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Speaker Builder

THE LOUDSPEAKER JOURNAL

SNAIL III
BUILD A BIG HORN IN A SMALL BOX
BILL FITZMAURICE

TEST DRIVE
AUDAX'S A652 MTM-KIT
HILARY PAPROCKI

LAB MEASUREMENTS
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DESIGNING HIGH-ORDER FILTERS WITH MINIMUM PHASE
TIM SANDRIK

BUILD A POWERED SUB WITH METAL CONE

DICKASON TESTS A TASTY DANISH 8″


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Reader Service #6

Good News

➲ HONORABLE TOWER

Westlake Audio recently received the following three awards in Japan for The Tower HR-7: Best Overseas Component Award (from *Swing Journal*), 1997 Components of the Year Award, and the Hi-Fi Grand Prix Award (from *Stereo Sound*). You may choose one of two crossover systems: the two-way MRX-2 designed specifically for optimizing bi- or triamp operation, or the four-way HR-X for powerful active quadamp operation. The sculpted cabinet is available in a variety of hardwood veneer finishes, brown or black grilles, gold hardware and WBT inputs, and more. Westlake Audio, 2696 Lavery Ct., Unit 18, Newbury Park, CA 91320, (805) 499-3686, FAX (805) 498-2571, Website http://www.westlakeaudio.com.

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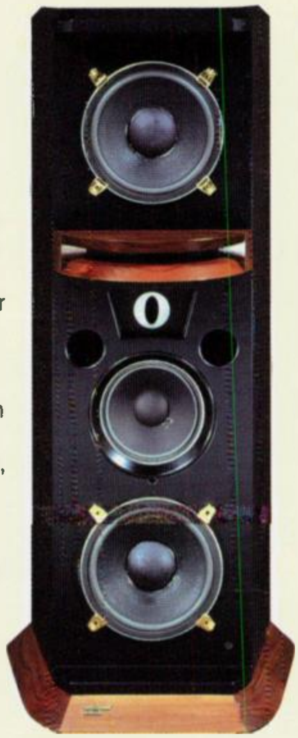

➲ FLAT SPEAKERS

NCT Audio Products, Inc., introduced the Gekko™ flat speaker product line for home theater and home audio. They are less than 2″ in depth and are framed in wood cabinets, which are available in three sizes (9″ × 11″, 11″ × 14″, and 18″ × 24″). You can wall-mount or customize them with the company's ArtGekko™ collection of printed speaker grilles and replacement frames. Options include replacing the grille with one of hundreds of print selections. Custom options also include a wide selection of replacement frames which you can hang over the standard speaker frame so that it becomes virtually invisible. Frame choices include polished wood in blonde, natural, cherry, maple, oak, walnut, and black, as well as gold and pewter. Noise Cancellation Technologies, Inc., 1 Dock St., Ste. 300, Stamford, CT 06902, (203) 961-0500, FAX (203) 348-4106, Website www.nct-active.com.

Reader Service #134

■ ESL DESIGN

InnerSound recently launched Eros, a hybrid electrostatic (ESL) loudspeaker system. It features electronic crossovers, 400W bass amp, transmission-line bass loading, and an ESL midrange/tweeter. Eros includes a pure dipole radiator for precision imaging and transient response, and a separate chassis for the amplifier and electronic crossovers. InnerSound, Inc., 1875 Mitchell Rd., Ste. E, Mableton, GA 30126, (404) 696-1998, FAX (404) 691-1411, Website www.innersound.net.

Reader Service #138

■ COMBAT VIBRATION

Dynamic Control's patented sound-damping material, Dynamat, is a thin, lightweight, yet effective sound-damping agent, designed to absorb and convert noise-causing vibration into a silent, low-grade thermal energy. According to the company, by converting this energy, Dynamat combats the negative effects of vibrational noise, improving acoustics. Dynamic Control, 3042 Symmes Rd., Hamilton, OH 45015, (800) 225-8133, FAX (513) 860-5095, Website www.dynamat.com.

Reader Service #139

■ EDGAR'S HORNS

The System 60T from edgarhorn utilizes a full-range 6.5″ Tannoy driver in a Voigt tapered pipe enclosure, which provides bass response from 100Hz down to 50Hz. The company also presents the 35Hz Horn Sub Seismic System. This 18″ PAS woofer and horn provide bass extension and realism with low distortion and quickness. With a 50–100W amp such as the optional NHT subwoofer amp, the company claims you can hear and feel shock waves from some of the Telarc and Sheffield CDs. You can also use the horn sub for home-theater applications. edgarhorn, 22113 S. Vermont, Torrance, CA 90502, Voice/ FAX (310) 782-8076.

Reader Service #136

About This Issue

When he's not touring on the road with his band, musician and speaker designer **Bill Fitzmaurice** enjoys listening to the latest in his folded-horn series in the quieter confines of his living room. He meticulously details how you can construct this tower-style design ("Snail III," p. 8). Be sure to stay tuned, because more Snails are (slowly) on the way.

You don't have to sacrifice power, response, and range in a minimum-phase design. Loudspeaker researcher **Tim Sandrik** offers driver-selection tips and shows us several high-order filters that make minimum phase practical ("Minimum Phase, High-Order Filtering," p. 16).

We are pleased to present a reprint of an article from the German publication *Klang&Ton*. "A Powered Subwoofer" (p. 22) details how you can hook up a high-quality, affordable subwoofer from RCM Akustik to your system.

The best speaker system improperly positioned can produce disappointing results. **Bohdan Raczynski** presents the second installment of his look at loudspeaker placement ("Computerized Loudspeaker Placement, Part 2," p. 34). His simple application of FEM reveals places to avoid: the nulls of the room resonant modes, for example.

Kit builders will want to check out **Hilary Paprocki**'s efforts in assembling the Audax A652 loudspeaker kit ("Test Drive," p. 38). The completed system, tested by **Joe D'Appolito**, promises high-quality performance for a reasonable price.

Vance Dickason focuses the driver spotlight in this issue on Peerless's 8″ woofer, the CSX 217 H ("Driver Test," p. 30).

Industry insider **Mike Klasco** continues his series on speaker components with a look at the structure and function of the voice coil ("Trade Secrets," p. 58).

Paul Szabady reviews an interesting work that takes a look at how we respond to music (*Music, the Brain and Ecstasy*, "Book Report," p. 60).

Speaker Builder®

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

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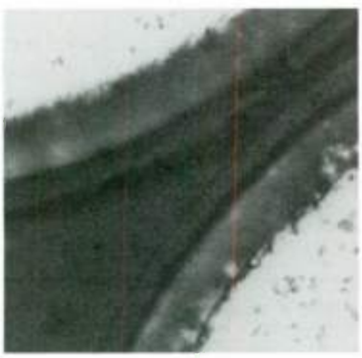

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SNAIL III

By Bill Fitzmaurice

The first two cabinets in my Snail folded-horn series were live-performance models. For those of you who desire a folded horn's advantages in a cabinet that fits comfortably into the average listening room, Snail III is an answer.

Unlike traditional horns, which are usually very large and boxy, this cabinet is a "tower" style. It visually resembles a transmission line, though its 100dB/W average efficiency with a usable low-end frequency of 32Hz outperforms any TL, or any other design in a 4ft^3 cabinet. Also unlike traditional horn cabinets is the MTM mid- and high-frequency driver alignment, providing imaging that is beyond the capabilities of traditional horn-loaded cabinets.

SMALL IS BETTER

Snail geometry, which loads the horn throat with both the driver front wave and port output, allows for a very small horn length and mouth area, far smaller than traditional horn theory predicts will perform to low frequencies. The response graphs reflect corner of room placement; mid-wall placement will result in a 3–6dB reduction in sensitivity below 80Hz.

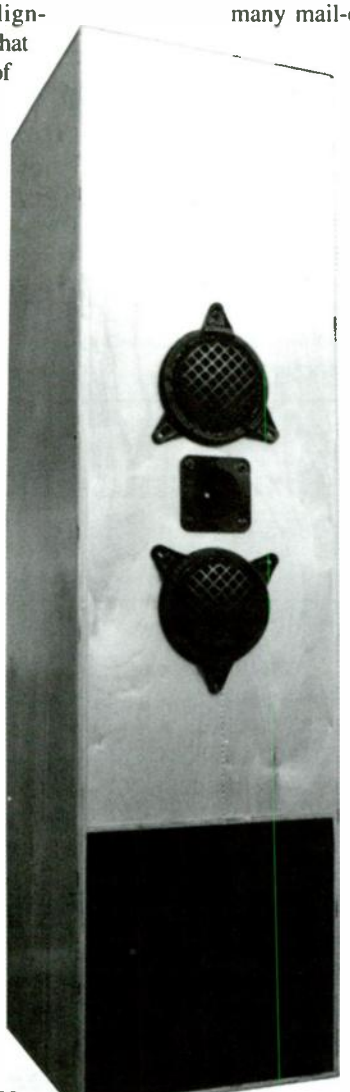
The MTM array's fairly low height off the floor may require you to tilt back the cabinets somewhat so that the tweeter axis is aimed at the listener's head; when so aimed, the apparent "center channel" blooms quite nicely. Driven by a 50W-per-channel amp, this puts out a solid 110dB/1m even when equalized for flat response down to 42Hz. Note also that to take into consideration the cabinet's 5Ω average impedance, the frequency-response graphs are done with an input of 2.0V, instead of the usual 2.83V for an 8Ω load.

This is a very loud speaker, in spite of its 60W rating. Best of all, this level of performance is achieved with very inexpensive drivers; as described, you can build it for less than $200. Using more utilitarian materials (MDF, particleboard, or the like), the cost could be as low as $125.

The woofer is an 8″ Pioneer dual voice coil, model #B20FU20-52D, available from many mail-order houses for about $25. Each coil is rated at 6Ω, which normally would give 3Ω when parallel wired. However, horn loading raises the average impedance to 6Ω. You may use instead any good-quality 8″ driver with an f_s of less than 40Hz, a Q_{TS} of less than 0.25, and either dual 6 or 8Ω voice coils wired in parallel, or a single 4Ω voice coil.

The midrange drivers are also Pioneer, #B11EC80-02F, widely available for about $15 each. Two drivers wired in parallel deliver adequate efficiency to keep up with the horn-loaded woofer and tweeter. You may use other midranges providing they can run down to 500Hz and have a sensitivity at 8Ω of 93–95dB.

The tweeter is a Radio Shack model, stock #40-1278, about $15. Nominally rated with 98dB efficiency, this tweeter will actually put out 110dB/W near its 5kHz crossover point, which is compensated for in the crossover. A different tweeter would require a specially optimized crossover.



The completed Snail III.

CABINET CONSTRUCTION

The cabinet is constructed with 3/8″ and ½″ Baltic birch panels. Since it was a prototype, I did not go to great effort or expense on the exterior finish, using waterbase urethane. I butted the joints and fastened them with 1″ paneling nails, puttying over the heads on the exterior joints, and used drywall screws on joints inside the box. You could use an exterior shell of particleboard or MDF, either veneered or painted for a truly utilitarian look.

The self-bracing design of the cabinet makes it rock solid, even with ½″ plywood panels, though you may use thicker materials if you wish. All joints are secured with

TABLE 1

PARTS LIST

All parts are cut from materials as noted in text. Dimensions may have to be altered to compensate for different material tolerances or substitutions. Part letters and numbers indicate the corresponding circled part locations on *Figs. 1, 2, 3*, or *4*.

A. Horn brace	36″ × 6″ (Pattern cut from same stock as back brace; two copies also required—see text.)
B. Sides	47″ × 12½″ (2)
C. Chamber back	24″ × 12″
D. Front	35½″ × 12″
E. Chamber top	3 5/8″ × 12″
F. Mouth plate	5″ × 12″
G. Baffle	10″ × 12″
H. 45° throat reflector	3½″ × 8″
I. Horn plate 1	7 7/16″ × 12″
J, K. Top and bottom	13″ × 13″
L. Horn plate 2	39″ × 11 15/16″
M. Back	47″ × 13″
N. Lower reflector brace	5½″ × 10″ (3)
O. Baffle center reflector	10″ × 2″
P. Baffle wing reflector	12¾″ × 2″ (2)
Q. Horn-plate center reflector	7 7/16″ × 2″
R. Horn-plate wing reflector	8¼″ × 2″ (2)
S. Upper curved reflectors	11 15/16″ PVC (2)
T. Lower curved reflector	13″ × 11 15/16″
U. Back brace	36″ × 8½″
V. Duct	2″ PVC: 2 3/8″ diameter, 7″ long
1. Pioneer woofer	
2. Pioneer midranges	
3. Radio Shack tweeter	

either woodworking glue, hot-melt glue, or construction adhesive, as noted. *Table 1* is the parts list, with the capital letter for each part referencing its location on *Figs. 1–4*.

Construction begins by laying out the horn-brace/back-brace pattern, which you cut from ½″ plywood, 37″ × 9″. Draw a line across this piece ½″ from its top, followed by a series of mutually parallel lines at 4″ intervals, with the final one ½″ from the bottom (*Fig. 1*). Measuring from the left edge, make marks on these lines, from the topmost to bottommost, at 2 5/16″, 2 9/16″, 2 7/8″, 3¼″, 3¾″, 4 3/8″, 5 1/16″, 5 15/16″, 7″, and 8 7/16″. Drive a 1″ brad into the plywood at each of these points.

Now, from a sheet of 3/8″ plywood, rip a strip 40″ × ½″ and place it on the plywood, bending it against the brads and securing it in place with more brads (*Photo 1*). Trace the curve formed on both sides of the strip, remove the strip and the brads, and on a bandsaw cut along both lines. Trim ½″ of material from both the top and bottom of the resulting back brace, and a full inch from the top of the horn brace (*Photo 2*).

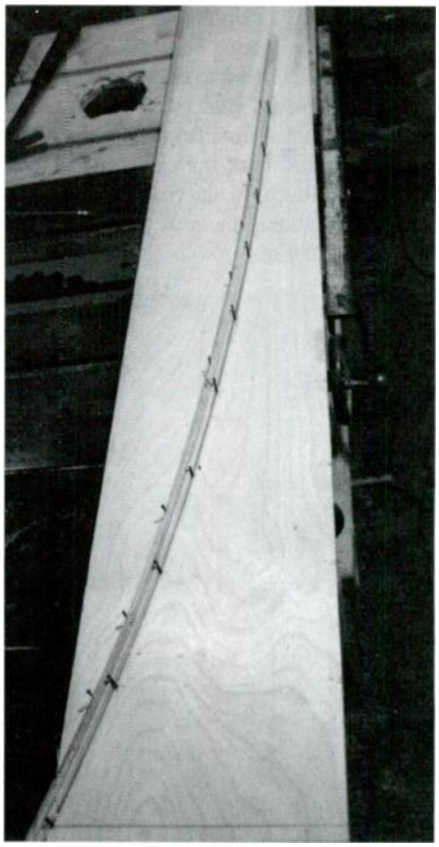


PHOTO 1: 40″ × ½″ plywood strip in place on plywood and secured with brads.

Cut the sides, and draw on them the locations of all parts, mirror image to one another, according to *Fig. 1*. Trace the locations of the horn and back braces from the patterns. All panels are ½″ plywood except horn plate 2, which is 3/8″ plywood to facilitate bending, and the cabinet front, also made of 3/8″ plywood, since it is not subjected to any acoustic pressure.

PIECE INSTALLATION

Install the chamber back first; note that the lower end of this piece is cut at a 30° angle where it intersects the horn point. After attaching it to one side, you join the chamber top to it, and then attach the baffle, horn plate 1, and the mouth plate. Note that you must cut the driver hole and install the "T" nuts for driver mounting on the baffle prior to assembling the parts (*Photo 3*). Chamfer the baffle hole from both sides, using a ¼″ radius rounding bit.

Next, install the throat reflectors (*Fig. 4*), starting with the four pieces over the baffle. Cut the ends of the outer reflectors at a 15° angle where they join the chamber top, as well as the opposite ends where they are curved. You make these cuts by tilting the bandsaw table or angling a sabre saw.

Likewise, when you're cutting the 45° reflector, compound angles are involved where it joins the outer reflectors. Since a precise fit is not easy to achieve here, glue these parts with construction adhesive to fill gaps on the joint lines. The reflectors attached to horn plate 1 are also cut with compound angles.

You can safely cut the ends of the plate reflectors to the required 82° angle only by using a tablesaw equipped with either a taper or panel-cutting jig (*Photo 4*). Again, fill the joints of the reflectors with either construction adhesive or hot-melt glue for void-free joints (*Photos 5* and *6*).

You cut the upper curved reflectors from 4″ PVC

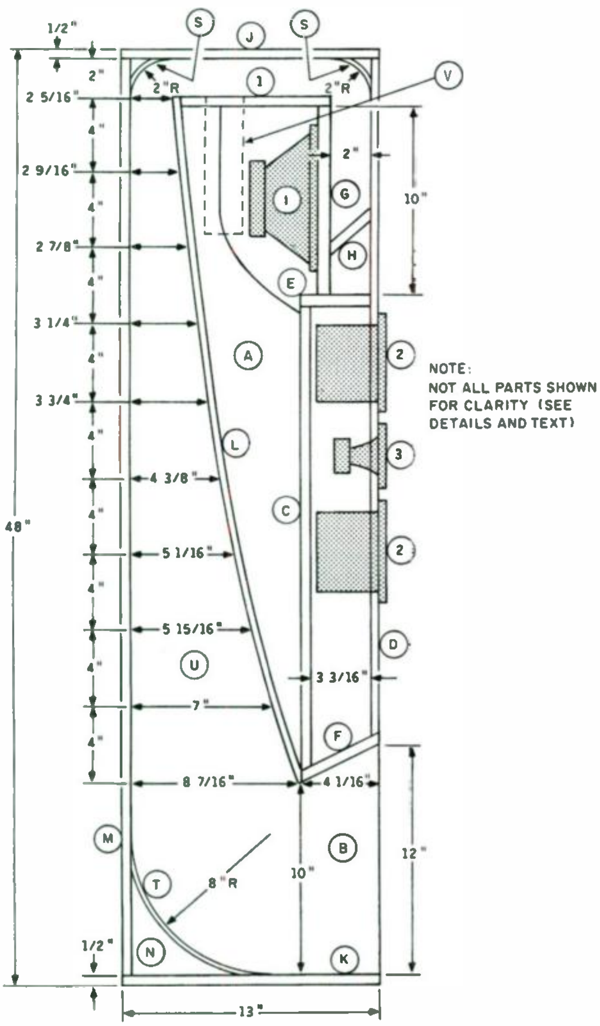


FIGURE 1: Side view of Snail III; for clarity, not all parts are shown.

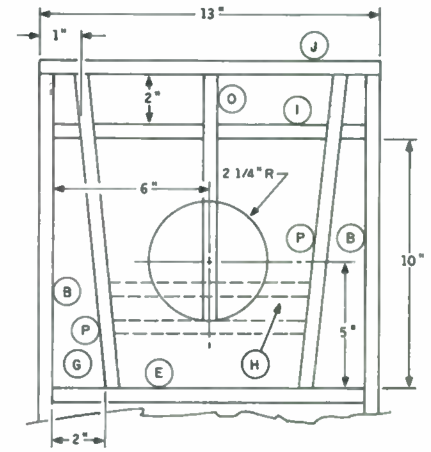


FIGURE 2: Front view of baffle, with cabinet front removed.

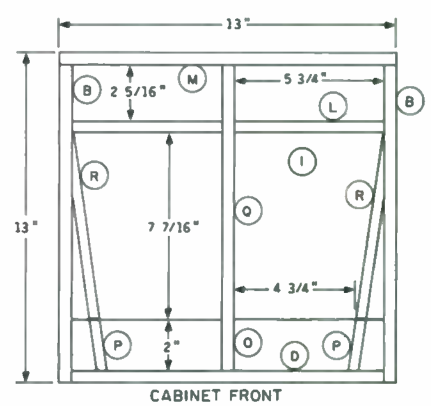


FIGURE 3: Top view of cabinet with top removed.

drain pipe that is rip-cut on a table saw to yield 2″-radius pieces. Take the 3/16″ thickness of the material into consideration when cutting the curved ends of the throat reflectors so that when installed they will fit flush against the inside of the cabinet front, top, and back. Attach the curved parts with hot-melt glue, holding them in place for a few minutes until it sets (*Photo 7*).

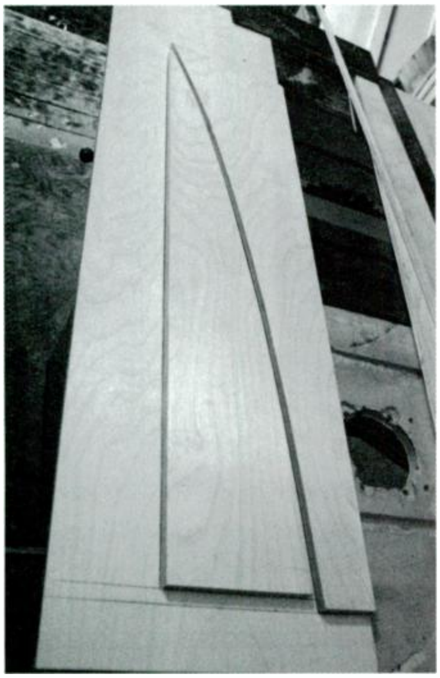


PHOTO 2: Back brace and horn-brace pieces.

ACCESS PORT

Cut two more horn braces from either ¾″ plywood or pine stock, or from 5/4″ pine, tracing them from the original horn brace and trimming them so they are 1½″ wide. Where the original horn brace extends over the driver, you must trim it so it clears the driver.

On one side of the cabinet, cut the opening for driver access. This hole should be approximately 4″ × 10″, with its flange rimmed by the horn brace and scrap pieces of plywood or pine. Be absolutely sure that you are able to fit the driver through the flanged access hole. Assuming you are building two cabinets, place the access ports on opposite sides of their respective cabinets, so the wiring runs on the wall side of each.

Attach a horn brace to the side, and attach the original horn-brace pattern to the baffle and chamber back. Sprinkle some contractor's chalk dust on the tops of the baffle reflectors. Now put the cabinet front in place and rap on it smartly with your fist to get a chalk impression of the reflectors on its inner side, showing where to drill pilot holes for nails (or screws, as the case may be). If necessary, sand down the reflectors and chamber top for proper parts alignment, and attach the cabinet front, using construction adhesive for filling the gaps where the front meets the curved piece and the reflectors (*Photo 8*).

Now attach the second side to the assembly, and the remaining horn brace to it. Next install horn plate 2, using construction adhesive and 1¼″ drywall screws every four inches. First secure this at the joint with horn plate 1, pulling it gradually into place with long clamps until you can fasten it to the mouth plate. You should cut this part a bit long, and sand off the selvage after the glue has set. There is no practical way of testing the cabinet for air-tightness after assembly, so make sure all joints are liberally caulked with construction adhesive.

GLUE, NOT SCREW

The back brace is next, glued in place with construction adhesive. You cannot use screws here, since there is no access to the inside of the chamber. Lay the cabinet on its face and clamp a couple of pieces of scrap

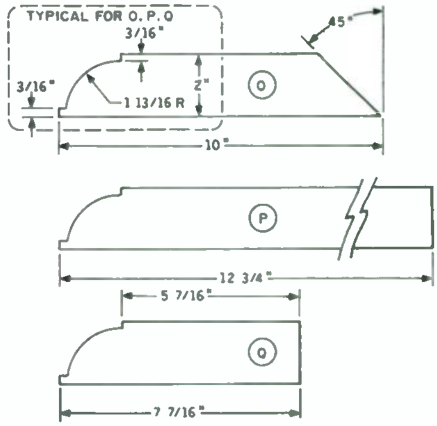


FIGURE 4: Horn throat parts: baffle center reflector; baffle wing reflector; and horn plate center reflector.

wood across the cabinet back to hold the brace in place while the adhesive sets. When it's cured, attach the remaining curved reflector, again using hot-melt glue at all contact points (*Photo 9*).

Using the chalk technique, locate and drill pilot holes through the back where it will join the back brace, and then attach the back. With a hole-saw, drill a hole to accept the duct in horn plate 1, locating the duct on the opposite side of the cabinet from the access cover. The duct is a piece of 2″ CPCV 7″ long, secured in place with hot-melt glue. Place a straight edge across the cabinet top to make sure no reflectors are too high, sanding as necessary before chalk marking.

Now drill pilot holes and attach the top, again with construction adhesive for void filling. Next, attach the bottom, and to it and the back the three lower reflector braces. Cut these braces from either plywood or pine stock, using a compass to draw on them arcs of 8 1/8″ radius (see *Photo 5*); adding the 1/8″ thick reflector results in a final reflector radius of 8″.

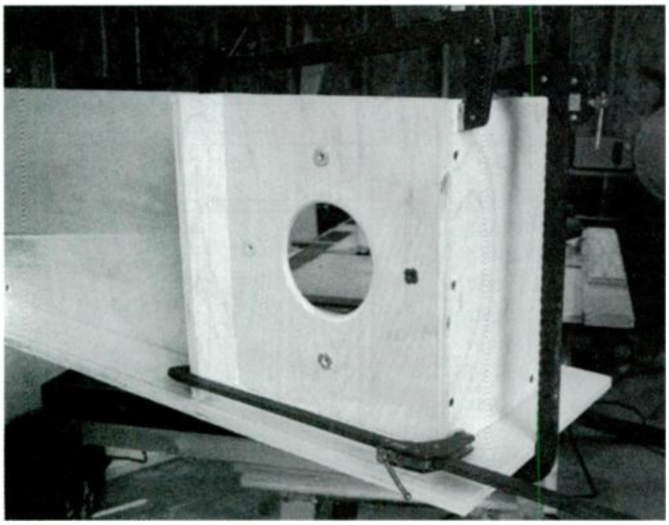


PHOTO 3: Driver hole and T-nuts installed on baffle.

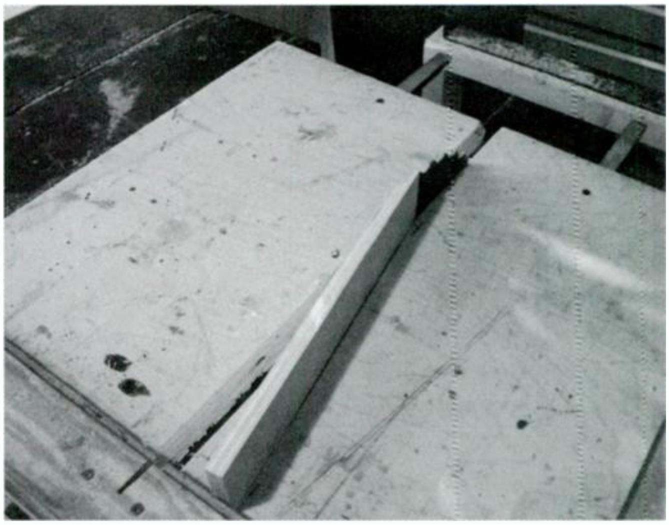


PHOTO 4: Cutting a plate reflector's ends.

