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Speaker Builder

THE LOUDSPEAKER JOURNAL

***Nancy MacArthur* builds a DICKASON/AUDAX TWO-WAY KIT**

A NEW CROSSOVER DESIGN GAME

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REVIVING THE CLASSIC KLH-9

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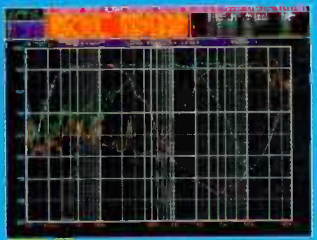
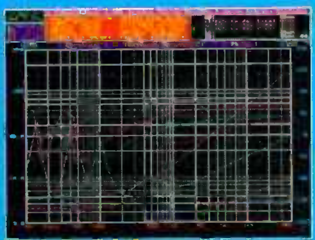


SPL Response

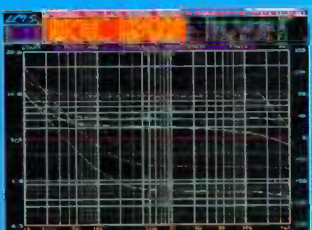


Impedance Curves

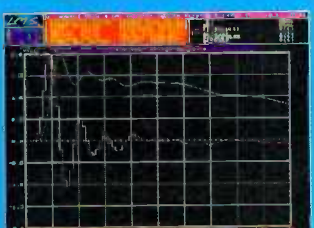
Nyquist Real/Imaginary

Polar SPL Response

Network Transfer Functions



Inductance/Capacitance



Impulse/Step Response

At last, there is a complete and affordable analyzer system that provides quality data suitable for real electro-acoustic engineering purposes. The LMS system provides a vast array of powerful computer based features which are specifically focused on the unique requirements of loudspeaker development and QC production testing.

Whether your application is professional audio, consumer stereo, car stereo, or contract installation, LMS is the perfect tool for development and testing of loudspeaker systems.

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- ✔ SPL/Z Combo Conversion
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- ✔ Polar Plot Conversion
- ✔ Tail Slope Correction
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- ✔ SPL Measurement Range: 35-125 dB-SPL
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LINEARX

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Good News

■ **COOL CABS**

Floyd T. Bear's handcrafted guitar cabinets are made from 11-ply, void-free Baltic birch and covered with ABS plastic. Other protective features include aluminum edging, steel corners and spring-recessed handles, 3" heavy-duty casters, and removable face plates. The cabinets, which can be customized with a choice of colors and drivers, range from entry level to professional touring quality. Floyd T. Bear, PO Box 972, Urbana, IL 61801, (217) 846-3138.

Reader Service #105

➲ **SOFTWARE OFFER**

For a limited time, Panasonic is offering Lenel MultiMedia Works CD-ROM software with its book-sized EAB-710P multimedia speaker system. The software package combines three multimedia utilities: Universal Player, Show Server, and Show Builder. The 2.25" × 10.5" × 10.6" EAB-710P has separate amplifiers for woofer and tweeter, double-folded horn-shaped acoustic tube, built-in subwoofer, and magnetic shielding. The units will fit on a desktop next to a monitor, and can also be stacked. Panasonic Communications & Systems Co., 2 Panasonic Way, Secaucus, NJ 07094, (800) 742-8086, (201) 348-7000.

Reader Service #110

■ **CHANNEL SURFING**

The Rialto, a 7-channel equalizer with built-in crossover, offers total control of room acoustical environments through left, right, center, two subwoofer, and two surround channels. The unit provides five custom-contoured equalizer controls for the surround channels, seven for the subwoofer channels, and eleven for the front and center channels. Module frequency programmability allows the 24dB/octave Linkwitz-Riley crossover to be customized to many different speaker combinations. AudioControl, 22410 70th Ave. W., Mountlake Terrace, WA 98043, (206) 775-8461, FAX (206) 778-3166.

Reader Service #107

■ **FRONT-END SERIES**

A new series of front ends for a variety of instruments, including DAT recorders, has been released from Scantek. The Type 336 dual-channel unit is similar to many DAT recorders. The 8-channel Type 335 is compatible with the Sony PC-200 and TEAC RD100 series, and comes with a small rack to mount the appropriate DAT. Scantek, Inc., 916 Gist Ave., Silver Spring, MD 20910, (301) 495-7738, FAX (310) 495-7739.

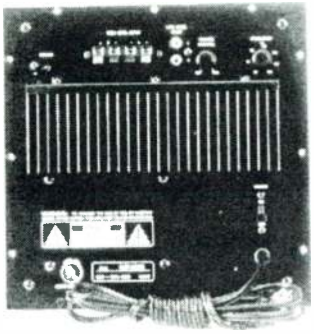
Reader Service #109

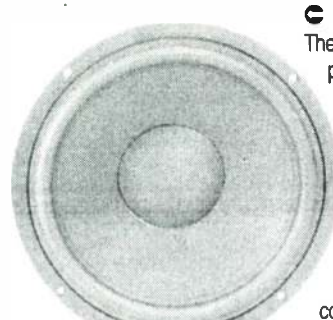
■ **PHONO PREAMP**

The new DB-8 phono preamplifier (6.2" × 4.5" × 2.2") tracks RIAA to ±0.04dB. Intended as an add-on for equipment without a phono section, it has no controls. Features include a separate wall-mounted DC supply for low hum, gold-plated jacks, and 37dB gain. Input overload is 50mV, with less than 0.01% distortion. DB Systems, Main St., Rindge Ctr., NH 03461, (603) 899-5121, FAX (603) 899-6415.

Reader Service #108

Good News





CUSTOM SUBWOOFER

The Sub Ten C consists of an 11″ × 11″ × 5″ power amplifier/electronic crossover module with a long-throw, high-output 10″ subwoofer transducer. Designed for low-frequency reproduction, the amplifier delivers 100W of continuous power. Its self-contained electronic crossover utilizes a 24dB/octave low-pass, and is continuously variable from 50–150Hz. The 10″ driver employs a fiber cone, long-throw suspension, and butyl-rubber surround. MB Quart Electronics, 25 Walpole Park So., Walpole, MA 02081-2532, (508) 668-8973, FAX (508) 668-8979.

Reader Service #114

EDGARHORN

The System 100 delivers dynamics, imaging, and low distortion, without coloration. Combined with a powered subwoofer, the horn system is easily integrated into a typical listening room. Specifications are: sensitivity of 103–105dB, 100Hz–20kHz, and dimensions of 47″ × 21″ × 24″. For more information, contact Dr. Bruce Edgar, Box 1515, Redondo Beach, CA 90278, (310) 370-1302, FAX (310) 371-8085.

Reader Service #101

HAPPY ANNIVERSARY

Audiophile Audition, the only national radio program devoted to high-end audio and home theater, will observe its Tenth Anniversary on April 1. The one-hour weekly program on new classical CDs also provides interviews with leaders in the audio and music industries, as well as pointers on improving music and home theater systems. In addition to the approximately 130 public radio and concert stations that carry it, the program has been selected by "Music Choice" to present selected public radio productions via their local cable systems. For more information, contact (800) 934-0442.

NO-COMPROMISE CAPS

MusiCap® coupling and speaker capacitors are constructed of separate layers of conductive foil and polypropylene film, with custom-stranded, silver-plated copper leads. Lead-free silver bearing solder is used for tinning and attachments. Insulation on 22-gauge leads (coupling) is 1kV Teflon®; speaker leads are 16-gauge. The devices are approximately 100% larger than metalized capacitors, and have a maximum value of 10µF (but can be combined for larger values). Hovland Co., PO Box 629, Culver City, CA 90232, (209) 966-4377, FAX (209) 966-4632.

Reader Service #106

DESIGN CALCULATOR

Porta-Calc II offers computer-aided system design for calculating enclosure and port sizes. Used primarily for car audio enclosure design, the device allows you to choose either frequency response or enclosure size. Porta-Calc also calculates the size of each piece of wood needed for your design. Other features include a built-in Speaker Parameter Library that holds up to 400 design parameters. For detailed information, call Installer Institute, (800) 354-6782.

Reader Service #112

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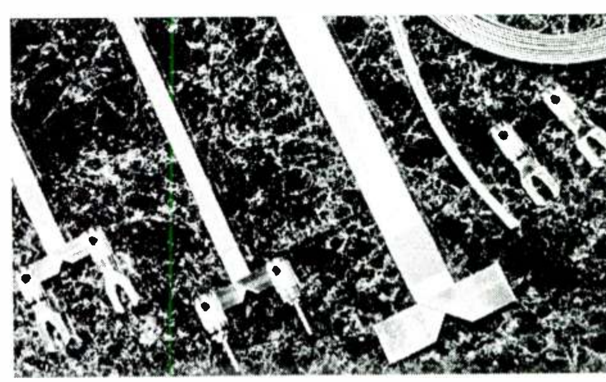
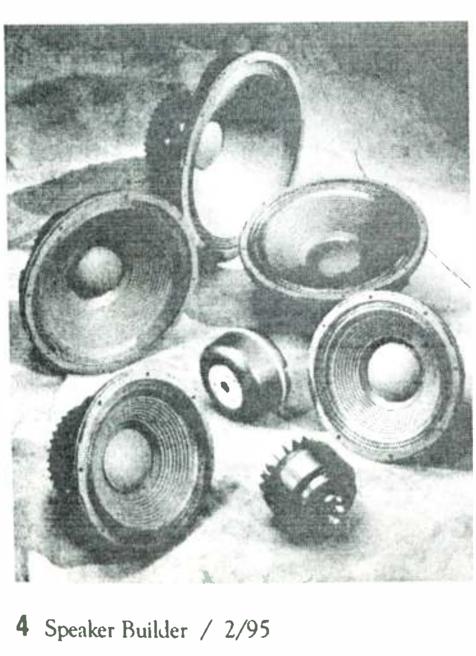


WIRE SYSTEM

Goertz MI speaker cable has a flat shape, with minimum space between conductors, for low inductance and virtually zero distortion. Its 2–4Ω characteristic impedance results in improved imaging, better clarity, less high-frequency rolloff, and better definition at low frequencies. Other benefits are virtual elimination of skin effect, hum caused by adjacent power wiring, crosstalk between channels, emitted EMF, and microphony from strand interaction. Alpha-Core Inc., 915 Pembroke St., Bridgeport, CT 06608, (203) 335-6805, FAX (203) 384-8120.

Reader Service #113



IMPROVED SPIDER

The new Gauss XR Series is a line of five woofers designed for professional sound reinforcement and studio monitoring applications. The improved double-spider system uses flex-life material and a "creep-resistant," high-temperature Lexan spider spacer. Gauss woofers also function as heatsinks. Gauss Loudspeakers, 10500 W. Reno Ave., Oklahoma City, OK 73126-0105.

Reader Service #115

FIRST-RATE FINISH

Texturelac is a one-part, air-dry finish that allows you to regulate textured patterns and colors. By adjusting the air and fluid pressure on any standard air-spray gun or HVLP system, you can produce stone, leather, pebble, stucco, marble, or cobblestone patterns. Texturelac eliminates the seams and boxy patterns which cannot be avoided with laminates. In addition, it can lower paint finishing and labor costs by 70% or more. For more information, contact Abilene Research and Development Corp., PO Box 294, Hewlett, NY 11557, (516) 791-6943, FAX (516) 791-6948.

Reader Service #102

Good News

■ NAME CALLING

As of January 1, 1995, Polydax Speaker Corp. has officially changed its name to Audax of America. The company, which covers the entire North American market, is a subsidiary of, and direct factory link to, Audax Industries of France, manufacturers of high-quality loudspeaker components for the OEM and distribution markets. The mailing address, telephone, and FAX numbers remain the same: Audax of America, 10 Upton Dr., Wilmington, MA 01887-4401, (508) 658-0700, FAX (508) 658-0703.

■ FULL-RANGE MINIS

The compact (6¼″ × 9″ × 12½″) two-way Stratus Mini loudspeaker offers a "woofer-over" array. This helps the response remain unchanged through a full range of positions, resulting in a broad useable listening area. The unit is designed for free-standing use or with a high-performance subwoofer. A matching, optimal-listening-height stand is also available. PSB International, Inc., 633 Granite Ct., Pickering, ON L1W 3K1, Canada, (800) 263-4641.

Reader Service #111

■ DESIGN DATABASE

Speakerphile™ project management database for loudspeaker system designers and engineers provides seven functions: component database (information on loudspeakers and related products); source database (contact information); queries and searches (find a component or other information); project management (assign components to user-defined projects); reference (formulas and techniques); utilities (conversions and calculations); connections (importing, exporting, and data linking). The database runs under Microsoft® Windows. Acoustical Supply International, 895 Cherokee Blvd., Chattanooga, TN 37405, (615) 756-0706, FAX (615) 756-0860.

Reader Service #104

PROGRAM UPDATE

BassBox 5.1 is an updated version of the low-frequency loudspeaker enclosure design program for PCs that run Microsoft® Windows. The new version features a high-resolution mode, new amplitude, phase and group delay graphs with cursors, and graph memories. The easier-to-use bandpass, vent calculator, and print setup windows have added capabilities. In addition, an expanded loudspeaker database now includes over 1,300 woofers and can be searched under a variety of parameters. Harris Technologies, PO Box 622, Edwardsburg, MI 49112-0622, (616) 641-5924, FAX (616) 641-5738.

Reader Service #103

Speaker Builder

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

JOHN STUART MILL

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About This Issue

As you settle back with this issue, here's a question you might ponder: Is it time for your car's tune-up? We mean audio tune-up, of course. This issue's lead article ("From Sad to Sparkle: A SAAB Story," p. 10) combines two American passions: audio and autos. You can take your lead from **Mark Florian's** restoration of his SAAB and apply it to your own model. You'll be amazed at the ways you can block out noise and reduce rattles to prepare your vehicle for a new sound system.

Audio veteran **Bill Fitzmaurice** shares his portable PA system design, which meets the needs of today's traveling band ("Compact Two-Way PA System," Part 1, p. 14). Unlike the typical, oversized, overweight PA speaker, this road-worthy solution sounds as good as it travels.

The application of Baekgaard's famous bridging speaker technique is limited to certain designs. **G.R. Koonce** demonstrates how to expand its use to produce constant-voltage results ("Baekgaard Crossover Technique," p. 20).

For the intrepid audiophile, **Charles Close** presents a method to restore the classic KLH-9 to its original condition ("Rebuilding the KLH-9 Power Supply," p. 24). Not for the fainthearted, this project requires skill, patience, and some time alone in the kitchen. The rewards, according to the author, are worth the effort.

If you dread the prospect of designing crossovers, turn to "Driver Offset-Related Phase Shifts," Part 2, p. 26. **Bruno Carlsson** extensively demonstrates phase shift effects on crossover filters and illustrates how to minimize these errors.

Do you remember your initial foray into the world of speaker-building? **Nancy MacArthur** chronicles her first attempt with the Audax A652 kit ("Kit Report," p. 42). Her detailed report is both entertaining and informative and includes, based on her successful undertaking, tips for other novices about to take the plunge.

For speaker builders as concerned about how their projects look as how well they sound, **Bob Wayland** presents an easy, "sand-free" way to prepare your wood surface for finishing ("Wayland's Wood World," p. 38).

Speaker Builder
THE LOUDSPEAKER JOURNAL
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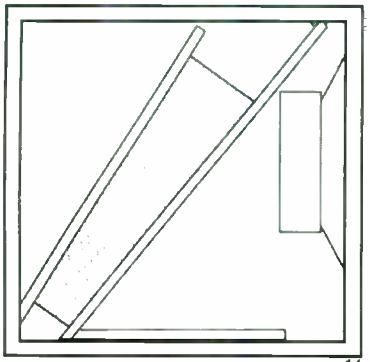
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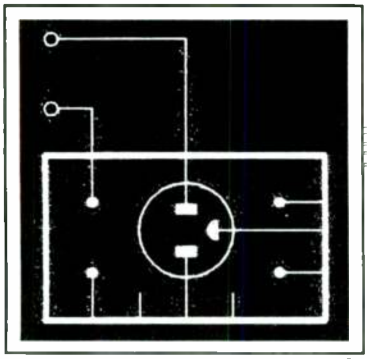
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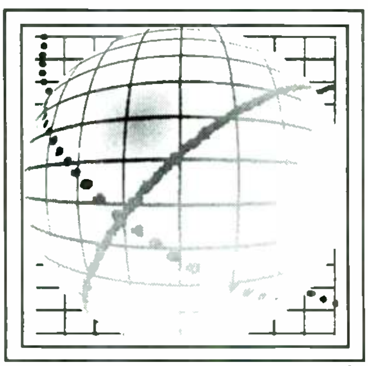
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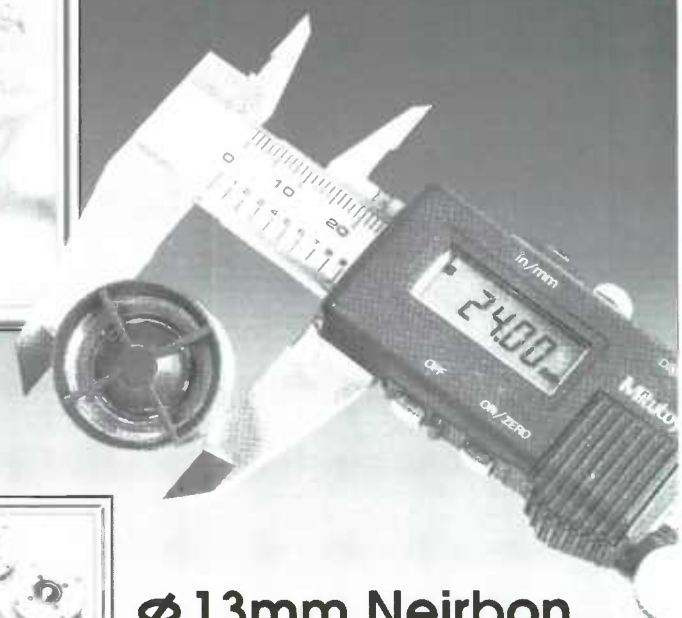

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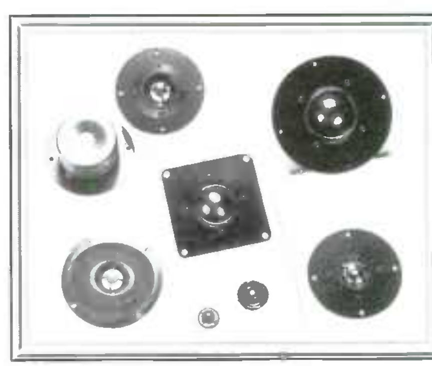

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Guest Editorial

PEERING INTO THE FUTURE

By Dick Campbell
Contributing Editor

Once in a while we are privileged to catch a glimpse of the future. Sometimes it takes the form of projecting an experience into the future by applying your own far-reaching precociously radical thoughts on the subject. Someone witnessing the first flight at Kitty Hawk, for example, may have immediately realized that 500 people would someday take to the air together in some phantasmic conveyance, without ever, of course, embodying the thought in the shell of a Boeing 747.

Some of us have tried virtual reality helmets in arcade games or at technical exhibitions. The stereo visual sense comes to us via postage-stamp-sized TV screens right in front of our eyeballs, and the aural sense via built-in high-quality headsets. The leap forward is to the Entertainment Deck on the Starship Enterprise.

The audio part of virtual reality, called auralization, is not difficult for those with a working knowledge of digital signal processing (DSP) to understand. If you are willing to accept that high-quality headsets are acoustically flat-responding for a constant-voltage input, then the DSP solution is all electrical and computational, but you need a bloody fast microprocessor. Auralization with headsets is becoming old hat. Room acoustic computer models can generate the impulse responses required at a particular seat location to effectively place the listener in that seat, hearing on a headset what a performer on stage will sound like.

Accomplishing this effect with the listener unencumbered by a headset is an immensely difficult task because now the acoustic field conditions surrounding the listener's virtual space must be reproduced exactly as it occurred in the real space. I have little doubt that people listening to headset auralization made this leap into the future. "Just wait until we can do this in free space," they would say.

Recently, 28 members of the Greater Boston Chapter of the Acoustical Society of America met at the Bose Corporation in Framingham to hear a demonstration of the Bose Auditioner©. With this weird-looking contraption, the leap has been accomplished for speech, but not quite yet for wideband music.

Picture a breadbox sitting on four stubby legs with two outstretched arms, left and right, holding tiny speaker enclosures at the ends. One small end of the breadbox features a chin rest, which, when you are seated at a table, is at the correct height for you to position your chin. The two little speakers are about a foot away on each side. The output of the subwoofer exits from two wide slots in the top of the box under your chin, and the DSP-generated signals to the power amplifiers inside the box come from a computer.

If you think you would look ridiculous sitting with your chin resting on this contraption, let your ears be your guide. It's truly amazing. This may convince you:

During final evaluation in an auditorium, the subject was given a switch, which allowed him/her to listen to either a person speaking into a microphone over the hall PA system or close-miked speech (with the same human voice) processed by the Auditioner's real-time convolver with the PA system shut off. The impulse response of the seat which was used in the convolver was derived using The Bose Modeler© program. *In most cases, the subject could not tell the difference!* Try that with headphones.

Bose personnel have stated that it took nine years of research to reach this point. I can think of no other loudspeaker manufacturer with the financial wherewithal, the perseverance, and the superb technical engineering skills in signal processing and electroacoustics to pull this off.

Congratulations to the Bose Auditioner design team.

CUTTING UP AND DOWN

As I write this the powers that be in Washington, in their "wisdom," are considering cutting all support for National Public Radio and the Public Broadcasting System. In response I have substantially increased my gifts to two of my local outlets. I owe so much of my love of music to the stimulus the Boston stations provided in my early years that I believe we cannot do without this cultural resource. I also find that both these channels provide me with news and analysis of the news which I do not find elsewhere. In a world where the tobacco lobby is more persuasive than Big Bird, we are called upon to make some kind of gesture which our elected officials cannot miss. You will, of course, make your own decision about how you believe your tax dollars should be spent. I offer my own two cents worth for your consideration.

Beginning with the next issue, Audio Amateur Publications will be making some cuts as well. Our printer advises us that our paper now costs an added 14% beginning with the issue you hold in your hands. The US Postal Service, in its wisdom, has increased Second Class postage, also by 14%. The postal increases in other classes will also make doing business more expensive in promotional efforts as well as in billing and customer service. We are not announcing an increase in subscription or advertising rates at this time.

What we will be doing, beginning with the next issue, is reducing the margin size of the page. From its present 8½″ × 11″ size, it will shrink to an 8″ × 10½″ dimension. The weight reduction cuts our delivery costs, but does not affect the information delivered on each page. It is, unfortunately, a hardship for those of our wonderful advertisers who develop ads using the entire space of the current page size. While not the first publication to resort to this economy, we regret the change, but are sure you will understand.—E.T.D.

← Reader Service #52

Part 1

FROM SAD TO SPARKLE: A SAAB STORY

By Mark Florian

Several years ago, a friend sent me a card that depicts a woman wearing a cookie jar on top of her head. Inside the caption reads, "Getting our heads into new and different things is what it's all about." This rings especially true for speaker builders and car audio.

After completing the Swan IV system,[1] I became increasingly aware of the poor quality of the audio in my car, a four-door SAAB (an acronym for *Svenska Aeroplan Aktiebolaget*) 900T. At times I wondered whether I was still playing the same tape. The factory 4 × 10 rear drivers had long since been replaced with a pair of Infinity 6 × 9s, which really improved the sound and added some needed bass. But the system lacked the coherent soundstage, depth, and air that I had become accustomed to with the Swans.

I considered various options, none of which seemed appropriate for this car. All SAABs, including the four-door sedans, have rear seatbacks which fold down to greatly expand the trunk; thus, I didn't wish to add a woofer box that would be in the way. This article presents my solution to the problem of poor sound, while retaining the car's generous cargo capacity. Even if you don't own a SAAB, I'm sure you'll find something here that you can use in your own vehicle.

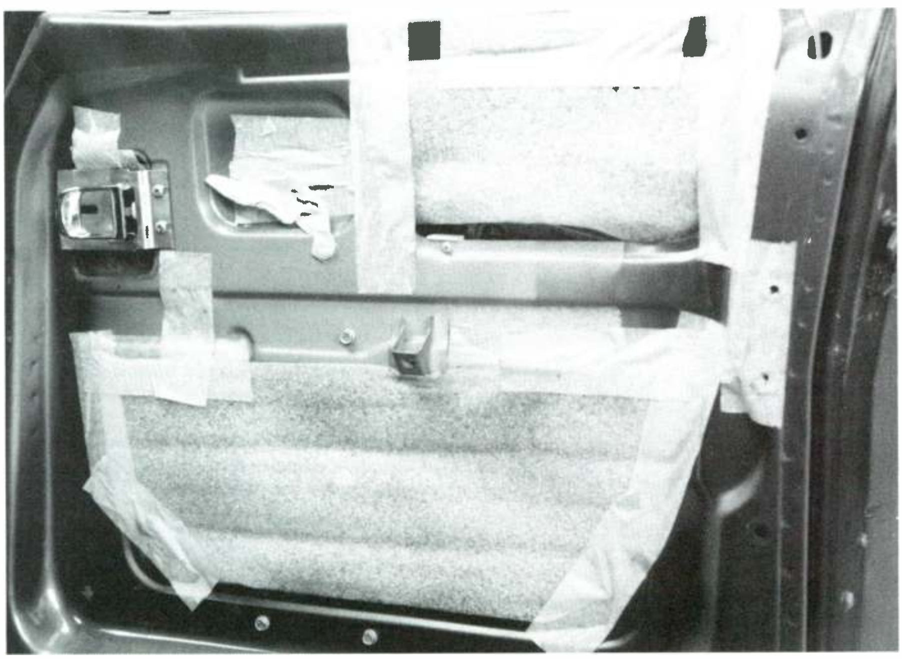

PHOTO 1: Passenger door with interior panel removed. Covering material is 1/8" closed-cell foam.

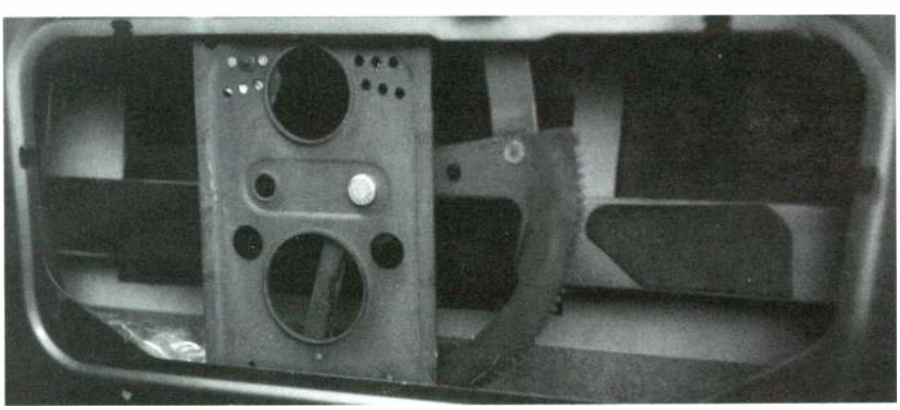

PHOTO 2: Same door panel showing installation of Q-pads on the backside of outer sheet metal to limit noise transmitted into passenger compartment.

FOUR-WHEEL SPEAKER ENCLOSURE

I began by treating the car body in the same way as a speaker enclosure. That is, by preventing rattles, deadening panels that ring, improving isolation from engine, drivetrain, and road noise, and ensuring that the weather stripping around the doors, sunroof, and trunk was intact. My goal was to make the interior as quiet as possible.

I started by driving down a smooth road with the radio off and the AC fan on low, making mental notes of what I heard: wind noises, whistles, squeaks, and rattles. When I folded down the rear seat and listened again, I heard lots of tire noise emanating from the rear wheels, a deep exhaust note, and the jumper cables rattling in the accessory pan under the trunk floor. I decided to attack first those sounds my ears would be closest to and then work outward to the trunk and engine compartments.

Photo 1 shows the front door with the interior panel removed. The process is very simple and straightforward. I unscrewed the door lock button that protrudes from the top of the panel, then the two screws that hold the armrest in place and snapped off the plastic cover behind the interior door handle. Sliding a 1" putty knife between the panel and the frame, I worked around the door's circumference, carefully prying off the plastic clips at each location. The panel then lifted up and out.

I found that the moisture barrier was loose, the tape was brittle and left a sticky residue, and the large openings allowed highway noise to intrude into the passenger compartment. *Photo 2* is the same door with the tape and plastic sheeting removed. Electronic degreaser or WD-40 will eliminate any sticky residue.

From an auto body shop supplier, I obtained several packages of bitumen pads, called Q-pads. Each package contains six 12" × 12" pads with a very sticky adhesive backing. To apply, simply peel off the back and stick it on! I rapped with my knuckles on the various door parts and stuck on a pad wherever I heard a sharp "ping," thereby reducing it to a dull "punk."

The interior of the door was heavily damped to prevent noise from entering. The thick steel bars across each door frame that SAAB uses for side-impact protection needed to be damped as well. Q-pads are easily cut into any shape with scissors, but use an old pair. You can clean off any asphalt residue with WD-40 or mineral spirits.

BEHIND THE DOOR SEAL DETAILS

Photo 3 shows a completed door. I decided to cover the large openings with Q-pads and tape the seams with duct tape. The pads are moisture-proof and provide an excellent weather barrier, but be sure they do not interfere with the window operating mechanism. Before I reinstalled the interior door panel, I teased some loose-fill polyester and stuffed it into the space between the pads and the panel.

While working on the doors, I noticed that the seals were either torn or cracked in several places. Through one 1/8″ gap in the driver's door, I could hear cars pass by on the freeway, and it whistled when I reached a certain speed. This application is perfect for 3M's Weatherstrip and Gasket Sealant, which is available at any hardware store. The incredibly sticky yellow glue adheres to all types of weather stripping and to metal surfaces, painted or unpainted. I added a little to each piece, let it dry a bit, then joined the ends and clamped them with a small spring clamp.

Some seals needed additional backing to ensure a tight closure with the door frame. For this I used a small piece of bicycle inner tube cut to fit and held in place with a spot of sealant. Make sure no gaps exist anywhere in your door or window gaskets, where air and noise can enter.

After repairing the front doors and their gaskets, I took a test drive to see what effect it had. In my case, it was rather dramatic. After 182,000 miles, my '85 has accumulated its share of squeaks and rattles. The interior was now noticeably quieter. I could barely hear cars pass, and repairing the door seals had eliminated the whistles. Motivated, I headed home to complete the damping of the rear doors, which I treated the same as the front.

The next noise problem to be solved was the sunroof. Only 4-5″ from my ears, it had rattled for longer than I'd care to admit. Using my car manual, I pulled off the top to reveal the insides, as shown in *Photo 4*. Basically, the lower shell is a piece of fiberglass, and the rattle was caused by the latching mechanism clanking against it.

I cleaned the inner surfaces with a degreaser and applied large Q-pads to damp the fiberglass panels, as well as a piece between the linkage and the fiberglass. After reassembling everything, I went for another drive. What a difference! I no longer heard passing cars and the sunroof didn't rattle.

PHOTO 3: Driver's door panel with all large openings covered with Q-pads. Note small pad behind door latch plate.

An eerie silence came over the SAAB's cockpit, one I had not heard for quite some time. The purring of the healthy exhaust note seemed farther away; however, I now noticed more squeaks which had been washed out by the others. Somewhere, plastic rubbed on plastic, and those emanating from under the dash would be hard to locate. So I headed back home to remove more interior.

UNDER THE DASH

The lower kick panel is one long piece held in place with three bolts: two on either side of the engine compartment and one in the middle behind the ashtray. In order to remove it the center console must come out, and, to allow more room to work, one of the seats. By this time, my neighbors thought I was having a driveway sale, as more and more of my car's interior went on display. With the lower kick panel removed, though, it's very easy to access all the wiring and check for squeaks.

With the driver's seat removed, I could lie on my back and look up into the dash with a small trouble light. I used LPS #2 Industrial Strength Lubricant on all throttle, brake, and clutch linkages as well as on the steering column u-joints. This excellent lubricant is sometimes hard to find. (I've seen it in a small local hardware store, but only after I had first called the company and was referred to an industrial supply house.) While you're under the dash, lubricate sparingly anything that moves, squeaks, or rattles.

