

Speaker Builder

THE LOUDSPEAKER JOURNAL

A young girl with brown hair, wearing a red t-shirt with a gold anchor and a red and white striped skirt, stands on a wooden dock. She is smiling and holding a large, white, circular speaker cone. The speaker cone is mounted on a wooden post that has a white, fabric-like covering around its middle section. The background shows a body of water and trees under a bright sky.

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McCAULEY SOUND has begun production of their Model 6520 2" compression driver. This high frequency driver features a 150W RMS power rating, sensitivity of 112dB at 1W at 1 meter and a frequency response from 500Hz to 16kHz. The 6520 is specifically designed for commercial installations and sound reinforcement touring systems. It has a retail price of \$383 and a five-year warranty. For more information contact McCauley Sound, Inc., 13608 94th Ave. E., Puyallup, WA 98373, (206) 848-0363.

Fast Reply #KD407

SIGNET has introduced a subwoofer/satellite loudspeaker system, the SL230. The woofer has been separated from the midrange and high frequency drivers, and the compact subwoofer enclosure is dedicated solely to frequencies below 200Hz. Since low frequency sound is not perceived directionally, the subwoofer can be placed anywhere in the room and the satellite speakers, which produce the directional information, can be placed in optimum locations.

Each satellite contains a ferro-fluid cooled 3/4" titanium dome tweeter and a 3 1/2" midrange driver with rubber surround and injection molded anti-resonant basket. The subwoofer has two downfiring 6" high compliance long-throw drivers with foam surrounds and high-temperature voice coils. For more information, contact Signet, 4701 Hudson Dr., Stow, OH 44224, (216) 688-9400.

Fast Reply #KD23

CARBONNEAU, manufacturer of custom engineered loudspeakers, is offering a product line of custom designed drivers, available in three categories: 1) Polypropylene cone with 20% carbon-graphite reinforcement and a high compliant foam suspension (5 1/4"-12"). 2) Polypropylene cone with 20% carbon-graphite reinforcement and a rubber edge suspension (5 1/4"-12"). 3) Isotropic lacquer-treated paper cone with a rubber edge suspension and Kapton™ voice coil formers (5 1/4"-10"). For further information contact Carbonneau, 609 Myrtle N.W., Grand Rapids, MI 49504, (616) 456-9528, FAX: (616) 456-5648.

Fast Reply #KD392

Good News

POLYDAX SPEAKER CORP., a division of Audax Industries of France, announces the new DTW 100 TI 25 BA CAV FF tweeter, a one-inch dome tweeter with a diaphragm composed of a soft polymer with a thin coating of titanium. The titanium coating increases the strength and stiffness of the dome structure. The vented pole piece which loads into a tuned cavity on the back of the magnet reduces distortion around the resonant frequency, extending the bass end response. The new tweeter has a recommended crossover point of 1.5kHz and has an efficiency rating of 88dB SPL. For more information contact Polydax, 10 Upton Dr., Wilmington, MA 01887, (508) 658-0700, FAX: (508) 658-0703.

Fast Reply #KD45

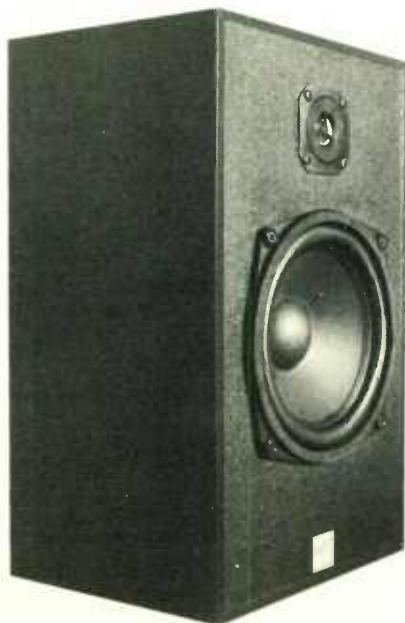


CERCA SPEAKERS announces a new omnidirectional loudspeaker, the Victoria 200, designed as an antique ceramic (raku finish) ginger jar. Manufactured in Wales by Pontypridd, the unit is marketed in the US by Asti Nikko Technology Corp. of America (ANTECA) and is a three-way speaker with an 8" cobex base, a 5" polypropylene midrange and a 1" metal dome tweeter. The Victoria 200 is approximately 36" high, has a frequency response of 36Hz to 20kHz (+3dB) and maximum power of 220W. The base enclosure is 31 liters. The unit is available in several colors, comes with an antiqued wood stand and is priced at \$2,199.95/pair.

Also available from ANTECA is the omnidirectional Cerca Hi 150 System,

two separate raku satellites that can be suspended or affixed to a wall. They can supply 200W of power from 36Hz to 20kHz, when used together. One satellite—11 7/16" W by 8 1/2" H—contains a 5" bass/midrange and a 1" dome tweeter which reproduces the 100Hz to 20kHz range. The second enclosure—12 2/16" W by 29" H—holds two 6 1/2" bass drivers in push-pull. Suggested retail for the system is \$999.95, for the midrange/tweeter (Cerca Hi 65) \$399.95, and for the bass subwoofer system (Cerca 150) \$599.95. For more information contact ANTECA, 5816 Corporate Ave., Suite 170, Cypress, CA 90630 (714) 821-3875.

Fast Reply #KD452



DANA AUDIO has been selling the Model 1 speaker for nine months. This speaker incorporates Audax 3/4" titanium tweeters and 6 1/2" woofers. Efficiency rating is 90dB, 1W/meter. They can handle peaks over 100W while retaining a flat response down to 63Hz. The components are mounted in an MDF enclosure, 14 3/4" H by 8 3/4" W by 7 1/2" D. The cabinet is finished in a black, scratch resistant, laminated vinyl.

The Model 1 comes with a three-year warranty and a 15-day money back home trial program and is available only direct from Dana Audio at a price of \$155/pair. For more information, contact Dana Audio, PO Box 1, Austin, TX 78767, (512) 251-7701.

Fast Reply #KD449



DYNAVOX ELECTRONICS has introduced five new models of home audio speakers from an 8" two-way through a 15" three-way, retailing from \$99.95 to \$269.95. The DP-1200A is a 12" three-way bass reflex system which will absorb maximum input of 240W (140W RMS) and will hit 32Hz-24kHz frequency response. For more information contact Dynavox Electronics, 248 N. Puente Ave., City of Industry, CA 91746, (818) 336-0516.

Fast Reply #KD408

Bill Fitzpatrick of **SITTING DUCK SOFTWARE** has written a new, menu-driven version of Ralph Gonzalez' Loudspeaker Modelling Program. SD-LMP is written and compiled with QuickBASIC and is presently available for IBM PCs with CGA, EGA or Hercules graphics capability. Improvements include: fast data-field entry of driver and crossover models, high-resolution LMPG-style graphics output of predicted frequency response, easy file selection, on-screen crossover configuration diagrams, error handling and compatibility with existing LMP/LMPG files. The program is available on 360k 5¼" floppies from Old

CASP'er (Computer Aided Sheet Planner) is the second version of Plywood Planner, a program from **ROGER** and **RYAN DRUMMOND** that generates layouts for anyone cutting sheet material into pieces for specific applications. This program is intended to give the user a quick visual aid in determining a usable layout for all types of sheet projects. CASP'er is IBM compatible, requires 185K of memory and can be used with CGA color graphics with color or monochrome monitor. It is priced at \$89.95. Plywood Planner is available for the IBM at \$49.95 or for the Commodore 64 at \$39.95. For more information contact Roger and Ryan Drummond, 10 Pike St., Herminie, PA 15637, (412) 446-0159.

Fast Reply #KD458

Colony Sound Lab, PO Box 243, Peterborough, NH 03458 for \$49.50. If you already own the earlier LMP or LMPG version, you can obtain the upgrade for \$39.50 by returning the original disk or a dated sales receipt. For more information contact Sitting Duck Software, PO Box 130, Veneta, OR 97487.

Fast Reply #KD404

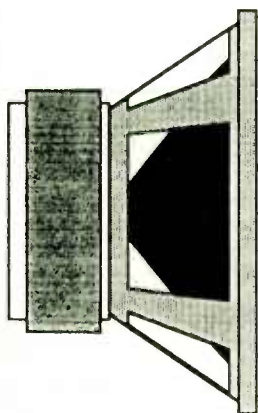
ACOUSTIC SCIENCES CORP. has introduced the 11" Super Trap, a high-efficiency broadband sound absorber, as an addition to its line of Tube Trap acoustic control products. The Super Trap features extended bass response and enhanced damping of standing waves into the 70Hz range. Specified for rooms with an eight-foot ceiling, they control fundamental floor-to-ceiling resonances often accentuated by dynamic speakers and subwoofers. An internal reactive acoustic circuitry achieves self-regulating absorption. A built-in patented sound diffusion panel adjusts to scatter mid and high frequencies. Available in standard (three and four foot) or custom lengths, Super Traps are covered with Guilford 701 commercial standard fire-resistant fabric. For more information on any of the Tube Traps, contact ASC, PO Box 1189, Eugene, OR 97440, (503) 343-9727, FAX: (503) 343-9245.

Fast Reply #KD280

LOUD
carbonneau
SPEAKERS

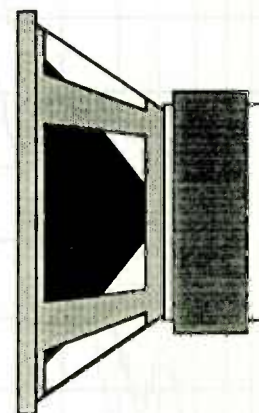
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Fast Reply #KD392

ARIA FIVE



ARIA SEVEN



ANOTHER D'APPOLITO LOOK-ALIKE OR...

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

Joseph D'Appolito



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

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About This Issue

James Lin lives in a small apartment and wished for good bass to match his venerable pair of Quad electrostatics. The Hartley 24" driver with quads may seem an odd couple, but if the big cone is configured as a dipole, Lin says the result is practical and pleasing (p. 10). If your woofer driver has no affordable incarnation, **Brian Smith's** cone and magnet tricks may work a Cinderella miracle for you (p. 22).

Canadian **Wayne Cox** likes Paradigm's 7se but was sure it could be made better. His narrative and findings begin on page 26. **Peter Hillman** gets down to the challenging details of building, installing and evaluating his monumental dual transmission lines (p. 32). For neither the faint of heart nor apartment dwellers.

Dave Davenport reports on Focal's latest "Egg" (p. 49); **Peter Muxlow** looks at some arcane technology (p. 58) and don't miss the excellent, multi-featured *Craftsman's Corner* and *Tools, Tips & Techniques* on pages 52 and 56 respectively.

This is *SB's* final 1989 issue. If your label says "XX89" in the upper right-hand corner, then your sub is up for renewal. Our first 1990 issue is coming along in just two months. You have three good reasons for renewing right away: Your first issue will arrive promptly, Old Colony will be offering a gala 45-day sale on *Speaker Builder* specials which you may miss if you delay, and you'll want to be the first on your block to see **Roger Sanders'** stunning Electrostatic/TL combo, **Bruce Edgar's** bass horn and the first segment of a powered system with driver-generated feedback. It's going to be a delicious year.

Speaker Builder

THE LOUDSPEAKER JOURNAL

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NOVEMBER 1989



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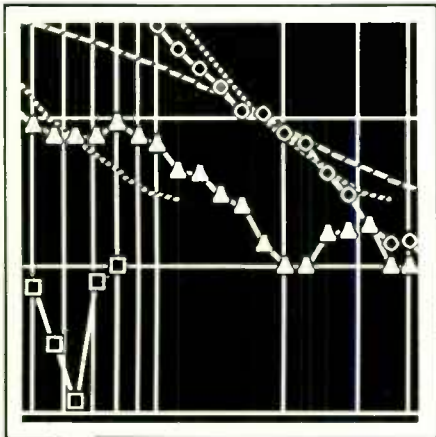
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Cover photo: Tracy Schmetterer, twelve, holds one of the 24" Hartley drivers which her father Richard manufactures in Wilmington, North Carolina. Chris Spell photographed Tracy, all 4' 11" of her, against the backdrop of Wilmington's Cape Fear river.



TRANSDUCER TECHNOLOGY

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



Cabasse

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Editorial

MILESTONE TEN

One of our contributing editors called me the other day, obviously pleased and excited because he could report another small step toward our understanding of loudspeaker technology. I don't want to steal any of his thunder, since an article will be coming to these pages early next year with the details of the new discovery.

This editor was going through one of those personally grinding situations at his workplace where the whole institution is in a near crisis over critical matters that were affecting everyone. A huge, important project was coming to a final conclusion with the typical deadlines, frayed nerves, and long hours. Into this atmosphere we sent a speaker builder's letter, the last thing, I would have thought, anyone in this editor's situation would have welcomed.

To our editor, however, it was a delicious opportunity to turn with relief from the harrowing atmosphere at work to the challenge of a reader's question. The problem, having also nagged this editor's mind for years, called for some research. Digging into references, his answer popped out quickly and with unexpected ease. And remarkably, the mathematical model of the problem, matched quite neatly with the real-world prototype.

At the time our editor called, I was thinking of this editorial. My theme is centered on our birthday: the issue you are holding completes a decade of *Speaker Builder's* publication. I was recalling the reaction of loyal *Audio Amateur* subscribers in 1979 when I announced we were moving all the loudspeaker articles out of *TAA* and into a new, separate publication.

Many readers feared the surgery would sink either one or both magazines, some doubted enough material could be found on so narrow a subject, while others suspected greed in the publisher. I confess to having had no better crystal ball about *Speaker Builder's* chances than the readers. And even I, with all my hopes, was not prepared for what happened.

Speaker Builder's subscriber list grew faster than we had anticipated; within two years the flow of articles became a flood. Most of the authors were new to us, never having written for *Audio Amateur*, even though one out of every six *TAA* articles was on a loudspeaker topic. The title evidently appealed to many highly competent scientists, whose avocation was loudspeakers and who have become our authors and editors, as well as thousands of other music lovers who were fascinated by the idea that they just might build boxes with drivers in them that sounded good.

I saw a sign recently on the side of a building in one of New York City's suburbs. It said "This is not your serendipity parking lot!" I laughed at the depth of feeling the building owner obviously conveyed and could imagine the frustration which had prompted it. The word serendipity, however, fits *Speaker Builder* like a glove. This publication is a serendipitous place which meets every other month.

What is most awe inspiring for me as publisher is the fact that our authors are not just so many containers of arcane information that is poured, in installments, onto the pages of the magazine, but each of them is pursuing a mystery whose method and clues are shaped, to a very significant extent, by the shared curiosity, thirst for knowledge and frustration of readers.

Authors are on a journey of discovery just as surely as each

reader has his or her own pursuit of sonic happiness. And what readers request stimulates the imagination and engages the skills of the authors. We have all discovered, at one time or another, that we have information in ourselves we did not know we possessed, until we were confronted by a well-defined problem.

The interaction produces more in both authors and readers than is possible for each one of them alone.

Just two years ago we had the good fortune to recruit the help of a person new to our staff but a veteran at what he does best. Rally Dennis was about to retire from the staff of *Ham Radio*, one of our fine friends among our publishing neighbors, and decided to join us as a one-week-a-month sales force. We felt we were very fortunate to have his help since he brought many years of experience as well as an inextinguishable enthusiasm to his work.

He has succeeded in establishing a new relationship between *Speaker Builder* and a host of new advertisers—as is evident to any of you who have been subscribers for two or more years. This has brought a new vitality to the look of the magazine since not only do advertisers bring revenue to the enterprise, their use of color makes editorial color affordable as well.

But the increased advertising would not have added any significant strength to the magazine without your response to it. Advertisers tell us your reaction through our fast reply numbers is not only gratifying, but that a large percentage of you convert inquiry into action by buying goods.

What I am most pleased about is that you are not only responding to advertisers and sharing your questions and perplexities with authors, but that you are, on the evidence of letters I see daily, a highly supportive group for each other as well. This isn't really surprising, I suppose, when we remember how exciting it is to find someone who shares our feelings about an avocation.

As I write this in late November, the Berlin Wall has been breached in several places. I'd like to believe that the new communication technologies which have been growing at a dizzying rate since World War II, have been responsible for spreading the hope for freedom and self-determination to those countries whose populations have been oppressed politically and economically. Putting up a wall cannot isolate a citizenry any longer.

Our new powers to communicate with each other are also a means toward technological freedom. Our collective knowledge is growing at an awesome rate, far faster than we are able to assimilate it individually, or to try the new possibilities. This is one reason magazines have become more and more specialized over the last 30 years. And magazine publishing technology itself becomes less and less expensive and therefore affordable to further enable special interest publications.

Many of you have said appreciative things about our efforts over the years. My own personal pleasure in publishing for you is a gift I consider you have given me. It is a vocation that suits me wonderfully well. We speaker builders aren't a large or influential group in the overall picture of America at the end of this decade, but I like to think we have, all of us, added something unique to the world's store of information, and to the pleasure of quite a few.—E.T.D.

A DIPOLE SUBWOOFER FOR QUADS

BY JAMES LIN

I've always liked my Quad electrostatic speakers—very clean, natural sound, but, well...they are a touch shy in the bass, and they overload easily, especially in the deep bass. With the advent of digital, or even some audiophile records, this can be a real problem. I really don't mind so much not hearing deep bass, but I prefer not to destroy my speakers. My solution is a dipole subwoofer using the 24" Hartley driver, and a dedicated active/passive crossover.

THEORY. Although the test of any design is how well it works, I've often found the design process to be as interesting as the final result. Therefore, I'm going to explain some of the reasons behind my choice of speaker and crossover design. Those who hate theory may go directly to the construction section.

WHY A SUBWOOFER? Several reasons, some obvious, some not so obvious. First, a separate subwoofer with active crossover lessens the low frequency load on the main speakers. Since the Quads are especially susceptible to low frequency overload, this is a definite advantage. Also, it decreases distortion in both the main speakers and the amplifier. The main speakers no longer have to deal with the large excursions required by low frequency signals, resulting in better linearity. The amplifier power supply no longer is modulated by the relatively long term drain of low frequency signals, resulting in a more stable supply voltage. Both can lead to cleaner sound.

ABOUT THE AUTHOR

James Lin was a graduate student in physics before switching to medicine. He is currently an Oncology Fellow at Sloan-Kettering Memorial Cancer Center. He has built several electronic kits and projects for Audio Amateur, but this is his first speaker project.

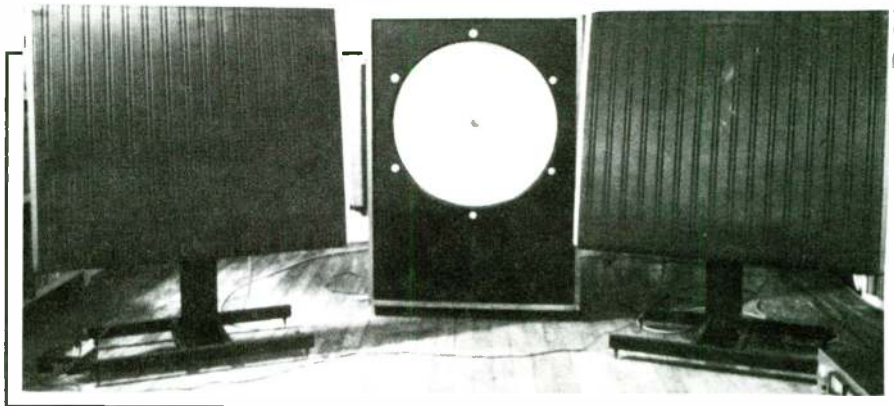


FIGURE 1: The HQ-24 subwoofer.

Second, a subwoofer can give not only more bass, but better bass, because the driver is optimized for low bass.

Third, a subwoofer can help us to achieve better overall tonal balance. An old rule states that a balanced response is achieved when the product of the low and high frequency cutoff points equals 400,000 (i.e. $20\text{Hz} \times 20\text{kHz} = 400,000$). Thus, for example, a speaker which rolls off below 100Hz will sound balanced if the highs roll off above 4kHz, a speaker that extends down to 50Hz could extend up to 8kHz, and so on. The Quads are specified to roll off below 45Hz, and above 18kHz (-6dB points), which gives a product of 810,000. One would therefore predict that they would tend to sound a bit light, and they do.

Finally, a separate subwoofer can allow smoother low frequency response while maintaining optimum imaging and overall response smoothness, since the best position to achieve the one may not be best for the other.

These advantages are not without cost, however, not only in terms of money and space, but also complexity. Most people regard a subwoofer as an add-on, a device which pastes an extra octave or so of bass onto the bottom end. But it would be more accurate to regard a sub-

woofer as a piece of an overall system. Just as you cannot expect to get good results by throwing a random woofer and tweeter together with an off-the-shelf crossover, the same holds true for a subwoofer and main speakers. The combination must be regarded as a whole new system, with due consideration given to an appropriate choice of crossover slope and frequency, and the possible need for repositioning of the main speakers, as well as positioning the subwoofer, for optimum results.

WHY A DIPOLE SUBWOOFER? A dipole subwoofer has two advantages. First of all, there's no cabinet, hence, no cabinet resonances. That's an oversimplification, of course, since there is a panel to hold the driver, and this must be suitably sturdy. However, the panel area is considerably less than that of a closed cabinet, and hence, less of a problem. Now, woofer motion increases with decreasing frequency, causing greater fluctuations in internal cabinet pressure, leading to more cabinet wall motion. Also, reproducing low frequencies with reasonable efficiency dictates a large cabinet, with a large surface area which becomes increasingly difficult to brace adequately.

Moreover, that large surface area cou-

ples efficiently with the air at low frequencies to produce sound. I recall a subwoofer design in *Electronics World* many years ago which actually used the cabinet sides as a passive radiator. Any unwanted motion contributes to a muddy sounding bass, and may be one cause of the complaint that a box subwoofer often sounds "slow" compared to the "fast" dipole upper range. A dipole design removes most of the cabinet, thus greatly decreasing the problem.

Second, and rarely discussed, is the problem of radiation pattern. In fact, the only discussion of this problem I've read was by Keith Howard in *Hi Fi Answers*, Sept. 1982, p. 19. My discussion is based on his. All planar speakers, including the Quads, are inherently bidirectional. That is, their dispersion pattern resembles a figure 8, or in three dimensions, two tennis balls glued together. On the other hand, speakers in boxes, whether closed, vented, transmission line, or whatever, tend to have an omnidirectional radiation pattern at low frequencies.

Now, if an omnidirectional speaker and a dipole speaker are adjusted to put out the same sound pressure level on-axis, the omnidirectional speaker will be putting out 4.8dB more acoustic power in all directions. In other words, if we try to match an omnidirectional woofer with a dipole main speaker, we find an inherent mismatch. Either we match the direct sound, in which case the woofer will be putting out 4.8dB more power into the room as a whole, or we match the overall power levels, in which case the woofer will be putting out 4.8dB less direct sound at the listener's position. In my opinion, this is one of the reasons many people have found the combination of dipole speakers and box subwoofers unsatisfactory (even tin ears can hear frequency response). Also, the different radiation patterns of dipole and omnidirectional speakers excite room modes differently, further complicating the matching problem.

FLAWLESS DIPOLE? Unfortunately, all is not perfect, or, as one of my physics professors used to say, God is not always on your side. Speaker designers learned many years ago that open baffle, or dipole speakers have weak bass, unless the baffle is very large (infinite baffle). The reason is that the sound wave produced by the back of the driver can come around and cancel the sound wave produced by the front side, resulting in less sound, and this effect becomes stronger as the frequency decreases (front-to-back cancellation).

As an analogy, if you put your hand in a basin of water and wiggle it back and forth rapidly, you will produce strong high frequency waves. However, if you now move your hand back and forth very slowly, nothing much happens, because the length of the wave is so long that the crest of the wave produced by the back of your hand has enough time to flow around to fill the trough of the wave being produced by the front of your hand. Therefore, a bass dipole speaker needs to be big (and unsightly). Below a frequency which is determined by the size of the baffle—roughly speaking, at wavelengths greater than the square root of the baffle area—the response will roll off at 6dB/octave due to front-to-back cancellation until we reach the driver resonance point, below which the rolloff approaches 18dB/octave—the 6dB/octave rolloff due to cancellation plus the 12dB/octave rolloff of the driver below resonance.

It's easy enough to equalize the 6dB/octave rolloff to get flat response, but of course, the price of this is additional speaker cone excursion just in the area where excursion demands are greatest to begin with. So the volume displacement required of a dipole driver at low frequencies is greater than for any other design, because a significant portion of the output is lost due to front-to-back cancellation, and the lower the frequency, the worse the problem. Or, to put it another way, for the same driver, the dipole has less output than any other design at low frequencies. To compensate for this requires a long throw, large area driver or set of drivers in addition to a large baffle.

Thus, the trade-off for the dipole advantages of decreased cabinet resonances and consistent radiation pattern are size, of both baffle and driver, cost, decreased output capability, and also, perhaps, a requirement for electronic equalization. The problems are somewhat eased because the floor acts as a sound mirror, which effectively doubles the baffle area, extending the response by a half octave. Placing a dipole at a floor/wall junction doubles the effective baffle area again, extending the response by a full octave below that expected for the same baffle in free space. Some additional decrease in baffle size can be achieved by folding back its edges to produce a shallow box, open at the back. Too deep a box will result in box colorations, however.

A driver for a dipole subwoofer therefore needs to have a large cone area combined with a large linear excursion capability, or to quote Tom MacCahill, the

motoring journalist, "There is no substitute for cubic inches." In addition, since we have no box to help boost the low end response, the driver Q should be high. R. J. Newman, in his *JAES* article on dipole speakers (*Journal of the Audio Engineering Society*, Jan/Feb 1980, p. 35), on which the preceding discussion has been based, suggests a Q of 0.7 to 1.0 for the driver, considerably higher than the values that are optimum for closed or vented box speakers.

In terms of needed baffle size, Newman shows that a baffle that is 0.9 meters (roughly 35 inches) square, with a 0.15 meter (6 inch) fold back at the edge, will roll off below 100Hz. This is not an unreasonable size, being only slightly larger than the Quads, but does require a 12–14dB boost for flat response to 20–25Hz.

SINGLE OR DOUBLE? For playing LPs, a mono subwoofer has certain advantages, since a great deal of the spurious output from warps and rumble is due to vertical stylus motion which is out-of-phase, and hence is cancelled out. Since many record makers blend low frequencies anyway, the losses should be minor. However, CDs do not have blended lows, and there may be more of a loss here. As for low frequency imaging, *Stereophile's* J. Gordon Holt, in a recent review (N-R 1204 subwoofers, *Stereophile*, April 1988, p. 122) comments that he noted a slight loss of detail with a mono subwoofer crossed over at 62Hz but no change in stereo imaging, compared with stereo subwoofers.

However, even if stereo imaging at such low frequencies is not affected, the ambience or "room sound" which is due to low frequency out-of-phase components would be lost in a mono system. Nevertheless, even a mono system may be an improvement, since the original system was incapable of reproducing these low frequencies at all. Dual subwoofers also excite the room in a more complex, and perhaps more natural sounding way. One undoubted advantage of dual subwoofers is decreased excursion requirements. The advantage in output is only 3–6dB, but the advantage in linearity may be much greater.

Overall, I believe stereo subwoofers are the perfectionist's first choice, with provision for switching to mono for troublesome LPs. However, in my particular case, practical considerations intrude. First, I can only afford one driver, and second, even if I could afford two, I couldn't physically fit them into my room (*Fig. 1*).

CROSSOVERS. Well, we need one. A crossover, that is. This is where a lot of problems can occur. For example, consider that audiophile favorite, the simple 6dB/octave type. In order for the combined response to be within 1dB, each driver must be flat for three octaves on either side of the crossover frequency. Thus, if the crossover to a subwoofer occurs at 100Hz, the main speakers must be flat down to 12.5Hz to give a combined response flat to 1dB (the subwoofer also has to be flat to 800Hz). Well, if your main speaker is flat down to 12.5Hz, what are you doing messing around with subwoofers? The transient-perfect "subtraction" crossovers, where the high pass section is derived by subtracting the low pass from the input, suffer from a similar sensitivity to phase and frequency problems in the component drivers. To avoid problems, a good rule of thumb is that any driver anomalies or rolloffs should be suppressed at least 20dB by the crossover in order to be "negligible."

Since dipole speakers roll off at 18dB/octave below driver resonance, any high pass crossover to the main speakers will have an 18dB/octave acoustic filter "built in" before we do any additional compensation. The simplest alternative, therefore, is to roll off the subwoofer at 18dB/octave at the resonance point of the main speakers, and run the main speakers full range, relying on the dipole acoustic rolloff for the high-pass function. The result is a third-order crossover—third-order electrical low pass and a third-order acoustical high pass.

The crossover will not be exact, unless the main speaker response is exactly Butterworth in form, but it will likely be close enough. We can get away with this because room effects at such low frequencies will swamp any minor offenses in crossover response. However, this approach has two problems. First of all, odd-order crossovers are more sensitive to phase differences between drivers than are even-order crossovers, such as might be caused by driver offset. Since one of the advantages of a separate subwoofer is placement flexibility, a placement-sensitive crossover topology is not helpful in this regard, whatever other advantages it may have. Second, we lose the potential advantages in protection from driver overload and decreased distortion in the main speakers.

The next step up is a fourth-order filter, such as the popular Linkwitz-Riley all-pass configuration. This can be approximated by a 6dB/octave passive filter to the main amplifier at the resonance fre-

quency of the main speakers, plus a 24dB/octave active filter for the subwoofer amplifier. This has the advantages of decreased low frequency demands on the main amplifier and speakers (although, at a mere 6dB/octave rolloff, the advantage is a modest one) and relative insensitivity to driver offsets, allowing more leeway in subwoofer positioning. In addition, both subwoofer and main speaker are connected in phase. It is also easily implemented by a simple RC crossover between preamp and main amplifier, which combines with the 18 dB/octave dipole rolloff to produce a 24dB/octave high pass function, along with an active 24dB/octave low pass to the subwoofer.

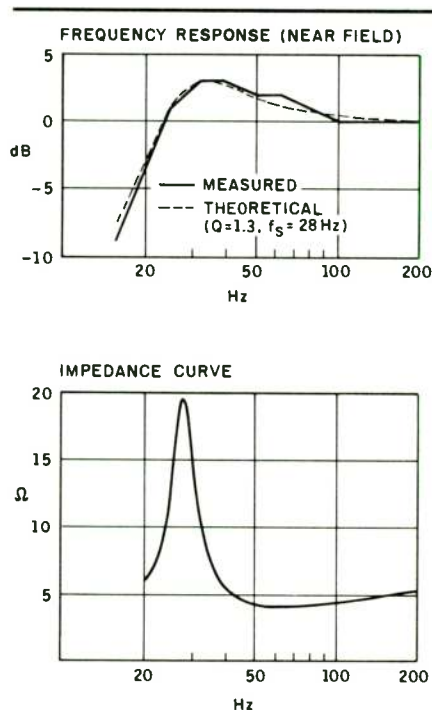


FIGURE 2: Near-field response (1/3 octave warble tones) and impedance curve of the 224-HS driver.

For these reasons, this is the design I chose to use. This is not the only choice available since I have not discussed factors such as group delay, constant voltage vs. constant power, and others, which can affect crossover topology. However, I strongly believe the subwoofer and its crossover must be designed as part of a total system, rather than as an add-on.

In any system incorporating a subwoofer, we are of necessity working at or near the lower limits of the main speaker, in a region where its rolloff and phase shift will have significant effects on the overall response. A good system crossover design must take these factors into account. Thus, my design is a "dedicated" crossover, with the crossover point and slope

designed specifically to match the low frequency characteristics of the Quad main speakers, although it can easily be adapted to other dipole speakers by changing the crossover frequency, rather than being a "universal" crossover which is likely to give universally unacceptable results with all possible speakers. I believe universal crossover use in commercial subwoofer systems is a major factor in causing problems with integrating such designs into a satisfactory system.

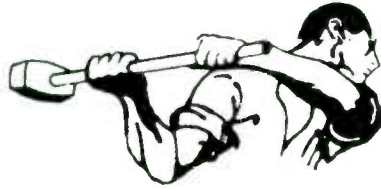
CONSTRUCTION. In my case, the theoretical considerations came together when I acquired a suitable driver—a used 24" Hartley woofer, which I found advertised in *Speaker Builder* (naturally). This is an impressive piece of work—cast aluminum frame, beautiful construction—a friend remarked that it reminded him of the speaker in *Back to the Future* that blasts Michael J. Fox across the room.

A letter to the Hartley Corporation elicited the reply that "Thiele-Small parameters are not relevant because of its unusual mechanical structure and magnetic suspension." In my opinion, this reflects a serious misunderstanding of the theory behind the Thiele-Small model. Be that as it may, it does not prevent someone from measuring them himself. The person who sold the driver to me measured $f_s = 29\text{Hz}$, $Q_{ts} = 1.17$, while my own rather crude measurements yielded 28Hz and 1.3, respectively. Using the TAA Warbler (Dick Crawford, "The Warbler," *The Audio Amateur*, 1/79, p. 22), Heathkit Audio Analyzer and Heath sine wave generator I measured a near-field response and impedance curve which exactly fits these parameters (Fig. 2).

These measurements are also consistent with those reported by *The Audio Critic* several years ago when they reviewed this driver. They reported that this speaker in a 12 cu. foot box yielded a 6dB peak ($Q = 2$) and a resonance frequency of 48Hz. Using Small's equations for a closed box system, the ratio of system Q to driver Q equals the ratio of system resonance to driver resonance. Thus, my driver, in a box which gives a system resonance frequency of 48Hz, would have a system $Q = 2.2$, which is pretty close.

In contrast, Hartley claims a frequency response of 16–250Hz $\pm 3\text{dB}$, although the conditions of measurement are not stated. It is also quite efficient; Hartley claims 93.5dB/watt for their subwoofer using this driver, although again the conditions of measurement are not stated. I got around 84dB at 3–5 feet with approximately 0.1W input using a warble tone centered at

Continued on page 14



Sledgehammer Pro by Electro-Voice

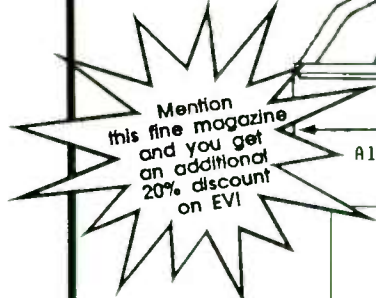
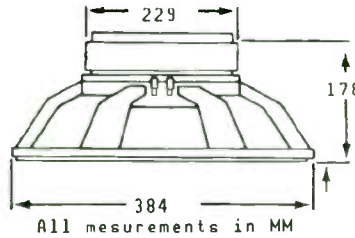
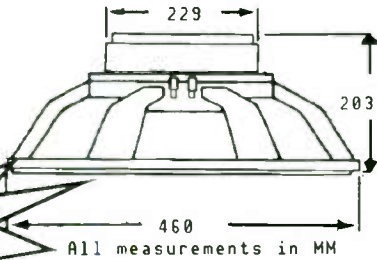
| | | | |
|-----------------|------------------------------|-------------------------|---------------------------|
| | 18 inch Ω | 15 inch Ω | T35 Tweeter Ω |
| Fs | 33 Hz ± 2 Hz | 43 Hz ± 2 Hz | 5 KHz |
| Vas | 516 lt. $\pm 2\%$ | 225 lt. $\pm 2\%$ | ~ |
| Rsc | 5.2 Ω | 5.2 Ω | 6.1 Ω |
| Sd | 1140 cm ³ | 855.3 cm ³ ~ | ~ |
| Qms | 8.37 | 12.89 | ~ |
| Qes | .37 | .30 | ~ |
| Qts | .36 | .30 | ~ |
| Xmax | 3.3 mm pk | 3.3 mm pk | ~ |
| Cone: | Black paper | Black paper | Fiber |
| Magnet: | 4.9 lbs. | 4.9 lbs. | 8 oz. Ceramic |
| Voice Coil: | 2.5 inch | 2.5 inch | 1 inch |
| Surround: | cloth | cloth | ~ |
| Power Handling: | 200 Watts EIA | 200 Watts EIA | 5 Watts Cont. (50 W peak) |
| FREQ. Response: | 40-600 Hz | 50-720 Hz 3.5K-15K Hz | 104 DB 1W/1M |
| Efficiency: | 96.2 DB 1W/1M | 98.1 DB 1W/1M | High Freq. Reinforcement |
| Uses: | Pro-sound, Home or Autosound | Subwoofer | |

Price each

\$165.00

\$125.00

\$38.00

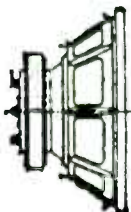


PRO-18 Box Suggestion:
 VB: 200 Liters
 FB: 45 Hz.
 F3: 48 Hz.
 Vent Diameter 6" Vent Length 4.5" Use two vents.

PRO 15 Box Suggestion:
 VB: 90 Liters
 FB: 55 Hz.
 F3: 63 Hz.
 Vent Diameter 6" Vent Length 3.5"



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



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Continued from page 12

160Hz, so the claimed efficiency seems reasonable. The driver is rated at 125 watts continuous and 400 watts peak input power.

In any case, this driver is a good one for our purposes, with a large cone area (363 sq. in.) and a large excursion capability of $\frac{3}{4}$ " peak-to-peak claimed, although the voice coil itself is only $\frac{3}{4}$ " long. I would estimate the linear excursion as $\frac{1}{2}$ " peak-to-peak, based on the visible voice coil overhang. The Q of 1.2-1.3 is a little high, but can be ameliorated, as will be discussed below.

I should mention one interesting anomaly I found while measuring the speaker—when I tried driving it at frequencies above 250Hz using the Warbler, it suddenly started emitting high frequency harmonics. I was not abusing the speaker, since the drive level was considerably less than one watt. I can only conclude that this driver, or at least my sample, should never see frequencies above 150-200Hz. I also second David Ruether's recommendation ("The Big Bass Box," *The Audio Amateur*, 2/78, p. 4) of checking the magnet gap to make sure it is clean. I didn't blow a fuse, as he did, but when I first played my woofer it made a scraping noise, which went away after I cleaned out the gap from the front using a $\frac{1}{2}$ " strip of coated photographic paper.

Figure 3 shows the details of the subwoofer baffle. I chose the height to match my Quads, which are mounted on 12" Quadropod II stands, and I made them wide enough to fit between the Quads in

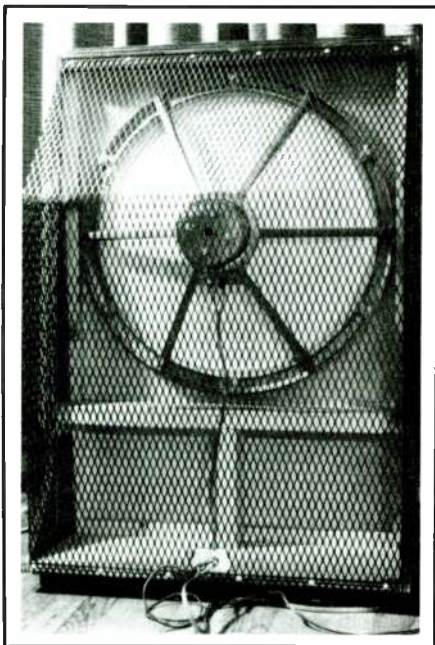


FIGURE 4: Back of the HQ-24 subwoofer, showing the protective grille and binding post mounting arrangement.

