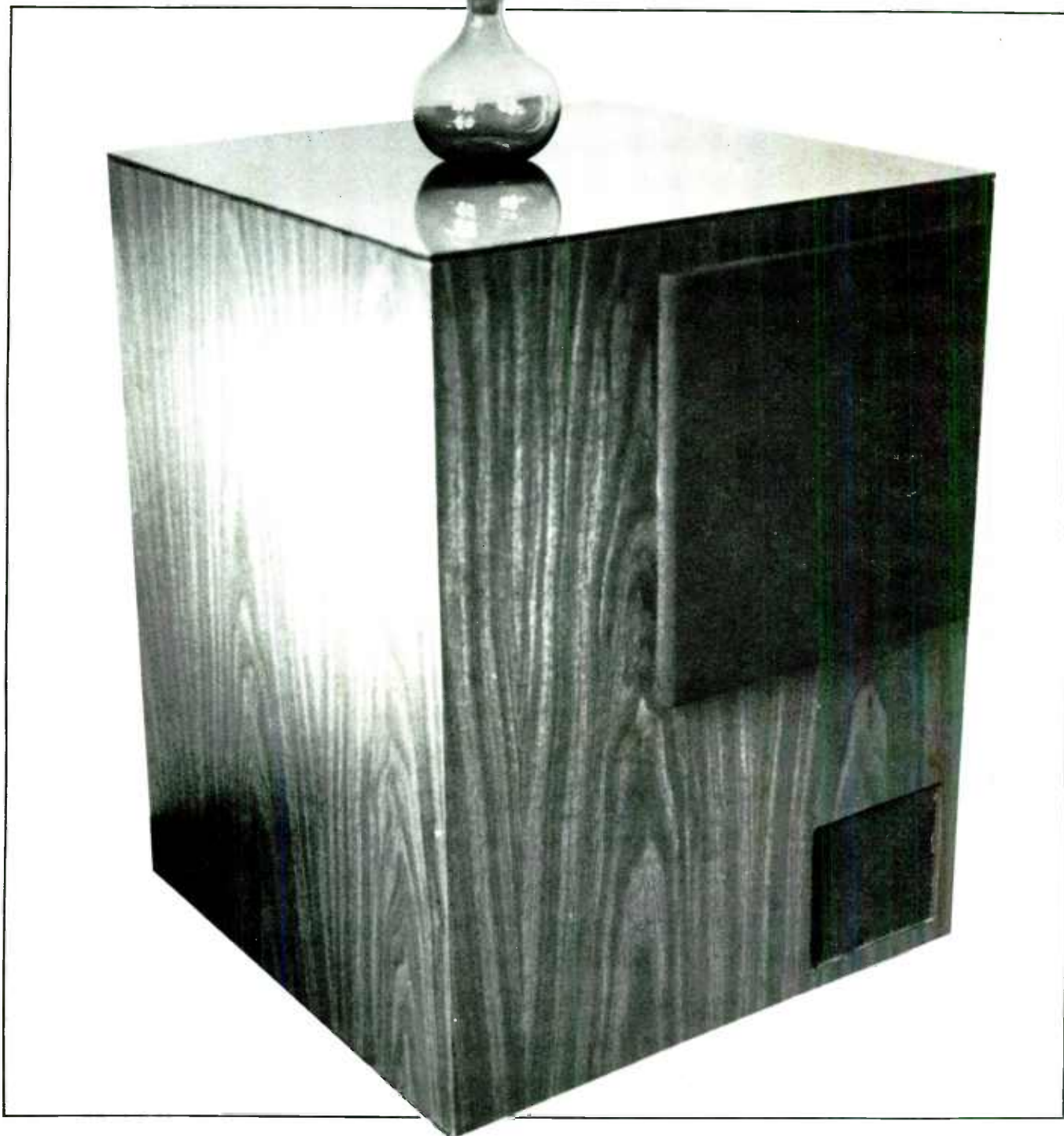


Speaker Builder

THE LOUDSPEAKER JOURNAL



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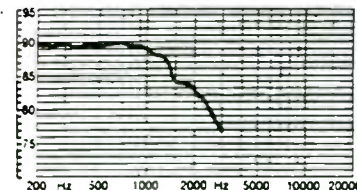
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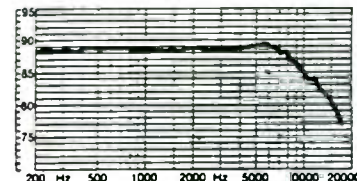
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FAST REPLY #EB201

Good News

MAXIMUM EFFORT SOFTWARE has released a new version of LoudSpeaker, an interactive loudspeaker design program for IBM PCs and compatibles.

Written by *SB* author Max Knittel, the new LoudSpeaker lets users set a specific box volume for vented and passive-radiator enclosures; design sixth-order vented box alignments; design driver impedance equalization circuits for cone-type drivers, and driver impedance equalization/resonance cancellation circuits for dome-type drivers; design first through fourth-order all-pass or constant-power, two or three-way crossover systems; produce printed tables of tweeter and midrange attenuators.

The user's guide has doubled in size (40 pgs.), and includes equalizer, attenuator, and crossover circuit diagrams plus a complete sample loudspeaker design.

LoudSpeaker, also available in a math co-processor version, has a suggested retail price of \$29.95.

For complete details and ordering information, contact Maximum Effort Software, 2701 Cedarwood Ave., Bellingham, WA 98225.

Fast Reply #EB765

Audiophiles now have a weekly radio show, **AUDIOPHILE AUDITION**, airing on most of its 175 outlets at 2 PM (EST), Sundays.

The show, hosted by San Franciscan John Sunier, is a mix of audiophile recordings and interviews with audio industry stars and recording artists. The interviews have a rather stronger than expected technical content, although not the kind of "red meat" readers of *SB* are used to.

The show is taped on a Sony F1 and distributed via satellite in digital format, so the musical portions lose very little in transmission. A letter to your local PBS (Public Broadcasting System) station will confirm local broadcast times and support a worthwhile effort.



eton has released a new 7" Hexacone-Diaphragm® woofer, the 7-380/32-hex.

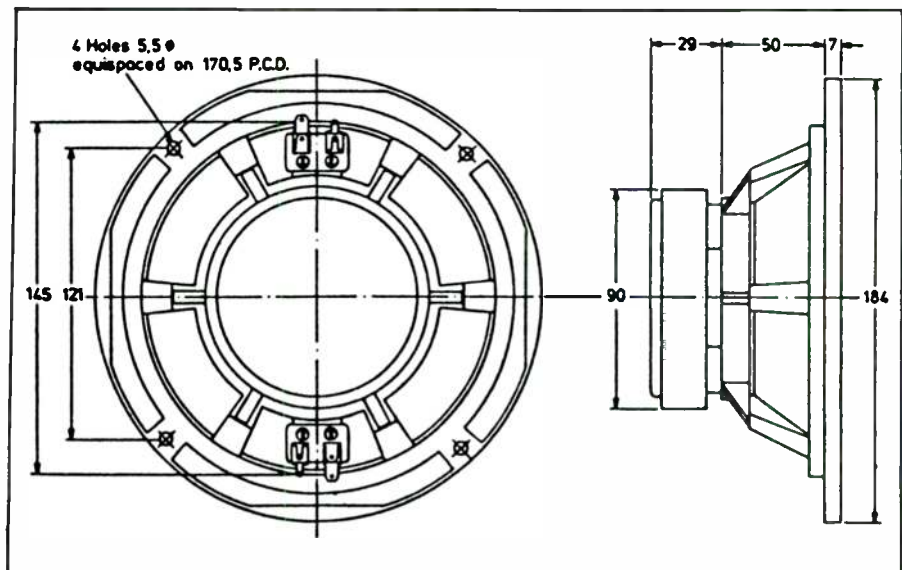
According to the manufacturer, the woofer's patented design makes it comparable with electrostatic and electromagnetic drivers. The totally stiff, extremely light design is said to help transfer signals without resonance break-up.

The woofer is constructed of two fiberglass layers coated with a duroplastic res-

in, and has a honeycomb internal structure. Its frequency and step function are said to make the woofer well-suited for high-end, two-way bass reflex systems.

For more details and pricing information, contact: eton Deutschland Electro Acoustic GmbH, PO Box 1321, D-2860 Osterholz Scharmbeck, West Germany.

Fast Reply #EB1107





DRA has introduced TransView, a menu-driven FFT spectrum/transfer analyzer which, when used with the company's new A2D-160 sampling data acquisition board, is claimed to form a complete analyzer for less than \$2,000.

The IBM PC, XT, or AT software package is designed for measuring loudspeaker and room acoustics.

According to the manufacturer, TransView supports cascaded AFM-50 anti-aliasing filter modules programmable as 8-pole Bessel, Butterworth or Chebychev filters, with up to 80dB/octave roll-off. Filter gain is said to be programmable from 0.2 to 500, while filter bandwidth is programmable from 1Hz to 40kHz. Other features include a graphics function that lets you plot individual data points or connect them with lines, plus time and frequency domain plots.

Suggested retail price: \$250.

The A2D-160's listed features include 12-bit resolution and accuracy, up to 166,000 samples per second, and dual channel capability (simultaneous sample and hold).

Applications include FFT (Fast Fourier Transform) analysis, digital oscilloscope uses, audio frequency speaker testing and measurement, acoustic testing and measurement, and vibration testing.

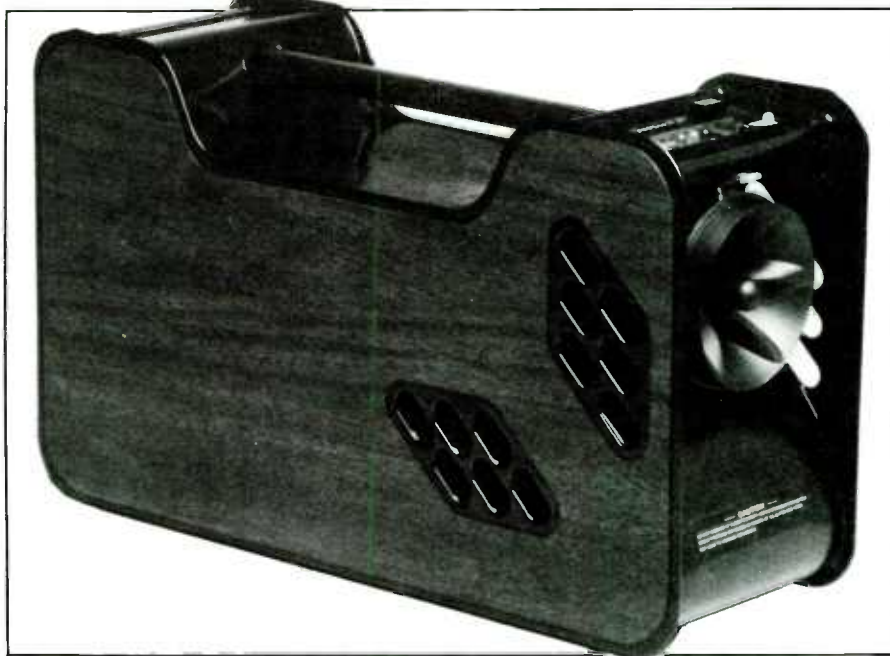
Suggested retail price: \$1,295.

For complete details on both products, contact the distributor: MicroWay, Inc., PO Box 79, Kingston, MA 02364, (617) 746-7341.

Fast Reply #EB964

INDUSTRY WEST ELECTRONICS has introduced the Hypersound 115. Manufactured by Ivie, this hand-held system measures $4\frac{7}{8} \times 8\frac{1}{4} \times 4\frac{1}{4}$ inches. Features include a high-fidelity SPL of 115dB/1M, three-way triplex amplifiers, tri-band peak processor and two-thirds piezo. More information can be obtained by contacting Industry West Electronics, 270 N. Geneva Rd., Orem, UT 84057, (801) 226-0583.

Fast Reply #EB228



Two new products have been released by **RAPID SYSTEMS, INC.** The R360 is a turnkey spectrum analyzer and digital signal processing peripheral for IBM PCs, XTs, ATs and compatibles, while the R100 is a new series of digital sound processing courses.

The R360 is said to be the only PC-based instrument featuring the TI TMS32010, and offers four-channel real time spectrum analysis. Applications include multiple channel spectrum analysis to 250kHz, vibration analysis, impact testing, power line monitoring, and audio and speech analysis.

Suggested retail price: \$2,699. The R360 is also available with a less expensive data acquisition module for \$1,499, and alone lists for \$999.

Rapid Systems' new digital signal processing course lets you use a PC to teach hands-on basics. The course includes a 250 page text which, when coupled with enclosed hardware and software, is said to turn a PC into a turnkey digital oscilloscope, FFT spectrum analyzer, data logger, or data acquisition module. Chapters include sampling, digital filtering, FFT and spectrum analyzers, and experiments and problems.

Price for the course varies from \$1,299 to \$3,299 depending on hardware options.

For complete details on both products, contact: Rapid Systems, Inc., 433 N. 34th St., Seattle, WA 98103, (206) 547-8311.

Fast Reply #EB948

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Speaker Builder is published four times a year by Edward T. Dell, Jr., PO Box 494, Peterborough, NH 03458. Copyright © 1987 by Edward T. Dell, Jr. All rights reserved. No part of this publication may be reprinted or otherwise reproduced without written permission of the publisher.

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 (four issues) \$15, two years (eight issues) \$25. All sets of back issues are available beginning with 1980. Caribbean and Canada add \$4 per year for postage. Overseas rates available on request. NOTE: All subscribers residing the Western Hemisphere are served by air.

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Speaker Builder (US ISSN 0199-7920) is published four times a year at \$15 per year; \$25 for two years, by Edward T. Dell, Jr. at 5 Old Jaffrey Rd., 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

Enthusiasm for transmission lines continues unabated and the search for the smallest possible internal volume may be approaching with **Craig Cushing's** article beginning on page 9. **Ralph Gonzalez** is already familiar to readers through his copious correspondence in *SB's* pages. He introduces his program for modeling loudspeakers beginning on page 18. Next time we will see some practical examples of using the program.

Coil winding by hand isn't very difficult if you don't care whether you wind neatly or not, but even then counting the turns is no cinch. Contributing Editor **Bruce Edgar** has wrestled with the difficulty and comes up with his succession of answers to the need on page 25. Few serious speaker builders have not wished, or been asked, to make a pair for someone else. If the someone else is a relative, you will want to provide some performance data. **Ken Robinson** built several pairs of the "Model One" and his system's details begin on page 28.

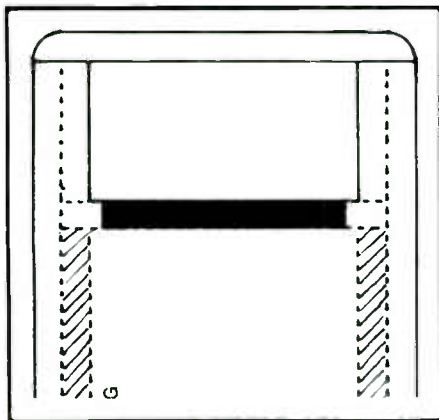
You have built yourself a new listening room. Now you face the questions: "Where's the best place to locate the speakers and where do I sit?" **Charles Ulrich** had the bittersweet circumstance of both a new room and the troublesome questions. His odyssey begins on page 32. **Dave Davenport** is back (p. 42) reviewing Focal's bass system.

Speaker Builder

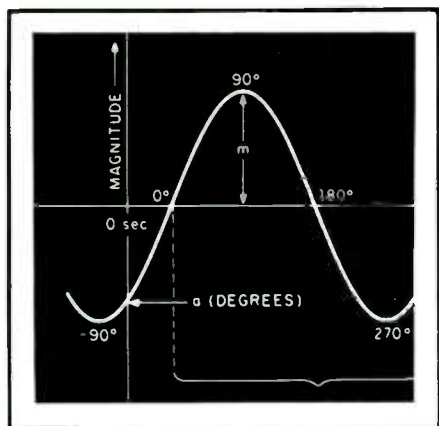
THE LOUDSPEAKER JOURNAL

VOLUME 8 NUMBER 1

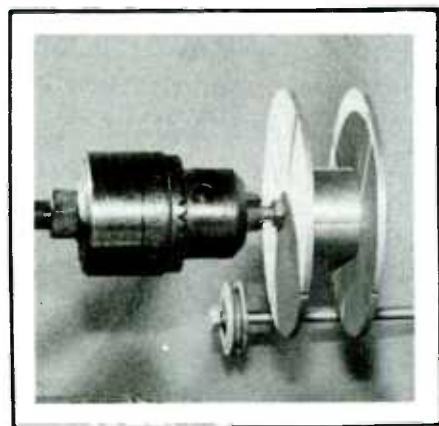
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Is Flat Beautiful?

Amateur speaker builders are on the brink of a new era of advanced design techniques. With the increased access to microcomputers, we are beginning to see more and more software either written specifically for speaker design or which could be adapted for that purpose. In the past we relied upon the technical pioneers such as KEF and B&W to provide the loudspeakers we wanted. We are now capable of doing a respectable job for ourselves. Granted, it will not be as "technically perfect" as the job these companies have done, but it will be as good as we can accomplish without their elaborate instrumentation.

Some of the factors in loudspeaker design we can examine using a modest home computer are:

1. Cabinet proportions to suppress internal standing waves.
2. Placement and type of damping materials within the cabinet.
3. Explore cabinet shape effects on diffraction.
4. Maximize angular coverage by optimum driver placement on the baffle.
5. Determine the pistonic capabilities of a driver within its thermal limits.
6. Model the enclosure structurally under dynamic conditions using finite element analysis.
7. Determine the large- and small-signal responses of a given box/driver combination.
8. Optimize the passive components of a crossover to take into account the complex impedance of the driver and response irregularities.
9. Discover the approximate time delay necessary to align the acoustic centers of two drivers.
10. Driver level matching based on measured Thiele/Small parameters.

11. CAD (computer-aided design) software for designing electronic crossovers and all-pass delay circuits.

The above techniques enable us to design a superior home system.

With all these new skills, what can we expect?

I envision a loudspeaker that is tri-amped using electronic crossovers. These would incorporate amplitude equalization and inter-driver time delay compensation. We will have done our homework regarding all the things mentioned in items one through eleven and will be ready to test the results. Theoretically we have come as close as we can without exotic measuring devices.

What will it sound like?

Well, not exactly as good as we thought it was going to.

Why?

I think we spend a great deal of time trying to achieve a flat response loudspeaker when, in fact, we would not like it if we had it. Let's suppose we built this system so we could adjust all the variables including crossover frequency, inter-driver delay, individual driver gain and the transfer function of the crossovers themselves. After many hours of tinkering we arrive at a "believable" sound.

If we then measured the results we would be amazed at how "non-flat" it had become and even more surprised that we liked it. Does this mean that we should not pursue a flat response? I believe the answer should be "No." Starting with a flat response gives us a common starting point with which to compare any change we make in pursuit of what it is we do like.

Few of us have identical rooms and no two of us have the same pair of ears. Music is a highly individual experience as is the art of speaker building.

A MORE COMPACT TRANSMISSION LINE SUBWOOFER

BY CRAIG W. CUSHING

Photos by Carol Cushing

Drawings by the Author

The transmission line (TL) subwoofer design I am presenting in this article is a synthesis of my earlier folded design⁵ and B.J. Webb's classic reducing-section line¹². This package is compact and powerful, with bass that extends through the bottom octave. The exterior dimensions—21" square x 28½" tall (including base)—are not appreciably larger than subwoofers with 12" drivers using other bass-loading systems. Although my design is not in the "superwoofer" TL class (18-24" driver), neither does it overpower the room in which it is placed. Instead, this design is easy to live with, both in size and aesthetics, and is concurrent with excellent musical values.

In addition to its considerably reduced box size, this subwoofer has several advantages:

1. retained low F3 cutoff;
2. relatively simple construction, with 45° angle cuts needed only for corner baffles;
3. reduced amount of stuffing because the line volume is less than that of a constant-section line which does not go below the woofer cone area dimension;
4. easily adjustable stuffing;
5. extensive internal baffling which minimizes cabinet resonances.

Low frequency advantages of a correctly designed transmission line speaker system include: non-resonant, accurate bass, with no "boxiness"; capability for an F3 matching the woofer's free-air resonance; a gradual (12dB/octave) roll-off below system resonance further extending useful bass.

Several restrictions, however, have traditionally governed transmission line design. First, TL systems that do

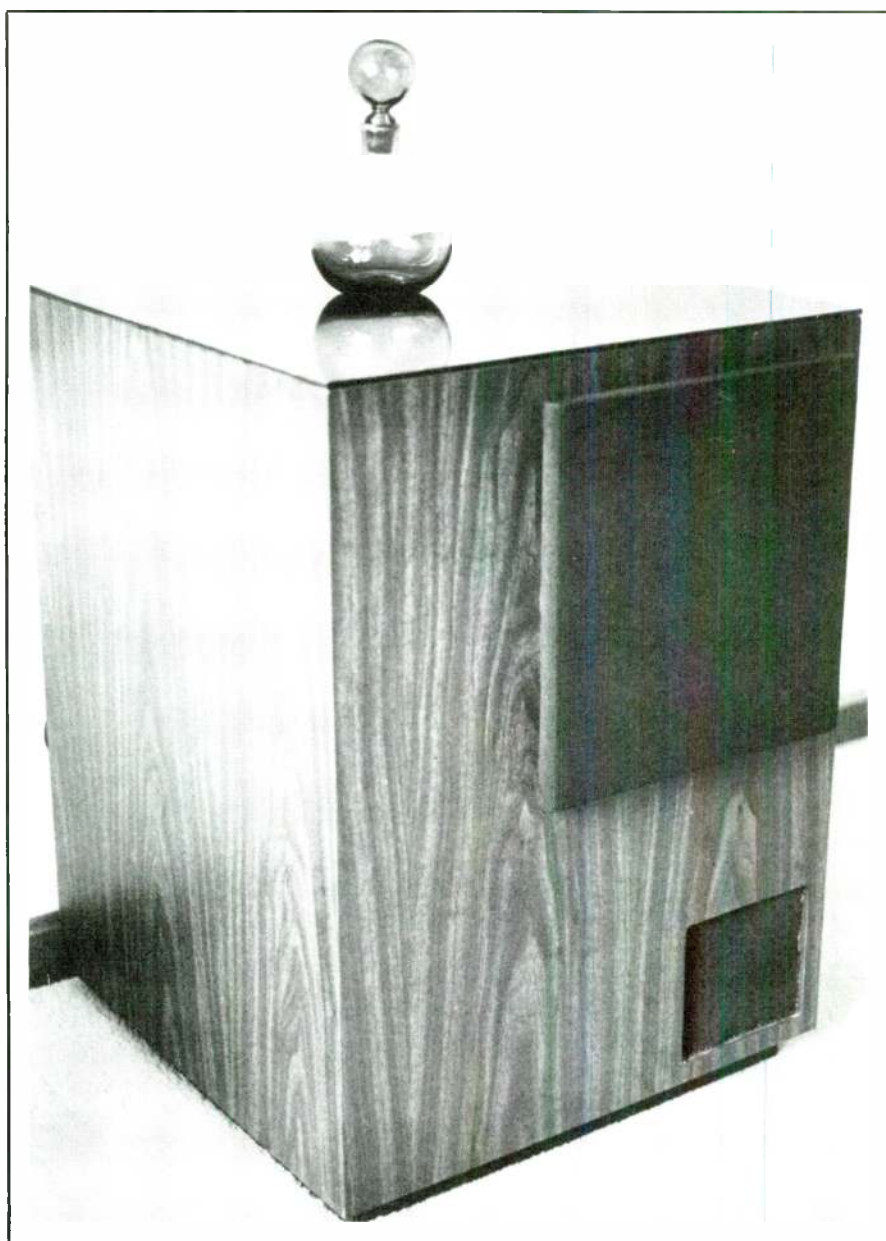


PHOTO 1: The author's completed compact transmission line system.

not have line cross sections and which taper to a size appreciably less than that of the working area of the woofer cone are inevitably large for a given woofer size, and considerably larger than other loading formats. Second, practical evidence suggests, in general, only certain driver types work well in a TL configuration: low Q, half-roll surround (PVC, butyl rubber or foam), and synthetic cone materials (Polypropylene, Bextrene and the like). Third, it is often difficult to construct a transmission line enclosure because considerably more parts and angle cuts are required than with the conventional six-sided box. Fourth, because it is best to stuff the line with long-fiber wool (according to Bradbury³), multiple-pound quantities can be expensive. You can use Dacron polyester "fluff," but it will produce an audible decrease in sound quality⁸.

A.E. Bailey's 1965 article¹, which introduced the TL design principle, warned against making the line's cross-sectional area smaller than the woofer's effective cone area. His redesign article² continued the cross-sectional area warning, although he noted the line terminus could be about half the area of that of the woofer cone. Jastak⁹, Ruether¹⁰, Sanders¹¹ and Galo⁶ have all directly or indirectly warned against cross section reductions that go below this theoretical minimum.

The one notable exception to these designers is Bert Webb, who addressed the issue in his article, "A Proven Transmission Line Loudspeaker¹²:" "This cross-sectional area is progressively reduced along the length of the pipe, which is perfectly permissible as rear radiation is increasingly absorbed throughout the length of the line." About a year ago, I finally heard a pair of the legendary Webb speakers and was astonished by their general excellence, especially their deep, natural bass. I was also surprised by their compactness, given the KEF B139 woofer size and the 40Hz cutoff.

My original "compact" subwoofer design had a cross-sectional line area at least twice that of its 8" woofer cone (except at the terminus). The sound of the Webbs, however, convinced me if I could substantially taper the line, I could make a significant size reduction without compromising sound quality. The Webb design has a cross-sectional taper that, at the terminus, is less than one-third that of the woofer cone area, and one-sixth that of the chamber

cross section immediately behind the woofer.

Although, in my current subwoofer design, the line's cross section at the terminus is less than half that of the woofer's working cone area, I suspect even further reductions are possible. I have no empirical or theoretical data, however, to substantiate my suspicions. Webb's design tapers at approximately a 6:1 ratio in just over seven feet, while my design reduces in section approximately 4:1 in the same distance. For construction ease, the last four feet of my line is a constant section.

As with most TL bass systems, mine operates on the ¼ wave principle (Gary Galo's article in SB 1/82 provides a clear synopsis of the theory). To take full advantage of the F₃ of the driver used in this design (a Peerless TA305F, now discontinued by the Danish manufacturer but available as a Precision Loudspeakers Inc. [PLI] driver with the same designator), you need a line giving an F₃ of 25Hz/11.3 feet. You can also use drivers with a lower resonant frequency, but the F₃ will remain the same because it is

determined by the length of the pipe, measured along its center line.

Other drivers which will work well in this configuration include the SpeakerLab W1208R ("Polylam" treated paper cone model tested) and the Becker 91227. The Dynaudio 30W54, which has excellent power-handling, low Q and a synthetic cone, is probably less suitable for this project because, according to Madisound (a Dynaudio distributor), in a TL configuration, it's voice coil can be easily pushed into non-linear excursions when driven hard at low frequencies.

When I started working on this design, I planned to use the superlatively-built Dynaudio woofer. The people at Madisound, however, steered me away from the 30W54 and toward the Peerless woofer, despite the fact that the Dynaudio unit cost nearly three times more. Other 12" drivers are undoubtedly suitable for this subwoofer, and I would appreciate hearing from fellow builders about other likely candidates.

Thomas Cox's recently published investigation into TL driver/line interactivity⁴ pointed out that optimum line

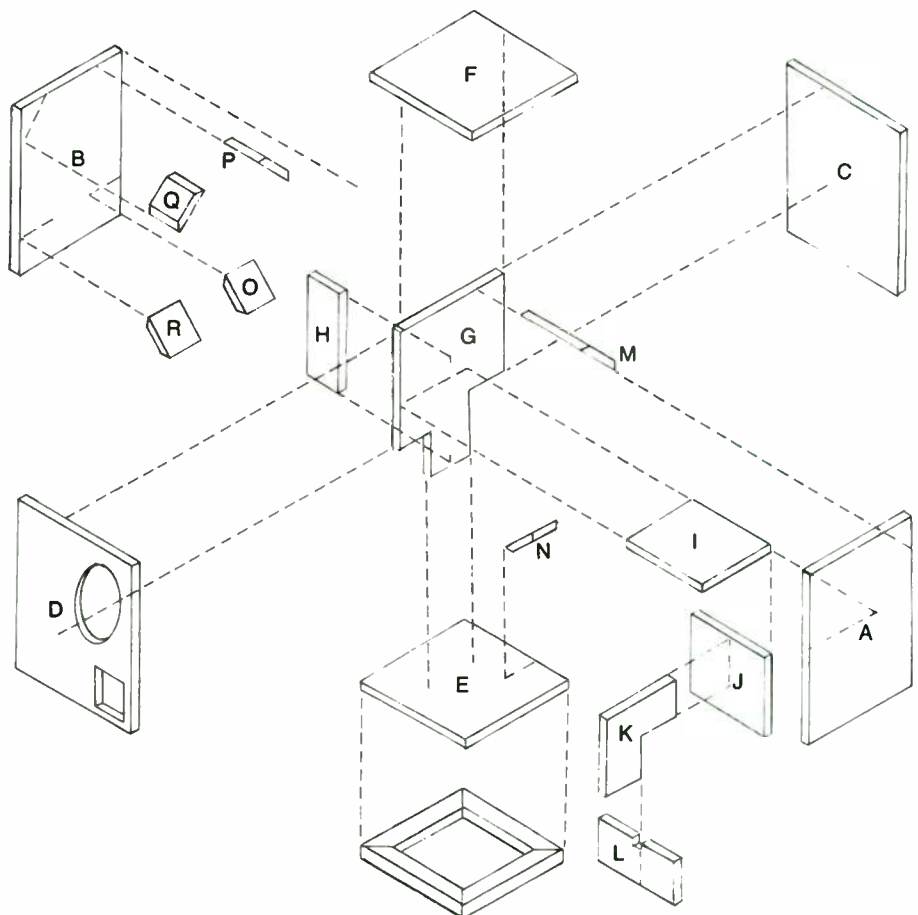


FIGURE 1: Construction lettering guide for the author's system.