I next discovered several leaks in the air distribution box just below the blower, so I applied siliconized latex caulk to all the joints. This helped improve air distribution and quieted some whistles. The kick panel's acoustic foam had also begun to deteriorate with age. I stuffed egg-crate foam into the

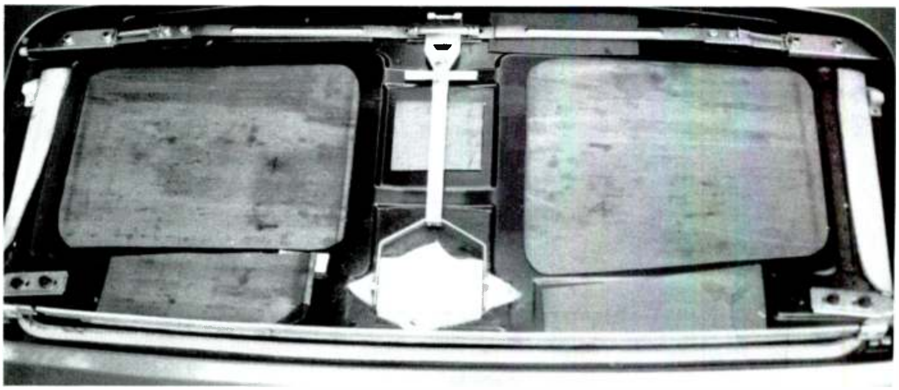

PHOTO 4: Outer sunroof panel removed, showing pad placement on fiberglass shell.

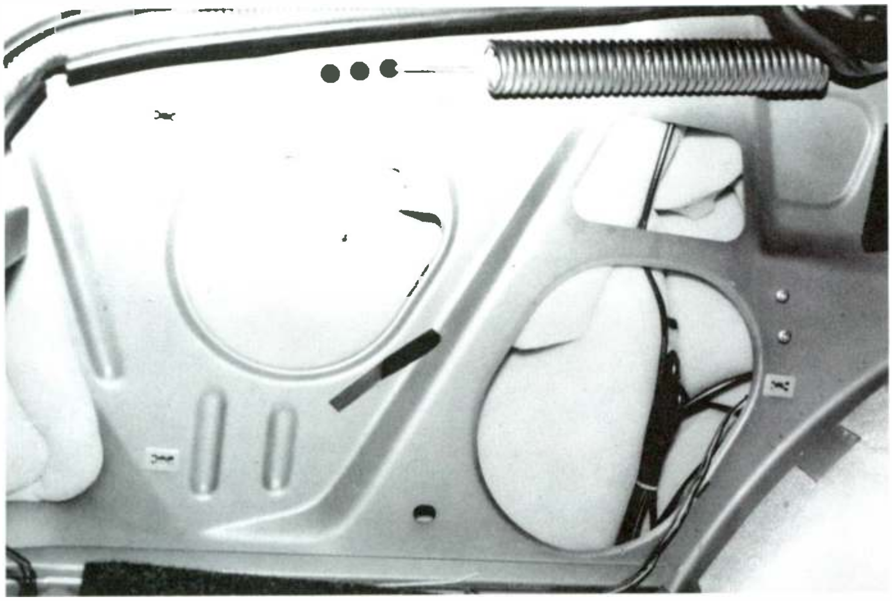

PHOTO 5: Driver's side cargo area with carpeting removed, showing foam installation.

cracks and crevices to reduce noise behind the dash.

Check for any air leaks into the engine compartment around cables and linkages that penetrate the firewall. They not only let in air but also engine fumes, dust, and noise. Plug them with caulk. Plastic-on-plastic noises can be omitted with silicone spray. Rattles and squeaks can also be caused by loose screws or parts rubbing against each other. Take your car on test drives to check your progress and locate new trouble spots. You will be amazed by the reduction in noise, especially with an older car.

INTO THE TRUNK

With the cabin taken care of, I turned my attention to the cargo area, removing the floorboards and dark grey carpeting from both sides. One of the trunk lid springs squeaked whenever I opened or closed it, so I sprayed it with LPS. A piece of foam between the jumper cables and the floor pan quieted that racket. For the rear floorboard, which rattled against the top of the spare tire, I cut a piece of rubber-backed carpet to fit between them. Thick carpet padding would also work.

In the rear of the car is an air space between the outer body panels and the structural member that actually carries the load (*Photo 5*). I rapped on the outer metal skin while listening for resonances inside the trunk and heard a particularly loud one near the outside vents on the C pillars. A Q-pad didn't help. I next tried tensioning the outer panel by wedging a short wooden dowel between it and the structural member. Although this worked, the dowel wouldn't stay in place due to the angle. A piece of rubber inner tube finally secured it. I didn't wedge it in so tightly as to cause a bulge in the outer panel—just enough to hold it in place. When proceeding with this technique, use good judgment.

A couple of drain lines carry water down to the floor pan drains: be careful not to block these with foam. I used egg-crate foam extensively in the side panels to dampen sounds coming through the outer body, placing the waffle side toward the noise source. Use Q-pads to deaden any ringing panels, then back up these with foam (*Photo 6*). The result is even less noise from the tires and the turbo's deep exhaust note. You might find additional benefit from stuffing the void between the rear side-wall carpet and the structural frame.

The entire floor pan in the passenger compartment is covered with an OEM substance very similar to Q-pads, so I didn't add any here. This was topped with a heavy asphalt pad backed with foam that served as carpet padding. I tried some additional foam underneath the front carpet to mask out transmission and road noise, but it raised the carpets and made them bulge, so I pulled it out. Perhaps thinner material would work.

By the time all was said and done, I had applied 4½ packages of Q-pads for a total of 27 ft² of material. Once you start, you'll be amazed at how many places you can use it.

In Part 2, I'll describe the next step: designing and installing the system.

PHOTO 6: Driver's side speaker plate before modification. The original 4″ driver used a square mounting plate.

REFERENCE

1. J. D'Appolito and J. Bock, "The Swan IV Speaker System," *SB* 4/88.

SOURCES

LPS Laboratories, Inc.
Tucker, GA 30085-5052
(800) 241-8334
LPS #2 Industrial-Strength Lubricant

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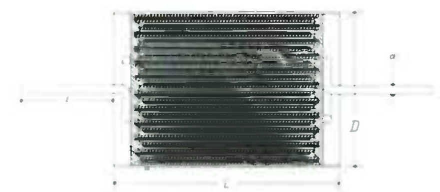

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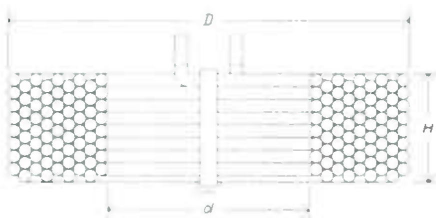

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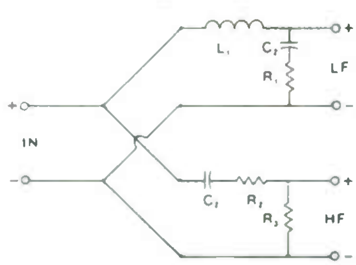

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Part 1

A COMPACT TWO-WAY PA

By Bill Fitzmaurice

Since I started in the music business some 30 years ago, PA systems have evolved. The stages then were dominated by behemoth guitar amps blasting away, while mediocre column speakers tried valiantly—but usually unsuccessfully—to project vocals above the din.

Today's trend is toward small amps onstage with the entire band mixed through the PA (*Photo 1*). Thanks to the digital revolution, portable systems are now more sophisticated than the best studio gear of a decade ago. But while consoles, power amps, and effects continue to shrink in size and cost, the average PA speaker remains oversized and overweight.

My two-way system *(Photo 2)*, designed to be small and light without sonic compromise, is specifically for small to medium-sized clubs (300 seats or less) or small outdoor venues. Nationally known acts have used it and been quite impressed by its performance/size ratio. Its only limitation lies in the extreme bottom end: bass-heavy reggae or techno-pop acts should augment it with an 18″ bandpass subwoofer for the 30–80Hz range.

Due to the high SPLs required (over 118dB on average), efficiency is the most important consideration when designing PAs—even at the expense of flat response. With this in mind, I designed the bins around JBL E140 woofers.

These drivers have a Q_{TS} of 0.17, V_{AS} of 10.5 ft^3, and will operate in 1 ft^3 with 100dB efficiency, although an f_3 at only 95Hz gives a weak bottom octave. While this is not critical for PA, with most rock music voiced from 80Hz and up, these bins beef up the bottom by firing the port output into a folded horn. In the ideal setup—6″ in front of a wall or stage—the bass response becomes fairly respectable, as shown in *Fig. 1*. Nevertheless, to conserve power amp headroom and prevent driver over-excursion, I recommend a high-pass filter of at least 12dB slope set at around 60Hz on the input of the power amp.

PHOTO 1: Control section for a modern PA system.

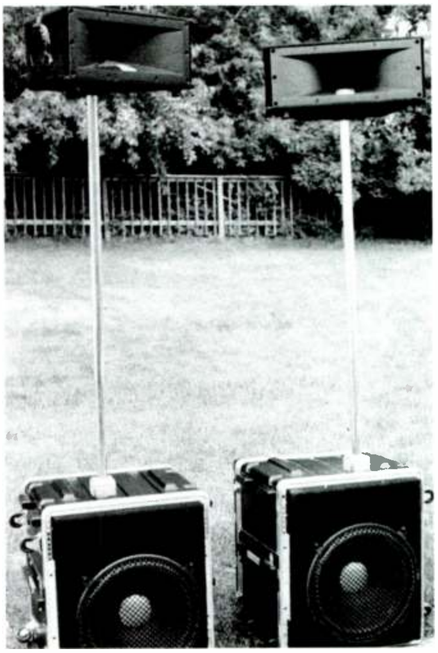

PHOTO 2: The assembled system.

ROAD WARRIORS

The cabinets are mounted inside SKB-brand weatherproof road cases. Constructed of aluminum and plastic, these cases are intended for rack mounting electronic components, and are a natural for speakers as well. The space between the cabinet and case walls is filled with expanded foam insulation for a totally rigid structure despite the ½″ plywood walls (*Photo 3*). At $150 each, these cases are not cheap. So, if you avoid them, use ¾″ plywood and adjust the dimensions accordingly. Build the cabinets with dado joints, as described, if you have a router; otherwise, glue blocks will work fine.

The first step is to cut the two sides and draw on them the actual parts layout as mirror images (*Fig. 2*). Use this full-size layout to determine the exact dimensions of the remaining parts and cut them as well. Cut parts of like dimension sequentially on a table saw, without changing the rip fence setting. Their exact size is far less critical than the pieces being identically cut.

Using a router with a ½″ pattern following bit (the bearing above the cutter head), dado a 1/8″ deep groove where the parts joint the sides. You'll need a straight piece of 1 × 3 about 3′ long, preferably oak, as a guide-

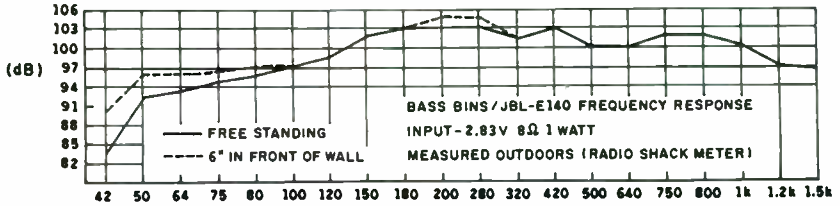

FIGURE 1: Bass bins/JBL E140 frequency response.

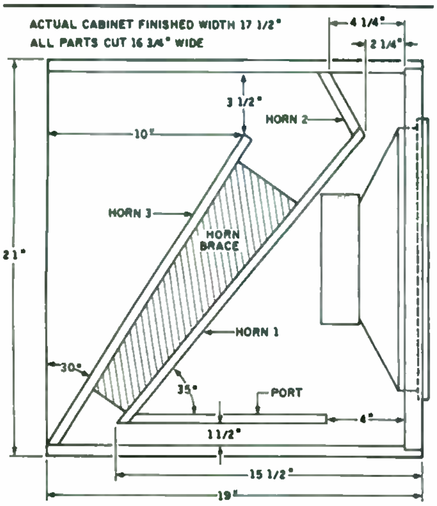

FIGURE 2: Bass bin layout, side view.

PHOTO 3: Completed bins with and without travel cover in place.

board, into which you'll drill and countersink holes every 6″ or so. With two or three 1″ drywall screws, attach the board directly to the cabinet side along the desired cutting line (*Photo 4*). Then run the router along the board for a perfect dado. After the sides, dado the top and bottom for the baffle joint, and run channels down the entire middle length of Horn Plates 1 and 3 into which the horn brace will slide (*Fig. 3, Photo 5*).

When the routing is complete, predrill and countersink holes every 6–8″ through the dadoes. Drill first from the inside, using the dado groove to identify the hole locations. Countersink extra deeply along the baffle joint to allow rounding over the cabinet edge without hitting screwheads. For assembly, use 1¼″ drywall screws and plenty of glue (the dado joint makes caulking unnecessary). A 1/16″ pilot drilled into the receiving parts prior to assembly will help avoid splitting the thin ½″ plywood.

TABLE 1

BASS BINS PARTS LIST

Part	Description
Woofer	JBL E140
SKB case	Model 19-12
Top, bottom	16¾″ × 19″
Baffle	16¾″ × 20¼″
Port	16¾″ × 10″
Horn Plate 1	16¾″ × 20″
Horn Plate 2	16¾″ × 3 7/16″
Horn Plate 3	16¾″ × 19¼″
Horn brace	16″ × 2″ × 3½″ trapezoid
Sides	21″ × 19″

Miscellaneous

1¼″ drywall screws
3/8″ thumbscrew and screw insert for pole mount
¼″ phone jacks
Jack plate for ¼″ jacks
12-gauge hook-up wire
¾″ aluminum angle stock
3″ drywall screws for top box block
2″ drywall screws for casters
1¼″ od aluminum tubing for top box pole
4′ long hardwood block (preferably maple) for pole mount 3″ × 3″ × 2″
Casters, driver mounting bolts and t-nuts, carpet covering, metal grille, glue, spray glue for carpet, aerosol expanding foam insulation, four-pole pro speaker connectors, polyfill stuffing

Note

Materials are per cabinet; double for a pair. All parts are ½″ plywood, except ¾″ for baffle (sizes approximate).

AN ORDERLY ASSEMBLY

In order to align the parts, you *must* assemble the cabinet pieces in correct order. First, attach Horn Plate 1 to one of the sides, then the port to that same side but not yet to Horn Plate 1 (to allow parts jockeying later). Now join the second side to the previously assembled parts. When everything is secure, fasten the joint of Horn Plate 1 and the port with screws. To this master assembly, slide into its dado and secure Horn Plate 3, the bottom, the horn brace, Horn Plate 2, and the top, in that order. The last piece you will attach is the baffle.

True the front edge around the baffle of any overhang and round it with a ¼″ radius. Cut a 14″ hole for the driver (it should be off-center to prevent standing waves), and rout a ¼″ recess in which to set the driver. Now is the time to cover the cabinet with carpet.

If you're using an SKB case, cover only that part of the cabinet which will be exposed. Leave the rear cover in place. With the cabinet inside, lay the case on its back. Cut and drill two pieces of ¾″ aluminum angle about 12″ long to use as mounting brackets, and mount the cabinet to the case. Inject expanding foam into the space between cabinet and case, running a bead around the cavity perimeter. Do this in stages, allowing at least two hours of cure time between successive beads. Trying to inject the entire cavity at once will result in bowing of the outer case walls.

After the foam has cured, attach the top box pole mount. Use 3″ drywall screws to penetrate the case and foam, and anchor to the inside cabinet. Drill a 1¼″ hole through the mount and case, so the pole rests on top of the inner cabinet. Then drill the mount and install an insert for the thumbscrew that secures the pole (*Fig. 4*).

Casters, if you decide to use them, are also screwed through the case and foam and anchored to the inside cabinet. By mounting them on the side of the case, rather than the bottom, you maintain better stability when set up for performance.

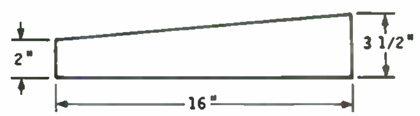

FIGURE 3: Horn brace detail.

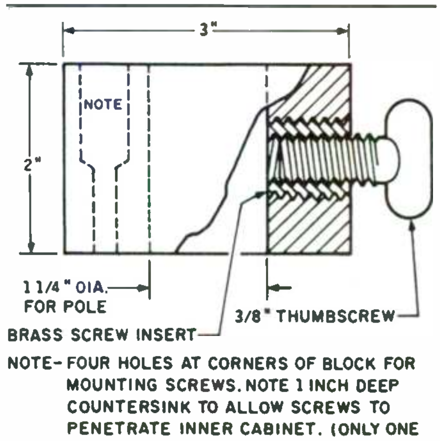

FIGURE 4: Horn pole mounting block detail.

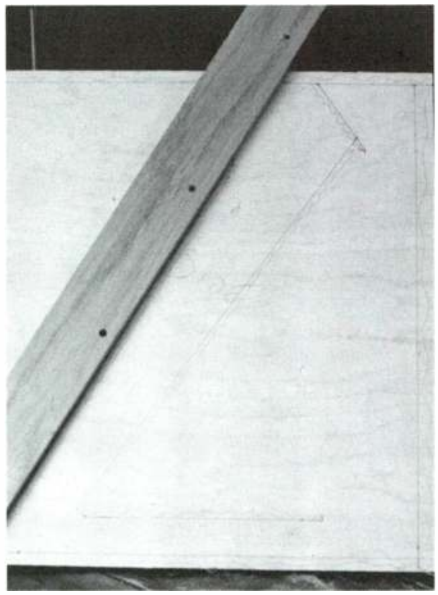

PHOTO 4: Router guideboard screwed to cabinet side, ready for dado cutting.

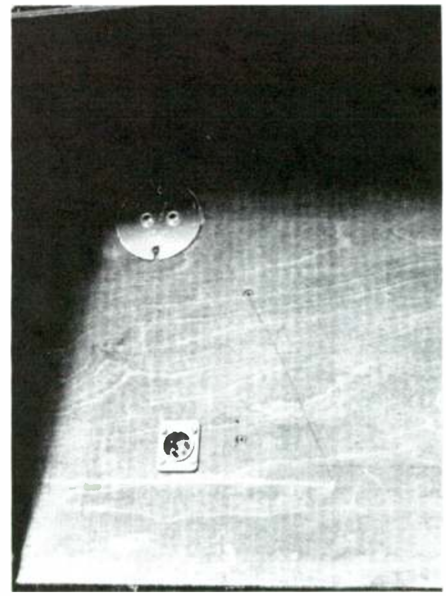

PHOTO 6: The jacks. Note the four-pole jack for connection to the power amps, and ¼″ jacks for routing the high end only to the top box.

WIRE WORKS

The best method of power amp wiring is with a pro speaker connector. Use a four-pole jack and plug with three-conductor, 12- or 14-gauge type SJ wire. One conductor connects to low-frequency out, one to high-frequency out, and one to common ground. This allows using one speaker cable from the power amp rack to each PA stack.

The four-pole jack mounts on Horn Plate 3, as shown in *Photo 6*. A ¼″ hole drilled behind it through Horn Plate 1 is for the driver hook-up leads. Also mounted to Horn Plate 3 are ¼″ phone jacks, which are wired to the high-frequency poles of the four-pole jack. A standard 6′ phone-to-phone speaker line then connects these to the high-frequency top box for performance setups. (The extra jack enables connection of two top boxes.) When the SKB back is attached for transport, there is plenty of room in the horn throat to store the cables.

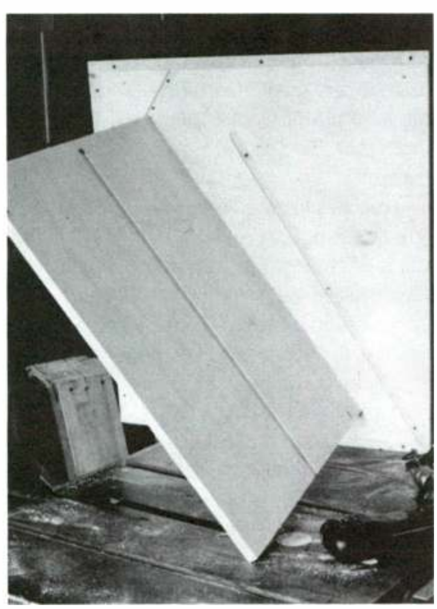

PHOTO 5: Horn Plate 1 attached to the side. Note the groove down the middle of the horn plate, into which the horn brace will later fit.

This system has no crossover, because passive crossovers just don't cut it for high-power use. Biamping is the only way to go for maximum output and driver protection.

Finally, drill the baffle for t-nuts for the driver and the protective metal grille. Stuff the enclosure with polyfill, and run a hook-up wire from the four-pole jack through the ¼″ hole in Horn Plate 1. Caulk it airtight, wire and install the driver and grille. Triple-check your connections to ensure all wiring leads to the correct driver: a reversed speaker connection could spell instant destruction for a horn diaphragm!

In Part 2, I will discuss the top box.

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Model	Size Description	Imp. Ω	Fs Hz	Qts	Vas Liters	X-Max mm Peak	Power Watts	Rating db @Freq	Sens. 1W/1M db	Cost Per Unit
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D19TD-05	3/4" Dome [1,3]	8	1700				80	12@5K	89	**$11.00**
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D25TG-55	1" Dome [1,3]	6	1500				100	12@4K	91	**$13.50**
D25TG-85	1" Dome [1,2,3]	6	750				100	12@3K	90	**$18.75**
D26SG-05 Shielded textile	1" Dome [***1,4]	6	1450				60	12@4K	92	**$19.00**
D26TG-05	1" Dome [1,4]	6	1500				100	12@4K	91	**$15.00**
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D27TG-35 Flat Face	1" Dome [1,2,SILK]	6	650				100	12@3K	90	**$19.50**
D27TG-15 Bulged Face	1" Dome [1,SILK]	6	1000				100	12@4K	91	**$15.00**
D27TG-45 Bulged Face	1" Dome [1,2,SILK]	6	650				100	12@3K	90	**$19.50**
H25TG-05 Horn Loaded	1" Horn [1,3]	6	1500				100	12@4K	95	**$16.00**
H25TG-35 Horn Loaded	1" Horn [1,2,3]	6	750				100	12@4K	94	**$20.00**
D75MX31	3" Dome Mid [4]	8	300	Both these mids require chambers.		.5	80	12@500	92	**$30.00**
M10MD-39	4" Cone Mid [6,8,10]	4,8	110			.65	80	12@700	88	**$19.50**
P13MH-00	5" Cone Mid [6,7,10]	4,8	60	.33	10	1	40	6@200	89.5	**$32.00**
M10-IC, M13-IC	Isolation chamber for M10MD-39—**$1.50**				Isolation chamber for P13MH—**$4.00**					
M11WH-09	4.5 " Woofer [6,8,10]	8	68	.31	4.3	3	30		87	**$31.50**
P11WH-00	4 1/2" Woofer [6,7,10]	8	52	.21	10.3	3	30		88	**$31.50**
M13SG-09 Shielded Magnet	5" Woofer [***,6,8,10]	8 / 16	54	.35	12	2	35		88	**$30.00**
P13WH-00	5" Woofer [6,7,10]	4,8	60	.33	10	4	40		88	**$32.00**
C17WG-69	6 1/2" Woofer [8,9]	8	44	.55	35.8	3	50		89	**$17.00**
M17SG-09 Shielded Magnet	6 1/2"Woofer [***,6,8,10]	8	34	.34	53	3	50		89	**$32.00**
P17WJ-00	6 1/2" Woofer [6,7,10]	4,8	37	.35	35	4	70		88	**$32.00**
P17SJ-00 Shielded Magnet	6 1/2"Woofer [***,6,7,10]	8	41	.35	33	4	70		87	**$40.00**
M18WO-09	6 1/2" Woofer [6,8,10]	4/8	35	.37	28.5	4	70		87.5	**$42.00**
P21WO-12	8" Woofer [6,7,10]	8	33	.34	85	3	70		91	**$42.00**
P21WO-20	8" Woofer [6,7,10]	8	28	.33	113	4	80		91	**$43.00**
M22WR-09	8" Woofer [6,8,10]	6	30	.33	55	6.5	150		88	**$62.00**
P25WO-00	10" Woofer [6,7,10]	8	24	.28	178	4	80		90	**$46.00**
M26WR-09	10" Woofer [6,8,10]	8	26	.32	130	6.5	130		88.5	**$65.50**
Automotive Speakers and Home Applications Requiring 4 Ω Speakers. (All drivers are suitable for automotive use!)										
D26NC-05 Neodymium	1" Dome [1,4]	6	1800				30	12@3K	88.5	**$24.00**
Flush mount kit Each or Wedge surface mount Each										**$3.50**
A13WH-01	5" Coax [6,7,10]	4	110	.50	3.5	3	40		89	**$45.00**
A17WG-01	6 1/2" Coax [6,7,10]	4	58	.60	15	3	60		84	**$49.00**
M22WR-19	8" Woofer [6,8,10]	4	48	.70	20	5.5	150		88	**$60.00**
M22WR-29 Dual Voice Coil	8" DVC Woofer [6,8,10]	4/4	47	.66	20	5.5	75/75		87	**$63.00**
M26WR-19	10" Woofer [6,8,10]	4	44	.69	53	5.5	150		90	**$68.00**
M26WR-29 Dual Voice Coil	10" DVC Woofer [6,8,10]	4/4	40	.67	53	5.5	75/75		89	**$71.00**
Grills	D25/D26/H25/M10MD ----**$7**/Pair				P13—**$12**/pair		P17—**$15**/pair		P21—**$18**/pair	

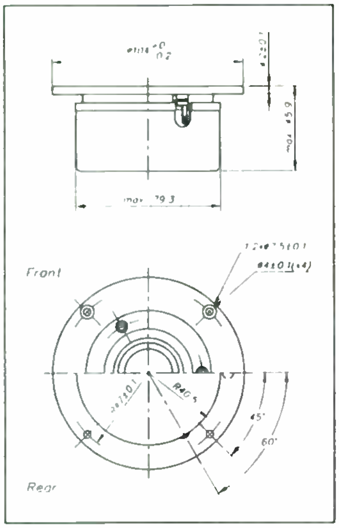
1) Ferrofluid
2) Chamber and Tinsel Leads
3) Polyamid dome
4) Textile dome
5) Aluminum dome
6) Magnesium Cast Frame
7) Mineral Filled Polycone
8) Very stiff conical Paper cone.
9) Foam surround
10) Rubber surround
*** Double Magnet/ Shielded

Reader Service #38

1" TWEETER — D26SG-05-06

SPECIAL FEATURES:

- FABRIC DIAPHRAGM
- MAGNETIC FLUID
- "BUTTERFLY" VOICE COIL ASSEMBLY
- MAGNETIC SHIELDED / DOUBLE MAGNET
- PREPARED FOR CUSTOMIZED FRONT



NOMINAL IMPEDANCE	6	Ω
VOICE COIL RESISTANCE	4.8	Ω
NOMINAL POWER (IEC 268-5)	80	W [1]
SHORT TERM MAX. POWER (IEC 268-5)	900	W [2]
LONG TERM MAX. POWER (IEC 268-5)	400	W [3]
OPERATING POWER	3.2	W
SENSITIVITY (1W, 1m) / (2.83V, 1m)	91/92	dB
FREQUENCY RANGE	3-30	kHz
FREE AIR RESONANCE	1450	Hz
VOICE COIL DIAMETER	26	mm
VOICE COIL HEIGHT	1.6	mm
AIR GAP HEIGHT	2	mm
EFFECTIVE DIAPHRAGM AREA	7.1	cm²
MOVING MASS (incl. air)	0.33	g
MAGNET WEIGHT (2 magnets) (15.2 oz)	432	g
FORCE FACTOR, Bxl	3.7	Txm
Qms	0.93	
Qes	1.01	
Qts	0.48	

D26SG-05-06

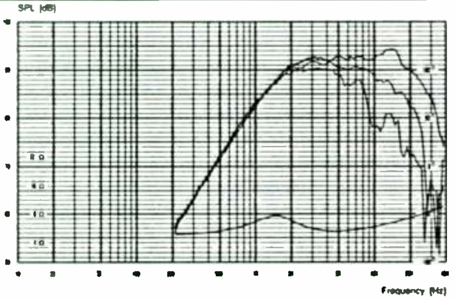
DISPERSION PLOT
0, 30 and 60 deg.

Input: 2.83 V
Mic.: 1 m

Mounted in infinite baffle.

16.11.94 PM

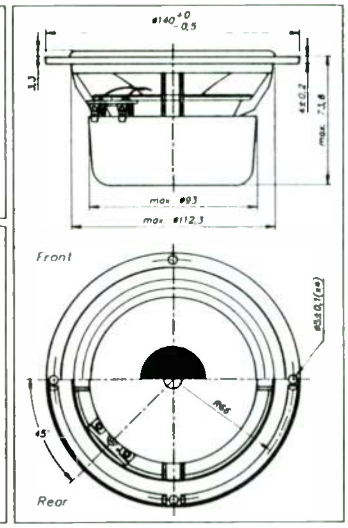
Anechoic room 6x7x8 meters.
Half space free field above 100 Hz.
Brüel & Kjær 2012 Audio Analyzer.



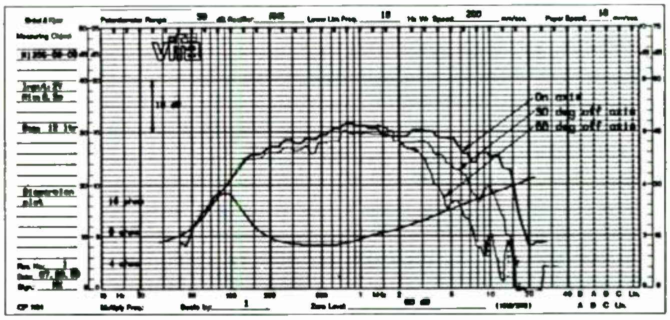
5" WOOFER — M13SG-09-08

SPECIAL FEATURES:

- MAGNETIC SHIELDED/DOUBLE MAGNET
- SPECIALLY DESIGNED FOR TV SETS
- VERY SMOOTH FREQUENCY RESPONSE
- HIGH DAMPING RUBBER SURROUND
- WELL SUITED FOR BASS REFLEX



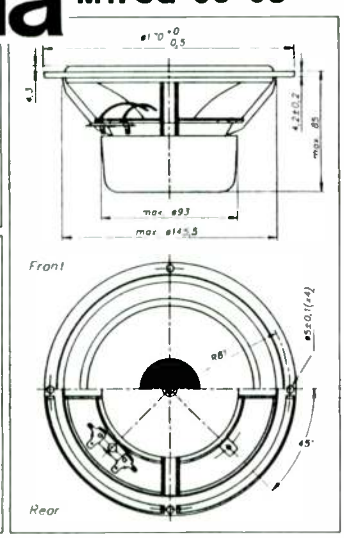
NOMINAL IMPEDANCE	8	Ω
NOMINAL POWER (IEC 268-5)	35	W
MUSIC POWER (DIN 45500)	70	W
FREQUENCY RANGE	54-5000	Hz
SENSITIVITY (1W, 1m)	88	dB
EFFECTIVE CONE AREA	80	cm²
VOICE COIL RESISTANCE	5,6	Ω
VOICE COIL INDUCTANCE	0,7	mH
OPERATING POWER	8,3	W
VOICE COIL DIAMETER	25	mm
VOICE COIL HEIGHT	10	mm
AIR GAP HEIGHT	6	mm
FREE AIR RESONANCE	54	Hz
MOVING MASS (incl. air)	6,5	g
FORCE FACTOR, B x l	5,2	Txm
MAGNET WEIGHT (12,1 oz)	344	g
Qms	1,50	
Qes	0,46	
Qts	0,35	
Vas	12	ltr



6½" WOOFER — M17SG-09-08

SPECIAL FEATURES:

- MAGNETIC SHIELDED/DOUBLE MAGNET
- SPECIALLY DESIGNED FOR TV SETS
- VERY SMOOTH FREQUENCY RESPONSE
- HIGH DAMPING RUBBER SURROUND
- WELL SUITED FOR BASS REFLEX
- VENTED THROUGH SHIELD

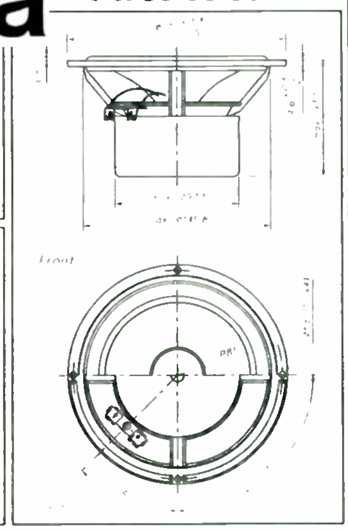


NOMINAL IMPEDANCE	8	Ω
NOMINAL POWER (IEC 268-5)	50	W
MUSIC POWER (DIN 45500)	80	W
FREQUENCY RANGE	34-5000	Hz
SENSITIVITY (1W, 1m)	89	dB
EFFECTIVE CONE AREA	137	cm²
VOICE COIL RESISTANCE	5,8	Ω
VOICE COIL INDUCTANCE	0,7	mH
OPERATING POWER	5,0	W
VOICE COIL DIAMETER	25	mm
VOICE COIL HEIGHT	12	mm
AIR GAP HEIGHT	6	mm
FREE AIR RESONANCE	34	Hz
MOVING MASS (incl. air)	11	g
FORCE FACTOR, B x l	5,3	Txm
MAGNET WEIGHT (12,1 oz)	344	g
Qms	1,36	
Qes	0,47	
Qts	0,34	
Vas	53	ltr

6½" WOOFER — P17SJ-00-08

SPECIAL FEATURES:

- MAGNESIUM BASKET
- MINERAL FILLED POLYCONE
- HIGH DAMPING RUBBER SURROUND
- VERY SMOOTH FREQUENCY RESPONSE
- MAGNETIC SHIELDED / DOUBLE MAGNET



NOMINAL IMPEDANCE	8	Ω
VOICE COIL RESISTANCE	5.6	Ω
NOMINAL POWER (IEC 268-5)	20	W [1]
SHORT TERM MAX. POWER (IEC 268-5)	350	W [2]
LONG TERM MAX. POWER (IEC 268-5)	150	W [3]
MUSIC POWER (DIN 45500)	120	W
OPERATING POWER	8	W
SENSITIVITY (1W, 1m) / (2.83V, 1m)	87/87	dB
FREQUENCY RANGE	35-5000	Hz
FREE AIR RESONANCE	41	Hz
VOICE COIL DIAMETER	32	mm
VOICE COIL HEIGHT	14	mm
AIR GAP HEIGHT	6	mm
VOICE COIL INDUCTANCE	0.84	mH
EFFECTIVE CONE AREA	136	cm²
MOVING MASS (incl. air)	12	g
MAGNET WEIGHT (2 magnets) (25.4 oz)	721	g
FORCE FACTOR, Bxl	6	Txm
VAS	33	ltr
Qms	1.28	
Qes	0.48	
Qts	0.36	

P17SJ-00-08

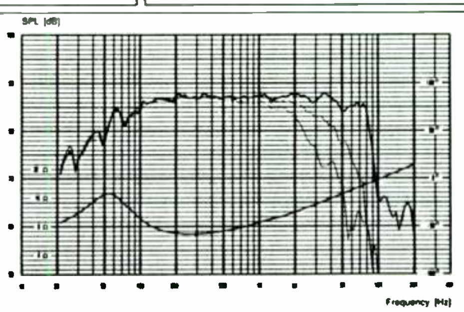
DISPERSION PLOT
0, 30 and 60 deg.