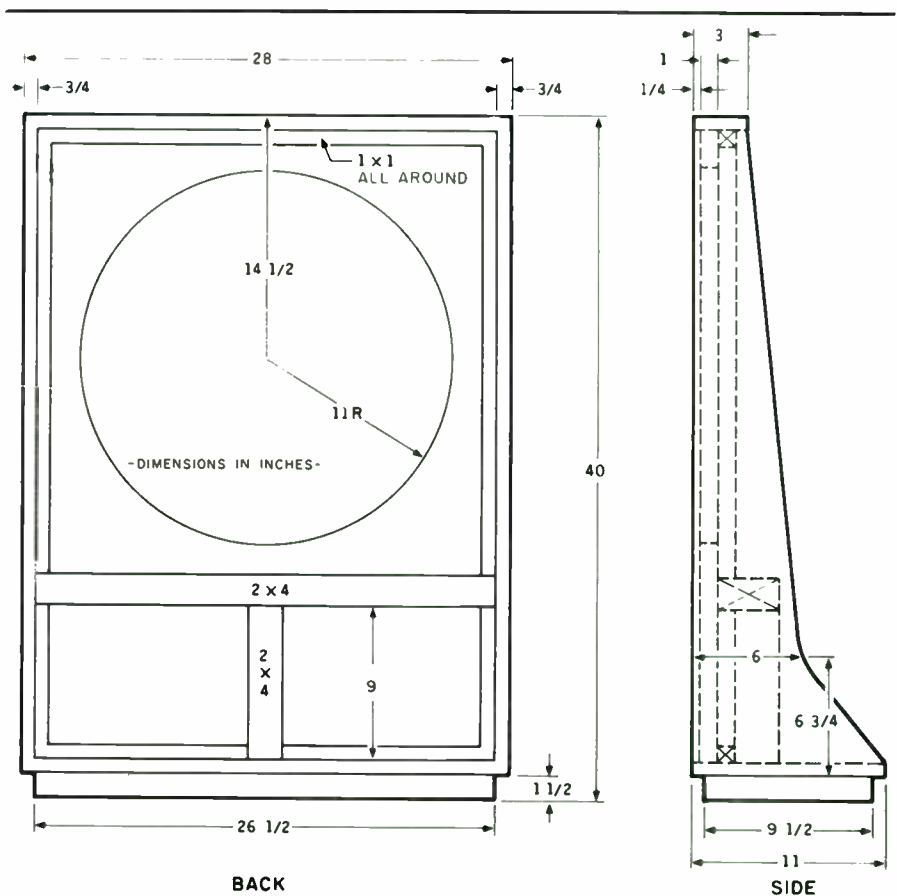


FIGURE 3: Subwoofer baffle design.

my rather narrow room (12' wall-to-wall, further decreased by bookshelves). The side panels act to provide additional path length between front and back, lowering the baffle cut-off point without increasing frontal area. This technique was suggested by Newman in his dipole speaker paper in JAES. The dimensions shown should give a rolloff below about 100Hz or so. With a linear cone travel of $\frac{1}{2}$ " peak-to-peak, I estimate that the system should be able to produce excursion-limited peak sound pressure levels at one meter into half space (subwoofer sitting on an infinite floor) of 92dB at 20Hz, increasing to 98dB at 25Hz, 104dB at 32Hz, and 109dB at 40Hz. At higher frequencies, the levels are power limited to 112dB at 50Hz, and 114dB at 63Hz.

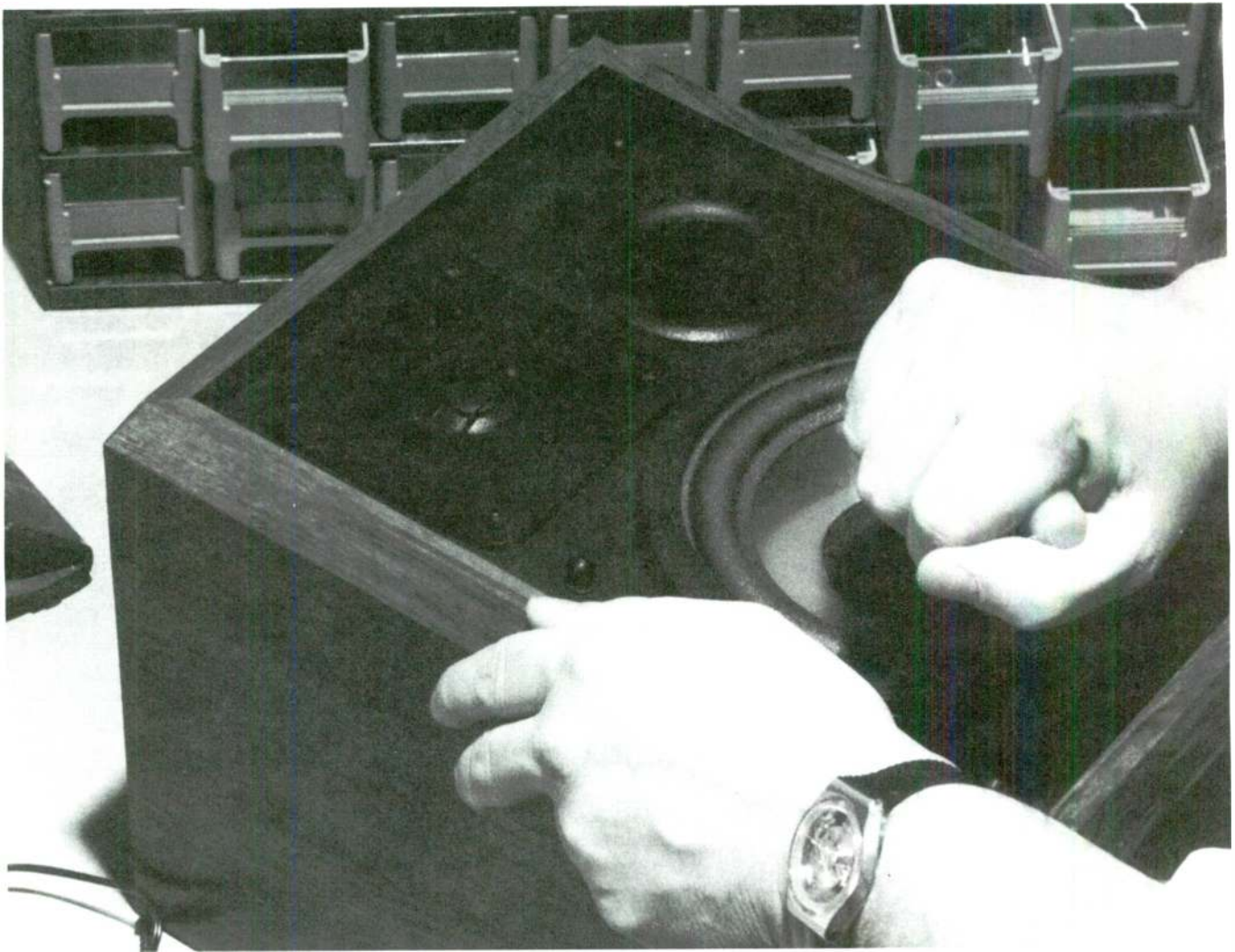
Construction is straightforward. I braced the front and sides with 1" x 1" braces all around, plus 2" x 4" braces across the baffle below the driver. For the baffle, I recommend 1" thick particle board (I actually used $1\frac{1}{4}$ "), with $\frac{3}{4}$ " board for side, top and bottom panels to avoid a "heavy" look. I used birch plywood panels for the latter with excellent results. The whole thing is held together by screws and glue, and the driver is rear mounted with carriage bolts.

I used a perforated metal grille, bent and

folded over, to protect the backside of the driver (Fig. 4). The grille does rattle when tapped, but this doesn't seem to be a problem when playing music. The ideal solution is to leave it off, but for most people, the likelihood of poking fingers from friends or children (or pets) requires some sort of protection. I used a short piece of aluminum L section to mount the heavy duty binding posts at the base of the speaker. I recommend heavy gauge speaker wire, say 14 gauge or better—I used some old Vampire wire. I don't have a front grille at present, but I suggest $\frac{1}{4}$ "- $\frac{3}{8}$ " plywood for a frame—those with children or pets may wish to put a wire mesh screen across the front for additional protection.

THE CROSSOVER. Figure 5 is the schematic. As you can see, it is a 24dB/octave active low pass to the subwoofer, with the channels combined, and a passive RC crossover to the main amplifier. I chose 63Hz as the crossover frequency, based on the anechoic data I could find on the Quads. It is implemented using two of Old Colony's WJ-3 filter boards with a TL075 op amp on the first board, and a TL075 or a 4136 quad op amp on the second. The choice of the second op amp is non-

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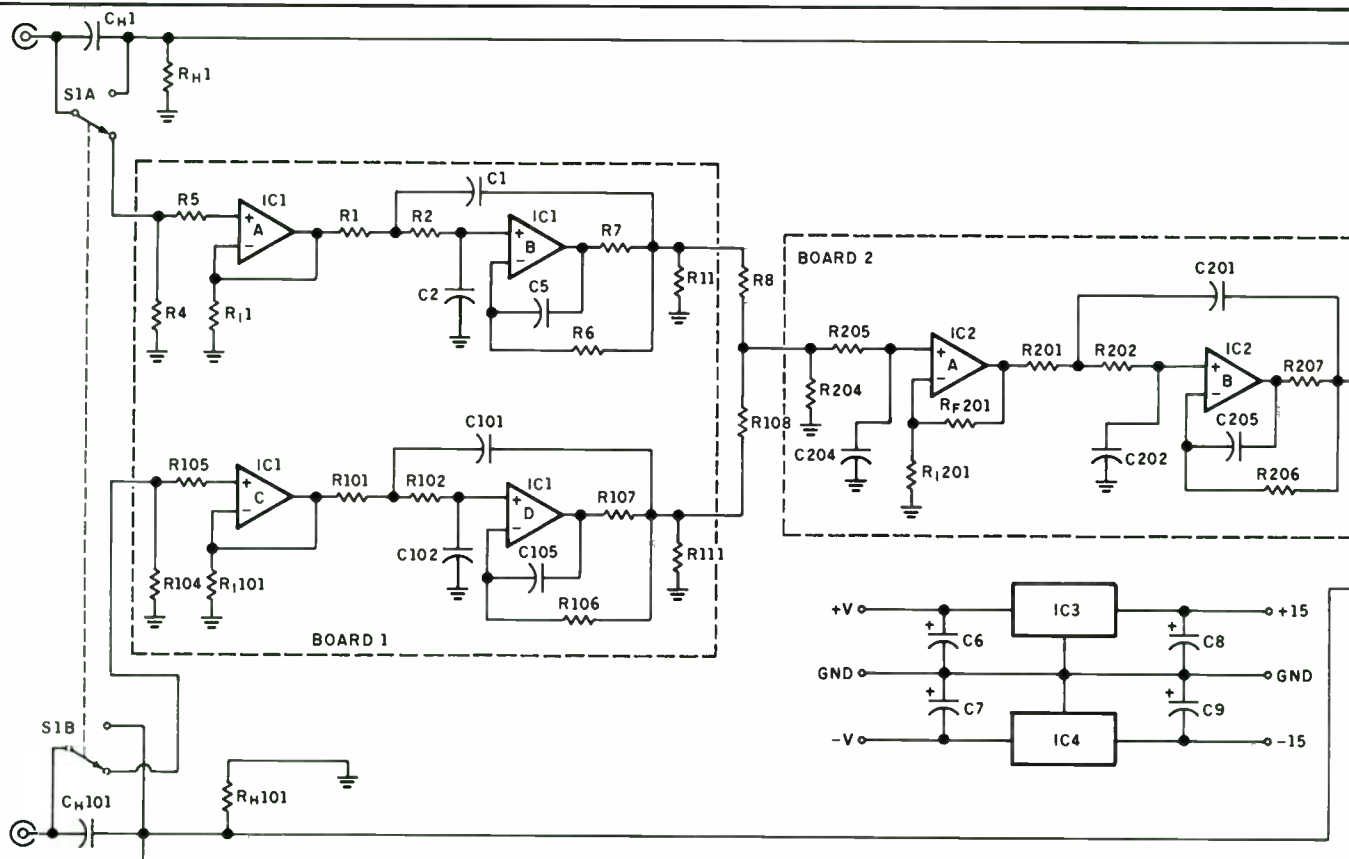
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PARTS LIST

Continued from page 14

critical, because any high frequencies have already been filtered out by the first board. In my case, the 4136 gave a lower output offset than the TL075, and was a bit cheaper as well.

IC1A,B and IC1C,D make up the first filter section of the right and left channels, respectively. Each channel consists of a 12dB/octave Butterworth low-pass filter. The outputs of both channels are mixed in IC2A. The mixing resistors R8 and R108 cause a 6dB loss, so IC2A is set up for a 12dB gain, which compensates for the mixing loss, and provides additional gain to cover other circumstances, such as a low sensitivity amplifier.

IC2B forms the second 12dB/octave Butterworth filter section, to yield an overall Linkwitz-Riley 24dB/octave low pass output. This then passes through the level control. I used an audio taper control at this point. Another possibility is to change R304 to 10kΩ, and use a 100kΩ linear control connected to ground through a 5kΩ resistor. This is the so-called "law-faking" resistor scheme suggested by Ben Duncan (*Hi Fi News & Record Reviews*, July 1984, p. 33, or *Stereophile*, Feb. 1988, p. 78). This gives better resolution in the middle range (approximately -6 to -26dB), but the subwoofer cannot be completely shut off. However, its biggest advantage appears if a stereo

Capacitors

| | |
|----------------------------|--------------------|
| C1, 101, 201, 301, 302, CF | 0.068μF PP |
| C2, 102, 202 | 0.033μF PP |
| C4, 104 | omit |
| C5, 105, 205, 305 | 0.1μF PP |
| C204 | 1000pF polystyrene |
| C _H 1, 101 | see text, Table 1 |
| C6, 7 | 100μF/35V |
| C8, 9 | 330μF/16V |

(PP = polypropylene)

Resistors

| | |
|--------------------------------------|-------|
| R1, 2, 101, 102, 201, 202 | 53.6k |
| R4, 11, 104, 111, 204, 211, 304, 311 | 100k |
| R5, 105, 205, 305 | 1.0k |
| R6, 106, 206 | 107k |
| R7, 107, 207, 307 | 100k |

| | |
|----------------------------|-------------------|
| R8, 108 | 10k |
| R301, R _F 301 | 115k |
| R302, 306 | 232k |
| R _F 1, 101 | jumper |
| R _F 201 | 20k |
| R _I 1, 101, 201 | 6.65k |
| R _I 301 | 38.3k |
| R _H 1, 101 | see text, Table 1 |

All resistors 1/4 watt metal film

P1 see text

Integrated circuits

| | |
|-----|-----------------|
| IC1 | TL075 |
| IC2 | RC4136 or TL075 |
| IC3 | 78L15 |
| IC4 | 79L15 |
| S1 | DPDT switch |

control is needed, where the better tracking of a dual linear control is useful.

IC2C provides low frequency boost between 80Hz and 20Hz at 6dB/octave to counteract the baffle rolloff, and IC2D provides a subsonic rolloff at 12dB/octave below 14Hz, to minimize warp-induced problems and any other subsonic garbage. This section may not be necessary in a CD based system. This results in a maximum boost of about 8dB in the 20-25Hz range and an overall response, including baffle rolloff, compensatory boost, speaker Q effect and subsonic filtering, calculated to be

flat to 32Hz, -3dB at 25Hz and -9dB at 20Hz.

The alert reader will note that the low frequency boost is up 3dB at 80Hz, although I stated in the previous section that the baffle rolloff begins at 100Hz (3dB down), but the Hartley's Q of 1.2-1.3 also boosts response, tending to counteract the baffle rolloff. With a more nearly flat driver, the boost should begin at 100Hz. To do so change R_I301 to 28.7kΩ.

The high pass section is a simple RC filter, with the resistance chosen so that, in parallel with the input resistance of the

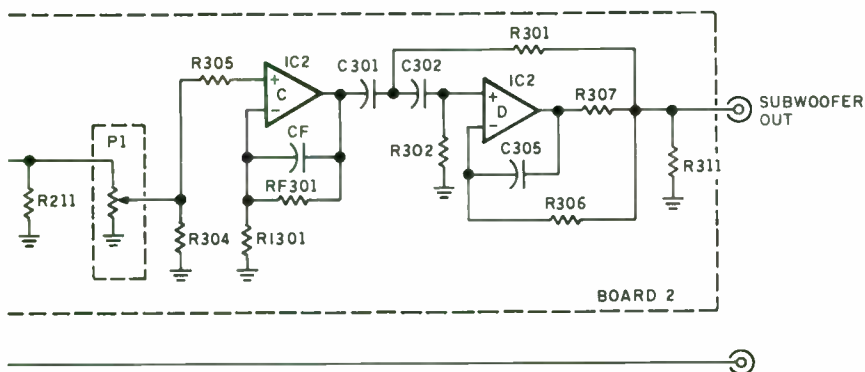


FIGURE 5: Crossover schematic. The first board contains the first 12dB/octave low pass section for the right and left channels. These are combined before going to the second board, which contains the second 12dB/octave low pass section, the low frequency boost and the infrasonic rolloff.

TABLE 1

| | $C_H = .033$ | .01 | .0033 |
|---|--------------|--------|--------|
| R | | | |
| 10k | — | — | 32.4k |
| 20k | — | — | 12.4k |
| 25k | — | — | 11.0k |
| 47k | — | 54.9k | 9.09k |
| 50k | — | 51.1k | 9.09k |
| 75k | — | 38.3k | 8.45k |
| 100k | 324k | 34.0k | 8.25k |
| 250k | 110k | 28.0k | 7.87k |
| 470k | 90.9k | 26.7k | 7.87k |
| R_{eff} | 76.55k | 25.26k | 7.655k |
| $R_H = (R \times R_{eff}) / (R - R_{eff})$ | | | |
| R = amplifier input resistance | | | |
| R_H = crossover high pass resistance | | | |
| R_{eff} = effective resistance of R and R_H in parallel | | | |
| C_H = crossover high pass capacitor | | | |

main amplifier, the -3dB point is 63Hz. Table 1 shows suggested values of R_H for different values of C_H and various common values for input resistance. R_{eff} is the effective input resistance, due to R_H in parallel with the amplifier resistance, which is seen by the high pass capacitor C_H . Some of the smaller capacitor values can significantly load the preamplifier,



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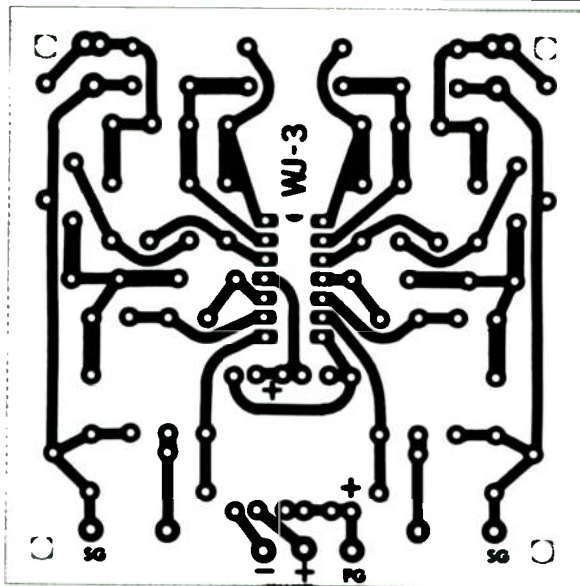


FIGURE 6A: Foil side of board.

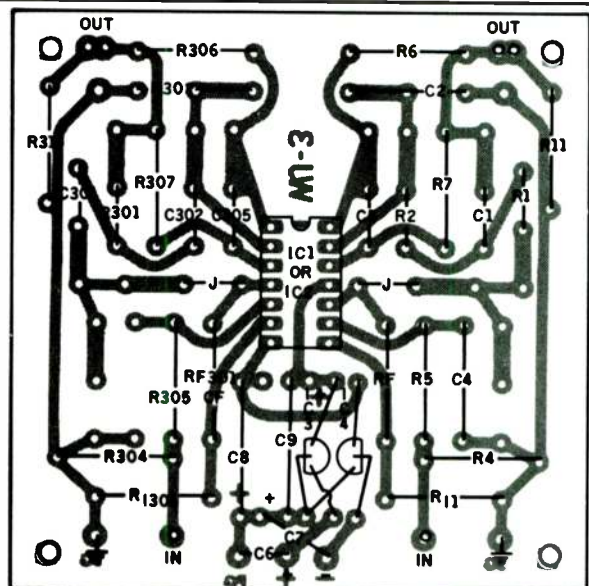


FIGURE 6B: Board layout. The right-hand side of the board shows the layout for the first three sections of the crossover design, the left-hand side shows the layout for the last section. Note the two jumpers (J) on each board, and the IC regulator layout which replaces the zener diode regulation.

and I suggest you avoid them if you can, especially if you are using a tube preamplifier, which often has problems driving a low impedance.

I have included the formula for calculating R_H in the table in case your amplifier has an oddball input resistance value. This results in only a modest decrease in low frequency demands on the main speaker/amplifier, but on the other hand results in little loss of low frequency imaging. For a speaker with a different rolloff point, the frequency setting resistor values should be adjusted accordingly ($R_{new} = R_{old} \times 63\text{Hz}/f$).

The ratio of capacitor values in the low-pass filter sections should ideally be exactly 2:1. The values I have chosen, 0.068 and 0.033, are the closest to that ideal ratio among readily available standard values. We could do slightly better by paralleling two smaller caps for the larger value, but the circuit board as designed makes no provision for this, and practically speaking, I doubt that it makes a significant difference. Close tolerance caps are needed for the filter sections, and matching them channel to channel is strongly recommended.

The numbering system is consistent with that used in the original article (*The Audio Amateur* 4/75, p. 14), with 100, 200 or 300 added to the original numbers to refer to different sections of the first or second board (i.e., R1, R101, R201 and R301 refer to the same resistor in each section). The board layout is shown in Fig. 6B. The right-hand side shows the layout for the first three sections, and the left-hand side shows the layout for the last section.

As the schematic shows, a bypass switch is included. I used a DPDT switch mounted on the back panel between the input and output jacks, and hardwired the high pass capacitor and resistor directly to the switch and output jack (Fig. 7).

I made a couple of changes on the boards. Instead of zener diode regulation, I adapted 78L15 and 79L15 3-terminal IC regulators (TO-92 package) to the board. This required a bit of kludging, so the result is not particularly neat in appearance, but the results are superior to zener regulation. I have diagrammed this change in Fig. 6B. The boards will need a raw power supply capable of supplying $\pm 18\text{V}$ at 40mA or so—Old Colony has a suitable supply. Alternatively, you can use 12V regulators, and a 24Vct transformer, diode bridge and capacitors from Radio Shack or any number of other suppliers. I had a spare transformer lying around and managed to fit the whole works into a

3" x 5" x 8" Bud Box (Fig. 8), although it is a bit more cramped than I would have liked.

Incidentally, the two mounting holes on the output end of the circuit board are quite close to the output circuit trace, and I recommend insulating spacers for those holes; initially, I used metal spacers which shorted the output and couldn't figure out why I wasn't getting any low pass signal. I also recommend using metal film resistors and polypropylene or polystyrene capacitors for the best stability. Everyone has their favorite brands—I have found Panasonic P-Series polypropylene caps to be compact and close tolerance (2%).

PUTTING IT TOGETHER. Dipole subwoofers, like dipole speakers in general, have different positioning requirements from "normal" box speakers. In particular, unlike box speakers, which tend to produce more bass as they are moved toward a wall, dipole speakers tend to produce less bass as they are moved toward the back wall, because the out-of-phase rear wave reflects off the wall and cancels the front wave. This occurs at frequencies whose wavelength is greater than eight times the speaker-to-wall distance. Thus, as the distance decreases, the frequency at which cancellation occurs increases.

Hence, a dipole subwoofer needs to be positioned well away from the back wall—in theory, the farther, the better. Of course, in practice, things are more complicated because of position-dependent excitation of room modes, which selectively reinforces certain frequencies. The

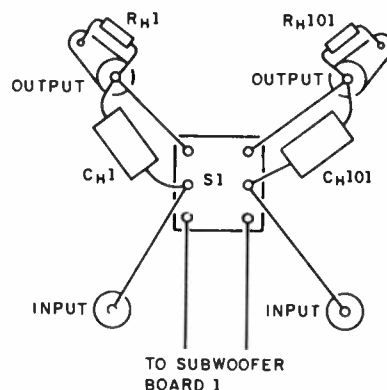


FIGURE 7: Input and output jacks, bypass switch and high pass layout.

problems such room modes can cause depend not only on the room and the position of the speakers, but also the position of the listener, so you must experiment with speaker positioning. Nevertheless, as a general rule, I recommend that you start with the subwoofer positioned between the main speakers, and within two to three feet of a line drawn between them, to minimize time delay and imaging problems.

Although the crossover contains a bypass switch, its utility in setting up the system is somewhat limited, for a couple of reasons. First, the ear's sensitivity to level changes at such low frequencies is somewhat less than in the midrange, thus making adjustment by ear more difficult. Second, the slow 6dB rolloff of the high pass section will affect the octave or two above the crossover frequency, thus leading to changes in the timbre of midbass instruments such as cellos. This can be compensated by changes in main speaker positioning, but obviously makes bypass comparisons difficult.

The point here is that the main speaker/subwoofer combination is a new and more complicated system, and both parts may need to be adjusted for optimum results. Because of this, the use of a spectrum analyzer, such as the excellent

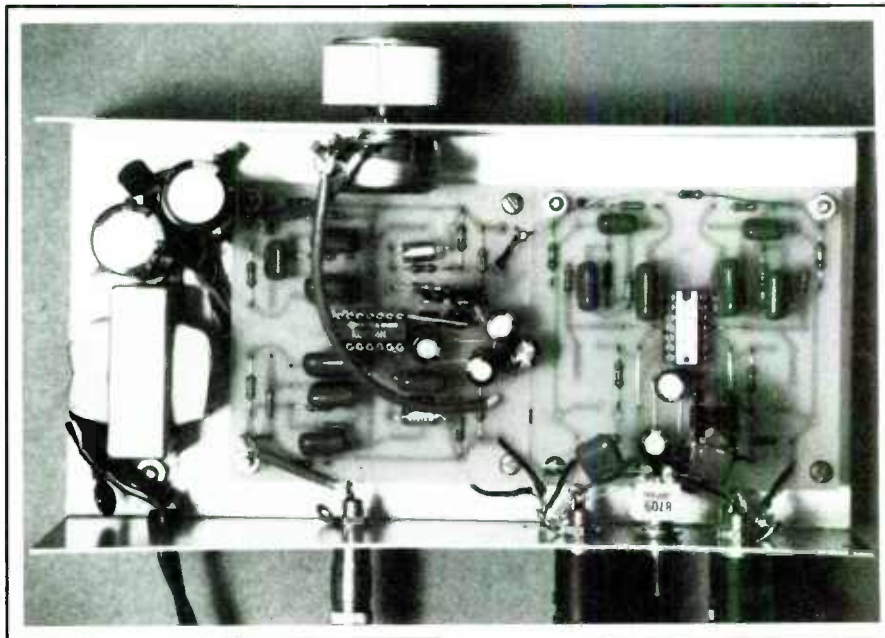


FIGURE 8: The crossover box.

Heathkit Audio Analyzer, and a warble tone generator or a pink noise generator, such as the Muller pink noise generator (Bernhard Muller, *Speaker Builder 4/84*, p. 16) is very helpful, and in the case of a tin ear like myself, absolutely essential, in setting up the system.

Figure 9A shows the subwoofer/cross-

over response at my listening position as measured by the Warbler and Heathkit analyzer. As you can see, there is good agreement between theory and practice. Using the Heathkit analyzer and the Muller pink noise generator to integrate the subwoofer into the system, I was able to get flat response within ± 3 dB from

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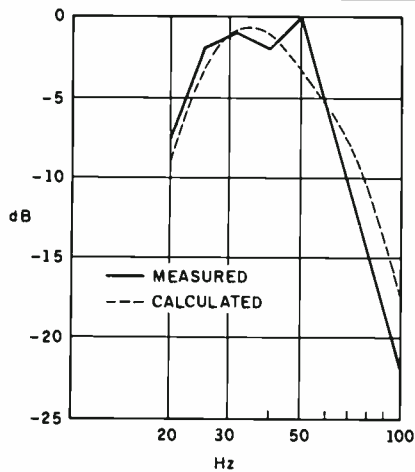


FIGURE 9A: Crossover/subwoofer response, $\frac{1}{2}$ octave warble tones.

32Hz up to 5kHz or so, beyond which the Quads roll off (Fig. 9B). Note that this is a single "snapshot" of the response at my listening position and is only intended as an indication of what can be achieved (and yes, I think I'm pretty lucky to get such a flat curve, so I immediately quit). Once you achieve a flat overall response using instruments, mark the level control position. Further adjustment can be made to taste, and a return to flat response can always be made.

Like all fourth-order crossovers, both upper and lower range speakers should be in phase with each other. To check for correct phase between the subwoofer and main speakers, connect the subwoofer in random phase, adjust the subwoofer level for flat response, then reverse the subwoofer connections. If there is more bass, the new connection is correct, if less bass, the previous connection was the correct one.

Both the Quads and the Hartley invert absolute phase, relative to the convention that a positive signal corresponds to a pressure wave (those of you who read David Ruether's article will note that he stated that the Hartley does *not* invert phase, but remember that his bass box had the rear of the speaker facing outward). To check for this, use a flashlight battery—connecting the battery (positive to red terminal) should cause a forward movement of the woofer if its absolute phase is correct, and disconnecting it should cause a return to rest position. On the Quads, the latter is more obvious than the former. For those who can hear absolute phase, I suggest reversing the connections to both the Quads and the Hartley (assuming that the electronics are non-inverting).

HOW DOES IT SOUND? My present system consists of the Quads, driven by

a Berning EA-230 tube amplifier, and the Van Alstine Super-PAS. The primary sources are a partially POGGE'd Magnavox 560 CD player, and a VPI HW-19/II turntable. The Hartley subwoofer is driven by a Dynaco Stereo 400. This is definitely overkill—a power rating equal to the sum of the power in the main amplifier channels should be sufficient to achieve peak levels in the deep bass equal to peak midrange levels. This should be more than adequate, since nearly all of the time, the midrange will peak higher than the deep bass. Even organ records tend to have their maximum levels at 40Hz and above. I also suggest a solid-state amplifier with good current delivery and a high damping factor, and large gauge, short speaker wires, because of the low impedance and underdamped characteristic of the Hartley driver.

Believe it or not, I don't consider myself a bass freak (I own exactly two organ records, and I rarely listen to cannons), so I had to dig around a little to find a few records with genuine low bass. On a lot of material, there is very little difference between the Quads alone or with the subwoofer, although I sometimes seem to get a better sense of the hall in which the performance was recorded, and perhaps slightly better depth and imaging. These are subtle differences, however. I have also noticed that pedal sounds on some piano records (for example, the first Glenn Gould recording of the Goldberg Variations—CBS CD MYK 38479) are much more noticeable than previously. These mechanical, extramusical thumps have a low frequency component whose accurate reproduction definitely adds to the feeling of listening in on the recording session.

On recordings with obvious low bass, such as the Telarc Holst Suites for Band (CD-80038, the infamous bass drum), the results are impressive—the bass is deep and powerful, but at the same time, I have no sensation that the bass is coming from a separate source. All the sound

seems to be coming from the Quads. On the Telarc Michael Murray organ recording of Bach's Toccata and Fugue in d(CD-80088), I can easily follow the musical progression of the pedal line—and the floor in my apartment vibrates.

Interestingly enough, I have a Newcomb peak power indicator (*Speaker Builder* 2/84, p. 17) connected to the subwoofer amp, and it seldom lights up, and never beyond the second LED (at first, I thought it was broken), equivalent to 12 watts peak into 4 ohms; at the same time, I have measured 110dB peak on the bass drum at the listening position. On the Dyna, I have the meters set to the most sensitive setting (5 watts into 8 ohms) and it never gets beyond 0dB. This is at volume levels that will occasionally clip the main amplifier (30 watts/channel).

ALTERNATIVES. So, is this the ultimate subwoofer? Probably not. Certainly, it does not meet all of the criteria set forth by Fielder and Benjamin in their recent paper on subwoofer requirements (*Journal of the Audio Engineering Society*, June 1988, p. 443), but almost no published or commercially available subwoofer design does. They recommend flat response down to 16Hz (10Hz for optimum cannon reproduction at overall peak levels of 120dB!), capable of a minimum of 100dB peak at 20Hz, 110dB peak at 40Hz and above, with low distortion (below 3% second harmonic distortion and less than 1% third harmonic distortion).

The HQ-24 would come close in terms of output if stereo subwoofers were used, although I doubt if it would qualify in terms of their stringent distortion criteria (they state in the article that no tested subwoofer, up to 24" in size, passed their distortion criteria at 20Hz and 92dB, 50Hz and 108dB and 100Hz and 101dB SPL). Back in the real world (so to speak), I imagine that the IRS and WAMM subwoofers can play louder and deeper than the Hartley, but this system should match most other subwoofers in terms of bass ex-

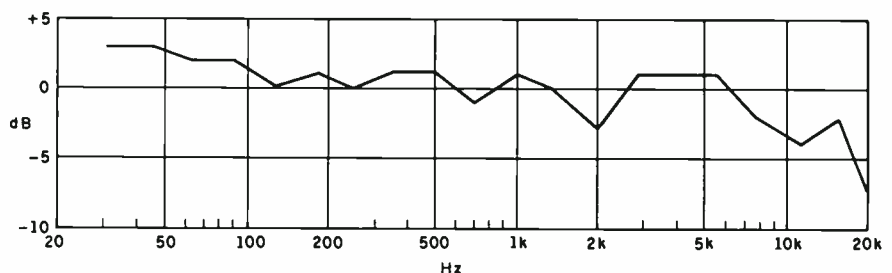


FIGURE 9B: Overall system response at the listening position, stereo pink noise, $\frac{1}{2}$ octave spectrum analysis.

tension, if not sheer output. Of course, ElectroVoice used to make a 30" driver. Hmmm...

As a final comment, you may be wondering whether this subwoofer system can be adapted to other drivers and other dipole speakers. The answer is yes, but you must make adjustments. For example, the low frequency boost requirements may need to be changed—a driver with a lower Q of 0.7 to 1.0 will need a boost starting at 100Hz rather than 80Hz. I discussed the driver requirements in the theory section. However, since I have had no experience with other drivers, I cannot suggest suitable substitutes, although I would not recommend using a driver or set of drivers with less volume displacement.

The boost will also need to be altered if the dimensions of the baffle are changed; basically, the rolloff point will be changed proportional to the square root of the ratios between the new and old baffle areas. For those who can afford double subwoofers, the crossover can be modified for stereo by adding a third board, identical to the second, and feeding the second and third boards directly from the two sections of the first board. The most versatile option for level control is the use of dual mono controls, which can compensate for possible variations in efficiency due to driver variation or placement problems. Alternatively, a stereo control such as the Alps can be used.

Finally, if different main speakers are used, the crossover frequency will need to

be changed to the -3dB point of those speakers. These are relatively easy calculations to make, however, and I encourage others to try their hand and report their results. Oh yes, I almost forgot. Curious about the subtitle? Well, remember MacCahill's comment, "There is no substitute for cubic inches"? A simple calculation of the volume displacement of the Hartley driver, assuming a 3/4" peak-to-peak cone throw, yields 270 cubic inches, which, if memory serves, is very close to the displacement of the classic small block Chevy. Good luck and good listening.

Continued on page 78

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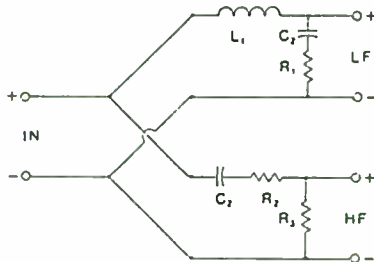
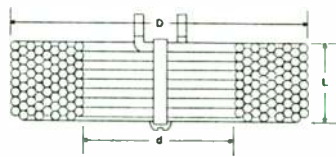
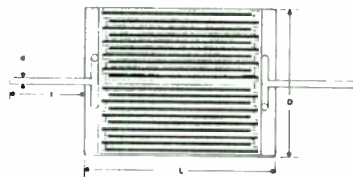
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ADJUSTING WOOFERS FOR HIGH PERFORMANCE

BY BRIAN D. SMITH

If you thumb through a speaker catalog with a calculator on your lap in search of the perfect woofer, you will discover how rare this creature is. If it belongs in a reasonably sized cabinet, it probably will not play below 40Hz. If it plays low, it requires a cabinet the size of a refrigerator. Small woofers that play low into a reasonably sized cabinet bottom out at too low a listening level. When you finally find a driver that plays low into a liveable cabinet and is large enough to play loud, the price is outrageous. Some woofers are as expensive as buying a good used subwoofer in a cabinet.

SOLUTION. With this in mind, I have attempted to modify a reasonably priced woofer so it will perform as well as drivers costing many times as much. In addition to being cost effective, you can choose the low frequency cutoff and optimize the driver for this cutoff. You don't need to settle for an alignment less than what you want.

My design goals were to achieve a 3dB down point below 30Hz with a box volume of 3 or 4 cubic feet and a Q_t of 1.0 or less. To simplify construction, I chose a closed-box alignment instead of a vented cabinet. With a closed-box alignment, the rolloff rate below system resonance is slower. This makes the bass output below cutoff louder than it would be if the cabinet were vented. I have listened to both vented- and closed-box cabinets of the same f_3 and the same driver size and am

ABOUT THE AUTHOR

Author Smith holds a BS in Electrical Engineering and a BS in Business. He is currently working in technical sales for Texas Instruments, Inc. He has constructed a pair of Roger Sanders' ESLs (SB 2, 3, 4/80), a pair of four-foot-tall ribbons and a pair of tractrix horns which are in service at a church in Columbus, Ohio.



PHOTO 1: Philips 12-inch unmodified driver.

convinced that closed boxes have more low bass given the same f_3 . If you build a subwoofer as I describe here, your results will be nearly identical to mine.

DRIVER. I used a Philips 12-inch model #12600 which has a paper cone and a porous dust cap. *Photo 1* shows an unmodified driver. *Table 1* summarizes the measured parameters for the driver in all of its various stages. The pre-modification Q_{ts} of this driver is 0.83 and is too high for good performance in any kind of box. It might work well if you cut a hole in your floor and used your basement as an infinite baffle but few wives would let husbands do that.

You have a choice of two possible routes in modifying this driver. In the first you add mass to the cone to lower its resonant frequency as well as increase the magnet mass behind the driver. Otherwise, if you are satisfied with the 30Hz resonance of the stock woofer, you can add magnets and leave the cone as is. In both cases, I advise adding felt to the rear of the speaker basket.

THE CONE. A paper cone can absorb moisture in a humid climate. This will degrade performance in a properly aligned

system by altering the f_s of the woofer as well as Q_{ts} . The first remedy is to seal the cone from moisture which also adds some stiffness. I used Varathane brand liquid plastic to coat the cone. The first coat must completely soak the paper—you should see the paper darken from behind. Let this coat dry overnight. Apply a second coat to ensure a good seal. These two coats added enough mass to lower the speaker resonance to 26Hz and raise Q_{ts} to 1.05.