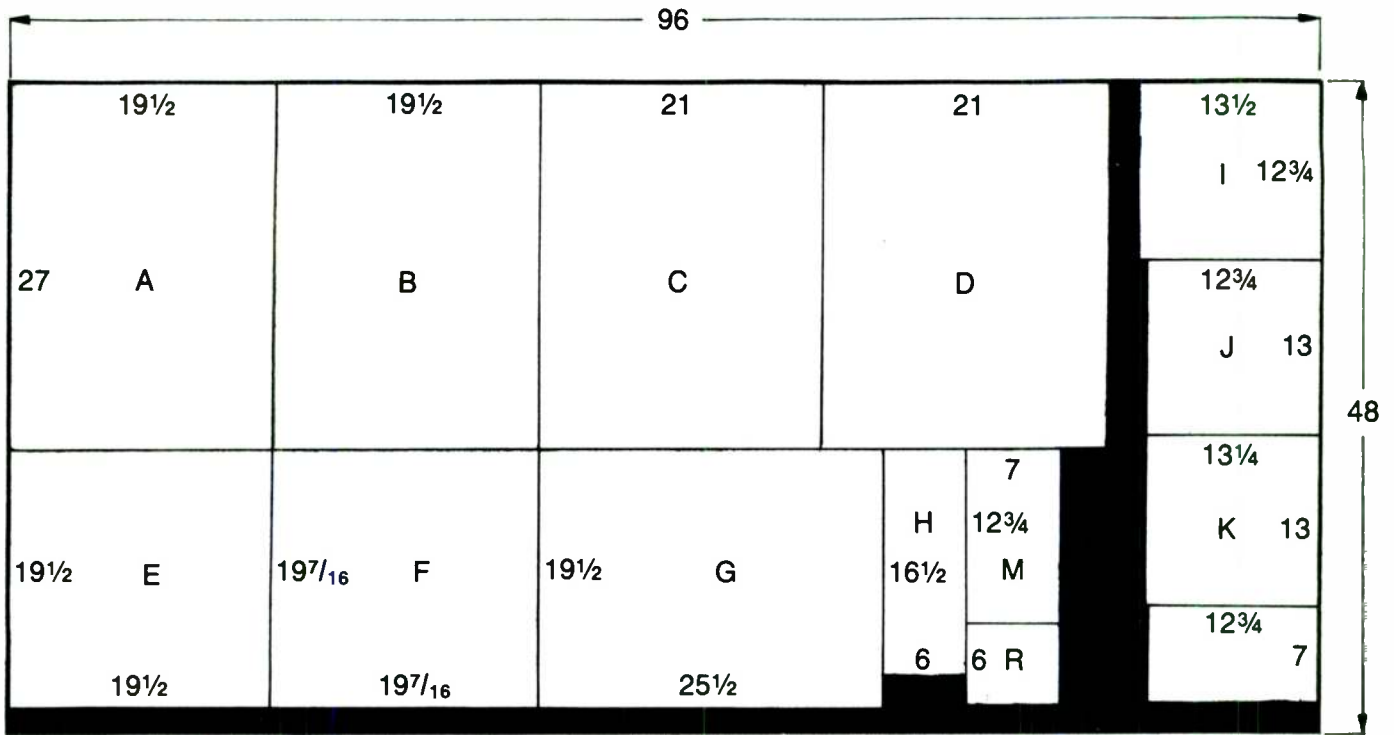


FIGURE 2: Particle board cutting guide. Note that there is little margin for error.

length for a folded and stuffed line may differ from that of a theoretically-determined length based on an unfolded, unstuffed line. For several months, I tried to devise a test box patterned after Mr. Cox's, but I had no success. I was unable to design a box that could accommodate my design's

14 right-angle bends at the proper distance ratios and with diminishing cross section. My hypothesis is that numbers of bends in the pipe, degree of bend (90°, 180°), and degree/distance of cross section reduction all interrelate with the driver and stuffing to vary real world response. The Cox

article draws aside another veil in the TL design process, but TL design remains somewhat Zen-like. Although my subwoofer follows only theoretical design principles, it "listens" very well. A properly designed test line, however, would doubtless allow design optimization.

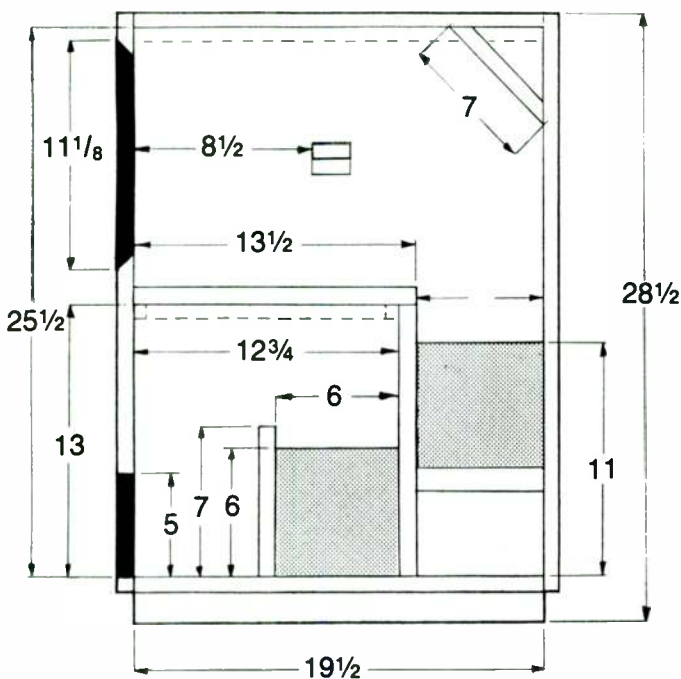


FIGURE 3: Right view of the system, panel A removed.

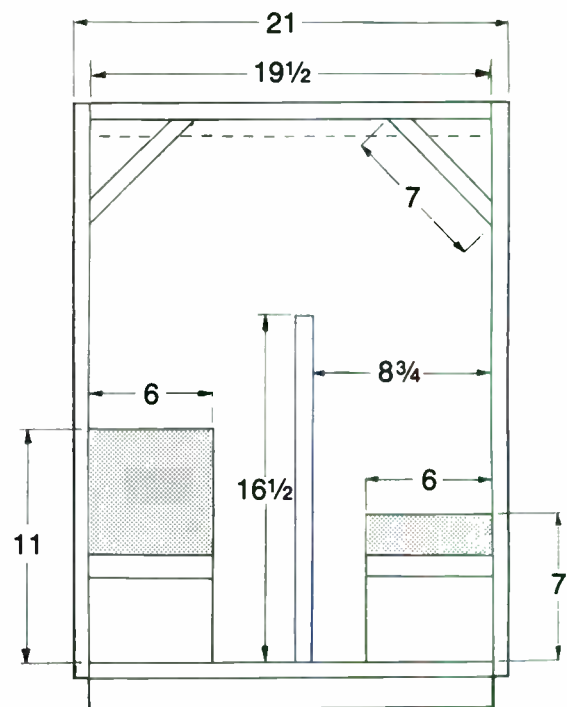


FIGURE 4: Left view with side B removed.

TABLE 1

MATERIALS LIST

- 1 sheet cabinet-grade particle board, 4' x 8' x 3/4"
- 1 box 100 2" #8 Phillips head wood screws
- 1 box 100 1 1/4" #8 Phillips head wood screws
- 2 Five-way binding posts
- 1 Peerless or PLI TA305F 12" polypropylene cone woofer, or equivalent (see text)
- 1 package Radio Shack grille cloth material (#40-1935)
- 1 roll 3/8" square open-cell, adhesive-backed foam insulation
- 1 pint flat black paint
- 1 tube latex caulking compound
- 1 8' two-by-four
- 1 21" square x 1/4"-thick smoked glass sheet for top (optional)
- 1 4' x 6' #232 Formica laminate (optional)
- 1 package Radio Shack fiberglass acoustic insulation (#42-1082)
- 2 1/2 lbs. long-fiber wool for stuffing
- 4' 14-gauge wire (or larger)
- 15-20' 3/4" square hardwood stock for cleats, battens and panel sound deadening
- 8 yds. nylon netting
- 1/2"- diameter dowel (about 6" long)
- small quantity of Velcro.
- 13 1/2" square piece of 1/2" thick particle board

As I noted in my earlier article (SB 1/85), because of the huge inductors necessary for the required low cross-over point, passive crossovers for sub-woofers are notoriously difficult to design and properly execute. If your full-range system has bass performance that reaches to 50 or 60Hz in a reasonably flat fashion, then an active crossover with 6dB/octave slopes at 60-80Hz will work well. If your speakers start to roll off an octave to an octave and a half further up, as is common with so-called "satellite" speakers of the small woofer variety (4-6 1/2"), a 100-125Hz crossover at 18dB/octave is probably best. It will prevent large signals from entering the small mid/woofers (which would otherwise increase distortion in the mid-bass), and simultaneously allow the system to image properly (its ability would be diminished by a higher crossover point).

BOARD CUTTING. If you are careful, you can cut all the panels from one 8' x 4' x 3/4"-thick sheet of cabinet-grade particle board. There is little margin for error. The cutting guide (Fig. 2) and Figs. 8, 9, and 10 illustrate that certain "scrap" becomes angle baffles N, O, P, Q and R.

Cut the first angle baffle N from the woofer cutout area before you make the circular cutout for the woofer. Cut angle baffle O from front/rear sub-divider K, as shown in Fig. 10. Cut angle baffles P and Q from front/rear main divider G, as shown in Fig. 9. Cut 45° tapers on both long dimensions of angle baffle M. You can taper the woofer cutout inward at a 45° angle, as shown in Fig. 7, if you want to surface-mount the driver; otherwise, rout a 1/2" wide x 3/8" deep recess around the periphery to flush-mount the driver. You should cut top panel F 19 7/16" square to allow easy installation/removal. Make sure all other panel dimensions are exact, and the panels are cut perfectly square.

ASSEMBLY. Use plenty of Tite-Bond or Elmer's carpenter's glue, and 2" #8 Phillips head screws, spaced 3-4" apart. You can drill and countersink each screw hole in one pass with a Stanley "Screwmate." A variable-speed drill with the proper size Phillips head bit will also be a major assembly shortcut. Certain areas of the assembly, such as battens, will require installation with #8 1 1/4" Phillips head screws. To ensure air-tightness, caulk

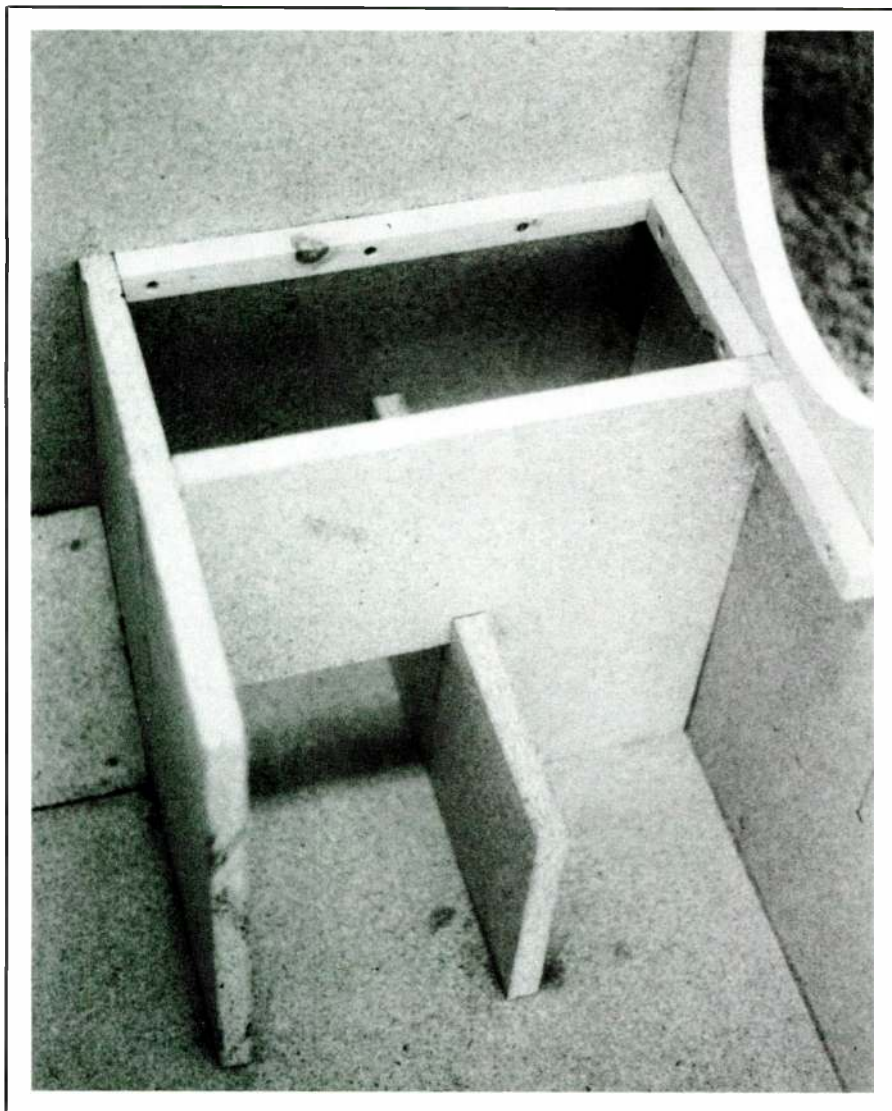


PHOTO 2: The subenclosure, showing panels J, K and L, angle baffle N, and two battens.

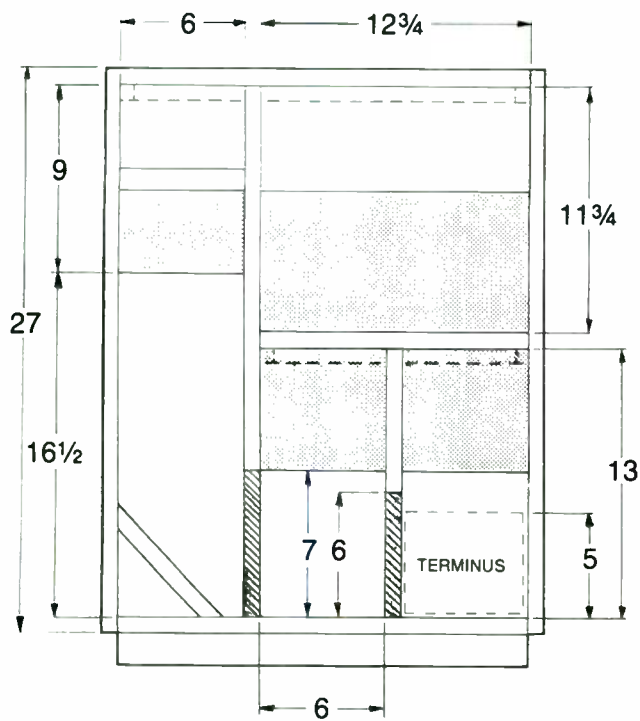


FIGURE 5: Front view, panel D removed.

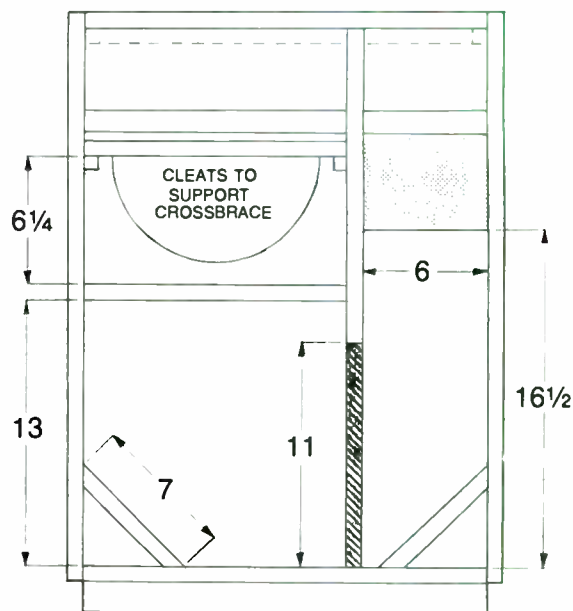


FIGURE 6: Rear view, back C removed.

all mating joints as you assemble the structure.

I found it easiest to first build the main cabinet (bottom E, front D, back C and side A), then assemble the subenclosure (panels J, K, and L) except for the top I, and install it as a unit in the main cabinet. Use plenty of screws and glue.

Install angle baffle N next, then install front/rear main divider G and angle baffle M. Install divider H, securing it to panel G and bottom E. For now, secure angle baffles R and O to bottom panel E only. Now attach angle baffles Q and P to panel G, as shown in Fig. 1, then install side panel B, making sure you screw and glue all

angle baffles at each mating surface.

To facilitate mounting the subenclosure and main enclosure tops, install the necessary 3/4" square-stock battens (dashed lines in the dimension drawings). Photo 2 illustrates the partially-battened subenclosure. Use the 1/4" #8 Phillips head screws for this step. Allow 13/16" between the top

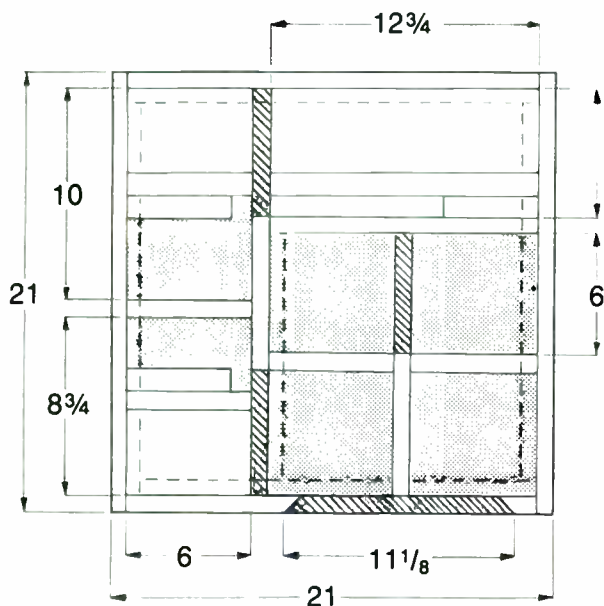


FIGURE 7: Top view with top F removed. Dotted lines indicate battens for mounting panels F and I.

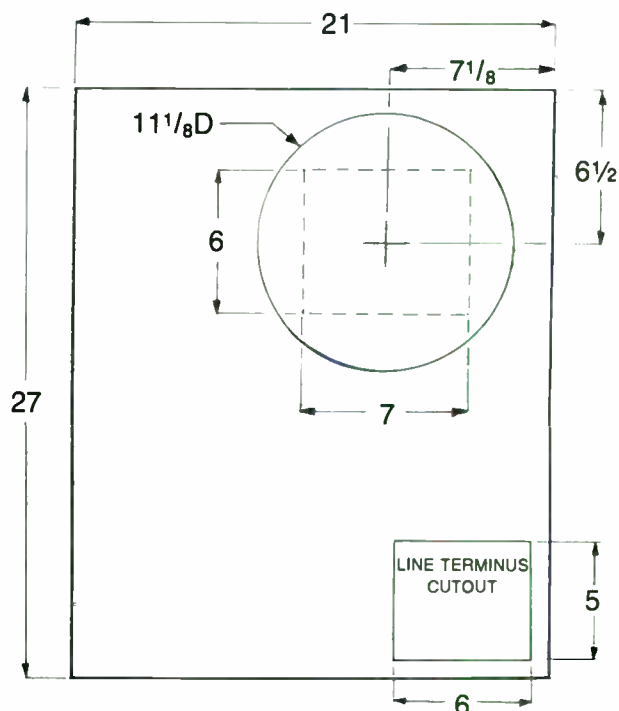


FIGURE 8: Dotted line in panel D shows where you must cut out baffle N before cutting the woofer opening.

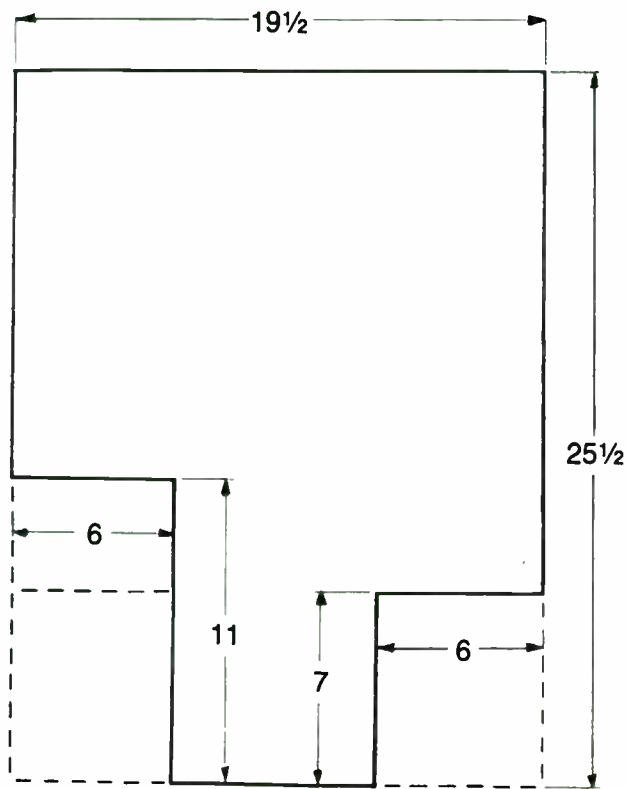


FIGURE 9: Dotted lines indicate where to cut front/rear main divider G and baffles P and Q.

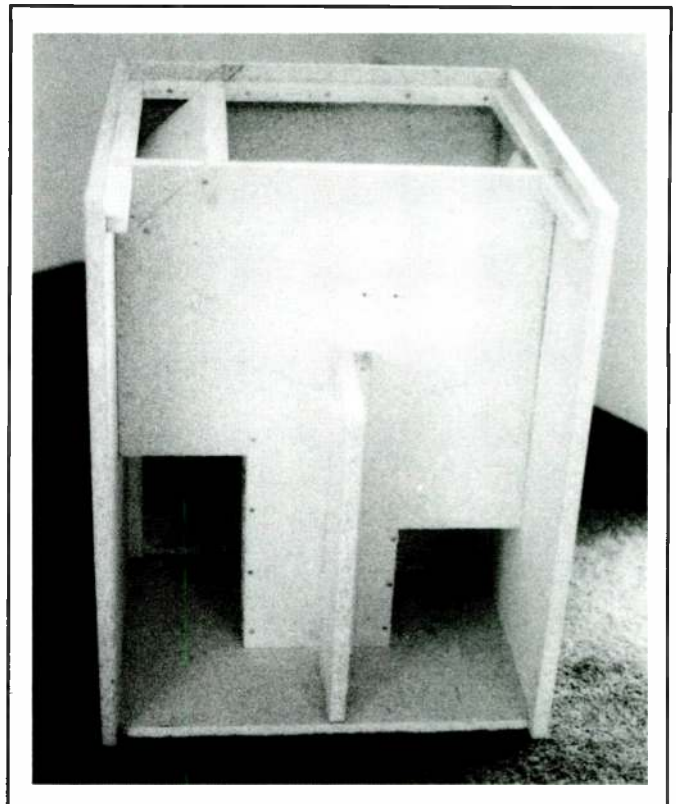


PHOTO 3: View of the main assembly, side B removed. Divider G, angle baffle M, baffle H, and 3 battens for top F are visible.

of the upper battens and the cabinet top to accommodate the compressed insulating foam, which you will install before stuffing the cabinet and installing the top flush with the cabinet edges.

Although for clarity reasons they are not shown in the drawings, I also in-

stalled a series of $\frac{3}{4}$ " braces diagonally along the inside of any panel area that resonated when I rapped it sharply (e.g., any area more than 10" square). This will result in a very solid and inert structure. I found it unnecessary to apply asphaltic undercoating to the line's interior, but you may wish to

apply such a coating as a resonance-limiting measure.

If you plan to experiment with a variety of woofers, attach the hardwood crossbrace in the woofer chamber to the $\frac{3}{4}$ " square cleats with screws only because you must remove it to allow for installation/removal of

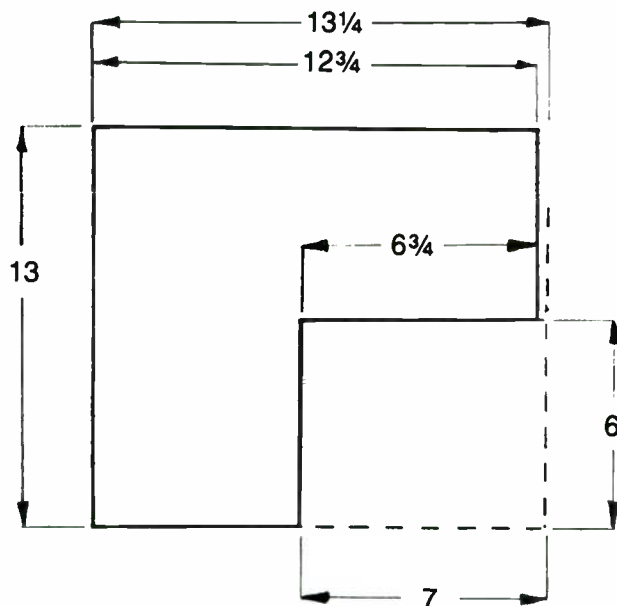


FIGURE 10: Slightly oversize the cut for front/rear subdivider K (as indicated) to allow baffle N to be cut to dimension.

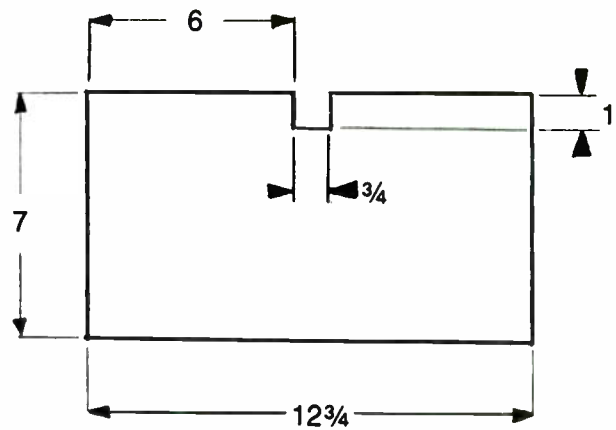


FIGURE 11: Left/right subdivider L.

the subenclosure top during stuffing changes. If you plan no changes, use the recommended amounts of wool in the chambers and seal the enclosure. This procedure, however, will preclude the fun of experimentation, which, after all, is what this hobby is all about.

FINISHING THE CABINET. The finish on my system, shown in *Photo 1*, is #232 Formica, a nicely figured matte surface walnut grain oriented vertically. Each of the four vertical surfaces, including the back, is covered with the laminate. The base, which is screwed and glued to the cabinet bottom, is made of 45°-mitered two-by-fours, each section of which is 19" long (see *Fig. 1* for detail).

I covered the top surfaces and base with several coats of flat black paint, and sanded lightly between coats. To hide the screw heads that secure the top in place, I also painted them flat black. I avoided unwanted resonances by placing soft, clear plastic standoff disks under the ¼"-thick smoked glass top.

The woofer lead-in wire is 14 gauge or larger, soldered to five-way binding posts which I then installed on the underside of the cabinet. After you mount the binding posts, caulk the mating surfaces to ensure air-tightness. Use insulated wire brads to firmly attach the wire to the cabinet's interior.

If you wish to downplay the high-tech look of an exposed driver, you can easily make a readily-removable grille assembly. I cut the frame for mine from ½"-thick particle board, 13 ½" square, with ⅜" 45° bevels routed on the vertical exterior edges to minimize diffraction effects. The woofer opening in the outer face of the frame is 11" in diameter, with a 45° flared bevel which you can easily cut with a saber saw. After you paint the entire frame flat black, cover it with acoustically-transparent Radio Shack grille cloth material, stapled or glued to the back side of the grille frame. You can make the finished grille "float" away from the cabinet face by inletting four ½" holes ⅜" deep, approximately 1½" from the corners on the back of the grille frame. Then, glue ⅞"-long dowels in the holes. Tip the ends of the dowels (after the flat-black treatment) with circles of Velcro hook material, and contact-cement into place. These will mate with Velcro pads, which attach to the face of the cabinet face in the same manner. The finished assembly, including the thick-

ness of the Velcro, will hold the grille out from the cabinet just a bit more than ¼".

To cover the line terminus on the lower right cabinet face, cut ¼" grid wire "hardware cloth" about 1" over-size. Then bend a ½" wide edge of each side 90° forward. Recess the assembly about ½" into the opening, and staple into place. This rigid backing will support a piece of 3/8"-thick acoustic foam cut to size, effectively hiding the stuffing material. The foam will in no way degrade the sound of the system.

LINE STUFFING. To minimize standing waves and reflections in the area immediately behind the woofer, staple or glue Radio Shack fiberglass to the woofer chamber interior surfaces: a 1"-thick layer to both side walls, underside of top F, and upper surface of subenclosure top I; two layers to the upper section of the main cabinet back and angle baffle M.

Before I summarize the stuffing process, detailed in my earlier article, you must know the only way to get the best sound from this subwoofer is to use long-fiber wool as your stuffing medium. Dacron polyester "fluff," which is widely available, is audibly a distant second, but it can be used as an economical filter. To get similar stuffing results, use approximately a half-pound more of the Dacron (48 oz.) than the amount of wool.

The best way to prepare the stuffing is to wrap it in a material called "netting," available for a nominal price at any fabric shop. The material is nylon and quite stiff, so there are no deterioration or settling problems.

I designated nine "chambers" from the beginning of the line to the end, and calculated the corrected volumes for each of the chambers at a rate of ½ lb. wool/cubic feet of chamber space. Then, I thoroughly teased out the wool with a comb, and wrapped it in appropriately-sized netting which I whip-stitched at the ends and along one side to prevent it from unrolling during installation.

To give you an idea of how much netting to use, the first chamber (or woofer chamber) requires two equal packages of wool because of the cross-brace—one for below the brace and one for above it. The total amount of wool required is about 14 oz., equally divided and teased out. Make sure you tease the wool thoroughly. A teasing comb, available from any drug store's

beauty department, is a real time-saver.

The woofer chamber is 19½" deep front to back, so cut a 20"-wide piece of netting about 4' long for each of the two packages. Put 7 oz. of evenly-distributed teased stuffing on each spread-out piece of netting, then roll each strip into a spiral shape so it resembles a fluffy cinnamon roll. After whip-stitching the spiral, make a trial installation in the cabinet, primarily to make sure the wool package is large enough to fill up half the chamber. You may have to re-roll the package if it is too tightly wrapped.

When filling the line, fill the subenclosure first, then install the subenclosure top. To ensure air-tightness, place ⅜"-square foam weatherstripping along the top edges of the subenclosure chambers before you install the top with 1¼" #8 Phillips head screws (spaced every 3" or so). Pre-drill all holes for the subenclosure top.

Reading backwards from the chamber at the "end of the line," wool stuffing amounts are:

Chamber #	Wool/Oz.
9	2
8-6	2¼
5	3¾
4*	4¼
3	4¼
2	4½
1 (woofer)	14 (2 eq. pkg.)

*top front/rear horizontal area to left of woofer chamber.

Before you install any of the stuffing packages, spray them thoroughly with a good moth-proofer; otherwise, in time, the sound could change markedly.

Once you install the weatherstripping on the requisite horizontal edges at the top of the cabinet (battens, angle baffles, and front/rear main divider), install top F (with screw holes pre-drilled and countersunk every 3-4") with #8 1¼" Phillips head screws. Draw down the screws evenly until the top is flush with the cabinet edges.

