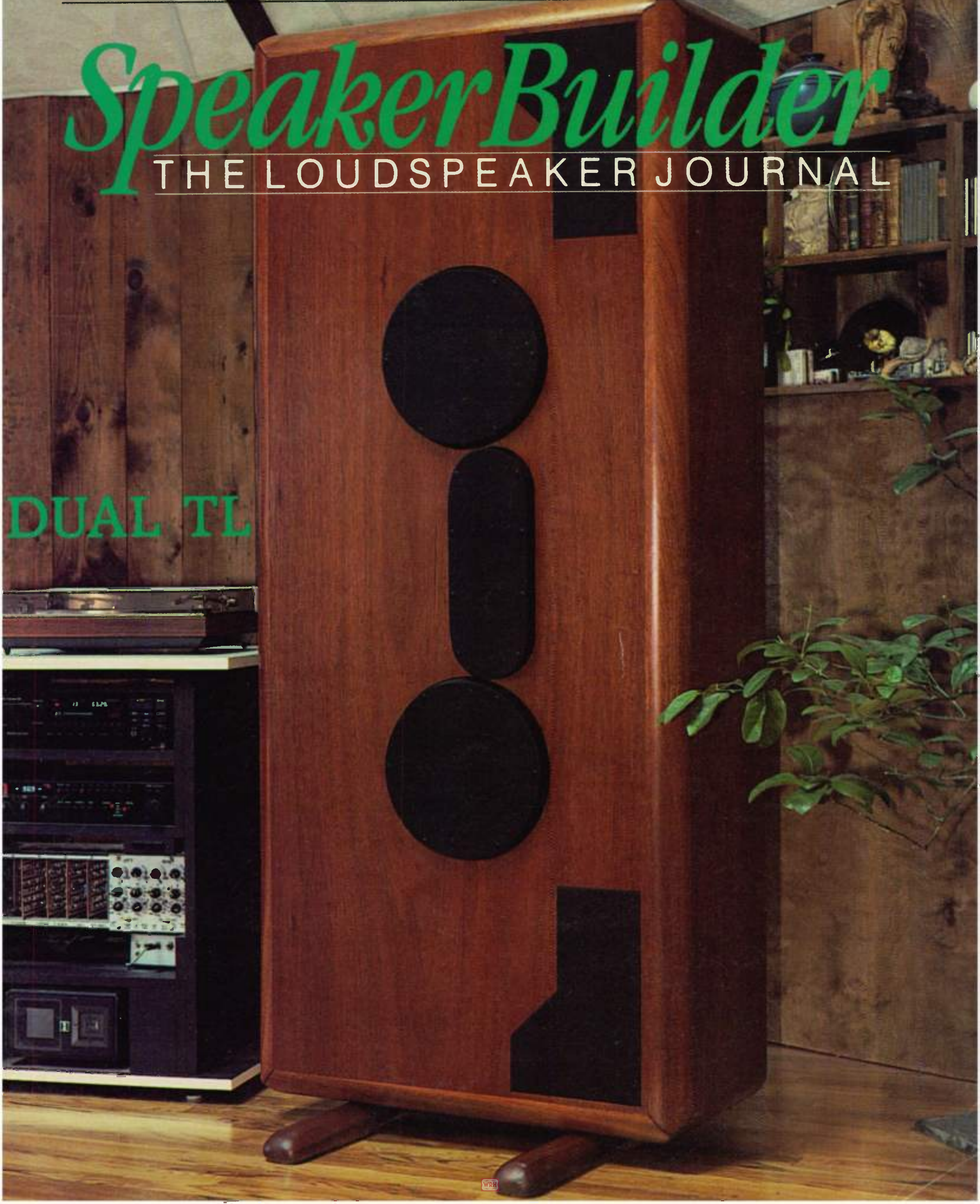
FIVE/89

U.S. $[illegible]
CANADA [illegible]

Speaker Builder

THE LOUDSPEAKER JOURNAL

DUAL TL



ARIA FIVE

ARIA SEVEN

ANOTHER D'APPOLITO LOOK-ALIKE OR...

"Perhaps the greatest challenge for any loudspeaker system designer is that of designing a good 2-way full range system. When Kimon Bellas asked me to design such a system for Focal America using my symmetric 3/2 geometry and Focal's new K2 Kevlar® Sandwich cone drivers and Kevlar® concave dome tweeters, I jumped at the chance. The compromises inherent in the 2-way format make the resulting system a deeply personal statement of a designer's philosophy and priorities in high quality sound reproduction. The classical compromise turns on the tradeoff between bass extension and midrange definition and finding the right balance between them. In the end I produced two systems, making what I believe are definitive statements at each end of the 2-way system spectrum. The first system, based on Focal's 7″ K2 dual voice coil mid-bass driver combines good bass extension to 40 Hz and below with excellent midrange definition and high frequency extension in an elegant tower. The second, smaller system, based on Focal's outstanding 5″ K2 mid-bass driver, gives up the bottom two-thirds octave of bass for an uncanny midrange clarity together with a broader, more uniform polar response in this same range. The smaller system is also an ideal candidate for bass augmentation with a new bandpass subwoofer system I am currently designing in collaboration with Kimon Bellas. Whichever system you choose, I hope you will gain as much pleasure from building and listening to them as I had in designing them."

Joseph D'Appolito

A FREE pamphlet on these two new kits, with complete data and measurements, plans for cabinets and X-overs, components source list (including specially made cabinets), is waiting for you: simply WRITE to:

FOCAL America, Inc.
1531 Lookout Drive
Agoura, CA 91301 U.S.A.

K2 KEVLAR® SANDWICH CONE

Speaker Builder

Edward T. Dell, Jr. *Editor/Publisher*
Karen Hebert *General Manager*

Contributing Editors
Joseph D'Appolito, Robert Bullock
John Cockroft, David Davenport
Vance Dickason, Bruce C. Edgar
Gary Galo, G. R. Koonce

Steve Jewett *Managing Editor*
Christine Holt *Graphics*
Kendall Hawes *Graphics Assistant*
Katharine Gadwah *Circulation Director*
Rebecca Robinson *Assistant Advertising*
Techart Associates *Drawings*

Advertising Rates & Schedules
Rally Dennis
PO Box 494
Peterborough, NH 03458
Advertising Phone: (603) 924-6710

Editorial and Circulation Offices
Post Office Box 494
Peterborough, New Hampshire 03458
(603) 924-9464
FAX: (603) 924-9467

Speaker Builder is published bi-monthly by Edward T. Dell, Jr., PO Box 494, Peterborough, NH 03458.

All subscriptions are for the whole year. Each subscription begins with the first issue of the year and ends with the last issue of the year. A sample issue costs $4 in the US, $5 in Canada.

Subscription rates in the United States and possessions: one year (six issues) **$20**, two years (twelve issues) **$35**. All sets of back issues are available beginning with 1980. Caribbean and Canada add **$4** per year for postage. Overseas rates available on request. Subscribers residing the Western Hemisphere are served by air.

To subscribe, renew or change address in all areas write to Circulation Department or call (603) 924-9464 for MC/Visa charge card orders. For gift subscriptions please include gift recipient's name and your own, with remittance. A gift card will be sent.

A Note To Contributors

We welcome contributions for possible publication in the form of manuscripts, photographs or drawings, and will be glad to consider them for publication. Please enclose a stamped, addressed return envelope with each submission. While we cannot accept responsibility for loss or damage, all material will be handled with care while in our possession. Receipt of material is acknowledged by postcard. Payment is on publication.

Speaker Builder (US ISSN 0199-7920) is published bi-monthly at $20 per year; $35 for two years, by Edward T. Dell, Jr. at 305 Union St., Peterborough, NH 03458 USA. Second class postage paid at Peterborough NH and additional mailing office.

POSTMASTER: If undeliverable send to **SPEAKER BUILDER**, PO Box 494, Peterborough, NH 03458.

About This Issue

Combine the best transmission line know-how for bass with the D'Appolito mid/high format, design cabinetry for a spiral-shaped dual line, mix well with three years of spare time and you have the first installment of **Peter Hillman**'s magnum opus starting on page 10, as well as beautification for our cover.

The inimitable **John Cockroft**'s Microline, page 28, is another TL but is at the other end of the size spectrum. The transmission format, this issue's theme, even extends to **Scott Wolf**'s Craftsman's Corner article, where a PVC "line" solves some mysteries.

Contributing Editor **Bruce Edgar** shares a tool he's devised to measure driver voice coil inductance and even offers hand-calibrated resistors to help readers build their version (p. 36). Brasil's **Jorge O. F. Oliveira** has some news on his findings concerning tweeter Q.

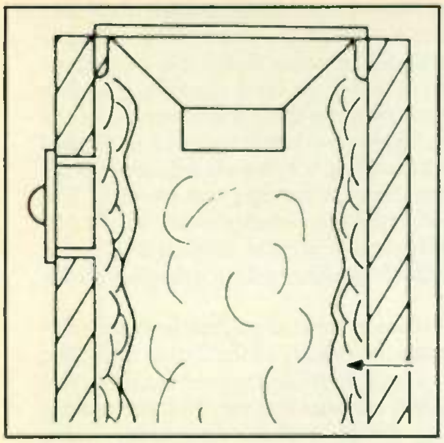
Next time **James Lin** marries a 24″ Hartley dipole to Quads, **Wayne Cox** revises the Paradigm 7se, and we'll have more from **Peter Hillman** as well as **Brian Smith**'s recipe for woofer health.

We regret omitting due credit to photographer Glenda Huff, of Dallas, Texas, whose work graced our 4/89 cover. We thank *American Way* magazine for permission to use color separations.

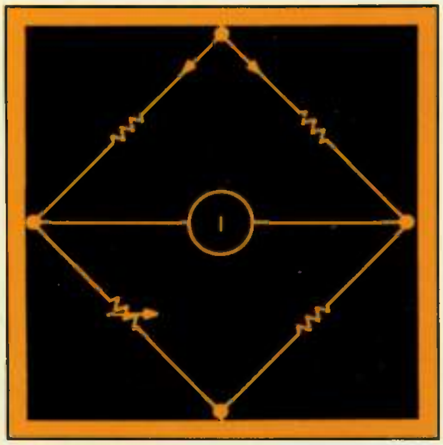
Cover photo: Peter E. Hillman

Speaker Builder
THE LOUDSPEAKER JOURNAL

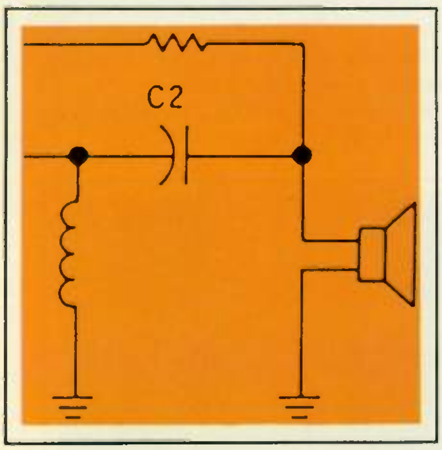
VOLUME 10 NUMBER 5 SEPTEMBER 1989



28



36



40

FEATURES

DEPARTMENTS

Good News

MB QUART's 650S column loudspeakers are handcrafted from its proprietary variable-density, five-layer woods using tongue and groove joints. The speaker has a low-mass 8-inch woofer, 400Hz crossover, Supronyl dome midrange and titanium dome tweeter, and is available in nine finishes. Suggested retail price is $1,499 per pair.

Another new offering is the MB Quart 310 subwoofer, with a 12-inch front firing woofer in a cast aluminum frame using a fixed 100Hz, 18dB/octave crossover. Suggested retail price is $899 each.

For more information contact MB Quart Electronics USA, 25 Walpole Park S., Walpole, MA 02081, (508) 668-8973, FAX: (508) 668-8979.

Fast Reply #JD356

The Model 511 **ALTEC LANSING** four-way tower loudspeaker system features mono/bi/tri/quad amplifier inputs and a crossover system with four level controls. The first control provides three rolloff curves for the two long-throw woofers; three additional controls allow −3dB level adjustments for upper bass, midrange and tweeter. The basic crossover configuration is 200Hz, 1.5kHz and 3.5kHz at 12dB/octave. Input terminals are heavy-duty gold-plated copper.

A diamond-coated polyimide material increases the rigidity of the 2-inch midrange and 1-inch ferrofluid cooled tweeter. The 6.5-inch midbass and two 10-inch woofers have woven carbon fiber/epoxy resin cones. Cabinet dimensions are 57 by 13 by 13½ inches. Suggested retail price is $3,000 per pair.

For additional information contact Andrew Bergstein, Altec Lansing Consumer Products, Milford, PA 18337, 1-800-548-0620.

Fast Reply #JD328

TECHNISOUND has developed Omnisound 101, a dual-function loudspeaker and Dolby surround sound processor. This one-piece, three-way system detects, decodes, amplifies and transmits ambient sound from audio/video sources using a second voice coil bound to the primary voice coil. Decoding of ambience surround sound takes place in the binary coil.

Omnisound draws power from the the owner's existing receiver, thus an additional audio amplifier is not required. Used with Technisound's SSII front speakers, Omnisound generates three-dimensional sound, or can be used separately. Suggested retail price is $99.

For more information contact Technisound, 60 E. Ida St., Antioch, IL 60002, (312) 395-6321.

Fast Reply #JD321

DELTA TECH RESEARCH has introduced MicroScan, an OEM damping process that offers a practical solution to the problem of enclosure panel vibrations in loudspeakers.

The system converts energy from its audible mechanical state to its inaudible thermal state with the use of a series of thin, rectangular plates made of viscoelastic polymers. The damping plates are typically secured to the inside enclosure panels and the back plate of the woofer magnet.

The desired degree of damping is achieved through the delay in response of an imperfectly elastic material to the forces affecting it. This delay results in hysteresis loss. The actual energy loss begins early in each cycle of the vibrations, as the forces normally generated in the loudspeaker enclosure are transferred through the series of resonance-tuned damping plates.

Further information is available from Delta Tech Research, Inc., 2440 Leghorn St., PO Box 7231, Mountain View, CA 94039, (415) 964-6660.

Fast Reply #JD355

ACUTRES introduces the new Vieta Prestige Series, unique speaker systems for the demanding audiophile. The Series includes new designs, but also improved versions of some well-known models. This is the case of L'ADAGIO, the top-of-the-range model, which features omnidirectional sound using a 12-inch woofer, five 5½″ midrange units and four 1″ tweeters.

The connecting array gives separate access to the treble and bass/mid sections, allowing both biamplifying and bi-wiring. The binding posts are gold plated for low contact resistance, and can take heavy-duty audiophile speaker cable with a variety of terminations, including single and double bananas.

Van den Hul 3.5mm² cable is used for internal wiring.

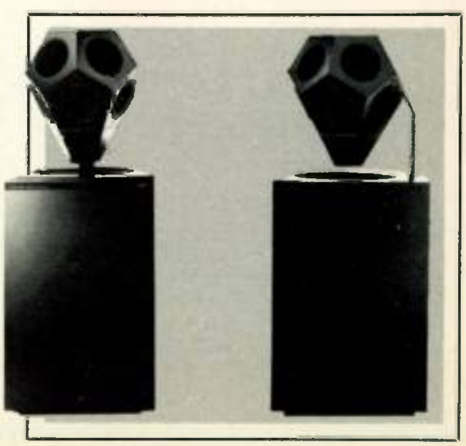
L'ADAGIO PRESTIGE can be placed on the floor, but best results will be obtained when using the supplied spikes, that can be screwed to the base of the cabinet. These spikes assure the maximum stability, improving low frequency reproduction and stereo imaging.

The cabinet itself is made of high density material, and internally braced for higher rigidity, reducing coloration caused by panel resonances.

The cabinet surfaces are piano-type black lacquer finished, while the treble/midrange upper module includes a fine red trace that can be self-illuminated.

Acutres also includes L'Orfeo, a bass-reflex pyramid design; L'Acord, a three-way infinite baffle design with F_0 of 36Hz; L'Andante, a floor-standing sealed-box; the Vieta Pro-20, a bass-reflex three-way with a 10″ woofer; and the Vieta Pro-10, a high-efficiency bookshelf speaker.

Contact Acutres, Bolivia, 239-08020, Barcelona, Spain.



Fast Reply #JD103 ➤

Good News

The latest in the line of **AUDIO CONTROL** Technical papers, Number 106, is available. It is a discussion of the equalizer topology known as constant Q and is written by sound engineer Rick Chinn. For more information, contact Audio Control, 22313 70th Ave. W., Mountlake Terrace, WA 98043, (206) 775-8461, FAX: (206) 778-3166.

Fast Reply #JD123

From **AUDIO CONCEPTS**, AC acoustical foam is now available. Using the foam on room surfaces controls reflections that may cause distortions with stereo sound, smeared transients and details and poor stereo imaging.

The foam can be attached directly to the walls, or to panels that can be placed anywhere in the room. Two or four sheets placed to the sides and rear of the speakers enable improvements in sound, and the foam can be glued to walls and ceilings if a completely dampened room is desired.

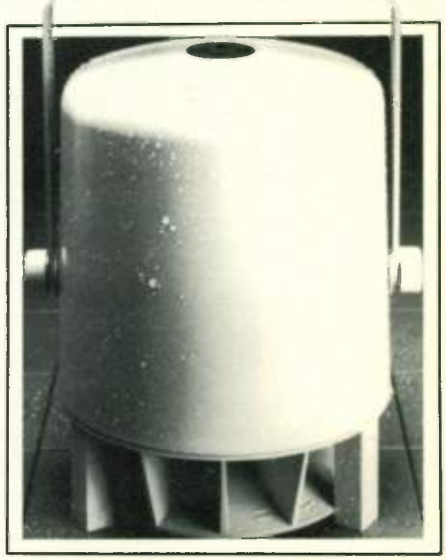
Other applications include sound reflection reduction for vans and campers, recording studios, and control rooms.

AC foam comes in sheets, 27 by 84 by 2″, charcoal grey with a convoluted surface; thermal conductivity, 0.28; noise reduction coefficient, 0.93; random incident sound absorption, 125Hz-0.21, 250Hz-0.58, 500Hz-1.07, 2000Hz-1.03, 4000Hz-0.95.

Another dampening product available is AC Glop,™ a co-polymer compound created for audio applications. It may be poured or brushed on a surface, applied in layers to the inside of speaker cabinet walls. It may also be carefully painted on to the chassis and magnets of speaker drivers. Glop™ absorbs vibrations and resonances that are problems in common box type speaker designs.

Before application, Glop™ has the consistency of thick glue with sand mixed in. It cures in 20-48 hours, maintains a rubbery texture almost indefinitely and is non-toxic and safe to use. One quart covers four square feet to ⅛″ thick.

For information contact: Audio Concepts, Inc., 901 S. 4th St., La Crosse, WI 54601, (608) 781-2110, or 1-800-356-2255, ext. 1122 (orders only).



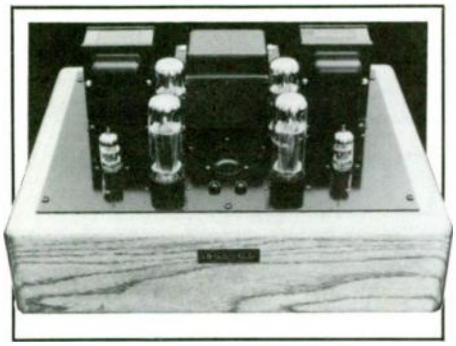
DESIGN ACOUSTICS has redesigned its DA-360 omnidirectional weather-resistant outdoor loudspeaker system. The improvements include adding a foam surround to the woofer, coating the cabinet's inside with a damping compound to eliminate resonances, and a new finish that allows easy repainting.

The single speaker achieves its omnidirectional sound by using a 6-inch cone woofer and 1½-inch piezo tweeter in a downfiring configuration. The DA-360 has a swivel mounting bracket for convenient installation. Suggested retail price is $119.95.

For more information contact Design Acoustics, 1225 Commerce Drive, Stow, OH 44224, (216) 686-2600.

Fast Reply #JD345

Fast Reply #JD370



The **WRIGHT AUDIO** P-75 is a 35W/ channel vacuum tube power amplifier presented on a 1½-inch-thick solid red oak base. All parts are hand-wired. Sensitivity is 1.3V. Output impedances are 4 and 8Ω with 16Ω on special order. Price is $850 with a one year warranty. For more information contact Wright Audio, 308 North New St., Staunton, VA 24401, (703) 886-4307.

Fast Reply #JD403

The Beovox Cona subwoofer from **BANG & OLUFSEN** is drum-shaped with a concave top, 17-inch diameter by 10½ inches high. The 8-inch driver incorporates two separate voice coils, enabling the single subwoofer to reproduce the low frequency range (40–195Hz) from both channels without interference or phasing problems. The net volume of the bass reflex cabinet is 25 liters.

Designed for use with compact loudspeakers such as Bang & Olufsen's CX100, CX50, Beovox 3000 Panel or RL35, the Cona has continuous RMS power handling of 60W and a crossover frequency of 195Hz. Suggested retail price is $395.

For additional information contact Bang & Olufsen of America, 1150 Feehanville Dr., Mount Prospect, IL 60056.

Fast Reply #JD535

INFINITY SYSTEMS' RS Series high performance loudspeakers consists of six full-range speaker systems, with an active subwoofer designed for use with each. The woofers use injection molded graphite (IMG) cones like those of its IRS system. The dome drivers of the new series use a proprietary new material called Polyspherite, which consists of tiny, hollow graphite spheres bonded to an ultra-thin diaphragm of polypropylene.

The RS Series includes some dimensional changes, for example, the RS 5001 is now 31 by 11.5 by 9.4 inches. The RS speakers are finished in either Chatsworth Oak or Black Oak vinyl veneer. For more information contact Infinity Systems, Inc., 9409 Owensmouth Ave., Chatsworth, CA 91311, (818) 707-9400.

Fast Reply #JD354

"The Science of Speakers," a new pamphlet written by Keith O. Johnson, is available from **PRECISE ACOUSTIC LABS**. Mr. Johnson, designer of the Precise Loudspeaker systems, discusses his theories and philosophies concerning listenability, eigensonics, DSMA and cone material; realism, resonance, distribution and equalizing networks; and articulation, speed, intertransient silence and unkind physics.

For more information contact Precise Acoustic Laboratories, Suite B, 200 Williams Dr., Ramsey, NJ 07446, (201) 934-1335.

Fast Reply #JD103

AUDIO CONTROL's Phase Coupled Activator,™ a unique bass restoration stereo component for home and dance club type stereo systems, has just received the distinction of a US patent.

The bass recovery action restores the low frequencies inevitably lost during the recording and mastering processes. The Phase Coupled Activator and also the Epicenter,™ for auto sound systems, reproduce deep, clean bass for added depth and impact to music, according to test reports.

For information contact Bill VanGundy, Audio Control, 22313 70th Ave. W., Mountlake Terrace, WA 98043, (206) 775-8461, FAX: (206) 778-3166.

Part I

SYMMETRICAL SPEAKER SYSTEM WITH DUAL TRANSMISSION LINES

BY PETER E. HILLMAN

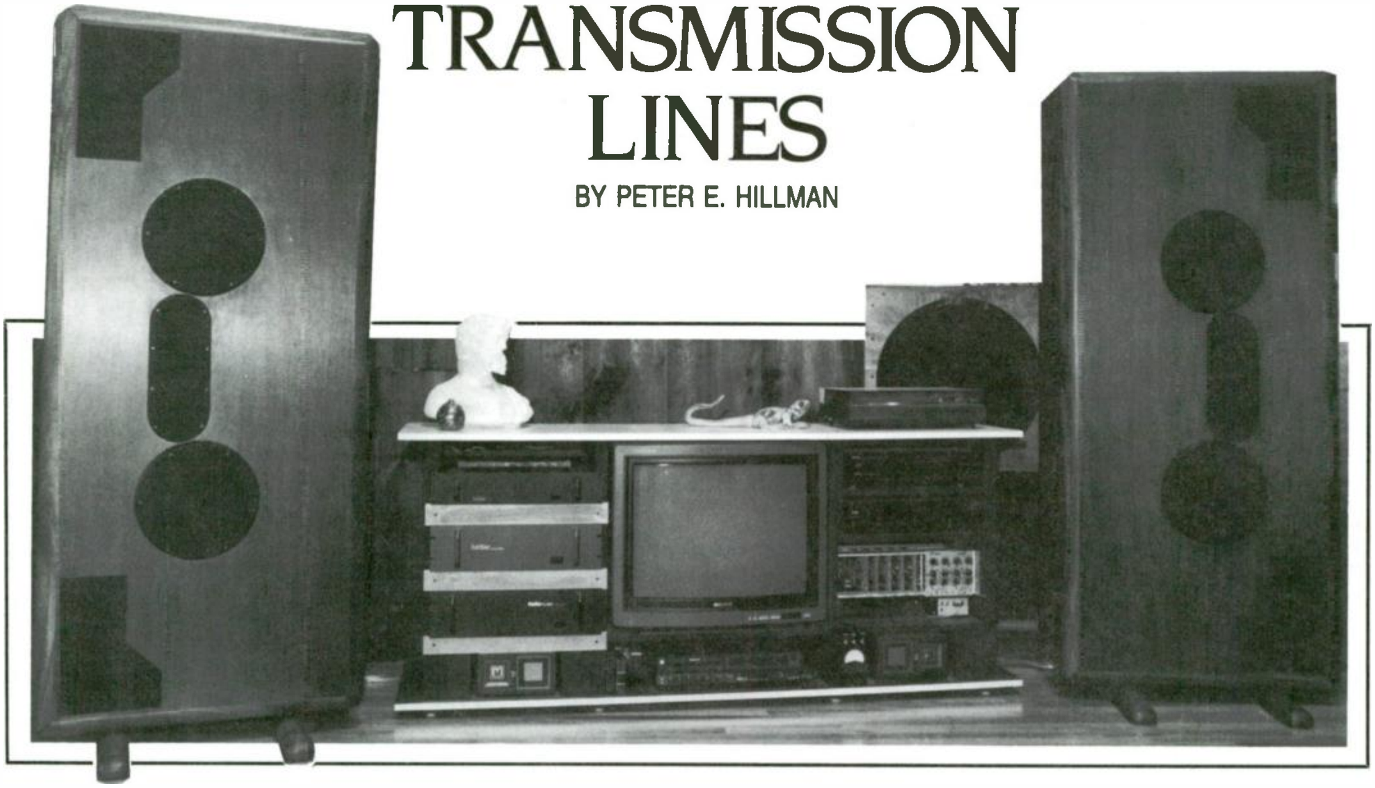


PHOTO 1: Completed system in author's living room. A 24-inch Hartley in a transmission line is lurking in the background (not included as a part of this loudspeaker project).

I'm willing to bet you have dreamed of building the "perfect" loudspeaker of simple, inexpensive construction and characterized by: excellent imaging, flat frequency response, excellent sonic detail, bass response flat to 20Hz, the ability to play at realistic levels at very low distortion, and being handsome enough that your spouse will allow it in the living room. I had such a dream over three years ago; unfortunately, the loudspeaker that materialized from my dream turned out to be neither perfect nor inexpensive and easy to build. Nevertheless, it is close enough to my dream to make it worthwhile for me to share it with you.

To say that it was not easy to build is an understatement. I seriously doubt that many of you will attempt to build these cabinets since their construction is tedious and complex. On the other hand, I think you will find many facets of my loudspeaker useful in your own design. Such facets include measurement and theory of a workable transmission line (TL), a three-way implementation of D'Appolito's symmetrical design, a relatively non-resonant cabinet with minimum diffraction edges, design strategies of electronic crossovers, minimum equipment for successful loudspeaker response measurements and dealing with speaker/room interactions.

I have always been impressed with the low frequency capability of TLs; subjectively I believe that they have a natural and tight sounding bass. Unfortunately, very little theory is available to properly design TL enclosures, unlike the situation for vented or sealed boxes. Therefore, I had a problem in properly designing a TL with the correct length, cross section and filling. With a little experimentation and collaboration with Robert Bullock on TL theory,[1] I decided to build an 8-foot line which tapers from a cross-sectional area of about 2.5 times the driver's diaphragm area (S_d) to a port area equivalent to the driver's S_d, and to uniformly pack the line with Dacron Hollofil fiber, at 0.5 lbs. per cubic foot.

Also I was intrigued by D'Appolito's article on his symmetrical satellites,[2] enough so that I built a pair for my parents' fiftieth wedding anniversary. For the base units of their system, I built TL enclosures placed below each satellite, using the same 8″ drivers as I used in my experimental TLs.[1] Satisfied with the sound of their system, I decided to try a full-range, three-way version of D'Appolito's symmetrical design using a dual TL for the low frequency reproduction.

THE CHALLENGE. I wanted to design two separate lines in a single box with little wasted space, while still keeping the two woofers in their desired positions just

ABOUT THE AUTHOR

*Peter Hillman, 46, holds a graduate degree in zoology from Washington State University. For the last 15 years he has studied the physiological interactions of farm animals to their environment while working in the Department of Agricultural and Biological Engineering at Cornell University. He also taught an introductory microcomputer applications course for the last five years. A builder at heart, he has been constructing loudspeakers for the last two decades. In 1975 he built his own house and two years later he machined and tested a replica of Edison's first tin-foil phonograph for the centennial of the phonograph (*Audio*, Dec. 1977).*

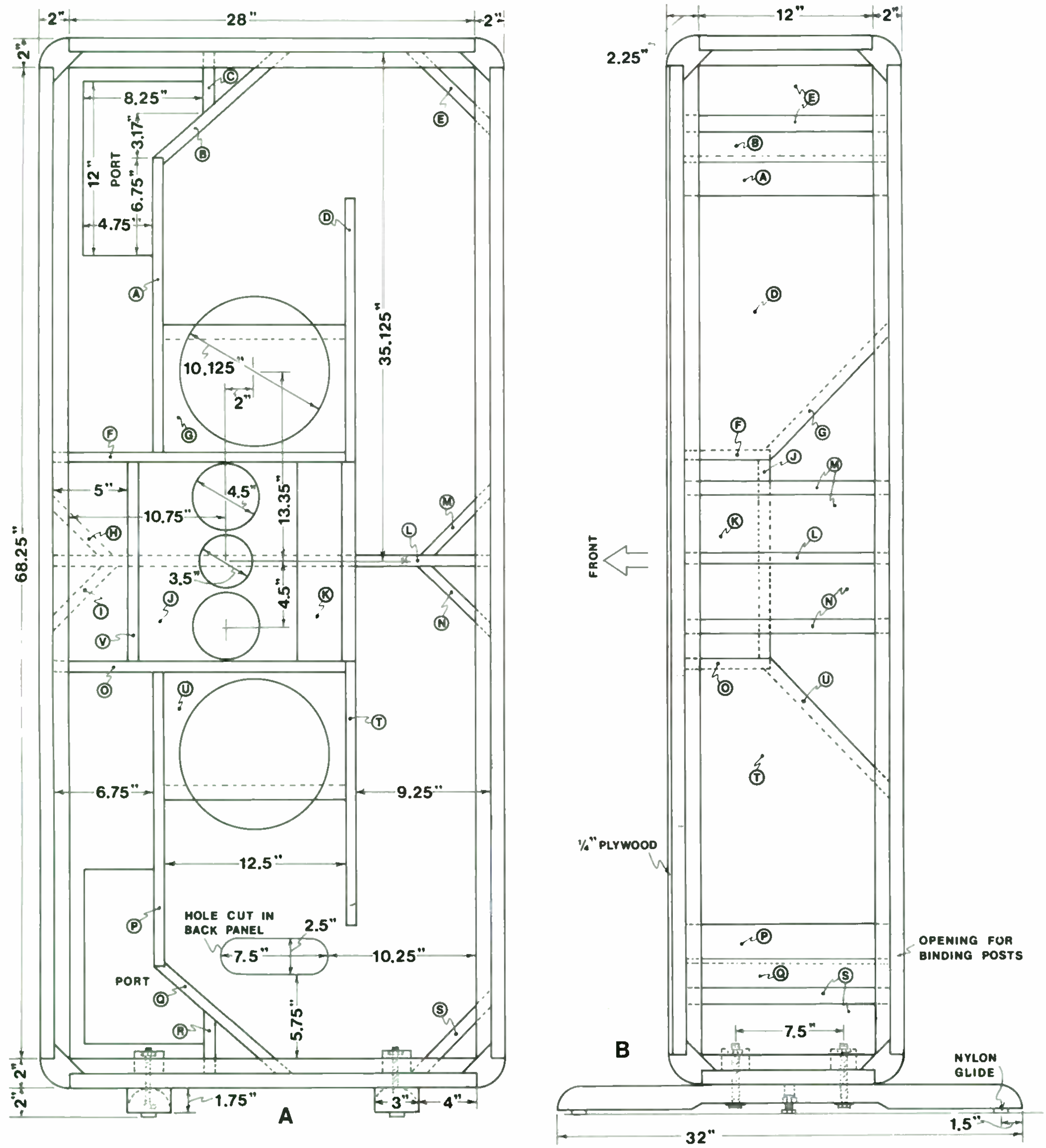


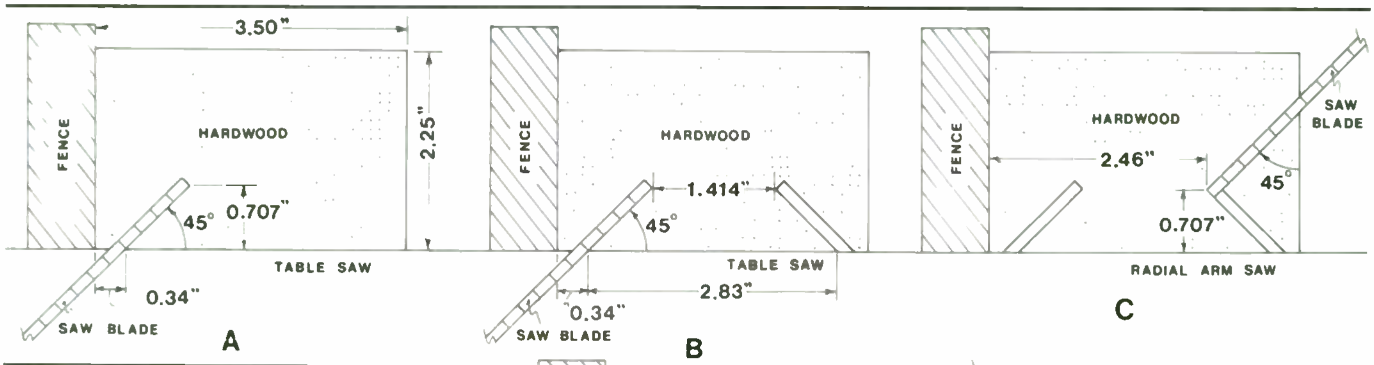
FIGURE 1: Front and side views of the left enclosure. The right enclosure is identical except that the feet are mounted at the other end.

above and below the midrange/tweeter array. After more tries than I care to admit, I finally arrived at a design where the two lines form a double pinwheel (*Fig. 1*). The size was immense! The only way I could convince my wife to allow these monsters in our living room was to build the cabinets to as handsome a form as possible; my wife selected the type of wood and finish.

In addition to using a D'Appolito three-way design and TL loading, I wanted to select the best drivers that could be tightly packed together, to minimize cabinet edge and grille frame diffraction, and use an electronic crossover with its ease and flexibility for adjusting time delays, crossover slopes and response anomalies.

In this article I present my project in the order I conceived and constructed it and finally turned it into the completed system. We can only hope that any project conceived with the best intentions and careful planning will succeed. I think I am a typical amateur who doesn't have the resources to carefully test a design, before embarking in the costly and time-consuming process of building a one-time completed enclosure. It is always a gamble that your long hours of toil could end up with a speaker that falls short of your minimum expectations.

