SNEAKING UP ON DRIVER QUIRKS WITH A CEPSTRUM

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Speaker Builder

THE LOUDSPEAKER JOURNAL

BIG CONSTRUCTION ISSUE

CONCRETE-WALLED, WITH FOUR DRIVERS FOR BIG 20-Hz BASS

TOM PERAZELLA

BUILDING A PAIR OF MONITORS FROM SAWING TO SOUND

MARK ZACHMANN

HOW TO INVENT A NEW DUAL-MODULUS MATERIAL FOR SPEAKER WALLS

HAJO PRODAN

FIGURE OUT THE ROOM WITH *VISUAL EARS*

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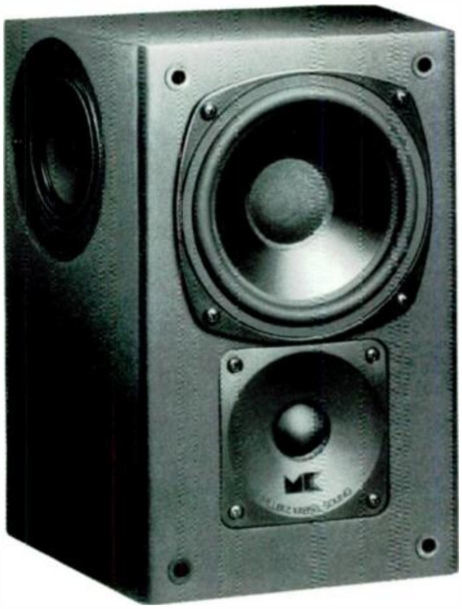


NO PLACE LIKE HOME (PAGE)

Caig Laboratories manufactures environmentally safe chemical products—including ProGold, DeoxIT, and the CaiLube MCL line—for manufacturing, maintenance, and service. Caig's new home page at http://www.caig.com features technical product information, pictures, and material safety data sheets. Quick e-mail access and the publication of a question-and-answer segment further accent the web site. Caig Laboratories, Inc., 16744 W. Bernardo Dr., San Diego, CA 92127-1904, (800) CAIG-123, FAX (619) 451-2799, e-mail caig123@aol.com, Internet http://www.caig.com.

Reader Service #107

YOU CAN'T TOP IT

BenchTop™ Plus software, an upgrade to BenchTop Lite, is newly available from PC Instruments with a free lifetime upgrade policy. Functions include pulse analysis, to analyze pulse responses and digital communication signals; an FFT, to assess frequency domain; a phase angle meter, to analyze power distribution, filters, gyroscopes, and other sensors; a boundary test function, to compare waveforms with limits; and Automated Test Language, to control instruments during testing. PC Instruments, 9261 Ravenna Rd., Bldg. B11, Twinsburg, OH 44087, (216) 963-0800, FAX (216) 425-1590, http://www.pcinstruments.com.

Reader Service #106

ONE HORN'S FACELIFT

Motorola's Ceramic Products' division announced a newly restyled KSN1016B horn. Its high-tech, bezeled appearance gives the horn a 21st century look and distinguishes it from imitations. Motorola, 4800 Alameda Blvd. N.E., Albuquerque, NM 87113, (505) 828-4261, FAX (505) 821-7651.

Reader Service #102

ALL ABOARD THE SS-SPEAKER

Miller & Kreisel Sound introduces the SS-150 Tripole™, which is user-selectable as either a standard dipole or tripole speaker. Ideal for 5.1 channel discrete digital recordings, the SS-150 operates in tripole mode as a point-source direct radiator with a 5¼″ woofer and 1″ soft-dome tweeter; as a dipole speaker, it offers two high-performance 3¼″ poly-cone mid-tweeters. Miller & Kreisel Sound Corp., 10391 Jefferson Blvd., Culver City, CA 90232. (310) 204-2854, FAX (310) 202-8782.

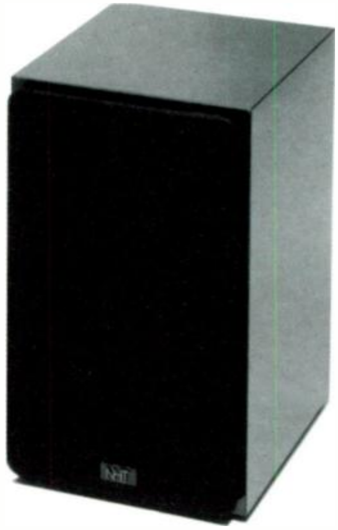
Reader Service #101

HANG IT UP

Pictures, by Bandor Loudspeakers, are 2″-thick wall-mounted loudspeakers encased in a solid wooden frame, complemented by a ceramic cabinet front. With a single advanced driver and 2″ spun-aluminum cone, Pictures exhibit an impedance of 8Ω and an 80Hz–20kHz bandwidth. Pictures excel as rear speakers in four-channel or surround-sound systems, as extension speakers for small rooms, or in applications requiring moderate listening levels or extreme bass extension. Bandor Loudspeakers, 11 Penfold Cottages, Penfold Lane, Holmer Green, BUCKS, UK HP15 6XR, phone/FAX (+44) 1494-714058.

Reader Service #109

Good News



⊃ A BIRD, A PLANE? NO, IT'S A SPEAKER

Now Hear This (NHT) introduces the SuperOne as a "big brother" to its SuperZero mini-monitor speaker, incorporating two-way acoustic suspension, a video-shielded 6½″ woofer, and a 1″ fluid-cooled soft-dome tweeter. Available in high gloss black or white laminate, the SuperOne handles 25W–150W per channel, offers sensitivity of 86dB, and achieves a frequency range of 57Hz–25kHz. Now Hear This, 535 Getty Court, Benicia, CA 94510, (707) 747-3300, FAX (707) 747-1252.

Reader Service #105

A (FLUSH) CUT ABOVE

The 9000 Series Micro-Shear® flush wire cutters are available in several configurations from Xuron Corporation. Designed for special manufacturing and field service applications, these compression-type cutters incorporate cutting edges hardened to produce a clean, square cut with little force. Micro-Shears, constructed of heat-treated alloy steel, offer a choice of tapered or oval heads, cushioned rubber hand grips, lead retainers, standard or long handles. Xuron Corporation, 60 Industrial Park Rd., Saco, ME 04072, (207) 283-1401, FAX (207) 283-0594.

Reader Service #108

BEHOLD THE TITAN

ACI's Titan powered subwoofer is an enhancement to high-quality stereo systems. Excluding the cabinet, the Titan kit comes complete with a 12″ woofer and all other necessary components. The pre-assembled and tested electronics module offers 20Hz response, 250W RMS, and current-sensing feedback; as well as self-limiting and adjustable crossover frequency, volume, and phase. ACI, 901 South 4th St., La Crosse, WI 54601, (608) 784-4570, FAX (608) 784-6367.

Reader Service #104

MAX YOUR MINI

AudioSource's MCSW-1 mini-component power subwoofer was designed with bookshelf and computer systems in mind. With a 50W built-in powered amplifier matched to an 8″ reinforced driver, the MCSW-1 has gold-plated RCA and speaker-level inputs and outputs, in addition to individual controls for input level, crossover frequency, and phase reverse. AudioSource, Inc., 1327 North Carolan Ave., Burlingame, CA 94010, (415) 348-8114, FAX (415) 348-8083.

Reader Service #103

⊂ OBJET D'ART SPEAKERS

In the tradition of the decorative Domain™ series speakers, MB Quart offers Terra ceramic speakers wrapped in a kiln-fired finish. Scheurich, Europe's advanced ceramics producer, molds, glazes, paints, and fires each of Terra's handcrafted, free-form designs. In addition to a subwoofer composed of dual long-throw 6″ woofers, Terra systems include a satellite/surround speaker and a center-channel speaker that both incorporate a ¾″ titanium tweeter and 5″ polypropylene woofer/midrange. MB Quart Electronics USA, Inc., 25 Walpole Park S., Walpole, MA 02081-2532, (508) 668-8973, FAX (508) 668-8979.

Reader Service #110

About This Issue

Tom Perazella's search for true low-frequency capabilities finally leads him straight into the closet, where, instead of skeletons, he uncovers the perfect place for his speaker project ("True Bass," p. 10). The author relates his design, construction, and testing procedures, through which we discover how he achieves high acoustic output at low frequencies with low levels of distortion.

Once again, software developer **Bill Waslo** demonstrates the versatility of his speaker-measurement programs as he takes a close look at cepstral analysis ("Reflecting on Echoes and the Cepstrum," p. 20). We'll learn what this term means as it relates to horn measurement, and more about the hearing process. Bill also tests our anagrammatical skills by introducing such terms as quefrency, saphe, and alanysis.

After almost a 20-year hiatus, **Mark Zachmann** returns to speaker building to tackle an ambitious five-speaker project, which includes crossover design ("The Convertible Monitor," p. 28). His versatile setup serves his family's audio and audio-for-video needs.

What do you get when you mix two contrasting materials such as rubber and sand? For German engineer **Hajo Prodan**, this is the recipe for an original cabinet material that combines low- and high-frequency benefits for high-quality acoustic sound ("The Opposite Moduli (OM) Speaker Cabinet," p. 42). His patented panels not only perform well, but also promise to spruce up the appearance of your system.

In addition, *Voice Coil* editor **Vance Dickason** reviews Visual Ears, a flexible program to help you with loudspeaker placement and listening room design ("Software Review," p. 48).

Speaker Builder®

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JOHN STUART MILL

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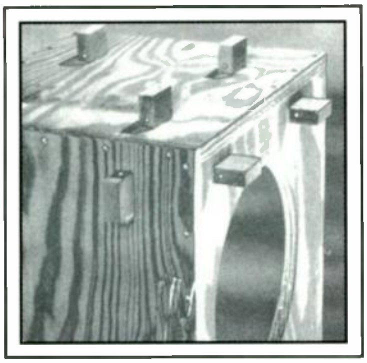

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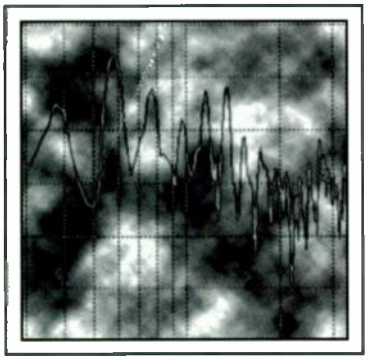

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Cover photo shows artist's impression of a speaker built from Opposite Moduli (OM) panels. See p. 42.

DEPARTMENTS

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by FOCAL

ORCA is bringing to you from France a whole new and exclusive line of fine drive units specifically designed by Kimon Bellas, ORCA, and by Gilles Brun, FOCAL SA. Why ACCESS ?

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ACCESS 6A	Efficient (92 dB –) and transparent 6" midrange. A single inductor might be all you need to get the quintessence of this beautiful drive unit.
ACCESS 6B	Surprising weight in the low end, which is powerful and well defined. This little woofer does not seem to be much embarrassed by any signal.
ACCESS 7A	Extremely smooth 7" midrange/midbass. Excellent prospect for a simple efficient 2-way bass reflex , It can also be used in surround systems main speakers, with or without a subwoofer.
ACCESS 7DB	Outstanding 7" dual voice coil midbass. Powerful, crisp and efficient, this drive unit will play anything your amplifier will throw with panache and relentless enthusiasm.
ACCESS 8A	Very efficient (93 dB +) 8" midrange/midbass. One of the truly rare 8" that can be used in 2-way designs. You will need a very good and efficient tweeter to match this unit (at least 92 dB/W/m)
ACCESS 8DB	Outstanding 8" dual voice coil midbass. Efficient, smooth and crisp sounding it is also capable of handling large dynamics and true low frequencies with the authority of a much larger woofer.
ACCESS 10A	Impact & dynamics (94 dB/W/m). If a 10" midbass can make it to the tweeter range, this is the one. Its nearly perfect roll-off will allow direct wiring without filtering. Rare unit for 2-way 10" designs !
ACCESS 10B	Deep and musical 10" woofer. Ideal for medium size 3-way systems , with one of the 4", 5" or 6" ACCESS midranges. A classic.

Reader Service #62

TRUE BASS

By Thomas Perazella

If you've ever tried to achieve true bass, you might think finding The Holy Grail is an easier task. It also depends, of course, on what you consider true bass. Parameters that come immediately to mind are response to at least 20Hz, low distortion, good transient response, and high acoustic power output. (For a good understanding of low-frequency reproduction, see Bill Duddleston's article on sound reproduction in the catalog from Legacy Audio, 3201 Sangamon Ave., Springfield, IL 62702, 800-283-4644, FAX 217-744-7269.)

GOAL

The goal for this project was to develop a subwoofer with flat response from 60Hz to at least 20Hz, acoustic levels of 110dB at the prime listening position, and distortion below 10%. This would be an aggressive aim in a normal listening room. However, the room for this project is a 21′ × 16′ loft open to a lower family room of almost identical dimensions that in turn opens on a breakfast area and kitchen. The total volume is therefore quite large, putting severe demands on the system to achieve the above goals.

Another primary concern was to have an enclosure as unobtrusive as possible. Previously, bass had been provided by six Bozak B199A woofers in modified Bozak Symphony enclosures. Active EQ had provided bass extension below resonance, but at the cost of higher distortion. And the large enclosures had to go.

A fortunate aspect of the loft listening area is a carpeted closet extending the entire 21′ length of the room where the ceiling slopes downward, and having a volume of approximately 445ft^3. Using that closet as an enclosure turned out to be the answer, meeting both the volume and visual requirements.

DRIVER SEARCH

The next step was to find suitable drivers. The final decision, thanks to advice from Eric Busch, of DLC Design, was to use multiple 12″ woofers from Audio Concepts. If you have the enclosure volume, the DV12 woofer is a hard device to beat as far as volume displacement per dollar is concerned. Claimed specifications are: F_S = 17Hz; X_{MAX} = 10.5mm; Q_{TS} = .44; and sensitivity of 89dB/W.

In addition, the DV12 provides two 8Ω voice coils for greater flexibility. The downside is a V_{AS} of 380 liters. This could be a problem with a typical enclosure, but in a 445ft^3 closet, it was not.

Having been discouraged with the performance of the previously considered 24″ woofers, I ordered one DV12 for testing. When it arrived, I was quite pleased to find that it exceeded its claims. The F_S was 14.5Hz, and, although I could not easily measure X_{MAX}, the total excursion appeared to be almost one inch. This is truly amazing in a low-priced driver.

To generate the target acoustic levels at 20Hz, I decided to use eight of the DV12s. That resulted in over 50ft^3 of closet space per driver, a more than adequate volume. The calculated Q would be .5, based on that space.

I first thought I would place the drivers using a mounting plate near the floor, with the drivers spaced to fit between the wall joists of the closet. However, a friend, Perry Sink, suggested an open-box enclosure placed between the joists, with the drivers mounted on opposite sides and the mouth of the box open to the room.

According to Perry, the opposed mounting would tend to turn the mechanical vibrational energy of the drivers into tension and compression forces within the enclosure, rather than transmitting them as rocking movement to the closet walls. In addition, having two drivers on one wall facing into

PHOTO 1: The "hole in the wall" speaker.

TABLE 1

PARTS LIST

1. One 4′ × 8′ sheet of ¾″ ACX grade plywood.
2. Two 4′ × 8′ sheets of 1/8″ luan.
3. Three eight-foot 1″ × 2″ furring strips.
4. Three boxes of 50 #6 × 1½″ flat-head wood screws.
5. One box of 50 #10 × ¾″ pan-head all-purpose screws (can be used for wood or metal).
6. Three boxes of 50 #10 × 1″ pan-head all-purpose screws.
7. One roll of 16 GA soft steel wire.
8. One quart of carpenter's glue.
9. One box of #2 common nails.
10. One 12″ Sonotube.
11. Five 80 lb sacks of sand-mix cement (not concrete).
12. Five gallons of floor-leveler latex masonry adhesive.
13. One quart of primer.
14. One quart of black paint.
15. One tube of clear silicone seal.
16. One box of drywall screws.
17. Eight ¼″ × 2″ lag bolts with flat washers.
18. One bag of plastic cable clamps for Romex electrical wire.
19. One 8′, 2″ × 4″ stud.
20. Terminals or terminal strips to receive speaker cables from amplifier.
21. One 50′ spool of #18 red-stranded wire.
22. One 50′ spool of #18 black-stranded wire.
23. ¼″ push-on terminals for speakers (if direct-solder connection not desired).
24. Solder.

ABOUT THE AUTHOR

Mr. Perazella is the Director of Information Systems for a national retailer of professional photographic equipment headquartered in the midwest. Prior experience includes work as a Criminalist in the San Diego and Long Beach California Crime Labs and as Director of Marketing for a photographic wholesale distributor. In addition to speaker design, Mr. Perazella has designed commercial high-powered electronic flash equipment as well as numerous pieces of audio electronics for his own use. Other leisure activities include cooking, golf, scuba diving, and motorcycles.

the box and the other two facing out, as well as connecting them in reverse polarity, would result in cancelling some of the even-order harmonics. This was the final concept I used, with two enclosures, each housing four DV12s (*Photo 1*).

DESIGNING THE BOX

In order to function properly, the enclosure had to fit between the wall studs of the closet with the open mouth facing into the room and the side-mounted drivers facing into the closet. Even though opposing the drivers would convert most of their vibration into tension and compression in the walls of the box, I wanted to provide sufficient mass to minimize any remaining rocking movement.

To achieve this mass at a low cost while adding rigidity, I decided to build a double-walled box with cement between the walls. I chose cement for its low price, its self-supporting nature (making the box construction easier), its stiffness (a help in distributing the tension and compression forces), and its stability (a filler such as sand might settle and cause voids).

I planned the ¾″ plywood box so that the interior walls would fit snugly between the wall studs. The drivers would be mounted on the plywood surface and an outer shell of 1/8″ luan would serve as a form for the cement and to hold the input terminals. Small wooden blocks would space the luan from the plywood and hold it in position while I poured the cement. To make sure the cement would adhere to the box, I would drive #10 screws into the outside of the plywood and connect them with wire as a sort of "re-bar." I would also use a latex-based masonry additive in mixing the cement to further enhance adhesion.

Since this was to be a double-walled construction with the drivers mounted to the inside surface of the plywood and cement poured between the walls, I had to devise a way to seal the through holes. The perfect solution is to use the cardboard tubes designed as forms for pouring deck piers. Sonotube™ is one trademark name.

I sized the plywood panels to fit between the studs and provide a maximum internal volume consistent with all ten pieces being cut from one 4′ × 8′ sheet with minimum waste. As a result, two sheets of luan were necessary because the outer shell would be larger than the plywood box.

CONSTRUCTION DETAILS

Locate the proper positions for the holes in the wall. Allow a spacing of one joist from the corners to let the end-mounted woofers breathe. Don't assume that the wall joists will be where they should be (16″ on center), or that they will be straight, plumb, or in any other way in conformance with good construction practices.

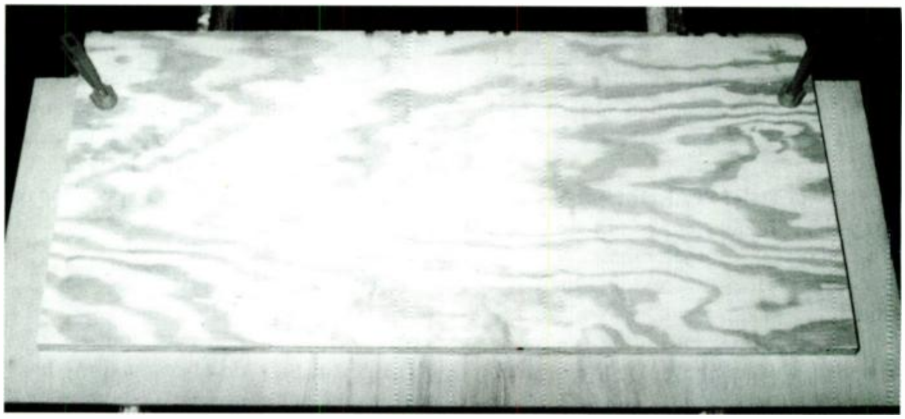

PHOTO 2: Plywood and luan side panels clamped for pilot-hole drilling.

The first step is to mark out and open the holes in the wall. Locate a stud in the area and then, using a level and square, mark the drywall inside the closet with the appropriate dimensions. Using a key-hole saw, carefully cut along the inside of the studs from the floor to the top of the opening. The height will be affected by the depth of any flooring material on the inside of the closet. As a rule of thumb, you are better off making the hole a little taller than needed. Adding a filler is easier than trying to enlarge a hole at a later time.

Once you have cut a hole in the closet side of the drywall, fashion a 2″ × 4″ header to fit between the two studs flush with the cut edge of the drywall. Glue and screw the header in place, effectively sealing off the space between the studs above the housing. Repeat for the other opening. Be sure to accurately measure the spacing between the studs at multiple locations up and down the opening. In my case, the space was not the same for both openings, nor was it consistent from top to bottom.

The width of the speaker housing must fit between the *narrowest* spot in the opening, or you will spend a lot of time chiseling and filing. Be sure to use silicone seal where electrical wires or plumbing pass through the studs. Obviously, you should try to pick locations where there are no obstructions. The final step is to use drywall screws to fasten the cut sections of the drywall to the stud frame.

At this point, you should decide whether to open the holes on the room side of the wall or wait until you've built the housings. For the sake of keeping my wonderful marriage intact, I chose the latter.

CUTTING THE WOOD

The parts list for building the housing is shown in *Table 1*. Construct each enclosure from five pieces of ¾″ plywood and five pieces of 1/8″ luan board, plus various miscellaneous pieces. It makes handling of the large raw sheets easier, if you have the building-supply people make the initial rips of the 4′ × 8′ sheets to conform roughly to the widths needed, and then make the final cuts with a circular saw yourself.

For the plywood, have the sheet ripped in the long dimension to give two strips 16½″ wide, for the side, top, and bottom pieces. The remaining piece yields the two back panels. Dimensions are as follows, to be adjusted for stud spacing:

• Four side pieces	33″ H × 16½″ D
• Four top and bottom pieces	16½″ D × 14½″ W
• Two back pieces	34½″ H × 14½″ W

The 14½″ widths for the top, bottom, and back pieces assume that width as the minimum internal spacing between the studs. In practice, you may need to adjust this for actual dimensions. Also, allowing a space of 1/8″ between the housing and the stud openings will make getting the housings into place easier.

The luan pieces must be larger than the plywood to allow space for the cement. In addition, you must offset the outer luan box 2¼″ back from the opening of the plywood box to allow the front edge of the inner box to extend into the space between the wall studs, to which you will fasten it. I had the first sheet ripped in the short dimension into four strips of 17 7/8″ and one strip of 16½″. The second sheet was ripped in the short dimension into three strips of 16½″. Dimensions are as follows:

• Four side pieces	37½″ H × 16½″ D
• Four top and bottom pieces	16½″ D × 17 7/8″ W
• Two back pieces	37 7/8″ H × 17 7/8″ W

Note that none of the side panels will be symmetrical once you cut the holes for the drivers and wiring. Be sure to mark all pieces as top, bottom, front, back, inside, and outside. The plywood should be cut so the "A" side faces inside the box, with the "C" side facing the cement filler, since this results in a better mounting surface for the drivers.

ROUTING THE SPEAKER HOLES

To facilitate final assembly of the housings, you drill the pilot holes for the speaker openings through the plywood and luan at the same time. Clamp a side sheet of luan to a side sheet of plywood in the same offset position it will assume during final assembly (*Photo 2*). You then mark and drill the pilot holes from the plywood side. The holes should be 7″ from the back and 8″ from the top and bottom of the plywood side pieces. Repeat the procedure for the remaining three sets of sides.

For two sets of side pieces, drill an additional 7/16″ hole in the top rear corner, 2″ from both the top and back of the plywood edges. A piece of tubing will connect these two holes as a guide for running wires from the inside to the outside of each final housing.

Once you've drilled the holes, separate the luan and plywood for routing. For the DV12 drivers, I drilled 11″ holes in the plywood. Clamp the plywood and rout the eight holes. For the luan, select a hole size large enough to allow the cardboard-tube sections to pass through. I used a hole size of 12¼″ to accommodate the 12″ Sonotube. Because the luan is so thin, be sure to clamp a scrap backup sheet to it when cutting the holes.

After you finish the routing, mark and drill the driver-mounting pilot holes, using one driver as a template. If available, a drill press will make this job easier, as you can set the depth of the holes so you do not penetrate the other surface of the plywood. If a drill press is not available, use a drill stop on the bit of your hand drill.

ASSEMBLING THE HOUSING

Assemble the plywood portion of the housing by mounting the top and bottom plates to the edges of the side plates, and the back plate to the edges of the top, bottom, and sides. Before beginning assembly, drill and countersink pilot holes for the #6 × 1½″ wood screws.

Drill holes along the sides of the top and bottom plates, front to rear, beginning ¾″ from the front edge with 3″ spacing. The distance from the side edge should be 3/8″ to center the holes with the mating end of the side pieces.

Now drill holes along all edges of the back plate as follows: 12 along each side, starting ¾″ from the top edge, with 3″ spacing; and five along the top and bottom with 3″ spacing (start by centering the middle hole).

Start assembling the housing by running a bead of wood glue along the top edge of one of the side panels and attaching a top panel with the wood screws. Run a glue bead along the top edge of the other side panel and screw the other side of the top panel to it. Carefully invert the assembly and attach a bottom panel in the same way. Lay the assembly front-edge-down and repeat the gluing and screwing to fasten the back panel. Repeat for the other assembly and allow both to dry for 24 hours. *Photo 3* shows a completed inner box from the mouth side.

While the inner shells are drying, cut 52 2″-long pieces from 1″ × 2″ wood. These will be the support spacers for the outer luan shell. To prevent them from splitting, drill pilot holes at 45° angles at each cut end for the nails that will attach them to the inner plywood shell. Also cut two pieces of 2″ × 4″ to fit horizontally across the mouth of each housing to add rigidity.

When the housings are dry, drill two holes in each side of the mouth to fasten the 2″ × 4″ braces in place. Mark a center line from the front of the mouth to about 6″ back on each side. The first hole should be 4″ back from the edge of the mouth along the centerline, and the second 5½″ back. The brace will then be 3″ back from the front of the mouth along the center lines. Check the braces for proper fit and sand the ends as necessary to achieve a snug fit without spreading the mouth. Remove the braces, add glue, and reposition and screw them into place.

ADDING SPACERS

Space equally, glue, and toe-nail the spacers to the inner shell, with four spacers each on the top and bottom panels, and six each on the side and back panels.

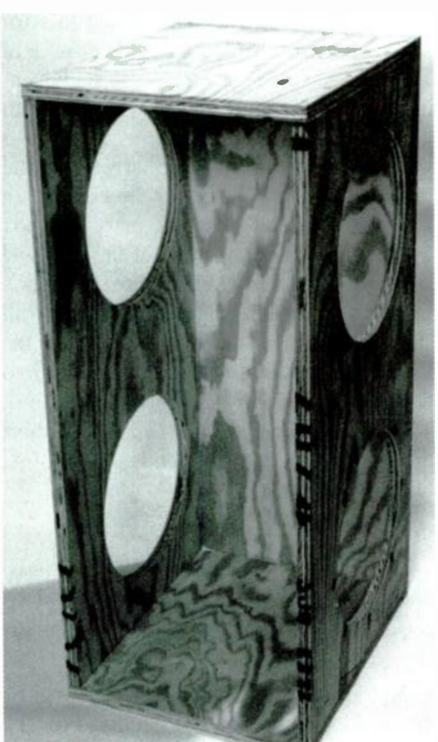

PHOTO 3: Assembled plywood inner box.