WOOFER INSTALLATION. Depending on your preference, you may either surface or flush-mount the woofer. You will need a router for flush-mounting, but it will look better. Surface-mounting is simpler, but some builders claim diffractive effects are audible, although I have never actually heard a difference. To my ears, the only time mounting makes an audible

difference is when you rear-mount a woofer on a thick baffle.

As a precautionary measure, to prevent any wool stuffing from making contact with the back of the woofer cone and degrading the sound, cut a piece of the netting material to cover the openings in the woofer frame. Tape into place with masking or plastic electrical tape.

You have several mounting options. One method is to glue the driver into place with silicone glue, allowing it to dry for at least 24 hours while the cabinet is on its back. For heavier drivers, such as the Peerless, I prefer to use the $\frac{3}{8}$ " foam insulation at the edge of the woofer cutout, and then secure the woofer with T-nuts and bolts.

The latter mounting method requires careful pre-drilling preparation, but it is particularly secure. Make sure, however, you do not over-tighten the bolts because the stamped-steel frame can warp, possibly causing voice coil misalignments. Draw down the bolts sufficiently to get good compression (and therefore sealing) of the insulating foam. With the cabinet on its back, put the woofer face down on the baffle and pull out enough lead wire to comfortably reach the speaker terminals. Solder them in place, making sure the polarity is correct, then install it according to your preference.

HOW DOES IT SOUND? Currently, my system is tri-amped, using a DeCoursey electronic crossover with 18dB/octave slopes at 2kHz and 100Hz. The woofer signal is summed. Satellites are extremely slender towers, configured according to Joseph D'Appolito's two-way, three-driver design, but transmission-line loaded. My mid-bass drivers are Audax 5 $\frac{1}{4}$ " HD13B25H4C12s, and the tweeters are flat-flange Dynaudio D-28 AFs. Power is Hafler throughout, and the primary signal source is by compact disks on a Magnavox/Philips player.

Although the entire musical spectrum reproduces with great power, clarity, and depth of image, the low bass is notably fine. Anything by Michael Murray (pipe organ) on Telarc is a source of sustained deep bass, with extraordinary fundamentals. Drums, too, make good tests for deep bass. Sheffield's "Drum Album" is designed for testing purposes, and the orchestral bass drum on Telarc's "Star Tracks" album has powerful percussives at the low threshold of hearing.

Whatever your listening preferences are, you'll find that building a TL subwoofer (or two) like mine will greatly enhance your listening pleasure. Please let me know how yours turn out. If you have any comments or questions, please write to me, c/o *Speaker Builder*.

SUPPLIERS:

PLI drivers:
Madison Speaker Components
8608 University Green
Box 4283
Madison, WI 53711

Long-fiber wool:
J. Ebbert
431 Old Eagle School Road
Strafford, PA 19087

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ABOUT THE AUTHOR

Craig Cushing is chairman of the English/Social Science Department at New Hampshire Technical Institute in Concord, NH. Along with his supervisory duties, he teaches composition, a variety of literature courses, and technical and engineering communications. After having flirtations with a variety of speaker systems, Mr. Cushing admits to being a transmission line fanatic.

au·dio·phobe / od-ē-ō-fōb / n 1: An audio hobbyist with an all-consuming fear that he does not possess this month's "IN" equipment, the most expensive equipment or the least available equipment. 2: Someone who uses music as a medium by which to evaluate equipment, usually manifested by an extreme dread of having to listen to music without talking or getting up to check something in the system. 3: Someone who would freely consider spending twice the value of his record collection on a power amplifier. 4: Someone who loves to talk about audio but never expresses an opinion of his own, all discussion being based on what he has read, not on what he has heard.

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As an evolutionary development with revolutionary implications for amplifier evaluation standards, this latest David Hafler circuit may be the most important power amplifier event in recent years. Described as **EXCELINEAR**, it demonstrates previously unattainable levels of amplitude, phase and transfer characteristic linearity. For the first time, an amplifier is so accurate, it can be directly compared with the classic zero-distortion reference: a straight wire. In a differential arrangement the straight wire and the amplifier are fed the same signal, with the input signal to the amplifier adjusted for an overall gain of unity. This subtracts the input from the output of the amplifier; the difference, or residual, is the total distortion content.

In this test the speaker reproduces *only the distortion*. The test surpasses conventional measurements in its sensitivity and precision. The test is definitive with any program content—music, sine waves, white or pink noise. It justifies some unquantifiable 'golden ear' assessments of differing amplifier sounds. Amplifiers which do not perform as well on this test are, quite simply, less accurate.

In a differential comparison with a straight wire the XL-280 is the first amplifier to achieve a null at all audio frequencies which taxes your perception. Its EXCELINEAR design reduces all distortions to inaudibility—even those which have not yet been identified or quantified. Over most of the audio band, the XL-280 achieves nulls of 60 dB or more. Other amplifiers rarely exceed 40 dB.

As delivered, the XL-280 has exemplary harmonic and intermodulation distortion specifications comparable to the current Hafler DH-220 amplifier. It includes a phase correcting circuit which enables individual adjustment for the differential null. This has been set at the factory for optimum interfacing with a 'standard' loudspeaker load. Different speaker designs present varying loads to the amplifier which can introduce minute phase and amplitude related variations. This is one reason why all amplifiers do not sound the same, and why the sound of any one may vary on different speakers.

For the purist, the XL-280 includes the capability for 'tweaking' each channel to optimally match (null with) your speaker. This range of adjustment is entirely within the XL-280's printed specifications, and is of significance only to 'golden ears'. But it can be performed without test instruments, with patience, in quiet surroundings. It does require very precise adjustment of the amplifier's input level. The procedure is described in the XL-280's manual, and we will supply details to those who request them. Comparing 'nulls' of other amplifier designs is sure to provide grist for erudite discussion.

The XL-280 appears similar to a DH-220, but is an inch wider. It retains the traditional Hafler full complementary circuit driving MOSFET outputs. It has J-FET input stages for lower distortion, lower noise, and improved thermal stability. We've eliminated the conventional input capacitor to reduce low frequency phase shift. The output choke has vanished to improve high frequency phase characteristics, yet excellent stability has been retained. Overall feedback has been reduced about 30dB. This further reduces its already low TIM distortion. And you can switch to bridged mono operation when you need a real powerhouse.

But the biggest changes are to separate power supplies for each channel, and in the output stage. Only the transformer is common to the two channels. Power supply capacitance is up 56%. There are separate high and low voltage supplies on each channel. And we've added another pair of the same rugged MOSFETs on each side. The results are improved channel separation and greatly increased power into low impedance loads. Evolutionary—yes. But of revolutionary significance. And the price goes up only \$100! Check with your dealer now.

XL-280 STATISTICS

Rated Power: 145 watts into 8 ohms, each channel, both channels driven, at less than 0.05% THD, 20-20 kHz, or 0.04% IM.

Power Output Capability:

400 watts continuous into 8 ohms in mono, 20-20 kHz.
180 watts each channel into 8 ohms, clipping @ 1 kHz.
200 watts each channel into 4 ohms, 0.1% THD, 20-20 kHz.
280 watts each channel into 4 ohms, clipping @ 1 kHz.
360 watts each channel into 2 ohms, clipping @ 1 kHz.
325 watts each channel into 1 ohm, clipping @ 1 kHz.

Frequency Response: 0.1 Hz to 500 kHz, ± 3 dB @ 1 watt.

Slew Rate: 75V/ μ s; 10 kHz, 60 volts p-p square wave.

Damping Factor: > 180, 20-20 kHz into 8 ohms.

Phase Shift: Less than $\frac{1}{2}$ degree, 20-20 kHz.

Maximum Output Current: 20 amps RMS.

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AN INTRODUCTION TO FREQUENCY RESPONSE AND LMP

BY RALPH GONZALEZ

In this article, I present an introduction to the phase versus frequency and magnitude versus frequency responses of filters as they relate to loudspeaker system design. In addition, I will offer a BASIC computer program (LMP) which allows you to model driver and crossover responses to produce a graph predicting the frequency response of your loudspeaker. You may obtain a suitable crossover configuration from another source (such as Robert Bullock's excellent series beginning in SB 1/85), and use this program to determine whether the drivers you have chosen will produce the desired results, or whether changing the crossover values and cabinet design will yield improvements. This trial-and-error method is also useful when adapting existing two and three-way crossover formulas to the design of systems for four or more drivers.

First, we need to notice the response behavior in some moving-coil drivers is quite complex, due in part to unequalizable impedance variations at low frequencies and to sudden deviations from pistonic motion at high frequencies. The model used by LMP (Loudspeaker Modelling Program) is a relatively simple one and, at present, no evidence guarantees all drivers can be modelled well enough with LMP to yield a useful prediction of any multi-driver system. In my opinion, however, a well-chosen LMP model will allow you to improve upon the common practice of using "stock" crossovers without consideration of driver responses. As I will mention at the end of the article, listening tests and/or acoustic measurements may be useful to further improve your results.

Part I treats basic theory, and describes several important loudspeaker response features which can be modelled with LMP. Part II describes more of these features, and explains how you can model them with LMP, and how to draw conclusions from the results. Then I will discuss two instructive applications.

FREQUENCY RESPONSE. A loudspeaker driver translates an electrical input signal into an acoustic output signal. For our purposes, this driver is a linear system which can be characterized by the output signals it produces in response to sinusoidal inputs of various frequencies. A sinusoid is a periodic function which can be characterized by its frequency (f), phase angle (a), and magnitude (m), as shown in Fig. 1. Hence, we can describe a loudspeaker driver by the effect it has on the phase angle and magnitude of sinusoids over the frequency range of

interest. (Ogata¹ gives a good introduction to the mathematics behind frequency response analysis.)

Figure 2 is a graph of the phase angle and magnitude of a typical moving-coil driver's output relative to those of sinusoidal inputs over the audible frequency range. This is the loudspeaker's frequency response graph (also called a logarithmic plot, or Bode diagram). Most manufacturers omit the phase angle plot from their "frequency response curves." On this graph, frequency is plotted logarithmically from 20Hz (20 cycles per second) to 20kHz (20,000Hz). A measure of acoustic magnitude is the Sound Pressure Level (SPL), which I have normalized in this instance so a magnitude of 1, or SPL of 0dB (decibels), occurs at 300Hz. Note that for a magnitude m ,

$$\text{SPL(dB)} = 20 \log m \text{ (logarithm base 10),}$$

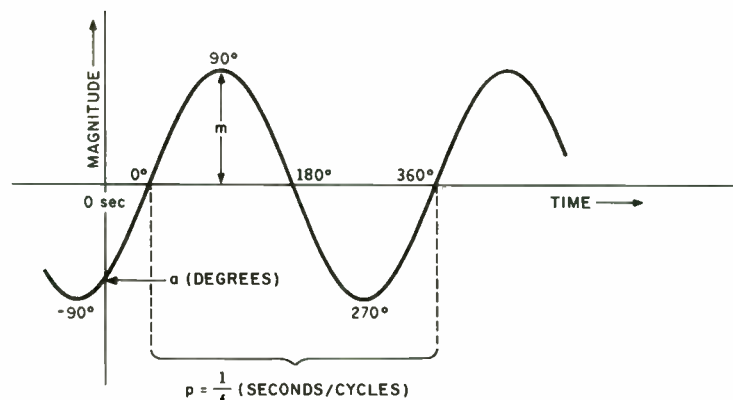


FIGURE 1: A sinusoid of period p , frequency f , phase angle a , and magnitude m .

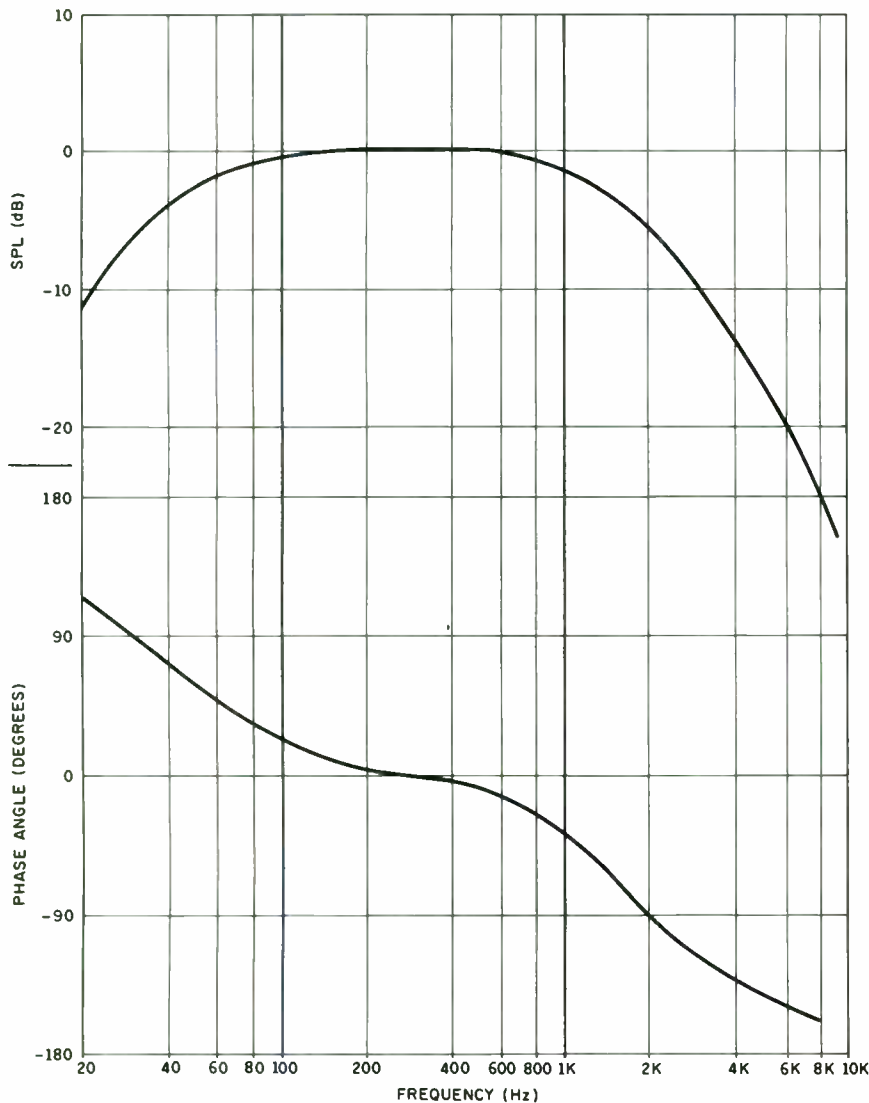


FIGURE 2: Frequency response of a hypothetical moving-coil loudspeaker.

so that $\frac{1}{2}$ magnitude corresponds to -6 dB. Also, notice that for continuous sinusoids, a phase angle of -180° is indistinguishable from $+180^\circ$. Hence, we need only plot angles between -180° and $+180^\circ$. The loudspeaker in Fig. 2 reproduces a 300Hz sinusoid almost perfectly, but alters the phase angle and magnitude of a 2kHz signal, as shown in Fig. 3.

As *minimum phase* filters, individual loudspeaker drivers and electronic filters exhibit a relationship between the shapes of their magnitude and phase angle graphs: for a given magnitude response, these filters have the least possible variation in phase angle. For example, a minimum phase filter with a flat magnitude response will have a phase angle of 0° everywhere. (Most—not all—loudspeakers using two or more drivers in combination are non-minimum phase, exhibiting flat

amplitude responses but non-zero phase angles about their crossover frequencies.)

The minimum phase condition is illustrated in Fig. 4(a) for a *first-order low-pass* electrical filter, whose output magnitude gradually decreases at frequencies above the *corner frequency* (f_c), and whose output phase angle goes to -90° at high frequencies. The graph of a first-order *high-pass* filter is shown in Fig. 4(b).

The magnitude of a *second-order* filter may peak at its corner frequency if the filter is underdamped, or it may be overattenuated at the corner frequency if the filter is overdamped. The response of a second-order low-pass filter is shown in Fig. 5(a) for various values of the *damping ratio* (d). Note the ultimate rate of decrease in magnitude of the second-order filter at high frequencies is 12dB per octave (per

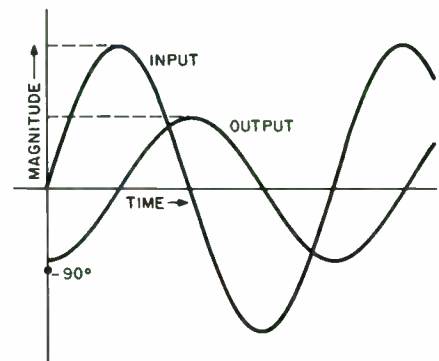


FIGURE 3: Output of the loudspeaker shown in Fig. 2 at 2000Hz.

doubling of frequency), twice that of a first-order filter. Also, its phase angle reaches -180° at high frequencies. The response of a second-order high-pass filter is shown in Fig. 5(b).

First- and second-order filters can be *cascaded* to obtain a higher order filter whose order, dB magnitude, and phase angle will be the sum of those of the first- and second-order filters of which it is composed. In particular, note that a second-order low-pass filter with $d = 1$ can be obtained by cascading two first-order low-pass filters with the same corner frequency. An n th order high- (low-) pass filter will exhibit a magnitude response that rolls off at 6n dB/octave below (above) its corner frequency, and a phase response which goes to $90n^\circ$ ($-90n^\circ$) at low (high) frequencies.

How does all this apply to loudspeaker modelling? A moving-coil driver often can be modelled as a second-order *bandpass* filter, exhibiting second-order rolloffs at both the top and bottom of its working frequency range,^{2,3} as shown in Fig. 2. Crossover networks also consist of linear filters, typically producing first-, second-, third- or fourth-order high- or low-pass responses. (Actually, the theoretical on-axis sound pressure response of an ideal moving-coil driver has an ultimate first-order high-frequency rolloff, while the acoustic power response has a second-order rolloff due to increasing directivity³ (p. 26). Practical diaphragms depart from the ideal piston due to high-frequency breakup. A second-order model for the on-axis response is more flexible and can approximate many rolloff shapes—including the first-order rolloff).

Since a loudspeaker driver cascaded with its crossover filter (henceforth called a "driver/crossover section") is still a linear system, you can calculate

the response of a multi-driver system by summing the responses of the individual driver/crossover sections. Their relative phase angles and magnitudes determine the phase angle and magnitude of the total system output at each frequency. For example, if two driver/crossover sections each reproduce a sinusoid of a particular frequency with the same phase angle and magnitude, the summed response will be a sinusoid of double the magnitude (6dB higher SPL). On the other hand, if the two drivers reproduce this sinusoid with equal magnitude but with a 180° phase disparity, the summed response will be of zero magnitude (infinitely low SPL) at this frequency.

Most crossover networks are designed as though the drivers to be used are not bandpass filters, but rather have perfectly flat responses over all frequencies. In practice, drivers whose rolloffs are several octaves above and/or below their crossover frequencies usually permit the crossover to function as intended.

Problems arise when a driver is being crossed over near the upper or lower limit of its working frequency range, as is very often the case. The driver's inherent second-order filter is now cascaded with the crossover filter, to produce a higher-order rolloff than intended. This may severely alter the desired frequency response in the crossover region(s) of a loudspeaker containing two or more drivers. (Nelson Pass discusses and gives examples of this problem in *SB 2/82*.)

EXAMPLE. Suppose you have a two-way system with a high-quality 6½" woofer and 1" dome tweeter, crossed over at 2kHz. The crossover you chose was designed to produce second-order low and high-pass responses for the woofer and tweeter (respectively), each with a damping ratio of 1.0 (a Linkwitz-Riley second-order crossover) and corner frequency of 2kHz. The tweeter's polarity is inverted relative to the woofer (as is recommended for the second-order crossover), so you must subtract 180° from the phase response curve of a second-order high-pass filter to obtain the phase response of the tweeter's crossover section (see "Polarity Inversion"). *Figure 5* indicates that at 2kHz, both driver/crossover sections should be 6dB down in magnitude (½ magnitude) and should have a common phase angle of -90°. This will result in the drivers summing perfectly to unity magnitude at 2kHz, yielding the desired flat frequency re-

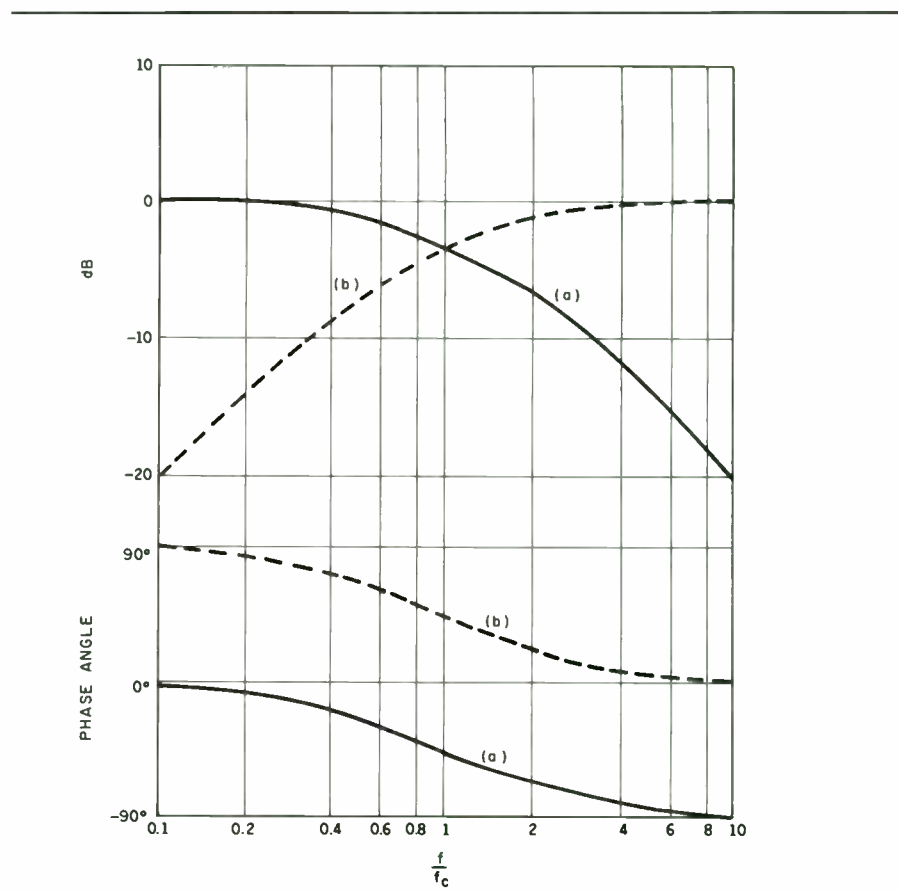


FIGURE 4: First-order low-pass (a) and high-pass (b) filters.

sponse through the crossover region.

Unfortunately, this assumes the drivers have no rolloffs of their own. The tweeter is likely to exhibit a second-order high-pass response of its own with a corner frequency around 1kHz, while the woofer is likely to exhibit a second-order low-pass response with a corner frequency around 4kHz. At 2kHz, this additional filtration will contribute about -45° to the woofer's phase response and about +45° to the tweeter's phase response, and may also somewhat reduce each driver's output (depending on the respective damping ratios). In addition, suppose both drivers are mounted on a flat baffle so the woofer's diaphragm is about 1" behind the tweeter's. This relative time delay contributes another -55° to the woofer's phase angle at 2kHz (see "Time Delay"). At 2kHz, the total 145° interdriver phase disparity will lead to a 10dB dip in the system magnitude response.

Two general methods avoid the problems introduced by driver rolloffs: (1) the rolloff may be partially corrected in some instances; (2) the rolloff may be incorporated into the crossover design so that the driver/crossover sec-

tion—not the crossover alone—has the desired low- or high-pass response. LMP will help you predict the need for, and success of, these methods.

DRIVER MODELLING. LMP allows you to describe each driver as a linear bandpass filter with second-order high- and low-frequency rolloffs. The diaphragm of most practical drivers is not moving like the theoretical piston but is "breaking up" at high frequencies (indicated by a sudden deviation of its off-axis curves.) I believe a well-chosen second-order approximation is useful in most of these cases (see "Fourth-Order Rolloffs" in Part II), and is an improvement over the common practice of ignoring the rolloff entirely. Although a woofer in a vented cabinet is usually better described as a third- or fourth-order high-pass filter, this low-frequency corner is usually far enough from the crossover frequency to be safely ignored.

To determine the nature of your driver's inherent response, start with the manufacturer's frequency-response curve. Comparing with the low-pass filter in *Fig. 5(a)*, choose the damping ratio which produces a mag-

nitude curve closest in *shape* to that of the high-frequency response of your driver, taking careful note of the spacing of the SPL and frequency scales. For the chosen damping ratio, find the magnitude at $f/f_c = 1$ "in", Fig. 5(a). Now find the frequency at which your driver has the same magnitude relative to the flat portion of its response. This is the corner frequency of the high-frequency rolloff of your driver. For the example in Fig. 6(a), it appears the damping ratio of the high-frequency rolloff is .7 and the corner frequency is 3kHz.

For closed-back tweeters and mid-ranges, the same procedure may be used—in conjunction with Fig. 5(b)—to find the corner frequency and damping ratio of your driver's low frequency rolloff. The tweeter in Fig. 6(b) has a low-frequency rolloff at 1.7kHz with a damping ratio of about .8. For open-backed woofers and midranges, you must use a response curve for your driver in the enclosure you will employ. Alternatively, you may calculate the closed-box resonant frequency and system Q from the driver parameters f_s , V_{as} , and Q_{ts} ([Radio Shack part #62-2309] gives formulas and charts for this. Note that:

$$f_{CB}/f_s = Q_{CB}/Q_{TS}$$

The corner frequency is simply f_{CB} —the closed-box resonant frequency—and the damping ratio may be obtained from the system Q (Q_{CB}) by calculating:

$$d = \frac{1}{(2 \times Q_{CB})}$$

CROSSOVER ALTERNATIVE. A driver's inherent second-order rolloff is indistinguishable from an electrical second-order crossover filter, enabling an interesting crossover configuration. Calculate the corner frequency and damping ratio of your woofer's high-frequency rolloff. Calculate the high-pass crossover network required by the tweeter for a *second-order* crossover at this corner frequency. (Recall that the tweeter's polarity should be inverted for a second-order crossover.) If you are lucky (see suggestion #6 in "Trial and Error," in Part II), the damping ratio of the woofer's rolloff will be similar to that of a second-order low-pass crossover filter ($d = .7$ to 1.0), and the woofer may be used without any electrical filter in the completed two-way system. In Part II, you'll find an example in "Executing LMP."

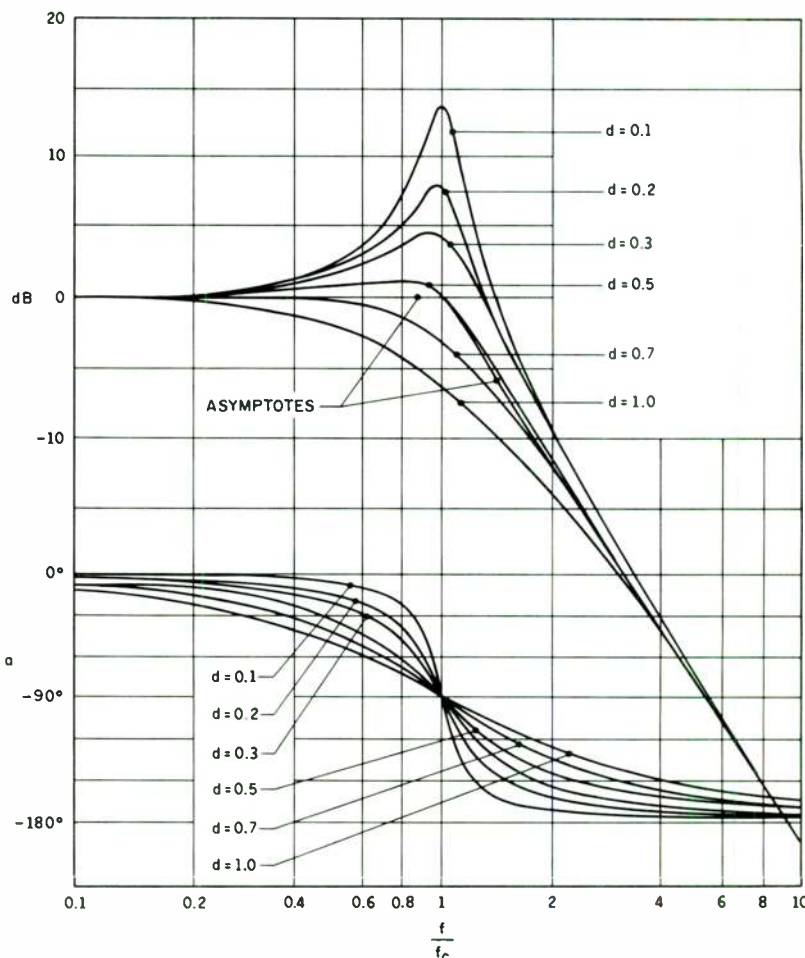


FIGURE 5a: Second-order low-pass filter (Katsuhiko Ogata, "Modern Control Engineering," ©1970, p. 386. Adapted by permission of Prentice-Hall, Englewood Cliffs, NJ).

As an alternative, you may try a first- or second-order electrical filter on the woofer at its corner frequency and a third- or fourth-order filter on the tweeter, to match the third- or fourth-order rolloff of the woofer cascaded with its electrical filter. Here, best results will be obtained if the woofer's damping ratio is near $d = 0.5$. LMP can tell you how successful these methods will be for your particular drivers.

Unfortunately, many woofers have irregular responses and narrowing dispersion near their high-frequency roll-offs which cause a problem with the above application. If you place the crossover frequency about an octave below the woofer's corner frequency, you can experiment with second- or third-order crossovers, with only a first- or second-order (respectively) electrical filter attenuating the high frequencies of the woofer. At the crossover frequency, the woofer's second-order rolloff may approximate a first-order rolloff whose corner frequency is the crossover frequency.

A few more notes on this method: (1) you may apply the same techniques to a tweeter's *high-pass* filter, if you ensure the electrical filter is of a high enough order and at a high enough frequency to adequately protect the tweeter; (2) this technique assumes the drivers' cones are aligned (see "Time Delay") since you are attempting to *use*, rather than correct for, a driver rolloff.

POLARITY INVERSION. It is often necessary to invert the polarity of one of the drivers in a loudspeaker system. This involves interchanging the connections to that driver's plus and minus terminals. Polarity inversion, or "phase inversion," does not affect the magnitude versus frequency response of the driver, but it increases (or decreases—same effect) the phase angle by 180° at all frequencies (Fig. 7).