ENCLOSURE DESIGN AND CONSTRUCTION. Even if you do not build these enclosures, the following design and



construction details should provide you with some useful tips for your projects. Such tips include: structurally-strong rounded corners for low diffraction, a compact midrange-tweeter array, a low diffraction grille cloth frame and a tested TL design.

Should you decide to go all out and duplicate these enclosures, be forewarned that they are time consuming and intricate to construct. They are best tackled by the advanced builder, who takes pride in cabinetwork, is unconcerned about deadlines, does not keep track of hours and has a flair for masochism. I worked on the cabinets on and off for over a year, before I could install the drivers! Admittedly, I took considerable time figuring out how to do things as I went along.

The enclosures are large, tower-like monoliths in the listening room (*Photo 1*): they are 6⅕ feet tall, 2⅔ feet wide and 1⅓ feet deep (not including the feet). Each weighs approximately 280 lbs! *Figure 1* is an overall view of the enclosure. Each has two woofers and each woofer has its own TL. These are folded into a spiral shape: one clockwise and the other counterclockwise.

The slanted baffles, G and U, behind each woofer help break up standing waves behind the driver and provide adequate space for the sound path as it passes between the backside of the slanted baffle and center of the cabinet. Baffles B, Q, E, S, M, N, K, H and I are added to smooth the corners of the spiral sound paths. Although the tweeters and midranges are of the closed back design, I isolated them further by placing them in a chamber separate from the woofers. To enhance the vertical response I kept the interdriver spacing to a minimum.[2]

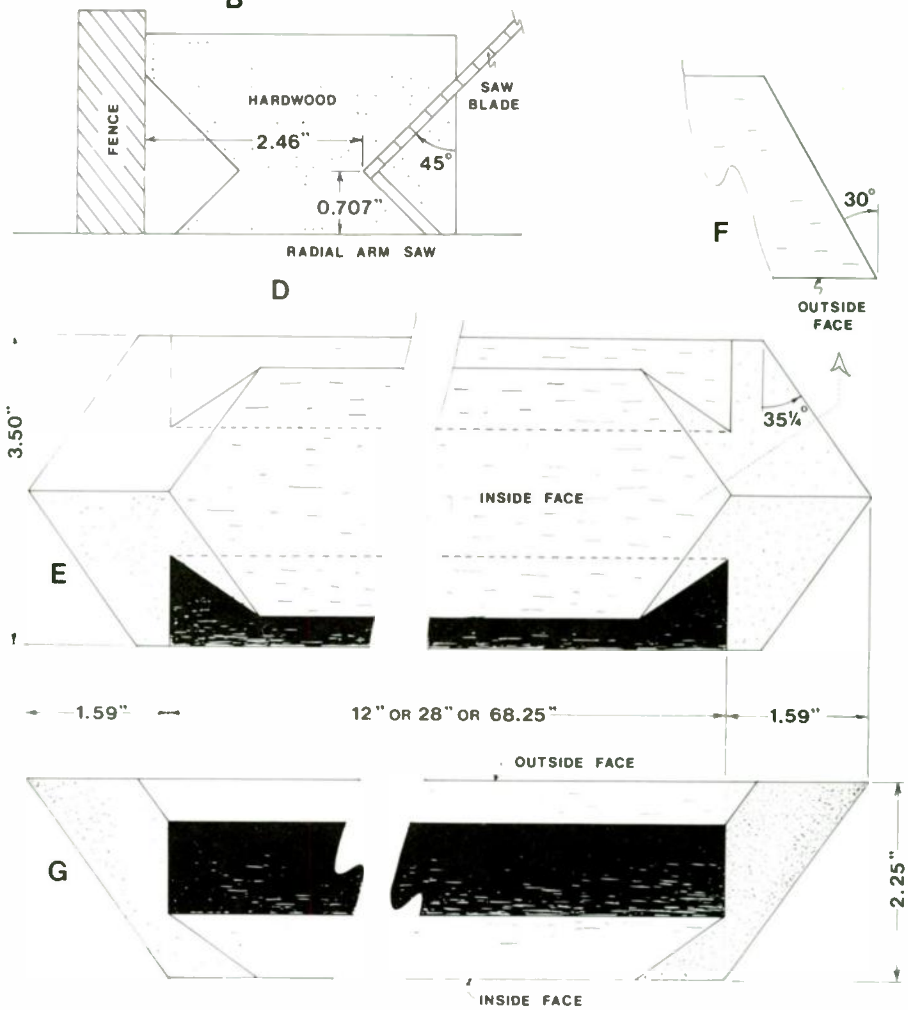


FIGURE 2: Cutting directions for the hardwood corner pieces.

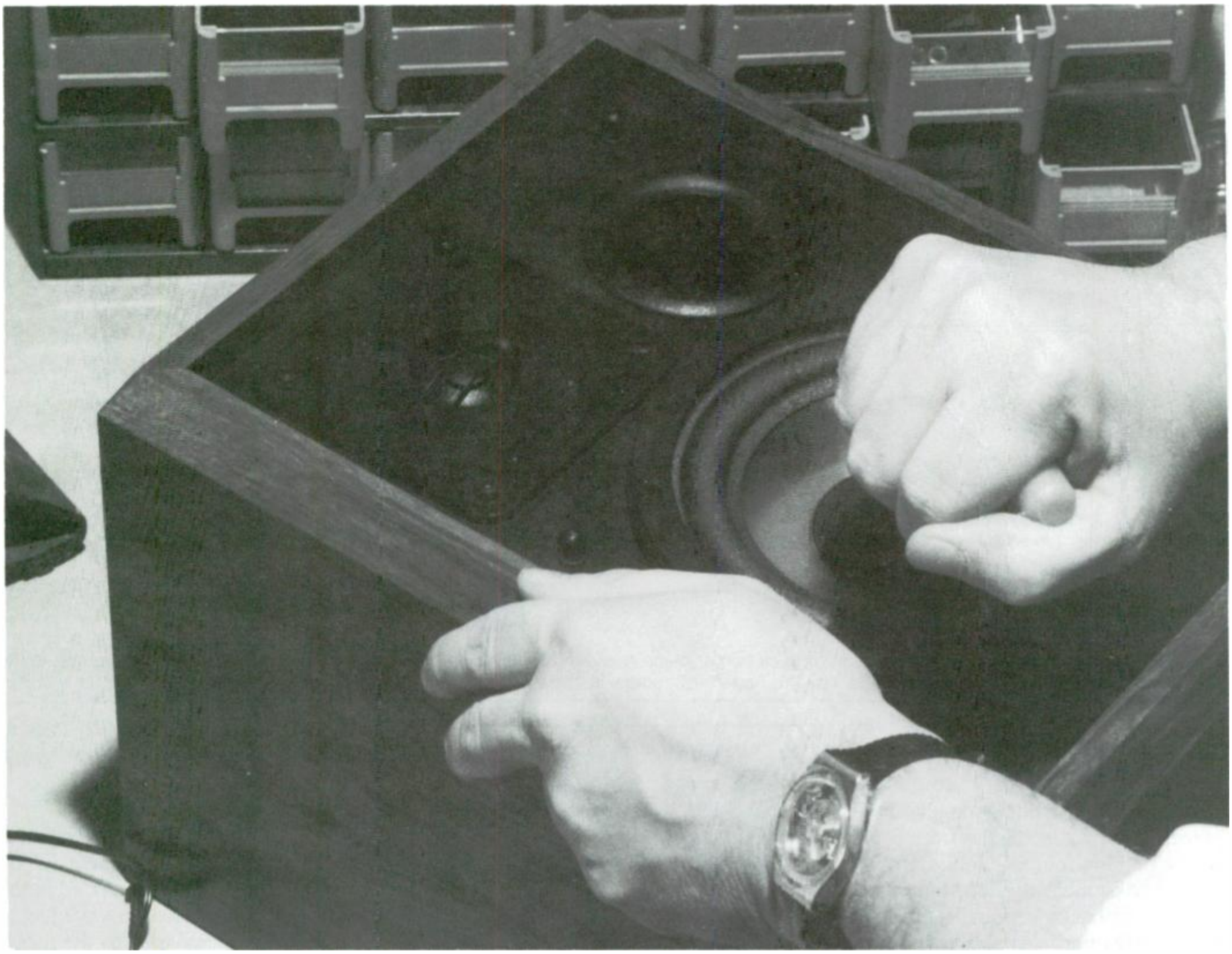
ROUGH ASSEMBLY. Precut 12 pieces of 1" cabinet grade particle board (not illustrated) for both enclosures: four pieces 28" x 68¼", four pieces 12" x 68¼", and four pieces 12" x 28". I assume you can find particle board that is actually 1" thick; the particle board I used measured 1 1/32" thick. For the corner pieces, size your 12 pieces of 8-foot-long hardwood to 2¼" x 3½". Remove a 32" section from the end of each of four of the 12 pieces, to be used later for the feet.

Finding hardwood 2¼" thick may be difficult, so you might consider bonding two thinner pieces together, although I have not investigated this procedure properly. I was lucky to have a local distributor of hardwoods (Cotton-Hanlon in Cayuta, NY) from whom I could select seasoned pieces of thick hardwood (I used African mahogany) still in their rough-cut state.

GROOVE CUTTING. First cut the two V-shaped grooves in four cuts (A, B, C and D of *Fig. 2*) for accepting the particle board during assembly. I used a table saw for the first two cuts and a radial arm saw for the last two. For safety and control, I prefer a table saw for the first two cuts, although you could use a radial arm saw. Cutting the ends is confusing, so practice on a piece of scrap. Tilt the blade of a radial arm saw 30° from the vertical and pivot the arm of the saw 35¼° for cutting the ends (E, F and G of *Fig. 2*).

Meet these cuts to the center line of the inside face of the hardwood and measure the distance between the points formed

Continued on page 14



Innovative components for creative hands.

Whether you're the weekend hobbyist or the serious installer, you know where the sound comes from. Speaker builders all over the world are choosing MTX drivers and components because they mean better sound for your money. Consistent specs. Superior reliability. From our famous bass drivers, mid-ranges and tweeters to our indestructible grille kits and state of the art crossovers, you can rely on MTX, the most installed speakers in the world.

MTX®

MTX • Makers of the world's best loudspeakers and sound components • Winslow, IL
The Mitek Group • One Mitek Plaza • Winslow, IL 61089 • 815/367-3000

Fast Reply #JD186

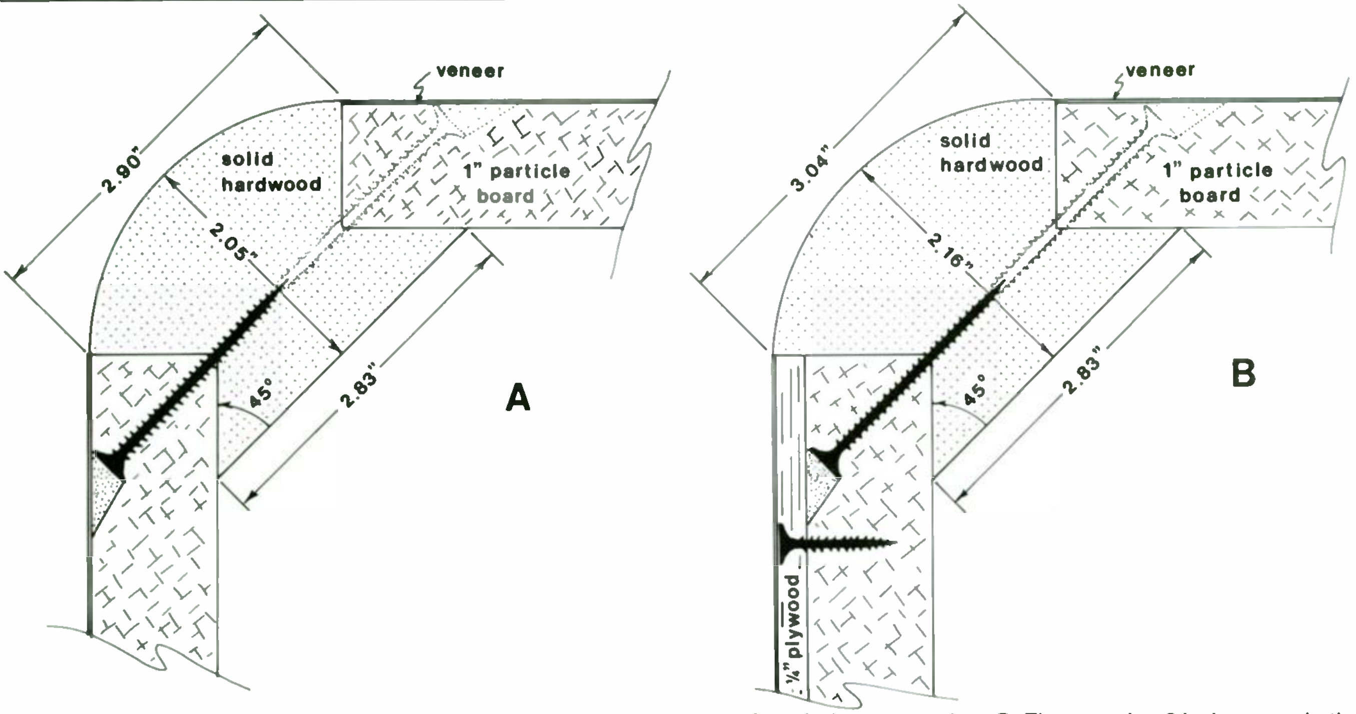


FIGURE 3: Cross section of the top, bottom, or back corner piece A and the front facing corner piece B. The opposing 2-inch screws in the hardwood are offset by 3 inches, which is why the upper right screw is shown in silhouette.

Continued from page 12

on the inside face to 12 or 28 or 68¼ inches. Cut one 12" and one 68¼" corner piece from each of the eight 8′ long hardwood pieces. Cut two 28" pieces from each of the remaining four 64" long hardwood boards. Assemble the top, bottom and sides to the back, forming a coffin-sized box. Join the particle board to the corner pieces using PL400 construction adhesive and 2" screw nails every six inches along the edges (see A of *Fig. 3*).

SEALING. Construction adhesive is easy to apply. It fills large gaps to ensure an airtight seal. When dry, it does not become brittle and any excess is easily trimmed with a razor blade. I made a jig to accurately predrill the holes for the screw nails. Although I used wallboard screw nails, I would have used hardened furniture screws[3] if I had known they were available.

Measure the internal dimensions of the box to see whether your box matches design specifications. If they are out of spec, adjust internal baffle boards (A through V) for a snug fit (*Figs. 4a* and *4b*). Install the internal baffles (A through V) using PL400 and screw nails at 6" intervals.

Cut a hole as per *Fig. 1* in the back panel for three sets of binding posts. Mount the posts on a 4½" x 9½" nonconductive plastic board (such as fiberglass circuit board material) and secure the plastic to the inside face of the back panel. In this manner the binding posts will not protrude beyond the backside surface of the enclosure. Route and secure high quality speaker wire with globs of PL400 every six inches or so inside the enclosure to keep them from rattling (*Photo 2*). Provide enough to wire the woofers in parallel and the midrange domes in parallel.

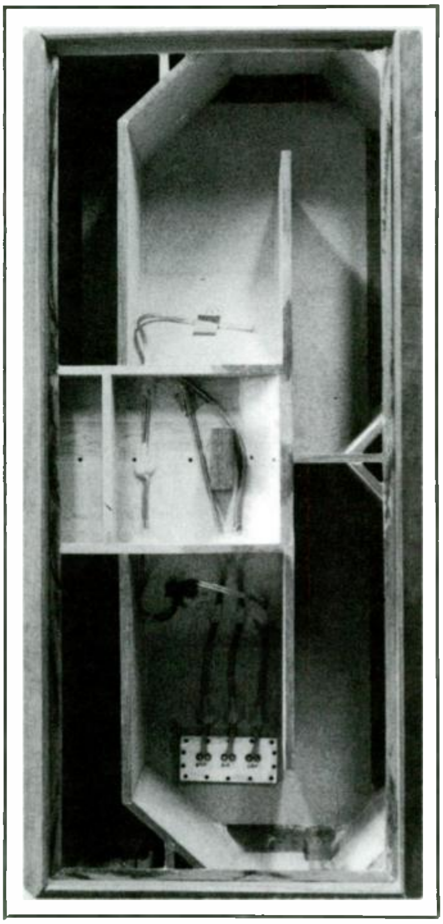


PHOTO 2: Partially completed enclosure before the front baffle is added.

FOOT ATTACHMENT. Attach four predrilled 2 by 2 by 1.5-inch hardwood blocks with ½"-13 nuts imbedded in the tops of each block (for bolting the feet to the bottom of the cabinet) to the inside face of the bottom particle board as shown in *Fig. 1*. To end up with one speaker with the drivers to the left side of the enclosure and the other with the drivers to the right, secure the feet attachment blocks as shown in *Fig. 1* for one speaker, and for the other, secure the blocks to the other end (which will effectively flip the speaker depicted in *Fig. 1* upside-down).

STUFFING. Before the front baffle is secured in place, install stuffing (Dacron Hollofil fiber at a packing density of 0.5 lbs. per cubic foot) where it is not easily accessible from either the woofer openings or the ports. Stuff the cavity formed under the slanted speaker baffle G and baffles J and K to the center divider L with 0.57 pounds (258g) of fiber. Place an equal amount in the matching cavity for the other driver under baffle U. Stuff 1.15 pounds (524g) into each of the adjoining sections which run along the side opposite the port to either the top or the bottom of the cabinet and bordered by baffle D or T.

Later, after the cabinets are completed, you will add 0.77 pounds (348g) of fiber behind the port and extending to the edge

Continued on page 16

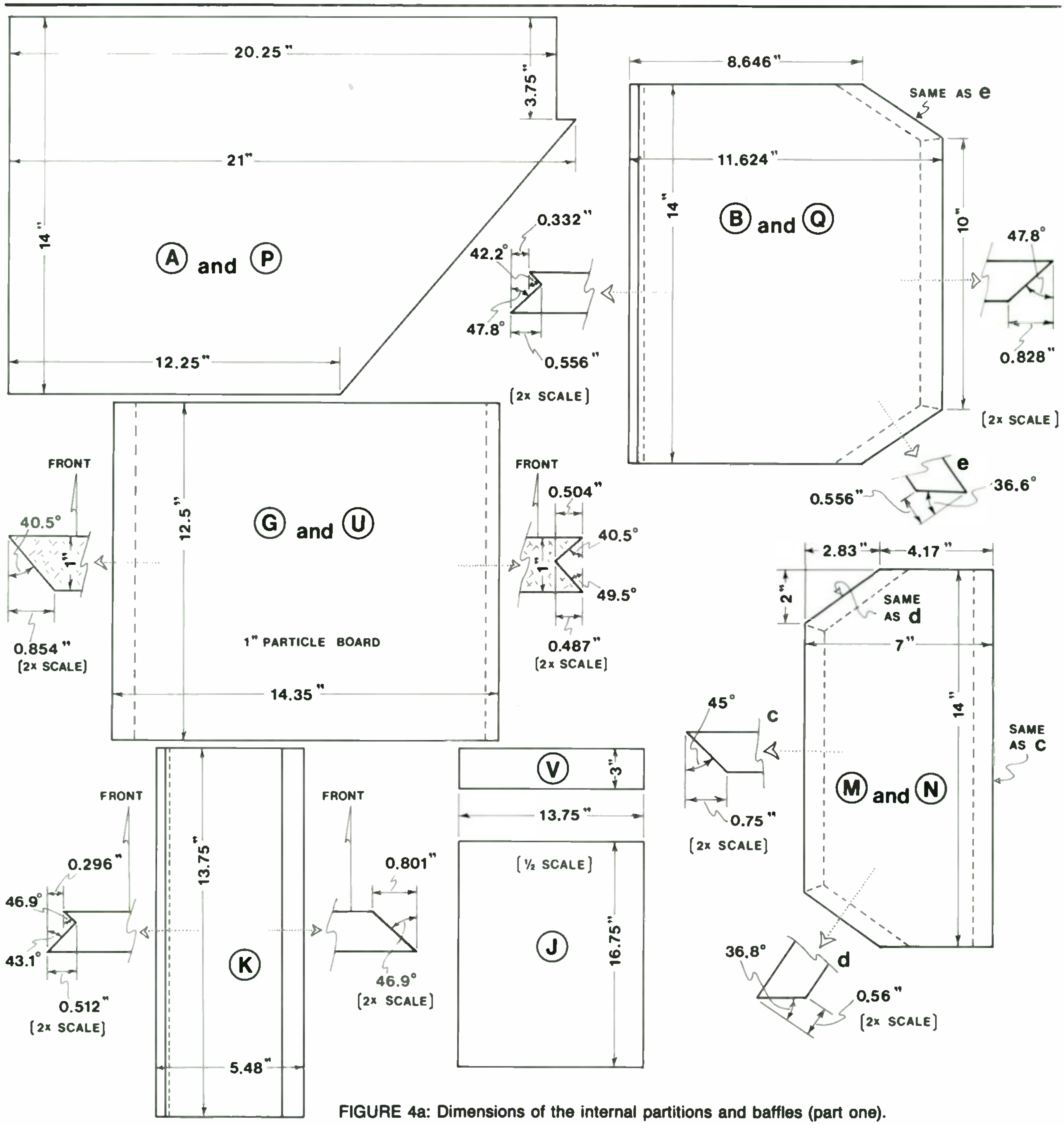


FIGURE 4a: Dimensions of the internal partitions and baffles (part one).

Continued from page 14
of baffle J. Under the woofer to the top or bottom of the cabinet you will add 1.07 pounds (484g). If you add fiber behind the port or woofer openings at this stage of construction, the jig saw will catch the fibers when you cut these openings.

Attach the front baffle of particle board to the edges and dividers as you did the other panels. Using a high quality jig saw and fine toothed blade, cut holes for the drivers. Adjust your saw to ensure that your blade is cutting perpendicularly to the front face. When cutting the ports, saw flush to the baffles A, B, C or P, Q, R because these baffles may not be accurately placed as given in *Fig. 1*.

ROUGH ASSEMBLY MATERIALS FOR TWO SPEAKERS

12 pieces of 2¼" x 3½" x 8′ hardwood
3 sheets of 1" x 5′ x 8′ (or 4 sheets of 1" x 4′ x 8′) cabinet grade particle board
2 sheets of ¾" x 4′ x 8′ cabinet grade plywood
5 quarts of heavy-duty sub-floor adhesive (PL400, Rexnord Chemical Products, Minneapolis, MN 55435)
8 pounds of 2" screw nails (approx. 600 screws)
6 pairs of 5-way binding posts
30′ of high-quality dual-conductor speaker wire
14.2 lbs. Dacron Hollofil fiber
8 machine bolts and nuts: ½"-13 x 2½"
4 machine bolts and nuts: ½"-13 x 1"
12 machine nuts: ½"-13

FINAL ASSEMBLY. To finish the enclosure you have a choice of two methods: a. the veneering method I used or b. the

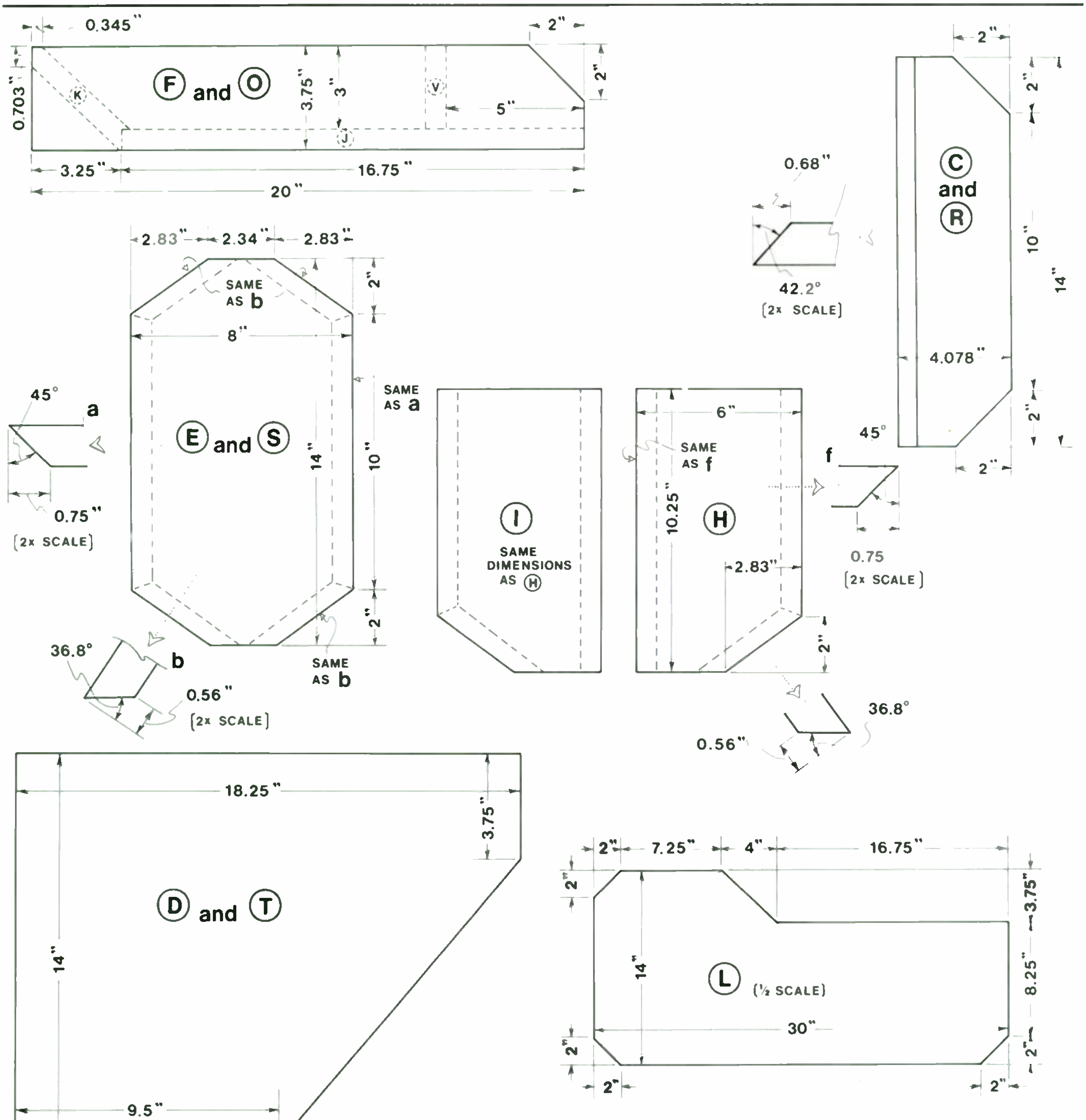


FIGURE 4b: Dimensions of the internal partitions and baffles (part two).

method I would probably use next time, which would be to bond ¼" veneered-faced plywood to all the particle board faces.[4,5] With either method you bond a veneered-faced ¼" plywood to the front baffle particle board (B of *Fig. 3*). Measure the frame formed by the front hardwood corners and cut a sheet of ¼" plywood for a snug fit. With a large sheet of paper, trace the driver holes and port openings in the particle board and use it as a template to position the openings depicted in *Fig. 5*.

Depending upon the final size of the port opening you cut in the particle board, you may need to modify the dimensions of the port shown in *Fig. 5*. The grille cloth frame for the ports needs a ½" (or more) ledge for support. Leave a uniform ½" width of plywood on the outer edges of the port opening for esthetics and strength.

I bonded the ¼" plywood to particle board with white glue and ¾" screw nails (one for every 36 in^2). Use clamps to hold the thin plywood around the outer edges of the ports while the glue dries. Fill the shallow depressions of the screw nails holding the plywood to the particle board with auto body filler and sand flush. Alternatively you could bond the plywood to the particle board with epoxy.[4,5]

VENEERING. If you decide to veneer your cabinets, not only will you veneer over the particle board, but also you will need to veneer over the veneered-faced ¼" plywood on the front baffle to cover the filled screws and to match the wood species of the hardwood corners. Unfortunately, a few months after I completed the veneering, the veneer was perceptibly raised above filled screws, where the veneer was applied directly to the surface of the particle board. I really don't know why. I didn't coat the inside or the outside surface of the particle board with a sealer like polyurethane, therefore shrinkage of the particle board relative to the filler could have raised the veneer. Whatever the cause, applying ¼″ veneered-faced plywood to all the particle board surfaces as discussed below should avoid this problem.

SANDING. Before veneering, round the hardwood edges. Temporarily hold pieces of sheet metal, slightly thicker than the veneer, against the inside edge of the hardwood corners, to gauge the amount of wood removed while sanding so that the veneer will be flush with the corner pieces. Use a hand plane to remove the bulk of the wood and a hand-held belt sander to finish the rounding process.

Belt sanders remove wood quickly, so sand a little and check often. Hand sand for the final smoothing. I used hot animal glue (hide glue) to bond the veneer to the flat surfaces, utilizing the old hammer-veneering technique.[6] When I did my veneering two years ago, I was unaware of heat-activated sheet glue,[7] which should be a superior bonding agent.

Rather than veneering, I would recommend an alternate method for finishing the flat surfaces of the enclosure: that is, to epoxy veneered-faced ¼″ plywood to the particle board as described in detail by Joseph D'Appolito and James Bock.[4,5] The only problem with this technique is that your selection of wood available in ¼″ plywood will be limited compared to those available with veneers.

Please note that the 2¼ x 3½-inch hardwood corners are large enough to accommodate veneered-faced ¼″ plywood on both sides of the rounded corners. I think it would be best to round the corners, as described above, before bonding the plywood to the particle board, to reduce your chances of sanding through the thin veneer surface of the plywood.

ADDING FEET. To keep your speakers from tipping over and crushing the family pet, you will need to add feet as illustrated in *Fig. 1*. Use the four aforementioned 32″ hardwood pieces saved for this purpose. Round the tops of the feet, where they extend beyond the box. Two ½″-13 x 2½″ bolts secure each foot to the enclosure.

A ½″-13 x 1″ bolt is placed at the center of each foot with its nut imbedded in the wood. In a lowered position, this center bolt will keep the enclosure from rocking side to side. Without it the feet behave like leaf springs on a car suspension, being supported only at the ends where the nylon glides touch the floor. When the center bolt is raised, the nylon glides allow you to slide the speaker around on a hard smooth surface such as a hardwood floor. Don't ask me what to do if you have wall-to-wall carpeting.

You have a wide variety of choices in wood finishes. For example, you could use two coats of hand-rubbed natural Watco Danish oil finish (as I did), epoxy[4] or polyurethane.

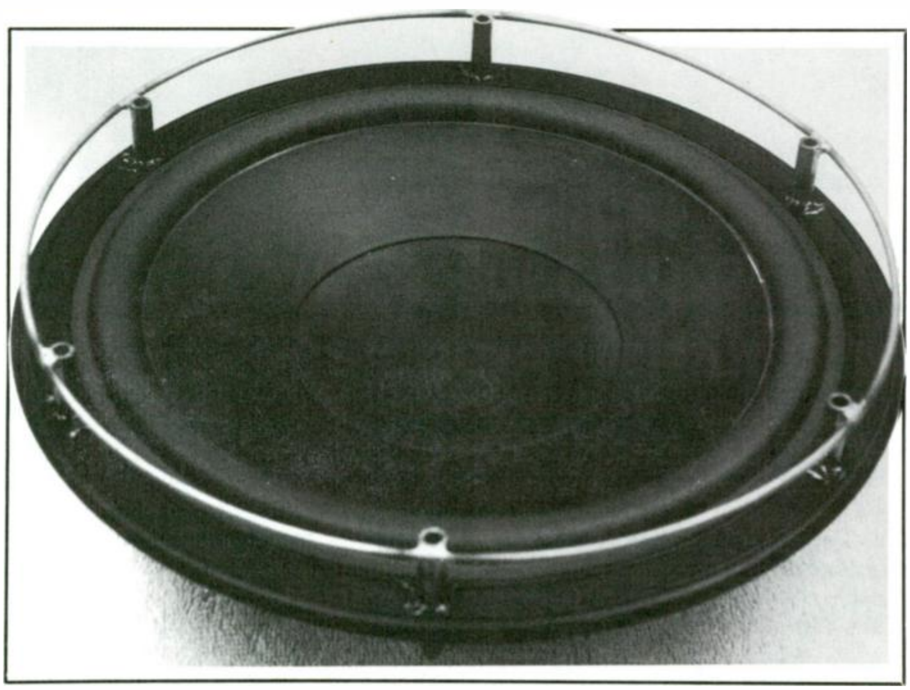


PHOTO 3: Woofer with supporting framework for the grille cloth.

FINISHING MATERIALS FOR TWO SPEAKERS.

Method I: Veneering

6′ long pieces of veneer with widths adding up to about 200 inches (which is about 10% more than the finished width to allow for overlap of adjacent pieces and edges)
2 sheets of ¼″ x 4′ x 8′ cabinet grade plywood
1 pound of 1″ screw nails (approx. 150 screws)
white glue and hot animal glue
wood finish of your choice

Method II: Veneered-faced plywood

4 sheets of veneered-faced ¼″ x 4′ x 8′ plywood epoxy (Gougeon Brothers)[4]
wood finish of your choice

GRILLE HOOP. Wrap double-knit speaker cloth around a wire frame of the woofers as shown in *Fig. 6*. The wire-hoop frame (*Photo 3*) is supported by hollow standoffs. They are hollow for passage of the mounting screws. Fabricating the wire-hoop frame is tricky. Use a lathe to cut ⁵⁄₁₆″ OD x ³⁄₁₆″ ID stainless steel tubing to 1⅛″ and to square off the ends.

Build a jig comprising two metal plates with holes for bolts to hold the standoffs vertical, spaced to match the bolt spacing of the woofer frame. Prebend a ⅛″ stainless steel rod into a hoop of the appropriate size. Silver solder the hoop to the standoffs mounted in the jig. To true the bolt head recesses of the cast frame of the woofer use a ⁵⁄₁₆″ endmill. Epoxy the completed wire-hoop frame to the woofer frame. Stretch double-knit cloth over the hoop and attach the cloth to the back of the woofer flange with contact adhesive. To do this, saturate the cloth with adhesive in one spot and, while holding it, let it dry long enough that it stays put.

Continue with this technique as you work around the frame. Some brands of contact adhesive, like the one I used (see list below), will allow you to reposition the cloth to get a taut fit. Once the cloth is secure, use a cotton swab to apply a small amount of contact adhesive to the cloth immediately above the standoff. When dry, use the hole at the end of the standoff as a guide and cut a ³⁄₁₆″ hole with a pointed surgical blade for the mounting screw to pass.