Input: 2.83 V
Mic.: 1 m

320 ltr. box mounted in infinite baffle.

09.12.94 PM

Anechoic room 6x7x8 meters.
Half space free-field above 100 Hz.
Brüel & Kjær 2012 Audio Analyzer.

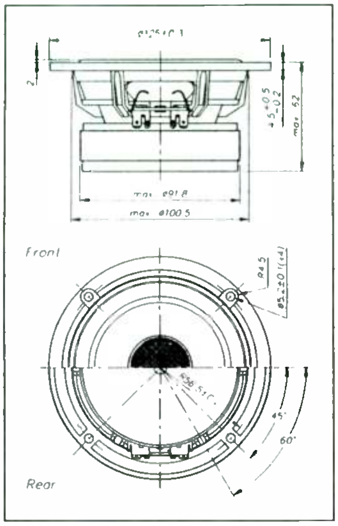


4½" WOOFER — M11WH-09-08

SPECIAL FEATURES:

- LONG STROKE, LOW REFLEXION, MAGNESIUM BASKET
- BLACK COATED PAPER CONE
- LOW DAMPING RUBBER SURROUND
- VENTED THROUGH V. C. FORMER AND POLE PIECE
- NEUTRAL MIDRANGE REPRODUCTION

NOMINAL IMPEDANCE	8	Ω
VOICE COIL RESISTANCE	5.4	Ω
NOMINAL POWER (IEC 268-5)	30	W [1]
SHORT TERM MAX. POWER (IEC 268-5)	140	W [2]
LONG TERM MAX. POWER (IEC 268-5)	70	W [3]
MUSIC POWER (DIN 45500)	60	W
OPERATING POWER	8	W
SENSITIVITY (1W, 1m) / (2.83V, 1m)	87/87	dB
FREQUENCY RANGE	70-5000	Hz
FREE AIR RESONANCE	68	Hz
VOICE COIL DIAMETER	25	mm
VOICE COIL HEIGHT	10	mm
AIR GAP HEIGHT	4	mm
VOICE COIL INDUCTANCE	0.6	mH
EFFECTIVE CONE AREA	57	cm^2
MOVING MASS (incl. air)	5.8	g
MAGNET WEIGHT (14.6 oz)	415	g
FORCE FACTOR, Bxl	6.0	Txm
Vas	4.3	ltr
Qms	1.79	
Qes	0.37	
Qts	0.31	



M11WH-09-08

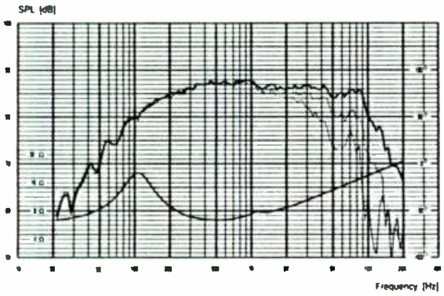
DISPERSION PLOT
0, 30 and 60 deg.

Input: 2.83V
Mic.: 1m

1,8 ltr. box mounted in infinite baffle.

06.08.93 FKJ

Anechoic room 8 x 7 x 8 meters.
Half space free-field above 100 Hz.
Brüel & Kjær 2012 Audio Analyzer.

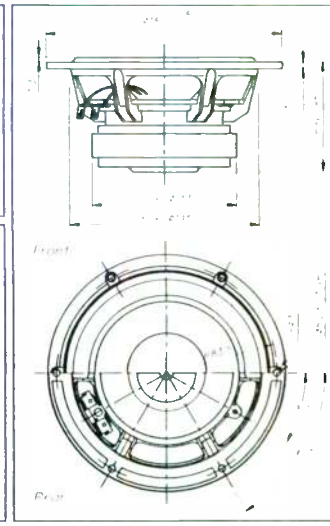


6½" WOOFER — M18WO-09-08

SPECIAL FEATURES:

- NEW LONG STROKE, LOW REFLEXION, MAGNESIUM BASKET
- STIFF AIRDRIED PAPER CONE
- LOW DAMPING RUBBER SURROUND
- KAPTON® V. C. FORMER
- LONG THROW MAGNET SYSTEM
- OPTIMIZED FOR BASS REFLEX

NOMINAL IMPEDANCE	8	Ω
NOMINAL POWER (IEC 268-5)	70	W
MUSIC POWER (DIN 45500)	90	W
FREQUENCY RANGE	35-4000	Hz
SENSITIVITY (1 W, 1 m)	87.5	dB
EFFECTIVE CONE AREA	132	cm^2
VOICE COIL RESISTANCE	5.7	Ω
VOICE COIL INDUCTANCE	0.90	mH
OPERATING POWER	7.1	W
VOICE COIL DIAMETER	40	mm
VOICE COIL HEIGHT	14	mm
AIR GAP HEIGHT	6	mm
FREE AIR RESONANCE	35	Hz
MOVING MASS (incl. air)	17.5	g
FORCE FACTOR, Bxl	7.5	Txm
MAGNET WEIGHT (24.6 oz)	698	g
Qms	6.70	
Qes	0.39	
Qts	0.37	
Vas	26.5	ltr

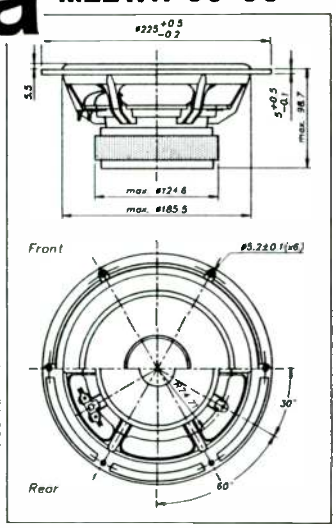


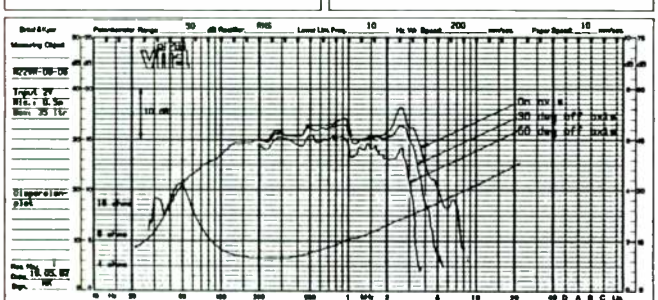
8" WOOFER — vifa — M22WR-09-06

SPECIAL FEATURES:

- NEW LONG STROKE, LOW REFLEXION, MAGNESIUM BASKET
- VERY STIFF CONICAL PAPER CONE
- LOW DAMPING RUBBER SURROUND
- MAGNET SYSTEM WITH 2" VC AND LARGE VENT
- OPTIMIZED FOR BASS REFLEX

NOMINAL IMPEDANCE	6	Ω
VOICE COIL RESISTANCE	4.3	Ω
NOMINAL POWER (IEC 268-5)	150	W
MUSIC POWER (DIN 45500)	200	W
OPERATING POWER	7.5	W
SENSITIVITY (1W, 1m)	88	dB
FREQUENCY RANGE	30-1000	Hz
FREE AIR RESONANCE	30	Hz
VOICE COIL DIAMETER	50	mm
VOICE COIL HEIGHT	21	mm
AIR GAP HEIGHT	8	mm
VOICE COIL INDUCTANCE	1.1	mH
EFFECTIVE CONE AREA	224	cm^2
MOVING MASS (incl. air)	36	g
MAGNET WEIGHT (37.4 oz)	1062	g
FORCE FACTOR, B x L	8.8	Txm
Vas	55	ltr
Qms	2.73	
Qes	0.38	
Qts	0.33	



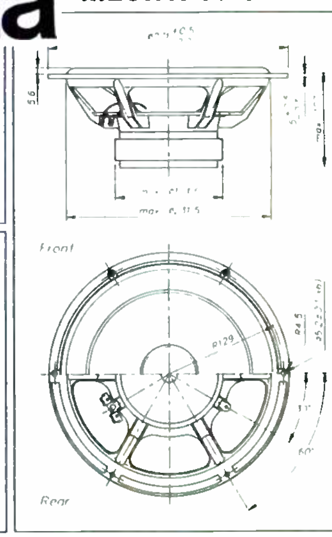


10" WOOFER — vifa — M26WR-09-08

SPECIAL FEATURES:

- NEW LONG STROKE, LOW REFLEXION, MAGNESIUM BASKET
- VERY STIFF CONICAL PAPER CONE
- LOW DAMPING RUBBER SURROUND
- MAGNET SYSTEM WITH 2" V. C. AND LARGE VENT
- OPTIMIZED FOR BASS REFLEX

NOMINAL IMPEDANCE	8	Ω
VOICE COIL RESISTANCE	5.9	Ω
NOMINAL POWER (IEC 268-5)	160	W [1]
SHORT TERM MAX. POWER (IEC 268-5)	>500	W [2]
LONG TERM MAX. POWER (IEC 268-5)	300	W [3]
MUSIC POWER (DIN 45500)	200	W
OPERATING POWER	5.6	W
SENSITIVITY (1W, 1m) / (2.83V, 1m)	88.5/88.5	dB
FREQUENCY RANGE	26-1000	Hz
FREE AIR RESONANCE	26	Hz
VOICE COIL DIAMETER	50	mm
VOICE COIL HEIGHT	21	mm
AIR GAP HEIGHT	8	mm
VOICE COIL INDUCTANCE	1.8	mH
EFFECTIVE CONE AREA	337	cm^2
MOVING MASS (incl. air)	45	g
MAGNET WEIGHT (37.4 oz)	1062	g
FORCE FACTOR, Bxl	11	Txm
Vas	130	ltr
Qms	2.82	
Qes	0.36	
Qts	0.32	



M26WR-09-08

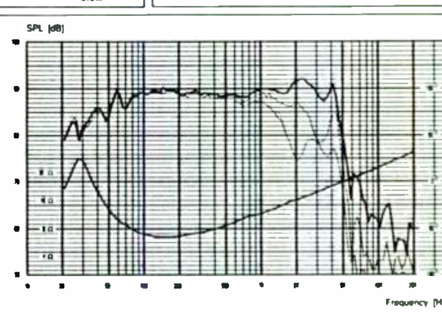
DISPERSION PLOT
0, 30 and 60 deg.

Input: 2.83V
Mic.: 1m

320 ltr. box mounted in infinite baffle.

06.08.93 ABC

Anechoic room 8 x 7 x 8 meters.
Half space free-field above 100 Hz.
Brüel & Kjær 2012 Audio Analyzer.



THE BAEKGAARD CROSSOVER TECHNIQUE

By G.R. Koonce

I was very interested in D.E. Stenton's well-researched System III Loudspeaker design article in *SB* 5/94 (p. 8), because of his use of the Baekgaard "bridging" speaker technique.[1] Although Baekgaard uses the term "filler" speaker, I will stay with Stenton's terminology.

Baekgaard adds a bridging speaker to "fill" the infamous notch that results when a two-way, second-order Butterworth crossover is used and both drivers are connected with normal polarity. This technique converts a crossover that is normally unacceptable, because it is not all-pass (AP), to one that is not only AP but constant-voltage (CV). With a CV crossover, the on-axis response is constant (i.e., an AP), and it maintains the phase so the outputs sum to unity. Such a device has no distortion of its transient response and is thus considered ideal. This is really a case of creating a "silk purse from a sow's ear."

Generally, only first-order passive crossovers will provide this CV characteristic. Since Stenton covers the requirements for driver frequency overlap about the crossover frequency, driver directivity, and also addresses the bandpass (BP) filter requirements for the bridging speaker, I will not repeat this information.

Both Stenton and Baekgaard use passive implementations. Interestingly, an active filter circuit topology exists that produces all three of the outputs needed to use the Baekgaard approach: low pass (LP), high pass (HP), and BP. And it is easily tunable!

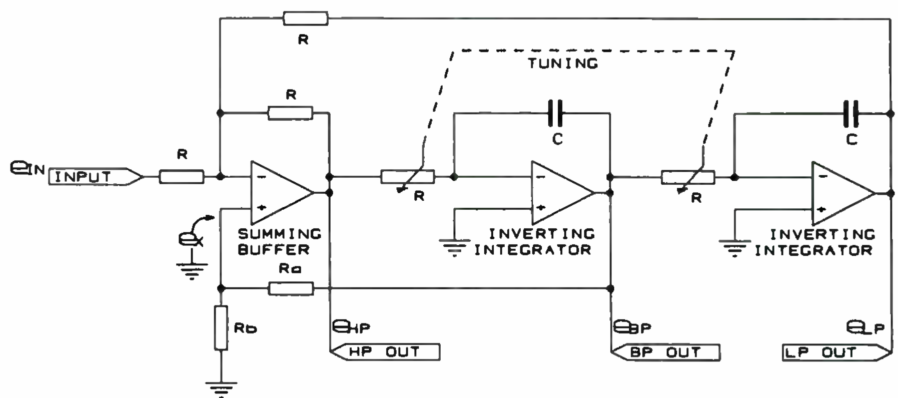
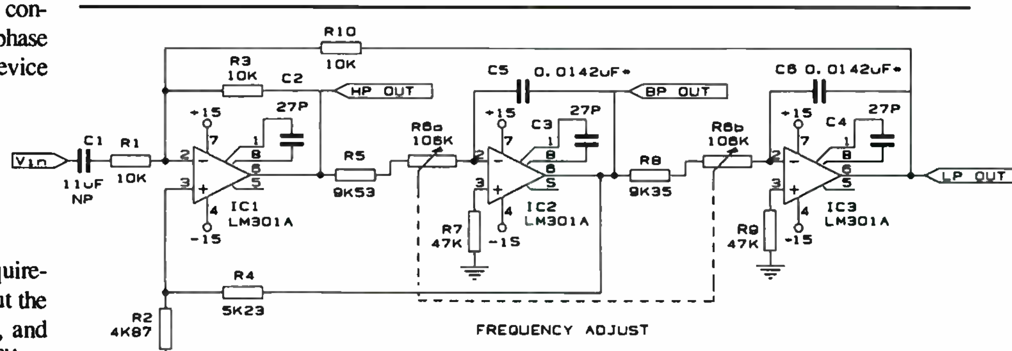


FIGURE 1: The state-variable filter implementation.



*C5, C6: 0.0142uF FOR LOW-PASS, 0.0014uF FOR HIGH-PASS

FIGURE 2: Schematic for breadboard state-variable filter.

AN ACTIVE APPROACH

Back in 1979 I decided I needed a tunable crossover for speaker development work. I concluded that finding a potentiometer of more than two sections (a dual pot) that could be used for crossover tuning would be unlikely. This led me to develop a two-way, second-order Butterworth device. Searching the literature, I found that the state-variable filter topology looked best for my intended use. This topology is covered in Lancaster.[2] The basic implementation is shown in *Fig. 1*.

The steady-state gain equations for this configuration are:

$$\frac{e_{LP}}{e_{IN}} = \frac{-(\omega_0)^2}{(\omega_0)^2 - \omega^2 + j(\omega\omega_0/Q)} \qquad \text{at } \omega \ll \omega_0 \quad \frac{e_{LP}}{e_{IN}} \cong -1$$

$$\frac{e_{BP}}{e_{IN}} = \frac{j\omega\omega_0}{(\omega_0)^2 - \omega^2 + j(\omega\omega_0/Q)} \qquad \text{at } \omega = \omega_0 \quad \frac{e_{BP}}{e_{IN}} = Q$$

$$\frac{e_{HP}}{e_{IN}} = \frac{\omega^2}{(\omega_0)^2 - \omega^2 + j(\omega\omega_0/Q)} \qquad \text{at } \omega \gg \omega_0 \quad \frac{e_{HP}}{e_{IN}} \cong -1$$

where ω = radian frequency of interest
Q = filter Q (0.707 = Butterworth)
ω_0 = 1/RC = frequency to which filter is tuned

The state-variable filter section has all three Butterworth outputs. It so happens that the BP output is the proper crossover function for the bridging speaker. When you tune the state-variable filter, the three outputs tune together.

Figure 2 is the schematic for a breadboard state-variable filter. Remember, this work was done some 15 years ago; I'm sure different op amps would be selected today. The three breadboard filter outputs are shown in *Fig. 3* at a crossover frequency of 95Hz. If you compare these responses with Stenton's Fig. 6 (p. 12), you will see they agree, except that the BP gain is not unity. *Figure 4* shows what is required to convert the state-variable filter outputs into a noninverting CV crossover. The equations confirm that these outputs do, in fact, sum to unity, and will do so at any frequency to which the crossover is tuned:

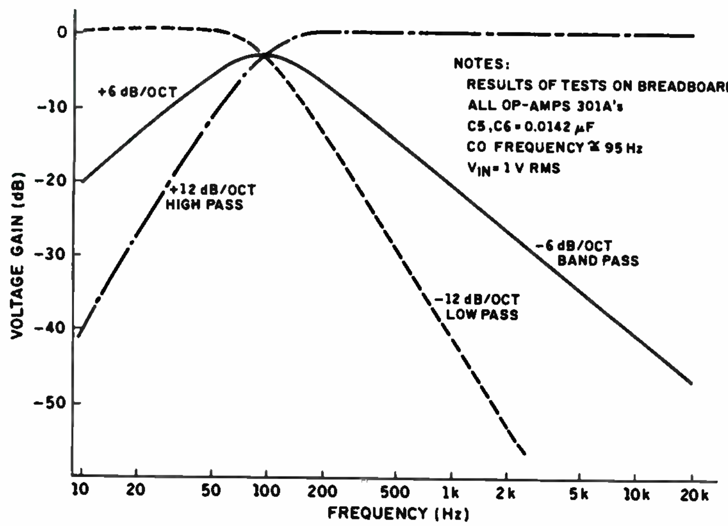


FIGURE 3: Three outputs from breadboard state-variable filter.

$$\frac{e_H}{e_{IN}} = \frac{S^2}{S^2 + (\omega_0/Q)S + (\omega_0)^2}$$

$$\frac{e_B}{e_{IN}} = \frac{(\omega_0/Q)S}{S^2 + (\omega_0/Q)S + (\omega_0)^2}$$

$$\frac{e_L}{e_{IN}} = \frac{(\omega_0)^2}{S^2 + (\omega_0/Q)S + (\omega_0)^2}$$

$$\frac{e_H + e_B + e_L}{e_{IN}} = \frac{S^2 + (\omega_0/Q)S + (\omega_0)^2}{S^2 + (\omega_0/Q)S + (\omega_0)^2} = 1$$

PLAYING GAMES

One circuit of the type shown in *Fig. 4* will provide a two-way, second-order Butterworth crossover function with the desired bridging speaker capability. Its direct use in a two-way system would require three drivers and triamping. When building a two-way system, you may find drivers with sufficient frequency overlap for the woofer to also handle the bridging speaker requirements (refer to Stenton for details).

You would simply sum the LP and BP outputs to drive the woofer, resulting in a two-driver system that is biamped and has a CV crossover function. The tweeter would have the protection of a second-order HP, with the woofer crossover section rather unusually shaped due to the LP-BP summation. Because it is tunable, you can move the crossover point about somewhat to optimize the system performance.

Finding drivers with sufficient frequency overlap and proper directivity to build such a system may be difficult, but things should improve for a three-way system. This would require building two of the state-variable functions from *Fig. 4*. Again, drivers may be available which let the woofer act as the bridging speaker for the lower crossover frequency, and the midrange driver serve this purpose for the upper crossover frequency.

The result is a three-driver, three-way system with CV crossover, and the tweeter protected by a second-order HP. If you build three of these circuits, with the proper buffers and switching, they can be configured as any of the following *tunable* crossovers:

1. multiple two-way, second-order Butterworth with bridging speaker BP output;
2. a three-way, second-order Butterworth with both bridging speaker BP outputs;
3. a two-way, fourth-order Linkwitz-Riley (no bridging speaker needed).

KEEP IN MIND

The popular fourth-order Linkwitz-Riley (LR4) crossover, functionally two cascaded second-order Butterworth sections, is difficult to implement passively. The tunable implementation above requires three state-variable functions, which can get messy to

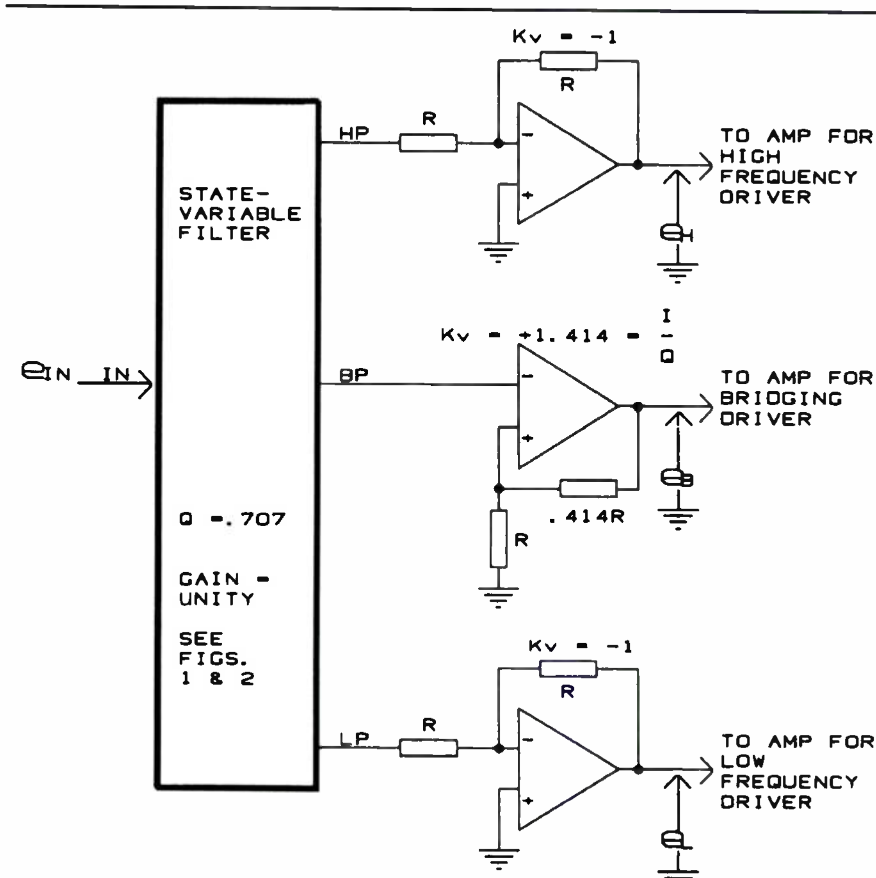


FIGURE 4: Constant-voltage crossover function with bridging speaker.

REFERENCES

1. E. Baekgaard, "A Novel Approach to Linear Phase Loudspeakers Using Passive Crossover Networks," JAES (May 1977): 284–294. This work is also included in the original *AES Loudspeakers—An Anthology*, p. 411.

2. D. Lancaster, *Active-Filter Cookbook* (Howard W. Sams, 1975): #21168.

3. D.A. Bohn, "A Fourth-Order State Variable Filter for Linkwitz-Riley Active Crossover Design," AES Preprint 2011 (B-2), Oct. 1983.

4. J. Vanderkooy and S.P. Lipshitz, "Power Response of Loudspeakers with Non-Coincident Drivers: The Influence of Crossover Design," AES Preprint 2049 (F-4), Oct. 1983.

tune. Bohn proves the LR4 crossover can be implemented with a single fourth-order state-variable filter.[3]

The AP and CV crossover functions will produce a flat on-axis response if the drivers are properly located. This does not guarantee they will also produce a flat power response, which could affect the imaging. Vanderkooy and Lipshitz have shown that, with noncoincident driver locations, these crossover functions may not have such responses in the real world.[4]

Here we have addressed the use of Baekgaard's technique with a bridging driver for second-order crossovers. Reference 1 also discusses applying the same approach to higher-order crossover functions.

Once you go to an active crossover, there are numerous ways to develop a CV function. For example, generate the HP by subtracting a unity gain LP from the input signal. The state-variable implementation is only one tunable approach that should be considered.

CROSSOVER RESULTS

The state-variable topology produces an excellent general purpose two-way crossover. Mine is still in service and can be tuned from 100Hz to 8kHz in three overlapping bands. I bought a number of bargain dual 100kΩ pots and selected the best one in terms of resistance tracking. This crossover's performance over its full range is shown in *Fig. 5*.

The filter slopes are well-maintained to nearly 50kHz, and all crossover points are down the theoretical 3dB. Generating a null quickly shows how well a filter maintains phase. The two-way, second-order Butterworth does this inherently at the crossover frequency if the two outputs are summed. *Figure 6* shows the theoretical null that should occur (solid line) and the test results for my crossover (the "X" points). The measured null, which is down 50dB, may be limited by the summing resistors.

One of the worries with a tunable crossover is whether you dare tune it during use, or will undesirable and possibly dangerous spurious signals be generated. My experience with the state-variable approach has been that tuning the crossover, and even switching ranges, produces no unwanted signals.

I believe you could use switched attenuators to tune the crossover, rather than the pot, if shorting-type rotary switches are used to avoid an open circuit during switching. This would allow a higher-order crossover function. A friend built a pair of these units, which he can cascade to produce a fully tunable three-way, second-order Butterworth crossover.

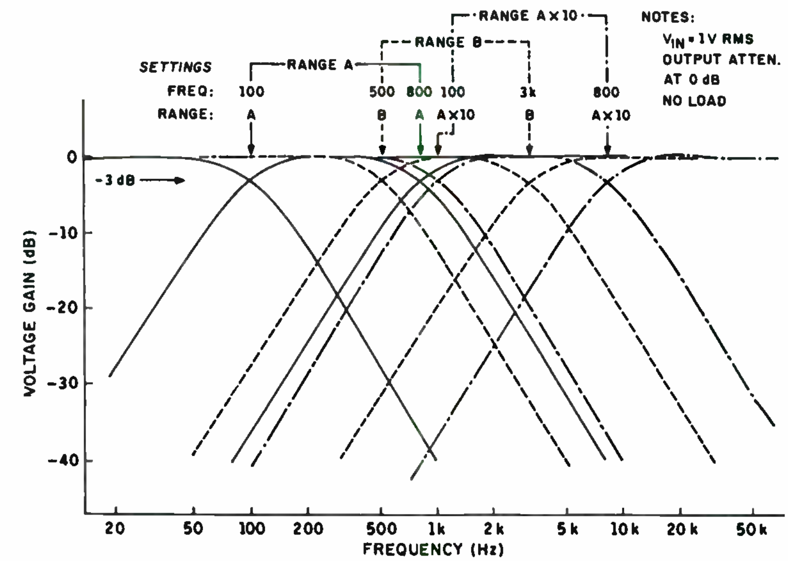


FIGURE 5: Gain versus frequency over entire tuning range for two-way crossover.

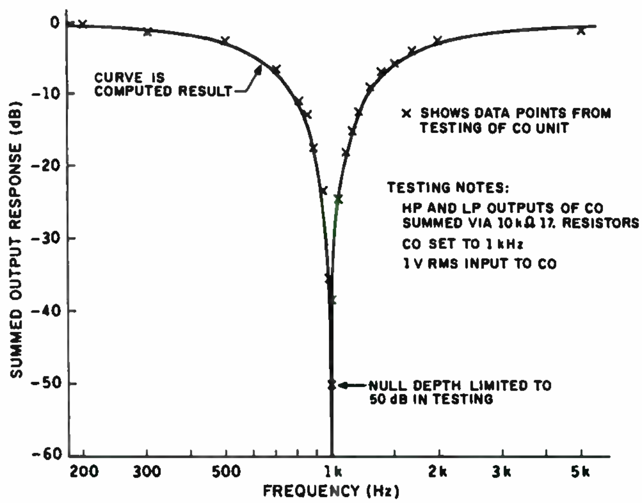


FIGURE 6: Notch produced by summing outputs of two-way second-order Butterworth crossover.

THE BAEKGAARD APPROACH

[Note: This material is presented courtesy of JAES.—Ed.]

Erik Baekgaard was born in 1939 in Mors, Northwest Jutland, Denmark. He worked for Bang & Olufsen A/S in Struer, Denmark, when he published his work on the bridging speaker technique in 1977. The main body of this document worked with the two-way, second-order Butterworth passive crossover, and developed the requirements for the crossover function to deliver to a bridging driver the signal necessary to "fill" acoustically the notch normal to the basic two-way crossover function, resulting in a constant-voltage crossover function.

Appendices to this work show how the same approach can be applied to third-order crossover functions with a single bridging driver and even higher-order crossover functions, but multiple bridging drivers may be required. This work is a truly novel approach to a passive crossover solution to the notch resulting at the crossover frequency with a second-order Butterworth crossover function. Properly applied, the result is the superior constant-voltage crossover function.

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Reader Service #49

REBUILDING THE KLH-9 POWER SUPPLY

By Clarence C. Close, M.D.

In 1961 I purchased two pairs of KLH-9 full-range electrostatic speakers and lived happily with them for 24 years until I sensed degradation in their usually superb sound. I contacted Arthur Janszen (the designer), who advised me to check the polarizing voltages and replace the worn-out selenium rectifiers. With an electrostatic voltmeter, I found the voltages were less than half the specified voltages of 1.1kV on the tweeter and 5.7kV on the woofer midrange (*Fig. 1*).

Janszen suggested using a high-quality avalanche-protected silicon diode such as the 1N4007. He was uncertain how many were needed to produce the proper voltage. I obtained the proper diodes and set out to return my speakers to their original condition. I was able to do that and more, since the silicon diodes should last for a very long time.

PREPPING THE POWER SUPPLY

The following procedure is how I handled the problem. You may determine other solutions, but this one worked for me. Remember, you will be dealing with very hot potting material and high voltages, so use care and caution.

If you're reluctant to perform this repair, I will do it for $200/power supply, or you can contact Blue Hill Industries, Box 387, Boston, MA 02119, (617) 427-6300. You can have damaged panels repaired by contacting Wm. Barton, 243 Heath's Bridge Rd., Concord, MA 01742, (508) 371-1441.