TIME DELAY®. If two or more drivers are mounted on a flat, vertical loudspeaker baffle, it is likely the distance from the listener to the driver's

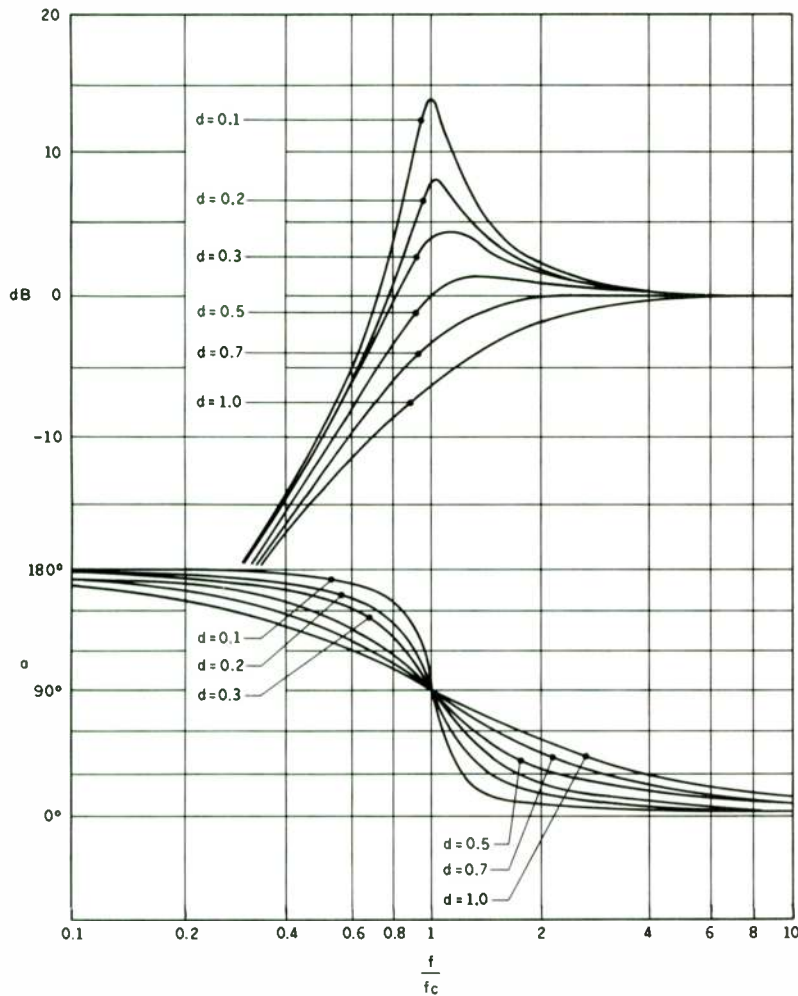


FIGURE 5b: Second-order high-pass filter (Katsuhiko Ogata, "Modern Control Engineering," ©1970, p. 386. Adapted by permission of Prentice-Hall, Englewood Cliffs, NJ).

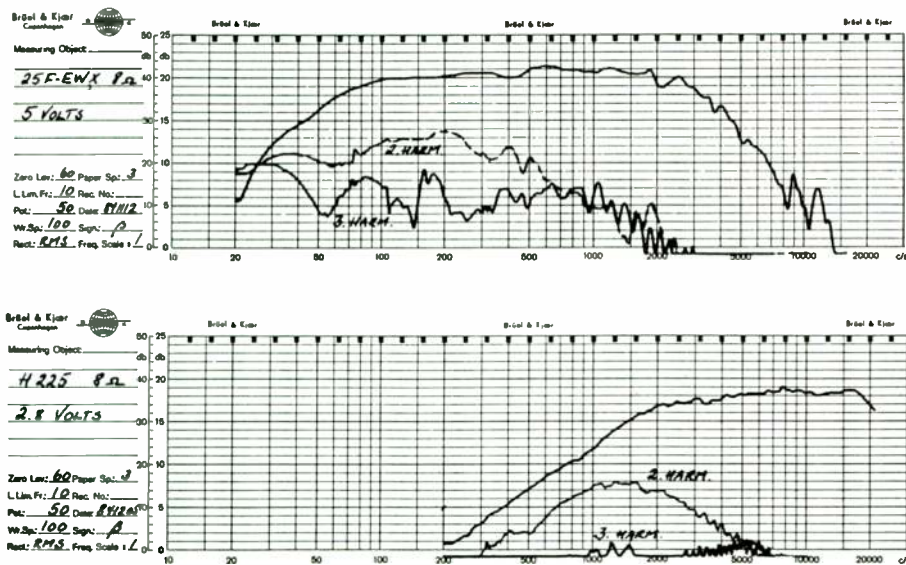


FIGURE 6: Sample of manufacturer's frequency response curve: (a) SEAS 25F-EWX in 28 liter closed box; (b) SEAS H225 in 0.6m by 0.8m baffle. Measurements made at 0.5m distance, distortion curves raised 20dB.

diaphragm is different for each driver. For example, the diaphragm of a 1" dome tweeter is about 1/4" in front of the baffle, whereas (most of) that of an 8" woofer may be 1" behind the baffle. If we assume the listener is on-axis with the enclosure, this 1/4" relative displacement—or .1 millisecond time delay—will cause an additional 120° interdriver phase shift at 3500Hz, based on a speed of sound in air of 13,500"/sec. This is enough to produce a 6dB dip in the system's magnitude response, with an otherwise ideal second-order crossover at 3.5kHz.

Think of a time delay as a non-minimum phase filter which makes the driver's phase angle more negative with increasing frequency without affecting its magnitude response (Fig. 8). (These curves would be straight if not for the logarithmic frequency scale.) Note that a given time delay causes little phase shift at low frequencies where the period (Fig. 1) is much longer than the time delay.

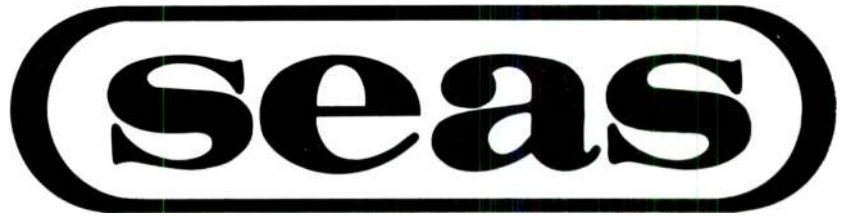
If the tweeter in the above example is situated above the woofer on the baffle, you could avoid the time delay by slanting the front baffle back (or tilting the entire enclosure back) or placing the woofer on a "step" on the baffle. (Place acoustic foam between the tweeter and this step to avoid reflections.) Another approach, used occasionally (particularly in active systems), is to electrically delay the tweeter's signal to correct the interdriver time delay³ (pp. 183, 191, 200).

On the other hand, you may use an existing (or deliberately created) time delay to partially correct a driver's phase shift at rolloff, and test the results with LMP. For example, you may place the woofer diaphragm an inch or two closer to the listener than the tweeter, to correct the phase shift of the woofer's natural rolloff, over a limited frequency range. This is only an approximate correction because (1) the phase shift from the woofer's time "lead" (Fig. 8) only corrects that of a second order filter (Fig. 5(a)) over a limited range, and (2) no correction of the woofer's magnitude response is made.

To determine your system's interdriver time delays, assume a 0" depth displacement for the tweeter and measure the displacement of the other drivers relative to the tweeter. Use a positive displacement for a driver whose diaphragm is in front of the tweeter and a negative displacement for one behind the tweeter. When measuring the displacement of a

Continued on page 24

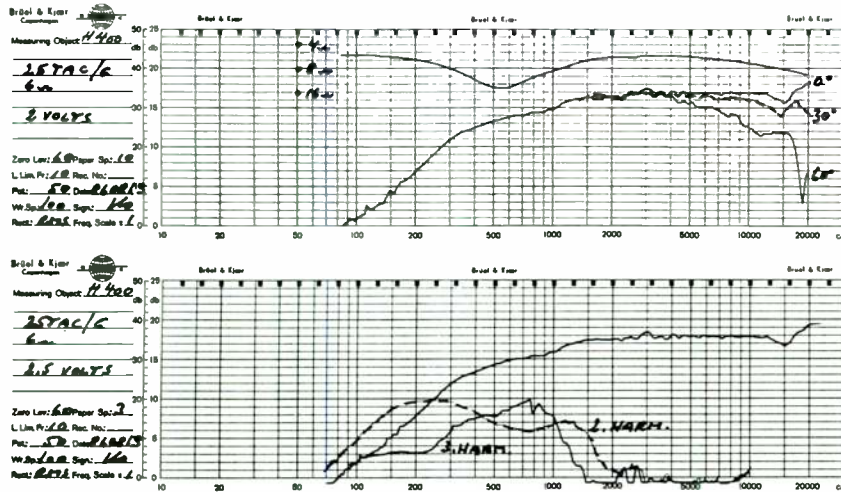
SUPERIOR LOUDSPEAKERS from NORWAY



You will find SEAS drivers in speaker systems by some of the most prestigious names in audio. With innovation tempered by years of experience, our conservative application of the newest materials has produced a series of new domes, new heavy magnet (40+ ounces) woofers, and new dual voice coil woofers.

Some of these are so new that data sheets are not yet available, but an example is the H-400 tweeter. Its 1" aluminum dome is mounted in a soft polyamide surround, and is protected by a fine mesh screen. A damped vented pole piece and posterior tuned chamber enable a low free air resonance of 660Hz.

H-400 Impedance: Response on and off axis; and Distortion (up 20dB).



SPECIFICATIONS	
Recommended freq. range	2000-25000Hz
Nominal power (DIN 45573)	50W*
Operating power (DIN 45500)	3.2W
Nominal impedance	6Ω
Characteristic sensitivity (1M, 1W)	91dB SPL
Voice coil resistance	4.8Ω
Voice coil diameter	26mm
Voice coil height	1.5mm
Air gap height	2.0mm
Magnet weight	0.25kg
Flux density	1.8T
Force factor	3.5Wb/m
Effective diaphragm area	7cm ²
Moving mass	0.33g
Free air resonance	660Hz
Weight	0.54kg

*Crossover at 2500Hz. 12dB/octave

Other new SEAS drivers for which samples and/or detailed specifications are, or soon will be available from the authorized distributors listed below:

H-377 1" polyamide dome tweeter	H-359 8" large magnet woofer
H-392 1" polyamide dome tweeter with ferro fluid	H-373 8" dual voice coil woofer
H-382 1" aluminum dome tweeter	H-361 10" large magnet woofer
H-398 1" aluminum dome tweeter with ferro fluid	H-372 10" dual voice coil woofer
H-395 5" polypropylene woofer with cast frame	H-339 13" dual voice coil woofer
H-393 5" polypropylene woofer with large magnet	

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(608) 781-2110

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CIRCLE SOUND (ITC)
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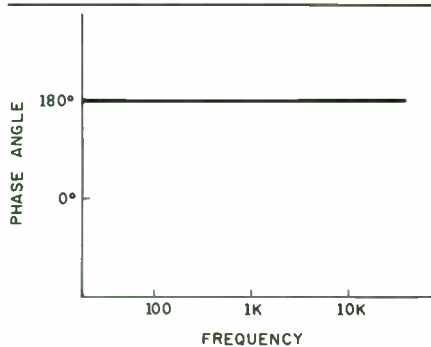


FIGURE 7: Polarity inversion.

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driver's diaphragm, I suggest you measure the displacement of the deepest and shallowest points on the diaphragm and use a value midway between.

If the interdriver displacement is small compared to the wavelength of sound at the crossover frequency (f), the additional interdriver phase shift will be less than about 15° , and you can safely ignore the effects of the time delay. Calculate this wavelength from:

$$L \text{ (inches)} = \frac{13,500}{f}$$

The phase shift at this frequency caused by a D'' displacement is then:

$$a \text{ (degrees)} = \frac{360 \times D}{L}$$

Incidentally, don't confuse the problem of aligning two drivers' diaphragms with that of finding a driver's "acoustic position" at a particular frequency. Assuming no depth displacement exists between the drivers' diaphragms, the "acoustic position" is the depth displacement corresponding to the time delay which would produce a phase angle equal to a driver's inherent phase angle at a single frequency in the region of its high- or low-frequency rolloff. This time delay varies over this range of frequencies so that (as seen above) repositioning the drivers (or using an electrical delay network—or other "phase shifting" filters for that matter) can only approximately correct their inherent phase discrepancies.

SENSITIVITY & IMPEDANCE. A driver's *sensitivity* is the sound pressure level at one meter produced by applying a specific voltage (typically 2.83V) at a frequency in its working range. Its rated *impedance* is the value of a resistor which may be used to approximate

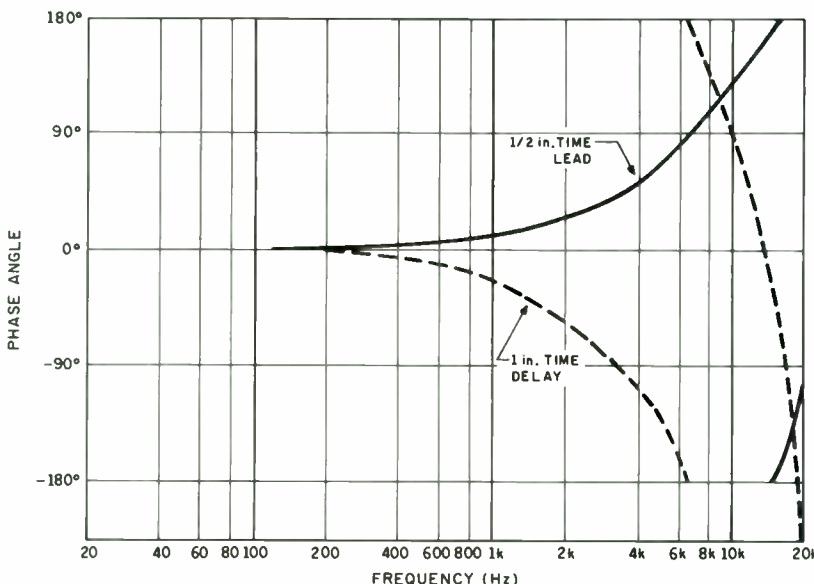


FIGURE 8: Time delay and time "lead."

the driver's impedance versus frequency curve for crossover calculations. For this approximation to be successful, the driver's impedance curve should be nearly flat within an octave around the crossover frequency (or frequencies). This often requires *impedance compensation*.^{5,6} Impedance compensation circuits do not affect the driver's sensitivity and need not be included in the following calculations nor in crossover calculations.

Series and parallel resistors are often used to alter the driver's sensitivity and impedance ratings. Since these resistors are not included in the crossovers considered in this paper, you must calculate the net sensitivity and impedance of an imaginary driver built up from your actual driver and the resistors you use. For example, suppose you have an R_d -ohm driver with a sensitivity of S_d dB SPL, arranged as in Fig. 9. Using voltage division, notice your driver only receives:

$$V_i = \frac{R_d}{(R_d + R_s)} \quad \text{(IF ONLY } R_s \text{ USED)}$$

$$V_i = \frac{R_p \times R_d}{R_p \times R_d + R_s \times (R_p + R_d)}$$

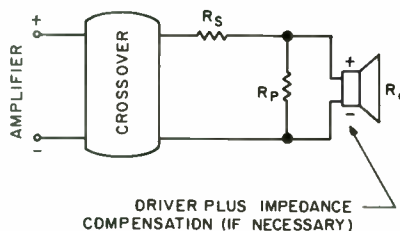


FIGURE 9: Attenuating resistors.

as much voltage as it would in the absence of attenuating resistors, so the sensitivity of the imaginary driver is:

$$S_i \text{ (dB)} = S_d + 20 \times (\log V_i) \quad \text{(logarithm base 10)}$$

Using the formulas for finding the equivalent impedance to two resistors in series and in parallel, we see that the impedance of the imaginary driver is:

$$R_i \text{ (}\Omega\text{)} = R_s + \frac{R_p \times (R_d + R_s)}{R_p + R_d + R_s}$$

If you are not using R_p , the above formulas are still valid except:

$$R_i \text{ (}\Omega\text{)} = R_s + R_d$$

In Part II Mr. Gonzalez will discuss The Response Step.—Ed.

ABOUT THE AUTHOR

Ralph Gonzalez has a BS in mathematics from the University of Delaware. He and his wife live in Philadelphia, where he is completing his PhD in Systems Engineering at the University of Pennsylvania. In addition to his audio interests, Mr. Gonzalez is a disk jockey at the university's FM radio station, and plays fretless bass guitar.

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A COIL WINDER PROJECT

BY BRUCE C. EDGAR
Contributing Editor

If you are like most builders, you started out purchasing ready-made crossovers. Then, as you began tailoring your speakers and crossovers, you discovered you needed specific combinations of coils and capacitors to get the best results.

Now that Bob Bullock (*SB 1, 2/85*) has given us new and better crossover designs, you have even more incentive to "roll your own." You are still restricted, however, by specific crossover capacitor values, so coil inductance (besides attenuation) is the only fine tunable parameter available for optimization.

Years ago, my first introduction to coil winding involved handwinding a crossover coil on a wooden form. It was a tedious job for a teenager, and I knew there must be a better, easier way. The next time, I borrowed my father's hand drill, chucked into a vise, and wound my coils much faster than before. Later, as I began lab research, I had access to motorized coil winders and became accustomed to their precision and operational ease.

A SIMPLE WINDER. As my speaker building activities grew, I knew I needed a coil winder for my garage shop. I first thought about the hand drill method of earlier years. I bought a nice Millers Falls hand drill, with a broken chuck, for a few dollars at a garage sale. After repairing the chuck, I mounted it on a plywood base, as shown in *Photo 1*.

I planned to use wood scraps to elevate the drill off the base. I removed the side knob from its threaded hole, pushed a 1/4" diameter bolt through a

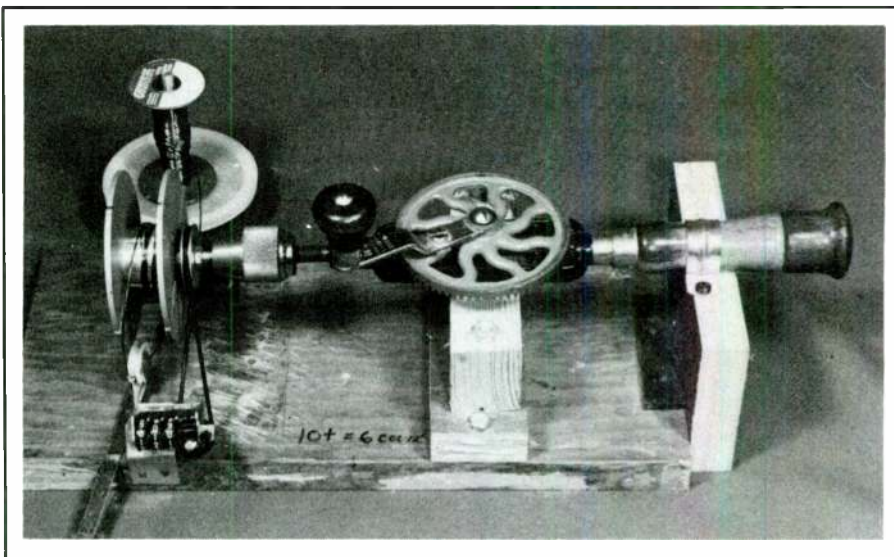


PHOTO 1: The first version of Mr. Edgar's coil winder used a hand drill.

hole in the mount and threaded it into the drill. A pipe strap clamp held down the end of the hand drill.

I found a surplus turns counter at a local electronics store, but it was not geared 1:1. In fact, ten turns only registered as six counts. By trial and error, I worked out the correct diameter for the drive pulley mounted on the coil form shaft, which compensated for the counting discrepancy.

I made a masonite disk pulley wheel with a circle cutter, and sandwiched it between two large fender washers. A large O-ring served as a drive belt. A machinist friend made the coil form shown in *Photo 1*. I will give specifications on a homemade version later.

The wire spool was held by a long bolt mounted on a rear platform. I used a plastic coffee can top to serve

as a turntable for the wire spool, and a grooved wheel on a metal strip (standard sliding door hardware) for a wire guide.

This arrangement worked for 1 or 2 pound rolls of wire, but when I started to buy wire in 10 pound rolls, the hand drill proved to be geared too high to pull the wire off the heavier rolls. I knew I needed a stronger winder.

A BETTER WINDER. I found a mandrel at a local hardware store (\$17, Chicago Die Casting, Franklin Park, IL 60131) with a pulley wheel mounted on a 1/2" diameter threaded shaft. The mandrel was designed to be belt-driven from an electric motor and to have grinding wheels mounted on the shafts. I mounted it on a plywood base, as shown in *Photo 2*, installed a

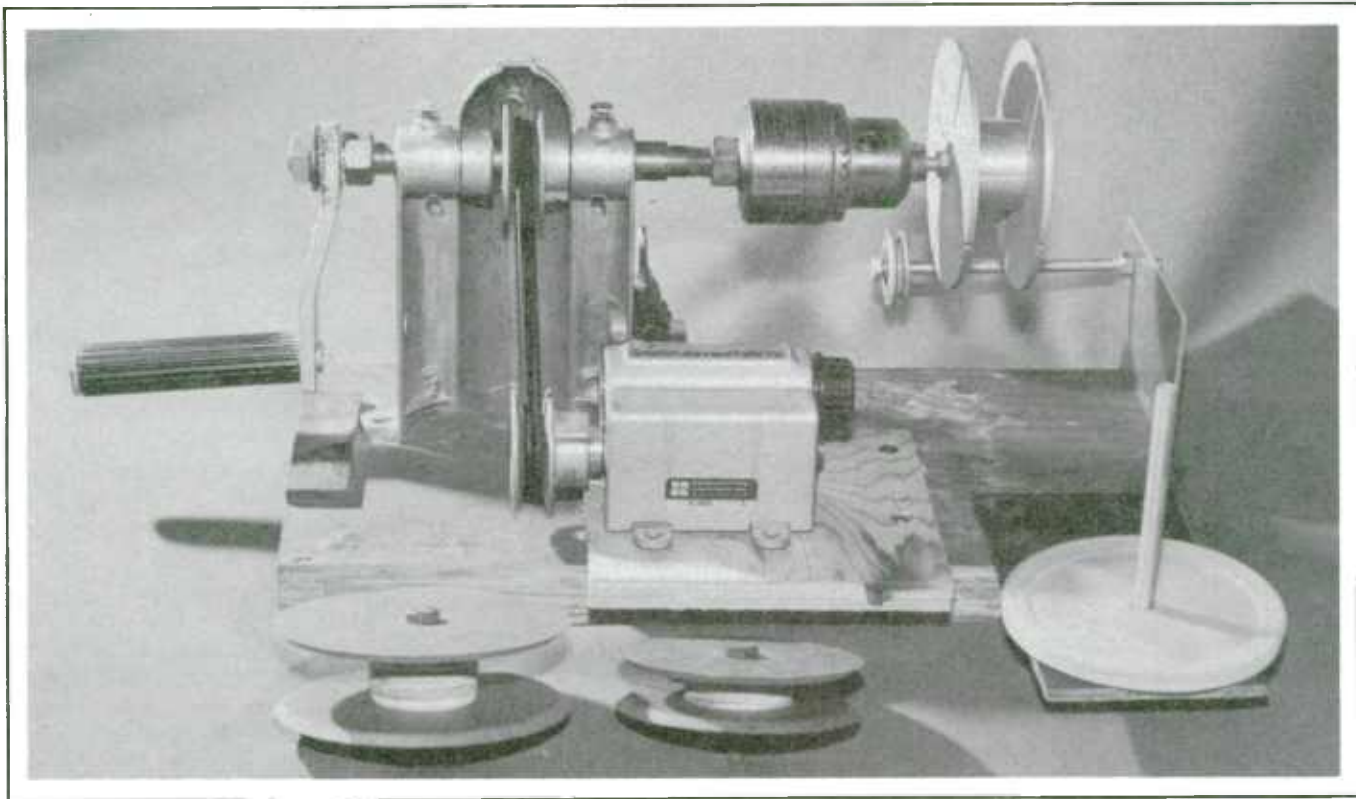
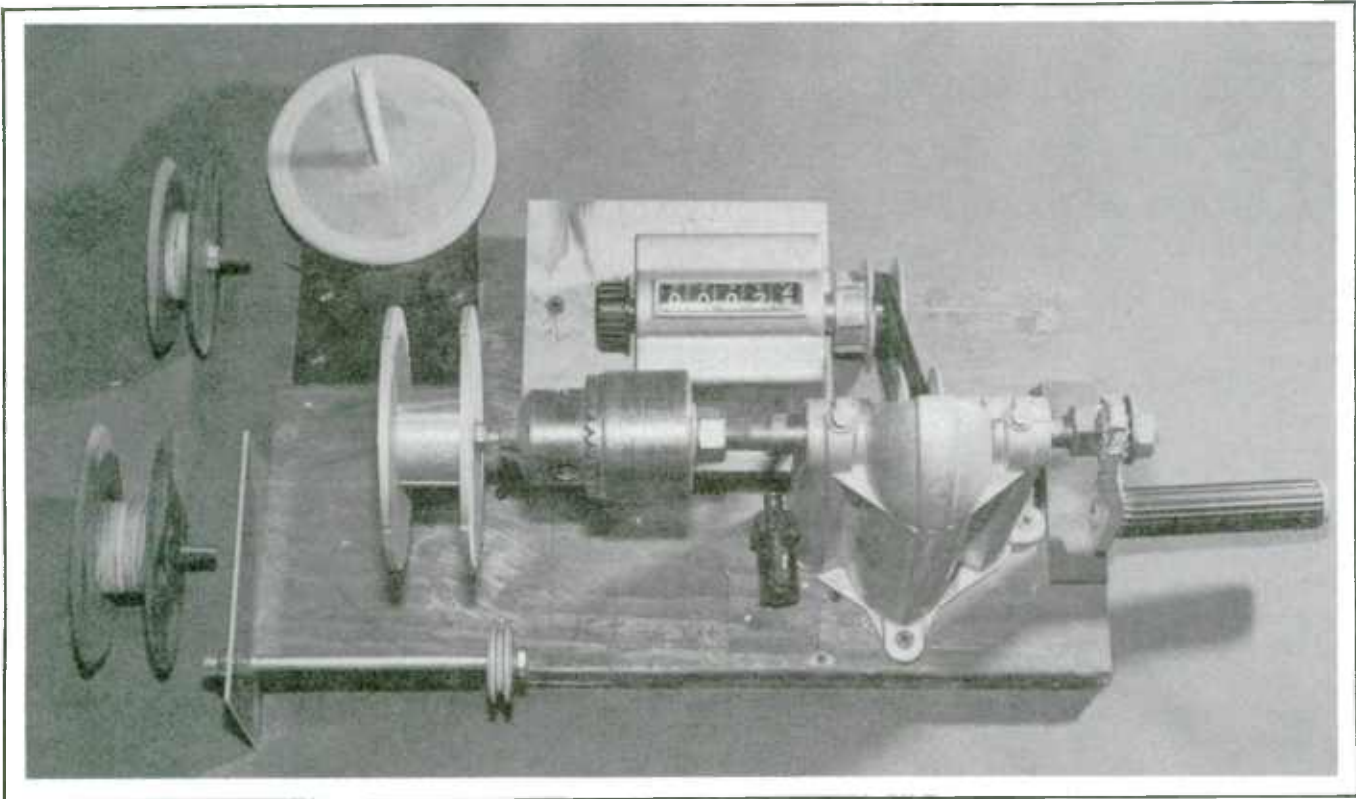


PHOTO 2: Front (a) and back (b) views of a heavy-duty coil winder with mandrel.

$\frac{1}{2}$ " diameter Jacobs replacement chuck (\$15 at hardware stores) on one shaft, and a hand crank on the other. The central pulley wheel drove a 1:1 turns counter (bought at a swap meet) by way of two O-rings in tandem. You

can also use vacuum cleaner belts. My wire guide was a sliding window guide wheel on a $\frac{1}{4}$ " diameter bolt.

Finding a suitable hand crank was an interesting exercise. Except for hand-cranked ice cream freezers, the

hand crank has literally disappeared from our automated society. Eventually, I found a replacement winch handle in a boat store for \$5, but I had to shorten and rebend it into the offset shape. Since then, I have discovered

that Penn sells a replacement ocean fishing reel handle (#24-57) for less than \$5.

Some of you may want to dispense with the hand crank and mount a pulley wheel on the shaft so it can be driven by a low-speed motor. You could also use a foot-operated speed control, as found in professional coil winding models.

The mechanical turns counter I used costs at least \$50 new. As another alternative, you can use a reed switch that activates an impulse counter. Perhaps an *SB* reader could suggest a suitable circuit and parts selection.

INDUCTANCE SPECS. Previous articles (such as Coyle, *SB* 3/82, p. 20) have suggested you use wire weight or length to determine coil inductance values. I find these procedures cumbersome and time-consuming. With a coil winder and a turns counter, however, you can wind coils to any inductance value just by counting the turns. The trick is to wind several coils of differing turns count with the same coil form, measure the inductance on an impedance bridge, and plot the inductance versus turns on a semi-logarithmic graph. By connecting the points with a straight line, you wind up with a graph that tells you how many turns of wire you must put on a specific form to achieve the desired inductance value.

When winding my coils, I use #18 gauge magnet wire for large coils over 1mH. This reduces DC resistance. For small coils of 1mH or less, I use #20 gauge. *Figures 1 and 2* show the coil forms' dimensions and their respective turns-inductance characteristics.

To make the forms, use a circle cutter and a drill press to cut out the sides

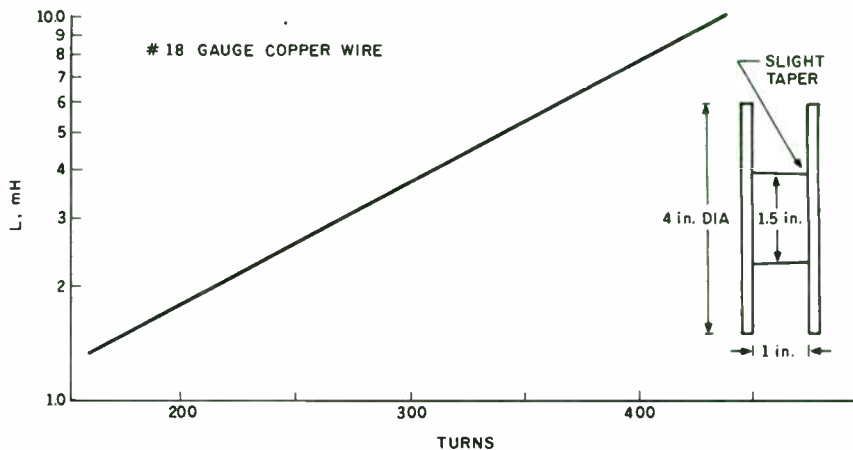


FIGURE 1: Coil turns versus inductance for the large coil form.

from 1/8" masonite, and the cores from plywood (1/2" and 1" thick). After cutting the 1 1/2" diameter core, mount it on a bolt and chuck it into the drill press. With a file or a sanding block, put a very slight taper on the form. The taper will allow you to easily slip the coil off the core after winding.