Q_{ts} may be lowered to an acceptable level if you attach felt to the driver basket back. Simply cut pieces of felt to fit the basket rear openings and glue them in

TABLE 1

| MEASURED DRIVER PARAMETERS AT VARIOUS STAGES OF MODIFICATION | | |
|--|------------|----------|
| State of Driver | f_s (Hz) | Q_{ts} |
| No modifications | 30 | 0.83 |
| One coat of Varathane | 26 | 1.00 |
| Two coats of Varathane | 25 | 1.05 |
| Two coats of Varathane plus felt on back | 26 | 0.67 |
| 1.5 ounces of Rubberize It! on dust cap | 18 | 0.85 |
| One magnet on pole piece | 18 | 0.68 |
| Unmodified driver with one magnet on pole piece | 30 | 0.64 |

place with rubber cement. Adding the felt lowered Q_{ts} to 0.67. You could stop at this stage and use the modified driver with good results. The best, however, is yet to come.

ADDING MASS. To lower the driver resonance enough for an f_3 below 40Hz in a sealed box you must add mass to the cone. I used Rubberize It! brand liquid rubber. It is helpful to measure the driver's resonant frequency as you apply the liquid. Place the speaker with the cone facing up so that you can pour enough liquid around and on the dust cap to lower the resonance to 18Hz. The required amount is about 1.5 ounces. I taped weights to the cone to find the amount necessary to bring the resonance to 18Hz. If you do not have the facilities to measure the loudspeaker's resonance as detailed in "Build A Widget Box to Measure Loudspeaker Parameters," by Richard Saffran (SB 1/81, p. 7), you can weigh the liquid applied to ensure a proper resonant frequency.

To do this, use a scale capable of weighing to the nearest half ounce. Open the can of liquid rubber. Weigh it and record the weight. Carefully pour a small quantity on the dust cap and reweigh the can. Continue until the can is 1.5 ounces lighter. The speaker resonance will now be approximately 18Hz.

Let the speaker dry in this position for at least 24 hours. It is best to do this outdoors or at least with open windows because the fumes are hazardous.

Photo 2 shows the modified cone. Q_{ts} has increased to 0.85 as a result of the added mass.

I found that the Rubberize It! loses much of its mass as it dries. When it dried the driver f_3 increased to 24Hz. You should initially lower the driver f_3 to about



PHOTO 2: The modified cone— Q_{ts} has increased to 0.85 as a result of the added mass of the goop.

12Hz with the liquid rubber. The amount is three to four ounces. It takes about three or four days for the rubber to completely dry when applied in thick layers as we are doing here. This liquid rubber is designed to be applied in thin coats.

METHOD #2. A better method for adding mass as well as stiffness to a paper cone involves the use of polymers. EnviroTex brand two-part polymer is ideal. An 8-ounce kit containing two 4-ounce bottles will easily coat two woofers and costs about \$6. It is available from most paint stores. You mix it the same way as epoxy, using equal amounts of resin and hardener. Mix it thoroughly and spread it on the cone trying to coat it entirely.

A small pool will form around the dust cap. If the driver f_3 is not below 20Hz, you can easily add mass by dropping BBs into the polymer pool. I use K-Mart's Crossman Copperhead brand BBs. They are heavy and two dozen should be sufficient to weight the driver's f_3 below 20Hz when you use about an ounce of polymer. The polymer has the added advantage that it does not lose mass but merely hardens instead of drying. The driver will have nearly the same f_3 after the polymer hardens whereas the driver coated with liquid rubber will exhibit a marked rise in f_3 after it dries.

The hardened polymer is incredibly stiff. It is far stiffer than the dried liquid rubber. You may omit the Varathane process if you smear the polymer completely around the cone before you add the BBs. This modified cone seems stiffer than polypropylene cones to which I compared it. The polymer coating is better overall, but the liquid rubber will do the job if you cannot obtain a polymer kit. Photo 3 shows a driver treated with polymer and BBs.

MORE ATTRACTION. Adding magnets to the back of the driver reduces the Q_{ts} of the driver and raises the driver sensitivity. Our cone modifications lowered the resonant frequency of the driver but at a cost of lower sensitivity and higher Q_{ts} . We can improve both properties of the driver by adding a magnet to the rear assembly as shown in Photo 4. This photo also shows the felt pieces attached to the rear of the driver.

Place the driver face down so that the magnet is uppermost. Holding a magnet tightly in your hand so you can see one of the flat sides, bring it near the speaker magnet assembly. You will feel a force between the two magnets as you bring them close together. The force will either cause the two magnets to attract or repel.



PHOTO 3: A driver treated with polymers and BBs.

It is critical that you attach the new magnet correctly, so the force is repulsive. Mix a small quantity of two-part epoxy and put a small coat on the driver's pole piece. Put two or three strips of masking tape on the back of the new magnet, place it atop the pole piece, and hold it there with one hand while you fix the tape to the driver's original magnet. The tape will hold the new magnet in place until the glue is dry.

I attached an empty Purina cat food can with a cardboard roll piece inside over the magnet assembly (Photo 4), completing the magnetic circuit from the new magnet to the driver basket. This should prevent the new magnet from losing its strength over time. Remove the tape when the glue is dry. Q_{ts} of the driver is now 0.63. This value of Q_{ts} is low enough to make the driver work in a 3-to-4-cubic-foot cabinet with a system Q_t of about 1. This will result in a peak about 1dB above system resonance. This peak is not objectionable since it is in the low bass.

The modified driver in a 2.9-cubic-foot cabinet has a measured system resonance of 42Hz and a Q_t of 1.1. The low frequency cutoff will be about 22Hz, a very low 3dB down frequency. Few commercial systems at any price can match this performance. In a 6-cubic-foot cabinet Q_t should be about 0.9. This 20% reduction in Q_t is probably not worth the added cabinet size.

PERFORMANCE. My current speaker system consists of an M&K stereo subwoofer, four Audax 5.25-inch midranges per side and a pair of 4-foot-tall ribbon tweeters. The M&K drivers are heavy and appear to be well made, with a resonant frequency of 15Hz and a Q_t of about 1.0 in the 2.9-cubic-foot box. The subwoofer shakes my windows when music contains loud passages below 40Hz. I confirmed that the frequency of the window shaking was below 40Hz with a signal generator.

MATERIALS LIST

| MATERIAL | SOURCE | COST |
|-----------------------|----------------|---------|
| 12" Philips driver | Zalytron | \$12 |
| Magnets | Zalytron | \$1 ea. |
| Rubberize It! | | \$5 |
| Felt* | fabric store | \$1.35 |
| Varathane | hardware store | \$5 |
| Epoxy glue | | |
| Rubber cement | | |
| EnviroTex (8-oz. kit) | | \$6 |
| BBs | K-Mart | |

* You may want to try wool felt, which I suspect is less reactive than polyester felt and may perform better

LISTENING TEST. I replaced the right channel M&K driver with the modified Philips driver and did an A-B test. I played only the subwoofer using Telarc's *Beethoven or Bust* CD, which contains a lot of low bass information. This disc can destroy small woofers at loud levels. I used the preamp balance control to select one channel at a time. Passages with low bass were played over and over while moving the balance control back and forth. The modified Philips driver is 1 or 2dB less sensitive than the M&K driver. I adjusted the level control to compensate for this.

Other than volume, the two drivers sound almost identical. Both have very deep bass and will rattle the window in

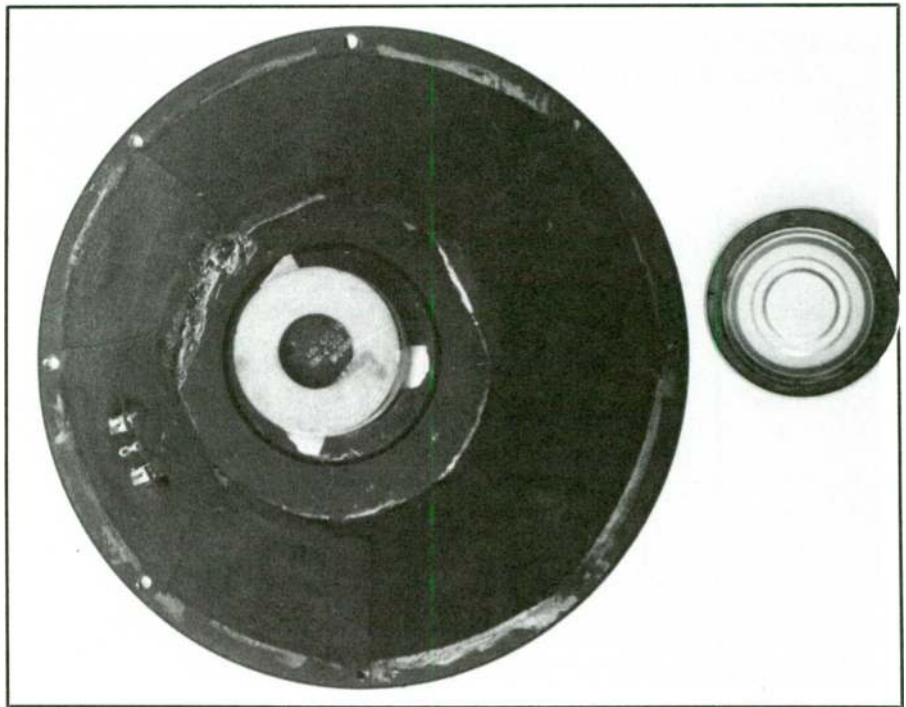


PHOTO 4: A cat food can with a cardboard roll piece inside over the magnet assembly completes the magnetic circuit.

my concrete floor listening room. The M&K driver has a characteristic paper sound in the midrange which is still audible despite using an 18dB/octave electronic crossover. The modified Philips

driver loses this characteristic paper sound as a result of the Varathane treatment, I believe. If you omit goop on the dust cap, I recommend the Varathane treatment.

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CONCLUSIONS. 1. It is possible to transform an inexpensive woofer into a top flight performer capable of very low bass reproduction as well as very loud listening levels. 2. You do not have to pay through the nose for expensive woofers to get the performance you want. Inexpensive modifications can do wonders. 3. The difference between poorly designed woofers and good ones is attention to detail.

MODIFIED DRIVERS

Modified drivers can be obtained from the author (2714 Holy Cross Lane, Garland, TX 75044) at a cost of \$30 plus \$4 shipping each (money order or certified or cashier's check). They are quite labor intensive which will mean a few weeks lead time between order date and delivery. They will include individual specifications for each driver as well as recommended enclosure size and guaranteed low frequency cutoff for this enclosure.

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Fast Reply #K0317

MODIFYING THE PARADIGM 7se

BY S. WAYNE COX

As a result of the article "Incredible Bass Performance From A Two-Way Design"¹ I was approached by an audiophile, dissatisfied with the sound of his high-end components (Naim integrated amplifier, Linn turntable and cartridge, and Paradigm 7se loudspeakers). He had discussed his disenchantment with several audio dealers and technicians who could not identify the source of his anxiety. The main focus of his concern were the loudspeakers, which he was ready to replace if necessary. I had previously heard the Paradigm 7ses and remembered being favorably impressed, both with the high driver quality and with the neutral, uncolored sound. After considerable dialogue, I made the following observations:

1. While his system used very good components, capable of fine sonic resolution, it was somewhat low-powered (at 18W RMS/channel into 8Ω and 25W RMS/channel into 4Ω). I pointed out this could very well be part of the problem, since the 7ses are reputed to like powerful amplifiers.

2. He needed a subsonic filter (at least 12 and preferably 18dB/octave, below 15Hz or so) to make the best use of available power. Not only would this help avoid power-robbing woofer cone float, but it would also reduce consequent modulation (Doppler²) distortion of higher frequencies. Few people, including many audio salespersons, understand that reflex speakers need a subsonic filter, since woofer cone motion in such designs is



basically undamped below system resonance.³ Any signal below this frequency (particularly those due to warped record infrasonics, but also some from well-recorded CDs) can cause wild and potentially damaging woofer excursions, as well as the above related problems.

Since he was planning to visit my town, I asked my audiophile friend to bring along his speakers so Bob Palmer and I could look at them. Due to time constraints, we would concentrate only on areas we felt would benefit most

from modification. Primarily, this would involve examining the effects of negating the inductive reactance of the woofer's voice coil. Previous experience had shown that, unless woofer impedance was constant above the system's second (in a reflex design) impedance peak, the crossover would not function satisfactorily.^{4,5}

No matter what the order of crossover sections used, or the value and quality of components in them, the phase response through the crossover region would be modified by the phase angle due to the woofer's voice coil inductance.⁶ Since this phase angle is 25–50 degrees,⁴ simple driver lead inversion will not correct for it. Sonically, it is manifested as a gritty character in the upper male/lower female vocal range, narrow midrange dispersion (horizontally), and a general lack of clarity across the entire audible band.

ATTACK. The first step was to hook up the Paradigms to one of our own systems⁷ (complete with subsonic filter) and ask our friend to point out what he felt were the offending sonic characteristics. Comparing this with our own evaluation, we then discussed how to proceed. We would:

1. Measure the impedance of the 7ses across the band as in our previous article,^{8,9}

2. remove both drivers from each cabinet, and run impedance sweeps of the raw drivers individually,^{8,9}

3. examine, measure and evaluate the stock crossover, noting general format, layout and component quality, and

4. if required as indicated from the results of 1 and 2 above, choose woofer impedance compensation circuitry (or Zobels¹⁰) which would effectively negate inductive voice coil reactance and subsequent rise in phase angle with rising frequency.⁶

ABOUT THE AUTHOR

Wayne Cox has a BS in Biology and has also studied dentistry. He is self-taught in electronics and enjoys designing and building test equipment and active filter circuitry. He plays contemporary guitar and has built several projects associated with this hobby, in addition to dabbling in speakers.

RESULTS. In *Graph 1*, a large impedance peak of 36.5Ω centered at 1.427kHz suggests that there are significant amounts of phase shift for at least an octave on either side of the crossover region.⁴ Since ferrofluid-cooled tweeters such as the VIFA D25 TG-55 used in the Paradigm 7se characteristically exhibit very small impedance peaks at resonance (f_s), it is probable that this large impedance anomaly is mainly due to the inductive effects of the woofer's voice coil. *Graph 2* shows that overall tweeter impedance varies only $\pm 0.6\Omega$ from 500Hz – 10kHz , with an f_s peak of only 6.9Ω at 1.725kHz .

Thus, there is very little reason to Zobel out the tweeter's impedance peak in this case. However, as *Graph 3* shows a rising woofer impedance above the 4.4Ω minimum at 160Hz (to a value of 30.0Ω at 3.15kHz , and even greater above that point), the need for a woofer Zobel is paramount. Since minimum woofer impedance was 4.4Ω , we chose a matched pair of $4.7\Omega/10\text{W}/10\%$ wirewound resistors for the resistive component of the Zobel's (using a digital VOM), setting the desired range.¹¹ We tried several different values of non-polar electrolytic capacitors in the 10 – $47\mu\text{F}$ range before finally selecting $33\mu\text{F}$ as the correct value. We found a matched pair using a capacitor match-

maker constructed from an electronics magazine article.¹²

PREVENTING RATTLES. We then soldered each Zobel into place on the crossover itself, at the points where the woofer leads were connected. Five-minute epoxy secured them to the ferrite-cored woofer section, preventing rattles. An easier point of attachment is on the woofer terminals themselves. We chose the crossover location since we were measuring the values of the various crossover components anyway, which required removing the crossover from the cabinet to permit unsoldering of several joints. The very flat impedance curve in *Graph 3* (displaced -5Ω for clarity) demonstrates the effectiveness of the Zobel's circuit, $5.5\Omega \pm 1.3\Omega$ from 160 to $3,150\text{Hz}$.

Graph 1 shows overall system impedance with Zobel's in place (again, the curve is displaced -5Ω for clarity). Note that there is a new third impedance maximum of only 12.8Ω , at 2.5kHz , while the stock system peak was 36.5Ω at 1.427kHz . By displacing the peak higher up in the band, and drastically reducing its magnitude, most of the problems referred to earlier can be markedly reduced. The overall impedance curve is not absolutely flat, indicating that other, less significant factors

are involved which we would address given more time. Minor crossover changes are often required following woofer Zobel'ing,¹³ but after experimenting with different crossover slopes and frequencies, we decided the effort would yield only marginal performance gains. Short of a complete crossover redesign, we felt it best to keep things simple.

Comparing the sound of the stock Paradigm 7se with the Zobel'ed version, the latter exhibits a dramatic improvement in horizontal dispersion, particularly in the vocal range (perhaps the best I have ever heard in this regard). Sonic clarity shows remarkable improvement at all frequencies across the band. All traces of fuzziness (what I call "sonic smear") are gone. Bells and cymbals are crystal clear, appearing and then decaying with incredible speed. Even the bass seems cleaner and, strangely, more extended. I attribute this to the woofer's "release" from the effects of the inductive reactance of its voice coil. Even when driven to peaks of 200W per channel for extended periods, the modified version never becomes harsh or strident, unlike the stock version. In blind A/B comparisons, several audiophiles and one "normal" person consistently identified and preferred the modified version of the Paradigm 7se.

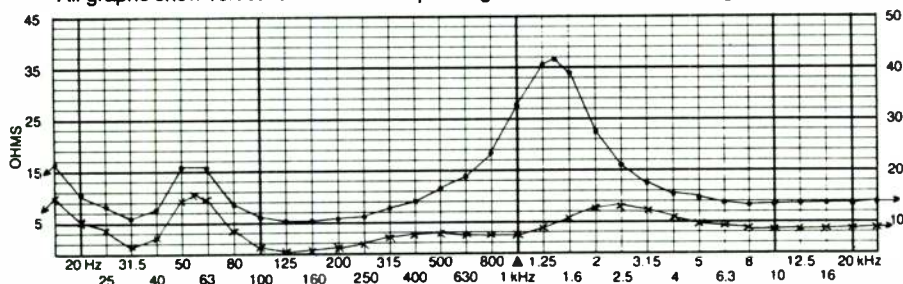
NOW WHAT? Since we only had a few hours in which to work, Bob and I chose to limit our modifications to areas in which minor changes would yield dramatic gains. We did not do the myriad of before-and-after frequency response measurements that would normally be a part of such upgrades. Ideally, you should do close-field driver frequency analysis and on- and off-axis wideband frequency response evaluation, both before and after Zobel'ing. However, Bob and I have done quite a bit of this type of work, and we are confident our ears are an accurate barometer of the results.

In this case, modification was simple, yet effective. Our new audiophile friend is once more pleased with his stereo system, and he has saved himself the cost of unnecessarily replacing one or more of his components.

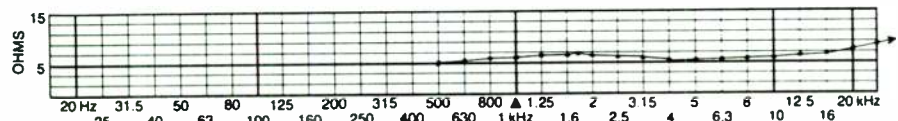
I was so impressed with the VIFA drivers used in the Paradigm 7ses that I intend to buy a set soon and design my own system from scratch. This is ultimately the best way to proceed, although you can achieve very good results by performing simple "tweaks" to otherwise very good systems. Refer to *Figs. 1a* and *1b*, *Graphs 1–3* and *Table 1*.

A SECOND LOOK. Subsequent to modi-

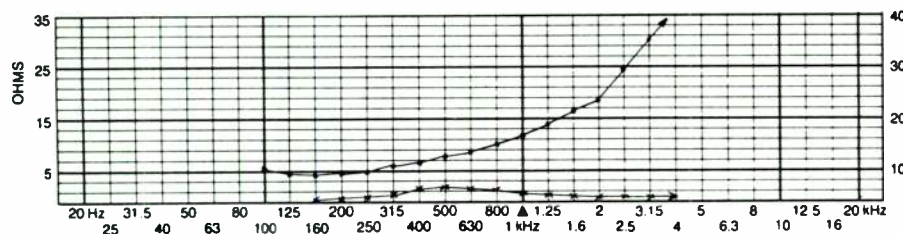
All graphs show vertical divisions corresponding to 2Ω . All tests done with grilles removed.



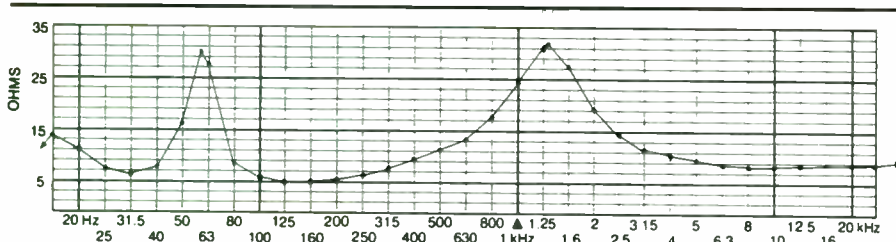
GRAPH 1: Impedance of stock (upper curve) and Zobel'ed (lower curve) Paradigm 7se.^{8,9} Note: Impedance of modified 7se is shown displaced by -5Ω for clarity.



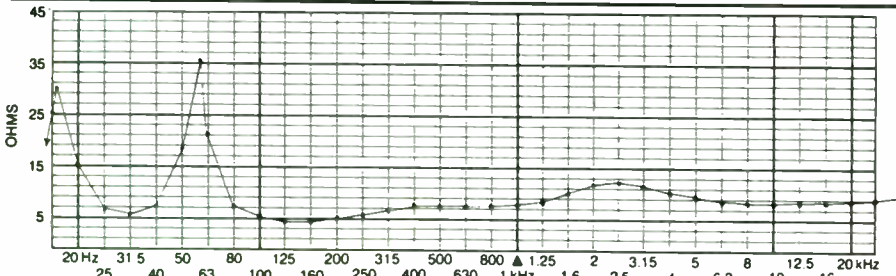
GRAPH 2: Tweeter impedance (VIFA Model D25 TG-55).^{8,9} Note: Tweeter f_s is 1.725kHz at 6.9Ω .



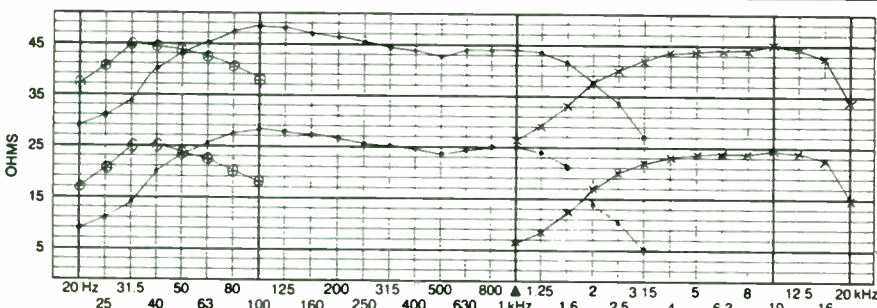
GRAPH 3: Impedance of unmounted stock (upper curve) and Zobel'ed (lower curve) woofer.^{8,9} Note: Impedance of Zobel'ed raw woofer is shown displaced by -5Ω for clarity. Woofer f_s is 31.58Hz at 30.0Ω .



GRAPH 4: Impedance of stock Paradigm 7se (2nd pair, SN 78115).



GRAPH 5: Impedance of Zobelled Paradigm 7se (2nd pair, SN 78115).



GRAPH 6: Quarter-inch close-field frequency response of stock and Zobelled Paradigm 7se (2nd pair, SN 78115). Note: Loudspeaker placed atop 35½" cabinet, with front baffle 21¼" from wall. Stock response (upper curve) displaced by +20dB for clarity. All tests using Technics SH-8000 Audio Frequency Analyzer (½-octave warble tones). All d = ¼". Port: mike height = 42¾"; 0dB set at 70dB at 31.5Hz. Woofer: mike height = 47½"; 0dB set at 70dB at 1kHz. Tweeter: mike height = 55"; 0dB set at 70dB at 10kHz.

fying the Paradigm 7se, I was able to take a second, more detailed look at a more recent version, which appeared outwardly identical. Since time was not limited, I was able to do close-field and on- and off-axis frequency response evaluations, before and after Zobelling. I also repeated impedance sweeps of the stock and Zobelled versions (Graphs 4–9).

Graphs 1 and 4 show similar impedance peaks of 36.5 and 31.8Ω at 1.427 and 1.340kHz, respectively. These peaks, due to woofer voice coil inductance⁶ were reduced by the woofer Zobels circuit of Fig. 1a to a value of approximately 9Ω. At first I was bothered by the remaining 12.05–12.8Ω peaks circa 2.5kHz (because of potential phase and frequency response anomalies that might accompany them), until I realized they were due to the paralleled 3.9Ω resistor/1μF capacitor circuit placed in series with the rest of the tweeter crossover section. This type of circuit is commonly used to tame a hot low-end response¹⁴ and raise the high end of a tweeter.¹⁵ We used a similar circuit before¹ to control the smoothness of the

"knee" of a tweeter's rolloff, in addition to boosting the extreme highs.

If I build my own speakers using the same drivers as the Paradigm 7ses, I would like to play around with the component values in this circuit, or perhaps eliminate it altogether and observe the effects on both impedance and frequency response through the 1.6–5kHz region most affected by the woofer Zobels. The

latter might require some readjustment of other component values in the high-pass section.

IS FLAT BEST? While the manufacturer has achieved a commendably flat frequency response over much of the band (Graph 7), we should also look at the rising phase angle of the woofer impedance. The above approach is capable of giving improved phase response and flat frequency response together. In my humble opinion, the tweeter amplitude adjusting part of the high-pass section permits flat output through the critical crossover region by "fixing" the wrong problem in the wrong driver.

In Graph 6, note the change in the slope of the woofer rolloff in the Zobelled (lower) as compared to the stock (upper) curve in the 1.6–2.5kHz region. The effect of this change is reflected in Graphs 7–9, which show a slight decrease in output of the Zobelled loudspeaker in this area (more about this later). This is preferable to allowing the phase angle of the impedance of the woofer to rise unchecked with increasing frequency (above f_s), causing problems through the crossover region. (A quick listen to the Zobelled versus the stock 7se will confirm this statement.) I have heard terrible-sounding loudspeakers whose frequency response was ruler-flat, while others having a few small "bumps" in charted output sounded much better. Thus, flat frequency response must not be the primary consideration in loudspeaker design.

Below 100Hz, stock (Graphs 1 and 4) and Zobelled (Graphs 1 and 5) impedance curves are significantly different for the two pairs of Paradigm 7ses I tested. Before-and-after curves for the original pair showed very little change in the height or shape (Q) of either the first (port resonance) or the second (woofer resonance) peaks with Zobelling. However, the Q of these peaks in the second pair (Graphs 4

TABLE I

PARADIGM 7SE MANUFACTURER'S SPECIFICATIONS

| | |
|--------------------------|--|
| Design | 2-way, bass reflex |
| Frequency response | 35–20kHz ± 2dB @ 0° 35–15kHz ± 2dB @ 30° |
| SPL (1W/meter) | 89dB anechoic 92dB room |
| Nominal impedance | 8Ω |
| Low/mid frequency driver | 8" polypropylene cone with rolled rubber surround; 1" voice coil; cast aluminum basket |
| Tweeter | 1" polyamide dome; <0.3gm moving mass; 1" ferrofluid-damped voice coil |
| Crossover frequency | 2.3kHz |
| Internal volume | 32 litres (1.13 ft ³) |
| Recommended placement | using speaker stands |

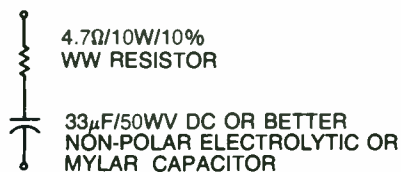


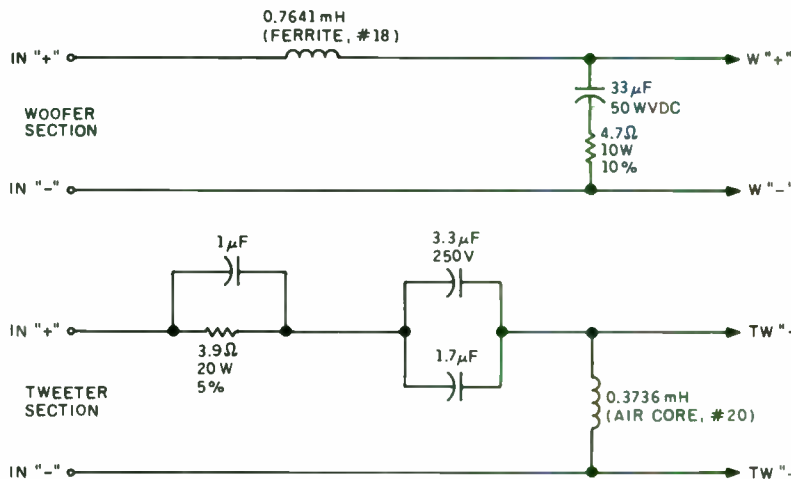
FIGURE 1A: Zobel's circuit used in modification.

and 5) increases significantly when a woofer Zobel's is fitted. Both peaks increase in height and become narrower, corresponding to an increase in Q .¹⁶

DAMPING MATERIAL. Insofar as the stock loudspeaker peak heights are concerned, the difference between the two pairs might be due to the change in the type or amount of damping material used.¹⁶ The bluish long-fibre cotton waste of the first pair (SN 62552 and 62553) was changed in the second (SN 78114 and 78115) by the manufacturer to a finer, off-white blown mat type cotton waste. While the effects of different damping materials on high-frequency absorption are well documented,¹⁷ the effects of low-frequency damping, particularly with respect to port resonant peaks in reflex systems, are more obscure.

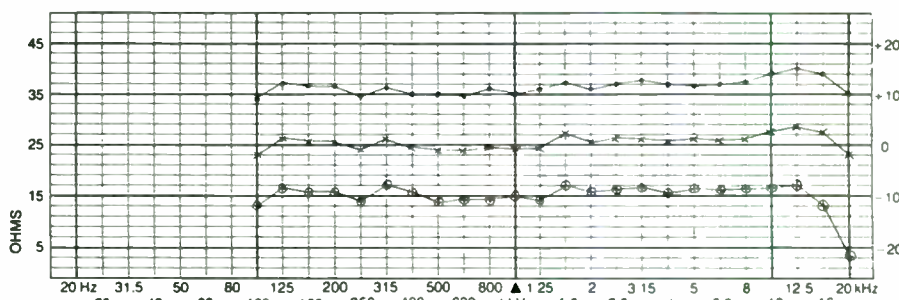
I have experimented with varying amounts of polyester batting and found the height and Q of both port and woofer resonant peaks can be reduced by adding more of the material to the cabinet of reflex designs. From this I deduce that the damping material in the two pairs of Paradigm 7ses I looked at was not the same either in amount or in acoustic effect. I suspect that this inequity was at least partially responsible for the increase in peak height and Q of the later version. Whether this was done because of limited availability of the earlier bluish material, or to artificially enhance perceived bass output by decreasing damping at resonance, I don't know. In any case, you can adjust the Q of these peaks according to preference, simply by changing the type or amount of damping material. I prefer the bass response of the first pair (Graph 1), both before and after Zobel'ing, since it was more damped.

The increase in Q of both resonant peaks noted in the second (but not the first) pair of 7ses after Zobel'ing might have caused bass overhang if excessive.¹⁶ Higher Q translates into a greater output at resonance,¹⁸ which may or may not cause boominess. I did not find this to be the case in either pair of 7ses described here, before or after Zobel'ing. The earlier pair, however, seemed to have "cleaner" bass fundamentals.

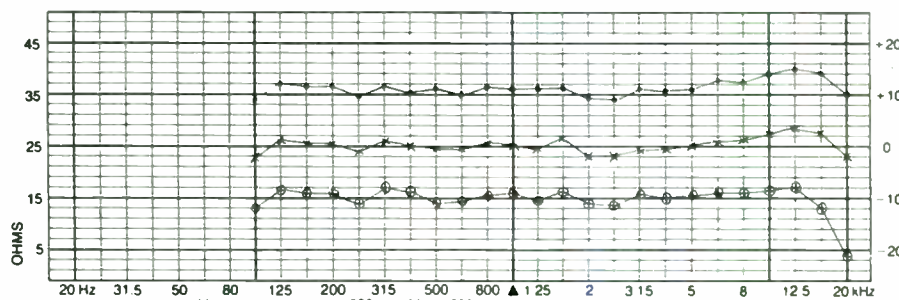


NOTE: BOTH DRIVERS WIRED IN PHASE, AS IN UNMODIFIED 7SE.

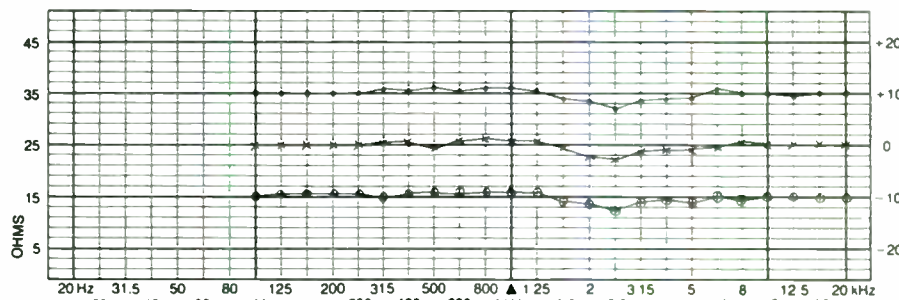
FIGURE 1B: Modified Paradigm 7se crossover with Zobel's.



GRAPH 7: Frequency response of stock Paradigm 7se at 0° on-axis and +15 and +30° horizontally off-axis (2nd pair, SN 78115). Note: All curves use mike $d = 18"$. Upper curve: 0° on-axis; mike height = 52 1/2"; mike position halfway between tweeter and woofer dust caps. Loudspeaker placed atop 35 1/2" cabinet, with front baffle 21 1/4" from wall. Curve displaced by +10dB for clarity. Middle curve: +15° horizontally off-axis. All else as for 0° curve above. Lower curve: +30° horizontally off-axis. Curve displaced by -10dB for clarity. All else as for 0° curve above. Frequencies below 100Hz not recorded because of boundary effects.



GRAPH 8: Frequency response of Zobel'ed Paradigm 7se at 0° on-axis and +15 and +30° horizontally off-axis (2nd pair, SN 78115). Note: Test conditions as for Graph 7, except with 4.7Ω/33μF woofer Zobel's clipped onto wires coming out of port from woofer terminals.



GRAPH 9: Net change in frequency response in Paradigm 7se after Zobel'ing (2nd pair, SN 78115). Data derived from Graphs 7 and 8.

TABLE II

SOME MEASURED PARADIGM 7SE SPECIFICATIONS

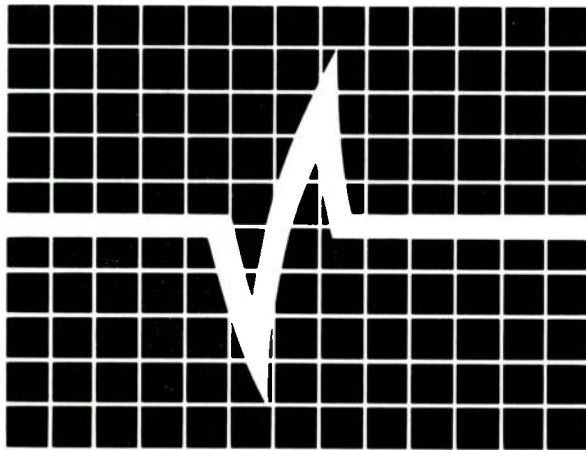
| | | |
|--------------------------------|--|---------|
| SN | 78115 | |
| Stock DC nominal impedance* | 4.05Ω | |
| Zobelled DC nominal impedance* | 4.05Ω | |
| Tweeter DC nominal impedance* | 4.70Ω | |
| Woofers DC nominal impedance* | 3.85Ω | |
| Woofers f_s (unmounted)*† | 94.0Ω @ 34.30Hz | |
| Stuffing** | Off-white, fine, blown mat type cotton waste | |
| Driver lead wiring | Tweeter | Woofers |
| | + Blue | Red |
| | - Green | Black |

*measured with a Sanwa ED-450C digital VOM

†vs. 30.0Ω @ 31.58Hz in 1st pair, SN 62552

**vs. bluish, long-fibre shredded cotton waste in 1st pair

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MAGNET SIZE. Note that the woofer f_s (unmounted) in SN 78115 was 94.0Ω at 34.30Hz, while in SN 62552 it was only 30.0Ω at 31.58Hz. Driver Q, which was clearly not the same for the two drivers, can be adjusted at the manufacturing level by altering magnet size (or, presumably, strength).¹⁶ A large magnet decreases Q by damping the cone better at resonance. Thus, the significantly greater Q in the woofer of the more recent 7se is probably due to a decrease in the size or strength of the magnet used. I have no means of determining magnetic field strength, nor was I able to compare magnet sizes, as I worked on the two pairs of speakers at different times.

Weems states that poorer magnetic damping associated with high Q drivers can cause poor bass transient response, but I did not note any deficiency in this regard. He goes on to say that low-frequency hangover "has the effect of pulse stretching, which can make the bass more audible without noticeably changing the character of the overall sound."¹⁶ I do recall that one of my first impressions (which are often the most accurate) upon hearing the second pair of Paradigm 7ses was that there was remarkable extension in the bass, even more than I remembered from the first pair. Perhaps my ears were fooled by the manufacturer's use of reduced magnetic woofer damping in conjunction with a poorer grade of damping material.

While stock Paradigm 7se dispersion is already very good (Graph 7), woofer Zobelting caused slight changes in measured performance (Graph 8) which correspond to rather dramatic audible improvements. The Zobelting procedure, though simple to perform, is very rewarding in terms of improved clarity and dispersion across the entire audible band. Although all of the curves in Graphs 7 and 8 are very flat, they are only an indication of what the calibrated microphone saw at one particular location in relation to the drivers, cabinet, and room. Other curves taken at different mike positions (or in different rooms) would likely vary in flatness. Vertical mike position can be critical, due to lobing effects,¹⁹ so non-anechoic frequency response curves should only be used to indicate trends, and not be taken as absolute. I have therefore included Graph 9, which shows relative changes in on- and off-axis response for a single mike position with Zobelting.

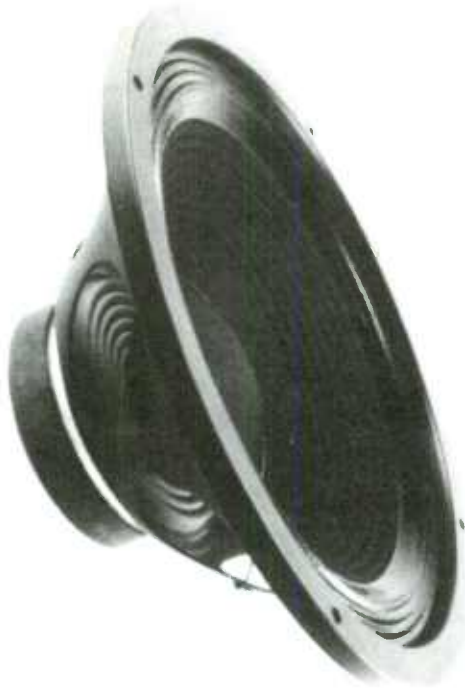
The findings here have pointed the way towards achieving a truly "super" Paradigm 7se. I realize that any manufacturer must make choices dictated by factors

Continued on page 79

THE SOURCE

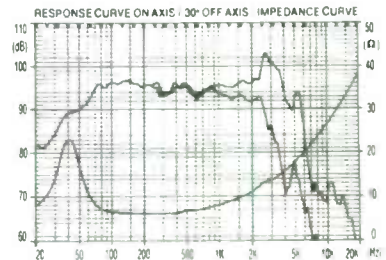
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SYMMETRICAL SPEAKER SYSTEM WITH DUAL TRANSMISSION LINES

BY PETER E. HILLMAN

ELECTRONIC CROSSOVER DESIGN

One of the greatest challenges of this project was to integrate the non-ideal response of the drivers into the crossover design. As with the design and construction of my enclosures, I do not anticipate that many of you will duplicate my crossover, which is the major reason I have not taken the trouble to do circuit board layouts. On the other hand, the procedure and logic I went through to design my crossover should be useful to many of you.