The power supply is "potted" in a wax resin material which becomes liquid at about 300°F. All of the internal components (i.e., transformers) are held in place, not by any

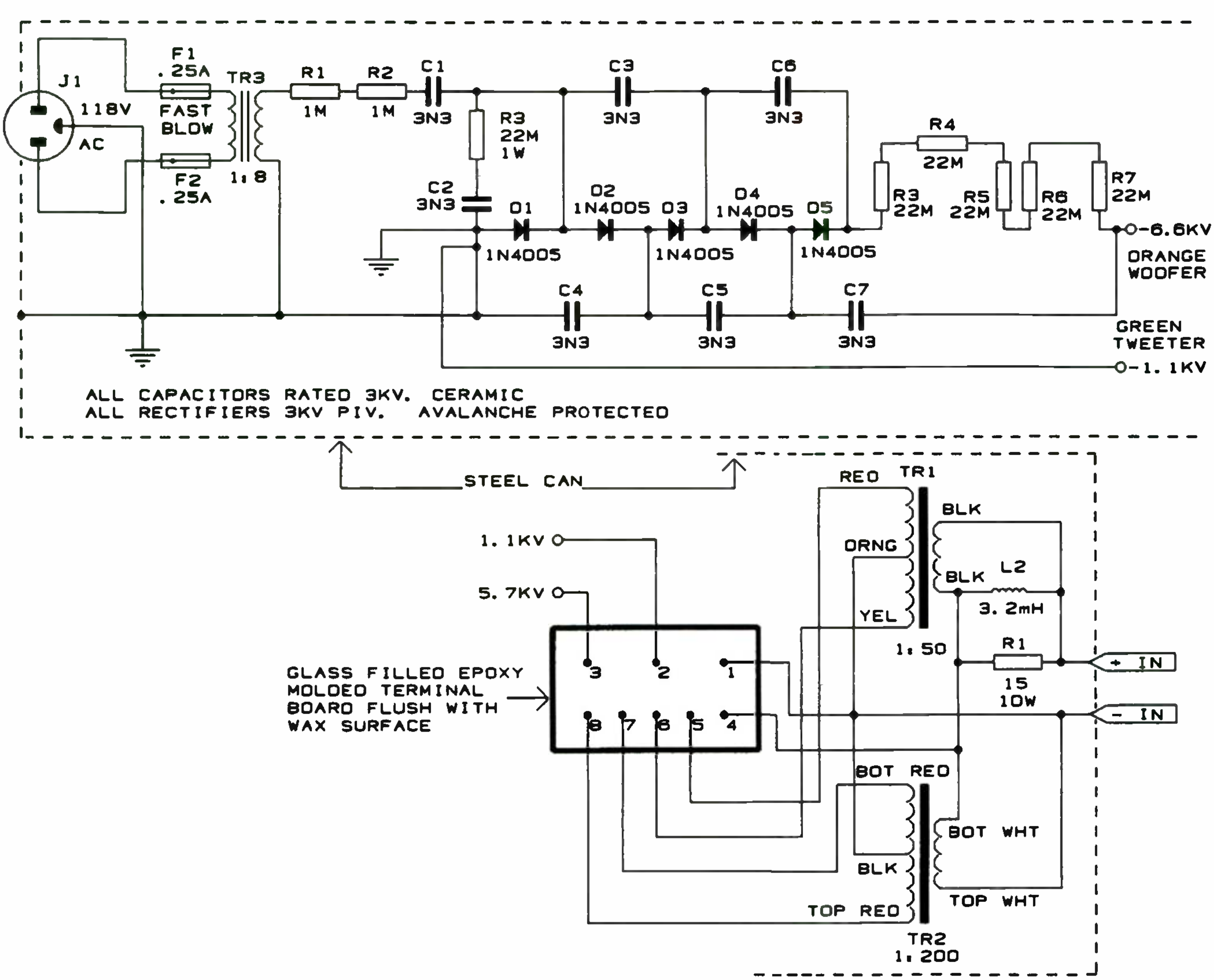

FIGURE 1: KLH-9 power supply schematic.

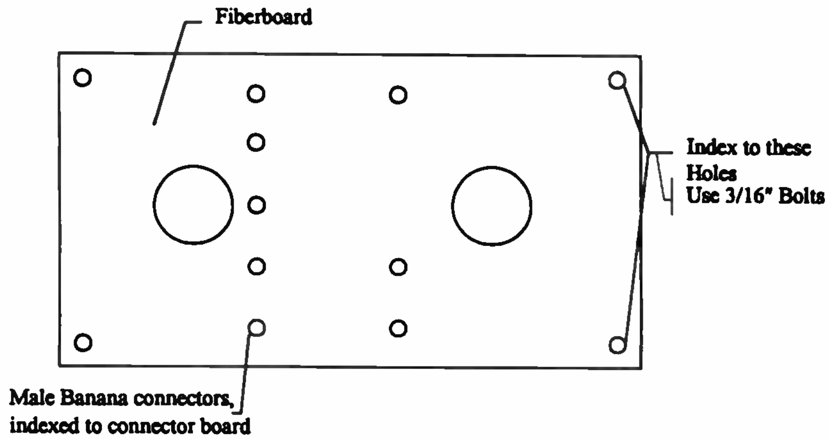

FIGURE 2: Cut two 3″ holes in your jig.

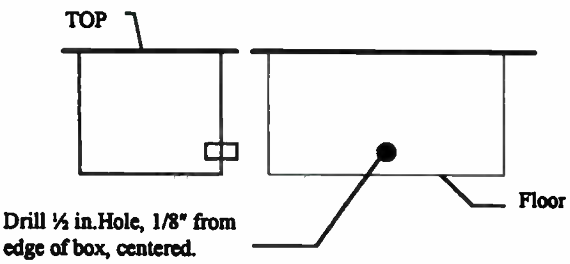

FIGURE 3: Drill a hole in the power supply and plug it with a rubber stopper.

mechanical means (i.e., screws), but by the potting material. A critical area is the connection board that holds the female banana plugs that mate to the speaker base.

You must construct a jig of masonite or fiberboard, and drill it to bolt male-threaded banana plugs with washers and nuts to mate exactly with the circuit board. Drill slightly oversized holes, inserting the plugs into the connector board and tightening the nuts to maintain accurate mating. Be sure to use the four holes in the corners of the power supply box for indexing the jig at the same time. Also, cut 3″ circles to allow you access for pouring the potting material and positioning the circuit board (*Fig. 2*). Note: Only one jig is needed for the right and left power supplies.

WHAT'S COOKING?

After you have built the jig and are sure it mates properly, remove it and drill a ½″ hole at the midpoint of the power supply box where the power supply contacts the floor. Drill only ½″ into the power supply and save the potting material, making sure no steel chips remain inside. Plug the hole very securely with a rubber chemistry stopper (*Fig. 3*).

Put the power supply into an oven at 300°. Be sure to place a pan under it to catch any overflow and protect the oven. When the potting material begins to liquefy, remove some of the fluid with an old spoon or turkey baster, since as it heats it expands and tends to run over. It is also a good idea to insert the right-sized wooden dowels prior to heating into each of the female banana plugs, since the liquid potting material tends to rise and clog the opening.

When the entire potting material has become liquid, remove the power supply to a table well-covered with newspaper or other covering. Slide it slightly over the edge and carefully remove the rubber stopper to allow the liquid to run out. Watch out—it tends to spurt. Also, it just fills up a 3 lb coffee can, and you will need to save as much as possible.

After all of the liquid has run out (tip it only very slightly or the transformer will shift), you will see the components (*Figs. 4* and *5*). Carefully desolder the various wires to the connector board and remove the board and its associated rectifiers and capacitors. You should be able to easily recognize the selenium rectifiers, which you will need to take out. Be sure to note and label where each wire connects.

CLEANUP

The board will be covered with potting material, which you can clean off in one of several ways. I found carefully applying a heat gun causes most of the potting material to run off, without damaging ceramic or mica capacitors and the resistors. Another method is to immerse the whole mess into denatured alcohol to disintegrate the waxy material, which you can then easily scrape off.

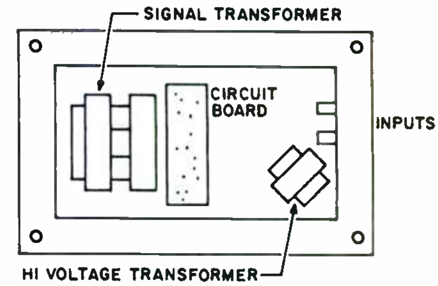

FIGURE 4: Power supply components.

After desoldering and removing the selenium rectifiers, measure the distance between the connection points (*Fig. 6*). Using a piece of corrugated cardboard as a jig, construct a daisy chain of *five 1N4007* silicon rectifiers, with good mechanical connection, and then solder. You will need *five daisy chains*. The original contained six selenium rectifiers, but the voltage was an excessive 6.6kV. Removing one chain and *substituting five 22MΩ* ½W resistors worked well and acted somewhat as a filter.

After you have positioned and soldered these to the connector board, you are ready to repot. Using the jig, position the connector board, making sure to index the jig to the box. Be sure the connector board is about

Continued on page 64

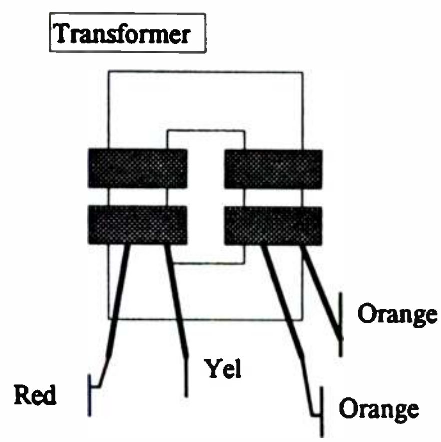

FIGURE 5: Power supply transformer.

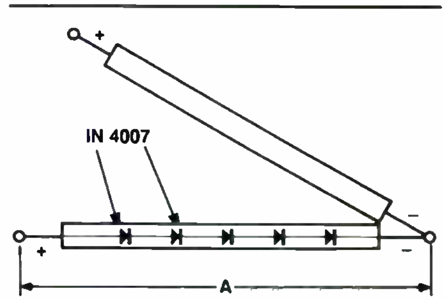

FIGURE 6: Measuring the distance between the connector points. Polarity must be the same for all assemblies.

ABOUT THE AUTHOR

Clarence C. Close, M.D., is a retired family physician whose hobbies are hi-fi and amateur recording. He has extensively recorded Northwestern University bands and orchestra and produced several records. His most recent CD recorded (taped) originally in 1964 was released as "John Seng and the Mundelein Organ Revisited."

Part 2

DRIVER-OFFSET-RELATED PHASE SHIFTS IN CROSSOVER DESIGN

By Bruno Carlsson

In Part 1 (*SB* 1/95, p. 26), I examined the effects of driver-offset-related phase shifts on various crossover filters and investigated one way to reduce filter sensitivity to phase shifts, that is, using filters with asymmetrical slopes. Part 2 covers two other ways to minimize signal errors, and some practical ways to estimate driver offset in speaker systems.

ADJUSTING FILTER OVERLAP

Another method of minimizing the effects of driver-offset-related phase shifts is to adjust the cutoff frequencies of the low-pass (LP) and high-pass (HP) filter sections, allowing for more or less overlap between the filters. For a nominal crossover frequency of 1kHz, for example, you can design the LP filter for a cutoff frequency of 909Hz and the HP filter for 1.1kHz, reducing the overlap between the two sections by 10%. Unfortunately, it's difficult to know whether to reduce or increase the overlap to counteract a phase shift.

Often, when you adjust filter overlap, the change in phase angle at crossover produces a correction which is opposite to the correction from the change in amplitude. Without the aid of computer simulation, you can't accurately predict the effect on the response. You need to consider both the amplitude and the phase response of each filter section.

As a rule of thumb, if the response needing correction has a hump, the overlap should be decreased. If the response dips, then the overlap should be increased. However, the effects vary with the order of the filter as well as with the type. To see how this works, let's examine some popular filter types.

SECOND-ORDER FILTERS

Since the response of the second-order Butterworth filter shows a peak at the crossover frequency, it seems logical to pull the two filter sections apart. *Figures 19* and *20* show the response when you move HP and LP sections apart by 15% and 30%, respectively. In most situations the 15% adjustment is superior, and, by changing polarity at 70°, we can cover the entire range from 0° to 160° with an acceptable error. The 30% reduction, which often provides a flat response from the second-order Butterworth at a 0° phase shift, produces an acceptable error between 0° and 35°, as well as between 70° and 150°.

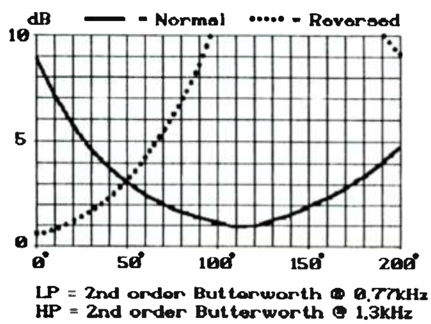

FIGURE 20: Second-order Butterworth with 30% adjustment.

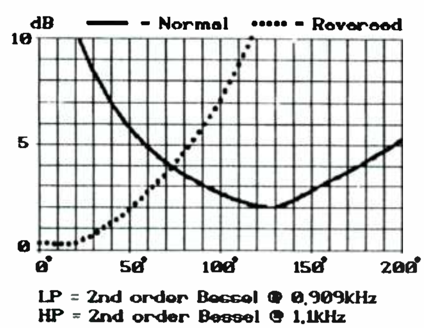

FIGURE 21: Second-order Bessel with 10% adjustment.

With a second-order Bessel filter, pulling the filter sections apart by 10% gives the response in *Fig. 21*. The minimum error of Fig. 4 in Part 1 shifts from 40° to 10°, but the difference between this response and the response with both sections at 1kHz is not significant. The 10% adjustment provides a suitable correction to make the second-order Bessel filter flat for a 0° phase shift. Its performance is acceptable from 0° to 50°.

The second-order Linkwitz-Riley filter is already flat at 0°, but by increasing the filter overlap by 15% (*Fig. 22*), we can improve the response from 30° and up. However, the response starts showing significant error around 60°, so the improvement is limited to between 30° and 60°. Even in this range, the improvement is small, making the second-order Linkwitz-Riley a poor candidate for manipulation by increasing (or decreasing) filter overlap.

THIRD-ORDER

The third-order Butterworth filter is already fairly insensitive to phase shifts, but by pulling the filter sections apart, you can reduce the error. *Figure 23* shows the

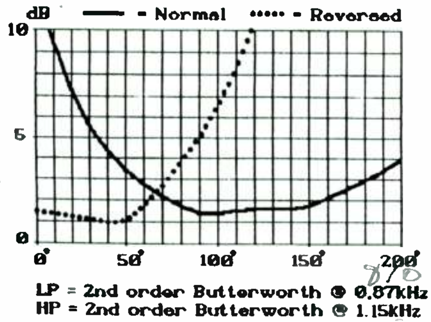

FIGURE 19: Second-order Butterworth with 15% adjustment.

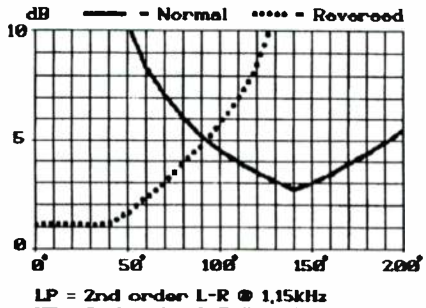

FIGURE 22: Second-order Linkwitz-Riley with 15% overlap increase.

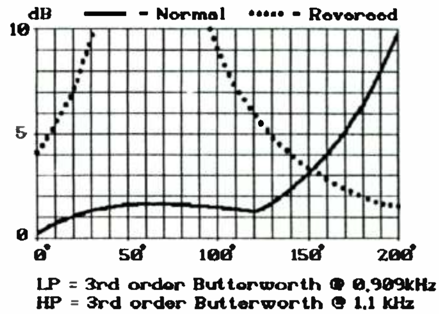

FIGURE 23: Third-order Butterworth with 10% less overlap.

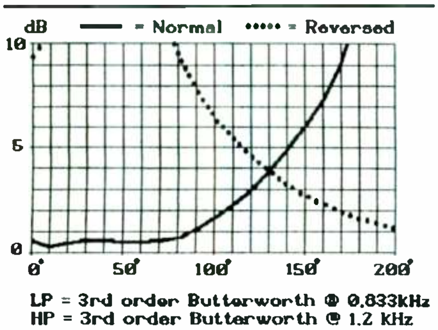

FIGURE 24: Third-order Butterworth with 20% less overlap.

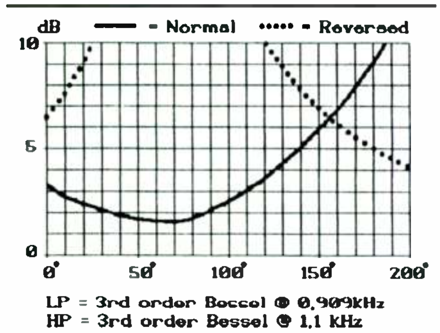

FIGURE 26: Third-order Bessel with 10% decrease.

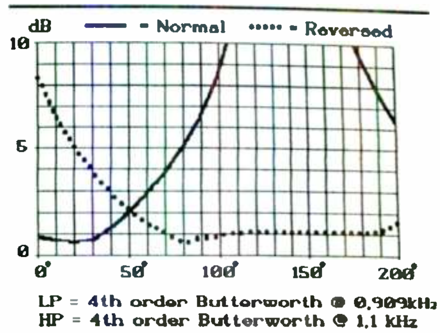

FIGURE 28: Fourth-order Butterworth—10% adjustment.

response for 10% less overlap. The maximum error in the flat part of the response is about half of what you'd expect without a change in filter overlap. If we adjust by 20% (*Fig. 24*), we'll obtain a filter which has less than 1dB error between 0° and 90° and shows acceptable error to 110°. Clearly, this filter configuration is very useful when the exact phase shift is unknown.

The third-order Bessel filter is somewhat difficult to improve by adjusting the overlap between filter sections. *Figures 25* and *26* depict the results when the overlap is either increased or decreased by 10%. The normal response in the two figures is almost identical, and they are also virtually identical to the response in Fig. 7.

The reversed connection is more sensitive than the normal connection to adjustments in the filter overlap, and if the overlap is increased by 10%, the reversed connection becomes usable for a 0° phase shift (*Fig. 25*). The behavior of this filter type makes it a poor candidate for manipulation by changing the filter overlap.

FOURTH-ORDER

In general, the higher the filter order, the smaller the frequency adjustment necessary. While a 20% change in overlap may be appropriate for a second-order type, 5% may be a better starting point for a fourth-order model. In a fourth-order Butterworth filter with the sections pulled apart by 5% (*Fig. 27*), the normal and reversed responses are mirrored around 70° instead of 90° as in Fig. 8.

If we adjust the frequency by 10% (*Fig. 28*), the normal connection is usable between 0° and 50°, and the reversed connection shows exceptional performance between 70° and 200°. In general, *Figs. 27* and *28* improve upon Fig. 8, and the fourth-order Butterworth is probably best used with some adjustment in filter overlap.

You can make the fourth-order Bessel filter, which was a bit of a disappointment without any adjustment, much more useful by increasing the overlap. *Figures 29* and *30* illustrate the response with 10% and 20% increases, respectively. When choosing between the two different adjustment factors, note that the 20% increase in overlap is superior at almost all phase shifts; the fourth-order Bessel is usable for phase shifts between 0° and 100°.

Finally, the fourth-order Linkwitz-Riley filter improves at larger phase shifts by increasing the overlap between sections. With a 5% increase (*Fig. 31*), the error is lower above 40° (compared to Fig. 10), with usable performance to around 90°. If you increase the overlap by 10% (*Fig. 32*), the error is lower than the unadjusted response above 50°, and the response is now usable to 100°. In addition, the reversed connection improves above 150°, where the error is small.

PHASE SHIFT NETWORKS

Several different networks change the phase of a signal without changing the amplitude. *Figure 33* shows probably the least complicated implementation of such an all-pass network and includes the proper formulas for calculating the values of the inductors and capacitors. F is the design frequency, and R is the speaker resistance.

To assist you in using this network, *Table 1* lists the frequency (for a design frequency of 1kHz) at which the network has a given phase shift. Note that the phase shift is negative, and therefore has a similar effect as the driver-offset-related phase shift.

Let's assume we have a phase shift of 70° at a crossover frequency of 2.5kHz. *Table 1* shows 70° of phase shift at a frequency of 700Hz, or 0.7*F. Since we want this phase shift at 2.5kHz, we know that 2.5kHz is equal to 0.7*F. By solving for F, we get F = 2,500/0.7, or 3,571Hz.

Next, calculate L and C from the formulas in *Fig. 33*, using the proper value for R and 3,571Hz for F. Finally, insert the all-pass network between the HP filter and the tweeter. This adds the same –70° of phase shift to the tweeter that driver offset adds to the woofer, forcing the phase angle between woofer and tweeter to 0°. You can now design the crossover filters as if no driver-offset-related phase shifts exist.

To show you the effectiveness of the all-pass network, I used *Table 1* to compensate

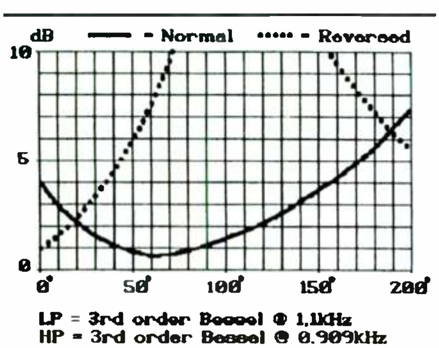

FIGURE 25: Third-order Bessel with 10% increase.

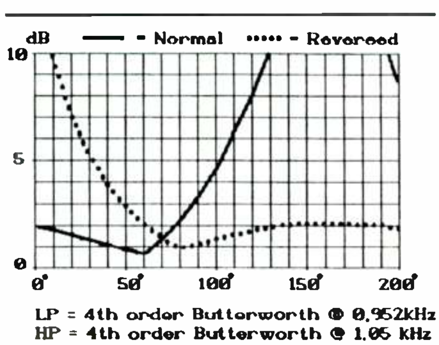

FIGURE 27: Fourth-order Butterworth—5% adjustment.

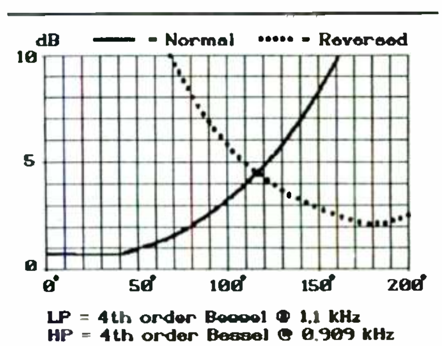

FIGURE 29: Fourth-order Bessel with 10% increase.

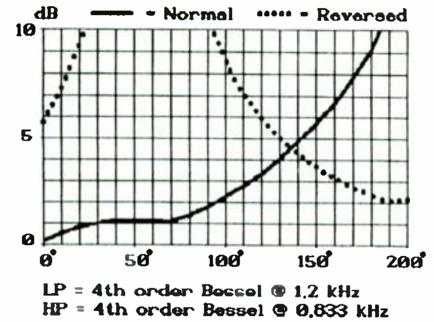

FIGURE 30: Fourth-order Bessel with 20% increase.

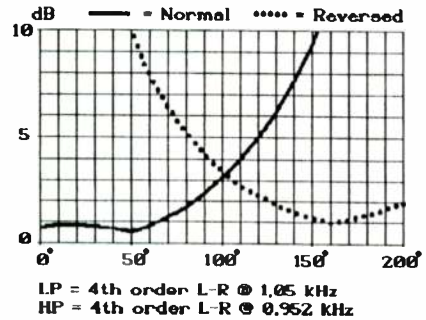

FIGURE 31: Fourth-order Linkwitz-Riley—5% adjustment.

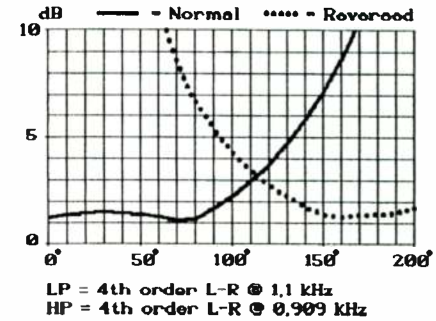

FIGURE 32: Fourth-order Linkwitz-Riley—10% adjustment.

for phase shifts between 20° and 160° and simulated the network response when used with the HP section of second- and fourth-order Linkwitz-Riley types. The results (*Fig. 34*) are better with fourth-order, but regardless of filter type, the correction is quite effective. When fourth-order is used with the network, the response shows lower errors than for any other solutions.

USING THE GRAPHS

We have now covered many different filter combinations and their performance when driver-offset-related phase shifts are introduced. You may now be saying, "Looks very interesting, but what good will it do for me?" To address that question, let's look at the information in the different figures, keeping in mind that readers belong to one of two groups. The first group knows (or at least thinks it knows) the phase shift at the crossover frequency, while the second lacks the capability to obtain this information. I address the latter group first.

If you lack the necessary equipment to measure phase shift, you can still use the wealth of information in the figures. You should concentrate on finding filters which are relatively insensitive to phase shifts. By using an insensitive filter, and maybe keeping the crossover frequency on the low side, you can increase the chances that any errors related to driver offset will be relatively small.

Also keep in mind that even if you have no test equipment, you can easily perform one test: simply look at the drivers. In chapter 7 of *The Loudspeaker Design Cookbook*, Vance Dickason states that you can use the center of the voice coil with reasonable accuracy to establish the zero delay plane (the plane from which the driver appears to radiate sound) of a speaker.

Measure the distance from the back of the mounting flange to the center of the voice coil for each driver and calculate the offset from the difference. Then use the formula from Fig. 1 to convert the distance into a phase shift at the crossover frequency. Unless a very large difference in depth between drivers exists, you can usually contain the estimated offset inside a range which is narrow enough to use the filter graphs.

For example, suppose you are building a two-way design with a 3kHz crossover frequency. The center of the woofer voice coil (you could also use the apex of the cone) is 1.25″ behind the mounting flange, while the tweeter voice coil is 0.5″ back. The difference is 0.75″, which translates into 59.9° of phase shift at 3kHz. Next, find a filter type with little error at 60° and which is flat on both sides of 60°, allowing for some error in your estimation. One example is the third-order Bessel in Fig. 7.

KNOWN PHASE SHIFT

To determine the phase shift, you must measure in one of two ways: with either an FFT-type analyzer or a phase meter. If you have access to an analyzer such as the IMP, which uses FFT methods to calculate and display amplitude as well as phase, you simply measure each driver's phase response from the same distance. By subtracting the tweeter phase angle from that of the woofer at the crossover frequency, you obtain the phase shift at this frequency. However, the calculated phase shift will be the sum of the driver-offset-related phase shift and phase shifts related to driver roll-off. Later, I will explain how to remove the roll-off-related phase shifts from the driver-offset phase shift.

The basic method is the same with a phase meter, but to minimize the effect of unwanted reflections, you will probably use a shorter distance between speaker and microphone. In the setup (*Fig. 35*), you must move the microphone vertically from one driver to the next, maintaining the same distance to the baffle. As with the FFT analyzer, you calculate the driver-offset phase shift by subtracting the phase angle of one driver at the crossover frequency from the other driver's phase angle.

Either method gives you only an approximation of the driver-offset phase shift at the crossover frequency. The reason is that the difference in phase angle contains phase shifts from driver high- and low-frequency roll-off, as well as from driver offset. The effects of the roll-off-related phase shift will be included in the crossover filters response,

Continued on page 32

TABLE 1

NETWORK PHASE SHIFT

Phase Shift (degrees)	Frequency (Hz)
20	176
30	268
40	364
50	466
60	577
70	700
80	839
90	1K
100	1,188
110	1,424
120	1,731
130	2,142
140	2,743
150	3,721
160	5,661

TABLE 2

MEASURED PHASE SHIFT

Frequency	17WLQ Phase (degrees)	17WLQ Delay (µs)	D-260 Phase (degrees)	D-260 Delay (µs)	Delay Difference (µs)
1k	−104	−290	+22	+60	350
1.2k	−125	−290	0	0	290
1.4k	−111	−220	−18	−35	255
1.7k	−135	−220	−43	−70	150
2k	−187	−260	−65	−90	170
2.2k	−202	−255	−79	−100	155
2.4k	−225	−260	−95	−110	150
2.7k	−253	−260	−117	−120	140
3k	−281	−260	−135	−125	135
3.5k	−353	−280	−176	−140	140
4k	−418	−290	−230	−160	130
4.5k	−502	−310	−259	−160	150
5k	–	–	−270	−150	–
6k	–	–	−324	−150	–
7k	–	–	−403	−160	–
8k	–	–	−432	−150	–
10k	–	–	−558	−155	–

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AIRR SOUNDBLASTER SOUND CARD SPEAKER RESPONSE SOFTWARE — **SOF-AIR1B3G** — **$49.95**
Julian J. Bunn

AIRR (Anechoic In-Room Response) offers a cheap alternative to loudspeaker measurement for owners of PCs equipped with a SoundBlaster (this brand only) sound card. Based on the principle of pulse mode excitation of the loudspeaker followed by Fast Fourier Analysis, AIRR features full color real-time plotting of both the digitized pulse received by the microphone and the frequency response of the loudspeaker system. Requires PC with SoundBlaster 16 sound card; VGA screen with at least 640 x 480 resolution, preferably color; and microphone (usually supplied with the sound card).

BASSBOX 5.1 FOR WINDOWS — **SOF-BAS1B3G** — **$99**
Harris Technologies

BassBox 5.1 is a great program that aids in the design of bass loudspeaker enclosures in two ways. First, it models how a speaker will sound in a variety of boxes, and second, it models the maximum loudness of the loudspeaker/box combination. Once these tools help you decide what size and type of box to use, BassBox will then help you calculate the dimensions of its port, if the design is vented, and the box itself. Many other capabilities. Windows 3.1+; DOS 5.0+ recommended; IBM 386SX+; 4Mb RAM; mouse; 4Mb hard disk space (cannot be run from floppy). Also available:

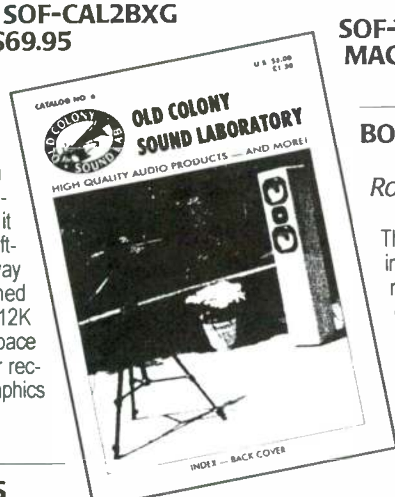
SOF-BAS1B3G/X BASSBOX 5.1 PLUS XOVER 2.03 (below) $118

XOVER 2.03 FOR WINDOWS — **SOF-XOV1B3G** — **$29**
Harris Technologies

This package helps in the design of 2-way and 3-way passive dividing networks, as well as simple load compensating circuits, and calculates the component values for many common first-, second-, third-, and fourth-order networks. Two-way designs include Bessel, Butterworth, Chebychev, Gaussian, Legendre, Linear-Phase, and Linkwitz-Riley, while 3-ways include 3- and 3.4-octave spreads between crossover frequencies. Windows 3.1+; DOS 5.0+ recommended; IBM 386SX+; at least 2Mb RAM (4Mb recommended); mouse; 1.5Mb hard disk space.

CALSOD 1.30 STANDARD WITH GRAPHICS — **SOF-CAL2BXG** — **$69.95**
Witold Waldman/Audiosoft

From Australia, CALSOD (or "Computer-Aided Loudspeaker System Optimization and Design") is one of the world's most famous software packages in the field of crossover network design. It combines the transfer function of an LC network with the acoustic transfer function of the loudspeaker, by using some form of iterative analysis. CALSOD creates, through the process of trial-and-error curve fitting, a suitable transfer function model which it can then optimize. The program differs considerably from other software in that it models the entire loudspeaker output of a multi-way system, including the low-end response, as well as the summed responses of each system driver. For PC/XT/AT and PS/2 with 512K of free RAM and DOS 2.10 or higher. Hard disk with 1.6Mb free space recommended (except for demo). 8087/80287/80387 coprocessor recommended but not necessary. CGA, EGA, VGA, or Hercules graphics card required. IBM—PLEASE SPECIFY DISK SIZE.



CALSOD 3.00 PROFESSIONAL WITH GRAPHICS — **SOF-CAL3BXG** — **$269**
Witold Waldman/Audiosoft

Although CALSOD Standard 1.30 is an excellent and popular package which more than does the job for most people, CALSOD Professional 3.00 differs in that it is more extensive and aimed (as CALSOD was originally intended) at professional engineers. Additional features of 3.00 include double ported bandpass enclosure models; vented-box, closed-box, and passive-radiator simulations; active crossover network simulation; impedance optimizer for designing zobels; SPL optimization; importing of SPL and impedance data from MLSSA, SYSid, System One, LMS, and IMP loudspeaker test systems; optimizing Thiele/Small parameter estimator; piston approximation for driver models; simulation of the effects of room gain; and much more. IBM—PLEASE SPECIFY DISK SIZE.

PXO PASSIVE CROSSOVER CAD — **SOF-PXO3B5G** — **$50**
Robert M. Bullock III, Robert White

New PXO version adds improved ease of use, faster performance, and high resolution graphics to six great programs: PASSIVE TWO-WAYS, PASSIVE THREE-WAYS, EQUALIZER UTILITY, RADIATION PATTERNS, EX(CURSION)-LIMIT, and CROSSOVER TRANSFER FUNCTION. Also has transient response capability for combined crossover sections. 1 x 5-1/4", DS/DD. IBM only.