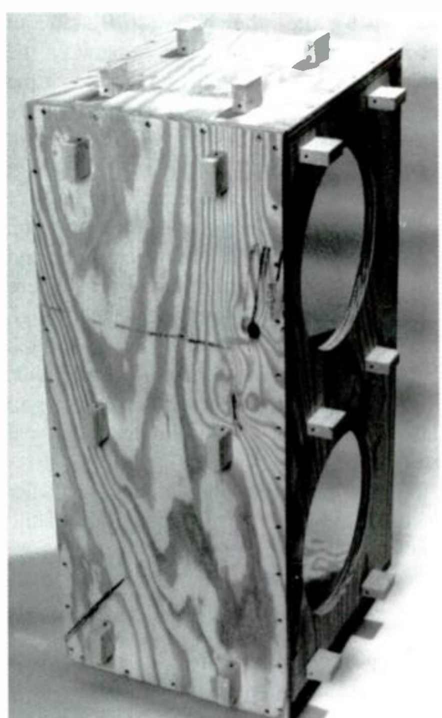

PHOTO 4: Spacers in position on the outside of the plywood inner box.

PHOTO 5: Support wiring on the outside of the plywood inner box.

Reader Service #52 →

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* IN-WALL SPEAKER * TWEETERS

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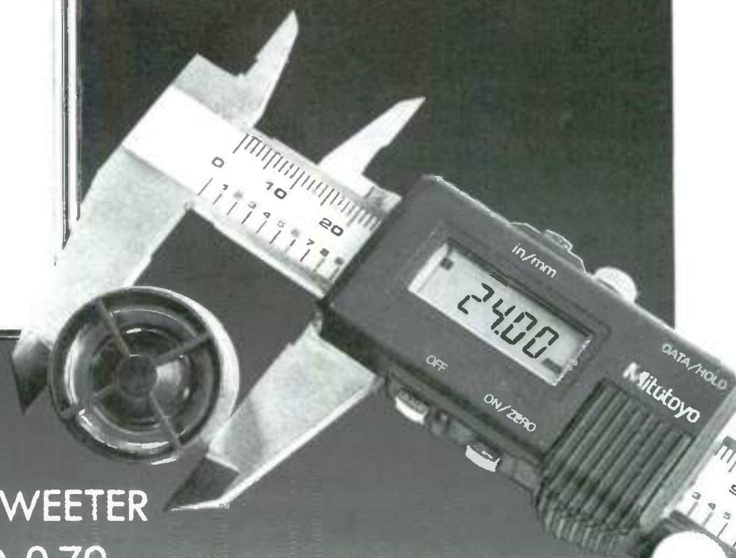
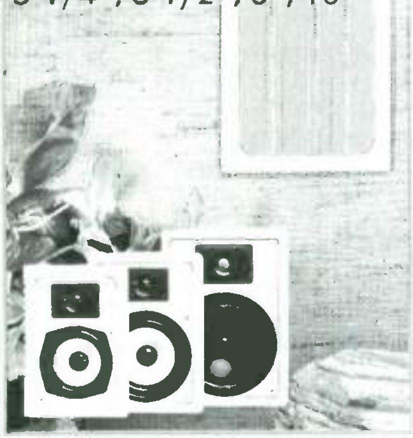
Super-Tweeter



In-Wall/Ceiling Speaker
5-1/4", 6-1/2", 8", 10"



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The alignment of the spacers must allow the concrete to flow as smoothly as possible. To that end, place them so their longer dimensions run from front to back on the top, bottom, and side panels, and from top to bottom on the back panel (*Photo 4*). This facilitates pouring the cement with the housing on its back.

After another 24 hours to let the spacers harden in place, you add the reinforcing screws and wire. Drive #10 × 1″ all-purpose screws into the top, bottom, back, and side panels so that approximately ½″ remains above the plywood surface to anchor the wire and provide more surface for the cement to wrap around (*Photo 5*). For ease of wiring, use nine screws each for the top and bottom plates, 14 each for the side plates, and 21 for the back plate.

When installing the wire, make sure it stands up from the plywood inner housing so that the cement can flow all around it.

PHOTO 7: Detail view of cardboard through tube.

INSERTING THE TUBE SLICES

The cardboard tube slices are the pathways between the inner and outer shell. Using a ring size of 1¾″ provides a slight extension of the ring above the luan to allow for gluing. Mark off the appropriate sections and cut them with a jig saw.

Place the housing with one side down. On the side facing up, align the Sonotube sections over the holes, position a luan side piece and place a section of the wire-conduit guide on the side where it will be used. Make sure all pieces fit properly, using a straightedge to align the side pieces with the edges of the spacers on the top, bottom, and back plates, and adjust as necessary.

Remove the luan side panels, cardboard tubes, and wire conduit. Make supports for the speaker terminals out of pieces of 1″ × 2″ cut to size. Glue and nail the supports to the outside of the luan side piece where the wires will come through. Add glue to the tops of the spacers on one side, replace the luan side panel, check the alignment, and then nail the luan to the spacers.

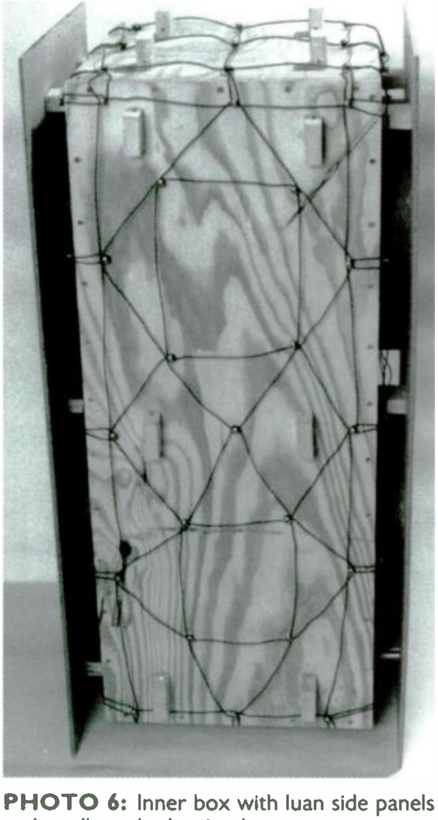

PHOTO 6: Inner box with luan side panels and cardboard tubes in place.

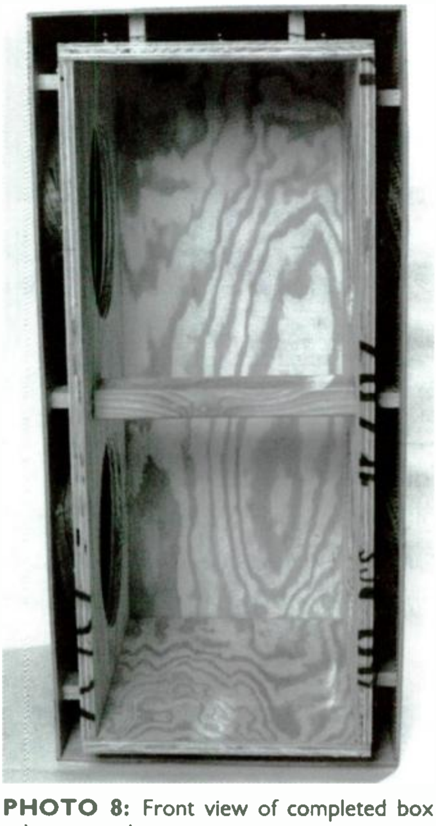

PHOTO 8: Front view of completed box prior to pouring cement.

Insert and glue the wire conduit into place. Then run a bead of glue on the plywood around the holes where the Sonotube will make contact. Insert the tube through the hole down into the glue, but before the tube reaches the plywood, run a bead of glue around the tube at the luan level. Seat the tube and make sure there is glue all around the top and bottom edges so no cement will leak through. When cleaning up any excess, leave a small fillet of glue at the joints. Repeat for the second tube. Allow to dry for 24 hours before doing the other side. *Photo 6* shows the side luan pieces attached, with a detailed view of the Sonotube placement in *Photo 7*.

Now, glue and nail the top, bottom, and back luan pieces (*Photo 8*). Allow the completed assembly to dry for 48 hours before pouring the cement. In the meantime, make a funnel out of scrap luan to help in pouring the cement (*Photo 9*). It should fit between the inner and outer walls and stay in place by itself when you're pouring. Also cut a 3″ × 36″ strip of luan to use for tamping the cement through the funnel mouth.

POURING THE CEMENT

Lay one of the housings on its back with the bottom facing toward the mixing pan. Position the funnel and shovel the cement into it. Use the tamping board frequently to get the cement into the spaces and to eliminate trapped air bubbles. Move the funnel as needed.

Once the cement has reached the upper lip of the luan all around the housing, use a small scrap piece of luan as a float to smooth the surface. Repeat the process for the second housing. I let the cement set for one week before moving the housings, which will probably weigh as much as 200 lbs.

INSTALLING THE HOUSINGS

Since the housings will be inside a closet, out of sight, finishing consists of priming all sides with a good primer and then painting with a flat black latex paint. If you have not yet opened the wall on the listening-space side, do it now. With the help of some strong friends, move the housings into position. There should remain a space of about ¼″ between the cut-out drywall and the front edge of the luan.

On each side of the housing mouth, drill two pilot holes for the ¼″ lag bolts that will go through the housing and into the wall studs. The holes should be approximately aligned with the center line of the drivers. Install the bolts with flat washers.

Cut a filler of scrap wood for the space

under the mouth and above the floor and force it into place to seal that opening. If a filler is necessary on the top side, install it also. Use silicone seal all around the joints between the mouth and studs or fillers. Repeat for the second housing.

INSTALLING THE DRIVERS

Each driver has two 8Ω voice coils that you connect in series to produce an effective 16Ω. Then you connect the four drivers in parallel for a resultant 4Ω impedance.

For each driver, you identify and connect together a positive terminal on one voice coil and a negative terminal on the other. Be careful if you're soldering the wires, since over-heating terminals is one of the primary causes of driver failure. As the impedance is 16Ω, #18 wire is more than sufficient. Repeat for all eight drivers.

For each housing, you should wire the two drivers facing into the housing in a normal polarity; that is, the red wire should go to the open positive terminal of one voice coil, and the black wire to the open negative terminal of the second voice coil of the same driver. The resulting wiring pattern for any inward-facing driver should be: red wire to the positive terminal of voice coil #1; negative terminal of voice coil #1 connected with a jumper to the positive terminal of voice coil #2; black wire to the negative terminal of voice coil #2.

You should wire two drivers facing out of the housing in a polarity opposite to those facing in; that is, in the description above, reverse the red and black wire connections. Therefore, a black wire is connected to the positive terminal, and a red wire to the negative. By doing this, both sets of driver cones will move either into or out of the enclosure at the same time.

Following the wiring convention described above, connect to two of the driver terminals appropriately color-coded #18 wires of a length sufficient to reach the terminals on the outside of the housing. First mount the two drivers that will face into the enclosure, using #10 × ¾″ all-purpose screws. Tighten these in a staggered pattern to avoid warping the frame. Next mount the two drivers facing out of the enclosure, using #10 × 1″ screws because of the extra thickness of the front mounting gasket.

Connect a pair of color-coded #18 wires to each driver facing out of the housing and route the wires inside the enclosure to the wire conduit using cable ties and mounting pads (*Photo 10*). Pass the wires through the speaker-housing conduit and connect the pairs of color-coded wires from all four drivers in a parallel configuration to the speaker terminals. Fasten the terminal assembly to the terminal support blocks. Fill the wire conduit with silicone seal to complete the wiring.

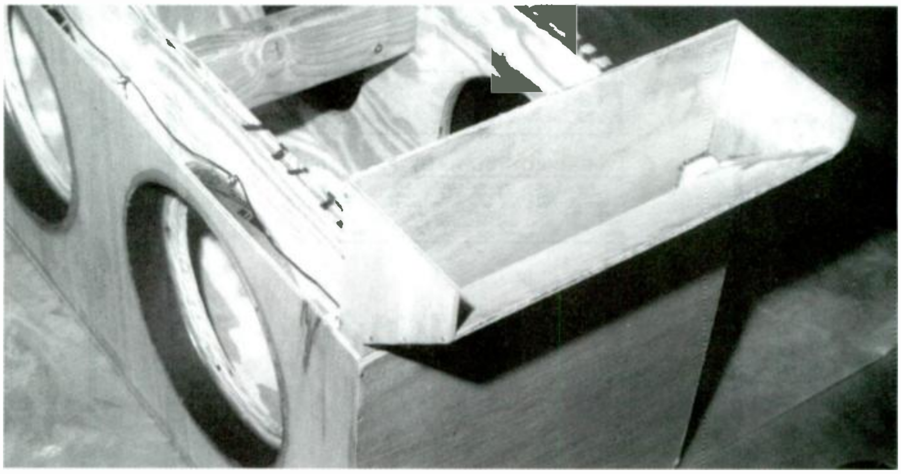

PHOTO 9: Funnel in place in preparation for pouring cement.

To connect the enclosures to the power amplifier, use #12 zip cord. To keep these leads out of the way, fasten them with plastic Romex clamps to the molding that runs along the floor, and then feed them through a hole in the wall. For appearance's sake, I ran the wires through a wall box that was originally installed for a TV coax lead, and then made a cover plate out of wood to dress everything up.

GRILLES

You can produce grilles to cover the housing mouths by making frames out of 1″ × 2″ furring strips and covering them with the same material as the main speakers. The frames are rectangular, with outside dimensions of 18″ × 35½″. A horizontal cross piece in the middle gives additional rigidity.

Use ¼″ hanger bolts to fasten the grilles to the wall. These are bolts with a wood screw on one end and a machine thread on the other. With the grilles held in place against the opening, drill small pilot holes through the frame into the wall to ensure proper alignment. Center one bolt on the top of the frame and place two more along each side strip, for a total of five per frame.

Now drill larger pilot holes in the wall studs and install the hanger bolts so that ½″ of the machine thread protrudes from the wall. Enlarge the pilot holes in the frames to 15/32″ from the inside, without going all the way through to the outside. Then prime the frames, and paint them flat black. Place small pieces of gum rubber tubing (½″ OD, ¼″ ID) in the frame holes. The slight compression of the tubing as it is pressed into the 15/32″ holes provides the necessary reduction of inside dimension to grab onto the machine threads of the hanger bolts.

To mount the frames, align the hanger bolts with the tubing pieces and push until the frames reach the wall. A side benefit of the rubber tubing is that it will rebound a little, moving the frames slightly off the wall, which prevents rattling.

INTEGRATION INTO THE SYSTEM

Each driver in the system has its own amplifier, with the frequency division done by a custom four-way electronic crossover. I originally designed crossover points for the system at 60Hz, 400Hz, and 2.5kHz. The slopes are all 12dB/octave. The range from

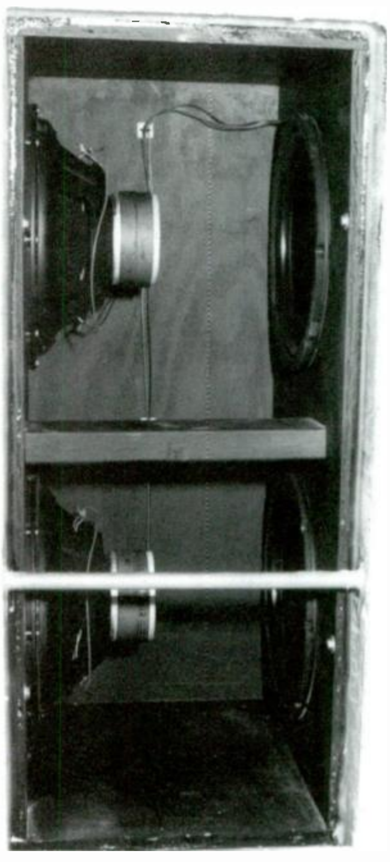

PHOTO 10: View from listening area of installed housing, showing driver mounting and wiring. (The line running in front of the two lower woofers is an existing electrical conduit covered with silicone seal.)

60–400Hz is covered by a 10″ Peerless CC line woofer, mounted in a sealed 2ft^3 box. A 7″ Kevlar cone Eton midrange, mounted on an open baffle, covers from 400Hz to 2.5kHz. Above 2.5kHz is covered by a Heil Air Motion Transformer mounted directly above and through the same baffle board as the midrange.

The main speakers are located 9′ from the prime listening position, and are toed in toward that position. The right-hand subwoofer is 15′ from the prime listening position, and the left sub is 16′ away.

TESTING

Testing presented some unusual problems. Never having had so much really clean low-frequency energy available, I was not prepared for the effect it had on the house. A word of caution: levels in excess of 120dB at 16Hz with low distortion can shake a lot of things off shelves and walls before you know what is happening. *Don't* connect a sine-wave generator and do sweeps. Things will fall and break, and your significant other will become very unhappy.

Many thanks to Tom Nousaine, who spent a lot of time helping me with the measurements. Although I have an HP distortion analyzer, the thought of nulling each test frequency at high levels was not attractive. Tom dragged over his MLSSA to run most of the tests.

We measured at the prime listening position, with distances as noted above. The first sequence was to measure the frequency response of the whole system by ear so that it "sounded good." *Figure 1* shows that above 63Hz, the in-room response was approximately ±4dB out to 18kHz. Below 63Hz, there was a rise of another 5dB, with a maximum at 32Hz. Using an Orban parametric equalizer, we determined that a cut around 60Hz with a slope of 12dB/octave cleaned up the in-room response very nicely. *Figure 2* shows the sub-only response before (solid line) and after (dotted) equalization.

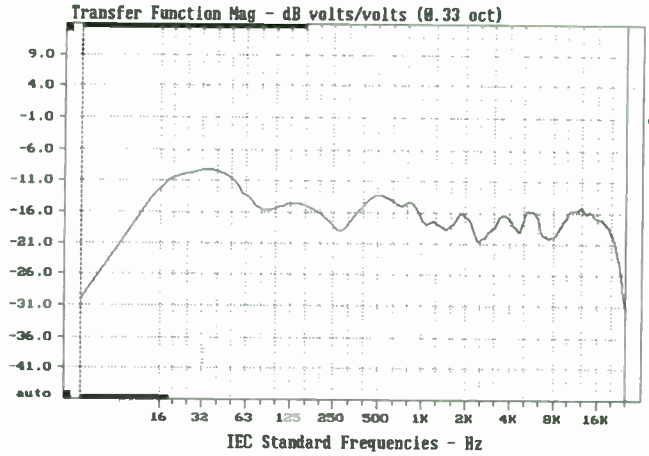

FIGURE 1: System spatially averaged response at middle position.

Since the active crossover has a 12dB/octave slope, we decided to try dropping the crossover frequency of the sub to 45Hz. This required simply changing a few resistor values in the crossover. *Figure 3* shows the result of this drop in crossover point on the blend of the sub and woofer at the listening position. The response was now ±2.5dB from 12.2–200Hz.

TEST-TONE BURSTS

As exciting as this result was—exceeding the first goal of flat response to at least 20Hz—we still needed to determine the

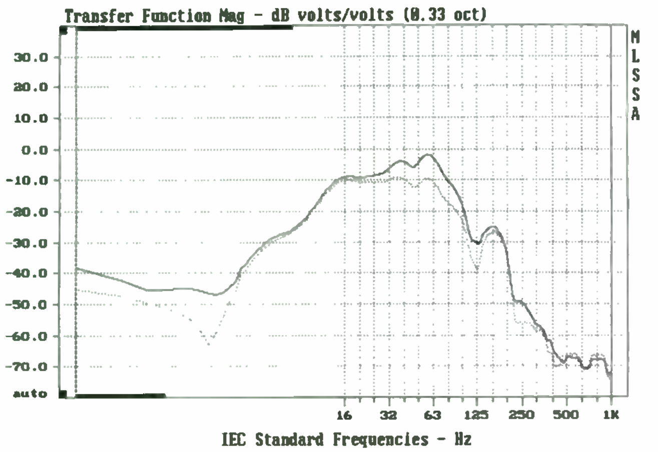

FIGURE 2: Subwoofer at mid-listening position with and without equalization.

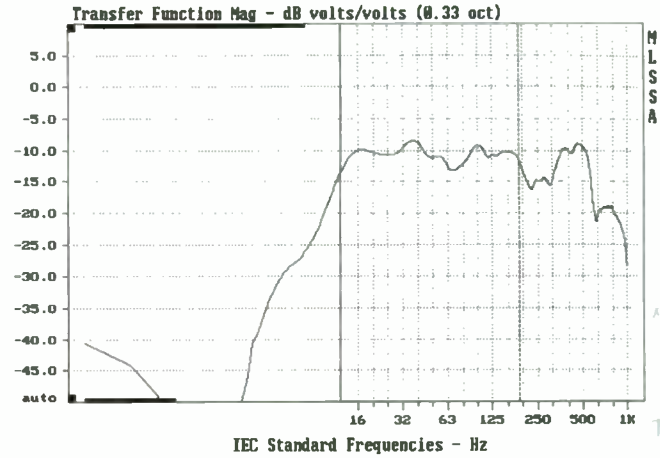

FIGURE 3: Response after sub crossover adjustment.

acoustic power levels that could be generated before 10% distortion set in. To do this, we used a special CD with test-tone bursts—for only a few seconds—and tested with only one sub. The results of measurement (using a Bruel and Kjaer model 2209 sound level meter as a microphone and mike preamp to feed the MLSSA) are in *Table 2.*

It is interesting to note that the SPLs at 12.5 and 16Hz were set by ear to a level lower than those at 25 or 31.5, even though the ear is less sensitive at those frequencies. The reason for this was that at those frequencies, the loft was doing a lot of shaking. Also, at 31.5Hz, even though we used tone bursts, a stack of paper cups fell off a shelf in the main bathroom upstairs.

A brief test at 31.5Hz using just one, and then both subs, showed a 5dB increase when the second sub was added. Therefore, you should add 5dB to the levels shown above to indicate the actual SPLs at the listening position with both subs working. You can see that the second goal of 110dB at the prime listening position with less than 10% distortion was also exceeded.

LISTENING

The best way to describe the bass is that it is extremely dynamic and effortless. It is common for some magazine editors to describe the bass from mini-monitors or small free-standing units as "kick-butt." Trust me, you don't understand the meaning of that phrase until you hear eight DV12s working in the low registers. The low Q, combined with low distortion and flat frequency response, makes the bass extremely tight and well defined.

Bass drums seem to roll the sound across the floor. Low organ notes simply move the air all around you. And when the frequencies start to increase, heaven be thanked, the sound does not become boomy. Pianos are powerful and rich without sounding muddy. The string bass takes on new life. All in all, a success.

It is interesting to note that you don't need to spend mega bucks on an amplifier to drive the subs. Power for both subs comes from one old Phase Linear 400 amp that I've had for years. I reinforced the power supply by adding extra filter capacitors, but the amp is otherwise stock. That is another advantage of separate amps for each driver. The amps all have an easy job because the full frequency spectrum is not handled by one device, and there are no complex high-level passive crossovers to drive.

TABLE 2

MEASUREMENT RESULTS

F IN HZ	PEAK SPL	AVG. SPL	DIST. %
10	90	86	14
12.5	111	107	9.6
16	116	112	2.5
25	118	114	6.5
31.5	118	114	6.3

REFLECTING ON ECHOES AND THE CEPSTRUM

By Bill Waslo

With great interest, I read Newell and Holland's "Round the Horn" (*SB* 8/94, p. 24). This single article included a discussion of horns, an intriguing application of a relatively obscure digital signal processing technique called *cepstral analysis*, and a reported link between the audible sound signature of driver types with a form of data measured from them. And beyond all that, the authors held out a very tempting audiophile carrot: the possibility of a midrange driver that can sound like a Quad and can play at 125dB SPL!

Horns have always fascinated me. There is something very seductive in the complete effortlessness with which they can handle diverse levels, maintaining the same character from loud to soft. Horns also often provide an unusual sense of clarity. Since I was in the market for a mid/tweeter driver with relatively narrow dispersion for my "Focused Array" echo-resistant speaker concept (*SB* 4/95, p. 10), horns seemed like the natural choice.

Unfortunately, coupled with their ability to sound the same at greatly differing levels is the horns' reputation for not particularly good sound at these levels. If only horns wouldn't *honk* like that. And if only you could listen to a horn-based system without being constantly made aware of the distinct existence of each horn driver. Horns are seldom admired for blending well. Could a new measurement tool help design horns which don't have these unpleasant characteristics?

The discussion of cepstral analysis, although brief, sent me back to the computer. I had read about the cepstrum (an anagram of the word "spectrum") and its use in speech synthesis and analysis in various DSP texts. Dr. Holland's use of the power cepstrum for investigating drivers was a new wrinkle. As a developer of loudspeaker measurement and analysis software (IMP, IMP/M, and Liberty Audiosuite), I have the means available to combine existing and newly developed procedures for relatively easy implementation of various analysis techniques as they become of interest. As a result, Liberty Audiosuite is capable of performing cepstral analysis.

A reported connection between similarity in cepstrum plots and similarity in sound character is interesting for the great promise of developing better drivers. But it also raises intriguing questions about why the ear might be sensitive to the kinds of sound characteristics that register on a power cepstrum plot. At the end of this article I offer a few conjectures, some analogues, and an hypothesis or two on this subject.

DISCLAIMER

Since cepstral analysis is a new subject to most readers, there will inevitably be many questions and some difficulty understanding the concepts. But please do not assume that I am an expert on this subject, horns, or the theory of hearing. Rather, like you, I am a student of these topics, not a final authority. So consider this article as my notes. Consult the cited references for more concrete information.

QUEFRENCY DOMAIN

No, that is not a typo. The terminology surrounding the computation of the cepstrum came from an article by Bogert et al., in which the authors rearranged various terms from signal processing (spectrum, frequency, phase, analysis) into anagrams (cepstrum, quefrency, saphe, alanysis).[1] The reason was to highlight the unusual treatment of frequency-domain data as if it were time-domain data in generating a new data set that had across its x-axis values (the quefrencies) in units of seconds, but which indicated variations in the frequency spectrum. Evidently, only the term cepstrum remains in common use, but I prefer to retain at least the term quefrency as a

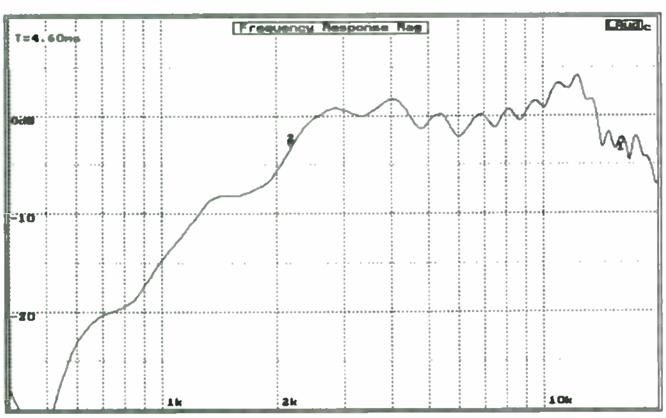

FIGURE 1: Response of axisymmetric horn with large reflector.

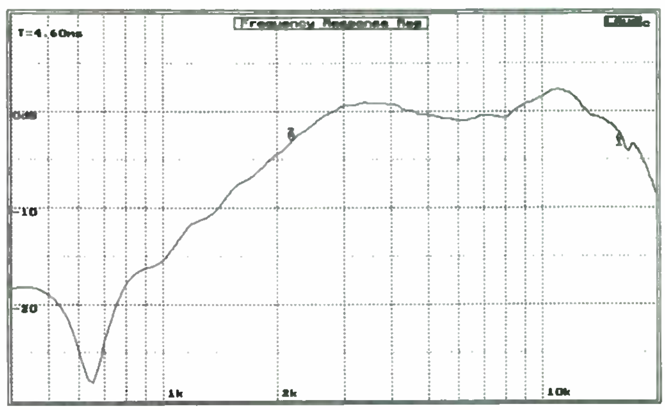

FIGURE 2: Response of same horn, without reflector.

