transformers, Talema UR0300-2-012 (300VA, dual 12V secondaries), $40 each; Morel MW220 woofers, new/unused, $45 each; Audio Quest panel-mount RCA connectors (R/L pairs), $7 set; Vampire speaker binding posts, one stereo set, $15. Dan Patten, 1768 N. 980 W., Orem, UT 84057, (801) 224-8080 (work), (801) 225-8577 (home), or E-mail dpatten@dasengr.com.

Audax Aerogel HM210Z0 woofers, 8" cast frame, $50 each or four for $150; pair Grenier cabinets, slanted baffle, natural oak finish, mint condition, $200; pair 15mH laminate core inductors, 15 AWG, low DCR, $25. Rick, (919) 662-5253, 7–11:30 p.m. (EST).

Two beautiful, custom-built, smooth-sounding four-way speakers. Each has 15" Altec 411 sub plus Bozak 8" bass, 6" mid, and six 2" Z3 tweeters, time-aligned in 50" tall × 24" × 24" cherry-stained oak cabinets. Bi- and tri-amp wired, $1,000. Bob, (310) 676-4629.

Carver 4000T preamp with sonic holography, noise-reduction system, digital time lens, and surround-sound; mint condition; $600. Doric Model 130 capacitor meter, ranges from 0.1pf to 200,000µf, LCD display, mint condition, $100. Nick, (209) 583-6511.

AR9, XA, XB, EB-101; Bryston 10B; Berning OTL; Bruel Kjaer; Dynaco (unassembled) DH-101, DH-500, PAT-4, SCA-80Q, QD-1; ENTEC SW-1; EV30W; Quad ESL; 22+11; H-P 1704A 100MHz, 8903B; JBL B380, BX63A; Levinson ML2B, ML6A, ML6B, LNC-1, LNC-2, D23, F500, F700, F850; Soundlab A1, Sally; Tympani 1-D; Vandersteen 4A. John, (408) 737-2980, FAX (408) 735-1426.

JVC (Japanese Victor Company) auto-reverse cassette deck, two heads in each direction, in good working condition; Shure headphone amplifier. Input for magnetic cartridge and tuner, output for two stereo headphones, 25 years old, has dual-voltage-line transformer, best offer. Dr. L. H. Steinberg, (215) 592-9765.

Pair of Audio Concept Sapphire I speakers, $600 or best offer. Bob, (508) 630-4455.

Pair Advent I tweeters, $20; E-V RE85 Dynamic Lavalier mike, $35, E-V 649B Dynamic Lavalier mike, $25; Audio Technica AT816 unidirectional Dynamic mike, $20; one University N2B crossover, $10. Also have Advent I woofers (needing surrounds) and Advent I crossovers. Jim, (708) 425-6719.

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Calrad CH-300 multicell horn; four 15" PA woofers, cheap; Radio Shack Linaeums. Bob, (916) 273-9679.

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EICO uniprobe and Heath manual for IB-2A impedance bridge. Dave Platt, 636 Marion Ave., Springdale, PA 15144, (412) 274-8149.

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Please note that ad submissions that do not meet the above criteria will not run.

Thank you in advance for your understanding and cooperation. On behalf of the entire staff here at Audio Amateur Corporation, we look forward to providing you with the very best products and subscriber services possible.

Respectfully yours,

Edward T. Dell
Publisher

AUDIO Amateur CORPORATION

Reader Service #55

from page 55

resolve the impedance value relative to power. In circuits with several reactance components and a non-sinusoidal, but repeating, input wave form, the actual phasing of the currents and voltages in the various circuit components may bear little relation to the "solved for" phasing given by the network ratio of resistance and reactance. This "solved for" phasing is only relative to the power dissipation in the circuit, and gives the effective value of the RMS current or voltage relative to power *and the impedance magnitude.*

I disagree with Dr. Staggs' suggestion that drivers are purely resistive for most inputs. Any circuit component that stores and returns energy to the circuit will always return some of the energy. The characteristic of being "out of phase" with the driving current appears to the source as a change in impedance magnitude.

As mentioned in the original article, the classical consideration of reactance as a non-power-absorbing circuit element depends upon the return of energy stored in the electrical and magnetic fields of a capacitor or inductor to the energizing circuit. In the moving coil and cone of a driver, this energy is stored in the structural deflection of the cone structure (compliance) and in the momentum of the cone mass.