THE PRIVATE FILES OF G.R. KOONCE — **SOF-KPFNBXG** — **Each $14.95**
G.R. Koonce

At long last, we have persuaded Mr. Koonce—one of America's great computer/loudspeaker gurus—to make available to the public this 1.7Mb, five-disk set containing 19 unique programs from his own personal library. As wide-ranging in purpose as they are fun to use, these handy IBM files developed over the years for Koonce's personal use can now benefit you! Disk #1: Vented Box Design. Disk #2: Closed Box Design/Testing. Disk #3: Crossover/Padding Design. Disk #4: Miscellaneous Box Design/Testing. Disk #5: Driver Evaluation/Overshoot Function. PLEASE SPECIFY IBM DISK SIZE AND REPLACE "N" IN THE PRODUCT CODE ABOVE WITH THE DISK NUMBER YOU DESIRE. Also available:

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THE LISTENING ROOM FOR IBM — **SOF-TLR1BXG** — **$47.50**
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This interesting program predicts standing wave modes in small rooms and is designed for positioning speakers—and the listener—in such a way as to minimize standing wave effects and other room-generated influences. It allows for a full range of speaker and listener movement in 3D space and continuously updates a standing wave Pressure Versus Frequency display. IBM 256K RAM; DOS 2.11+; CGA, EGA, VGA, or Hercules graphics required. Also available, by Ralph Gonzalez:

SOF-TLR3M3G THE LISTENING ROOM FOR MACINTOSH $47.50

BOXMODEL VERSION 3.0 WITH GRAPHICS — **SOF-MOD4BXG** — **$59.95**
Robert M. Bullock III, Robert White

This worldwide best seller's regular capabilities and features have included sealed, vented, and passive radiator designs; four concurrent design capability; on-line help; 8088 through Pentium support; no coprocessor required, but recommended; DOS real-mode application; auto-detect CGA, EGA, VGA display; pull-down menu; inclusion of atmospheric effects on design; port length calculations; inclusion of box, port, and absorption losses in analysis; filter-assisted alignments; equalized alignments through 8th order; and automatic file save/recall. Graphing capabilities in BoxModel have included maximum and relative SPL; voice coil impedance magnitude and phase; acoustic phase response; vent air speed; driver piston excursion; and passive radiator excursion. Now, transient response and group delay have been added as new graphs. In addition, other new features in BoxModel include series and parallel compound and isobaric designs; graphics printer dumps, support for over 300 printers; generation of optimized flat alignments; display of coefficients of transfer function; and redesigned user interface. IBM—PLEASE SPECIFY DISK SIZE. Also available:

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MACSPEAKERBOX — SOF-MSB1M3G — $39.95

Eldon Sutphin

This software allows you to design and examine the low frequency characteristics of bass reflex, closed box (acoustic suspension), and infinite baffle types of enclosures. Thiele/Small driver parameters are used to calculate the response for various design tradeoffs. Macintosh 512K, Macintosh Plus, or Macintosh SE required. ImageWriter or ImageWriter II recommended for hard copy.

BOXRESPONSE WITH GRAPHICS — SOF-BOX2B5G — $50

Robert M. Bullock III, Robert White; Glenn Phillips

Very straightforward, menu-driven, and flexible, this package provides model-based performance data for either closed-box or vented-box loudspeakers with or without a first- or second-order electrical high-pass filter as an active equalizer. It can be used for designing closed, vented, passive radiator, and electronically augmented vented boxes. The disk also contains seven additional programs: AIR CORE, SERIES NOTCH, STABILIZER 1, OPTIMUM BOX, RESPONSE FUNCTION,L-PAD, and VENT COMPUTATION. IBM 5-1/4", DS/DD.

LDCAD — SOF-LDC2B5G — $11.95

Madisound Speaker Components

Produced as an innovative supplement to the The Loudspeaker Design Cookbook, LDCAD is a special collection of programs and resource lists on a single 360K, DS/DD floppy disk designed to introduce speaker enthusiasts to the kind of work possible on IBM-type personal computers. The disk includes four design programs, including BOX PLOT and EASY CROSSOVER DESIGN, as well as information on Madisound's audio bulletin board and its contents. IBM only.

LOUDSPEAKER DESIGN POWERSHEET PROFESSIONAL — SOF-PSH2BX — $69.95

Marc Bacon

The Professional version of this program covers 19 different kinds of bass loading with extensive graphing capabilities; volume calculation for 5 different enclosure shapes; evaluation of cavity resonances, rectangular panel resonances, and the coincidence effect; 24 different types of crossovers; 10 miscellaneous programs for shaping circuits, zobels, room interaction, and coil design; 8 programs for evaluating driver parameters and losses; electrical laws; conversion factors; room acoustics; and more. A Basic version which includes 41 of the above programs is also available. IBM PC or compatible with 640K of memory, preferably a hard disk, and Lotus 1-2-3, Quattro Pro, or another spreadsheet which can use Lotus *.WK1 files. PLEASE NOTE THAT SPREADSHEET SOFTWARE IS NOT INCLUDED, AND PLEASE SPECIFY DISK SIZE. Also available:

SOF-PSH2M3 LDP PROFESSIONAL FOR MAC — $69.95
SOF-PSH1BX LDP BASIC FOR IBM — $49.95

WOOFER-SATELLITE OFFSET — SOF-WSO1BXG — $34.95

Sitting Duck Software

When, due to aesthetic considerations, woofer systems are placed at distances from the listener which are different from that of the satellites, serious dips in frequency response may result. The magnitude, width, and frequency of the dips are a function of the distance differential and the crossover network in use. This program plots the frequency and phase response curve which results from user-determined offset differentials and network configurations. 256K RAM; CGA, EGA, VGA, or Hercules graphics required. IBM only.

QUICK BOX — SOF-QBX1BXG — $34.95

Sitting Duck Software

QUICK BOX allows you to rapidly design closed, vented, and fourth-order bandpass boxes. The program's Library Manager, which allows "quick preview" of driver parameters and box possibilities, comes complete with data for 38 common drivers—more are easily added by the user. Supports CGA, EGA, VGA, or Hercules; coprocessor; LaserJet or dot matrix. IBM only.

LMP LOUDSPEAKER MODELING PROGRAM FOR IBM — SOF-LMP3BXG — $49.95

Ralph Gonzalez, Bill Fitzpatrick

LMP models multiway loudspeaker systems, with the resulting frequency and phase response curves predicting the on-axis SPL produced by your choice of crossover, drivers, and enclosure design. The Macintosh version adds visual and audible square-wave prediction using the internal speaker or audio output jack. CGA, EGA, VGA, or Hercules graphics capability required. PLEASE SPECIFY DISK SIZE. Also available:

SOF-LMP3M3G LMP FOR MACINTOSH — $39.95

QUICK & EASY TRANSMISSION LINE SPEAKER DESIGN — SOF-QET1B5 — $8.95

Larry D. Sharp

This unique new booklet starts with the basics: what a TL is, where it came from, and how it evolved over the years. Then it lays out a step by step process for designing a TL system that will sound good every time. And for those of you who own a personal computer with Lotus 1-2-3 or equivalent on it, there's also a computer worksheet diskette included that does the math for you and prints out your system design information. 1993, 22pp., 8-1/2 x 11, spiralbound; IBM 5-1/4" DS/HD. Booklet is easily usable without software, but PLEASE NOTE: LOTUS 1-2-3 OR EQUIVALENT SPREADSHEET SOFTWARE IS REQUIRED TO RUN WORKSHEET DISK AND IS NOT SUPPLIED WITH THIS PACKAGE.

ROOM DESIGN POWERSHEET — SOF-RDP1BX — $59.95

Marc Bacon

This program covers a wide range of knowledge in an easy-to-use spreadsheet format. Working from a main menu, the user can access programs dealing with room resonances, reverberation, boundary augmentation, wall diffuser design, resonance traps, and so forth. Requires an IBM PC or compatible with 640K of memory, hard disk, and Lotus 1-2-3, Quattro-Pro, Excel, or any other spreadsheet which can use Lotus *.WK1 files. COMPATIBLE WITH EXCEL AND LOTUS 1-2-3 FOR WINDOWS; NOT USABLE WITH QUATTRO PRO FOR WINDOWS. PLEASE NOTE THAT SPREADSHEET SOFTWARE IS NOT INCLUDED. PLEASE SPECIFY IBM DISK SIZE DESIRED.

SPEAKER SYSTEM DESIGNER 4.2+ FOR WINDOWS — SOF-SSD2B3G — $279

Bodzio Software

SSD4.2+ enables you to create, evaluate, and then optimize 2-, 3-, 4-, or 5-way loudspeaker systems prior to starting enclosure assembly. You are also able to model the behavior of the crossover when loaded by the driver in an enclosure and observe the dramatic effect on the frequency response curve of the crossover which the driver may have. Functions available in this package include driver reference library creation; loudspeaker enclosure design and optimization; compensation of the driver impedance or amplitude; crossover filter design and optimization; system frequency response evaluation and optimization; frequency response of the system "in room"; L-pad, series LRC, and zobel network calculators; impedance peak suppressor; and much more. IBM 286+; 2Mb RAM min.; min. 2.5Mb hard disk plus 1Mb to install; Windows 3.1; SVGA with 800 x 600 pixels, 16 colors.

TERM-PRO LOUDSPEAKER DEVELOPMENT — SOF-TRM2BXG — $399

Wayne Harris

High-resolution graphics, on-line help, and a menu-driven format that makes this program extremely easy to use. Features common to TERM-1 and TERM-PRO include a 10,000-driver-capacity database with multiple library support; enclosure design capabilities for sealed, ported, and isobarik sealed and ported; predicted enclosure response and SPL plots; port and enclosure layout design functions, including wedge, rectangular, or bandpass designs; passive crossover design for 1st, 2nd, and 3rd order HP, BP, LP, notch filters; L-R, Bessell, BEC, Butterworth, Chebychev design; and acoustic curve overlays with crossover enabling toggle. TERM-PRO (only) also includes single reflex bandpass (4th); isobarik SRBP (4th); SRBP with coil (5th); isobarik SRBP with coil (5th); dual reflex bandpass (6th); isobarik DRBP (6th); DRBP with coil (7th); and isobarik DRBP with coil (7th). Originally intended for auto sound use, but of universal value. IBM XT/AT, 640K RAM; MS-DOS 3.0+; CGA, EGA, or VGA. PLEASE SPECIFY DISK SIZE DESIRED. Also available:

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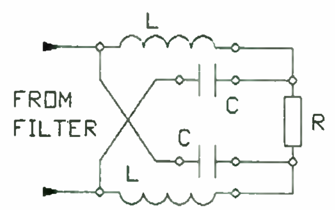


$L = \frac{0.1592\ R}{F}$ $C = \frac{0.1592}{F\ R}$

FIGURE 33: Simple phase shift network.

Continued from page 28

so we need to remove these phase shifts as best as we can from the driver-offset phase shift.

The phase shift due to low-frequency roll-off will be positive, while the high-frequency phase shift will be negative. Each driver's measured phase shift will tend to be too negative at higher frequencies and too positive at lower frequencies.

MEASURING PHASE SHIFT

While writing this article, I was working on a two-way system using a Dynaudio 17WLQ woofer and a Dynaudio D-260 dome tweeter. Based on visual inspection, I estimated the acoustic depth of the woofer to be 1.5″ and the tweeter depth to be 0.25″. This produces an offset of 1.25″. The crossover frequency was 2kHz, so the driver-offset phase shift is 67° at this frequency. However, to increase my confidence in this estimate, I measured the offset. I used a setup very similar to *Fig. 35*, using a distance between microphone and baffle of exactly 2.0″.

Table 2 lists the measured phase shift for both drivers, covering a frequency range of 1–10kHz. To make it easier to find the offset, I also converted each phase shift reading to a time delay, which is shown under the delay column for each driver. The advantage of using the delay rather than the phase shift is that if the offset is constant, the delay will also remain constant over the entire frequency range while the phase shift will increase with frequency. To perform this conversion, use the following formula: Delay = Phase shift/(360*Freq). If you enter the frequency in hertz, you will get the delay in seconds.

I then subtracted the tweeter delay from the woofer delay and tabulated this reading under the Delay Difference column. The delay difference between drivers is 170µs at 2kHz. The corresponding phase shift is 122° (187° – 65°) at this frequency. This reading is quite different from our estimate of 67°, but it includes phase shifts from driver roll-off.

From the delay readings in *Table 2*, you can see that the woofer shows a fairly constant delay of about 260µs over the measured frequency range. The increase at 4.5kHz is due to high-frequency roll-off in the woofer, and the lower delay between 1kHz and 2kHz is probably due to amplitude dips in this range. Above 4kHz, the tweeter stabilizes at a delay of approximately 155µs. Below 4kHz, the tweeter delay decreases due to a positive phase shift from the low-frequency roll-off.

DON'T DELAY

Based on these measurements, I estimate the woofer delay to be 260µs and the tweeter delay 155µs, for a difference of 105µs, which is significantly lower than the 170µs difference at 2kHz. As you can see, it is important to measure the phase shift over a frequency range which allows each driver to show a nearly constant delay over a span of frequencies.

If we convert the delay difference of 105µs to a phase shift at 2kHz, we'll get a driver-offset phase shift of 76°, very close to the original estimate of 67°. The formula for converting a time delay to a phase shift is: Phase shift = Delay*Freq*360, with delay in seconds and frequency in hertz.

Finally, we can also calculate where the zero delay plane of each driver is located. The distance from baffle to microphone is 2.0″, which corresponds to a time delay of about 148µs. This delay is included in my measurements, so subtracting 148µs from the measured delay produces the delay referenced to the baffle. This results in a delay of 7µs for the tweeter and 112µs for the woofer.

If we convert these delays into a distance, we'll get 0.1″ for the tweeter and 1.51″ for the woofer. The formula for this conversion is: Distance = 13,500*Delay, with the delay in seconds. Once you determine the phase shift at the crossover frequency, you can use the various filter response graphs to select a filter type to work well with this phase shift.

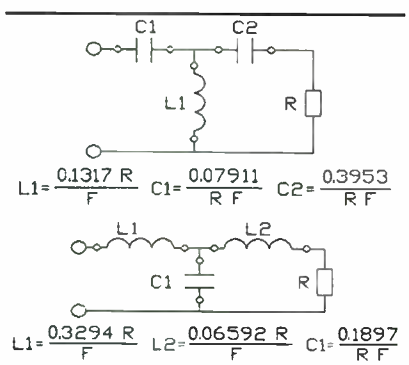
EXTENDING GRAPH RESULTS

In preparing the figures, I assumed the woofer will radiate from a point behind the tweeter. This should be the case for almost all available drivers, except for a few units, such as a horn-loaded tweeter or midrange, which could be deeper than the woofer. If this is the case, you can still apply most of the graphs with some adjustments.

When studying second-order or fourth-order filters, the graphs are the same. If you

APPENDIX

Only two filter types in this article do not appear in my speaker building bible, Vance Dickason's *The Loudspeaker Design Cookbook*. They are the third-order Bessel and sixth-order Linkwitz-Riley filters. To give you a chance to use these filter types, I spent some time calculating the proper values of inductance and capacitance used to implement them.



$L1 = \frac{0.1317\ R}{F}$ $C1 = \frac{0.07911}{R\ F}$ $C2 = \frac{0.3953}{R\ F}$

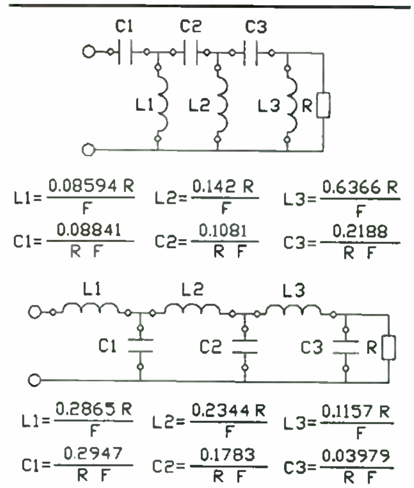
$L1 = \frac{0.3294\ R}{F}$ $L2 = \frac{0.06592\ R}{F}$ $C1 = \frac{0.1897}{R\ F}$

FIGURE 1A: Values for third-order Bessel.

The third-order Bessel (*Fig. 1A*) and the sixth-order Linkwitz-Riley (*Fig. 2A*) filters, with component values, should be self-explanatory, with R designating speaker resistance and F frequency. The HP filter is shown on top and the LP filter on the bottom of each figure.

If you plan to use the sixth-order Linkwitz-Riley, I offer some advice. This can be a great filter, in which the steep slope greatly attenuates driver response problems outside of the pass band, but unless the inductance and capacitance values are *really* close to the calculated values, you will have problems.

I recommend buying tight tolerance components, and if possible measure the values. You can then adjust the capacitance by paralleling capacitors and the inductance by adding series inductance as necessary. It is also a good idea to use low-resistance inductors. If possible, you should verify the filter response by measurement (using the speaker as the load) before final installation.—**BC**



$L1 = \frac{0.08594\ R}{F}$ $L2 = \frac{0.142\ R}{F}$ $L3 = \frac{0.6366\ R}{F}$

$C1 = \frac{0.08841}{R\ F}$ $C2 = \frac{0.1081}{R\ F}$ $C3 = \frac{0.2188}{R\ F}$

$L1 = \frac{0.2865\ R}{F}$ $L2 = \frac{0.2344\ R}{F}$ $L3 = \frac{0.1157\ R}{F}$

$C1 = \frac{0.2947}{R\ F}$ $C2 = \frac{0.1783}{R\ F}$ $C3 = \frac{0.03979}{R\ F}$

FIGURE 2A: Sixth-order Linkwitz-Riley values.

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3.30mh	0.451	$16.90
3.00mh	0.433	$15.74
2.70mh	0.386	$14.82
2.20mh	0.330	$12.60
1.80mh	0.301	$11.50
1.50mh	0.286	$11.25
1.20mh	0.240	$9.54
1.00mh	0.227	$8.32
0.82mh	0.191	$7.56
0.68mh	0.170	$6.86
.056mh	0.150	$6.10
0.47mh	0.131	$5.46
0.39mh	0.117	$4.94
0.33mh	0.100	$4.30
0.27mh	0.092	$3.98
0.22mh	0.082	$3.74
0.18mh	0.078	$3.48
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3.30mh	.191	$7.88
3.90mh	.210	$8.32
4.70mh	.241	$8.92
5.60mh	.270	$10.17
6.80mh	.281	$10.77
8.20mh	.321	$11.44
10.0mh	.370	$12.33
12.0mh	.417	$13.29
15.0mh	.456	$14.54
18.0mh	.519	$15.07
21.0mh	.580	$16.87

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Reader Service #45

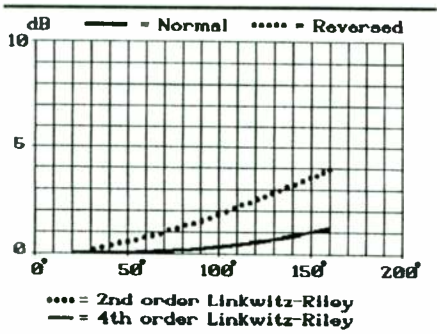

FIGURE 34: L-R filter response with network correction.

are using third-order filters, the reversed response in the graphs will apply to your system's normal response, and vice versa. If you use filters with asymmetrical slopes, you cannot use the graphs when the tweeter is deeper than the woofer. To provide graphs for these cases, you need to run new computer simulations with the negative phase shift added to the HP filter. Since situations in which the tweeter is deeper than the woofer are rare, I did not bother generating extra graphs for these filter combinations.

I also assumed that the LP filter will be of a lesser order than the HP filter for all filters with asymmetrical slopes. This assumption is justified in almost all cases, but since I am a firm believer in Murphy's Law, I am sure at least a few readers will absolutely need to connect the higher-order filter to the woofer. If you do this, you'll be on your own. In a few graphs, almost no difference occurs in the response if we change the higher-order filter to the LP filter. However, in most cases substantial changes exist.

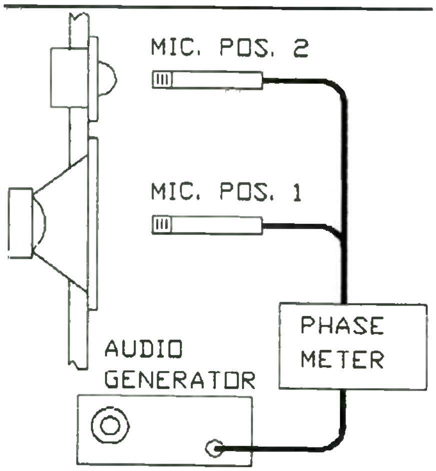

FIGURE 35: Phase shift measurement.

FINAL THOUGHTS

I hope you find this article useful when dealing with errors caused by driver offset. Unfortunately, lack of stamina on the part of the writer has limited the number of filter types investigated. Nevertheless, I've included most common filter types and combinations.

While there is no substitute for actual measurements in crossover design, I tried to help you avoid one common source of error when designing a crossover on paper, without the benefit of measurements. Even with measurements, this article should help you design crossover filters which work when used in the real world. I hope you also have gained some understanding of how the less than ideal environment in which they must perform affects crossover filters.

I wish that speaker manufacturers will start to publish data on driver acoustical offset, minimizing the need for measurements by the home builder. Since most, if not all, manufacturers use FFT-type analyzers, the data should be readily available. They should supply phase response curves at the zero delay plane, together with information about where this plane is located relative to the driver mounting plane.

Until this happens, it would be helpful if *Speaker Builder* readers who own measurement equipment such as the IMP share their measured phase responses with others. The goal is to build a database of phase response curves of commonly used drivers. By including the distance at which the phase response is measured, you could then calculate the location of the zero delay plane.

Finally, when evaluating the figures, keep in mind that we've covered only one aspect of crossover performance. While this article will help you select filters which produce a flat amplitude response on-axis, I have not accounted for a number of other variables such as the smoothness of the off-axis response or group delay. Those of you to whom these other variables are more important than the on-axis response will still benefit from reading this article.

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Magnet	10 Oz.

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Upper Frequency	7,000 Hz
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Upper Frequency	5,500 Hz
SPL 1W/1M	88 dB
Power Handling	80 W
Qts	0.24
Vas	27.83 L
Voice Coil	35,5 mm
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Layers:	2
Winding Length:	2.0 mm
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Value µF	Diameter mm	Length mm	SRP US$
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1.5	12	22	1.44
1.8	13	22	1.49
2.2	15	22	1.58
2.7	14	25	1.67
3.0	15	25	1.73
3.3	16	25	1.78
3.9	16	25	1.83
4.7	18	27	1.96
5.6	18	30	2.10
6.0	19	30	2.20
6.8	20	30	2.33
8.0	20	33	2.91
8.2	21	33	2.97
9.1	22	33	3.08
10.0	23	33	3.23
11.0	24	33	3.38

Value µF	Diameter mm	Length mm	SRP US$
12.0	25	33	3.56
15.0	25	38	4.18
20.0	29	38	5.16
24.0	29	43	5.98
30.0	32	43	7.30
33.0	32	48	7.74
41.0	35	48	9.32
50.0	37	53	10.96
51.0	37	53	11.16
56.0	39	53	12.00
62.0	39	53	12.98
75.0	43	58	15.12
82.0	45	58	16.28
91.0	47	58	17.50
100.0	49	58	18.76
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The problems are fairly well-known: a driver transforms electrical energy into mechanical energy. This mechanical energy is transformed into acoustical energy which is radiated to the outside of the cabinet - the useful front wave - and to the inside - the sometimes-useful back wave. Unfortunately, it is also transmitted though the frame of the driver to the cabinet itself, which acts as a very large "cone" of very small excursion. This means that the spurious resonances and vibrations of the cabinet have to be controlled in a predictable and reproduceable way. That's how we came to BLACK HOLE 5 and the BLACK HOLE PAD.

First, THE PAD. It's a thin (1/16 inch) black flexible viscoelastic damping material (filled vinyl copolymer) with maximum performance between 50 and 100 degrees F (we hope that that covers the temperature range of your listening room) and excellent flame resistance - it meets UL94 V-O. Thanks to its outstanding damping characteristics, THE PAD will dramatically reduce the vibration energy stored in the walls to which it is applied.

Easy to cut and apply, THE PAD has a pressure-sensitive adhesive back: simply peel off the release paper and press hard onto a clean surface. You can use THE PAD on just about anything you suspect of vibrating: driver frames, thin panels like car doors, and, of course, the walls of your speaker cabinets. And it can be used to recess a driver without using a router: just laminate enough layers to match the thickness of the driver frame and apply to the front baffle. Finally, it is the ideal material for "constrained layer" wall construction, where two panels are laminated on each side of a damping material for optimum transmission loss. Because THE PAD has a fine grain leather finish, you can wrap an entire cabinet exterior and give it an attractive appearance at the same time!

For applications which require **maximum damping, isolation and absorption,** we've developed BLACK HOLE 5. One and 3/8" thick, BLACK HOLE 5 is a high-loss laminate that provides optimum acoustical damping performance. It consists of five layers:

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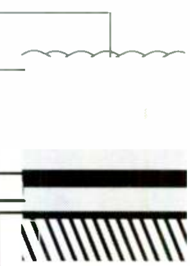
One-inch deep polyester urethane foam, structurally optimized for acoustical damping. Highly effective at "soaking" maximum sound energy with minimum thickness.



Barrier septum, 1/8 inch thick. Made of limp flexible vinyl copolymer loaded with non-lead inorganic fillers, it is a "dead wall" that isolates the vibrations in the walls of your cabinet from the vibrations created inside the enclosure.

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High-loss vibration damping material, same as The Pad. It is strongly bonded to the cabinet wall with pressure sensitive adhesive.

These layers are laminated using an adhesive-free mechanical and thermal process, thus optimizing performance and eliminating the risk of solvent fume damage. BLACK HOLE 5 can be used in any enclosure, as well as for acoustical panels to improve the characteristics of your listening room. *YOU PROVIDE THE MUSIC; BLACK HOLE FIVE WILL TAKE CARE OF THE NOISE!*

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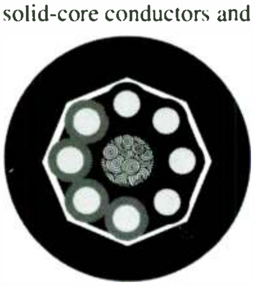

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Cable geometry: non interleaved spiral
Individual conductor insulation: 105 degree Celsius, UL approved PVC
Cable equivalent gauge: total - AWG 11, 2 conductors - AWG 17, 4 conductors - AWG 14
Individual conductors: solid core AWG 20 copper, long-grain and ultra-soft, free of all contaminants and oxygen.
Cable core: crushed polypropylene
Inner envelope: mylar film

Reader Service #32

Wayland's Wood World

SCRAPERS

By Bob Wayland

While recently preparing a coffee table for finishing, I realized that although I was ready to apply the first finishing coat, I had yet to use any sandpaper. Working your way through a sandpaper regimen to prepare the surface for finishing can be a tedious, time-consuming, royal pain. For this project I spent a minimum of time to produce a glass-smooth surface. OK, I cheated a bit—I used scrapers.

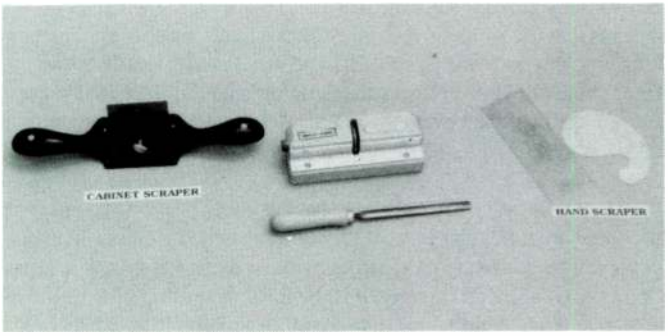

PHOTO 1: Hand and cabinet scrapers with tools. The upper middle tool is a burnisher jig, and the bottom middle tool is a hand burnisher.

When woodworkers learned how to effectively adhere "sand" to paper, especially for use in wet environs, scrapers slowly fell out of favor. The first wood scraper was probably a sharp rock used for scraping animal hides. You can use scrapers in the same way to scrape out wood.

The modern version is a simple tool with a sharp-edged blade of very hard steel that you pull or push across the wood surface planing off a thin layer of wood. You can use the blade by itself as a hand scraper or in a rig similar to a plane as a cabinet scraper (*Photo 1*). A fine cutting edge, called a burr, is turned on the tool's edge by drawing a harder piece of metal, a burnisher (*Photo 1*, center), along the cutting edge. This develops a tiny, high-angle cutting edge, and the scraper's body becomes a chipbreaker.

PHOTO 2: Using a mill file to prepare the edge of a hand scraper.

PHOTO 3: Sharpening the edge.

The main advantage of using scrapers is that with a single operation you can prepare a surface for finishing. Because you have cut off the top layer (the skin) of the wood, the pores are exposed. The only clearer preparation of the surface is to plane it. If you sand, the pores will be filled with dust and fibers, which are very difficult to remove. Also, you must be careful to use the correct sequence of grits to avoid scratching the surface.

This is not a concern with scrapers when used properly. They can produce a fast, tear-out-free stock that is satin-smooth on even the most difficult woods, and are also invaluable for removing glue and planer marks. The main concern is their preparation and maintenance, which differs for hand and cabinet scrapers.

HAND SCRAPERS

In its simplest form, the hand model is a rectangular piece of hard steel in various thicknesses; the thinner ones are most often used for finish work. The finest example is the Sandvik 475 ($11.95 from Woodcraft, #02Z61), a 2.5″ × 5-7/8″ × 0.80mm-gauge piece of hardened steel that retains its edge even after use on glue and old finishes.

If the long edges are not perfectly flat, or your scraper is new, you must flatten the edges perpendicular to the sides. The easiest method is clamping the scraper in a vise between two pieces of wood (*Photo 2*). Using a mill file, cut the edges flat. I used to do this by holding the file parallel to the scraper, until Ken Ronquillo, who is trained as a machinist and assists me in this column's projects, showed me that it is more efficient to hold the file perpendicular to the edge. With care you can file the edge flat to within a thousandth of an inch or so. Examine the edge from a low angle while pointing it toward a light source. You can quickly tell whether the edge is properly prepared or not.

With the edge now ready for sharpening, you need a flat, rather large, sharpening stone. (My favorites are the diamond sharpening stones that use water as the lubricating wash and can sharpen carbide and also flatten Arkansas and Japanese stones.) Holding the scraper perpendicular to the stone, position it diagonally to the direction of motion (*Photo 3*). Examine the edge frequently.

When you have removed all nicks and blemishes, a wire edge on each side of the

PHOTO 4: Removing the wire edge from a sharpened scraper.

PHOTO 5: Drawing out the cutting edge.

PHOTO 6: Using a special burnishing device to raise the burr.

PHOTO 7: Using a burnisher to draw the edge.

PHOTO 8: Forming the hook on a curved scraper.

scraper edge will probably remain. You should remove this by passing the scraper flat over the surface of the stone (*Photo 4*). You usually need just one or two passes. Some woodworkers slightly round the corners, too. I keep one with rounded corners and one without.

GAINING AN EDGE

To form the cutting edge, you actually draw out material from the scraper with a burnishing tool (*Photo 5*). With this tool flat with the side of the scraper, pull, using substantial force. You'll produce a burr running the length of the scraper, in about five to ten strokes. Some woodworkers who prefer that the burr not extend a bit farther from the edge of the scraper skip this step. The raised burr changes the scraper's cutting properties and also its ability to retain a cutting edge. I notice more cutting action if I raise the burr, but it will wear out sooner.

Next, roll the burr to form a good cutting edge at the correct angle (for most work, about 5°). Special burnishing devices (*Photo 6*) automatically produce the right geometry. If you are using a burnisher, hold it at an angle about 85° relative to the side of the scraper (*Fig. 1*) and draw the edge out (*Photo 7*). Usually, you'll need about three passes.

Feel the edge to be certain that a hook has been uniformly formed the entire length of the scraper. It will not be a large protrusion, but will definitely feel sharp enough to cut you if you ran your finger along the edge. If you are sharpening and preparing a curved scraper, the steps are the same except that the sharpening stones are tapered and the hook follows the scraper's pattern (*Photo 8*).

You can re-raise the hook a number of times until it becomes dull; just raise and reform the hook when it stops cutting well. You'll know you need to resharpen when, instead of shavings, you produce dust.

CABINET SCRAPERS

The cabinet version is very handy in ensuring that you both maintain the correct cutting geometry through the scraping stroke and apply steady pressure. Also, while the hand scraper will often become quite hot, the cabinet scraper removes your hand from close contact with the cutting edge, limiting exposure to heat buildup. Because the blade is firmly positioned, you can more accurately and uniformly scrape large areas. The hand scraper lets you work in confined spaces, but with a curved scraper, you can tackle irregular shapes. You need both when building a speaker enclosure.