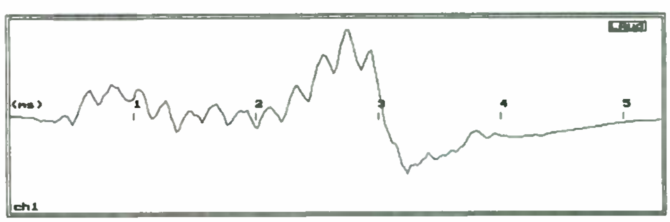

FIGURE 3: Sum of delayed sine-wave packets.

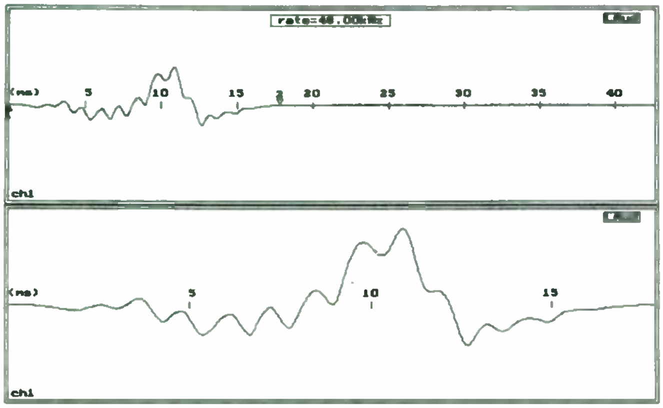

FIGURE 4: Windowed and weighted frequency-response shape.

reminder that the seconds shown on the plots don't represent time as you might normally consider it.

In simple terms, the power cepstrum is a measure of the periodic wiggliness of a frequency-response plot. IMP and Liberty Audiosuite users have no doubt noticed that the frequency-response curves of their speakers often have sine-wave-like ripples superimposed on the general shape. This will be particularly noticeable if the response measurement includes a distinct reflection from a wall, a grille, or a cabinet edge.

In the example shown in *Fig. 1*, I placed a large cardboard reflector 12″ from a horn tweeter prior to the measurement. An equivalent measurement without the reflector is shown in *Fig. 2*.

REFLECTION RESPONSE RIPPLES

By Fourier's theorem, you can mathematically represent signals as an infinite collection of sine waves of various frequencies, magnitudes, and phases. The idea of a frequency-response plot for a system is based on this concept, showing the output magnitudes and/or phases corresponding to the sine waves of each frequency, if all were applied at the input at equal levels and phase-aligned.

A speaker emitting a signal is equivalent to an emission of a collection of sine waves. When this signal bounces off an object, or is emitted a second time shortly thereafter by the speaker, two such sine-wave collections arrive at the measuring microphone together, but offset in time. At each sine-wave frequency, if the pair of emissions arrive exactly in phase, their amplitudes add. If they arrive exactly in reverse phase, the amplitudes subtract and will even cancel completely if the arriving amplitudes are equal. Phase differences between these extremes will cause less intense levels of reinforcement or cancellation.

The phase and amplitude of the sine wave resulting from the combination of two arriving sine waves of identical frequency depends on two factors: the delay between the arrivals and the frequency. In *Fig. 3* one packet of three sine waves is shown offset in time relative to an identical packet of three sine waves. In the lower part the relative pressure values of the waves (vertical center of each wave being 0) at each frequency have been combined to form a resulting sine wave at the same frequency. The arithmetic is done for each frequency separately. For a given delayed-second arrival time, the resulting sine-wave amplitudes will vary periodically with frequency, giving rise to response ripples (*Fig. 1*).

The rate of the ripple variation appears to increase with frequency in *Fig. 1* because the graph is in log-frequency format. Were the plot to be displayed in linear-frequency format (i.e., equal number of hertz per horizontal inch), the ripples would appear at a more steady rate.

IMP and Liberty Audiosuite view these variations on a log-magnitude (dB) scale, which enhances the sinusoidal appearance of the ripples. In scalar magnitude format, the shape would tend to look more like periodic notches taken out of the curve.

If you remember that the FFT of a sinusoidal time-domain trace results in a peak at the sinusoid's frequency, you can then imagine that an FFT of the log-magnitude frequency-domain trace would result in peaks at the frequency-response ripple rates. And these rates (in units of "per hertz," i.e., seconds) are related to the delay times between the multiple arrivals of echoes. We get a display of the echo or reflection intensity versus the delayed arrival time.

This information can be used to find, via the reported delay times, which baffle features might be causing the most dominant reflections and contributing to response errors. Second, you can use it to evaluate, design, or modify drivers or horns by providing a window into the way waves are bounced around on the cones, diaphragms, or horn necks. Perhaps, most importantly, the process of cepstral analysis may have some similarities to the way hearing works and to the sorts of sound characteristics to which we are sensitive.

PROCESSING TRICKS

My first attempt at obtaining usable results by merely performing an "FFT of a log-FFT" failed. I was able to achieve a pile of noise at the position of a very strong echo delay, but nothing that could reveal any driver subtleties. Fortunately, reader John Hanley kindly supplied me with a copy of an earlier article by Dr. Holland, describing in more detail the mechanisms of his calcu-

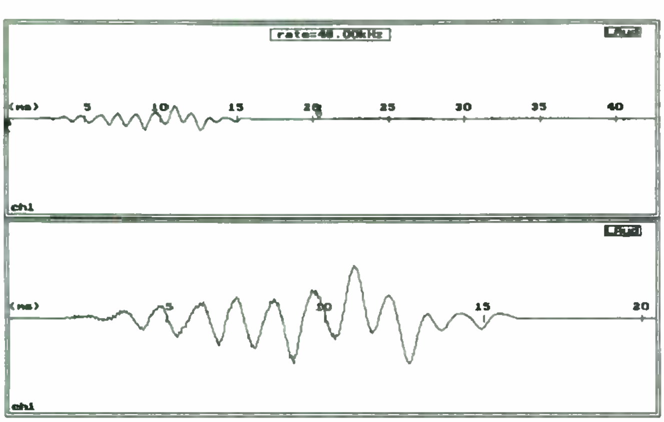

FIGURE 5: Windowed, weighted, and filtered frequency-response shape.

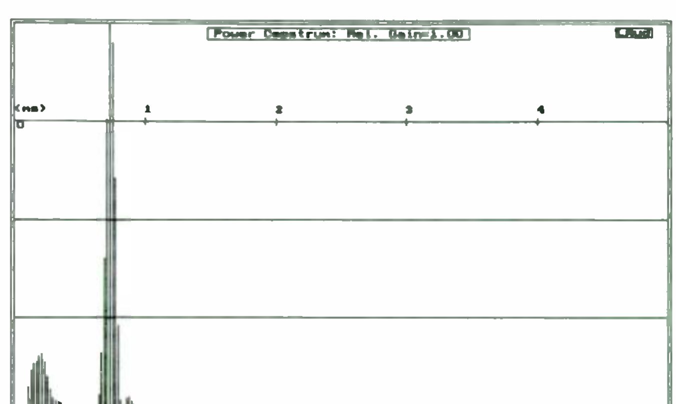

FIGURE 6: Power cepstrum of horn with reflector.

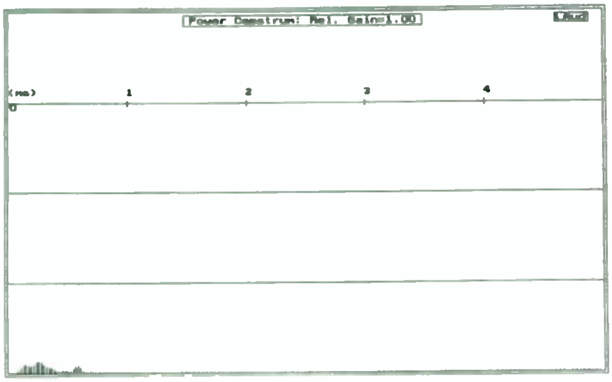

FIGURE 7: Power cepstrum, same scale, without reflector.

lation of the power cepstrum.[2]

One major problem in a mere FFT of the response shape is that the abrupt changes at the response extremes—coming from loudspeaker overall response shapes, A/D filtering, noise, and AC-coupling capacitor effects—are strong enough to overwhelm any resolution of more subtle details. This is similar to the spectral-leakage effect that can occur when a time-domain data curve is truncated in IMP; the fix is also similar: use a "window" on the data to taper the edges to a midpoint zero. Furthermore, at frequencies where a driver or speaker's response is weak, noise will cause significant peak-to-peak decibel variations, which can dominate the result.

Since you are probably less concerned with response ripples where the level is relatively low, you can deal with this by further weighting the response curve via an envelope that emphasizes the ripples in higher output regions of the spectrum. *Figure 4* shows the result of performing these two operations on the curve of *Fig. 1*. The general shape is centered, so the positive and negative halves are equal, i.e., the "DC offset component" of the spectrum is removed.

The shape of the general response curve is still strongly represented in the curve of *Fig. 4* (remember that this curve corresponds to a linear-frequency format presentation). This shape might or might not be a result of reflections of very short delay time, but in general it is useful to be able to minimize the contribution of this shape to the cepstrum curve so finer details are not swamped out.

The Liberty Audiosuite cepstrum facility offers an "hpFilter" (high-pass) option to emphasize the higher quefrency ripples and remove the more gradual shapes resulting from normal driver rolloffs. *Figure 5* displays the result of adding this preprocessing to the shape of *Fig. 4*. Because of the better resolution at mid and higher quefrencies, I left this hpFilter on during the generation of the remaining plots in this article.

An additional switch in Liberty Audiosuite allows you to select whether to include or ignore the "negative frequencies" of the source frequency-response data. Although negative frequencies may seem science-fictional (or the result of *really* good bass response), a Fourier transform normally provides data values for them. For real-world signals, these values are always of the same magnitude (but of inverted phase) as those of the corresponding positive frequencies, so they are normally ignored in audio analysis.

But in forming the power cepstrum, inclusion of negative-frequency data strongly affects the graph. I usually choose not to include them, as their effect seems to complicate efforts to relate the features of the plot to physical parameters, which is already a challenging task in most cases.

Figure 6 shows the end result of performing cepstrum analysis (using the hpFilter and neglecting negative frequencies) on the curve of *Fig. 1*. As stated earlier, I originally measured the response for this using a large reflector to introduce a strong intentional echo into a measurement of a short axisymmetric tweeter horn. Compare the cepstrum of *Fig. 6* to that in *Fig. 7*, which is the equivalent cepstrum for the no-reflector data of *Fig. 2*. The peak due to the reflection(s) is very prominent.

HORN EFFECTS

With the cepstral-analysis facility now functional within Liberty Audiosuite, it seemed appropriate to investigate horn behavior. The price of the AX2 horn and driver, described in the Newell and Holland article, was unfortunately too rich for my budget. Besides, like many speaker builders, I prefer the DIY approach.

The horn I used is a 6-inch-diameter, axisymmetric, homemade fiberglass affair, fabricated on a mold lathed from maple hardwood and generously waxed. I cut and drilled a round piece of fiberglass printed circuit board (with the copper removed) to mount a 1″ Audax titanium dome tweeter. I added a 1.1″ hole to clear the dome and serve as the horn throat, which I sanded and placed onto the horn mold. Then I applied resin-soaked fiberglass cloth in 3″ × 0.5″ strips, covering the entire bell with a thick layer and bonding the driver mount board to the horn.

When this hardened, I pried it from the mold, sanded it, and painted it with a black polyurethane paint. While more than an afternoon project, the operation was not as difficult as you might imagine. The resulting tweeter has proven very satisfactory in listening tests, and I used it to provide the higher frequencies in my prototype 9dB enhancement Focused Arrays speaker system.

When operated as a direct radiator, the tweeter had a somewhat rising on-axis

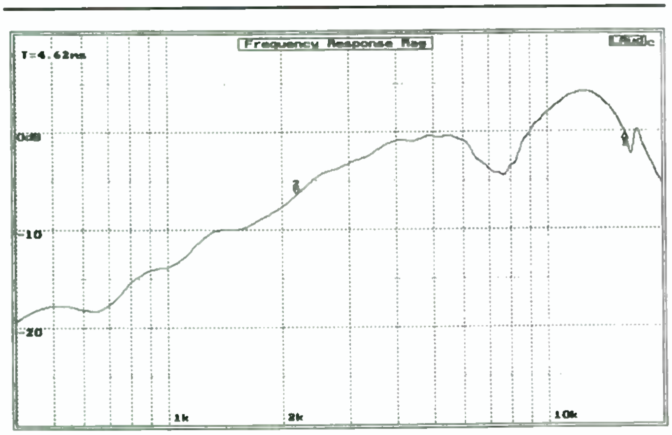

FIGURE 8: Dome tweeter on baffle without horn.

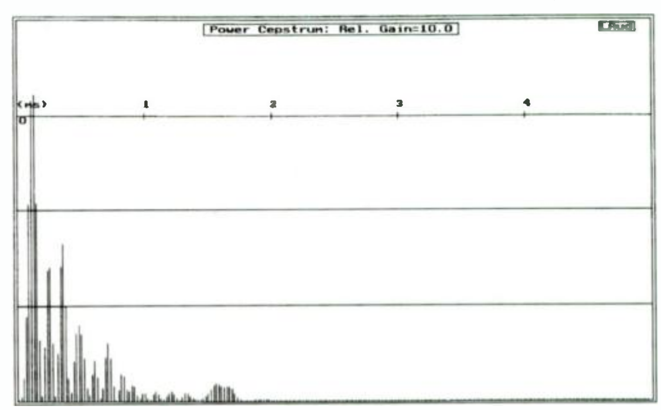

FIGURE 9: Power cepstrum of dome tweeter at increased display gain.

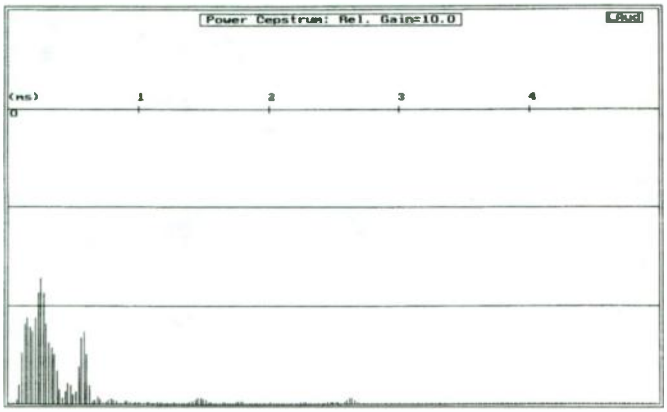

FIGURE 10: Power cepstrum of horn, scaled for comparison with Fig. 9.

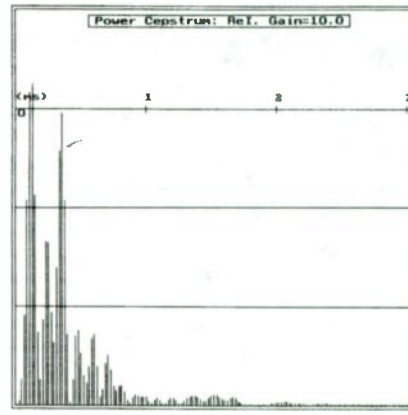

FIGURE 11: Power cepstrum of dome, with 1-inch-high reflector 4″ from center.

response, but in the horn, it had a falling response. For the measurements provided here, the horn-loaded implementation is flattened by a simple resistor-capacitor network. For all cepstrums, I first gain-adjusted the responses so the main flat-response regions of the spectrums were near the 0dB line (the Liberty Audiosuite cepstrum analysis applies the decibel display gain before calculating).

DIRECT-RADIATOR REFLECTIONS

With the tweeter centered in the same location of an identical cardboard baffle board as for the horn measurements, I measured the direct radiating response at the same distance from the baffle (*Fig. 8*). *Figure 9* shows the cepstrum of the direct-radiator measurement. Note that the scale of this plot is altered to utilize a display gain of 10, to better show the cepstral features. *Figure 10* displays the power cepstrum at the same scale for this driver with the horn attached.

The direct radiator's cepstrum shows more and stronger apparent reflections and at greater delays or higher quefrencies. Remember that the horn used is a short axisymmetric unit, not the more usual rectangular type that might generate, rather than suppress, reflection-induced ripples. Because of the tweeter dome's small size, which couldn't easily support long delay times, I hypothesized that some of these reflections might be coming from the baffle edges. Holland suggests that some of the cepstral features may be due to resonances and mechanical mismatches in a driver's construction, yielding results similar to those caused by reflections.

The actual reflections are probably stronger for the direct radiator than for the horn because the horn's directivity prevents significant energy from ever reaching the baffle edges. If such reflections are indeed audible and harmful to fidelity, a good case could be made *against* achieving wide dispersion. If reflections are to be avoided, it would seem wiser to direct energy toward a fixed listening position and avoid spraying the edges of the cabinet or the listening room with sound energy.

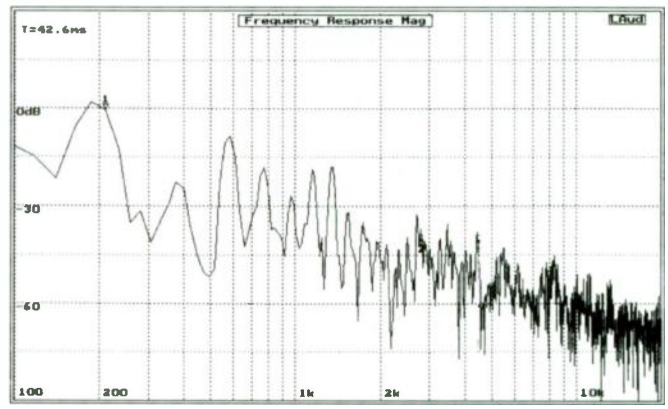

FIGURE 12: Voiced "aahh" at 400Hz pitch.

To test the dispersion theory for my tweeters, I taped a rectangular 9V battery on the face of each baffle 4″ from the tweeter center, to serve as a small reflector. For the horn-loaded version, the reflection was not visible in the cepstrum plot, which was essentially identical to the measurement without the reflector. For the direct-radiator version (*Fig. 11*), the reflection off the battery's case is clearly visible (in comparison to *Fig. 9*) as a larger spike in the cepstrum.

CAN YOU HEAR A CEPSTRUM?

If, as reported by Newell and Holland, the cepstral data is a significant indicator of the perceived character of a speaker, what could be the biological reason or explanation for this? It would certainly add to the plausibility of the idea if there existed a survival-related benefit to cepstral sensitivity and a physical means by which cepstral information might be perceptible.

The key may be in the nature of the human voice. Our ears are well-adapted toward discerning the sonic character of voices. While the consonants of speech are usually transient and of single-burst character, vowel sounds (and tones sung by a singer) are formed by repetitive emission of pulses into the vocal tract.[3] The emitted pulses will be wideband in nature, and the vocal tract will impart a frequency shaping to the overall output. But notice that this is again a short-term multiple emission of spectra (sinewave-packets) similar to what

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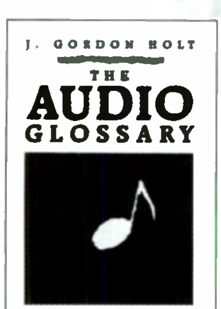

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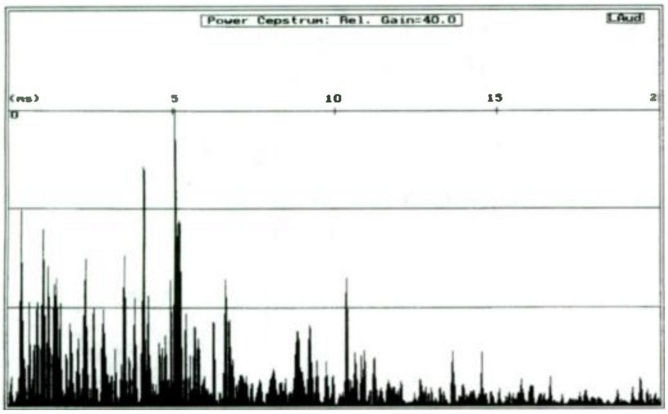

FIGURE 13: Cepstrum of voiced "aahh."

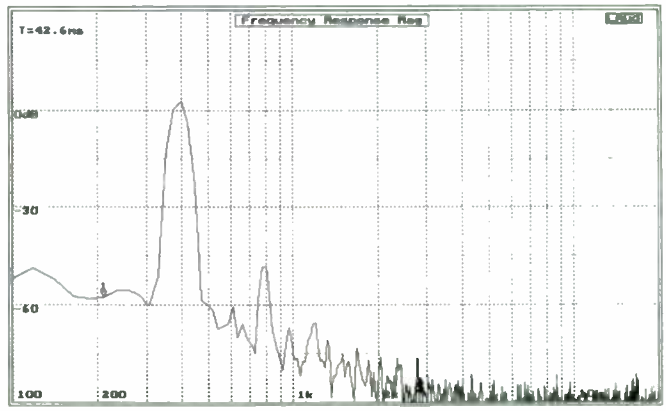

FIGURE 14: 400Hz sine wave from benchtop signal generator.

may result from multiple reflections of broadband signals.

The vowel sound or sung tone will contain much harmonic content. It requires no stretch of the imagination to perceive the periodic nature of a spectrum display containing coarse harmonic tones (*Fig. 12* shows my voice at a pitch of about 400Hz), resulting in the power cepstrum of *Fig. 13*. Note that there is relatively little signal actually at 400Hz, although this was the intended and apparent pitch (perhaps a result of nearly nonexistent singing ability). On the other hand, a single 400Hz windowed sine wave (*Figs. 14* and *15*) has little significant cepstral response (which, interestingly, occurs at twice the sine wave's period).

Sometimes an harmonically rich tone can actually be missing the fundamental, but still be distinctly "heard" by the ear.[4] The fundamental is not only the lowest tone present in an harmonic series, but it is also the frequency spacing between the many harmonic multiples, which would appear as a cepstral peak whether the fundamental were truly present or not. Note also that cepstral analysis is essentially immune to phase response, as many tests indicate the ear may be.

ECHO DETECTION

People are known to be sensitive to echo content in an acoustical environment. A listener may not be able to make a blindfolded identification of brands of speakers in a room into which he has been led, but he would very likely be able to, while blindfolded, estimate fairly well the size and wall placement of the room itself (perhaps the basis of an interesting experiment if anyone is in need of a research project).

There are some plausible biological and survival-related reasons for such hearing abilities. In darkness, it could be useful to know how far you, a prey, or an enemy may be from a boundary or escape route. The quantity and distribution of delayed reflections could give clues to how far away an unseen sound source may be behind you. The audibility of reflections

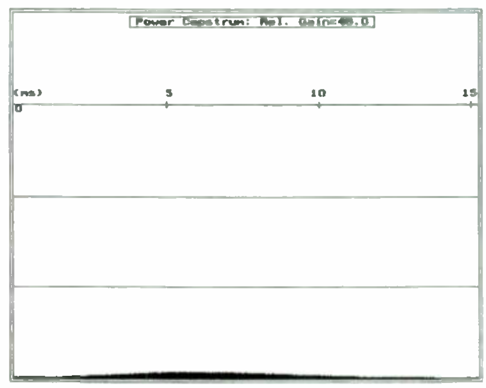

FIGURE 15: Cepstrum of 400Hz sine wave.

is easy to demonstrate even without test equipment. Read this sentence out loud in the middle of a room and then repeat it within 2′ of a wall or table surface; a sound difference is unmistakable.

The idea that biological apparatus could be able to extract spatial information from detected echoes is not far-fetched. Bats have such well-developed echolocation that they use it in preference to vision. Perhaps a scaled-down version of this ability in people is the source of some of the unconvincing sound fields often reported to be coming from hi-fi systems. With all the reproduced signal coming from one of two sound points, a 20-piece orchestra could give a loudspeaker-induced echo pattern indicating that all of its 20 pieces are at the same spacings from the cabinet edges or from your walls!

Another proposed experiment (for those better equipped with hardware): Configure a general-purpose digital signal processor as a filter to introduce response variations to recorded music, to be auditioned via headphones. If the ear is indeed sensitive to cepstral content, then the presence of the filter, for the same slight peak-to-peak decibel variation, should be more audible when the variations are periodic (in frequency) than when they are random as a function of frequency.

ULTIMATE REVERSE ENGINEERING

Given good reasons why—and some evidence that—our hearing is sensitive to cepstral content, how might such processing be accomplished? Probably there is no internal A/D converter or two-tiered FFT process running in our brains to form the time-domain waveform, the frequency response, and then the cepstral response. How then might "periodic wiggles in the spectrum" be detected?

In a fascinating and highly recommended article[4], Robert H. McEachern describes a system of human hearing, based on banks of bandpass filters (the ear is known to use sensitive hairs placed along a resonant structure, providing multiple-tuned bandpass characteristics). By comparing the ratios of the log-magnitude of energy detected in two such adjacent bandpass structures, both frequency and level can be accurately determined.

By doing this between multiple filter pairs tuned to different sets of center frequencies, multiple detections of an input are accomplished. This scheme is particularly well-suited for detecting harmonically related tones and matching them via their similarly scaled frequency modulations to recognize them as coming from a single source. Thus, a voice can provide the ear with wideband-redundant information to provide immunity to interference: If one set of tones is masked by interference or by the cancellation effects, duplicate information content is obtainable via one of the other harmonics. This works even if the fundamental is missing entirely.

Furthermore, by this matching, multiple sounds can be sorted and differentiated (as in the "cocktail party effect") by recognizing the harmonic sets. McEachern hypothesizes that the ear may use this sensing and evaluation scheme using vowel tones (relatively narrowband) to sort out "channels" (frequency ranges) to be emphasized or desensitized in reception and interpretation of the wider band consonants, which carry the bulk of speech information.

This ability to detect and sort harmonically related tones seems very similar to the requirement for detecting ripples in a broad spectrum modified by echoes. In both cases, periodic log-magnitude changes in spectrum as a function of frequency, similar to cepstral data, are key. The separated frequency peaks caused by reflection of a broadband signal would not carry the common frequency modulation, which would allow the ear to group the peaks together. But a hearing mechanism that identifies nongrouped periodic spectrum peaks for purposes of detecting interference might also further use such an ability for extracting information about the space around a sound source.

I don't doubt that, at some level, echo patterns present the ear with clues about the three-dimensional environment in which a sound field exists. Whether this characteristic is best identified and analyzed in terms of a power cepstrum or by some other technique has yet to be determined. But reproducing the echo patterns of an original recording environment, and not that of the listening room (or those generated by loudspeaker cabinets or mimicked by driver colorations), is an area of speaker design likely to keep many of us busy for a while.

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THE CONVERTIBLE MONITOR

By Mark Zachmann

PHOTO 1: Author's completed speaker system.

I recently found myself with some time on my hands and decided to build some speakers, which I had not done since the late '70s. I began by reading *Audio* and *Stereo Review*, looking for advertisements for speaker drivers. I also immersed myself in *Speaker Builder*, buying the last four years of the magazine, bought a copy of *The Loudspeaker Design Cookbook*, and got a few catalogs from companies such as A&S and Madisound. (Madisound, by the way, gets major kudos for including manufacturer's spec sheets in all of their driver inventory.)

I read through *SB* hoping for some comparative evaluations of drivers and wanting to see if anything leapt out at me as great—thus obviating the need to design crossovers and pick drivers. Unfortunately, the answer was no on both counts. Hence, this article. I also thought that readers might appreciate a more detailed discussion of start-to-finish construction from a novice—I certainly would have.