Swans M2 kit

High sonic resolution
Loudspeaker
with room friendly performance

The Swans M2 is a floorstanding model that features several technological achievements and sound quality distinctions.
The speaker system is a two-way bass-reflex design with MTM driver configuration. The front baffle is very narrow with rounded edges to reduce cabinet diffraction for better clarity and imaging. The internal panels and corner reinforcement bars substantially suppress unwanted cabinet vibrations. The bottom part of the cabinet is sealed and can be filled with sand or lead shot for better stability and further performance improvement. A port is mounted on the rear panel.
The drivers used in the Swans M2 represent a new high performance design from Hi-Vi Research. The 5-inch paper/Kevlar cone bass-midrange has a rubber surround, cast aluminum frame and a magnetically shielded motor system. This driver utilizes a central phase plug to avoid air compression, improving frequency response and dispersion. The extremely rigid cone is hand coated with a special dampening compound to further maximize its performance. The cone is coupled to a selected grade rubber surround, this provides break-up free operation and very low distortion even at high power levels. These key features greatly contribute to the Swans M2's clear transparent sound and effortless dynamic performance. Swans M2 delivers amazing bass without ruining in "doubling" or Doppler distortion problems.
The tweeter is a high-tech planar isodynamic design that employs Neodymium magnets and extremely light Kapton® film, with flat aluminum conductors.
The vibrating element of the tweeter is almost weightless in comparison to a conventional dome driver. This unit provides an immediate and precise response to any transients in original signal, and gives the Swans M2 an exceptional ability to reveal the true dynamics of instruments with a complex high frequency spectrum.
The crossover is a second order Linkwitz-Riley type resulting in an in-phase connection of the drive units. The crossover frequency between the two drivers is 3.3 kHz and only high quality polypropylene capacitors are used. Each filter has it's own dedicated board mounted on a special rubber interface to reduce vibrations and microphonic phenomenon. The filter boards are spaced inside the loudspeaker with the inductors positioned at right angles to minimize the interaction.
Swans M2 provide very even acoustic power dispersion. The important horizontal early reflections that create spatial impression and add to the overall presentation have the same even spectral balance as the direct sound, these are crucial features of a good loudspeaker.
On the contrary, the vertical dispersion is well controlled in the midrange and high frequency domain in a 15° arc symmetrically to the reference axis. While 15° create adequate room for adjusting a listening position, the floor and ceiling reflections are well down in amplitude. This feature greatly contributes to the clarity of sound and imaging of the system.
Swans M2 kit includes:
- 4x F5 paper/Kevlar bass-midrange drivers,
- 2x RT1C isodynamic tweeters with sealing gaskets,
- 2x dedicated tweeter crossovers,
- 2x dedicated bass-midrange crossovers,
- two ports and two Swans logos,
- two pairs of heavy-duty gold plated terminals.

Cabinets are not included.
For those who are interested in a home theater set up, the instructions and parts for correspondent central channel speaker are available.
The drawings of the cabinet shown here represent general dimensions required for optimum bass performance. Rounded corners are advisable as they improve imaging and clarity. Actual finish and appearance is a matter of personal taste. The system should be installed on adjustable spikes and slightly tilted back to aim tweeter axis at listening position.
Retail price: US$ 530.00 (delivered)
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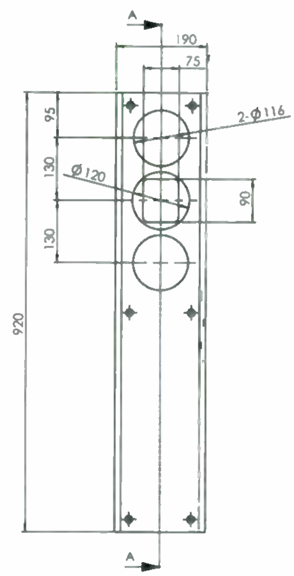
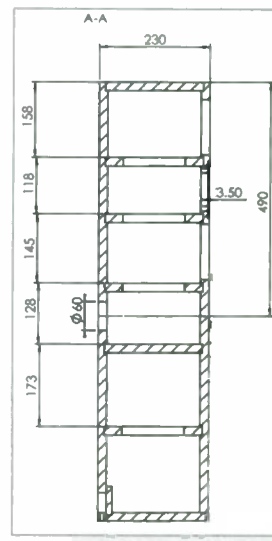
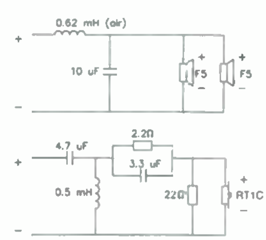
RT1C Tweeter F5 Bass-midrange Filter







SPECIFICATIONS

Frequency response (1m,half space)	53Hz-20kHz,±2.5dB
Sensitivity,1W/1m (100Hz-8kHz averaged)	87.5 dB
Nominal impedance	4 ohms
Harmonic distortion At 90dB SPL, 100Hz-10kHz, 1m	THD less than 1%
Power handling	80W nominal, 150W music
Dimensions,HxWxD (without spikes)	920x190x230 mm 36 1/4x7 1/2x9 inches

Amplifier requirements:
30W recommended minimum.

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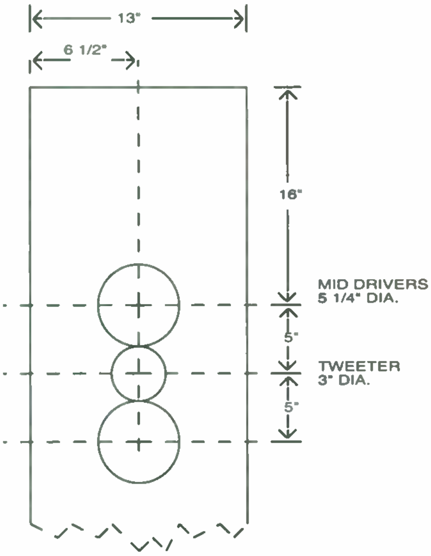


FIGURE 5: Front view of midrange and tweeter locations.

You can fashion the lower reflector from 1/8″ plywood, masonite, or a piece of plywood-backed wall paneling. Glue it in place with construction adhesive, using drywall screws to pull it to the braces; be careful to use shorter screws at the joints with the back and bottom so as not to go through them.

With a router or belt sander, or both, true all the exterior joints and round off all corners to a ¼″ radius. Using a hole saw or a jigsaw, cut the midrange and tweeter mounting holes (*Fig. 5*), and then finish the cabinet with urethane, paint, or veneer as desired.

WIRING

In the access cover, cut a hole large enough to accept your choice of binding posts, using a plywood backing piece (*Photo 10*). Drill holes through the access cover and mounting flanges for bolts and "T" nuts, and weatherstrip the flange for an airtight seal. Drill two holes from the inside of the driver compartment to the mid-tweeter chamber, and run a hookup wire through each, marking them as to driver assignment and polarities, and sealing the holes with hot-melt glue.

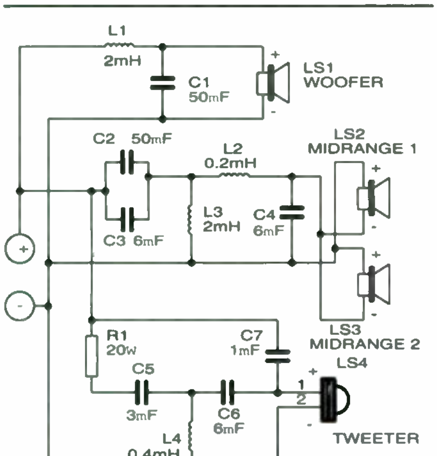


FIGURE 6: Crossover schematic.

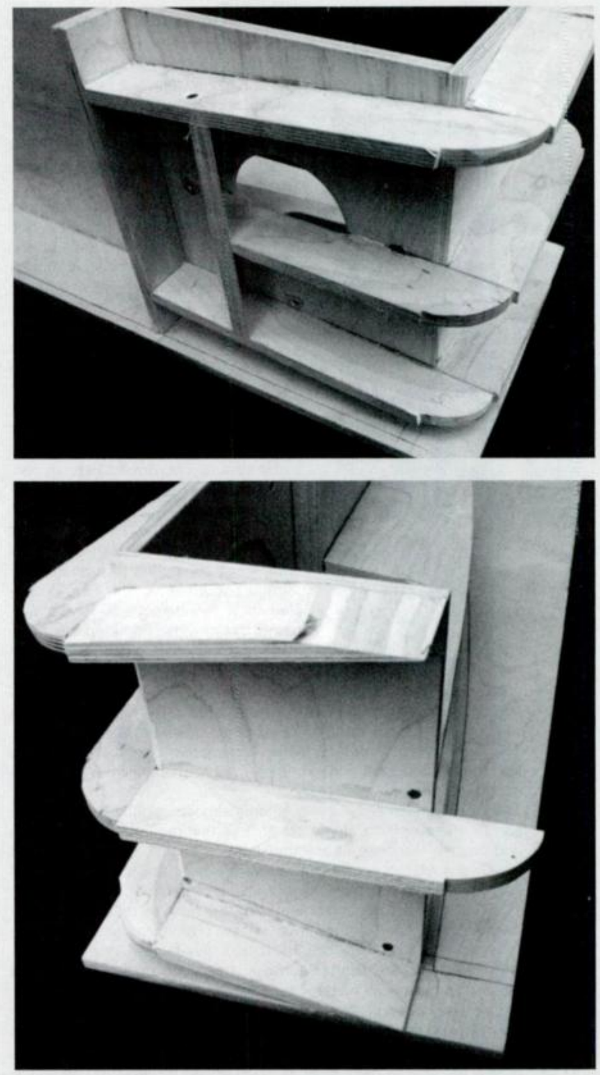
Wire the tweeter and screw it in place. The midranges need a second piece of wire when you hook them in parallel—making sure of polarity—before you screw them to the cabinet and install protective grilles. Loosely stuff polyfill in the lower part of the woofer chamber (behind horn plate 2). Wire the woofer, pass it through the access hole, and bolt it in place.

You may install the crossover coils and caps (*Fig. 6*) on the inside of the access cover, attaching them with hot-melt glue. The woofer uses 12dB low pass at about 500Hz, the midranges a 12dB bandpass, and the tweeter an 18dB high pass at 4kHz. Since the woofer's response is rolled off above the crossover point by the folded horn, no Zobel is required. The tweeter's very high efficiency near the crossover point is attenuated by the 20Ω series resistor, while its decreasing sensitivity above 10kHz is compensated for by the 1µF cap that bypasses the resistor.

Pay close attention to driver polarities: the woofer and tweeter are wired in phase with each other, the midranges out of phase with respect to the other drivers. Failure to wire the midranges out of phase will result in major response dips at the crossover points with both the woofer and tweeter.

For crossover components, electrolytics will do for the 50µF caps, but all others must be high-quality polys or Mylars. Air-core coils will suffice for all except L1, which must be a high-quality bar core with less than 0.5Ω resistance. An air-core coil of 1Ω or more resistance will cause an insertion loss of up to 2dB on the woofer.

When wiring is complete, loosely stuff some more fiberfill in the upper woofer



PHOTOS 5 AND 6: Construction adhesive filling the reflectors' joints.

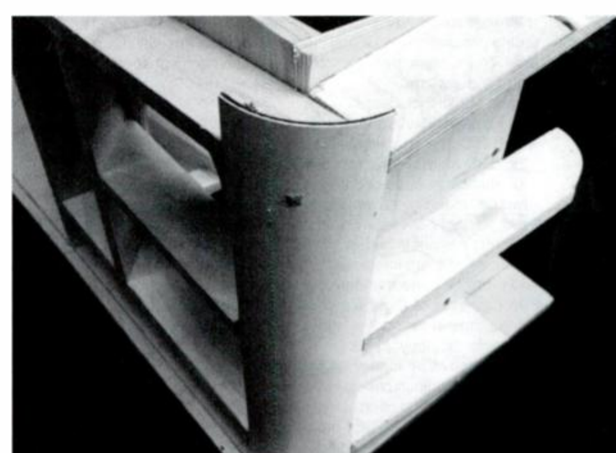


PHOTO 7: Attach the curved reflectors with hot-melt glue.

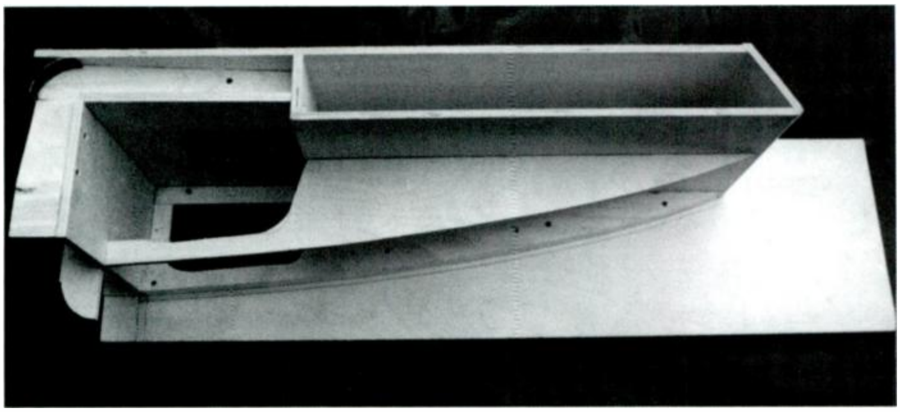


PHOTO 8: The cabinet front attached, showing where it meets the curved piece and the reflectors.

chamber, bolt the access cover in place, and test the airtightness of the cover seal by feeding the cabinet with some heavy-material bass, or a low-frequency test tone.

THE SOUND

The most obvious characteristic about the sound of this cabinet is how much louder it is than a non-horn-loaded box when A/B comparisoned with the same signal input. Also, it is clear that in the lower register it actually sounds differently, even when adjusted for equal-volume output.

Bass guitar and kick drum have more impact, with a real "in your face" sensation. This probably is due to the driver's being hardly stressed at all, while the ultra-efficient horn loading transforms very small cone movements into high sound pressure levels.

The response graph (*Fig. 7*) plots the sensitivity of Snail III, comparing it to the idealized prediction of the woofer's performance in an optimally tuned T/S box. The additional average of 8dB gained above 100Hz would in itself be impressive, but it is the range below 80Hz where the Snail's port-loading of the horn throat really shines, giving better relative performance the lower it goes. At 32Hz, the Snail III is fully 25dB higher in output than the T/S model. You can equalize this cabinet to give flat response with high output from 32Hz to 18kHz, making a separate subwoofer unnecessary.

The impedance graph on *Fig. 7* shows that the horn loading keeps the woofer's average impedance at 6Ω, double the driver's nominal load. The horn's passband starts at 64Hz, indicated by the impedance dip at that point, while the dip at 28Hz denotes the frequency of the ducted chamber (without the horn, the box frequency would be 32Hz).

Unlike either closed-box or ducted cabinets, there are no significant "peaks and valleys" on the impedance graph, indicating a very smooth loading of the driver. That the cabinet performs to full efficiency only down to 100Hz is due to the horn's length and mouth-area limitations.

Theoretically, you could continue the horn's expansion to arrive at a cabinet capable of +100dB efficiency all the way down to 64Hz. This would, however, result in a very large cabinet, one capable of power levels beyond any home's needs—which is precisely why I plan to build one, just to see what it can do. Don't let your subscription lapse—there are more Snails to come!

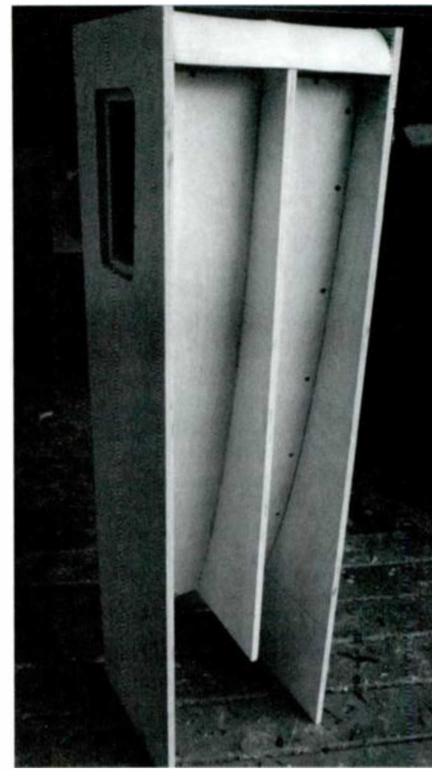


PHOTO 9: The curved reflector attached with hot-melt glue.

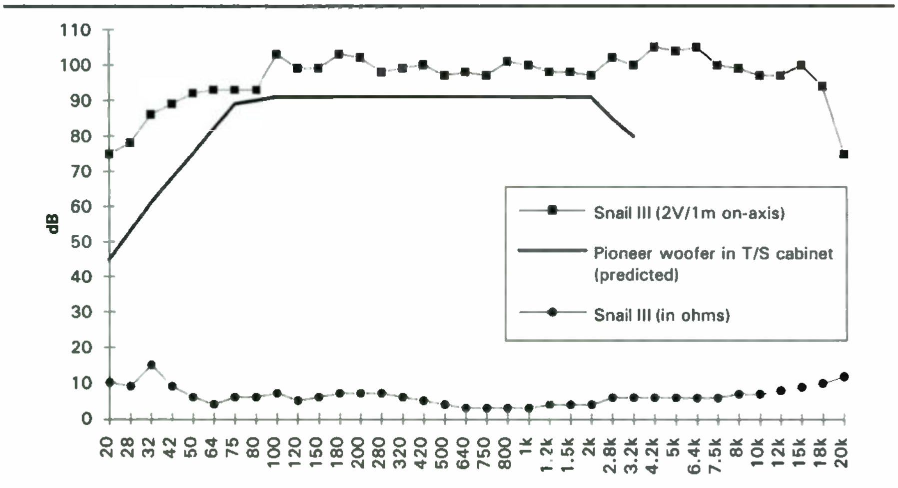


FIGURE 7: Frequency response.

PHOTO 10: Binding posts installed in the access cover.

MINIMUM PHASE, HIGH-ORDER FILTERING

By Timothy E. Sandrik

There are many instances where it is desirable to have the benefits of both a minimum-phase and a high-order system. When selecting drivers, proponents of minimum-phase systems must be careful to ensure adequate power handling and manageable frequency response at the extremes of and outside of the driver's frequency range.

In many cases, this eliminates minimum-phase design as an affordable option, but you *can* build a minimum-phase system using high-order filters. This enables you to do the following:

1. Improve the dynamic range of an already good minimum-phase design;
2. Use tweeters you might not normally consider because of high resonance or low power handling;
3. Use drivers with rough or peaky response beyond the desired crossover point.

Numbers 2 and 3 above may result in less expensive systems by allowing you to use cheaper drivers, or drivers that are otherwise excellent, but generally used in high-order systems, such as some metal-cone midranges.

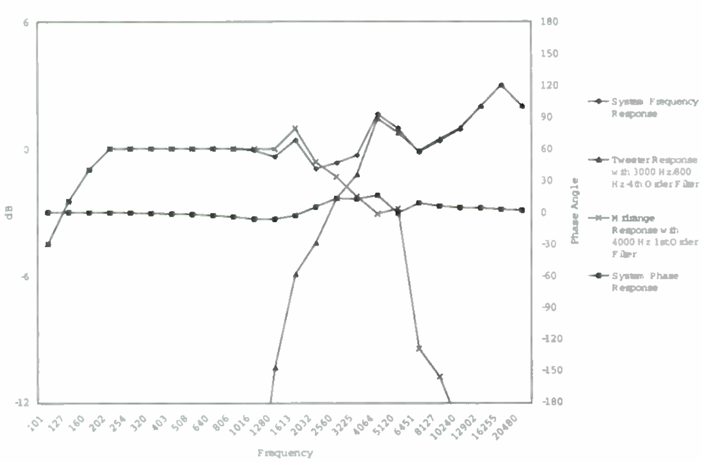


FIGURE 1: System response with a first-order rolloff.

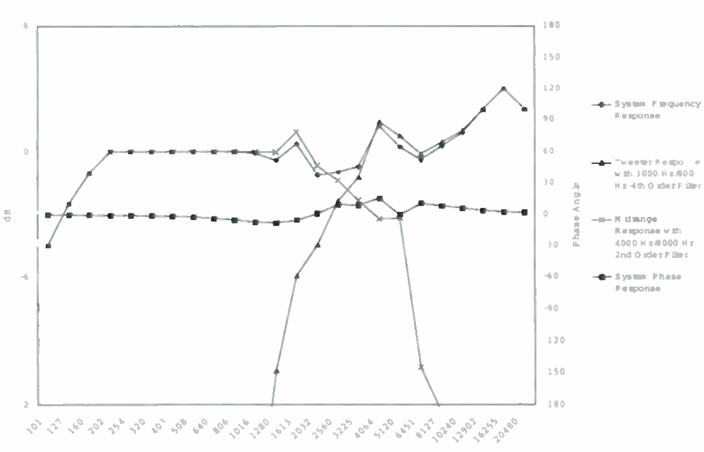


FIGURE 2: Increasing the slope to second-order above 10kHz provides minor equalization.

DESIGN EXAMPLES

In this article, I will present design examples with several affordable drivers, namely, the Focal Access 5A and 6A, and the Orca T1 tweeter. The driver responses I use are rather arbitrary, but working with realistic responses demonstrates that the theory works in real-world situations. I obtained the system frequency-response and phase-response data from modeling acoustically time-adjusted drivers in an infinite baffle with a point of summation 120″ from the tweeter center.

For two of the examples (*Figs. 1* and *2*), which I believe are excellent overall designs, the components for realizing the filter responses appear in *Table 1*, and a schematic diagram is provided in *Fig. 3*. *Figure 4* is a plot of the responses of the drivers used in the examples (response data is from manufacturers' data sheets).

The summation of two signals depends on the magnitude and phase of each. If one is significantly stronger than the other, it will have more effect on the sum. In the crossover region, two drivers usually have similar amplitudes, and introducing a high-order phase shift into one or both will result in a phase shift in the sum.

Figure 5 shows the frequency and phase responses of a typical two-way configuration. In this design example, I applied a first-order filter to the Access 5A midrange at 4kHz. The Orca T1 has a high resonance at 1.55kHz and average power handling (50W), so I used a fourth-order filter at 3kHz, and reversed the driver's polarity for good blending. (In each example with the Access 5A and Orca T1, the center of the 5A is 5″ below the center of the T1.)

Figure 6 shows a second design example, with first-order filters applied to the 5A and T1 drivers. The purpose here is to demonstrate a design with frequency-response characteristics similar to those of the previous example, but with minimum phase shift in the summed response. The remaining examples use high-order filters on one or both drivers. Each exhibits a frequency response similar to the first two examples, and a minimum phase response similar to the second example.

PROTECTING THE TWEETER

Since tweeter power handling and over-excursion often make inexpensive minimum-

ABOUT THE AUTHOR

Tim Sandrik is a proud graduate of Michigan Technological University, where he was an officer and member of the AES Student Section for two years. Tim is also a founding member of the 306WD Engineering Team. He is currently employed at Klipsch, LLC, where he is involved in professional and consumer loudspeaker research and development.

Reader Service #35 →

Swans M3 kit

The Swans M3 is a floorstanding model which represents evolution of our Swans M1 minimonitor. Along with technological achievements and sound quality distinctions of M1 model, Swans M3 features two W6 drivers with SMD type magnet system resulting in extended and undistorted low bass reproduction.
The speaker system is a three-way bass-reflex design with rounded cabinet edges for better clarity and imaging. The internal panels and corner reinforcement bars substantially suppress unwanted cabinet vibrations. A port is mounted on the front panel. It has a large flared opening for smooth transition from the port to cabinet boundaries. This provides linear bass performance and absence of port noise. The heavy-duty gold plated binding posts are mounted directly on the rear panel to enable easy cable connection. The M3 is shielded to provide a safe placement in a close proximity to A/V systems.
The drivers used in Swans M3 represent a new high performance design from Hi-Vi Research. The 6.5-inch woofers have filled polypropylene cone with rubber surround, cast aluminum frame and SMD type magnet system. SMD magnet system provides lower distortion and higher power handling then a conventional design. The 5-inch paper/Kevlar cone bass-midrange has a rubber surround, cast aluminum frame and a magnetically shielded motor system. This driver utilizes a central phase plug to avoid air compression, improving frequency response and dispersion. The extremely rigid cone is hand coated with a special dampening compound to further maximize its performance. The cone is coupled to a selected grade rubber surround. this provides break-up free operation and very low distortion even at high power levels. These key features greatly contribute to the Swans M3's clear transparent sound and effortless dynamic performance.
The tweeter is a high-tech planar isodynamic design that employs Neocymium magnets and extremely light Kapton® film, with flat aluminum conductors.
The vibrating element of the tweeter is almost weightless in comparison to a conventional dome driver. This unit provides an immediate and precise response to any transients in original signal, and gives the Swans M3 an exceptional ability to reveal the true dynamics of instruments with a complex high frequency spectrum.
The crossovers are based on a second order Linkwitz-Riley type resulting in an in-phase connection of the drive units. The crossover frequencies are 3.3 kHz and 250 Hz. Each filter has it's own dedicated board mounted on a special rubber interface to reduce vibrations and microphonic phenomenon. The filter boards are spaced inside the loudspeaker with the inductors positioned at right angles to minimize the interaction.
Swans M3 is designed to provide very even acoustic power dispersion. The important horizontal early reflections that create spatial impression and add to the overall presentation have the same even spectral balance as the direct sound, these are crucial features of a good loudspeaker.
On the contrary, the vertical dispersion is well controlled in the high frequency domain in a 15° arc symmetrically to the reference axis. While 15° create adequate room for adjusting a listening position, the floor and ceiling reflections are well down in amplitude. This feature greatly contributes to the clarity of sound and imaging of the system.
Swans M3 kit includes:
- 4x W6 woofers,
- 2x F5 paper/Kevlar bass-midrange drivers,
- 2x RT1C isodynamic tweeters with sealing gaskets,
- 2x dedicated tweeter crossovers,
- 2x dedicated bass-midrange crossovers,
- 2x dedicated woofer crossovers and two Swans logos,
- two ports and two pairs of heavy-duty gold plated terminals.

Cabinets are not included.
For those who are interested in a home theater set up, the instructions and parts for correspondent central channel speaker are available.
The drawings of the cabinet shown here represent general dimensions required for optimum bass performance. Rounded corners are advisable as they improve imaging and clarity. Actual finish and appearance is a matter of personal taste.
The system should be firmly installed on adjustable spikes.
Retail price: US$ 960.00 (delivered)
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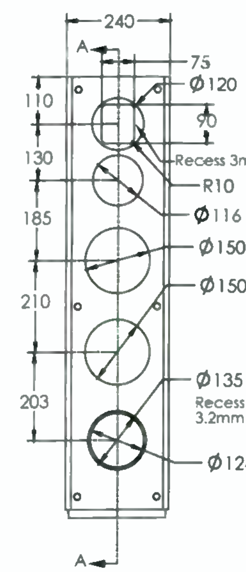
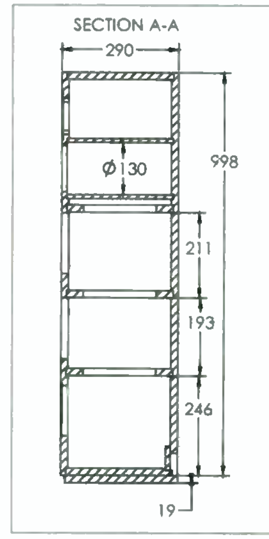
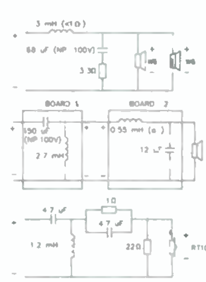
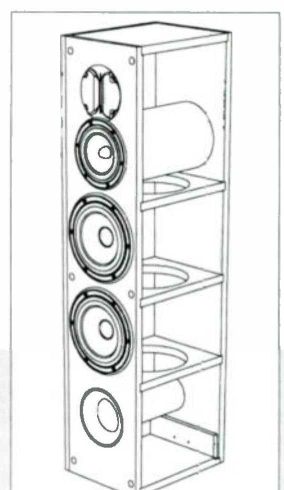
W6 Woofer


Filter









SPECIFICATIONS

Frequency response (1m,half space)	46Hz-23kHz, ±2dB 35Hz-40kHz (-6dB)
Sensitivity,1W/1m (100Hz-8kHz averaged)	88dB
Nominal impedance (3.5 ohms minimum at 300 Hz)	4 ohms
Harmonic distortion At 90dB SPL, 100Hz-10kHz, 1m	THD less than 0.8%
Power handling	120W nominal, 250W music
Dimensions,HxWxD (without spikes)	1020x240x290 mm 44x9½x11 inches

Amplifier requirements:
30W recommended minimum.