In general, I have found handwound coils yield good results, with tolerances of 2-3%. Your own hand-arm system will sense the force needed to pull the wire off the reel, so your coils will end up with a nice self-tensioned shape. With the aid of a guide wheel, I try to distribute the turns evenly across the form.

After you wind the coil, undo the bolt holding the side and core together, slip the coil off the core, and attach several cable ties to hold the coil shape. Without the ties, the coil will probably unwind like a spring if you let go of it.

I highly recommend this project if you wish to "roll your own" coils. It may take time to collect all of the parts you need (it took me a year of touring swap meets), but the end result will enhance your speaker building capabilities.

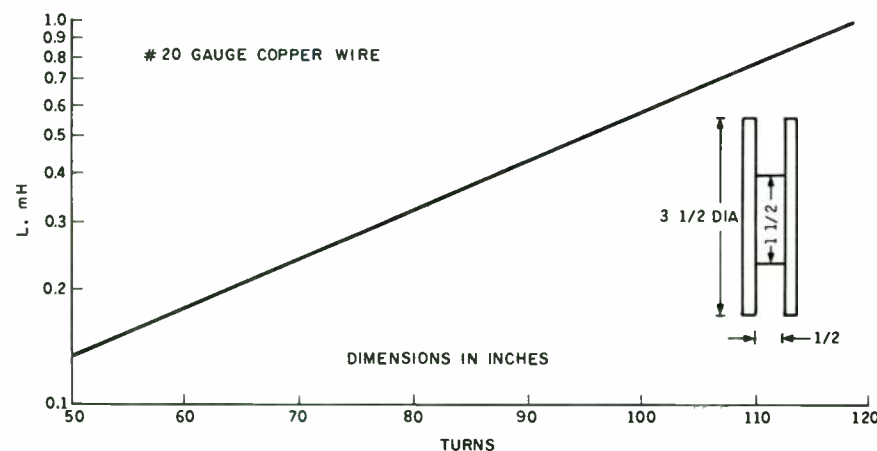


FIGURE 2: Coil turns versus inductance for the small coil form.

A LETTER



Asking
For
Help
Without
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Self
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Goes
HERE!!



PLEASE!!

THE MODEL-ONE SPEAKER

BY KENNETH ROBINSON

For some time, I wanted to try my hand at speaker building, but I knew nothing about design considerations. I subscribed to *Speaker Builder* (plus back issues), and bought David Weems' book, *Building Speaker Enclosures* (from Radio Shack), and SpeakerLab's *The Loudspeaker Design Guide*. Both books were easy to understand and helped me get started. I also obtained information on drivers and crossovers by writing to a number of dealers.

For my first project, I set a goal to build three sets of speakers as Christmas presents for my children (now adults). Because their respective apartments had space limitations, I decided small speakers would be best.

Mr. Dell's article on "The Timbers" (*SB* 2/83) triggered my imagination, and I eventually established the following design goals:

Enclosure size	.5 cu. ft. (int. vol.)
Minimum bass freq.	50Hz
Imp.	8 Ω nominal
Efficiency	89-90dB SPL
Q _{TC}	1.0 to 1.1
Power	100W
Cost/pair	\$100.

I decided to experiment with different types of drivers in both ported and closed-box configurations, so I built two prototype enclosures with removable front baffles from 3/4" scrap lumber. I purchased various drivers and crossovers from Radio Shack and Madisound, and began experimenting with two-way and three-way designs. This was quite a learning experience for me, and I was amazed at the different sounds I could obtain with different components and configurations.

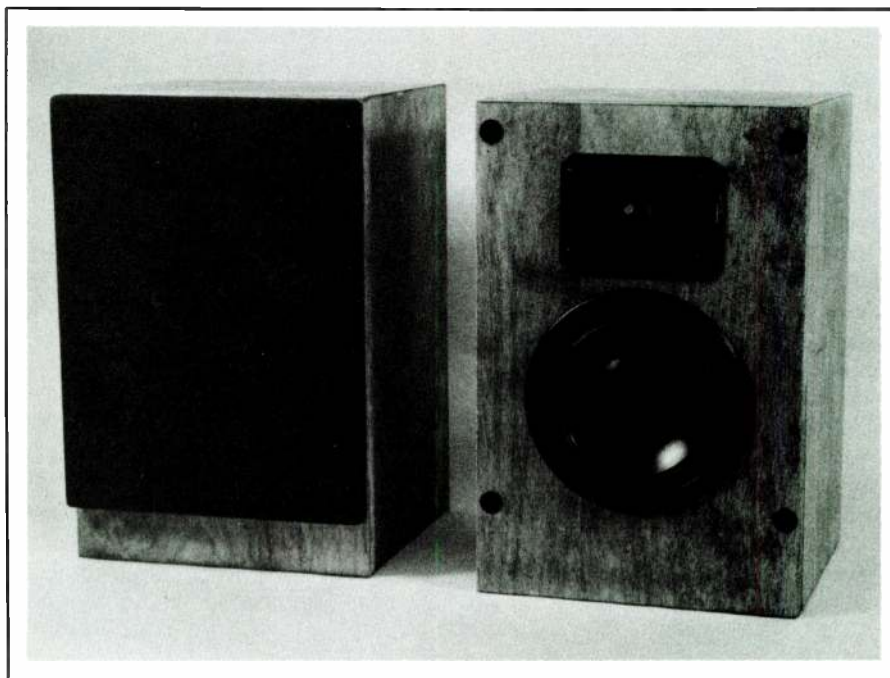


PHOTO 1: The completed Model One

I finally settled on a two-way, closed-box design. It seemed to be the easiest and most economical to build. Like Mr. Dell, I used the Audax 1" dome tweeter (HD12x9D25) since it sounded best to me—excellent clarity, broad frequency range, and flat response. For the woofer, I chose the Dynaudio 7" unit (17W-75ER) because of its power-handling ability (150W), low frequency response, and fast transit characteristics. (Mr. Dell used an Audax unit.) The woofer's specifications also fit well with the 0.5 cubic foot enclosure I wanted to use (V_{AS} = 0.66 cubic feet; Q_{TS} = 0.74; F_s = 39Hz).

I used a passive crossover, crossing at 2.5kHz with 6/12dB octave slopes. Drivers, crossovers, and accessories

(hedlocks and input terminals) were all purchased from Madisound Speaker Components (8608 University Green, PO Box 4283, Madison, WI 53711), where Larry Hitch was most helpful. These components cost about \$120/pair.

I used 3/4" birch veneer plywood (\$20/4'x4' sheet) for the entire cabinet, lined the interior with polyester filling, and finished with WATCO medium-dark walnut finishing oil (applied with a brush and #600 wet paper). The dark brown grille cloth (stretch polyester from Radio Shack) set up nicely against the medium-dark walnut cabinet. See the construction steps for details.

Although by no means reaching a professional conclusion, I tested these

units with my ten-band dbx 10/20 analyzer-equalizer unit (with pink noise), and the frequency response appeared as designed: a ± 3 dB reading from 60Hz to 16kHz, falling off to about 6dB at 32Hz (the limit of my analyzer). I didn't test the upper limits of power-handling capacity, but with my Carver 250W/channel amplifier, they certainly handled 100W easily. Their efficiency seemed right on the money, about 89dB SPL-1W. (One additional note, per manufacturer recommendation: the woofer needs about 30 hours of break-in to achieve the best low frequency response, which is about 5-8Hz lower than start-up.)

Since I came close to my original design goals, I assigned the following specifications to these units:

Freq.	45Hz-20kHz ± 3 Hz
Imp.	8 Ω
Eff.	89dB SPL
Power	15-150W
Qrc	1.1
Int. vol.	0.54 cubic feet

Total cost for each pair was around \$150. I missed my target budget of \$100 per pair, but the end results were well worth the extra cost.

How did they sound? Just great! Naturally, I am partial to my first effort, but I auditioned these units with a good cross-section of listeners, and they all marvelled at the expansive sound these little units put out. The midrange was full and exciting, the high-end was crisp and clear in detail (without harshness or stridency), and

the bass was tight and pronounced. They also imaged well, with a broad sound stage (good dispersion).

As you can imagine, my kids were delighted with their gifts and couldn't believe their "old man" really made these little gems. In fact, I liked them so much that I'm building another pair for myself, and I plan to build a sub-woofer unit for my next experiment. I guess I'm just hooked!

ABOUT THE AUTHOR

Ken Robinson is vice president of sales and marketing at Cablewave Systems (manufacturer of microwave transmission products) in North Haven, CT and resides, with his wife Ingrid, in Guilford, CT. His musical tastes range from classical, to jazz, to marching bands. About six years ago, he became an active audio hobbyist and continues to be fascinated with sound reproduction.

Construction Guide

(Refer to outline drawing of enclosure and grille frame, Figs. 1 and 2.)

- Cut various pieces (see cutting guide, Fig. 3).
- Use a saw to miter top and side pieces.
- Cut driver holes in front baffle and input holes in back piece. (Not shown. Hole size will depend on your input terminal.)
- Glue cabinet together (except front baffle) with Elmer's carpenter's wood glue. To save time, I glued and nailed all joints. As an aid, I glued/nailed a cleat to the top of each side to assemble the mitered joint to the top piece. All other joints were the butt type, and glued/nailed together with 1x16 brads which were then countersunk and filled with Elmer's wood filler.
- Sand all surfaces with medium, then fine sandpaper.
- Using a medium-hot iron, apply $\frac{3}{4}$ " birch veneer edging to sides and top of front baffle board. Sand.
- Apply silicone sealant to all internal joints.
- Apply oil finish to cabinet and front baffle.
- Solder hook-up wires to crossover (Fig. 4). Cut 6-8" lengths for input terminal and 16-18" lengths for drivers. (This will make it easy to solder the wires to the drivers

and terminal outside the enclosure.)

- Mount crossover to the rear board, about 1-2" above input hole. Use a bead of silicone for mounting.
- Line the enclosure with about $\frac{1}{4}$ lb. of polyester fiber filling. Use staples in a few places to avoid shifting.
- Mount front baffle board with

a bead of silicone around the entire front edge of the cabinet, pressing the front baffle for proper seating. Since time was of the essence for me, I couldn't wait 24 hours for the silicone to dry, so I placed a bead of silicone on the interior edges and Elmer's glue in the center edges, then clamped the baffle for 30 minutes until the glue dried.

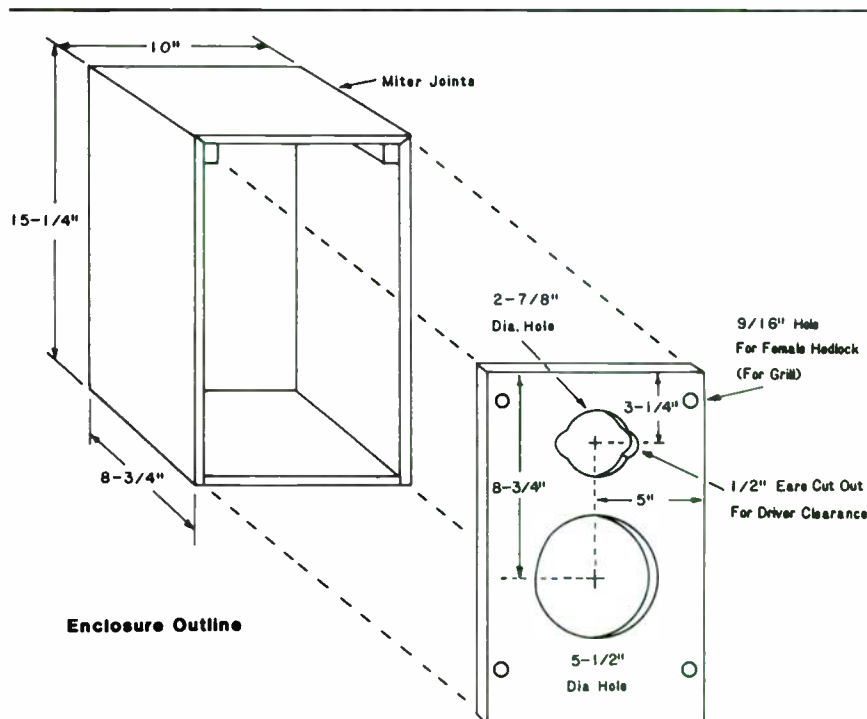


FIGURE 1: The author's enclosure outline.

TABLE 1

MATERIALS LIST (PER PAIR)

1	sheet ¼" birch plywood, 4' x 4'
1	roll ¾" birch veneer edging, iron-on tape
2	Audax 1" dome tweeter (HD12x9D25)
2	Dynaudio 7" woofer (17W-75ER)
2	crossover (2.5kHz, 6/12 slope)
8	sets hedlocks for grille
2	input terminals
1	roll brown Mortite
1	1 lb. bag polyester fiber filling
1	roll dark brown grille cloth
1	package 18ga. hook-up wire, assorted colors
1	tubé silicon sealant
1	bottle Elmer's carpenter's wood glue
1	box 1 x 16 wire brads
1	jar Elmer's wood filler
1	sheet medium sandpaper
1	sheet fine sandpaper
1	quart WATCO medium-walnut Danish Oil Finish
1	sheet #600 wet paper
8	¾ x 10 round head screws (paint heads black if you can't locate black screws)
12	1 x 6 Phillips head black screws
1	roll felt weather stripping, ¾" thick x 5/8" wide

TABLE 2

THE MODEL-ONE SPEAKER

(As an added kick, to accompany these gifts, I used copies of various published data to make up a product information brochure on the speakers. This gave my kids an idea of how their speakers were made. It reads as follows:)

This speaker has been designed to reproduce a natural musical sound over a wide frequency range with the following characteristics:

- Excellent detail and clarity
- Fast transient response
- Linear dynamic range
- Smooth and uniform phase response
- Very low distortion
- High power capability
- Superb imaging and depth
- Wide sound stage
- Solid bass response
- Flat frequency response (without room effects)

Specifications

Type:

Acoustic suspension (sealed-box) system
 Frequency response:
 45Hz-20kHz ±3dB with a 6dB roll-off to 32Hz
 Nominal impedance: 8Ω
 Power-handling: 15-150W
 Efficiency: 89dB SPL, 1W
 Crossover: 6/12dB octave slopes at 2.5kHz
 Drivers: 1" Audax (France) impregnated fabric soft dome tweeter; 7" Dynaudio (Denmark) woofer with PHA cone and 3" coil

Dimensions

15¼"H x 10"W x 9½"D (plus grille)
 Internal volume: 0.54 cubic feet
 Weight: 12 pounds
 Material: ¾" birch veneer plywood, oil finish, medium-walnut

Grille Frame

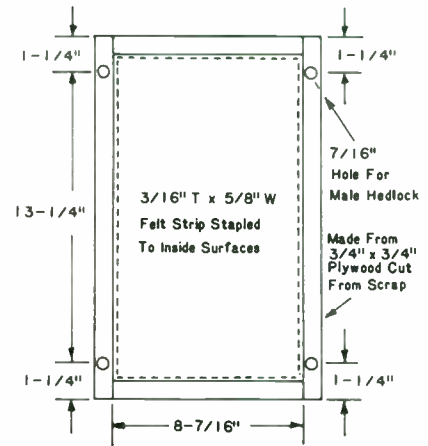


FIGURE 2: Guidelines for the grille frame.

- Cut ¾ x ¾" strips from the remaining plywood, then butt glue the frames (with clamps for 30 minutes). For a smooth finish, sand the frames, particularly the edges. I also quickly stained these frames with a walnut stain so they

- wouldn't show through the grille cloth. This step is optional.
- Position the grille frames on the front baffle, center about ¼" from the top and sides, clamp down, and drill pilot holes with a ¼" drill bit about 1¼" from the top and

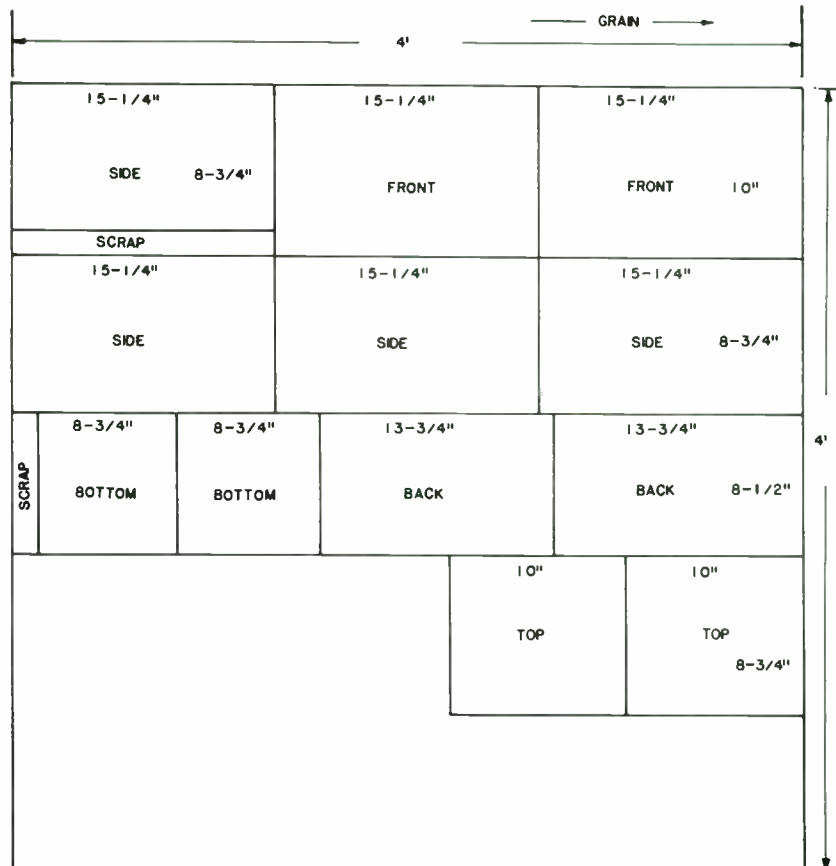


FIGURE 3: Suggested cutting guide, using 4' x 4' birch plywood.

bottom. Make sure holes go through frame and into front baffle board.

- Drill larger holes for the hedlocks— $\frac{7}{16}$ " hole in the baffle board for the female end, $\frac{7}{16}$ " in the grille frame for the male end. Tap the hedlocks into their respective holes on baffle only—not into the grille frame yet.

- Turn enclosure on its side, pull input wires out and solder them to the input terminals. Mount the terminals with a complete bead of silicone around all edges. You can use two screws to hold the terminals on until the silicone dries. Insert speaker wire from receiver.

- With enclosure now on its back, pull out the respective wires for the drivers. With the drivers face down on some wood strips, next to the enclosures, solder all wires.

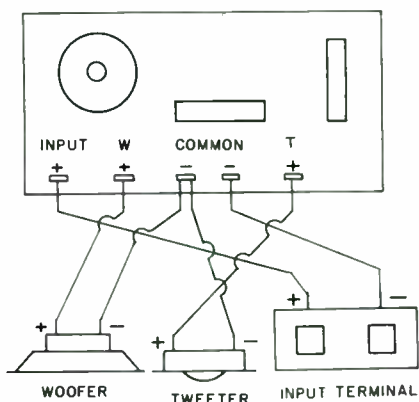


FIGURE 4: Crossover filter guideline.

- Test all connections by turning on your receiver (or amp) at low volume.
- Mount drivers. For sealing, use one bead of Mortite around com-

plete tweeter hole and two beads around woofer hole. Push tweeter down and mount with $\frac{3}{4}$ x 10 screws (heads painted black). Mount woofer with 1 x 6 black screws (you can use other sizes; T-nuts would probably be best).

- To minimize diffraction, mount felt strips to inner surfaces of grille frame with $\frac{3}{8}$ " staples.

- Mount the grille cloth to the frame with $\frac{3}{8}$ " staples, starting at the middle of one side and working to the ends, stretching tight as you go along. Tap in male hedlocks.

- Mount grille to speaker, and all is finished.

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ONE MAN'S LISTENING ROOM ODYSSEY

BY CHARLES E. ULRICH

About five years ago, I moved into a new house. With it came the luxury of an exclusive music room, but like most, it was not complete luxury. My exclusive room is in my finished basement, and is 24.5' long, 12.5' wide, and 7.5' high. *SB* readers familiar with listening rooms realize these dimensions are far from ideal, although the total volume is respectable. With only a carpet on the floor, my room sounds more like a cave than a music room. Let's begin this odyssey of how I remedied the situation with a detailed room description.

The concrete floor is covered with a thin wall-to-wall mat and a medium thick wall-to-wall carpet. The three outside walls are concrete block, covered with 1/4" wood paneling for the first 3', then skim-coat plastered to the ceiling. The one inside wall is skim-coat plastered from floor to ceiling. There are two windows covered by thin drapes. Furniture consists of a couch, two chairs, a record cabinet, and two equipment cabinets. A diagram of the room is shown in *Fig. 1*. The first ten calculated room modes are shown in *Table 1*.

TABLE 1

FREQUENCY (Hz) & ROOM DIMENSION(s)				
Mode	L	W	H	Comb.
1	23	45	75	90
2	46	90	150	181
3	69	135	225	271
4	92	180	300	362
5	115	225	375	453
6	138	270	450	543
7	161	315	525	634
8	184	360	600	725
9	207	405	675 </td <td>815</td>	815
10	230	450	750	906

I calculated the individual and combined room modes using equations 1 and 2 respectively:

$$F = M(C/2)/D \quad (1)$$

$$F = (C/2)\sqrt{[M/L]^2 + [M/W]^2 + [M/H]^2} \quad (2)$$

Where:

F = Frequency of mode M

M = Mode (1, 2, 3, 4 etc.)

C = Sound velocity in air, 1127 ft/sec

D = Distance (ft) between parallel walls

L/W/H = Length, width and height

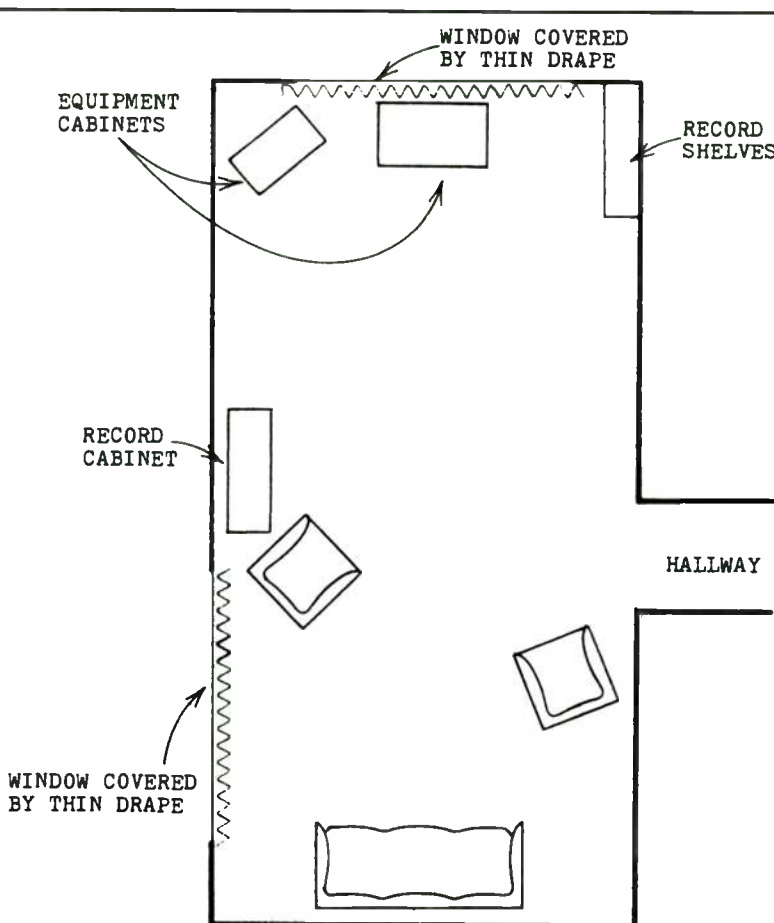


FIGURE 1: Layout of author Ulrich's listening room before experimenting with speaker placement.

The data indicates I might expect to have trouble with frequencies around 45, 90, 150, and 225Hz. Before attempting some "fix" based on textbook theory, however, I decided to listen to some music. I spent about six months moving my speakers (Dahlquist DQ-10s) and listening positions, trying to find an arrangement I could live with. The more I moved and rearranged, the more confused I got. Finally, in desperation, I decided to collect some quantitative data to help me locate speaker and listening positions.

MEASUREMENT SYSTEM. There are four ways to measure room response:

1. use computerized spectrum analyzers
2. use real-time octave analyzers, such as the Ivie, with a pink noise source
3. use Fourier transformation on impulse responses
4. use swept frequency tones with specially calibrated chart recorders.

Every method requires expensive equipment not readily available to most audio enthusiasts, including myself. Therefore, I decided to put together my own measurement system, based on method 4 above.

The first requirement is an *inexpensive* microphone which is reasonably flat or has a known frequency response. I had solved this problem some years earlier by writing to every microphone manufacturer I could find, asking which models they would recommend for non-professional instrumentation use, what the cost would be, and if they would supply an individual calibration curve.

As expected, the response was quite varied. Most manufacturers sent back a packet of descriptive literature. One manufacturer, however, proved to be a goldmine. Primo Microphone, Inc. (2468 Delta Lane, Elk Grove Village, IL 60007) offered their model EM-518 for \$20 (1978 price), and offered to supply an individual calibration curve for an additional \$6. This is an omnidirectional electret-type microphone—just what the doctor ordered. I should note that Muller and Krueger¹ (*The Audio Amateur* 3/84, p. 38) have since discovered a much better buy and probably a better microphone for instrumentation use. *Figure 2* shows a reproduction of the calibration curve supplied with my microphone.

Now that I had a microphone, I

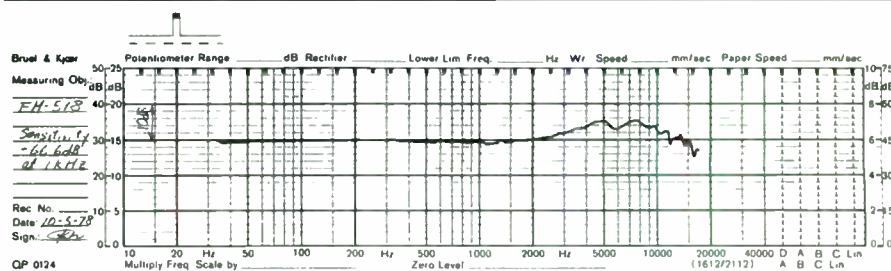


FIGURE 2: Calibration curve for EM-518 omnidirectional electret-type microphone.

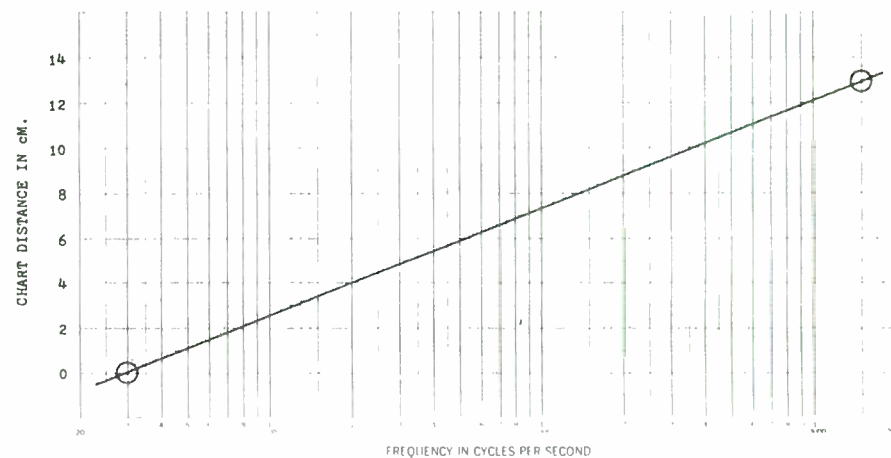


FIGURE 3: Frequency calibration for recorder using CBS STR-140 record.

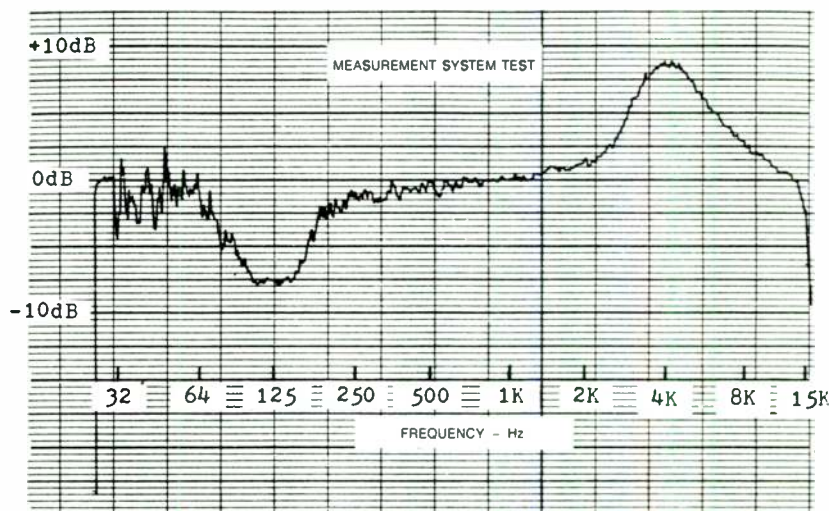


FIGURE 4: Results of calibration check on measurement system.

needed some sort of amplifier, preferably one with logarithmic or dB output. This project is what prompted me to design and build the "RMS AC Voltmeter with dB Converter" (*TAA* 2/83). While the converter output was displayed on a strip-chart recorder, I plugged the microphone directly into the converter input. For a most reasonable price, I purchased a used strip-chart recorder from a test equipment rental house. I set the converter in the dB output mode, with the gain set as needed, usually at X20dB. This setup permitted me to record sound pressure

levels on a logarithmic (dB) scale. Once I solved the microphone and logarithmic display problems, the only remaining hurdles were the signal source and its calibration to the strip-chart recorder.