Spray paint the heads of the screws with Rust-Oleum satin black paint. This paint is scratch resistant if you bake it on for about one hour in the oven at about 200°F. A flat washer between the screw and the cloth will usually prevent the cloth from twisting when the screw is tightened. To

Continued on page 20

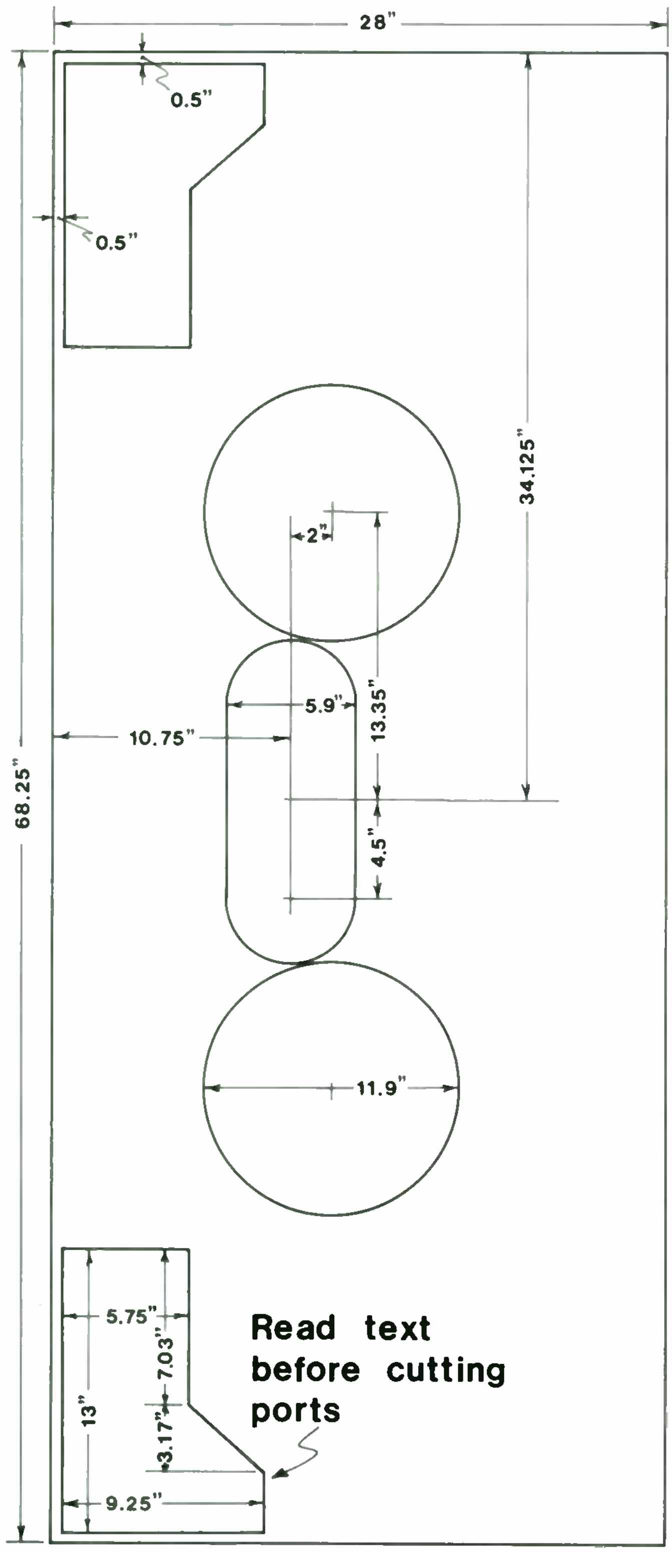


FIGURE 5: Dimensions of the plywood facing for the front baffle.

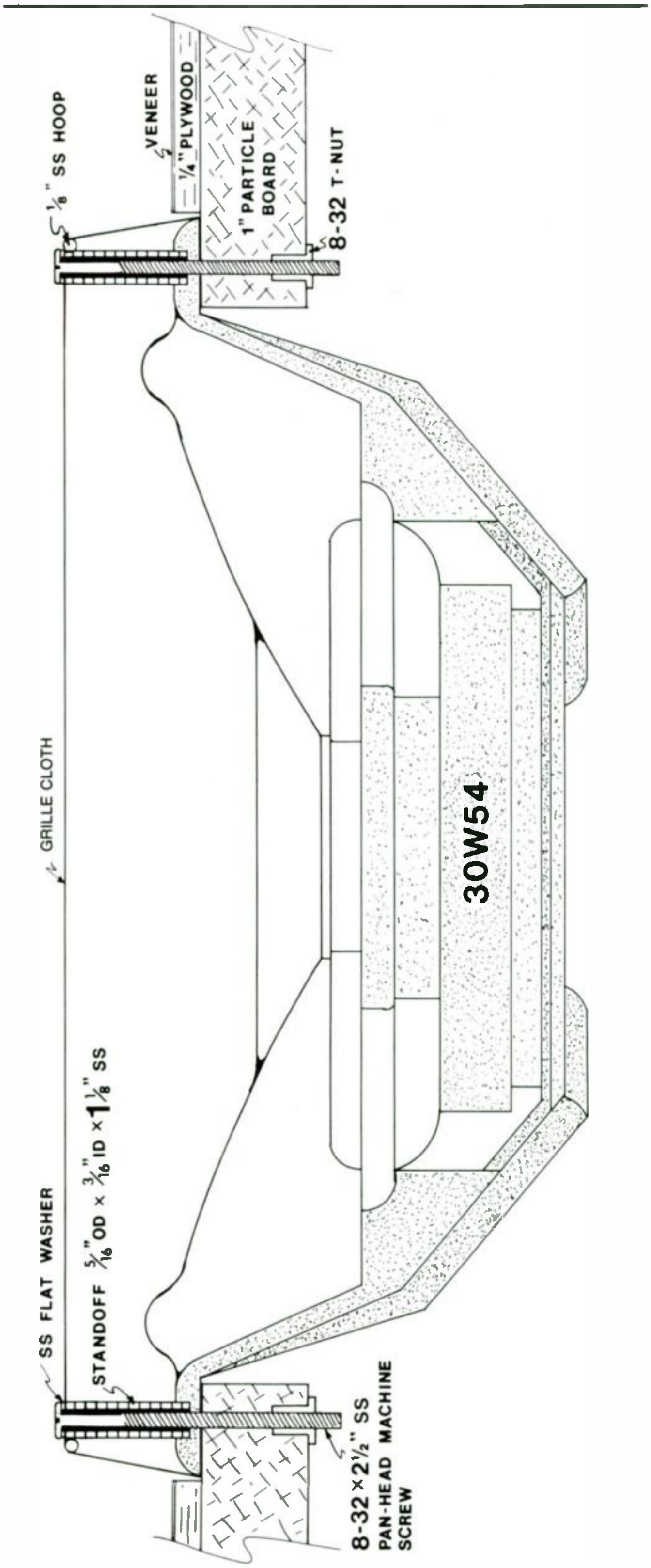


FIGURE 6: Cross section of the Dynaudio 30W54 woofer and grille mounted on the front baffle.

Continued from page 18
ensure an airtight seal around the woofer flange, attach adhesive open-cell foam tape (3/16" thick x 3/8" wide) to the particle board beneath the woofer flange.

MIDRANGE-TWEETER. The midrange-tweeter array is composed of two Dynaudio D76 midranges flanking a Dynaudio D28 AF tweeter mounted onto an aluminum plate with wire-hoop frame for the grille cloth (*Fig. 7* and *Photo 4*). The mounted array with grille cloth is shown in *Photo 5*. I fabricated the wire-hoop frame and attached the grille cloth in the same manner as with the woofers. Use the two plates (C of *Fig. 7*) for a temporary jig to hold the standoffs in position as you silver solder the hoop to the standoffs. Install a 1/32" gasket between the tweeter flange and the mounting plate to

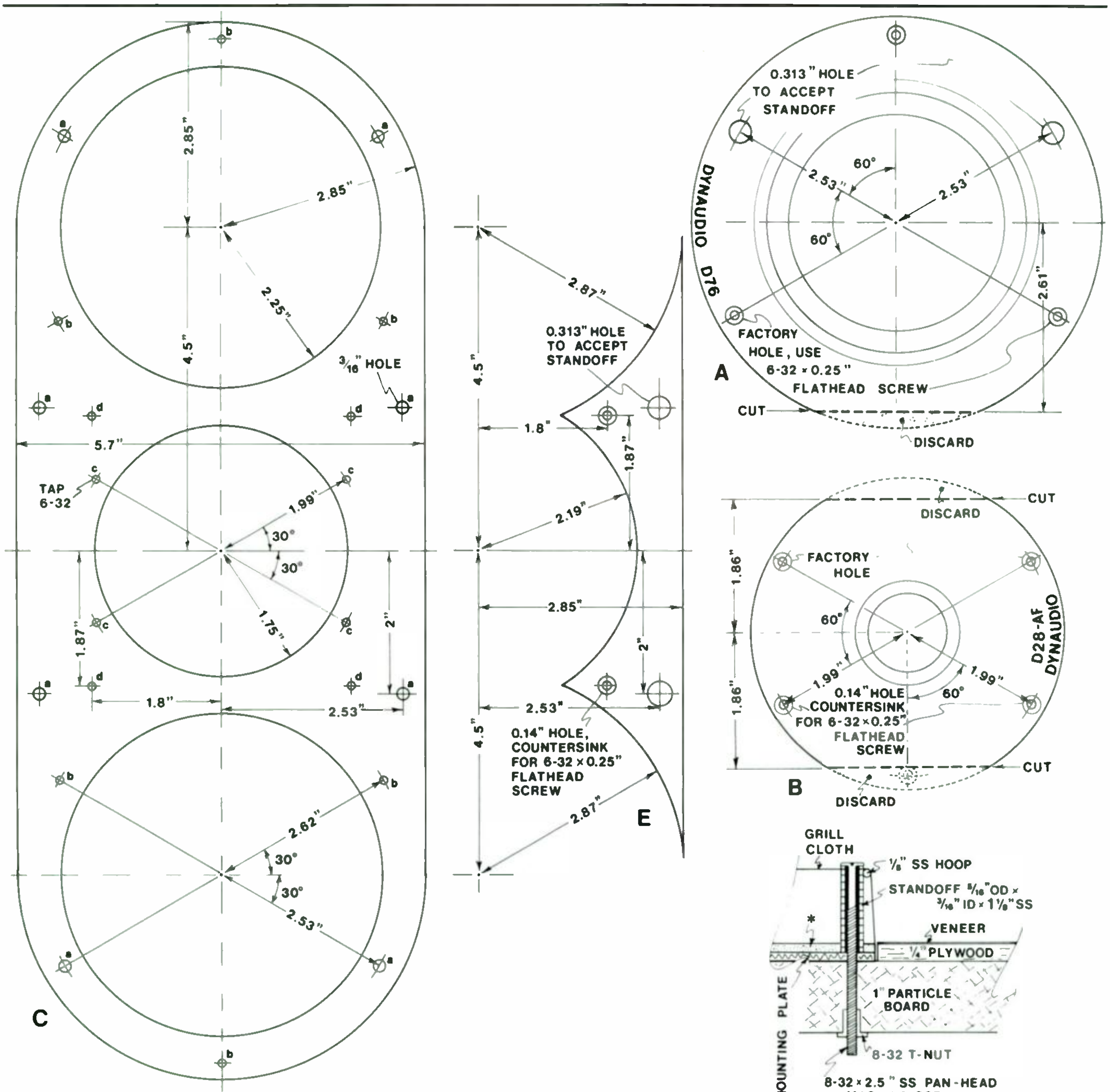


FIGURE 7: Midrange-tweeter array, including midrange A and tweeter B flange modifications, aluminum mounting plate C, grille mounting details D and aluminum filler plate E (two required).

raise the surface of the tweeter flange flush with the midranges.

The grille cloth frame for the ports (not illustrated) is fabricated from ⅛" sheet aluminum. Using a piece of paper, trace the outline of the shelf formed between the outer layer of plywood and the underlying particle board of each port opening. From each tracing, individually mark each aluminum frame for cutting because they will undoubtedly differ slightly in size. Before you cut the aluminum, reduce the outside width and height of the tracing by about 1/16 inch to allow space to wrap the grille cloth around the edges of the frame.

I attached the cloth to the backside of the frame with contact adhesive as I did for the grille cloth of the drivers. Attach four 1" pieces of Velcro to hold the completed frame to the enclosure. The combined thickness of the Velcro, grille cloth and ⅛" aluminum frame will bring the outer surface of the grille cloth flush with the finished front baffle.

DRIVERS, GRILLES AND MOUNTING HARDWARE FOR TWO SPEAKERS.

4 woofers: Dynaudio 30W54
4 dome midranges: Dynaudio D76
2 tweeters: Dynaudio D28 AF
2 yards of double-knit grille cloth (Radio Shack or Audio Concepts in LaCrosse, WI)
18′ of ⅛" stainless steel rod
40 stainless steel standoffs: 5/16" OD x 3/16" ID x 1⅛"
40 panhead stainless steel screws: 8-32 x 2½"
40 stainless steel washers: 5/16" OD x 5/32" ID
40 T-nuts: 8-32
1 pint contact adhesive (Macklanburg-Duncan)
15′ of adhesive open-cell foam tape (3/16" thick x ⅜" wide)
1 can Rust-Oleum satin black (#7777) spray paint

12″ x 21″ of 1/8″ aluminum sheet for midrange-tweeter mounting plates
2 pieces of ⅛″ x 13″ x 16″ aluminum sheet for the port grille cloth frames
2′ of Velcro

TRANSMISSION LINE: MEASUREMENT AND THEORY

MEASUREMENT TECHNIQUE. Accurate measurement of the anechoic frequency response of any low frequency driver in its enclosure is a difficult, if not impossible, task for the amateur speaker builder. You *could* place the microphone one meter away from the enclosure (far-field technique), provided the enclosure is suspended five meters above an open field or is buried face up in it to avoid the effect of reflections. Obviously, the amateur needs an easier method. Keele's near-field technique[8] is fine provided you take into account the port's phase response relative to the driver.[9]

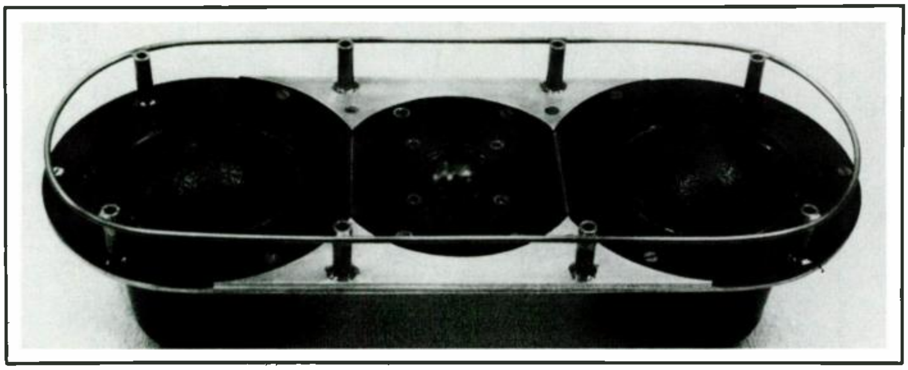


PHOTO 4: The completed midrange-tweeter array with support for the grille cloth.

I measured the near-field amplitude response of all four drivers and four ports, separately and with a single electret condenser microphone (Panasonic model P9932 from Digi-Key, PO Box 677, Thief River Falls, MN 56701) in conjunction with a microphone preamplifier.[10] Using a single microphone avoids measurement error due to frequency and phase response differences from one microphone to the next. My microphone is not calibrated so I don't know its true response, although others have used it and indicate that it is reasonably flat, especially down to low frequencies around 20Hz.

With the grille cloth removed, I placed the microphone close to the center of each Dynaudio 30W54 driver (about ⅛″ away from the cone). Place sound absorbing material between the driver and port during the near-field measurements to prevent cross talk between port and driver.[9] I did observe cross talk between the two without any sound absorbing material, therefore the data I report are for the measurements taken with a sofa cushion, my "sound absorber," held tight against the enclosure between the driver and the port.

TIME DELAY. To measure the port waveform's time delay (or advance) relative to the driver phase, I used the signal generator's sync output to trigger my scope which fixed the driver and port waveforms on the scope relative to my input signal. I noted the time difference between the driver and port waveforms as they passed through zero volts. I took care to center the waveforms on the scope relative to the zero horizontal axis.

For the phase and amplitude measurements I fed a continuous sine wave into the speaker for the two decades above 10Hz in ⅙th octave increments. I repeated the phase and amplitude measurements for the ports.

The phase and amplitude across the driver piston surface and the port opening were quite stable for the frequencies below about 160Hz. The driver's effective piston area is 62 square inches while the actual port area is about 70 square inches. Considering that the amplitude drops toward the edges, I suspect the effective port area would be similar to that of the driver, although I did not carefully map the effective area for this project. Assuming the piston and port areas are the same, the following equation can be used to calculate the near-field response of the TL enclosure.

Response (in dB) =

$$20 \log_{10}\left(\frac{\sqrt{D_{mv}^2 + P_{mv}^2 + 2D_{mv}P_{mv}\cos\phi}}{REF_{mv}}\right)$$

where, D_{mv} is the driver response in μV, P_{mv} is the port response in μV, ϕ is the angle between D_{mv} and P_{mv}, and REF_{mv} is the voltage in millivolts to give zero dB at an arbitrarily selected 200Hz.

FREQUENCY RESPONSE. The average amplitude response of the four TLs is given in *Fig. 8* for the drivers alone and ports alone, and the combination of the two using the equation above. The phase shift between the port and the driver is also shown. The only difference I observed between the four TLs was 1 to 2dB reduced output of the upper drivers and ports as compared to the lower drivers and ports in the range of 30 to 70Hz. Presumably the close proximity of the lower drivers and ports to the floor plane boosted their apparent near-field output. Otherwise, the output of the four TLs was amazingly similar, which is why they are averaged in *Fig. 8*.

LINE PHASE SHIFT. The phase shift created by the line filled with Dacron Hollofil fiber is of special interest. At 37Hz the line is ½-λ long, where 0° phase shift is observed. This means the inverted wave from the rear of the driver is inverted another 180° by the line and thus is in phase with the front of the driver, assuming the driver and port are close to each other.

At ¼-λ (14Hz) and ¾-λ (72.5Hz) the port affords partial augmentation of the driver's output. At 112Hz the line is one wavelength long, where maximum cancellation occurs. Looking at *Fig. 8*, you can see that from about 80 to 130Hz the port cancellation of the driver's output causes about a 1.5dB dip in the overall response.

As previously mentioned, I used Hollofil fiber (tubular Dacron) to pack the transmission line. Dacron has a specific gravity of 1.38 (Merek Index) and thus is more dense than long wool fiber, which has a specific gravity of about one.[11] I assumed the "effective" density of the fiber of Hollofil to be less because it is hollow. The outside diameter of Hollofil fiber is 22.5μ, measured under the microscope.[1] The inside diameter of the fiber is 12.5μ. Therefore the "effective" specific gravity was calculated to be 0.954.

We can determine the phase shift in degrees of the port relative to the driver output at a given frequency, where the phase shift of the line is subtracted from the inverted radiation from the rear of the driver (note: I am using the convention where positive degrees means the port wave is in advance of the driver's frontwave and negative degrees means the port wave is delayed relative to the frontwave):

$$\text{phaseshift} = 180° - 180°\left(\frac{2\alpha Lf}{a_0}\right)$$

where L is the line length in meters, f is frequency, α is determined from Bradbury's equation #4a which is a function of the fiber radius, specific gravity and packing density, and a_0 is the speed of sound in free air.[11] Phase shift calculated using Bradbury's equation is shown in *Fig. 8*. I was pleasantly surprised to see that Bradbury's equation closely matches the measured phase shift.

LINE ABSORPTION. Bradbury also gives the absorption of sound in dB by a fibrous tangle given the radius, specific gravity and packing density of the fiber (*Fig. 8*).[11] My measurement of absorption is calculated as the difference between the near-field driver and near-field port amplitude response. The fit between measured and theoretical absorption is not as good as the fit between measured and theoretical phase shift. Had the Hollofil fiber absorbed as much as indicated by theory in the range of frequencies from 50 to 130Hz, the dip around 100Hz in the overall response would have been less.

I can only speculate why Hollofil did not have as much absorption from 50 to 130Hz. Notice the periodic nature of the absorption. Possibly the periodic deviation from theory is a result of acoustic cross talk between the port and the driver or cross talk through the internal TL dividers. Maybe it is caused by the unequal path lengths due to the bends of the TL.

TL THEORY. The TL in this project follows, more or less, the "guidelines" which have been developed through trial and error over the years.[12-16] "Guidelines" followed here include: a line length of 6 to 8 feet, packed with 0.5 lbs. Dacron per cubic foot, which begins with a cross-sectional area exceeding the effective piston area just behind the driver and tapers down to a port area approximately equal to the piston area, smoothing the bends with angled corner pieces, and using a slanted reflector behind the driver to spread out the frequencies reflected back through the cone.

Although relating "guidelines" to mathematical theory has been attempted, it has not been completely successful.[1,11,17] Given what I know at this point, I will attempt to describe what is known and to relate this to the TL in this project.

This TL enclosure behaves as a broadband, inverting (180° phase shift) lowpass filter. Radiation from the port is in phase with the front radiation of the driver, having been delayed by ½-λ from the out-of-phase radiation from the rear of the driver. It is "broadband" inasmuch as the port output augments the front radiation of the driver through about 2 octaves (i.e., from about 15Hz to about 60Hz).

ON DICKASON. In *Fig. 8* you can see that the output from the line substantially augments the output of the driver by 2 to 3.5dB from 14 to 60Hz. Dickason's recommendation[16] that TL builders select a line length 6 to 8 feet long corresponding to a ¼-λ at 45–35Hz is misleading, because a ¼-λ at 45–35Hz refers to an open line and not a TL normally filled with a fibrous tangle. An 8-foot line with 0.5 lbs. per cubic foot Hollofil actually results in a ½-λ shift at 37Hz, not a ¼-λ shift. The line filling effectively absorbs higher frequencies radiated from the rear of the driver (*Fig. 8*).

Although the phase shift and sound absorption by the fiber tangle in the TL appears predictable by Bradbury's equations,[11] the acoustic impedance of a typical, fiber-filled TL is not as predictable by his equations. This may be due to the fact that Bradbury assumes a line with a fixed diameter, whereas typical TLs are

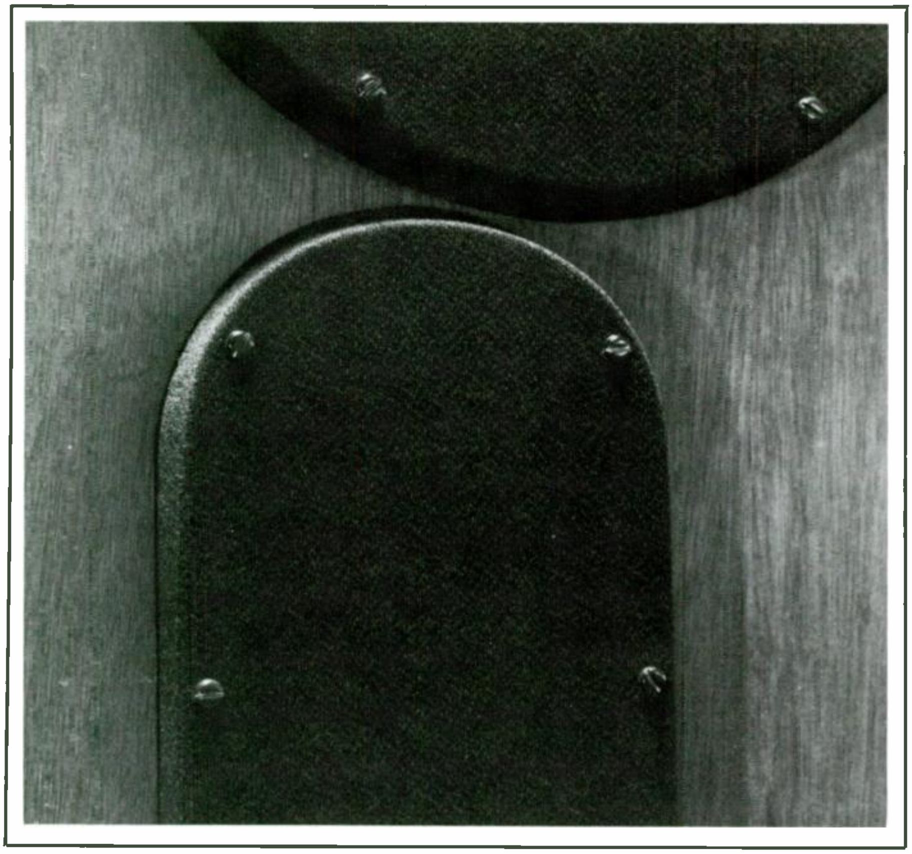


PHOTO 5: Detail of grille cloth and mounting screws of the installed woofer and midrange-tweeter array.

tapered. We know that the acoustic impedance of the line influences the output behavior of the driver (the driver "views" the acoustic impedance of the TL as a mechanical impedance): a high impedance decreases the output of the driver. The impedance of the TL is complex because it is strongly influenced by three factors: line length, shape and filling material.

LINE LENGTH. First, we will consider line length effect on mechanical impedance. The wave from the rear of the driver travels to the open end of the TL where it is reflected back toward the driver.[17] When the frequency of the reflected wave equals the TL's ½-λ (or multiples of a ½-λ, such a 1 λ), it is in phase with the driver, having traveled a full wavelength. At this frequency, the reflected wave presents a low mechanical impedance to the driver. When the frequency of the reflected wave equals the TL's ¼-λ (or multiples of a ¼-λ, such as ¾-λ), it is out of phase with the driver, having traveled half a wavelength. In this situation it exerts a high mechanical impedance or damping action upon the driver.

With an acoustical labyrinth, which is a TL with an empty line (although the walls of the original labyrinth[18] were lined with absorbing material), the damping action of the TL's ¼-λ frequency is chosen to match the resonant frequency of the driver and thereby dampens its motion. Unfortunately, the reflected waves in an empty line cause a very uneven mechanical loading on the driver resulting in a highly irregular response.[11,17]

PACKING. Filling the line with a fibrous tangle greatly ameliorates an empty line's uneven impedance effects, where the fiber filling levels out the low and high mechanical impedances caused by the reflected wave of the TL. The effectiveness of fiber filling in smoothing the impedance, depends upon its diameter, specific gravity and packing density.[11] Long-wool fiber, Hollofil, and fiberglass all differ with respect to their diameter and specific gravity.

Long-wool fiber and Hollofil are similar in diameter and specific gravity, except that long-wool is a tapered fiber (unpublished observations). Being tapered, wool is of many different diameters, which might make it a non-resonant filling superior to a fiber of uniform diameter like synthetic Hollofil.

Fiberglass, which is a smaller, denser fiber than either long-wool or Hollofil, is not as satisfactory. This becomes apparent when we use Bradbury's equation #8 to compare the impedance effect of fiberglass to Hollofil, assuming for both fibers a packing density of 0.5 lbs. per cubic foot in an 8-foot line.[11]

The two fibers differ little from 50Hz to 400Hz, where the specific acoustic impedance of fiberglass is only slightly higher than Hollofil. Below 50Hz, however, the specific acoustic impedance of fiberglass becomes more erratic than Hollofil, peaking to 3.2 Newtons-sec per cubic meter at 40Hz and dipping to 1.3 Newtons-sec per cubic meter at 25Hz (compare this to the specific acoustic impedance for Hollofil in *Fig. 8*). For both fiberglass and Hollofil, acoustic impedance above about 25Hz is dominated by resistance, rather than reactance, of the fibers.

SHAPE. Finally, let's consider TL's shape, the third factor which complicates our understanding of the impedance created by the TL. The TL in this project tapers (as do many implementations of TLs) from a cross-sectional area approximately 2.5 times the piston area of the driver down to a cross-sectional area slightly larger than the piston area of the driver. In other words, it looks like a backwards horn. We could also say that our line has an enlarged volume behind the driver which behaves as a coupling volume.

Letts looked at the influence of a coupling volume on TL performance.[17] His experimental results show that the coupling volume gives the line compliance which, like a capacitor, decreases its impedance with increasing frequency. The uneven mechanical impedance on a driver in an empty TL at higher frequencies (i.e., above about 100Hz) is ameliorated by the coupling volume and the fiber filling. Both cause the TL to have little mechanical impedance at higher frequencies, which is obviously desirable in order to retain the driver's efficiency and natural response at higher frequencies.

We can say that the driver is mechanically "decoupled" from the line at higher frequencies. To date, we have yet to successfully model the mechanical impedance created by a TL where line length, fiber filling and TL shape are all considered. As a final note, tapering should also reduce the tendency of a line to reflect any one frequency back through the cone or to cause the line to resonate at a particular frequency.

VOICE COIL IMPEDANCE. When we measure the voice coil impedance of a driver mounted to a TL, we typically observe two impedance peaks, especially with short lines. Using experimental lines packed with 0.5 lbs. of Hollofil per cubic foot, a 3.9-foot line had impedance peaks at 38Hz and 60Hz. A 5.6-foot line had peaks at 40Hz and 53Hz.[1] Cox also observed two impedance peaks in his shorter experimental lines.[19]

Sometimes when the length of a fiber-filled line is increased, one of the two impedance peaks is no longer apparent, leaving only one peak. My observations suggest that the lower impedance peak is due to the resonant frequency of the driver, while the upper peak results from the excitation of the fundamental resonance of the TL. At this fundamental resonance the woofer oscillates synergistically with the air moving in the line, which in turn causes the back-EMF responsible for the upper impedance peak.

In free air the woofer resonates at a frequency given by the expression: $f = \sqrt{s/m} / 2\pi$, where s is the stiffness of the driver's suspension and m is the moving mass of the cone. [Note: Stiffness is a force which restores the system to its original position, as a spring would. It is not to be confused with frictional resistance, which converts energy to heat. Frictional resistance does not influence the frequency of resonance, but rather it dampens the resonance. Moving mass has inertia, the tendency to continue in motion once set in motion.]

Likewise, the TL also resonates following the same expression given for the woofer, with its own mass of moving air and fiber and its own stiffness (the tendency of air to spring back when compressed). A TL is analogous to an organ pipe: a tube closed at one end (driver end) and open at the other (port end). The masses and the springs of the woofer and the TL do not operate independently of each other, nor are they directly additive. Adding the masses together into a single mass and the springs together into a single spring would result in one resonant frequency, which is not the case. Instead, we have an example of a coupled oscillator where the mass of the driver is coupled to the mass of the TL via the spring of the TL.

OSCILLATORS. It appears that the two masses move in phase with each other at the lower resonance point and 180° out of phase with each other at the upper resonance point. For example, an empty unflanged tube, 3.5 feet long and closed at one end with a driver, has a fundamental resonance around 76Hz, provided the driver is not allowed to move. At 76Hz the wave from the back of the driver that is reflected from the end of the tube is 180° out of phase with the back of the driver (note that acoustic impedance is high at this frequency).

When I measured the voice coil impedance peak of a driver on a 3.5-foot experimental tube, I discovered that it occurred at 96Hz, rather than 76Hz. Using the mathematics of coupled oscillators I found that 96Hz was a reasonable value for the upper resonant frequency, given the masses and spring values of the woofer and TL that I used in my test setup.

MORE STUFF. When fiber is added to the line, it becomes difficult to predict where the two impedance peaks of the voice coil occur. Increasing the length of the fiber-filled line lowers the frequency of both impedance peaks.[19] This would be expected because the moving mass of the fiber and the air in the line increases as the line is lengthened (also true of empty lines). When the moving mass of the line is coupled to the mass of the driver, the resonance of the driver (i.e., the lower impedance peak) is lowered. Increasing the length of the line also lowers the fundamental resonance of the line and predictably lowers the upper impedance peak of the driver. Like-

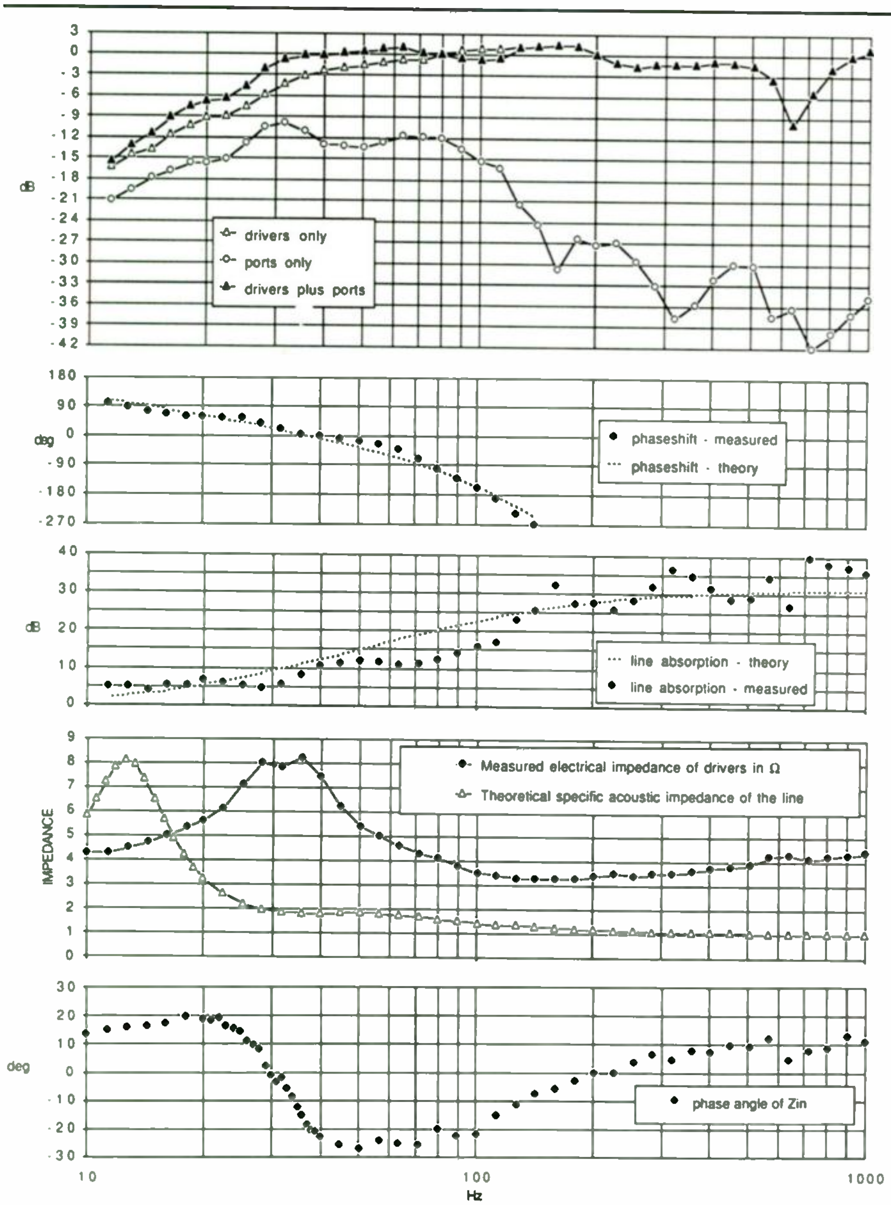


FIGURE 8: Response characteristics of the Dynaudio 30W54 woofer mounted on an 8-foot transmission line, including (top to bottom) near-field amplitude response, phase shift by the line, absorption by the line, electrical and acoustic impedance of the line and phase angle of the woofer voice coil impedance.

wise, adding more fiber to a line without changing its length, lowers the upper resonant peak because the increased packing slows the speed of sound, thereby increasing the apparent length of the line and lowering its resonance.

An unexpected thing happens to the lower impedance peak when you increase the fiber packing density without changing the length of the line. The lower impedance peak goes up in frequency, rather than down as one would normally expect given the fact that the moving mass of the line increases as more fiber is added. A 3.5-foot line I packed with 0.25 lbs. of Hollofil per cubic foot had its lower impedance peak at 27Hz (using an 8″ driver with a free air resonance of 43Hz). The peak rose to 50Hz when the packing density was increased to 0.6 lbs. per cubic foot. The added fiber appears to increase the stiffness of the line (fibers will spring back after you compress them in your hand) more than it increases the moving mass of the line, with the net result of raising the resonant frequency.

The amount of stiffness is sensitive to how uniformly the fiber is teased out. In one instance I measured a lower impedance peak at 35Hz for a 3.5-foot line packed with 0.5 lbs. of Hollofil per cubic foot, in which the fiber had not been fluffed out very well. I removed the fiber, fluffed it out uniformly, repacked the line and the lower impedance peak jumped up to 41Hz! Evidently, teasing out the fibers allows the fibers to move freely like a collection of unimpeded miniature springs.