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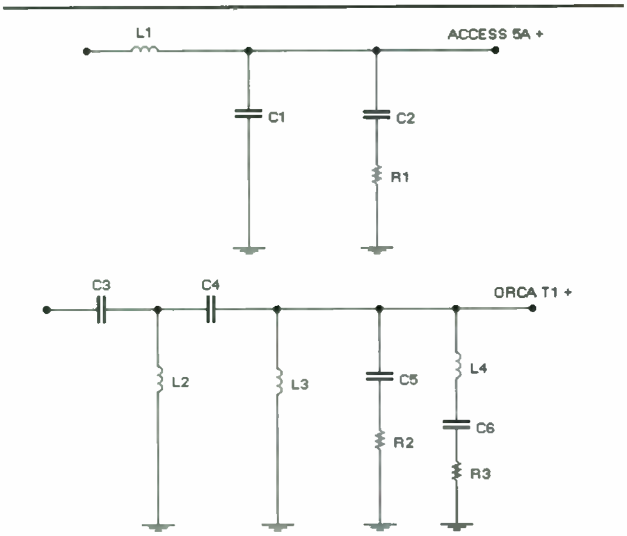

FIGURE 3: Schematic diagram.

phase designs impractical, the third design example involves protecting the T1 tweeter while maintaining good system frequency and phase responses. This minimum-phase, high-order design can handle two to four times the transient power of the previous first-order example, and can manage almost twice the continuous power.

Figure 1 is the response of the system with a first-order rolloff beginning at 3kHz, which grows steeper to fourth-order around 800Hz. You can see there is little change in the frequency or phase response from the example described in *Fig. 6*. The additional phase shift in the lower tweeter response at 1kHz has served to slightly reduce the small peak the midrange contributes to the total response, thus equalizing it.

In this third example, I applied minimum-phase, high-order filtering to the midrange as well. Two of the various benefits of this application are:

1. To reduce the energy driving high-frequency resonance(s) and cone breakups outside of the midrange's passband;
2. To equalize the on-axis system response. Recall that an out-of-phase signal can cause minor cancellation in the system response. *Figure 2* illustrates how increasing the slope of the midrange filter to second-order above 10kHz provides minor equalization to the total response just above the crossover response, where the tweeter has a bump.

You should consider crossover "formulas" as guidelines useful in understanding theory and finding a place to start. Rather than publish formulas, which may mislead you to believe that one easily calculated answer is the only correct one, I provide some guidelines here. The best loudspeakers are designed with endless tuning and retuning, so the foregoing design examples, the following definitions and guidelines, and a design walkthrough should provide a place to start.

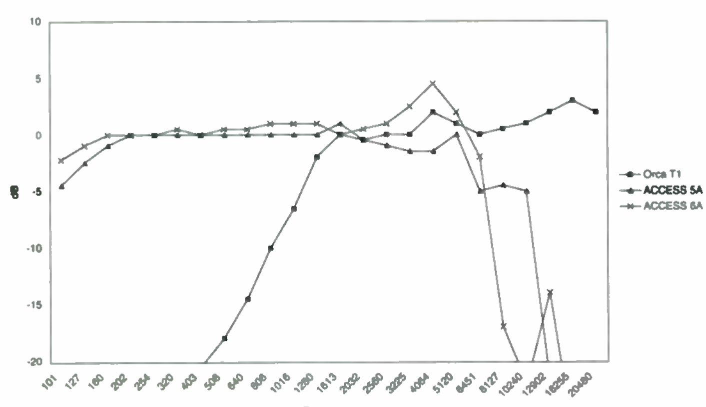

FIGURE 4: Driver responses.

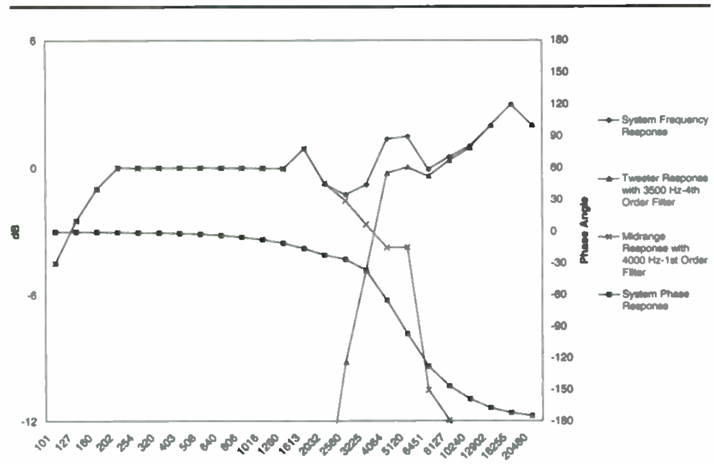

FIGURE 5: Frequency and phase responses of a typical two-way configuration.

TABLE 1

COMPONENTS REALIZING FILTER RESPONSES

DESIGNATOR	FROM *FIG. 1*	FROM *FIG. 2*
C1	Not used	0.68μF
C2	10μF	10μF
C3	10μF	10μF
C4	20μF	20μF
C5	2μF	2μF
C6	20μF	20μF
L1	0.22mH	0.3mH
L2	1.5mH	1.5mH
L3	2mH	2mH
L4	0.8mH	0.8mH
R1	4Ω	4Ω
R2	6Ω	6Ω
R3	10Ω	10Ω

DEFINITIONS

Final slope: the maximum slope of the filter response. A filter that begins a first-order rolloff and then grows steeper to fourth-order has a fourth-order final slope.

f_3: the crossover −3dB frequency or first-order roll-off point.

f_{fs}: the point where the slope grows steeper to the final slope.

GUIDELINES

1. The f_{fs} should occur n octaves away from the f_3, where n = 1 for second-order (final slope), n = 1.5 for third-order, n = 2 for fourth-order, and so on. If you are interested in equalizing a system response, then moving the f_{fs} slightly closer to the f_3 will provide cancellation to equalize the response. If you expect the system response to be weak around crossover, due to particular driver responses, you might wish to move the f_{fs} farther away from the f_3.

2. Fourth-order is typically the recommended final slope for high-pass filters intended to protect a tweeter. Even higher-order does not offer significantly more protection and becomes very costly, while lower-order offers significantly less protection. I recommend that you always use a filter with a steep final slope as a high pass on a tweeter. Useless excursion and voice-coil heating only increase distortion.

3. Use minimum-phase, high-order filtering as necessary for low-pass filters. In most cases, low-pass filter shape will more directly affect radiation pattern; so, while there is potential for improv-


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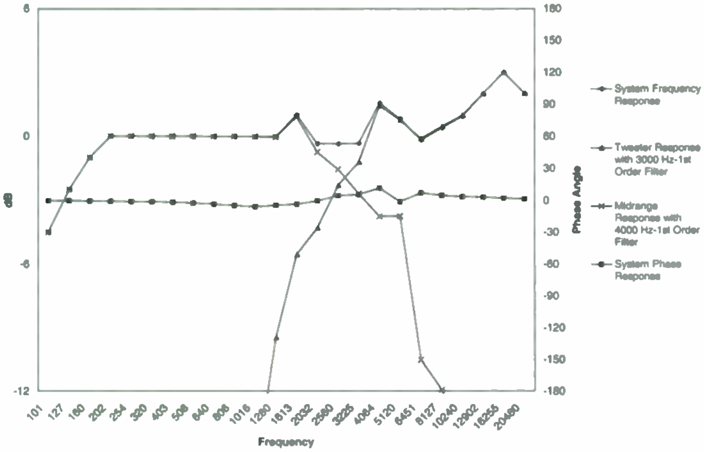

FIGURE 6: A design example illustrating first-order filters applied to the 5A and T1 drivers.

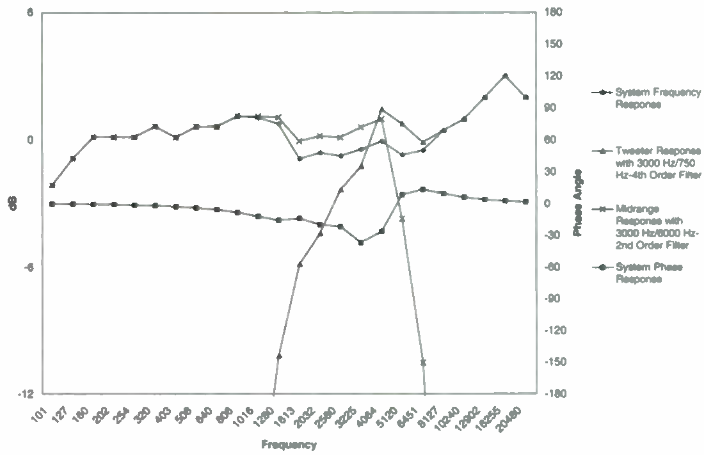

FIGURE 7: The on-axis system response for the starting point.

ing a speaker—including its radiation pattern—a good understanding or tweaking is more critical for low-pass implementation. Second-order is typically recommended for the final slope.

DESIGN WALKTHROUGH

Step 1: Choose drivers, configuration, and crossover point. For this example, use the Access 6A and the Orca T1 tweeter. Place the center of the 6A 6″ below the center of the T1. The crossover point will be 3kHz.

Step 2: Apply the guidelines to find a starting point. Both the woofer and tweeter have first-order slopes that begin at 3kHz. Following the guidelines, the woofer's slope increases to second-order at 6kHz, and the tweeter's slope increases to fourth-order at 750Hz. *Figure 7* shows the resulting on-axis system response for the starting point.

You can see that the frequency response is fairly flat and the phase response is also good. I was unable to tweak the design to my satisfaction using simple filters, so further steps are omitted, since filter optimization is not the focus of this article.

The ideas I present here are not new, and to those with mathematical background or experience with filter optimization, the conclusions must seem rather obvious. Even so, it is not often that you read of a design featuring filters of this type. Following the simple guidelines may allow more freedom in choosing drivers for minimum-phase systems, since more system power handling is possible, and you can reduce peaks outside of a driver's passband.

More experienced designers may use these techniques to equalize on-axis response, or to tweak radiation pattern and directivity. The design examples described in *Figs. 1* and *2* represent tweaked designs with optimized on-axis frequency and phase response, and smooth horizontal and vertical radiation patterns. Of these two, the design represented in *Fig. 2* has a slightly smoother radiation pattern. You might need to make minor adjustments to component values due to variations between drivers, or to add components to compensate for diffraction loss.

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A POWERED SUBWOOFER

(Translated and reprinted from the German loudspeaker magazine, Klang & Ton, *3/97.)*

By Bernd Timmermanns

Ideally, a subwoofer should accomplish two things: reproduce rich, deep bass, and support high volume levels. In a price-conscious setup, however, both goals cannot be accomplished simultaneously—you must compromise on at least one of them. This article emphasizes deep bass, rather than volume.

THE SPEAKER

The speaker chosen for this project includes a 175mm driver from RCM Akustik with rich design details that make it ideal to use as a subwoofer (*Photo 1*). For example, the 25mm moving coil is 20mm in length, so inside the 6mm-deep air gap, it's able to move 7mm in either direction before it reaches the limits of linear excursion.

The voice-coil casing has several openings, making drilled vent holes behind the dustcover unnecessary. The central spider also sports perforations to make use of the air volume behind it. The smart engineering of this construction reduces mechanical losses to a minimum, and its performance is more akin to that of a high-quality speaker whose basket behind the spider is opened up and has a phase plug installed.

The cone membrane of the RCM-17 is made of aluminum—an important step up from paper or polypropylene. Curiously, the basket is made of plastic, but the performance of this speaker construction is still far superior to that of a cast-iron/paper combination.

SURROUND SOUND

This subwoofer offers another interesting engineering detail: behind the main magnet structure is a compensatory magnet that pushes back the magnetic dispersion field as far as possible. Tests in the *Klang & Ton* (*K&T*) laboratories showed that you can place the subwoofer within 20cm of a number of different television sets without causing distortion or Gaussian blurs. This includes those with Sony Trinitron systems, which are notoriously sensitive to magnetic interference. Since that minimum distance is maintained by the speaker enclosure itself, this subwoofer is ideal for home-theater applications, even if placed directly under your TV set.

COMPUTER SIMULATION

Exploring the applications of the 17cm aluminum driver via computer simulation reveals that the subwoofer is best housed in a bass-reflex speaker enclosure with a volume of 45 ltr. This extends the response down to an attention-getting maximum of 32Hz (–3dB). It will also fit in a 35-ltr enclosure, but the maximum response then will be limited to 37Hz and result in a slight overemphasis in the midrange frequencies. (Speaker measurements are shown in *Figs. 1–5.*)

The frequency amplitude of the membrane shows that the large casing does not mechanically strain the driver. At 1W and 50Hz, the amplitude is 1.7mm; the smaller, 35-ltr enclosure reduces the maximum amplitude only slightly to 1.6mm. Simple calculations produce the following maximum values: at 30W, the speaker produces 102dB SPL.

There is a safety reserve above this limit because the membrane can move another 6mm in or out before the moving coil exceeds limitations and results in suspension distress. At this point, you would reach 107dB and need to be concerned about both mechanical and thermal overload. (More technical data is shown in *Table 1.*)

MAXIMUM DEEP BASS

The subwoofer is good for 102dB–105dB. That's a lot for a 17cm speaker to accomplish, especially when it extends down almost to 30Hz. A 50W amplifier is sufficient to get the performance you wish. That's why *K & T* decided to use the RCM Akustik Detonation! DT105 subwoofer module (see description at the end of this article). Although this module is especially economical at a price of 279 German marks (DM) ($149 in the US) it still comes nicely equipped with an automatic power-on feature, a phase switch, and an electronic high-pass filter for the satellite speakers.

On the down side, this filter is not exactly practical. At 175Hz, its crossover frequency is set too high—a range of 100Hz–120Hz would be more desirable. Moreover, its slope

PHOTO 1: RCM Akustik's active subwoofer suitable for Dolby Surround.

TABLE 1

TECHNICAL DATA

Dimensions:	(mm) 300W × 494H × 450D
Volume:	45 ltr
Type:	Bass reflex
Driver:	175mm subwoofer with aluminum cone
Input impedance:	45kΩ
Output power:	48W/8Ω
Thiele-Small parameters:	
f_s = 43Hz	
R_e = 7.3Ω	
Q_{ms} = 3.3	
Q_{es} = 0.53	
Q_{ts} = 0.46	
S_d = 129cm^2	
V_{as} = 37 ltr	
C_{ms} = 1.6mm/N	
M_{ms} = 9g	
R_{ms} = 0.72kg/s	
SPL = 89dB	

ABOUT THE AUTHOR

Bernd Timmermanns is a loudspeaker design engineer, author, and editor of *Klang & Ton*, one of Germany's leading audio magazines (Ruhrorter Str. 9, D-46049 Oberhausen 1, Germany). This article, adapted from the German by technical translator Dr. Helfried Zrzavy (Zrzavyhc@aol.com), and the images in it are used by permission of Mr. Timmermanns and the publisher of *K & T*, Michael E. Brieden.

of 6dB per octave is meager. On the other hand, the deep bass from the third-order, continuously variable (50Hz–175Hz), lowpass filter leaves little to be desired and can handle all sonic situations.

If you wish to avoid the compromise, forget about the electronic high-pass of the DT105 and use only the subwoofer section. You can play the satellite speakers without passing the signals through the high-pass filter or running them simultaneously through a passive crossover-frequency network.

BUILDING THE ENCLOSURE

The subwoofer enclosure uses 19mm MDF. Three braces against the side walls result in excellent stability. For the bass vent, do not use a plastic tube, but instead construct a square chamber out of MDF. This chamber will not be visually obtrusive, since its opening is recessed at the bottom front of the speaker. (The three-sided speaker base forms the vent, since its missing fourth side is the opening.) The speaker base consists of the base plate itself, with 10mm × 25mm solid-wood border strips glued vertically along three edges (*Photo 2*).

The model built in the K & T laboratories used six deck screws to connect the base to the rest of the enclosure. This was done to facilitate experimentation with different lengths for the bass-reflex channel, but it is unnecessary for the final version. You can attach the base in any manner you choose. (Enclosure dimensions are shown in *Fig. 6*; *Table 2* is the parts list.)

At 65cm^2, the size of the bass-reflex resonator is very generous in comparison to the 129cm^2

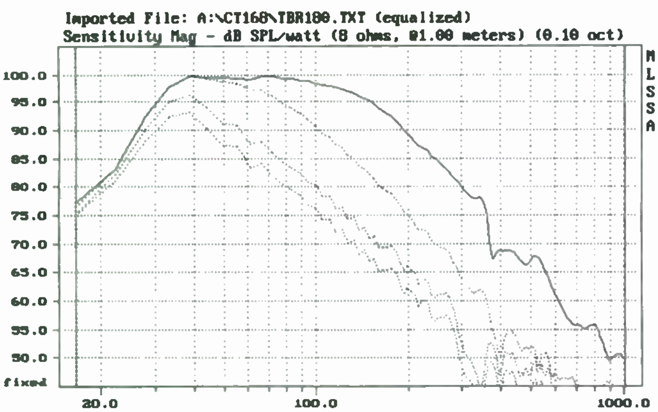


FIGURE 1: SPL overlays for the 40Hz, 80Hz, 120Hz, and 180Hz positions of the crossover frequency pot.

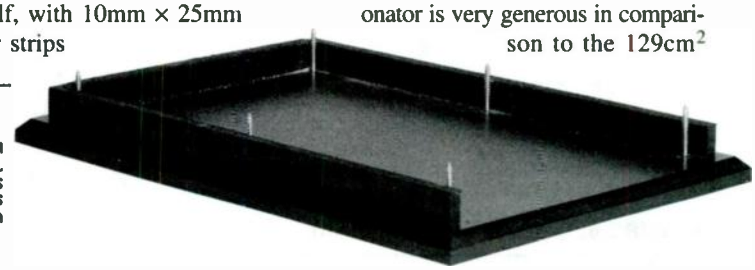


PHOTO 2: The base for the enclosure becomes the bass-reflex vent.

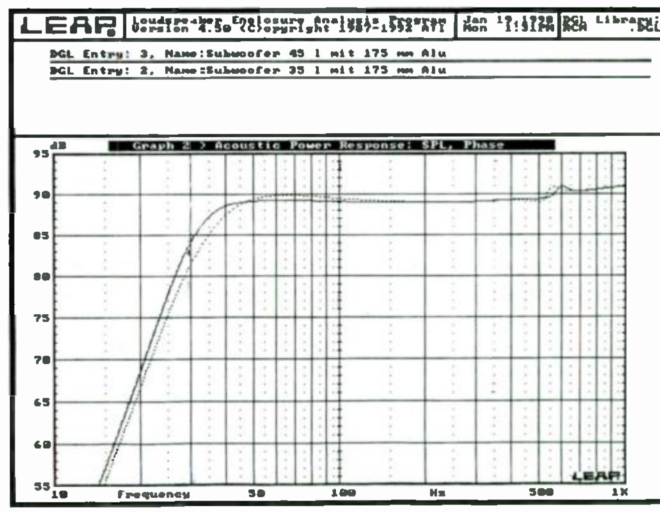


FIGURE 4: Simulation of SPL in 35-ltr and 45-ltr enclosures with 2.83V input.

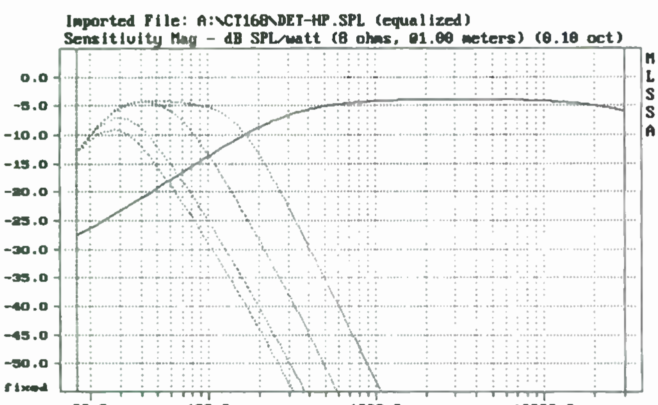


FIGURE 2: Electrical frequency response and satellite output, same positions as in *Fig. 1*.

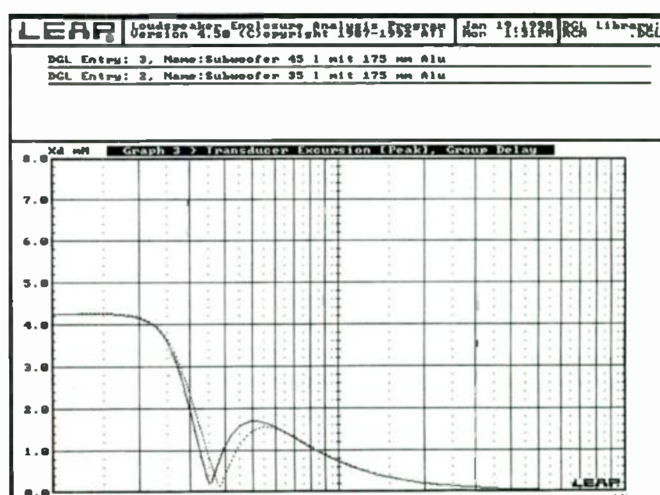


FIGURE 5: Simulation of cone excursion (35 ltr and 45 ltr at 2.83V).

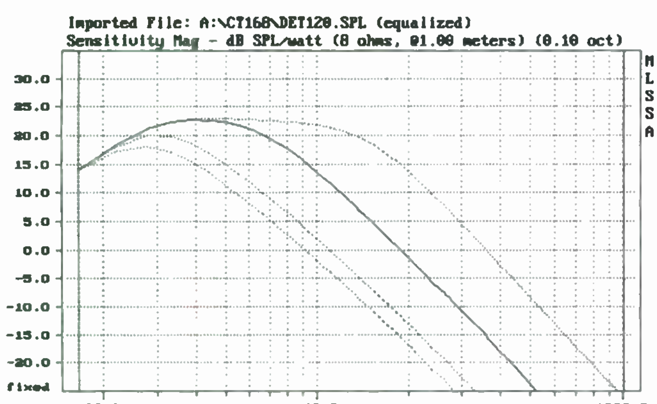


FIGURE 3: Electrical frequency response, same positions.

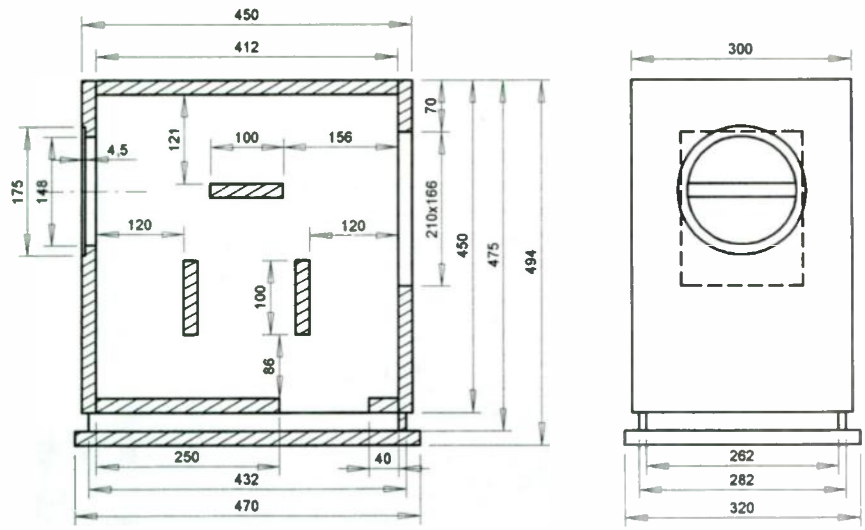


FIGURE 6: Enclosure dimensions (mm).

TABLE 2

PARTS LIST

Chipboard or MDF, 19mm:	
	2 sides = 450 × 412 (all in mm)
	1 each, front and back = 450 × 300
	1 top = 412 × 262
	1 base = 470 × 320
	1 vent piece = 262 × 250
	3 braces = 262 × 100
Heavier wood for base:	
	2 sides = 10 × 25 × 432
	1 back = 10 × 25 × 262
Damping material, 8mm fiber or 12mm foam:	
	1 piece for box cover = 40cm × 25cm
	1 piece for the vent top and front wall below the speaker = 45cm × 25cm
Other:	Screws; speaker wire; sealant for airtight box assembly

of the aluminum membrane. The velocity of the air flow remains low, and the construction distinguishes itself with extremely low mechanical losses.

INSTALLATION OF THE SUBWOOFER MODULE

All you need for the subwoofer module is a rectangular cut, slightly smaller than the module's panel (*Photo 3*). The module is airtight and thus does not need a separate enclosure. It even comes with a built-in foam insulating pad that rests between the lip of the panel—through which it is screwed to the enclosure back—and the back itself, acting as a seal. Electric wiring is restricted to the speaker wires that come with the module to connect it with the woofer. Because the length of these wires is rather modest, you should shorten them and then extend them again with proper wire (at least 1.5mm in diameter).

The woofer will fit into a round cut with a diameter of 148mm. Perfectionists will want to use a milling tool or router to sink the speaker in flush with the wood surface. If you don't own a router, you can always use the old trick of the doubled-up sonic wall by attaching a 4mm plywood or chipboard face in which a hole coinciding with the speaker's outline has been cut. This can replace the router treatment.

It is not necessary to put a lot of internal damping into the enclosure, since the midrange frequencies, which benefit most from it, are not accessed by the subwoofer. A little damping material, covering about 30% of the interior surfaces, is beneficial, however. Otherwise, minor distortions may be detected at the bottom of the bass-reflex channel.

CONNECTING TO YOUR STEREO

The Detonation! DT105 module has both RCA-style jacks and post-type terminal connectors for loudspeaker wires. If you have the choice, and have a preamp-out jack available, use the RCA connectors because they produce better sound. Otherwise, just use the speaker-level connections. Since the amplifier module draws very little electrical current, small-diameter copper wire is sufficient. Coaxial cable is entirely suitable. Both stereo channels contribute to the signal, which is summed by the amplifier module.

HOW TO SET UP YOUR SUBWOOFER

(Adapted from Klang & Ton, *4/96.)*

In order to find the right setting for volume, crossover frequency, and phase, it is imperative that you have enough patience and time, as well as a CD with which you are intimately familiar. The first step is to find the right place for the subwoofer. It works best if placed in the corner of a room, or at least close to a wall. The settings you come up with will work for the chosen location only; if you move the subwoofer, you must repeat the setup procedure.

All settings must be made with the main speakers on. To adjust the subwoofer while running it by itself is not recommended, because it will produce the wrong setting results.

Follow these steps to achieve the best setup of your subwoofer:

1. Set volume and crossover frequency to their respective middle positions and then find the phase-switch setting at which bass reproduction is greatest.

2. Set the volume of the subwoofer to zero and then slowly increase it until it is a discrete and pronounced sound source. Then reduce the volume again until it is just about to merge into the total sonic experience and is no longer perceived as distracting.

3. The crossover frequency must be matched to the satellite or main speakers. Set the crossover frequency to its maximum and then slowly reduce it until the bass no longer feels soft and spongy. It may be necessary to readjust the volume setting at this point. Finally, you may want to recheck the phase switch for maximum bass sound.