Before we go through the design procedure, I want to emphasize that I am partial to electronic crossovers because they are easier to tailor to the imperfect response of the drivers, enclosures, and the room than are passive crossovers. You may balk at the prospect of buying more amplifiers, but it can actually be cheaper to buy multiple amplifiers for use with electronic crossovers than it is to buy a single-amplifier passive crossover system.

For example, a biamplified system with a 100W low-frequency amplifier and a 25W high-frequency amplifier is equivalent to a single 225W amplifier in a conventional passive crossover system.²² A single amplifier with more watts than the combined wattage of two smaller amplifiers commonly costs more than the two smaller amplifiers. High sound quality also may be less expensive in multi-amplified systems compared to single-amplifier systems.

In response to a reader's question about biamplifying the satellites of the Swan IV system, Contributing Editor D'Appolito suggests that sonically superior amplifiers such as Krells show little improvement with multi-amplification, while medium-priced amplifiers such as Haflers benefit from multi-amplification.²³ Should two Haflers in a multi-amplified system benefit enough to sound as good as a single-

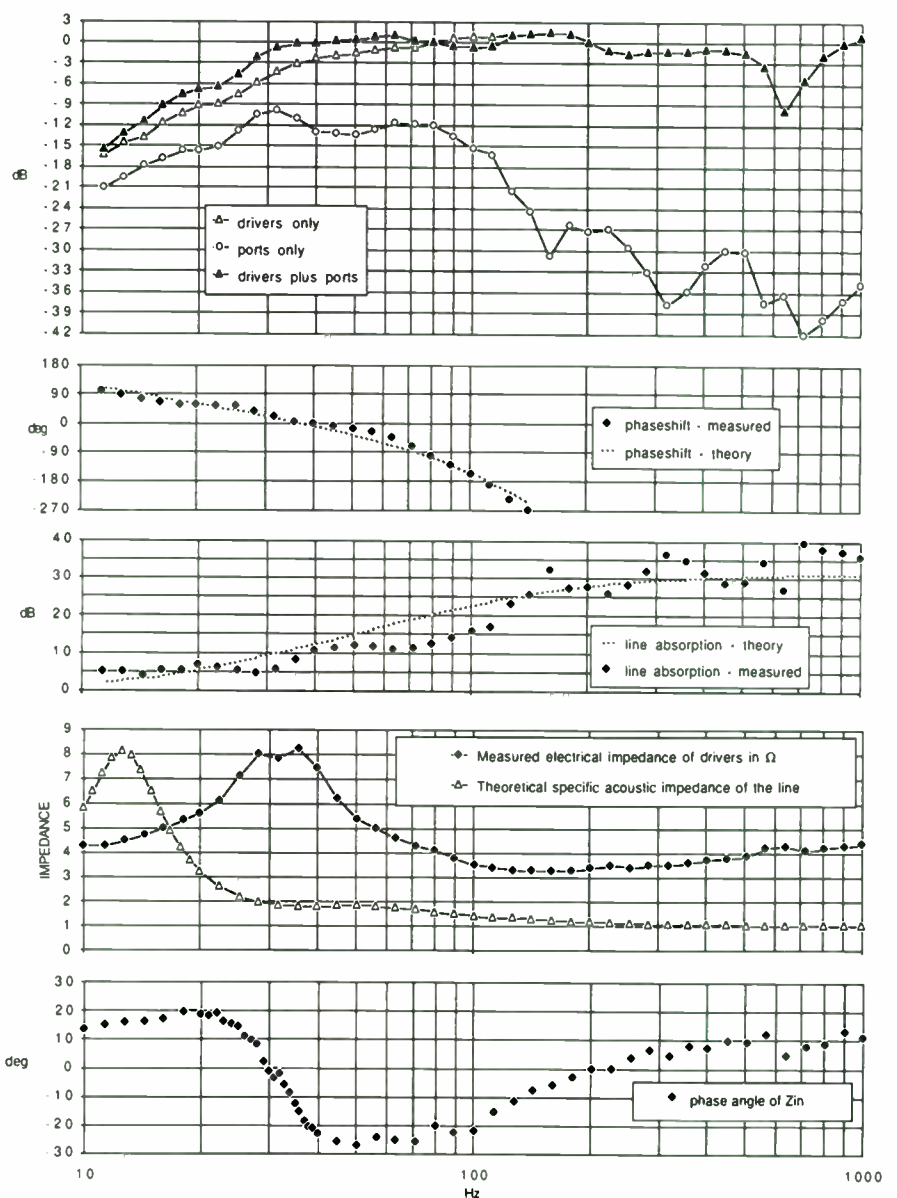


FIGURE 8: Response characteristics of the Dynaudio 30W54 woofer mounted on an 8-foot transmission line, including (top to bottom) near-field amplitude response, phase shift by the line, absorption by the line, electrical and acoustic impedance of the line, and phase angle of the woofer voice coil impedance.

amplifier system with one Krell, you could save a lot of money since two 145W Haflers cost about \$1,300, while one 200W Krell costs \$5,500. I am not suggesting that two Haflers are the best choice. The amplifiers should be selected to drive the frequency range in which they are known to have exceptional sound quality.

BEGIN. The first step in designing an electronic crossover is to measure the amplitude and phase response of the individual drivers, with the enclosure located more or less in its desired listening position. From these measurements you will find information needed for selecting crossover points, crossover slopes, and correcting for cabinet diffraction, that is, where the output of the drivers shifts from half space (2π steradians) to full space (4π steradians), and nonlinear responses of the drivers and the room. You will also have some clue about the relative arrival time of sound from each driver to the listening position.

ONE-METER RESPONSE. Don't trust manufacturer's data sheets . . . measure! We will start our testing procedure by measuring the drivers at one meter, on-axis, and at listening height. One meter is a good distance because it includes the effect of the cabinet shape and size and is not much affected by room reflections provided you use a gated time-measurement tool like Linkwitz's shaped toneburst generator,²⁴ which excludes late arrival reflections.

Linkwitz's shaped toneburst generator takes the signal from a sinewave generator and creates a burst of five cycles following a raised cosine function. The spectral energy in this toneburst is contained within a $\frac{1}{3}$ -octave response centered at the frequency of the sine wave fed into the toneburst generator. I only used the toneburst generator circuit of Linkwitz's schematic,²⁴ not the microphone preamplifier or peak detector. I fed the output from the electret microphone-preamplifier, as was used for the near-field woofer measurements, directly into one of the vertical amplifiers of my oscilloscope where the peak-

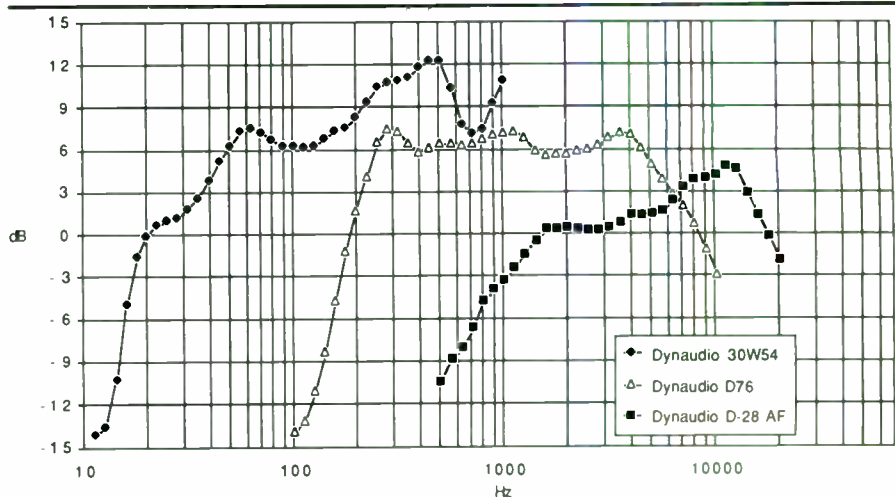


FIGURE 9: Average 1m response inside the author's listening room of both woofers, both midranges, and the tweeter mounted in the completed enclosure, including grille cloth.

to-peak voltage of the pulse was recorded through a range of frequencies in $\frac{1}{3}$ -octave increments.

The peak-to-peak voltages were converted to dB using the relationship, $\text{dB} = 20 \cdot \log(V/V_{\text{ref}})$. I would urge Old Colony Sound Lab to offer the board and parts for the toneburst generator section of Linkwitz's schematic. Not only does it provide an inexpensive method of avoiding most late arrival reflections but it also yields information on resonant and diffraction problems of the enclosure and/or drivers. I agree with Linkwitz,²⁴ that tonebursts are much easier on your ears and equipment than are continuous sine waves. [Old Colony attempted to get working Linkwitz toneburst boards produced for five years, without success. If anyone has a working system and an article to help readers implement it, OC and SB will welcome it.—Ed.]

TEST RESULTS. Let's examine the results of the 1m response test for the Dynaudio 30W54 woofers, D76 midranges, and D28 AF tweeters (Fig. 9). The same voltage input signal was used to drive both woofers (wired in parallel) or both midrange drivers (also wired in parallel) or for one tweeter, so that the relative efficiency of the drivers could be compared (0dB is arbitrary). You will note that the Dyn-

audio D28 AF tweeter has a pronounced broad peak of about 4dB around 11kHz (Arthur Brown²⁵ also shows this peak).

If this peak is attenuated with a notch filter, the D28 AF will be about 6dB less efficient than the two Dynaudio D76s in parallel. The D76s have a much smoother response than the tweeter, being within $\pm 1\text{dB}$ of their operating range from about 250Hz to about 4.5kHz. The 1m response of the woofers is not nearly as smooth as their near-field response (compare to Fig. 8). Taking the relative difference between the 1m response and the near-field response (Fig. 10), it is easier to sort out the degradation of the near-field response when we move one meter away.

The woofers show the effect of cabinet diffraction loss as the drivers shift from radiating their energy into half space (approximately 250Hz) to full space (approximately 160Hz). We would expect diffraction loss to begin at the frequency in which its wavelength is twice the smallest dimension of the cabinet (i.e., the wavelength at 212Hz is 64" or 2×32 ", the width of the cabinet).² In addition to diffraction loss at 1m, some wave cancellation occurs around 32–35Hz and below 20Hz, presumably due to out-of-phase room reflections combining with the direct wave.

The 1m response helps identify the type of acoustic rolloff of the tweeter and of the midrange domes (Fig. 9). Our filter design needs to incorporate acoustic rolloff. The D28 AF tweeter rolls off at 6dB/octave, starting at about 1.6kHz. The D76 midrange domes, on the other hand, roll off at 18dB/octave, starting at about 250Hz. These rolloffs should be equivalent to a first-order high-pass filter and a third-order high-pass filter. As it turns out, these interpretations are incorrect as we will see in the next section when we examine the phase response of the acoustic rolloff.

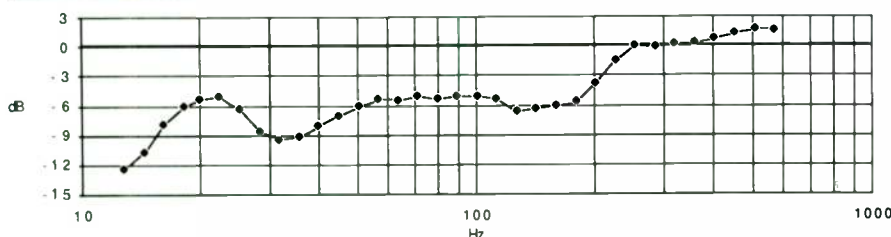


FIGURE 10: Effect of the room reflections and enclosure diffraction on the woofer response at one meter. This plot is the difference between the near-field response and the 1m response.

PHASE RESPONSE. First-order filters have a total phase shift of 90° , with the 45° point occurring at the -3dB cutoff frequency. Second-order filters have a 180° phase shift, with the 90° point occurring at the -3dB cutoff frequency for a maximally flat filter (i.e., Butterworth). In the passband the drivers are in phase with the input signal. As you drop in frequency below passband the phase of the driver's output is ahead of the input signal, behaving as though the signal is generated before the input signal arrives. This confused me. How can a driver create a sine wave before the input wave arrives?

Aside from the fact my brain is usually

only hitting on three out of four synapses, I realized that phase shift advance is simply a time distortion of the input signal rather than occurring ahead of the input signal.

To measure phase shift, place the microphone about 1mm beyond the grille cloth, aligned to the center of the driver. Make sure you know the true polarity of your microphone setup. My setup inverts the waveform. The output waveform will be in phase with the input waveform in the passband with a more or less constant offset due to the distance between the microphone and the acoustic center of the driver ($74\mu\text{s} = 1''$).

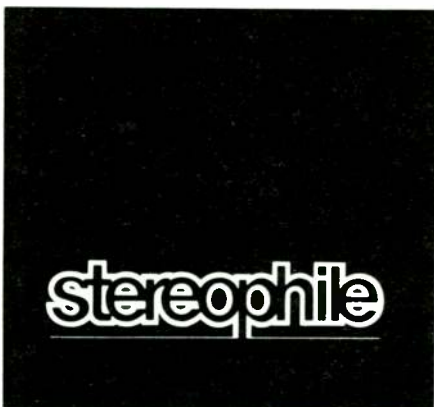
The acoustic center from the grille cloth at passband was 1.2" for the tweeter (around 4kHz), 2.3" for the midrange (at 2 to 6kHz), and 3.5" for the bass drivers (at 300 to 400Hz). As we will see later, these are *not* the distances to correct for when we align our drivers for coincident time arrival at the listening position, because they do not match the relative alignment of the drivers within the crossover region nor do they include possible phase shift anomalies of the electronics.

ORDER PLEASE. Looking at the drivers' phase shift (Fig. 11), we see that the bass drivers and the midrange domes both behave as second-order filters (the ideal phase shift for a second-order filter is included for comparison). Although the midrange appears to have a third-order amplitude response, it has a second-order phase response. Actually the midrange also has a second-order amplitude response, because the observed third-order response includes the first-order diffraction loss of the enclosure (by coincidence it occurs at the same frequencies as the rolloff of the midrange) and the second-order response of the driver. Our crossover will account for the second-order response of the midrange and a circuit for correcting for diffraction loss for both the woofer and the midrange.

The phase response of the tweeter, on the other hand, will cause us some grief. The tweeter's rolloff of 6dB/octave does not match a first-order phase response very well (Fig. 11). I suspect this tweeter is normally a second-order driver and that the ferrofluid used in it changes it from a 12dB/octave rolloff to a 6dB/octave rolloff (see comments by Linkwitz²⁶ on the effect of ferrofluid with this driver).

So how do we characterize the high pass behavior of this driver? I assumed that it behaves as a first-order filter because it rolls off at 6dB/octave and because its 62° phase shift at its cutoff frequency (-3dB at 1.2kHz) is closer to the 45° of a first-order than the 90° of a second-order filter. You may wonder why I chose a tweeter with a pronounced peak at 11kHz and a poorly defined high-pass filter response. I can only respond by saying that it is difficult to change when the enclosure specific to it has already been built. Nonetheless, you will see that this non-ideal tweeter can be improved with an electronic crossover.

CROSSOVER TOPOLOGY. Now we have enough information to plot the strategy for our circuit design (Fig. 12). Equalization adjustments should be completed before the signal reaches the crossover's



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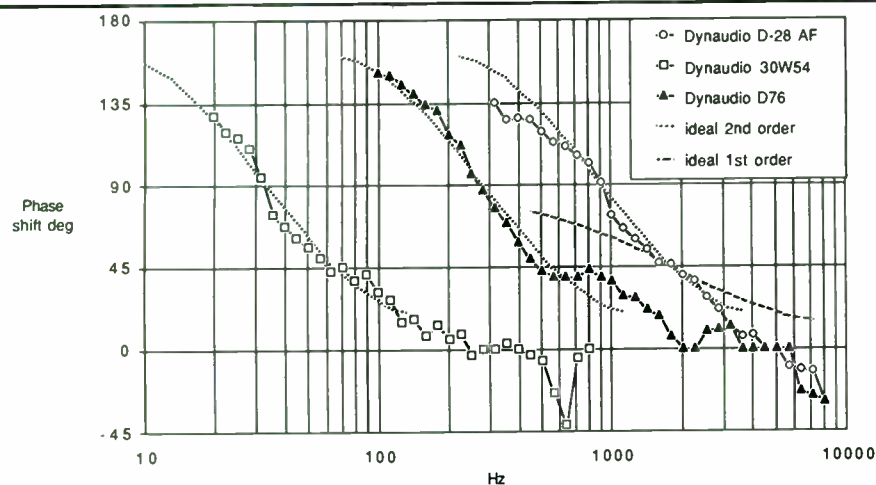


FIGURE 11: Measured phase response of the three drivers compared to the phase response of an ideal high-pass filter.

filters. This will ensure that when, for example, we modify the frequency response to compensate for diffraction loss, it equally affects the phase changes of the high- and low-pass sections of either the woofer-to-midrange cross or the midrange-to-tweeter cross.

As noted previously, our diffraction equalizer (C in Fig. 12) will compensate for the diffraction loss occurring within the frequency range of both the woofers and the midrange drivers. Equalization will also include a tweeter notch filter (B), a two-band parametric equalizer (D) and a rumble filter (E). The parametric equalizer allows adjustment of frequency and bandwidth (i.e., adjustable Q) for two bands in each channel. The equalizer is targeted for low frequencies (< 1kHz), where room interactions are most prominent. A rumble filter protects the woofers from unwanted excursions in subsonic frequencies that can occur in our TL below 10Hz where the acoustic impedance of the line quickly approaches zero.

Once you equalize your input signal, you can divide it into the three frequency ranges to drive the three amplifiers (see the "Crossover Filter" section of the topology in Fig. 12). Originally I experimented with odd-ordered Butterworth filters in conjunction with my symmetric drivers, as suggested by D'Appolito,^{2,27} to yield a stable vertical polar response without the sharp nulls $\pm 46^\circ$ off-axis when even-ordered Linkwitz-Riley (LR) filters are used and the interdriver distance is two-thirds a wavelength at crossover. After I did so, I tried to solve the problem of floor reflection cancellations (discussed later).

To deal with the problem I tried using even-order LR filters to take advantage of the $\pm 46^\circ$ null in order to reduce the reflected energy from the floor, which cause the out-of-phase cancellations.²⁸ Although

I haven't been able to confirm this advantage to my satisfaction, I discovered to my delight that these filters are simple to integrate with the high-pass acoustic response of drivers. In addition, the accurate implementation of these filters is easy to verify. Another advantage is that even-order LR filters can avoid, for the most part, the problem of three-way filters

(especially when the crossover frequency ratio is three octaves), where the woofer-to-midrange crossover interacts with the midrange-to-tweeter crossover, resulting in deviations up to 4dB from a flat response.²⁹

CROSSOVER POINTS. Having made the decision to use even-order LR filters, the next step is to select crossover points. The mid- and high-frequency drivers should be allowed to operate only above the frequency where they will produce the desired undistorted SPL, which is a function of the linear peak-to-peak excursion and effective diameter of the drivers.³⁰ The crossover point should also be high enough to protect the upper frequency driver from over-excursion. Drivers are excursion limited at a rate of 12dB/octave below cutoff frequency. In order to keep the drivers from being overdriven below the pass band, the electrical high-pass filter should limit the amount of power going into the drivers with at least a second-order filter and a crossover point at or above the driver's cutoff frequency.

Selecting too high a crossover point will also cause problems. The lower frequency

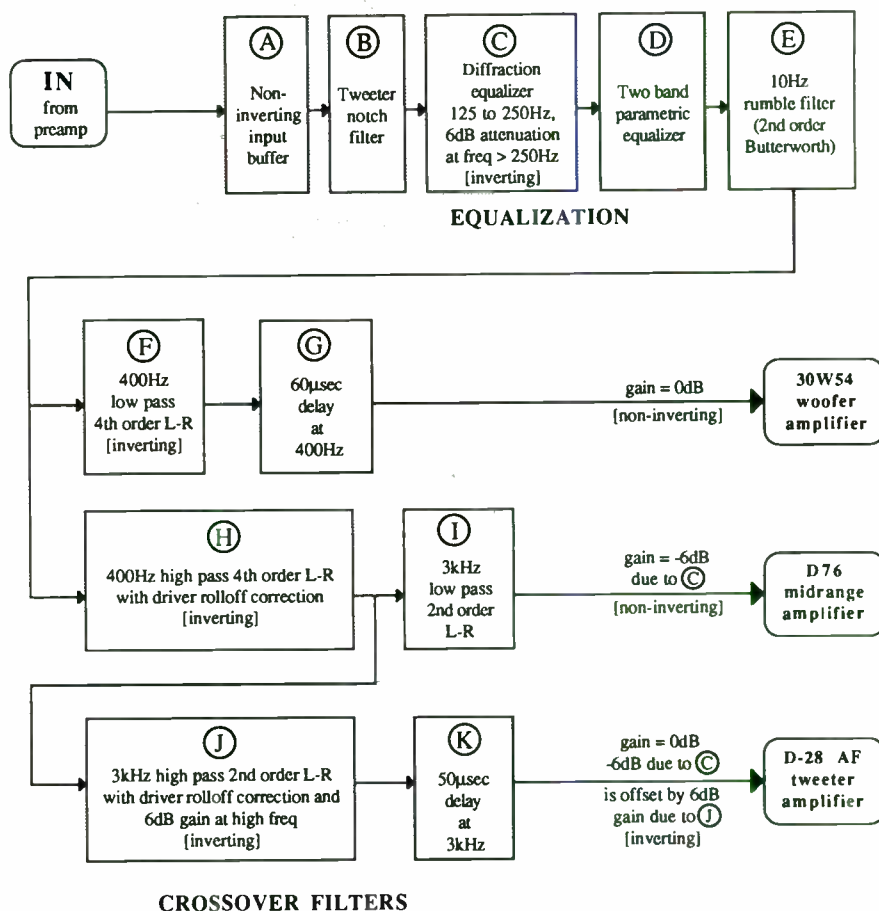


FIGURE 12: Electronic crossover topology for one channel.

driver of the crossover pair will be too directional if its diameter is equal to or less than one wavelength at crossover.³¹ The vertical lobing of the polar response will be too narrow if the interdriver distance in the D'Appolito symmetrical system is much greater than two-thirds the wavelength of the crossover frequency.²

First let's look at the midrange-to-tweeter crossover point. A desirable design goal of modern home loudspeaker systems is to be capable of 110dB. A single Dynaudio D28 AF tweeter into half space is capable of 110dB down to 2.5kHz and only 98dB at 1.2kHz, its -3dB cutoff frequency (Fig. 9). As noted above, we need at least a second-order electronic filter to protect the driver from over-excursion, if we are going to use a crossover point at 1.2kHz.

CASCADING. Obviously if we cascade the first-order acoustic response with a second-order electronic filter we will not end up with either a second-order or a fourth-order LR filter. Recall that you need to cascade two first-order high-pass filters for the high-pass section and two first-order low-pass filters for the low-pass section to create a second-order LR filter. Likewise to create a fourth-order LR filter you need cascade two second-order high-pass Butterworth filters for the high-pass section and two second-order low-pass Butterworth filters for the low-pass section.³² You cannot cascade the first-order acoustic response with a third-order electronic filter to create a fourth-order LR filter, instead you have to construct a complex filter to achieve a true fourth-order

LR filter which is beyond the scope of this project and me.²⁸

My solution was to raise the crossover frequency to 3kHz and add an electronic first-order filter to the acoustic first-order filter to create the high-pass portion of a second-order LR filter. Between 1.2 and 3kHz (i.e., from the cutoff frequency of the driver to the crossover frequency of our LR filter), we need add another first-order electronic high-pass filter in the form of a first-order shelving equalizer. It behaves like a first-order electronic filter down to 1.2kHz, at which point it stops behaving as a filter at all (i.e., no effective amplitude or phase shifts).

Raising the crossover point to 3kHz gives our tweeter more protection against over-excursion below the passband than would a second-order high-pass filter at 1.2kHz. Unfortunately, raising the crossover point to 3kHz creates another problem, because the 4.5" interdriver distance between it and the tweeter is now greater than 3", the design goal of two-thirds of a 3kHz wavelength. In fact it is equal to one wavelength at 3kHz, which narrows the vertical off-axis nulls of our LR filter to $\pm 20^\circ$.² The directivities of our midrange domes are not too narrow in their polar response because their diameter is not greater than one wavelength at crossover.

WHAT'S THIS? The selection of our woofer-to-midrange crossover point is not plagued by potential over-excursion problems or narrow vertical lobing, but rather by an entirely new problem as we will see in a moment. The SPL capability of our two D76 midranges (76mm in diameter,

3mm peak-to-peak excursion) to half space is 110dB at 300Hz. At 200Hz they are capable of 103dB into half space, although for the size of the enclosure of this project the output of the drivers are in transition to full space at 200Hz (Fig. 10). The need for electrical protection to prevent over-excursion of our midrange domes is not necessary as with the tweeter because we can conveniently cascade the second-order high-pass acoustic response of the midranges with a second-order high-pass electronic filter to form a fourth-order LR filter.

Woofer directivity is not a problem until we get to 1.5kHz. Likewise the interdriver spacing between the midrange and the woofer doesn't equal two-thirds the wavelength until 1kHz is reached. Given that the amplitude or phase response of the 30W54 woofers is not very smooth above 500Hz, we should not select a crossover point above about 400Hz. From the preceding discussion we should limit our woofer-to-midrange crossover point to a range of about 300 to 400Hz. I selected 400Hz as my optimal crossover point for the reason discussed in the next section.

Having selected our crossover points at 400Hz with a fourth-order LR filter and at 3kHz with a second-order LR filter, we can assess the amount of unwanted interaction between the two crossover points to the total response of our system. These unwanted interactions result from the overlapping transfer functions of two crossovers, which by themselves in a two-way system are well behaved. Joe D'Appolito discusses both the magnitude and the solutions to this problem with three-way systems.²⁹

One solution is the layout of the crossover topology where the signal is first divided between the low and mid frequencies (F and H in Fig. 12). Next the output from the high-pass section (H) is further divided between the mid and high frequencies (I and J in Fig. 12). Finally, D'Appolito adds a phase-compensating network immediately following the woofer low-pass filter (F). Deleting the phase-compensating network results in only a -0.2dB deviation from flat summed response if even-ordered LR filters are used and if they are separated by three octaves.²⁹ Since a -0.2dB deviation is small, I omitted the phase compensation network.

FLOOR CANCELLATION. The other problem I alluded to with the selection of the woofer-to-midrange crossover point is the cancellation of the direct wave at the listening position by the floor reflection

Continued on page 38

System Report

I spent a portion of a Saturday afternoon with Peter Hillman and his wife reviewing his system. We played some of my test CDs as well as some of Peter's. We also hooked up the Linkwitz test setup Peter used for most testing. I can report the following observations:

The system sounds excellent; it's extremely clean, with good dynamics and proper imaging. I had wondered whether systems this large with the totally symmetrical speaker layout wouldn't have an unusual imaging pattern; however, the test CDs imaged just as on the more conventional speaker arrangements. Listener motion produces no undesirable vertical or horizontal venetian blind effects. While the system is optimized for the listening "sweet spot," moving from this location causes only a shift in image posi-

tion, with no major change in tonal balance.

For my taste, the system is slightly lean on deep bass, and I don't like heavy bass. This is because transmission line systems are so "tight" in the bass area and also because Peter has actually equalized the system for the listening position. Room effects which would normally add to the bass have been tuned out. This represents no problem to any potential builder as the system has plenty of bass capability and can be equalized any way the builder desires.

These handsome speakers have been constructed with the utmost care, and it shows in their appearance and sound. They are, however, very large! When finished you will need several strong friends to move them to the final location.—G. R. Koonce

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wave. At certain frequencies the floor reflection is delayed enough, due to the greater distance it travels, that it is out-of-phase with the direct wave, resulting in a cancellation or dip in the response.

In my listening setup, the path length of the direct wave at tweeter height is 144" to the listener, while the floor reflection from the tweeter is 162" to the listener. This amounts to a 1.4ms delay of the floor reflection to the direct wave, which is equivalent to half a 360Hz wavelength, the frequency where cancellation occurs. When my first experimental crossover point was set at 250Hz, I was dismayed to discover a 12dB dip around 400Hz, measured at the listening position! I confirmed that this dip resulted from the floor reflection by placing pillows on the floor in front of the speakers to absorb the energy. The dip was reduced by about 4dB!

A large dip in the frequency response due to the floor reflection is a recognized problem with loudspeakers. In a recent *High Fidelity* test report the reviewer commented that a dip around 300Hz appeared in most of their speaker-response measurements, a result of the floor reflection in their listening room test setup.³³ Kates' model of the human auditory system reveals that the midrange frequencies are the most important region in our percep-

tion of coloration where early reflections, especially floor reflections, are more important than later reflections.³⁴

DRIVER PLACEMENT. Changing the height of the driver off the floor changes the path length of the reflected wave arriving at the listener. If you raise a driver off the floor, you increase the path length of the reflected wave, which lowers the frequency at which cancellation occurs. A loudspeaker designer can take advantage of this height effect. For example, in a two-way system, if the designer places the center of a small woofer 4.5" off the floor and the tweeter 38" off the floor at ear height, the cancellation frequency is 3kHz for the woofer and 360Hz for the tweeter, both of which are outside the operating range of the drivers if the crossover point is set around 1.5kHz and the listener is 12 feet from the speaker.

Obviously the resulting large inter-driver distances of this design will create vertical polar response problems. The dip can also be controlled by placing a carpet in the area where the floor reflection occurs. Unfortunately, carpets are only partially effective sound absorbers in the 200 to 500Hz region where they are needed most. As you might expect, the absorption coefficients vary from carpet to carpet depending upon their thickness, composi-

tion and the type of pad used. Nonetheless, if we take a typical example of a heavy carpet on 40-ounce hairfelt, it will absorb less than 10% of the sound energy below about 125Hz, 24% at 250Hz, 57% at 500Hz, and about 70% above 1kHz.³⁵

Relocating the drivers closer to the floor is not an option in my speaker system. However, as we will see in a moment, the depth of the cancellation notch is influenced by the selection of the woofer-to-midrange crossover point within the 300 to 400Hz range. To understand this influence, I wrote a short computer program. Let's analyze what happens. In my system the listener's ear is 144" from the center of the tweeter and 38" off the floor. One woofer is 24.5" off the floor, one midrange is 34", the second midrange is 42", and the second woofer is 51.5", where cancellations occur at 548Hz, 400Hz, 328Hz and 272Hz, respectively. (The direct wave path length only changes slightly between the midrange [144.06"] and the woofer [144.63"].)

Note that the two woofers or the two midrange domes are at different heights and have correspondingly different cancellation frequencies. The program shows that the cancellation dip is smaller with the combination of two identical drivers at differing heights than with either driver

Continued on page 40

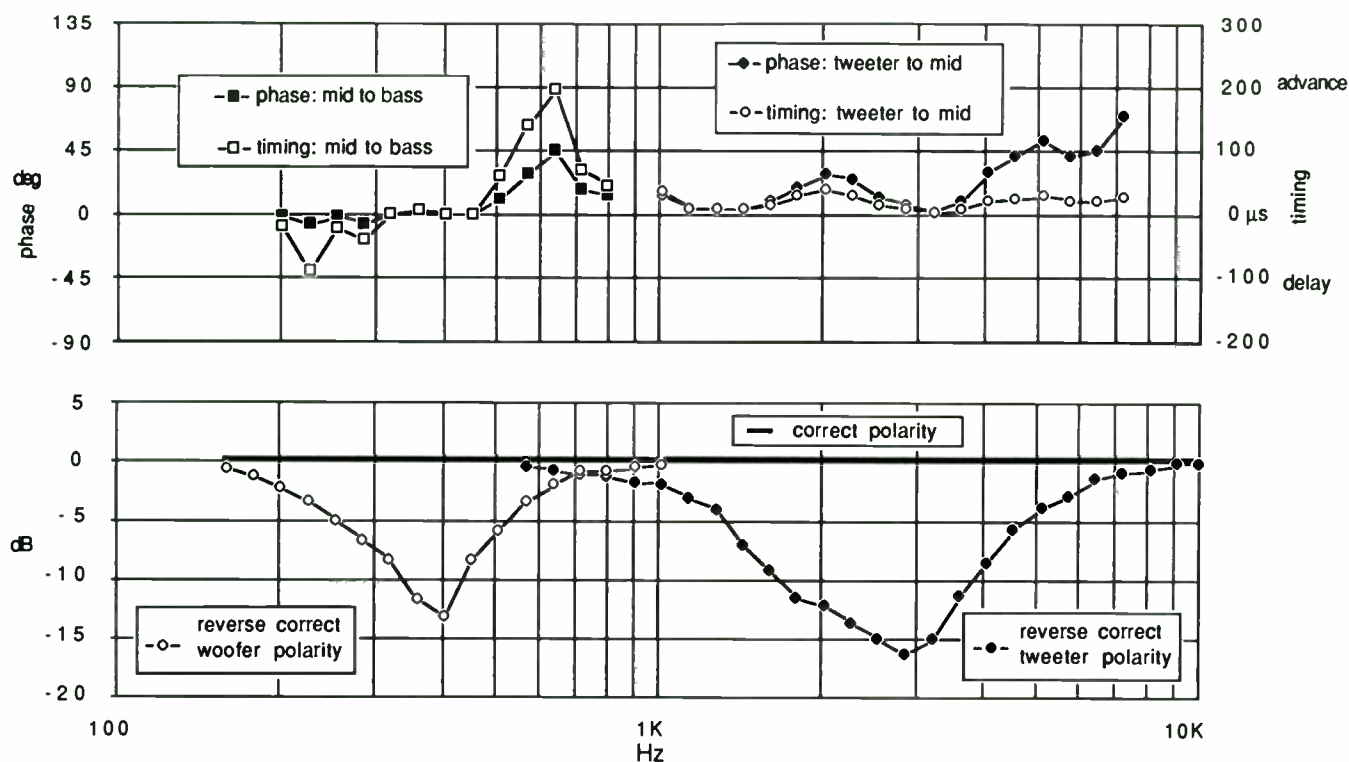


FIGURE 13: Measurement check of fourth-order LR filter (woofer-to-midrange) and second-order LR filter (midrange-to-tweeter). Ideally the phase difference (top graph) between the two drivers should be 0° throughout the crossover region. Reversing the correct polarity of one driver (bottom graph) should cause a sharp null in the amplitude response at the crossover point. Small variations (± 2 dB) in the correct polarity are adjusted to 0dB.

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alone. It also shows that when the vertical displacement between two identical drivers is increased, the cancellation dip created by them is decreased. Our two woofers with their 27-inch vertical displacement have a cancellation dip 20dB less than the dip created by the two midranges with their 8-inch vertical displacement. Placing a carpet, as described above, in front of the speakers reduces the 20dB difference to about 5dB.

Combining all four drivers and including the fourth-order LR slopes and the absorption of the carpet, we find that the cancellation dip occurs at about 350Hz for either a 250 or a 400Hz woofer-to-midrange crossover point. On the other hand, the depth of the crossover dip does differ; the dip for the 250Hz crossover point being about 3dB deeper than with the 400Hz crossover point. With the 400Hz crossover, more energy is coming from the woofers than the midranges which takes advantage of the smaller cancellation dip of the widely spaced woofers than the larger cancellation dip of narrowly spaced midranges. This is the reason I selected 400 rather than 300Hz for my woofer-to-midrange crossover point.

TIME DELAY CORRECTION. The beauty of LR filters comes from the ease of testing for coincident arrival times of drivers at the listening position. When the drivers are in perfect time alignment, both drivers will be in phase throughout the crossover region (approximately ± 1 octave from the crossover point for a fourth-

order filter and approximately ± 2 octaves for a second-order filter) and no tilting of the lobe in the polar response will occur. The test is simple. Use the same basic technique as with my phase measurements of the TL ports, except that two microphones are used instead of one (assuming, of course, that you compensate for any phase differences between the two microphones).

At higher frequencies small changes in microphone location make a large difference in phase shift, so do not move the microphones from their position in front of the grilles throughout the test. The phase shifts I have plotted for Fig. 13 are corrected for the additional distance from the center of midrange domes (0.06" or about $4\mu\text{S}$) and woofers (0.6" or $45\mu\text{S}$) to the listener than is the distance from the listener to the tweeter. Phase shifts plotted in Fig. 13 include the electronic time delay needed for minimum phase shift at the crossover point, i.e., $60\mu\text{S}$ delay for the woofer at 400Hz (G in Fig. 12) and $50\mu\text{S}$ delay for the tweeter at 3kHz (K in Fig. 12).

You will note that these delays are different than would be predicted from acoustic center of the drivers in their pass-band, which emphasizes the importance of time correcting drivers within their overlapping crossover frequencies. You will also note that the phase-shift variations at 650Hz and above 5kHz result from the nonlinear phase response of the woofer and the tweeter, respectively (compare Fig. 13 with Fig. 11).

As a final check of time alignment, reverse the correct electrical polarity of

the drivers and measure the amplitude response throughout the crossover region (note: the correct polarity for fourth-order LR filters is normal, while the correct polarity of the second-order LR filters is reversed). I did this test at 1m on axis, even though I aligned for the listening position (Fig. 13). The results are quite satisfying in that I did get the expected sharp null in the response at the crossover point when the correct polarity is reversed.³⁶

CIRCUIT DESIGN. The crossover topology illustrated in Fig. 12 was laid out on four 3677-2 Vector DIP plugboards: left and right equalizer boards (A through D) and left and right crossover filter boards (E through K). I mounted them into a rack mount enclosure. All ICs are dual op amp Signetics NE5532, except for ICs 3 and 8 which are single op amp Signetics NE5534. All ICs are socketed and the power supply leads to each are bypassed with 0.1 μF monocraps. In addition, I used 100 μF bypass capacitors at the input supply to each board. All resistors are 1% metal film. All capacitors in the signal path are 2% polypropylene (Digi-Key, Thief River Falls, MN 56701), except for the 1 μF polyester film capacitors in section E of Fig. 14 and the silver mica capacitor with values less than or equal to 150pF. I used cermet trim pots, mounted at the end of the boards so that they can be easily adjusted. I was very careful to ensure compact, minimum-length layout and low resistance ground paths.³⁷

Figure 14 shows circuit diagrams for the input buffer, tweeter notch filter, diffraction equalizer and rumble filter. The input buffer is non-inverting, to keep the entire crossover from inverting the outputs to the woofer or to the midrange amplifiers and to keep the tweeter amplifier output inverted for the second-order LR crossover. I fixed the tweeter notch filter at 11.5kHz with adjustable Q and attenuation (see Fig. 5-29 of Jung's book).³⁷ I set the trim pots of the filter to yield -3.5dB at 11kHz, -2dB at 8 or 16.5kHz, and -1 at 6 or 23kHz. I set the inverting diffraction equalizer (C) for $f_1 = 126\text{Hz}$ and $f_2 = 253\text{Hz}$, utilizing the D'Appolito circuit design.² Let the capacitor in (C) equal 0.021 μF , where R_2 is the 60k resistor parallel to C and R_1 is the other 60k resistor in the feedback loop, given the relationship $f_1 = 1/(2\pi CR_2)$ and $f_2 = (R_1 + R_2)/(2\pi CR_1 R_2)$. The 120k resistor at the input to pin #6 of IC2 sets the gain. The rumble filter (E) is a unity gain second-order HP Butterworth filter.³⁸ It is mounted on the crossover filter board because IC9 is shared with the 400Hz HP filter (F).