The more fiber you add to a TL, the more it takes on the stiffness characteristics of an enclosed cabinet. Now you can appreciate the difficulty in predicting where the two impedance peaks will occur for a fiber-filled line considering the complex effect the fiber has upon the moving mass and stiffness of the line.

Before we end our discussion of the effect of TLs on the voice coil impedance of the driver, let's comment on the ability of a typical TL to damp the driver's resonance. As noted earlier an empty line has almost no acoustic impedance (i.e., the specific acoustic impedance = 0 Newtons-sec per cubic meter) when the reflected wave equals the TL's ½-λ, and a high acoustic impedance when the reflected wave equals the TL's ¼-λ. The bandwidth of this high impedance is very narrow in an empty line. Therefore it is difficult to control the driver's resonance, since you must have a near perfect match of high impedance peak to the driver's resonant peak.

On the other hand, for a fiber-filled line (*Fig. 8*) the specific acoustic impedance remains above 2 Newtons-sec per cubic meter (twice the impedance load of free air) through a wide bandwidth. Although the specific acoustic impedance is not particularly high, it is high enough to control the resonance of the driver (i.e., my 8-foot TL reduces the Dynaudio's 30W54 free air impedance peak of about 34Ω down to 8Ω). In fact it is similar to the control afforded by a sealed enclosure. As you see, tuning a fiber-filled TL to control the resonance of the driver is not nearly as critical as with bass reflex designs.[20]

PHASE ANGLE OF Z_{in}. There has been a lot of press comment about how different speakers present different loads (with respect to impedance, phase shift, capacitance, etc.) to amplifiers, which influences the sound we hear. As a final measurement, G.R. Koonce suggested I determine the phase angle of the woofer voice coil impedance.[9] The results of this measurement are shown on the bottom of *Fig. 8*. Notice that the phase angle swings to +20° and then to −25° on either side of the impedance peak(s), passing through 0° at or between the impedance peak(s).

Koonce has measured the phase angle of Z_{in} for both vented box (VB) and closed box (CB) enclosures.[9] In one VB the phase angle rises to about 50° below the lower impedance peak, then it does a −40 to +30° swing between impedance peaks before it drops back to −40°, slightly above the upper impedance peak. It passes through 0° for both impedance peaks. The shape of the phase angle for CB systems is similar to the TL, where in one CB a single ±50° swing was observed on either side of the single impedance peak, passing through zero at the peak.

The question that arises from these observations is whether or not they are related to the "tighter bass" some listeners observe in TL and CB systems as compared to VB systems. Certainly, the gradual, single phase swing of the TL should present an easier load for either passive crossovers or amplifiers, than the abrupt, double phase swing of the VB input impedance.

TL MODEL STATUS. To complete our measurement and theory discussion, I will comment on the present status of TL models compared to VB and CB models. The goal of a TL model is to calculate the optimal parameters (packing material, line length, packing density, and taper) for constructing a TL enclosure for a given driver and to calculate resulting efficiency, box size, power handling, transient response, small signal response and large signal response of the completed driver-TL enclosure system. In such a model a builder could use "alignment tables" or programs similar to BOXRESPONSE[21] which are available for VB and CB systems.

Unfortunately TL models are at an early stage of their evolution; we are still attempting to predict the frequency and impedance response of a given driver-line combination, let alone having a model which suggests the optimal enclosure for a given driver. One of the problems is the transcendental nature of the pipe functions, which are difficult to use and are necessary for building TL models.[1]

Ultimately, I think the effort to take TL models to the level of VB and CB is worthwhile because TL systems offer non-critical tuning, a rigid enclosure by virtue of their dividers, extended low frequency response, transient response comparable to CB systems and an easy load for passive crossovers or amplifiers: all of which should appeal to the amateur speaker builder despite the fact that TLs require large, complex enclosures with baffles and reflectors.

The second part of this article, covering electronic crossover design and adjustments and listening tests, will be published in a future issue of *SB*.

REFERENCES

1. Bullock, Robert M. and Peter E. Hillman, "A Transmission-Line Woofer Model," AES Preprint 2384, presented at the 81st Convention of the Audio Engineering Society, Nov. 1986.
2. D'Appolito, Joseph, "A High-Power Satellite Speaker," *SB* 4/84.
3. Edgar, Bruce, "The Cordless Revolution," *SB* 1/89.
4. D'Appolito, Joseph and James W. Bock, "The Swan IV Speaker System, Part II," *SB* 5/88.
5. Bock, James, reply to Tom Basinski's letter "On Veneering" in *SB* Mailbox, *SB* 1/89.
6. Frid, Tage, *Teaches Woodworking. Shaping, Veneering, Finishing*, The Taunton Press, Newtown, CT, 1981.
7. Basinski, Tom, *SB* Mailbox letter "On Veneering," *SB* 1/89.
8. Keele, D.B., Jr., "Low-Frequency Loudspeaker Assessment by Nearfield Sound-Pressure Measurement," *JAES* April 1974.
9. Koonce, G.R., contributing *SB* editor, personal communication, 1988.
10. Szekeres, Greg, "Economical Electret" in Tools, Tips & Techniques, *SB* 3/85.
11. Bradbury, L.J.S., "The Use of Fibrous Materials in Loudspeaker Enclosures," *JAES* April 1976.
12. Bailey, A.R., "A Non-Resonant Loudspeaker Enclosure Design," *Wireless World* Oct. 1965.
13. Bailey, A.R., "The Transmission-Line Loudspeaker Enclosure," *Wireless World* May 1972.
14. Jastak, J.Theodore, "Transmission Line Speaker," *Audio Amateur* 1/73.
15. Galo, Gary A., "Transmission Line Loudspeakers, Part I: Theory," *SB* 1/82.
16. Dickason, V., *The Loudspeaker Design Cookbook*, 3rd. ed., The Marshall Jones Co. Publ., Francestown, NH, 1987.
17. Letts, G.S. "A Study of Transmission Line Loudspeaker Systems," Honours Thesis, The University of Sydney—School of Electrical Engineering, 1975.
18. Olney, Benjamin, "A Method of Eliminating Cavity Resonance, Extending Low Frequency Response and Increasing Acoustic Damping in Cabinet Type Loudspeakers," *J. Acoust. Soc. Am.*, Oct. 1936.
19. Cox, Thomas E., "An Experimental Transmission Line," *SB* 4/85.
20. Mallory, Roy, *SB* Mailbox letter "Baffling Trans," *SB* 2/82.
21. Bullock, Robert M. and Bob White, "BOXRESPONSE an Apple Program for the Thiele-Small Models," *SB* 1/84.
22. Siniscal, A., "Bi and Tri Amplification," *Recording Engineer/Producer* March-April 1971.
23. D'Appolito, Joseph, reply to Les Winter's letter "Satellite Smorgasbord" in *SB* Mailbox, *SB* 6/88.
24. Linkwitz, Siegfried, "Shaped Tone-burst Testing," *JAES* April 1980.
25. Brown, Arthur, "A Stereo System Odyssey," *SB* 1/89.
26. Linkwitz, Siegfried, reply to David Stanton's letter "Of Isobariks and Ferrofluids" in *SB* Mailbox, *SB* 1/86.
27. D'Appolito, Joseph, "A Geometric Approach to Eliminating Lobing Errors in Multiway Loudspeakers," AES Preprint 2000, presented at the 74th Convention of the Audio Engineering Society, October 1983.
28. D'Appolito, Joseph, contributing *SB* editor, personal communication, 1988.

Continued on page 72

THE MICROLINE

BY JOHN COCKROFT

FIGURE 1: The Microline.

The Microline came into being when I was trying to simplify and shorten the Octaline (*SB* 3/87). This was two years before I conceived the equations for designing short transmission lines ("The Unline," *SB* 4/88). My intent was to design a small loudspeaker system of excellent quality that was very easy to construct. I wanted to come up with a Volkswagen of loudspeakers that practically anyone could construct and enjoy. The Microline comes very close to achieving those goals.

Being a small system with only a 5¼" driver, it is naturally not going to be at home in a large living room, but in a smaller room or in an apartment a pair will bring a joyous amount of fine sound, with surprisingly natural bass, to your ears. If you are sensitive to the timbres of live acoustic music you'll find the Microline a refreshing alternative to the small speakers in the commercial marketplace.

When a delicate nuance is called for it is deftly delivered. When authority is required it comes from somewhere and is presented with great musicality. Its appearance is like a shrunken Shortline (*SB* 1/88). In actuality it is the Shortline's dwarfish parent. Like its progeny it performs best against the wall and away from corners and overhead obstructions. If the back of the enclosure is within one-half inch of the rear wall, all should be well.

LINE TO BOX. The Microline, like my other short transmission lines, is a hybrid in that it uses a larger cross section and higher density stuffing than the classic transmission line, presented to the world by A. R. Bailey in 1965.

In my systems I often use drivers with a higher Q_{ts} than is generally associated with the Bailey type line. As those who read my Unline article will remember, as the length of the transmission line is shortened, you must increase stuffing density to compensate. This requires an increase in cross-sectional area to aid "breathing."

You may then need to raise Q_{ts} to offset possible overdamping. As the line continues to shorten the system begins to behave as a stuffed box without a bottom. On the other hand, the aperiodic, pressure-relief type of enclosure proceeds from the sealed box and heads towards the bottomless box, becoming at some point essentially similar to my hybrid short lines. They behave like one big happy family.

THEORIES. As I mentioned in my Octaline article, I think most of what happens in a transmission line happens because of the slowing and attenuation of the wave motions by the acoustic stuffing material in the line. I am aware that many may disagree, but this is my present belief. Unstuffed lines have wild fluctuations due to the action of the line, which is similar to a pipe with one end closed (actually a fluctuating closed end), but a stuffed line is another animal altogether.

Acoustic stuffing in densities high enough to slow the speed of sound in air by a factor of three, or so, is exerting a great amount of frictional damping in the line, causing a considerable reduction of its natural functions. The highly damped impedance peaks and the smooth sound characteristic of transmission lines testifies to this condition. The impedance peaks remaining in a properly stuffed line are like the appendix that most of us carry around for no known purpose. The peaks merely express intimations of their pipe heritage.

I believe a transmission line behaves as a stuffed folded baffle. The length of the line is the "width" of the baffle from the center to the edge. The acoustic stuffing, by slowing the speed of sound, acts to increase the "width" of the baffle. At the same time the stuffing also attenuates the magnitude of the sound to a fraction of that issuing from the front of the driver. The sound emerging from the line terminus has only enough energy at best to partially cancel the frontwave, even though the rear wavelength might be longer than the baffle is wide. It may or may not be in phase with the frontwave, depending on the wavelength, the line length and the stuffing density.

Ideally nothing would escape from the terminus port, which would allow the frontwave to operate unimpeded, but in the real world such niceties don't often happen. Given a single density of stuff-

ABOUT THE AUTHOR

John Cockroft is a senior cryogenics technician at the Stanford Linear Accelerator Center, where he has worked for 26 years. His interest in designing loudspeaker systems dates from around 1958.

ing (say the 0.5 lb./ft.^{3} that seems almost standard), it makes sense that longer lines would exhibit better bass characteristics because the additional attenuating material in the line reduces the backwave. The "baffle" is also wider.

DRIVERS. I originally designed the Microline for the Radio Shack (40-1022) 4½-inch driver. However, when I discovered Radio Shack had altered the parameters (while pretending not to have done so) I decided to use another driver. I couldn't locate any 4½-inch types that seemed to have reasonable parameters. Fortunately I had been quite conservative with the enclosure cross section, which allowed me to consider 5¼-inch drivers as substitutes.

I settled on the new Danish Peerless K050 WFX PP, which has the following published specs: F_{sa} 60Hz, Q_{ts} 0.43 and V_{as} 0.353 in.^{3} (although V_{as} isn't an important transmission line parameter, I include it for the benefit of those who might want to use this driver for some other project).

F_{sa} was higher than I liked, so I added three grams of ⅛" solid solder wire (two pieces about ¾-inch long, curved to fit around the outside of the dust cap; I glued them in place, 180° apart using white glue) to reduce the resonant frequency a bit. This was a compromise. I wanted to lower F_{sa} a little more, but Q_t was relatively high to start with and a bit of restraint was necessary. Also I didn't want to reduce efficiency any more than necessary with the added mass.

ADJUSTMENTS. As they do in fairy tales, things worked out well. Assuming a moving mass (M_{MD}) of about 6g (the actual mass wasn't specified) which was the mass of the old American Peerless 5¼-inch cone, the added weight should give a new F_{sa} of about 49Hz and a new Q_{ts} of about 0.52, which is in line with the figure in *Table I* presented in my Unine article for 25-inch lines. The Microline is actually 23¾" along its centerline.

With this modified woofer in place I observed an impedance peak of 13.2Ω at 101Hz and no lower peak. By removing 39g of stuffing I located a peak at 33Hz of 11Ω. (I did this just to see what was going on down there, then replaced the stuffing.) The stuffing density of the Microline is 0.9 lbs./ft.^{3} I used 4.6 oz. of polyester pillow stuffing (130.5g).

Microline construction is simple and straightforward. A 2 x 3-foot piece of ¾-inch particle board is more than enough. For stereo, of course, two will be required. I prefer to cut all of the pieces first and fit them together. This tends to eliminate surprises. All pieces are simple butt joints, so no exceptional ability is required to build the Microline. While I recommend cutting all the pieces beforehand, in most cases cutting the holes for the drivers and the feedthroughs is more easily done after the assembly is partially complete. It is easier to grab a structure than hanging on to a loose board when using a saber saw.

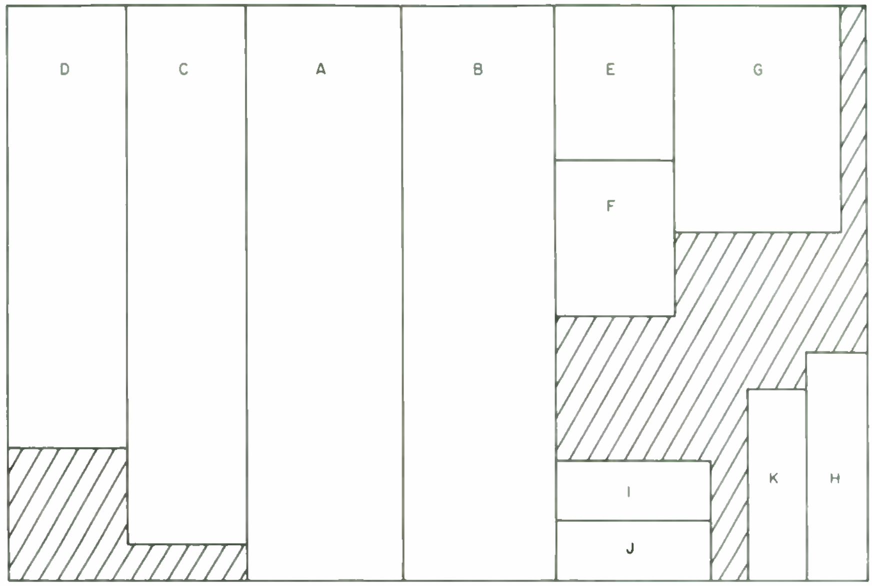


FIGURE 2: Cutting guide—¾-inch particle board, 24 by 36-inch sheet.

PARTS LIST

For a stereo pair everything on the list should be doubled. Don't forget to make the side ports on opposite sides of the pair for symmetry.

Particle board

1 pc. ¾ by 24 by 36" from which the following parts are cut as per the cutting guide:

2 pcs. 6½ by 24" front/back A/B
1 pc. 5 by 22½" long side C
1 pc. 5 by 18½" short side D
2 pcs. 5 by 6½" top/bottom E/F
1 pc. 7 by 9½" base top G
1 pc. 2½ by 9½" base front H
2 pcs. 2½ by 6⅜" base sides I/J
1 pc. 2½ by 8" base back K

Components

1 ea. Peerless K050WFXPP (Danish) 5¼" foam surround poly woofer. No substitute. Judging from the specs in the new Peerless catalog, the 831745 woofer appears to be the same as the K050WFXPP. I sure hope so.

1 ea. Peerless K010DT (Danish or American OK) 1" dome tweeter. No substitute

1 ea. 8Ω L-pad 15W or better—Madisound/ Radio Shack

C1, C2 3.7µF Mylar capacitor 50V or better—this may be made by paralleling a 2.7µF and a 1µF, listed in Madisound catalog

Cz 6.5µF Mylar capacitor 50V or better—this may be made by paralleling a 5µF and a 1.5µF, listed in Madisound catalog

L1, L2 1mH Sidewinder air core coil—no substitutes (Madisound)

R1 0.5Ω resistor 10W or better
This could be made by paralleling two 1Ω resistors. Madisound doesn't list the correct values. It is probable that this resistor could be eliminated from the circuit.

Rz 8.34Ω resistor 10 watt or better
This could be made by paralleling a 10Ω and a 50Ω resistor, or paralleling three 25Ω resistors. Madisound doesn't list correct values, try local source

Misc.

4 ea. feedthroughs. Could be 10-32, 1¼" brass panhead machine screws with lugs, nuts and washers or whatever excites you.

8 ea. #6, ¾" sheet metal screws for mounting the drivers

2 ea. banana jacks or whatever you like for input terminals Radio Shack

1 ea. roll of surgical or "household" cotton. Note: Don't double up on this item for a stereo pair. There is enough for both.

16 gauge zip cord for wiring (Radio Shack)

White glue

RTV Silicone Sealant (Bathtub Caulk) to mount crossover parts

Duxseal or Mortite to seal drivers (or whatever you like)

Sources

Madisound Speaker Components
8608 University Green
Box 4283
Madison, WI 53711

Mahogany Sound
2430 Schillingers Rd. 488
Mobile, AL 36695
Acousta-Stuf costs $7 a pound. Postage is an additional $1 a pound.

Radio Shack

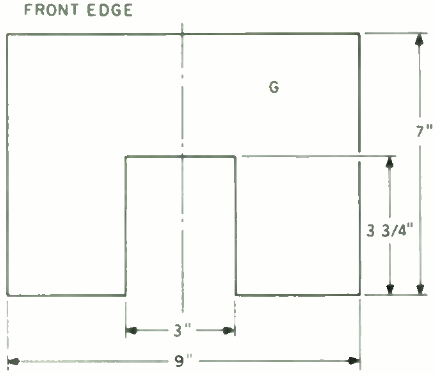


FIGURE 3: Base top showing notch to clear feedthroughs.

ASSEMBLY. First, pre-glue all the joints, brushing a coat of white glue on both faces and letting it dry. A much stronger joint is accomplished in this manner. I also urge you to go over the joints at least once (twice would be better) during assembly, adding extra glue to the outsides of all joints for added rigidity and to make sure that they are sealed.

I construct my enclosures entirely with glue-only joints, using weights and fixtures for alignment and relying on well fitting pre-glued joints. This is mainly because of the environment where I build my speaker systems (an apartment kitchen table). Assembly would no doubt be much quicker using four-penny finishing nails to hold the parts together while the glue dries. The nailheads could then be set about 1/16-inch below the surface of the wood and the depressions filled with spackle. Even when using nails you should pre-glue the joints.

Before I get into the construction details I must confess a goof I made when I built the Microline. After working 12 hours the night before, I came home one morning with the idea of cutting the hole for the tweeter before going to bed. My mind apparently crawled into bed ahead of me, because I cut the hole in the wrong panel. This meant that when the tweeter faced forward the line terminus port faced to the side, instead of to the front as I had planned.

After looking at the enclosure for a couple years and noting the clean looking columnar front as compared to the gaping mawed front of the Shortline, I think that my subconscious mind must have merely taken over the design and improved upon my original thinking. I can think of no reason why the Shortline couldn't be built in the same manner for improved looks. For symmetry, the right and left speakers should have the ports on opposite sides. Either system should work well with either port placement.

CONSTRUCTION. Begin by fastening the top to one of the 6½ by 24-inch pieces. Follow this with the 5 by 18½-inch piece and the 5 by 22½-inch piece, then the bottom piece. I refer to the dimensions rather than calling the pieces front or side, and so on, since I don't know where you plan to put the port.

When the glue has dried and the regluing has dried, it is a good time to cut out the driver holes. If the tweeter is on the panel not yet glued, set it in place (the panel, not the tweeter) and cut the hole. This supports the board and allows space beneath it for the saw blade. Ideally the back corner of the woofer hole should be rounded off to make a smoother path for the sound to exit from the speaker back, but the speaker sounds well without this effort. I leave it to you.

Since the tweeter has a sealed back, this nicety isn't required for its hole. After the holes are cut, brush a couple of coats of glue in an area about one inch beyond the front edge of the hole. This makes it easier for the sealing material to do its job.

CONNECTIONS. The four electrical feedthroughs may now be installed. The simplest thing to use would be 1¼-inch, 10-32 panhead brass machine screws with nuts, washers and lugs, but use what you like.

Now solder the speaker wires to the feedthroughs inside the enclosure. I used 2½-foot lengths of 16-gauge zip cord, available at Radio Shack or hardware stores, where it is often known as "heater wire." Fasten all the wires together with tape or a rubber band and bring them all out of the woofer hole to get them out of the way. Now is a good time to mark them and the feedthroughs for polarity and what speaker they are associated with.

Mark both ends of the feedthroughs and the outer ends of the wires. You will probably want to trim the wires a little when you mount the speakers, so don't mark them at the extreme ends. Little flags of tape work well for marking the wires. A felt tip pen is fine for marking the feedthroughs.

STUFFERS. The upper part of the enclosure should be lined with surgical cotton to help reduce midrange reflections from the enclosure walls. Use the roll just as it comes from the box and cut two lengths (for double thickness) long enough to go around all four inside faces of the box (maybe just a little longer to be sure). Use the full width. Glue or staple it to one of the side walls, right at the top so one edge is touching the speaker baffle. Continue

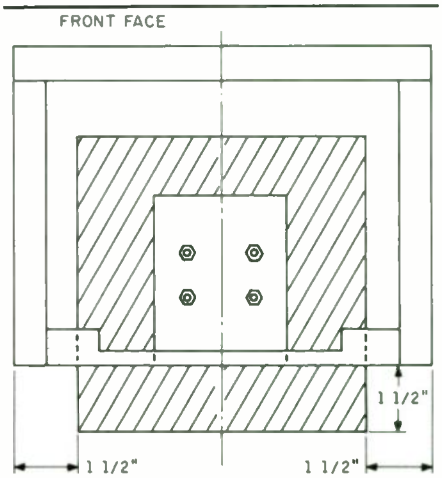


FIGURE 4: Bottom view showing base in relation to bottom of enclosure (shaded area).

with the other two sides. The final panel isn't yet in place, so let the rest of the cotton flap in the breeze awhile.

The cotton can be placed right over the tweeter hole (leave it a little loose). Then, just poke two holes for the wires with the point of a pencil and feed them through. If you are building the side port version the hole is in the panel that isn't glued on yet so you don't have to worry about it at this time. Make sure the wires aren't pulled out too tightly, but are allowed to remain a bit loose and relaxed in the enclosure. This is so there won't be any strain on the solder joints at the feedthroughs and the speaker terminals and to minimize any effects of vibration in the wire being transmitted to the outside.

Now it's time to stuff the Microline. Lay the enclosure on a table with the opening caused by the missing panel facing up. I have used polyester fiberfill from several sources with good results. K-Mart, Woolworth's and local dry-goods stores are probably the easiest sources. Use a scale to measure the amount (4.6 oz.) if you have one available. If not, buy a 12-oz. package and attempt do divide it into three equal parts. From the third pile take a handful of the stuffing that when compressed as tightly as possible in your fist makes a ball about two inches in diameter. After refluffing, add one of these to each of the other piles.

STUFFED. Take one of the piles, lay it on a spread-out newspaper and pull it apart and fluff it up as best you can (this sounds a lot fluffier than you will actually get it, but don't worry, just do your best and let it go at that). If the texture is reasonably even and the big hard lumps are pulled apart all is well.

Place the material in the enclosure as

Continued on page 32

TRANSDUCER TECHNOLOGY

Our company's objective is to provide the best components based on applied design, materials, engineering and production technology to the most exacting amateurs and professionals. After an exciting search and a scrupulous selection of outstanding drivers from around the world, we are now proud to offer exclusively from our stock a unique selection of today's state of the art speaker components.

Cabasse

Made in France by Cabasse Electro-acoustique. A complete range of beautifully engineered convex rigid dome tweeters and midranges, foam 4" midrange, mid and bass units using true concave honeycomb diaphragm in rectified cast frame. Plus a specialty line consisting of a 9 Lb carbon tweeter to a 36 Lb 22" honeycomb concave woofer!

ACCUTON

Ceramic concave dome diaphragm tweeters and midrange drive units made in West Germany by B. Thiel GmbH. Very wide and even frequency response. Extremely musical drivers.

VIETA

A unique 13" woofer made by Accutres in Spain. PVA impregnated pure cotton cone. Inner and outer winding of the voice coil offers maximized magnetic coupling and air flow cooling.

AUDIOM by FOCAL

Very high quality components with ultra light moving parts together with massive and efficient magnet structures results in the ability of the drivers to produce musical signals with realism and very high sound pressure levels while maintaining low distortion.

Fast Reply #JD401

A Division of Watters Sound Wave Co. • 4320 Spring Valley Road, Dallas, Texas 75244 • TEL: 214/ 991-6994 • FAX: 214/ 991-5016

Continued from page 30

evenly as possible, going right over the cotton at the top, right down to the bottom of the enclosure. Lift up the speaker wires and place some of the fluff beneath them so they won't rattle against the enclosure walls. Work carefully and use a gentle touch, but remember, this isn't neurosurgery, so don't work yourself into a pathological wreck over the stuffing.

A while back (but after I completed the Microline) I received a sample of Acousta-Stuf, similar to the pillow stuffing I have been using, but the longer fibers are much more evenly distributed, which is excellent for this application and it is much easier to use. I reviewed this material in *SB* 4/88; available from Mahogany Sound. I prefer its qualities over any similar material I have found.

When the stuffing is complete, fold the final flap of the surgical cotton batting in position, trim if necessary and press it down a bit. If you cut the tweeter hole in the unmounted panel, now you can make the pencil holes in the cotton batting and carefully bring the wires through the stuffing and out the holes. To accurately locate the holes just lay the panel in place and use the tweeter hole as a guide.

GLUING. Then glue the remaining panel in position. Make sure all the mating surfaces have been pre-glued (you only get one chance at this panel). Gently press the cotton and fiberfill away from the joint areas to eliminate the possibility of getting fibers in the joints. Run generous ¼-inch glue beads on all of the joint surfaces of the structure (not on the free panel). If the tweeter hole is in the free panel, feed the tweeter leads (which have been poked through the cotton before gluing) through the tweeter hole and then carefully lay the panel in place on the glued surfaces. (As an alternative you may bring the tweeter leads out of the tweeter hole after the glued panel has dried.)

Glue will squirt and ooze and drip, so place the enclosure on old newspapers. Line up the panel and weight it down (or nail it down) first and then clean up the mess with a damp paper towel or cloth. Make sure the panel is lined up on all four corners before securing it. Let the glue dry overnight.

BASES. While the enclosure is drying assemble the base. I want to bring up a point here regarding the base. Due to the design of the Microline, the enclosure must be placed as close to the rear wall as possible (¼–½ inches). The base is designed to allow this to happen. If you have oversized baseboards or other problems in the area where you plan to use your speakers, you may have to redesign the base.

With that decision out of the way, start by gluing the base front to the underside of the base top (make sure the feedthrough cutout is cut first). Then glue one side, followed by the back and then the other side. When the gluing and the regluing has dried, mark the location of the enclosure on the top of the base. Pre-glue the bottom of the enclosure and the mating area of the base top. When this is dry place a generous amount of glue on the base top where it is to receive the enclosure.

The joining procedure is best done on a table top, or a bench top, on newspapers. Set the enclosure in place on the glued base and try to line it up. It will want to slip about on the glue puddle like a new ice skater. Keep pressing the enclosure down and keep realigning it until all of the excess glue is squeezed out and the enclosure stays in place. Wipe off the excess glue and let it dry overnight (you sure can get a lot of sleep on this project) or about 12 hours.

After a couple of hours add a fillet of glue around the partially dried joints. If you live in an environment where the speakers may be treated roughly (read kids), you might want to run a couple of long screws through the base into the enclosure. I have had no trouble with just glue. My kids (and grandkids) have grown up.*

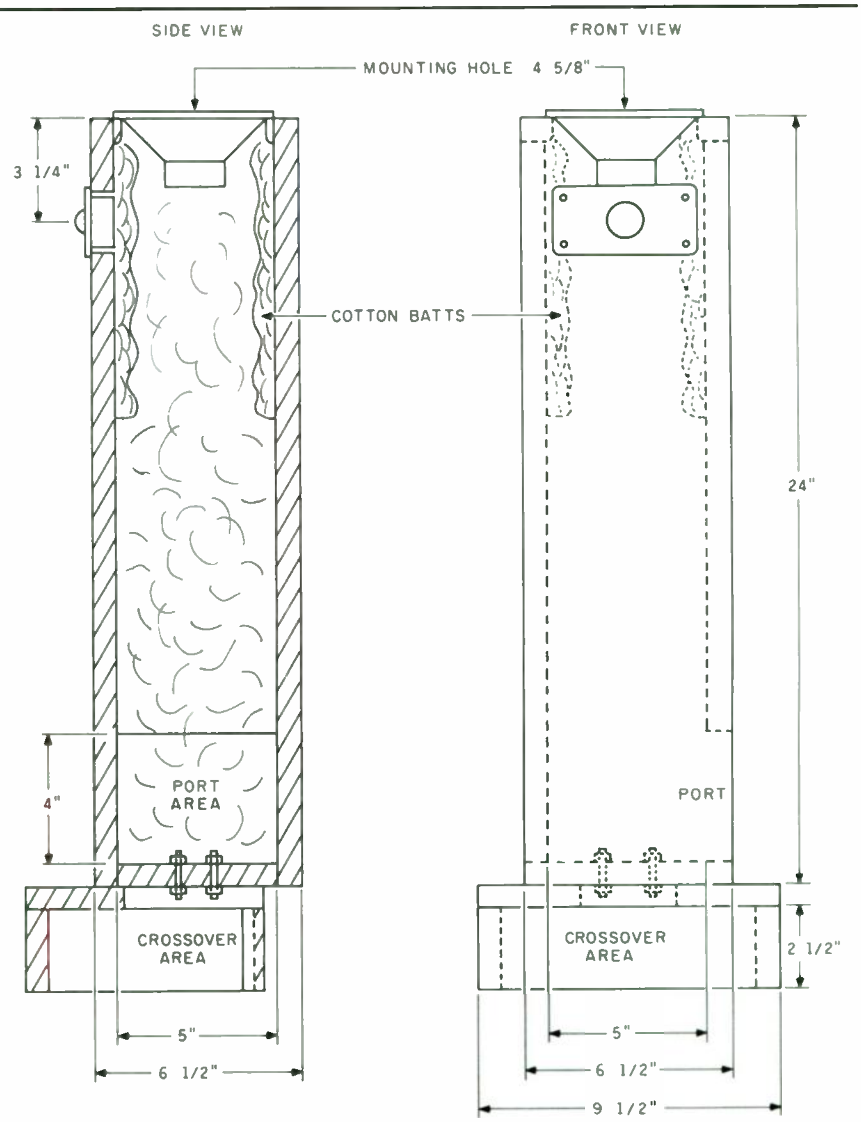


FIGURE 5: Front and side view. For a stereo pair place the port on opposite sides.

WIRING. With the enclosure upended, the open bottom of the base is exposed, making it easy to work on the crossover and attenuating circuits, which should be done at this time. I used standard banana jacks for the input sockets because I think they make the simplest connections and they have excellent conductivity. They require ⁵⁄₁₆-inch holes and are placed in the necked-down section of the base back, which will also contain the 8Ω L-pad. I used 16-gauge zip cord for all of the connections.

I fastened the crossover components in place with RTV silicone seal (bathtub caulk). Many speaker systems have the crossovers mounted inside the enclosures. This is probably fine in some cases, but when working out a new design, it's better to have the critter where you can get at it (again and again). Even later, since I am a tweakerholic, it is comforting to know I can get my hands on the crossover, the heart of the system.

After you choose the drivers and the enclosure, the crossover is where it's at. The photograph in my previous article apparently confused some readers because it showed capacitors (or resistors) the schematic did not call for. I merely used several smaller units in parallel to obtain the required values. This is sometimes necessary. (I wasn't trying to trick you.)

SEALERS. The drivers should be mounted at this time. Don't forget to brush glue around the outside edges of the speaker holes, and let the glue dry before proceeding. If you are planning to paint your Microlines it is a good idea to paint the area under and around the drivers before mounting them.

The speakers may be sealed in many ways. Some builders use foam weatherstrip material, others use silicone rubber (RTV bathtub seal). I prefer to use Duxseal, which is a putty-like material made by Johns-Manville for sealing ducts and electrical boxes. I use it because it is available and because it allows easy driver removal later, if required.

Before sealing with the Duxseal, place the driver to mark the mounting holes and drill pilot holes. A drill bit of about ³⁄₃₂-inch diameter works well for this if you use #6 sheet metal screws (panhead) as I did. Before you drill, run your finger into the speaker hole and around to the back of where the pilot hole will come. Make sure the fiberfill, or cotton is not close to the area. Press it down so that when the drill exits the wood it can't get caught in the stuffing. It can wind up on the drill bit and make a real mess.

TIGHT TRICKS. For a small woofer I make a ball of Duxseal about ⅞-inch diameter and roll it between the palms of my hands until it becomes pliable. I then press it with a rolling motion so it begins to elongate. I continue to press it, pull it and otherwise manuever it until I have a sort of rope about ³⁄₁₆-inch in diameter and long enough to fit around the back of

*Just to make a liar out of me, my daughter, Laura, called as I write to say another round is on the way!

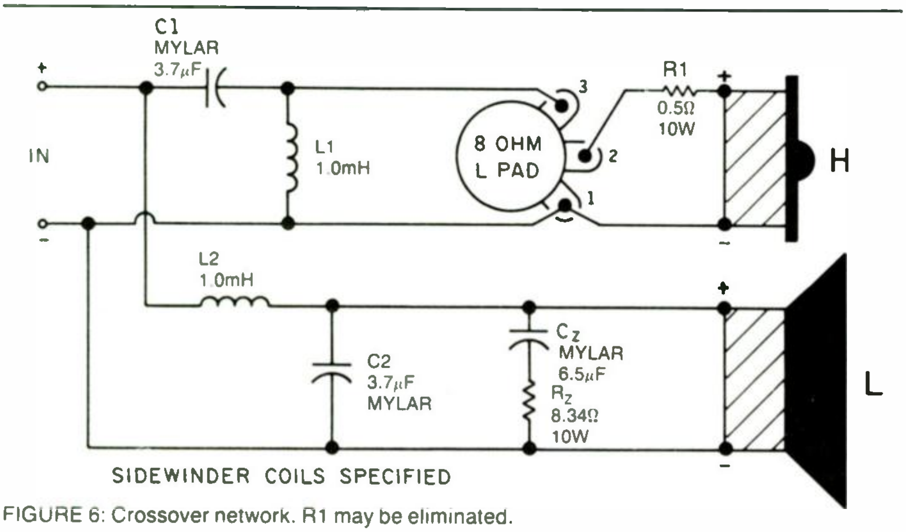


FIGURE 6: Crossover network. R1 may be eliminated.

the basket flange, where it will seal against the enclosure when the driver is pressed in place.

Break the Duxseal so the the ends overlap slightly. Work the joint with your finger until it becomes like the rest of the ring. With your fingertip press the entire ring firmly in place, flattened a bit so that it will tend to squish outward and not mushroom into the holes in the basket when the driver is secured. Push the Duxseal away from the four mounting holes so you can locate the pilot holes.