For a signal source, I used the CBS Laboratories STR-140 RIAA pink noise acoustical test record. This record provides left, right and left-right 1/3 octave-wide pink noise signals, swept logarithmically from 30Hz to 15kHz. I calibrated the strip-chart recorder to the record as follows:

- I determined the time required for

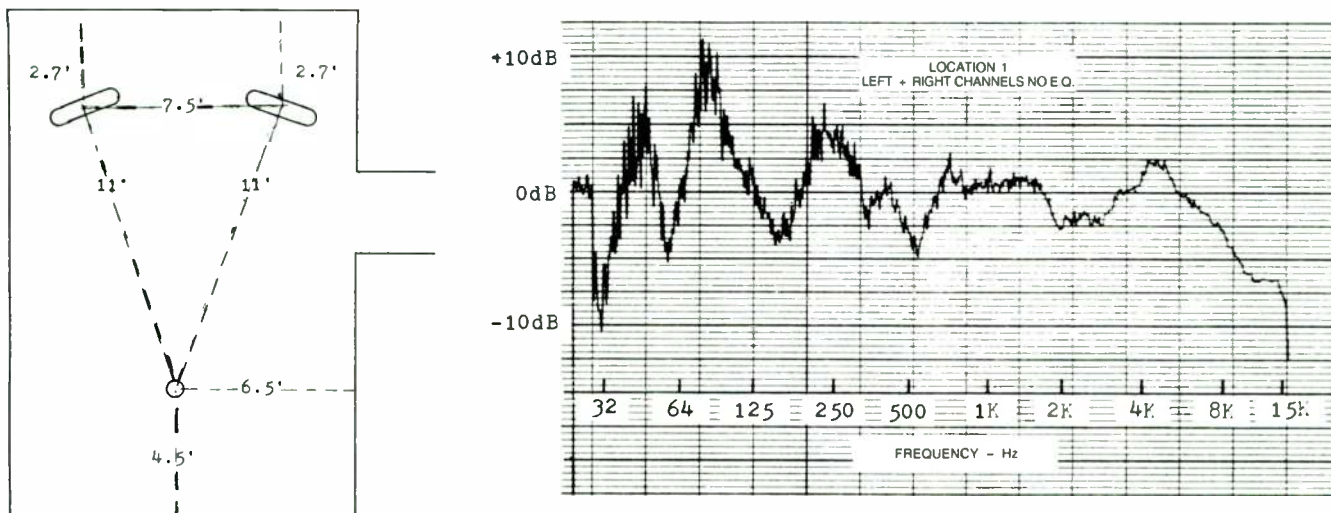


FIGURE 5: The author's original speaker placement arrangement and room response chart.

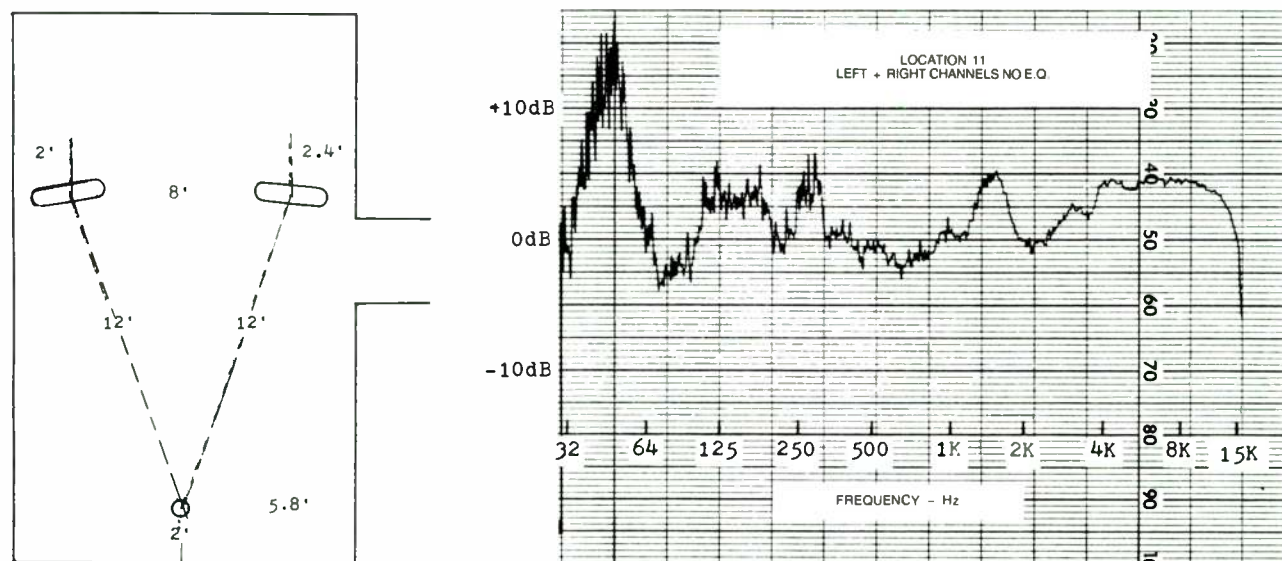


FIGURE 6: Minor rearranging produced smoother midbass and an improved high-end.

30Hz to 15kHz sweep to be 3 minutes and 14 seconds.

- I selected a chart speed for the strip-chart recorder that would provide a reasonable looking trace; 4cm per minute produced a 5" long tracing.

- Next, I recorded an actual sweep on the chart recorder to determine the exact chart distance (on the X-axis) from 30Hz to 15kHz. This turned out to be 12.9cm, just what the calculated distance should be.

- Using a sheet of audio frequency graph paper (K&E No. 46 6882), I constructed a calibration graph which related chart distance to frequency (see Fig. 3).

- From this graph, I read off distances associated with selected frequencies.

I selected these frequencies to be at octave intervals starting with 32Hz.

Using this calibration procedure, I was able to locate any particular frequency on the strip-chart. I verified this calibration procedure by passing the swept pink noise signal through an octave equalizer with the 125Hz band set at -10dB, and the 4kHz band set for +10dB. The test signal was patched to the RMS converter, and displayed on the strip-chart recorder. Figure 4 illustrates the results. As you can see, the 125Hz and 4kHz perturbations were accurately displayed. Since the dB output on the converter was 0.1V/dB, I set the gain on the recorder for 1.0V per 20 chart divisions, thus setting the calibration at

0.5dB per chart line. Armed with a measurement system, I was now ready to conduct some room measurements.

ROOM RESPONSE. Some preliminary comments: the room response measurements presented in this article were collected over a four year period. Each new speaker placement arrangement was identified by a "location number." In order to reduce the possibility of mix-ups, I have retained the original location number identification, even though I will not present data from all tested locations. Each tracing starts with a reference signal, a short section of noise 1/3 octave-wide, centered at 1kHz. I used this signal to

Continued on page 36

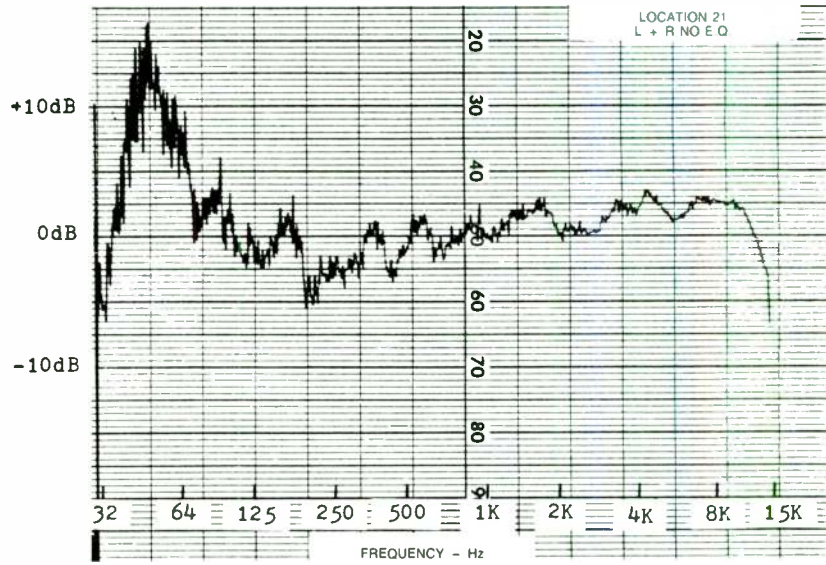
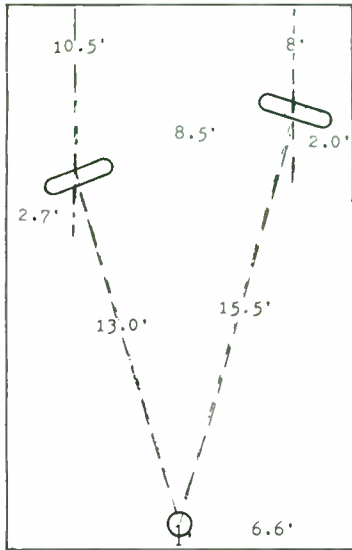


FIGURE 7: This location was the author's first attempt at controlling room modes by using an asymmetrical speaker placement.

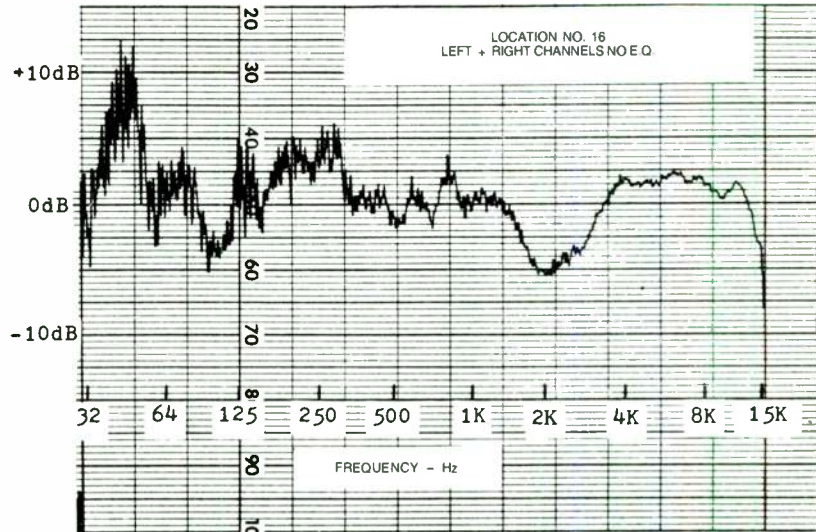
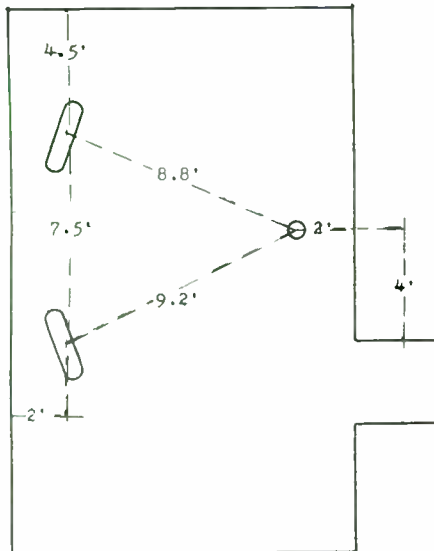


FIGURE 8: Low bass hump was just one problem with long wall speaker placement.

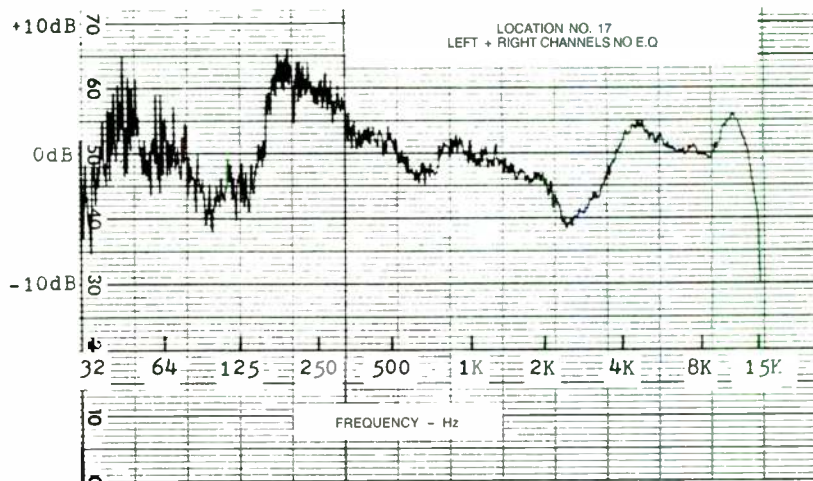
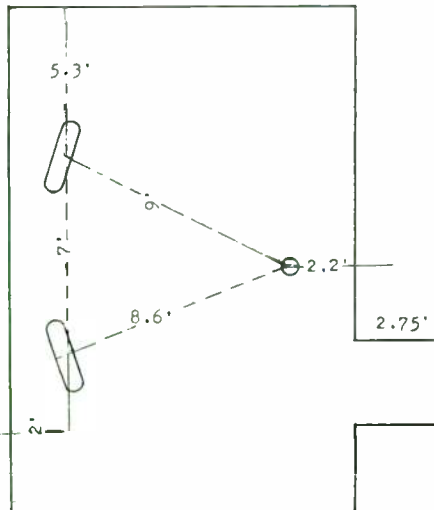


FIGURE 9: This arrangement produced a marked change in room response.

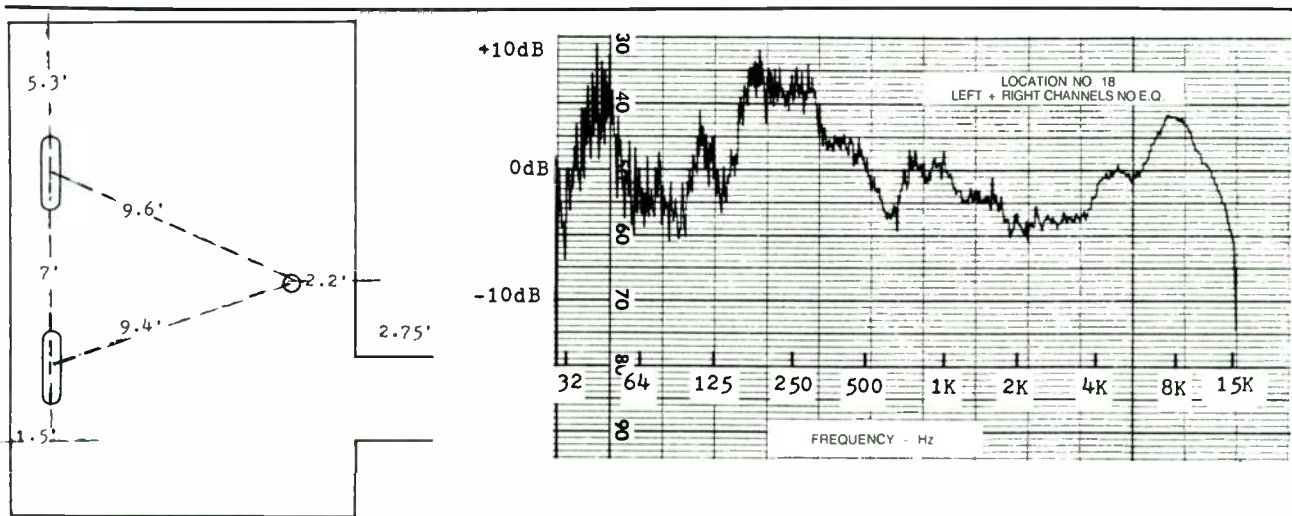


FIGURE 10: Speaker angling netted less than favorable results.

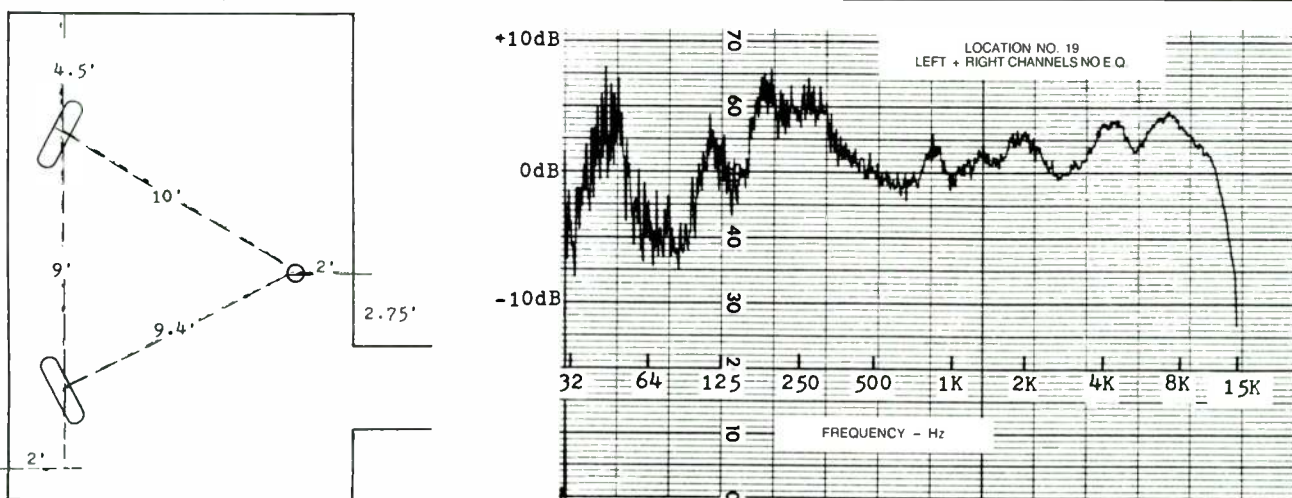


FIGURE 11: By moving the speakers farther apart, the author found a smoothing of the mid and high range.

Continued from page 34

set the pen position at a convenient location on the chart. In all cases, I positioned the microphone 3' above the floor (indicated as a circle on the figures). I placed the speakers on 1' high stands, and when I moved the speakers to different locations, I also moved the two chairs and the record cabinet. The equipment cabinets and couch were not moved.

My original speaker placement arrangement (Location 1) is illustrated in Fig. 5. This rather symmetrical room arrangement was aesthetically pleasing, but the room response (also shown in Fig. 5) was poor. The predicted room modes were prominent, with peaks or dips at 45, 90, 160, and 250Hz. The high frequency roll-off beginning at 7kHz was quite noticeable. Keep in mind that the microphone has a 5dB peak at about 7kHz. Listening to music with this arrange-

ment was fatiguing and unenjoyable.

By moving the speakers and listening position slightly, I came up with Location 11 with its associated room response (Fig. 6). The midbass was somewhat smoother, but a large 50Hz peak developed, while the high-end improved significantly. The latter was likely due to less angling of the speakers.

Once again, I moved the speakers and listening position but kept the same general room arrangement. Location 21 and the associated room response are shown in Fig. 7. This was my first attempt at controlling room modes by using an asymmetrical speaker placement. The results were quite promising. The asymmetrical speaker placement broke up the room modes above mode-2, but left the severe 50Hz peak.

I also experimented with putting the

speakers on the long wall rather than on the short wall. Locations 16-19 with their associated room responses are shown in Figs. 8-11. I spent up to two months living with and listening at each location. Without trying to summarize all my notes on relative sound differences, suffice it to say none of these locations provided enjoyable listening.

What can we learn from this data? Let's look at Location 16 and 17 (Figs. 8 and 9). Location 16 has two problems: the low bass hump at 45Hz, and the suck-out at 2kHz. Location 17 reduced the low bass hump and slightly improved the midrange suck-out, but the 225Hz peak was exaggerated. Note the marked change in room response compared to a rather modest change in speaker and listener locations.

Next, I experimented with speaker angling (Location 18, Fig. 10) to see

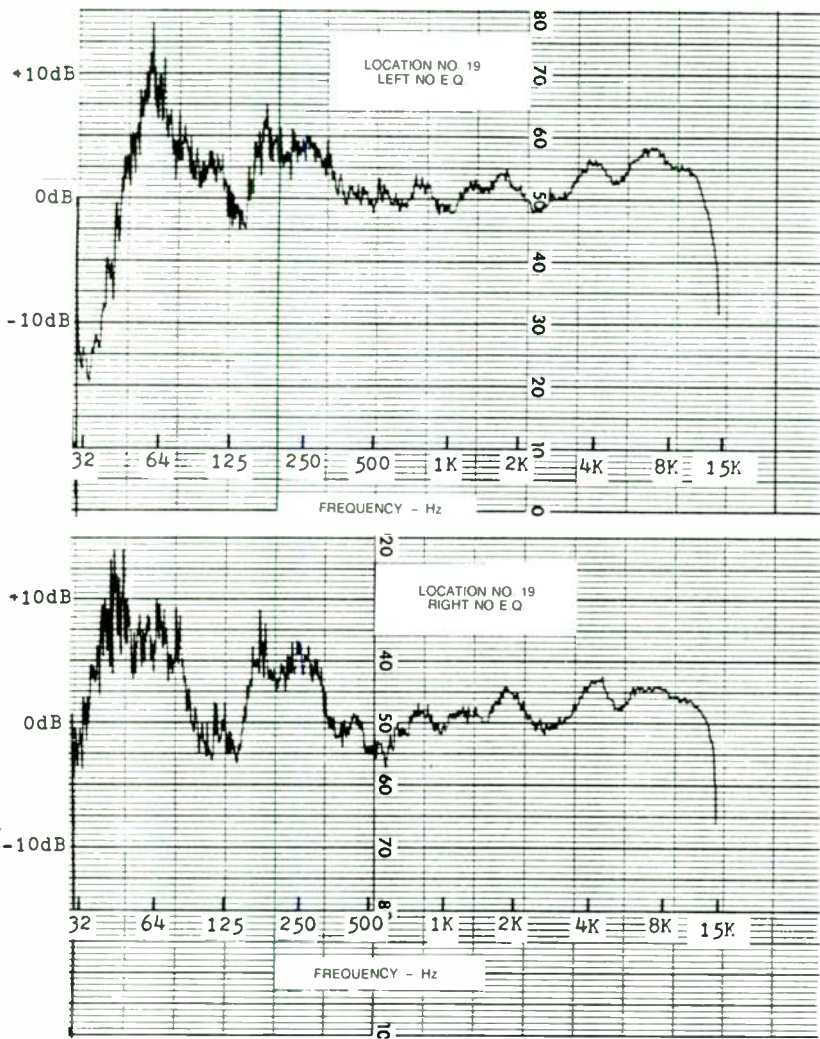


FIGURE 12: A comparison between left and right channels.

what improvements could be made in mid and high frequency response. Compared to Location 17, the mid and high ranges were decidedly worse. Unexpectedly, however, I observed the return of the 45Hz hump, which probably resulted from moving the speakers slightly closer (about 6") to the rear wall.

The results from Location 19 (Fig. 11) illustrate the smoothing of the mid and high range by moving the speakers further apart, and angling them in.

Next, I thought it might be interesting to look at the difference between left and right channels. Figure 12 shows these curves. Compared to the left channel, the marked increase in the right channel's low bass response is the result of placing the speaker closer to a corner. This left-right difference was not that noticeable, at least to me, probably due to the overpowering influence of the exaggerated low bass. Irrespective of the frequency response anomalies, I found it unpleasant to sit facing the long wall. Besides, the DQ-10s really need space behind them to achieve their full potential.

Based on the information presented above, as well as measured responses from a number of other room arrangements, I found the smoothest response generally resulted from a diagonal arrangement of speakers and listener.

Figure 13 shows the room arrangement and resulting room response for

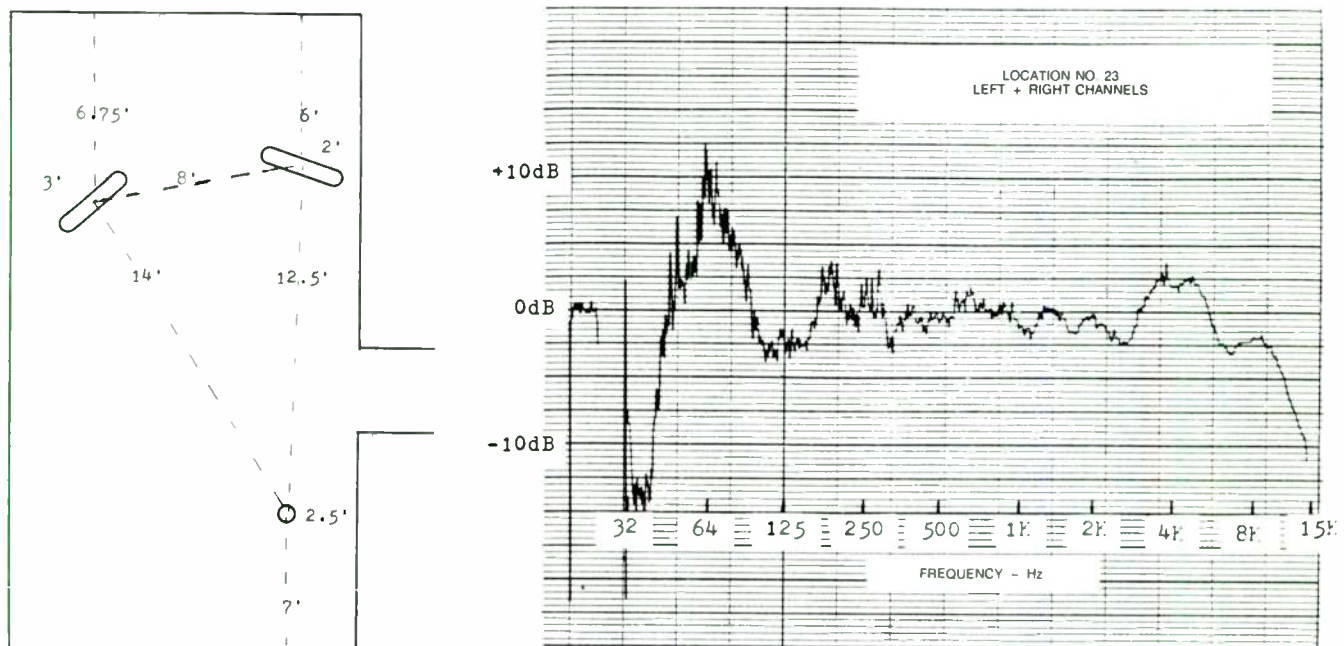


FIGURE 13: The author settled on this arrangement as the best compromise for his DQ-10s.

Location 23. The diagonal relationship between speakers and listener produced asymmetrical spacings which broke up most of the room modes. The exaggerated response at 4kHz is probably due more to a function of the microphone than to speaker placement. The 64Hz peak is not only apparent on the room response plot, but also noticeable while listening.

With only one major frequency response aberration, I attempted to make some corrections with an equalizer. When doing so, be sure the aberration is centered on a band available on the equalizer. Otherwise, in my experience, the results will be far from acceptable. To illustrate how difficult this rather simple case can be, look at Fig. 14. Here, I applied either -6 or -10dB of attenuation at 64Hz. Sure enough, the 64Hz peak was controlled, but the minor suck-out at 125Hz was accentuated.

Having spent many months trying to equalize out midrange and bass room response anomalies with an octave equalizer, I have concluded it can't be done effectively. This is not a new revelation. Similar advice has been given by others, but what surprised me was even simple cases cannot be dealt with effectively. To repeat, if the anomaly you wish to remove is not centered on one of the equalizer's controls, you stand little chance of improving your situation. The broader the anomaly, the more difficult it will be to control. From my experience, I don't think a 1/3 octave equalizer would be much help, but a parametric equalizer could be much more effective.

CONCLUSION. I have finally settled on Location 23 as the best compromise for the DQ-10s in my room. I generally do not use the equalizer. Asymmetrical speaker placement can be effective for controlling room mode aberrations, but maintaining good imaging at the same time is difficult. The sound available with Location 23 is fine for small ensembles, but large orchestral works do not reproduce nearly as well. I assume the more complex relationships between direct and reflected sound inherent in large scale orchestral works are substantially altered by asymmetrical speaker placement. As a result, many of the aural clues we listeners use to reconstruct the sound images are destroyed.

One of the lessons I learned from this odyssey is that speaker placement is, at best, a series of compromises, even when room decor is not a con-

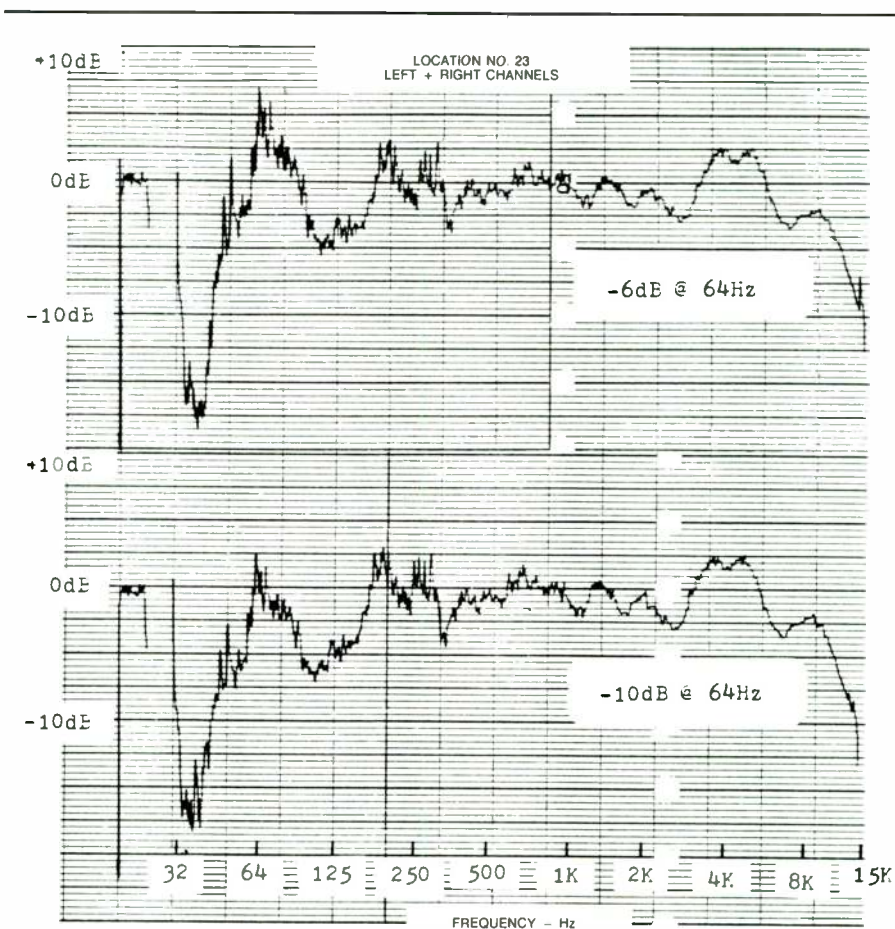


FIGURE 14: Results from attempted corrections with an equalizer.

sideration. I find it hard to imagine what the average audiophile is listening to if he or she has not taken the time and energy to investigate various speaker locations.

ABOUT THE AUTHOR

A professional inhalation toxicologist, Charles Ulrich has been an audio enthusiast since his teen years in the early 1950s. His first modification projects involved a Zenith 3-band radio phonograph console, and his first scratch-built project, in daily use for about ten years, was a 30W power amplifier, described in a 1966 issue of Radio-Electronics. He has since built many kit projects from Dyna, Heath and Hafler. His latest project was a scratch-design preamp, using POOGE principles. Mr. Ulrich's musical tastes include chamber music, piano, violin and cello.