The circuit diagram (Fig. 15) for the

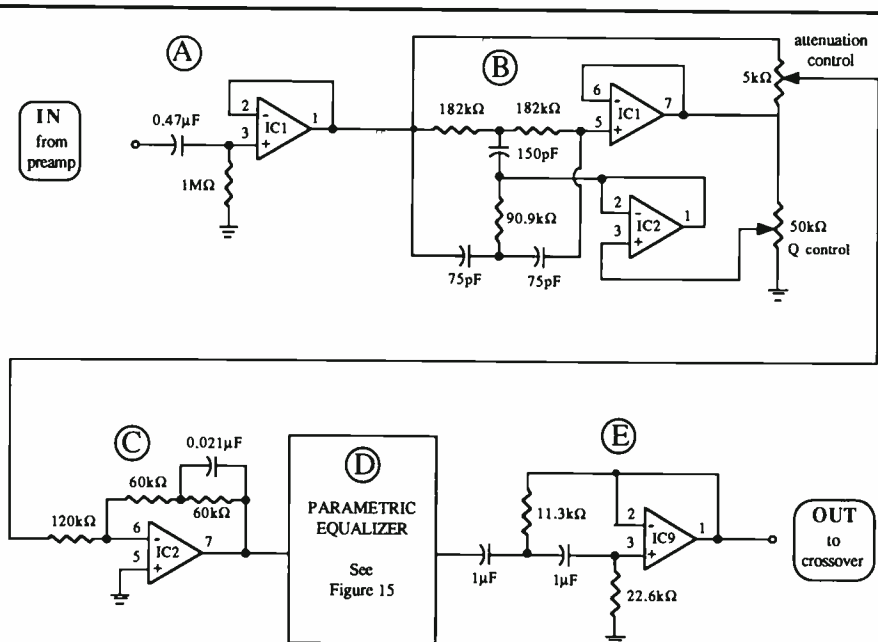


FIGURE 14: Circuit diagram of the input buffer (A), tweeter notch filter (B), diffraction equalizer (C) and the rumble filter (E).

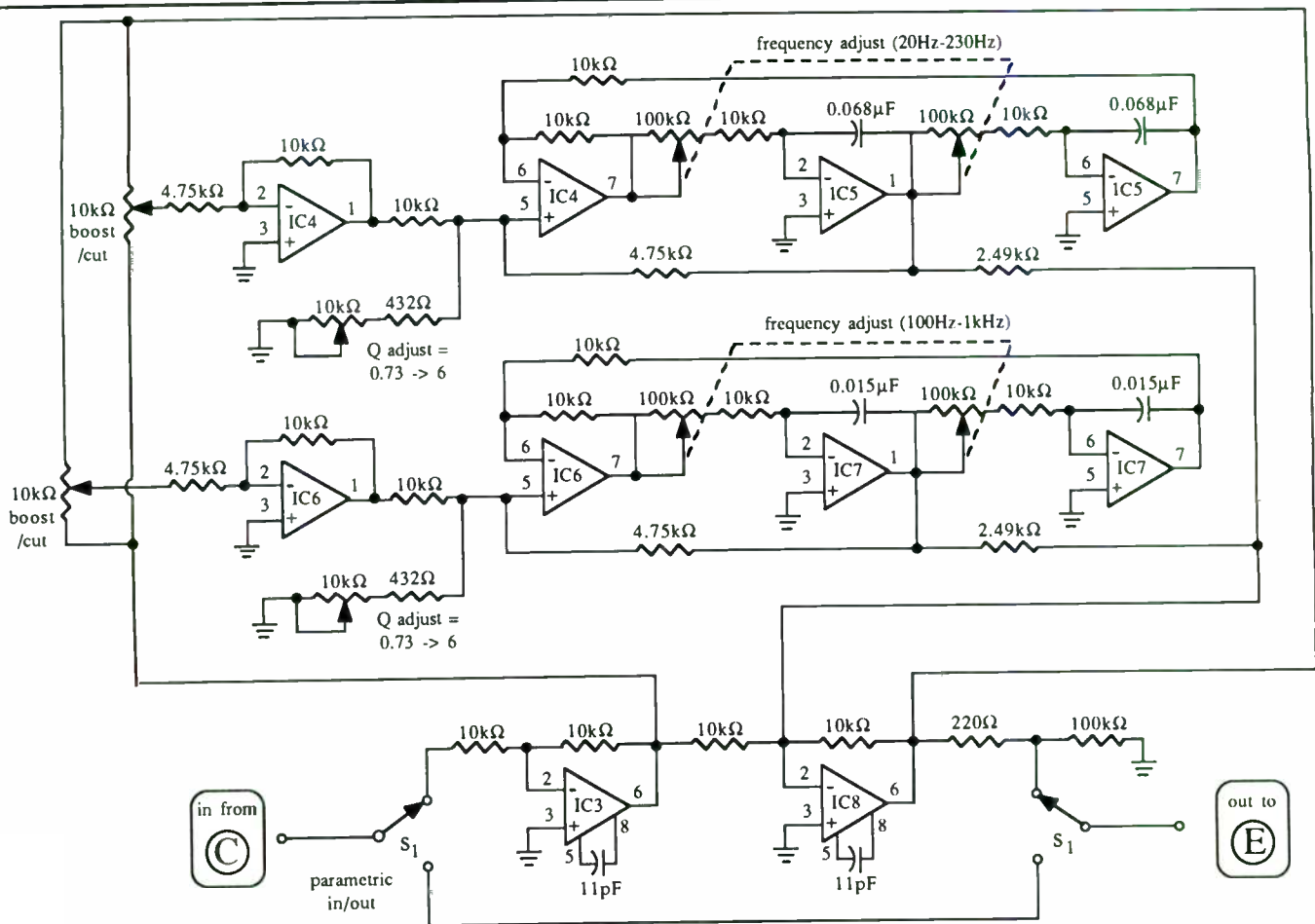


FIGURE 15: Circuit diagram of the two-band, parametric equalizer. Adapted from Figs. 5-26 and 5-27 of Jung's book.³⁷

parametric equalizer (D) is a two-band version of the three-band parametric equalizer given by Jung (see Figs. 5-26 and 5-27).³⁷ The circuit diagrams in Jung's book have typographical errors. Jung's R17, R16, R15 and R14 should be 10kΩ, not 10Ω. I omitted C3 of Jung's circuit, because the next stage, the rumble filter (E), will take care of any DC offset. I also changed the values of the Q adjustment resistors to allow Q to be increased to a maximum of 6. I used one-turn linear pots for the boost/cut and Q-adjust (although audio taper would be better) and one-turn dual audio taper pots for the frequency adjustment (Alps 100KAX2 available from Radio Shack as #271-1732). The pots for the parametric equalizer are mounted outboard from the circuit boards and are equipped with knobs and calibration marks.

Section F of the crossover filters cascades two second-order 400Hz LP Butterworth filters (Fig. 16). The first stage of the 400Hz LP filter inverts (Huelsman's³⁹ circuit design) and the second is non-inverting.³⁸ Both stages combine to invert the overall filter section, so that the outputs to the woofer will be non-inverting. The 400Hz HP, section H, cascades two sec-

ond-order 400Hz HP Butterworth filters. The first 400Hz HP filter compensates for the D76's acoustic rolloff utilizing a Linkwitz design circuit.⁴⁰ This design requires that you know the resonant frequency f_0 and the Q_0 of the driver. My D76 midrange domes have an f_0 of 292Hz and a Q_0 of 0.75, which I determined from impedance measurements using Linkwitz's method.⁴¹ For the same reason as with section F for the woofer, section H inverts overall, with the first stage in H inverting and the second being non-inverting.³⁸

SHELVING EQUALIZER. Section I is a second-order 3kHz LR LP filter, which cascades two first-order 3kHz LP filters. Section J is the second-order 3kHz LR HP filter, which cascades one first-order 3kHz HP filter with a first-order shelving equalizer. The shelving equalizer combines with the first-order acoustic rolloff of the tweeter to yield a first-order 3kHz HP filter. I determined the component values for the shelving equalizer³⁸ by experimentation, since I did not have the design analysis given by Linkwitz⁴⁰ that I used in section H. The shelving equalizer has a 6dB gain in the passband, which conveniently gives the tweeter 6dB more gain

than the midrange and therefore compensates for the 6dB lower output of the tweeter relative to the midrange domes (Fig. 9). Overall, section J inverts the output from H so that the tweeter output is inverted relative to the midrange, as required of second-order LR crossovers.

Finally, section G delays the woofer by 60μs and section K delays the tweeter by 50μs, both relative to the midrange as we determined previously. These delay circuits are first-order all-pass networks.^{32,41} You will note that two 25μs delay networks are cascaded together in section K, while only one 60μs network is used in section G. All-pass networks have a fairly constant delay provided that their component values yield an $f_0 = 1/(2\pi RC)$ which should be at least three times greater than the crossover frequency.³² The f_0 of G is 5.3kHz, 13 times greater than 400Hz, and f_0 of each section of K is 11.7kHz, 3.9 times greater than 3kHz.

SPEAKER PROTECTION. Although not illustrated, I protect my speakers from turn-on or turn-off thumps originating from the crossover with two of Jung's timer circuits (one per channel).⁴² Each timer activates a 12V DC 4PDT relay with

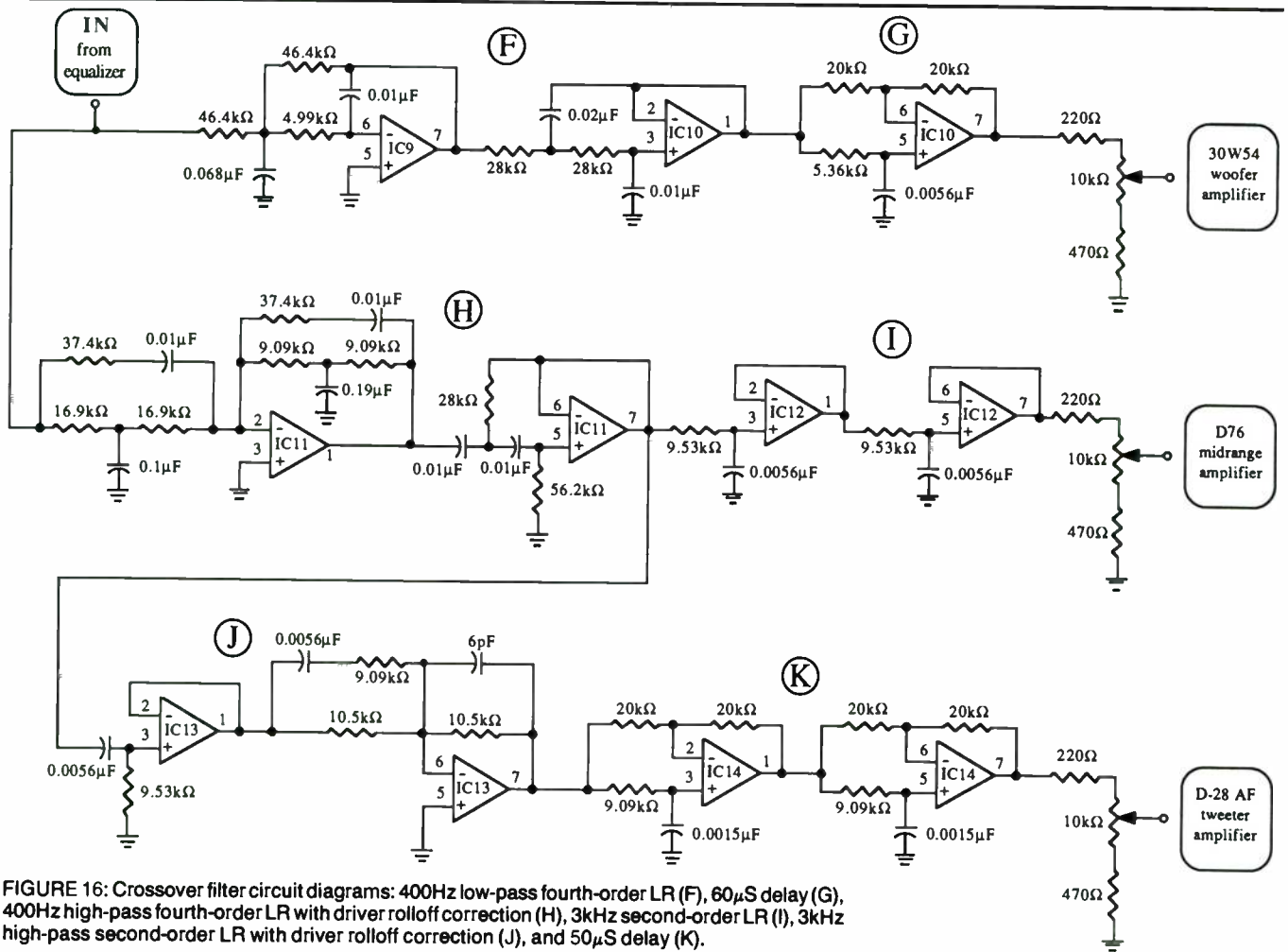


FIGURE 16: Crossover filter circuit diagrams: 400Hz low-pass fourth-order LR (F), 60µS delay (G), 400Hz high-pass fourth-order LR with driver rolloff correction (H), 3kHz second-order LR (I), 3kHz high-pass second-order LR with driver rolloff correction (J), and 50µS delay (K).

an 80mA coil five seconds after turn-on and quickly turns off the relay after turn-off. When turned on these relays make contact between the crossover and the amplifiers. When deactivated they short the input to each amplifier across a 470Ω resistor. For low noise and reliability, the relays must have gold-plated contacts and be hard-wired into place. Don't use relay sockets.

ADJUSTMENTS AND LISTENING TESTS

It was frustrating to adjust the frequency response of this loudspeaker system within my living room, based on frequency response measurements. Do you use measurements at the listening position or some other measurement location? In addition, I was unprepared for the need to critically place the speakers and the listeners within the room. Slight adjustments in frequency response or placement have a profound effect on a system's ultimate sound. I'm convinced that you can devastate the sound of any excellent sound system with a haphazard setup and adjustment procedure.

The methods I used and the reasons I used them are at best my own naive in-

sight into this final stage of achieving a good sound system. Those of you with considerably more experience than I can certainly improve upon my procedure, and those of you with less experience can use my observations as a starting point for the final adjustments of your system.

SPEAKER PLACEMENT. For proper stereo balance and imaging the frequency response of both the left and right speakers should match each other as closely as possible. Reflecting surfaces, like the floor bounce discussed previously, cause frequency response aberrations. Other reflections, such as off walls or the ceiling can cause cancellations or reinforcement at various locations within the listening room.

For example, a reflection off the back wall will cancel at the frequency where its quarter wavelength equals the distance from the front of the enclosure to the back wall.⁴¹ This is especially true at low frequencies where the enclosure is radiating into full space. If the woofer is six feet in front of a back wall, a cancellation will occur at 47Hz wave because the reflected wave off the back wall will travel 12 feet

(half the wavelength of 47Hz) before it recombines with the frontwave. Reinforcement of the frontwave would occur at 94Hz when the reflected wave is in phase with the frontwave. If your speakers are not equidistant from reflecting surfaces, cancellations will occur at different frequencies between the two and their frequency responses will not match.

After you place the speakers in similar reflection environments, you must select a critical listening position which is equidistant from either speaker and centered between the two for the best stereo image. Likewise, the toe in or toe out of either speaker should be the same relative to the critical listening position. At first I tried to deviate from these procedures for the sake of room decor, but I was unhappy with the result. If you are faced with the dilemma of optimal placement versus decor, at least try optimal placement first so that you and the other members of your household can honestly weigh the importance of placement versus esthetic considerations.

PRACTICALITY. In addition to the aforementioned procedures, I made some

Continued on page 44

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other adjustments based on practical considerations and listening sessions. For the listening tests I recruited the aid of David Ruether, a friend whose keen listening abilities I trust. These listening sessions resulted in the following setup:

(a) the midrange-tweeter arrays are to the outside of the enclosures as shown in *Photo 1* (SB 5/89);

(b) the tweeter of either speaker is 144" from the center of the listener's head at the critical listening position;

(c) the enclosures are 9.5 feet apart measured from tweeter to tweeter, which is about 24° to either side of the forward facing direction of the listener in the critical listening position; and

(d) toe out of the enclosures is about 4° relative to the imaginary line from the center of the listener's head to the center of the enclosures.

The enclosures in my living room are approximately six feet in front of the wall behind them as measured from the front of the enclosures and the critical listening position is about 14" in front of a wall which runs approximately parallel to the speakers. These distances from reflecting walls are not by design, but rather are the compromise of practical placement and listening tests. Should you build these speakers, only use my placement as a rough guideline from which to start your placement and adjustment procedure.

FREQUENCY ADJUSTMENTS. The electronic equalizer and crossover allows for an ample amount of adjustment through the use of a two-band parametric equalizer for bass frequencies, a tweeter notch filter, and the independent level adjustments for the woofers, midranges, and tweeter. The problem is, what is a proper method for analytically adjusting your system? When I tried to balance the frequency response to measurements taken at the listening position, using the Linkwitz toneburst generator as previously described, the results were unsatisfactory.

This method probably does not sense

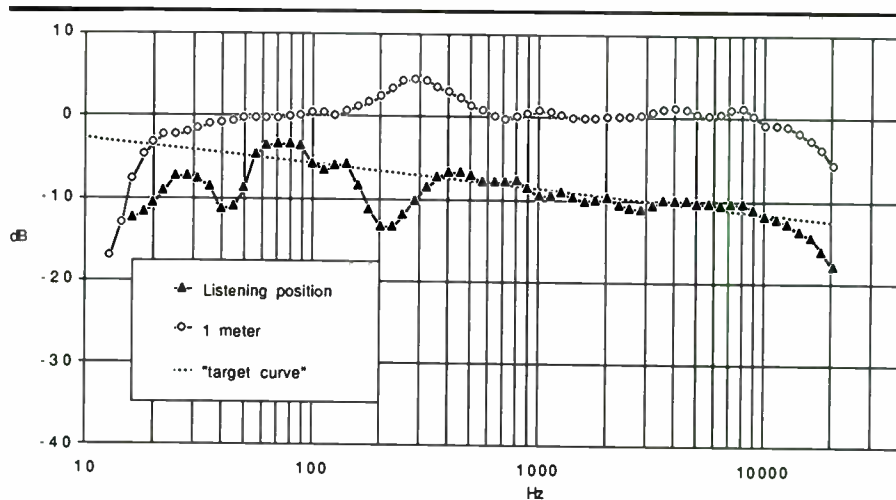


FIGURE 17: One meter response versus listening position response after the final adjustment of the system. Listening position response is compared to a "target curve."

sound in the same way as do our ears and brain, especially in the time domain. More elaborate techniques, which simulate the auditory central spectrum model are certainly more accurate.³⁴ When I adjusted the speakers to measurements taken at one meter (in line with the listening position and the tweeter), the floor cancellation at the listening position was too objectionable. Ultimately, I compromised between the measurements at one meter and the listening position (Fig. 17), where the boost at 180Hz helps compensate for the cancellation notch at the listening position. I didn't want to completely remove the listening position notch because the resulting large peak at one meter would be audible.

The parametric settings I used for resulting response shown in Fig. 17 are given in Fig. 18. Note that the right speaker is adjusted differently from the left. The right speaker, unlike the left, is in front of a built-in counter and bookshelf, creating a different reflective environment than the left speaker. The amplifier level adjustments of the crossover 10kΩ trimpots (depicted in Fig. 16), were set to -0.5dB for the left and -0.2dB for the right tweeter amplifiers, -1.3dB for the left and -1dB for right midrange amplifiers, and

-1dB for the left and -3dB for the right woofer amplifiers. The tweeter notch filter settings were given in the previous subsection on circuit design.

CANCELLATION. The response curves in Fig. 17 require comment. Using the parametric equalizer, it is possible to adjust the overall system response to ± 2 dB or so from 30Hz to 17kHz at one meter. I did so when my woofer-to-midrange crossover frequency was first set at 250Hz. However, as I mentioned earlier, it resulted in a cancellation at about 400Hz at the listening position. With the present woofer-to-midrange crossover frequency set at 400Hz, the measured cancellation notch is about 180Hz, when the 1m response is adjusted flat. My computer simulation predicted that the floor cancellation would have less of a notch but would remain at 360Hz. I cannot explain the discrepancy between the measured notch frequency at 180Hz and the predicted 360Hz.

A second item requiring comment is the effect of reflections from wall surfaces. With my speakers six feet from the back wall I would expect a cancellation at 47Hz and reinforcement at 94Hz, instead the cancellation occurs at about 33Hz (Fig. 10) and a peak at about 65 to 70Hz (which is attenuated, see Fig. 18). Perhaps the wall opposite the speakers (behind the listener) is more important than the wall behind the speakers, because the sound wave must travel a total of 18 feet from 1m location to the opposite wall and back again (which will cancel at 31Hz and reinforce at 62Hz).

Finally, I will comment about the observed rolloff in the response at the listening position compared to one meter (Fig. 17). The listening position response is compared to an "optimal listening-room curve" or "target curve." Such curves are

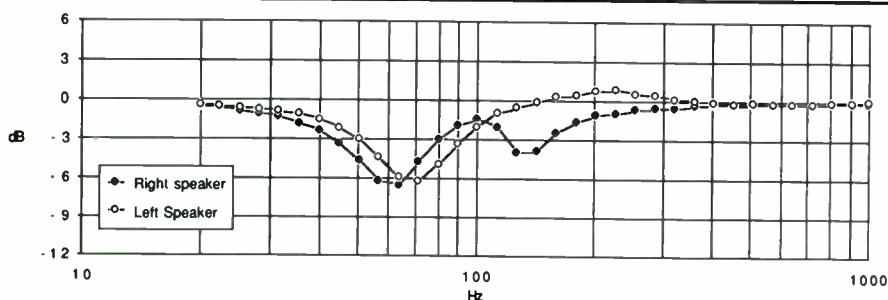


FIGURE 18: Parametric equalizer setting for the response depicted in Fig. 17.

based on listener preference at the listening position in a typical domestic room. Floyd Toole reviews the work of several workers, which are consistent with one another in that the "target curve" appears to have a slope of -3dB/decade with increasing frequency.⁴³

Why such a curve occurs in a domestic listening environment is unclear. Toole points out several factors which may influence the curve; including sound diffusion, frequency-dependent absorption, adjacent-boundary interactions, and loudspeaker directivity with its effect on the direct-to-reverberant ratio of the sound. I hope someone will sort out all of this so an amateur like myself can make useful measurements within a listening room that correlate with what we actually hear.

Before we leave this section on frequency adjustments; I can recommend a simple method, suggested by Muller⁴⁴ and Ruether, to see how successful you have been in balancing the left and right speakers. Take the mono output from a pink-noise generator and feed it to both channels and carefully listen to the noise. The noise should appear to come from a narrow vertical line centered between both speakers. Slight imbalances are clearly audible where certain frequencies of the noise spectrum appear to the left or right of center. It is very difficult to pass this test without any apparent imbalances. Unfortunately, it is even more difficult to correct for imbalances even when frequency adjustments are at your disposal. Using the methods outlined above, I was able to satisfy myself enough with the results of this test that I could invite listeners to evaluate my system. Their impressions are discussed next.

LISTENING TESTS. You might expect me to praise the sound quality of my system and to include a list of CDs which it reproduces with uncanny accuracy, matching the live performance. I won't do that. You wouldn't believe me anyway, knowing full well that I would be biased having spent as much time as I have on this system. Nevertheless, you need to know how it sounds, should you contemplate building this system. So I recruited Contributing Editor G. R. Koonce to subjectively evaluate the system. I also recruited eight other listeners, including an audiophile, a professional musician/composer, two amateur musicians and four college students who enjoy music.

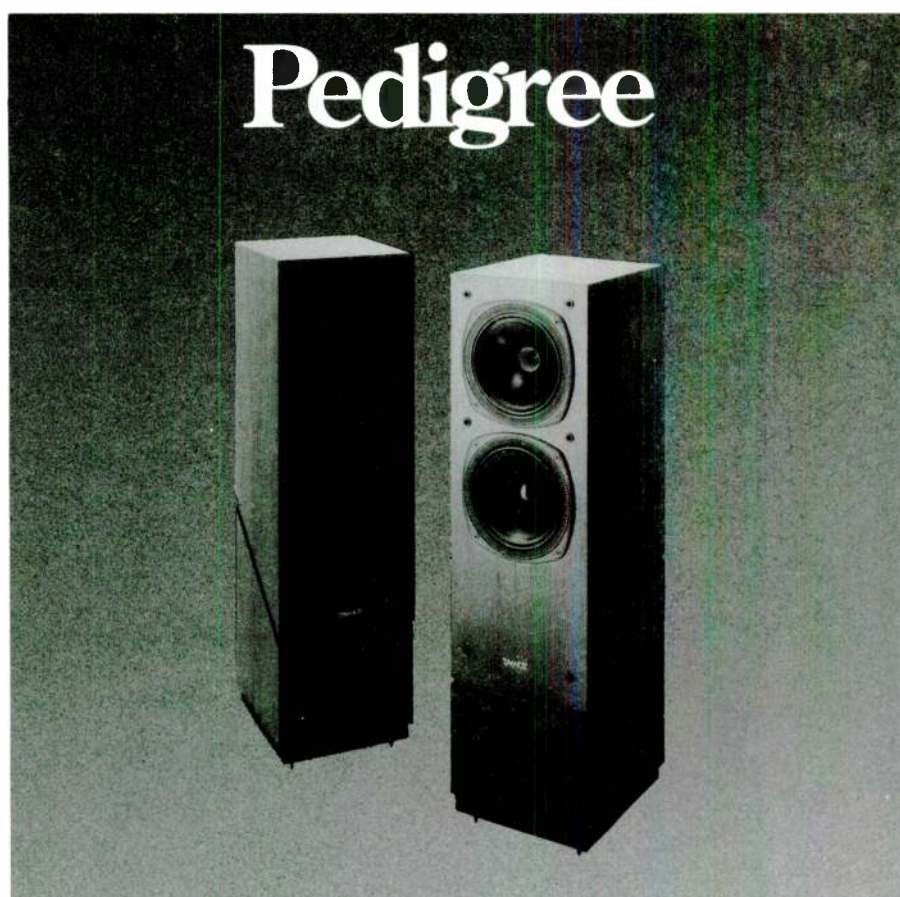
We used musical selections of mine as well as theirs. After about two hours of listening, I asked them to appraise the spatial and sound quality, based on a slightly modified questionnaire developed by

Floyd Toole.⁴⁵ We used a scale of 0 (worst imaginable) to 10 (no improvement possible). Figure 19 summarizes individual responses. Although the headings are self-explanatory, you can get a more detailed explanation of the headings from the Appendix, "Instructions to Listeners" in Toole's 1985 paper.⁴⁵

My listeners filled out the questionnaires without knowledge of the other listeners' responses. For all listening tests I used the following associated equip-

ment: Hafler DH-120 (tweeter amp), Hafler DH-220 (midrange amp), Hafler XL-280 (woofer amp), Denon DCD-1700 compact disc player, ADCOM GTP-500 tuner/preamplifier. Source program material was limited to compact discs.

Obviously the subjective evaluation of my speaker system lacks the controlled conditions in Toole's study. My listeners were guests in my house and my listeners have no comparative reference other than some preconceived notion of what a live



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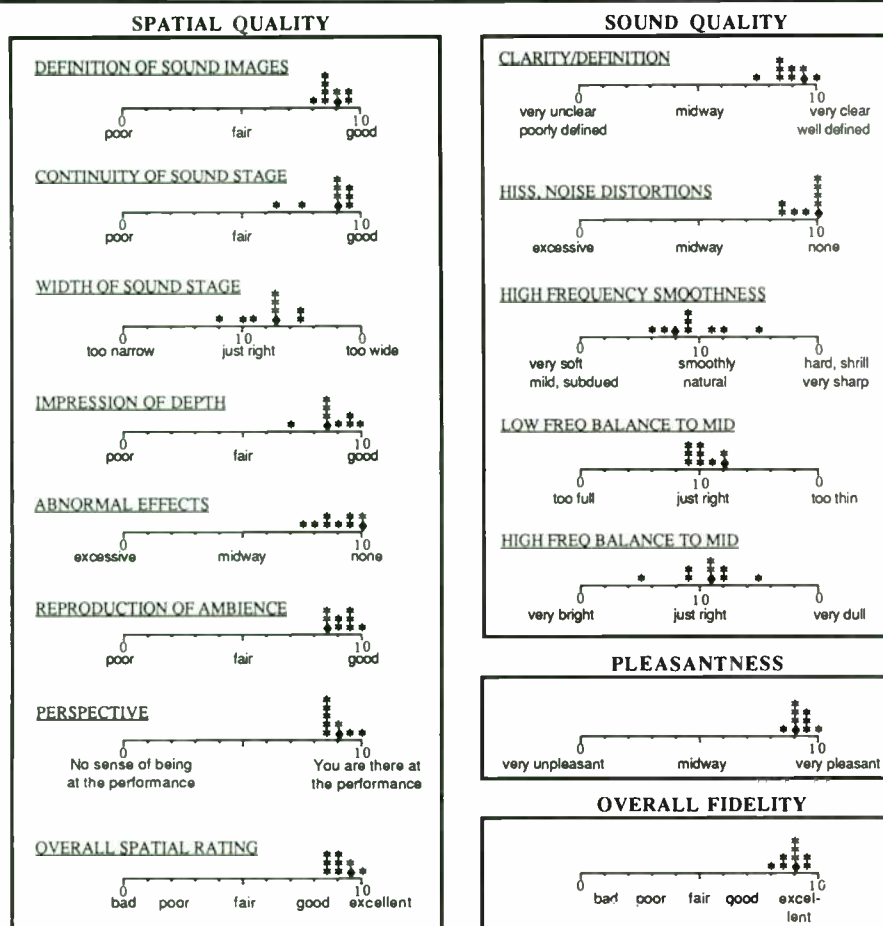


FIGURE 19: Subjective listening response of nine people of the complete sound system. Response items adapted from Floyd Toole's listening questionnaire.⁴³ Responses by G. R. Koonce are indicated by diamonds.

performance sounds like, both of which add bias to my listening test. Still it does give you an idea of my system's performance and also it suggests a reasonable technique to subjectively evaluate your own creations.

IMPROVEMENTS NEEDED. I will conclude by suggesting some improvements for this project. Many listeners commented that the soundstage is too wide, although not so wide as to break its continuity (Fig. 19). Obviously you can move the speakers closer together to the width of the soundstage you prefer. Some of my listener's commented that my system is suppressed at both ends of the audible sound spectrum. Certainly, my measurements confirm this.

The high frequency attenuation may be caused in part by the grille cloth. D'Appolito and Bock note that double knit grille cloth causes increased loss with increasing frequency reaching 3dB or more at 20kHz.⁴ I made all tweeter measurements with the double knit grille cloth in place. Open cell foams, which do not selectively attenuate high frequencies, might be an alternative to double knit fabric.

At the other end of the frequency spectrum, the Dynaudio 30W54s do not have enough linear excursion (7mm peak-to-peak)⁴⁶ to exceed 105dB at 25Hz under the best circumstances (all four drivers operating together into half space). Doubling the excursion to 14mm peak-to-peak would yield another 6dB. These woofers do, however, provide smooth response up to and exceeding the 400Hz crossover point used in my system. (Although not considered a part of this project, I can supplement the low-frequency response of my system with a 24" Hartley in a transmission line.⁴⁷ The Hartley is only useful for about a half dozen of my CDs and since it is not integrated into my system as much as I would like, it is seldom turned on. You can see the placement of the Hartley in Photo 1 (SB 5/89). Listening evaluations did not include the effect of the Hartley.)

Finding ideal drivers remains an ongoing challenge. The greatest improvement would be to achieve the same sound quality for less fuss and less bucks. Suggestions in this regard not only require careful thought and a great deal of work, but are beyond the scope of this project.

This loudspeaker project has been a

rewarding learning experience, which has only fueled my appetite for future explorations. Transmission lines deserve more attention as a viable alternative to sealed- or vented-box systems. The acoustics of the listening room need more study to yield guidelines for the amateur in dealing with speaker-room interactions. Not only are these interactions the weakest link in the sound production chain, but also, by virtue of their complexity and unattainable perfection, they make speaker building the interesting and challenging avocation that it is.

ACKNOWLEDGMENTS. This project reflects the contributions of several individuals. David Ruether gave me invaluable advice on sound quality during the setup and adjustment of the sound system and was responsible for my original interest in transmission lines. Joseph D'Appolito unraveled some perplexing questions I had during the development of the crossover. Robert Bullock provided insight into transmission line theory. G. R. Koonce not only took time to evaluate my system for the benefit of SB readers, but also gave me considerable help in interpreting my measurements. The subjective appraisal by the other listeners: Barney Cole, Greg Fine, Marjory Hillman, Paul McAdams, Carol Miles, Ray Repp, Sam Thomas and Jay Rietz, is greatly appreciated. Finally, I thank my wife Lydia and my daughter Tara who have endured countless hours over the past three years that I have worked on this project. ▶

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| 13M/8535 | 5" paper cone, 38 mm v.c. | 90 db | 250-6,000 Hz | 100 watt |
| 13M/8636 | 5" KEVLAR cone, butyl rubber surround 38 mm v.c. | 89 db | 250-10,000 Hz | 100 watt |
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| 18W/8542 | 6½" | 90 | 60 | 42 | 30 | 62 | .23 | 3000 |
| 18W/8543 P | 6½" | 90 | 100 | 42 | 34 | 62 | .25 | 3000 |
| 18W/8544 K | 6½" | 90 | 100 | 42 | 35 | 40 | .27 | 4000 |
| 21W/8552 C | 8" | 92 | 100 | 42 | 24 | 148 | .20 | 2000 |
| 21W/8553 P | 8" | 92 | 100 | 42 | 26 | 105 | .27 | 4000 |
| 25W/8561 | 10" | 94 | 100 | 42 | 29 | 175 | .38 | 1500 |
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Kit Report

Focal's New Egg

By David W. Davenport

Three years ago I reviewed the Focal 280 Egg and gave it a resounding thumbs-up (SB 4/86). Since then Focal has been busy, making changes in an attempt to improve an already fine product. They have changed the enclosure, updated the drivers, and redesigned the crossover—there's nothing left of the old Egg. Such extensive modifications have rendered my recommendation obsolete, so a new review is in order.

The new system, designated the Egg II, is similar to the first one in shape and size: 16 inches high and 12 inches wide. The walls are somewhat thinner, resulting in a larger internal volume: .53 cubic foot versus .37 cubic foot for the original. Improvements are obvious; the dimensions are held to tight tolerances, and everything fits as it should without any cutting or scraping. The interior of the heavyweight fiberglass-resin casting is coated with a dense damping material, making it as acoustically inert as its predecessor. The face of the enclosure is molded to accept Focal's tweeters and 7-inch drivers.

A dual-coil, bass-midrange driver is recommended for this system. Focal uses the two coils as if they were separate drivers sharing a common cone, which allows crossing over to two different frequencies on the same unit. The two coils work together in the lower range, while only one is effective in the midrange. An increased efficiency and a simplified crossover is claimed for the dual voice coils as compared to a design employing two separate drive units.

Focal makes three different 7-inch dual-coil units—the 7C014-DBE, 7N412-DBE, and 7K011-DB—that will fit the Egg recess. All these drivers share the same high quality cast aluminum frame, butyl-rubber surround, and apparently the same motors. The difference between these drivers is in the cone material. The 7C014-DBE is made of cellulose fiber, the 7N412-DBE of Neoflex, and the 7K011-DB of Kevlar.

The 7N412-DBE is an upgrade of the 7N402-DBE used in the original 280 Egg, the only differences being the cast aluminum frame replacing the stamped steel one, and a new vented dust cap. Focal says Neoflex has a lower density than any other plastic material currently used for driver cones. For this one they claim excellent dispersion, linear response, and a smooth rolloff.

The 7K011-DB is a new addition to Focal's driver line. The "K" designates its

Kevlar cone, a space-age synthetic used in bullet-proof vests, which Focal believes is lightweight, stiff, and has high internal damping. It is a sandwich of two layers of Kevlar cloth bonded together by a compound of synthetic resin and micro balls of foam. Improved dispersion and exceptional transient response are two characteristics claimed for this driver.

Focal's tweeters all have concave domes made of impregnated fiber cloth. These tweeters' voice coils are smaller than their foam surround suspension domes. According to Focal, the radiating area of their tweeters decreases as the frequency increases and tends to be a point source radiator. They claim the concave dome can disperse a greater amount of acoustical energy and has a superior off-axis response. Focal's older T120 tweeters, which are still available, have fiberglass domes. A new tweeter, the Kevlar domed T120K looks the same as the old T120. Focal claims higher sensitivity for the fiberglass domes and extended frequency response for the Kevlar types.

I mixed and matched drivers for my evaluation, using both the old T120 and new T120K tweeters, and 7N412-DBE and 7K011-DB bass-midrange drivers. The combination of T120 with the 7N412-DBE gave me something similar to that used in the original Egg for a reference, while the combination of the T120K with the 7K011-DB gave me an opportunity to hear the latest of Focal's technology.

Figure 1 shows the crossover Focal suggests for use with the Egg. Both coils of the dual-coil woofer are fed through (different) first-order filters, one designed to augment the other. The impedance compensation for the woofer is not part of the crossover as recommended by Focal; rather, it is an improvement I added as a result of my listening evaluation. The high-pass section is a fourth-order filter coupled with parallel LC and RC networks to shelve the level, as well as provide some shaping and taming of the high frequencies.

Focal does not provide a kit for this crossover—you're on your own. As always, I strongly recommend that you use only the best quality components. I built the crossover with air core inductors and metalized polypropylene capacitors. I bypassed the large capacitors with WonderCaps to achieve the correct value as well as improve sound. For example, I used a parallel combination of $4\mu\text{F}$, $.68\mu\text{F}$, and $.02\mu\text{F}$ to achieve the value of $4.7\mu\text{F}$. Focal imports a custom-made $4.7\mu\text{F}$ polypropylene capacitor if you would prefer a smaller package.

Focal provides ABS pipe for the vent, driver gaskets, socket head screws, and heavy-duty binding posts with each enclosure. The binding posts are impressive, machined from solid brass.

Constructing the Egg II

The Egg II is designed as a vented system, with a 2-inch hole in the back of the enclosure to accept the vent, which consists of

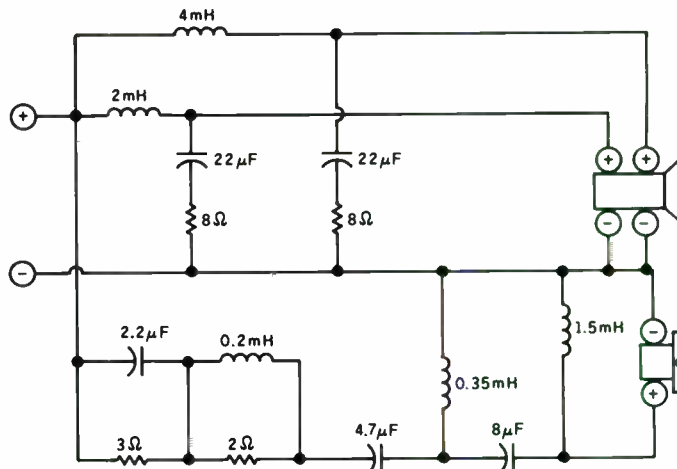


FIGURE 1: The recommended crossover has a first-order filter for each coil of the woofer, and a fourth-order for the tweeter.

two pieces of 2-inch ABS plastic pipe joined by a right angle. After a little experimentation, I found the adhesive used by plumbers for this type of pipe worked best for installing the duct. Focal provides a rubber grommet to seal and finish the joint; I discarded it and recommend that Focal save their money and yours by not providing it. I sealed the joint with Plastic Lead, a compound plumbers use. It hardened to form a perfect, smooth transition from pipe to Egg.