CONNECTING. With the Duxseal in place it is time to wire the leads to the speaker terminals. Bring the wires out from the speaker cavity. Make sure you have the right ones and they are correctly marked for polarity. You might want to trim the wires a bit. I usually just let them coil down into the cavity when I insert the speaker. Before soldering, it is a good idea to place a bit of tape on the basket below, so there is less chance of shorting out the speaker terminals. Electrical tape is best, but in a pinch, adhesive or even masking tape (two layers) will do.

Turn the woofer over on its face near the edge of the hole. Some of it will be over the hole, with the wires coming out next to it. If this is done with gentle care no damage will come to the driver suspension which will be temporarily flattened a bit. Strip the wires back about ½-inch and tin the leads with solder.

Also tin the terminals. It is hard to get 16-gauge wire into the terminal holes so I usually just solder the wires at right angles across the terminals and bend the wires back a little so that when the speakers are in the proper mounting position the tension on the wires is relieved.

MOUNTS. When mounting the driver make sure the wires aren't caught on the edge of the hole where they will damage the seal. Make sure they are going nicely into the hole. I should have mentioned that you must pull apart the zip cord for about 6 inches so that each wire is separate and can find its own way into the enclosure. Be a little generous with the solder so that fillets are formed at the joint for added strength. Before inserting the woofer, compress the stuffing beneath the hole a bit to allow the woofer a little space. Be gentle, don't pack the fill down too hard.

Next, mount the tweeter in a similar manner. As the screws draw down the drivers the Duxseal will squirt out at the edge. Leave it alone until all the screws are in. By the way, just tighten the screws until everything seems firm; don't overtighten. With a putty knife or a screwdriver scrape along the baffle next to the edge of the speaker flanges, and the Duxseal will be cleanly removed leaving a neat-looking mounting job.

Now stop and listen to your Microlines, for a while. After all that work you deserve to enjoy yourself. You might start out with the treble control turned to a bit less than ¼-turn rotation from the off position. From there you're on your own.

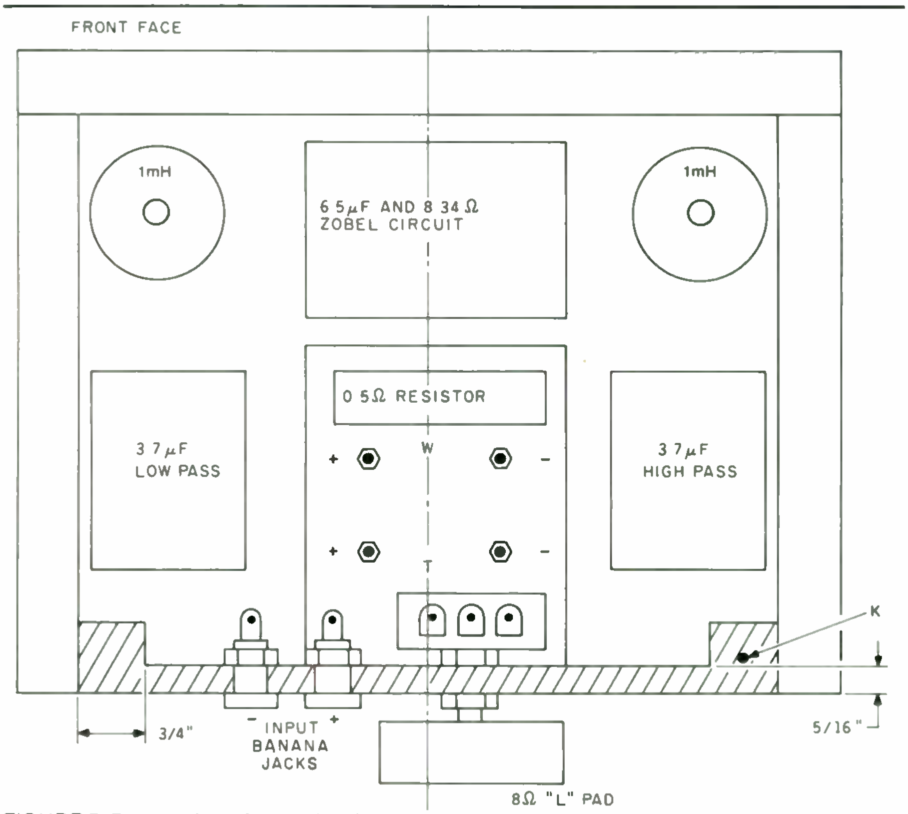
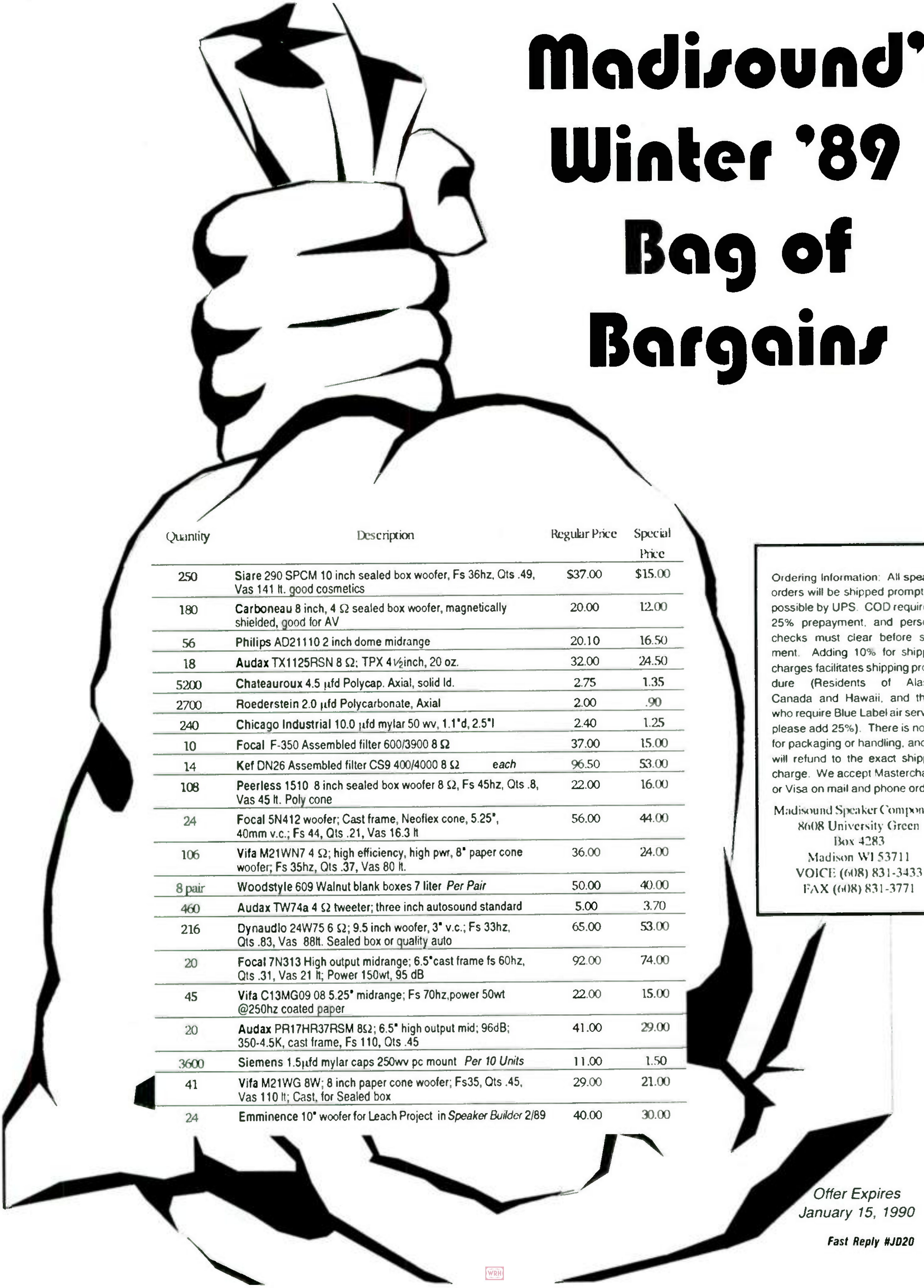


FIGURE 7: Bottom view of base showing crossover arrangement. Note: Base back (K) is undercut to allow banana jack installation. Alternately, use ¼-inch plywood with corner cleats.

Madisound's Winter '89 Bag of Bargains



Quantity	Description	Regular Price	Special Price
250	Siare 290 SPCM 10 inch sealed box woofer, Fs 36hz, Qts .49, Vas 141 lt. good cosmetics	$37.00	$15.00
180	Carboneau 8 inch, 4 Ω sealed box woofer, magnetically shielded, good for AV	20.00	12.00
56	Philips AD21110 2 inch dome midrange	20.10	16.50
18	Audax TX1125RSN 8 Ω; TPX 4½inch, 20 oz.	32.00	24.50
5200	Chateauroux 4.5 μfd Polycap. Axial, solid ld.	2.75	1.35
2700	Roederstein 2.0 μfd Polycarbonate, Axial	2.00	.90
240	Chicago Industrial 10.0 μfd mylar 50 wv, 1.1"d, 2.5"l	2.40	1.25
10	Focal F-350 Assembled filter 600/3900 8 Ω	37.00	15.00
14	Kef DN26 Assembled filter CS9 400/4000 8 Ω *each*	96.50	53.00
108	Peerless 1510 8 inch sealed box woofer 8 Ω, Fs 45hz, Qts .8, Vas 45 lt. Poly cone	22.00	16.00
24	Focal 5N412 woofer; Cast frame, Neoflex cone, 5.25", 40mm v.c.; Fs 44, Qts .21, Vas 16.3 lt	56.00	44.00
106	Vifa M21WN7 4 Ω; high efficiency, high pwr, 8" paper cone woofer; Fs 35hz, Qts .37, Vas 80 lt.	36.00	24.00
8 pair	Woodstyle 609 Walnut blank boxes 7 liter *Per Pair*	50.00	40.00
460	Audax TW74a 4 Ω tweeter; three inch autosound standard	5.00	3.70
216	Dynaudio 24W75 6 Ω; 9.5 inch woofer, 3" v.c.; Fs 33hz, Qts .83, Vas 88lt. Sealed box or quality auto	65.00	53.00
20	Focal 7N313 High output midrange; 6.5"cast frame fs 60hz, Qts .31, Vas 21 lt; Power 150wt, 95 dB	92.00	74.00
45	Vifa C13MG09 08 5.25" midrange; Fs 70hz,power 50wt @250hz coated paper	22.00	15.00
20	Audax PR17HR37RSM 8Ω; 6.5" high output mid; 96dB; 350-4.5K, cast frame, Fs 110, Qts .45	41.00	29.00
3600	Siemens 1.5μfd mylar caps 250wv pc mount *Per 10 Units*	11.00	1.50
41	Vifa M21WG 8W; 8 inch paper cone woofer; Fs35, Qts .45, Vas 110 lt; Cast, for Sealed box	29.00	21.00
24	Emminence 10" woofer for Leach Project in *Speaker Builder* 2/89	40.00	30.00

Ordering Information: All speaker orders will be shipped promptly, if possible by UPS. COD requires a 25% prepayment, and personal checks must clear before shipment. Adding 10% for shipping charges facilitates shipping procedure (Residents of Alaska, Canada and Hawaii, and those who require Blue Label air service, please add 25%). There is no fee for packaging or handling, and we will refund to the exact shipping charge. We accept Mastercharge or Visa on mail and phone orders.

Madisound Speaker Components
8608 University Green
Box 4283
Madison WI 53711
VOICE (608) 831-3433
FAX (608) 831-3771

Offer Expires January 15, 1990

Fast Reply #JD20

A WHEATSTONE BRIDGE FOR YOUR VOICE COIL

BY BRUCE EDGAR
Contributing Editor

Anyone who has ever tried to measure voice coil resistance (Re) with a digital voltmeter (DVM) has sometimes encountered resolution and accuracy problems. Your DVM may measure DC resistance with a resolution of 0.1Ω, but how accurate is it? One of my friends had two DVMs that differed by 0.5Ω, which can amount to a 10% difference for a 5Ω voice coil. If you use the Small method to calculate Q_{ts} as described by Saffran and Bullock (*SB* 1/81) that relies upon the measurement of Re, then a 10% error in measuring Re will throw the Q_{ts} off by a comparable percentage which could result in the misalignment of your speaker design. To reduce my measurement error, I decided to build an alternate, but more accurate device: the Wheatstone bridge.

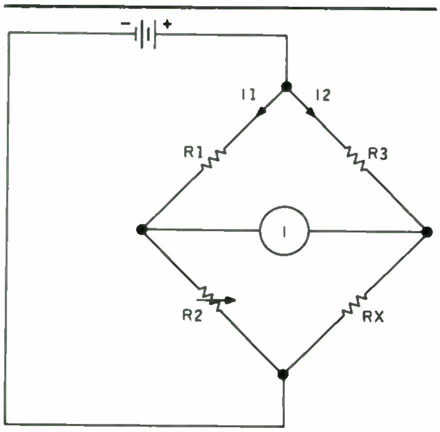


FIGURE 1: The classic Wheatstone bridge circuit.

THEORY. The Wheatstone bridge is one of the oldest accurate electrical instruments around, although Wheatstone was wrongly credited with its invention.[1] In the 1840s, Wheatstone used the bridge principle, which was based on previous work by S.H. Christie in 1833, to measure resistances. Wheatstone's work popularized the bridge, and so in the public's eye, Wheatstone's name was forever linked to the bridge that bears his name.

The Wheatstone bridge (*Fig. 1*) works by adjusting R2 until the potentials at the left and right points of the diamond network are equal and no current flows through the current meter. Since the voltage drops across R1 and R3 are equal and the same is true about R2 and Rx (the unknown resistance), then:

$$I1 \times R1 = I2 \times R3, \text{ and } I1 \times R2 = I2 \times Rx.$$

Combining the two equations and eliminating I1 and I2, we obtain the familiar bridge equation:

$$R1/R2 = R3/Rx$$

In practice, you shouldn't calculate the ratio, but adjust R2 until no current flows through the meter and then read the resistance from a calibrated dial on R2.

THE CIRCUIT. This version of the Wheatstone bridge is a simplification of a circuit published by *Popular Electronics* in 1972.[2] The voice coil bridge circuit (*Fig. 2*) requires a few high quality parts: two calibrated 10Ω resistors, a ten-turn potentiometer and a 50-0-50 microammeter. The calibrated resistors cannot be obtained over the counter at your parts store but will be available through Old Colony. The ten-turn pot can be purchased at industrial electronics parts stores or through Old Colony. The microammeter can be found sometimes as a surplus item (500-0-500, 100-0-100 or 25-0-25 microammeter movements may be substituted). An alternative is to use your DVM as a null meter since it can measure plus or minus DC voltages or currents, without adjustment.

A 120kΩ resistor in series with the 50-0-50 microammeter allows it to operate as a 6-0-6 voltmeter, so that you don't pin the meter needle when you are off null. When the resistor is shorted by S2, the meter functions as a high sensitivity microammeter as null is achieved for high accuracy.

CONSTRUCTION. The bridge (*Photo 1*) is housed in a bakelite box with all the controls and functions on the front

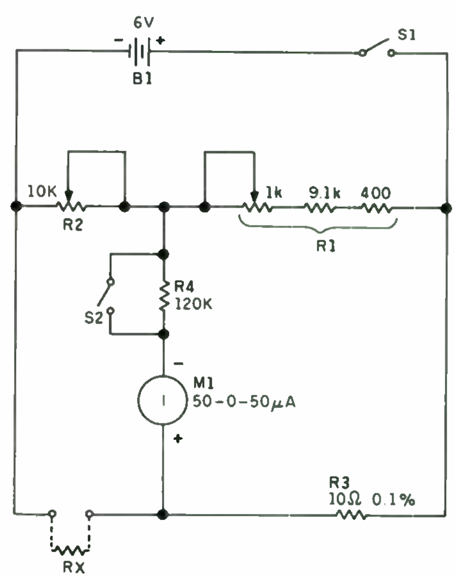


FIGURE 2: The voice coil (0–10Ω) Wheatstone bridge circuit.

panel, which I designed so your left hand can toggle the power and sensitivity switches while your right hand adjusts the ten-turn pot. Left-handers can reverse this arrangement. The size of the box dictated the use of C-cells, but if you use a bigger box, I recommend D-cells. The two momentary-on switches (SPDT types wired as SPST switches) prevent the accidental drain of the battery and allow for the temporary increase of meter sensitivity. I assembled the adjustable 10k resistor (a 9.1kΩ, a 400Ω and a 1kΩ trimpot in series) and a calibrated 10Ω resistor on a piece of perf board with L-bracket supports. I mounted the trimpot so the screw adjustment is pointed up for easier adjustment.

CALIBRATION. Once you complete the wiring and check it, plug one end of a pair of banana plug connector leads into the Rx jacks and attach the other 10Ω calibrated resistor (Rcal) to the other end of the leads with alligator clips. Move the ten-turn pot dial to 10.00 and turn on the bridge in the low sensitivity mode. Adjust the trim resistor until the needle passes zero on the meter. Then switch to high sensitivity and adjust the trimpot further until null is reached. The bridge is now calibrated. Keep these cables and clips with the bridge since their small resistance contributions (sometimes as much as 0.1Ω) are part of the calibrated bridge. Before calibration, you may want to treat the plugs and jacks with

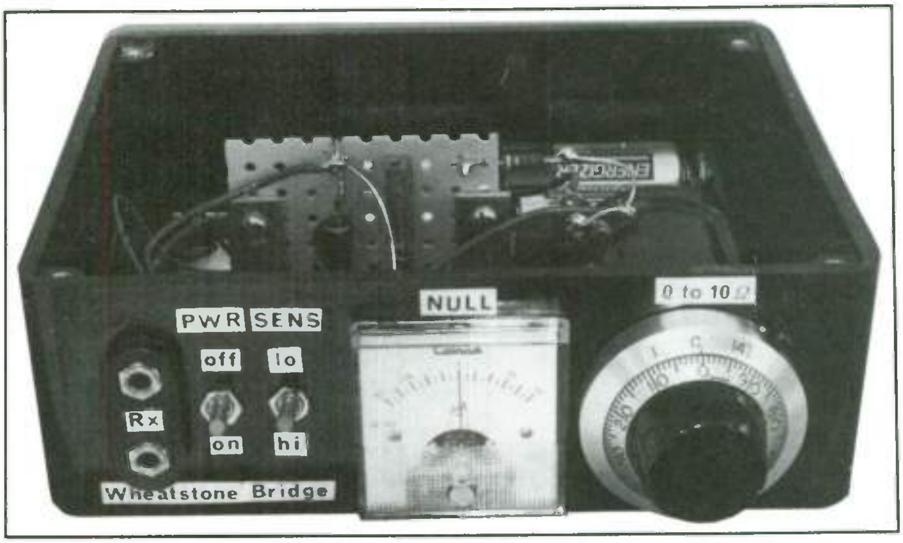


PHOTO 1: The Wheatstone bridge mounted in a phenolic box.

PARTS LIST

R1	9.1kΩ, 1W, 10% resistor; 400Ω, 1W, 10% resistor; and 1kΩ trimpot (Radio Shack 271-342) all in series.
R2	10kΩ ten-turn potentiometer (Heliopot Type A or equivalent)
R3, Rcal	10Ω calibrated resistors (Old Colony)
R4	120kΩ, 1W, 10% resistor
M1	50-0-50 microammeter (Calrad 60-169 or equivalent)
S1, S2	SPST momentary switches (Radio Shack 275-619)
B1	6V battery (4 C-cells)

Chassis Box 6½″ by 4¹⁵⁄₁₆″ by 2⅛″—inside dimensions (GC#16-044)

Misc.: Duodial RB turns counting dial, banana jacks, perf board, brackets, C-cell battery holder.

BOOKS *from Old Colony Sound Lab*

BUILDER'S GUIDES, general

S-25	ELECTRONIC PROTOTYPE CONSTRUCTION	$17.95
MH-2	HOW TO MAKE PRINTED CIRCUIT BOARDS	$8.90
S-27	DESIGN OF OP AMP CIRCUITS	$12.95
S-31	HOW TO READ AND INTERPRET SCHEMATIC DIAGRAMS	$12.95
T-8	ENHANCED SOUND—22 ELECTRONICS PROJECTS FOR THE AUDIOPHILE	$10.95
T-10	ACOUSTIC TECHNIQUES FOR HOME AND STUDIO	$18.95

SOUND ENGINEERING, REFERENCE WORKS

BKX-1	PERCEPTION OF REPRODUCED SOUND	$35.00
B-1	LOUDSPEAKER AND HEADPHONE HANDBOOK	$97.50
S-19	SOUND SYSTEM ENGINEERING	$39.95
MH-1	HANDBOOK FOR ELECTRONICS ENGINEERING TECHNICIANS (2nd Ed.)	$48.95
PH-1	HANDBOOK OF SIMPLIFIED SOLID-STATE CIRCUIT DESIGN	$39.95
S-28	HANDBOOK FOR SOUND ENGINEERS: The New Audio Cyclopedia	$79.95
MH-4	AUDIO ENGINEERING HANDBOOK	$85.00

TUTORIAL

BKAA3/1	AUDIO ANTHOLOGY (Vol. 1)	$16.95
BKAA3/2	AUDIO ANTHOLOGY (Vol. 2)	$16.95
P-8	INTRODUCING MUSIC	$5.95
S-29	PRINCIPLES OF DIGITAL AUDIO	$29.95
G-1	LIVING WITH HI-FI	$7.95
D-1	REPRODUCTION OF SOUND	$6.00
D-3	MUSIC, PHYSICS AND ENGINEERING	$14.25
MH-3	LEARNING ELECTRICITY AND ELECTRONICS THROUGH EXPERIMENTS	$12.95
T-7	BASIC ELECTRONICS COURSE	$15.95
S-4	UNDERSTANDING IC OPERATIONAL AMPLIFIERS	$12.95

BUILDER'S GUIDES, specific (cookbooks)

S-10	IC OP AMP COOKBOOK	$21.95
S-13	AUDIO IC OP AMP APPLICATIONS	$17.95
S-9	REGULATED POWER SUPPLIES	$21.95
S-14	ACTIVE FILTER COOKBOOK	$15.95
S-17	IC TIMER COOKBOOK	$17.95
S-18	TTL COOKBOOK	$14.95
S-26	CMOS COOKBOOK	$18.95

LOUDSPEAKERS (see also sound engineering)

BKAA2	THE LOUDSPEAKER DESIGN COOKBOOK	$19.95
BKAA1	AUDIO AMATEUR LOUDSPEAKER PROJECTS	$20.00
W-1	HIGH PERFORMANCE LOUDSPEAKERS	$34.95
T-6	ELECTROSTATIC LOUDSPEAKER DESIGN AND CONSTRUCTION	$15.95
S-11	HOW TO BUILD SPEAKER ENCLOSURES	$6.95

GUIDEBOOKS AND DATABOOKS

S-30	TUBE SUBSTITUTION HANDBOOK	$5.95
P-1	THE PENGUIN GUIDE TO STEREO RECORDS & CASSETTES	$12.95
P-1A	THE PENGUIN GUIDE TO COMPACT DISCS, CASSETTES AND LPs	$14.95
N-5	VOLTAGE REGULATOR HANDBOOK	$7.00
N-6	LINEAR DATA BOOK 1	$16.95
N-7	LINEAR DATA BOOK 2	$10.95
N-8	LINEAR DATA BOOK 3	$10.95
N-678	LINEAR DATA BOOKS (3-volume set)	$35.00

DICTIONARIES

S-22	MODERN DICTIONARY OF ELECTRONICS	$39.95
T-9	THE ILLUSTRATED DICTIONARY OF ELECTRONICS	$24.95
P-2	DICTIONARY OF ELECTRONICS	$8.95
U-1	THE AUDIO DICTIONARY	$14.95
P-3	A NEW DICTIONARY OF MUSIC	$8.95

To order from **Old Colony Sound Lab**, please write each book's number below with quantity of each and price. Total the amounts and remit by check, money order, MasterCard, or Visa. *For charge card orders under $10 add $2 service charge.* Please add $1.75 for postage on the first book; 50¢ per additional book. For Canadian orders, please add an additional $4.50 for postage. For overseas orders, add 20% of the total cost of the order for shipping and handling. All remittances must be in US funds. *Please use clear block capitals.* NOTE: *Prices are subject to change without notice.* **Books are not returnable for exchange or credit.**

OLD COLONY SOUND LAB

Qty.	Book No.	Price
	Postage	$
	TOTAL	$

☐ Check/MO ☐ MasterCard/Visa

NAME — MAGIC NUMBER

STREET AND NO.

CITY — STATE — ZIP

MASTERCARD OR VISA NUMBER — EXPIRATION DATE

OLD COLONY SOUND LAB
PO Box 243, Peterborough, New Hampshire 03458 USA
Telephone Charge Card Orders: (603) 924-6371 or 924-6526
FAX: (603) 924-9467
Weekends and after 4:00 p.m. MC/VISA ordering line: (603) 924-6371

Tweek or Cramolin to reduce contact resistance.

OPERATION. To measure the Re of a voice coil, remove Rcal and connect the clips to the speaker terminals. In the low sensitivity mode, adjust the ten-turn pot until the meter crosses zero. Switch on high sensitivity and adjust the pot until null is again achieved. Then you can read Re from the dial to two-decimal-point resolution.

I am not recommending that you throw away your good DVM, but if you are dissatisfied with it, the voice coil bridge becomes an inviting alternative which will give you more confidence in your measurement. But at the very least, you should perform a check of your DVM's accuracy with a calibrated 10Ω resistor.

APPENDIX
CALIBRATING RESISTORS

You can make a calibrated 10Ω resistor by first taking an ordinary 10Ω, 10% resistor and measuring it on an impedance bridge. If it is over 10.0Ω, you can calculate the value of a padding resistor (Rpad) that will bring down the parallel combination very close to 10.0Ω. The formula is:

$$Rpad = R \times 10/(R - 10)$$

where R is the measured resistor value. Select the 1% resistor which is the closest to the calculated Rpad value and connect it in parallel to the 10Ω resistor. Your accuracy of the resultant calibrated 10Ω resistor will depend on the impedance bridge's accuracy.

For example, a 10Ω, 10% resistor measured 10.548Ω on a laboratory impedance bridge. Rpad for this case was calculated to be 192.5Ω. A 192Ω, 1% resistor paralleled with the 10.548Ω resistor gives a 9.99Ω reading on my impedance bridge for a 0.1% accuracy. But if your bridge only measures to a 0.1Ω, then you would calculate Rpad to be 210Ω. The resultant parallel combination would be 10.04Ω, giving an accuracy of 0.4%, which is still fairly good.

REFERENCES

1. Atherton, W.A., "Pioneers—Charles Wheatstone," *Electronics and Wireless World*, April 1987, pp. 381–82.

2. West, R.P., "Inexpensive Wheatstone Bridge," *Popular Electronics*, March 1972, pp. 34–35.

TWEETER Q PROBLEMS

BY JORGE O. F. OLIVEIRA

In the course of building my new speakers, I couldn't resist the temptation of comparing my old reliable Audax HD12X9D25 tweeters to the new SCANSPEAK 2010/8513 I had just purchased.

The SCANSPEAK sounded better, as expected, lacking "hardness" in some female voices, which I previously attributed to bad LP pressings. However, the improved quality was not as apparent as I expected in the highs, so I decided to analyze this midrange anomaly and share my conclusions and solutions.

Today, you basically can find two philosophies regarding low-frequency resonance of tweeters:

- The high Q_{ms} types (Q_{ms} 2–5) are usually identified by a flat response up to the resonance frequency, of which the Audax is a typical example, as well as others from KEF, MB and so on.
- The low Q_{ms} (approximately 0.6) types are usually identified by a rolloff of some 10dB at the resonance frequency, of which the SCANSPEAK is a typical example, as well as others from companies such as Dynaudio and Morel.

The problem with a high Q_{ms} type is that the dome will "ring" at F_s unless damped by the magnetic circuit, which requires a low-generator impedance.

Even-order crossovers present that low impedance. However, a second-order section usually is not steep enough and a fourth-order type is seldom used. The classic third-order solution, as well as any odd-order crossover, will present a high impedance to the tweeter at F_s and almost no electrical damping.

ABOUT THE AUTHOR

Jorge O. F. Oliveira hails from Brazil and is a chief engineer equally at home with linear and digital circuits. His interest in audio dates back to his teens, the days when tubes were still widely used and transistors had just begun.

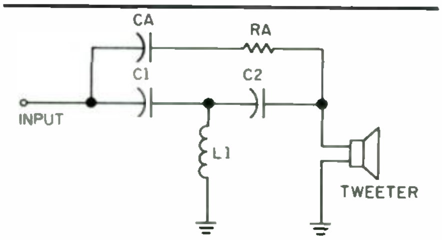


FIGURE 1: Sample of standard crossover.

This problem becomes critical when you consider that these small domes will achieve a high amplitude of movement for relatively small amounts of power at F_s, with consequent high distortion and the cited "hardness."

THE AB CROSSOVER. Some years ago, to solve this problem, KEF introduced a modification for its R.104 speaker called the Acoustic Butterworth (AB) crossover, which they still use in a slightly modified form.[1] I decided to try this mod in my crossover. The sound improved so much that the difference between the Audax and SCANSPEAK became very slight. There is one catch however; to use this mod you must have a third-order high-pass crossover.

I will present a simplified procedure you may follow to change your crossover if you decide to test the AB concept.

1. Start with your present crossover, which will be similar to the one presented in *Fig. 1*, using your current values of C1, C2 and L1 or those given by any standard crossover equations. Ca and Ra are the components for the AB mod.
2. From the manufacturer's data sheet, get the tweeter resonance frequency, F_s. Because of some simplifications, F_s

Continued on page 72

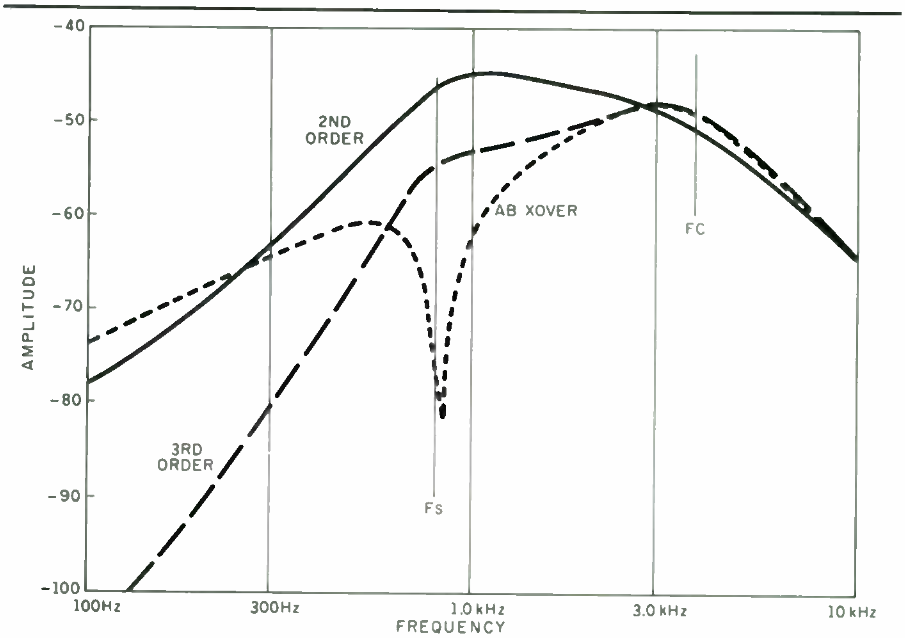


FIGURE 2: Audax HD12X9D25 simulated dome amplitude response.

Ask Speaker Builder

MEASURING SENSITIVITY AND POWER RATINGS

By Richard Pierce

Having worked as a driver and system designer for some time now, I am somewhat privileged with the "inside scoop" on many aspects of loudspeaker design and the business. That this is a mixed blessing is no longer a surprise to me. It's heartening to meet and share information with a wide spectrum of people. I encounter not only the so-called *illuminatti*, who have spent considerable professional time and effort exploring the science behind music reproduction, but also those who are just as inquisitive but lack the experience that might make them at home in a discussion with the more famous audio greats.

I have also rubbed elbows with a different sort, the kind of person that Frank Hubbard, in his landmark book on Baroque keyboard instruments, *Three Centuries of Harpsichord Making*, refers to as "cranks, charlatans and dilettantes." These are the people who surround their products (or theories) with hype, legend and mystery, knowing full well the depths of their deception and the shallowness of their stories.

Somewhere in between these extremes lies a vast grey area of misinformation and misunderstanding. This is often accentuated by a lot of non-standard "standards." Mr. Tod Whitley, of Gardendale, Texas, sent us a letter that lands squarely in the middle of this grey territory:

"I am curious to know what, if any, standard measurements exist for determining sensitivity and power ratings for raw drivers and complete speaker systems.

"For example, all driver and system sensitivity ratings I have seen are given in decibels, sound pressure level, measured at one meter with one watt input. However, the sensitivity tests performed by Julian Hirsch, of Hirsch-Houck Laboratories, are measured with a 2.83V pink noise input signal rather than one watt. What is the standard, and are both inputs of a wideband pink-noise character?

"Perhaps it is just ignorance on my part, but I can't make head nor tail of power rating specifications. For raw drivers I've seen: 'Power Handling DIN,' 'Music Power Handling DIN' and 'Rated Power IEC' specifications. For speaker systems I've seen: '. . . Input power of 40W(DIN) or 80W(EIA),' and perhaps a more useful rating of 'recommended power amplifier is 20 to 100W.' What do these DIN, IEC and EIA ratings mean and how are they measured? Also if the same standard power ratings are known for two or more different drivers, and they are assembled into a system, is there a method for determining a pseudo-accurate power rating of that system without performing any tests?

"Please enlighten me. I am having a hard time seeing through the handwaving."

Indeed there are several standards for measuring driver parameters. For example, the Audio Engineering Society published a standard (AES2-1984, *a.k.a.* ANSI S4.26-1984, "AES Recommended Practice: Specification of Loudspeaker Components Used in Professional Audio and Sound Reinforcement") which describes what measurement parameters should be published and provides guidance on how they should be derived.

For efficiency measurements, the best guidance we have is in section 4.3.1.5, "Reference efficiency (half-space acoustic load)." Not terribly helpful in and of itself, to say the least. But if we refer to Small,[1] as the standard does, we find that the reference efficiency of a driver can be derived directly from its Thiele-Small parameters. Specifically:

$$n_0 = 9.64 \times 10^{-10}\, V_{AS}\, F_S^3 / Q_{ES}$$

where V_{AS} is the equivalent compliance volume measured in liters, F_S is the free-air resonance in hertz, and Q_{ES} is the free-air electrical Q. The result, n_0, is the efficiency *factor*, that is, the ratio of electrical power input to acoustical power output. Typical high compliance, low resonance drivers suitable for high quality sealed or vented box systems have reference efficiencies in the range of 0.25–2%. An example driver with a V_{AS} of 100 liters, an F_S of 32Hz and a Q_{ES} of 0.3 would have a reference efficiency of 0.01, or 1%. That means we would need an *electrical* input of 100W to produce an *acoustical* output of 1W.

That doesn't seem like much. In fact, to most people, it doesn't seem like anything at all, because most people don't have a handle on what is meant by one acoustic watt. Just how loud is one acoustic watt?[2]

Fortunately, it's a relatively trivial calculation. There is a direct translation between power per unit area and the sound pressure level. We pick a standard "area," that of a hemisphere with a radius of one meter, calculate its area, then see what the resulting power density of 1W spread out over this area is (in watts per square centimeter). The net result is that one acoustic watt produces a sound pressure level of about 112 dB SPL, one meter away from the sound source, when radiating into a hemisphere.