I call my speakers monitors because they are really too large to be minimonitors, and they have full extension from a video standpoint. They're convertible because they actually can operate both as bass-reflex and as acoustic suspension. I configure the rear pair in a video system as bass-reflex, which has a full-range response for video. I run the front speakers as acoustic suspension, with a subwoofer for full-bass response. This provides nearly perfect timbre matching, while also giving a more taut and much more extended bass for the front speakers.

INTENT

I must admit that nowadays I spend as much time watching movies as listening to the stereo, so I wanted a five-speaker system for surround sound. My constraints were:

- All five speakers had to fit in a smallish (12′ × 15′) viewing room.
- The speakers had to sound great, although I planned for a subwoofer, and so allowed limited bass.
- Wide dispersion was necessary to accommodate more than one person in the listening room.
- I wanted the speakers to be usable for front/rear and center channels, so that the timbre wouldn't change as the various speakers came into use during a movie.
- I preferred to use real wood in construction—not MDF or plywood.
- The speakers should be essentially flat 90Hz–16kHz (preferably down to 70Hz for movie soundtracks in the rear channels and center channel).

END RESULT

I ended up with four speakers (two mirror pairs) and one subwoofer (*Photo 1*). The center speaker is still to be done. They are all two-way designs, made from the Focal 6K412L bass-mid and the ScanSpeak D2905/9000 tweeter. I designed the enclosure to be usable both as a bass-reflex (for the rear and for subwooferless operation) and as an acoustic suspension (for the front, when used with a subwoofer). The subwoofer is an acoustic suspension using the NHT1259 12″ driver (allegedly the same as in the NHT3.3 speaker).

The two-ways are ±3dB from 60Hz to 20kHz, used as bass-reflex (with one or two minor artifacts) and similarly flat down to about 100Hz used as acoustic suspension, while the subwoofer is down 6dB at 27Hz. I measured with either an LMS test system or an IMP/M with handmade microphone. In either case, measurements were ±1dB.

To my ears, these units are dynamite. The

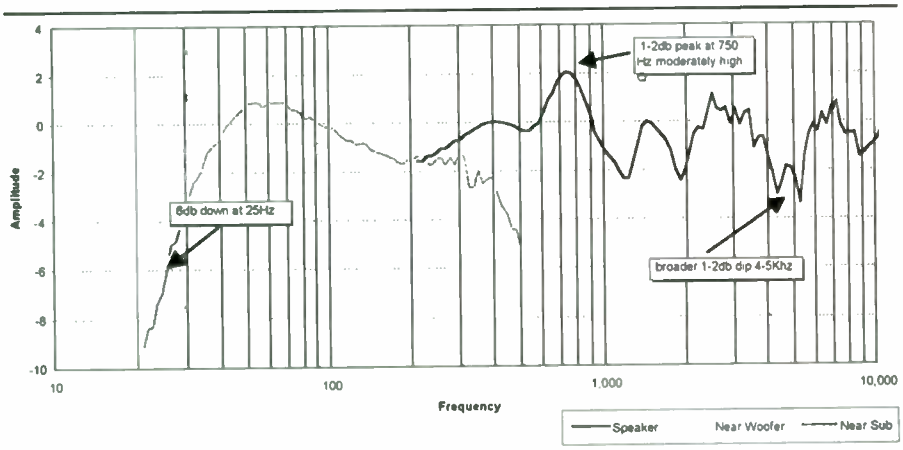


FIGURE 1: Anechoic frequency response of speaker and subwoofer suspension alignment.

two-ways suffer from shriek at very high volume levels, partly due to crossover choice (more on the trade-offs later), but otherwise the sound is wonderfully clear and timbrally accurate. When the speakers are configured as bass-reflex, the bass seems less well-defined, but the extension increases and the power and timbral accuracy remain (and, theoretically, distortion decreases).

Meanwhile, the subwoofer can noticeably shake my house with reasonable articulation! *Figure 1* shows the subwoofer response. Note that it does not include the crossover. Adding a 12dB/octave crossover at 75Hz completes the picture and produces a very flat response. Luckily the "subwoofer out" on my Adcom GTP-600 uses exactly that electronic crossover, so I did not build another.

If you decide to build these speakers, realize that they are expensive. The drivers for two speakers cost about $450 (including subwoofer), and the crossover adds probably another $150, assuming you use first-rate components. You can use substitute drivers to lower the cost substantially, but fidelity or power handling may suffer, and the crossover will need to change.

Throughout this article I'll discuss trade-offs and what perhaps could have been done differently, since speaker building is an art of compromises.

TEST EQUIPMENT

If you plan to build speakers from scratch, it is absolutely vital to get the best test equipment you can afford. Most manufacturers' specs are approximations, impedances in particular, and proper crossover design requires a good testbed. I ended up spending more for the test equipment than for the speakers.

I recommend that you consider getting an IMP/M from Old Colony Sound Lab (PO Box 243, Peterborough, NH 03458-0243, 603-924-6371, FAX 603-924-9467). I built a microphone using the capsule that came with it, and tested it against a calibrated LMS microphone. Error was on the order of ±1dB throughout the range (except above 15kHz, where it increased to ~3dB). I highly recommend the IMP/M, especially as a frequency-dependent impedance tester.

If you can't afford the IMP/M, I urge you to use good-quality drivers and measure their impedance versus frequency (in and out of enclosure) carefully. You can get by with a test CD, a good AC volt/ohmmeter, and some 10W resistors. It's fairly easy to read a free-air impedance chart for a known driver and infer that unit's variation from spec. The box-enclosed driver's impedance can tell you whether there are air leaks, whether the inside volume is within spec, and if the port (if bass-reflex) is functioning and tuned properly. You merely can't measure the frequency response for reliable results.

When building the crossover, pretest all coils and capacitors. My audiophile capacitors tended to have a consistent bias downward—within spec, but annoying. In one case, I actually received inductors that were 25% greater in value than specified (and labeled), and it cost me a day of tweaking crossovers and tearing my hair out before I realized what was happening.

TEST SOFTWARE

As the project progressed, I relied on the following software:

- LMP: this is a nice program for designing bass enclosures. It did a good job of picking port size for the speaker and estimating response based on a simple crossover. I downloaded the shareware version from the Madisound BBS.
- SPICE: I used this a lot in the tuning stages. I modeled the drivers (using standard techniques) and added crossovers to see the end result, visually adding the driver irregularities. I downloaded the shareware version from CompuServe.
- SpeakerCalc: this is a great little calculator for speaker work. I wrote a few

macros for it to find resonant frequency, impedance of a cap/inductor at a frequency, and Q of a resonant circuit. It let me see numerically what SPICE was showing me graphically. I downloaded my copy from the Madisound BBS.

Although I used the shareware versions of most of these products, I strongly recommend their commercial counterparts. SPICE's shareware version runs out of nodes, and the shareware version of LMP is not as flexible and easy to use as the commercial version.

SELECTING DRIVERS

Selecting drivers was without a doubt the most difficult and confidence-shaking aspect of the work. Since I had neither the time nor resources to test all of the drivers on the market, I was forced to explore drivers indirectly, by reading reviews and examining kits of speakers that use them. I ended up with drivers I'm happy with, but I don't feel I made the decision on the basis of full information.

After poring over kit specs for a while, it became clear that an 8″ driver would not have a wide enough dispersion near the crossover (assuming a 1″ or smaller tweeter). It would also require cabinet sizes verging on the unacceptable. On the other hand, a 5″ driver would not have enough bass to be really appropriate for a video system and would also have trouble driving enough volume.

Most movie sound encodings go down to 70Hz in the rear channel, and I didn't plan to put a subwoofer on the back. Thus, the system pretty much needed to be a 6.5″ or 7″ bass-mid with a tweeter. I considered the Focal and Eton 7″ drivers, but their response just didn't look flat enough.

After a few days of intense eyestrain try-

TABLE 1

SCANSPEAK D2905-9000 SPECIFICATIONS

Style	Cloth dome
R_E	4.9
F_S	800Hz
Sensitivity	90dB/W/m
Q_{TS}	0.5
L_E	0.38mH
X_{MAX}	±0.5mm (linear), ±1.5mm (max)
Moving mass	0.4gm
VC diameter	28mm
VC height	3.5mm
VC	Aluminum
Air gap height	2.5mm
Force factor	4.6Tm
Max power	150 continuous, w/12dB/oct @2.5kHz

TABLE 2

SCANSPEAK PUBLISHED vs ACTUAL SPECS

	PUBLISHED	#1	#2	#3	#4
R_E	4.9	5.69	5.71	5.53	5.86
F_S	800	839	906	956	915
Q_{TS}	0.5	0.45	0.55	0.51	0.56
Z_{MAX}	n/a	11.95	12.9	11.01	12.99

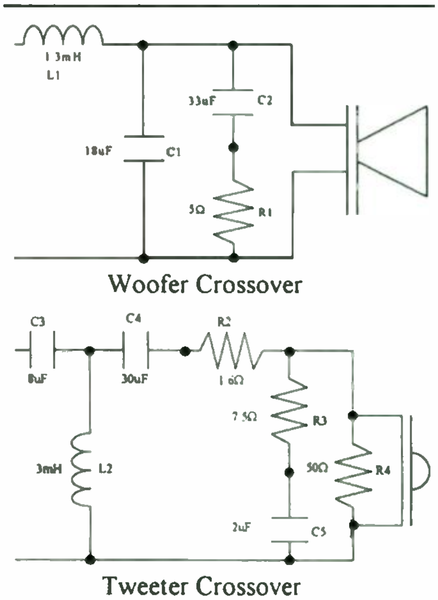


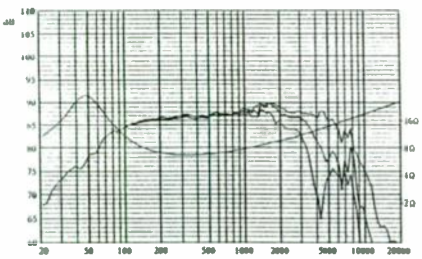
FIGURE 2: Crossover scheme.

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

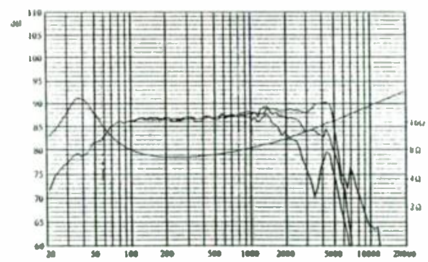


850122 6.5" CSX WOOFER $61.00

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

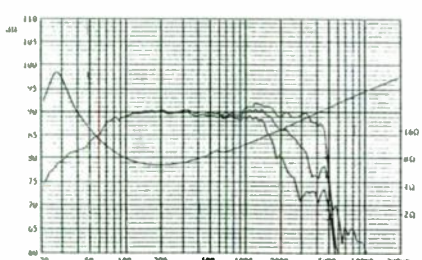


850136 8" CSX WOOFER $70.00

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

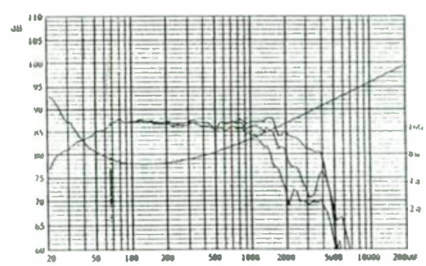


850146 10" CSX WOOFER $98.00

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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Reader Service #1

ing to read specs (and wondering how real they were), I finally settled on the Focal 6K412L 6.5″ midbass and the ScanSpeak D2905 tweeter. The midbass was in none of the speaker designs I examined (maybe because it was new), but I preferred a high-tech midbass using some nonpaper material for improved transient response.

I also prefer a soft-dome tweeter, and the D2905 was used in *SB* 5/93 in a nice two-way with an 8″ woofer, as well as in the Signature 717S (a D'Appolito MTM design). In fact, the driver sizes are relatively standard, so you can physically substitute other drivers with little difficulty. For example, I've been told the Focal 6V412 is a very nice driver.

THE TWEETER

The ScanSpeak D2905-9000 is a soft-dome tweeter using a fabric dome coated with a sticky substance. The published specs for the tweeter (*Table 1*) are very good. It seems to be able to take a lot of power without hiccuping. A number of times I have driven the speakers extremely loudly, and the woofer always complains first.

The D2905 does, unfortunately, suffer from a serious flaw: the soft dome is extremely sticky. I bought four of them at $54 each and then found the hard way that all sorts of things would stick to the dome (such as a piece of metal shaving from the screw hole). I love their sound, but they need some time to dry out and let dust stick to them. If you use them, avoid placing them near fireplaces, and don't put them under hanging plants. I strongly recommend a baffle. Someone ruined one of my tweeters by pressing a plastic bag lightly against the entire surface, and the dome's coating came away with the plastic when I peeled it off.

I really like soft domes, and these sound excellent. They also measure ±1.5dB from 2–17kHz (±2dB 1.2–20kHz)! I picked these drivers because I saw them in one or two good-looking designs and products, and because their published specs were outstanding. As for variance among samples, however, the news was not so good (*Table 2*). My four samples were all over the map in impedance and particularly in resonance (spec is 880Hz).

One of the tweeters (I believe it was sample 3) had a very pronounced impedance hump at about 2kHz. I retested a couple of times to make sure of this, since it usually indicates an error somewhere in the tweeter.

TWEETER TESTS

After testing the 2905s on a large baffle, I was satisfied that they would do the job (despite some misgivings about their stickiness). Their frequency response was virtually identical to the published (nearly ruler-flat) response, except that the knee of the response for each driver was at its resonance. Everything I've seen indicates that driver variance is expected and usual, so I would either need to build a crossover with tolerance for the variations, or custom-fit each crossover to the drivers.

By the way, if you wish to pretest your tweeter's frequency response, you must mount it recessed (flush) into a large panel. (I used an 8′ × 8′ with a hole cut out of the middle.) This acts like a half-wave device (infinite baffle), and you get essentially anechoic results.

I originally tested my drivers by clamping them to a tall tripod ("free air" I guess), but the results were skewed by the tweeter shaking and by reflections off the tripod, the surroundings, and the tweeter baffle edges. I was ready to return them until I decided to try the recommended large-panel approach; not only was this easier, but the results were totally different!

Although the variances were acceptable, each of the 2905s was worse than spec. Other manufacturers make a number of products that have the same size and imped-

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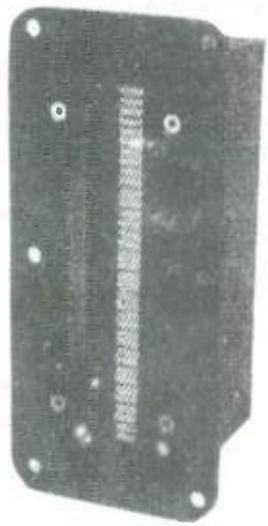

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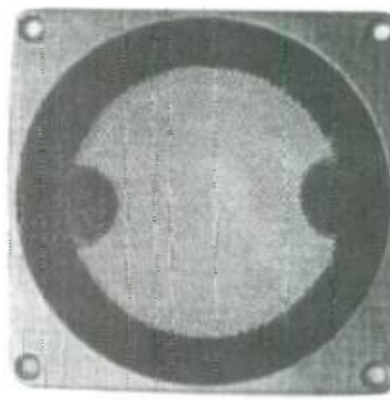

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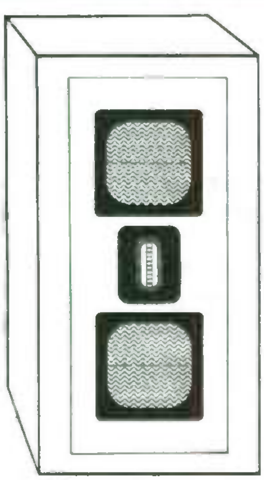

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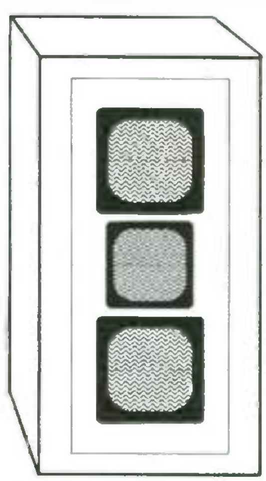

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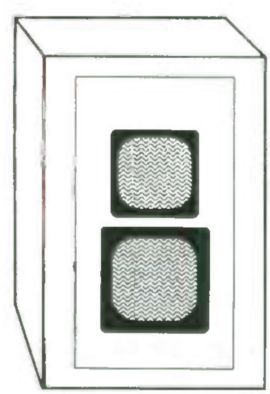

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FOR ALL YOUR SPEAKER NEEDS OR INQUIRIES - WRITE OR CALL ASK FOR ELLIOT ance as the D2905, but are made from substances such as aluminum, titanium, and (unsticky) silk. It might be worth investigating these.

TABLE 3

FOCAL 6K412L SPECIFICATIONS

Style	Kevlar sandwich cone
R_E	6
F_S	43Hz
Sensitivity	90.5dB/W/M
Q_{TS}	0.322
L_E	63mH
X_{MAX}	±3.9mm
Moving mass	11gm
VC diameter	40mm
VC height	13.8mm
VC	Copper flat
Air gap height	6mm
Force factor	7.17
Max power	90 nominal

TABLE 4

FOCAL 6K412L MEASURED VALUES

R_E	6.22Ω
F_S	49.22Hz
Q_{ES}	0.4
Q_{MS}	5.21
Q_{TS}	0.371
L_E	1.19mH
V_{AS}	16.5L

TABLE 5

CROSSOVER PARTS LIST

(PER CHANNEL, ALL PARTS 1 EACH)

CAPACITORS	
C1	18µF, 200V
C2	33µF, 100V
C3	8µF, 200V polystyrene or better
C4	30µF, 200V polystyrene or better
C5	2µF, 100V
INDUCTORS	
L1	1.3mH, 14-gauge PW or better
L2	0.3mH, 14-gauge PW or better
RESISTORS	
R1	5, 20W
R2	1.6, 10W
R3	7.5, 5W
R4	50, 5W

TABLE 6

ENCLOSURE PARTS LIST

(TWO MIRROR-IMAGE SPEAKERS)

Left front	Refer to
Right front	Fig. A in
Left rear	"Construction
Right rear	Details" sidebar.
Long sides	2 (13.45-2d × 8.5)
Short sides	2 (11.5-2d × 8.5)
Bottom	2 (10.75 × 8.5)
Top	2 (7.4 × 8.5)
Left tweeter plate	2 (use 2 for extra depth)
Right tweeter plate	2 (mirror of above)

Longevity of the tweeter is a consideration. As of this writing, I have tried replacing one damaged tweeter with a Vifa 1″ model. Vifa makes a number of tweeters that are physical substitutes and electrical near-substitutes for the ScanSpeak. Audibly, the Vifa tweeter is a very close match, although it is rated at only one-third of the ScanSpeak's power.

THE BASS-MID

One reason I selected the Focal 6K412Ls midbasses is that the technology fascinated me (*Table 3*). They incorporate a Kevlar® sandwich approach, with a low-density but high-stiffness filler between two layers of Kevlar sheet. Upon trying one, I was really impressed by the driver and determined to use it. Not only was it one of only two drivers I could find that was even close to my requirements, but I also found a number of reasonable-looking designs using other Focal drivers.

As advertised, the Focals come with anechoic frequency-response charts. Unfortunately, the scale markings for the standard chart-recorder output aren't labeled, so you can't really tell whether the driver is ±2, ±4, or ±6, or how large the humps are. At least the four sets were approximately the same shape, so the drivers were well matched. I later bought two more 6K412Ls (for the center channel) from the same shop. This pair's frequency-response charts were substantially inferior to those of the first two pairs—obviously a different production run.

I tested the Focal impedances, but there's no need to comment on them other than to note they were pretty much right on (except for a slightly high, albeit consistent, resonant frequency). I did not test the Focals in a large baffle, because large for them would be 80′ × 80′, a size my local Home Depot does not stock. I tested them in free air, simply as a quick check of integrity. An impedance test is just as good a descriptor of quality, and I knew the enclosure would substantially alter the measured frequency response.

The Focals sound very *immediate*—the transients seem sharp and well defined. My only real worry is that because I'm using relatively low-order (second) crossovers, the woofers will tend to shriek at high-volume levels. I tried a fourth-order crossover, but didn't like the sound (see the crossover section). Anyway, to define high-volume levels, I drive each speaker with 200W amps in a very large living room (about 8,000ft^3).

THE WOOD

Convinced that I wanted to use an exotic wood, I ventured to my local exotic-wood place, which carried only two types of wood in sizes sufficient for a speaker: mahogany and wenge. I ruled out mahogany (not very interesting) and settled on the wenge, which is a very dense, dark wood that splinters if you look at it cross-eyed and wears out sandpaper and saws at an amazing rate. It tends to abrade your skin (always wear gloves), and routers chew it up. Finally, because it is so dense, it has a sharp acoustic resonance that is difficult to tame at a high frequency.

Crafting the four enclosures took fully three weeks and tired me out physically (partly due to my having a limited set of tools). Nevertheless, the final result is striking, with a beauty unattainable with other materials, and it does sound good. One of my most important discoveries in using this hardwood was that driver vibrations are transmitted throughout the speaker cabinet. I finally tamed this by switching to Norsorex gaskets, which seem to dampen vibrations from the driver. If I had it to do again, would I use an exotic wood? Maybe I'd use a softer wood that was easier to work, but there's no doubt that MDF and a veneer (or paint) would suffice.

THE ENCLOSURE

Once I had selected and tested the drivers, the next step was to determine the enclosure volume (system Q) and the port size, if so aligned. I built four different enclosures—three sealed boxes and one ported type—out of high-density fiberboard (HDF), easily obtainable nearby. Two speakers had the same volume, with the driver holes on different sides to determine any frequency differences caused by wall reflections and baffle radiation. This also let me determine the Qs of the drivers more exactly by using two measurements (sealed and free air). I then built a closed box of approximately the optimal volume for the driver to make sure I had calculated correctly and that the Q would appropriately drop to the design value once the enclosure was stuffed with wool.

Here are some cautionary comments on prototyping boxes:

- *Air Leaks*: First, I wasted oodles of time due to air leaks. To avoid them, use Fun-Tak™ or Blue-Tak™, a gasket-sealing material (available at crafts or hardware stores) that looks like modeling clay, but never hardens. Also, always seal the joints thoroughly with glue and a second inner layer of silicone. Even in a prototype, air leaks can ruin the measurements. Whenever I had leaks, I also noticed that the impedance chart would allow a "glitch" or peak at the free-air resonance of the driver.
- *Flushing*: Failure to position the driver

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Specifications

Impedance	8 Ohm
Resonance	65 Hz
Upper Frequency	10,000 Hz
SPL 1/W/1/M	84 dB
Power Handling	50 W
Qts	0.41
Vas	4.54 L
Voice Coil	25.5 mm
Magnet	10 Oz.

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Resonance	45 Hz
Upper Frequency	9,000 Hz
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Qts	0.49
Vas	13.88 L
Voice Coil	25.5 mm
Magnet	10 Oz.

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- Polypropylene Cone
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- Closed Box or Small Bass
- Excellent Power Handling

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Impedance	8 Ohm
Resonance	36 Hz
Upper Frequency	8,000 Hz
SPL 1/W/1/M	86 dB
Power Handling	60 W
Qts	0.36
Vas	29.26 L
Voice Coil	35.5 mm
Magnet	18 Oz.

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Specifications

Impedance	8 Ohm
Resonance	33 Hz
Upper Frequency	6,500 Hz
SPL 1/W/1/M	87 dB
Power Handling	60 W
Qts	0.44
Vas	75.73 L
Voice Coil	35.5 mm
Magnet	18 Oz.

$31.05 EA

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- Double Magnet with Cup
- Home Theater Center Channel
- Computer Multimedia
- Sealed Box Enclosure

Specifications

Impedance	8 Ohm
Resonance	65 Hz
Upper Frequency	10,000 Hz
SPL 1W/1M	85 dB
Power Handling	60 W
Qts	0.35
Vas	6.3 L
Voice Coil	25.5 mm
Magnet	5 & 10 Oz.

$19.17 EA

DOB165R-PP/8SC 6-1/2"

- Double Magnet with Cup
- Home Theater Center Channel
- Computer Multimedia
- Vented Enclosure

Specifications

Impedance	8 Ohm
Resonance	36 Hz
Upper Frequency	6,000 Hz
SPL 1/W/1/M	86 dB
Power Handling	80 W
Qts	0.30
Vas	35.28 L
Voice Coil	25.5 mm
Magnet	5 & 10 Oz.

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flush with the enclosure also causes frequency irregularities (especially with tweeters) and a height irregularity at the driver baffle size, so look for resonances there (e.g., about 2kHz for a 6″ driver).

- *Beveling*: The edges of the enclosure also cause noticeable changes in frequency response. I think this is due to a gentle drop-off in edge length, detuning the distance from the driver to the edge of the speaker. Look for irregularities at wavelengths that are multiples of front-baffle widths. These seem to widen and decrease in intensity with beveling.

One of the reasons my speakers are a bit too small in volume is that during testing I stuffed the enclosure with wool, decreasing the Q. For a bass-reflex design, adding wool simply increases the loss of the enclosure. Adding series resistance (e.g., crossover coils) can also increase the required volume. Hence, if you are designing for bass-reflex, don't stuff the cabinet during volume analysis, and consider building it oversize.

Except for building them out of that incredible hardwood, my completed speakers were virtually identical to the last prototype. The most important change was decreasing the radius of the port to reduce its length so as to lessen audible ringing at the tube-resonant frequencies. The original tube resonance was both detectable and extremely annoying if excited just right.

- *Baffle Diffraction*: This is caused by sound wrapping around the baffle up to a certain frequency (so only half of it reaches you), after which it all bounces off the baffle toward the listener. The frequency at which this begins to happen is near one-half the wavelength determined by the width/height of the front baffle (e.g., assuming sound travels 1,000ft/sec, a baffle that is 1′ across would cause a response rise at around 500Hz). On a frequency-response chart, this is visible as a 3–6dB rise that begins near the bounce frequency. Worse yet, the rise is directional, and becomes inaudible off-axis. You can help this by minimizing the dimensions of the front baffle.
- *Reflections*: I think reflections off the interior speaker walls are audible as loss in definition and are a weird intermodulation distortion (not to mention clear frequency-interference effects). Particularly with a port, the sound just bounces off the back (if a front port) and then right out the port.

FINAL DESIGN DECISIONS

- *External Crossover*: I decided to use an external crossover because
  1. it requires less hardwood, as the crossover volume can be in an MDF box elsewhere;
  2. it shields the crossover from the driver magnetic field and vice versa;
  3. it allows the crossover to occupy a larger area, which then minimizes crosstalk between coils;
  4. it allowed me to seal the speaker and still be able to tweak the crossover;
  5. the crossover could be active.
- *Separate Woofer/Tweeter Enclosures*: I put the tweeter in its own baffle so the tweeter-baffle shape could be independent of the woofer-baffle shape and I could pulse-align the tweeter and woofer. The tweeter baffle rests on two small wood blocks on the top of the woofer enclosure and is braced with a single long piece of wood extending to the rear of the top. I pulse-aligned it empirically, using the IMP/M time display to line up the pulses.
- *Enclosure Size and Volume*: I tried to construct the enclosure so it would be virtually perfect for a reflex alignment that would get me down to 55Hz or so with low ripple. I did this interactively with a computer program after analyzing the driver. I assumed that stuffing would lower the

Q a bit, but this really wasn't true, so the box is a bit smaller than optimal, but the enclosure works by accepting a longer tube and a slightly higher cutoff than the driver is capable of (in this case I tuned it to xxxHz versus a possible yyyHz with a larger box). In fact, this is a nearly optimal box size for the sealed alignment, so it doesn't really bother me. If you had a larger box, you could use a wider tube (theoretically a feature) and the Q of the system could be a bit lower, improving the sound.