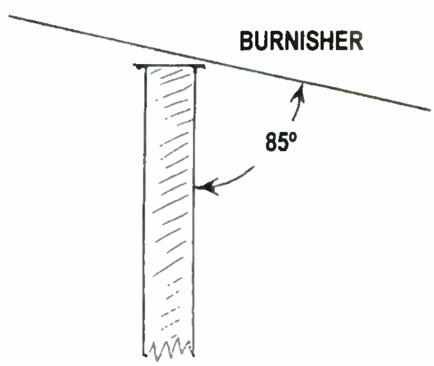

FIGURE 1: Forming the cutting edge of your hand scraper.

PHOTO 9: Smoothing the base plate on a cabinet scraper using a diamond sharpening stone.

PHOTO 10: Flattening and polishing the blade face of a cabinet scraper.

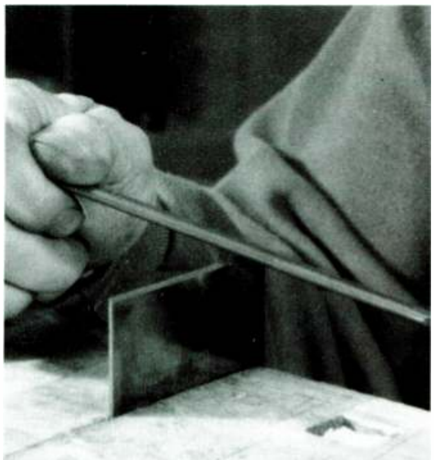

PHOTO 11: Forming a hook on a cabinet scraper blade.

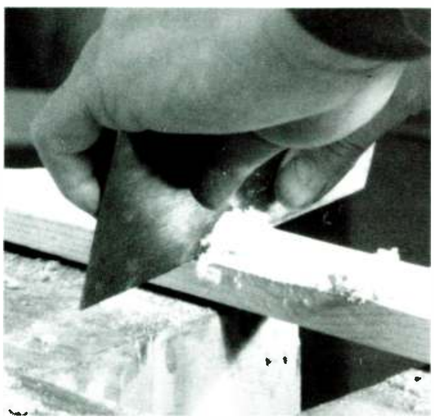

PHOTO 12: Pulling the hand scraper.

If your cabinet scraper is new, or hasn't been properly tuned, a few quick steps will greatly increase its usefulness. First, smooth the face of the holder by simply removing the blade and using your sharpening stone (*Photo 9*). After you remove the ridges from the face, apply a hard nonstaining wax to cut down on friction and protect the surface from rusting. This procedure also works wonders on other tools, such as planes, that make direct contact with wood. Flatten and polish the face (the flat side) of the blade on a stone (*Photo 10*). Now file a bevel of 45° on each long side and sharpen both edges on a stone, while maintaining a straight cutting edge.

In the same way you draw the hand scraper, draw the edges on the face side of the blade about ten times with moderate to firm pressure, keeping the burnishing tool flat against the face. You must form the edge of the bevel into a hook. Most woodworkers accomplish this in a series of rolling strokes with the burnisher. Start with an angle of 40–50° relative to the flat surface of the blade and make a pass. Increase the angle to 60–70° and draw a pass or two on the edge. Then for the final draw, hold the burnisher at an angle of about 85° (*Fig. 2*) and make one or two more passes (*Photo 11*).

Adjustment is very simple. After loosening the thumbscrew and the clamp screws, insert the blade into the clamp with the bevel side towards the thumbscrew. Set the scraper on a hard flat surface, such as your table saw top, and, while lightly pressing down on the blade, tighten the clamp screws. Tightening the thumbscrew adjusts the blade. Later I describe how to determine when the cabinet scraper is properly adjusted.

APPLICATION

Using a scraper is a task that can only be learned by doing. So why am I writing about it? I learned by reading a general description and then spending a couple of hours experimenting. Use this introduction to develop your own techniques; there is no right or wrong way.

Hold the hand scraper with both hands and press against the center (*Photo 12*). Some woodworkers prefer a small bow on the scraper, but I avoid this because it can cause an uneven surface. Start pulling (or *pushing*) the scraper toward (*away*) from you. As you move it along with the cutting edge flat on the wood surface, tip it in the direction of travel until you feel the burr start to cut into the wood. Usually this will be at an angle of about 60° relative to the wood surface. While moving the scraper, change the angle until it produces many shavings (*Photo 12*).

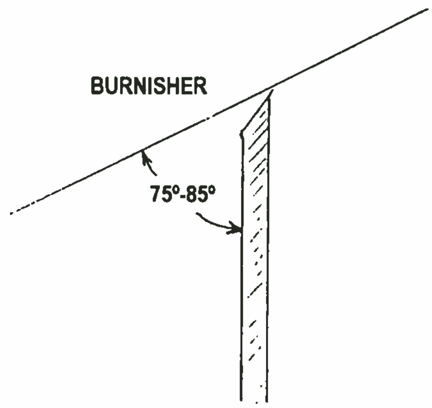

FIGURE 2: Drawing the edge of a cabinet scraper.

Remember, it's okay to either pull or push (*Photo 13*) the scraper firmly into the wood. Use whichever method feels right for you. Often different grain patterns require different techniques. Also, it is a good idea when you are doing much scraping to change the cutting edge periodically by rotating to a new edge. If you are trying to remove planer marks, position the blade at an angle to the ridges. This tool is also useful for cleaning up sawed edges. Hold the scraper's cutting edge against the sawed edge and pull it along the surface.

The cabinet version is used much the same way as the hand model, except that the adjustment is with the thumbscrew. Start with the adjustment screw lightly pushing on the blade and increase the displacement on the blade until you are making thin, even shavings. Either the push (*Photo 14*) or pull (*Photo 15*) method works.

PHOTO 13: Pushing the hand scraper.

PHOTO 14: Pushing the cabinet scraper to smooth a wood surface.

PHOTO 15: Using the cabinet scraper in the pulling mode.

PHOTO 16: Using a chisel as a scraper.

PHOTO 17: A commercial razor scraper, which, like a chisel, does not produce as fine a surface as conventional scrapers.

When you need a quick fix for a problem spot on a wood surface, you can use a chisel as a scraper (*Photo 16*). This is useful in corners of enclosures and for removing glue. An extension of this technique is a commercial holder for a razor blade (*Photo 17*).

TROUBLESHOOTING

Here are a few hints that may make using a scraper a little easier:

1. Producing dust, instead of shavings, indicates the scraper is dull and needs to be sharpened.
2. If you notice when you sight along the edge that the burr is broken, you may have rolled the burr over too far.
3. If the scraper begins to cut only when it is almost parallel to the surface, you probably have rolled the burr over too far.
4. Scraping with a sharp corner may produce ridges or gouges on the surface. Either be more careful in your technique or round off the sharp corners.

Remember, as in all woodworking, *how*, rather than *what*, is the important point. If it works for you, then just do it.

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Kit Report

AUDAX OF AMERICA A652
FROM THE VANCE DICKASON SIGNATURE SERIES

By Nancy MacArthur

Audax of America A652, Vance Dickason Signature Series, Audax of America (formerly Polydax Speaker Corp.), 10 Upton Dr., Wilmington, MA 01887, (508) 658-0700, FAX (508) 658-0703.

Specifications: Tweeter: Audax of America TW025M0 1″ soft dome. Woofers: Audax of America HM170C0 6.5″ carbon fiber. Frequency response: 60Hz–20kHz ±2.2dB, f_3 53Hz. Nominal impedance: Unspecified, appears to be 4Ω. Sensitivity: 90dB 1W/m, maximum output 105dB. Crossover: Fourth-order Linkwitz-Riley at 2.8kHz. Internal dimensions: 24.875″ × 7.5″ × 9.0″. External dimensions: 26.375″ × 9″ × 10.75″. Dimensions of Madisound enclosures vary slightly: Internal: 23.5″ × 7.75″ × 10.0″. External: 25.0″ × 9.25″ × 11.75″.

If it weren't for the chicken pox, I would never have built these speakers. Our four-year-old son Colin had a blossoming case of the disease when the letter arrived from Ed Dell asking if I would like to build and review an Audax of America speaker kit. I had planned to put the letter away and think it over by myself for a few days, but between dabbing calamine lotion on Colin's spots and wailing "Stop! Don't scratch that," I didn't get around to stashing the letter before my husband Duncan came home from work.

Duncan found the letter instantly. He bounded into the kitchen waving it in the air. "Nancy! You're going to build speakers," he said.

"Oh, no, I'm not."

He tried a new approach. "But it's an honor. The editor liked your last article so much that he wants you to write another one."

I eyed him with suspicion. "The editor," I said, "probably wants to see if these designs are idiot-proof and thinks I'd make a good idiot. I can't build speakers. I don't even know how to solder."

Over the next several days Duncan adopted a new tactic: he dropped the matter completely. He never mentioned the word "speakers." Every once in a while when he thought I wasn't looking, he would gaze into the distance and heave a mournful sigh.

I held out for three days before I surrendered. I found Duncan sitting with Colin in the living room, staring gloomily into space. "All right," I muttered, "I can't stand it any more. I'll build the speakers."

Duncan's face bloomed like a desert flower after the rain. "You'll have fun, Nance, you'll see. I'll help you when you get stuck. Colin can help too."

"Over my dead body. Do you know how long it takes to vacuum the living room when Colin helps?"

"I want to help *tooooo*," howled the small spotted boy on the couch. I buried my face in my hands. This was going to be a long project.

KIT QUANDRY

Duncan and I then argued about which kit to build. I had been told to pick one of four speaker kits designed by Vance Dickason for his Signature Series. Duncan lusted after the A851, a tall three-way speaker. I thought the A651, a two-way bookshelf design, would be easier to build. We compromised on the A652, shown assembled in *Photo 1*.

PHOTO 1: The assembled Audax A652 loudspeaker in a cabinet by Madisound.

The A652 is a two-way design using three drivers mounted in the D'Appolito configuration. I built the speakers with drivers supplied by Audax of America, a kit supplied by Madisound, and a second set of crossovers built from components supplied by Solen. Although Audax manufactures the drivers, they don't sell them directly to the consumer. They've published a helpful booklet, *Kit Plans: Build Your Own Loudspeakers,* which I strongly recommend obtaining before building these speakers. (Available from various dealers, or call Audax, (508) 658-0700, and ask for their automated request line to obtain a free copy.)

Once we'd chosen the speaker we settled back to wait for the parts to arrive. The drivers came first, with woofers and tweeters packed securely in individual cardboard boxes with inserts protecting each one.

Next to arrive were the crossover parts, which I had pictured as being small and delicate but actually are large and quite heavy. When the low-pass crossover boards were finished, they weighed 1.5 lb each. Although all the parts supplied by Solen met Dickason's quality standards, one slight variation was the heptalitz wire used in the two smaller inductors.

MISSION IMPOSSIBLE

The next night Duncan taught me how to solder, which wasn't as difficult as I'd expected it to be. I'd always thought of soldering as an esoteric masculine ritual, but it turned out to be a lot like melting sealing wax to put on envelopes—an activity I liked when I was 12.

The following day's work went less smoothly. With several hours of peace and quiet in front of me, I thought I'd be able to make good progress on the crossovers. I started confidently: I'd learned how to solder, hadn't I? I pulled out the four 4″ × 6″ rectangles of ¼″ plywood that Duncan had sawn for me the night before, along with the pile of parts from Solen. I planned to lay the parts on the boards in the proper order.

Half an hour later, I was still staring at the pile. I had a circuit diagram from the kit plan booklet, but I wasn't sure which part was

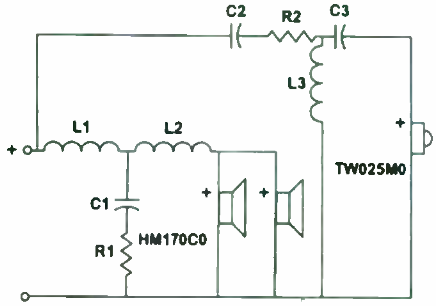

FIGURE 1: Vance Dickason's Audax A652 crossover network.

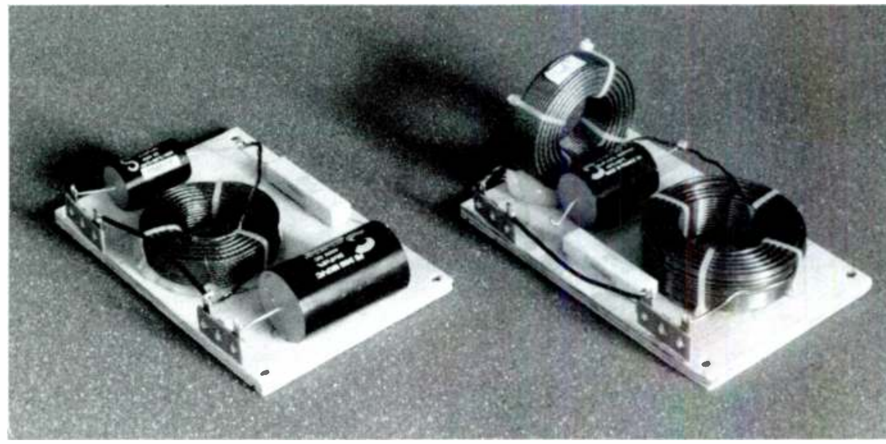

PHOTO 2: High- and low-pass Audax A652 crossover boards. These boards were built according to Vance Dickason's circuit diagrams, with the addition of two small terminal strips on each board for input and output connections. Components for this set of crossovers came from Solen.

which. What did an inductor look like? A capacitor? I spent another ten minutes wondering why I, who had no previous electronics experience, had been demented enough to agree to build a pair of speakers.

Eventually I calmed down and realized I could figure out which part was which by looking at the values on the parts and cross-checking them against the parts list. The red coils of wire turned out to be inductors, the battery-like objects with wires coming out of each end were capacitors, and the things that looked like tiny cement blocks were resistors. I placed the parts on the boards according to Dickason's circuit diagrams.

The next day I learned how to use a drill. I removed the parts from the boards, taking care to keep them in the correct order, and took the boards to the garage for drilling. I planned to use terminal strips for the input and output connections, so I marked holes with a pencil and drilled them using a 1/8″ drill bit. (Fellow first-time drillers should refer to "Tips For Novices" for an important safety rule.) Then I drilled 3/16″ holes for the mounting screws in the boards about 3/8″ from each corner. I fastened the terminal strips to the boards with 1/8″ rivets and a pop riveter.

Before wiring the crossovers, I needed to remove the insulation from the ends of the inductor wires. The large single-wire inductor was easy, but the two smaller heptalitz coils presented a problem. Duncan told me about chemical solutions that would strip all the little wires at once, but we decided against using chemicals in our household.

Instead, I spent a few tedious hours with a jackknife scraping red stuff off zillions of tiny wires. Then I twisted the heptalitz wires back into shape and attached all the crossover components to the boards using vast quantities of silicone glue.

A LESSON LEARNED

Soldering the components according to Dickason's circuit diagrams was relatively easy. I soldered each connection, let it cool, and snipped off any excess wire. *Figure 1* is Dickason's crossover schematic; the boards are shown in *Photo 2*.

During this step I learned why Duncan had told me to avoid applying excessive heat to the wires during soldering. I left the soldering iron on one of the terminal strip lugs for too long and was startled when the plastic on the strip turned liquid and began to bubble.

In the meantime, the double-boxed and well-cushioned enclosures arrived from Madisound. A separate box contained crossovers and all the smaller items needed for constructing the A652s. Madisound's cabinets are pictured in *Photo 3*.

At this point I had two sets of crossovers: one from Madisound and another that I'd built from Solen parts. I decided to build the complete Madisound kit, take the speakers apart, then rebuild them with the Solen crossovers and compare the two versions.

In addition to Audax's kit plan booklet, the Madisound kit included a six-page, step-by-step instruction packet. Barring two minor inconsistencies in the dimensional drawings on the final page, the packet is well done. The instructions are clearly written, and each step is accompanied by detailed illustrations.

Madisound has apparently geared these instructions toward speaker builders with little experience. Duncan, with 25 years of experience, told me they gave more detail than he needed. As a beginner in need of remedial help, I appreciated the detail Madisound offered but had trouble with the terminology they used. I ended up calling Duncan at work to ask what various words meant, such as "to tin," lug, and DB cup (it turned out to be Madisound's part number for the input cup).

SOLDERING SUGGESTIONS

I started building the kit by taking the grilles off the enclosures and storing them on a high shelf. I was afraid that if I left them on the floor they would accidentally get ruined.

Using the drivers and the input cups as templates, I marked the pilot holes on the fronts and backs of the boxes. (Drivers are fragile: trim your fingernails before handling them.) Madisound's enclosures were prefinished, so extra care was needed to avoid marring them. I drilled the holes on the back of each box using a 3/32″ bit. By drilling the backs first, I hoped to ensure that detritus resulting from the second round of drilling would not scratch the fronts. I flipped the boxes over and drilled 12 more pilot holes on the front of each box. After I drilled each set of holes, I used a handheld vacuum to clean up most of the sawdust.

I turned next to the Madisound-supplied crossover boards (*Photo 4*). Dickason's plans had specified separate boards for the high- and low-pass sections, but Madisound's preassembled crossovers consolidated both sections onto one board. Following their instructions, I cut the wires and stripped 3/8″ of insulation from the ends.

Later I discovered that while all the specified wire lengths worked, changing them slightly would have made final assembly easier. The 16″ wire to the tweeter was a bit short and should be lengthened to 18″ or 20″. Those to the woofers were too long: I would suggest reducing the 26″ to 22″ and the 24″ to 20″. The wire to the input cup should be lengthened from 10″ to 12″. (Note: These wire lengths are for the Madisound

TIPS FOR NOVICES

1. When placing crossover components on their boards, make sure the labels giving their values face up or to the side, so you can see the numbers after you've glued down the components.
2. A rectangular symbol for an inductor on a circuit diagram means that you should place it vertically on the board; a circular symbol indicates that you should place it horizontally.
3. Don't jiggle the components while soldering or you'll risk a cold solder joint, which can cause a bad connection.
4. If a tool doesn't work for you, work around the problem by finding another tool or a different technique which better serves your needs.
5. Find out about appropriate safety precautions (glasses, earplugs, face mask) before using a power tool for the first time. If your hair is long, pin it up as well as tying it back. Also, avoid wearing loose clothing when using a drill or other power tools.
6. Before gluing crossover components to the boards, do a dry run to make sure all the wires will meet in the proper places. I placed the first two or three components on the board by eye, but drew a pencil line around the last few to make sure I would be gluing them in exactly the right places.
7. When attaching the crossover components to the boards, use enormous quantities of silicone glue, which will keep the components from shaking loose when the speaker vibrates.
8. When gluing vertical inductors to the board, use a toothpick to draw glue up along the sides of the coil to form a little cradle. The cradle will hold the inductor securely to the board.
9. Mark holes before drilling by drawing a little circle using a pencil and your templates. Then make a small hole with an awl in the center of the circle to serve as a guide for your drill bit. Be sure to hold your pencil vertically.
10. When you drill through hard, thick wood or particleboard, your bit may slow down if the channels get clogged with sawdust. Pull the bit out of the hole and let the sawdust fly free. The bit will drill faster when you put it back into the hole.
11. After you use the drivers as templates, pick them up and put them away before they get damaged.
12. After stripping multistrand wire, twist it back together before proceeding to the next step. To protect your fingers, put cloth or a paper towel between your fingers and the wire.
13. "To tin" means to impregnate with solder. Use your soldering iron to heat the wire, lug, or other object to be tinned, then melt solder over the hot object.
14. The shaft of the soldering iron as well as the tip is hot. Try not to touch components with the shaft when maneuvering the tip into position. Capacitors in particular are easily melted.
15. As soon as you've completed soldering each joint, take the soldering iron away. If you use too much heat, you can melt the plastic on a terminal strip, fry a capacitor, or ruin a tweeter.
16. A pair of needle-nose pliers with a rubber band holding its handles together can serve as an extra pair of hands. Use the pliers to hold wires and components steady when you're soldering. A ponytail holder works even better than a rubber band because it slides easily up and down the plier handles.
17. When soldering near prefinished cabinets, shield the surface to keep drips of solder from marring the finish.
18. Drivers are fragile: do not rest your hand on them when soldering near them or when screwing them to the cabinets.
19. A red terminal on a driver is positive, as is a terminal with a red spot placed near it.
20. Be careful when using a screwdriver or pair of pliers near a driver. If the big magnet on the back of the driver sucks a small tool out of your hand, the tool can puncture the cone.
21. When using a screwdriver near the woofers and tweeters, put your fingers near the bottom of the blade and use them to guide the screwdriver. This technique will protect the driver from the screwdriver blade. Use Phillips-head screws to keep the screwdriver from slipping.
21. When screwing in the drivers, install the second screw diagonally opposite the first one to avoid stressing the speaker basket.

crossovers in their boxes. If you're using the separate high- and low-pass crossover boards specified by Dickason, or if you're building your own boxes according to his original dimensions, you will need to measure different wire lengths.)

I then tinned the ends of each wire and soldered them to the appropriate lugs on the crossover boards. Madisound's detailed illustration of this step was particularly helpful. Unfortunately, the soldering technique they described—laying a wire flat on each lug, then soldering the wire and the lug together—did not work well for me, especially where I needed to solder two wires to a single lug. When I tried to solder the second wire to the lug, the first wire invariably came loose, spraying liquid blobs of solder all over my work area. I did try to solder both wires at the same time but never managed to accomplish this feat without burning my fingers.

Two other soldering techniques served me better than the one Madisound suggested. In places calling for a single wire attached to a single lug, I put a hook in the stripped end of the wire, passed the wire through the hole in the lug, crimped the hook to the lug, and soldered. In places where attaching two wires to a single lug was called for, I made a hook in the stripped end of the first wire, put the hook through the hole in the lug, and crimped the hook to the lug. Then I wrapped the stripped end of the second wire around the first one near the lug and soldered everything together.

In future kits Madisound should consider providing lugs with larger holes. Another possible approach for the two wires leading to the woofers would be two separate lugs standing beside each other instead of a single lug.

I appreciated Madisound's reminders to observe polarity with each step that involved soldering. As I was trying to remember so many new concepts, without the reminders I would have forgotten several times about polarity and soldered the wires in reverse order.

STRONG-ARM TACTICS

After attaching the wires to the crossovers, I applied the Deflex panels. Dickason's kit plan calls for using ACI acoustic foam or its equivalent inside the cabinets on the top, back, and side walls, except near the location of the port. The Madisound kit included an upgrade to the original materials: Deflex panels to be attached on the inside rear walls as well.

The instructions on the Deflex adhesive jar say to paint the area to be covered with the adhesive, then wait two or three minutes

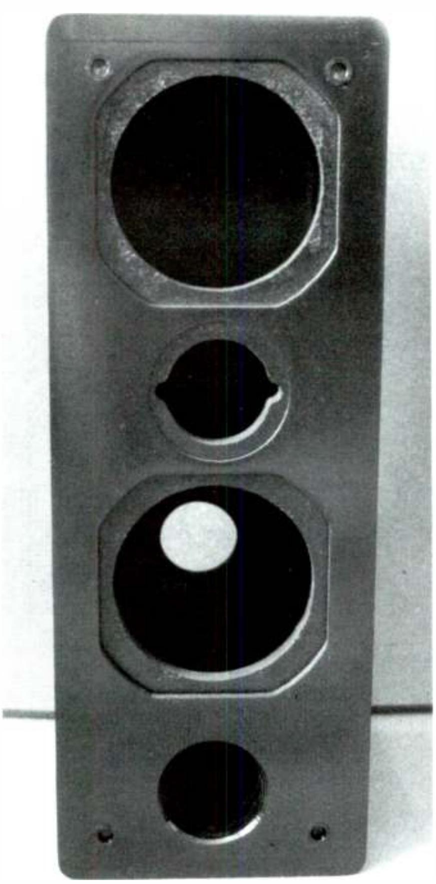

PHOTO 3: A652 cabinets supplied by Madisound.

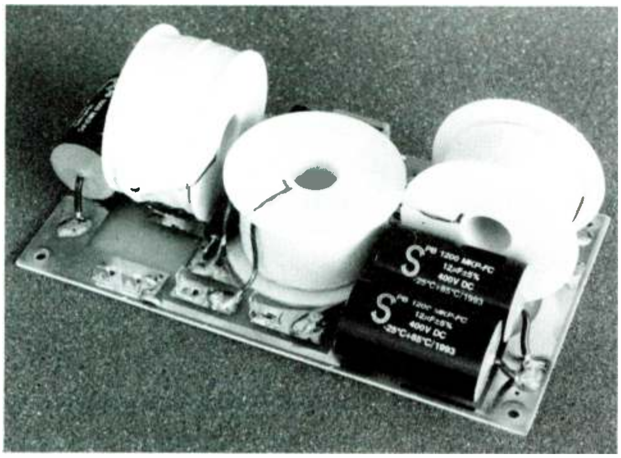

PHOTO 4: Madisound's preassembled A652 crossover board. Both high- and low-pass filters are included on this board.

before applying the panels. In our dry New Mexico climate a two-minute wait was sufficient. When I paused for three minutes before applying the panels, they developed an instant death grip on the cabinet walls. After two minutes I could move them around a little and ease them into place.

The Deflex instructions also state that the adhesive is "solvent free and safe to use." Nevertheless, it has a distinctive odor which persists for at least a week, especially in closed rooms. I would recommend keeping your enclosures in a well-ventilated room for a week or two after this process.

I cut a 2″ horizontal slit in the Deflex for the input wires, then attempted to mount the crossovers inside the boxes. This turned out to be the only step I was unable to complete without hands-on help from Duncan.

Since Madisound had placed each set of screws in separate, clearly labeled packages, finding the #6 ¾″ panheads for mounting the crossovers was simple. There was no need to squint at the screws while trying to distinguish their type. Orienting the crossover boards inside the enclosures was also easy. I could refer to the detailed drawings in the instructions whenever I felt hazy about which wires were input leads and which output.

I met my Waterloo over a purely physical problem: getting the screws into rock-hard particleboard in a space which allowed for very little leverage. In the box's close quarters, I couldn't get enough arm strength behind the screwdriver to start the screws turning in the fiberboard.

After an hour of frustration, I asked my husband for help. Duncan, with larger hands and many years of woodworking experience, also had trouble. He managed to insert the first two screws with much grunting and an occasional curse. The third screw he put in by bearing down on a bit brace and turning the chuck by hand. He gave up entirely on the fourth one.

This step does not work for speaker builders who lack massive hand strength. Several possible solutions include reducing the length of the crossover board from 7″ to 6″ so more arm pressure can be applied on the screwdriver, and drilling the mounting holes ½″ closer to the middle of the board. Another possibility would be to use a small electric screwdriver (ours was large and wouldn't fit inside the box). Larry Hitch of Madisound has suggested a fourth alternative: using a pencil-sized drill to bore pilot holes.

MEMORIES OF U

With the crossover boards mounted, I next attached the input wires to the input cups. Although the 10″ wires were long enough to make the connection to the cup, they didn't allow using Madisound's suggested solder-

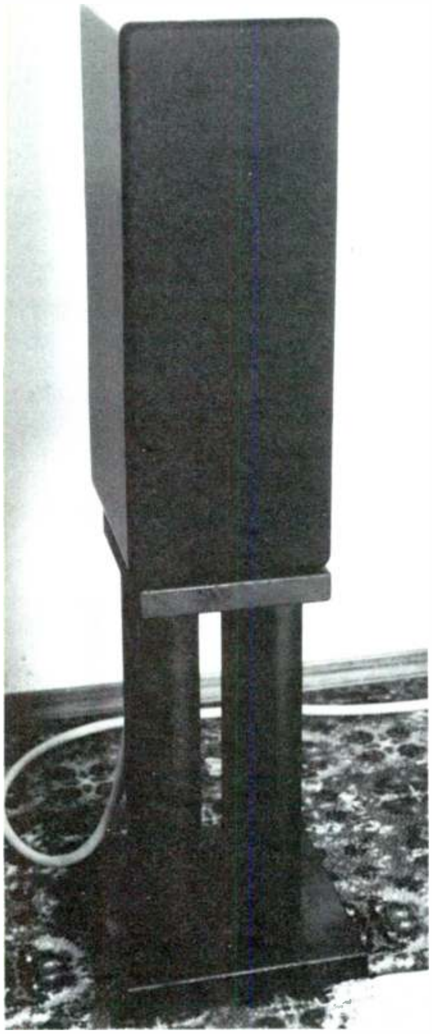

PHOTO 5: The completed A652 speaker with grille cloth in place, mounted on Duncan MacArthur's four-poster speaker stands.

ing technique. Builders who wish to use this technique should substitute a 12″ wire, as suggested earlier. Instead I made a hook in the input wire, passed the hook through the small hole in the lug, and soldered.

Next I placed sections of 5/8″ foam on the cabinet's side, top, and bottom inside walls. The foam came in a 27″ × 42″ sheet, which actually turned out to be a little smaller than specified by the instructions—26¾″ × 41½″. This slight change in dimensions didn't seem to make much difference in the finished product, however.

I measured four 9″ × 26¾″ foam rectangles, marked them with a felt-tip pen, and cut them out using a pair of sewing shears. According to the drawings in Madisound's instructions, the next step involved fitting each panel inside the boxes along the tops and sides and bottoms and sides in a squared-off "U" shape.

Placing the panels in the tops was not a problem, although I noticed that the foam bowed out in the corners of the boxes to create a true "U" rather than the desired squared shape. On the other hand, fitting the panels under the port tubes in the bottoms of the boxes proved difficult in one enclosure, impossible in the other. The space under the tubes was a little too narrow for squeezing in even a compressed piece of 5/8″ foam. (Dickason's original design allows for an extra 2¼″ space under the port tubes.)

I worked around this difficulty by cutting two of the 9″ × 26¾″ panels in half crosswise and fitting the cut ends under the tubes as far as possible. This technique resulted in a small gap (1¼″) along the bottom of the speaker underneath and behind the port tubes.

Next I pulled the wires through the appropriate holes and stuffed the boxes, measuring the wool by the fistful. I wasn't sure whether I was supposed to hold a thin wad of wool loosely or cram as much of it as I could hold in my hand. I tried to use a moderate amount, but later Duncan told me it was too much. According to him I should have filled the box loosely instead of stuffing it like a pillow, so I removed some before proceeding to the next step.

TURN OF THE SCREW

Before soldering the output wires to the woofers and tweeters, I attached Norsorex gaskets to the back of each driver. Some of the gasket mounting holes were still filled with rubber, so I punched them out with a toothpick. Then I peeled off the adhesive backing and carefully applied the gaskets.

The next step is to connect the output wires to the drivers. Since this kit does not use push-on terminals, these connections must be soldered. Duncan helped by holding the wires in place while I used the soldering iron. The holes in the tweeter terminals were quite small, so I used Madisound's suggested method of tinning the lug, tinning the wire, laying the wire on the lug, and soldering.

Duncan impressed upon me the importance of using minimal heat on the terminals to avoid overheating the drivers' internal wires, especially the tweeters. I realized how serious he was when his face turned red and he asked in strangled tones if I knew how much the driver cost. He was upset because the tweeter lugs were wobbling as the nearby plastic flanges started to melt.

After this incident I used as little heat as possible on the terminals. I removed the iron as soon as the solder started to melt when tinning the lugs. I let them cool before soldering the wire to them, held the soldering iron to the wire only, and removed it promptly when the solder started to flow. Nevertheless, I found this step confusing because the warnings to avoid overheating were mixed with admonitions to avoid cold solder joints.

If you're an experienced speaker builder who's helping a novice, your student will need close supervision during this part of the process. Because watching a beginner overheat tweeter terminals is likely to be a hair-raising experience for you, explain in advance exactly what you mean by overheating and give step-by-step instructions on how to avoid it.

Next I tucked the wires into the holes in the cabinets and installed the drivers using #8 1″ panhead screws for the woofers and #6 ¾″ panheads for the tweeters. The pilot holes I'd drilled earlier did not match perfectly the mounting holes in the drivers, probably because I hadn't held the pencil vertically when marking them. Luckily, they were only a little off, and I could still use them to install the screws.

I started the screws with a Phillips-head screwdriver, then switched to a bit brace for the bulk of the process. Since I needed both hands to work the bit brace, Duncan guided the bit with his fingers to avoid putting the drivers at risk. (An electric screwdriver would have been faster but would have offered less control.) For the last few turns I switched back to the screwdriver. *Caution*: Don't overtighten the tweeter screws. The TW025M0 flanges are made of plastic, and the screw heads are only slightly larger than the mounting holes. If you tighten the screws too far, the heads will slip through the holes and deform the plastic. The woofer flanges are made of metal and are much harder to damage.

I then carefully plucked a few flecks of Styrofoam off the drivers with tweezers, put on the grilles, and placed the speakers on 22″ four-poster stands. Madisound recommends using 24″ stands, but by the time their kit arrived Duncan had already built stands

SOURCES

Full kit available from Madisound Speaker Components, PO Box 44283, Madison, WI 53744-4283, (608) 831-3433, FAX (608) 831-3771. Drivers $336, cabinets in black oak or clear oak $216/pair, preassembled crossovers $102/pair, miscellaneous small parts (not including gaskets) approximately $60. 10% discount when entire kit is purchased.