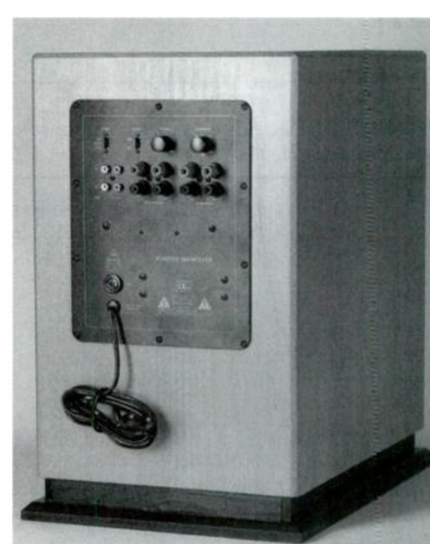


PHOTO 3: The airtight DT105 subwoofer module fits into a rectangular cutout in the enclosure back.

The choice of crossover frequency and volume is a question of personal taste, unless you have access to technical equipment to help with the fine tuning. You can determine the correct phase setting only through trial and error, while the polarity knob should be adjusted until bass reproduction reaches its maximum.

Unlike stereo loudspeakers, a subwoofer may be placed in a corner; in fact, it will produce 3dB more there than if placed close to a side wall. It should not be placed close to the listener, however, since the woofer would distort the harmonic stereo imaging. (See "How to Set Up Your Subwoofer.")

THE RIGHT TIMBRE

Klang & Ton combined this subwoofer with a pair of its own Ganymed-design satellite speakers fitted with Philips 0021601/RT 8 tweeters and Audax HM 130 C0 midrange/woofers. The trio's performance was truly compatible—especially when the satellites were passively separated. Bass response extended to impressive depths, and the subwoofer felt precise and delivered punch on demand.

High volume settings were impossible to achieve, however. Grand orchestra pieces, such as the drum sequence in Carmina Burana, immediately pushed speaker dynamics into the critical-load zone. At moderate volume levels, there are no such problems.

THE BOTTOM LINE

For moderate volume levels, this subwoofer is ideal. Due to its excellent magnetic shielding, it is also ideal for use in home theaters. At a price of 408 DM ($228 in the US) for the amp and speaker, plus another 50 DM or so (about $30) for installation materials and custom-cut MDF panels, this unit is so inexpensive that not even passive subwoofer alternatives approach its value.

The unit features very deep and clean bass with adequate power-handling capabilities, and is suitable for nearly every pair of satellite speakers because of continuously variable low-pass. Because of its variable volume and crossover controls, this subwoofer already is adaptable to most listening conditions.

THE DETONATION! DT105

(Adapted from Klang & Ton, *2/97.)*

The construction of an active subwoofer is an easy project recommended to any novice in do-it-yourself speaker construction. One reason for the high rate of success in subwoofer construction is that active subwoofer modules such as the newly introduced Detonation! DT105 provide all the necessary electronic components ready to go.

If you're a do-it-yourselfer, you practically have only one job left: building an enclosure that matches the woofer of your choice. To accommodate the active subwoofer module, all you need do is cut a rectangular opening in the back of the enclosure, attach the amp with the provided screws, connect its wires to the woofer—and you're done.

To assist you in the construction of the best possible speaker enclosure, the *Klang & Ton* laboratories have computed the optimal speaker-enclosure volume for a number of subwoofer models (*Table A*) and made recommendations regarding the diameter and the length of the bass-port tube. You merely need to choose a woofer, and then construct a stable enclosure with the recommended volume and a matching port.

For the active subwoofer module Detonation! DT105, a rectangular opening is all that is needed; a separate chamber is not necessary because of the module's airtight construction and because the manufacturer (RCM Akustik) provides foam damping pads for expert installation.

SETTING THE ACTIVE CROSSOVER

The DT105 module allows you to adjust

TABLE A

ENCLOSURE SUGGESTIONS FOR SELECTED SUBWOOFERS

	ACTIVE CROSSOVER					PASSIVE CROSSOVER				
	Vb (l)	fb (Hz)	dR (mm)	lR (mm)	f3 (Hz)	Vb (l)	fb (Hz)	dR (mm)	lR (mm)	f3 (Hz)
Audax PR 300 M0	170	28	100	100	36	230	25	100	100	32
Conrad Audio KT-300-E	25	50	100	0	63	32	45	100	290	55
Focal 12 V 726	87	28	100	270	34	115	25	100	240	30
Teufel TT 310 THX	150	23	100	230	21	215	20	100	190	18
Monacor SPH-31	62	31	100	310	40	82	28	100	280	35
Monacor SPH-300 KE	140	26	100	170	29	205	24	100	130	24
Morel MW 1275	270	x	x	x	25	350	x	x	x	23
Peerless CCX 315	290	21	100	110	22	465	19	100	70	17
Visaton W 300 S	157	27	100	130	33	200	25	100	110	29
Visaton TIW 360	61	39	100	180	46	87	35	100	150	39

the crossover frequency to match your stereo speakers. Drivers with strong bass capacity will be able to take advantage of the lowest crossover setting, while smaller satellite speakers will benefit from the acoustic support provided by settings higher than 100Hz.

To improve the power handling in satellite speakers, the DT105 provides an active electronic crossover option, albeit only when the crossover frequency is set at 175Hz. While this setting does not make sense for large drivers, the sound reproduction in small speakers profits tremendously from the active crossover option. The absence of extreme cone movements, typical of the lower frequency ranges, allows the speakers to provide a more relaxed sound and to remain distortion-free, even when played at high volumes.

The filter characteristics of the satellite crossover are optimized by setting the subwoofer to its maximum crossover frequency of 175Hz. *Klang & Ton* has shown as early as 1993 that a crossover-frequency setting even that high does not negatively impact the typical speaker's ability to provide accurate stereo imaging.

CONNECTING THE DT105 TO YOUR SYSTEM

Connecting the subwoofer to your stereo system normally requires several feet of cable unless it is located close to the amplifier. A pair of RCA-style stereo jacks provides the connection from the preamplifier line-level output to the DT105 module and back to the main-in jacks of the amplifier. If the satellite crossover option is not used, you omit the loop back.

In case no preamp is installed, the DT105 is versatile enough to accept speaker-level input from a receiver via post-type terminals that easily accommodate large-diameter (Monster) speaker cables. For speaker-level signal input, there is a passive high-pass filter that essentially consists of an average-quality capacitor. However, the passive high-pass filtering of satellite speakers through the subwoofer module should be avoided, since it almost never works. The strong variations of the impedance curve in the lower frequency ranges inhibit the proper working of this filter function.

The active module sums the two stereo channels into a mono bass signal. The signal is transferred to the subwoofer's built-in amplifier, which has a maximum output level of 64W into 4Ω and nearly 50W into 8Ω. The amplifier module also sports control knobs for precise volume adjustments and for phase switching.

PHASE SWITCHING AND VOLUME SETTING

Phase switching is required when the combination of subwoofer and main speakers does not yield the desired addition of sound, but instead produces a frequency hole through sound subtraction and cancellation. This acoustic miscomputation is easily identified, since there appears to be no audible bass sound coming from the speakers, despite the addition of the subwoofer.

When in doubt, a simple listening test will do. The phase-switch setting that generates the most unfettered, solid bass reproduction is the right one. You should also consider your listening preferences when adjusting the volume level of the subwoofer module. It should be set just high enough for maximum enrichment of the listening experience, but not so high as to drown out the midrange frequencies.

The ergonomically advanced design features of the DT105 also include an automatic power-on switch. Besides the on and off positions, the main switch permits an "auto" setting, in which the in-jacks are electronically monitored, and the built-in amplifier is activated only when incoming music signals are detected.

HOME THEATER

A subwoofer goes with a Dolby surround-sound system like ketchup with hamburger—unless your main speakers already provide more than ample low-frequency response. Many surround-sound decoders come with subwoofer out-jacks built-in, typically with a fixed crossover frequency set between

TABLE B

DT105 technical data

Dimensions:	Mounting plate (mm) 203W × 254H aluminum
Cutout size:	165mm × 210mm
Depth into box:	105mm (non-milled installation)
Milling depth:	2mm
Protrusion from plate into room:	25mm (speaker terminals)

Test results

Frequency response:	25Hz–143Hz (–3dB); 50Hz–175Hz (–6dB)
Subwoofer crossover:	18dB/octave, infinitely variable
Satellite crossover:	175Hz (–6dB), 6dB/octave, fixed
Passive high-pass:	100μF, 6dB/octave (left, 95μF; right, 85μF)
Output power (1%Kges/50Hz):	64W/4Ω, 48W/8Ω
Input sensitivity:	305mV/4Ω, 440mV/8Ω
Output impedance of satellite channel:	1kΩ
Clipping edge of satellite channel:	7V
Input impedance:	45kΩ (100Hz)
Output impedance:	0.2Ω (50Hz)
Damping factor:	20 into 4Ω(50Hz), 40 into 8Ω (50Hz)

Correction table for the crossover frequency scale

Nominal	–3dB	–6dB
40Hz	41Hz	50Hz
80Hz	46Hz	56Hz
120Hz	73Hz	89Hz
180Hz	143Hz	175Hz

(In a separate series of tests, *K & T* evaluated a number of subwoofer amps from different manufacturers and found that the markings of all were off in one way or another. That not withstanding, and without prejudice toward *K & T*, RCM Akustik suggests that users will be well satisfied with the original RCM markings.)

80Hz and 100Hz. The decoder's lower crossover frequency setting takes precedence over the one in the DT105. If the crossover frequency is set too low in the decoder, it is advisable to use the main speaker jacks and to leave the subwoofer out-jacks open.

MATCHING DRIVERS

The DT105 can be matched with a wide variety of speaker models, ranging from 17cm (7″) to 38cm (15″) drivers. To match the module with SPL-quality long-throw woofers does not make sense, however, since the dynamic range of these speakers is too big for the relatively modest output levels of the module's on-board amplifier. For example, in *Table A* the THX subwoofer by Teufel, the TTTW360 by Visaton, or the top woofer model by Focal would be overkill, but the W 300 S by Visaton would be an excellent match. If you wish more amplifier power, you could choose a larger amplifier model, the 150W Detonation! DT109 (reviewed in *Klang & Ton,* 4/96; send a #10 SASE to Burnett Associates for a copy).

For the smaller drivers, the danger of mismatching the speakers with the performance characteristics of the DT105 is negligible: The module will adequately handle almost all 17cm drivers, and most models in the 20cm range will provide equally nice performance fits.

THE BOTTOM LINE

The Detonation! DT105 ranks among the more modestly priced active subwoofer modules, yet it offers solid performance and ample features. It's the perfect module for the cost-conscious do-it-yourselfer who wants to build an active subwoofer.

DISCLAIMER

In the interest of full disclosure, *Speaker Builder* readers should know that this material from *Klang & Ton* was first brought to our attention by Jack Burnett, former manager of our Old Colony Sound Lab products department and current proprietor of Jack Burnett Associates. JBA is a North American representative for RCM Akustik GmbH, and indeed sells the Detonation! series subwoofer amplifiers and aluminum-cone drivers mentioned here.

Further, Mr. Burnett arranged for permission to use this material, as well as for its translation and slight adaptation to American English style. However, we assure our readers, as Mr. Burnett has assured us, that no deletions whatsoever have been made here of any commentary that might be considered negative with respect to the RCM Akustik products.

As with all *Speaker Builder* editorial matter, we publish this material from *Klang & Ton* for no other reason than that it is interesting and topical, and can provide to our readers a fun project with which to add value and performance to their systems.

SOURCES

North American distributor:
Burnett Associates,
PO Box 26, W. Peterborough, NH 03468, 603-924-2383, FAX 603-924-3392, E-mail FDTF77B@prodigy.com.
RCM-17 subwoofer is about $89 including s/h;
DT105 amp is about $159 including s/h.

International:
RCM Akustik GmbH,
8 Meinwerkstr., 33098 Paderborn, Germany, (+49)-5251-22324, FAX (+49)-5251-22325,
E-mail rcmakustik@t-online.de.

Driver Report

PEERLESS CSX 217 H WOOFER

By Vance Dickason

PHOTO 1: The Peerless CSX 217 H woofer.

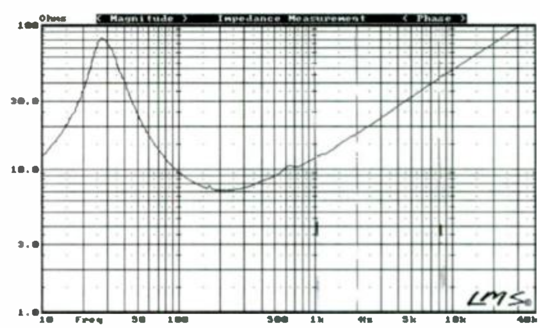


FIGURE 1: CSX 217 H impedance plot.

FIGURE 2: 2.83V box simulation (solid = sealed, dot = vented).

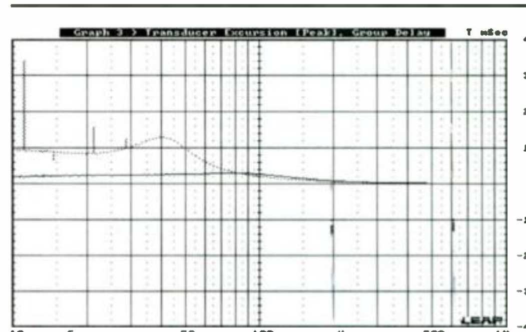


FIGURE 3: Group-delay curves for *Fig. 2* (solid = sealed, dot = vented).

In this report, I focus on the 8″ Model CSX 217 H woofer from Peerless Fabrikkerne's (Denmark) CSX series.

Features: The CSX 217 H 8″ woofer has a 33mm-diameter voice coil suitable for both two-way and three-way applications. As with the rest of the CSX series, this woofer has a stamped surface-mount frame (one of the nicest stamped frames in the industry), composite sandwich paper cone, inverted dustcaps, aluminum shorting ring for lower distortion, flat linear compliance spider, and rubber surround.

Measurements: Using the LMS analyzer, I produced the free-air impedance curve shown in *Fig. 1*. I then transported this data to LEAP software to produce the T/S parameters in *Table 1*.

Although the sample data differed somewhat from published factory data, box simulations with factory vs. sample data showed only about 1dB variation. Given this, I performed a sealed-box simulation in a 0.27ft^3 box and vented simulation in a 0.75ft^3 enclosure tuned to 41Hz. Results at 2.83V are supplied in *Fig. 2*. The 217 H yielded an f_3 of 88Hz with a –3dB phase angle of 90° (box Q_{TC} = 0.7) in the sealed box and an f_3 of 43Hz for the vented enclosure. *Figure 3* displays the associated group-delay curves for both simulations. Increasing the voltage until cone excursion goes to X_{MAX} + 15%, I generated the SPL curves shown in *Fig. 4*. With the sealed box at 21V, the woofer produced an SPL of about 108dB and, with the vented box at 15V, the SPL was 105dB (cone-excursion curves are depicted in *Fig. 5*).

Next, I mounted the driver in an enclosure with a 16½″ × 11″ baffle. *Figure 6* illustrates the on- and off-axis frequency response of the 8″ woofer, which is very even out to nearly 5kHz with no major response anomalies.

TABLE 1

PEERLESS CSX 217 H PARAMETERS

	SAMPLE A	SAMPLE B	FACTORY
f_S	28.7Hz	25.7Hz	28.2Hz
R_{EVC}	5.91	5.88	5.9
Q_{MS}	3.03	2.63	3.5
Q_{ES}	0.22	0.20	0.29
Q_{TS}	0.21	0.18	0.27
V_{AS}	85.2 ltr	110.6 ltr	79.7 ltr
Sens.	92dB	92dB	89.5dB
X_{MAX}	4mm	4mm	4mm

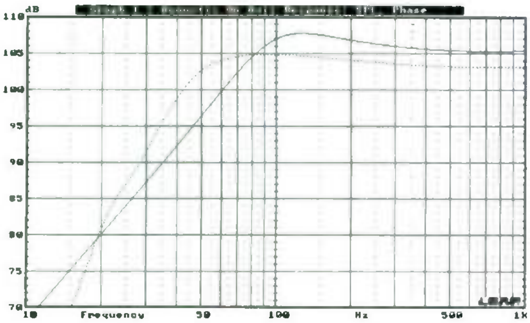


FIGURE 4: Box simulation at 21V (sealed) and 15V (vented) (solid = sealed, dot = vented).

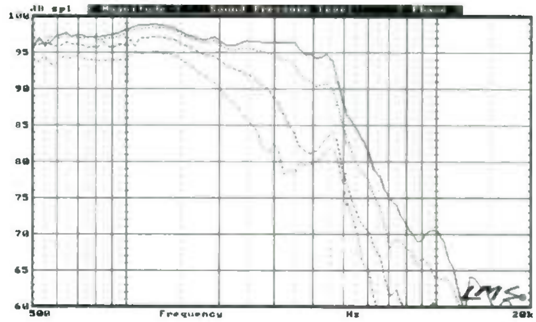


FIGURE 6: On- and off-axis frequency response (solid = 0°, dot = 15°, dash = 30°, dash/dot = 45°).

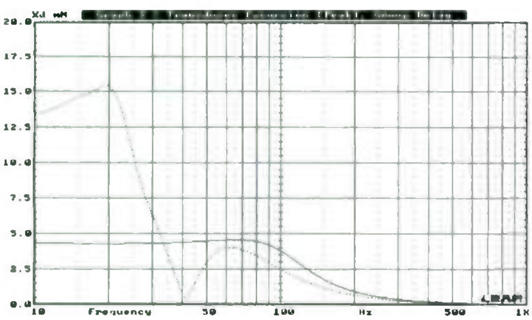


FIGURE 5: Cone-excursion curves for *Fig. 4* (solid = sealed, dot = vented).

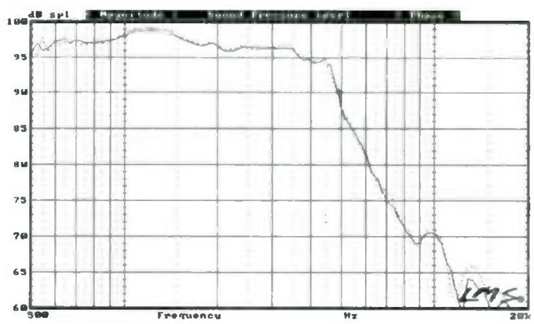


FIGURE 7: SPL comparison for two samples.

This woofer should easily produce a very tight ±2dB or less response with a crossover up to 2–2.5kHz. *Figure 7* demonstrates the two-sample SPL comparison which shows a tight match between the two CSX 217 H units.

The CSX 217 H woofer may be purchased from: Madisound Speaker Components (8608 University Green, Madison, WI 53744-4283, 608-831-3433, FAX 608-831-3771, Website www.madisound.com) or Circle Sound (2772 West Olympic Blvd., Los Angeles, CA 90006, 213-388-0624, FAX 213-384-1137).

LA PASSION DU HAUT-PARLEUR

AUDAX

Audiophile Price List April 1998

MADISOUND SPEAKER COMPONENTS
8608 UNIVERSITY GREEN
P.O. BOX 44283
MADISON, WI 53744-4283 U.S.A.
TEL: 608-831-3433 FAX: 608-831-3771
e-mail: madisound@itis.com
Web Page: http:/www.itis.com/madisound

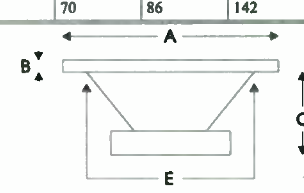
Model	Size Description	Ω	Fs Hz	Qts	Vas Ltrs	Xmax mm	Power Watts	dB	Cost Each
Soft and Hard dome tweeters									
TM010A7	Micro Series 10mm ion deposited gold dome ,very small	8	3000	-	-	0.25	25	87	$10.10
TM025F1	Micro 25mm textile dome, neodymium mag. 70mm flange	8	1250	-	-	0.05	70	92	$19.10
TM025F9	Same as TM025F1, but with truncated flange (flat top and bottom)	8	1250	-	-	0.05	70	91	$19.10
TW010E1	10mm polymer dome, 60mm x 60mm flange, shallow, 6KHz +	8	3000	-	-	0.25	25	90	$5.60
TW010F1	10mm polymer dome, 74mm round flange	8	3000	-	-	0.25	25	90	$5.20
TW010I1	Titanium coated 10mm dome, protective grill, 74mm flange	8	3000	-	-	0.25	25	91	$8.35
TW014F1	14mm polymer dome tweeter, 74mm flange	8	2050	-	-	0.25	45	91	$8.35
AW014G1	14mm polymer dome, Shielded, 80mm square flange	8	2050	-	-	0.25	45	95	$11.60
TW025A0	25mm textile dome, 100mm round flange, 74mm hole	8	900	-	-	0.30	55	90	$19.10
TW025A2	As above but 4 ohm, used in many older Spica speakers	4	900	-	-	0.30	55	93	$19.10
TW025A1	Same as TW025A0, ferrofluid cooled voice coil	8	1200	-	-	0.30	70	90	$19.55
TW025L0	25mm textile dome, 90mm x 120mm flange	8	900	-	-	0.30	55	90	$19.10
TW025L1	As above, but with ferrofluid cooled voice coil	8	1200	-	-	0.30	70	90	$19.55
TW025M0	25mm textile dome with decorative face plate	8	900	-	-	0.30	55	92	$20.00
TW025M1	As above but with ferrovluid cooled voice coil	8	1200	-	-	0.30	70	92	$20.50
AW025M1	Shielded magnet 25mm textile dome, ferrofluid cooled	8	1000	-	-	0.30	70	90	$27.00
AW025S1	Shielded magnet 25mm titanium dome, ferrofluid cooled	8	1050	-	-	0.30	80	92	$36.30
AW025S3	Shielded magnet 25mm aluminum dome, ferrofluid cooled	8	1150	-	-	0.30	80	92	$33.50
DTI01	25mm Titanium dome with protective phase ring	8	1700	-	-	-	50	94	$25.50
TW034X0	34mm textile dome, 132mm round flange, 103mm hole	8	800	-	-	0.25	70	93	$33.50
Prestige Series Aerogel Cone Drivers - Cast Frames, Rubber Surrounds									
HM100Z0	4" Aerogel cone mid/bass, smooth to 4.5KHz, phase plug	8	250	0.81	0.84	1.25	40	93	$49.45
HM130Z0	5.25" Aerogel cone mid/bass, good for Sat. Or MTM design	8	68	0.31	8.3	2.0	50	92	$67.80
HM170Z0	6.5" Aerogel cone woofer, smooth response, good for 2-way	8	40	0.40	45.3	3.75	60	91	$79.10
HM210Z0	8" Aerogel cone woofer, rolls off niecely at 3khz, perhaps no x-over	8	30	0.31	108.0	4.25	70	91	$93.60
Reference Series Coated paper Cone Drivers - Cast Frames, Rubber Surrounds									
HM100G0	4" Coated Paper cone mid/bass, good as woofer or midrange	8	55	0.25	6.2	2.1	40	89	$34.00
HM130G0	5.25" Coated paper cone mid/bass, good for 2-way or MTM	8	41	0.23	23.1	2.3	50	92	$39.90
HM170G0	6.5" Coated Paper cone woofer, good for efficient 2-way or MTM	8	42	0.36	32.5	3.0	60	90	$47.00
HM210G0	8" Coated Paper cone woofer, very flat response, good in 2-way	8	30	0.32	116	4.15	70	91	$59.90
Reference Series Carbon Fiber Cone Drivers - Cast Frames, Rubber Surrounds									
HM100C0	4" Carbon fiber cone mid/bass, very flat response, low fs	8	54	0.21	6.4	1.8	40	89	$51.00
HM130C0	5.25" Carbon fiber cone mid/bass, smooth response, low fs	8	46	0.31	18.0	3.0	50	90	$55.90
HM170C0	6.5" Carbon fiber cone woofer, good for 2-way or MTM design	8	42	0.32	30.6	3.0	60	90	$68.55
HM210C0	8" Carbon fiber cone woofer, good bass and mid frequencies	8	31	0.39	83	4.15	70	90	$83.00
Classic Series Kevlar Cone Drivers - Stamped Frames, Rubber Surrounds									
HT100K0	4" Kevlar cone mid/bass, good bass response for small 2-way	8	58	0.40	5.21	3.0	30	88	$30.65
HT130K0	5.25" Kevlar cone mid/bass, exceptional bass for small 2-way	8	44	0.25	17.8	2.5	40	90	$40.70
HT170K0	6.5" Kevlar cone woofer, good midrange for 2-way	8	48	0.42	23.1	2.5	50	89	$44.60
HT210K0	8" Kevlar cone woofer, good efficiency and smooth response	8	28	0.31	108	4.5	70	90	$50.40
Professional Series Drivers									
PR120I1	Horn tweeter, ¾" titanium dome, bullet tweeter, 8K plus x-over Rec.	8	8000	-	-	-	120	105	$52.45
PR125T1	Horn tweeter, 1" textile dome, low fs and high efficiency, smooth	8	1200	-	-	0.65	70	97	$33.00
PR170M0	6" Paper cone midrange, usable down to 250Hz, smooth response	8	117	0.51	5.52	0.5	100	100	$67.75
PR170Z0	6" Aerogel cone midrange, phase plug, good response	8	185	0.40	3.31	0.50	100	99	$77.25
Often Requested Miscellaneous Drivers									
HT080M0	3" Paper cone full range, 3.75" round flange, 3" cut out, 2" deep	8	80	0.60	1.9	1.5	20	86	$16.50
AT080M0	Shielded version of HT080M0, 3" square flange, 3" cut out, 2.2" D.	8	82	0.69	1.8	1.5	20	83	$18.00
HT080G0	3" Paper cone full range, rubber surround, decorative faceplate	8	80	0.53	1.9	1.5	20	86	$18.90
HT100M0	4" Paper cone mid/bass, 4.7" flange, 3.6" cutout, 2" deep	8	60	0.34	6.1	3.0	30	88	$21.00

Model	Size Description	Ω	Fs Hz	Qts	Vas Ltrs	Xmax mm	Power Watts	dB	Cost Each
AT100M0	Shielded version of HT100M0, 4" square flange, 3.6" cutout, 2.3" D.	8	64	0.48	4.41	3.0	30	88	$22.40
HT130M0	5.25" Paper cone woofer, good response to 4kHz, 5.5" flange	8	59	0.33	9.05	3.0	40	91	$23.75
Autosound drivers									
TM010A1	Micro Series 10mm polymer dome, for autosound, very small	4	3000	-	-	0.25	25	90	$9.00
250018P / Pair	Flush mount kit for TM010A1, 40mm Ø x 20mm deep	-	-	-	-	-	-	-	$12.50
250019Q / Pair	Surface mount kit for TM010A1, 33mm Ø x 15mm deep	-	-	-	-	-	-	-	$12.50
VE101F0	4" Fiberglass cone mid/bass, smooth to 12kHz, 4" flange, 3.7" hole	4	120	0.69	1.1	1.5	30	89	$24.75
VE130F4	5.25" Fiberglass cone woofer, good to 3kHz, 5" flange, 4.6" hole	4	74	0.44	8.1	1.0	50	90	$29.50
VE170F8	6.5" Fiberglass cone woofer, very good to 7kHz, 6.5" flange, 5.5" H.	4	56	0.45	18.0	1.0	50	90	$36.00
HT170Z0	6.5" Aerogel Cone woofer, good to 4kHz, favorable responses	4	50	0.56	10.9	3.5	60	87	$44.60
VE4X6F0	4" x 6" Fiberglass cone mid/bass, good response to 7kHz	4	90	0.73	2.5	1.5	30	88	$28.50
VE6X9F0	6" x 9" Fiberglass cone woofer, good response to 5kHz, good bass	4	45	0.43	33.6	2.5	60	92	$57.00
Discontinued Audax Products - Limited Quantities									
TW51A /890pcs	10 mm polymer dome tweeter, 51mm square, like TW010E1	8	3000	-	-	0.25	25	90	$3.50
TW60Ti /160pcs	10mm titanium coated polymer dome, 60mm square flange	4	3000	-	-	0.25	25	93	$5.00
Hinged Wedge	Hinged wedge mount, fits TW010E1, TW60Ti & Seas H623 tweeters	-	-	-	-	-	-	-	$4.50
DW50M /490pcs	14mm Polymer dome tweeter, no mounting holes, 50mm round	4	2050	-	-	0.30	45	94	$8.00
DW50C /75pcs	Smaller magnet version of above	4	2050	-	-	0.30	45	93	$7.00
DW50C /175pcs	Same as above, but 8 ohm	8	2050	-	-	0.30	45	90	$7.00
Tweeter Replacement Voice Coil Assemblies									
RW025A0	Replacement voice coil for TW025A0, TW025A1, TW025M0, TW025M1, TW025L0, TW025L1								$6.90
RW025A2	Replacement voice coil for TW025A2 or can be used to change any of above to 4 ohm								$6.90
RW025V2	Replacement voice coil for TW025V2 - now discontinued tweeter								$6.90
RW025S1	Replacement voice coil for AW025S1								$11.90
RW025S3	Replacement voice coil for AW025S3								$11.30
RW034X0	Replacement voice coil for TW034X0								$12.90
RW037Y0	Replacement voice coil for TW037Y0 - now discontinued tweeter								$21.00
RP120I1	Replacement voice coil for PR120I1								$28.30
Audax Kits on the Web - www.audax.com - Audax Kit Brochure Available on Request									
Model A651 Kit	Designed by Vance Dickason, the A651 Kit is a 2-way design using the HM170Z0 woofer and AW025S3 tweeter in a small bookshelf type cabinet.								
Model A652 Kit	Designed by Vance Dickason, the A652 Kit is an MTM design using two HM170C0 woofers and a TW025A0 tweeter in a bookshelf type cabinet.								
Model KLS9 Kit	Designed by Noel Keywood, the KLS9 Kit is a 2-way design using the HM210Z0 woofer and the TW025M0 tweeter in a floor standing cabinet.								
Model HTG1780 Kit	Designed by Audax, the HTG1780 Kit is a Mini Satellite / Subwoofer system using an HT080G0 and TW010E1 in the satellite and an HT170G8 dual voice coil subwoofer.								
Model VAT414 Kit	Designed by Audax, the VAT414 Kit is a shielded center channel speaker using four AT100M0 woofers and an AW014G1 tweeter in a narrow cabinet designed for horizontal placement.								