The wood I used determined some of the enclosure sizing. It was exactly wide enough for the speaker (what a coincidence!). Also, it was so difficult to work that I was unwilling to slope the back of the enclosure outward, something I am convinced will microscopically improve the speaker's definition.

- *Port Size*: I determined the port length algorithmically and then hand-tuned it experimentally to the desired frequency. At first I used a 2″ port (per spec for the power I was expecting to pump through it), but the necessary length (around 6″) was hard to fit into the box and caused audible ringing. I changed to a 1.5″ port (only 2.75″ long) and carefully flared the ends and the hole in the wood (to reduce wind noise), and it seems to work great. I may have heard wind noise at extreme volume levels, but it's difficult to tell because of stress to my ears at those levels.
- *Baffle Size and Shape*: The baffle for the woofer was as skinny as possible (to move that 6dB diffraction bump higher in frequency). The shape was a function of the desired wall slopes (to avoid acute angles between walls) as well as a woodworking requirement to keep one wall at a 90° angle. I arrived at the height via volume and golden-ratio considerations. By making the sides nonparallel, I could reduce the baffle width as well as side-to-side reflections.

FINAL ENCLOSURE

With all the above in mind, the measured values (from the IMP software, given free-air and sealed-impedance curves) for the 6K412L are shown in *Table 4*. According to LMP, the optimal zobel for this is 30.8μF with 7.8Ω, and the optimal box sizes for this set of data (assuming a series resistance of 0.3Ω due to inductor and wiring) are:

Closed: 8 liters for the closed box with a Q_{TC} of 0.70 and an f_3 of 86.7; or, using my value of 10.5L, this gives a Q of 0.62 and an f_3 of 90.7 for a slightly overdamped alignment when used standalone, although good with a crossover.

Ported: 12 liters with a 3″ length of 1.5″ diameter port tuned to 52Hz. Note that if you assume 0.5Ω of series resistance, the ported results change to 15 liters, with 2.59″ of 1.5″-diameter pipe tuned to 50Hz, so series resistance (mainly the series inductor in the bass crossover) really is important in getting the tuning right. If you compare the two LMP response curves for 0.5Ω, you see that 15L (optimum) produces an f_3 of ~49Hz, while 11L produces an f_3 of ~55Hz, so it isn't a big deal to me either way, given my 70Hz spec (and 15L is noticeably larger). Note that the 14ga 1.3mH coil is rated at 0.27Ω, so I recommend good soldering and large gauge (at least 12) speaker wire.

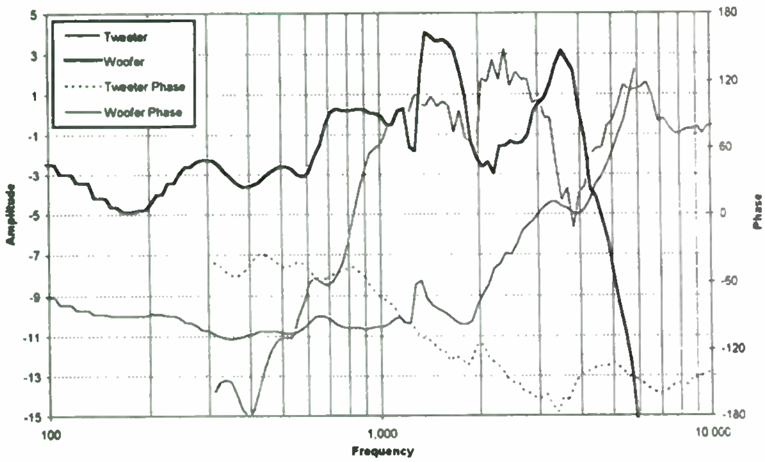

FIGURE 3: Drivers in enclosure, no crossover.

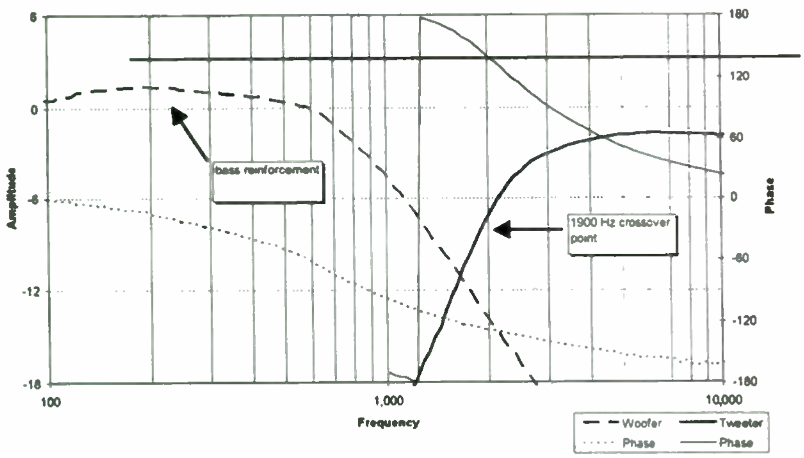

FIGURE 4: Electrical crossover response.

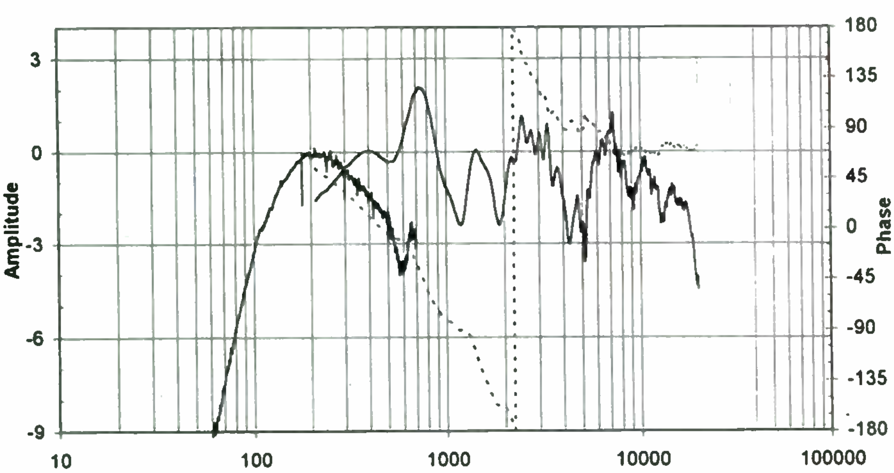

FIGURE 5: Acoustic response, no crossover.

LOOKING BACK

If I had it to do again, I would probably: a) make the enclosure about 15% larger (to allow for a lower Q and a shorter port) by sloping the back wall down and away, thus further reducing rear reflections and the internal box resonances caused by the rear-wall distance being similar to the average side-wall distance; b) somehow reduce the distance between the tweeter and woofer to improve the vertical characteristics.

I am happiest about: a) the Time Alignment® of the tweeter and woofer, which simplifies crossover design and appreciably improves the sound quality; b) the size of the speakers, which is just right for stand mounting—and they are very attractive; c) the small enclosure that gives them excellent dispersion; d) their overall awesome sound.

I am unhappiest about: a) the 1–2dB peak at about 700Hz, which I think is caused partly by front-back reflections (correctable) and partly by compensating for the diffraction bump (a trade-off with the lowish Q crossover's better transient response). Although I derived a crossover that removed the peak (while lowering response below 700Hz), I didn't like its effect on music—it sounded too lean.

THE CROSSOVER

Designing the crossover and tweaking it for best sound actually occupied most of my time in building the speaker. I estimate I spent about two to three months prototyping and then building the enclosure. I then spent another nine months designing, building, and tweaking the crossover.

In designing the crossover, I started off with a textbook fourth-order design. As expected, this didn't work so well. The response at crossover point was irregular and changed all over the map with the vertical position of the microphone.

I finally ended up with a second-order, low-pass filter for the bass-mid and a quasi-third-order, high-pass filter for the tweeter. When interacting with the tailed-off low-end response of the tweeter and the tailed-off high-end response of the woofer, this worked out close to a fourth-order acoustic filter. The modification to the low-pass filter incorporates a bit of peaking in the lower treble ranges (around 300–500Hz) to minimize the baffle diffraction effect and to correct for driver irregularities.

Figure 2 shows a schematic of the final crossover. *Table 5* contains the parts list.

The power and voltage ratings are approximate. You could almost certainly scrimp on some of the wattages and some of the voltage ratings, but why bother? You could also use a less expensive coil for L2, but that would affect the Q of the filter.

RESPONSES

The main points of interest in *Fig. 3* are the rising frequency response of the woofer (caused primarily by baffle effects) and the rather large dip in the tweeter response at 4kHz. As far as I can tell, the tweeter dip is caused by bounce off the top of the enclosure, which will be directional and rather benign, albeit measurable on-axis. The raggedness in the tweeter response is also caused by imperfect flushing of the tweeter.

Note that when I tested the tweeter on an infinite baffle, the response was nearly a ruler-flat 2–20kHz. Since the final frequency-response chart reflects these irregularities, you should actually be able to get rid of that 3–4kHz dip just by better affixing the tweeter. Also, note that the tweeter is more efficient than the woofer, hence the dropping resistor in the tweeter crossover.

Figure 4 is a graph of the response curve of the crossover elements (into the drivers). I've manually flattened the tweeter phase response below 300Hz, since the response is down so far that the phase calculation jitters all over the chart.

In this crossover, note that:

1. The response is 180° out of phase from 20kHz to 4kHz, dropping to about 90° at 2kHz, and then to 60° below 1kHz. This adds more or less correctly to the phase variations caused by the drivers.

2. Both sides of the crossover have a fairly gentle slope. This makes the delay curves smooth, which I think improves the sound. In no cases are the Qs of a very high level. One of my early attempts to produce a flatter response with a high-Q crossover sounded terrible, as though some of the bass was in a tunnel. Perhaps that was subjective, but it was *after* the high-Q filter sounded so badly that I did the relevant research to explain it objectively as time-delay distortion.

3. You must use a high-quality inductor for the 1.3mH in series with the woofer. I used a perfect-wound, 14-gauge copper coil, which is the most resistance I'd want in that inductor. Also, use low-impedance (14-gauge or larger) speaker wiring to achieve the best bass response. I first used 8-gauge monster wire, which was impossible to solder and route. I ended up using 16-gauge hookup wire within the crossover.

In the acoustic response of the drivers in the enclosure without any crossover (*Fig. 5*), there are really three areas of minor concern:

1. At 750Hz, there is a 2dB peak at a moderately high Q. I'm not sure what causes this, although I believe both the driver (the bass-mid) and the enclosure are responsible. It does not seem very audible, and it is the worst artifact in the frequency chart. This area also has more average energy than later in the frequency-response chart, but that is intentional.

2. At 1.2kHz and 1.9kHz, there are 2dB dips. These are quite narrow and, to my mind, very difficult to notice.

3. Between 4–5kHz there is a ~3dB dip in the response. I believe this is caused by bounce from the tweeter off the top of the midrange enclosure (something measurable that does not seem audible) and by bounce from the tweeter edge, where I have not yet dared to produce a flat surface (by permanently sealing the edges!). In any case, this artifact does make the sound a teeny bit less "warm."

CROSSOVER TIPS

Before settling on this crossover, I tried a number of others, keeping in mind the following:

1. Always check your solder joints before measuring a speaker/crossover.

2. Worry about alligator clips (if you are clipping a prototype), because the impedance at the alligator jaws can audibly (and measurably) affect your frequency response.

3. Don't assume your amplifier is flat.

First, I tried a standard fourth-order LR crossover, which seemed to work from an electrical point of view, but the SPL measurements from the drivers were junk and I scrapped it.

I then tried to produce an acoustic fourth-order L-R using my measurements. I started by downloading a Basic language crossover optimization program from one of the audio BBSes. This program crashed constantly, so I ended up putting in a few hours to make it run reliably and to get the arithmetic right and the output in a usable format. All of this work produced a four-element (per driver) crossover that did indeed correct the peak in the response around 700Hz, but it sounded like garbage.

I decided that it was using a high-Q, second-order filter to correct the peak, and that the ringing and group-delay changes this caused were both measurable (via my IMP subsystem) and audible. Out went the fourth-order attempt. Worse yet, the optimization algorithm had some serious problems, so I eliminated it also.

After several attempts at a crossover, I ended up with the current design, which produces almost exactly the correct response, using low-Q, low-order filter sections with a minimum of both components and series resistance. The tweeter has enough protection to absorb lots of power, while the woofer has some shaping for better response. All told, it was the best I heard.

Despite my criticisms of the crossover, the final response curve compares well with high-end speaker-response curves. Sure, there are a few things that could be done to tweak the response (and I may try those), yet the overall result is commercial+ quality.

CONSTRUCTION DETAILS

Don't forget that left and right speakers are mirror images of each other (this includes the tweeter baffle). Also, prepare the wood carefully before gluing it together. I built the enclosures out of solid 1-1/8″ wenge boards that were irregular in depth (ranging from 1″ to 1¼″); hence, some of my measurements were ad-hoc.

The front set of plates in *Fig. A* obviously pertains only to the left speaker. The right speaker is a mirror image. Since the speaker uses butt joints, you just need to cut the pieces to size and then make sure they fit together before attaching permanently. In addition to these two front plates, you will need two sides, a top, a bottom, and one back plate per speaker. The back plate is identical to the front (although if you use single-finished stock, also finish the back of the back plate). Cut the two sides appropriately to fit the speaker (11.5″ and 13.46″ long, respectively, and about 9″ deep; I used 8.5″). The top and bottom are then obvious (*Table 6*).

If you use MDF rather than the incredibly hard wood I found, I strongly recommend some additional bracing, and also suggest using two layers of MDF for the front panel. I ran a brace from the front to the back and from side to side after gluing the boxes together. I also strengthened the tweeter panel with a long brace to the rear (see *Photo 1*).

The tweeter enclosure consists of two pieces of wood glued together, with an appropriate hole cut through the middle. You then mount it onto the top of the woofer cabinet using two cubes (about ¾″ on a side) and a long brace (about 8″) from the tweeter to the back of the cabinet top. You can do this last. It should be aligned perfectly straight with the front of the cabinet and recessed to get the phase right. This doesn't need to be perfect.

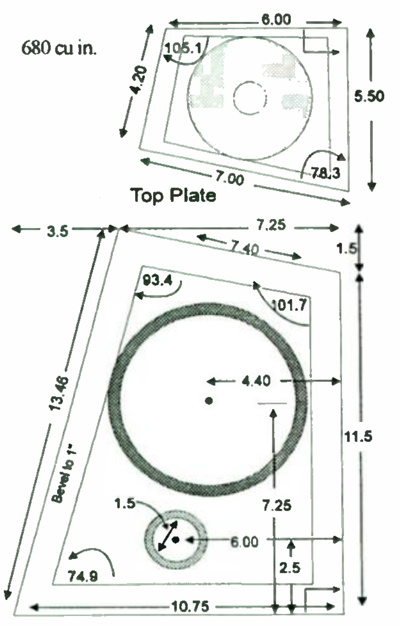

FIGURE A: Left-speaker construction details.

RUNNING WIRES

I ran wires from the tweeter plate down through the woofer box and then back out through five-way posts on the top-back of the box. This looks neat, but frankly the extra holes in the enclosure for the tweeter cable are tough to drill and seal correctly. You are welcome to run them directly from the tweeter to the five-ways.

I have two pairs of five-way binding posts on the woofer—one pair for the tweeter and one for the woofer. The crossover requires this. Also, don't scrimp on the speaker's five-ways; you need a low-resistance connection there, or the crossover will not work well.

I used silver-based wonder solder for all solder joints. That's really not necessary, and the silver has very little mechanical strength. If you do use silver solder, it should not be used as a glue. I like the fact that the melting point of silver solder is lower, so components don't heat up as much. Those large crossover capacitors, in particular, seem somewhat heat sensitive.

Before assembling the pieces, rout some free space inside the top so you can put the binding posts on top of the speaker. My five-ways were not deep enough to fit through the top, so I routed an area for them. As an afterthought, it works OK (and adds some protection to the posts, which become recessed), but it doesn't look very well.

Also before construction, rout a port-tube hole, which should be just large enough for the tube in the rear of the front plate and match the inner diameter of the tube for the front. After construction, you can rout a serious flare in the front (*Fig. B*).

When you build the box, glue the port tube with a silicon glue/sealer by rubbing glue on the outside of the tube and sliding it into the hole (without getting glue in the port itself, or in the 1.5-inch-wide front part of the hole). I routed an area a bit too large, so I just bought some felt, inundated it with silicon sealer, and wrapped it around the port tube until it just fit in the hole. Then I very carefully slid in the wrapped port tube. This worked perfectly with plenty of silicone. — MZ

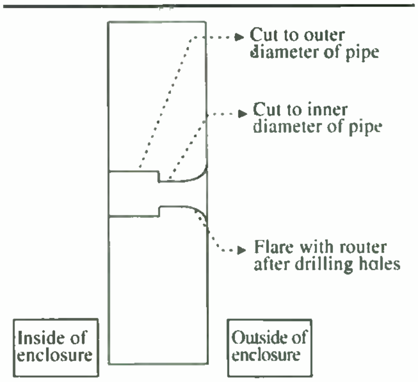

FIGURE B: Hole construction for enclosure.

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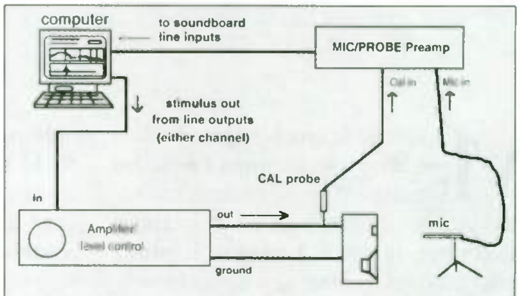

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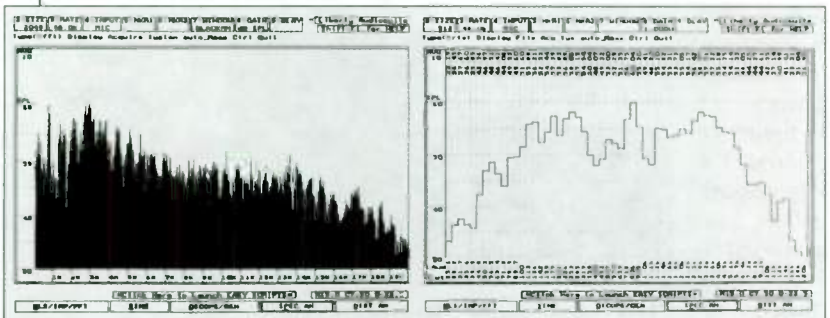

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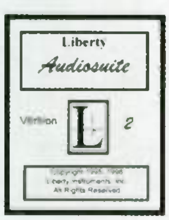

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THE OPPOSITE MODULI (OM) SPEAKER CABINET

By Hajo Prodan

My interest in speakers goes back to the early 1960s, when I installed some crude music systems into so-called jazz cellars that were much in vogue at that time. In 1988, I tried to improve speaker cabinets by pouring some from ordinary concrete. The results were rather poor, but it made me think more deeply about rigid-body acoustics.

From more experiments, I learned that cabinets made from very hard materials, such as marble, were good in the bass region, but exhibited problems in the mid and high ranges. Boxes made of softer materials, such as heavy cardboard (*Photo 1*) or bituminous fiber board, performed poorly in the bass area, but fine in the higher frequencies.

BLENDING OPPOSITES

One day it occurred to me to try joining two contrasting materials with modern grouting compound. I consulted *Physics for Scientists and Engineers*, by Raymond A. Serway, and a British science data book to learn more about density, expansivity, tensile strength, Young's modulus, the speed of sound, and other information having to do with solids.

I found out that diamond on one side and rubber on the other could be the right partners. Since I could not afford diamonds, I chose quartz sand as a substitute because it has a very high Young's modulus and a high rate of sound transmission. In contrast, rubber shows a low Young's modulus as well as a very low speed of sound in a thin specimen.

PHOTO 1: Testing a cardboard speaker (right).

A nearby tire-recycling plant provided a free sack of granulated vulcanized rubber. As a grouting compound, I chose an epoxy resin that is normally used for general building repair. I mixed the epoxy concrete with quartz sand, granulated rubber, and ilmenite ($FeTiO_3$) powder, the last ingredient serving as a weight-control additive.

The basic formula for 1kg of the mix was 431g of oven-dried quartz sand, 72g of the granulated rubber, 104g ilmenite, and 393g of epoxy resin (two components). You can omit the ilmenite, but you must then replace it with 98g of quartz sand.

PANEL TESTING

The mixture of the ingredients made a nice dough, which I poured into a waxed flat form. After three days of curing, I had a panel that was ready for testing. I named it the Opposite Moduli (OM) panel (*Photo 2*).

The first comparative tests revealed that this was a kind of eureka event. The effect of

PHOTO 2: Artist's impression of an OM box.

ABOUT THE AUTHOR

Hajo Prodan is a free-lance engineer from Germany. During the last 15 years, he has been involved in electronic workshops, communications systems, and radio broadcasting in countries such as South Korea, Indonesia, Peru, and Sri Lanka for Deutsche Welle (voice of Germany). His current activities are mainly room acoustics and international technical consulting.

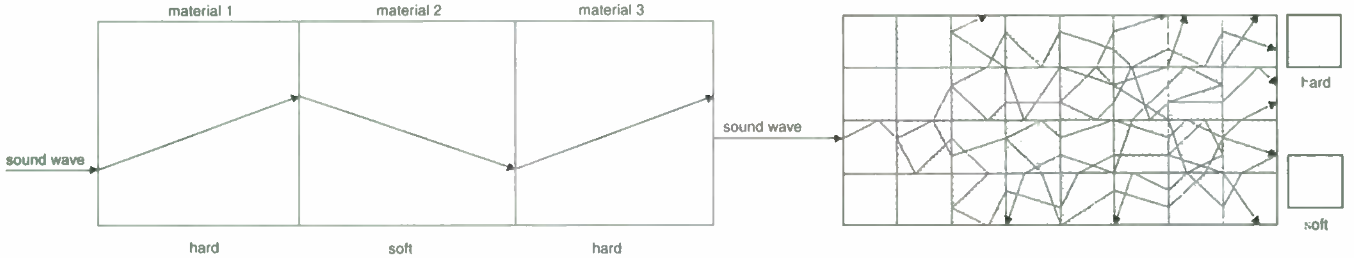

FIGURE 1: Panel effects.

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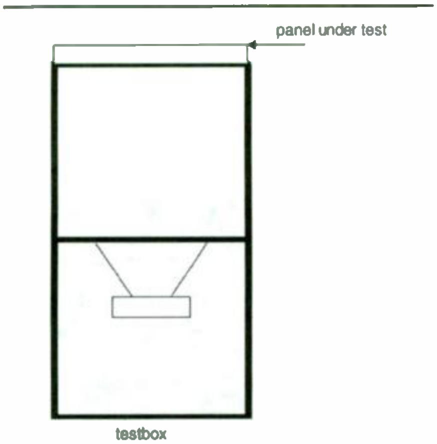

FIGURE 2: Testbox.

PHOTO 3: Test setup for vibration measurements.

the panel in acoustic terms was much better than I expected.

The explanation of the sound-energy absorption effect is as follows (*Fig. 1*). Basic acoustic theory holds that a sudden change in the properties of a compressible medium alters the speed of sound, resulting in a refraction or change of direction of wave travel. It follows that hard/soft variations occurring continually within a rigid body will cause multiple changes in speed, impedance, direction, and phase. As there remains no dominant direction of wave travel, it becomes "lost" inside the body, and the energy is absorbed at maximum.

In a long sequence of comparative measurements, I checked all conceivable kinds of speaker-cabinet materials, including natural wood, particleboard, glass, plastic, metal, natural stone, concrete, sandwich panels, and designed OM panels.

I performed the measurements using the following equipment (*Photo 3*): vibration transducer (Kemsonic 1628), precision preamp (home-brew), sine-wave generator (Hameg HM 208), distortion meter (Hameg HM 8027), a computer-based audio test system (Kemsonic AMS PC 1656), and a testbox (home-brew).

The testbox was a massive, double-walled cabinet, poured from concrete, with dimensions of 380mm × 620mm × 380mm and weighing approximately 40kg (*Photo 4* and *Fig. 2*). The top consisted of the panels under test—all of them the same size: 300mm square. For absolute tightness, I used two thin, soft PVC gaskets and a fitting high-quality plywood frame. The torque of the bolts was measured and balanced by a torque wrench to achieve equal conditions for each panel.

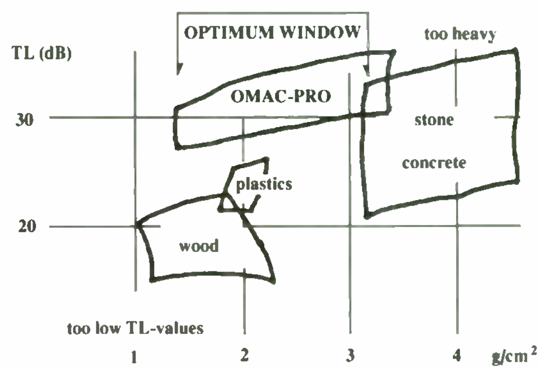

FIGURE 3: Graphing the different materials tested.

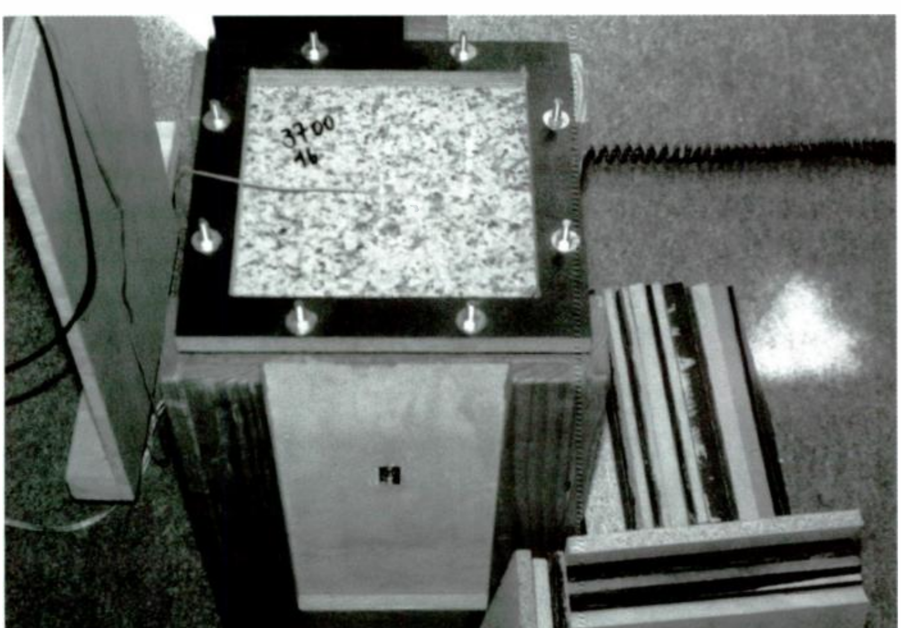

PHOTO 4: Testbox and test panels.

PHOTO 5: OM speaker box.