Drivers are also available separately from a number of other companies including A&S Speakers, McBride Loudspeaker Source (Canada), Parts Express, Speakers, Etc., Solen Inc. (Canada), and Zalytron Industries. Prices vary depending on the dealer.

Crossover components and miscellaneous small parts are available separately from a wide variety of companies. Crossover components for this review cost about $57 and were supplied by Solen Électronique Inc., 447 Ave. Thibault, St-Hubert, QC J3Y 7T9, Canada, (514) 656-2759, FAX (514) 443-4949.

using Dickason's specified height. The A652s are shown with the stands in *Photo 5.*

FINELY FINISHED

Madisound's unexpectedly elegant A652 cabinets have rounded, solid-wood corners and a black finish. With their black drivers and finished fronts, they look good even without their grille cloths.

The kit took me about 13 hours from start to finish. I spent an additional 7½ hours building the Solen crossovers. Keep in mind that, as a total beginner, I needed extra time to learn all the techniques. Duncan estimates that finishing the kit would have taken him two evenings, with two more hours for wiring the extra set of crossovers.

The speakers were now ready for testing. Madisound recommends using a "D" cell to test polarity, but an old-fashioned Simpson VOM can also serve as a battery. I set the meter to the R × 1 scale. When the red VOM lead touched the positive speaker terminal, all four woofers moved forward slightly, indicating that the polarity was correct.

We had a brief delay in performing the second test, because the binding posts on the enclosures were larger than the spade lugs on the speaker cables. Madisound suggests checking the speakers in mono with pink noise or FM interstation noise. Duncan explained that playing music at very low levels would also work.

I was worried about what the A652s would do next. Maybe I'd see a puff of black smoke followed by a small explosion. But when I put my ear next to the drivers, I heard music coming faintly from each one. When Duncan turned up the volume, my jaw dropped open. The speakers worked!

TEST SETUP

Over the next week we constantly played a wide variety of music on the A652 speakers with the Madisound crossovers. The sound during the break-in period was not indicative of the A652s' final performance: they improved continuously over the period. The midrange sounded good from the very beginning. At first the midbass was absent, but it appeared in fine form later. The tweeters' initial harsh, bright sound calmed down considerably after we'd played the speakers for a week. For a faster break-in time, substitute pink noise or a specially designed break-in recording for musical CDs such as we used.

Our test system included Philips CD-50 and DAC960 D/A converter with POOGE-5 and custom volume control modifications. Although we used a pair of VTL Tiny Triode tube amplifiers for most of the testing, we also experimented with an old Hafler 220 solid-state unit with POOGE-2 modification. The cables were twisted-pair silver-plated solid (digital) and Neglex microphone (analog). For speaker connections we tried both Monster M1 and Apature 12-gauge cables. All listening was done with the grille cloths in place.

We listened to the A652s in a 13′ × 18′ room with an 8′ ceiling. Speaker placement within the room made a great deal of difference in the sound. First we tried placing them along the 18′ wall, 20″ from the rear wall and 50″ from the side walls. This arrangement accentuated the highs and resulted in poor imaging. Along a shorter wall, 60″ from the rear wall and 40″ in from the side walls, the highs were more mellow and the imaging improved.

Their angle relative to the listener also made a substantial difference in the A652s' sound. We set them up as two points of an equilateral triangle, with the listening position forming the third point, and experimented with aiming them in various directions. When pointed directly toward the listener, the result was slightly hot highs; pointing them directly forward produced extra midbass but poorer imaging. Aiming the speakers toward a point slightly in front of the listener seemed to result in better imaging and more soothing highs.

GIVE A LISTEN

Once the A652s had been broken in, we listened to a wide variety of music over a period of weeks. These speakers have a clean, detailed, spacious sound with excellent definition, particularly in the midrange and midbass. On orchestral recordings each instrument stood out separately and clearly. With rock we could hear every nuance in a singer's voice.

The Audax A652s exhibit good dynamic contrast, with rapid and distinct transitions between soft and loud passages. With the Madisound crossovers, imaging is good but not superb. We could hear individual instruments spread across a wide soundstage but not the razor-sharp localization of each instrument.

As small speakers go, the A652s are quite efficient. Our wimpy little Tiny Triodes (25Wpc) were capable of playing them at a level we found too loud for comfort (the definition of which can vary according to age and musical tastes). Those people who crank up the volume on their stereo systems may prefer to pair the A652s with a more powerful amplifier. Although the Triodes could easily handle most recordings played through the A652s, on a few occasions they showed signs of strain. The massed horns on Strauss's *Also Sprach Zarathustra* were too much for them. That was one of very few passages which sounded better played through the more powerful Hafler.

While Duncan and I like these speakers a great deal, we have some caveats. The A652s require careful matching with the other components in your system. With most recordings these speakers sound better played through the Tiny Triodes than through the Hafler. In fact, most of the time they sound wonderful with the Triodes and horrible with the Hafler. The sound through the latter is harsh, mushy, and less dynamic, with reduced midbass.

Choice of speaker cables made a major difference in the sound. Oddly enough, the Apature cables sounded much better with this system than the Monster M1s. The sound was more dynamic, with tamer highs, while highs heard through the M1s seemed harsh and brassy. We weren't sure whether the improved sound through the less expensive Apature cables was due to their interaction with the Tiny Triodes or the speakers.

The A652s are unforgiving of poorly recorded source material. One of my favorite CDs, *Skeletons in the Closet: The Best of the Grateful Dead,* played through them produced screeching highs that made me grit my teeth and reach for the eject button, whereas well-recorded CDs consistently sounded good. Since the highest quality CDs were also the recordings that sounded best, the obnoxious highs probably came from poorly recorded individual CDs.

Like any speakers with 6.5″ woofers, the A652s do not produce spine-tingling deep bass. The thunderclaps in the *Grand Canyon Suite*, for example, have startling dynamics, but they lack the deep rumbling of real thunder. Dickason has a point when he suggests using these speakers as satellites in conjunction with a subwoofer.

We compared the A652s with a pair of custom-designed satellite speakers made from two Focal 5K013L woofers and a T120K tweeter mounted in the D'Appolito configuration in a small sealed box tuned to 100Hz. The Focals, which have a higher f_3, must be paired with a subwoofer. The A652s would undoubtedly sound better with a subwoofer but can be played alone.

The A652s have better midbass than the Focals, probably because the former have larger woofers. In addition, they are more dynamic, with a more natural midbass and better imaging. On the other hand, the Focals have smoother, more extended high frequencies.

NEW TRICKS

The next step of the reviewing process was to substitute the Solen crossovers for Madisound's preassembled units. Taking the A652s apart was simple and uneventful. Rebuilding them was, with a few exceptions, much like the original process. This time I used silver bearing solder along with 18-gauge, solid-core twisted-pair wire instead of the solder and the #14 stranded wire.

Installing the crossover boards once again caused difficulties. Dickason suggests mounting the high- and low-pass sections on separate boards, and placing them on opposite walls of the enclosure as far as possible from the woofer magnets. Due to the trouble we'd had mounting the previous boards, we thought we should place the new crossovers in an area where we could apply some leverage. They ended up on the back wall of the upper chamber, with the high-pass section behind the tweeter and the low-pass section behind the upper woofer. (We later regretted that we'd mounted them on the back wall. Try using an alternate technique, such as drilling pilot holes with a pencil-sized drill, to allow side-wall mounting.)

It proved much easier to mount the low-pass crossover behind the upper woofer than behind the tweeter. Installing the high-pass section was still difficult; however, this time the boards were only 6″ long, so Duncan had better access to the screws and could apply more leverage. He used a bit brace again, bearing down with one hand and turning the chuck with the other. This time he managed to put in all four screws.

Resoldering the woofers was easy because their polarity was obvious. (The red dots next to the positive terminals had survived my earlier soldering attempts.) I used desoldering braid to remove solder from the holes in the terminals. For soldering the lugs I put a hook in the wire, passed the hook through the hole in the lug, crimped the hook, and soldered.

The tweeters, on the other hand, gave me a nasty surprise. When soldering them to the first set of crossover output wires, I'd managed to remove all the red coloration from the positive terminals. No polarity indication was left. Duncan, who was at a loss for words for the first time since we started this project, finally told me to call the manufacturer and ask for advice. Audax's technical advisor, Ron Salb, suggested connecting the tweeters to a 1.5V AA battery. He said that connecting the terminals, positive to positive and negative to negative, would cause the dome to leap forward. If nothing appeared to move, I was to tap lightly on the dome to see if I could feel pressure on my fingertips.

Ron's technique worked: I could see the domes jump forward. I resoldered the tweeters by tinning the wire, laying it against the lug, and soldering. The lug was already covered with solder, so I didn't tin it. I chose Madisound's suggested technique over my usual soldering method because the holes in the tweeter terminals were quite small, and I was also worried about overheating the tweeters while trying to remove solder from them.

Remounting the drivers and input cups also required a few new techniques. Before soldering them, I cleaned up the mounting hole edges with a few turns of a hand countersink for a better seal later. When I installed the drivers and input cups, I took extra care to avoid stripping the screw holes.

Unfortunately, when I'd overtightened them earlier, I'd deformed some of the mounting holes on the tweeters. I added #6 washers to keep the screw heads from slipping through the holes. Another approach would be to substitute #8 panheads for the #6s.

With two exceptions, the rebuilt A652s sounded similar to the originals. The imaging was much improved with the Solen crossovers. Also, the highs and upper midrange had a brighter sound. Perhaps this was because we'd mounted the crossovers in a less-than-optimal position; or perhaps the Solen crossovers provided less mask-ing of inadequacies. The midbass and lower midrange remained excellent in this configuration.

In an attempt to calm the highs, I added 5½″ foam donuts around the tweeters, using material left over from lining the boxes. The donuts reduced the effect to some extent but not completely.

Someday I may track down the source of extra harshness in the rebuilt A652s. Until that time I prefer the sound of the Madisound crossovers. Duncan favors the overall sound of the Madisounds but continues to sigh over the Solen's improved imaging.

THINGS TO COME

The Audax A652s are not for people who plunk their speakers down in the middle of a room, pair them with random components, and expect them to sound good. They require high-quality source material and electronics. If you choose these speakers, be prepared to spend time matching and positioning them. With the right recordings and setup, the A652s are capable of producing very good sound at a reasonable price.

Although I pick at a number of nits with Madisound's A652 kit, it is fundamentally well-conceived and executed. The instruction packet is detailed and clearly written, and Madisound supplies high-quality parts.

Many of the difficulties I had were minor, but Madisound may wish to correct two of the more significant problems in future kits. Extra technical advice on mounting the crossover boards would be helpful, along with a different method of soldering two wires to one lug.

The Madisound A652 kit can be constructed by a speaker builder with a small amount of experience. A novice with no experience can build it *if* that person has access to advice from a more experienced builder.

In the future I hope to make a number of changes to the A652s and their setup. I'd like to buy a pencil-sized drill and remount the crossovers in a better location using the technique suggested by Larry Hitch. Replacing the foam donuts with a front-panel-sized foam sheet with driver cutouts might further improve the sound. It would also be fun to find out how these speakers sound with a more powerful tube amplifier, a more modern solid-state amplifier, and/or a subwoofer. Another possible experiment would involve substituting a different tweeter, such as the Focal T90Ti.

At first Duncan was taken aback when his wife started pestering him for ideas on how to improve her speakers. But lately he's been taking this new state of affairs for granted.

The other day strains of Bach came wafting through the house. I found Duncan lounging on the sofa with his eyes half closed, listening to the A652s.

I patted him on the shoulder. "You like these speakers, don't you?" I asked.

He smirked. "Yeah," he said. "Next time you can build me a subwoofer."

MANUFACTURER'S RESPONSE

We appreciate very much the excellent review Nancy MacArthur has written for Speaker Builder *readers and the many positive comments about Madisound. More than any article in recent memory, Ms. MacArthur has captured the pleasures of our shared hobby.*

Based on the author's experiences, we have made changes in the instructions to minimize confusion in assembly. As for soldering problems, I am reminded of the time several years ago when I suggested to Madisound Engineer Tom Roberts that we should have our clerical and production employees build an amplifier kit we were offering for sale. Tom thought about it for a few minutes and then suggested that we would need five hours of instruction: the first four and a half hours would be devoted to proper soldering techniques, and then the final half hour could be spent on the actual construction of the amp.

Lawrence Hitch
Madisound Speaker Components

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Tools, Tips & Techniques

REPLACING WOOFER SURROUNDS

Are your woofer surrounds shot? After about 9–10 years, foam surrounds deteriorate and disintegrate, leaving your poor woofer cone flapping in the breeze, making distorted sounds. Replacing them is easier than you might think; take it from someone who was very much daunted by the thought of attempting it (until recently)!

Refoaming your woofers can be expensive, as much as $25–30 per woofer. For a little bit more, you can buy new woofers. But if you refoam them yourself, you'll save money and become empowered in the process.

Foam surrounds for 12″ woofers cost about $10 each. You can usually buy application glue from the same supplier. While we're on the subject, I much prefer Elmer's Household Cement to Duro Household Cement. Elmer's goes on smoother and is easier to apply, so you use less and produce neater results. Its odor is not particularly offensive. Duro goes on lumpier, is more difficult to control because it dries too quickly, so you end up using more, and it smells worse.

[Author's note: The glue to attach the woofer surround to the speaker cone and to the woofer basket is a.k.a. "cement," "household cement," or "model cement," and is not the regular Elmer's white glue or Elmer's yellow wood glue.]

Once you've obtained the appropriate-size surround for your woofer(s), you're ready to begin the refoaming process.

TEN STEPS TO SUCCESS

1. Remove all the old foam from the woofer cone and basket frame edge. Also remove any cardboard or rubber gasket on the basket frame edge, but be careful, because you'll be reusing it later. Take your time with this step to avoid damaging your cone, but make sure to scrape off as much foam as possible. I achieved good results with a bread knife. Remember, you need a clean surface to affix the new foam.

2. Next, apply a solvent such as alcohol or nail polish remover (acetone) to remove any further residue or remnants of the old foam. If you have a plastic cone, make sure the solvent won't damage it. I have Peerless polypropylene woofers, which were unaffected by either substance.

3. Use a sharp cutting knife or blade to carefully cut around the dust cap, which you do not need to remove completely—simply separate from its site. Be careful not to cut through the voice coil leads. You can avoid this by noting where they enter the side of the cone. Then start at a point close to but safely away from the most clockwise lead. Cut at the base of the dust cap all around in a clockwise direction and stop just before the other lead. You will have made a "C" pattern. At this point, you can lift up the dust cap on its "hinge."

4. This next very important step "locks" your woofer cone in place to prevent the voice coil from rubbing in the gap. Your supplier might have plastic or paper "shims" for you to use. If not, make your own from any thin card or plastic sheet that you can roll into a cylinder. I used a card from those card "decks" advertising computer supplies and entrepreneurial opportunities. Roll up the shim into a cylinder/cone and introduce an edge into the gap, easing in the rest of the shim. The cone will "lock up" and not move, which is desirable when applying the glue and foam surround to the cone's edge.

[Author's note: After you roll the shim into a cylinder, ideally you could then insert it into the voice-coil gap surrounding the voice coil. However, this step is difficult and awkward. It's probably better to roll up the shim into a cone-shape (like a megaphone) to insert one of its edges into the voice-coil gap to get started. It will then be easier to insert the rest of the shim into the gap.]

5. Apply the glue or cement to the cone's edge and basket frame edge and allow it to set for a few moments until it becomes tacky.

6. Position the foam surround in place on the cone, then press the foam and cone together in a circular direction, making sure good contact and adhesion of surround to cone occurs. Do the same for the basket frame edge. Place the foam, without stretching, to follow the old configuration, which is evident by a darkened or shaded area. If you have a gasket mentioned in step #1, apply glue to the frame edge and apply the gasket.

7. Turn the driver cone face down and allow to dry for 24 hours.

8. Remove the shim in the voice-coil gap. Press down on the woofer cone, moving it up and down. It should move freely without rubbing in the voice-coil gap.

9. Return the dust cap to its original position. Apply glue so the dust cap edge adheres to its base. Apply a little more glue if necessary to ensure the dust cap is securely glued in place and will not leak air. Allow to dry.

10. You are done, and are now the proud owner of a resuscitated woofer!

POSTSCRIPT

Editor Dell observed that overlapping the shim on itself in the voice-coil gap results in the overlapping section to be thicker than the rest of the shim and will cause the cone to be off-center.

In speaking with one of the technicians, Scott, from The Speaker Exchange, I learned that, for the most part, this is not critical. I can attest to this, having replaced the foam surrounds on 8″ and 12″ woofers without any apparent rubbing in the voice-coil gap, and the woofers sounded just fine.

If this concerns you, however, you can cut the shim so it approximates the circumference of the voice coil. This means a different-size shim for each different-size woofer/voice coil. JBL, for instance, uses custom-size shims for its surround replacement.

When the shim overlaps, you can also cut two or more small strips of the material and insert them into the gap at strategic locations around the voice-coil gap for a more even distribution. This is appropriate for a small, tight gap in a very high-precision, expensive speaker.

For large gaps, you might need to use two shims or one shim of greater thickness to hold the speaker cone in place.

Angel Luis Rivera
Bradenton, FL 34209

ACKNOWLEDGMENT

Thanks to Rob and Scott of The Speaker Exchange in Sarasota for good advice and helpful information.

SOURCES

Simply Speakers
(800) 767-4041

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POWER SPLIT POSTSCRIPT

In addition to my comments on power division for multiway speaker systems ("More Power," SB Mailbox, *SB* 8/94, p. 62), I would like to add this "protective" information:

Woodgate (*JAES*, Vol. 33, No. 4, April 1985, p. 249) cautions you to also assess the effects of short-term signals dominated by a single note (frequency), as these have the potential to exceed the power-handling capacity of delicate tweeters.

Witold Waldman
Audiosoft
Melbourne, Australia

MORE HORN RESULTS

I have some questions regarding "Round the Horn" (*SB* 8/94, p. 24), which was an interesting and useful article. Are the measurements in Fig. 1 made in the same way as those of Fig. 2? If so, why are the measurements for the Son Audax PR17-HR100-1AK7 cone midrange driver different in Figs. 1B and 2F? The differences are large enough to call into question the measurement system. Also, why are Figs. 2O (Vitavox/EK175) and 2P (JBL2370/2426) identical?

The article compares the sound of the different drivers and the flatness of their frequency response, and concludes that a "reasonably good connection was achieved here (around 80% similarity) between the calculated waveform similarity and the listening tests." This seems a higher correlation than I could achieve by studying the cepstrum results.

Dick Crawford
Los Altos, CA 94024

Philip Newell responds:

Thank you for your detailed interest in the article. As you will have gathered, this work was the result of much research and data gathering, and the article dealt mainly with the conclusions. We submitted the original report on this work, which also explained the test setup, to Speaker Builder *about two years ago, but it would have taken up an entire issue. The publisher, Edward Dell, was at one point even considering making a short book out of it.*

With reference to your question about the discrepancy in the caption plots for the Son Audax driver, the answer is that they were Son Audax drivers (plural). Figures 1B and 2F represent two drivers taken from the same production batch, so I will quote from the fuller account of the proceedings:

"Sample 6: Audax PR17/HR100/1AKS

Taken from the same production batch as archetype "B," Sample 6 served as a similarity control. Only 1% of the test results showed any ambiguity whatsoever. Less than 10% of the results were placed in the "none" column, those being mainly on the transient or the noise sounds, while 90% of the total number of questionnaire ticks quite unambiguously stated a similarity to its twin, B. The result was encouraging in terms of showing the validity

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of the test, as no listener ever indicated a definite likeness to any of the other archetypes, A, C, or D. While the transfer functions of B and 6 shown in Fig. 3 are commendably similar, the cepstra show marked differences, which explain more readily the audible differences between the two nominally identical drivers on wideband signals."

*The transfer function from Fig. 3 and the master listing of unambiguous questionnaire "ticks" (*Table 1*) show that disagreement about sound similarity occurred only with the "twin" driver results. They suggested that although a difference existed, it did not cause "6" to sound like any of the other reference archetypes. The ticks indicate that 6 (*Fig. 1*) either sounded like B (*Fig. 2*) or sounded like none of the other archetypes.*

Incidentally, "Sample 3" was the "non-similar" reference sample, and as you can see from the same table, produced a very small number of ticks in the column for each of the four archetypes, but a very large number in the none *column. Samples 6 and 3 thus set the boundaries of similarity or nonsimilarity within normal production tolerances. The signals 1-9 are listed at the end of this response.*

You further suggest that the 80% similarity from the waveform similarity (wss) calculations indicates a higher correlation with the results than the cepstrum analysis. The text emphasizes those not included in the 80%. "Unfortunately, some results refused to correlate in a most glaring way." In other words, some of the archetypes and samples, which the waveform spectral similarity (taken from the pressure amplitude response [frequency response]) suggested should sound very similar, sounded very dissimilar on the listening tests, and vice versa.

The pressure amplitude and phase responses define the time response, so what occurs in the time response must also appear in the amplitude/phase response, although they are not necessarily easy to recognize from the plots. We used cepstral analysis to highlight anything which might be happening in the time domain and explain the disagreement in the waveform spectral similarity/listening test results, which was not evident from the comparisons of the pressure amplitude responses.

Third-octave averaged "frequency response" is widely considered as the biggest single factor in the similarity between the loudspeaker sounds, and the 80% agreement between the wss/listening test results is in

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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 •

1993 Waslo's IMP, Pt 1-3 • Quasi-Monotonic Vented Alignments • Making Your Room Hi-Fi, Pt 2-3 • A&S Soundoff Winner, Pt 3 • Flexible Dipole Woofer • The Simpline • Stalking F_3 • A Bi-Structural Enclosure • A Sixth-Order T/S Subwoofer Design • Speaker Enclosure Screws • Electric Bass Tri-Horn • Prism V Satellite/JBL Subwoofer, Pt 1-2 • Fitduct: Program for Designing Duct Software • Compact Coincidental Point Source Speaker • IMP: Measuring T/S Parameters • KIT REPORT: Rockford's Beginner Software/Driver Paks • SOFTWARE REPORT: Low Frequency Designer 3.01 • Three Affordable Measurement Microphones • Two Ways to Realize a Dream • Matching Driver Efficiencies • Two-Woofer Box System • Designing a Dual Voice Coil Subwoofer • SOFTWARE REPORT: Blaubox 1.2 • Tale of Three Speaker Projects • A&S Sound-off 1992 • Monolith Horn • Orbiting Satellites • Real-World Three-Way Crossovers • The Simplex • Living with a Speaker Builder • The IMP Goes MLS •

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

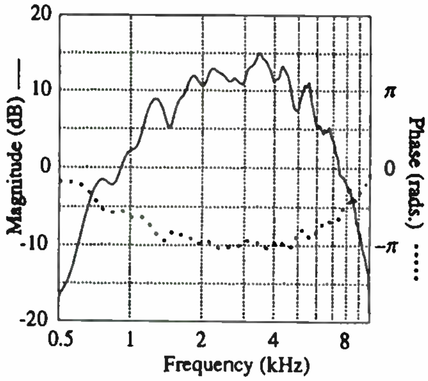

FIGURE 1: Sample 6.

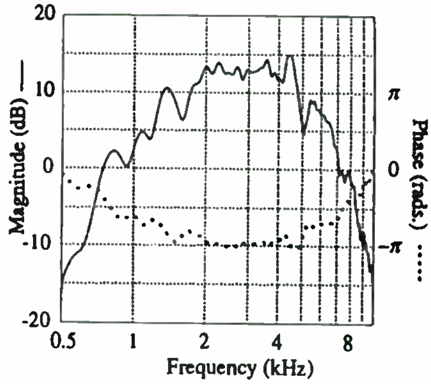

FIGURE 2: Reference B.

TABLE 1

LISTENING TEST RESULTS: UNAMBIGUOUS TICKS

	Sample 1					Sample 2					Sample 3					Sample 4				
Signal	A	B	C	D	None	A	B	C	D	None	A	B	C	D	None	A	B	C	D	None
1	-	1	2	4	1	-	2	4	1	-	-	3	1	1	-	-	6	-	2	1
2	-	2	1	3	3	-	4	2	1	2	-	-	1	2	3	-	6	-	-	2
3	-	3	-	4	1	-	7	1	-	1	1	-	1	1	4	-	6	-	2	1
4	-	2	-	1	4	-	3	-	-	5	-	-	-	-	8	-	5	-	-	4
5	-	1	1	2	2	1	4	-	-	4	-	-	1	-	9	-	6	-	-	4
6	-	5	-	3	3	-	4	-	1	2	-	1	1	1	5	-	3	-	-	3
7	-	1	-	2	4	-	3	1	-	2	-	-	-	-	9	-	7	-	-	2
8	-	4	-	5	-	-	5	-	1	-	-	2	-	2	4	-	6	-	1	2
9	-	3	-	3	3	-	9	-	1	-	-	-	-	-	5	-	1	-	2	4

	Sample 5					Sample 6					Sample 7					Sample 8				
Signal	A	B	C	D	None	A	B	C	D	None	A	B	C	D	None	A	B	C	D	None
1	-	3	2	2	-	-	6	-	-	-	-	5	1	-	-	-	1	-	4	1
2	-	5	1	1	1	-	7	-	-	3	-	5	2	-	2	-	1	-	5	3
3	-	2	1	4	1	-	8	-	-	-	-	3	2	-	1	-	1	1	3	1
4	-	1	-	1	4	-	11	-	-	1	1	2	-	1	5	-	1	1	2	4
5	-	2	1	2	4	-	12	-	-	-	-	1	-	1	4	-	1	-	2	6
6	-	2	1	2	1	-	8	-	-	1	-	3	2	-	1	-	2	1	1	3
7	-	-	-	2	6	-	10	-	-	-	-	-	-	-	4	-	-	-	2	8
8	-	6	-	1	2	-	9	-	-	1	1	1	2	-	-	-	1	1	1	3
9	-	3	-	3	3	-	11	-	-	-	-	4	1	1	3	-	2	-	3	4

	Sample 9					Sample 10					Sample 11					Sample 12				
Signal	A	B	C	D	None	A	B	C	D	None	A	B	C	D	None	A	B	C	D	None
1	-	3	2	-	-	-	9	-	-	-	-	3	1	-	2	-	3	2	1	-
2	-	3	2	-	2	-	7	-	-	1	1	1	3	-	2	-	1	2	3	2
3	-	-	4	-	-	-	3	2	-	1	-	3	2	-	-	-	3	5	-	-
4	-	-	-	1	8	-	2	-	-	5	-	-	-	-	6	-	-	1	1	5
5	-	1	-	-	9	-	4	-	-	3	-	1	-	-	2	1	-	1	-	6
6	-	2	-	-	3	-	4	1	1	2	-	4	1	-	1	-	2	4	-	3
7	-	-	-	1	5	-	5	-	1	3	-	-	-	-	4	-	-	3	-	4
8	-	2	-	1	3	-	4	-	1	1	-	4	-	1	3	1	2	5	-	1
9	-	-	4	2	2	-	3	-	4	1	1	6	-	-	1	-	-	5	2	1

	Sample 13					Sample 14					Sample 15					Sample 16				
Signal	A	B	C	D	None	A	B	C	D	None	A	B	C	D	None	A	B	C	D	None
1	-	4	-	1	2	-	2	-	3	1	-	6	1	1	-	2	1	4	-	1
2	1	5	2	-	1	-	3	1	1	1	-	4	-	-	2	-	3	-	-	-
3	1	1	2	-	1	1	1	3	1	1	1	2	3	-	2	1	-	6	-	2
4	-	-	1	-	7	-	-	-	-	5	1	-	-	1	6	2	-	-	-	6
5	-	-	-	-	7	1	-	1	-	5	-	-	1	1	5	-	1	1	-	7
6	3	2	3	-	2	1	1	1	-	5	-	1	1	-	7	-	3	4	-	-
7	2	-	1	-	4	1	1	-	-	5	2	-	-	1	5	-	1	-	-	7
8	3	-	4	-	2	1	-	6	-	1	1	1	3	-	4	2	-	5	-	2
9	2	-	3	1	3	-	-	6	-	3	1	1	2	-	3	-	2	4	-	2

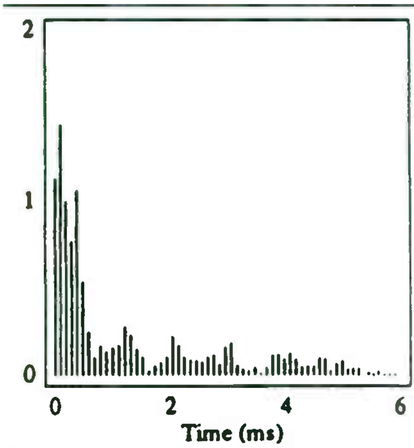

FIGURE 3: Corrected Fig. 2O.

good general agreement with this. We used cepstral analysis as a "microscope" to examine the problem areas.

As far as why Figs. 2O and 2P are identical in the article, the plot for the JBL 2370/2426 was inadvertently used for both figures. The correct plot for the Vitavox/EK175 combination is shown in Fig. 3.

The Sounds

The nine sounds are as follows:

1. A digitally generated chirp;

2. A digitally generated tone burst consisting of ten cycles at 2.5kHz, sounding similar to claves being struck;

3. Two notes from an anechoically, digitally recorded flute;

4. White noise;

5. Pink noise;

6. An anechoically recorded heavy book being slammed shut;

7. An outdoor recording of a waterfall, a short section of which was sampled and repeated;

8. A 30′ high, square section steel tube, open at one end, being struck by a peach stone. The phase dispersion causes the high-frequency reflections to lead the low frequencies, producing a "laser gun" sound.

9. An anechoic recording of an acoustic guitar chord, sampled and repeated.

PA PROBLEMS

My friend, who constructed Bill Fitzmaurice's Electric Bass Tri-Horn system (*SB* 4/93, p. 10), enjoys its power and individuality, but we have found some limitations. One problem is that the sound the bass player hears 3 or 4′ from the cabinet (which is on the floor) is different from what the audience hears. The midrange is almost on-axis for the audience, but very far from it for the players.

Another problem involves the speaker mikes. If we place a microphone at the mouth of the top horn, then we will miss the high end coming off the midrange, but if we mike elsewhere we'll lose the tightness associated with a mike close to the woofer.

I'm thinking of mounting a Pyle H3910E compression horn (I have a few around the house) to the front braces of the top horn opening. This requires moving the braces closer together, and I'm considering smashing in a place on the 15″ grille for the horn magnet. The Pyle horn would also require a sharper crossover point than the 5″ Pyle.

This would boost the high end to help the musician hear, and the Pyle horn's efficiency would be closer to the woofer's, thereby creating more sparkle and pop without much treble boost. I also wish to create a more coincident point source, making mike placement better.

The immediate problem is shrinking the top horn opening. Will this change the loading? Could I increase the slope of the baffle to widen the vertical opening and offset the area taken by the Pyle horn?

My other problem is mike placement. If I put a mike a few inches from the Pyle's front, will it clock the higher midrange from the woofer? Could I cut holes (nonsymmetrically) in the body of the horn to allow more midrange from the woofer cone to reach the mike?

Drew Gandy
Joliet, IL 60433

Bill Fitzmaurice responds:

You've described perfectly the bass player's dilemma: because of the instrument's nature it's virtually impossible for the sound in the audience to be the same as on stage. You're dealing with low fundamental, nondirectional tones augmented by wave development and room acoustics and column, as well as harmonic overtones which are very directional and are damped by room acoustics and subject to speaker "beaming." One reason the tri-horn sounds so good is its accentuation of the 200Hz to 500Hz band, which is largely unaffected by the above problems. The low placement of the mid driver on the cabinet is intended to mute the higher frequencies on stage and accentuate them out front to help balance the bottom end.

Since you'd prefer more midrange pres-

ence close to the cabinet, your idea to raise the mid driver's position is valid. However, I'd advise against the horn units, whose frequency response extends too high, and whose narrower dispersion angle would probably cause even more pronounced beaming effects.

To get more mid efficiency, I'd use two MH-516s wired in parallel for 4Ω impedance, with a 47µF capacitor for filter. This will give 6dB additional sensitivity above 1kHz. Mount these in two separate subenclosures at the top outside corners of the cabinet, between the baffle and the top. Spread and lengthen the top braces to act as the inside walls of the subenclosures. The resulting reduction in the size of the top horn mouth should have minimal effect, and may even result in better loading of the woofer.

This will also give you better mike-placement options, although I'd note that no placement on any cabinet will give a perfect feed to the PA, for the same acoustics and wave development reasons noted above. Unlike guitar, in which tone is largely dictated by speaker coloration and a mike is necessary, bass is best fed directly to the board—by splitter, direct box, or preamp line-out.

My final point for best bass sound is to use either a wireless rig or a long (25') cord so you can go into the audience during sound check and adjust your amp for the best tone out front, regardless of what it sounds like on stage. Also, make sure your sound man EQs his feed so the PA matches the sound of the stage rig. Nothing irks me more than setting my amp for a tight Jaco or Entwhistle tone while a thump-happy sound man EQs my feed to a bottom-heavy reggae boom.