If you choose to build the Egg II as a sealed system, you must find some sort of 2-inch plug to fill the hole. I think Focal could have picked a better color for the Egg; it is a medium-dark grey. However, this can be easily remedied with a coat of fiberglass paint in your favorite color.

Line the rear and sides of the interior with a 1-inch-thick layer of Dacron batting. You don't need any more than this because of the geometry of the enclosure.

The Crossover

If you use top-quality components as I recommend, you have a problem. The air-core inductors and polypropylene capacitors are very large. A crossover using these components is too big to fit inside the Egg. Rather than build a small one with inferior components, I mounted the crossover in its own external box.

Solder the wires to the drivers and mount them in place using the supplied Neoprene gaskets. Seal the screw heads with a little adhesive to block leaks.

Listening to the Egg II

In light of its heritage, I had great expectations for this speaker. I must admit there were some disappointments as well as anticipated successes. Rather than review a single offering, I evaluated several combinations of drivers and crossovers, resulting in specific recommendations to obtain the best sound.

The first version I built included the T120K and 7K011-DB. Anxious to hear the Egg IIs, I substituted them in my system for the originals. The family resemblance was immediately obvious. I didn't need the usual acclimation period; however, to be fair, I gave them the same two-week break-in that I allow for any speaker. I used the time to experiment with room placement.

Listening room location was not as critical as with some other systems; however, their placement relative to the listener is very important. Optimum position is about six feet apart, sitting two feet from the wall, with each speaker pointed directly at the listener and elevated so that the top of the woofer is at ear height. This provides a solid image with the soundfield in the plane of the speakers. Although the "sweet spot" was limited, the image outside this area was good, with no tendency to beam. When the speakers were toed in too much or not enough, everything seemed "bigger



PHOTO 1: The Focal Egg is a small two-way speaker that may be constructed as either a sealed or vented system. It uses Focal's 20mm inverted-dome tweeter and 7-inch dual-coil woofer.

than life" in a plane about two feet in front of them.

As with every speaker I evaluate, I experimented with tilting the enclosure. Slight differences in tilt can have a noticeable effect, so I carefully measure the vertical angle using a protractor. To achieve the tilt, I placed varying shim thicknesses under the enclosure front edge. Eight degrees back from vertical was optimal; the "plane of sound" dissolved and a three-dimensional soundstage emerged. The correct angle was elusive; two degrees either way destroyed the effect. When the enclosure was tilted six degrees, the image and soundstage were pretty good, but the sound was rough and gave the impression of too much going on. With a ten-degree tilt, the sound was smooth, but it was difficult to correctly place instruments in the soundstage.

Having completed the break-in period, I was ready to start my detailed evaluation. Since I had so many different things to investigate, I decided to concentrate on each part separately, listening to the contribution of a single component and isolating its

effects before moving on to the next. I started by focusing on the woofer that I had installed first, the 7K011-DB. Of course a woofer cannot be listened to in isolation; the enclosure has a lot to do with its performance. The bass produced by this half-cubic-foot speaker is impressive. It's not a lease breaker, but it is reasonably deep and well-behaved. Although lacking the very deep bass, it was clean and exhibited no hint of the mid-bass hump you hear so often in speakers of this size.

Moving on to the upper bass and lower midrange, I was disappointed. An aberration conveyed an overall "dark" cast to the sound. While only slightly noticeable on most material, it was particularly obvious on spoken male voice. I spontaneously wrote "dirty—Arrrgh—cardboard" in my listening notes. This is particularly ironic since spoken male voice was one of the strong points of the original 280 Egg.

The Culprit

I couldn't be sure what was causing this character in the sound. Was it the woofer,

the crossover, or the enclosure? I proceeded to isolate the culprit. Substituting the F280-DBO crossover from the original I quickly eliminated the crossover from suspicion. I returned the new crossover to the system so as to have only one variable. I then replaced the woofers with 7N412-DBE drivers. It was immediately obvious that the problem was gone. After a break-in period for the new woofer, I listened to see if the baby had been thrown out with the bath water. Such was not the case. The sound was essentially the same as produced by the older 7N402-DBE. I was not surprised since, except for the dust cap and cast frame, the two drivers are identical.

Happy with the woofer, I proceeded to the tweeter. No disappointments here; the tweeter performance was superlative. Solo piano provided a good example of its excellent definition and clarity. I could hear the individual strings vibrate within a sustained chord. Sometimes good definition and clarity are accompanied by harshness or glare. In this case, however, the presentation had a nice sheen, without a hint of harshness. The sound was delicate and sweet, with a light airy quality. The T120K is a much better driver than its predecessor, the T120; it is sweeter, and more open.

As a matter of course, I attach a felt diffraction ring around any tweeter that doesn't have one. I have never found a case where it doesn't help, if only a bit. Even though the egg shape reduces the effects of edge diffraction, the drivers are mounted on a flat surface molded into the face of the enclosure. The wavelength of the high frequencies produced by the tweeter are short enough to be affected by the edge; and sure enough, the felt ring had a very slight but noticeable effect, smoothing the high frequencies by eliminating a barely discernible time-smear. Detail in the treble was also improved.

I found nothing wrong with the crossover. As recommended by Focal, it did not include impedance compensation. I have always had good results using impedance compensation for a woofer, so I decided to experiment. Adding the RC networks across the driver (Fig. 1) made a noticeable improvement in the sound; it was cleaner and more open, with better definition and focus.

How does the new crossover compare with the original F280-DBO? Differences are subtle. I had to listen for quite a while to identify them. At first I thought I preferred the old crossover; it was a little smoother and fuller. But the new crossover was more detailed and cleaner. In the final analysis the new crossover is superior because it is more accurate.

Focal explicitly designed the Egg II as a vented system. However, I wanted to listen to it as a sealed system, so I plugged the vent. Not surprisingly, the bass was markedly weakened. Although the character of the bass was not bad, it was thin and constrained. On the positive side, the

sealed system produced an incredible soundstage with excellent instrument positioning, front-to-back as well as side-to-side. Although I can't recommend the sealed Egg II as a stand-alone system, it is definitely a contender as a satellite in a sub-woofer system.

F280 Update

If you own one of the original plaster eggs with a 7N402-DBE and T120, you may be wondering about updating them. The 280 is still a fine speaker, so don't feel you need to update. Replacing the tweeter with the T120K will make the biggest difference. The crossover is less certain. If you don't replace the tweeter, don't bother to replace the crossover. The differences are subtle, and to obtain the maximum benefit from the new crossover you need the new tweeter. The 7N402-DBE is similar enough to the 7N412-DBE that I don't advise replacement. This is fortunate because the chassis shape is different on the two drivers, which would require some plaster sculpturing for the old egg to accept the 7N412-DBE.

Conclusions

I recommend a vented Egg II built with a 7N412-DBE woofer and T120K tweeter. For best sound, incorporate impedance compensation in the crossover and use a diffraction ring around the tweeter. And of course, use only the highest-quality components for the crossover—it really makes a difference. If you plan to use the speaker as a satellite with a subwoofer, you should consider a sealed enclosure; otherwise, build a vented system.

The Egg II cannot be classified in terms such as "East Coast," "West Coast," or "British." Having no noticeable peaks or valleys in its frequency response to cause coloration, it is neutral. The unit is exceptionally detailed and transparent as well as analytical and revealing. The vented system performed admirably on all types of music, but particularly well on solo voices or instruments, and small groups. At the other end of the spectrum, large orchestras were well balanced, massed strings were smooth, and the soundstage was realistic.

Three years ago I said the 280 was the best small full-range speaker I had heard. I have listened to some excellent systems since then, but Focal has kept up with the progress, and I believe the Egg II now holds the honor of "best of breed."

Prices for the Egg enclosure are in the range of \$100 each. Depending on your choice of drivers and crossover component quality, total parts for a pair (including enclosures) should run \$500-\$525. The manufacturer's US representative, Focal-America (1531 Lookout Dr. Agoura, CA 91301), is available to answer questions; however, they do not sell direct to the public. Refer to the many advertisements in this magazine for dealers carrying Focal products. ▶

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Craftsman's Corner

Symmetrical Satellite

Upon reading Jean Margerand's excellent article on symmetrically loaded woofers ("The Third Dimension: Symmetrically Loaded" *SB* 6/88, 1/89) I decided to build a stereo pair to complement my Kef B110/Dynaudio D28, D'Appolito type satellites. Having never built a vented system of any kind, I thought this would be an interesting challenge.

I decided to use the Eclipse W1246R woofer. After a few hours with a calculator, I came up with the data for these drivers. I converted the metric data to inches to simplify building with my standard carpentry tools.

The cabinets are made of $\frac{3}{4}$ " high-density particle board covered with black plastic laminate. The top (front) compartment lid is removable, being attached with countersunk wood screws and sealed with self-adhesive foam weatherstrip. This gives me access to the vented compartment and will allow port or driver changes. The bottom (back) compartment is lined with Dacron on all sides while the front compartment is lined on three sides. I may try fiberglass in the front compartment since I understand

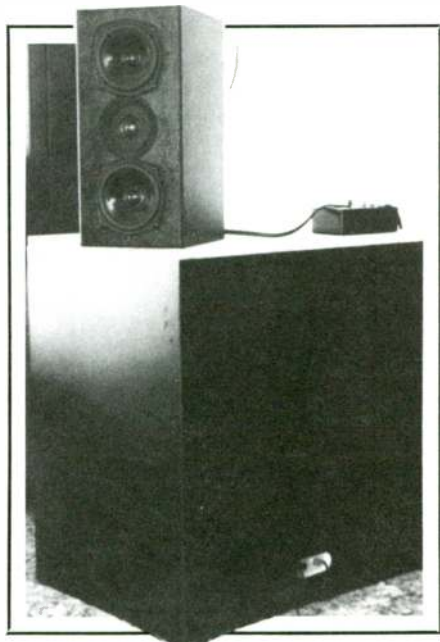


PHOTO 2: The satellite with the D28AF (flat range) tweeter before the D28 (horn loaded) was installed.

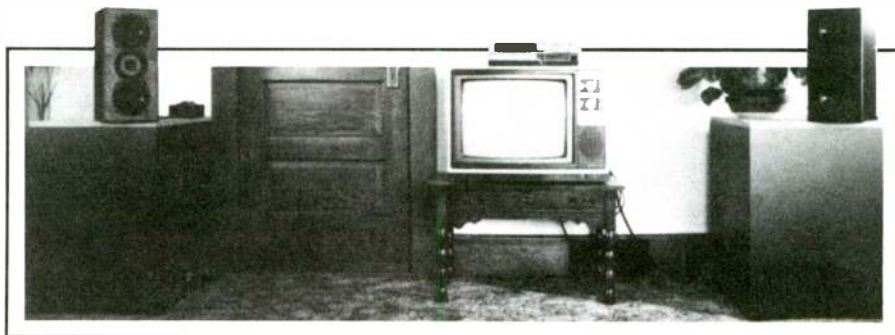


PHOTO 1: Hickerson's satellite system, viewed from the listening position.

it is more suitable for suppressing unwanted midrange output.

I recommend a minimum of one hardwood brace across the cabinet lid and one brace from the baffle to the bottom of the cabinet. More liberal use of bracing, wood screws and caulking should pay off in the long run.

The completed subwoofers are 28 inches high and place the satellites' tweeters at approximately ear level for a listener. I positioned the subwoofers with their ports facing the long wall of my 15 x 24-foot listening room. The cabinets are approximately five inches from the wall behind them.

The satellites are built following Joseph D'Appolito's design ("A High Power Satellite Speaker," *SB* 4/84) with a few changes. The cabinets are made of $\frac{3}{4}$ " medium density fiberboard (MDF) covered with black plastic laminate and lined with $\frac{3}{8}$ " of roofing felt. The baffles are also MDF with the outside edges rounded and painted with gloss black spray paint. The baffles are held in place with a thick bead of black RTV silicone.

I built passive second-order 100Hz high-pass crossovers for the satellites. About 20% of the total capacitance is Solen polypropylene. After a few days of listening I realized the bass was boomy in the cross-

over region, particularly on rock recordings. Upon reversing the subwoofers' polarity, the bass became much smoother and more natural sounding.

I must admit, when starting the subwoofer project I had no idea what the results would be. To check my ability to calculate the front and rear volumes and port dimensions I recalculated for a few of the drivers Margerand gave in his chart. When my results were consistent with his my confidence grew. After completing the system and performing minor fine-tuning to damping material, and so on, I believe symmetrical loading works, and works quite well.

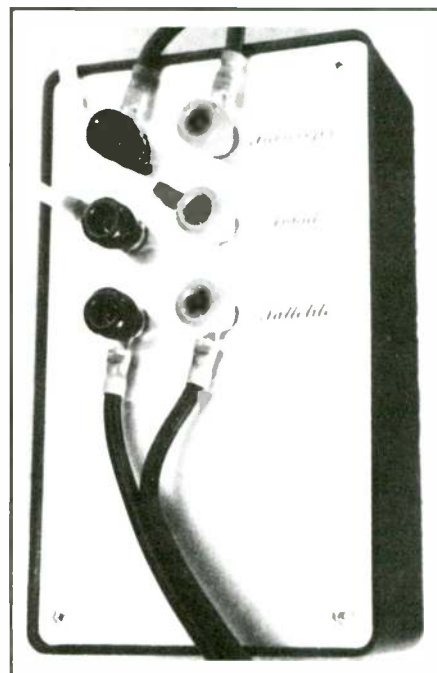


PHOTO 3: Junction box containing passive high pass for satellites.

DATA FOR ECLIPSE W1246R

| | |
|----------------|----------------|
| S | = .5 |
| V _F | = 74.5 liters |
| F _L | = 22Hz |
| Q _T | = .9716 |
| P _A | = -.5dB |
| F _H | = 95Hz |
| V _B | = 100.5 liters |
| D _V | = 10cm |
| L _V | = 11.3cm |
| F ₀ | = 41Hz |

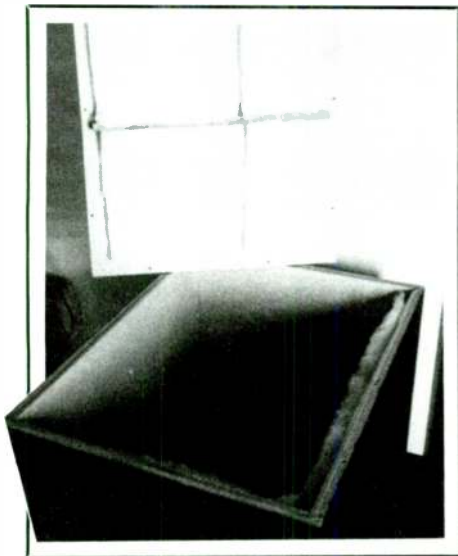


PHOTO 4: Subwoofer lid removed exposing front chamber, vent and front of woofer.

PANEL DIMENSIONS

- 4 Side panels 24 x 26½ inches
- 4 Panels (to be used front and back) 19 x 26½ inches
- 4 Panels (to be used top and bottom) 19 x 25½ inches
- 2 Speaker baffles 17½ x 24 inches

Lacking test equipment other than my ears I can say the bass sounds powerful and well controlled. The lowest organ pedal notes are loud and clear, assuming these terms can be used for something that is probably too low to hear.

Future improvements to this system will probably include bi-amplification, more cabinet bracing, heavier cable than the 16-gauge zip cord I am now using, and changes in cabinet damping materials.

I look forward to hearing whether other readers have had similar results using symmetrical loading. Without *Speaker Builder* I would not have known how to approach a project such as this.

Rod Hickerson
Portland, OR 97206

Camp's Big Dipole

I would like to share my latest loudspeaker system, a dynamic dipole consisting of twelve 10" Philips woofers, four 50mm Jordan modules and one Focal T120KF/8 tweeter per panel.

The panels are 26" W x 65"H x 4½"D and are constructed of 1" medium density fiberboard (MDF) with 2 x 2 and 1 x 2 fir bracing. The panel bottoms are 2" thick. Each panel is supported by two ¾" x 3" x 20" long steel plates which are drilled to accept three 2½" x ¾" diameter lag bolts each. Inset one inch from the front and rear of

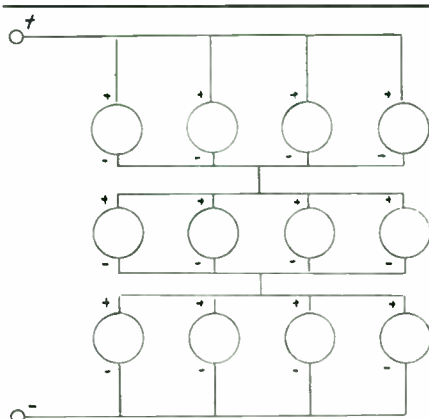


FIGURE 1: Woofer wiring diagram.

each footing is a ¼" tapped hole which is fitted with a 1/4 x 1½" long allen head bolt with the end ground to a point to act as a speaker spike.

I used twelve 10" woofers for each panel due to the volume displacement required to produce real bass from a dipole and to ensure low distortion and no signal compression. In order to maintain flat response to F_S I have a 12dB/octave boost at 20Hz, and $Q = 1$ in my electronic crossover. Each woofer has a Q_T of 0.8 and an F_S around 30Hz. A Q_T of 0.8 maintains level response down to F_S .

The bass boost is required to equalize the 1 rolloff of 6dB/octave which occurs

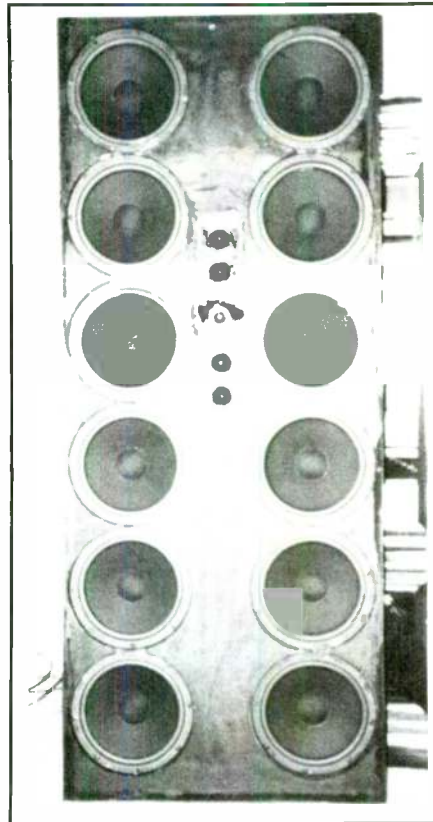


PHOTO 1: Camp's 17 driver per channel dipole uses twelve Philips woofers, four Jordan mid-ranges and a Focal tweeter.

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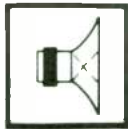


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PHOTO 2: White grille cloth covers the driver array on the right unit of the pair. The dipoles flank a handsome equipment cabinet almost five feet high.

around 100Hz for my panel dimensions. The low-pass section is a DB Systems 36dB/octave electronic crossover at 150Hz feeding a Harman-Kardon Citation 16 power amp. The high-pass section feeds an Audio Research D-52 power amp. I used a 6dB/octave passive crossover between the Jordan and the Focal tweeter at 5kHz.

For all internal wiring I used 14-gauge solid core. The cabinet side pieces are solid red oak with rounded edges. I mounted all drivers using silicone rubber.

The bass section cost is not too bad since the 10" Philips units are available for \$10 each through Zalytron. The Focal tweeters were \$100/pair, also from Zalytron. The Jordan modules must be ordered from England for \$75 each, and are wired in parallel to match the efficiency of the Focal tweeter. You need no resistors to damp the tweeter but please use a high current amp

to handle the low impedance. The woofers are wired in three sets of four in parallel; then the sets are wired in series (Fig. 1).

The sound meets all my expectations. Bass is tight and powerful, and on a good CD, sounds real. Soundstage, definition, and distortion are all excellent using the four Jordans and the Focal tweeter per panel.

Anyone using the Jordans may be surprised how much better they sound when operated in a dipole. Make sure you use a high slope crossover to protect them from over-exursion. They require a very good tweeter to reproduce the upper frequencies and the Focal is a good choice. Without the Focal the system will sound somewhat dull and lacking in "air."

Robert Camp
The Woodlands, TX 77381

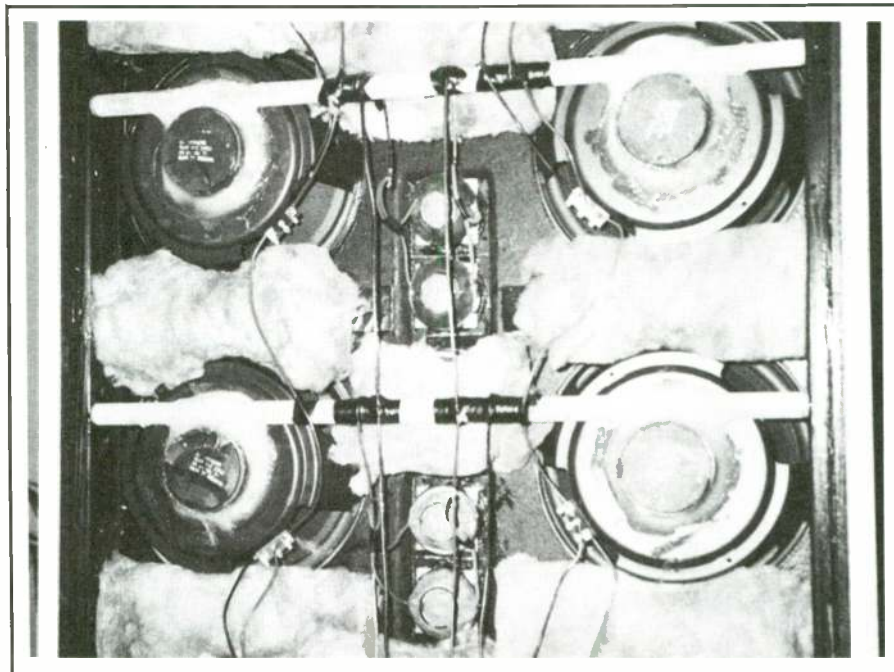


PHOTO 3: The red oak sides of the panel are supported by lateral dowels which also secure the wiring.

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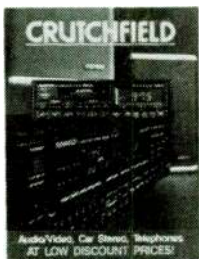
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Computer-Aided Loudspeaker System Optimization and Design
by Witold Waldman

CALSOD is a new entry into the field of crossover network optimizing software available for the IBM PC desktop computer. It combines the transfer function of an LC network with the acoustic transfer function of the loudspeaker, by using some form of iterative analysis. CALSOD creates, through the process of trial-and-error curve fitting, a suitable transfer function model which it can then optimize. The program is the subject of CALSOD author Witold Waldman's research paper "Simulation and Optimization of Multiway Loudspeaker Systems Using a Personal Computer" which appeared in the *Audio Engineering Society Journal* for September 1988, pp. 651-663. CALSOD differs considerably from other software since it models the entire loudspeaker output of a multiway system, including the low-end response, and the summed responses of each system driver.

The program performs a lot of tricks. One of the more spectacular of these allows the designer to specify the location of the driver acoustic centers using an XYZ coordinate system. Thus, if the designer expects to mount a driver combination on a flat baffle, the summed response can be optimized to compensate for rearward displacement of a woofer's acoustic center with respect to a tweeter. CALSOD can model up to seven drivers at a time in a four-way system giving the summed response and acoustic phase response of the entire system.

The CALSOD program comes on a single 360K floppy, and requires one directory and two subdirectories in installation, plus access to the DOS GRAPH-TABL file, which it uses for a couple of special symbols. The 133-page User Manual, provided on a second disk, is well written and adequately describes the various program functions and contains an excellent tutorial example, which demonstrates the use of the program. The files for the worked example contained in the manual also come on the program disk, so users can follow the design process and use and modify the files as they learn the procedures.

CALSOD V.1.20D is now available at a reduced price for a new Standard version at \$65 postpaid in the USA with a manual on disk. Two 5 1/4" 360K DSDD disks supplied. Add \$2.50 for 3 1/2" 720K disk. Add \$5 for delivery outside the USA. MC/Visa Credit Cards acceptable via phone or FAX. Call (603) 924-6526 or 924-6371 M-F, 9-4 EST. FAX: (603) 924-9467.



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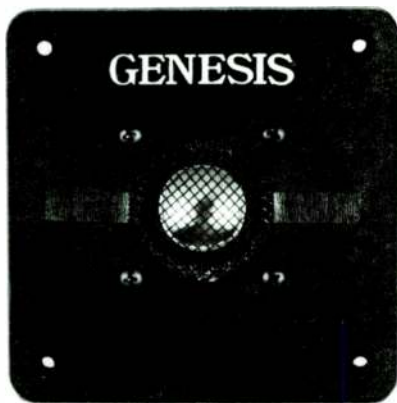
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Tools, Tips & Techniques

HOT WIRE

Here's a good way to remove cable insulation without damaging the conductor. First, bend the cable into a U. Then heat up a knife blade (preferably an old one). Press the knife to the outside of the U and it will melt through the insulation. Avoid a sawing motion. The light pressure needed to push the hot blade through the insulation ensures the conductors remain intact. Bend the cable the other way and repeat the procedure. Do this all the way around, then pull off the insulation. This also works well for removing the inner and outer insulation of coaxial cable.

Bryan T. Frane
 Orinda, CA 94563

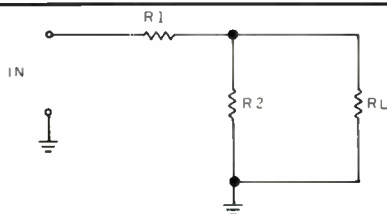
Where:

- A = attenuation in decibels expressed as a positive number.
- RL = Load Resistance
- RT = (R2 × RL)/(R2 + RL)
- R1, R2, RL, RT are expressed in ohms.

Kurt Klockeman
 Fridley, MN 55432

PRECISE L-PADS

I have put together a formula to determine resistor values in an L-pad attenuating circuit. The formulas I have seen determined the final impedance match exactly, but the attenuation has been off by a decibel or more.



This first one determines the impedance of R2 and the load in parallel:

$$RT = (1/10^{A/20}) \times RL$$

By subtracting the result from the load (in ohms) you establish the value of R1:

$$RL - RT$$

To determine the value of R2:

$$(RL / ((RL/RT) \times (RL - RT))) \times RL$$

The result will be exact. To check the answer by the voltage ratio:

$$RT/RL = V_{out}/V_{in}$$

And in decibels:

$$20 \log V_{out}/V_{in}$$

FAST FINISH

You're nearly finished with a speaker project and all that remains is to put a finish on the enclosure. You need something inexpensive, relatively simple and mess-free, that won't arouse any more of your wife's ire.

I was in a similar situation when a solution came to me: contact paper. Its low cost (79¢ per yard) and ease of application make it ideal. Contact paper comes in different colors and patterns, including many attractive "wood veneer" designs. On the negative side, it is not durable being subject to scratches and peeling.

The solution? A coat of clear spray acrylic gives it a tough protective layer, and with a spray, we have no brushes to clean afterward.

Make sure the enclosure surface is smooth, clean and dry. Apply the contact paper as smoothly as possible on the enclosure surface, using some traction when wrapping corners so it will make good contact, and flatten any wrinkles. (Recruit a helper.) Overlap your starting point since it adheres better to itself than to wood. Cut the edges as straight as possible.

Place your enclosure(s) on tarpaulins or newspapers and spray liberally. Allow to dry for 24 hours. I used Martin Paints #101 Clear Acrylic Spray Enamel (quick dry exterior). You'll be amazed how tough, protective, shiny and good looking just one coat is. It looks and feels like a quality Varathane finish. Apply some Crazy Glue to any loose edges. For more protection, apply additional coats.

Of course, there will be some odor, but I found it tolerable and, with the windows open, the fumes dissipate fairly quickly, leaving no lingering smell. [A window fan is a safer idea if you are working indoors.—Ed.]

Angel Luis Rivera
 Brooklyn, NY 11204

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*"I never realized that an absolute novice like me could really get into the electronics of my music system and make changes that would improve the sound so dramatically."
Gayle Farris, Denver, CO 80216*

*"I scratch-built the last PAS with certain modifications...a much more stiffly regulated heater circuit, and one cathode follower tube function in the RIAA stage...and it sounds great."
Zoltan Gal, Gyor Hungary*

*"The servo article (by Brian Clark) is now my pet project, and I'm trying to apply it to my PA Audio IV H preamp...it would allow me to eliminate three 100uF aluminum electrolytics from the signal path."
S. F. Lataros, Nazareth, PA 18064*

Sure, high tech audio has its share of mystery, hype and mystique. But all that clears up when you venture with us behind the front panel. At first, you may be satisfied to just look around, and check things out with the schematic. Very soon, you'll begin to understand what that mumbo jumbo is all about. Then whenever you like, you can start improving your system's performance in ways that mass production doesn't allow.

If that sounds overly optimistic, read that first quote again. It's from a reader who had never

opened the back of a set, never read a schematic or plugged in a soldering iron—before subscribing to *Audio Amateur*. And there are thousands more like her who've been turning garden variety preamps into something really special by replacing the power supply, upgrading the components, or actually improving the circuit design.

And this is only a fraction of what *Audio Amateur* has been doing for thousands of readers during the past twenty years.

We've done it in part by publishing authoritative articles about audio technology by people who have improved their own systems. Most often, they're non-audio engineers who recognize that there are better ways to reproduce sound than commercial products allow. We also publish original designs as good or better than those on the market—and always at far lower cost. We always tell you where to find the parts you need. Not surprising, there are specialist suppliers who offer kits based on the articles.

But it's not all "work." You'll meet the who's who in audio. You'll enjoy the lively exchange of ideas in our reader letters. Audio Aids is a forum where readers share their tricks and ideas. Booktalk has reviews of old and new audio books. And you'll learn about all that's really unusual among the new. Our free classified ads for subscribers and audio clubs provide a great meeting ground.

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Technology Watch

Electrostatic Loudspeaker Design

By Peter Muxlow

At least one major corporation, Philips Research Laboratories, shows a continuing interest in electrostatic loudspeaker (ESL) design. Mr. Streng, of Philips, has recently published a paper relevant to ESL design.¹ He has also applied for a patent.²

Electrostatic loudspeakers usually have a large diaphragm area which enables them to radiate adequate power at low frequencies. This large area causes high frequency directivity. To overcome this, Streng subdivides the electrode area of the ESL (Fig. 1). Each section is then driven via its own amplifier with its own cutoff frequency. Starting at the top, electrode area 1 receives the total bandwidth audio signal and radiates the full frequency range. Electrode area 2 receives its

signal through a low-pass filter and amplifier and radiates frequencies up to 10kHz. Area 3 receives its signal through another low-pass filter and amplifier and radiates frequencies up to 5kHz. And so on until areas 6a and 6b which are driven only to 100Hz.

The effective radiating area of the speaker decreases as the frequency which controls the directivity of the ESL increases. When you subdivide the electrode area (Fig. 1), you face the problem of preventing diaphragm vibrations in one area (for example, area 1) from causing diaphragm vibrations in the surrounding areas (2 or 6). Figure 2 shows how this problem is solved. If area 1 diaphragm is vibrating at 15kHz there will be no input to the non-inverting input of amps

A2a and A2b as they don't come into operation until below 10kHz because of the low-pass filter. However, diaphragm vibrations from area 1 causing vibrations in area 2 induce a feedback signal at the inverting input of amplifiers A2a and A2b.

These feedback signals are amplified and appear at both electrodes—area 2. This voltage suppresses the original diaphragm deflection which originates from area 1. The high feedback in the high voltage amplifiers effectively switches off the parts of the speaker that do not receive any signal.

Many readers will be interested in the omission of the costly step-up transformer. In its place, Streng uses optoelectronic cou-

Continued on page 81

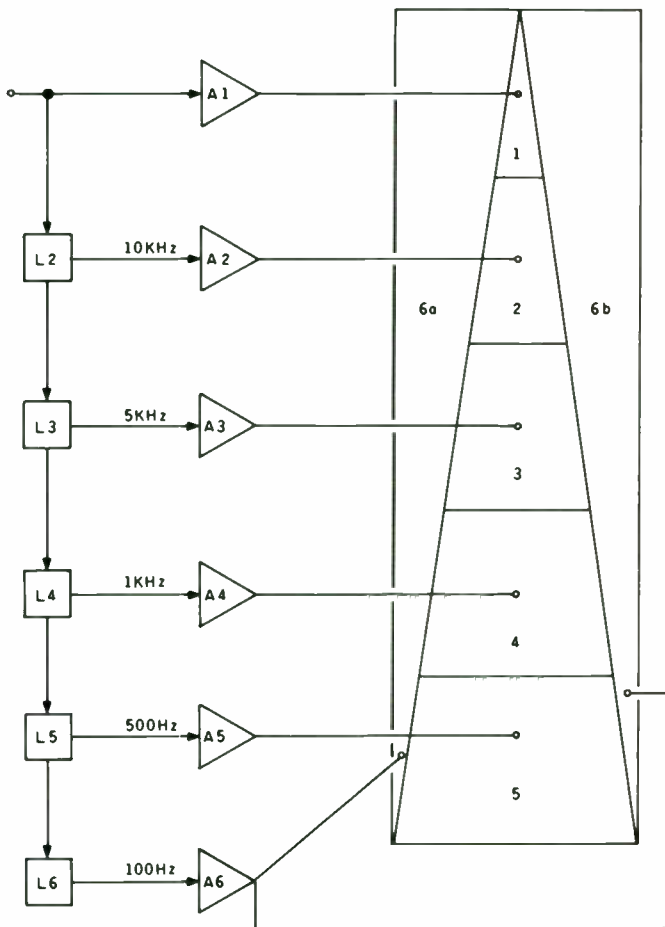


FIGURE 1: A = amplifier, L = low-pass filter. Note: Cutoff frequencies for the low-pass filters are not referenced in the patent. These frequencies are arbitrary.

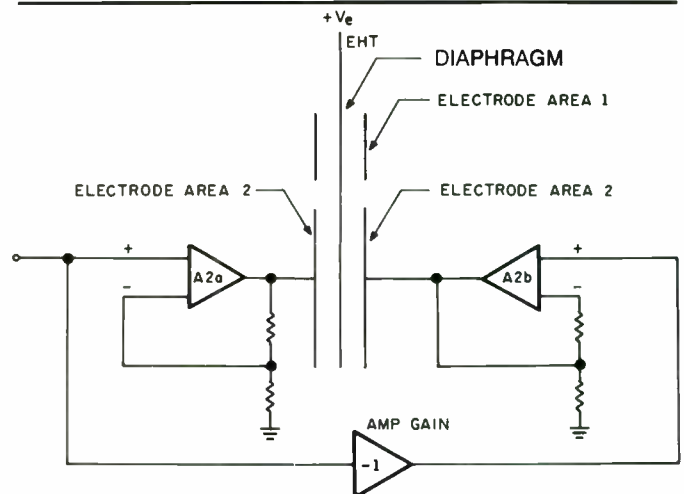


FIGURE 2: Simplified subdivision of electrode into two areas. The two electrodes are driven in opposite phase with the aid of the amp gain (-1).

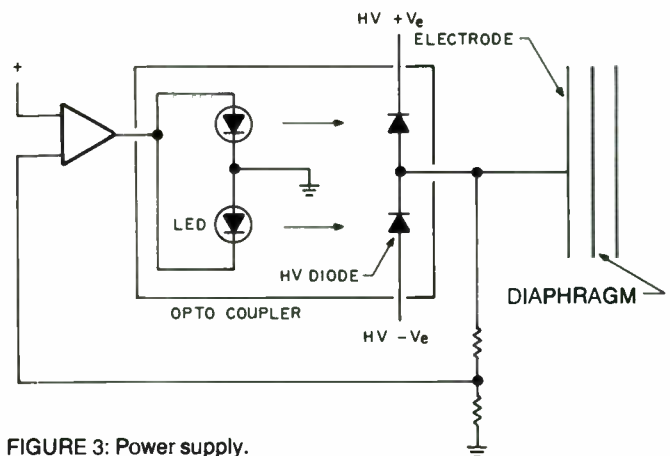


FIGURE 3: Power supply.