In operation, the driver cone is in constant acceleration, both positive and negative, and the current produced by the voice-coil velocity in the driver magnetic field is in constant change, both in magnitude and phase. The input sees this as a change in impedance magnitude, exactly the same condition as when a passive capacitor or an inductor is in the circuit. The power dissipation is only in the resistance of the voice coil, the bending work on the cone suspension, and the compression of the air surrounding the structure. Since power is not produced in the measured increased impedance, the resistance added to current flow must, by definition, be reactance.

HELP WANTED

Please help me locate a supplier for the PVA compound which is applied to a cloth speaker surround. I have called most of the repair services and they neither have it nor wish to sell it.

Vincent Mogavero
51-10 67 St.
Woodside, NY 11377

I am considering designing a set of small two-way loudspeakers. I wish to use the Linaeum dipole tweeter and am wondering if you have any advice concerning matches with this tweeter. One unit I am looking at is Audax's Aerogel 5¼". Have you seen any projects using the Linaeum?

Robert Clendenning
robnet@istar.com

Can anyone help me locate information on time-adjusting Klipschorns? I want to make my K-horns right in the area of time, image, and IM/vibrational distortions.

chuxin@aol.com

I understand how to build, design, and tune a fourth-order and sixth-order bandpass. Would you please explain the procedure to design and tune a Quasi-seventh-order, in which the rear chamber fires into the front and the front is ported to the outside of the box? Could you direct me toward a book on the topic?

Shane Anderson
33296 Century Cros.,
Abbotsford, B.C.
U2S 5V5 Canada

I have a 15" full-range speaker that I have never heard of. It seems to be a good-quality driver. I am curious to find out how old it is and whether it is worth anything to a collector. The ID plate on the back of the magnet structure reads:

Stephens Trusonic Inc.
Free Cone Speaker
Model No. 150 FR 16 OHM
Serial C 4830

It has a black cast frame, paper cone, red surround, and gold-color dust cap. The cabinet is plywood, which is rough looking but sounds great. I would greatly appreciate any info on this driver.

Rick O'Neill
PRSCH914@aol.com

Readers with information on these questions can correspond directly with the letter writers at the addresses provided.

Speaker Builder encourages reader feedback regarding published articles, do-it-yourself projects, technical developments, and industry happenings. Be sure to include your name and address. Send your questions, comments, and suggestions to:
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NOISE MASKING

Audiophiles normally think in terms of increasing signal-to-noise ratio and cutting down noise—reducing tape hiss, surface noise, hum, and extraneous sounds in the listening room. However, there are times when the opposite is more desirable.

A year ago, just before our daughter Tannah was born, my wife and I prepared the nursery for the new baby. My wife was concerned that the TV and other muffled sounds from our downstairs tenant directly below were overly intrusive.

We put down a large rug, which only slightly attenuated the noise. I did not relish what appeared to be our only recourse: trying to install some sort of insulation in the tenant's ceiling.

MAKING NOISE

Then I came up with another idea: noise masking. I had an old stereo receiver with one channel out and a speaker I could hook up. I positioned the speaker and receiver beneath the crib and tuned to FM interstation hiss. After wiring a 2mH inductor in series with the speaker, I discovered that by adjusting the tone controls I could produce a dull rushing noise which sounds much like a large heating vent and covers up the intruding sounds perfectly. It also helps drown out the noise *we* make while the baby is sleeping.

With the volume level carefully adjusted, you don't really notice that there is an artificial noise source when you enter the room. It just blends in with the other sounds you expect to hear around the house.

PHOTO 1: A carefully controlled environment can result in a well-adjusted baby and a happy childhood.

This method is often used in an office setting where an unobstructed open space is desirable for free interaction between workers but conversations on the other side of the room would be intrusive. It works beautifully, and the effects of a noise-masking system are only obvious when the system is turned off and you realize you can hear things that you couldn't hear before.

The source of noise doesn't need to be a speaker. It can also be the ventilation system, or, in the case of our own bedroom, a small fan to drown out traffic and other sounds at night.

Perry Sink
Lincoln, NB

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