Next, we convert the efficiency figure into a measure of sound pressure level versus input power. The relation is simple: Sens. = $112 + \log_{10}(n_0)$.

From this equation we can calculate that our 1% efficient driver has a sensitivity of 92 dB SPL at 1W input at 1 meter distance.

This is fine if we have access to accurate Thiele-Small parameters for the driver. For woofers and many midrange drivers, if necessary, simply measure them. For tweeters and some dome-type midrange drivers, these figures are very difficult to measure due to the relatively large influence of effects such as resonances and loading by the rear cavities in the magnet structure and so on.

In these cases, we can measure the efficiency directly. Place the driver in a baffle (which type is covered in the AES standard), apply a known amount of an input signal to the driver and measure the sound pressure with a calibrated microphone placed one meter away. Pink noise or warble tones are useful for this, with some limitations, though. The signal should be limited to some band which is within the driver's pass band. I usually limit the signal to a one octave band in the middle of the range in which I will be using the driver (such as the so-called "piston region" of a woofer, above its resonance but below its cutoff).

It might seem to make sense to use a standard drive level of 1W for these tests, for consistency's sake. This poses some problems. First, the impedance varies from driver to driver, meaning that we must carefully measure the impedance and set the amplifier output accordingly. Second, the impedance a driver presents is not purely resistive. This means that some of the power presented by the amplifier will not be absorbed or utilized by the driver. Third, the vast majority of our amplifiers are *voltage sources*. This means that the voltage the amplifier develops across the load is pretty much independent of the load impedance. To do this, the amplifier must be able to supply more current for lower impedance loads than for higher impedance loads. This results in more electrical power being developed for lower impedance loads, all other things being equal. But it is a recognition of this reality of modern audio amplifiers that leads me to specify efficiency referenced not to 1W, but to some fixed *voltage*.

The choice of 2.83V means that for pure 8Ω loads, 1W of electrical power will be developed in the amplifier, according to the relation: $P_E = V_{IN}^2/Z$. This also means that a 4Ω load will develop 2W, for the same input voltage. This would give a misleadingly high figure for the sensitivity of the 4Ω loudspeaker, all other things being equal. And, in fact, if you took two drivers with the same Thiele-Small parameters, save that one was 8Ω and one was 4Ω, and compared them hooked to the same amplifier, you would find that the 4Ω driver would sound and measure twice as loud as the 8Ω driver.[3]

If you have several drivers and need to measure their *relative* efficiency (or sensitivity), you can use any high-quality microphone (it need not be calibrated, but should be reasonably flat over the band of frequencies you will be using), a pink noise source, and an octave or so wide filter.[4] Play the noise through the filter and then through your power amp, making sure all the gain controls are set at some pre-determined and repeatable level. Use the microphone to measure the output of the drivers at some fixed distance. By performing this same procedure with each of the drivers, making sure that all the gain settings and distances are kept constant, you can get a good measure of the *differences* in the sensitivities between different drivers.

Remember that the final system efficiency depends only upon the driver's reference efficiency, not on whether the system is a bass reflex, sealed box or other direct radiator design. It is, though, affected by the crossover network's response and losses.

Dealing with the second issue, that of power handling, is *far* more complicated since there are many issues involved. For one, you have two basic limits to driver output: mechanical and thermal. Both are frequency dependent and both are determined by a variety of linear as well as nonlinear factors.

The easiest power limit to calculate is one due to the mechanical limit to excursion of the cone. Once you know the alignment of your system, you can determine the excursion versus frequency response of the drivers. This will then lead you to a figure of maximum output versus frequency due to the excursion limits of the driver. Does this then tell you directly how much power you can drive the system with when playing music? In a discouraging word, no.

Music presents a complex spectrum of power versus frequency. This distribution is further complicated by the fact that the spectrum for short-term musical transients is vastly different than for long-term averages, and it differs not only with the type of music, but also, obviously, from selection to selection. The German standards organization, DIN, has published a standard for power life testing of drivers[5] which uses a driving function which supposedly emulates average spectral music distribution. Mayr[6] describes several functions for determining the maximum and the average power handling levels and mechanical limits of drivers in multi-way systems, but these figures all depend upon some arbitrary spectral distribution function that may or may not correlate well with your personal listening habits.

The thermal limits of the driver further complicate the power handling maze. It's fairly easy to specify the maximum voice coil temperature that can be achieved without causing damage. You put it in an oven and cook it until something fails. This damage takes the form (for the most part) of softening of adhesives or (in extreme cases) the ignition point of some materials. There are other, more subtle effects. For example, some materials deteriorate at a faster rate at higher temperatures. Aluminum becomes brittle after a time and may fail for what seems to be mechanical reasons (the voice coil former breaks) rather than thermal.

Even the amount of heat generated is difficult to calculate. At system resonance, for example, the electrical impedance is quite high, so little electrical power is dissipated; while at higher frequencies, much more power can be dissipated in the voice coil. At low frequencies, the large excursion of the cone can aid in cooling the voice coil because of the large movements of air around it, but this can be counteracted by reduced radiational cooling if large areas of the voice coil are not close enough to the metal parts of the magnet structure to transfer heat evenly. Even the color of the various driver parts can have measurable influences on the voice coil temperature rise.

These complications make it nearly impossible to accurately determine and specify the power handling capacity of a driver or a speaker system under realistic listening conditions.[7]

REFERENCES

1. R. H. Small, "Direct-Radiator Loudspeaker System Analysis," *JAES*, Vol. 20, pp. 383–395 (June 1972).
2. For trivia's sake, a large symphonic orchestra playing *tutti* is capable of producing but a couple of acoustic watts. A similar amount of *mechanical* power is expended by one member of the audience rising to his feet and waving his hand at the end of the performance. A candle radiates combined thermal and light power at the rate of one watt. On the other hand a Saturn V at launch produced 50 *million* watts of acoustic power, "equivalent" to a sound pressure level of 186 dB at 1 meter or about 110 dB at 3 *miles*. Kinda puts everything in perspective, eh?
3. For this same reason two 8Ω drivers in parallel will (logically) produce twice the sound pressure level as one, when driven at the same voltage.
4. A cheap and effective way to get an octave wide filter that works well for this purpose is to use an octave-band equalizer. Set the slider for the band you want to measure to its maximum, and set all the other sliders to their minimum.
5. DIN 45 573, "Loudspeakers: Procedure for Checking the Power Handling Capacity by Means of an Accelerated Life Test," (Jan. 1969)
6. H. Mayr, "Signal Power Spectrum Aspects in Loudspeaker Design," *JAES*, Vol. 32, No. 9, pp. 673–677, (Sept. 1984)
7. That is, short of actually destroying the system and seeing what the driver *can't* do.

Book Reports

GETTING STARTED

Reviewed by Jim Stephens

1,001 Things To Do With Your Commodore 128, **by Mark Sawusch and Dave Prochnow**; TAB Books, 1986; softbound, 196 pp., $12.95.

Most second-generation books for a specific computer usually end up just paraphrasing the original user manual. This one is an exception. I could not resist the title, *1,001 Things To Do With Your Commodore 128*. After all, I thought if at least half of the programs could be used, the book would be quite useful. I was surprised and somewhat disappointed to find that only a small number of those 1,001 things were actually included in the book as user programs. Many are present only as ideas which the user can program.

However, the authors present hundreds of great ideas throughout the book that fire the imagination and motivate more experimentation. One or more short programs are presented as complete listings for each of the selections to demonstrate the category use.

The book is divided into eight sections, including finance, science, music, education and entertainment. Best of all, many technical formulas are given for each category for those who want to write their own programs. These include such formulas as Stock Price Index, Interest-principal, Rate of Return, Linear Regression and Heat Loss. Any reader should be able to apply many suggested uses and appropriate formulas for a wide range of interests. The formulas alone are worth the price of the book.

A good index is also provided for reference information on certain topics. Readers can go directly to any sections that may interest them.

The programs shown could easily be modified to run on a Commodore 64 and are simple enough to be understood by most beginner BASIC programmers. Therefore, I recommend it not only to Commodore 128 owners, but also to those with the earlier 64 model.

Although many lengthy programs are listed, all are also available on disk from TAB Books. This would be a good deal if one of the needed programs is Ohm's Law Calculator and Resistor Color Coder, which covers four entire pages.

If you are a programmer who is running out of ingenious ideas, this book is for you. It will give your imagination that needed boost to get you back to the keyboard. The book gives many short basic programs that could be enhanced for even greater value. It is a tremendous help with one of my biggest problems, getting started.

A REAL GEM

Reviewed by Vance Dickason
Contributing Editor

The GEM Operating System Handbook, **by Dave Prochnow**; TAB Books, 1987; softbound, 212 pp., $17.95.

Being a true GEM devotee and having what must be described as latent Macintosh tendencies, I was indeed delighted when asked to review Dave Prochnow's book on the GEM operating system. So, with an enthusiastic attitude, I set out to see if the standard DRI GEM documents needed any augmentation. The answer is a definite "yes."

The introduction begins with a fascinating historical survey of computer operating systems, with some interesting comments on the fate of CP/M and the Digital Research corporation. If you don't know the story of how we all (well, almost all) ended up as PC-DOS users instead of CP/M users, you'll get a good perspective on the fortunes of corporate warfare.

Mr. Prochnow's main point is that DOS prompts and endless command typing is boring at best. He makes it clear that if Apple did one thing right with the Macintosh, it was establishing the format for icon-based operating systems. All the world needed then was for DRI to come up with a graphic substitute for most of the mundane chores accomplished by PC/MS-DOS.

The rest of the book deals with the installation and operation of the GEM Desktop, the different types of hardware needed, and the operational details of the GEM Collection programs, as well as GEM Graph, GEM Draw, and GEM Wordchart.

Continued on page 49

SpeakerBuilder
THE LOUDSPEAKER JOURNAL

BACK ISSUES

1980
Realism Testing • Ambience Reproduction • Upgrade Mods for Small, Cheap Speakers • Diffraction and Cabinet Shape • Speaker Cables: Measurable and Audible Differences • A Three Enclosure System with Active Crossover and Delay (in 3 parts) • Electrostatic Speaker Construction Project (in 3 parts) • Double Chamber Enclosure: Deep Bass from an 8" Woofer • Corner Midrange Horn • Thiele/Small and Vented Speaker Design: Part I •

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

1982
Transmission Line Theory • Thiele/Small Sixth-Order Alignments • The Quad 63 • Table Saw Basics • AR-1 Modifications • Active Crossovers and Phase • Three Transmission Line Speakers • A Beginner's First Speaker • How Passive Networks Interact with Drivers • Horn Loaded Heil • Phase Correcting Active Crossover • Wind Your Own Inductors • Series and Parallel Networks • High Performance Corner Speaker • Using Zobels to Compensate for Driver Characteristics •

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

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

1985
Compact Transmission Line Subwoofer • Bullock Crossovers, Passive and Active, three parts • Drive Attenuator, Computer-Designed • Curved Vertical Array • Sontek Powered Subwoofer • An Isobarik System • Modifying Strathearn's Ribbon •Ambience Systems • Experimental Transmission Line • Small Double-Chamber Reflex • Loose Walled Speaker • Modifying the Daline •

1986
The Edgar Midrange Horn • Sand-Filled Stands • Crossover Networks: Passive and Active • 5-Sided Boxes • A 2×4 Transmission Line • The Free-Volume Subwoofer • Notch Filters • Bi-Wiring the LS3/5A • A Push-Pull Constant Pressure System • Current and Power in Crossover Components • The Unbox (Egg) • Upgrade Speakerlab's S-6 Crossover • Measure Speakers with Step Response • A Gold Ribbon System • A Visit with Ken Kantor • A Tractrix Horn Design Program • Reviews: Audio Concepts "G;" Seven T.L. Midranges; Focal's Model 280; the Audio Source RTA-ONE.•

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

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

BACK ISSUES ORDER FORM

Please send:
- ☐ The 1988 series @ **$20**
- ☐ The 1987 series @ **$15**
- ☐ The 1986 series @ **$15**
- ☐ The 1985 series @ **$15**
- ☐ The 1984 series @ **$12**
- ☐ The 1983 series @ **$12**
- ☐ The 1982 series @ **$12**
- ☐ The 1981 series @ **$12**
- ☐ The 1980 series @ **$12**

Amount enclosed $______
- ☐ Check
- ☐ MO
- ☐ MC
- ☐ Visa

My Magic Number ☐☐☐☐☐

UPS delivery add $2 for the first two sets, each additional set 50¢.
Canada add $4 postage per year. *Please make checks payable to Audio Amateur Publications.*

Name

Street & No.

City ST Zip

Card # Expires

Signature

Speaker Builder Magazine PO Box 494, Peterborough, NH 03458-0494 USA
MC/Visa Phone Orders: (603) 924-9464; FAX: (603) 924-9467

Continued from page 47
Each chapter is clearly defined and precisely covers each step so a novice user would have no trouble following it. I really appreciate this because logical organization and clarity are too often a rare commodity in computer literature, though the times are changing. My only criticism, if you want to call it that, is the DOS disk formatting procedure for the install routine was tirelessly repeated in five chapters.

Trivial criticism aside, the book provides not only the basic knowledge needed to mouse your way through the GEM environment, but also a number of useful tips and suggestions you probably won't find anywhere else. Oher books on the market deal with GEM, but in terms of teaching hands-on procedures, Dave has done an excellent job.

I think the last two chapters of the book are my favorites, along with the information in Appendix A. Chapter eight, "Twin GEMS," describes the sad fate of the original GEM version, for which Apple sued DRI. DRI settled out of court. A comparison with the Mac icon system leaves no doubt the GEM looks the same. If only Digital Research hadn't been so blatant about using such things as the Apple trash icon for deleting files. (Maybe a harp with the title "Memory Heaven" or a manhole cover and the label "Microsewer" would have been better.) Anyway, looking at the GEM Desktop version 2.1 in Appendix A leaves you somewhat disappointed, which I am sure is the intention. This book seems to imply, and I agree, that we are the real losers in that lawsuit. After all, DRI gave DOS users a valuable program, which is something Apple would never have done for the DOS environment. Adding insult to injury, chapter nine, entitled "Paste" (I think we are talking rhinestones here) points out that GEM is a more complete and useful graphic interface than any of its competitors such as DESQview, Windows, or Topview, especially when you consider that GEM can be made to function concurrently using DRI Concurrent PC-DOS 4.1

As if being an excellent text on the use of the GEM operating system isn't enough, the commentary about the way corporate whim and legal entanglement serve to hobble the steps of progress is very interesting. Frankly, I take it personally when it's my fingers on the keyboard, or, hand on the mouse.

Tools, Tips & Techniques

LOOSE SCREWS

Have you ever noticed one or both of your speakers sounding odd, only to discover a tweeter or two operating either intermittently or not at all? Don't rush to replace your tweeter(s) before reading on. Many dome tweeters are assembled using screws through the faceplate to tie the dome and faceplate to the magnet assembly. The heads of these screws are between the outside diameter of the dome and the inside diameter of the mounting screw hole circle on the faceplate.

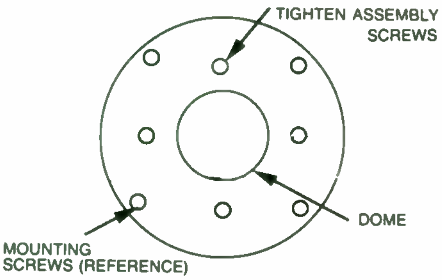


FIGURE 1: Front view of dome tweeter.

If these screws loosen, as can happen from vibration during use, the voice coil can become misaligned with respect to the magnetic gap in which the coil is designed to move. The result can be a tweeter that is inoperative or intermittent. You may be able to restore the tweeter to its design operation capabilities by evenly tightening these screws in a diametrically opposite pattern, moving back and forth across the dome until all of the screws are uniformly tight.

James T. Frane
Orinda, CA 94563

FAVORITE DISCS

In our two-part article on the SWAN IV bi-amplified loudspeaker (*SB* 4–5/88), we provided a short listing of recordings which we found useful in tuning up the system or in exploring bass extension, cone motion, imaging and the illusive quality of "being there." That listing has generated countless calls and letters seeking more recordings which we find useful.

We now have become experienced in demonstrating the SWAN IV at audio shows and in dealer listening rooms. We thank the many people in the audio world who have provided their suggestions for appropriate recordings. We also pay attention to what recordings the equipment reviewers use and several of those have made it to our now much longer list.

The list presented here does not duplicate the prior article listing, all of which remain favorite demonstrators.

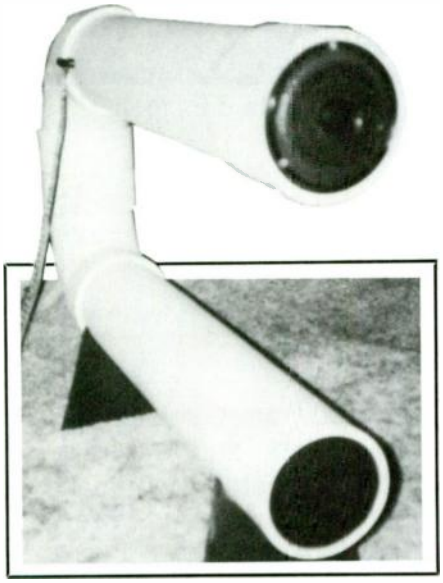
James W. Bock
Swan's Island, ME 04685

Short Title	Label	Number	Type	Comment
ASTREE*	Astree	7699	CD	Wide range of early music
Berlioz/Debussy	CBS	39098	CD	Beautiful Flicka
Reiner Sound	Chesky	RC11	LP	Very fine orchestral recording
Kije	Chesky	RC10	LP	Very fine orchestral recording
Daphnis et Chloe	Chesky	RC15	LP	Very fine orchestral recording
Symphonic Sound*	Delos	3502	CD	de Falla superb image, air
Beethoven Son. 57, 111	Delos	3009	CD	Great piano & pianist
Russian Easter**	Delos	3054	CD	Among the best of the best
Bach Harpsichord*	Denon	7233	CD	Accurate harpsichord
Pictures at an Ex.*	Dorian	90117	CD	Vast organ, very deep bass
Solid Brass	Dorian	90108	CD	Brass with miles of depth
Sing We Noel*	Elektra	71354-2	CD	3D image with movement
Britten War Req	EMI	47033	CD	Moving music, detailed image
Bruckner Motets*	Ex Lib.	6009	CD	Depth, width, air, stone walls
Gesualdo	Gimmell	015	CD	Sharp, deep focus
Brahms Motets*	Harmonia	901122	CD	Depth, width, air, stone walls
Faure Requiem*	Harmonia	901292	CD	Remarkably beautiful
Gesualdo*	Harmonia	901268	CD	Sharp, deep focus
Water Musick	Harmonia	907010	CD	Good stuff
Vivaldi flute	Harmonia	905193	CD	Well done & recorded
Emma Kirby Col.	Hyper.	66227	CD	Precise vocalist well miked
Holst Planets*	Lon	417553	CD	Big Bass
Beethoven #3	Nimb.	5007	CD	Super acoustics, small orch.
Beethoven #5*	Nimb.	5122	CD	Super acoustics, small orch.
3 After Vivaldi*	Philips	412116	CD	Organ with height and depth
6 Schubler Chor.*	Philips	412117	CD	Organ with height and depth
Cantate Domino	Proprius	7762	CD/LP	Tough brass to get right
Jazz, Pawnshop**	Proprius	7778	CD	Great presence, good music
Dafos	Reference	12	LP	Daffy, but loud
Tafelmusick	Reference	13	LP	Far better than CD
L'Histoire	Reference	17	CD/LP	Individuality of instruments
Serendipity	Reference	20	LP	Good music, well recorded
Star of Wonder	Reference	21	CD/LP	3D chorus, but fat bass
Nojima Plays L.*	Reference	25	CD/LP	Revealing piano & pianist
Rameau	Reference	27	CD/LP	Superb harpsichord, well done
I've Got the Mus*	Shef.	2	CD/LP	One of the all time greats
Track/Drum**	Shef.	14/20	CD/LP	Space, skin tone, cymbal decay
West of Oz*	Shef.	15	CD	Realistic voice
JNH & Friends	Shef.	23	CD	Rock
Firebird	Shef.	24	CD/LP	Dynamic, dead room
Creme de La**	Shef.	CRM	CD	Everything on one CD
Kodo	Shef.	KODO	CD	The biggest drum
Moscow Sessions**	Shef.	1000	CD/LP	Superb imaging, dynamics
Empire Brass	Telarc	80159	CD	Brass with bite
J. Johnson/Bach**	Titanic	162	CD	Busch Reisinger Flentrop
Haydn III*	Titanic	166	CD	Best fortepiano ever
Magnum Opus 1*	Wilson	8111	CD/LP	Superb Flentrop & recording
Magnum Opus 2*	Wilson	8314	CD/LP	Superb Flentrop & recording
Center Stage	Wilson	8824	CD/LP	Awesome winds, etc.
Winds of War &	Wilson	8823	CD/LP	Awesome winds, etc.

*a favorite among favorites **even more favorite than that

Craftsman's Corner

Boxes Farewell



Since 1984 I've been listening to a pair of speakers I built and I'd like to share some ideas with my fellow speaker builders. In the summer of '84 I purchased a pair of Morel Integra Is for $95 from A&S Speakers. Initially I built conventional boxes out of ironwood particle board. Ironwood board has a density greater than 70 lbs./ft.[3] The boxes (8″W x 11″H x 11″D) were also lined with Mortite.

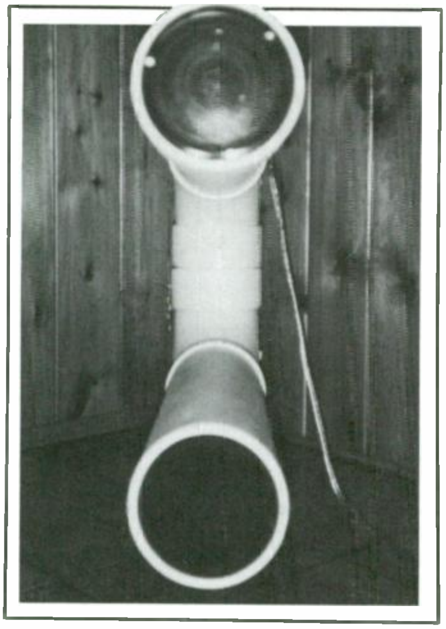
I happened to read Berman and Fincham's paper, "The Application of Digital Techniques to the Measurement of Loudspeakers," in the *JAES Loudspeaker Anthology, Vol. 1*. On pp. 444–5 the TDS plots of a 110mm driver illustrate the disadvantages of a small box. Internal reflections ruin a speaker's transient response, yet large cabinets color sound with their panel vibration.

While reading Bradbury's paper, "The Use of Fibrous Materials in Loudspeaker Enclosures," I decided to build a transmission line enclosure. Instead of using wood, and because the Integra's tweeter is mounted inside the woofer, I used 6.1″ ID polyvinyl chloride (PVC) pipe.

The pipe is fairly expensive, but the construction of the line literally takes minutes. Calculating a ¼-λ at 36Hz, I settled on a line length of 7.84 feet. To mount the woofers in the bell end of the pipe I cut out rings made from the ironwood (later MDF type 44) using a circle cutter and drill press. To mount the driver in the ring I used machine screws and nuts. The nuts are Superglued to the inside of the ring. The density of the ironwood makes the use of T-nuts impossible, and given the paper-like nature of the type 44 board, glue is less work. After removing the driver from the ring I used silicone rubber to secure the ring to the inside of the pipe.

There is no need to glue the pipe together. I filled the unglued U-shaped pipe with water and left it alone overnight. There were no leaks. Leaving them unglued facilitates easy filling with wool as the line can be taken apart within one minute.

Bradbury discusses using wool to decrease the velocity of sound to make the driver behave as if it were in a much longer line. I agree; the bass sounded deeper with .5 lbs./ft.[3] of wool stuffing, but bass output was very much less. I removed almost all the wool. I replaced the driver's single-



capacitor crossover with a composite capacitor of the same value, using IAR'S UR series (4.7μF at 4Ω). You will need some wool to absorb high frequency information, as it will come out the other end and smear the image. I've replaced the wool with Acousta-stuf; it does sound better.

The enclosure closely resembles the old labyrinth of A. R. Bailey. By using PVC pipe there is no surface area facing the listener to color sound via eigenmode vibration (parallel wall resonances).

RESULTS. How do the speakers sound? Well my friends keep hounding me to go into business. I have to admit they image nicely, no doubt due to the fact that the units are a true point source. The midrange seemed greatly improved. The bass shocked me though. It was very tight and clean. I was using Dynaudio 30W54s in 4.5-cubic-foot boxes crossed over at 400Hz when the Integras were in the conventional boxes. The bass from the pipes is deeper and more musical. (The bass cabinets were built around an extensively braced frame of 2″ x 2″ with MDF panels screwed to the frame with 250 2″ drywall screws per enclosure and then lined with 2″ of concrete.)

I'm thinking about building a new system using two Morel MW 164s, two Dynaudio D52s and two D21s or two Phillips ribbons in a symmetrical arrangement borrowing from Joseph D'Appolito ("The SWAN IV Speaker System," *SB* 4–5/88). I also have four Dynaudio 30W54s which would most likely sound breathtaking in 17-foot, 12-inch-diameter pipes.

While the PVC's cost is relatively high, I will never build a box again.

Scott Wolf
Framingham, MA 01701

KITS • COMPONENTS

OLD COLONY SOUND LAB

What's Included?

Kits include all the parts needed to make a functioning circuit, such as circuit boards, semiconductors, resistors and capacitors. Power supplies are not included in most cases. Unlike kits by Heath, Dyna and others, the enclosure, faceplate, knobs, hookup wire, line cord, patch cords and similar parts are not included. Step-by-step instructions usually are not included, but the articles in *Audio Amateur* and *Speaker Builder* are helpful guides. Article reprints are included with the kits. Our aim is to get you started with the basic parts—some of which are often difficult to find—and let you have the satisfaction and pride of finishing your unit in your own way.

PREAMPS

JOSEPH CURCIO

KS-6: CURCIO VACUUM TUBE PRE-PREAMP. [5:84] $135
KT-1: CURCIO TUBE PREAMP. [2:85] $385
KV-3: AUTO MUTE. [1:86] $18

ERNO BORBELY

KT-2: BORBELY PREAMP. [4:85, 1:86] $650
KT-2 SECTIONS. (1-5) Available separately. Inquire for pricing.
KT-2/KW-3: With supply upgrade to KW-3. . . . . . $795
KW-3: BORBELY IMPROVED POWER SUPPLY. [1:87]
Each $135 Two or more $125

SULZER PREAMP POWER

KL-4A: OP AMP PREAMP VOLTAGE REGULATOR. [2:80] $40
KL-4B: SULZER RAW DC SUPPLY. $48
KL-4C: SULZER RAW DC SUPPLY. Same as KL-4B but contains ILP ± 22V toroidal transformer. $60
KL-4D: ILP ± 22V toroidal transformer only. $55

POWER AMPLIFIERS

WILLIAM Z. JOHNSON

KH-6B: AUDIO RESEARCH ST-70-C3 CONSTRUCTION BOOKLET $5

ERNO BORBELY

KP-3A: BORBELY 60W MOSFET AMPLIFIER. [2:82] $90
KP-3P: BORBELY 60W MOSFET AMP POWER SUPPLY. [2:82] $80
KP-3PC: BORBELY 60W POWER SUPPLY. [2:82] $88
KS-1: BORBELY SERVO 100 MOSFET POWER AMP. [1:84] $150
KS-3: BORBELY DC 100 MOSFET POWER AMP. [2:84] $160
KS-3PA: SERVO 100, DC 100 POWER SUPPLY. [2:84] $175
KS-3PB: SERVO 100 or DC 100 MONO POWER SUPPLY. [2:84] $125
KS-3TA: SERVO 100, DC 100 TOROIDAL TRANSFORMER, 500VA ONLY. $120
KS-3TB: SERVO 100, DC 100 TOROIDAL TRANSFORMER, 225VA (mono). $75
KS-1M: COMPLETE BORBELY SERVO 100 MONO AMP with KS-3PB POWER SUPPLY. [1:84] Each $275 Two or more, Each $260
KS-1S: BORBELY SERVO 100 STEREO AMP with KS-3PA POWER SUPPLY. $450
KS-3M: BORBELY DC 100 MONO AMP with KS-3PB POWER SUPPLY. [2:84] . . . . . Each $285 Two or more, Each $270
KS-3S: BORBELY DC 100 STEREO AMP with KS-3PA POWER SUPPLY. . . . $470

JAMES BOAK

KJ-8A: DYNACO MARK III POWER SUPPLY MOD. [1:78] $38
KL-1P: BOAK REGULATED POWER AMP POWER SUPPLY. Pass Class A version. [1:80] $85

NELSON PASS

KJ-5-7: CLASS A 40W AMP A40. [4:78] . . . . . Each $465
West of Rockies, Each $475

REG WILLIAMSON

KK-13CH: WILLIAMSON 40/40 [4:79] $170

PASS-CITATION MOD

KM-7: MOSFET CITATION 12 MOSFET MODIFICATION. [2:81] $170

K. LANG

KV-2S: LANG CLASS A MOSFET POWER AMP. [2:86] $285
KV-2DM: LANG CLASS A MOSFET POWER AMP. [2:86] $350

CLOSEOUTS

These items are in limited quantity. Once gone, they will no longer be available.

KB-5B: WILLIAMSON POWER SUPPLY [2:71] $17
KP-8: VORHIS LAST PAS MOD. [4,5:82] $150
KP-6: GLOECKER MIKE PREAMP. [3:82] $35
KH-6: JOHNSON AUDIO RESEARCH ST-70-C3 MODIFICATION KIT. [4:77] $355
KL-1W: BOAK REGULATED POWER AMP POWER SUPPLY. [1:80] $45
KL-1D: BOAK REGULATOR KIT [2:81] . . . . . Each $65 Four for $199
KK-13P: WILLIAMSON 40/40 [4:79] $20
KA-2T: WILLIAMSON AVEL-LINDBERG 40/3018 TRANSFORMER for the 20/20 or 40/40. . . . . . $35
KM-8: BOAK-JUNG-AMER ST-150-BJ-1 DYNA 150 MOD. [2:81] $45
SBK-C2: BALLARD ACTIVE CROSSOVER. [SB 3,4:82] . . . . . Two chan. $60
KB-2R: THE 4 + 4 MIXER. [2:71] $45
KF-2: GATELY EQUALIZER [2:75]. Single channel kit $45
Two kits, as above $75
KG-1: GATELY PEAK OVERLOAD INDICATOR. [2,3:76] $8
KP-4B: BOAK HEADPHONE VOLTAGE REGULATOR. $12

CROSSOVERS

For KC-4A choose ONE frequency from those listed below. For KC-4B choose TWO frequencies from the list. NO OTHER FREQUENCIES ARE AVAILABLE FOR STOCK KITS. *60, 120, 240, 480, 960, 1920, 5k or 10kHz.*

KC-4A: ELECTRONIC CROSSOVER, KIT A. [2:72] $14
KC-4B: ELECTRONIC CROSSOVER, KIT B. [2:72] $18
KK-6L: WALDRON TUBE CROSSOVER: Low pass. [3:79] $60
KK-6H: WALDRON TUBE CROSSOVER: High pass. [3:79] $62
KK-7: WALDRON TUBE CROSSOVER POWER SUPPLY. [3:79] $110
SBK-A1: LINKWITZ CROSSOVER/FILTER. [4:80]
Per channel $75 Two channels $140
SBK-C1A: ELECTRONIC CROSSOVER. [SB 3:82] $32
SBK-C1B: THREE WAY, SINGLE CHAN. CROSSOVER. [SB 3:82] $60
SBK-C1C: TWO CHAN., COMMON BASS CROSSOVER. [SB 3:82] $64

MIXING AND RECORDING

KB-3: 4 + 4 MIXER POWER SUPPLY. . . . . . Each $16
KF-3: GATELY POWER SUPPLY. $52
KH-1: THE WILLIAMSON SUPER QUADPOD. [1:77] $38

AIDS & TEST EQUIPMENT

KE-2: REGULATED POWER SUPPLY. [4:74] $48
KE-5: OLD COLONY POWER SUPPLY. $20
KH-7: PRECISION 101dB ATTENUATOR. [4:77] $65
KJ-6: CAPACITOR CHECKER. [4:78] $90
KK-3: THE WARBLER OSCILLATOR. [1:79] $70
KL-3: INVERSE STEREO RIAA NETWORK. [1:80] $45
KL-6: MASTEL TIMERLESS TONE BURST GENERATOR. [2:80] $24
KM-3: CARLSTROM/MULLER SORCERER'S APPRENTICE/PAUL BUNYAN. [2,3:81] $290
KP-2: TWO TONE INTERMODULATION FILTER. [1:82] $26
SBK-D2: WITTENBREDER AUDIO PULSE GENERATOR. [SB 2:83] $80
SBK-E4: MULLER PINK NOISE GENERATOR. [SB 4:84] $35
KV-4: HANSEN CIRCUIT-SAFE CHECKER [CS 1:86] $20

CD PLAYERS

KW-1: MAGNAVOX CD PLAYER MODIFICATION. $12
KW-2: MODIFICATION. $16
KX-1A: DISC STABILIZER. $70
CDR/25: CD RINGS. .... pkg. 25 $25
KY-1: BEERS' BUDGET CD MOD. [1:89] $95
CDPV/2 PIERRE VERANY TEST DISCS. Please add $2.25 shipping and handling. .... Set $34

FILTERS & SPEAKER SAVER

KF-6: 30Hz RUMBLE FILTER. [4:75] $30
KH-2: SPEAKER SAVER AND OUTPUT FAULT DETECTOR. [3:77] $65

SYSTEM ACCESSORIES

KC-5: GLOECKLER 23-POSITION LEVEL CONTROL. [2:72] $48
KH-8: MORREY SUPER BUFFER. [4:77] $22
KL-2: WHITE DYNAMIC RANGE & CLIPPING INDICATOR. [1:80]
Single channel $58 Two channels $110 Four channels $198
KM-10A: SWITCHBOX. [2:81] $45
KM-10B: Same as 10A but with 12 gold-plated jacks. $55
KP-5: AUDIO SWEEP MARKER ADDER. [2:82] $32
SBK-D1: NEWCOMB PEAK POWER INDICATOR. [*SB* 1:83]
Each $7 Two for $11
SBK-E2: NEWCOMB NEW PEAK POWER INDICATOR. [*SB* 2:84]
Each $14 Two for $22

PARTS

Tubes

Siemens 6DJ8 .... $ 9.50*
Siemens 12AX7 .... $ 9.50*
Mullard 12AU7 .... $ 7.00*
National 6CA7 matched pair $32.00*
National 6L6GC matched pair $28.00*
TRW socket SKT9R pc board mount, 9 pin .... $ 2.15*

Integrated Circuits

Signetics NE5534 .... $4.75*
Signetics NE531 (8-pin DIL) $4.25*
Signetics NE5535 (8-pin dual FET op amp) $3.70*
Signetics LF351N (8-pin op amp) $1.25*
Analog Devices AD-711 (8-pin DIL single FET op amp) $2.40*

PARTS

Integrated Circuits

Analog Devices AD-712 (8-pin DIL dual FET op amp) $3.00*
Analog Devices AD-712KN Select (8-pin DIL dual FET) $8.50*
Motorola MC34081P input op amp $2.50*

Et cetera

MSLD-32: OLD COLONY SOLDER. .... 2 oz. $7.50*
KM-12: RESISTOR SAMPLE DESIGN PACK. $15*
KM-11: RESISTOR SENIOR DESIGN PACK. $125*
KM-6: CRAMOLIN CONTACT CONDITIONER. $20*
KM-9: WILLIAMSON RECORD CARE KIT. $12*
KM-9R: CLEANER REFILL. 4 ounces $6.95*
KM-9S: DE-STATIC LIQUID. refills ½ ounce. $6.95*

Connectors

SCXT7: ROYCE AUDIO PLUG. .... Pair $18* Two or more pair Each $17*
SCXT8: ROYCE AUDIO JACK. .... Pair $16* Two or more pair Each $15*
PHONO JACK A. .... Pair $7.50*
NYLON INSULATING WASHERS. 10 pairs per set.
⅜" size—Fits Phono Jack A $1.50*
¼" size—Suitable for ¼" phono jacks $1.50*
SB7550B: PHONO PLUG. .... Pair $7.50*
SCBPG: BRASS GOLD-PLATED BINDING POSTS. .... Pair $6.50*
SCBNG: GOLD-PLATED BANANA PLUGS. .... Pair $6.50*
SCSLG: GOLD-PLATED SPADE LUGS. For ¼" post, accepts 10-12 gauge wire. Solder or crimp. .... Pair $1.50*
INDIUM PLATED SCREWS. 10/32 x ½" .... Four $4.75*

& Cable

518: APATURE SPEAKER CABLE. .... Twin Lead, per foot $1.60*
2534: NEGLEX AUDIO CABLE. .... Per foot $1.25*
2477: NEGLEX SPEAKER CABLE. .... Per foot $2.50*
TK2477: TERMINATION KIT. For 2477 cable. .... Per pair $2.50*
2515: NEGLEX HOOK-UP WIRE. 25 foot spool in red or black. Specify. $10.00*

***Discount: $25–$75 = 10%; $75 and up = 15%**
DISCOUNT DOES NOT APPLY TO CLOSEOUT ITEMS

Potentiometers

Alps offers the finest in precision rotary controls. All mounting hardware is included.