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FILTERS & SPEAKER SAVER

KH-2: SPEAKER SAVER AND OUTPUT FAULT DETECTOR [3:77]. This basic two-channel kit includes board and all board-mounted components for control circuitry and power supply. It features turn-on and off protection and fast opto-coupler circuitry that prevents transients from damaging your system. The output fault detector has additional board-mounted components for speaker protection in case of amplifier failure. **\$65**

KF-6: 30Hz RUMBLE FILTER. [4:75] This kit implements a 1975 design for a low frequency garbage filter. The filter knee is set to 30Hz. Roll-off below that knee is the 18dB/octave characteristic of its three pole design. Gain for the filter is unity (0dB) but can be simply adjusted for up to 12dB of gain. The reprint of the article explores the use of the filter with other components in crossovers (see kits SBK-C1A, C1B). It shows how to obtain slopes of 6, 12 or 18dB in high and low pass filters. The kit contains all parts for building a two channel HPF including a board (3" x 3"), quad op amp IC, precision resistors and capacitors. Requires a bipolar supply of $\pm 15V$, the KE-5 is suitable. **\$30**

AIDS & TEST EQUIPMENT

KK-3: THE WARBLER OSCILLATOR [1:79]. This unit will produce a swept signal covering any $\frac{1}{2}$ -octave between 16Hz and 20kHz. The total harmonic distortion at the output is less than 1.5%. The output voltage is adjustable from 0 to 1V. When used with a microphone it is as effective as a pink noise source in evaluating speaker system performance. It also reveals the listening environment's effect on sound through reflection and absorption. The sweep rate is set at about 5Hz. The kit includes $3\frac{1}{4}$ " x $3\frac{3}{8}$ " circuit board, transformer, all parts and article reprint. **\$70**

KH-7: GLOECKLER PRECISION 101dB ATTENUATOR. [4:77] All switches, 1% metal film and 5% carbon film resistors to build prototype. Chassis, input/output jacks are not included. **\$65**

KC-5: GLOECKLER 23-POSITION LEVEL CONTROL. [2:72] All metal film resistors, shorting rotary switch and two boards for a two-channel, 2dB per step attenuator. Choose 10k or 250k Ω . **\$48**

KL-6: MASTEL TIMERLESS TONE BURST GENERATOR. [2:80] All parts with circuit board. No power supply. **\$24**

KP-2: TWO TONE INTERMODULATION TEST FILTER. [1:82]. This filter is designed to isolate the two high frequency tones at an amplifier's input from low frequency intermodulation products present at the output. The high pass filter corners at 2kHz and rolls off at 24dB/octave. A 5kHz signal at the low pass input will be down at the output by 80dB. An article reprint detailing design and use is included with the kit. All parts are supplied including quad op amp IC, circuit board and precision resistors and capacitors. **\$26**

SBK-D2: WITTENBREDER AUDIO PULSE GENERATOR. [SB 2:83] All parts, board, pots, power cord, switches and power supply included. **\$80**

SBK-E4: MULLER PINK NOISE GENERATOR. [SB 4:84] All parts, board, 1% MF resistors, capacitors, ICs, and toggle switches included. No battery or enclosure. **\$35**

CROSSOVERS

KC-4A: ELECTRONIC CROSSOVER, KIT A. [2:72] Single channel, two-way. All parts including C-4 board and LF351 ICs. Choose frequency of 60, 120, 240, 480, 960, 1920, 5k or 10k. KE-5 or KF-3 supplies are suitable. **\$14**

KC-4B: ELECTRONIC CROSSOVER, KIT B. [2:72] Single channel, three-way. All parts including C-4 board & LF351 ICs. Choose two frequencies of 60, 120, 240, 480, 960, 1920, 5k or 10k. **\$18**

KK-6L: WALDRON TUBE CROSSOVER LOW PASS: Single channel, 18dB/octave, Butterworth, [3:79] includes three-gang pot. Choose 1: 19-210; 43-465; 88-960; 190-2100; 430-4650; 880-9600; 1900-21,000 hertz. **\$60**

KK-6H: WALDRON TUBE CROSSOVER HIGH PASS: Single channel, 18dB/octave, Butterworth, [3:79] includes three-gang pot. Please specify 1 of the frequencies in KK-6L. No other can be supplied. **\$62**

KK-7: WALDRON TUBE CROSSOVER POWER SUPPLY. [3:79] Includes board, transformer, fuse, semiconductors, line cord, capacitors to power four tube crossover boards (8 tubes), 1 stereo bi-amped circuit. **\$110**

SBK-A1: LINKWITZ CROSSOVER/FILTER. [SB 4:80] Three-way crossover/filter/delay. 24dB/octave at 100Hz and 1.5kHz and 12dB/octave below 30Hz, with delayed woofer turn-on. Use the Sulzer supply KL-4A with KL-4B or KL-4C.
Per channel **\$75** Two channels **\$140** SBK Board only **\$14**

SBK-C1A: ELECTRONIC TWO-WAY CROSSOVER. [SB 3:82] 30Hz filter with WJ-3 board & 4136 IC adapted as one channel crossover. Can be 6, 12 or 18dB/octave. Choose frequency of 60, 120, 250, 500, 1k, 2k, 5k or 10k. The KL-4A/KL-4B or KW-3 are suitable supplies. **\$32**

SBK-C1B: THREE WAY, SINGLE CHANNEL CROSSOVER. [SB 3:82] Contains 2 each SBK-C1A. Choose high & low frequency. **\$60**

SYSTEM ACCESSORIES

KW-3: BORBELY IMPROVED POWER SUPPLY [1:87] This single channel, low impedance supply was designed for the exacting requirements of Erno Borbely's moving-coil preamp [2:86, 1:87]. The design utilizes polypropylene caps and 1% metal film resistors. LM317/337s are used in the preregulator and Signetics NE5534 in the op amp regulator. The kit includes a low profile 24V toroidal transformer, $4\frac{1}{4}$ " x $5\frac{1}{2}$ " circuit board and all board mounted components. Chassis and heatsink are not included. **\$135** Two or more **\$128**

KE-5: OLD COLONY POWER SUPPLY. Unregulated, $\pm 18V @ 55mA$. **\$20**

KF-3: GATELY REGULATED SUPPLY. $\pm 18V$ or $\pm 15V @ 100mA$. **\$52**

KL-4A: SULZER POWER SUPPLY REGULATOR. **\$40**

KL-4B: SULZER DC RAW SUPPLY. $\pm 20V @ 300mA$. **\$60**

KH-8: MORREY SUPER BUFFER. [4:77] All parts, 1% metal film resistors, NE531 ICs, and PC board for two-channel output buffer. **\$22**

SBK-E2: NEWCOMB NEW PEAK POWER INDICATOR. [SB 2:84] All parts & board, new multicolor bar graph display, red, green & yellow LEDs for one channel. No power supply needed. **\$14** Two for **\$22**

KL-2: WHITE DYNAMIC RANGE & CLIPPING INDICATOR. [1:80] One channel, including board, with 12 indicators for preamp or crossover output indicators. Requires $\pm 15V$ power supply @ 63 mils. Single channel. **\$58**
Two channels. **\$110** Four channels. **\$198**

KW-1: MAGNAVOX CD PLAYER MODIFICATION. Improves frequency response. Includes two Signetics NE5535s, two Panasonic HF series 330 μF capacitors and four 3.92k, 1% metal film resistors. **\$12**

KW-2: MODIFICATION. As above, but with two AD-712 op amps in addition to the NE5535s. **\$16**

KX-1A: DISC STABILIZER. Set of 3 Sorbothane feet, 3 Tiptoes and Mod Squad's Disc Damper with 15 centering rings. **\$70**

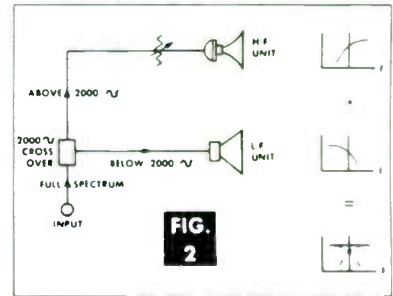
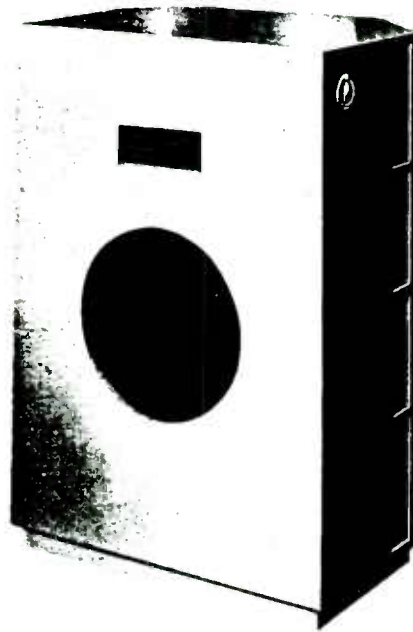
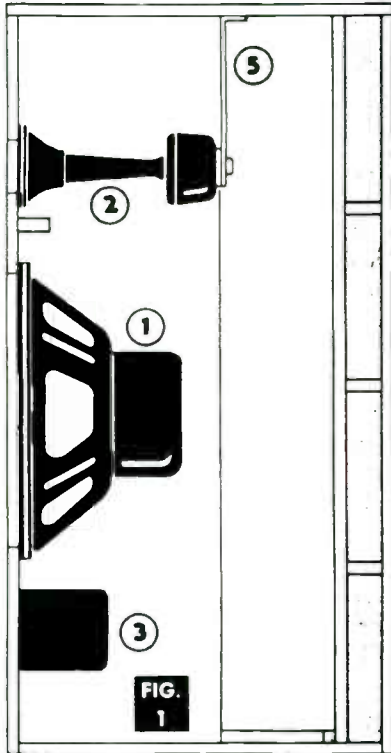
KY-1: BEERS' BUDGET CD MOD. [1:89] Kit provides POOGE-4 improvements without additional wiring or circuit boards. Complete parts for assembling amplifier modules and replacing DAC components. Article reprint included. Soldering skills required, not recommended for beginners. **\$95**

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

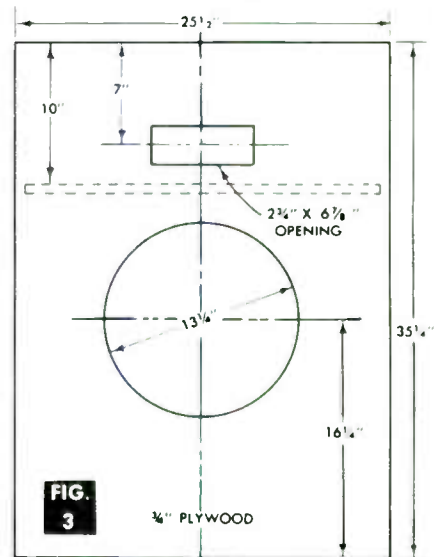
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Jensen Concerto-15 Reproducer

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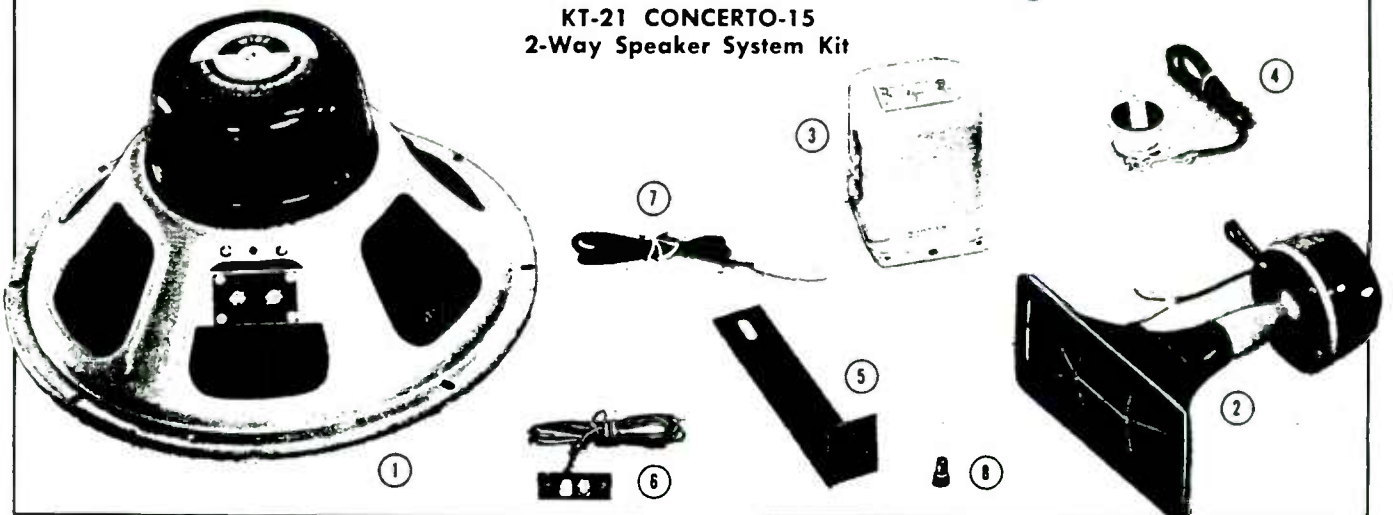
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| 5 | 1 | — | L Bracket |
| 6 | 1 | — | Input Cable Assembly |
| 7 | 1 | — | 10" 2-wire Cable |
| 8 | 1 | — | Solderless Connector |

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KT-21 CONCERTO-15 2-Way Speaker System Kit



SB Mailbox

DYNAUDIO 24W100

I am interested in the Dynaudio 24W100. I think its 9" diameter makes it an excellent candidate for use in a double-chamber reflex enclosure (Augsburger type) which I have used for 8 and 10" woofers with great success. However, upon examining the given driver parameters, I noticed that, although its Q_{TS} (.35) is within a normal range, its equivalent volume (62 liters) is quite small for a 9-10" woofer. May I assume that this is due to the oversized 4" voice coil, which reduces the cone area? Specifically, the area that comes in contact with the air *inside* the enclosure?

Dynaudio makes it clear the 24W100 can and should be used as a mid-bass, rather than low-bass. It appears that a big voice coil like this would provide the excellent pistonic motion, stability, and control necessary to reproduce mid-bass transients properly. However, when asked to dig way down into that last octave (@ 35Hz), wouldn't the lack of cone area (inside the enclosure) cut down the SPL significantly?

Someone once told me that for a good output in the lowest octave, you must increase the cone area while reducing the voice coil diameter. Of course small voice coils mean low power handling, but within reason.

My question is: How do big voice coil drivers sound? I realize this is a highly subjective question, so I would expect a highly subjective answer. But theoretically, would the 24W100 in a double chamber enclosure give me the three qualities I am looking for in woofer performance (deep bass, quick transients and less excursion limiting than with a good 8" woofer)?

This question can be applied to several other 3 and 4" voice coil woofers put out by Dynaudio and Morel. Can these drivers be used successfully in bass reflex enclosures, and if so, what sort of alignment should I use with the 24W100? If not, what sort of enclosure would work best?

I have previously used a Peerless TD295R 8" unit in a double chamber enclosure, and though I was satisfied with the deep bass, I felt the mid-bass was a bit "wallowy," as if the enclosure was too big. Also, its poor little 4-5mm excursion limited the SPL of my listening level. I am hoping the 24W100 with 8mm excursion and roughly the same V_{AS} will solve this

problem. Still, I am hesitant to pay such a high price for these drivers if it means giving up deep bass.

Stephen K. M. Wakeman
West Lafayette, IN 47906

Robert Bullock replies:

Your observation that the decreased rear cone area of the 24W100 should reduce the measured value of V_{AS} is correct if you measure V_{AS} directly in the conventional way. On the other hand, if you mount the driver on the test box so its front faces into the test box, the V_{AS} value would be the one normally expected.

You compare this driver to 9-10" drivers, but I would classify it as a nominal 8" unit on the basis of its piston area. In any case, a small V_{AS} is in and of itself not solid evidence that it is derived from the rear of the cone. It can also arise from a relatively high driver resonant frequency or a larger than usual driver moving mass.

It is not intuitively clear to me how the smaller rear cone area affects response, so I looked at a model of the situation using the 24W100 in the standard T/S alignment. Specifically, $f_B = 36$, $V_B = 1.2$ cubic feet and rear cone area = 140 square centimeters. The light line response plot is for equal front and rear cone area and the dark one for the smaller rear area (Fig.

1). So, it looks like the overall low frequency response is depressed, except in the immediate vicinity of the vent resonant frequency, where it has actually increased. You may decide whether you believe my model, and if so, whether the response change is significant.

I guess the 24W100 would work quite well in a closed box, because the box is used only to supply additional stiffening, and the rear of the driver does not contribute to the output as it does in a vented box.

Your objection to the mid-bass performance of the Peerless in a double chamber enclosure may not be due to the driver. I have modeled this type of enclosure and found that although it can produce good low bass, the response from 80 to 150Hz is usually depressed below the reference level by as much as 5 to 10dB, regardless of the driver's parameters. In other words, what you hear may be a side effect of the loading technique and not the driver.

Your hope that the 24W100 will offer improved performance over the Peerless TD205R because of its greater excursion capability will not be realized. Dynaudio gives this specification as a peak-to-peak value, so it must be divided by 2 before comparing it to the Peerless value. Thus, the two drivers have identical excursion capabilities. As a matter of fact, they are quite similar except for power handling capability and difference in the ratio of front to rear cone area. The wide discrepancy in price suggests a difference in workmanship, quality control and raw materials.

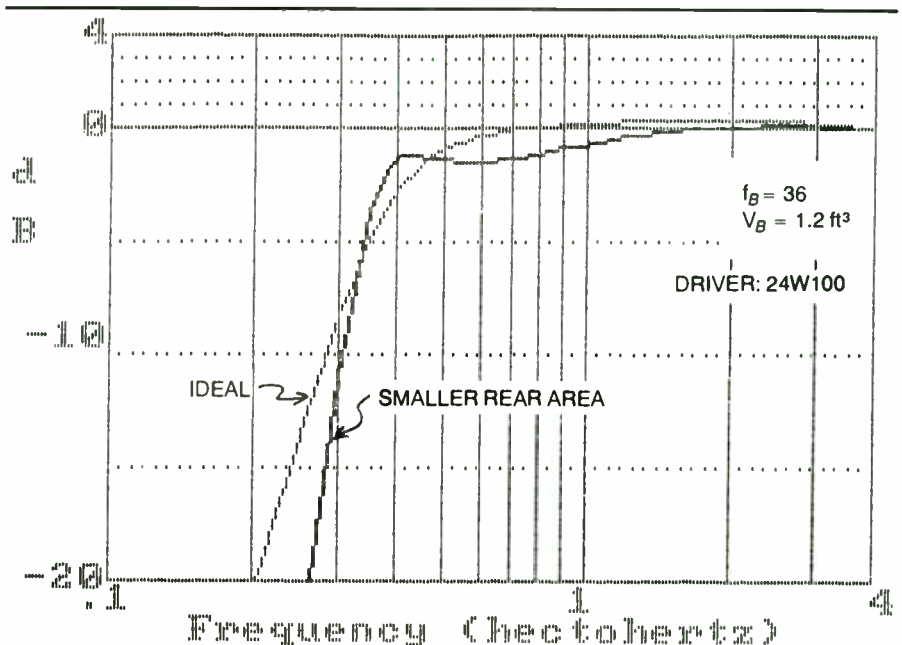


FIGURE 1: Small signal response.

I have never used a driver with a large voice coil, so I cannot make a subjective comparison. I suspect you would discern little difference between the two drivers at low frequencies, but there may be significant difference in the midrange.

MIDRANGE MEASUREMENTS

The survey of seven midrange drivers by Gary Galo (SB 2/86) invites comment. In particular, I do not agree with his conclusions for the KEF B110. Figure 1 shows response curves I measured for five driver pairs. The first four curves are recent B110/SP1057 units and the fifth is a 1979 vintage B100/SP1003. I used the Linkwitz "Shaped Tone-Burst Generator" (JAES, April 1980) with a Matsushita WM063 condenser mike at a distance of 700mm (28 inches). My measurements are essentially free-field, and the recovered burst signal can be compared to the input burst signal with a double beam oscilloscope to reveal resonances not visible from the frequency response curve of the particular unit. Tested in this manner the B110 does not show any serious resonances.

I mounted all units in a Linkwitz satellite enclosure, and from 100Hz to 1kHz, the results for each pair were virtually identical. From 1 to 10kHz there is some measured variation but nothing serious, and pair matching is excellent. The low end rolloff is a result of the small frontal area of the box and, to a lesser extent, measurement distance. Diffraction will affect the integrity of the measurements in the 2-6kHz region.

Although Mr. Galo meant well, I feel his

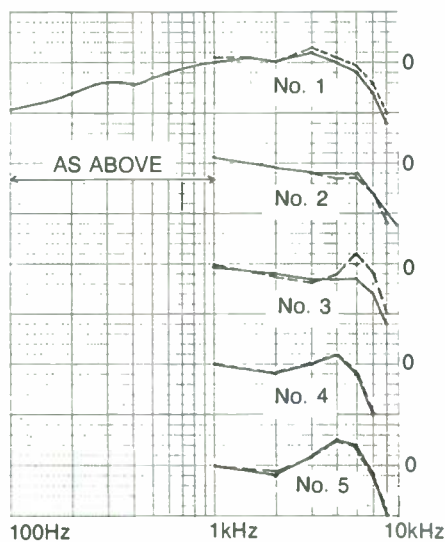


FIGURE 1: Frequency response curves for the KEF B110. Free-field response 700mm on axis. Curves No. 1-4 are B110/SP1057; No. 5 is B110/SP1003. One unit on the vertical scale equals 1dB.

results will discourage prospective builders from using this unit (B110). I suggest builders listen to a carefully built Linkwitz satellite system (or an LS3/5 clone). I do not favor dome units for the midrange although recent examples are very good. The very best British loudspeakers never use domes for the midrange. Strong evidence supports the use of a single unit (plus a woofer and tweeter) to cover the range from 100Hz to 1.5kHz. In this respect, a Linkwitz system is fundamentally correct and represents the best possible compromise. Improved drive units and enclosure construction techniques will improve the system further.

In summary, I recommend the B110 for

the Linkwitz system or an LS3/5 clone. You could also use units from Audax or Focal in the Active system although I have not measured 13CM units from these suppliers.

John A. Kasowicz
Melbourne, Australia

Gary Galo replies:

The response curves supplied by Mr. Kasowicz differ from my own measurements, and I do not dispute his findings. What is interesting is the variations he has measured from one sample to the next. The five supplied curves are very different from one another. At 4kHz, Samples 5 and 3 vary by 4dB. This may be

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Fast Reply #KD123

of no consequence if 1.5kHz is the upper limit, but many designs use mid-bass drivers as high as 3kHz, in which case the variations become more serious. Although my two samples did not differ in their frequency response, the review points out that the distortion measurements were radically different. Mr. Kasowicz and I are, in fact, in agreement on one point: the B110 varies from sample to sample. We simply disagree on their significance. Perhaps my frequency response irregularities are not typical of B110 samples. Mr. Kasowicz's measurements indicate that later versions are better than his earlier samples.

There is much to be said for the view that a single driver should cover the critical midrange from 100Hz to 1.5kHz. Unfortunately, it also creates a new set of problems. Very few tweeters can be crossed over at this low a frequency. Many dome tweeters have resonant frequencies in the 1 to 1.5kHz region and must be crossed over at least an octave above this. I prefer a 24dB/octave Linkwitz crossover which allows lower crossover frequencies, but they are difficult to implement passively. Electronic crossovers become a virtual necessity. Being a believer in multi-amplification, I have no problem with this, but many builders aren't willing to build or purchase three amplifiers for their systems.

I think the Dynaudio D76 will change the views of those who have disliked dome midrange drivers in the past. It is a superb driver and I stand by my previous views. If Mr. Kasowicz's findings are typical of newer B110 samples, there should be no problem operating them in the 100Hz to 1.5kHz region. I still feel they are overpriced. Focal competes at lower prices. One mid-bass driver worthy of consideration is a 6 1/2" polypropylene unit sold by Meniscus Systems and manufactured by Carboneau Industries. This appears to be virtually identical to the Carboneau driver used by Fried.

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Fast Reply #KD247

LMP UPGRADE

Several readers have recently asked whether it would be possible to upgrade LMP (Loudspeaker Modelling Program, SB 1-3/87) to allow driver models with non-constant impedance curves. With a fair amount of effort we could do this, but we would greatly reduce the program execution speed.

More importantly, I consider non-resistive driver modelling a low priority for several reasons: 1) You can almost always determine an impedance compensation circuit to make the driver appear to be a resistive load (SB 1/83, p. 11). At present, such circuits *must* be used if your LMP results are to be valid, unless the driver's impedance is already nearly flat about the crossover frequency. 2) It is easier to predict the effect of a crossover design if the drivers are resistive or have been compensated to appear so. 3) A passive crossover which has been designed to work with resistive drivers can be readily translated into an active version.

It is occasionally desirable to combine a standard crossover configuration with a *notch filter*, to eliminate a peak in a driver's

response. While presently there are no LMP subroutines to directly model this effect, you can use notch filters with any LMP-designed crossover as follows: 1) Use the formulas in my letter on p. 46, *SB 4/86* to calculate the notch filter required to eliminate your driver's peak. 2) Use the formulas in the same letter to calculate *impedance compensation for the notch filter, to eliminate its interaction with the crossover.* (Strictly speaking, the series impedance of the crossover may still influence the Q of the notch filter, but this effect should be small when the notch frequency is in the crossover's passband. Otherwise, you may wish to adjust the resistor in the notch filter to produce the desired response, and recalculate the resistor in the notch impedance compensation accordingly.)

3) Now produce an LMP model for the driver which *ignores* the response peak, and experiment with LMP to determine good crossover values. 4) Finally, construct the finished crossover by combining it with the notch filter, notch impedance compensation, and driver impedance compensation, as illustrated in the aforementioned letter.

Using notch impedance compensation has the same benefits as using driver impedance compensation: You can more easily predict the effect of the notch and translate the overall crossover into an active version if desired.

Ralph Gonzalez
Wilmington, DE 19803

MTM ENHANCEMENT

I am interested in the concepts outlined by John Levreault ("A High Quality Dome Midrange/Tweeter Array," *SB 2/88*, p. 9) which go a long way to obtain full range reproduction from a moderately sized speaker system. For some time I have been interested in building a system around the Dynaudio D76 and 21W54 but was put off by the apparent lower frequency response dip of the D76. Having read Gary Galo's report on the D76 (*SB 2/86*, p. 32) it appears this response dip could be diffraction loss. Mr. Levreault, is your winged baffle arrangement designed to overcome this problem? Does it work (have you taken any response measurements)?

Could the benefits of using the D28 (with a crossover similar to the D'Appolito) work better in your new MTM satellite for the same reason it does on D'Appolito's design (despite the normal superiority of the D28AF)?

The 6dB crossover at 3kHz doesn't look steep enough to roll off the response peak in the D76 at 4.0-4.5kHz. Is this the case in practice?

Please elaborate on circuit design changes particularly for the bass equalizer

using your preferred AD711 single FET amps. Is there a standard circuit board that could be used?

Frank J. Habrle
Auckland, New Zealand

John Levreault replies:

From your remarks I assume you are concerned about the slowly rising D76 frequency response shown in Dynaudio's literature. The D76 data sheet I received from Madisound has two curves: the first indicates frequency response versus off-axis angle, the second, amplitude and phase response versus frequency. The two are not identical; the first (on/off axis) graph shows a much flatter response than the second.

Consequently, I am skeptical of the manufacturer's published response curves. They don't even agree with themselves. If the driver response had been measured without a baffle, the response irregularities could indeed be due to diffraction loss, but I am just not familiar with their test methods. Personally, I am more concerned with the smoothness of a driver's response, and the D76 performs favorably over a wide bandwidth. My winged baffle arrangement is only intended to minimize cabinet-induced diffraction, not to overcome actual problems with the drivers themselves. I believe my baffle arrangement allows you to hear the drivers and not the cabinet.

I am not a proponent of the "aim the speakers at the listener" school. I have found that a loudspeaker system's imaging characteristics are best when the drivers are firing straight ahead. Coincidentally, the



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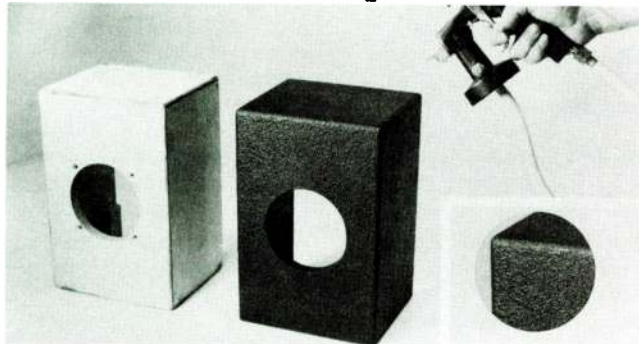
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4kHz response peak you mention would be less evident off-axis, an effect known to experienced listeners and shown in the Dynaudio literature. Furthermore, you can significantly improve the upper midrange response of most midrange drivers by using Zobel networks, although crossover network interactions cannot be ignored. Anyway, I am not aware of any such upper midrange anomalies, although I have made no attempt to "measure" the system. Perhaps an interested reader with an FFT analyzer might have some advice.

I do not care for the original horned Dynaudio D28. Although it was very efficient, I found its colorations unacceptable. An intelligently designed active crossover such as D'Appolito's can overcome virtually any driver response problems. I subscribe to a minimalist school of audio design and believe simpler is better, and I do not believe the system published can be simplified any more without compromising the sound. Of course, if you wish to complicate things...

I have made several changes to my system worth mentioning. First, I glued/nailed some 3/4" quarter-round molding along the top of the MTM baffle to further reduce cabinet diffraction, resulting in a much better sense of space in the reproduced image. Second, I used a 2 1/4" hole cutter and drilled a hole in the back

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of the plastic cup enclosing the D76 magnet assembly and removed about 50% of the fiberglass damping material. This change eliminated a slightly muffled coloration and opened up the sound on dynamic passages, albeit at the expense of a voided warranty.

Alas, my poor 21W54 woofers succumbed to a lightning strike that felled an 80' (27m) tall pine tree that (once) stood 50' (17m) from my house. Fortunately, the tree fell directly away from the house, but the woofers nonetheless suffered melted voice coils, taking their amplifiers with them to audio heaven. Curiously, the MTMs and their amplifiers were spared.

I replaced the 21W54s with a single Madisound 1054 per side. I made no change to the woofer enclosure, save for a new front, and removed the equalizer. The resulting QB3 alignment is sonically quite good, offering deep bass extension, good dynamics, and a clean mid-bass, and I am pleased with the results. However, the flimsier basket on the 1054s coupled more vibration from the woofer into the woofer enclosure, unacceptably coloring the sound from the arrays, which sat on top of the woofers. Consequently, I moved the MTM arrays onto stands, which cleaned up the sound and also allowed me to better align the array listening axis at ear level. The result is a more neutral and dynamic system, retaining the nuances of smaller-scale acoustic music.

Analog Devices has released the AD713, a quad version of the AD711. This part is a pin-for-pin replacement for the 4136 op amp used in the Old Colony active crossover/rumble filter, kit #SBK-C1A. Similarly, the AD711 is a plug-in replacement for the op amps specified in the Old Colony SBK-C1C kit. I recommend reviewing SB 3 and 4/82 for their discussions on active crossovers. The ideas presented are compatible with the requirements of my design.

The AD-713 will be reviewed in *Audio Amateur* and is available from Old Colony.—Ed.

HAVING A BALL

I built my speaker system from scratch and I must admit, I'm surprised at how solid the cabinets are. They measure 41.5" tall (on their casters), 24" wide and 20" deep, with a 2" extended front hood. I framed them with finished grade 2 x 2s, with metal angles at every joint, using over 300 screws and no glue. I finished them with real wood veneer on 3/4" board.

Each speaker contains 44 lbs. of drivers: a 15" University subwoofer, a 15" Pyle woofer, a Pyle midrange, a Radio Shack soft-cone midrange, two Pyle soft dome tweeters and a Radio Shack super tweeter—14 drivers in all. I go from subwoofer to super-tweeter in each cabinet. I use two crossover networks plus the super tweeter network in each cabinet—all by Radio Shack. The bass relief ports (four 2 1/2" holes in each cabinet) face the floor. The casters have 3/4" plywood backing the 3/4" board.

Bass will not rattle these speakers. I used nylon window screen and detailed molding wood for the grilles. They have metal angles in each corner, secured by kitchen

cabinet door magnets so they snap on and off. Necessity is the mother of invention and in this case she worked well.

I run dual leads to the primary and auxiliary outputs of my amp. I am running a four-speaker system in two cabinets. My Kenwood equalizer smooths things out. Yes, the bass is a bit heavy, but it's not boomy. All in all they make that cheap Fisher 100W amp sound better than it should. I have about \$700 in materials in each cabinet. The University speakers were \$250 each.

I bit the bullet and went ahead and ordered the vacuum tube logic (VTL)

preamp, amps and CD player. I may want to alter my setup, but at least I will have a good basic power source.

I've always liked tubes and built the Heathkit 55A amplifier, back in 1963. It wound up as part of a custom installation in a new home and included remote speakers with faders. I had a lot of fun.

I believe that's the whole idea—to have fun with music. I'm not a musician, but if I could build good cabinets, or do custom installations, I'd have a ball.

Gerald L. Norway
Seattle, WA 98115

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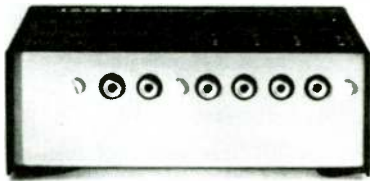
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Fast Reply #KD298

SELF-EDUCATION

I enjoy your magazine very much. I find it not only interesting, but also educational, even though I have an MS in Mechanical Engineering. Presently, I'm going through back issues and assembling the articles in correct order to learn from the fundamentals on up. I've noticed most of your authors have Electrical Engineering backgrounds and convert electrical theory to mechanical variables. This leads me to my only suggestion. In addition to the book reviews, I would like to see reviews of self-educational electrical engineering courses. I've had trouble researching this area and have come up with only one: Heathkit's series. If you could help everyone here, your readers would elevate themselves to a higher plateau of understanding.

Mark A. Beach
Cincinnati, OH 45242

Gary Galo replies:

The Heathkit series is, undoubtedly, the most comprehensive educational series available, and their use of trainer boards gives hands-on experience with concepts sometimes elusive on paper.

I can recommend several other books which may provide what you're looking for. I have one important bias regarding electrical theory—I don't like books which teach conventional current flow (positive to negative). Such theories may be useful to physicists, but they offer confusion more than anything else if you desire a proper understanding of electronics. I prefer texts which deal with electron current flow (negative to positive). An excellent introduction to electronics is R. H. Warring's *Understanding Electronics*, Tab Books #3044, a book I have used as a text in my Audio Fundamentals class for several years. Warring starts at the very beginning with Ohm's law concepts and takes the reader through tube and transistor theory, offering many examples of working circuits.

For those desiring a more comprehensive and detailed course, I recommend the series published by the Texas Instruments Learning Center. Two volumes cover DC circuits: *Basic Electricity and Circuit Concepts* and *Circuit Analysis Methods*. Two more, bearing the same titles, cover AC circuits. These four volumes used to be sold by Radio Shack. Why they stopped selling them is beyond me, but they should still be available from the TI Learning Center, PO Box 225012, MS-54, Dallas, TX 75265. Radio Shack still carries other books in the TI series, including *Understanding Solid State Electronics*, #62-2035, and *Understanding Digital Electronics*, #62-2010. The *Understanding* series, when combined with the four volumes on AC and DC, makes an excellent electronics course.

Another book which crossed my desk recently is Norman Crowhurst's *Basic Electronics Course*, 2nd Edition, Tab Books #2613. Crowhurst has an excellent ability to explain concepts to the newcomer, but his book is grounded in the conventional current flow approach, which I believe should be abandoned in all electronics textbooks. Aside from this limitation, Crowhurst's book may be useful.

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| 12 µfd: | 26 D, | 47 L | 120 µfd: | 54 D, | 83 L |
| 15 µfd: | 28 D, | 47 L | 150 µfd: | 60 D, | 83 L |
| 25 µfd: | 32 D, | 53 L | 180 µfd: | 58 D, | 108 L |
| 35 µfd: | 35 D, | 65 L | 200 µfd: | 60 D, | 108 L |

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Fast Reply #KD114

CLEANING SOLUTION?

I recently inherited 30 old (25 years) records I would like to clean up. They are Flamenco Music, which is virtually unobtainable these days.

Please tell me the best way to clean them (without spending a fortune), since I plan to make tapes from them.

I am familiar with "Disc Washer" and am not impressed with it. As an aerospace engineer, I know if I could locate someone with a large ultrasonic cleaner tank, it would probably dislodge any embedded grit. Unfortunately I don't know of any units today where someone would be willing to immerse records.

I will appreciate any help.

E. M. Bortmes
Tulsa, OK 74135

See Reg Williamson's article on cleaning disks (*Audio Amateur*, 2 & 4/81). Supplies for his method are available from Old Colony.—Ed.

17W75/D28 SATELLITE

I read your article on the Dynaudio D'Appolito design ("Dynaudio Drivers and Sheetrock" by Allan Millikan, *SB* 3/89) with some interest since I, too, have been using the 17W75/D28 combination as a satellite speaker. However, I seem to have had less success than Mr. Millikan, primarily because of the crossover network. I've tried both first- and third-order designs but neither has worked well; both have a very hard mid-treble sound when pushed. (I don't think this is due to the cabinet resonances since I packed pillows around the speakers and obtained the same results.)

Would you be kind enough to share the schematic of your crossover? After a year of experimentation, my gratitude is assured.

Sanford Kern
Fort Collins, CO 80524

Allan G. Millikan replies:

My three-way satellite speaker system is ultimately intended for triamping with active crossovers. The original prototype (*SB* 3/89) used Dynaudio 17W75s with the D28 and a passive crossover derived from D'Appolito's (*SB* 4/84) work for the 2kHz crossover. The bass crossover was at 90Hz with 6dB/octave. The second version now uses a Marchand 24dB/octave crossover at 125Hz from a pair of Madisound 12-inch drivers in a ported 4-cubic-foot box to the Dynaudio 17W75s/flat flange D28AF satellite. I achieved time alignment of the D28AF by recessing them $\frac{3}{8}$ -inch behind the mounting plane of the 17W75s and utilizing a $\frac{1}{2}$ -inch foam liner on the inside of the periphery

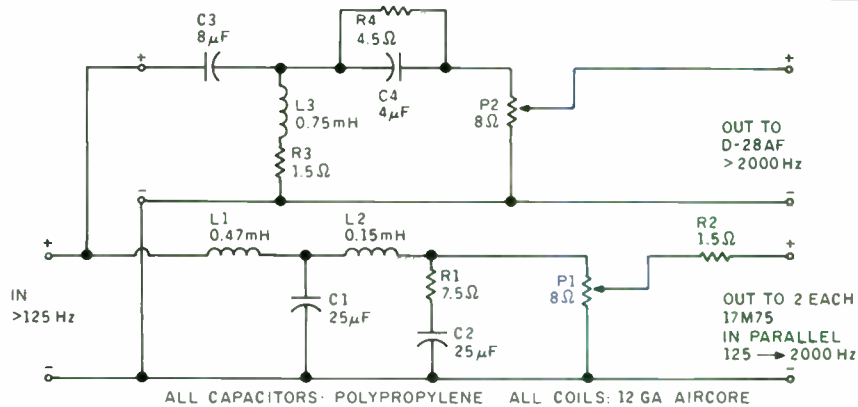


FIGURE 1: 2kHz crossover.



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Dr. Hugh Christian or Kevin E. Davis

Fast Reply #KD333

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The Audio Critic, Inc.,
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The Audio Critic

of the cylindrical cavity. I simply used my old 2kHz crossover (Fig. 1) with the addition of R2 to match the midrange to the reduced output from the tweeter. Lethargy and satisfactory sound caused me to leave the R4/C4 network in place. My present setup leaves both P1 and P2 adjusted to give maximum output.

When I changed the woofer/satellite 6dB/octave passive crossover to 24dB/octave active at 123Hz, I heard a notable improvement in the transparency and pleasantness of the midrange. I look forward to using a 24dB/octave crossover for the 17M75/D28AFs.

I believe the steepness and in-phase output make the integration of the drivers easier. (I have adjusted the bass crossover in the frequency range from 90Hz to 200Hz in 5% steps with remarkably subtle changes in sound.)

I hold no special claim for my passive configuration except to say that a number of knowledgeable listeners like the result.

Dynaudio recently published an elaborate design (SB 2/89, pp. 40a-40d) for a 2kHz crossover between the 17M75/D28AF pair in an advertisement for a speaker design called Twynn. Perhaps it will meet your needs.

THE BIG BOX

Unfortunately, a room is just a big box. We can go on tolerating it as I did for years, or we can give it the same loving care we give our speaker boxes, applying all sorts of ingenious tricks to prevent "box talk." After all, the big box may be considered an extension or even an integral part of the speaker system. In any event I finally got around to doing something about it.

We cannot completely neutralize the room but we certainly can attack the basic problem—reflections. Covering the walls with Acoustifoam, Somex or other absorbent material is a step in the right direction. An innovative Chicago area audio firm has an installation with Acoustifoam wall covering which was turned into a work of art with soft loose weave fabrics, so appearance need not be a deterrent. Personally, I like the looks of the raw stuff—once the music starts I don't see anything anyway.

I tried the barrier panel type control system as shown on page 61 of SB 3/89 mainly because it lends itself to rapid experimental adjustments. Also, it seemed a good idea to tackle the errant sound at the transmitter and receiver directly; that which got through would have to penetrate the barrier on the return trip. Of course, additional panelling at the reflective surfaces themselves adds materially to overall effectiveness.

Incidentally, you can make the panels even more effective by filling the 2" void between layers with a loose pack of Dacron, fiberglass or other similar material. A combination of wall covering and panels is another possibility. I have yet to reach a point of overkill as long as placement doesn't interfere with desired direct sound. Symmetrical placement is a must,

however, since even misdirected residual reflections can adversely affect imaging.

And how does a low Q listening environment sound? It doesn't, it merely lets all that glorious sound you designed into your listening machine arrive at the ears intact and unsullied.

Here is one who will never again criticize the two-channel format nor the many recording engineers who are getting the most out of it.