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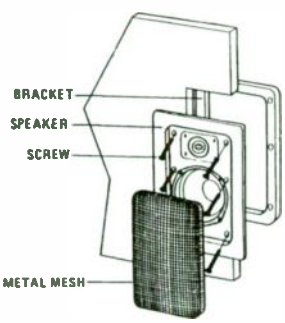

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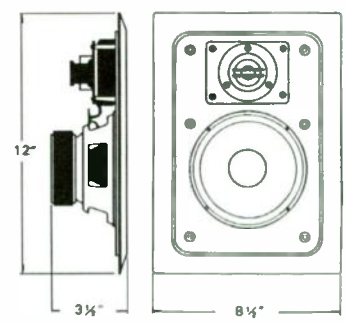

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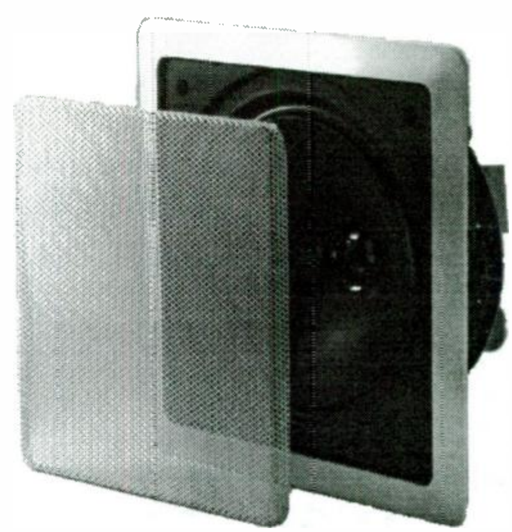
Madisound is pleased to introduce the **WS008A** synchronized in-wall speaker system. You will not find this type of sound quality in a conventional in-wall speaker. The 1" aluminum dome tweeter is mounted at the base of the woofer cone, bringing the voice coils into alignment. This type of configuration creates a point source, allowing the listener to hear the music from both the woofer and tweeter, in exactly the same point in time. This speaker has good imaging throughout the room, without having to be a "sweet spot". Just because you are going to hide your speaker in a wall, doesn't mean you need to compromise on the sound.



The **WS008A** is constructed from a one-piece baffle and chassis to reduce vibrations. The woofer has a mineral filled polypropylene cone with a rubber surround and high temperature Kapton voice coil. The tweeter is a 1" Aluminum dome with a Neodymium magnet and ferrofluid cooling. The crossover is 24dB per octave, with polypropylene capacitors in the tweeter circuit for greater clarity.

The **WS008A** is easily mounted in existing drywall, or we have kits for framing in on new construction before drywalling. The frame and grill are white and can be easily painted to match your decor.

WS008A: 8Ω impedance, 89dB sensitivity, 35-20KHz frequency response, 2.8KHz x-over, 3.8" depth. Cutout 210mm^2. **Price per pair: $220.00** **New Construction Kit: $18.00**

Clip and Save Coupon

Take an additional discount of 15% on the WS006 or WS008A In-wall speakers. Just send in this coupon or mention this ad to receive your discount. Offer does not apply to dealer or OEM pricing. Offer good until December 1, 1996.

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Reader Service #38

TABLE 1

CHARACTERISTICS OF SELECTED PANEL MATERIALS

RANK	MATERIAL	THICKNESS	PF
1	OM	16	9.52
2	glass	15	6.93
3	OM	7.8	6.19
4	polyurethane	16	6.03
5	MDF	19	5.47
6	MDF	22	4.83
7	particleboard	22	4.67
8	particleboard	19	4.49
9	acrylic sheet	16	4.21
10	MDF	16	4.21
11	marble	16	3.66
12	hard PVC	15	3.36
13	slate	16	3.03
14	particleboard	16	3.00
15	ceramic	15	2.41
16	concrete	16	2.35
17	polyethylene	16	1.36
18	steel	15	0.17

Note: The extremely poor performance of steel is due to a very high Q at resonance.

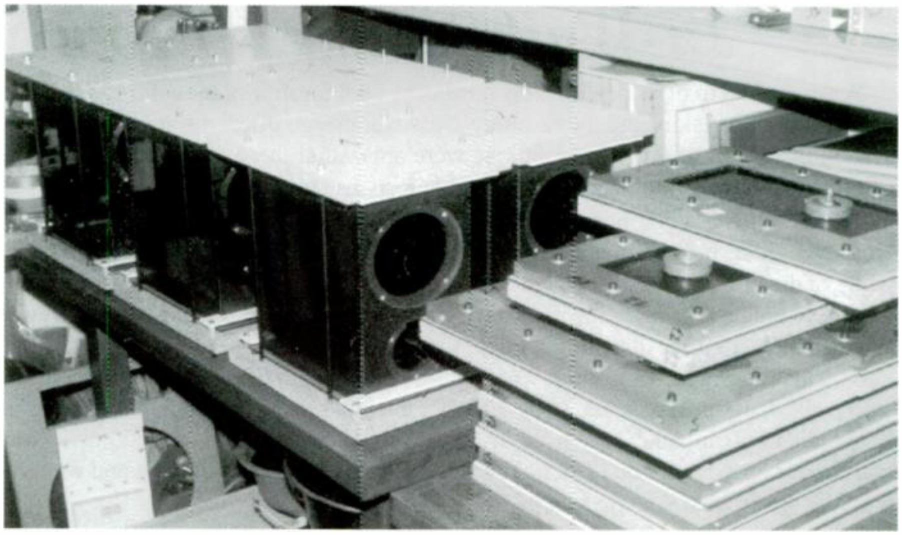

PHOTO 6: Enclosures being manufactured.

TEST RESULTS

The newly designed OM panels turned out to be the winners in all categories: wideband transmission loss, decay time, distortion, and resonance Q. As you can see in *Fig. 3*, there was a gap in mass per unit area between wood and plastics on the one hand, and concrete, stone, and ceramic on the other. OM material closes this gap in high-quality acoustic terms.

For a better understanding and overview of the test results (*Table 1*), I introduced a so-called P-factor (PF), which squeezes the important readings into one number: PF = T_L/EDF, where T_L = transmission loss, normalized in dB/(gram/cm^2); EDF = energy decay factor ($Q_{hi} \times T_D \times V_{pp}$); Q_{hi} = Q at highest resonance; T_D = decay time in seconds; and V_{pp} = volts peak-to-peak at Q_{hi} frequency.

Speaker boxes made by the OM technique sound neutral and natural (*Photo 5*; *Photo 6* shows these boxes being assembled). The bass is dry and tough due to rigidity and the absolute air-tightness of the cabinet material. In the fundamental tone range, sound reproduction is of very high fidelity, thanks to the best possible stiffness-ductility ratio. The presence and brilliance ranges are crystal clear and very lively, due to widely spread resonance energy in the cabinet's walls. Finally, treble tones are free and airy, because there are no "eigensounds" from the speaker cabinets.

As an interesting side effect of the testing, particleboard peaked at 22mm of thickness, whereas MDF peaked at 19mm. This means that there is no reason to use cabinet walls made from 38mm particleboard; 22mm is, acoustically, the better choice. This is due to the pressure applied during the production process of the particleboard—at least in Germany. It may be different in the US.

I hope that my work helps lead you to new ideas and better speaker cabinets.

Note: After a lengthy period of experimentation, I obtained both German and US patents for the OM technology and OMAC-PRO (Opposite Moduli Acoustic Compound for Professionals). The use of my OM technique for your private purposes is free of restrictions; for commercial use, however, please contact me.

Reader Service #63 →

AΞON 250 VDC 5% FINE CAP

Metallized polypropylene capacitors for loudspeaker passive network.

Another brand of metallized polypropylene capacitors ? Well, not exactly ... At Orca we have been thinking for a while about how to make polypro caps more affordable for a larger number of speaker builders, people who use caps only for speaker passive X-over network. We thought that it would be tremendous if we could offer a line of polypro caps that would be so affordable that people would have no reason to use cheap mylar, as they would be able to get for not much more money a much much better cap. As you know, even extremely powerful solid state amps (we are talking KW here) can barely produce rail voltage higher than 60 V. So it is safe to assume that a 100 VDC cap would be a pretty robust cap to use in a passive loudspeaker network. So to be really safe, we decided to make all the AXON cap of our FINE CAP basic line 250 VDC. Now that's about where the compromises start and stop. On the other hand for example, you may or may not know that when a cap value is said to be 10.0 µF with 5% precision, it means that the manufacturer of caps sets its winding machine to 9.7 µF and then produces this series with 2% tolerance (not very difficult with numeric controlled winding machines). The result: the manufacturer saves more than 3% in material, the precision is respected, but chances are all your caps will measure on the low side ! Orca made the special arrangement that all the AXON caps were to be wound with 5% precision with the target value set at exactly the nominal value. That means now, as most of you do, and rightly so, expect, that you should find a much greater proportion of caps very close to exactly 10.0 µF, if not 10.0 µF exactly! As for the rest, we could display here all sorts of figures and graphs that would only makes sense to 1% of our customers, but what for ? We can simply tell you this is the first polypro cap at a price closing on mylar caps. It is made by the same company that makes all our high voltage and very high voltage SCR caps, as well as our film and foil caps. Some of the best loudspeaker manufacturers have already made that easy choice. Now see for yourself and ... let your ears make the call.

Value µF	Diameter mm	Length mm	SRP US$	Value µF	Diameter mm	Length mm	SRP US$
1.0	11	21	1.23	12.0	25	33	3.56
1.5	12	22	1.44	15.0	25	38	4.18
1.8	13	22	1.49	20.0	29	38	5.16
2.2	15	22	1.58	24.0	29	43	5.98
2.7	14	25	1.67	30.0	32	43	7.30
3.0	15	25	1.73	33.0	32	48	7.74
3.3	16	25	1.78	41.0	35	48	9.32
3.9	16	25	1.83	50.0	37	53	10.96
4.7	18	27	1.96	51.0	37	53	11.16
5.6	18	30	2.10	56.0	39	53	12.00
6.0	19	30	2.20	62.0	39	53	12.98
6.8	20	30	2.33	75.0	43	58	15.12
8.0	20	33	2.91	82.0	45	58	16.28
8.2	21	33	2.97	91.0	47	58	17.50
9.1	22	33	3.08	100.0	49	58	18.76
10.0	23	33	3.23	120.0	51	63	21.98
11.0	24	33	3.38	130.0	54	63	23.38

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Software Review

VISUAL EARS

Reviewed by Vance Dickason

Visual Ears, KB Acoustics, PO Box 50206, Eugene, OR 97405, (541) 935-7022. Visual Ears is available from Old Colony Sound Lab as #SOF-VER1W3G for $89.50 plus $5.13 S/H in the USA. A demo version is available for $5 plus shipping of $2.35 USA, with the $5 price deductible from a later purchase of the full package.

I reported on "The Listening Room" program from Sitting Duck Software in the May 1990 *Voice Coil*. Since that time, the program's DOS version has undergone several iterations, but it has never been released as a Windows program. Recently, Sitting Duck combined efforts with another programmer and mathematician to form a new company, KB Acoustics, to market an improved Windows version of "The Listening Room," renamed "Visual Ears."

Visual Ears is written in Windows Visual Basic, and the single 3.5″ floppy contains about 708K of code. The program lacks an install routine, so you must create a directory and copy the files to the hard drive. The company supplies a bitmap ICON file, so you can readily set up the software in your Windows program group.

Figure 1 shows the basic opening screen, which is divided into four sections: a room diagram showing placement of the various loudspeakers and the listener (upper left), the coordinates of the speakers and the listener (in inches or centimeters) relative to the floor and left and front walls (lower left), a standing-wave graph (upper right), and a boundary reflection graph (lower right).

Two main menus for setting up any given room and speaker situation are available. First, enter the room dimensions by clicking on the icon to display the menu (*Fig. 2*). You can configure dimensions only as square or rectangular rooms (future versions promise to handle L-shaped rooms); however, the program can simulate simple cathedral ceilings. A menu switch indicates the presence of carpet in the room, and lets you choose between English or metric units. You can configure VE for both single full-range speakers or separate subwoofer and satellite systems. The program also accounts for surround-sound speakers, but does not require their dimensions.

Figure 3 shows the Speaker Parameter menu, which is displayed by clicking on the Speaker icon. VE is quite flexible and will

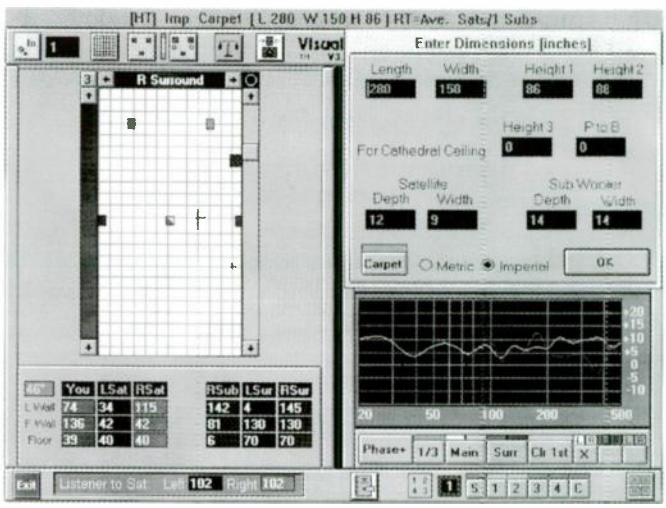

FIGURE 2: Room dimensions menu.

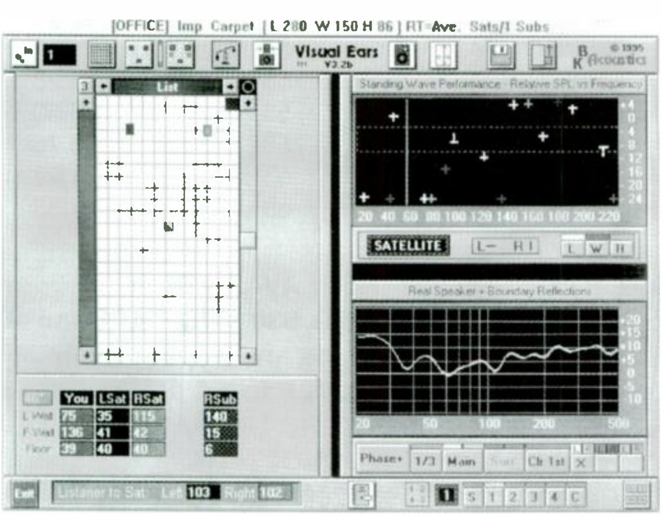

FIGURE 1: Opening screen for Visual Ears.

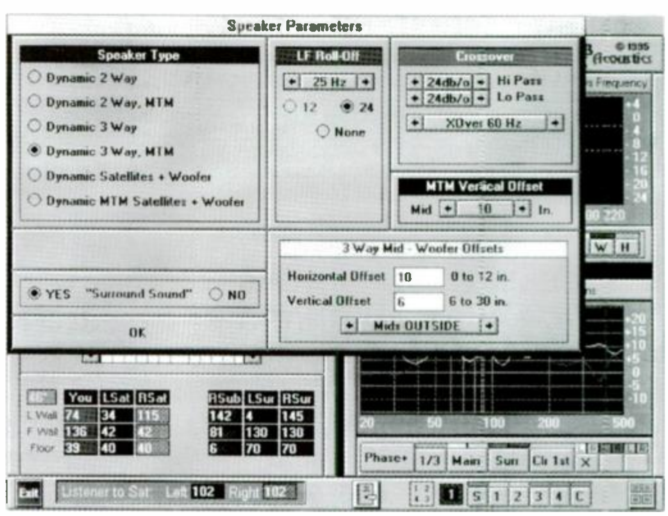

FIGURE 3: Speaker parameters menu.

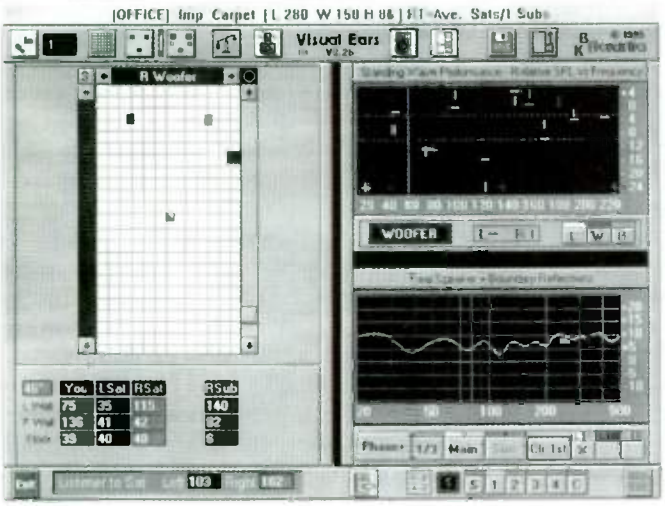

FIGURE 4: Result of relocating subwoofer on right wall.

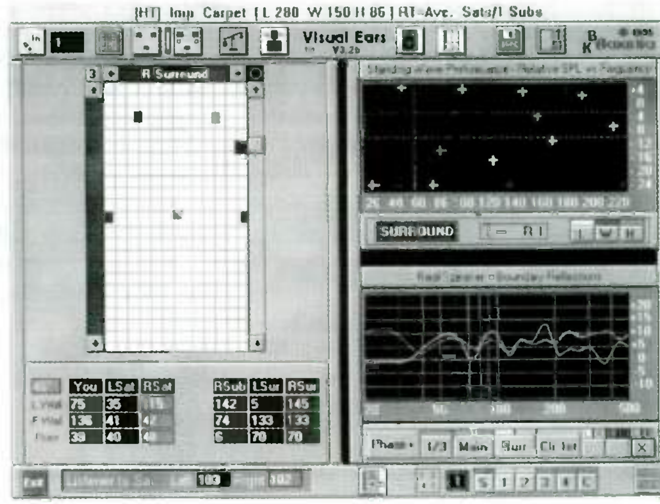

FIGURE 5: Home-theater setup including surround-sound speakers.

simulate two-way and three-way speakers, with single driver per frequency configurations, or D'Appolito MTM-type configurations, and separate satellite and subwoofer systems. You can specify low-frequency rolloff between 25–99Hz for either second-order sealed boxes (the software will ask for the box Q_{TC}) or fourth-order vented enclosures. You must also specify crossovers in the 50–400Hz region with a choice of 12/18/24dB/octave for high-pass networks and 6/12/18/24dB/octave low-pass networks.

As the designs become more complex, the program requires additional data about driver placement. For MTM two-ways, VE asks for the vertical separation of the two woofers. For three-way speakers, it requests the vertical distance between woofer and mid, as well as the horizontal displacement if the drivers are offset (not centered), and whether the offset (if any) is to the inside or the outside of the two-speaker array. When you select the satellite and subwoofer configuration, the program asks for the number of subwoofers and the sensitivity of the sub in relation to the satellite (0 to –9dB). For home theater, the program has an option to add two left/right surround speakers.

Once you have correctly specified all the room and speaker data, you can then experiment with different locations and placements in the room to see the resulting standing waves and boundary reflection problems. The process is simple and quick; you move a speaker on the room grid for immediate results. Simply click on the speaker and drag it to the new location. You can do this for each speaker or for the pair.

The room dimension readout area below the room grid shows the included angle from the listening position to the two main left/right speakers—46° in this example. You can also relocate speakers by clicking on the speaker and then the scroll arrows to step the speaker horizontally and vertically (with selectable step speeds). The right scroll arrow adjusts the height above the floor for the selected speaker (or the listener location).

The results are displayed in both the curve in the boundary reflection graph and the length/width/ height hash marks in the standing-wave graph. The dashed lines on the standing-wave graph represent the "target area" for standing wave relative to SPL. This changes depending on the nature of the room—live, average, or dead (the live target is above and the dead target below the average target displayed in *Fig. 3*). The goal is to get as many of the length modes into the target area as possible; however, you must consider a number of different criteria, some of which are discussed in the program documentation.

Figure 4 shows the result of moving the subwoofer location from the corner to along the right wall. You'll note the change by comparing it with the boundary graph in *Fig. 1*. Left and right speakers are displayed individually, but in this case both curves nearly overlap (incidentally, the program assumes an anechoically flat speaker), so the differences are not apparent. *Figure 5* adds the surround speakers to the mix. The change to the standing-wave graph wasn't really enormous, but their SPL in regards to boundary effects is shown as a separate curve.

VE can hold four separate room setups, which you can print out (*Fig. 6*). The program is fun to use and, from my experience with the previous DOS version, reasonably accurate. Price is $89.50 plus $3 S&H ($6 overseas air). The program requires either Windows 3.1 or Windows 95 and a mouse.

Set Up One	Left Wall	Front Wall	Floor
Listener	136	75	39
Left Woofer			
Right Woofer	15	140	6
Left Speaker	41	35	40
Right Speaker	42	115	40
Left Surround	268	4	33
Right Surround	268	145	33

FIGURE 6: Sample room setup display.

DEVELOPER'S RESPONSE

We appreciate Vance Dickason's favorable comments on Visual Ears, but have two points to clarify.

Visual Ears is not an improved, renamed Windows version of The Listening Room. Although the two programs are similar in intent, Visual Ears is a newly conceived and considerably more comprehensive effort written from the ground up in the C programming language. Visual Basic was used only to create the user interface and provide a link to the 32-bit C code.

Also, we would like to add that slanted, as well as cathedral, ceilings are handled by the program.

Bill Fitzpatrick
KB Acoustics

NEW SOFTWARE
NEW TEST CDs

MODES FOR YOUR ABODES

SOFTWARE FOR WINDOWS

Modes for Your Abodes by Joseph Saluzzi is a simple yet powerful program that provides you with a given room's modal frequencies. In addition, it calculates standard deviations and mode spacing, and detects the number of coincidences. User-friendly, intuitive, and easy to use, featuring on-line and context-sensitive help; glossary; fast 32-bit code (Windows 95 version); MS Access 95 database engine that creates databases automatically and transparently; thirteen view screens; and high-quality Crystal Reports output of mode and overview tables. IBM 3.5" DS/HD only. SPECIFY Windows 3.x or Windows 95 version.

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#CDJA5. High Resolution Master Sound. 20-bit digital recording of seven musical pieces, plus 16-bit version of six musical and fifteen audio check features.
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Developed especially to allow high-quality test and evaluation procedures to be made easily and quickly, this CD contains 62 individual bands of test signals. Some bands also contain individually addressable Index Points, so that families of test signals can be accessed individually by keying in the appropriate track and index numbers on your CD player or its RC unit. This feature also allows you to play tracks in any order or to repeat tracks. Includes L/R test, piano chord, 88-note piano scale, loudspeaker polarity test, sine waves at each octave center, pink and white noise, impulse clicks, much more.

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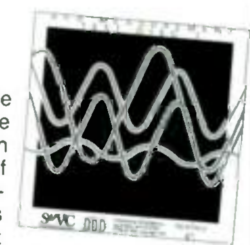
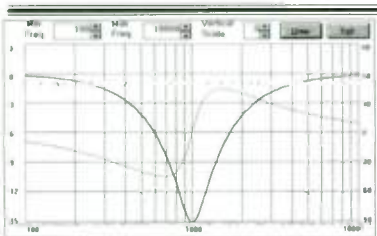


These discs are tools to aid the sound engineer in the evaluation of sound reinforcement systems which must project English speech with a highly accurate reception rate by listeners. Through the use of modified rhyme tests and both male and female talkers, they give the user a repeatable, transportable, standard comparison of speech intelligibility for use anywhere needed. Other test stimuli are also included on the disc, and the package also contains printed copies of the tests for recopying and distribution to the listener groups. 2-CD set.

#CDSA2 . . . .$169.95*



Filter Workshop band-reject filters graph.

FILTER WORKSHOP FOR WINDOWS V.1.01

This program by Frank Ostrander combines a useful set of passive network design tools with an instructional resource for network design. Calculations include design of attenuation networks (L-pads); high- and low-pass filters; shelving networks (both high- and low-pass); band-reject filters; inductor winding; and impedance correction networks. Determines component values based on resistive termination as opposed to complex driver SPL and impedance load functions. Straight-forward and easy to use. "Undoubt-edly one of the best (resistance-based) network calculators I have seen"—Vance Dickason, editor, *Voice Coil.* IBM 3.5" DS/HD only.

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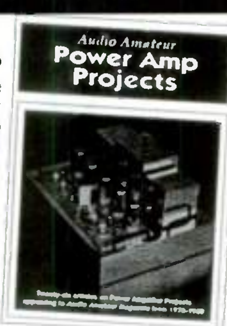

This new handbook features 26 of the best articles on power amps as they appeared in the pages of *Audio Amateur* from 1970-1989. Authors from six different countries offer an array of designs to provide almost any high-quality audio power needed by the resourceful amateur who prefers the pleasure of building his or her own. Predominately solid state. 1996, 8-1/2 x 11, 205pp.

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SB *Mailbox*

DO NOT CLONE

Readers should note that the design used in Michael Hildebrand's Adria (*SB* 3/96, p. 24) is for personal use only. Any reproduction of this for commercial purposes is an actionable offense.

DIFFERING DATA

I was thinking of building a relatively small stage/PA speaker for my band—one with enough bass extension that our bass player could plug directly into the mixing board and be heard through the PA system if necessary. After looking through a few catalogs, I decided that the Swan 305 would make a good choice for the woofer section of the PA speaker because it offers long X_{MAX} and good power handling and is cheap enough that I could buy four (or more) without a major investment.

I have both Boxmodel (v. 3.0) and Topbox (v. 2.2), which I bought because they have non-overlapping capabilities (one provides driver-excursion curves; the other does bandpass box modelling). Their predictions for box volumes for the Swan 305 differed substantially, however. When I entered the necessary parameters (for a single driver) into Boxmodel, it calculated V_b = 66.181, max. SPL = 113dB, and F_3 = 35.71Hz (vented box), whereas Topbox calculated V_b = 1441, max. SPL = 112dB, and F_3 = 25.5Hz (vented box).

After much puzzling, I discovered that part of the reason that Boxmodel and Topbox gave me such different answers regarding the Swan 305 was that I was comparing very different drivers. The Swan 305 specifications in the database that comes with Boxmodel are quite different from those listed in the May '95 version of the Madisound catalog. In particular, the electrical Qs are much different (0.34 versus 0.4).

I ran the calculations in Boxmodel again using the catalog specifications and got V_b = 126.691 and F_3 = 27.2Hz (max. SPL unchanged). These values are much closer to those produced by Topbox (1401 and 25.5Hz), but are still far enough apart that I'd like to know what's different about the models the two programs use that results in their not producing the same values when they're given the same input. Could Dr. D'Appolito help me out here?

Jay Doherty
mhcarter@ix.netcom.com

Contributing editor Joe D'Appolito responds:

Mr. Doherty compares designs he gets with Boxmodel and Topbox loudspeaker-design programs when using parameters for the Swan 305 loudspeaker and asks for a possible explanation for the differences he gets. I assume both programs are using the same driver parameters: for Boxmodel, V_b = 126.7 and F_3 = 27.2; for Topbox, V_b = 140 and F_3 = 25.5.

Both Boxmodel and Topbox accept free-air driver parameters as input data. When such parameters are measured in free air, *there is essentially no acoustic loading on the diaphragm. When placed in an enclosure, however, there is an increased mass reactance loading on the cone, because the front and back waves are now isolated from each other. Air particles in the immediate vicinity of the cone tend to move with the cone, thereby increasing its effective mass. This increase in mass loading lowers driver-resonant frequency in the enclosure relative to its free-air value and raises its electrical Q.*

Topbox computes the mass reactance loading, corrects f_S and Q_E, and computes an optimum enclosure for the corrected parameters. To the best of my knowledge, Boxmodel does not make this correction. Assuming both programs are aiming for a quasi-Butterworth alignment, Topbox will generally give a larger box volume and a lower tuning frequency. The mass reactance loading is a significant factor for the larger woofers. For 12" and larger drivers, this loading can be as much as 10% of the driver cone mass.

PRAISE THE XVR-1

I very much appreciated Fred Janosky's article on building the XVR-1 crossover (*SB* 2/96). I built it in one weekend, with the e-mailed help of the author, who gave me some component values I could not figure out myself.