Unit	A mm	B mm	C mm	D mm	E mm
TM010A7	29.5 Ø	14	-	29.5	-
TM010A1	29.5 Ø	14	-	29.5	-
TM025F1	70 Ø	2.5	30	25	50
DW50M	49.5 Ø	9.8	14.5	45	49.5
TW010E1	60 x 60	2.4	14.4	29x29	48
TW010F1/1I	74 Ø	2.6 / 4.2	14.4	29x29	48
TW014F1	74 Ø	2.5	19.5	32	49.5
AW025...	100 Ø	1.5	28	62.5	62.5
TW025A...	100 Ø	2	23.5	73.5	73.5
TW025L...	120 x 90	2	23.5	73.5	73.5
TW025M..	100 Ø	1.5	23.5	73.5	73.5
TW034X0	132.2 Ø	2	29	102.5	102.5
DTI01	114 Ø	4.2	22	71	71
PR120I1	95 x 95	6.3	56	73.5	73.5
PR125T1	100 Ø	1.5	58	73.5	73.5
PR170M0/Z0	190 Ø	8	70	124.6	145
HM100...	110x110	6	52	85.8	94
HM130...	136x136	6.8	70.5	102.5	115.4

Unit	A mm	B mm	C mm	D mm	E mm
HM170...	166x166	7.2	77	124.6	145
HM210...	210x210	7.3	89	124.6	186.5
HT100K0	119	6	56	73.5	91
HT130K0	142	7	62	102.5	113
HT170K0	173	7	71	102.5	142
HT210K0	213	9.2	88	102	184
HT080M0	96 Ø	4.3	50	56.2	78
AT080M0	78 x 78	2.9	55	53	78
HT100M0	119 Ø	6	52	73.5	91
AT100M0	104 x 104	7	59	65	91
HT130M0	142 Ø	7	58	86	113
HT170Z0	167 Ø	7.8	70	86	142

25.4mm = 1”
28.3 ltrs = 1 ft^3



Madisound Speaker Components; PO Box 44283, Madison WI 53744 USA, Tel: 608-831-3433, Fax: 608-831-3771

COMPUTERIZED LOUDSPEAKER PLACEMENT, PART 2

By Bohdan Raczynski

In the article (see *SB* 1/98) to which this is the sequel, I described the calculation of a room's resonant frequencies and their corresponding sound pressure distributions within that space. Knowing the room modes is the essential first step to understanding the acoustical properties of your listening environment. As before, the Finite Element Method (FEM) facilitates modeling the sound field of a complex-shaped space.

In this sequel, I will focus on altering the placement in the room of a sound source that radiates at nonresonant frequencies and room modes. I have kept the shape of the room the same as that in Part 1 in order to highlight the application of the FEM to the problem at hand.

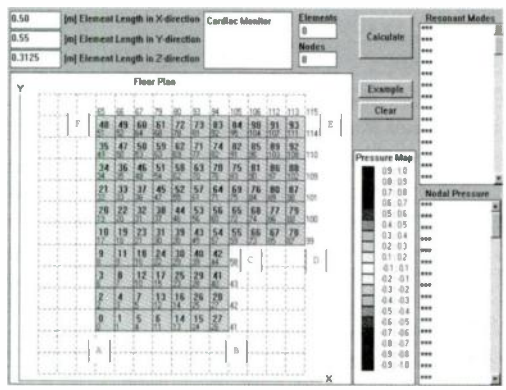


FIGURE 11: Shape of the listening room. (Screen shots generated with SoundEasy V3.1, Bodzio Software. Part #SOF-SOU is priced at $269 and is available from Old Colony Sound Laboratory, PO Box 876, Peterborough, NH 03458-0876, 603-924-6371, FAX 603-924-9467, E-mail custserv@audioxpress.com, Website www.audioxpress.com.)

THEORETICAL BASICS

In order to model the harmonic acoustic behavior of an enclosed space with a sound source, the following equation is sufficient:

$$(K[][] - k^2M[][] + j\omega C[][])p[] = j\rho_0\omega v[]$$

where $k = \omega/c$, $\omega = 2\pi f$, $j = \sqrt{-1}$, K[][] is the so-called acoustic stiffness matrix, M[][] is the acoustic mass matrix, C[][] is the system damping, p[] is the sound-pressure vector, v[] is the excitation vector in cubic meters per second, f is the test frequency, and c is the speed of sound.

Assuming C[][] = 0 (no system damping), the previous equation simplifies to:

$$(K[][] - k^2M[][])p[] = j\omega v[]$$

For the sound source, I assume a "point source," which is convenient, since you can locate it at any of the mesh nodes. You would need to make any larger source a part of the room boundary. Mathematically, the problem now reduces to assembling the K[][] and M[][] matrices and converting the expression in the parentheses. In this way, you can find the sound-pressure vector p[] for any frequency and location of the sound source represented by excitation vector v[]. For room modes,

$$(K[][] - k^2M[][]) = 0$$

In Part 1, I used many "brick" (eight-node) elements to approximate the volume of the listening room, and the functions describing the pressure distribution between the nodes were linear. This is important, because if you know the pressure at the nodes, you can calculate the pressure at any point in between them.

One of the limitations of this approach is that FEM cannot model the close-field sound pressure very accurately. It would take a much more dense (finer) mesh to do this job properly. I am not, however, concerned with this limitation, because the job at hand is to look at the whole room.

To illustrate the application of the FEM method, I selected the listening-room shape shown in *Fig. 11*. This is an L-shaped room with wall A-B slightly longer than wall D-E.

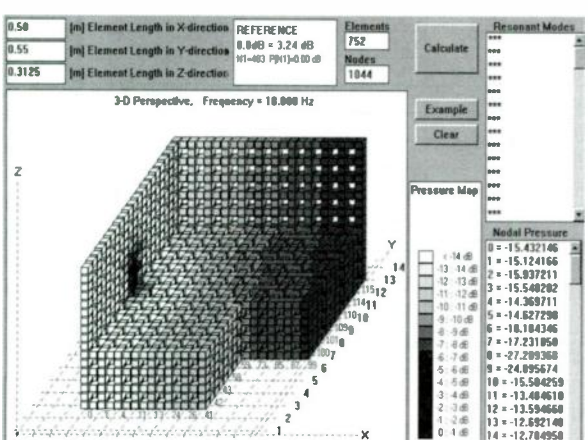


FIGURE 12: Placing the point source in front of a hard wall increases the sound pressure.

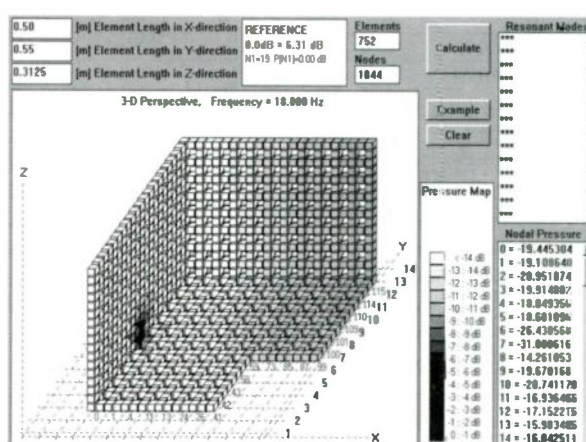


FIGURE 13: Moving the source to the wall/floor junction further reinforces the sound pressure.

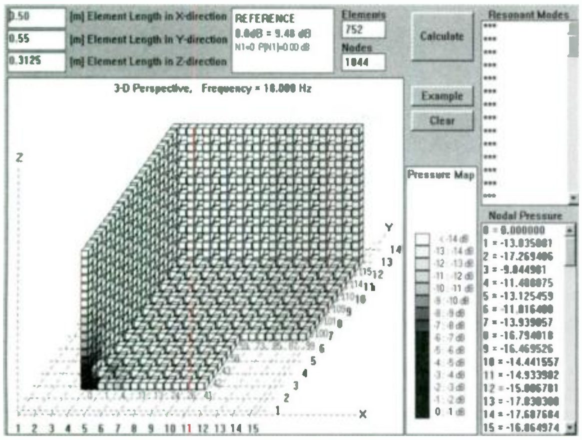


FIGURE 14: A 9–10dB sound-pressure increase occurs if you move the sound source into the corner of the room.

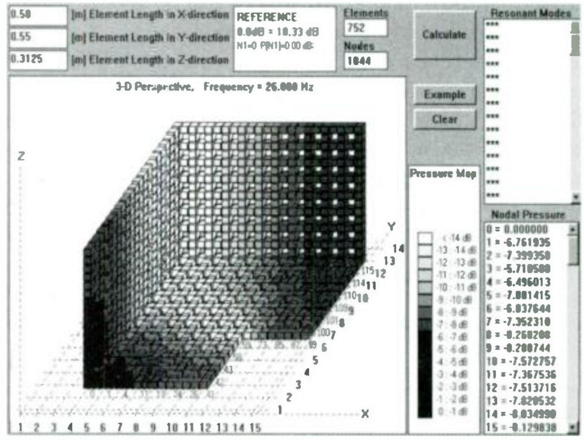


FIGURE 15: The expected sound field is beginning to take shape, but the resonance has not yet quite developed.

This deliberate lack of symmetry perhaps makes the analysis more difficult, but it emphasizes the usefulness of the FEM.

INTRODUCING A SOUND SOURCE

Think about the following sequence. If the "point source" radiates in free space, it produces some sound pressure, which you consider to be at 0.0dB level. When you place this source in front of a hard wall (*Fig. 12*), the reflections from the wall reinforce the sound pressure, causing a +3dB pressure increase.

If, in addition, you move the source to the wall/floor junction, the resulting sound pressure is further reinforced (*Fig. 13*). Finally, if you move the source of the sound into the corner of the room, the sound pressure increases by some 9–10dB (*Fig. 14*). Now, if the sound-source frequency happens to be one of the room-resonant modes, the sound pressure at the source is dramatically magnified by the resonant effect and lack of damping (assuming that matrix C[][] = 0).

The display is arranged so that nodal pressure is normalized to the maximum pressure within the room. This maximum pressure is marked 0.0dB, so all other nodes will exhibit negative pressure values, as on the color-coded pressure map on each screen dump (colors not shown here).

The actual level of the "REFERENCE 0.0dB=" is displayed, and its value is relative to the sound pressure radiated from a point source in free space. Generally, if the reference is above the 10dB mark, you would be approaching a resonant mode. When the reference exceeds 20dB, you have reached the mode. Levels below 10dB relate to various locations of the source at non-modal frequencies.

In general, you can model the sound field of a complex-shaped enclosure for any location of the source or sources of the sound. For the non-modal frequencies, the resulting sound field at low frequencies typically exhibits variations in the near-field and a gradual increase in intensity toward the opposite wall.

APPROACHING THE RESONANT MODE

With the source located in corner A (node 0), you can select a test frequency close to, but not equal to, the lowest room mode. *Figure 15* depicts the situation for a frequency of 26.0Hz, where the expected sound field is beginning to take shape, but the resonance has not yet quite developed. The reference parameters just exceed the 10.0dB level.

Figure 16 shows the source radiating at the first room mode. The pattern is familiar, showing a characteristic pressure increase at the source due to the resonant effect developed in the room. The pressure null, or cancellation of sound, is marked half-way to the opposite wall. The total pressure increase at the source includes reinforcement attributable to the corner location, as well as an additional increase due to the sharp resonant effect of the volume of air in the room, resulting in the reference level of 32dB.

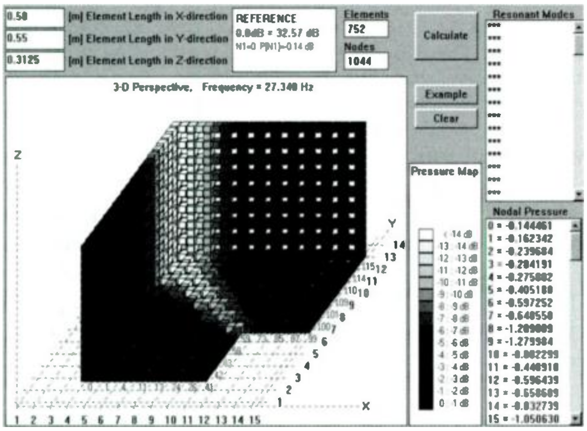


FIGURE 16: The source radiating at the first room mode.

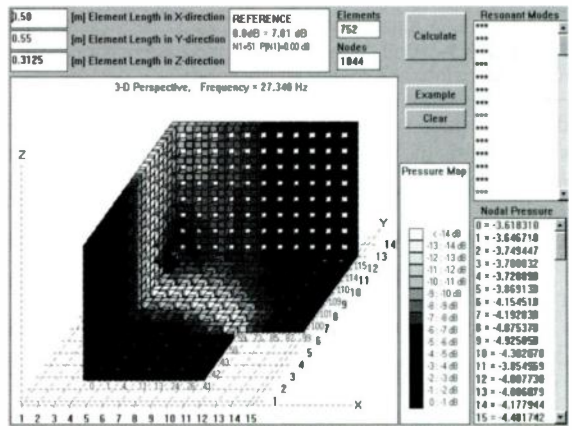


FIGURE 17: Moving the source to the pressure-null line.

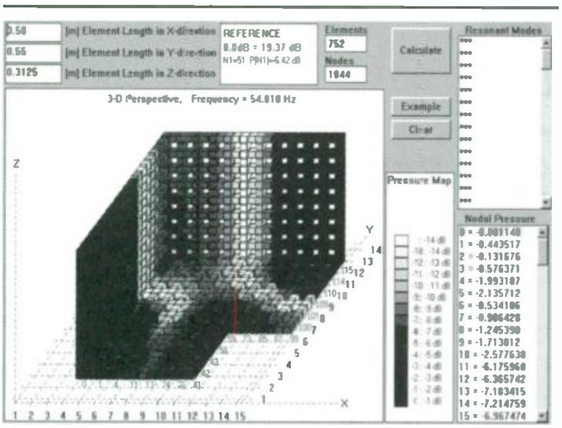


FIGURE 18: Switching the test frequency to the second-order mode.

Please note that computer-rounding errors also contribute to the value of the reference at modal frequency, and also that the modal frequencies, as in Part 1, are rounded to two decimal points; as in real life, there is no need for greater accuracy.

SOURCE AT THE NODAL LINE

Now keep the test frequency at the first room mode, but move the source to the pressure-null line of the first mode. *Figure 17* shows this situation, and you can easily observe that—despite radiating the exact modal frequency—the source fails to energize the room mode.

The sound field fades away quickly around the source and increases slightly in strength toward the opposite walls. The reference parameter is close to a typical wall/floor value of 6dB. The source was located at node 51, which is not exactly at the corner, due to the asymmetrical shape of the room.

Next, you maintain the source's location, but switch the test frequency to the second-order mode along this wall (*Fig. 18*). Again, as is predictable, the source fully energizes the mode, and the reference parameter shows a typical modal value close to 20.0dB.

CONCLUSION

Despite the simplifications noted at the beginning of this discussion, the FEM is quite capable of providing much useful information about the sound field in your listening room. You can couple your understanding of the room gain and room modes with the predicted distribution of the sound field at non-modal frequencies, and use the results of the analysis to improve the placement of the loudspeakers and select an optimum listening position. *Figures 12, 13,* and *14* are typical for frequencies below the first room mode, and are indicative of the expected difficulties when you attempt to reproduce low frequencies in a small room.

Locating the loudspeaker at node 51 (*Figs. 17* and *18*), will not fully energize the first room mode, but it will energize the second, and this results in a 12dB difference in maximum sound pressure in favor of the second mode (54.0Hz). Also, moving the speaker from a corner (*Fig. 16*) to a null location (*Fig. 17*) reduces the relative SPL from 32dB to 7dB—a massive 25dB decrease! You may not desire this additional sound coloration if your goal is to set up your speakers for maximum sound pressure at the lowest frequencies.

If you read Part 1, you may notice that all the plots presented here appear to have a "finer mesh." This is due to pressure-distribution functions being linear between the nodes, enabling you to easily calculate and display the pressure at any point between them.

Kit Review

THE AUDAX A652 LOUDSPEAKER KIT

Reviewed by Hilary Paprocki

Audax A652 Loudspeaker Kit, *Zalytron Industries Corp., 469 Jericho Tpk., Mineola, NY 11501, (516) 747-3515, FAX (516) 294-1943.*

Speaker kits present a quandary. On the one hand, you know that you can save some decent money by building your own cabinets, and maybe even by taking advantage of the driver overstock sales that are sometimes advertised in *SB*. You could build a system very similar to the ones the rich guys enjoy for a very ordinary cash outlay. On the other hand, you know that your MDF masterpiece is going to have zero resale value; but, you're not going to sell it anyway, so that's not a problem.

The big problem is that you have no idea what you're going to end up with. Depending upon your tastes, you may not even like at least half of the expensive systems that the hi-fi magazines recommend. And if the completed, available, hearable systems are this variable, how do you know that a sight-unseen, sound-unheard, shot-in-the-dark loudspeaker is going to "push your buttons?"

It is the object of the *SB* review articles to remedy this situation. This series of reviews is going to have an epochal influence on the feasibility of home speaker building. Now, the speaker-kit approach will for the first time have documentation—and it should be a safe and reliable path for all those people (like me) who never would have tried it otherwise. And if you build one of these reviewed systems, well, thanks to these articles, your speakers will very likely have a resale value that they never would have had before.

Manufacturer's Specifications

Drivers: two Audax HM 170C0 6½″ woofers, one Audax TW025MO tweeter

Cabinet: ported for QB3 response, f_3 at 53Hz, vertically centered D'Appolito arrangement, 26½″ high × 10½″ wide × 12″ deep

Crossover: fourth-order Linkwitz-Riley (realized with three electrical elements plus inherent driver rolloff)

Crossover frequency: 2.8kHz

Response: 60Hz–20kHz ±2.2dB, approximately 90dB efficiency

The star of today's show is the Audax A652 kit (*Photo 1*). It is part of the Audax Signature Series, a group of systems designed for Audax by Vance Dickason, professional loudspeaker consultant and author of *The Loudspeaker Design Cookbook* (available as #BKAA2-V from Old Colony Sound Lab, 603-924-6371, FAX 603-924-9467, E-mail custserv@audioxpress.com). Ralph Nichols at Audax says that the company did not give Dickason any marketing-based direction; rather, they just said, "design us something good." He returned with four systems: a smallish monitor (reviewed in *SB* 6/97), the monitor expanded into a D'Appolito-style system (the A652), and a couple of larger floor-standing units. These designs are detailed in a booklet entitled *Kit Plans*, published by Audax; in fact, a copy of this book comprises the instructions that you'll receive with the kit.

The rationale behind the driver choices or the intended sonic effect is not discussed in the book. The 652 kit uses a textile dome tweeter, and its data sheet speaks of a very rigid dome shape and a high degree of linearity. The tweeter's published response curve looks a bit curious, with one shelf from 0.9–3kHz and a second, higher shelf from 4–20kHz.

The woofer measures 6½″ and has a carbon fiber cone. Its data sheet describes Audax's effort to achieve "the best possible transient response, and an exceptionally natural top-end roll-off." The frequency plot is pretty flat but uniformly tilted up about 4dB all the way from 60Hz–5000Hz, with a funny little bump at 600Hz (I wonder why).

The driver has a reverse rubber suspension; I'm curious to know why Audax chose to do this. You would think that the only difference between a concave and a convex edge suspension is that airflow and diffraction would be much smoother around a convex one. The concave surround seems like an awful aerodynamic disruption between the cone and your baffle. We'll see.

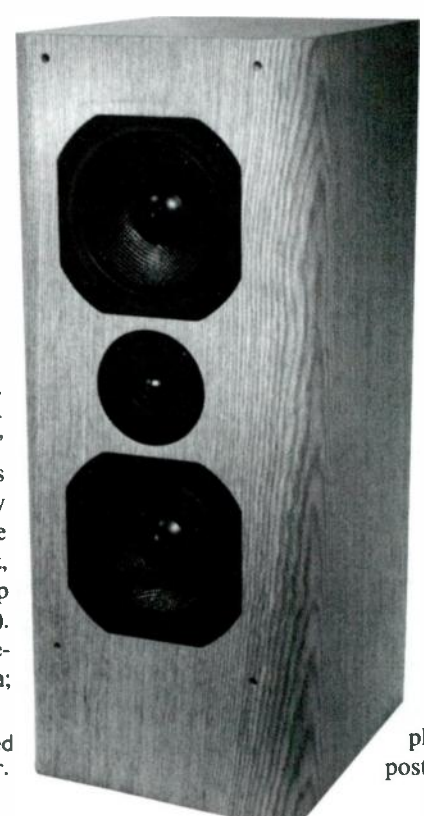


PHOTO 1: Completed Audax A652 loudspeaker.

THE ARRIVAL

My first reaction when the three boxes arrived was "Geez, I didn't realize these things were going to be so big!" They sat for a couple of days until there came a rainy autumn Sunday, a perfect time to tear into the boxes and build some new speakers. My second impression came when I opened the small box containing the crossover components. When I pulled the box flaps open, I found no packing material, just the parts carefully placed into the box, free to roll around and beat each other up during the ride here (*Photo 2*). The nice, beefy 14ga inductors did quite a number on the capacitors. I assume that this is not standard practice, and others won't be like this. Just one lone person somewhere made one isolated goof. Nothing looked really busted, though.

The capacitors are the perfectly nice Axon brand, by the way, with a couple of SCR-brand caps included for trimming. I'd say that the part quality is just fine. There are ritzier components available, but not many of us will want to pay for those very high levels of sound quality/status/mystique.

I *will* complain about the terminal cup assemblies. They look nice and all, with gold-plated knurled binding post banana receptacles,

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PHOTO 2: Crossover components as they arrived.

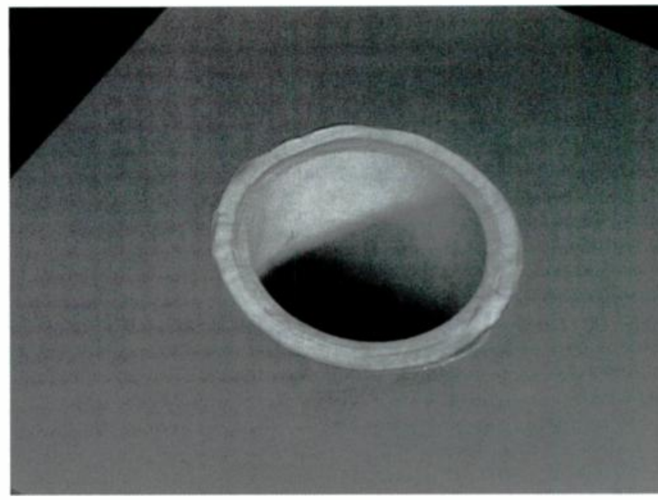

PHOTO 3: Silicone sealer packed between the port tube and cabinet.

but the cup is much too small to allow you to tighten the terminals with your fingers. Worse, the tabs provided for you to solder your internal wire onto are steel. You should not run audio through steel. It sounds about as good as it tastes.

The small cups do have an advantage in rigidity, however. If you decide to go for these speakers, you might consider buying a set of nonferrous hex-head binding posts, so you can use a nutdriver on them instead of your fingers. I built the kit with the parts provided, because that's what this exercise is all about.

THE CABINETS

The cabinets are beautifully made. When I first saw them, I said, "Holy cow, these were done on a CNC machine!" Actually, it turns out that they weren't, but the templates were. You are not very likely to do routing as precise as this by hand. If you do want to build your own boxes, ask the vendor for a baffle-and-grille (only) kit, which will spare you the really annoying and exacting work, especially on grilles. What a pain it is making grilles!

The Zalytron-built boxes provided with the kit conform to the internal dimensions of the Audax plan, but differ in a few ways.

First of all, they're made of double-thick fiberboard (except the small top and bottom panels), which means they're 1½″-thick all around and quite heavy. The extra thickness permits a nice sweeping radius on the sides of the baffle (there's a faint corner in the beginning of the curve). It also convinced the box builder that he could do without the one simple brace called for in the instructions, and who's to argue? This box isn't going to vibrate too much.

Deviating from the Audax book, the port was moved from the front to the back of the cabinet, and the driver-mounting positions were spread out a little (which works against the D'Appolito ideal of closely spaced drivers). The port is good old reliable plastic plumbers' pipe, and the not-so-pretty outlet of the port is capped with a cosmetic black plastic ring. The ring doesn't fit perfectly, though. I would have belt-sanded the pipe end flat to the panel and trimmed the plastic laminate that covers the back of the cabinet (a very nice touch, by the way) to the inside of the pipe, so the laminate would cover the edge of the pipe.

I noticed gaps between the port tube and the cabinet wood on the inside of the box, so I tried to work in some liquid wood glue. It ran through in a couple of places, which means that there were leaks. Maybe the cabinet port-hole edge should be beveled or rabbeted, the tube inserted, and some sealer poured into the resulting moat. That sure wouldn't leak, as long as the ring of sealer was present, and it would be rigid, too (one of these tubes wasn't). I just freehand-routed a ¼″ square trough around the tube, cutting about 1/16″ into the side of the pipe, and packed the space with some leftover silicone bathtub sealer (*Photo 3*).