VR-10KB: Stereo volume control, no detents. $40
VR-50KB: Stereo volume control, no detents, as above. $32
VR-100KB: Stereo volume control, 41 detents. $32
VR-100KD: Stereo balance control, single center detent. $32
VR-100KJ: Stereo volume control, 31 detents. $22
VR-250KB: Stereo volume control, 41 detents. $42

OLD COLONY'S KIT ORDER FORM

ORDERING INFORMATION: Prices, except as noted, include shipping via UPS, which requires a street address. If you cannot receive UPS delivery, please include an extra $2 for insured service via Parcel Post. We cannot accept responsibility for safety or delivery of uninsured Parcel Post shipments. For charge card orders under $10 please add $2 service charge. *UPS Next Day and 2ND Day Air available to some areas.* PRICES SUBJECT TO CHANGE WITHOUT NOTICE.

ITEM	QUANTITY	PRICE

NAME MAGIC NUMBER

STREET

CITY

STATE ZIP

Enclose check or money order payable to:
OLD COLONY SOUND LAB, PO Box 243,
Peterborough, NH 03458-0243, USA

SUB-TOTAL
ANY ADDITIONAL CHARGES
TOTAL

For credit card order, please bill my ☐ MasterCard ☐ Visa

CARD NUMBER EXPIRE

SIGNATURE

OCSL has added an answering machine for the convenience of our customers. For after 4:00p.m. EST weekdays, and weekends please call (603) 924-6371 to place your MasterCard or VISA order. Please remember this is an ordering line only.

CHARGE CARD
PHONE ORDER SERVICE
Mon.-Fri. 9am-4pm
(603) 924-6371
FAX: (603) 924-9467

SB Mailbox

OLIVEIRA CORRECTION

In *SB* 2/89, p. 63, we inadvertently made an error in a letter from Jorge O. F. Oliveira. The second formula should read:

$$\text{compound } V_{as} = 4 \times (\text{speaker } V_{as})^2 / \text{speaker } V_{as} + V_b$$

—Eds.

ALIGNMENT DEBATE

The debate about correction for "delay alignment," whether physical or electronic, still appears to have some elements of disagreement. I am unsure how the varying positions can be tied in together. It would be of particular interest if Mr. Rumreich could relate his electronic time delay line measurements and results (*SB* 3/88) to those of Max Knittel ("Step Response of Loudspeakers," *SB* 4/86) or Arthur Brown ("Mailbox," *SB* 1/88, pp. 48–51).

In his reply to Ralph Gonzalez (*SB* 5/88, p. 57), Mr. Rumreich stated, "a final check using a pulse generator and HP3562A Dynamic Signal Analyzer showed proper delay alignment..." Could the author relate his measurements to the "physical" step response necessary and whether they correlate at all to:

1. Step response adjustment for drivers without crossovers;
2. Step response adjustments with crossovers in-circuit;
3. Something else?

Or should we adjust physical alignment of speakers "by ear" as Mr. Carlberg did (*SB* 1/84)?

F.J. Habrle
Epsom, Auckland
New Zealand

Mr. Rumreich replies:

I believe your question is about the best method for determining delay alignment. I think Mr. Knittel in particular has done a good job of addressing this in his article and letter.

I'd like to differentiate between delay alignment and phase alignment. Delay alignment implies optimum time coincidence of the drivers' outputs with respect to the input signal, to provide good tran-

Continued on page 57

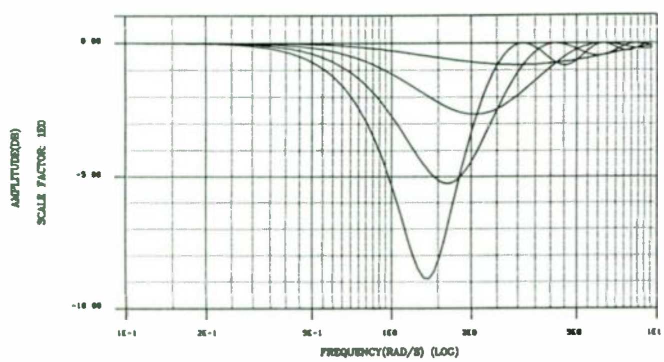


FIGURE 1a: Second-order L/R—amplitude response versus delay (0, 0.5, 1, 1.5, 2sec).

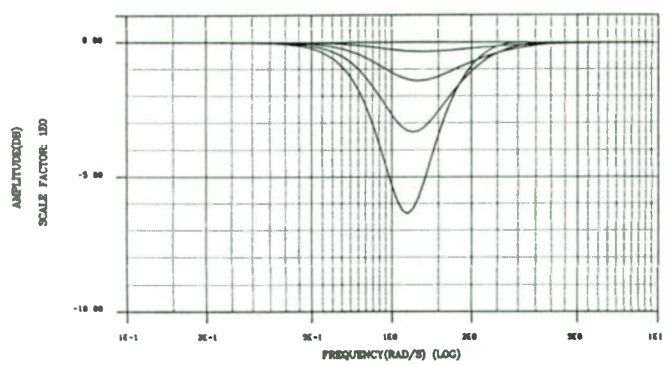


FIGURE 1b: Fourth-order L/R—amplitude response versus delay (0, 0.5, 1, 1.5, 2sec).

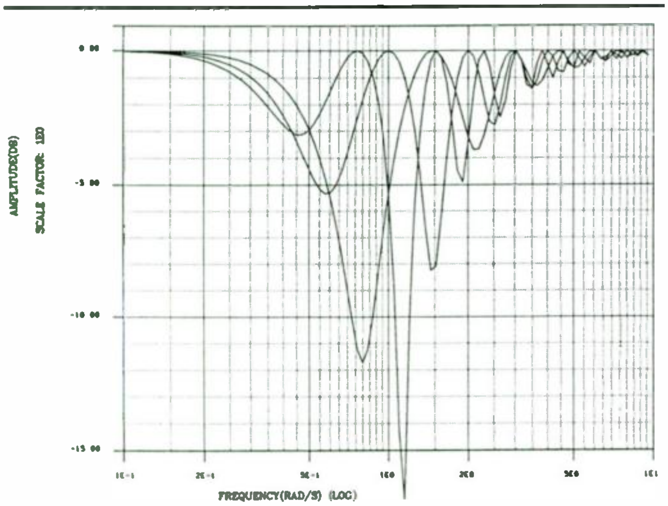


FIGURE 2a: Second-order L/R—amplitude response versus offset delay (−2, 0, 2sec).

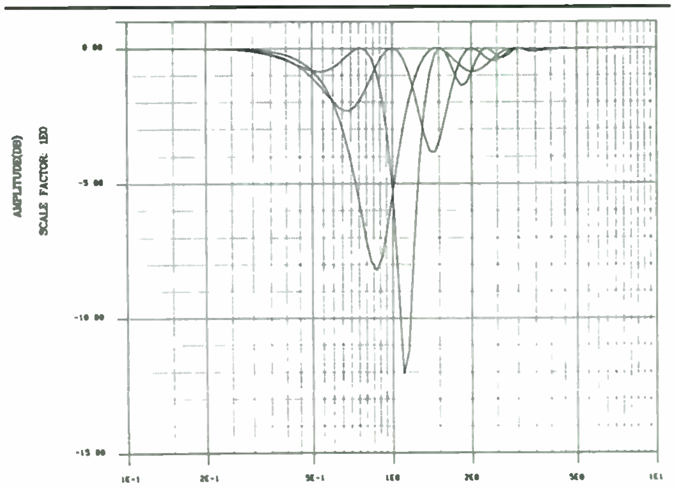


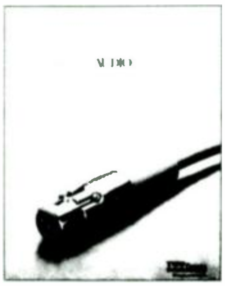
FIGURE 2b: Fourth-order L/R—amplitude response versus offset delay (−2, 0, 2sec).

CATALOG CORNUCOPIA

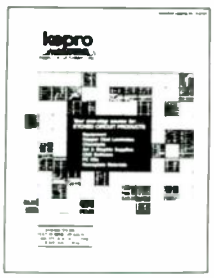
Speaker Builder's Catalog Cornucopia is designed to make it easy for you to obtain the parts you need for your audio construction projects. Analog multimeters to zener diodes can be shipped directly to your home from the companies featured below.

On the order form simply circle the number for each catalog you wish to receive, write down your magic number, and mail the form to us, including a check or money order for the catalog's cost (if applicable) and $1 for handling. Choose as many different catalogs as you'd like. Your catalog will be sent directly to you from each company.

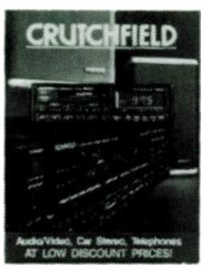
1338: ITT Cannon
FREE to *Speaker Builder* readers—the newly updated ITT Cannon product guide to audio connectors. These connectors are known for consistent dependability, ultra-quiet operation and the elimination of EMI/RFI interference. Catalog also includes detailed specifications on a full range of Cannon audio connector accessories and tooling that makes any assembly simple. **Free.**



1331: Kepro Circuit Systems, Inc.
Speaker builders deserve the highest quality and best performing electronic circuits that can be developed by the hobbyist. Kepro Circuit Systems is your one-stop source for etched circuit products including equipment, copper clad laminates, chemicals, PC kits, and art and graphic supplies. Call toll-free 800-325-3878. **Free.**



1332: Crutchfield
FREE to *Speaker Builder* readers—the Crutchfield catalog featuring the latest stereo and video equipment. Low, discount prices on car and home equipment from Sony, Pioneer, JVC, Proton and more. Plus, raw drivers (MTX, Pyle, etc.), crossovers, and lots of accessories. Video and telephones, too. Over 100 full-color pages complete with descriptions and specs. **Free.**



1337: Old Colony
In addition to kits, parts and modifications from articles in *Audio Amateur* and *Speaker Builder*, we offer a wide selection of books, loudspeaker design software, test records and CDs, gold-plated connectors and audiophile quality cable. For 1989 catalog use order blank or call (603) 924-6371. **Free.**

CATALOG CORNUCOPIA

To order, circle the numbers for the catalogs you would like to receive. Cut out this form and send it along with a check or money order (in U.S. funds) for the cost of the catalogs, plus $1 handling charge to: Audio Amateur Publications, Catalog Cornucopia, PO Box 576, Peterborough, NH 03458. Please include your magic number or your mailing label on the form.

1331: **Free**
1332: **Free**
1337: **Free**
1338: **Free**

I am enclosing:
$________ total cost of catalogs
+ $1.00 handling charge
= $________ total enclosed

Please ship to: ☐ **NOT A SUBSCRIBER**

NAME ______ MAGIC NUMBER ______

ADDRESS (PLEASE GIVE UPS) ______

CITY ______ STATE ______ ZIP ______

Offer expires Dec. 31, 1989 **Please allow 4-8 weeks for delivery**

CIRCUIT BOARDS

Old Colony's Boards are made of top quality epoxy glass, 2 oz. copper, reflowed solder coated material for ease of constructing projects that have appeared in ***Audio Amateur*** and ***Speaker Builder*** magazines. The builder needs the original article (indicated by the date in brackets, i.e., 3:79 for articles in ***Audio Amateur*** and SB 4:80 for those in ***Speaker Builder***) to construct the projects.

C-4: ELECTRONIC CROSSOVER (DG-13R) New 2 × 3¼" board takes 8 pin DIPs. Ten eyelets for variable components. [2:72] Each **5.50**

F-6: 30Hz FILTER/CROSSOVER (WJ-3) 3 × 3" [4:75] High pass or universal filter or crossover. Each **$6.00**

H-2: SPEAKER SAVER. (WJ-4) 3¼ × 5¼" [3:77] Each **$7.00**

J-6: SCHROEDER CAPACITOR CHECKER. (CT-10) [4:78] 3¼ × 6" Each **$7.25**

K-3: CRAWFORD WARBLER 3¼ × 3⅜ [1:79] Each **$6.00**

K-6: TUBE CROSSOVER. 2 × 4½" [3:79] Two needed per 2-way channel. Each **$6.25** Four **$20.00**

K-7: TUBE X-OVER POWER SUPPLY. 5 × 5⅝" [3:79] Each **$7.00**

L-2: WHITE LED OVERLOAD & PEAK METER. 3 × 6" [1:80] One channel. Each **$10.50**

L-6: MASTEL TONE BURST GENERATOR. 3½ × 6⅝" [2:80]. Each **$8.50**

L-9: MASTEL PHASE METER 6⅝ × 2⅜" [4/80] Each **$8.00**

SB-A1: LINKWITZ CROSSOVER BOARD 5½ × 8½" [SB 4:80] Each **$14.00**

SB-C2: BALLARD CROSSOVER BOARD 5½ × 10" [SB 3:82 & SB 4:82] Each **$14.00**

SB-D2: WITTENBREDER AUDIO PULSE GENERATOR 3½ × 5" [SB 2:83] Each **$7.50**

SB-E2: NEWCOMB NEW PEAK POWER INDICATOR 1 × 2" [SB 2:84] Each **$2.50**

SB-E4: MULLER PINK NOISE GENERATOR. $4^1/_8 \times 2^3/_{16}$" [SB 4:84] Each **$8.50**

More than 80 boards in stock. Write for complete list.

Old Colony Sound Lab
PO Box 243, Dept. SB, Peterborough NH 03458

To order, please write each board's number below with quantity of each and price. Total the amounts and remit by check, money order, MasterCard or Visa. U.S. orders are postpaid. **For orders under $10 please add $2 service charge.** Canadians please add 10%, other countries 20% for postage. All overseas remittances must be in U.S. funds. **Please use clear block capitals.**

NAME ______

STREET & NO. ______

CITY ______ STATE ______ ZIP ______

No. Bds.		Price
....	Board No.	$ ......
....	Board No.	$ ......
....	Board No.	$ ......
	Total	$ ....

Continued from page 55

sient response (step response, impulse response and so on). Phase alignment implies optimum "meshing" of adjacent drivers' outputs in the crossover region in an attempt to provide good lobing. Both can be achieved, but in the real world we must always compromise between them. (The degree of compromise depends on the drivers and the crossover.)

In prioritizing performance attributes of loudspeakers, I believe that on-axis amplitude response comes first. Off-axis amplitude response is next, and on-axis transient response is subordinate to both. This means that delay alignment (as opposed to phase alignment) should be considered only for systems that provide good on-axis and reasonable off-axis amplitude responses (with delay alignment). The beauty of this is that for systems meeting this criterion, delay alignment is identical to phase alignment and on-axis amplitude alignment. This greatly simplifies delay alignment of such systems.

This criterion did not apply to the system described in my article and therefore a difficult delay alignment procedure was required. I chose the delays to align the midband acoustic centers of each driver rather than optimize the interdriver phase relationships. Because the crossover was first-order ("transient perfect") and the drivers were sufficiently close to ideal in their passband (three-way system with amplitude and phase equalization for each driver) this approach provided the expected optimization of pulse-trains using the HP3562A and B&K microphone at the listening position. This experience emphasizes that "pure" delay alignment requires fancy equipment and procedures. It is also subject to errors caused by microphone phase response. (The two-microphone technique described by Mr. Knittel is a clever example of avoiding this problem.)

For systems where delay alignment is identical to amplitude alignment (fourth-order Linkwitz-Riley, for example), delay alignment is easy. For other systems it is possible to take advantage of "delay alignment by amplitude alignment" by using a suitable temporary "alignment crossover." This suggests the following method of delay alignment using amplitude response measuring equipment:

- Drivers to be aligned should be driven through a complementary phase crossover system (second- or fourth-order L-R are good examples). This might be the actual crossover or could be an active test crossover.
- Locate a microphone in the expected listening position with respect to the speaker.
- Adjust interdriver delay to minimize the notch in the amplitude response (*Fig. 1*). (Readjust relative levels of each driver as needed to maintain equal amplitude above and below crossover region.)

Figure 1 shows amplitude responses using second and fourth-order Linkwitz-Riley crossovers for various amounts of delay misalignment. The response versus delay is the same for positive and negative delays so only positive delays were plotted. *Figure 2* shows what happens when phase is aligned but delay is misaligned by one cycle of the crossover frequency. Additional notches appear (some below the crossover frequency) and there is no longer symmetrical behavior as you vary the delay about the point which maximizes the response at the crossover frequency.

With this approach, variations in the drivers' phase responses can degrade the delay alignment (at the benefit of on-axis amplitude response). If you use an active "alignment crossover" remember that you have aligned the delay of the drivers as driven by voltage sources—you must consider the effects of driver impedance on the crossover's response (which will become, in effect, the system response).

CONSTANT-CHARGE THEORY

In my recent ESL response ("Mailbox," *SB* 1/89) I unfortunately fell into the same trap as others[1] in misunderstanding constant charge operation in electrostatic speakers. Roger Sanders is quite correct in pointing out the Beveridge patent[2] doesn't use the constant charge mode. The use of the high resistivity stators is to limit power arcs between the stator and the low impedance diaphragm.

Brushing up on my theory, I found the best detailed explanation was by Peter Baxandall.[3] The use of high impedance stators with one contact point isn't necessarily a disadvantage. It is deliberately used in one ESL to control the polar characteristics.[4] The radiating area is made to decrease at a controlled rate as the frequency increases and this controls the directivity of the speaker at higher frequencies. The Beveridge patent is different. The signal contact is the same everywhere on the stator. The total stator surface has a low conductive layer on the outside—the opposite side of the diaphragm. Therefore, different parts of the speaker area are not frequency selective.

1. *Wireless Engineer*, March 1956.
2. US patent #3668335.
3. *Loudspeaker and Headphone Handbook*, J. Borwick, ed.
4. US patent #4703509.

Peter Muxlow
Wellington, New Zealand

KLIPSCH MISINFORMATION

At the back of the past issue I saw a letter from Dave Wharran ("Anatomy of an SK," *SB* 1/89) about his correspondence with Bruce Edgar and Pat Snyder regarding his Speakerlab SK. I hadn't seen the earlier correspondence, but from the current letter it appears misinformation abounds. First, The Speakerlab SK (and the K) was a direct copy of the famous Klipschorn, with tribute given to the actual designer in the product's name, but nowhere else.

Paul Klipsch and I visited Pat Snyder in Seattle once. He was making an ersatz Klipschorn based directly on the original Klipsch patent disclosure. Paul good-naturedly suggested Pat should copy a good horn if he was going to go to the trouble. Paul has admitted the patent version wasn't much of a speaker. Pat seems to have taken Paul at his word, hence the development of the "K" and "SK."

The 39-in.^{2} throat opening and wedge constitute, if I remember correctly, the third major upgrade to the Klipschorn; the first being the 500Hz high-frequency horn and the second, the addition of a tweeter to the system. Paul credited Diana Rorer of Portland, Oregon with making him examine the performance of the Klipschorn woofer near the crossover to the midrange and helping him recognize the sonic importance of the rolloff of the original woofer above 250Hz.

His solution was what he has called the "rubber throat"—the 3 by 13-inch baffle opening and the wedge shown in the excellent drawing accompanying Dave's letter. Together these give the woofer an initial flare rate about double that of the rest of the woofer horn, resulting in increased output in the octave from 200–400Hz. About the same time, Paul developed the K-400 horn to replace the K-5 midrange horn, which also gave a smoother response to the Klipschorn.

Pat Snyder apparently misunderstood the function of the smaller baffle opening if he thought it merely added mass-loading to the woofer driver. And Dave Wharran can be forgiven for thinking, given the wrong explanation, that the effect is to compensate for the wrong driver.

Dick Moore
Bremerton, WA 98312

Peter Drexler of Drexler Audio Systems asks us to inform readers that the Bandor loudspeaker was not designed by Drexler, but by Bandor of the U.K.—Ed.

EDGAR DEFENDS HORNS

In *The Audio Dictionary* review (*SB* 3/89, p. 49), Gary Galo remarked that essentially he didn't like horns because they distort. I think we have both heard horn drivers that would lead to that conclusion. But making such a blanket statement is like stating, "I don't like LP records because all the pops, ticks, and scratches distort the sound." And I know Gary would take offense at that statement. So I could qualify that statement, for example, "I like LP records in spite of the surface noise problems, because of the higher resolution inherent in an analog recording process."

Regarding horns, Gary could have said: "In many commercial horns designed for PA applications, you may encounter overload distortion and coloration problems that render them unacceptable for audiophile applications. However, no-compromise horns built to the exact dimensions specified by horn theory are capable of very realistic sound reproduction with very low distortion."

The problems with commercial horn systems are manifold. The mouths of the bass and midrange horns are usually too small and lead to resonance spikes in the response. The drivers have inadequately sized magnets which must be compensated for by throat correction structures. These problems can easily be remedied by home builders who do not have cost and size restrictions that are imposed by marketing people in a commercial situation.

In *Speaker Builder*, I endeavor to come up with horn designs that can be used for audiophile applications. However, I've found that horns work best in all-horn systems. Attempts to marry horns to other types of drivers have usually led to unsatisfactory results. So stay tuned as I make steady progress in bringing horn designs up to the status now enjoyed by other direct radiator speaker technologies.

Bruce Edgar
Contributing Editor

Contributing Editor Gary Galo responds:

Bruce Edgar raises some important points. My references regarding horn loudspeakers have been those designed by Klipsch, and I have not heard one that I would use in an audiophile system. I keep hearing the same problems with commercial horn loudspeakers: lack of definition and inner detail, a poorly defined stereo image and a less than neutral tonal balance. I hope Bruce would agree these problems are not confined to PA loudspeakers but are apparent in some of the best commercial horns designed for audiophile applications.

My comment was in no way intended to reflect on Bruce's work, which would appear to be far ahead of what commercial manufacturers have chosen to offer, be it for lack of technical sophistication or their interest in reducing manufacturing costs. Unfortunately many of us have not had the opportunity to hear Bruce's designs and therefore must rely on the industry standard Klipsch loudspeakers as our references for audiophile horn loudspeakers.

I fully agree with his last statement. I too have never heard horns integrate well with other types of loudspeakers.

GAUSS LIVES

I thoroughly enjoyed the interview with Keith Johnson in *SB* 6/88. I would like to know whether Johnson's former company, Gauss Electrophysics, is still in business. If so, could you please provide a mailing address?

The magazine's new look is attractive. I particularly look forward to your editorials and articles by Bruce Edgar and David Davenport.

H. Ray Mills
Winston-Salem, NC 27103

Contributing Editor Edgar replies:

The company is currently Cetec Gauss, 9130 Glenoaks Blvd., Sun Valley CA, 91352; (213) 875-1900; Walter Dick is chief engineer, loudspeaker products.

PLANAR PATENTS

Mr. L. Paul Monahan of Reston, Virginia was enquiring about design info on Planar Magnetic speakers in the 2/88 *Speaker Builder*, page 48. I can recommend to him an excellent patent by W. Lee Torgeson, U.S. Patent #4,468,530, Aug. 28, 1984. This patent offers a wealth of design data and is one of the clearest, best laid out patents of its type, with more than enough info to get any amateur up and running. Jim Winey also has numerous patents on the topic. Patents may be obtained from The Commissioner of Patents and Trademarks, Washington, DC 20231, for $2 each. Other Winey patents include #3,674,946 and 3,919,499, to list just two.

Moray J. Campbell
Calgary, Alberta, Canada T2B 1N5

DIPOLE PLOTS

I am interested in building a dipole subwoofer, as described in Technology Watch (*SB* 1/89). Peter Muxlow has given a general description of the methods, but I would like enough detail to design and build one myself. Where would I find the equations necessary to predict the frequency responses based on the driver and baffle parameters? Also, does Mr. Muxlow know of any available drivers that would be suitable?

Ben Stitt
Kennewick, WA 99337

Peter Muxlow replies:

I suggest that you obtain a copy of Carver's patent (European #0267650) by writing to the American patent office (Commissioner of Patents and Trademarks, Washington, DC 20231). The patent details the equations that you ask about—some specifications on the drivers Carver used are included.

Unfortunately, I cannot help with suggestions because I have no experience with drivers available on the American market. R.J. Newman's article

("Dipole Radiator Systems," *JAES*, Jan. 1980) is another good source of information. Finally, since Carver's ideas are covered by patent law, this obviously precludes their use for any form of commercial manufacture. The next issue of *SB* will include James Lin's dipole subwoofer matched to Quad ESLs.—*Ed*.

HELP FOR JANSZEN Z-700s

I have a pair of Janszen model Z-700 bookshelf speakers. They were manufactured by Neshaminy Electronic Corp. of Furlong, PA in the early 1960s. They have an 11″ woofer and two electrostatic tweeters. I have been quite pleased with their sound, especially on strings like solo classical guitar and violin. Recently my power amplifiers developed an RF oscillation and cooked something in the tweeter circuit. After extensive diagnostics, I have concluded that the cooked component is the matching transformer that converts the 8Ω input to a high voltage and impedance feed to the electrostatic elements. The transformers have no apparent markings. I'd like to identify them and/or find a good substitute. If any readers have any suggestions, I'd sure like to hear from them. Thanks.

H. Michael Lowry
PO Box Q
Grand Coulee, WA 99133

The Editor replies:

Neshaminy made the transformers. It is more likely to be the power supply—either the HV rectifier or the resistors used to equalize the load. See diagram. Sometimes P-1 opened, too.

MAGNET SNAG

I enjoyed Mr. Painter's article, "A Low-Cost, Two-Way Ribbon System" (*SB* 4/88). I would like to build a pair, but I have run into a snag. I called Edmund Scientific to purchase magnets and learned those items have been discontinued.

Does the author know an alternate magnet model or another source? Since I live in the Chicago area, perhaps I could try a local source. Also, does it make a difference which output jack is plus or minus? Since the article was published, has Mr. Painter heard from readers on different procedures, ribbon material, and so on?

Tom Finn
Lombard, IL 60148

Richard Painter replies:

I checked and found Edmund part #H41,799 is available and in stock as of May 1989. These ceramic magnets work very well and cost only $15.90 for a package of 12. Fisher Scientific may carry a similar item in Chicago (nice town—I like Victor's Stereo in particular).

To get the correct phase, hook a voltmeter's black lead to one jack and the red lead to the other. Set the voltmeter to read resistance; when the polarity is correct the ribbon will move inward. Mark the jack hooked to the red lead as plus.

I have heard from readers experimenting with aluminized Mylar and longer ribbons (up to 36 inches). Perhaps *SB* will get some feedback, positive I trust, on these experiments. Thin aluminum foil from scrap capacitors remains my favorite material. I wish you the best of luck with your project and let me know how things work out.

By the way, I experienced one ribbon failure, caused by a nearby lightning strike (100 feet), which knocked out all power in the area. Electrostatic effects or electromagnetic power (emp), literally burned out the ribbon material. Apparently they cannot handle a lightning bolt's power.

MIKE TESTING

Thanks for the article about servo controlling the AR-1 (*SB* 3/89). Mr. Brown proved the Panasonic mike's performance is respectable at low frequencies, probably much better than dynamic mikes except for their compression range.

I certainly question his test methods, though. *Figure 3* looks more like a phase error response than response alone. Most electret elements exhibit a response peak between 5–7kHz, but I've used the Panasonic (WM-063T) for recording and a +12.5dB peak would be unlistenable.

I didn't want others to get discouraged with these results. Perhaps Mr. Brown could test the B&K against another "calibrated" mike and compare those results, or experiment with different cartridge mounting methods (see my "Tools, Tips and Techniques" item, *SB* 3/85, p. 42) to perhaps learn how to get the most out of these and other elements.

Greg Szekeres
Pittsburgh, PA 15236

Arthur E. Brown replies:

I appreciate your letter on the Panasonic microphone and the opportunity to describe my technique of testing the mike. To begin, I am unable to repeat or do additional testing since the lab has moved some distance from me. I am severely limited in testing mikes at home, much to my displeasure. As you know, transducers are the most difficult component to evaluate in the development system of audio equipment.

Let me describe the mounting of the mike I tested. I used a phono plug that consisted of the 1/4-inch shank, a metal body that could separate at the wire end to allow a rubber gasket to be compressed around the wire connected to the plug as a strain relief. I found the mike element was slightly larger than the gasket and the outlet hole, so I could support the element between the end of the body and the gasket with slight compression. The mike's membrane end pointed out where the wire would go and the connections between the mike and the phono plug completely inside. The mike could be mounted in any phono jack.

The initial setup involved a shaker, with a 1.5-inch-thick Styrofoam flat panel mounted on its driven surface. The panel was two feet on a side. The two mikes were suspended about 6 inches above the panel, about one inch air space between them. The shaker was driven by the pink noise, and the two mikes' output was processed by the FFT analyzer for about two hours, averaging the frequency results. This amount of time provided a result that appeared to have stabilized, that is, it did not change with added data.

I carried out this process in a quiet room, about 30 by 30 by 8 feet, which I estimate had a background noise of about 50dB. I also estimate that the sound level in the room with the test signal was between 85 and 90dB. The result of this test (*Fig. 2* in my article) showed excellent low-frequency performance for the Panasonic mike.

The higher frequency data was obtained in the same room, but I used a three-way loudspeaker system, comprised of a 15-inch low-frequency driver, a midrange horn loaded driver above the low-frequency driver and a high-frequency horn loaded driver above the midrange driver. These drivers were spaced at two, three and three and a half feet from the floor. The enclosure stood about four feet tall, and about 30 inches across. I mounted the mikes in front of this speaker system, centered with the three drivers and about two feet from the front panel of the enclosure, within six inches of each other, one above the other. I do not remember which was on top. This description is from memory and I hope accurate on the significant details. The test results (*Fig. 3*) indicate a significant rise in response in the Panasonic mike. As I pointed out in my article, this second test setup could introduce errors. Mr. Szekeres suggests phase errors. I could not be as specific. I agree that the test is open to serious question.

I hope that someone who reads this magazine is able to describe a better test for microphones that can be performed by experimenters and/or who can present better data on this or other low-cost mikes. The work is very much needed. Mr. Szekeres sent me copies of the manufacturer's response of the Panasonic WM-063T mike, which shows the mike to have some response wiggles in the 15–20kHz range of less than ±2dB, but otherwise a straight line. I have never seen actual data for any mike that was a straight line, not even very expensive laboratory units costing thousands of dollars.

The B&K mike I used for a standard was randomly varying within ±1dB about the average throughout the frequency range. I have seen data on two or three other electret mikes and they all had rises in the region above 3–5kHz, up to 6dB, generally peaking about 10–12kHz. One of these is the Radio Shack Sound Pressure Meter (No. 33-2050) mentioned in my article in *SB* 1/89. Its curve in the manual was a straight line except for the 6dB rise above 3kHz.

Thank you for the opportunity to discuss this matter.

MINIMUS MOD

I am a recent subscriber so I was particularly pleased to see William Hoffman's "Modifying Radio Shack's Minimus-7" (*SB* 1/88) from the back issues I ordered. As a novice speaker builder and owner of a pair of these, I think this mod is the perfect start to what I intend to be a rewarding hobby. Before tackling this project, I have a few questions.

My Minimus-7s are in a walnut cabinet, not the metal version in the article. Would this elicit changes in the design?

I know little about various crossover components or quality construction methods. Which sources would be useful to gain a sound understanding of the principles and practices involved?

I thank Mr. Hoffman for his great ideas and look forward to pursuing a successful modified Minimus.

William Tyrrell
Tracy, CA 95376

William Hoffman replies:

The electrical equalization that you apply to the system only affects the response above about 2kHz—a point where the basic size and shape of the enclosure has little effect. As long as no major obstructions occur around the face, the speaker's response above about 1,200Hz is almost solely due to the direct output of the woofer and tweeter. In other words, the wood cabinet will make no real difference.

To answer your second question, I would advise looking through the pages of *SB* where many companies advertise crossover parts for sale. Most have sales people who can help you in selecting what you need. As far as building up the add-on circuit, conventional soldering is fine for the inductors and capacitors. A small layout guide was given in the article. You may install the circuit in any convenient enclosure and wire it to the system with at least 18-gauge wire. Most inductors are manufactured from enameled wire and the coating must be scraped off or otherwise removed from the coil wire ends before soldering. As far as learning about speakers, crossovers and so on, several popular books are available. David Weems' book on loudspeakers, available from any Radio Shack store, seems to be a good introduction to the subject.

Best of luck to you.

JBL UPDATE

Regarding Bob White's upgrade to the JBL L-100 (*Software Report, SB* 1/89), I revised a friend's pair using the computer-generated crossover from the article with good results. I substituted Vifa's newest D26TG-35 instead of White's suggested Focal model, adding a 0.5Ω resistor in series.

I'm curious about the midrange polarity indicated in *Fig. 18* (p. 48). I've read that the polarity should be reversed relative to the woofer and tweeter, but a check on the JBL midrange drivers confirms the DC polarity *is* reversed relative to the woofer, that is, plus to red and minus to black pulls the cone in, not out.

Did Mr. White take this into account in his schematic, or should all three drivers be wired in phase in his revised crossover?

Finally, I need some help to determine the reasons for the failure of a 10-inch woofer that I'm testing. With no connection, the cone moves freely throughout its full stroke. But when the terminals are shorted together (or connected to a power amp) the voice coil rubs. It does not matter whether I move the cone slowly by hand or actually drive it with an amp; it still rubs. Removing the short, or connecting a series 600Ω resistor between the amp, immediately frees the coil. Any ideas?

Matthew Honnert
Carol Stream, IL 60188

Bob White replies:

I had a hunch some JBL L-100s were still out there. I'm glad my experiments worked out for you. Substituting the Vifa tweeter is probably fine. As it turns out, the tweeter crossover is the least sensitive to the load placed on it by the driver. As long as the tweeter resonance is significantly below the crossover point, the optimized component values do not stray far from their textbook values.