More importantly, this is a superb-sounding piece of equipment. It lives up to everything the author says in the original article, with simplicity and elegance.

I would also like to thank the proprietor of Meniscus, who first suggested a year ago that I try a Dynaudio woofer in a cabinet design for which he sent me the plans. These subs really kick!

I am using the XVR-1 in a system made up of the subwoofers, a pair of Klipsch KT-LCR shielded satellite speakers, a former Dyna Stereo-70 modified to do 15W/ch in triode configuration, and a B&K 100W/ch amp for the woofers. The Dyna really sings now, since it is freed from having to push those 15W into the below-80Hz region.

I built the XVR-1 with "standard" 80Hz third-order slopes for the lows (plus some "custom EQ," +6dB at 32Hz), but with second-order filters at 80Hz for the highs. The Klipsch speakers (rated at 92dB efficiency) are quite good down to 40Hz by themselves.

I also installed a pair of 0.047 capacitors into C27, and a quick listen tells me they are beginning to roll off somewhere around 100Hz with the tube amp. I will investigate that more later.

The best part is that I have achieved what I originally set out to do, which is create a system that has something near the dynamics of pro-sound speakers (I have some experience in that area), while retaining the detail and clarity of home "high-end" stuff.

Larry DiGioia
larryd@interramp.com

Fred Janosky, XVR-1 designer, responds:

We have received many favorable comments from SB *readers all over the world. Many of them mentioned that XVR-1 is exactly what they need for their biamplified loudspeaker projects. We are very pleased to make a useful contribution to the speaker-building/audiophile community.*

Because of the substantial investment we made for professional CAD work for the XVR-1 printed circuit board design and layout, we have chosen not to supply the board foil pattern. We believe that the article gives much useful design and application information, while offering readers a source for a complete kit at a very reasonable price for XVR-1's high level of quality.

AIRR ON A POWERMAC

In Julian Bunn's article, "AIRR: Anechoic and In-Room Response Measurement" (*SB* 8/94, p. 10), the amplifier is connected both to input and output on the soundcard. Is the input needed when using the AIRR? With games that use SoundBlaster, I think it will work if I can manage with one microphone input and one line output, but if I need a second input, I am in trouble.

I bought the Mac SLM and found it nearly useless for frequency measurement. The graph is very small. It is not scaleable, nor can you limit it to a portion like 20-200Hz. The only way to export it is with a screen dump! And worst of all, you get only the graph—no numerical values are available. Even shareware programs like Spectrogram also provide the results as a textfile, which can then be opened by Deltagraph, CricketGraph, or whatever. So now I am thinking of using SoftWindows and AIRR. Please advise.

Thomas H Eberhard
Stockholm, Sweden

Speaker Builder BACK ISSUES

1981 A Testing Unit for Speaker Parameters • Variable-Volume Enclosure • Thiele/Small Theory, Pt 1-3 • Easy to Make Enclosure Using Concrete Blocks • The Tractrix Horn: Good Dispersion From an Old Design • Diffuser Port for Small Boxes • Mini-Speaker Made From PVC Tubes • Closed vs. Vented Box Efficiency • Interview with P.G.A.H. Voigt • Dual 8" Symmetrical Air Friction Enclosure • Thiele/Small Calculator Computation • Thiele/Small Parameters for Passive Radiators •

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1983 Building the Two-Way Dynaudio • A Crossover That Offsets Speaker Impedance • Using a Calculator for Box Design • Choosing a Calculator • A Simple Peak Power Indicator • A Small Horn Speaker •Audio Pulse Generator • How to Use Speaker Pads and Level Controls • An Easy-to-Build Voltmeter for Speaker Measuring • Nomograms for Easy Design Calculations • Interview with KEF's Raymond Cooke • Build a Simple Wattmeter • A New Type of Speaker Driver •

1984 Build an Aligned Satellite/Woofer System • BOXRESPONSE: A Program to Calculate Thiele/Small Parameters • Casting with Resins • A Phase Meter • An Interview with Ted Jordan • Building the Jordan 5 System • Self-Powered Peak Power Indicator • Closed Box Design Trade-offs • How to Build Ribbon Tweeters • Build a Dual Measurement Impedance Meter • A High-Power Satellite Speaker System • Build and Use a White/Pink Generator • Sound Pressure Level Nomographs •

1985 OUT OF PRINT, some single issues still available at $7 each •

1986 The Edgar Midrange Horn • Sand-Filled Stands • Crossover Networks: Passive and Active • 5-sided Boxes • A 2 x 4 Transmission Line • The Free-Volume Subwoofer • Notch Filters • By-Wiring the LS3/5A • A Push/Pull Constant Pressure System • Current and Power in Crossover Components • The Unbox (Egg) • Upgrade Speakerlab's S-6 Crossover • Measure Speakers with Step Response • A Gold Ribbon System • A Visit with Ken Kantor • A Tractrix Horn Design Program • Reviews: Audio Concepts "G"; Seven TL Midranges; Focal's Model 280; the Audio Source RTA-ONE.

1987 A Compact TL Woofer • Frequency Response and Loudspeaker Modeling, Pt 1-3 • A Manual Coil Winder • The Model-One Speaker • Designing a Listening Room • A Sixth-Order Vented Woofer • Tapered Pipe Experiments • Visiting Boston Acoustics • A Vented Compound System • The Octaline • Spreadsheets for Speaker Design • In Memoriam: Richard Heyser, Pt 1-2 • Using Non-Optimum Vented Boxes • Building Speaker Stands • Evaluating Driver Impedance Compensation • Tuning Bass Reflex • Six Woofers Compared • Bullock on Passive Crossovers: Alternate Bandpass Types • Fast, Easy Filter Calculations • A Mobile Speaker • Polk 10 Mod •

1988 Electronic Turns Counter • Two-Way Design • Minimus-7 Mod • Dome/Midrange/Tweeter Array • Plotting Complex Impedances • A Driver Design Primer • A Cabinet Primer • Tuning Up Old Systems • Low-Cost AR-3 Upgrade • Electronic Time Delay • Enclosures Shapes and Volumes • Minimum-Phase Crossovers • Spot Sound Absorbers • How to Add a Subwoofer • The Swan IV System • Sub-Bass Power Boosting • The Unline: A Short TL • Active Filter Computer Design Program • Low-Cost Two-Way Ribbon • Amp-Speaker Interface Tester and Construction Plans • The QB_3 Vented Box is Best • A Pentagonal Box System • Keith Johnson Profile • Sheathed Conductor ESL • A Symmetrically Loaded System, Pt 1 • Ceramic Enclosure • Inductance Measuring Technique • Polk 10 Mods •

1989 (4 Issue Set: VERY LOW STOCK) The Audio Laboratory Speaker System • A Passively Assisted Woofer • Digital Filter Tutorial • The Listening Arc Alignment • Small IC Power Amp & Crossover • Easy Surround Sound • Building Speaker Spikes • An Isobarik in a Thunderbird • Sheetrock Cabinetry • A Picket Speaker • Servo-Controlling AR-1 • Silent, Safe Muting System • Equalizing the Klipsch Cornwall • A Test Switcher • Visiting the Klipsch Kingdom • Rehab for Kitchen Music • Spreadsheet Design • A Subwoofer/Satellite System • Impedance Measurement as a Tool • Practical Passive Radiators • A Symmetrical Dual Transmission Line, Pt 1 • The Microline • A Voice Coil Wheatstone Bridge • Tweeter Q Problems •

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1991 Students Building Systems • Servo Subwoofers • An Apartment TL • L-R Crossover for the Swan IV • More or Less Power • New Guidelines for Vented Boxes • The Pipes • Macintosh's Wave and Sound Programs • Creating Professional Looking Grilles • Octaline Meets D'Appolito • Using Radar to Measure Drivers • Deep Bass for GMC • PSpice LF Response Calculating • Pipe and Ribbon Odyssey • The Delac S-10 • Infrared Remote Volume Control • Backloaded Wall Horn Speaker • Mod for the Minimus 7 • Simplifying Cabinet Assembly • Fibrous Effects on TLs • The DOALs • Loudspeaker Cable • Speaker to Ear Interface • Speaker Sensitivity to Errors in T/S Parameters • TL Speaker Evaluation • Cable and Sound • Kit Reports: Little V; Audio Concepts' Sub-1 •

1992 Rumreich on Box Design & Woofer Selection • MLSSA • Double-Chambered Reflex by Weems • Active Crossover and Delay • Electrical Circuit Bandpass Enclosure • A Dreadnaught System (satellite swivels) • Designing Real-World Two-Way Crossovers • 20-foot Ribbon Dipole Speaker • Biamping the Sapphire II • Capping Passive Crossovers • A High Quality Speaker Cabinet • 1/3-Octave Noise Source • Disappearing Loudspeaker • The A&S Soundoff Winner, Pt 1-2 • Alignment Jamming • Marc Bacon's "Danielle", Pt 1-2 • Double-Chambered Isobarik Bass • Ferguson's Pickup Installation • Electronic Counter for Coil Winding • Oakley on Speaker Placement • Making Your Room Hi-Fi, Pt 1 • More on Dust Caps • Spreadsheet for Nonoptimum Vented Box Design • Acoustic Resistance Tuned Enclosure •

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Dr. Julian J. Bunn responds:

The SoftWindows products from Insignia Solutions run on a Macintosh computer and emulate a PC running Microsoft Windows. After making a study of the available documentation from Insignia on their Web server (http://www.insignia.com/), it appears to me that support for PC applications that require a SoundBlaster-compatible card is limited to those written for the Windows sound system. AIRR is a DOS application that makes direct use of DMA and DOS interrupt vectors to access the SoundBlaster card.

SoftWindows is thus unlikely to be capable of running AIRR in an emulated Windows DOS-box. If your heart is set on a PowerMac, then you may want to consider buying a DOS compatibility card that plugs into the PowerMac and then allows you to switch between the two native operating systems. You could then insert a SoundBlaster card in a vacant slot on the compatibility card.

The AIRR diagram to which you refer shows connections from the SoundBlaster card to an amplifier. These connections are only necessary if you wish to measure the frequency response of the amplifier itself (perhaps to subtract that response from that of the loudspeaker). Otherwise, and in the vast majority of cases, all you need is a connection from your microphone to the mike socket on the sound card, and a connection from the line-out socket on the sound card to the loudspeaker under test (the SoundBlaster 16 is quite capable of driving most loudspeakers directly to the required levels).

Since the AIRR article was published, several improvements have been made to the software, and I would like to take this opportunity of describing them briefly. The impulse-generation and response-measurement method now uses DMA, which allows guaranteed sampling rates from 8–44kHz regardless of the CPU speed of the PC. You can now directly select the DMA sampling rate required, which is useful, for example, when measuring response at lower frequencies.

The time-domain data can now be convoluted with a half-Hanning window, which reduces aliasing effects. A new display is available that plots the phase of the system response, and this can be adjusted with a user-specified delay.

A new format for the output data file includes the phase information, and this format is now understood by the latest version of CALSOD. Finally, some cosmetic improvements have been made to the Waterfall plot

Speaker Builder BACK ISSUES *Continued*

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and the appearance of the AIRR display.

Several people have asked me about plans for a Windows or MLS-capable version of AIRR. I have no current plans for a Windows version, but AIRR does run perfectly well in a DOS box under Windows95, and an MLS version is currently in the final stages of development. It uses a software trick to get around the apparent lack of simultaneous play-and-record on the SoundBlaster 16-bit cards.

Dr. Victor Staggs responds:

The graphs from Mac SLM are many times larger than the tiny ones provided by some of the analog measurement equipment of the past, which were only about 2" × 4". It is the largest size that will fit on a PowerBook® screen and still leave room for the controls. If you need to scale it, you can save a screen snapshot, open it in SimpleText, and cut out the part you want. Then you can paste it into MacDraw®, ClarisDraw®, ClarisWorks®, or any other graphics program, and scale it to your heart's content. I have tried this, and it works.

I kept Mac SLM's plot to a fixed size to avoid some very complex programming and because it draws in real time, which most other graphics programs do not. The frequency range is not changeable because the resolution is determined by the octave band resolution and by the length of the measurement period, and expanding the scale will not produce more detail. Choosing a low sampling rate will increase the sampling period and the low-frequency resolution, and then you will see more detail and be able to expand it and edit it as above.

When you push the Save button on the control panel, Mac SLM does save the numerical data. The file is in ASCII format, the creator is ORBs (note the mixture of upper and lower case), and the file type is SPCT. There are utilities (such as ResEdit) for changing the file type to TEXT. You can edit this file with SimpleText and then import it into MathCad® or a compatible spreadsheet program and do whatever you wish with it. If there is enough demand, I can add an option to Mac SLM to save the file as TEXT.

The first line of the file contains the name you have given it and the number of frequency intervals. Then there is a table of two columns, with the center frequency of each band in the first column, and the spectrum level in the second. This format is observed even if you display the spectrogram in spectral-density form in Mac SLM.

I use the data in my own software that makes least squares fits to it. This second program is not truly user-friendly, and I have no plans to offer it for sale. However, I do have an oscilloscope program running, and I *hope to add anechoic and impedance-measurement capability to the program suite. These will be PowerMac®-only applications. An integrated measurement and design system would be ideal, but it has too large a development overhead.*

SOFTWARE SEARCH

I am looking for software, or developed templates, for calculating the throat acoustical impedance and reactance characteristics of exponential horns of finite length. I am also interested in the same information for Hypex horns for "T" constants of 0.5 to 1. I use Mathcad and Excel 4.0 on my Mac computer.

Either of these programs can do the calculations I need, but I face two problems:

1. I don't know how to simplify with confidence the generalized horn equations by Harry F. Olson, (Acoustical Engineering, 1964). For example, Olson's equations numbered 5.12 and 5.80 through 5.85 have me buffaloed. When I try to use them to achieve impedance traces shown by Olson for specific horns (e.g., Sec 5.28, Fig. 5.11D), my figures are wrong by several hundred percent.
2. I have difficulty overcoming the learning curve associated with using Mathcad. Attempts to query Mathsoft (copyright owner of Mathcad) on the availability of templates have proven unproductive.

Do you know of any user-friendly software that offers templates in attacking acoustic horn equations, or perhaps an individual who could give me guidance? Also, do you know of any textual source that shows a spread of simplified equations that were derived from the generalized acoustic equations?

My interest in this area stems from having constructed four close copies of the Klipschorn from the ground up. The throat development of the first two followed comments Mr. Klipsch sent to me by letter; the second two followed his published comments suggesting expansion by the square of the distance from the throat. Both patterns worked very well. My next project is to construct two or more non-corner horns, and for this I need to start with some impedance calculations in hand.

H. Donn Hooker
Tilghman Island, MD

Contributing Editor Bruce Edgar responds:

I am not aware of any software packages for the acoustic horn impedance calculations. I suggest that you try to find someone local *with a math or physics background to help you sort out the vagaries of the equations. For straight full size midrange horns with compression drivers, the impedance formulas seem to reproduce the experimental results. But it is very hard to reproduce the experimental results for bass horns, because there are many other factors involving folding, mouth size and relative location with boundaries, structure resonances, and so forth.*

My experience suggests it is better to work out a practical design, construct it, measure the results, seek out corrective measures to correct deficiencies, and, in general, learn from your results. In each case, I've tried to push one design parameter beyond the accepted limits to see what the results are, whether good or bad. The understanding gained from an experimental approach is far more valuable for the individual constructor.

CROSSOVERS, BEGONE!

After ordering a sample copy of your magazine, I was able to borrow my neighbor's B&W 802 speakers. A-B listening to them and my old JBL L44 Lancers that I bought at Goodwill confirmed what I had long questioned: how come my JBLs sound so good with a one-element crossover and a cone tweeter? What am I missing?

Well, I always knew that I was missing the low end, but it wasn't much in most recordings, especially after I boosted the bass a notch. I should mention that my receiver is a Pioneer VSX-901S. I actually preferred my JBLs to the B&Ws! The difference I attributed to my woofer-midrange's lack of any crossover elements.

That startling knowledge gave me the impetus (and courage) to rip out the crossover in my Audio Concepts AV-1 that I had built two years ago. I bought the kit because, after all, how could I design a crossover without the computer programs and hours of listening tests? The AV-1 never sounded right (muffled), and when I played Michael Nesmith's "Tropical Campfires" (recorded in Dolby Stereo), it would flutter at some points even though I had Dolby Pro-Logic set on Normal. Now, the voices it reproduces sound natural, as though there were a live human being in my room!

This experience makes me question whether speaker builders ever listen to their designs without a crossover to compare with their crossover design. I read somewhere that the ability of a driver to reproduce a single frequency is not the same as its ability to reproduce music consisting of a wide range of frequencies at once! That statement made sense to me, and speaker designers should keep that in mind. Of course, the consumer might feel ripped off

AD INDEX

if he buys just a box with mounted drivers!

At any rate, I now know that I prefer speakers without crossovers, and your articles aren't so useful, since they all contain them and crossover design seems to be the main discussion topic of your magazine. After all, how can I build a speaker without spending a lot of time (and money) designing the crossover?

William Fouste
Beaverton, OR

Mike Dzurko, of Audio Concepts, responds:

It's a big world, with room for diversity of opinions. If Mr. Fouste prefers speakers that have a big boost of energy in the upper midband, that is his choice. At ACI, our goal has been to design speakers with a natural and accurate sound. Most of our customers agree that is what we have done. But Mr. Fouste has given me a great commercial idea: how about a "retro" line of ACI speakers that will sound much like the old forward-sounding JBLs of the '60s? Instead of spending countless hours developing speakers with a linear response, I'll just throw some cones in boxes and away we go! For more on our latest designs (retro not!), we invite you to visit us at http://audioc.com.

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Pair Altec 604-8K, $750; pair Altec 414-8E 12″, $200; pair JBL 2425, $275; pair JBL 2415, $150; pair JBL 2441 (pro version of 375), $550; UREI 6260 amplifier, 170W/8Ω/channel, $500; Crown DC-300A amplifier, $400; BGW 7000 amplifier, $325. Kent Elliott, 3143 W. 46th Ave., Kansas City, KS 66103, phone/FAX (913) 677-1824.

JBL 2245H 18″ woofer with 8′3″ heavily-braced vented cabinet & EQ/bridging device that transforms a stereo amp into a mono amp with quadruple the power, response down to 20Hz, $800. Angel Rivera, 7804 22nd Ave. West, Bradenton, FL 34209-5208, E-mail: arivera@acomp.usf.edu, (941) 792-3870.

Cary SLA 70B signature amp, 60W/channel, oil caps, black ($1,850), $1,350; ProAc studio 100 monitors, oak, target stands ($1,625), $1,250; Focal 7K011-DBL drivers, kit plans ($175), $130. Mr. Willes, (800) 227-6121, weekdays.

Technics (Matsushita) leaf tweeters, EAS 10TH400B, 2 lb magnet each. Mint condition, never used, $65 pair. Bill, (702) 647-2563, day & early evening PST.

Dyna ST-70 with new output Telefunken tubes, good cosmetics and electronics, some new parts including quad cap, $325; ReVox A77 MK II, good cosmetics, cleaned and tuned, I paid $350, like to break even; pair Dyna MK III output transformers, guaranteed perfect, no rust or scratches, $225. Lloyd Foster, (617) 232-2887.

2 pairs AR3a and 1 pair AR3, beautiful walnut cabinets, all drivers in excellent condition, best offer. Steve Reasoner, (614) 262-5958.

Acoustic Monitor 4; Audio Authority Switchers; Athena ML 1/5/10 case; Bryston 10B; CBS STR-140; Doutech-1000; Eico ST-70; Electro-Voice EV30W 30″ subwoofer (NIB); Heathkit AD1308/1309; Infinity RS4.5; JBL B380/BX63; 4435; KEF 107/2 Rosewood; KUBE; Klipschorn; Nakamichi T-100 audio analyzer; Pioneer SF-500, SF-850; RTR ESR-15; Quad ESL; VMPS cabinets; best offer. John Ng, (408) 737-2980.

LMS (Loudspeaker Measurement System) by LinearX, new PC board with calibrated microphone, latest version of software (v3.6), and latest manual. Lists for $1,495, asking $850. Joe D'Appolito, (508) 470-3822.

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Marchand BASSIS; LS3/5A speakers; Audio Source AMP-1; GeoDisc or other cartridge alignment tool. Angel Rivera, 7804 22nd Ave. West, Bradenton, FL 34209-5208, E-mail: arivera@acomp.usf.edu, (941) 792-3870.

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By Dick Pierce

Knock, knock!

"Come in, Jimmy!"

"Gosh, thanks, Mr. Wizard. What are we going to talk about today?"

"Well, Jimmy, I thought we'd take a look at coaxial speaker cables."

"Wow, that sure sounds impressive, Mr. Wizard! What's it all about?"

"Well, Jimmy, a lot of folks have been talking about using coaxial cable for speakers. And especially about matching the impedance of the cable to the speaker."

"Golly, I thought speakers had an impedance that varied with frequency, Mr. Wizard. How are you going to match that?"

"Simple, Jimmy! Just pick a frequency. Now take that impedance and match the cable to that! If that frequency gives a number you don't like, just choose another!"

"But, Mr. Wizard, what about all those other frequencies?"

"Well, Jimmy, someday you'll understand as much as those very smart folks at Monster. They make wires that carry each group of frequencies separately!"

"Gosh, that's keen! But how do the frequencies know which wire to take?"

"Er, well...we're getting off the subject, Jimmy. Those aren't coaxial cables. Now, way back a long time ago, in the late '70s, there were coaxial speaker cables."

"Nooo, really? Did they have 'stereos' that long ago, or just '78s?"

"Gracious no, Jimmy. They had the very best sound you could possibly get: vinyl LPs! And they were stereo, too. On 'both' sides, not like those grainy, etched CDs you kids have now. Yessir, way back then they made these coaxial speaker cables from folks like Mogami, with an impedance of about 9Ω. And there were also other low-impedance designs, too, from folks like Polk, Discwasher, and Audiosource."

"Wowie zowie, Mr. Wizard! I thought all these fancy cable things were all new designs! So what happened to all these cables?"

"Well, Jimmy, they tended to fry a lot of amplifiers back then. Those poor amps just couldn't handle the extra capacitance of these cables. So, the companies bailed out quickly at their lawyer's advice."

"Gee, Mr. Wizard, where did you learn about this stuff?"

"From reading, Jimmy. Try looking in *Boston Audio Society Speaker* around December '78, March '79, or April '80. Or some of the articles by R.A. Greiner in the May '90 *JAES*. Even Nelson Pass had a good article in *Speaker Builder* 2/80. These coaxial cables are really technical sounding, and 'impedance matching' sure sounds like a good thing to do! You wouldn't want to 'mismatch,' would you?"

"OK, Mr. Wizard. But, you know, I learned in school that impedance matching in audio systems doesn't make any sense, either for interconnects or speakers. 'Cause, gosh, the cables are soooo short compared to the wavelengths involved. Anyway, this simple two-wire cable I'm using works just fine, and costs way less, too! Gotta go! I've got some spare cash left over from not buying that coax cable, so I'm taking Sally to the movies! See ya next Saturday, Mr. Wizard!"

YOUR HELP IS NEEDED

Last November Dick Pierce, an independent speaker consultant living in Pepperell, MA, and a frequent author on loudspeaker issues as well as a programmer of unusual capabilities, was suddenly stricken with acute necritizing hemmoragic pancreatitis and underwent emergency surgery. He was transferred to the intensive care unit at New England Medical Center, Boston, where he remained in a coma for 48 days. He was hospitalized for an additional two months and cared for much of the time by his wife Linda, who is a graduate nurse.

Pancreatitis is an almost always fatal disease with a survival rate for those under 40 of 1%. Many of his friends thought several times we were going to lose him. As you may imagine, the medical bills, even with insurance, have become astronomical in size, and since neither Dick nor Linda have been able to work at their regular pace, finances for the Pierce family have deteriorated in a major way. Dick is still unable to work and is slated for more physical therapy and possibly additional operations later this year.

I have taken the liberty of setting up a fund at our local financial institution, Granite Bank, Peterborough, in the name of Dick and Linda Pierce. I invite Dick's many friends and associates to join me in contributing as generously as you can (and every dollar counts) to help in some small way to alleviate their financial woes. Please make checks payable to Richard and Linda Pierce, c/o The Pierce Fund, Audio Amateur, Inc., PO Box 576, Peterborough, NH 03458-0576. Thank you in advance for any help you may be able to give.