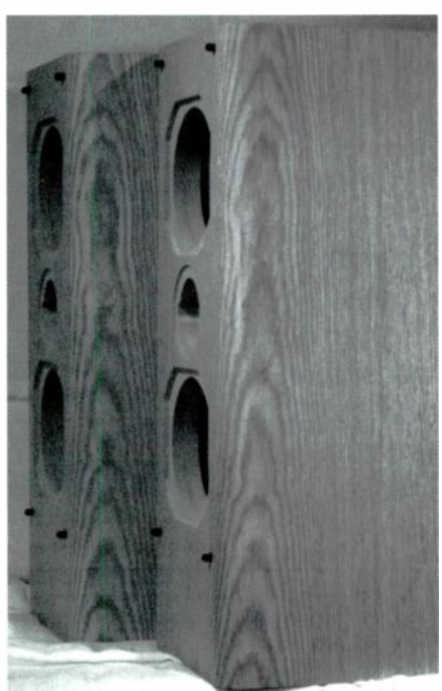

PHOTO 4: A thoughtful extra effort: grain patterns are matched between the two cabinets.

Speaking of plastic laminates, the cabinets were covered with a red oak veneer, and heavily coated with some plastic stuff that makes them look like Formica in a loudly grained pinkish-tan wood shade that takes a little getting used to. It's a shame, too, because Audax made the thoughtful extra effort of matching grain between the two cabinets (*Photo 4*). It must be said, though, that the cabinet looks much better with the drivers in place. They seem to set off the color, and those carbon-fiber cones lend a high-tech flavor.

Audax distributor Zalytron said that you are encouraged to call and discuss the wood and finish that you'd like to have. They'll give you whatever you want. White oak, walnut, teak, and a few other choices are available, but don't get the red oak unless you really enjoy a sharp stick in the eye. Note also that wash finishes are starting to show up in the stores, so you can choose "Fabulous Fifties" blonde if your tastes go that way.

One more thing: Apparently, there had been a little design change in the TW025MO tweeter, and the tweeters I received didn't fit their openings. The boxes had little reliefs cut into the tweeter-mounting hole for the driver terminals. These reliefs were not in the right place (*Photo 5*). No problem, I just pulled down the router and fixed it. Don't worry about the kit you're going to buy; I'm told the design will have been straightened out long before you read this.

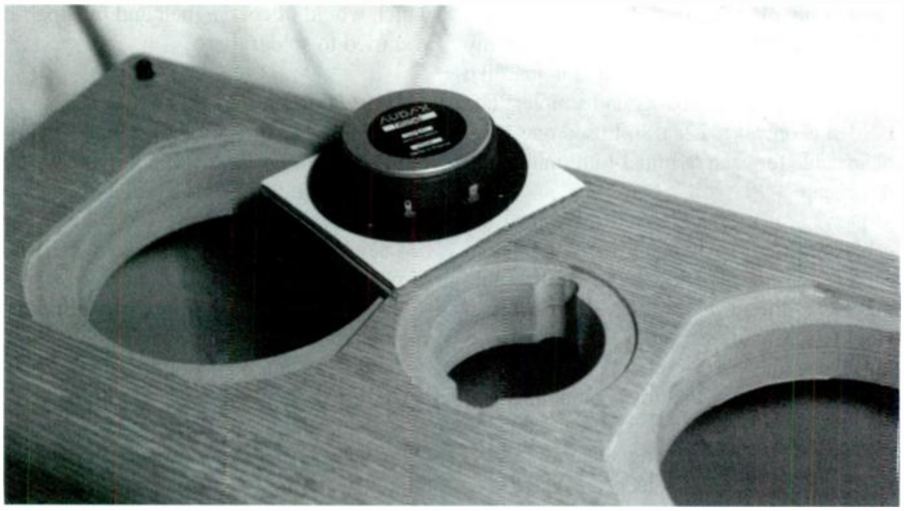

PHOTO 5: The redesigned tweeter no longer fits the mounting hole.

DOING THE WORK

You'll need to purchase some ¼″ plywood to build the crossovers. You'll need to cut and drill little breadboards for the parts. And drop by the fabric store for some fluffy polyester pillow stuffing, too. And get some wire for the drivers. Don't forget some screws and T-nuts for mounting the drivers, the terminal cup, and the crossover boards. Oh, and buy some epoxy and plastic ties to hold the parts onto the crossover boards. You'll need some solder terminal tags, of course, so that the wires aren't just dangling off the capacitors. And get some push-on connectors for the tweeter terminals, too.

Now, you might be thinking, "What kind of kit is this that makes me do all this shopping?" Well, it's a pretty good one. You're not just saving your money screwing the speakers together. That's the easy part. You're saving money because the manufacturer doesn't have to choose, search out, purchase, inventory, count out, package, and generally deal with a hundred little parts. If you're a manufacturer, that's annoying and time-consuming work, which ends up being expensive.

And remember what I just said about Zalytron giving you anything you want? They'll provide you with wires, screws, plywood, cabinet mods, anything—just ask. Black grilles are included, and they're very nicely executed—rigid and staple-free. Of course, the boxes are finished on all visible sides, so you needn't use the grilles if you'd rather not.

THE DRIVERS

Have you ever seen one of these Audax woofers? It's really something. You know how a speaker frame looks: there's a big ring and a smaller ring connected by struts. The big ring holds the speaker surround and bolts to your baffle board. The smaller ring holds the magnet on the back side and the spider on the front side.

Well, in the Audax woofer, there are three rings. The spider is pasted to the middle ring, then there's open air for a few millimeters until you get back to the ring that holds the magnet. You can actually look in between the rings and see the voice coil (*Photo 6*). Apparently, this lets the spider fly around in free air without being influenced by unpredictable air pressure fluctuations on the usually closed magnet side. The center of the magnet is vented, too, for the sake of the back of the voice-coil assembly.

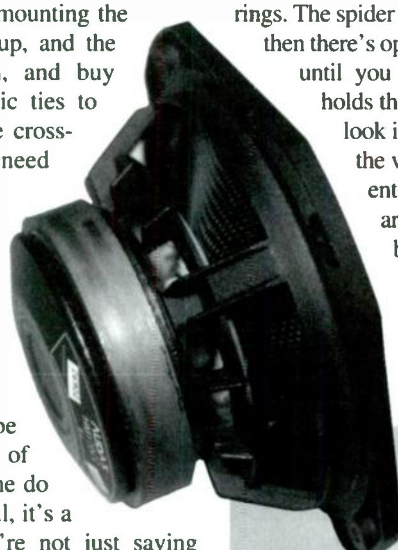

PHOTO 6: With the Audax woofer, the voice coil area is open behind the spider.

As for the merits of the carbon fiber cone, who knows? There are many really nice ways to make drivers, some of which sound good and some of which don't. We'll see.

CONSTRUCTION

There's nothing particularly mysterious in the construction, but I can mention a couple of things that you ought to keep in mind. You'll be building the crossovers on little ¼″ plywood boards (*Photo 7*). The book says to build separate high-pass and low-pass sections and to mount them on opposite sides of the cabinet, away from the driver magnets. That means on the top and bottom, and that's a pain because the port is in the way. You'll need a long drill to make the mounting holes, and long drills don't get much smaller than 1/8″ diameter. So be sure to get #10 mounting screws for the crossovers, so they'll work in an 8″ hole. And remember that the cabinet top and bottom are only ¾″ thick!

Oh, and don't forget that the crossover-assembly drawings in the book don't match the schematic! Dennis Colin mentioned this point when he reviewed the A651 kit (*SB* 6/97). The schematic is right. The parts drawing is wrong. Follow the schematic!

There's almost 8′ of two-conductor speaker cable inside each one of these cabinets (because of that business of separating the crossover sections). This suggested to me that I use a better grade of cable, so I purchased some Audioquest Type 4. It's inexpensive, seems to have been favorably reviewed, and looks like what I would have designed if it were up to me: stepped-gauge

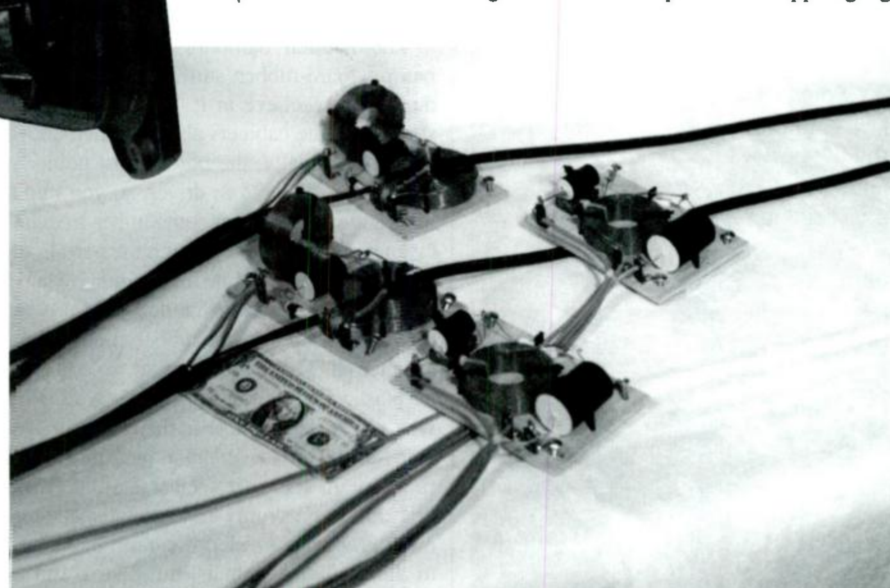

PHOTO 7: Crossovers built on plywood. Make sure they won't rattle apart; tie everything down tight.

solid copper conductors, PE insulation, and so on. The tweeter circuit was done with my old friend Belden 1242A, which is just like the Audioquest but smaller and simpler. The Belden is only 4 × 22ga, so I used one complete cable for each terminal-to-terminal run. It's cheap.

Don't ask me how much difference the cable made. I'm not likely to A-B internal cabinet wiring any time soon. But if cable makes a difference outside the box, you would reasonably presume that it makes a difference inside as well, no?

I used T-nuts for the driver mounting, and the word here is precision. Make sure that the holes are where they belong, that they're perpendicular to the cabinet face, and that the T-nut flanges are dead flat against the inside of the baffle. The screws will come straight up out of the T-nuts, and the holes in the drivers had better be right there where they do. The tweeter uses 8-32 × 1.5″ screws, and the woofers use 10-24 × 1.5″. It's a good idea to get little nylon washers so the screwheads don't tear up the driver faces. Try to get Phillips pan-head screws, too; the straight-slot round-head screws from the hardware store aren't very good-looking, and there's a tendency for your screwdriver to slip out of the slot and possibly stab the cone. (I found my hardware at Herb's Wholesale Supply, 716-254-7460, which is a great little place that doesn't charge enough.)

After you drill the holes for the drivers' T-nuts, clean up the holes on both sides with sandpaper. Then you can put a little epoxy on the nuts if you want, start them into the holes with your channel-locks, and draw them in the rest of the way with a sufficiently sized C-clamp. Of course, you'll have a wood cushion on the outside cabinet face when you do this, right?

The internal damping provided is that bumpy foam-rubber stuff. I used it, but I don't really believe in it. The book says to stop lining the cabinets about an inch above the port. Actually, the port almost points at the back of the bottom driver, so you might reasonably suspect that some upper-frequency energy will get out through the port. Look for an update some time in the future, when I try some padding that's a little more guru-approved. Who knows, the rubber might be better after all. The instructions say to add a little plastic fluff pillow stuffing as well, so it won't be just the rubber in there.

After the crossovers, T-nuts, rubber, and fuzz are in there, it's clear sailing. Each driver has one skinny and one fat spade terminal, for polarity identification. I soldered to the woofer terminals, but had to run to the store for push-on terminals for the tweeter. It looked as though the tweeter's terminal lugs were staked into plastic, which would of course melt and fall apart if you tried to solder there.

...JUMP FORWARD TWO MONTHS

The telephone rings. "Hello, Hilary, this is Joe D'Appolito. I have some good news for you and some bad news. The good news is that I've begun work on your speakers. The bad news is that the tweeters were wired out-of-phase."

"What? Everything I have says that the skinny terminal is positive, right?"

"On the tweeters, the fat terminal is positive."

Imagine that! All this time the tweeters were out of phase! After spending weeks listening to them and taking all those notes, moving all the furniture out of the big bedroom to make a dedicated listening room for this article, borrowing two other pairs of fairly expensive speakers for comparisons, hauling all these speakers in and out day after day for weeks, positioning correctly and making those tape marks on the floor, schlepping the speakers all the way to the Western New York Audio Society in Niagara Falls to engage 20 guys all night to listen and to fill out questionnaires—after doing all that work and calling in all those favors—the tweeters were out of phase! Imagine that, ha, ha. Out of phase! Hee, hee, hee. No, of course I'm not upset. Why would I be upset? WHAT MAKES YOU THINK I'M UPSET?

As soon as I got the speakers back from Joe I ripped them apart.

The data sheet for the woofers says that the skinny terminal is positive. The skinny terminal is painted red. If you apply positive DC voltage to the skinny terminal, the speaker cone moves out. That skinny terminal is absolutely, positively, positive.

For the tweeter there is no polarity notation on the data sheet and no red paint or engraved "+." The only artifact that denotes polarity is the skinny terminal, which is of course…positive…just like on my car-stereo speakers.

If the skinny terminal does denote positive displacement, I've been bamboozled. Wiring the speakers per the instructions causes a frightening notch in the frequency response and who knows what else. If the skinny terminal is negative, I've really been bamboozled. The polarity indication for the tweeter is opposite from that of the woofer.

The next day I borrowed a Keyence Laser Displacement Meter, a handy tabletop gadget that can measure displacements to the submicron level without touching. When I applied 1V DC positive to the tweeter's skinny terminal, the dome jumped back, almost exactly 210 microns. The skinny terminal was negative.

A LITTLE SOUL-SEARCHING

All you letter-writers and reviewer-reviewers out there are probably asking, "Why didn't this dimwit just fix it when he heard it?" Well, let me say two things about that. First, I made a conscious and deliberate decision at the outset that I was going to follow the directions exactly, question nothing, and report exactly what happened. My philosophy was that this is exactly what your average speaker-kit builder would do. Of course what happened is that I got murdered. But, I don't think that it was wrong to go about it this way. I did, after all, have a backup in the technical analysis that Joe would perform on the speakers.

Second, "Didn't those speakers sound a little weird?" Well, in fact they were a little, shall we say, distinctive. The amazing frequency-response graph notwithstanding, I really didn't have such high expectations of a kit speaker. I think that a lot of high-end speakers are awful. These samples could have sounded like weedwackers and I would have believed it. In this I was absolutely wrong. As you will see from the unbribeable Joe D'Appolito's charts, kit speakers are indeed capable of very precise performance. My apologies to the entire speaker-kit industry.

TO THE LISTENING ROOM

With great expectations, I set up the corrected Audaxes in the big bedroom, which really isn't that big and is a little square. When I fired them up, the sound was...muted, resonant, uninvolving—awful. This can't be right. I knew, however, that the sound I heard was an exaggeration of the sound of the room. What was needed was a big, characterless room: a near-anechoic chamber. And you know what? I have one.

My attic is as broad as the house (21′ × 26′), with a ceiling that is horizontal for about 5′ across and 7½′ high, and then slanted 45° to the floor. There is a large $8ft^2$ dormer, a large $6ft^2$ opening for the stairway. All of the walls consist of 4″- and 6″-thick glass fiber insulation with paper backing. If you want a hi-fi room, this is it. It is irregular and very dead, except for a little zing from the bare fir plank floor, and is lined by a few dozen boxes of books, old clothes, and other miscellaneous stuff. This will be perfect.

As for descriptions, of course, you don't want to hear me say how nice these speakers sound. That wouldn't mean much to anyone as an isolated statement. You want to know whether they sound better than your other speaker purchasing options. Thanks to the Western New York Audio Society, I was able to obtain a nice pair of NHT 2.5 loudspeakers (not the new i version) for comparison. The NHT is a popular loudspeaker that retails for about $1,100 per pair. Many of you may have heard them, which makes them a good basis for comparison.

GETTING SPECIFIC

Where the NHTs were at home in a typical room—smooth, lively, and eager to please—they sounded a little wiry in the attic. I'd compliment the designers of the NHTs for (presumably) making them sound best in real room situations. The Audax A652s were fuller and sounded as creamy-smooth in the attic as they sounded bad in the room. They were still a little weak on top, however, and lacked the bass of the NHTs, too. A consistent paperiness appeared in the A652s' sound, but it was minor and ignorable. A couple of other people also heard it, on a different system. (Could it have been the little series of resonances between 1–3kHz in the spectral decay graph?)

One gratifying aspect of the Audax units' performance was that I heard details on these speakers that I had never heard before: piano players grunting, valves flapping shut on horns, people shuffling around in orchestral recordings. I really like stuff like that, every bit as much as I hate overly precise sanitized studio recordings.

The NHTs were a little freer in the way that they tossed dynamics into the room, but the Audax dynamics were strong and possibly more literal. It seemed that the A652s didn't go as black as the NHTs did between pulses of sound. But the detail of the A652s was somewhat superior in that perfect environment, and the musicians' instruments did not bunch up as they did in the NHTs. You will wish that the Audax speakers had just a tiny bit more tweeter output.

As good as they were, though, I couldn't say that I liked them. It was like drinking lukewarm water—they just didn't have

THE EQUIPMENT

The power amp I used at home was a Dynaco Stereo 70, modified with a giant power supply, modern (but not boutique) resistors and capacitors, increased bias current, and decreased negative feedback. The circuit itself is stock. The CD player was an old Magnavox CDB-465, with D/A conversion by an Audio Alchemy Ultra-Dac. Speaker cable is the Audioquest Type 4 mentioned in the article. Interconnects are unshielded twisted single-conductor pure copper wires in polyethylene insulators and no jacket.

what I thought they should have. They were very precise but kind of blah, not engaging, Dullsville. They just didn't have legs.

Legs! That's it! I ran down to the pro-sound shop and rented a stereo electronic crossover. I connected the Stereo 70 full-range to the Audaxes. And I used a big solid-state amp with the NHTs, crossed over at 45Hz so that only the subwoofers were in operation.

That did the trick! Now, the system sounded good, very good. The truncated frequency response of the unassisted A652s only made them sound strange given their clarity otherwise. With the bottom octave tastefully filled out (a 50Hz crossover point sounded a little juicy, 40Hz a little dry) the sound was big and convincing. The addition of woofers even made a difference in the tone of an alto sax, believe it or not.

And, come to think of it, don't many commercial range-limited speaker systems throw a little bump in their bass response in an attempt to compensate for the missing octaves? The Audax systems don't—they're comparatively flat—and the effect without augmentation is very much of a strange incompleteness.

The Audaxes imaged the best (and the best was awesome) when pointed straight at the listener. With too much toe-in, the image bunched up in the middle; with too little toe, the image split to the sides during crescendos. I don't know why that should be, but that's what happened. Straight on, the image was big, realistic, and free of any sense of coming from two boxes, assuming, of course, that the recording was good.

The bottom line seemed to be that the Audax A652s may be very good speakers, but they don't really aim to please unless you add a subwoofer or two. Do that, and they are tremendous. You certainly can live with them while you save up for the woofers. Or start with something cheap, like a garage-sale pair of old original Advents for the bottom octave (under $50). That would be much better than nothing, until you can afford to get fancy.

And take note also, the A652s will sound very much like the space in which you install them. They are much more tolerant of a mediocre amplifier than of a bad room. If it's a terrible space, you will get terrible sound. If it's great, they'll sound great!

ONE LAST ADVENTURE

I took the speakers (again) to a meeting of the Western New York Audio Society, a good old bunch of regular guys from the Buffalo area. Ten gentlemen among the group of listeners chose to respond.

The tracks I played were from a few discs that sounded good in the attic: Erato EDC 88018 Chabrier, "Espana," Orchestre National de France: track 1, "Joyeuse Marche;" Verve 314 528 408-2 Cannonball Adderly, "Sophisticated Swing" (1956): track 1, "Bimini;" Teldec 2292-46315-2 Dvorak, "Serenades," St. Paul Chamber Orchestra: track 1, "Serenade in EM, op. 22;" Rhino R2 7160, "Don't it Sound Good: the Great Atlantic Vocal Groups" (and by the way, if Rhino can make a good-sounding vintage vocal group CD, why can't anyone else?): disk 2, track 16, Drifters' "Ruby Baby;" and Columbia G2K 45037, "The Jazz Masters": track 1, Miles Davis' "Summertime."

Did the respondents like the speakers? The collected answers were: yes, yes, initially, nice at $500, yes, not a bad kit effort, ok, nothing special, yes, and yes. Respondents' estimations of a proper price if these were finished store-bought speakers ranged from $350 to $1,500, with the average at $765, for the pair.

There were many specific observations and descriptions given by the group, but the gods weren't finished playing with us yet. The speakers sounded so much worse at the club meeting than they did at home—boomy, thick, and slow—that I am convinced there was something terribly wrong with the equipment used for the club demonstration. In fact, the system clipped using a very large amplifier, and the volume really wasn't that high. I will only report that the general response was positive; to bring up specific comments and an equipment list would be unfair. Still, the club members were positive regarding the units' smoothness and big soundstage.

THE CENTRAL QUESTION, THEN

You can build these loudspeakers for about $300 for drivers and maybe another hundred or two for the wood and all the other stuff. For that price, it's a pretty good deal. It'll cost a little more if you buy the cabinets all finished, but you'll have a nice-looking pair and enough work that you'll have a feeling of accomplishment. You can experiment, if you

A NOTE ON TESTING

The Audax A652 kit was tested in the laboratories of Audio and Acoustics, Ltd. using the MLSSA and CLIO PC-based acoustic data-acquisition and analysis systems with an ACO 7012 ½" laboratory-grade condenser microphone and a custom-designed wide-band, low-noise preamp. Polar response tests were conducted with the aid of a computer-controlled Outline turntable on loan from the Old Colony Sound Lab division (603-924-6371) of Audio Amateur Corporation.

want, with internal slanted baffles and exotic stuffing, biwiring, and subwoofers. Note that there is another Audax tweeter in the Zalytron catalog—the DTI01—with a couple of dB more output for about the same price. If you do succeed in bringing these speakers to their ultimate development, you'll end up with a genuine high-end speaker system for a pretty low price.

As for the review experience, I have never seen so many things go wrong in one project in my life. And I didn't even tell you about the lost photographs, or the burst shipping boxes, or finding out when I got home that the store cut one of the speaker cables a yard short. Man, oh man, oh man. But, you are forewarned. Now that you know everything that can happen, you are equipped to cruise right through this project. And the Audax A652s really are quite good speakers.

ACKNOWLEDGMENTS

I wish to thank the WNYAS for providing comments, twice; Tom Machamer for providing the NHTs; Eliot Zalys at Zalytron, for answering all those questions; and Ed Dell for his saintly patience.

TESTING THE AUDAX A652 LOUDSPEAKER KIT

By Joseph D'Appolito

I ran a series of impedance, frequency-response, and distortion tests on the Audax A652 kit constructed by Hilary Paprocki. I first ran a quick frequency response to make sure there were no gross problems. I usually do not report this test. Unfortunately, there was a problem. *Figure 1* shows the reversed polarity frequency response run, revealing a broad 20dB-response notch centered at 3.1kHz. Clearly, the tweeter polarity was incorrect. I opened the first sample to find that the tweeter terminals were unmarked, making it an easy matter to guess incorrectly. Reversing the tweeter leads produced the second, and in-phase, response curve shown in *Fig. 1*. Now the real testing could begin.

Figure 2 is a plot of the A652 system impedance. Below 200Hz, you see the classic double-peaked curve of a vented system. The minimum impedance of 4.2Ω between the peaks places the box frequency at 37.6Hz. The overall minimum of 3.7Ω occurs at 218Hz, qualifying the A652 as a 4Ω system. Below 200Hz, impedance phase ranges between +52° and −60°. Some tube amps and amps with poor low-frequency stability may have a problem with this load.

Figure 3 shows the on-axis frequency response of the A652. This curve is a composite of the quasi-anechoic response data above 200Hz, taken with the microphone placed on the tweeter axis at 48″ and combined with near-field woofer and port data below 200Hz to complete the curve. The plot is normalized to a 1m distance to measure system sensitivity.

It is difficult to assign a single sensitivity to this system. Response slopes gently

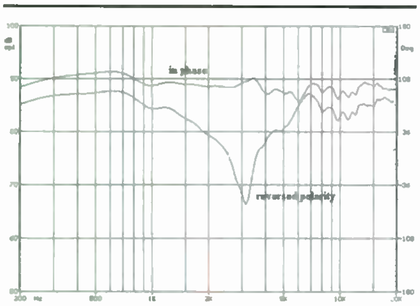

FIGURE 1: Tweeter phasing test.

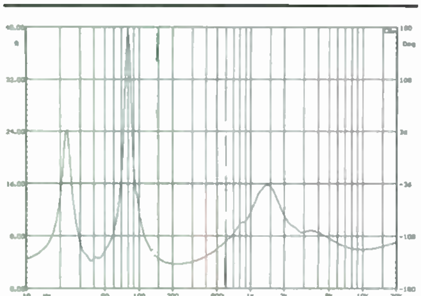

FIGURE 2: The A652's impedance.

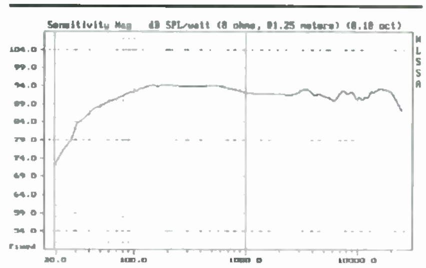

FIGURE 3: System response on tweeter axis at 48″.

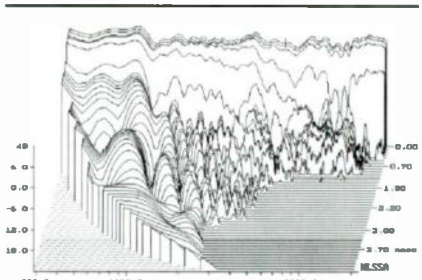

FIGURE 4: Cumulative spectral decay.

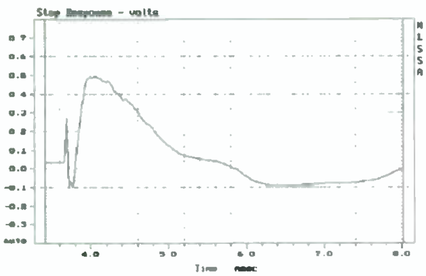

FIGURE 5: Step response.

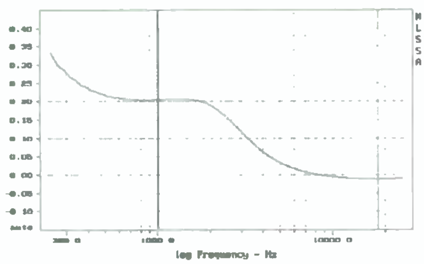

FIGURE 6: Excess group delay.

downward from 700Hz–2kHz. In the two octaves centered about 1kHz (500Hz–2kHz) sensitivity averages 92.3dB/2.83V/1m, but between 100Hz–1kHz it is 93.5dB and from 1–10kHz it is 91.6dB. The plot is quite smooth. Many listeners prefer this gently falling response to a flat response. It is often less fatiguing during long-term listening sessions.