About the polarity: JBL drivers are usually reverse polarity, that is, a positive voltage applied to the red terminal moves the cone backward. This is the case with the 123A woofer and the LE5-2 midrange. With this in mind, I wired the woofer "out of phase" to get a positive movement with a plus voltage applied to the red (+) input terminal of the system.

Next, if we connect the midrange to a second-order filter, we normally must invert the midrange leads. Now this is becoming confusing. Like a good boy, I followed the textbooks and wired the woofer in-phase, the midrange out-of-phase and the tweeter in-phase. I fired up the system and was pleased...for a while. I placed my ear close to the driver and listened in turn to each, checking for level, extraneous noises and, yes, polarity. It seemed the marriage of the mid to the tweeter was much better than the mid to the woofer.

Then, I concocted two phase-reversal switches (*Fig. 1*), which I wired in the midrange and tweeter crossover sections, just before the drivers, and brought the leads out the port. I marked each switch "in" and "out" to indicate polarity. I set the polarity according to the book and the mismatches appeared. A flick of the mid switch improved the midrange-woofer match, but ruined the mid-tweeter blend. Another flick of the tweeter switch brought the whole system together.

So, I ended up with positive displacement of the

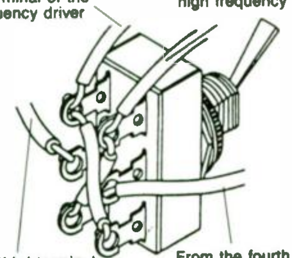


FIGURE 1: Phase reversal switch (DPDT toggle). Used with permission from JBL Inc.

woofer and midrange, but negative for the tweeter, which, by the way, is shown in my original schematic, *Fig. 18*.

I recommend this little technique when determining absolute polarity. If it sounds better one way or the other, don't worry what the theory says; I promise the "techno-police" will never find out. This method is invaluable if all you are building for now is textbook or junk-box makeshift crossovers.

As for your rubbing voice coil, it sounds as if it isn't properly attached to the cone. Your examples that generate the rubbing involve current passing through the voice coil which generates flux lines in opposition to those from the magnet. Even with the voice coil shorted, moving the cone will generate current. So my guess is the voice coil is loose or warped and a current going through it displaces it more, causing it to rub.

VENTED-BOX FORMULAS

I think I have a pretty good grasp of sealed loudspeaker design. Using the formulas in the *Loudspeaker Design Cookbook* by Vance Dickason, I even wrote a program to do all the tedious calculations for me. But vented systems are another story. All I seem to be able to find are tables—no formulas with which to make a new program. I cringe at the thought of loading those tables in as program content. A few formulas will eliminate this. In *SB* 4/80, R. M. Bullock provides some simple formulas that can vary from stated table values by as much as 25%. He says he generated his tables using an HP3000 minicomputer. I would greatly like to use the correct (precise) formulas. Long, complex formulas are no problem using the computer. Can you tell me where to find them? —Steven A. Crosby

Contributing Editor Bullock replies:

You can't find any exact formulas for calculating vented-box alignments because there are none. Let me try to explain why.

Vented-box alignments are constructed by using the Thiele-Small model to obtain the speaker response function. This function is the transfer function of a fourth-order electrical filter. The commonly known fourth-order filters are examined to find ones that have a good response for a loudspeaker. Chebychev and quasi-Butterworth filters are two examples of such filters. The problem then is to choose α and h so that the vented-box response function is identical to some Chebychev or quasi-Butterworth filter transfer function.

This problem is solved by equating the response function coefficients with the filter transfer function coefficients. The result is a system of equations in α, h and possibly some other parameters that describe the filter. Alignment formulas are obtained by solving this system of equations for their unknowns α, h and filter parameter values.

Here is the difficulty, because very few systems of equations can be solved explicitly for their unknowns. For example, the system of one equation in one unknown given by:

$$x^5 + bx^4 + cx^3 + dx^2 + ex + f = 0$$

cannot be solved explicitly for x in terms of a, b, c, d, e and f. This fact was proved almost two hundred years ago by a mathematician named Galois.

Since formulas for solutions to the equations can't be found, how do you find solutions? The answer is that you find approximate solutions. The best known technique for doing this is due to Newton, but he could not apply it generally because it is computationally intensive, and only the computer makes it a practical alternative today. With enough computation, solutions to "nice" systems can be found to any desired degree of accuracy.

Alignment tables for vented-boxes are found by programming Newton's method to construct solutions to the system of equations described above. The programming is not difficult, but the details are complicated enough that some expertise in mathematics is needed.

In my opinion, alignment tables or formulas are unnecessary for anyone with their own computer. Tables and formulas describe only some of the good alignments, but there are a lot of others that could be used. It is better to buy, or write, a program like BOXRESPONSE (offered by Old Colony). This program takes proposed system parameters (α, h and those of the driver) and determines the resulting system response function. You can then examine this function (either graphically or in tabular form) and decide for yourself if it is a "good" loudspeaker response. In addition, you can find the power and excursion capabilities and the input impedance of the alignment at the same time. I strongly urge you to use this approach, rather that rely on formula alignments.

VENTED ALIGNMENTS

Over the years I have read with great interest articles by Sanders, Galo, Pappanikolaou, Cox, Cockroft, Weems et al. concerning variations of damped open line systems. Several authors have reported two small resonant peaks in the line impedance curve. This suggests that these systems may be a type of highly damped fourth-order alignment rather than a true acoustical analog of an electrical transmission line. I have never read nor heard of any specific or extensive discussion relating to this topic. Would any of these good authors care to comment?

Would it be possible to describe these alignments with the same rigor that Thiele and Small have done with fourth-order vented enclosures? Robert Bullock has done much to clarify the nature of vented alignments. His comments would also be appreciated. —Bruce Kizerian

Robert Bullock replies:

It is more likely that a vented box is a transmission line than it is that a transmission line loudspeaker is a fourth-order filter. The purpose of the electrical models is to provide a mathematical theory that can be applied to analyze and predict the behavior of the loudspeaker. Naturally, it is easiest to use the simplest model that mirrors the properties of the modeled device. We can predict the behavior of a vented box fairly well by modeling it as a simple fourth-order filter, as long as the amount of acoustic stuffing or lining is minimal. But when an appreciable amount of stuffing is used, it's harder to get the electrical filter model to mirror the behavior of the vented box. The advantage of the more involved electrical transmission line model is that acoustic stuffing can be mirrored in the model in great detail.

This ability to model acoustic stuffing is the reason that the electrical transmission line is viewed as an appropriate model for a transmission line loudspeaker. An optimal form for the electrical line to best mirror the loudspeaker has not yet been found. This is an area where Peter Hillman and I have done some work, and thus far the model is not of sufficient accuracy to use as a basis for calculating loudspeaker alignments.

TRY FIBER COMPOSITE

I read Mr. Millikan's article ("Dynaudio Drivers and Sheetrock," *SB* 3/89) with interest. I noted his comment that he "spent more than a year looking for a practical method to build such a complex structure of Fiberglas-reinforced plastic and have so far failed." This letter's purpose is to describe a solution.

For many years I have built all sorts of projects using fiber composite technology. These projects have all been vastly more complex than a simple speaker enclosure, ranging from aircraft and snowblowers to telescopes, and have used many types of fibers including Fiberglas, carbon fiber and Kevlar.

The process is simple. I make the basic shape using a foam core, then coat it with the fiber of choice embedded in epoxy resin. With incredible strength, lightweight, and high damping qualities, this type of construction should be ideal for a speaker enclosure. You have complete control of shape and strength since foam is extremely easy to sculpt and you can position the fibers in the number and direction you desire. (Of course, I recommend you use the usual safety apparel when working with these materials.)

For example, a speaker enclosure could be made with nonparallel walls. The wall thickness could be tapered and you could add more fibers in the center than at the edges for increased bending strength. The joints could be filleted and covered with fiber as well, so they are stronger than the walls—just the opposite of the norm. In short, you can do *anything* with this stuff.

For a basic speaker "box" you could simply buy 1- or 2-inch foam, cut it to shape on your table saw and cover it with Fiberglas, then glue the "boards" together.

However, we usually use a hot wire bow and templates to cut complex shapes from foam. For example, a better shape would be a truncated cone with the driver mounted in the side and with nonparallel top and bottom. Such a rounded/tapered enclosure should have an infinite number of tiny resonances rather than two or three large ones typical of box enclosures. Curved surfaces are also far more rigid than flat surfaces so enclosure radiation would be nearly nonexistent. Edge diffraction effects would also be eliminated.

Such a shape would be easy to make with a hot wire bow utilizing circular disks as templates. The basic shape could be made in one piece by taking sheets of 4- or 6-inch extruded polystyrene foam, cutting off chunks and gluing them together with five-minute epoxy. You would then attach a disk to the top and bottom and cut the finished size around these with a hot wire bow.

If you wanted 1-inch walls, you would use two more discs, each 1-inch smaller than your first ones, as the inside templates. You could even vary the wall thickness by using different disk sizes, or by offsetting one of the disks. The tapering and offsetting is designed to spread any resonances around, of course. No matter how complex you would like your "perfect" enclosure to be, you can build it with fiber composite technology. Your imagination is the only limit.

I trust that I have pricked your interest in this exciting technique. I wrote an article on this subject, detailing a very large telescope mount I made in this way (*Sky and Telescope*, Jan. 1984, pp. 79–84; 49 Bay State Rd., Cambridge, MA 02238) that should give you further ideas.

Roger R. Sanders
Halfway, OR 97834

ULTIMATE QUESTIONS

I am about to build my "ultimate" speaker involving much of the design theory (and the fewest compromises) from information in *Speaker Builder*. I have been planning this for some time but recently obtained *SB* back issues 1982–88, which has given me the necessary resolve.

Robert Carlberg's comments regarding his "ideal speaker" ("Speaker Builder's Odyssey, Part VI," *SB* 2/84) with coexistent front facing and rear facing Yamaha drivers hit a responsive note with me. I own Shahiniam Obelisk speakers and have heard the excellent Mirage M1s, both of which are multidirectional.

I favor a system using two sets of drivers for each speaker (Dynaudio D52AF and D21 in a D'Appolito configuration) with a 21W54 8-inch woofer in sixth-order vented arrangement (a la Levreault); one set facing forward and the other facing to the rear and aligning acoustic centers in a vertical plane through the center of the speaker cabinets. This could be achieved physically, but more probably by electronic delay.

The author's experience might assist with the following:

Would physical alignment of the two MTM arrays per speaker cause radiation interference effects if they were in "free space" as in his design or should they be incorporated into a baffle?

Could a better result be obtained by putting one set of drivers facing front and the other set facing the opposite speaker?

What did the author specifically listen to, and for, when aligning speaker acoustic centers? Should I do this with the crossovers in-circuit?

Finally, has his design progressed any further in the last five years?

Frank J. Habrle
Epsom, Auckland
New Zealand

Robert Carlberg replies:

I was quite surprised to hear from somebody asking about my "Speaker Builder's Odyssey" (3/82–2/84) nearly ten years since I wrote it (some publishing delays).

The good news is my Carlberg Mark Elevens, my "ultimate system," are still in daily use as my main system and still outperform anything I've heard commercially. In fact, just two years ago I purchased a new house, which provided the opportunity to build a "music room" around them, tuned to just the right liveness and reflectivity and their true potential has become apparent.

The bad news, if it is bad, is that with my system complete I have almost outgrown the audio lust which drove me to design them in the first place. Love of music, after all, was the impetus for originally entering the audio rat race, and it's gratifying to be able to return to appreciating music once the search for accurate reproduction is over. Consequently, I let my *SB* subscription lapse and have not, I confess, been following recent discussions therein.

My advice is presented in the article as I grappled with the same questions you ask. First, radiation interference between forward- and rear-facing drivers is definitely a problem, and your mounting (and room) must be configured to prevent it. Unfortunately, without using bi-directional drivers, physical co-location of the front and rear drivers is impossible, so you must also design around the resultant phase distortion. Most important, simply "aligning the acoustic centers in a vertical plane," either physicall or electrically, is not sufficient to prevent interdrive radiation interference either. This alignment, critica because "close" is worse than no alignment at all, must be done by ear and the drivers must be free-mounted on movable mounts.

Second, depending on your space and money limitations, I would definitely recommend a larger woofer than the Dynaudio 21W54 8-inch unit, unless your tastes run to light classical and AM radio. With a 12- or 15-inch unit, you also could avoid the nightmare of trying to match two production units in a bi-directional mounting. Bidirectionality is perfectly dispensable for properly loaded woofers and this simplifies construction considerably.

Third, facing the rear-radiation toward the center is a compromise between construction details, room placement and the drivers used. I think true rear-facing radiation is the ideal, although the loss in imaging from "canting" the rear has been minor, in my experience.

Last, the aligning-by-ear of the drivers *must* be done with crossovers in-circuit, due of course to the phase angle of the crossovers. Naturally I prefer crossovers with minimum phase angle, active crossovers above all else. When performing this alignment, specifically listen for "point-sourcing," that precise alignment where two drivers seem to merge into one. This is best done from close range with either pink noise or a recording of an acoustic instrument such as violin, banjo, dobro—anything with a readily identifiable character that you've heard before in person.

The drivers should be aligned two at a time, using one (probably the woofer) as the starting reference. As a final check, once correctly aligned there should be absolutely no image wandering (phase cancellations) when walking about in the listening chamber. Incidentally, be prepared for a tedious process to achieve your exact alignment—it took me several weeks. No wonder there are no commercially-aligned units on the market.

Good luck, and let me know how it comes out.

LEAKS AND DAMPING FACTOR

It was with great interest that I read Randall Bradley's article on passive radiator bass system design. I have been a friend of Randy's since about 1975, and I, too, worked for Pentagram. I do not disagree with Randy's statement about the importance of a leak-free system, but I would like to add some other information regarding those systems that are not leak-free.

If you take a passive radiator system that leaks, it does not have to sound "loose and boomy," but usually it will.

The exception to this rule is if your amplifier's damping factor is such that it makes the woofer and passive work together. Randy and I had the experience of listening to a Pentagram system driven by a Phase Linear 400 which has an extremely high damping factor, and we both had to cover our mouths so as not to offend the friend who owned the system—it was very easy to hear the woofer stop on a dime, yet the passive continued to "flub around."

My system uses passive radiator subwoofers (a modified Pentagram model) and Acoustat Twos driven by a modified Dyna Stereo 70. Up until I began using the modified Dyna, I felt the bass system had the characteristic passive radiator sound and that it was inherent in all such designs. Now I know better—I get deeper, more natural bass from my system than from any system that I have experienced.

With Randy's assistance, I have begun elimination of some of the air leaks in my bass system, and I must say that it makes a significant improvement. No doubt with the woofer and passive properly coupled (as Randy suggests), the necessity of having just the right damping factor is eliminated.

Alan Rauchwerger
So. Hackensack, NJ 07606-4354

P.S. Randy did not exaggerate at all about the bass capabilities of the system shown in Photo 2—if anything, he was modest!

VOLUME MISCONCEPTION

Peter Muxlow, in his report about Bob Carver's dipole speaker ("Technology Watch: Subwoofers, Part II," *SB* 1/89, p. 52) shows a common misconception about box size and efficiency (or is accurately reporting Carver's misconception, a scenario I find quite believable).

The closed-box efficiency is stated as:

$$n = 16 \times 10^{-12}\,(Fo^3 V_{as}/Q_c)$$

First, this equation is incorrect: it is in fact (with a slightly different constant) the expression for reference efficiency of a driver in an infinite baffle. The actual equation for closed-box efficiency is $n = K_n F3^3 V_{as}$ where K_n is 1.17×10^{-6} for a second-order Butterworth alignment (B2 response).

The problem comes in the statement, "efficiency is related to the volume of the box" for closed-box loudspeakers. This implies that merely changing the box volume will change efficiency, which is not true.

What is missing here (and in Small's original statement of the equation) is that, with a given driver, changing the box size also changes both the efficiency parameter K_n (because this parameter is dependent upon alignment), and the cutoff frequency F3, resulting in the reference efficiency remaining constant. Changing the driver parameters to change reference efficiency, so that a new system can be synthesized with a new box volume is the only way that efficiency can be made "dependent" upon volume.

The confusion arises from the implication that the equation, as stated above, has three independent variables, F3, V_b and K_n, leaving the efficiency n as the only dependent variable. This is not the case, as there is the implicit dependence of the efficiency parameter K_n on alignment.

Putting it in simpler terms, if we take a hypothetical 8-inch woofer with an F_s of 32Hz, a V_{as} of 80 liters and a Q_e of .37 (with a resulting Q_t of .32), we find that its reference efficiency (stated in dB SPL re 2.83V at one meter) is 89.24dB. This driver in a 25-liter cabinet will have an F3 of 63.5Hz, an F_c of 63.5Hz and a system Q_{tc} of 0.707, a perfect second-order Butterworth alignment.

Now, take that same driver and put it into a 40-liter cabinet. What happens? The F_c drops to 53.7Hz (although the F3 remains nearly the same at about 66.5Hz) and, importantly, the system Q_{tc} drops to

Why Your Magazine Doesn't Arrive

If you move and do not send us your new address in advance, your current issue is sent to your old address and may arrive after the Postal Service's six-month time limit on forwarding instructions has expired. If this happens, the Postal Service sends us a notice saying, in effect, they have forgotten where you now live, along with a bill for 25¢ to pay for this information. Meanwhile, they have trashed your magazine.

Since we have already paid for your destroyed copy, paid postage to attempt to deliver it to you and put a holding code in your computer record saying that we have no idea where you are, and further since we routinely act on the assumption that Murphy is overactive within most offices of the Postal Service, we send a first-class letter to your old address to determine whether you have, in fact, moved. We do this because from time to time some clerk mistakenly supposes a subscriber has moved and he or she has not. Then we write a nasty letter to the Postmaster suggesting the clerk is a vandal of sorts and how about paying for the magazine? So far, not one has sent any postage or even a repentant letter. Replies usually range from form to frowning to foaming.

So please inform us early when you move. Peel off your label, put it on a postcard, write in your new address and send it to us. We cannot afford to send you a duplicate, unfortunately. If your copy becomes a Postal Service casualty, the replacement copy will cost $4.

0.59, no longer the same B2 alignment. But, we find, the efficiency of the system has not changed, still at 89.24dB SPL re 2.83V. Why has the efficiency not changed, as the equation would have us believe? Because the efficiency constant K_n isn't a constant. It is dependent on a number of things, notably, in this case, the alignment parameters of the system. Our new, larger system will exhibit an over-damped, drooping response in the bass instead of the relatively flat response of the original alignment.

The same trap awaits those who believe that simply taking a driver from a closed-box system and putting it in a vented box will also gain them more efficiency, as the efficiency parameter for vented enclosures is almost twice that of closed boxes. Again, this is not so, as Koonce pointed out in an earlier article ("Closed Vs. Vented Box Efficiency," *SB* 3/81, pp. 10 and 11). The change will most likely buy you a lower F3, but no more efficiency.

One more unrelated point. That Dick Fierce fellow is just, I mean, so funny. I read his laws of acoustics and I thought they were just the neatest thing ever. I mean, this guy is *great*! I sat back after I finished reading them and said to myself, "Gee, I wish *I* had thought of that."

Dick Pierce
Pepperell, MA 01463

PASSIVE CROSSOVER NETWORKS

Would it be possible, and what results could I expect if I built John Levreault's woofer system as outlined in *SB* 2/87, and dome mid/tweeter array as outlined in *SB* 2/88, using a single power amp and all passive crossovers?

The system appeals to me for its simplicity in cabinet work. Not being very technical, and with limited electronics, I would love to build this system. If my request is possible would you supply a crossover diagram I may use? If not, would it be possible to purchase the active portion of the crossover in its entirety from anyone?

Gerald G. Readinger
Florissant, MO 63033

John E. Levreault replies:

The design of passive woofer-midrange crossover networks is extremely difficult, especially when the crossover point is fairly low. The main problem we face is compensating for the variations in woofer voice coil impedance.

As I explain in my article, I go to great lengths to ensure that the impedance the loudspeaker driver presents to the crossover is as constant as possible. This allows me to use textbook formulas to calculate the crossover element values. I also select the crossover point itself to be near the geometric mean of the lower frequency driver's natural rolloff and the higher frequency driver's resonant frequency, thus minimizing the effects of driver phase shifts.

Woofers in vented boxes display a familiar "double-hump" impedance magnitude versus frequency characteristic. You can carefully measure this characteristic and calculate the values of two series R-L-C circuits to be placed in parallel with the voice coil. And don't forget the Zobel network to linearize the high frequency impedance rise caused by the voice coil inductance. You may ignore the woofer resonant peaks, but I have found that doing so colors the sound of the system in the lower frequencies, especially the deep bass and midbass. Biamping avoids dealing with these problems, in addition to providing its other well-known benefits.

Speaker designers with access to network analysis software can "twiddle" the crossover elements to compensate for the effects of the various driver impedances. As a hobbyist, I do not have access to such software and must therefore resort to the techniques outlined in my articles. Perhaps an interested reader with access to such software can examine these effects and share his or her results with us.

Symmetrical System

continued from page 27

29. D'Appolito, Joseph A., "Active Realization of Multiway All-Pass Crossover Systems," *JAES* April 1987.

30. Linkwitz, Siegfried, "Excursion-Limited SPL Nomographs," *SB* 4/84.

31. Linkwitz, Siegfried, "A Three-Enclosure Loudspeaker System with Active Delay and Crossover: Part 1," *SB* 2/80.

32. Linkwitz, Siegfried H., "Active Crossover Networks for Noncoincident Drivers," *JAES* Jan.-Feb. 1976.

33. Ranada, David, test report on "Snell Type C/II Loudspeaker," *High Fidelity* Nov. 1988.

34. Kates, James M., "A Perceptual Criterion for Loudspeaker Evaluation," *JAES* Dec. 1984.

35. Hedeen, Robert A., Compendium of Materials for Noise Control. *DHEW* (NIOSH) Publ. No. 80-116, U.S. Gov. Printing Office, Washington D.C. 1980 ed. (as cited by F.Alton Everest, *Acoustic Techniques for Home and Studio*, 2nd ed., Tab Books, Blue Ridge Summit, PA, 1984).

36. Klapholz, Jesse and Allan Sohl, "Practical Applications of Crossovers in Real Loudspeaker Systems," AES Preprint 2136, presented at the 76th Convention of the Audio Engineering Society, Oct. 1984.

37. Jung, Walter G., *Audio IC Op-Amp Applications*, 3rd ed., Howard W. Sams, Indianapolis, IN, 1987.

38. Jung, Walt, "Active Filters Part I," *Audio Amateur* 1/75.

39. Huelsman, L.P., "Multiple-Loop Feedback Filters," Chapter 7 in *RC Active Filter Design Handbook*, F.W. Stephenson, ed., John Wiley & Sons, New York, NY, 1985.

40. Linkwitz, Siegfried, "A Three-Enclosure Loudspeaker System: Part 3," *SB* 4/80.

41. Linkwitz, Siegfried, "A Three-Enclosure Loudspeaker System with Active Delay and Crossover: Part 2," *SB* 3/80.

42. Jung, Walt, "The Speaker Saver: Thumpless Solid State Audio," *Audio Amateur* 3/77.

43. Toole, Floyd E., "Loudspeaker Measurements and Their Relationship to Listener Preferences: Part 1," *JAES* April 1986.

44. Muller, Bernhard, "A Stereo Noisemaker," *SB* 4/84.

45. Toole, Floyd E., "Subjective Measurements of Loudspeaker Sound Quality and Listener Performance," *JAES* Jan.-Feb. 1985.

46. D'Appolito, Joseph, reply to Stephen Katz's letter "Swan IV" in *SB* Mailbox, *SB* 6/88.

47. Ruether, David, "A Big Bass Box," *Audio Amateur* 2/78.

Tweeter Q Problems

continued from page 40

should be less than one-third the crossover frequency, which is usually the case, to avoid changes in the passband response.

3. Using *Fig. 1*, calculate C_s:

$$C_s = 1/[(2\pi F_s)^2 L1]$$

C_s is a hypothetical capacitor used only for calculations (usually, fairly large).

4. Calculate Ca:

$$Ca = C1C2/(C_s - C1 - C2)$$

You may round off the value to ±10%; use a polyester or polypropylene capacitor. Ra's value isn't critical, about 100Ω, 2–5W is okay. However, if you are a diehard, you may calculate Ra per:

$$Ra = R_{L1}(C_s/Ca)$$

in which R_{L1} is the resistance of L1.

Figure 2 shows computer simulator curves using second-order, third-order and AB crossovers for the Audax tweeter's relative dome amplitude. In each case the crossover frequency is the same. As you can see, the second-order crossover amplitude at F_s is 3.8dB higher than at F_c; third-order amplitude is 5.8dB lower and the AB crossover is 29dB lower.

Although not obvious, when you decrease the signal level at F_s, dome excursions are reduced and distortion is reduced in a compound way, clearing up the midrange.

Happy listening!

REFERENCE

1. Colloms, M., *High Performance Loudspeakers*, 3rd ed., *Figs. 6.17* and *6.18*. Note: in *Fig. 6.18*, Ca and Cb should be transposed.

CLASSIFIED INFORMATION

TYPES:

For Sale are personal and not for profit.

Trade feature items for sale or resale at a profit.

Wanted can fulfill your wildest dreams.

Club ads can help you start a club or find new members. Items cannot be offered for sale in "Club" ads.

PRICES:

For Sale, Wanted, and *Club* ads are free to subscribers up to 50 words; 20 cents per word thereafter. Don't forget to count your name, address, and phone number.

Please: only one ad per category per issue. Ads are open to nonsubscribers at 20 cents per word. All overruns and nonsubscriber ads must be prepaid.

Trade ads are 55 cents per word, prepaid. Two tearsheets are sent to the advertiser upon publication. Call for information about classified space ads.

WORDS:

We count words as any collection of letters or numbers with a space on both sides. No abbreviations, please, spell out all words. Ad copy should be clearly printed or typed, preferably submitted on the *Classified Order Form.* Illegible ads will be discarded.

DEADLINES:

Ad copy must arrive by the first of the month of the issue mailing. Ads arriving late will be run in the next issue. Ads are run only once, then discarded.

DON'T PHONE:

Personal ad questions, copy, and copy changes *cannot and will not* be answered by phone. All correspondence must be in writing.

MAGIC:

Please include your Magic Number with your ad copy (located in the upper left corner of your mailing label). If only your name and phone number are to appear in the ad, your address must accompany your copy.

R.S.V.P:

For acknowledgment of your ad, including issue date, include a stamped, self-addressed postcard.

THE ATLANTA AUDIO SOCIETY, a club for men and women interested in high quality home audio/video systems and recordings. Monthly meetings are conducted where special programs and guest speakers are often featured. Guests have been: Jack Renner, Richard Vandersteen, William Conrad, William Johnson, Louis Lane, John Cooledge and others. Annual dues are $25 and includes a monthly newsletter. For information call Chuck Bruce, (404) 876-5659 or write Atlanta Audio Society, PO Box 361, Marietta, GA 30061.

HI-FI CLUB OF CAPE TOWN, South Africa issues monthly newsletter for members and subscribers. Get a different approach to understanding audio, send two IRCs for next newsletter to PO Box 18262, Wynberg 7824 South Africa.

WASHINGTON AREA AUDIO SOCIETY (N. VA, MD and DC) is looking for sincere audiophiles who are eager to devote their time and get involved with the direction of the society and the publication of a monthly newsletter. Please contact: Horace J. Vignale, 13514 Bentley Circle, Lake Ridge, VA 22192-4316.

SAN DIEGO AUDIO SOCIETY forming for hi-fi tinkerers and do-it-yourselfers. If you enjoy collecting, building, rebuilding and repairing classic audio equipment, especially tube-type, call Mike Zuccaro (619) 271-8294 (evenings & weekends). Old timers and engineers welcome.

NEW JERSEY AUDIO SOCIETY meets monthly. Emphasis is on construction and modification of electronics and speakers. Dues includes monthly newsletter with high-end news, construction articles, analysis of commercial circuits, etc. Meetings are devoted to listening to records and CDs, comparing and A-Bing equipment. New members welcome. Contact Bill Donnally, (201) 334-9412 or Bob Young, 116 Cleveland Ave., Colonia, NJ 07067, (201) 381-6269.

PIEDMONT AUDIO SOCIETY—Starting an audio club in the Raleigh–Durham–Chapel Hill area of North Carolina. Interested in designing, building, and modifying speakers and electronics (solid state and tube). Beginners and old hands both welcome. Kevin Carter, 9009 Langwood Drive, Raleigh, NC 27612, (919) 870-5528.

THE VANCOUVER AUDIO SOCIETY publishes a bimonthly newsletter with technical information, humor and items of interest to those who share our disease. We have 40 members and meet monthly. Six newsletters per year. Call (604) 251-7044 or write Dan Fraser, VAS, Box 4265, Vancouver, BC, Canada V6B 3Z7. We would like to be on your mailing list.

MEMPHIS AREA AUDIO SOCIETY being formed. Serious audiophiles contact J.J. McBride, 8182 Wind Valley Cove, Memphis, TN 38115. (901) 756-6831.

Advertising Index

Pox Humana

What a New Tuner Can Get You...

By Dick Pierce

In the process of building my system, I lusted for the very best at the very cheapest. Consequently, I frequented the "used" departments of audio stores. Sometimes I won, sometimes I lost.

One of the ways I lost (in a really big way) was by buying a KLH tuner (a model 19, I think—I tend to remember more about the grimly bad stuff I own than the spectacularly wonderful). Here was a jewel of a tuner. It had trouble picking up interstation noise, much less music! Its capture ratio was specified as "maybe," and selectivity was measured at "not very." It was, in technical terms, a dog.

Well, the search went on for a replacement. I walked into a store and there was the fabled, top-of-the-line Sony tuner, on the "used" rack for $150! Wow! Sony tuners at the time were known for their ability to pick up attowatt signals originating from the backside of Jupiter! I bought it, and on the way home picked up a Finco FM-5 antenna and enough cable to extend the length of my parents' 163-foot-long colonial house.

After a weekend of stringing cable and rearranging cabinets, I debuted the tuner. Stations I didn't even think existed were popping up all over the dial. Hooking the KLH tuner to the antenna revealed it had two modes of operation: it either couldn't find the station, or was overloaded by it. I think the Sony was able to pick up ten times the number of stations.

Now I got into the practice of FM DXing (finding distant, faint stations). As a classical music aficionado, I was interested in finding as many classical stations as possible. One day, I picked up a mono station somewhere in western Massachusetts, belonging to one of the colleges out there (Amherst or UMass or something, I don't remember). They were in the middle of their first fund-raising marathon:

"This is W--- and we are here to provide you with the best in classical music. We're four hours into our marathon, and we've already raised $123. However, we have a long way to go to meet our goal of $35,000, so call now and make your pledge for independent classical broadcasting..."

The only thing missing was the telltale ringing of phones in the background.

A couple of days later, I tuned back in to hear: "...we've still got a long way to go, but with your help we can make it on time; the generous listeners out there have pledged over $200 so far, but we need your help..."

I had just spent almost $200, otherwise I would have sent something in, but that's another story. A week later: "...all the phones are free right now (yawn), so you should try to call in before they get busy again (sigh of despair). Remember, $263 is really not enough to run a station, so do your part..."

Well, this was like a soap opera, so I decided to tune in every day and see how they were doing. The next day, I tuned in and heard: "...hisssssssssssssssssss..."

Oh, well.

Fast Reply #JD81

high fidelity
range

The MDM 85 is a mid range 75mm soft dome unit of extremely high standard, both from a design and technical viewpoint.

It incorporates the renowned Morel double magnet and Hexatech voice coil techniques, and results in a unit of above average sensitivity with extremely low distortion and high power handling capability.

With an output level of 96dB distortion in the area of 400-800Hz is slightly over 1% falling to 0.015% from 1Khz.

There are two different types available, one with a rear enclosure and one without (MDM 85NE).
The type with the rear enclosure can be fitted into a cabinet as an integral unit.

The MDM 85NE without the rear enclosure can only be fitted into a system having a separate housing to enclose the unit. A volume of 0.7 litre is recommended for this housing, which is essential to prevent inter-reaction with the bass unit compressions and expansions. This housing must be filled full with damping material, such as fibreglass or rock wool.

The Thiele small parameters are given for both types under specifications. The contribution of this unit to a suitably designed system will be evident in the clarity and detail given in the 500-5000Hz region.

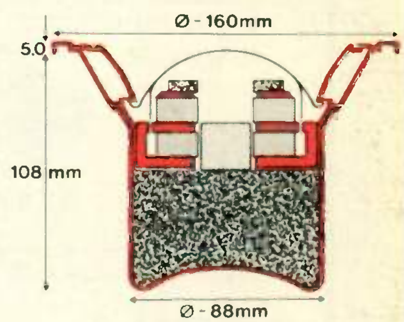
Specification

MDM 85 (with enclosure)

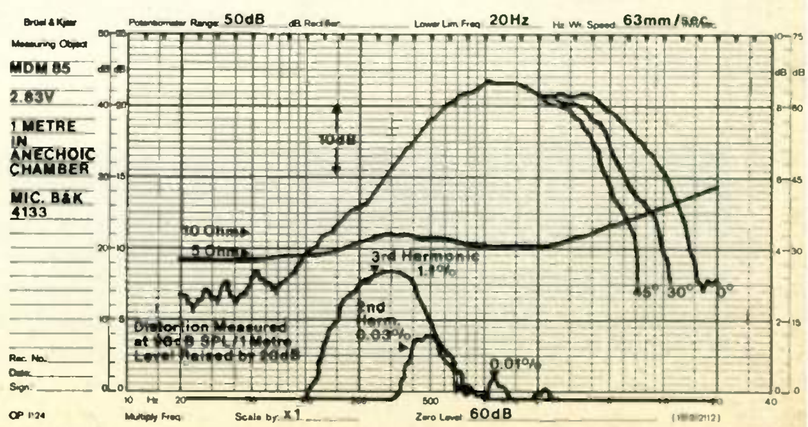
Overall Dimensions	Ø - 160mm x 113mm
Nominal Power Handling Din	300W
Transient Power 10ms	1500W
Voice Coil Diameter	75mm (3") Hexatech Aluminium
Voice Coil Former	Aluminium
Frequency Response	300-5000 Hz
Resonant Frequency	250 Hz
Sensitivity	92 dB (1W/1M)
Nominal Impedance	8 ohms
Harmonic Distortion for 96 dB SPL	<1%
Intermodulation Distortion for 96 dB SPL	<0.25%
Voice Coil Inductance @ 1 Khz	0.2mh
Air Gap Width	1.05mm
Air Gap Height	3.0mm
Voice Coil Height	6.0mm
Flux Density	1.0T
Force Factor (BXL)	4.6 WB/M
Rdc	5.2 ohms
Rmec	37.90
Qms	0.29
Qes	2.66
Q/T	0.20
Vas	0.33 litre
Moving Mass including Air Load	7.0 grams
Effective Dome Area	63.50 cm^2
Dome Material	Chemically Treated Fabric
Nett Weight	1.25 kg

Variations to specification for MDM 85NE (without enclosure)

Overall Dimensions	Ø - 160mm x 60mm
Frequency Response	250-5000 Hz
Resonant Frequency	170 Hz
Rmec	39.33
Qms	0.19
Qes	1.81
Q/T	0.17
Vas	0.7 litre
Nett Weight	1.05 kg



Specifications given are as after 24 hours of running.



morel (U.K.) ltd.
11 Foxtail Road,
Nacton Rd. (Ransomes)
Industrial Estate,
Ipswich, IP3 9RT
England
Tel: (0473) 719212
Telex:987601 Morel G

morel acoustics USA
414 Harvard Street
Brookline, MA 02146
Tel: (617) 277-6663
Telex: 6502499475

morel®