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SOURCES

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Tools, Tips & Techniques

"GRILLE-LESS" GRILLE

My grille design offers the cosmetic appeal of a loudspeaker grille, but with none of the well-known acoustically compromising side effects; no more complex or frail frames, unsightly foam grilles, or diffraction and rippled frequency response.

For a minimal cost, this design will give you smooth radius edges which will reduce diffraction to negligible levels, smooth frequency response, and audibly improve your current loudspeakers.

My design is semi-removable, and uses a spline or rubber cord to secure the grille cloth (similar to the way mesh screen is secured to your storm door). The cord squeezes the cloth into a narrow groove on the side of the cabinet near the front baffle. After you trim the excess cloth to get a clean, uncluttered look, you will see a grille, but the system won't. Consequently, it will deliver a clean, accurate sound.

First, however, your system must meet several conditions. Your cabinet cannot have raised edges. Recess or remove all mounting screws, drive unit frames, and so on, so the grille cloth can contact the front baffle without bulging. Of course, if your system has dome tweeters or large, bulging woofer surrounds, you cannot use my design. Large woofer excursions are also roadblocks, as are front mounted ports unless they are very large or straw-damped. Seas, Dynaudio, Morel, and others, however, manufacture quality semi-horn-loaded tweeters you can use.

Don't recess drivers so the mounting becomes weak or creates severe cavity diffraction. Make sure the port "breathes" so you can hear the grille cloth flapping on heavy bass notes. To make sure, stretch the cloth over the port. As an alternative arrangement, you can relocate the port on the rear or bottom by making a foam or felt blanket.

PREPARATION. If your system meets every requirement, measure the box's perimeter and purchase a corresponding length of rubber or foam spline/cord at your local hardware store. 3mm ($\frac{1}{8}$ ") cord looks best. Make sure you buy enough for

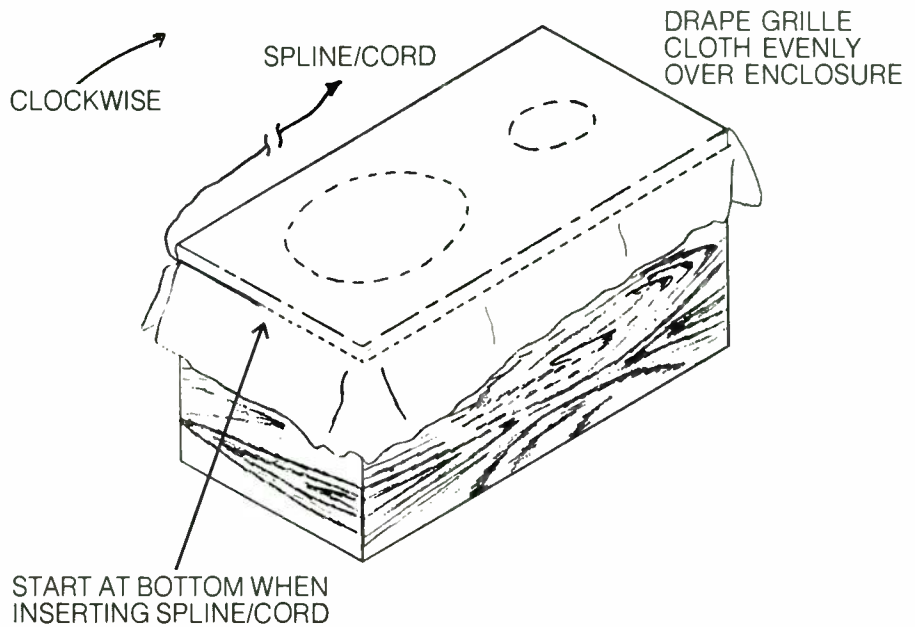


FIGURE 1: Author's drawing of the grille cloth installation.

INSTALLATION TOOL



ROLLER WHEEL WIDTH,
2-3mm

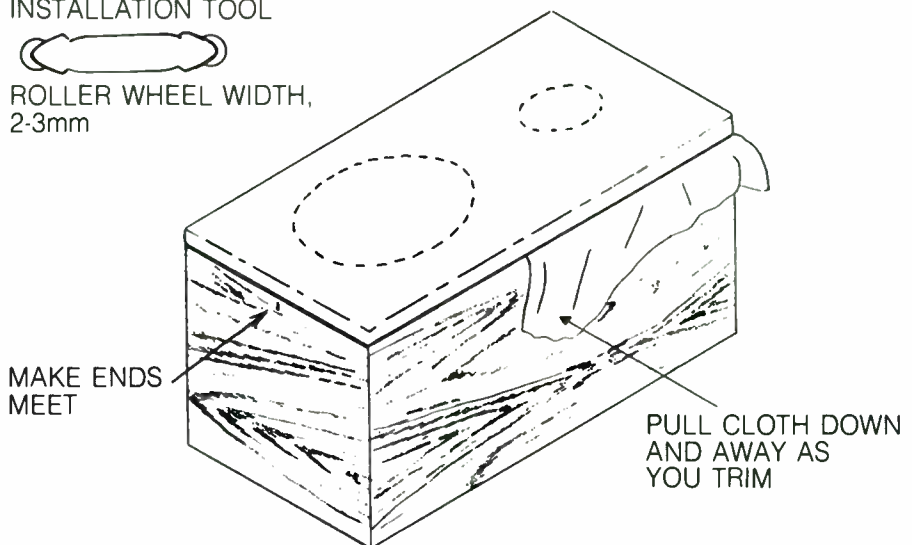


FIGURE 2: Trimming and completion guidelines.

future modifications. The cord applies best with a roller tool, which looks like a pizza cutter minus the teeth.

Purchase enough quality grille cloth to overlap your front baffle by about 8cm (3") on all sides. The grille cloth will be unusable after you remove it to make modifications, so buy enough material for future plans. (To make your modifications and crossover fine-tuning much easier, I suggest you run quality wire to the drive units and mount the crossovers on the outside.)

Use a table saw or router to cut a small groove, about 25mm (1") from the front baffle, on your enclosure's sides, top and bottom panels. Protect the enclosure with masking tape and newspaper before you slide it over the saw table. A standard $\frac{1}{8}$ " saw blade at a depth of 5mm ($\frac{7}{32}$ ") will make an adequate groove. The 3mm ($\frac{1}{8}$ ") spline/cord will fit well with a slight tension and will hold the cloth securely. For thicker splines, use a series of cuts, a dado, or a router. Make certain the groove is the same width as the spline's diameter. If the groove is too wide, it will not hold the cloth securely. If it is too narrow, the spline and cloth won't fit.

Be careful if you cut the groove on a table saw. Keep the front baffle against the fence at all times. When you're finished, paint or shellac the groove to strengthen particle board. (I do not recommend this design for enclosure panels less than 12mm ($\frac{1}{2}$ ") thick.)

Use a router or sander to radius the front baffle edges. A vibration/palm sander worked well for me. To roughly radius a free-front baffle, and to considerably reduce sanding time, make small angled cuts on a table saw.

INSTALLATION. To install the grille (Fig. 1), carefully follow these steps:

1. Place your enclosure on its back on a sturdy surface.
2. Before proceeding further, be certain you are satisfied with your system's performance and modifications, and make sure all screws are tightened.
3. Drape the new grille cloth over the front baffle, allowing equal overlap (about 8cm [3"]) on all three sides.
4. Use masking tape to fasten the cloth on top. Then, tape both sides to the enclosure walls, leaving small uncovered areas around the corners.
5. Insert one end of the cord in the groove, beginning at the center of the bottom panel and proceeding in a clockwise pattern.
6. Run the roller tool or the edge of a standard slot screwdriver along the length of the cord until it is fully in place.
7. Leave a 5-8cm (2-3") space before each of the four corners. Pull the cord slightly with one hand, and with the other, pull the grille cloth down and away from the corner region. Keep a uniform tension and partially insert the cord into the groove. Smooth all creases in the grille

cloth, then, use the roller tool to fully insert the cord around the corner. Follow this technique for each corner.

8. For the side panel, pull the cord along the entire side dimension and temporarily clamp it to the corner. Then, use the roller tool to fully insert the cord along the entire panel, leaving a small space preceding each corner. Follow this technique for the top and other side.

9. When working on the second long side, be sure the grille cloth is tight along its length. For the best appearance, try to keep the cloth "grain" straight. The cloth should be sufficiently "springy" to the touch.

10. Insert the remaining cord on the bottom panel until it meets the other end (Fig. 2). Carefully cut the excess cord and use the roller tool to fully insert the cord for a flush end-to-end result.

11. Smooth all corners, then carefully run the roller tool along the entire perimeter to be sure the cord is fully inserted.

12. Using extreme care, trim the excess grille cloth with a small sharp blade, pulling the cloth away as you trim so you get a clean finish.

CONCLUSION. Though this design is not suited for every loudspeaker system, you may be able to circumvent potential problems by modifying my idea to meet your needs. With this design, you can dramatically improve your system's imaging and retain protection and aesthetic appeal without a conventional grille frame.

Carmine Gitto
Thornhill, Ontario L4J 1A5

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Word of mouth helps us grow, and our growth means a stronger publication that can do more of the things that need doing in the pursuit of better speaker systems. If you have friends, associates, relatives or even enemies who share your enthusiasm for *SB*, either let us send you prospectuses to pass along to them or tell us their names and addresses, and we will send the word along. THANKS.

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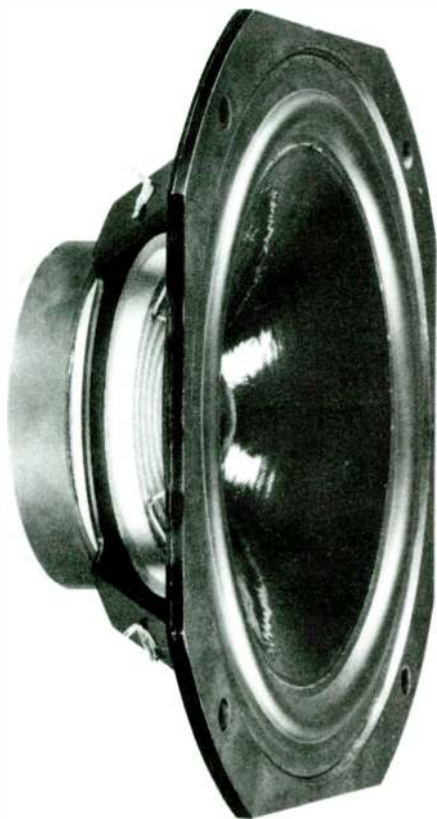
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Kit Report

Focal Model SW35 Subwoofer

mid-low frequencies. The result is less intermodulation and Doppler distortion.

The second factor has nothing to do with the subwoofer itself, and is only involved when the system is bi-amplified. In a normal system, the spectrum of frequencies is separated by passive components connected to the speaker drivers, and the system has a single amplifier for each stereo channel. You can set the relative level of the high and low frequencies by adding resistance in series with

one of the drivers. Sometimes, variable resistance is provided in the form of an L-pad.

In a bi-amplified system, the bass is separated from the rest of the music by an active filter located between the pre-amplifier and amplifier. The signal level is set with a variable resistor in the active crossover, while the subwoofer has a separate amplifier dedicated to it. In any case, the advantages of a separate bass amplifier are lower intermodulation dis-

I must admit, I have been a fan of subwoofers longer than they have been called subwoofers! Over the years, I have built many speakers; some very good, and some not so good (we won't talk about the failures.) I have tried many designs, but I always come back to subwoofers. I built my first pair in 1967 to augment the bass of a pair of my "Sweet-Sixteens." I used a passive crossover for a couple of years until I tried this wonderful thing called bi-amplification, and I have had an active (electronic) crossover in my system ever since.

Contrary to intuition, a subwoofer's job is not to produce more bass. A well-designed unit will afford a deeper bass extension without affecting the level of the mid and upper bass. Even this, however, is not the primary benefit of using a subwoofer. Let's face it, there simply is not enough deep bass available on recordings to warrant the trouble and expense of adding a subwoofer to your system. What, then, is the benefit of a subwoofer? Aside from the bass extension, the advantages are an open, relaxed character and a solid foundation for the music, both of which can be felt or sensed rather than heard.

Two factors combine to provide these benefits. The first is the woofer itself. The driver in the subwoofer handles the large excursions associated with the deep bass, thus relieving the main speakers from this chore. This is significant because the mid-low and ultra-low frequencies are not present in the same driver, so the ultra-low frequencies cannot modulate the

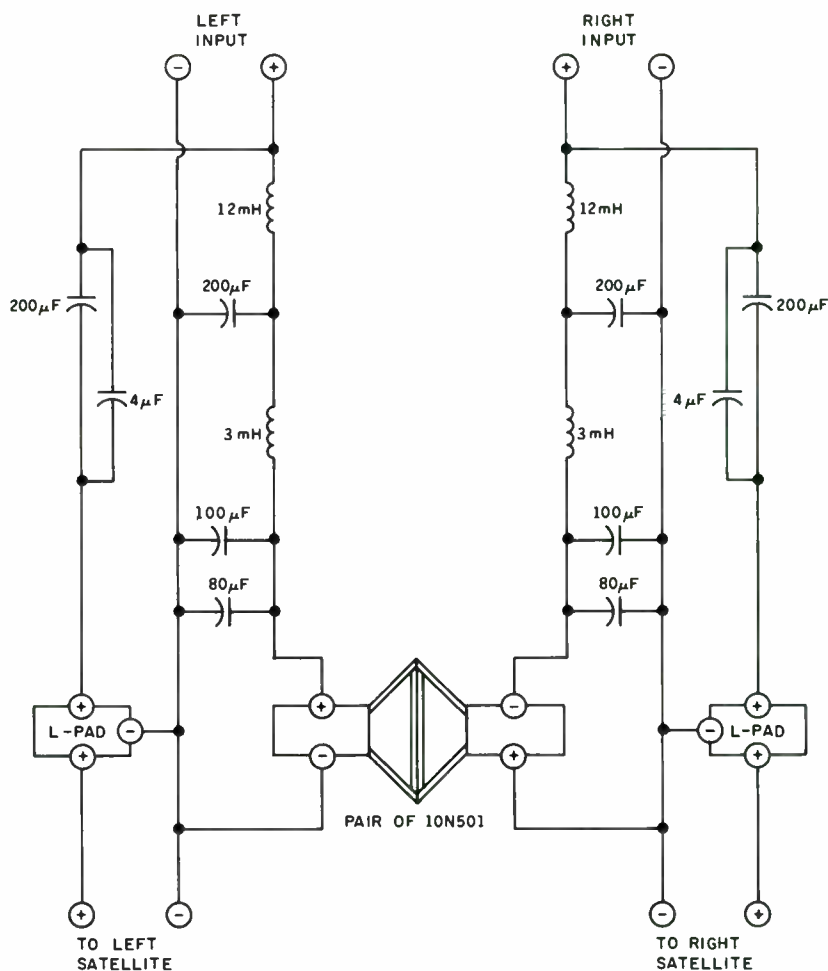


FIGURE 1: A pair of crossovers for the Focal SW35 subwoofer. The L-pads may be placed in series with the SW35 if it is more efficient than the satellites.

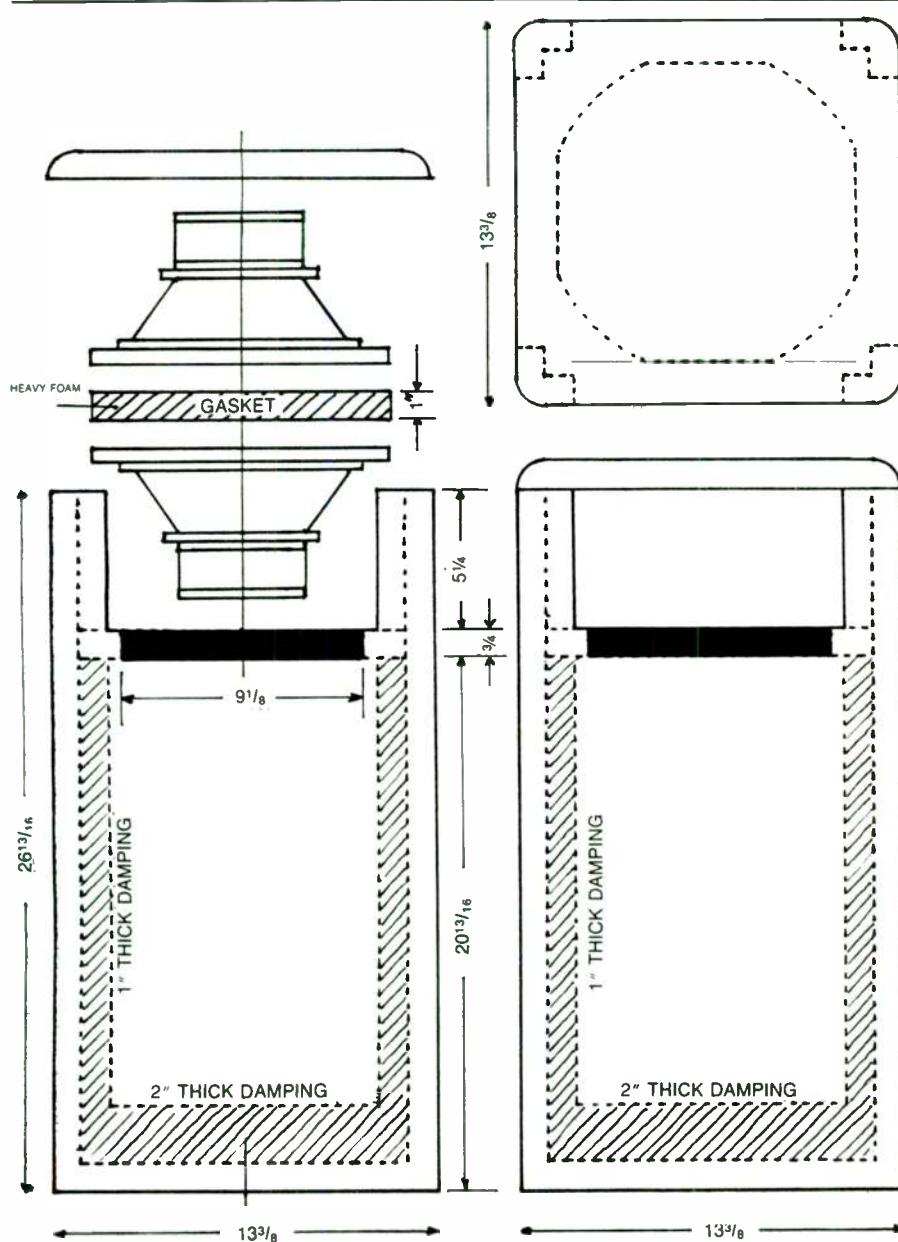


FIGURE 2: Dimensions for the SW35.

tortion, better peak power-handling, and an isolation from the effects of the massive power supply drain resulting from bass demands.

When you set the subwoofer level, it is important not to upset the balance in the bass; it is easy to get too much low bass. Adjusting the sound level of the subwoofer to match that of the main speakers is an exercise in frustration. I have tried, and tried, and tried every way I could think of to set up subwoofers: test records, white noise, pink noise, third octave noise, pure tones and warble tones. It all comes down to one thing: final adjustment while listening to music.

I have settled on warble tones to get in the ballpark, and then I fine-tune the setting by ear while listening to music. The warble tone is the only method that works for me. Some time ago, I bought

an Audio Control Richter Scale just for its warble tone generator and sound level meter. It is a fine tool at a reasonable price, and I recommend it to anyone who owns a subwoofer.

Although it goes without saying that the subwoofer itself must be capable of producing good, clean, deep bass, the prime requirement of a subwoofer is that it not degrade the quality of the main speakers' sound. Degradation can be due to two factors: the subwoofer, and/or the crossover.

One problem results from interaction in the bass region between the subwoofer and the main speaker, and it isn't always the subwoofer's fault. If the main speaker has an extended bass response, it may have sufficient output to affect the result. In this case, you must use a higher order filter in the high-pass section of the cross-

over, or cross over at a higher frequency. Also, if the filter order in the low-pass is too low, then sound from the subwoofer can affect the mid-bass. Everything must be right: the crossover frequency, the orders of the filters in the crossover, the signal levels presented to each speaker, and the speakers' acoustical frequency response.

The crossover can affect the quality when the music must pass through the crossover to get to the main speakers. This is true whether it is a passive crossover attached directly to the speakers, or if it is an active crossover situated between the preamplifier and the amplifier. If the circuit's design or the components' quality are not excellent, they will affect the music as much as any other device.

There may be two subwoofers in a system: one for each stereo channel, or the bass summed with a single subwoofer serving both channels. In theory, since little stereo information is contained in the bass, nothing will be lost by combining the channels.

In the SW35, Focal provides a method for a single subwoofer to serve both channels. Two drivers (one for each channel) share a single enclosure. The drivers are mounted face-to-face, wired out of phase, and work as a single composite driver. The advantage is the face-to-face woofers provide less distortion. You can use this subwoofer with either a passive or an active crossover. Focal recommends you use a particular passive crossover design with an L-pad to set the level.

The Focal SW35

In the past, subwoofers have been physically large. I have seen some the size of a small refrigerator. (What do you mean seen—you've owned some that big!) Recently, the trend has been toward smaller units, on the order of a couple of cubic feet. The Focal SW35 is one such as shown in their latest catalog.

The SW35 is not offered as a kit. Instead, the complete design, including the enclosure and crossover, is shown in the catalog. The drivers are Focal's 10N501, a 10" unit with a Neoflex cone and cast frame. The two drivers are mounted face-to-face and separated with a 1" Neoprene gasket.

The enclosure is a simple 1.7-cubic-foot box, optionally constructed as either a closed box or as an aperiodic enclosure. The aperiodic is a variation of a bass reflex design, with the enclosure tuned too low, and heavily damped to suppress the resonances.

Building the enclosure is a straightforward procedure, but be careful when applying the damping material to the vent in the aperiodic design. The amount is important: too much and the vent will be choked, too little and the enclosure will exhibit unwanted resonances.

The passive crossover has a third order low-pass section, and a first order high-

pass section, crossed over at 70Hz. I built a pair of crossovers shown in Fig. 1 using components provided by Focal. The low crossover frequency dictates large-valued components. The 3.0mH inductor has an air core, while the 12.0mH has a ferrite core in order to minimize the series resistance. Top quality capacitors with these values are expensive, so I made a compromise. The 4 μ F and 80 μ F units were polypropylene, but the other units were non-polarized electrolytics.

Listening to the SW35

When evaluating the SW35, I listened to many types of sources: classical, jazz, rock, popular, and even some spoken material. Some music I chose had a lot of bass, some had a moderate amount, and some had none at all. I used spoken voice and music with no bass to evaluate how the subwoofer affected such material (ideally, not at all).

I placed the main speakers on stands about 6' apart, and 18" out from the wall, with the subwoofer between them. For main speakers, I used Spica TC-50s and Focal 280 Eggs. When used with the SW35, I noticed an audible difference between the vented and sealed versions of the Focal 280 Egg. I preferred the sound of the sealed Egg because it was more accurate. When I used the vented version, the upper bass was accentuated; male voices were much too "full."

I evaluated both the sealed and aperiodic versions of the SW35. I do not favor the sealed version of the enclosure because it produced a "wooly," choked bass that was not well defined. I suspect this enclosure is too small to be used in a sealed configuration with a pair of 10N501s.

The aperiodic version of the enclosure produced clean, well-defined bass, and since there is no penalty, I recommend this configuration in all cases. The bass produced by the aperiodic SW35 had usable output down to 30Hz. It was not the deepest I've heard, but when you consider deep bass is not the prime purpose of a subwoofer, it is adequate, and very good if space is at a premium.

I tried the passive crossover recommended by Focal and the active crossover I normally use in my bi-amplified system. I was very disappointed with the sound from the passive crossover. The bass was all right, but in every case and in every configuration, the main speakers' overall sound was adversely affected. First, the sound had a "hard," "strident" character. Second, the sound stage was ruined. The sense of "being there" was lost.

I think the poor performance is due to a number of factors. I suspect the electrolytic capacitors have a detrimental effect, even though the high-pass section is bypassed with a polypropylene unit. The high-pass filter is first order, which may allow for some interaction in the bass. The subwoofer and the main speakers' sound levels are balanced with an L-pad.

As well as attenuating the input, an L-pad adds a resistance in series with the speaker, affecting the Q of the speaker.

I would guess that although it's theoretically possible to design a proper passive crossover for a particular subwoofer-satellite system, it's impossible to design an adequate "generic" passive crossover for any satellite and subwoofer. Remember, I admit to being a bi-amp bigot.

The sealed version of the Egg and the Spica TC-50 both mated perfectly with the SW35 when used in a bi-amplified system with an active crossover having third order high-pass and second order low-pass filters that cross over at 100Hz. With both of these speakers, the music opened up and had a nice, relaxed

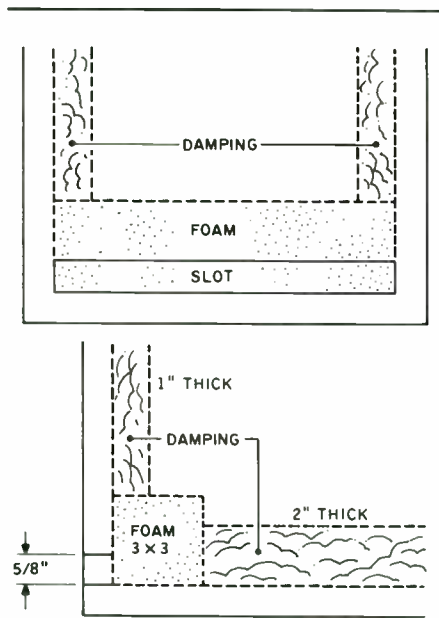


FIGURE 3: The aperiodic load option. Use open cell grey foam, and fiberglass insulating material for damping.

character. The music sounded clearer and seemed to have better separation between the bass and the upper registers. The bass was strong, providing a good foundation for the music without dominating the mid and upper bass. In short, the result was what I would expect from a good system with a subwoofer.

Conclusion

I heartily recommend the SW35 to anyone with a pair of high-quality small speakers and limited space. The SW35 did an excellent job as a subwoofer when used with either the Spica TC-50 or the sealed version of the Focal 280 Egg.

If you are considering adding a SW35 to your system, I suggest you use an active crossover. In particular, I cannot recommend Focal's passive crossover, and in general, I believe a good active crossover would provide better results than

any passive crossover. Old Colony and others offer many electronic crossover and amplifier kit choices.

I am sure once you have experienced the sonic improvements a good subwoofer can provide, you will never be without one.

David W. Davenport
Raleigh, NC 27615

1. Here is a question for the trivia buff: Who coined the term "subwoofer," and when?

Focal America, Inc., replies:

Designing a speaker comes down to making the best choice among various sets of compromises. Our goal was to offer to those who have little space and (maybe as a consequence) compact speakers but great aspiration for quality, a bass component which would fit into the same concept.

The SW35 is a central subwoofer rated at 91dB at 1 meter when receiving 1W from each channel (or a total of two times 1W into 8 Ω). As such, it is a natural match for small speakers rated up to 87-88dB/W/m.

The SW35 has been designed around what we see and have studied as a "composite" driver: two 10N501s tightly coupled together, which are really the equivalent of an authentic push-pull driver (not to be confused with any kind of "Isobarik" or similar systems which are various loading systems and not drivers). Such a "composite" driver offers absolutely outstanding linearity and control of motion, which are highly desirable for subwoofer application.

Looking at the technical characteristics (compared to the single unit) the V_{as} is more than halved while the F_{sb} and Q_{ts} are practically unchanged, thus allowing a much smaller volume for the same F_3 or a much lower F_3 in the same volume. The sensitivity is also much more than halved, and this is the trade-off: 10N501 alone = 91dB/W/m, composite dual 10N501 = 87dB/Wm.

In summary, we advise not to use any L-pad or attenuation on a subwoofer since it would change Q_{ts} and detune your system. Instead, choose a matched sensitivity subwoofer or go for bi-amplification. The SW35, as is, is the minimal version: you can improve the low frequency response by increasing the volume. Since location is part of the loading system for a subwoofer, choose between closed or "aperiodic" loading (Fig. 3.) depending upon your environment. You can use two SW35s for higher output. In this case, wire the two 10N501s in parallel for a 4 Ω "composite" push-pull driver on each channel, with the necessary changes in crossover component values.

We are currently working on other designs using composite push-pull drivers, and we'll be glad to share our experiences with you. Please feel free to contact us.

As mentioned in the last issue of SB, the new Egg enclosure that was being developed in California is now available. It is made of fiberglass and loaded with resin and silicate

Continued on page 52

OLD COLONY CLOSEOUT

Due to decreasing demand for the following items, Old Colony Sound Lab is offering them at a reduced price. Limited quantities are available and there will be no more after they're gone. First come first serve while they last. Now is the time to make that special purchase you've been meaning to.