I hope my suggested mod makes your tri-horn better-suited to your needs, and I'd be interested to hear your results.

SPEAKER TWEAKER

I have had trouble with the tweeters I specified for my near-field monitor design ("The Disappearing Loudspeaker," *SB* 3/92, p. 42). The tweeters in all four units have degraded, and were putting out only a weak signal. The problem seems to be that the ferrofluid affects the insulating varnish on the voice coil wire.

A&S Speakers (3170 23rd St., San Francisco, CA 94110 (415) 641-9228) has replacement diaphragms that are of more recent construction. They claim this makes the tweeter about 1dB more efficient than the original, which will be acceptable judging from my original frequency response plot. I won't know how long these new diaphragms will last until I observe them for several more years.

The tweeter I specified, the Audax DTW12X9T25FFF/8Ω unit, is no longer in the Audax catalog. The newer TW025A1 will work, but it has a round faceplate that interferes with mounting close to the woofer. A&S reports that they have a stock of rectangular faceplates, so you can adapt the newer tweeter to my front panel layout by swapping front faceplates.

If you need to adjust the tweeter level slightly, just treat the two resistors R1 and R2 in the tweeter network as the legs of an L-pad and work from there. Radical changes in the tweeter working voltage will necessitate retuning C1 and L1, so try to keep the changes small.

Victor Staggs
Orange, CA 92667

AR GLORY DAYS

It was nice to see the article "Resurrecting a Pair of AR2AXs" (*SB* 8/94, p. 20), in which author Hilary Paprocki described refurbishing (and modifying) a pair of garage-sale AR-2axs. However, Mr. Paprocki's attempts to please his ear actually *degraded* speaker performance. While he is entitled to do what he pleases to his speakers, of course, performance will suffer as a result.

The condition in which he found the AR-2axs with deteriorated woofer surrounds and burned-out tweeter was probably unacceptable. Clearly the speakers needed to be rebuilt, but the temptation here was to rebuild them *better* than original, a lofty ideal!

Early Acoustic Research models were landmark achievements of their day. The AR-1 was the first acoustic-suspension speaker and for many years a reference stan-

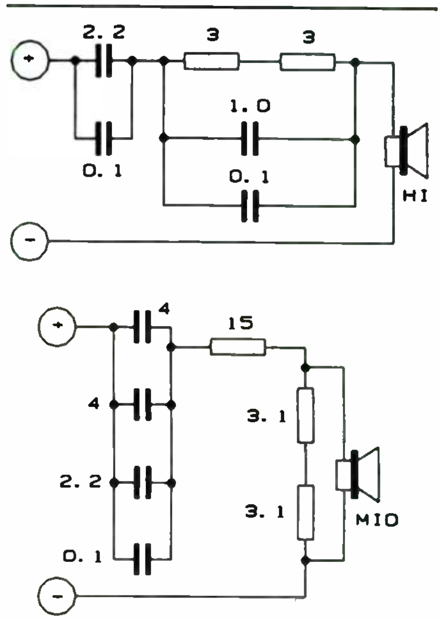

FIGURE 1: New AR crossover circuit.

dard. The AR-3, the first speaker with dome tweeters, was arguably the most accurate loudspeaker money could buy during the early 1960s. The AR-3a, an enhanced AR-3, was well-known to audiophiles during the late '60s and early '70s as one of the finest loudspeakers ever produced.

The AR-2, AR-2a, and AR-2ax were extensions of this same philosophy: maximum performance at affordable prices, but with certain design compromises, such as a loss of about one-third octave in deep bass, slightly higher distortion, and slightly degraded off-axis dispersion. Lower-cost components made it possible to sell them at lower prices. But even at $128, the AR-2ax was at the top of its performance class.

No one in the 40-year history of AR would agree with Mr. Paprocki's statement that, "AR was one of the first companies in hi-fi history to fine-tune their products primarily by ear." On the contrary, AR was probably the first company to extensively use anechoic and reverberant test chambers (AR had several of the finest in the country) to quantify speaker performance, which correlated with listening tests. How many companies published the frequency-response curves, on- and off-axis, power-response curves, and harmonic-distortion curves for all their speakers? During the '50s, '60s, and '70s no other speaker manufacturer published complete, objective, repeatable performance curves of their products, let alone defend them as AR did. Reviewers universally agreed that AR speakers had a fine sound quality, and many critics reluctantly agreed with the idea that "if it measures well it will sound good."

Why not, therefore, restore the AR-2ax to its original performance? Why jury-rig the speaker to make it seem better, only to degrade it? Why employ witchcraft and guesswork to redeem this speaker? I suspect that after a few months of listening to his "modified" AR-2ax speakers, Hilary Paprocki will begin to ask himself, "What's wrong here?" Answer: coloration. Referring to his specific modification steps:

1. Refoaming the woofer surrounds is, of course, a great idea, as nearly all speakers built 15 or more years ago with urethane foam surrounds have deteriorated. If the speaker has the earlier Alnico woofer, the surround is cloth, which can be treated with a silicone spray or treatment such as Armoral to soften the surround. You can refoam the speaker yourself if you are careful to align the voice coil properly. Many excellent kits are available.

2. The midrange and tweeter level controls on the AR speakers of that period are wonderful devices when they work properly. They give a complete range of adjustment from full "off" to full "on." Since Mr. Paprocki has elected to solder fixed-value

resistors in place of the level controls, the speakers can only sound balanced in a very few places.

It is true, as Mr. Paprocki states, that bad level controls replicate burned-out tweeters. A combination of oxygen and electricity across dissimilar metals in the level controls causes accelerated corrosion and oxidation, with the result of loss output at one or both drivers. But the level controls can be rebuilt since they are easy to disassemble, and once open can be burnished and polished to like-new condition.

I have done it many times, and in all but the worst cases it works. After you clean and polish them (a Dremel tool is a must), lubricate the controls with WD-40 or other dielectric lubricant. Remember that these controls give tremendous latitude in the output of the midrange/tweeter, and let you set the output for a pleasing and realistic balance, rather than a fixed balance good only for one place.

4. The problem with lowering the woofer/midrange crossover frequency is the flat-response range of the midrange driver will not allow a lower crossover point without distortion or attenuated output. Tampering with the woofer choke will invariably affect its flatness, but since Mr. Paprocki has given up on accurate sound anyway, it doesn't matter. If accuracy and flat output matter to you, then leave the crossover frequency alone.

Incidentally, what is meant by "faster, more agile, more detailed sound" in lowering the crossover? If the drivers were actually "ringing," this might be true, but they don't, and there are no frequency-response perturbations that indicate this problem anyway. If anything, lowering the crossover improves the dispersion while increasing distortion and lowering power-handling of the midrange driver.

5. If you have burned-out drivers (not oxidized level controls causing dropouts), replace them with authentic AR drivers. No one makes better drivers, and no one except AR makes replacement drivers for AR speakers (contact Alex Barsotti, AB Tech Services, 26 Pearl St., #25, Bellingham, MA 02019, 508-966-2201 for AR parts).

6. How will solid, pure copper wire subjectively or measurably improve the performance? The crossover wire is 18–22 ga. stranded copper wire, which is perfectly fine for the 10–20″ runs needed in the crossover. Besides, it is much harder to control solid wire from vibrating in the cabinet than more pliable stranded cable.

7. The out-of-phase wiring of the speaker helps eliminate some driver interaction problems at or near the crossover point; it was not intended to give a "simulated depth in the sound." It really doesn't affect accuracy in the sound field. Close-in or near-field listening might seem more "detailed," but actually represents too much energy close to the crossover points. In any event, these perturbations would probably be swamped in the reverberant sound field where most people listen anyway.

9. Are the eight strands of pure copper going to restore the speaker's original frequency response? Why not spend more time repairing the speaker to its original performance?

11. All but the newest AR-2ax models, with the newer and much higher-density MDF cabinet material, included a great deal of bracing inside the cabinet. But perhaps too much bracing won't hurt; certainly too much is better than too little in this case.

13. The cotton-ball treatment is probably not all bad. Consider that many manufacturers, including AR, used foam around the tweeter flange to reduce diffraction effects. But again, this effect is most noticeable in the near field, if at all, and probably will not affect the reverberant sound field. Using foam (probably 2–4mm thick) is better than the cotton balls since the cotton protrudes so much that it might cancel some of the tweeter's excellent off-axis performance.

So it all comes back to the same question: why not restore the AR-2ax to its original performance? What is gained by proper restoration rather than jury-rigging the speaker? The answer is simple: the AR-2ax was (and is) one of the finer speakers of its class ever made. Even today it holds its own if accuracy and tonal balance are your goals. So why not bring back these redeeming qualities? I am sure Mr. Paprocki intended to achieve improved sound, but it is absolutely certain that he has degraded the speaker compared to its original performance.

Tom Tyson
High Point, NC 27262

Hilary Paprocki responds:

Thank you for the opportunity to further discuss my work with the AR2ax speakers. This actually comes at an especially appropriate time, as I have a few bits of news for potential AR hot-rodders.

*First, my original crossover was the result of a quick spruce-up of what was already there. I have since spent a little more time with it (although I don't claim to have perfected it). The result is a new circuit (*Fig. 1*) that gives a slightly "west coast" sound, with gobs of detail and more transparency than you would have ever expected from these old horses. I'm enjoying that sound very much at the moment. If you'd rather have a more laid-back sound, and maybe someday I might, try decreasing the 6.3Ω resistor across the midrange driver. The reason for the multiples* *of parts in the drawing, by the way, is that I made up these values with the parts I had on hand; feel free to make up the values anyway you please.*

Second, it looks as if the supply of original tweeters for this model has dried up. After finally ordering a replacement for the second blown tweeter, I instead received a similar but not exact replacement job with noticeably different construction and a thin truing of rubbery stuff on the front plate. And it took two tries to get one that worked.

The new one matched the other tweeter pretty well, although I didn't bother to measure acoustic levels. I encourage you, if you wish, to find something a little more modern, keeping in mind, of course, that an appropriate crossover design for the different-sourced driver is completely up to you.

Tom Tyson is obviously a great fan of the original ARs, and genuinely committed to their restoration and preservation. I have some experience with his viewpoint. I once wrote a similarly agitated letter to a car magazine when some guy announced his plans to cut up his super-rare aluminum Studebaker factory race car to make one of those silly "street machines." I despise the destruction of unique, irreplaceable, historic pieces. Why didn't he cut up something ordinary, such as a Corvette?

Anyway, Mr. Tyson ought to realize that his viewpoint is not really the mainstream nowadays. We know that wires and capacitors have specific sound qualities. We know that uncontrolled diffractions ruin the focus of the reproduced sound. And, we know that the engineers working 30 years ago were not gods who perfected everything that ever needed to be perfected.

Mr. Tyson has shown in a couple places in his letter that he is not guided by human judgment of sound qualities. But clearly AR has made some choices in this speaker design that betray the application of the human touch, after the equations have all been satisfied. I hope I didn't imply that the entire design was done by means of some kind of seance.

In any case, I suspect that if the original AR designers were to develop a modern speaker in that same relative price range today, it would sound more like my tweaker AR than like the original AR2ax. I could mention any number of specifics, but let's just talk about the cotton balls. I want to be very clear on this point. Felt, thin foam, and such are primarily symbolic rather than functional when applied to control the diffraction of sound leaving the drivers. A thin, hard piece of felt does not soak up the sound anywhere near the way a big, semi-dense, fluffy cotton ball does. Not even close.

And besides, the protrusion is exactly the point. You need to stop whatever sound energy might hit the edges of the cabinet. To accomplish that, your barrier must be between the driver and the edges of the cabinet. With the cotton, you will still be able to see the tweeter dome from anywhere in the room in front of the speaker; consequently, you will hear it as well. Goshdarn it, all you need to do is think about this a little, and it annoys me that so many people won't.

A few statements in Mr. Tyson's letter seem a little sweeping, a little improbable, a little less than well-considered. I can only infer that he is devout in his regard for the ARs, as some people are for old Garrard turntables or single-ended tube amplifiers, and that this affects his perspective more than most people's fascinations affect theirs. This can be a good thing. The person who finds something worthy of his dedication is often thus saved from the despair that pursues us all, and I wish Tom all happiness and success in his efforts.

JUST DO IT

I suspect that journalism schools teach that contributing editors do not write letters to the boss for publication, but I can't resist commenting on Hilary Paprocki's article on "Resurrecting a Pair of AR2AXs."

It is singularly the most refreshing piece I've read in a coon's age. I am a strong proponent of "listen to the music, not the damn speaker," but in the bulk of the printed word, what I read is a lot of means justifying ends (I confess, my own words included from time to time).

"Tinkering with turn counts on the woofer inductor" until it sounds right is a great way to go through life. Also, every real audio engineer knows that fussing around with nine-dollar-a-foot Litz-like wire inside a loudspeaker box is utterly pointless, but Mr. Paprocki said it more gracefully than any technical article I have read debunking that myth.

Cotton balls around the edge, eh? Incredibly enough, the latest issue of the *Journal of the Acoustical Society of America*, Vol. 96, No. 6, in its patent review section shows No. 5,304,746, which indicates that "...small, fuzzy rectangular blocks...arranged in a pattern near the outer edge of the cone...suppress standing waves...." That quote is from reviewer George Augspurger, who goes on to say "...the patent document includes no theoretical support...."

We hear what we hear. Mr. Paprocki heard what he heard, and unabashedly wrote about it, much to the pleasure of *[nearly—Ed.]* all *SB* readers.

Dick Campbell
Contributing Editor

POWER AMP CHIPS

I would like to add to Ed Schilling's (*SB* 3/94, p. 49) and Timothy Perper's (*SB* 7/94, p. 56) letters about the power amp TDA 1514 IC. I believe that it is originally a Philips IC, as it appears in a June 1989 data book. So your local Philips distributor should be able to source them and provide the spec sheets.

The July/August/September 1993 issues of *Elektor Electronics* included an active 3-way system using the TDA 1514 to power the mid and top. PCBs are available for this project from the UK (and through Old Colony Sound Lab).

National Semiconductor includes a couple of interesting power amp ICs on their list: the LM3875 and 3876. (I can get the spec sheets and the ICs here in Australia, so they can't be that scarce.)

Andy Da Costa
Queensland, Australia

SB CRITIQUE

Is it my imagination or are you cutting down on the number of articles about speakers per issue? Also, are you getting less feedback? I counted 15 letters in *SB* 2/91 and only six in 2/94.

I have enjoyed your publication immensely and although I didn't start subscribing until the late '80s, I have all the issues. In fact, I am rereading them. I have had fun building two sets of speakers based on John Cockroft's articles on Isobaric speakers. Is it possible to rework some of these speaker articles, such as those in which the raw speaker is no longer available? The Radio Shack speakers he recommended in several of his articles have had design/quality changes and don't work with his system.

Ah, yes, now comes a sore spot with me. I am a USPS employee who works in bulk mail. Most publishers, at second-class rates, pay about $.29 to send a 5 oz magazine (about the same as a 1 oz first-class letter). For guaranteed first-class treatment, you need to pay the necessary money. *[With the new postal hike, such first-class treatment would cost almost five times the second-class rate, and the cost to magazine readers would need to increase accordingly.—Eds.]*

On a more cheerful note, the latest issue of *SB* (7/94) was just grand, especially the "Loudspeakers 101" and "Ask *SB*" articles. "Cheap Home Theater" was interesting and the setup was familiar: from side to side on my amplifier and using a 50Ω pot. I read that a while back in either *Stereo Review* or *Audio*. One other area you might consider, without ruffling too many feathers, is the high-end speaker system which uses a 6.5″ woofer and a 1″ tweeter and yet sells for $3,000 or more/pair.

I have had the pleasure of corresponding twice with John Cockroft, and *SB* is the only magazine that responds to my queries. I look forward to each issue.

Hugh H. Rea, Jr.
Traverse City, MI 49684

Thanks for your comments, Hugh. Rest assured that the magazine remains as vibrant today as ever. We see no letup in reader enthusiasm or participation levels. With an increase in frequency from six to eight issues in 1994, SB *featured a dramatic rise in the number of pages we published last year. But more importantly, we think the quality has increased as well.—Eds.*

KLH-9 Power Supply
Continued from page 25

3/16″ below the edge of the box. Dress all wires carefully so no contact is made (remember, 5.7kV).

SECOND HELPING

Replace the rubber stopper *firmly* and put your can of solid potting material into the oven to liquefy. Carefully pour the potting material—when perfectly liquid—into the box (power supply) and fill to about ¾″ from the top. Put the can back into the oven and wait for the initial pour to solidify. Then pour in the rest of the material.

Do not be surprised if you don't have enough. It tends to shrink. If you need more potting material, add enough plumber's wax to return to the original level.

After the mixture is solid, remove the jig. If you have done the job right, it will mate perfectly with the back of the speaker. If you have an electrostatic voltmeter, check the voltages, which should be 1.1kV and 5.7kV.

My friend mentioned that a TV technician's equipment can measure these, but beware of excessive loading, which, although won't damage anything, may give lower voltages. However, your ears should tell you if everything is OK. After you remove the stopper, snap in a plastic plug to seal the hole and act as a floor protector.

Loudspeakers 101

Continued from page 70

Well, several reasons for this exist, many of them are theoretical and many practical. For example, a vented box system is more complex to design and is more sensitive to variations in the driver parameters. We'll explore these and other topics in upcoming issues.

REFERENCES

1. "Direct Radiator Loudspeaker Systems," "Closed Box Loudspeaker Systems," "Vented Box Loudspeaker Systems," and "Passive Radiator Loudspeaker Systems," published in 1972 and 1973 in the *Journal* of the Audio Engineerng Society, New York.

2. The symbol η is not the letter *n*, but the Greek letter *eta*, so the parameter η_0 is pronounced "eta sub 0." That's important if you ever find this on an oral exam or a Jeopardy question.

3. For those interested in the actual numbers, the highest k_η can be for sealed boxes is 2.0×10^{-6}, and for vented boxes, it's about 3.9×10^{-6}, with V_B in liters and f_3 in Hz. k_η is derived by:

$$k_\eta = \frac{4\pi^2\ f_C^3\ V_{AT}\,1}{c^3\ f_3^3\ V_B\,Q_{EC}}$$

and results in a somewhat strange unit of measurement, sec³/liter.

4. This myth is one of the most common in the loudspeaker world. I am constantly debunking this for both readers and paying clients.

5. And this is precisely why some drivers have a combination of Thiele/Small parameters that are optimum for sealed boxes, while others are optimum for vented boxes.

Ask SB

By Dick Pierce
Contributing Editor

SECOND- AND FOURTH-ORDER SPEAKERS

A frequent question appearing in the various audio newsgroups is, very simply, "What is meant by second- and fourth-order speakers?" Just as frequently, someone provides an answer that, while not wrong, is quite incomplete. For example, a reader with the odd moniker "LunaGroup" lunagroup@aol.com wrote:

"These 'orders' refer to the crossover networks in the speakers. A first-order crossover has a gentle 6dB per octave slope with a lot of overlap, a second-order crossover has a little 'steeper' attenuation, 12dB per octave. A third-order has an 18dB per octave slope, and the fourth-order has 24dB per octave."

This is not necessarily true. The speaker system itself exhibits bandpass filter characteristics, and thus the concept of "order" is appropriate.

The notion of order, whether for a crossover or the low-frequency cutoff of a loudspeaker, is, among other things, a characteristic of the mathematics involved in describing the system behavior in the frequency and time domain. As a general rule (and as a gross simplification of such), the order essentially describes the highest exponent found in the terms of the transfer function's denominator, or, in another sense that some may be familiar with, it describes the order of the function.

A first-order equation (in which the highest exponent is 1) describes a first-order filter. For example, the transfer function for a first-order high-pass filter is:

$$G_{(j\omega)} = \frac{s}{s + 1}$$

Like the high-pass function, a second-order equation (exponent is 2) describes a second-order filter:

$$G_{(j\omega)} = \frac{s^2}{s^2 + ks + 1}$$

While this may seem very esoteric and disconnected from reality, the transfer function describes how the system behaves in both the frequency domain and the time domain.

In the context of the original question, in which the person asked about the order of speakers, we are specifically talking about the behavior of the woofer's low-frequency cutoff due to mechanical and acoustical effects. In that realm, the lowest-order is second-order, exhibited by closed box systems. This is the characteristic of a single-resonance system. In the case of a woofer, the interaction of the driver cone's mass with the combined stiffness of the speaker's suspension and the air trapped in the box forms the resonance.

Second-order types have the characteristic of rolling off (eventually or, to use the correct mathematical parlance, *asymptotically*; that is, to approach the *asymptote*, a line with the ultimate slope described by the equation) at 12dB per octave below that resonance. The resonance essentially defines the lowest practical operating point.

A vented box, bass reflex is fourth-order; that is, a double resonance system in which the driver cone mass and stiffness form one resonance, and the port acoustic mass and the cabinet's acoustic stiffness form a second. (See a trend here? The number of orders is essentially the number of resonant systems times two, another good "general" rule.) In this fourth-order model, the ultimate rolloff rate is 24dB per octave.

Another fourth-order type is the so-called simple "bandpass," in which one resonant system, the driver cone mass, and cabinet stiffness, and the other resonant system, the port mass, and the air *in front* of the driver together interact to form a fourth-order bandpass. In this and all bandpass systems, the ultimate rolloff rate *is not* the simple case of the number of orders times 6dB per octave. Rather, it exhibits a rolloff rate of 12dB per octave at the low end and 12dB per octave at the high end. By the way, the same is true of the bandpass section of multiway crossovers: the rolloff rates might be 12dB per octave at the top or bottom, but in reality it is a fourth-order bandpass.

This belies the rule of thumb that the rolloff rate is 6dB for each order. And to completely flummox this rule of thumb, another class of filters called "all-pass" can be high-order, but completely flat. There can be no appreciable effect in the amplitude versus frequency response, but the major effects are seen in the phase or time response of the filter.

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Altec 602D speaker with crossover, as new, $250 + shipping. For spec sheet, send SASE. Pat Paske, Box G, Flint, MI 48507, (810) 603-1500.

Pair Strathearn speakers, $175; Acoustat Spectra 22 (S.L.C. area only), $700; set of Marchand XM-1 24dB crossovers, $25; Shure V15 type V, $85; new Shure N95HE stylus, $10; new Stanton 500/500a, $5; new Shure 681A stylus, $5; new Shure M99E cartridge. Dan Patten, (801) 224-8080 work or (801) 225-8577 home (UT).

Matched MOSFETs for Pass/Thagard A75 amp being made available for second time. Last opportunity. Set includes 37 (two spare outputs) IRF devices. $185 per channel plus $10 shipping ($40 overseas). Prices in US dollars. Delivery about 6/95. Nick Mastrobuono, 2086 Lakeshore, Sarnia, ON N7T 7H6, (519) 542-0964, FAX (519) 481-2731.

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Audio test gear: LCR meter, audio (sine wave) generator; pair good Electro Voice T-35 horn tweeters. David Williams, 1620 San Francisco NE, Olympia, WA 98506, (206) 586-8182 weekdays, (206) 352-7615 eves., FAX (206) 664-2385.

Heathkit intermodulation analyzer, Robert, (602) 458-6072.

Information on Enigma subwoofers, specs of drivers, etc. and any experimentation with dipole subwoofers. Joe McQuade, 25 Seabrook Rd., Stockton, NJ 08559-2004, (609) 397-8315, collect before 11:00 a.m. and eves. (EST).

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THE WESTERN NEW YORK AUDIO SOCIETY was established in 1984 for the purpose of offering those people interested in the hobbies of music appreciation, stereo components, etc. the opportunity to meet other individuals who share similar interests. For further information regarding our organization, please write to The Western NY Audio Society, PO Box 312, N. Tonawanda, NY 14150, Atten: Denny Fritz.

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Ad Index

Loudspeakers 101

DRIVERS AND SYSTEMS

By Dick Pierce
Contributing Editor

Now that we've discussed the parameters of loudspeaker systems, it might be a good time to move on to some fundamentals about loudspeaker *systems*. Being very specific about the meaning, we define *system* as the combination of the loudspeaker driver and its enclosure. We'll explore two of the most popular types of loudspeaker/enclosure systems: sealed box (also sometimes known as acoustic suspension) and vented box (bass reflex, ported, and even passive radiator speakers).

Richard Small, in his landmark series on low-frequency loudspeaker theory,[1] established a relation between just a few fundamental parameters that led to a very powerful understanding of these systems. Called the maximum efficiency-bandwidth-volume relation, it's described by a very simple equation:

$$\eta_{0(MAX)} = k\eta\ V_B f_3^3$$

In this equation, $\eta_{0(MAX)}$ is the maximum reference efficiency,[2] the amount of electrical power that's actually converted to sound; V_B is the volume of air inside the box; and f_3 is the speaker system's low-frequency cutoff, or –3dB point. The remaining parameter, k_η, the so-called *efficiency constant*, is a very important value that we'll talk about later.

EFFICIENCY GAIN

This relation tells us that, simply, the bigger we can make a box, the more efficient the speaker *can* be; or, the lower the frequency, the lower the efficiency *must* be. An inefficient speaker with a high cutoff frequency (little bass) can be very, very small. But a high-efficiency speaker with a very low cutoff frequency must be very, very large. And, of course, this is true only if *all other things are equal*, which they need not be.

The efficiency constant, k_η, determines how the other three parameters must fit together. And k_η itself is dependent upon several factors: the ratio of the driver compliance volume (V_{AS}) to the box volume (V_B), the ratio of the driver's resonant frequency (f_S) to the system cutoff frequency (f_3), and the ratio of the system electrical Q (Q_{EC}) to the system total Q (Q_{TC}). And, in a somewhat complicated fashion, these depend very heavily on whether the box is sealed or vented. Our efficiency *constant*, it would seem, isn't so constant after all.

The efficiency constant (k_η) for vented boxes is about twice as much as for sealed boxes.[3] This has some very important implications. For example, imagine two loudspeaker systems with the same box volume (V_B) and cutoff frequency (f_3), and one is an optimized (from an efficiency standpoint) sealed box, while the other is a similarly optimized vented box. The efficiency of the vented box will be twice (3dB greater) that of the sealed box.

DEBUNKING THE MYTH

Now, before we all start adding vents to our sealed boxes to gain 3dB of efficiency, let me tell you that it won't work. A common myth is that the presence of the vent doubles the efficiency of a system. And that intuitively makes some sense, because we might think that "more sound" can come out of the port. Besides, the efficiency constant is twice as much, so *it must work*, right?[4]

Wrong. If we simply add a vent to a sealed box speaker, the response of the system will change, and the ratios between some of the critical parameters, such as f_S and f_3, will change enough to completely cancel everything out, so that the efficiency remains the same. In fact, the efficiency of the driver essentially determines the efficiency of the system. And even though we now have a new hole in our cabinet, the driver is the same, so the efficiency is the same. The frequency response in the low end has changed dramatically, probably for the worse.

Instead, we learn from this that given two cabinets—one sealed and one vented, both the same size, with the same cutoff frequency target for both systems—the vented box system can use a driver whose efficiency is twice as high as the driver for the sealed box to achieve these design goals. But to do so, the vented box speaker usually must have a larger magnet system, among other things.[5]

Well, you might ask, why can't we simply put that more efficient driver in the sealed box and increase its efficiency? Remember that our efficiency constant (k_η) depends upon many factors, including the electrical and total Qs of the system and the cutoff frequency (f_3). Even if everything else (such as the driver mass and compliance) is equal, this more efficient driver, with its necessarily lower Q_{ES}, will result in the system having the same resonant frequency. Because of the now lower system Q (Q_{ES}), the system response will be damped, and the cutoff frequency will now move higher in frequency, about one-third octave, to be precise.

DESIGN COMPROMISES

Let's explore the major trade-offs we can make between closed and vented box systems using the bandwidth-efficiency-volume relation:

- If we keep the efficiency (η_0) and the box volume (V_B) the same, the cutoff frequency (f_3) of a vented box can be one-third of an octave lower than a sealed box. That's the difference, for example, between 40 and 32Hz.
- On the other hand, if we keep the cutoff frequency and the efficiency the same, the box volume of a vented box system can be one-half that of a sealed box system. This could be the difference between a sealed box that's 12″ × 8″ × 24″ and a vented box that's 9½″ × 6-3/8″ × 19″.
- And, as we saw before, if we keep the box volume and the cutoff frequency the same, then the efficiency of a vented box system can be twice that of a sealed box system.

In fact, we can have several trade-offs at once, making a system a little bit smaller, a little bit more efficient, and a little lower in frequency.

But one implication in the relation for both sealed and vented boxes is always a constraint: high efficiency and low frequencies require big boxes, and there is no way around this simple fact. If you need to lower the f_3 of either a sealed or vented box system by one octave from, say, 40 to 20Hz, you are forced to build a cabinet that's *eight* times the volume (because, remembering the relation, the frequency term is *cubed*). If you wish to design a system that's twice as efficient, you'll need a box *twice* as big.

Even still, it seems that, all around, the vented box system is a winner. It can be smaller, more efficient, or have lower bass. Why on earth would anyone bother with a sealed box? After all, companies such as Acoustic Research enjoyed no small measure of success selling sealed box loudspeaker systems.

Continued on page 65

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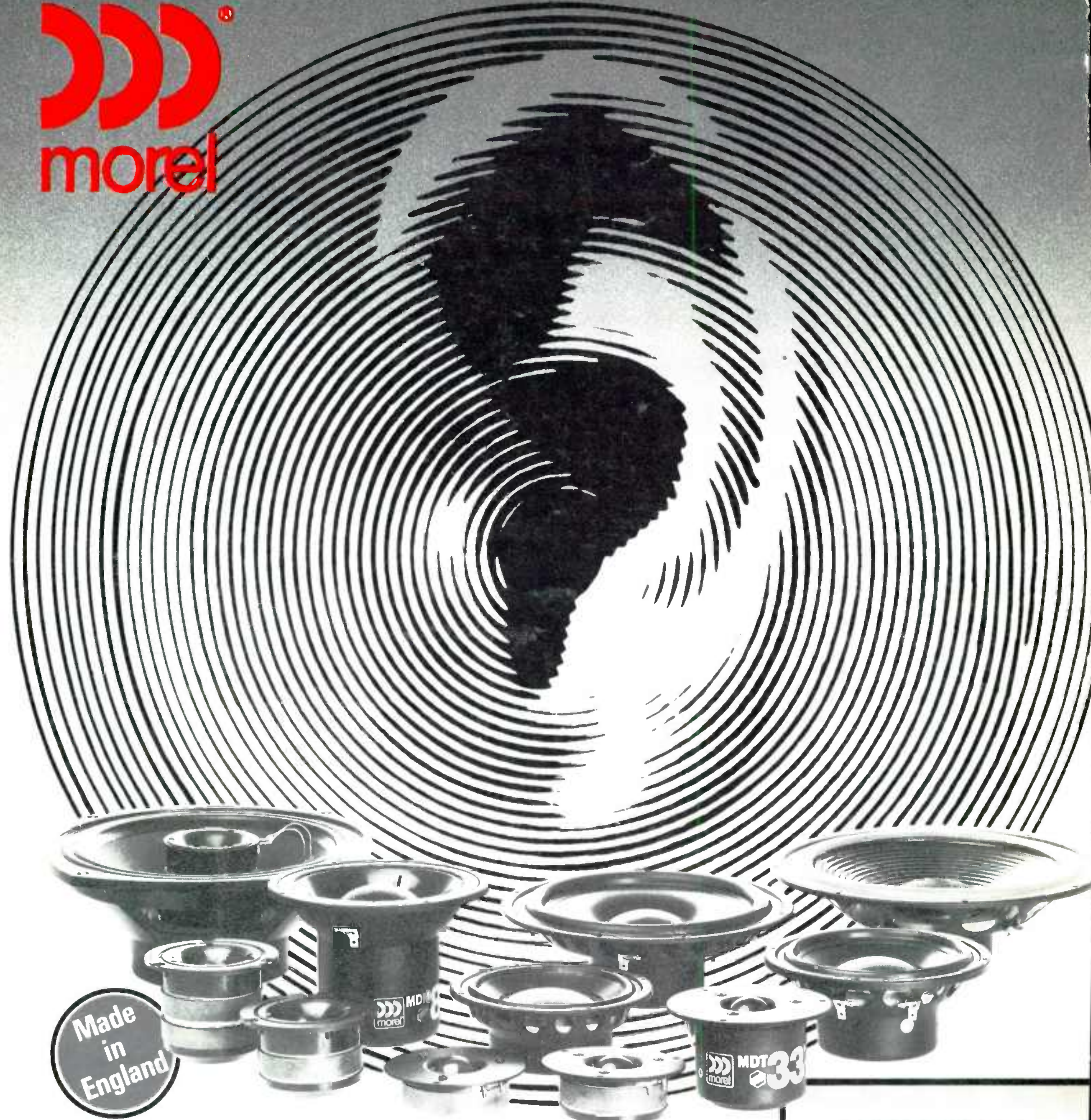

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