The cumulative spectral-decay response for the A652 is shown in *Fig. 4*. This plot shows the frequency content of the system decay response following a sharp impulsive input at time zero. The first four milliseconds (ms) are shown with a total dynamic range of 30dB. The tweeter response above 3kHz decays by 30dB in less than 1ms. This is very good. Decay response below 3kHz is controlled by the woofer and its crossover network. Here again, decay response is quite good. There are no distinct uni-modal ridges, although there is some hash starting out at about 1ms in the 1–3kHz range, which may possibly be heard as upper midrange congestion.

SYSTEM STEP RESPONSE

Figure 5 is a plot of system step response. The initial positive-going tweeter arrival is followed by the woofer arrival, peaking about 0.3ms later. The drivers are both connected with positive polarity, but with fourth-order acoustic crossovers, the system is not time coherent.

Another view of this behavior is seen in

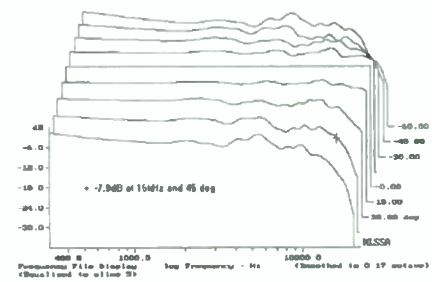

FIGURE 7: Horizontal polar response (−60° is 60° right).

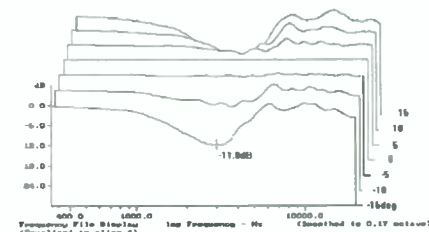

FIGURE 8: Vertical polar response (−15° is 15° below tweeter axis).

Fig. 6, a plot of excess group delay versus frequency referenced to the tweeter's acoustic phase center.[1] In a time-coherent system, this plot would be a flat line. Above 10kHz excess group delay is essentially zero, as it should be since it is referenced to the tweeter in this frequency range. The curve rises below 10kHz to a plateau starting just below 2kHz. The difference in excess group delay between 15kHz and 1kHz points is 0.215ms, which is the woofer/midrange delay relative to the tweeter.

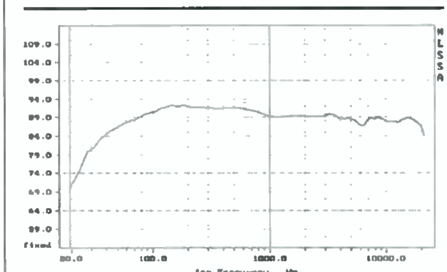

FIGURE 9: Response averaged over a ±30° horizontal window.

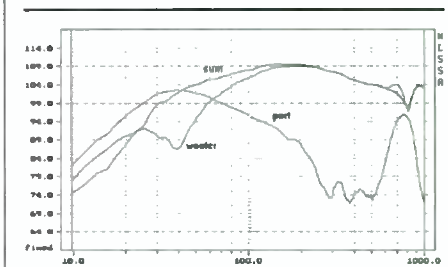

FIGURE 10: Near-field woofer and port responses and their complex sum.

This rise in excess group delay plus the notch shown in *Fig. 1* indicate a crossover frequency near 3kHz. Below 500Hz, excess group delay begins to rise again due to the 24dB per octave roll up of the vented system bass response. Excess group delay is a very accurate indicator of inter-driver time offset.

System polar response is examined in *Figs. 7* and *8*. *Figure 7* is a waterfall plot of horizontal polar response in 15° increments from 60° left to 60° right when facing the speaker. The microphone is placed at tweeter height for this series of curves. All off-axis plots are referenced to the on-axis response, which appears as a straight line at 0.00°. You can see the expected rolloff of tweeter response at higher frequencies and larger off-axis angles. Tweeter response is down 7.9dB at 15kHz and ±45°. For good stereo imaging, the off-axis curves should be smooth replicas of the on-axis response with the allowable exception of the rolloff at higher frequencies. This is clearly the case with the A652.

Figure 8 is the waterfall plot of vertical polar response for the A652. Responses are shown in 5° increments from 15° below (−15°) the tweeter axis to 15° above it. Response at ±5° is within 0.4dB of the on-axis response. At ±10° response dips 5.1dB, and at ±15° it is −11.8dB in the crossover region. This dip is caused by the wide separation of the drivers relative to the crossover frequency. The inter-driver separation is 1.2 times wavelength at the 3kHz crossover frequency. This is almost a factor of two greater than the separation recommended in my paper.[2] At vertical off-axis angles greater than ±7°, you should begin to notice timbral changes in frequency response.

The average response over a 60° horizontal angle (±30°) in the forward direction is shown in *Fig. 9*. The response is very smooth, sloping gently downward by about 2dB from 800Hz–15kHz. This is an excellent horizontal polar response and suggests good direct-field coverage in the primary listening area with little if any timbral change. Image stability should be very good.

Near-field woofer and port responses are shown in *Fig. 10*. These responses are summed by the MLSSA system, properly weighting the difference in areas of the combined woofers and the port, to obtain the complete near-field system response. This response is then spliced to the quasi-anechoic response at 200Hz to get the complete system response, shown in *Fig. 3*, without the use of an anechoic chamber.

The dip in woofer response just below 40Hz indicates the box tuning frequency. The port output is near maximum at this point. The port curve also shows a peak 860Hz, which is the result of an "organ pipe" resonance in the port tube. This resonance causes a dip in the overall near-field response, but because the port exit is on the rear of the enclosure, it does not show up in the far-field responses of *Figs. 3* and *9*.

Harmonic distortion tests were run at an average SPL of 90dB at 1m. *Figures 11* and *12* show second- and third-harmonic distortion levels in dB SPL versus frequency in 1/3-octave steps. System frequency response is also plotted on these figures. At 50Hz distortion, it is only about 20dB below the main output, roughly equivalent to 10% total harmonic distortion (THD). Second- and third-harmonic distortions are 3% and 1%, respectively, at 100Hz. Distortion falls below 1% above 200Hz and is at or below the 0.3% level above 1kHz.

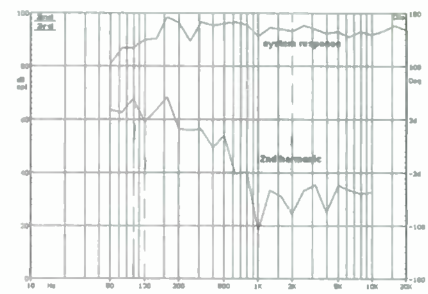

FIGURE 11: Second-harmonic distortion.

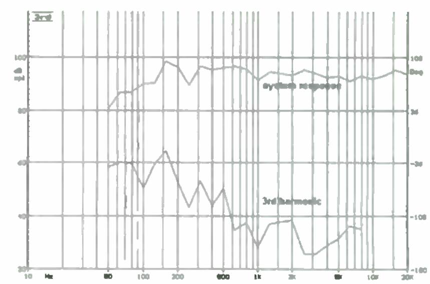

FIGURE 12: Third-harmonic distortion.

IM DISTORTION

With the latest revision to the CLIO software, I now have the ability to conduct intermodulation distortion (IM) tests. In this type of test, two nearby frequencies are input to the speaker. IM distortion creates output frequencies which are not harmonically related to the input. These frequencies are much more audible and annoying than harmonic distortion. Let the symbols f_1 and f_2 represent the two frequencies used in the test. Then a second-order nonlinearity will produce intermods at frequencies of $f_1 \pm f_2$. A third-order nonlinearity generates intermods at $2f_1 \pm f_2$ and $f_1 \pm 2f_2$.

Woofer intermods were examined first by inputting 900Hz and 1kHz signals at equal levels. These frequencies are far enough below crossover that little if any energy will leak into the tweeter. SPL with the two signals was adjusted to 90dB at 1m. The A652 output spectrum is shown in *Fig. 13*. The two largest lines represent the input signals. The primary distortion products and the place they originate are listed below.

1900Hz = 900 + 1000 (second-order)
800Hz = 2 × 900 − 1000 (third-order)
1100Hz = 2 × 1000 − 900 (third-order)
2800Hz = 2 × 900 + 1000 (third-order)
2900Hz = 2 × 1000 + 900 (third-order)

The majority of intermods are third-order, but the largest distortion product at 800Hz is 50dB below the main output, which is equal to 0.32%. This is better than many tube amps!

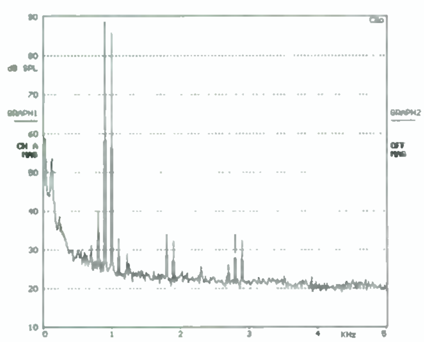

FIGURE 13: 900Hz/1kHz intermod distortion.

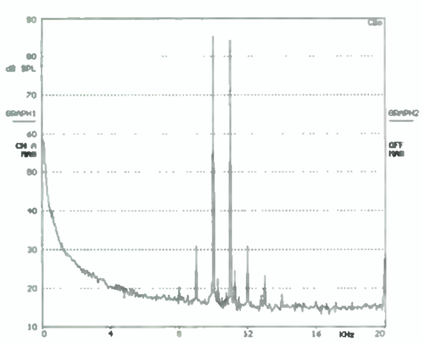

FIGURE 14: 10k/11kHz intermod distortion.

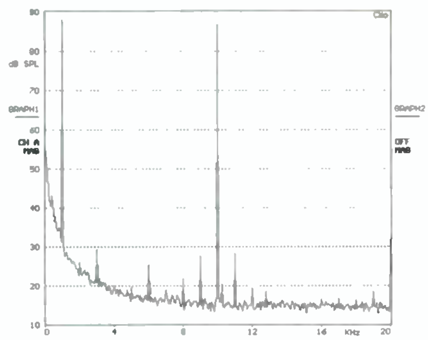

FIGURE 15: 1k/10kHz intermod distortion.

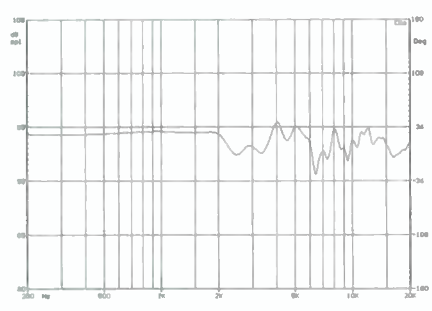

FIGURE 16: Effect of grille on frequency response.

Tweeter intermods were measured with a 10kHz and 11kHz input pair also adjusted to produce 90dB SPL. The results are shown in *Fig. 14*. Intermods are at 9, 12, and 13kHz. The last one is made up of (3 × 11kHz) − (2 × 10kHz). However, all intermods are down 60dB at 0.1%. This is very good performance.

The last intermod test examines the cross-intermodulation between the woofers and the tweeter using frequencies of 1kHz and 10kHz (*Fig. 15*). Spectral lines at 3kHz and 6kHz are woofer harmonic distortion. The lines at 8, 9, and 11kHz are intermods. Still the worst case intermod at 11kHz is at 28dB SPL, which is 62dB down from the main output at 0.08%. IM distortion does not appear to be a problem in the A652 at reasonable SPLs.

All of the above tests were conducted with the grille off. *Figure 16* shows the response of the A652 system with the grille on, but referenced to the response with grille off. That is, it plots the *difference* in response under the two conditions. Below 2kHz, the grille has no significant effect. Above 2kHz, however, the grille causes rather ragged response deviations of 5dB pk-pk. This grille is clearly of cosmetic use only.

One final comment: all of the above tests were made on one sample of the A652. Although not shown, response of the second sample was within ±1dB of the first. Quite impressive for a kit.

References

1. J.A. D'Appolito, *Testing Loudspeakers*, Audio Amateur Corporation, Peterborough, NH, 1998. (Available later this year as #BKAA45 for $34.95 plus s/h from Old Colony Sound Lab, PO Box 876, Peterborough, NH 03458-0876, 603-924-6371, FAX 603-924-9467, E-mail custserv@audioxpress.com.)

2. J.A. D'Appolito, "A Geometric Approach to Eliminating Lobing Error in Multiway Loudspeaker Systems," 74th Convention of the Audio Engineering Society, Preprint #2000, New York, NY, October 1983.

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SB Mailbox

CLIOLITE® CORRECTION

Figure 8 of Dick Pierce's "Product Review: CLIOLite," as published in *Speaker Builder* 3/98, is incorrect. The correct minimonitor response comparison diagram is illustrated in *Fig. 1*.

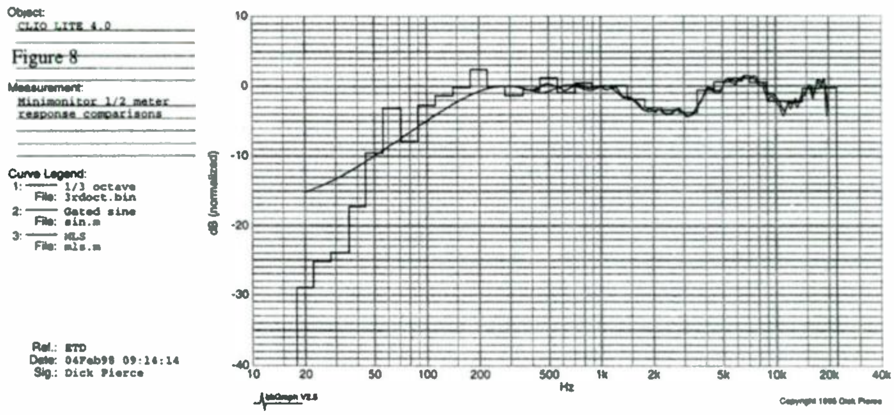

FIGURE 1: Pierce's minimonitor response comparison.

NOT PHASE LINEAR

The Reference Monitor (*SB* 2/98, p. 32) may well be a fine-sounding speaker system, but I don't believe statements made in the article about the phase-linearity of the system are supported by the data presented. Note that this discussion pertains only to the tweeter's frequency range; no multi-way loudspeaker system with a passive high-order crossover is phase-linear over its full frequency range without the use of phase-correction networks. Based on the input impedance peak shown in Fig. 5 of the article, the tweeter seems to be used from about 1.5kHz up.

Figure 4 shows the Reference Monitor phase shift versus frequency plotted as phase shift in degrees on a linear scale versus frequency on a logarithmic scale, i.e., a normal semi-log plot. The article states that since the phase shift in the tweeter range of Fig. 4 approaches a straight line, then the system is phase-linear in this range. I believe this statement is misleading, and, in fact, the data presented indicates the system is phase nonlinear.

A phase-linear system, also called a minimum phase system, is one in which the phase shift varies directly with frequency, indicating a constant group delay and thus no phase distortion. Such a system will have a phase shift that plots as a straight line on linear paper, i.e., both phase shift and frequency are linear axes. The equation for a straight line on linear paper is $y = mx + b$, while that for a straight line on semi-log paper is $y = m \, Log(x) + b$, which will not plot as a straight line on linear paper unless slope $m = 0$, i.e., a horizontal line. Thus, the only time it does not matter whether you plot phase on a linear or semi-log plot is when the phase shift is constant, yielding that horizontal line.

Since the Reference Monitor phase shift approximates a straight line on semi-log paper, it will not plot as a straight line on a linear plot. *Figure 2* shows my best efforts at reading the phase shift data from article Fig. 4 for the Revelator tweeter and plotting it on a linear graph. This is clearly not an approximation to a straight line and indicates the Reference Monitor is not phase-linear and will show phase distortion or what is referred to as time dispersion even throughout the tweeter frequency range.

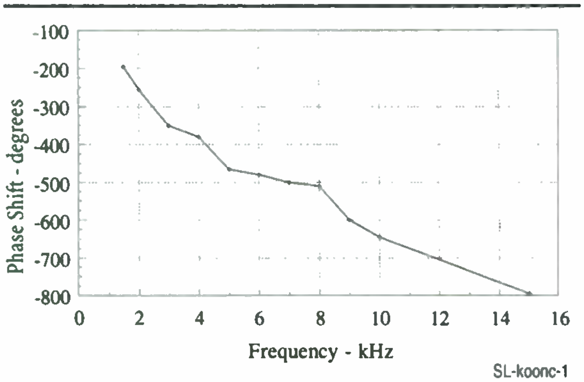

FIGURE 2: Linear plot of Reference Monitor phase shift through tweeter range.

Thus, a transient waveform played through the Reference Monitor will show a distorted waveshape in the acoustic output due to the nonlinear phase shift performance of the system throughout its full frequency range. Most speaker systems do this, and it is still being argued whether this effect has adverse audible consequences.

G.R. Koonce
Liverpool, NY

Rolph Smulders responds:

The Reference Monitor is not designed as a linear-phase loudspeaker: a glance at the shape of the enclosure and the filter circuit immediately shows this. The aim of the design was to obtain a phase characteristic with linear slope. The reason for this is that when the ear is listening to a loudspeaker, it is sensitive to phase jumps and not to gradual changes in the phase. I fear that Mr. Koonce has interpreted the measurements differently, but that, of course, is not my fault.

TOO HOT TO HANDLE

I have been reading Tom Yeago's "journey" through the rebuilding of his AR-3s with much amusement. The 2/98 installment included a comment about how he inadvertently demagnetized his speaker magnets after following a tip I offered in 1990.

His claim that 350°F demagnetized his magnets does not make sense to me. Upon reading this I immediately checked our reference department for the Curie point of ferrite magnets—the Curie point is the temperature at which the magnet will become demagnetized. Assuming the magnet to be a barium-based ferrite, that point is about 400–450°C (or about 750°F minimum). Heating the magnet to 350°F in the oven should not have had any effect on the magnet strength.

Striking, or dropping, the magnet will have much more deleterious effects on its strength. I use a vise or clamp to apply shearing force when disassembling magnet structures (while hot). Perhaps Tom's hammering caused the problem.

Lastly, a nonferrite alnico magnet would suffer about a 1.5% loss in total flux when heated to 200°C (about 390°F). This is almost unmeasurable, as well, so I suspect the problem is something other than heat-related.

Tom Yeago's article has been quite entertaining, to say the least. It's just amazing how much he can do with a mere $50 and 1,200 hours of free time.

Matthew Honnert
Product Manager
Alumapro Metal Cone Speakers

Tom Yeago responds:

Ah, Mr. Matthew Honnert is heard from.

I related my experience with loss of coercivity in some magnets after separating them from their iron using heat. These were type 1 ceramics (barium ferrite) in motors I was splicing onto some old AR 8″ woofers (a thankless task if ever there was one). If I understand Mr. Honnert, he maintains that as long as the magnets are heated short of their Curie temperature (460°C, or about 860°F for these ceramics), they will not suffer. No, that's not quite accurate: Mr. H. maintains that a stint in a 350°F oven will do no harm.

These motors looked like candidates for the job, but I wanted to add a Faraday ring around the pole and make some other slight changes, so I decided to use heat to pop the pieces apart, but not before I used my iron-on-a-tether to see how much it took to pull the "probe" free—350g. Instead of firing up the oven, I situated the motors over a gas burner at very low heat. I tested for heat by flicking some water on the iron, and when it vigorously boiled off I figured I was well clear of 212°F and in the range Mr. Honnert suggested. I then clamped the top plate and twisted off the rest of the motor using a strap wrench (no hammering here).

Then back to the burner and repeat the procedure to separate the magnet from the back plate. I went about my chores, and when I'd assembled the entire magnet structure—with a healthy magnet in opposition on the back—the gap would pull only about 250g on my iron-balance setup. I was not pleased. Later on, when I received Magnet Sales & Manufacturing's catalog in the mail, I read their excellent technology sections.

Here's what I found under temperature effects for ceramic magnets: "Up to about 840°F, changes in magnetization are largely reversible, while changes between 840°F and 1800°F are remagnetizable. For all ceramic magnets, the degradation of magnetic properties is essentially linear with temperature. At 350°F, about 75% of room temperaturemagnetization is retained, and at 550°F, about 50% is retained."

Other sections on permanent magnet temperature stability cover reversible losses, irreversible but recoverable losses, and irreversible but unrecoverable losses. As I understand it, if you're going to heat up a magnet, you want it to be flowing as much flux as possible for it to cool down without sapping its vigor. At least, that's what I thought when I wrote the paragraphs in question.

Then Mr. Honnert wrote in, sending me back to the technical pages, which, good as they are, don't address this specific point with absolute clarity. So I resorted to their 800 number, got a very helpful woman in technical support (whose name I failed to jot down), and, trying my best not to sound like a complete crank, related my story and asked for an answer. Turns out (ha ha), I'm right. Heating these magnets like this will get you some demagnetization on which you'd have to do a complete recharge to cure. If the magnets are flowing lots of flux, it's not so bad, but if you're separating the ceramic magnets from the steel pieces, well, that's a worst-case situation.

It looks to me like a statistical problem, believe it or not. Any time you heat something, you don't have absolute homogeneity of temperature throughout; you have a spread, with some bits hotter, some cooler, with the hotter bits getting closer to Curie temperature. This would explain the continuously higher loss of vigor as the magnet is heated, until you get to Curie, when the magnet domains are randomized and there's no net magnetic organization. Not unlike water going to vapor well short of 212°F.

Now, Mr. Honnert also mentions that impacts or physical shock will adversely affect ceramic magnets. I've read allusions to this, but nothing specific, and I note that the magnet houses caution us that magnets should be machined before they're charged. Does anyone out there care to enlighten us on this obscure topic?

Also, Mr. Honnert brings up something about alnico magnets that readers might not recognize as a correction to Mr. Klasco's piece in the same issue. On p. 47, Mr. Klas-

co mentions that the ferrite magnets just introduced were better than the alnicos they were displacing in their resistance to demagnetization by heat and physical shock. I think it's the alnicos that are the champs when it comes to resisting heat; it's adverse fields that are the alnico's Achilles heel.

Finally, I am pleased to have amused and entertained Mr. Honnert. I would prefer to have amused, entertained, and delighted, but we take what we can get. I am amused at the crack about 1,200 hours of free time: that works out to thirty 40-hour weeks. I admit to having too much free time.

For the record, I bought these AR-3as in May '95, and they sat until fall. By January '96 I'd finished the woofer described here and started work on the domes. By March everything was done except the old-style (alnico) woofer. I'd been glowering at it across the room, but finally got down to cases and had both units running by April '96. Bruce Shull borrowed them in October '96.

Now, for Mr. Honnert's amusement, my next trick will be to build my own high-power triode, using an old milk bottle and common items found in every kitchen.

DEALING WITH DIPS

After happily and successfully using your IMP loudspeaker measurement system for a number of years, I recently made a number of difficult-to-explain measurements on an experimental system. A frequency measurement (on-axis at 1m) on a flat electrostatic speaker (32cm × 98cm) gave a flat response between 1kHz and 20kHz.

Curving the plates over the 32cm to give a 30° opening angle shows a 10dB dip at around 9kHz; the height, width, and frequency of this dip depend on the distance from the speaker. The dip shows a second, smaller dip at slightly higher frequencies.

Moving the microphone to the side to 15° from the axis at 1m gives, again, a flat response. A normal sine-wave measurement in a reasonably "dead" room along the speaker axis does not show the dip.

I do not understand these phenomena and would be very grateful if you could cast some light on these differences.

Fred Pohlmann
The Netherlands

Bill Waslo responds:

After reading your description, I suspect that the 9kHz dip may be coming from a cancellation caused by the speaker acting like several signal sources rather than as a single distributed source.

If the planar speaker behaves like a continuous, homogeneous radiating area, the resulting frequency response is also likely to be a smooth curve without sharp dips (not necessarily flat, but at least generally smooth). This result is more likely with a single flat panel because when the diaphragm of the ESL is stretched, its natural tendency is to stretch into a flat plane to equalize the tension.

But if the speaker has "hot spots" or for some other reason acts like a set of multiple small flat panels, each can radiate a separate signal to the microphone or listening position. If the curvature is accomplished "piecewise" by an arrangement of several small flat panels, these separate pieces can act like separate speakers, each with different but not isolated radiation patterns and signal delays.

This can happen even if the panel is made using continuously curved stators. Stretching the diaphragm over a curve can result in flat or depressed spots, because any tension on the diaphragm along tangents to the curvature will tend to make the diaphragm want to straighten out in places between the spacers rather than follow the curvature of the stator plates. These areas might play hotter (from being nearer a stator) or act like small flat panel sections so that the system behaves like several separate speakers instead of a distributed arc.

When the microphone picks up two or more separate acoustic signals resulting from the same electrical signal, there can be a delay between them. If the levels sensed are similar, expect a dip or notch at the frequency that has a wavelength of twice the inverse of the delay time. In other words, if the signal (at some frequency) from one source arrives, due to delay, nearly inverted in phase from the signal from another source, there will be a notch in the response at that frequency.

The notch frequency, depth, and width will change with the measuring distance from the speaker because the relative delays will vary with distance. The relative signal strengths sensed will also change, as you move through different areas within the radiation angles of each virtual radiator, which will also be a function of distance. Since you see a flat response at 15° off-axis, I suspect that this position puts you essentially out of the radiation coverage of other virtual radiators in the system except one that beams in that direction.

I don't have a good suggestion as to why the sine-wave measurement doesn't show the notch except that perhaps the resolution may be inadequate. You would need to test in a detailed range around the notch frequency with continuous (non warbled) sine-waves without any room echoes, which would be *quite difficult to do at appreciable distances from the speaker.*

Depending on the severity of the dip and whether you believe it is audible and objectionable, your curved arrangement may still be a good compromise for getting better coverage from the speaker. A narrow dip at 9kHz is probably not going to have major effects on the sound.

TWO-WAY FOLLOW-UP

I am writing about a speaker system in *SB* 7/97 ("Low-Budget Two-Way with Top-Mounted Tweeter," p. 8) by Carl E. Richard.

I would like to know the brand name and number of the tweeter he uses on top of the speaker. He only shows information about the woofer and no parts list.

Fernand Binette
Quebec, Canada

Carl E. Richard responds:

Thanks for your interest in my project.

The tweeter I used was an LPG 26TSP, as stated in the article (second column, second paragraph, on p. 8). The specs for the tweeter are available from Madisound, where I bought them on sale. They had the flange cropped on two sides as shown in the article photos. Madisound may not have any of those left but will probably have the regular ones with a full flange that should work out just as well. I apologize for not including a parts list in the article.

Figure 3 *is the crossover schematic to help you. I've also added a Zobel around the woofer. It was added at the suggestion of one of* SB*'s regular contributors, G.R. Koonce, after he read my article. By pure coincidence, he had experience with the same woofer. He tested the hell out of it and found it had a natural 4kHz spike that showed up in my response. By adding the Zobel, it damped the spike by mitigating the rising impedance curve of the Parts Express woofer.*

If you have any further questions as you build your speakers, please feel free to write me. If you have computer E-mail capability my address is: carlspeak@aol.com. E-mail will get a quicker response.

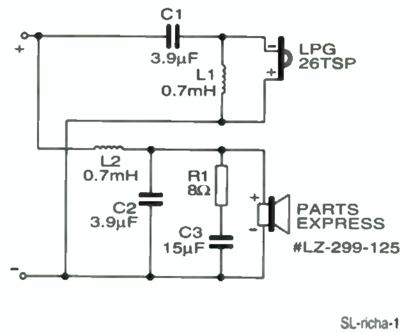

FIGURE 3: Carl Richard's revised crossover schematic.

DRIVER SIZE

I'm responding to Mr. Edge's question in "Letters" (*SB* 1/98, p. 60) as to why there are not many projects using drivers larger than 12″. It is a natural assumption that the larger the driver, the more capable it will be in bass reproduction. All other considerations being equal, the larger driver will produce better bass. However, considerations are never equal. In reality, there are few, if any, drivers that can produce the same amount of low-distortion bass as current 12″ drivers when compared on a volume-displacement-per-dollar basis.