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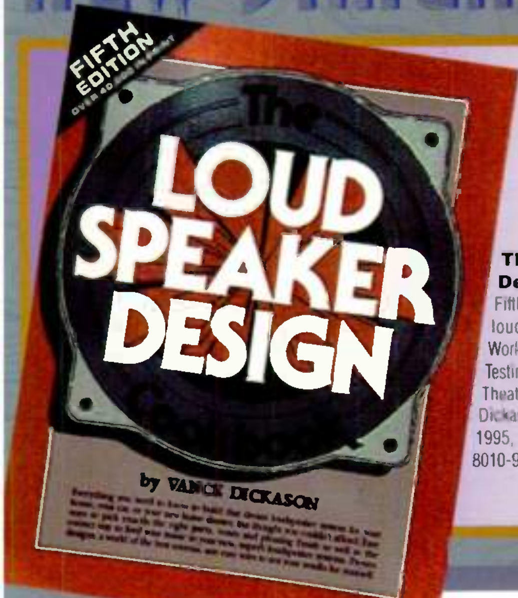
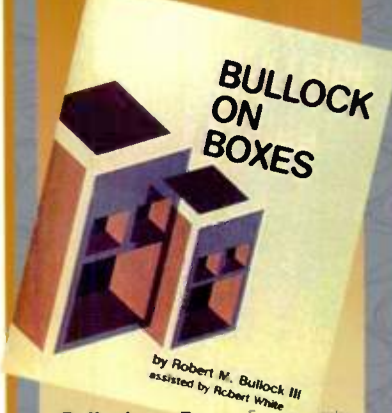
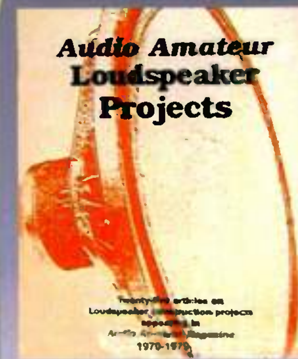


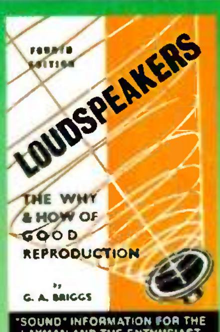
The Loudspeaker Design Cookbook Fifth edition of world's best-selling loudspeaker book. How Speakers Work; Enclosures; Drivers; Crossovers; Testing; CAD Software Reviews; Home Theater; Car Audio; much more. By Dickason. FOT #2102. Softcover, 5E 1995, 165pp., 8.5x11, ISBN 1-8825-8010-9. **#BKAA2-V $34.95**



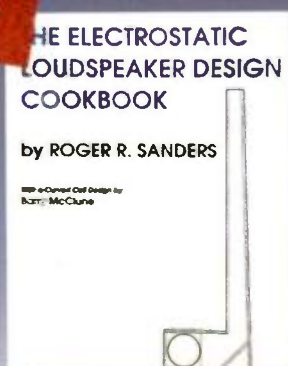
Bullock on Boxes Famous speaker guru's invaluable guide to designing and building vented box systems based on T/S models. Background theory as well as host of related information, including computer modeling techniques. Originally appeared in Speaker Builder magazine. By Robert Bullock. FOT #2113. Softcover, 1991, 72pp., 8.5x11, ISBN 0-9624-1915-X. **#BKAA8 $10.95**



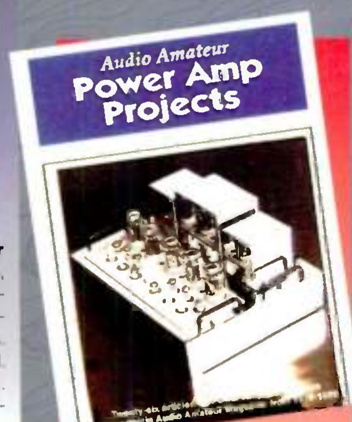
Audio Amateur Loudspeaker Projects Collection of the 25 best speaker articles in Audio Amateur magazine during the 1970s. Rich source of theory, practice, and design. Electrostatic and transmission-line pieces especially interesting and useful. By the editors of Audio Amateur magazine. FOT #2101. Softcover, 1985, 135pp., 8.5x11, ISBN 0-8338-0193-7. **#BKAA1 $20.00**



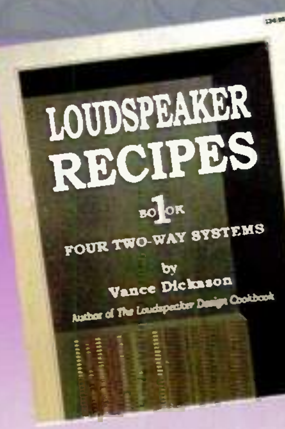
Loudspeakers: The Why and How of Good Reproduction Easy-to-read concise introduction to audio basics with special attention to loudspeaker characteristics. Classic text last revised in 1949. Comprehensive summary of early audio technology by acknowledged pioneer G.A. Briggs. FOT #2110. Softcover, 1949 1990, 88pp., 5.5x8.5, ISBN 0-9624-1913-3. **#BKAA5 $6.95**



The Electrostatic Loudspeaker Design Cookbook Construction advice, interface plans, drive requirements, power supply and crossover suggestions, as well as guidance for supplemental low-frequency systems. Issues, tradeoffs, technical questions explored. By Sanders, with McClune. FOT #2119. Softcover, 1995, 202pp., 8.5x11, ISBN 1-8825-8000-1. **#BKAA20 $34.95**

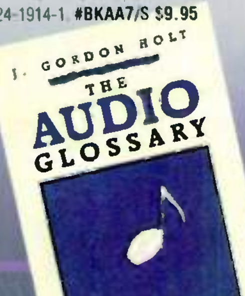


Audio Amateur Power Amp Projects Profusely illustrated handbook features 26 of best articles on power amps from Audio Amateur, 1970-89. Authors from six countries offer array of designs of many different types. Predominately solid state. By the editors. FOT #2132. Softcover, 1996, 205pp., 8.5x11, ISBN 1-8825-8008-7. **#BKAA40 $19.95**



Loudspeaker Recipes: Book One Computer-aided speaker design techniques for four two-way systems. Loudspeaker Design Cookbook author identifies issues, explores compromises, rationalizes solutions in real projects. Valuable insight even if you don't use CAD. By Dickason. FOT #2125. Softcover, 1994, 112pp., 8.5x11, ISBN 1-8825-8004-4. **#BKAA30 $24.95**

The Audio Glossary (Softcover) 1,900+ technical and subjective terms explained by founder of Stereophile magazine in precise yet at times humorous fashion. **#BKAA7/H ($17.95)** is hardcover edition. **#BKAA7/L ($30)** is limited, signed, hardcover edition with gold-embossed cover, dust jacket. By J. Gordon Holt. FOT #2112. Softcover, 1990, 152pp., 5.25x7.5, ISBN 0-9624-1914-1. **#BKAA7/S $9.95**



Electrostatic Loudspeaker Design & Construction How-to book and informative text gives step-by-step construction details, operating principles, sound parameters, performance considerations. Comprehensive, easy to follow, intended for audiophiles, musicians, craftsmen, beginner to expert. By Wagner. FOT #2131. Softcover, 1987 1993, 243pp., 7x9.625, ISBN 0-9624-1916-8. **#BKAA39 $19.95**

NOT PICTURED . . .

The World of POOGE Reputed acronym for Progressive Optimization Of Generic Equipment, POOGE stands for best traditions of audio tinkering. 7 articles from Audio Amateur magazine upgrade units such as Marantz 7C, Hafler DH-200, Magnavox CDB650, Philips DAC960. By various. FOT #2121. Photocopy, 1981-85-88-92-94-96, 110pp., 8.5x11. **#BKAA25 $24.95**

Of Mockingbirds and Other Irrelevancies Collection of Audio Amateur magazine editorials on audio, the passing scene, technical and ethical issues. Contentious, prophetic, philosophical, entertaining. For the audiophile who thinks he has everything. By Publisher Edward T. Dell, Jr. FOT #2114. Hardcover 1993, 100pp., 5.75x8, ISBN 0-8338-0208-9. **#BKAA9 $9.95**

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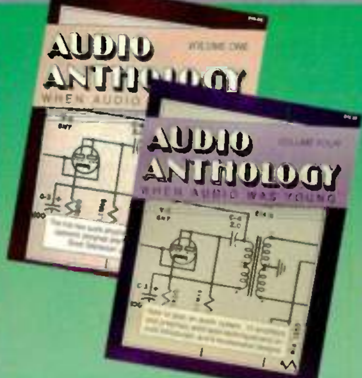
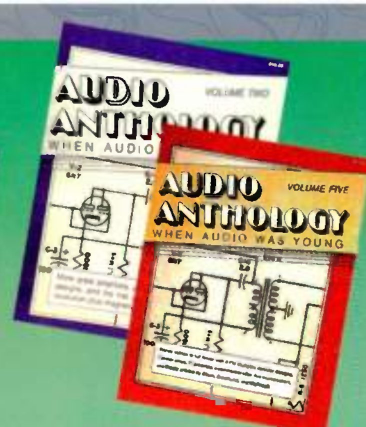




Audio Anthology Vol. 1 Provides a fascinating survey of the first audio amplifiers, preamps, tuners, and speakers designed after the long delays of the Depression and WWII. Features 38 of the best articles in Audio Engineering magazine, 1947-50. All volumes edited by McProud. FOT #2103. Softcover, 1950 1987, 124pp., 8.5x11, ISBN 0-8338-0195-3. **#BKAA3/1 $16.95**

Audio Anthology Vol. 2 Taken from Audio Engineering, 1950-52. 45 articles cover more great amp, preamp, and speaker designs, as well as magnetic tape recording aids. First glimpse of arriving stereo revolution. FOT #2104. Softcover, 1952 1989, 124pp., 8.5x11, ISBN 0-8338-0197-X. **#BKAA3/2 $16.95**

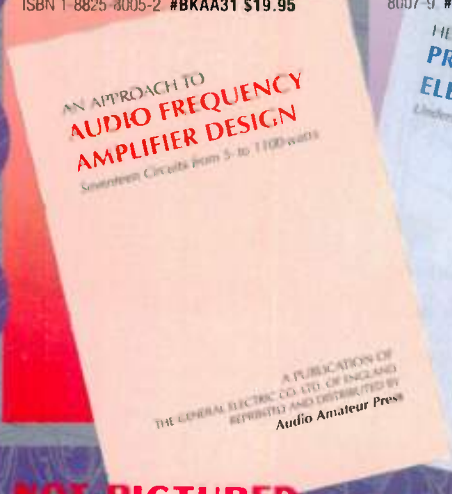
Audio Anthology Vol. 3 Anthology of 43 articles from Audio Engineering, 1952-55. Includes binaural recording techniques, 7 power amps, 18 preamps, and 12 loudspeakers, including 4 horns. FOT #2105. Softcover, 1955 1990, 124pp., 8.5x11, ISBN 0-9624-1911-7. **#BKAA3/3 $16.95**

Audio Anthology Vol. 4 34 articles from Audio Engineering, 1955-57, cover how to plan sound system, understand and maintain equipment. Solid state introduced. 12 amps and preamps, 6 loudspeakers. FOT #2106. Softcover, 1957 1991, 144pp., 8.5x11, ISBN 0-9624-1919-2. **#BKAA3/4 $16.95**

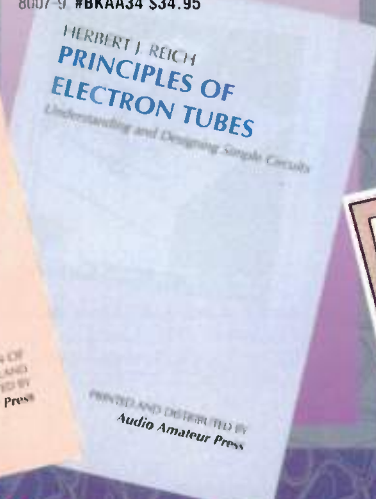
Audio Anthology Vol. 5 48 articles mainly on the shift from monophonic to stereo reproduction. 11 amps and preamps, 2 speakers, 2 crossovers. From Audio Engineering, 1958-59. FOT #2107. Softcover, 1959 1993, 144pp., 8.5x11, ISBN 1-8825-8001-X. **#BKAA3/5 $16.95**

Audio Anthology Vol. 6 The arrival of the transistor, along with stereo FM. 38 articles (four 2-part) from Audio (heretofore Audio Engineering), 1960-61, cover 8 power amps, stereo theory essentials, tape recording guidelines, phono arm tracking, and computers in audio. FOT #2108. Softcover, 1961 1994, 144pp., 8.5x11, ISBN 1-8825-8006-0. **#BKAA3/6 $16.95**

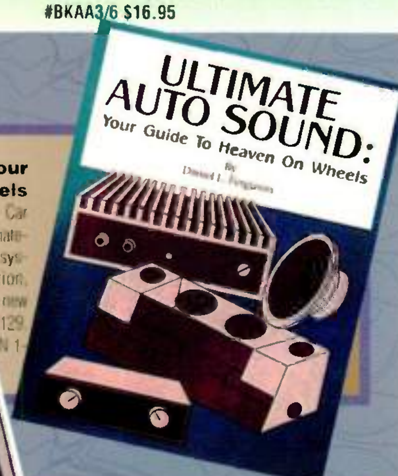
Audio Frequency Amplifier Design Most comprehensive tubed power amp design guide available. 9 chapters, 4 appendices cover Class AB and B power amps with supplies, and 2 preamps. From the famous research laboratories of the General Electric Company Limited, U.K. FOT #2126. Softcover, 1957 1994, 126pp., 6x9, ISBN 1-8825-8005-2. **#BKAA31 $19.95**



Principles of Electron Tubes All-time favorite from 1941 first served as text for beginners, today ranks as most comprehensive tube book available. Professor covers physics of tube operation, topologies and classifications of amplifiers, and literally everything in between. By Reich. FOT #2127. Softcover, 1941 1995, 398pp., 6x9, ISBN 1-8825-8007-9. **#BKAA34 $34.95**



Ultimate Auto Sound: Your Guide to Heaven on Wheels Improved, upgraded version of Killer Car Stereo contains twice as much total material, including updated information on system architecture, cabinet construction, crossovers, and installation, as well as new chapter on vans. By Ferguson. FOT #2129. Softcover, 1995, 100pp., 8.5x11, ISBN 1-8825-8009-5. **#BKAA37 $29.95**



Mullard Tube Circuits for Audio Amplifiers Do-it-yourself standby is complete guide to building eleven vacuum tube power and control amps, featuring fabled four-chapter tutorial on achieving best sound with tubes. First published in 1959 by Mullard, one of Britain's premier valve manufacturers. FOT #2123. Softcover, 1959 1993, 142pp., 8x10, ISBN 1-8825-8003-6. **#BKAA27 $16.95**

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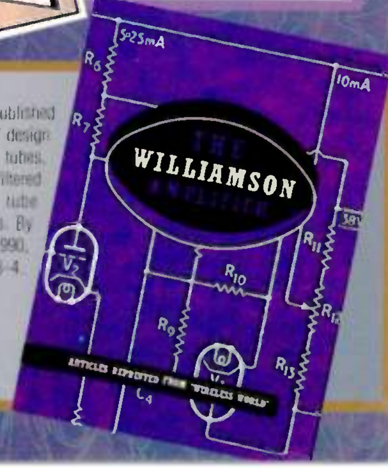
The Brute: Super Amplifier Stereophile magazine article photocopied by special permission describes construction of deluxe version of Dynaco Stereo 70 tube-type amp, beefed up by massive power supply and equipped with metering facilities for all voltages. A classic. By Dell. FOT #2120. Photocopy, 1966, 11pp., 8.5x11. **#BKAA23 $4.95**

Operating Features of the Audion Rare essay first appeared in 1917 Journal of the New York Academy of Sciences. Contains very first authoritative report on the triode vacuum tube's capabilities. Author was inventor of superheterodyne circuit, FM broadcasting, much more. By Maj. E.H. Armstrong. FOT #2122. Softcover, 1917 1993, 32pp., 6x9.5. **#BKAA26 $6.95**

Killer Car Stereo: An Easy Cure for Ho-Hum Auto Sound Provides quick, tested methods for upgrading auto sound. Easy-to-understand, hands-on advice for sedans, hatchbacks, pickups. By Ferguson. FOT #2109. Spiralbound, 1988, 118pp., 5.5x8.5, ISBN 0-9624-1910-9. **#BKAA4 $9.95**

The Williamson Amplifier Published by exclusive arrangement. Famous 1947 design uses excellent-quality push/pull output tubes, special output transformer, and highly filtered power supply. Unique insights into tube designer's problems and compromises. By Williamson. FOT #2111. Softcover, 1947 1990, 40pp., 8.5x11, ISBN 0-9624-1918-4. **#BKAA6 $4.95**



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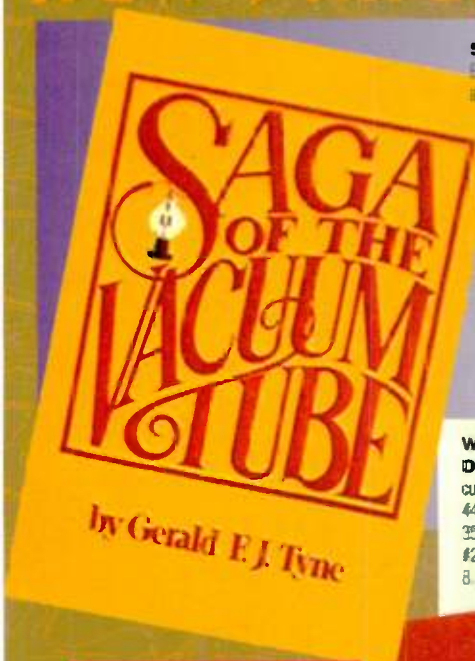
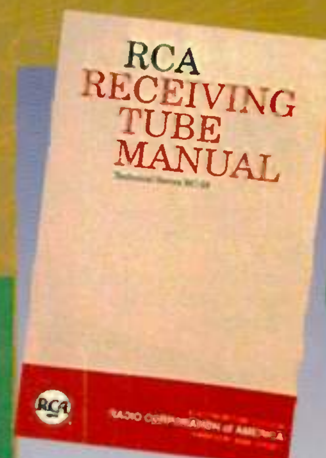


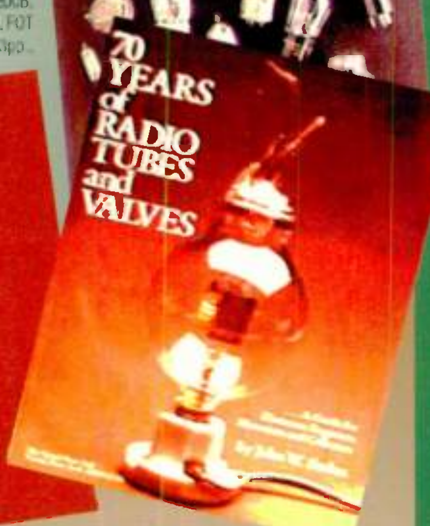
Saga of the Vacuum Tube Evolution of tube development. Photos and facts to help in identification of pre-1930 tubes. Histories of manufacturers. Very complete recounting of thermionic vacuum tube. By Tyne. FOT #2135. Softcover, 1977 1994, 494pp., 5.5x8.5, ISBN 0-6722-1470-9. **#BKAE1 $18.95**

75 Years of Western Electric Tube Manufacturing Former WE senior engineer covers early history of WE, complete listing of all WE tubes, including description, materials, equipment used in, parameters, dates of manufacture and discontinue. Over 750 tubes. By Magers. FOT #2140. Softcover, 1992, 144pp., 8.25x11, ISBN 0-9632-4401-9. **#BKAE5 $19.95**



RCA Receiving Tube Manual Receiving and picture tube outline drawings, characteristics, and basing diagrams. Reprint of 1959 RCA Technical Series RC-19. By RCA. FOT #2139. Softcover, 1959, 384pp., 5.375x8.375. **#BKAE4 $12.95**

Western Electric Tube Data Operating characteristics, curves, pictures, hard-to-find data for 44 unusual WE tube types (e.g., 300B, 350B, 205D). By Western Electric. FOT #2141. Softcover, 2E 1994, 253pp., 8.5x11. **#BKAE6 $17.95**



70 Years of Radio Tubes and Valves Superb illustrations and photos help describe the history of the receiving tube and the evolution of the home radio receiver. Fine source of tube dating and identification data. By Stokes. FOT #2132. Softcover, 1982 1992, 248pp., 8.5x11, ISBN 0-9115-7260-0. **#BKV1 $25.95**

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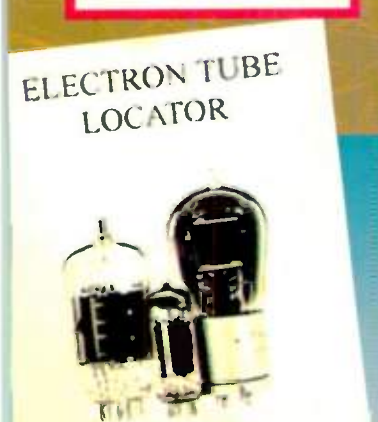
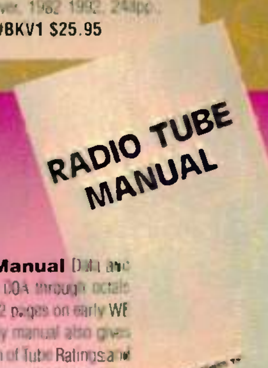
Tube Substitution Handbook Complete handbook of replacements for vacuum and picture tubes. Accurate, up-to-date, with complete instructions for three sections: vacuum tubes, picture tubes, tube basing diagrams. By Smith and Buchanan. FOT #2161. Softcover, 1992, 149pp., 6x9, ISBN 0-7906-1036-1. **#BKS30 $16.95**



Electron Tube Locator 12,000 different tube types with filament/heater characteristics, basing diagrams, and tube functions. Comprehensive listing of European and American receiving, transmitting, and industrial tubes also includes references to complete data on each. By Fathauer. FOT #2144. Spiralbound, 1994, 322pp., 8.5x11. **#BKAE9 $29.95**

RCA Transmitting Tubes RCA manual TT-5 reprint features outlines, technical data, typical circuits. Includes types up to 4kW plate input. By RCA. FOT #2145. Softcover, 316pp., 5.37x8.25. **#BKAE12 $12.95**



Radio Tube Manual Data and basing diagrams on 00A through octals and loktals includes 2 pages on early WE types. Reprint of early manual also gives concise Interpretation of Tube Ratings and Definition of Tube Terms (including amp classifications). Very handy. FOT #2143. Softcover, 1987, 39pp., 8.5x5.375. **#BKAE8 $4.95**

History of the British Radio Valve to 1940 Useful resource for dating and identifying early British tubes. Includes tube data and tube equivalent tables. Covers valve development in England from 1904-1940, includes sketches of major producers. By Thrower. FOT #2136. Softcover, 1992 1994, 213pp., 8.25x11.75, ISBN 0-9520-6840-0. **#BKAE2 $29.95**

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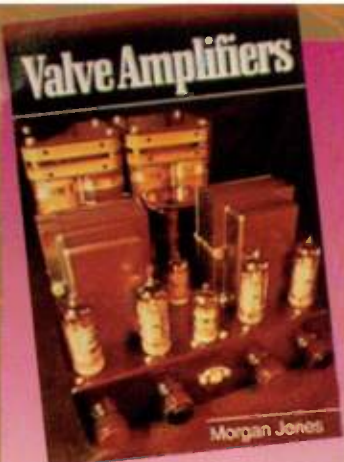
Principles of Power Practical guide to tube power amp design based on simplified method. Covers tube operation, circuit principles, amp classes, bias, push-pull, single-ended, front-end circuits. Includes complete designs using available transformers, tubes. 15-400W designs. By O'Connor. FOT #2152. Softcover, 221pp. **#BKAE19 $34.95**

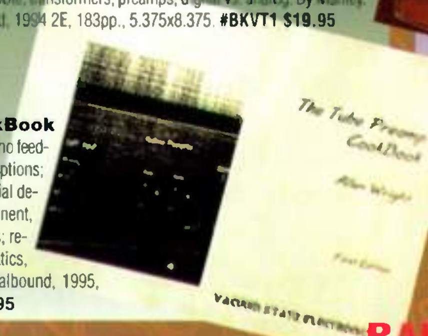


Valve Amplifiers Popular practical guide for tube users. Theory, circuit analysis, active devices, basic building blocks, component technology, power supplies, power amps, preamps. Practice: construction, safety, testing, fixing. Of value to both novice and expert. By Jones. FOT #2148. Softcover, 1995, 374pp., 6x9.25. ISBN 0-7506-2337-3. **#BKB40 $39.95**

The Audio Designer's Tube Register Vol. 1 Complete electrical, mechanical specs for 6C4, 6C10, 6CG7, 6DJ8, 6EU7, 6K11, 12AT7, 12AU7, 12AX7, 12AY7, 12BH7, 12DW7, 5751, 6922. Each type illustrated by eleven separate graphs based on new data. Cross references also provided. By Mitchell. FOT #2156. Spiralbound, 1995, 144pp., 8.5x11. ISBN 0-9628-1701-5. **#BKMC2 $17.95**

The Vacuum Tube Logic Book VTL Company's circuits, operating hints, as well as tube parameters, diagrams, measuring setups; inverse RIAA network; power conversion data; output classes; much more. Also broad discourse on speakers, cable, transformers, preamps, digital vs. analog. By Manley. FOT #2166. Softbound, 1994 2E, 183pp., 5.375x8.375. **#BKVT1 $19.95**

The Tube Amp Book Groove Tubes classic contains hundreds of pages of amp diagrams from more than two dozen makers. Also mods, maintenance, history, plus color photos. Weighs more than 2-1/2 lbs.! By Pittman. FOT #2154. Softcover, 4E 1993, 768pp., 5.75x8.25. **#BKGT1 $29.95**



The Tube Preamp CookBook Classic and exotic circuits; feedback/no feedback concepts; active/passive RIAA options; single-ended and balanced/differential designs; supplies; regulation; component, cable, tube choices; mods; upgrades; rebuilds; etc. Many diagrams, schematics, ideas. By Wright. FOT #2165. Spiralbound, 1995, 128pp., 12x8.25. **#BKVS1 $29.95**

Rohrenverstarker IN GERMAN. From Austria, most beautiful tube amp book in the world. No specs, no tests—just 215 gorgeous 4C photos of 65+ amps. Short description of each. Excellent 12-page explanation, history of tubes, tube amps. Appendix with addresses, tech data. By Kavsek and Kavsek. FOT #2146. Hardcover, 1995, 167pp., 9.625x12.5, ISBN 3-9014-6200-7. **#BKAO1 $59.95**

Tube Amplifiers ENGLISH VERSION of BKAO1. FOT #2147. **#BKAO2 $59.95**

Handbook of Radio, TV, Industrial & Transmitting Tube & Valve Equivalents Elaborate listings of commercial type equivalents; civilian, UK armed forces, US services wartime valves, US, European receiving valves; CRTs; radio, TV receiving valves; professional industrial and transmitting valves. Index of valve and tube types. By Babani. FOT #2160. Softcover, 1974 1994, 56pp., 5.75x8.25, ISBN 1-8988-0506-7. **#BKRV6 $7.95**

COMPREHENSIVE RADIO VALVE GUIDES

Book 1 Characteristics and base connections for English and US valves 1934-51. Covers frequency converters; screened tetrodes, pentodes; diodes; tuning indicators; regulators; thyratrons; rectifiers; triode amps; TV CRTs; US, UK subminiatures. By Bernard Babani Ltd. FOT #2155. Softcover, 1951 1994, 54pp., 5.75x8.25, ISBN 1-8988-0501-6. **#BKRV1 $7.95**

Book 2 Base connections from 1951-54. Also frequency converters, screened tetrodes and pentodes; diodes; tuning indicators; regulators and thyratrons; rectifiers; triode amplifiers; TV CRTs; subminiatures; single and twin output valves. By Babani. FOT #2156. Softcover, 1953 1994, 41pp., 5.75x8.25, ISBN 1-8988-0502-4. **#BKRV2 $7.95**

Book 3 English, European, US, 1954-56. Screened tetrodes and pentodes; output valves; TV CRTs; regulators, thyratrons. Also section on screened tetrodes and pentodes which appeared too late for classification. By Babani. FOT # 2157. Softcover, 1956 1994, 37pp., 5.75x8.25, ISBN 1-8988-0503-2. **#BKRV3 $7.95**

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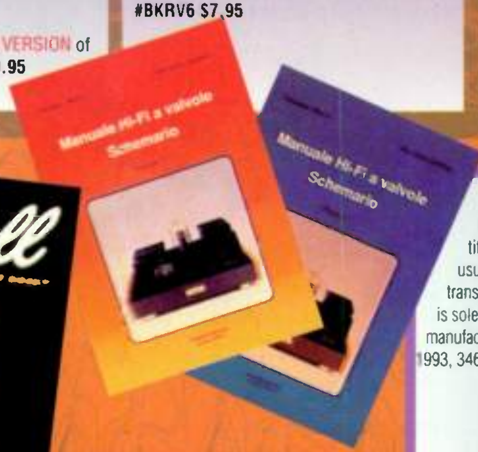

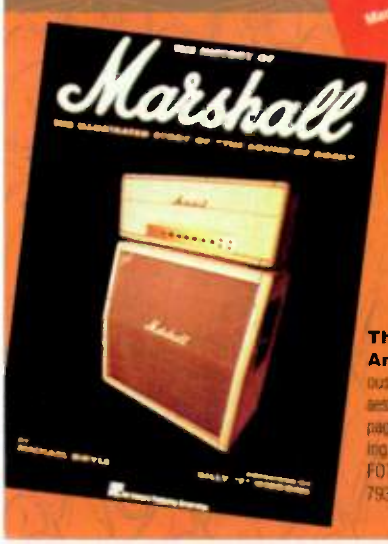

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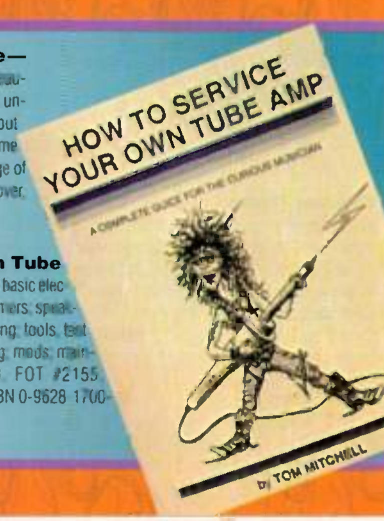

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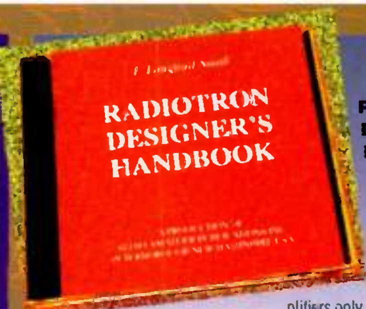

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