Donald F. Scott
Houston, TX 77087

GRATITUDE

I'd like to thank the mass of people who took the time to answer my letter (SB 2/89 pg. 68). I had thoughts of the Post Office delivering boxes and boxes of mail, and threatening to cancel my PO Box if it didn't stop. But alas, it was not to be. The replies went like this. One gentleman likes the Jordan modules. Another one likes the Eton 4-203s. And finally (I thought it would never come), the last gentleman likes 1. the Audax TX1125JNS and 2. Radio Shack's 1022. Well, there you have it. Everything you ever wanted to know about picking a good midrange but were afraid to ask. Hmm, I've just been told I'm laying it on a bit thick. Me? Not me, I don't have a sarcastic bone in my body. Anyway, to the people who did answer, between work, schools, new bottoms, home, and so on, I'll try to answer your letters, but I can't guarantee when.

John Yanek
Vernon, CT 06066

P.S. Now all we have to do is work on getting SB up to publishing monthly.

PASSIVE RADIATORS

Randall Bradley's article, "Practical Considerations for Passive Radiator Systems" (SB 4/89) was very interesting. I have built several systems over the years and found them to be a good compromise between bass reflex types that are boomy with high efficiency versus acoustic suspension which are solid but inefficient. More immediately, I have blown the 10" woofers in my passive radiator (PR) systems and need assistance in selecting the best replacements.

Are there equations/methodology or general guidelines for designing PR systems which you might provide? Which types of woofers serve best? What resonant frequency and stiffness? I have only used the "guess, cut and try" approach to date but have managed to create some pretty

listenable systems. I will also need an explanation of the variables, as it has been quite a while since I have dabbled in speakers.

Paul Davis
Atlanta, GA 30327

Randall Bradley replies:

Your questions about PR systems address several important areas. For me, designing with passive radiators is not strictly a "formula" based exercise. I'll try to explain some practical methods which I have found to be successful.

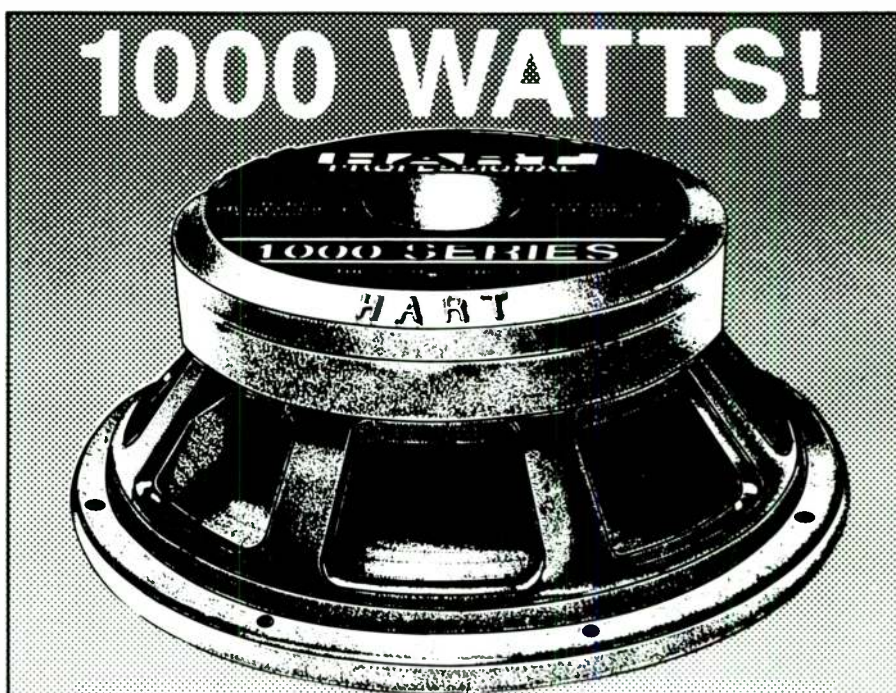
When writing for advice, give as much specific detail and background as you can. This detailed information is essential, as it provides a good basis for

a directed and complete reply. Questions about speaker design are so wide-ranging and convoluted that they often cannot be addressed adequately in just a few paragraphs. As a result, if your question is not based upon a specific case, only a generalized reply may be possible. Such a response may not be of any value to you.

For example, it would help to know what sort of systems you have built. The specifications of your drivers, specs that you measured, the box volume, the size and construction of the passive radiator, your amplifier's power, your room size. Any information of this type is very helpful when trying to "zero in" on an answer to your question.

Not having this information about your design and construction problems, I'll try to give you some insight into how I solved mine.

Only a few sources exist on passive radiator scien-



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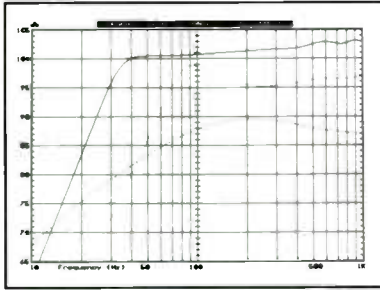
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Fast Reply #KD331

tific design data. Olson, referenced by Berenek in his book *Acoustics* (McGraw Hill), mentions the use of a "drone cone" as an alternative to the acoustical phase inverter, or port. More recently, the *AES Journal* (Vol. 22, pp. 592-601, 1974) has published extensive work by Thiele and Small on closed, vented and passive radiator systems.

The work in the *AES Journal* is valuable, but requires a strong working knowledge of college level mathematics. These papers form a good basis for designing and understanding the behavior of practical speaker systems. I struggle with these AES papers.

Like so many other scientific studies, this detailed work takes into account only certain aspects of possible design variables. Specifically, Thiele and Small consider only cases where the displacement of the passive is equal to the displacement of the driver, i.e., the same diameter and suspension. Unfortunately, this limits the paper to alignments where the excursion (X max) of the passive is equal to or less than the excursion of the driver.

This design limitation creates a problem. Most of the really good, effective and practical alignments require the passive to have an excursion *substantially greater* than the driver itself. As a result, the AES work becomes less useful than one might hope.

The easiest practical way to solve the excursion issue is to use a passive radiator with a diameter larger than the driver. I typically use one "two sizes up"; if the driver is a 10" (nominal) then I use a 15" (nominal) passive. Of course, what we commonly call a 10" driver is actually 10" mounting, the radiating surface is more like 8".

I always select woofers with a Q_T less than .3, and with the lowest possible resonant frequency (f_s). With regard to f_s , there is no right f_s , no absolute value to select. It all depends on the type of system you are designing, the application, and the power you will run through it. For example, a low f_s of 24Hz would be nice for a subwoofer or really low bass in a three-way design. But, most woofers with an f_s of 24Hz will not reproduce well much above 1kHz. Take this into account in selecting the rest of the system's components and parameters.

I suggest target alignments of a driver f_s of 25 to

Thin Bin

Mother Hubbard's cupboard was no doubt in worse condition than our file folders for SB's "TT&T" and "Craftsman's Corner" features, but we're about to get the "impending famine" warning light on our computer. Your handy tips, shortcuts and unique insights are all welcome, and SB pays \$7.50 minimum for them. (It's a great way to pay for your subscription.) Photos of your handiwork and an account of how and why you built your beautiful gear are also welcome. Payment for illustrated tips is \$15 and up, depending on length of copy and quality and number of photos.

35Hz, $Q_T < .3$, $V_{AS} < 400$ liters, these are only my preferences and are by no means the only choices. The passive should be mass loaded to resonate at a point equal to or below f_s (for a C4 alignment) by as much as $\frac{1}{2}$ octave.

In selecting a woofer, I generally use the manufacturer's specs as a point of departure, and to eliminate unlikely candidates. I use Bullock's methods (as published in *SB*, beginning in 4/80) to test the drivers myself. I am more interested in looking at the large than the small signal performance. Most published specs are small signal results.

The system, the driver, the passive and the box must all be tuned properly, though "properly" is difficult to define. I suggest you begin by fixing one parameter, like the box volume or the driver selection. The simplest point to start at is where alpha (V_{AS}/V_B) equals 1. Finding "good" system response usually requires a balancing act between the parameters of the driver and cabinet.

Robert Bullock's articles beginning in *SB* 4/80 provide a full explanation of this idea. The vented box alignments presented in these articles are similar to the results achieved with a passive radiator. There are differences which you must take into account, so the alignment charts do not have a 1:1 correspondence to the passive radiator case.

I usually build a box with alpha equal to 1 then reduce its volume, by adding bricks, until I am happy with the balance between the sound of the system, the excursion of the passive and the damping of the driver. If you try this, the balance will become self evident quickly. I find things begin to sound best where alpha is just below 2.

Almost all practical PR boxes I have built are actually C4 type alignments (*SB* 4/80, p. 8, *Figs. 2-6*). The ripple of this alignment is critical and you must be careful not to introduce too much ripple. You arrive at this alignment by reducing the box volume and lowering the f_p below f_s just enough so as not to introduce too much ripple in the response. Listening with a sine wave generator and amplifier driving your system at very low volume is a good way to hear ripple (drop out, or "holes" or peaks in the response). I find you can hear variations of 3dB or better with your ears, at low loudness levels. If you can take your box outside, you can eliminate room resonances from coloring your tests.

Whether room resonances can result in more serious variations in response than does system response ripple is arguable.

No matter where you place the f_p point, you should still be able to find f_s , as well as f_p , with a check of the impedance curve. Use this test to accurately determine these frequencies.

A Butterworth, B3 type alignment is possible, but it requires a larger box size (alpha ≈ 1) and $h \approx 1$, that is: f_p to be very close to or at the driver's f_s (f_s , but measured in the box, not free air). This is a difficult alignment to live with, as the box can get rather large and the sound can get a bit "fat" unless the driver is carefully selected for very low V_{AS} , low Q_T and excellent Q_B . F_C (the systems' low-frequency rolloff point) is also somewhat higher than with a C4.

I suggest you aim for a C4 like the one in *Fig. 8*, page 20, *SB* 3/81. This will give the ultimate in bass extension for a given driver, and with careful alignment, practically no audible ripple. For this alignment to work Q_L (cabinet losses) must be kept very high, with few or no leaks of any sort.

I hope these thoughts will give you a start at design-

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Bob Bullock's "BOXRESPONSE" program will be expanded to include models for the passive radiator format by mid-1990. Watch Old Colony's ads for announcements of the new version.—Ed.

MINIMUS CHANGES

Since the publication of my article, "Modifying Radio Shack's Minimus-7" (SB 1/88), it has come to my attention that Radio

Shack has made some changes in the woofer and tweeter. Some quick measurements show the following differences.

| | | |
|---------------|--------------|--------------|
| The woofer: | (old) | (new) |
| F_0 | 57Hz | 68Hz |
| VC DCR | 6.5 Ω | 5.8 Ω |
| VC Inductance | 1.54mH | 342 μ H |

The new specifications reflect a change from a four-layer voice coil to a two-layer one.

| | | |
|---------------|--------------|--------------|
| The tweeter: | | |
| VC DCR | 7.2 Ω | 6.9 Ω |
| VC Inductance | 39 μ H | 39 μ H |

The change in the tweeter, which can be recognized cosmetically as a new molded plastic plate with concentric circular rings around the dome itself, is otherwise only nominal.

Because of the drastic change in woofer voice coil impedance, I do not recommend my original modification. The results of using this mod on one of the newer systems will be a noticeable droop in the midrange around the crossover point.

To see which system you have, look for the rings on the tweeter mounting plate (easily seen through the perforated metal grille), or check the system DC resistance. You can do this with an ohmmeter connected to the speaker terminals on the cabinet back. If it measures about 6.5 Ω , you have an older system, if closer to 5.8 Ω , the system is one of the newer ones.

William R. Hoffman
Reno, NV 89502

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Air Core: This program was written as a quick way of evaluating the resistance effects of different gauge wire on a given value inductor. The basis for the program is an article in *Speaker Builder* (1/83, pp. 13-14) by Max Knittel. The program asks for the inductor value in millihenries (mH) and the gauge wire to be used. (NOTE: only gauges 16-38.)

Series Notch: Developed to study the effects of notch filters in the schematics of some manufacturers. Enter the components of the network in whole numbers (i.e., 10 for 10 μ F and 1.5 for 1.5mH) and indicate whether you want one or two octaves on either side of resonance. Output is frequency, phase angle and dB loss.

Stabilizer 1: Calculates the resistor-capacitor values needed to compensate for a known voice coil inductance and driver DC resistance.

Optimum Box: A quick program based on Thiele/Small to predict the proper vented box size, tuning and -3dB down point. It is based only on small signal parameters, therefore, it is only an estimate of the response at low power (i.e., limited excursion).

Response Function: Calculates the small signal response curve of a given box/driver combination after inputting the free-air resonance of the driver (f_s), the overall "Q" of the driver (Q_{TS}), the equivalent volume of air equal to the suspension (V_{AS}), the box tuning frequency (f_B), and the box volume (V_B). Output is the frequency and relative output at that frequency.

L-Pad Program by Glenn Phillips: Appeared in *Speaker Builder* (2/83, pp. 20-22). It is useful for padding down a tweeter or midrange while still retaining the same load as the driver itself.

Vent Computation by Glenn Phillips: Calculates the needed vent length for 1, 2 or 4 ports of the same diameter. Input box volume in cubic feet and required tuning frequency (f_B), output is vent length and vent area for each case.

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SHORTLINE REPORT

I have been eagerly reading *Speaker Builder* since a friend gave me a subscription three years ago. With back issues in hand and my own subscription currently running, I have been looking for a way to integrate the formidable math equations into my spreadsheet. However, I am not a computer whiz and thus was pleased to see Marc Bacon's offer in 4/89 supplying a program listing for Lotus 1-2-3.

A few comments, if I may? First, thank you for sending the magazine in its new cello wrap. The copies arrive intact and readable, a situation not true for many of the periodicals I order from the US. I wish more publishers would follow your lead and protect their valuable output. You are to be commended. [Unfortunately new Postal Service regulations make the plastic bags too expensive to continue.—Ed.]

Second, has anyone written to bemoan the insensitivity of the Shortline? I am going through voice coils on the Audax tweeter at an alarming rate. Notwithstanding the inefficiency of the transmission line, my 80W/channel does not seem enough. My room is not large nor are my volume requirements excessive.

My system consists of the Sony TAE 88 preamp driving a Yamaha DSP1 with the Sony TAN 88 for the Shortlines, two modified Dynaco ST35s for the effects channels which are handled by the modified Dalines and a pair of LS3/5As. Source material includes Sony's D10 portable compact disc, Sony's TCK 555 tape deck, Yamaha's PS2 linear table mounted with a Shinon Red moving coil and an old analog Kenwood tuner.

All of this fits into a room 14 by 10 by 9 (W/D/H) and my wife and two children do not permit me to play at concert hall levels.

As you can see by the room dimensions near-field conditions prevail so I should not be burning voice coils. Any suggestions?

Last but not least, I have recently built a function generator as published by *Radio Electronics* (3/89). In the article the author suggests that if the generator is to be used for testing drivers it should be used in a low impedance mode. This means deleting two resistors in series with the sine output. The resistors would normally give the generator a 600Ω output. This generator will develop about 1.5V in this manner at the output. But R. D. Crawford says, also in *SB* 4/89, your generator for impedance measurement should have a 600Ω output impedance. Which is correct?

Brent Hughes
Edmonton, Alberta T6K 3Z2
Canada

John Cockroft replies:

I am sorry you are losing so many voice coils. I know of two instances (prior to yours) in which the Audax tweeter has blown in a Shortline. I caused one to blow when I took the Shortline to work to demonstrate it in a fairly large room using only a 35W amplifier. One of the listeners liked loud music, so we kept turning things up. We experienced considerable audible distortion for a while before the tweeter went, so I think it safe to assume the failure was due to clipping in the amplifier with its attendant surge of harmonics.

The reason for the other failing isn't as clear to me. A reader reported the failure while listening to synthesizer music from CDs with a 135W amplifier. He didn't think the music was loud, but then he said that it was so clear, it could have been louder than he thought.

Admittedly, the Shortline is a bit inefficient, but not as inefficient as you describe. (I'm referring to mine, not yours.) My room is about 1,440 cubic feet, very close to the size of yours. I don't like extremely loud music. I seldom play it louder than 80-86dB. Occasionally, I have seen 90dB peaks on my sound pressure meter and I'm sure I could go higher (I just don't want to). I designed and tested the Shortline using a Sony 35W/channel receiver. I replaced this with a Parasound 80W/channel Class A amplifier and, more recently, a 60W/channel Adcom GFA-535. I also used an old 150W/channel Tandberg, until it finally gave up. The Shortline performed well on all these subsequent amplifiers, revealing a different personality with each one.

I really don't know what to say about the extreme inefficiency you are experiencing with your Shortlines. Did you weigh the acoustic stuffing or did you guess at it? If the stuffing is too dense that might account for it. Perhaps it is packed too tightly just behind the woofer. I am not familiar with the specific equipment you use. 80W/channel should be quite reasonable for your small room.

Regarding the tweeter: Perhaps there is some instability in your amp at high frequencies. Perhaps your preamp is overdriving your amp. If you have a neighbor with suitable equipment, try the Shortlines there and see whether the situation still exists.

I have heard the Audax 1" tweeter is a bit wimpy and tends to blow easily. I don't use them anymore. I have a system similar to the Shortline (a bit shorter)



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Fast Reply #KD181

Speaker Builder / 6/89 75

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Fast Reply #KD230

in which I use the Peerless KO10DT 1" tweeter. I have never had any burnout troubles with this tweeter and it sounds good. I have used them for over ten years in various systems. I went to the Audax because Gary Galo spoke highly of them in one of his pieces.

The Peerless might scare you because it doesn't have a replaceable voice coil. However, their new catalog lists the SR10/8 which has one. The curve, resonant frequency, efficiency and R_E are close. I haven't tried this, but I plan to. Incidentally, I now use the tweeter with the polarity the same as the woofer instead of reversed as in the article.

I am really sorry you have gone to so much trouble to have obtained little fulfillment. Other readers have had better luck constructing the Shortline. One person has built five pairs (at last count). Friends and relatives seem to make off with them.

Edward A. Yapchian (he of the five pairs) states the results were satisfying: "The bass is well extended, insofar as the program is recorded. The highs are well defined and the imaging is precise. I, as well as friends who have heard them, am amazed at the performance of this TL. I would not hesitate to compare the Shortline with any other speaker in the \$500-600 range." He then mentions that the only drawback is their relative inefficiency. He is driving them with a 20W/channel receiver.

He wrote a second letter about a week later: "My next step was to hook them into my friend's 200W power amp and really hear what they sounded like. To our surprise they sounded better than his \$700/pair Bose 401 loudspeakers. We played the Shortlines very

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Old Colony Software

Loudspeaker Modeling Program by Ralph Gonzalez

Speaker Builder 1, 2, 3/87. LMP produces a full-range frequency response prediction for multi-way loudspeakers, including the effect of the crossover, driver rollofs, interdriver time delay, "diffraction loss," etc. This software is available at \$17.50 per copy in four versions. The price includes author support via mail from Ralph Gonzalez, PO Box 54, Newark, DE 19711.

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loud to see how they would stand up: answer, just fine.

"Over to another system—a 130W integrated amp. We tied the Shortlines into the system and for the first seven minutes or so, the sound was clean and the imaging excellent. People said things like, 'It doesn't sound like you're listening to a speaker.' Then the right side of the room collapsed." This was when the second Audax tweeter burned out.

Foster L. Spain, of Atlanta, Georgia, stated: "I am completely satisfied with the sound quality and am quite amazed that such clean bass can come from a pair of Radio Shack speakers. My music is mainly from Telarc discs and my favorites are those with heavy transients such as the Cincinnati Pops conducted by Kunzel. The Shortline did a most creditable job with even the heaviest and loudest passages."

Larry Davis of Bedford, Texas, said: "I have found your speaker design delightful—especially on solo piano and guitar recordings. John Bayless' *Bach on Abbey Road* sounds wonderful. My wife loves the sound too, and she was the first to say the piano sounded as if it were in the room. I have listened to all sorts of music, from Verdi's *Requiem* to Simon and Garfunkel's *Greatest Hits*—on CD. As you said, these speakers are painfully accurate—especially on the *Greatest Hits*. But all that was well recorded sounds really fine."

I don't mean for this letter to sound like a testimonial, I merely wanted to show that your problem isn't a pervasive one.

INCOMPETENTS GALORE

SB 3/89 contains the potential roots of gang warfare . . . Gary Galo, in reviewing White's *Audio Dictionary*, comments on audio salesmen: "I honestly believe audio salespersons are the largest group of incompetents in the country. Most would be better off selling shoes." Quite apart from the slur on shoe

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Revue du Son (France)
June/July, 1989



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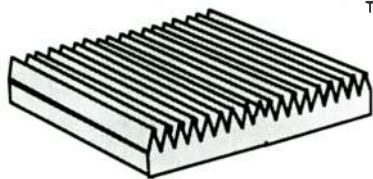
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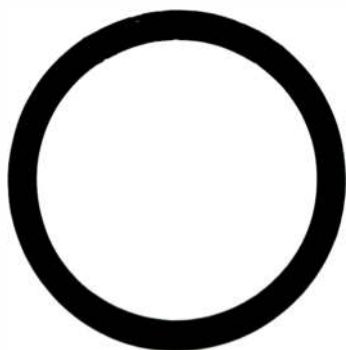


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salespersons (skilled footwear consultant operatives), he comes eyeball to eyeball with Dick Pierce ("Pox Humana") who is busy slugging off "expert" customers from the other side of the counter as "the crazies, the obnoxious and the professionally weird."

I must admit to being on Gary's side for many years when I did dozens of cartoons for *Hi-Fi News*, lampooning the doubtful hi-fi dealer trading under the name "Rookyu for Hi-Fi." Looking back, I find those years (1959-1965) alarmingly up-to-date.

The oldest real-life incident I remember was when I was buying a loudspeaker unit, which the salesman held up to his ear and said, "Just checking the mutual inductance, sir..." I replied, "If it's audible, I don't want it" and left. Recently, in a big hi-fi chain store they told me not to even consider Brand X amplifiers because "they're not fast enough for CDs." A mild protest about slew rates brought the classic salesman's sneer that hi-fi wasn't about theory, it was about listening.

I don't think we will ever solve this one. Many good hi-fi salespersons know their subject, and Dick Pierce appears to have been one. I only hope he doesn't leave his shop and become a reviewer. That will bring about an irreversible change of life.

Alan Watling
Colchester, CO4 3JD
England

Sorry. Dick left the shop years ago and did something far more dangerous. He became a designer.—Ed. 🐶



DIPOLE SUBWOOFER

continued from page 21

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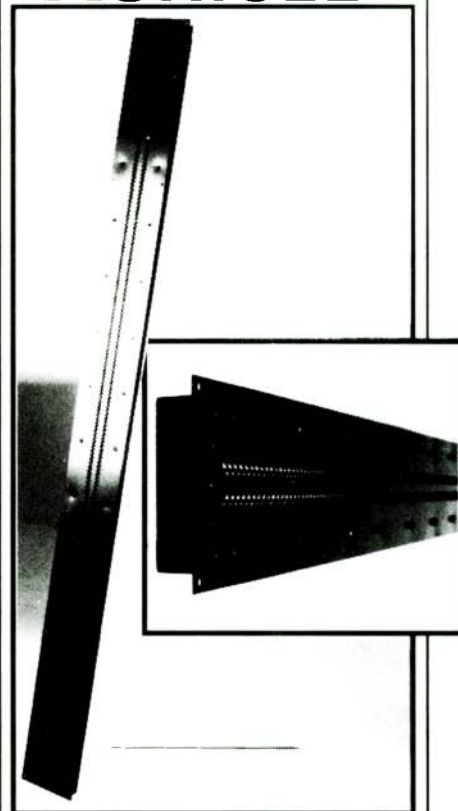
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Manufacturer's Comments

We certainly agree with Mr. Lin's arguments for the use of a subwoofer and, indeed, the

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Fast Reply #KD237

need for two whenever possible. Our research has confirmed that crossover frequencies above first octave of audible response do require two channels to fully realize stereo imaging, not just for tympani and organ, but for subharmonics of piano, guitar and so on.

We do, however, disagree with Mr. Lin on the matter of Thiele/Small parameters. Our drivers, like the 24", do in fact show up as an anomaly for some types of normal measurements.

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The audio measurements printed by The Audio Critic several years ago were not relevant at all. The 24" woofer was reviewed in a homemade box (of unknown quality) and was, indeed, half the cubic volume recommended by our factory.

The linear excursion of our current 24" model is slightly more than 3/4" peak-to-peak or 3/8" for each polarity, since the voice coil with magnetic suspension can move the magnetic field with it. The 24" woofer will actually reproduce high frequencies beyond most ears' range, due to the natural sound transmission quality of our polymer mixture used to manufacture our cones. However, these upper frequencies are sufficiently down in dB so as not to interfere with its usual range of 16-150Hz.

On phasing, older Hartleys used the 1950s electrical connector standard, black being positive. For a number of years now we have used the current conventional red-positive, black-negative.

In conclusion, we found Mr. Lin's article to be very interesting and timely, since a number of Hartley enthusiasts have been experimenting with dipole designs.

PARADIGM 7se MOD

continued from page 30

other than those purely required to get the best possible sound from his design. For many listeners, the stock Paradigm 7se is a very solid and honest performer, outstanding in its class. However, any loudspeaker can be improved upon, and you can realize significant performance gains in this case by applying a few sound principles and a little time and money to the existing design.

Continued on page 80

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Continued from page 79

ACKNOWLEDGMENTS

Thanks to R. G. (Bob) Palmer for his collaboration in this work.

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THE PITTS

Ken Kantor's two articles in *Audio* for November and December 1988 not only show readers how to use a computer to design a two-way speaker system, but provide a sealed box design and a crossover as well. Old Colony Sound is pleased to offer a kit of drivers for Ken Kantor's project: *THE PITTS*.

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Technology Watch

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Would like to correspond with anyone who has upgraded or is considering improving Klipsch Cornwall II speakers. Also, I'd appreciate any comments from people who have used "Acoustical Magic." Behzad Shahraray, 194 Sherwood Dr., Freehold, NJ 07728, (201) 431-0771.

Plans for Speakerlab's original SK, circa 1976-77, willing to pay for quality copying and postage. Also, new or used Klipschorn or Speakerlab SK midrange horns or equivalent. Peter Groth, 384 Trestle Lane, Clinton Corners, NY 12514.

Old Klipsch catalogs, components; *Audio Engineering* volumes 1-5; Diaphragm for International Projector LU-1000 high frequency driver; JBL 12-inch circular perforated plate horn/lens; early Polaroid polarizing film ads, literature; book, *The Throne of Merlin*, by R.C. Schaller; *High Fidelity* volumes 1-5. D.R. Schaller, 6704 Schroeder Rd., Suite 6, Madison, WI 53711.

Distortion analyzers, THD and IM. State make, model, condition and price. Kenneth P. Miller, Rt. 2, Box 134, Mexico, MO 65265, (314) 581-5413.

Dynaco power amplifier and other Dynaco equipment; Phoenix System's Audio Test Set TS-1. Please state condition. Lubos R. Palounek, 4804 Poland Place, Raleigh, NC 27609-5630, (919) 782-1839.

Altec 515, 416, 411 woofers; Altec high frequency horn tweeters; 811 horn; 1500/1600Hz crossovers; large furniture finish equipment cabinet(s) for heavy rack mounted equipment. David Rubenstein, 4 Ingersoll Rd., Mt. Tremper, NY 12457, (914) 688-5024.

CLUBS

CONNECTICUT AUDIO SOCIETY is an active and growing club with activities covering many facets of audio—including construction, subjective testing, and tours of local manufacturers. New members are always welcome. For a copy of our current newsletter and an invitation to our next meeting, write to Richard Thompson, 129 Newgate Rd., E. Granby, CT 06026, (203) 653-7873.

ESL DIY'ERS: A new electrostatic loudspeaker do-it-yourself group is now forming. Our purpose is to share valuable theory, how-to, and parts source information for building our own state-of-the-art electrostatic loudspeakers. For further information, please write (SASE please) to: Neil Shattles, 829 Glasgow Dr., Lilburn, GA 30247.

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

AUDIOPHILES IN THE DAYTON/SPRINGFIELD, OHIO AREA: We are forming an audio club. Please contact me if you're interested in construction, modifications, testing, recording or just plain listening to music. Ken Beers, 462 Bloose St., Tremont City, OH 45372, (513) 969-8402.

THE HI-FI CLUB of Cape Town, South Africa, sends a monthly newsletter to its members and worldwide subscribers. To receive an evaluation copy of our current newsletter, write to: PO Box 18262, Wynberg 7824, South Africa. We'll be very pleased to hear from you.

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

ORGAN MUSIC ENTHUSIASTS: If live recordings of fine Theatre Organ Music are your thing, SFORZAN-DO has room for a few new members. We lend you the music on cassettes. All operation is via the mail. SFORZAN-DO, c/o E.A. Rawlings, 5411 Bocage St., Montreal, Canada H4J 1A2.

PACIFIC NORTHWEST AUDIO SOCIETY (PAS) consists of 60 audio enthusiasts meeting monthly, second Wednesdays, 7:30 to 9:30 p.m. at 4545 Island Crest Way, Mercer Island, Washington. Be our guest, write Box 435, Mercer Island, WA 98040 or call Bob McDonald, (206) 232-8130.

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

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invites you to our informal monthly meeting. Join our friendly group as we discuss life, the universe and everything. The meetings usually feature a "show and tell" of members' projects and free-wheeling open dialogs on the subjects of your choice. No matter what your level of interest, experience, or preferences are, you are welcome to join in, or sit back and observe. Meetings are generally held on the second Wednesday of the month, in the evenings. We have been meeting at Rensselaer Polytechnic Institute in Troy, NY, together with the RPI Audio Club. Contact CAAS at 756-9894 (leave message) or RPI Audio Club at 276-5810, or write CAAS, PO Box 144, Hannacroix, NY 12087. See you there!

THE COLORADO AUDIO SOCIETY is a group of audio enthusiasts dedicated to the pursuit of music and audiophile arts in the Rocky Mountain region. We offer a comprehensive annual journal, five bimonthly newsletters, plus participation in meetings and lectures. For more information, send SASE to: CAS, 4506 Osceola St., Denver, CO 80212, or call Art Tedeschi, (303) 477-5223.



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THE WESTERN NEW YORK Audio Society (WNY Audio Society) is an active and growing audio club located in the Buffalo area. We issue a quarterly newsletter and hold meetings the first Tuesday of every month. Our meetings have attracted many local and distant manufacturers of audio related equipment. We are involved in all facets of audio—from building to purchasing at discount prices. For a copy of our current newsletter and information regarding our society, please write to M.A. Monaco, WNY Audio Society, PO Box 312, N. Tonawanda, NY 14120.

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THE INLAND EMPIRE AUDIO SOCIETY (Soon to become the Southern California Audio Society—SCAS) is now inviting audiophiles from all areas of Southern California and abroad to join our serious pursuit for that elusive sonic truth through our meetings and the IEAS' official speaker, *The Reference* newsletter. For information write or call: Frank Manrique, President, 1219 Fulbright Ave., Redlands, CA 92373, (714) 793-9209.

MEMPHIS AREA AUDIO SOCIETY being formed. Serious audiophiles contact J.J. McBride, 8182 Wind Valley Cove, Memphis, TN 38125, (901) 756-6831.



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If there's no club in your area, why not start one? Our club ads are free up to 75 words (\$.20 per word thereafter). Copy must be provided by a designated officer of the club or society who will keep it current.

SOUTHEASTERN MICHIGAN WOOFER AND TWEETER MARCHING SOCIETY (SMWTMS)

Detroit area audio construction club. Meetings every two months featuring serious lectures, design analyses, digital audio, AB listening tests, equipment clinics, recording studio visits, and audio fun. The club journal is *LC, The SMWTMS Network*. Corresponding member's subscription available. Call (313) 477-6502 (days) or write David Carlstrom, SMWTMS, PO Box 721464, Berkley, MI 48072-0464.

THOSE INTERESTED IN AUDIO and speaker building in the Knoxville-East Tennessee area please contact Bob Wright, 7344 Toxaway Dr., Knoxville, TN 37909-2452, (615) 691-1668 after 6 p.m.

TUBE AUDIO ENTHUSIASTS. Northern California club meets every other month. For next meeting announcement send a self-addressed, stamped #10 envelope to Tim Eding, PO Box 611662, San Jose, CA 95161.

WANT TO START OR JOIN CLUB IN CENTRAL ILLINOIS (Peoria, Bloomington, Champaign, Kankakee area)? Speaker building and audio in general. Trade info and parts. (815) 657-8488 evenings or weekends.

WASHINGTON AREA AUDIO SOCIETY (N. VA, MD and DC) is looking for sincere audiophiles who are eager to devote their time and get involved with the direction of the society and the publication of a monthly newsletter. Please contact: Horacio J. Vignale, 3730 Gunston Road, Alexandria, VA 22302.

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Pox Humana

When the Mercury Plummets

By Dick Pierce

Back in the days of my retail experience, we reviewed and sold some radically strange equipment. Most we simply rejected as too weird, unreliable, or impractical.

One moderately weird device was made by a tiny Irish company called Keith Monks Audio Limited. The product was the infamous KMAL Uni-pivot Tonearm. A uni-pivot tonearm has a single bearing upon which the arm sits, and around which it moves horizontally and vertically. Because of this single point of contact, kinematics dictates that the arm must be able to tip from side to side, as well. No matter, we simply make sure that the center of gravity (CG) is directly under the pivot at zero balance with the arm horizontal, and then apply tracking force by shifting the CG forward an appropriate amount. The stated advantage of a uni-pivot is significantly reduced friction, compared to arms with more bearings.

Keith Monks went several steps beyond, pursuing non-friction. They decided to eliminate tonearm wires, presuming the applied torque of the wires being twisted about was a nasty thing. What did they do?

Well, they simply replaced four wires with four mercury baths in a nylon cup underneath the pivot, each having a stainless-steel contact at the bottom connected to the tonearm leads. In the arm itself, there were four pins: two made of stainless steel, and the other two made of a somewhat conventional iron alloy. Because the particular stainless alloy was nonmagnetic, a magnet in the base of the tonearm could provide the needed (but nonadjustable) anti-skating force.

We had several doubts about the long-term reliability and safety (exposed mercury and all that) of the arm, but a long discussion with my physical chemist father (Ph.D.) revealed that a thin film of oil on the surface would reduce the corrosion and oxidation, as well as all but eliminate hazards from evaporated mercury (it turns out that the vapor pressure of mercury at room temperature is low enough anyway, but the extra margin was reassuring).

The tonearm performed quite well. Sure, it was difficult to set up, and yeah, it went out of adjustment a lot, and okay, it took a limited range of cartridges—but for the type of cartridge it was designed for (low-mass, high-compliance) there was nothing

else around that these things could be used in and track properly. Sonic results were very impressive. We had no doubt the arm and a good cartridge could track coarse sandpaper, if required.

Things went fine until one day Keith Monks tired of making tonearms. He sold the manufacturing rights to a company called Audio and Design. The new tonearms looked the same, save the change of the pin from steel to brass, and the mercury supplied looked simply awful, but a local trip to a chemical supply house yielded enough mercury for 1,000 tonearms for about \$30. (A&D would sell us a 10ml vial for \$12—what a deal.)

Everything was quiet until customers started bringing back their arms with one channel or another missing. They complained that the channel just disappeared while they were listening. Inspecting the arms revealed that the pins appeared to be broken off, but customers universally denied breaking the pins. We were mystified. We replaced the pins and sent the customers on their way, but they would return in a month or two, with the same

complaint. (Funny, it was always the same customers.)

After trying to figure out what was going on, I called my father. He listened to the problem and the design changes, and started laughing. "The jerks," he said, "Don't they know copper is soluble in mercury?"

Well, since brass is an alloy of copper and zinc, the copper simply dissolved in the mercury, leaving behind a flimsy matrix of zinc, which fell apart.

Things got worse. It turns out that A&D had also replaced the steel contacts in the bottoms of the mercury cups with brass. People were now complaining that not only were they out one or both channels, but also mercury was running all over their living rooms. One person's power amplifier even blew up after the mercury started dripping on it from the turntable on the shelf above. People were upset that their kids often found the stray beads of metal before they did. Of course, the specter of health hazards loomed again.

I called the A&D importer (Gary Warzin of Audiophile Imports, yes, the Linn importer), and he denied all knowledge of it. He even stated that he checked the story about the solubility of copper in mercury and declared it to be absolute hogwash. How could anything be soluble in a metal? (He neglected that many alloys are nothing more than a solution of one metal in another. The fact the service bulletins for the KMAL and the A&D arm both stated all connections must be made with silver solder, because the mercury would dissolve the lead in conventional solder, belied his stand.) As for the health hazard—he said swordfish do just fine with high levels of mercury.

Unfortunately for him, and fortunately for the rest of the universe, the physical laws are not subject to the whims of individuals. We began machining our own steel pins to replace the brass ones as they wore out (vanished?). The effort became so cumbersome we finally discontinued selling the arm altogether.

A story later circulated that the chief of A&D, to prove how safe mercury really was, swallowed a small test tube of pure mercury at the Chicago CES, then looked around at the incredulous crowd and said, "See?"


Lewis Carroll and the Mad Hatter would have loved it.



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

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

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

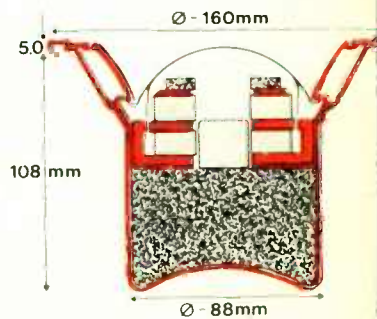
Specification

MDM 85 (with enclosure)

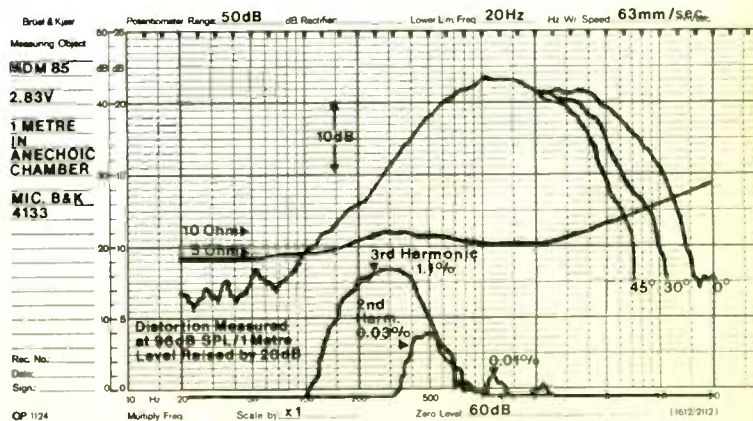
| | |
|--|---------------------------|
| Overall Dimensions | Ø - 160mm x 113mm |
| Nominal Power Handling Din | 300W |
| Transient Power 10ms | 1500W |
| Voice Coil Diameter | 75mm (3") |
| | Hexatech Aluminium |
| Voice Coil Former | Aluminium |
| Frequency Response | 300-5000 Hz |
| Resonant Frequency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

Variations to specification for MDM 85NE (without enclosure)

| | |
|--------------------|------------------|
| Overall Dimensions | Ø - 160mm x 60mm |
| Frequency Response | 250-5000 Hz |
| Resonant Frequency | 170 Hz |
| Rmec | 39.3 |
| Qms | 0.1 |
| Qes | 1.8 |
| Q/T | 0.1 |
| Vas | 0.7 litre |
| Nett Weight | 1.05 kg |



Specifications given are as after 24 hours of running.



Morel operate a policy of continuous product design improvement, consequently, specifications are subject to alteration without prior notice.

Fast Reply #KD1