The ear responds to pressure waves produced by movement of a speaker cone (assuming dynamic drivers). Regardless of the frequency involved, air must be displaced to produce this pressure wave. However, as the frequencies drop, the volume of air that must be displaced to produce an equivalent pressure must be increased. Although volume displacement is the goal at any frequency, from a practical standpoint, attaining that displacement is a problem mainly at lower frequencies, as each octave decrease in frequency requires four times as much volume displacement to achieve the same pressure level.

Volume displacement is a function of the area of the driven element times the distance that element moves. Think of it in terms of an automobile engine. When a car manufacturer says that its engine has a 350 in^3 displacement, he means that the pistons, which have a given surface area, move up and down a certain distance in the cylinder, displacing a total of 350 in^3 of volume from the bottom to the top of their travel.

In a like fashion, the moving surface of a driver has a certain area, but it is the combination of that area times the distance from maximum linear rearward position to maximum linear forward position that determines the useful pressure the driver can produce at a given frequency. Having a larger driver does not automatically mean it can produce a higher pressure. Pressure, as the product of area times distance, can actually be lower in a larger driver if the linear travel is significantly smaller than in a smaller driver with a significantly longer linear travel.

The situation of a large driver having less volume displacement than a smaller driver is not so uncommon. An example is a very high-quality 18″ driver having a maximum total linear travel of 8mm compared to another high-quality 12″ driver with a maximum total linear travel of 28mm. Although, after allowing for the actual moving areas of the drivers, the 18″ driver has about 2.25 times the area of the 12″ driver, the 12″ driver has 3.5 times the linear travel, resulting in 1.5 times more volume than the 18″ driver before excessive levels of distortion set in.

Another very important consideration of driver selection is price. In the previous example, the 18″ driver is more than double the price of the 12″ driver. This means you can buy two 12″ drivers for the price of one 18″, resulting in three times the volume displacement for your dollar.

Using multiple, smaller drivers can have other advantages over a single large driver. Drivers actually convert a relatively small amount of the input power into acoustical power. The rest is converted into heat and mechanical forces on the speaker frame, resulting in motion of the frame. That frame motion can cause unwanted resonances, clouding the sound. By using multiple drivers, the force from each is lower than a single large driver, and proper design techniques can be employed to use those forces in an opposing manner to cancel out resulting movement to a large degree. For an example of such a design, see the article "True Bass," in *SB* 5/96. It is also easier to produce a visually less obtrusive enclosure with multiple smaller drivers.

Note that I have not mentioned all the other driver parameters that add up to a successful design. Just having good volume displacement does not ensure good bass. However, having insufficient volume displacement will prevent a driver from producing high levels of low-distortion bass. And, for whatever the production or marketing reasons, there just seem to be more drivers with good volume displacement in the 12″ size range than larger sizes, especially when you consider price.

Two 12″ drivers with different characteristics but good volume displacement are the ASW 1201, available from Hsu Research (14946 Shoemaker Ave., Santa Fe Springs, CA 90670, voice/FAX 562-404-3848), and the DV12, available from Meniscus Audio (4669 S. Division Ave., Wyoming, MI 49548, 616-534-9121, FAX 616-534-7676). The ASW 1201 sells for $99, and the DV12 for $125. Both are very capable and are good starting points for a high-quality subwoofer.

These are by no means the only drivers offering good volume displacement for the money. Other drivers at still lower prices are available from companies such as Madisound (PO Box 44283, Madison, WI 53744, 608-831-3433, FAX 608-831-3771). Although they may not have the volume displacement per driver of the two mentioned previously, their lower prices make them competitive on a volume-displacement-per-dollar basis. This is a viable approach when you may need only one of the high-displacement woofers. Substituting two of the lower-displacement woofers in a vibration-canceling configuration can provide some of the benefits previously mentioned.

I hope this information helps explain the predominance of medium-sized driver designs available today.

Thomas Perazella
Sleepy Hollow, IL

LOUDSPEAKERS UNBOUND

To all those who have discovered just how poor the binding of the *JAES* anthology series *Loudspeakers, Volumes I–IV*, really is, here is a tip on how to have them re-bound for longer life. I took my four volumes into Alphagraphics. For about $6 per volume, they sawed off the original spines, then drilled through all the sheets, and installed a new spiral binding called "PlastiKoil." I also had them put clear protective sheets on the front and back.

Now the books open flat, and will never crack open the poor spine because it's not even there anymore. Try it, you'll like it.

Philip Bamberg
Tucson, AZ

HELP WANTED

I'm looking for some info on tweeters I managed to salvage from an ESS Performance Series Heil loudspeaker system (model 8) that were in pretty bad shape. I'm trying to assemble a speaker system to mate with my old Fisher X100-A and would like to find data so that I could use these tweeters. From what I've read about Heil's air-motion transformers, they seem to be very interesting drivers.

ESS Inc. is from Sacramento, CA. The loudspeakers from which I extracted the tweeters seemed to be of good quality (passive radiator two-way system in a sturdy enclosure with wool damping). I can't find anything about ESS on the net (I assume they're out of business), so I'm hoping fellow readers can help.

Silvio Albino
E-mail silvio@zipzap.ch

Readers with information on this topic are encouraged to respond directly to the letter writer at the address provided.—Eds.

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3/8 polymer dome tweeters from Germany, dimensions A—2 3/8, B—1 7/8, D—1 9/16, $2.75 each. 3,570 pieces available. K. Dombovari, (702) 828-1989.

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Trade Secrets

THE CRUCIAL VOICE COIL

By Mike Klasco

In this series, I take a close look at the speaker components themselves, providing an insider's perspective on how they work and how they can work better. In this third article, I look at the voice coil.

VOICE-COIL ASSEMBLY

Aside from the cone, the voice coil is the most critical element in the speaker. The voice-coil assembly consists of a coil of electrically conductive wire wound on a former. The wire may be made of copper, aluminum, or copper clad aluminum (*Photo 1*). Aluminum is lighter than copper, but copper is stronger. Aluminum is awkward to solder, which creates problems in attaching the leadout wires from the coil to the terminals. Copper-clad aluminum (*Photo 2*) has many of the benefits of both types of conductors. You are most likely to find aluminum or copper-clad aluminum wire in tweeters, compression drivers, and musical-instrument speakers.

The wire may be round, or it may have been flattened and wound on edge. Edge-wound flat wire puts more conduction in the magnetic gap, provides slightly higher sensitivity, and is often used in the highest-grade speakers. A single layer of flat (ribbon) wire has less inductance than multiple layers of round wire. This results in less current lag and a more linear phase response. The acoustic center of the speaker is also more stable throughout the frequency range. One supplier of premium flat wire (*Photo 3*) to the speaker industry is H.P. Reid.

INSULATION AND OVERCOATING

Voice-coil wire insulation is another consideration. Wire insulation can withstand temperatures as hot as 450°F. Voice-coil wire (also known as magnet wire) has an insulation layer to which an adhesive is applied (the "outer bond coat"). The adhesive may be applied at the wire manufacturer (with the adhesive dried and not fully uncured) or you may do so during winding (called "wet winding").

Typically, voice-coil adhesives are B-staged thermosetting polymers, which must be baked or cured to achieve their full strength. Thermosets reach a snapover temperature at which they molecularly crosslink or "cure." As the temperature rises further, thermosets will not melt, but eventually will carbonize—that is, burn.

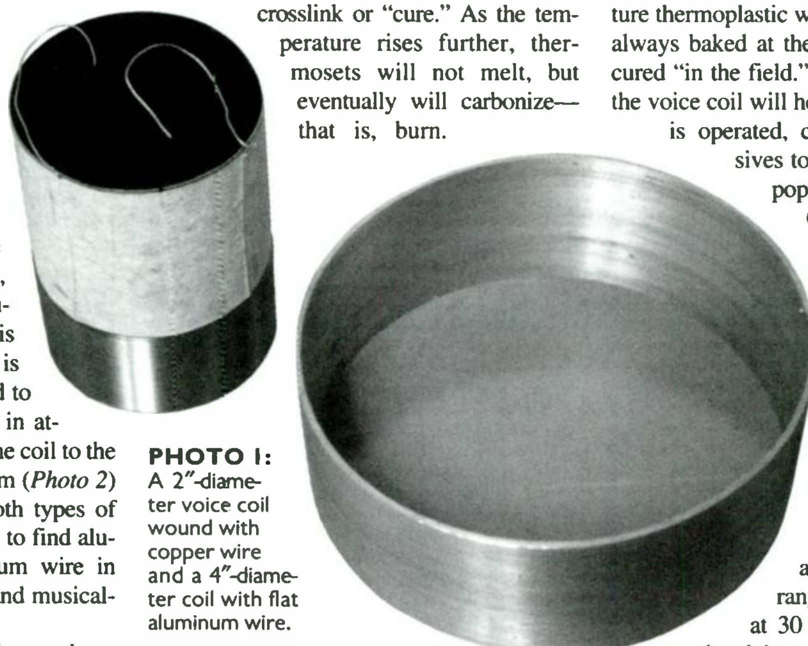


PHOTO 1: A 2"-diameter voice coil wound with copper wire and a 4"-diameter coil with flat aluminum wire.

Recently, SIA Adhesives introduced a line of specialty high-performance adhesives for voice coils offering increased temperature tolerance and structural strength.

The alternative to thermosets is thermoplastics, which do not fully crosslink when they are heated; rather, they melt and re-flow. More recent generation thermoplastic adhesive has temperature capabilities approaching 180°C, but coil winding must be done using heat activation. Even some "thermoset" adhesives approach a thermoplastic range before they fail at elevated temperatures. This can soften the adhesive and, on a bass transient, cause the entire coil to shift its position on the bobbin! This is usually fatal for the speaker.

The cheaper speakers use a low-temperature thermoplastic wire insulation that is not always baked at the factory, but instead is cured "in the field." The assumption is that the voice coil will heat up when the speaker is operated, causing the wire adhesives to cure. This technique is popular today in low-grade OEM car speakers. (Good luck.)

The gauge of the voice-coil wire is important since it affects the speaker's power handling, moving mass, and resistance. The larger the gauge number is, the finer the wire. Tweeter gauges are in the 35 AWG range, those of woofers are at 30 AWG or below, while headphone and mike wire can be in the range of 40 AWG (about the thickness of a hair). With every six gauges, the wire diameter doubles and the conductors'

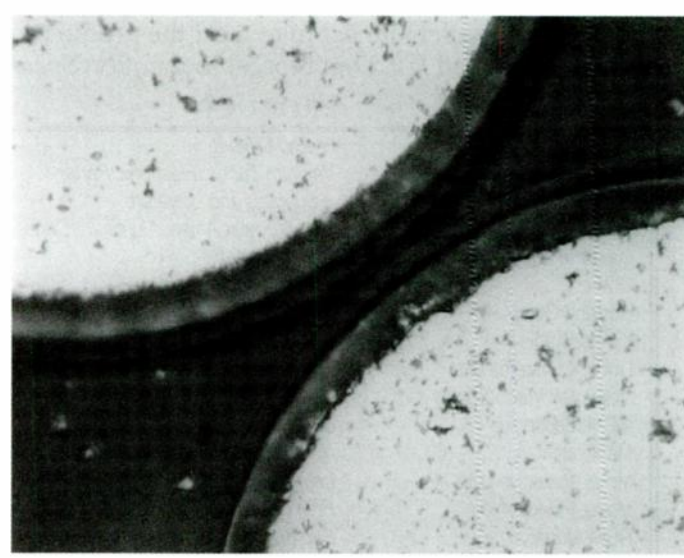


PHOTO 2: Microscopic cross-section of an insulated copper-clad aluminum wire; note the outer edge of copper.

current capacity shifts four times; and three wire gauges equal twice the current capacity.

THE BOBBIN

The voice coil is wound on a former, called a bobbin. Tweeter bobbins are typically 1 mil thick (0.001″), midrange speakers are 2–3 mil, and woofer bobbins are 3–5 mil. Kraft-paper formers were popular 30 years ago, since it is easy to glue to paper fibers. As temperature capacity increased, Nomex® paper from DuPont was commonly adopted for both cone speakers and tweeters.

About 20 years ago, speaker manufacturers desperate to reduce coil burnouts turned to aluminum bobbins. Aluminum offered high-temperature operation and thermal conductivity, pulling the heat off the coil and transferring it to the pole piece. Aluminum is also electrically conductive. This results in high eddy currents, which increases harmonic distortion and inductance. The higher inductance reduces top-end response and causes a self-heating phenomenon in the bobbin.

Still another unappealing aspect of aluminum is the nonlinear current flow. Due to the inductive eddy currents within the bobbin, the coil will rock during large excursions. What all of this means is that aluminum coil speakers do not sound as good as the identical speaker could with almost any other bobbin material. One of the most common bobbin materials today is DuPont's Kapton®, a polyimide resin film which is strong, light, and free of eddy currents.

Aside from power handling and eddy-current distortion effects, the bobbin material affects other aspects of the sound quality. All voice-coil vibrations must pass through the bobbin, by transconduction, before this audio motion can reach the cone and be radiated into the listening room. Bobbin torsional resonances and poor internal damping of the material itself can significantly degrade the transient response, clarity, and definition of the speaker.

The collar is a strip of kraft paper, Nomex, or Quin-T ceramic tape that is glued between the voice coil-stack and the cone. The collar strengthens the coil, helps keep it round, and holds the lead wires down. When the cone's internal diameter is too large for the bobbin, the collar can build up the bobbin to the cone to achieve a friction fit (some glues require this). If the leadout wires are not properly glued down to the collar, whistling modulation noises can result at high outputs. Similar anomalies occur if the vent holes that are often used in the bobbin are located too close to the coil and become partially submerged into the voice-coil gap on the backward stroke.

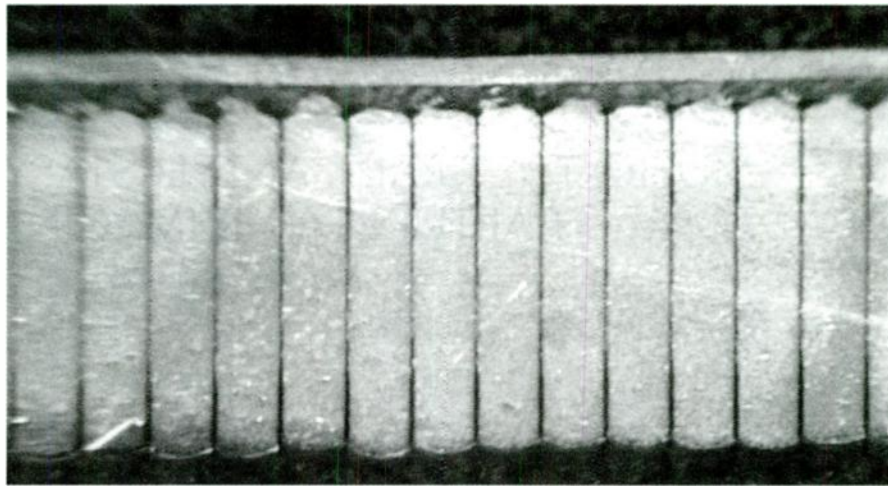


PHOTO 3: Microscopic cross-section of flat, edgewound aluminum wire coil.

NEXT

Transferring the heat from the bobbin to the top plate and pole piece is very important. It is not input power that burns out speaker coils, but high temperature on the voice coil. More insidious is the degradation of sound quality due to power compression effects. The key to wide dynamic range operation without degradation of sound quality is to pull heat off the coil. I will take a look at this practice when I discuss ferrofluids next time. I will examine what ferrofluids can and cannot do, and their effect on transient response, power compression, harmonic distortion, and frequency response.

SOURCES

DuPont Advanced Fiber Systems
Oak Run, Wilmington, DE 19880-0701
(800) 453-8527, FAX (800) 756-0672

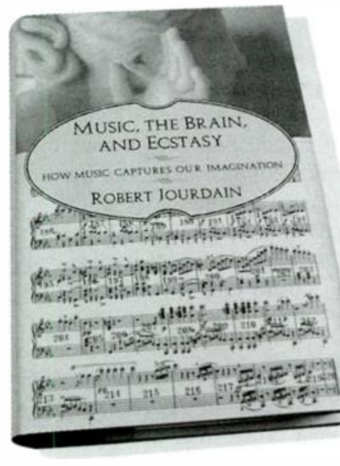
H.P. Reid
1 Commerce Blvd., Palm Coast, FL 32135
(904) 445-2000, FAX (904) 446-2244

Book Report

MUSIC, THE BRAIN, AND ECSTASY: HOW MUSIC CAPTURES OUR IMAGINATION

Reviewed by Paul Szabady

Music, the Brain, and Ecstasy: How Music Captures Our Imagination, by Robert Jourdain. Available as part #BKWM1, for $25 plus s/h in the US, $33 in Canada, from Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458, (603) 924-6371, FAX (603) 924-9467, E-mail custserv@audioxpress.com Published by William Morrow and Co., Inc., 1997, ISBN 0-688-14236-2. Includes 333 pages plus glossary, notes, bibliography, and index.



Ambitious intentions breed great expectations. Every music lover has wondered how it is that mere patterns of physical sound can engender in us such exalted emotions and feelings of beauty. Kaleidoscopic in intent and near encyclopedic in content, *Music, the Brain, and Ecstasy* ambitiously attempts to answer that question.

According to Jourdain, a pianist and composer as well as science writer, the book ventures "from trembling air to quavering consciousness." Combining acoustics, psychoacoustics, and musical psychoacoustics, flanked by brain science, and buttressed by the social sciences, this book is a brilliant summation of recent discoveries concerning how we listen to and respond to music. Mated to Jourdain's musical and aesthetic sensibilities, this book attempts to answer large philosophical questions with the discoveries of recent neurological science.

Recounting in ten chapters the path from sound to tone, then to melody, harmony, and rhythm, and on to composition and performance, the book then moves through listening and understanding to finally arrive at ecstasy. A quick glance at the bibliography shows most of the references dating from the late 80s and early 90s—as such, the book purports to be "cutting edge."

The music lover/audio enthusiast will find in Jourdain's book a coherent, in-depth, broad-based account of much that is germane to music and our experience of it. As Jourdain states in his introduction, "...(the book) requires no prior musical or scientific knowledge. What *is* required is a willingness to stretch your mind to every dimension that music occupies...."

Stretch your mind the book surely will. While simple enough to read as an introductory text, each chapter contains seeds of thought that erupt into deeper thoughts and questions in the reader's mind, questions that Jourdain anticipates and, for the most part, answers. Each chapter is rich in content, deep in information, succinct in form, and compellingly written.

It would be welcome to see some omitted topics included, but what is covered is so well done that every music lover and audio enthusiast ought to read this book, even if only as an education in acoustics and music. I found much of my largely autodidactic, 30-year education in music and acoustical matters clearly reflected in its pages.

AUDIO EQUIPMENT'S ROLE

Does any of this apply to our interest in audio equipment? Jourdain devotes little space to the details of electronic playback in the home other than to detail the difficulty of accurately recording live music (except for binaural headphone recording) and to relate the acoustic flaws of home listening rooms. Some essentials do, however, emerge.

He addresses the primacy of soundstaging and stereo localization, giving scientific credence to what has almost become the *raison d'etre* of the "high-end." An audio system's harmonic accuracy is critical to identifying an instrument's sonic signature, leading naturally to the ability to easily identify notes, and thus melody. This accuracy is essential to correctly perceive the harmonic structure of the music.

The ability of the entire system to start and stop accurately and quickly and to play minute variations of volume ("micro-dynamics" in high-end speak) is crucial in maintaining the interval between notes and in clarifying phrasing, pulse, meter, and rhythm. Also implied is that the richer the deep structure of the music and the more complicated its harmonic language, the more accurate, more high-end the system needs to be to communicate the music's message. Great music requires a great system to reveal its true artistic intent.

BRAIN RESEARCH

Much brain research focuses on finding the seats of perception in the brain, e.g., melody and the perception of harmonic intervals in the right brain, rhythm in the left. Jourdain's recounting of these findings dispels the simplistic popular notions of left brain versus right brain. His detailed analyses are carefully wrought, revealing the limitations of applying animal-brain research conclusions to human beings, and cautioning that computer-generated brain scans (which appear as literal photographs, but are definitely not) and "all mappings of brain function should be taken with a grain of salt."

Jourdain's honesty and far-sightedness is to be applauded here, as is his overall freedom from jargon. Particularly welcome is the absence of any metaphor of "the brain as computer."

While his main goal is to recount the results of this research and not to offer an in-depth critique, questions arose in my mind as to the credibility of some of these results. A particularly obvious example is the difficulty of experimenting on living, healthy human brains, and the consequent necessity of form-ing hypotheses based on the flawed abilities of damaged or diseased brains.

MUSICAL PERSPECTIVE

Jourdain's musical world-view is that of Western classical music, and while he is sufficiently sophisticated and catholic to include non-Western music, jazz, and popular music in his analyses, at times he clearly gives short shrift to nonclassical music. His analysis of music's construction, devices, and aspects is, however, cogent and compelling. While his view of American popular music is perhaps rightly jaundiced, these slights at times undercut some of the grand statements he makes.

For example, on p. 146 he states, "It's often said that rhythm is music's most 'natural' aspect, that it comes to music from pulsations we find in our bodies. This is one of those observations that, like the flatness of the earth, is blatantly obvious and blatantly wrong." But it is no secret that rock and roll derives its name from the rhythm associated with the carnal act and jazz from the act itself, and that both musical forms (at least in their origins) focus on rhythm (particularly sexual rhythm), which Jourdain, along with conventional musicology, considers mere "meter."

On the subject of the paucity of complex meter (polyrhythm) in classical music, however, Jourdain is masterful in explaining why Western composers forsook complex meter to begin the long experiment with harmony. Because long harmonic excursions need reinforcement by relatively simple rhythm to maintain comprehensibility, it was essential that there be a limitation of the complexity of the meter in order to explore the possibilities of harmony, possibilities which appeared to the composers as "the discovery of a new continent." Furthermore, this decision to ignore meter in favor of harmony was based accurately, if unconsciously, on the brain's inherent limitations in the processing of polyrhythm and harmony (limited in the former, large enough in the latter to allow 300 years of elaboration).

INDUCING ECSTASY

Jourdain ignores traditional societies' use of rhythmic, drum-based dance as a means to induce trance and ecstasy. Instead, he focuses on the social aspects of dance. Sorely absent is any mention of the religious use of music to induce states of ecstasy. From the attempt of Gregorian chant to lift the soul from the body, to the shaman's drum and rattle inducing ecstatic journeys to the spirit world, to the drone of the tamboura in Indian classical music evoking eternity behind the performance of sitar and tabla (paralleling the drone of the bagpipe in European folk music), there is no denying the rich religious aspect of music.

Telling also is the conspicuous absence of the blues in Jourdain's consideration of music and the emotions, as well as his exclusion of the emotional code of the Western preclassical modes and the emotional correlations of Indian scales. While he acknowledges that most musical brain research focuses on Western upper-middle-class subjects as well as using Western classical music, thus making it both class- and culture-bound, he regards it as nearly impossible to enter fully into another culture's music.

What he ignores is that a mastery of classical music does not necessarily preclude mastering alien music, although I must say that the classical devotees most expert in its harmonic language are, in my experience, the most likely to describe alien music (even as close to home as the blues) as "grating."

A discussion of music's meaning, with a long analysis that finds no neurological relationship between music and language, seems pointless: the comparison between poetry and music would seem to have been more apt. This is perhaps nitpicking, and the reader will no doubt find his own without nullifying the book's immense worth. Jourdain articulates exquisitely the ability of music to describe without symbolizing, to mimic and to perfect emotion and both inner and outer physical processes. Music can "carefully replicate the temporal patterns of interior feeling."

DEFLATED EXPECTATIONS

It is when the book reaches the conclusions of contemporary cognitive psychology regarding the emotions that the reader's great expectations suddenly deflate. Both the structure and title of the book lead us to expect a significant conclusion. But after recounting how current cognitive psychology rejects our common notions of emotion, Jourdain chooses as his definition of emotion the discrepancy theory of "emotion as a reaction to unexpected experience." He says that the ultimate purpose of emotion is to "...be on the lookout for the *most important activities* to which to devote oneself."

Emotion is seen as a special case of motivation useful in focusing on a goal. We anticipate something occurring, and if it does not, there is "...strong response because there has been a marked mismatch between anticipation and reality. Such discrepancies are believed to be the basis of emotion...."

Furthermore, according to Jourdain, all emotions are either negative or positive, the latter occurring when anticipations are met. Because music sets up anticipations and then answers them, it can create positive emotions. Conversely, by frustrating anticipations, it can create negative emotions. Jourdain then uses this analysis to explain why chords based on the major triad sound "happy," while those based on the minor sound "sad."

BATHETIC CONCLUSIONS

The conclusions verge on bathos, their banality intensely striking after the great expectations the book has inspired. Oh, they're all "true," given the presuppositions of the discussions, yet their unfulfilling nature nearly deflates the grand ambition of the book. To be fair, it's not Jourdain's fault. He is, after all, merely the messenger of the horrifying mundanity of much of our contemporary thought. Could a society not dominated by business-think and unobsessed with commercial goals even conceive of such a view?

It is cheering to think that cognitive psychologists are *not* the world's musicians and artists. If music and emotion did indeed work solely on these principles, music's exclusive application would be as background at the lamest pop-psych, motivational business seminars!

You could say that Western music's discarding of the medieval modes in favor of the major/minor scale resulted in an impoverishment of classical music's emotional content that can almost be simplified to "happy/sad." One of the salient features of modal music world-wide is its ability to evoke multiple, contradictory emotions simultaneously.

Consider the climax of Vaughan Williams' *Fantasia on a Theme of Thomas Tallis*, the songs of the Troubadours, the blues sung and played on bottle-neck guitar, the later music of John Coltrane, the high, lonesome sound of pedal-steel guitar in country music, the sound of the bagpipe in European folk music, the music of Jimi Hendrix and Ravi Shankar. Can the emotion evoked by these pieces be simplified into happy/sad or positive/negative? Even within the classical tradition, is Berlioz' *Symphonie Fantastique* happy or sad?

Music's ability to create new emotions in the listener, to expand experience, to alter consciousness, to educate the emotional life (as Jourdain himself discusses) would seem nearly impossible based on the application of the cognitive psychologists' theories. Can we "anticipate" a new unexperienced emotion? Are the attainment of ecstasy, the sense of the sublime, the perception of beauty positive or negative emotions?

ANOTHER VIEW

The book's view that the art of music gives order to and makes perfect the dissatisfaction and chaos of "real" life evokes comment. An alternative view is that we crave music and art not as a "useless" luxury granted by civilization, a recreational epiphenomenon of culture and the brain, but rather—as have traditional societies—because they are the foundation of the perception of reality, and thus society, culture, and organized thought.

Why even pursue ecstasy and the perfection of beauty? Because the ecstatic state can lead to an experience of what has been called "nonordinary" reality. The content of the experience of these states, whether they be attained by art, music, trance, mystical contemplation, or mind-altering drugs, seems to share a common core: that the reality experienced is *more real* than that of "ordinary" reality.

The message of these ecstasies is not that we get a brief reprieve from the flux and ugliness of so-called reality, but rather that it is our view of reality that is in error. Through the experience of these ecstatic states, the doors of perception are swept open, and we see reality as it *really* is—infinite.

I have touched on just a fraction of the book's contents. As Jourdain claims in his introduction, "you'll leave this book with quite an education. Be assured, music will never seem the same again." I whole-heartedly agree. Is it superfluous to say that the book is *highly* recommended?

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