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KJ-7: VTVM BATTERY ELIMINATOR KIT [4:78]

All the parts needed to build a battery eliminator into your vacuum tube voltmeter (VTVM). Not only does battery replacement become a thing of the past but the ohmmeter accuracy and measurement repeatability are greatly improved. The small circuit card (2¼" x 1½") obtains its power from the VTVM filament supply. Its output is a regulated and filtered 1.3V.
Was **\$8.50** Closeout **\$4.25** Each

KP-9: TANGENTIAL TRACKING TONEARM [4:82]

Conventional tonearm design is a compromise that in the end produces appreciable error and distortion. A properly designed 9" tonearm shows a tracking error of 2.3°. This error results in a distortion greater than 0.7%. With age and mechanical wear this error and the distortion it causes get worse. The conventional tonearm length and consequent mass are also a problem in low frequency mechanical pickup. This kit allows the builder to replace just the tonearm mechanism in his or her turntable leaving the original platter and its drive. The tracking servo in this design uses an optical sensor to keep tracking error below 0.2°. Another benefit of tangential tracking is the shorter tonearm length of 7¼". The kit is complete except for the servo motor (a readily available cassette motor may be used). A detailed article reprint is included.
\$160

KB-7: STEREO VU METER CIRCUIT [3:71]

This kit is an inexpensive way to add a stereo volume unit type metering system to audio equipment. The circuit uses an operational amplifier and precision components to compensate for the meter movement's ballistics. The result is a meter with more easily read peak indication. The kit is complete with all parts, meters (horizontal type, 1¾" x 1⅜"), circuit board (2" x 3") and an article reprint.
Was **\$23** Closeout **\$11.50** Each

KL-5: WILLIAMSON STEREO BANDPASS FILTER [2:80]

Reg Williamson's design creates two sonic "windows" extending from 20Hz-15kHz. With the components supplied the roll-off above and below the window is 24dB/octave. In the extensive article reprint Williamson describes the circuit and ways of customizing it. This unit requires a unipolar regulated supply of 18V @ 22mA. The kit is complete with all parts, board (3½" x 4"), ICs, precision resistors and capacitors. For a suitable power supply see the power supply section.
Was **\$35** Closeout **\$17.50** Each

SBK-D1: NEWCOMB MARK 1 PEAK POWER INDICATOR [SB 1:83]

This kit allows you to add to each speaker in your system a self-powered peak power indicator. The indication is the flash of an LED (typically located behind the grille cloth) when the instantaneous power across the speaker hits a programmable peak. Programming is accomplished with a single resistor over the range 5W-100W. Comes with all parts, a circuit board (2" x ¾") and a detailed article reprint.
Was **\$7** Closeout **\$3.50** Each

Was Two for **\$11** Each Closeout Two for **\$5.50** Each

CIRCUIT BOARDS

C-1: WILLIAMSON OCTALIZER Components board (RW-13) 2x7" [1:72]
Was **\$4** Closeout **\$2** Each

C-3: OCTALIZER POWER SUPPLY ±18V DC. (DG-12A) 2½x3" [1:72]
Was **\$3.50** Closeout **\$1.75** Each

G-2: PETZOLD WHITE NOISE GENERATOR & PINK FILTER. (JP-1) 2½x3½" [3:76]
Was **\$5** Closeout **\$2.50**

H-3: HERMEYER ELECTROSTATIC AMP BOARDS. (ESA-3) Set of three boards with plug-in edges for one channel. [3:77]
Was **\$19** Closeout **\$9.50** Set

H-6: AUDIO RESEARCH. (H-3) 4x9⅝" [4:77] For modifying Dyna Stereo 70 amplifier.
Was **\$75** Closeout **\$37.50** Each

J-1: JUNG-WHITE PAT-5 MOD. Preamp (JW33) 4⅛x2½" W/10-pin plug-in gold edge. [1:78]
Was **\$8.50** Closeout **\$4.25** Each

J-2: JUNG-WHITE PAT-5 MOD. Power supply. (JW32) 4¾x3½" [1:78]
Was **\$7** Closeout **\$3.50** Each

J-3: CARLSTROM TV SOUND TAKEOFF. (DC-1) 1¾x3½" [2:78]
Was **\$4.25** Closeout **\$2.13** Each

J-7: CARLSTROM-MULLER VTVM ADAPTER. (CM-1) [4:78] 1¼x2½"
Was **\$4.25** Closeout **\$2.13** Each

K-12: MacARTHUR LED POWER METER. 5½x8¼" [4:79] Two sided, two channel.
Was **\$16** Closeout **\$8** Each

SB-D1: PC Board Was **\$2.50** Closeout **\$1.25**

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Craftsman's Corner

Three-Way Plus Passive

This three-way system has a 10-inch woofer, with a 12-inch passive radiator, plus a midrange and tweeter. I chose the enclosure volume for optimum low-frequency response from the particular woofer; the passive radiator was mass-loaded in increments with taking successive impedance curves to determine proper added mass.

I constructed the enclosure from $\frac{3}{4}$ " lumber-core oak veneered plywood, with the exception of the back panel which is $\frac{3}{4}$ " particle board. The base is constructed of particle board and solid oak. A fir grille frame is covered with Belgian linen.

The first-order passive network is more notable for the quality of its parts than any sophistication of its

circuit. I have refined the network since building my first one, tailoring the electrical characteristics to the acoustic response of the drivers and to yield a symmetrical third-order acoustic rolloff for all three active drivers.

The low-frequency rolloff is a well-controlled fourth-order function



PHOTO 1: The author's three-way system includes a 12" passive radiator.

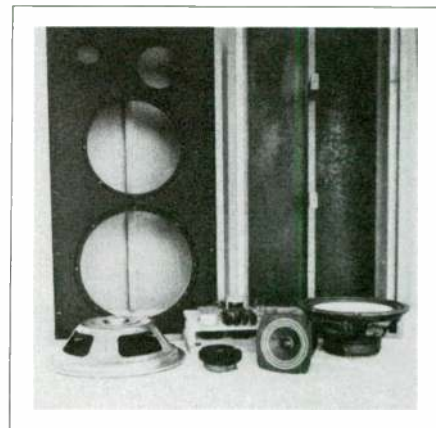


PHOTO 2: Before final assembly of the system, the crossover and drivers are ready to be installed.

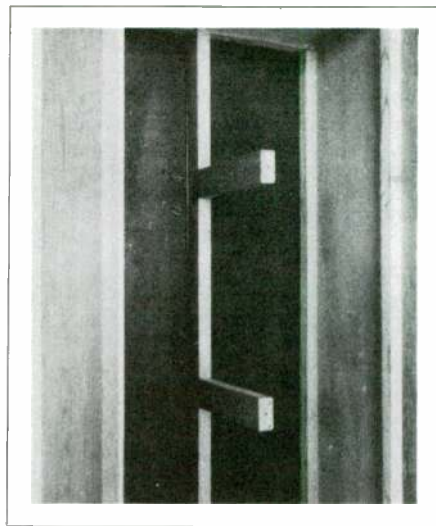


PHOTO 3: Internally, the cabinet is reinforced with corner cleats not only at the corners, but down the center of the back panel, with two front-to-back braces in place to reduce panel flexure.

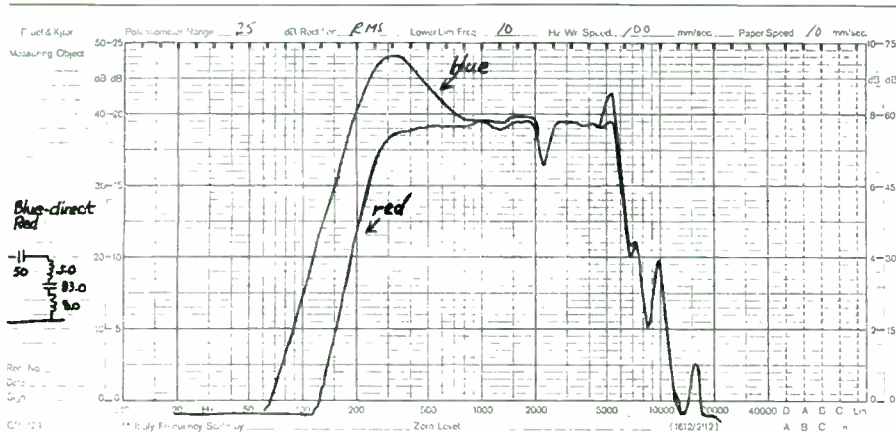


FIGURE 1



PHOTO 4: The cabinet base.

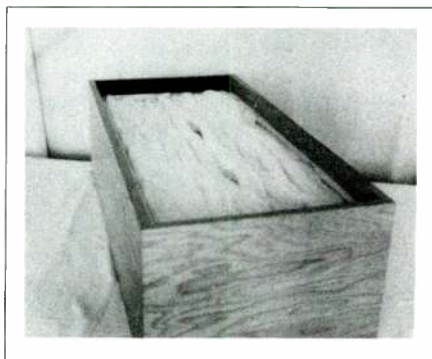


PHOTO 5: Before final assembly the speaker cavity is filled with fiberglass sheets on edge which increases the effective cabinet volume.

characteristic of vented systems, of which the passive radiator design is a special case. Figure 1 is a near-field measurement made with an Altec M30B mike of the later, enhanced version of the crossover, showing the response of the midrange driver only, without the high-pass section.

The pressure/amplitude response in a relatively dead room (T_{60} of 0.2 second at 1kHz) is ± 3 dB from 37Hz-18kHz measured at 1M from the midrange driver axis with pink noise input and a B&K microphone with $\frac{1}{3}$ -octave filter set. The speaker system is well away from the walls of the room for this measurement.

Douglas Greenfield
Mill Valley, CA 94941

ABOUT THE AUTHOR

Douglas Greenfield learned his loudspeaker ABCs working for Analog Speaker Systems in Gainesville after attending Florida Presbyterian College in St. Petersburg. He has since moved to San Francisco where he works for Dolby Laboratories. He is a long-time subscriber to Audio Amateur and Speaker Builder and a member of the Audio Engineering Society.

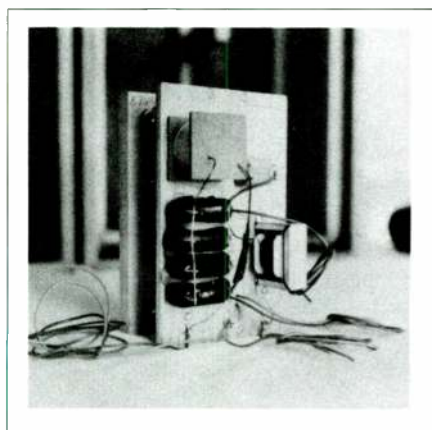


PHOTO 6: The original passive crossover network is a simple 6dB/octave device which has since been enhanced to produce better results. See Fig. 1 for a measurement of the midrange driver response.

Editor's note: Mr. Greenfield prepared and sent us his manuscript a good while ago and we have been systematically encouraging him for many months to expand this Showcase submission into a fully detailed article. If you are interested in seeing a full-scale presentation, drop me a postcard. Perhaps together we can be persuasive.

—E.T.D.

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GOLD RIBBON OMISSIONS

Two small gremlins showed up in my article, "A Gold Ribbon System" (SB 4/86). The first is near the bottom of page 16, middle column, where the equation $\alpha = 1 + P/P_a$ should have been $\alpha = \sqrt{1 + P/P_a}$.

The second is on page 18, first column, first paragraph under "Crossovers." The last sentence contains the phrase 2.5mSec delay. It should have read .25mSec.

Duke LeJeune
New Orleans, LA 70118

REDUNDANCY IS BEAUTIFUL

Lou Garner (SB 3/86, p. 44) did not regard the liter issue a little thing in my small table for cabinet computations (SB 1/86). But since the US has been using metric for a relatively short time, I considered the redundancy illustrative (that may have been a mistake since I'm not trained in teaching techniques).

This is a perfect example of the risks of participation. It is also a reminder that reader interest and knowledge varies.

Mr. Garner broke the ice with his letter. I hope he will follow through with more contributions.

Carlos Bauza
San Juan, PR 00936-1220

WHAT ABOUT LOADING EFFECTS?

I have been following Mr. D'Appolito's advice on using multiple woofer systems to increase power-handling and sensitivity in the parallel method.

I would like to build similar systems for my friends, something along the line of Connol Reid's system of two 8" woofers (SB 1/86, p. 48), but what about the loading effects on the amplifier (something which hasn't been discussed in depth)?

Many amps don't like to drive a low impedance load less than 3 Ω , and will tell you so either by shutting down, or worse, by burning out.

Even if you bring the impedance up to an acceptable level by adding a series resistor (which decreases sensitivity somewhat and causes the V_b requirements to increase), what happens to the impedance phase angle near resonance?

Audio magazine places great significance in phase angle measurements. They urge using only high quality amps to drive such largely capacitive loads. When does a speaker become potentially harmful to an amp? Do paralleling speakers cause a larger capacitive load and, if so, how much is too much and how do I measure it?

I wish to compliment Mr. D'Appolito on his well-written articles which have cleared up many mysteries for me (especially driver sensitivity). I'm still wondering, however, how to determine the sensitivity of a pair of dual voice coil woofers connected in series or parallel.

For instance, consider a DVC driver rated at 90dB @ 1W @ 1m, and each voice coil is 8 Ω . If I paralleled the voice coils (4 Ω) and then connected another identical driver in series with it so the end result is 8 Ω , what will be the total sensitivity when driven by 1W?

I presume if I first connect the voice coils of each driver in series (16 Ω) and then place both drivers in parallel, the result will be the same as the above. Is there any advantage to using one particular connection?

David Long
Dalton, GA 30720

Contributing Editor D'Appolito replies:

I have no general answer to your question about amplifier/loudspeaker compatibility. Each amplifier design must be individually examined to determine its load limitations. Concerning capacitive loads, however, most loudspeakers become capacitive [i.e., display negative phase angles] at some point in their frequency range.

Conventional dynamic woofers, for example, are usually capacitive in the octave or two above resonance. A capacitive load on an amplifier is not, in and of itself, harmful. Impedance magnitude is also important.

If the impedance is both low and highly reactive (large phase angle), it can cause excessive power dissipation in the output stage and/or activation of protection circuits. Paralleling two drivers will decrease the capacitive load impedance, but will also decrease the resistive portion of the load so the phase angle will remain unchanged. My satellites are capacitive in the region from 75-250Hz, as shown on the impedance plot in my SB 4/84 article. At no time, however, does the load fall below 4 Ω . This does not constitute an unreasonable load for any well-designed amplifier.

The specification for a DVC woofer sensitivity is a little confusing. A 90dB/watt @ 1m sensitivity can be thought of as being obtained by putting 1/2W into each 8 Ω voice coil, whether the voice coils are connected in parallel or in series.

Paralleling the two voice coils for 4 Ω will still produce a 90dB power sensitivity. Using the two DVC woofers will increase power sensitivity to 93dB by using either connection you have suggested, as long as the drivers are well-matched.

If any mismatch between the two drivers occurs, I would series the individual driver voice coils for 16 Ω and then parallel the two drivers. This connection will ensure the best load sharing between the two drivers.

SEASONING THE EGG

I enjoyed reading Clay Allison's alternative construction technique for an egg-shaped enclosure (SB 3/86). I believe his approach is easier than mine, but I recommend greater thickness for the back and the baffle board. My experience suggests extra rigidity in any speaker enclosure is usually rewarded with lower levels of perceived distortion.

I have used my original eggs steadily since the article "The Egg and I" (SB 2/84) was published. I have made a number of refinements to the networks and to my stands, but my most significant improvement was placing a 1x4" x6" rectangular, dense, felt pad over the tweeter. I cut a circular hole in the center of the rectangle for the tweeter's dome.

Since the enclosure is egg-shaped, I didn't think I would notice much dif-

ference. On the contrary, the felt pad reduced treble distortion, improved transient detail, and stabilized the stereo image.

I wonder how many speaker builders know the history of the egg-shaped enclosure? How old is the idea? Who built the first working model? When was the Focal 280 developed?

In the fifth edition of G.A. Briggs' *Loudspeakers* (October 1958, p. 214), the author describes an experimental spherical cabinet made from 2" polystyrene. Though I found no references to egg-shaped enclosures, I encourage historians to fill us in.

Rion Dudley
Seattle, WA 98119

STRETCH TO FIT

I have read Bob Ballard's two-part article, "An Active Crossover With Phase Correctors" (*SB* 3, 4/82), and I have a number of questions:

1. I wish to build a three-way system with subwoofers and satellites, crossing the transmission-line subs at 100Hz to a Dynaudio 7" woofer-mid (this driver is fabulously flat from about 70Hz to 5kHz) and then into the tweeter at 3kHz. My theory is the very linear woofer-mid would completely cover the crucial 100Hz-3kHz range. Because the subs are physically separated from the satellites, the crossover must be as low as possible.

Does changing the nominal frequencies from 400Hz to 100Hz and separating the woofer from the primary baffleboard invalidate Mr. Ballard's whole concept? I realize these changes alter his system considerably, but can I modify his design to meet my needs? Would the rumble filter seriously collide with the 100Hz low-pass?

2. Does the phase alignment of the mid-driver and tweeter obviate the need to physically stagger the tweeter? In the past, I tilted the enclosure approximately 30% back. Is this moot with Mr. Ballard's design?

3. Are the op amps (531 and 4136) still sonically valid? Have they been improved by newer models, and if so, how do I employ them?

4. I want to achieve my final goal of the most nearly phase-correct 24dB per octave crossover at the nominal frequencies of 100Hz and 3kHz for a sub and satellite system. If Mr. Ballard's design can be altered to fit my needs, what must I do?

James Nobel
San Francisco, CA 94122

Mr. Ballard replies:

At the very low frequencies encountered in a subwoofer, and since your system is an oc-

Continued on page 50

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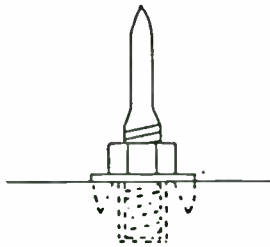
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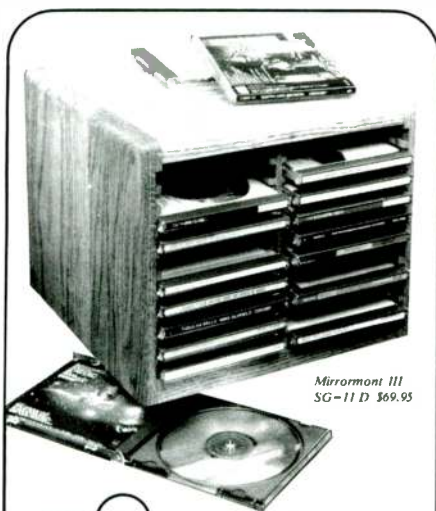
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Continued from page 49

tave or more removed from the 100Hz crossover (I assumed subwoofers would be operating in the 30Hz range), you should have no problem changing from the 400Hz crossover while retaining the bass boost and rumble filter.

Tilting or physically repositioning the tweeter achieves alignment by time, which is slightly different than phase alignment. By electronic means, time aligning can accomplish the same thing as phase alignment. Alignment by time, however, is a rather coarse or inexact correction for the amateur. Manufacturers who have the resources to buy the expensive equipment needed for delay spectrometry are able to acquire better accuracy in this technique. If you are tilting the speaker to align for time difference, it is a moot exercise when using phase correction. For other acoustical reasons, such as partial elimination of echoes and standing waves, I tilt my complete speaker assembly back about 15°.

The op amp 531 is still sonically valid. The TL075, however, is a BIFET quad op amp which is a great improvement over the 4136 and is pin-compatible with the artwork.

You can alter my design to achieve any crossover you desire. The choice of fourth-order filters for the crossover not only achieves in-phase output, but also provides a very narrow band for the crossover region in which two drivers simultaneously contribute output. Phase correction applies mainly to this narrow band. Outside the band, phase correction has no relevance, I believe, and is not required. (Note: Time Align® is a registered trademark.)

SPEAKING FROM EXPERIENCE

After reading articles in SB 3/86 by Michael Shea (Gold Ribbon design) and John Cockroft (push/pull speaker configurations), I was inspired to write about my experiences with both designs.

I received the original Gold Ribbon Concepts advertising packet just about the time I was working up the courage to make my first pair of speakers. I was considering a system based on either the Jordan modules or the Strathearn ribbons. I wanted a high resolution system, but I did not want to spend thousands of dollars on a ready-made pair. Though I was willing to risk making them myself, I felt uneasy and was not sure which way to go. Because of my small listening room's size, crowded furniture placement, and my wife's modest tolerance for larger speakers, I needed a satellite system in

which the upper range drivers would be as narrow as possible.

At the time, I had an M&K satellite-subwoofer system. Wide ribbon or electrostatic speakers which must be three to four feet away from the back wall, were out of the question. Gold Ribbon's drivers, however offered a narrow device which I could put in a cabinet in monopole design, allowing speaker placement close to the back wall. I was intrigued but scared to death about paying \$1000 (now \$1600) for a pair of drivers which I had never heard.

I called Audio Concepts, a distributor for the Golds, and they told me the ribbon drivers were very good, and that I would be happy with them. I felt like a gambler betting on the roulette wheel, but I sent away for the information packet and soon placed my order. This is where I wish to confirm Michael's experience—I never would have made such a risky purchase had it not been for the incredible patience and helpfulness of Alan, one of Gold Ribbon's engineers. Based on the dimensional limitations I presented to Alan, he completely designed my satellites. The cabinets are 5' x 14" x 7" trapezoids with two chambers, one for the Golds and one for the twin drivers. The latter cover from 45 to 300Hz, since I chose the lower cutoff frequency for the Golds. The low frequency drivers are in a transmission line-style (TL) chamber with the TL coming up the inside of the cabinet like a chimney and opening at the top. I planned to use subwoofers for the audio spectrum below 100Hz.

Alan helped me every step of the way: cabinet construction hints, crossover design, wiring, speaker placement and more. He even supplied the acoustic foam for the cabinet and the ferrite coils for the crossover. Alan and I talked so often on their 800 number, their phone bill probably ate up any profits from my purchase.

What was frustrating for Mr. Shea and me (and I'm sure for 20 or 30 others who bought Golds early) was during the summer of 1985, Gold Ribbon Concepts tried to increase production, but in doing so had many problems increasing the throughput of the Gold's vacuum deposition. As a result, they lost several production batches, and it took 16 weeks to get my drivers.

In the meantime, I finished the cabinets, and purchased the Dynaudio 17W75s (which were recommended at the time). By the time I got my drivers, the plastic used for the ribbons had been changed from Mylar to kapton, a type which could handle the tremendous heat generated during the deposition process. The benefits include a thinner ribbon which has even less mass, supposedly better transient response, and more importantly, another 3dB of sensitivity. Suddenly, my Dynaudios did not match the Golds.

Drivers which match the Golds in the

sub 400Hz region are the Focal 7N501s. The Focals would not fit easily into my \$580 custom-built cabinets. To get around this mismatch problem, I biamped the satellites and used a GSI electronic crossover with its independent balance controls to adjust each driver pair's relative volume. The GSI has a third channel at 70Hz for the subwoofers. (For the record, I use a P.O.O.G.E.'d Moscode 300 for the Golds, a Berning EA230 for the Dynaudios and, most recently, an Adcom 555 for the new push-pull subwoofers.)

After using the Gold Ribbon driver-based satellites for 10 months, I was ready for the final addition to my new system—a fast, clean replacement for the M&K subwoofers. I asked Alan to recommend either a subwoofer system or drivers which could match the satellites and still meet my size requirements. He said he had an idea and would get back to me in a week or so. To my amazement, the next week, he sent me complete plans for building a subwoofer system.

Each subwoofer was in an enclosed 6 cubic foot box with the corner taken off at a 45° angle. The drivers are mounted on that plane. He used an acoustically coupled, push/pull pair of Scan-speak 16" drivers which face each other. The outside driver's magnet and cone point into the room. This reduces the box volume, producing low, clean bass.

To lower box resonance Alan suggested using ¾" MDF with 2 x 4s screwed edge-wise to each inside plane of the enclosure. Finally, he suggested I coat the inside with about ¼" of roofing cement. I added adjustable braces side-to-side and front-to-back, made with cold water pipe and ½" carriage bolts, plus a nut and large washer for each bolt. The carriage bolt is actually loose at each end of the pipe until, by turning the nut, the bolt lengthens against the washer and presses against the speaker enclosure's walls. The braces markedly reduce cabinet resonance.

My hat is off to Alan and Gold Ribbon Concepts. Their ribbon driver is detailed and smooth. As the purchaser of my M&K subwoofers said, "They have the nicest top end I have ever heard for violins." (He is a professional musician and a happy Quad 63ESL owner.) The Golds' ability to image and project a truly 3D soundstage is remarkable. The subwoofers give detailed, fast and very low bass—a good match for the Gold Ribbons.

Knowing that the -3dB point of my new subwoofers is 24Hz, I realize my previous subwoofers couldn't have gone down to the claimed 20Hz without plenty of distortion. The difference is amazing, and the new subwoofer pair addition actually cleaned up the midrange.

The speaker system is far superior to my electronics now and, consequently, reveal any slight change I may make. The only negative aspect is, because I used only one pair of drivers, they are not truly line source speakers. The Gold 3.0s are

only 32" long. Consequently, the spectral balance is sensitive to vertical ear placement relative to the middle of the ribbon drivers. The sound stage "locks-in" as you move in and out of your seat. Horizontal movement does not distort the focus as much as vertical movement. As it is, I sit off-center from the two speakers, because the best seat is occupied by my woodstove.

Also, I had to tilt both speakers at exactly the same angle toward or away from the listening position. One of my speaker cabinets tilts forward about one degree more than the other. This difference is enough to reduce the sound stage focus and throws the apparent balance off-center

in spite of preamp balance adjustments. I added a carriage bolt (the carriage bolt is a great invention) adjustment to the speaker's platform, which is just an oak board on the cabinet bottom equipped with four carpet-type casters. I added wood spacers beneath the two rear casters which tilts the speaker forward. Turning the carriage bolt nut on the platform front adjusts one speaker relative to the other, achieving the best imaging.

I have yet to hear better speakers. The big Apogeos come close, but their image, to my ears, sounds more ethereal and the midrange more laid back. For overall dynamics and frequency balance, the Magnaplanar systems I have heard sound sim-

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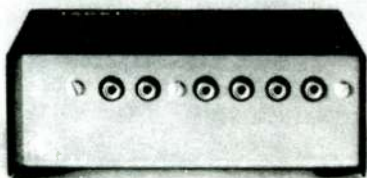
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SB Mailbox

ilar, but the Golds have much more detail and resolution. Both the Apogees and the Magnaplanars seem less sensitive than the Golds to listening position.

Stereophile gave Gold Ribbon Concepts a bad review a year ago. The review (which was before the kapton change) had little to do with the sound quality of their system and instead admonished them for their loud demonstrations at the CES.

These speakers deserve better treatment, which is why I wrote this letter about my experience with the Gold Ribbons and the people at Gold Ribbon Concepts—they're the greatest.

Thanks for a fun and informative magazine.

Chuck Belanger
Richmond, CA 94805

INTRODUCTION TO LMP

continued from page 24

5. Knittel, Max, "Impedance Compensating Crossover," *SB* 1/83, pp. 11-14.
6. Bullock, Robert, "Passive Crossover Networks, Part I," *SB* 1/85, pp. 19-22.

FURTHER REFERENCES

Boulais, Michael, "The Dynaudio: An Inexpensive Two-Way With Great Sound," *SB* 1/83.
Linkwitz, Siegfried, "A Three Enclosure Loudspeaker System," *SB* 2, 3, 4/80.
Olson, Harry, *Acoustical Engineering*, D. Van Nostrand Co., 1957, pp. 17-26.
Morse, Philip, *Vibration and Sound*, McGraw-Hill, 1948.
Hayt, W.; and J. Kemmerly, *Engineering Circuit Analysis*, McGraw-Hill, 1978.

Kit Report

Focal SW35 continued from page 44

instead of plaster. It offers the same outstanding acoustical qualities but without the mounting problems. Standard finish is glossy black. In addition, the new Egg comes with all necessary hardware (gaskets, plug, duct, and so on) to realize a closed or vented enclosure.

Once more, we wish to thank David Davenport for his work, and Speaker Builder for allowing us to detail our concept and bring you up to date on our progress.

Kimon Bellas

COX OFFERS MORE TIPS

I have a few comments and an addition to my article on the 2x4 transmission line (TL) [*SB* 2/86] which may reduce reader "head scratching."

Regarding design choices, the article by Schroeder (reference 2) contains his basic data, but you'll find additional interpretation of the result in a later article, "Binaural Dissimilarity and Optimum Ceilings for Concert Halls: More Lateral Sound Diffusion," *Journal Acoustical Society of America*, April 1979. My article incorrectly lists the journal as *JAES*.

To understand Klepper and Steele's article, you should first read the referenced pages (35-36) in Olson's book, *Acoustical Engineering*. Since this book has been out of print for some time, another source for the radiation patterns of a series of point sources is pp. 101-102 of Olson's *Music, Physics, and Engineering*, which is still available from Old Colony. My objective with the 2x4 was to provide the most uniform sound pressure distribution from a line source in both horizontal and vertical planes of a cylindrical wavefront which is restricted in vertical dimension to the driver line source height.

Regarding driver selection, I selected the European Loudspeakers of America (ELA) 4502 for my wide-range 4" polypropylene woofer, and a coaxially mounted, well-regarded Audax 3/4" dome tweeter. ELA is not exactly a household word, even among speaker builders. It is a house brand name used by Madisound Speaker Components for a line of automotive drivers another company manufactures for them. To my knowledge, this is the only 4" polypropylene woofer with a high quality tweeter coaxially mounted.

By using coaxial units rather than separate woofers and tweeters, all the space behind the driver panel is available for TLs, and the tweeters are coincident with the woofer line source center line.

I would have preferred using a 4" polypropylene or Bextrene 4Ω driver to complement the coaxial units. I was unable, however, to locate any drivers of this description with free air resonance that came close to matching the ELA 4502. I eventually selected the Audax MHD10P25FSC (4Ω version) paper cone driver, with butyl rubber surround and die cast basket.

Under the subhead Line Stuffing Procedures (p. 16), strike out the last two sentences in the second paragraph and substitute with: "cut the Polyfil Extra Loft material into 5x16" strips." See the box titled "A Structured Tuning Method" (p. 18) for more details.

Under the subhead Exterior Finishing (p. 16), in the fourth paragraph, I mentioned using carpet faced furniture glide buttons to provide isolation and protec-

tion from the floor. The 2x4, however, should not be placed on the floor unless you normally lie on the floor when you listen to your speakers.

Remember, the high frequency sound waves from the 2x4 are cylindrical with a height of roughly 18" (driver panel height). In practice, the sound pattern is not shaped that precisely, but you'll hear the drop in high frequency response by moving your head (near the drivers) from tweeter level to several feet higher.

This also explains why the top extends over the driver panel. The restricted line source vertical radiation patterns should minimize any edge diffraction or reflection problems in the vertical plane. The details of exterior finishing, however, are

certainly up to you since the 2x4 is acoustically complete as shown in *Photo 6*.

Thomas Cox
Wilton, CT 06897

GRILLED PLEAS

I have dabbled in the art of speaker building for the past 20 years, and I've always had trouble with one part of the assembly: the grille.

My first problem has been finding suitable fabric, and the second has been fastening the cloth to the frame. I overcame the second problem by using a

double-backed tape made by 3M which is 1" wide and will hold the cloth even when it's stretched tightly.

I'm still having trouble with the first problem. I cannot find a suitable knit cloth similar to what the speaker manufacturers use. The material I end up using is a double-knit fabric, which is a bit too thick when I try to wrap it around the grille frame's corners.

Does anyone know of a supply outlet where I can get a good, thin knit fabric?

Douglas Rauer
Tacoma, WA 98422

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

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MINNESOTA AUDIO SOCIETY. Monthly programs, newsletter, special events include tours and annual equipment sales. Write Audio Society of Minnesota, PO Box 32293, Fridley, MN 55432.

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Annual subscription price \$15. Location of the headquarters or general business offices of the publishers: Old Jaffrey Road, Peterborough, NH 03458. Publisher: Edward T. Dell, Jr., Old Jaffrey Road, Peterborough, NH 03458; Editor: same. Owner: Edward T. Dell, Jr., Old Jaffrey Road, Peterborough, NH 03458. Known bondholders, Mortgagees, and other security holders owning 1 percent or more of total amount of bonds, mortgages or other securities: None.

	Average # copies each issue during preceding 12 months	Single issue nearest to filing date
Total # copies printed	10,269	10,050
Newsdealer sales	90	90
Mail subscriptions	4,700	5,035
Total paid circulation	4,790	5,125
Free distribution complimentary	163	154
Total distribution	4,953	5,279
Office use, leftover	5,316	4,771
Return from news agents	0	0
Total	10,269	10,050

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