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THE LOUDSPEAKER JOURNAL

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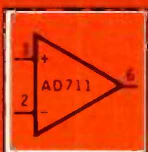

BUILD AN ARRAY

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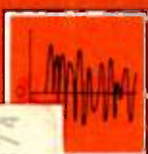

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Designed and manufactured in France to the highest quality European standards. Versa-Tronics had them designed to incorporate the latest state-of-the-art technology in woven Kevlar® and Carbon Graphite cone materials. The true form shaped cones are a decided improvement over the sandwich types which do not allow for any other cone shape other than a straight side. The possibility of curvilinear cones does not exist with sandwich honey-combed types.

The Carbon Graphite cloth is treated on the rear with a hard resin and the front of the cone is impregnated with a butyl-latex. This provides excellent internal damping along with the desired rigidity-mass ratio. The woven Kevlar® has a rear treatment of a hard lacquer type resin along with the face treatment of a specially formulated latex. Both the Kevlar® and Carbon Graphite diaphragms provide open sound without coloration. This plus many duo-voice coils, die-cast baskets and brass-capped pole pieces are offered in these new Versa-Tronics products.

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Sensitivity 1W/1M	90dB
Resonance Freq.	60Hz
Upper Freq.	8kHz
Voice Coil	1″ Nomex
Cone Material	Kevlar®
Surround	Rubber
Magnet Wt.	550 gm
Vas	8.86 L
Qts	0.316
Qes	0.365
Qms	2.4

F017R-KV 6½-Inch with Bullet

Impedance	8Ω
Music Power DIN	100W
Sensitivity 1W/1M	90dB
Resonance Freq.	45Hz
Upper Freq.	8kHz
Voice Coil	1″ Nomex
Cone Material	Kevlar®
Surround	Rubber
Magnet Wt.	550 gm
Vas	53 L
Qts	0.33
Qes	0.37
Qms	2.77

GQ20R-KVC 8-Inch Die Cast Basket

Impedance	8Ω
Music Power DIN	140W
Sensitivity 1W/1M	93dB
Resonance Freq.	45Hz
Upper Freq.	7kHz
Voice Coil	1½″ Kapton
Cone Material	Kevlar®
Surround	Rubber
Magnet Wt.	780 gm
Vas	45 L
Qts	0.39
Qes	0.60
Qms	1.05

F017R-CG DB 6½-Inch Duo-Voice Coil

Impedance	8Ω
Music Power DIN	100W
Sensitivity 1W/1M	89dB
Resonance Freq.	50Hz
Upper Freq.	5kHz
Voice Coil	1″ Nomex
Cone Material	Carbon
Surround	Rubber
Magnet Wt.	550 gm x 2
Vas	20.57 L
Qts	0.627
Qes	0.766
Qms	3.46

F020R-CG 8-Inch

Impedance	8Ω
Music Power DIN	100W
Sensitivity 1W/1M	90dB
Resonance Freq.	35Hz
Upper Freq.	8kHz
Voice Coil	1″ Aluminum
Cone Material	Carbon
Surround	Rubber
Magnet Wt.	550 gm
Vas	75 L
Qts	0.35
Qes	0.41
Qms	2.52

GQ25F-CGC 10-Inch Die-Cast Basket

Impedance	8Ω
Music Power DIN	120W
Sensitivity 1W/1M	90dB
Resonance Freq.	28Hz
Upper Freq.	5kHz
Voice Coil	1½″ Aluminum
Cone Material	Carbon
Surround	Foam
Magnet Wt.	780 gm
Vas	181 L
Qts	0.512
Qes	0.63
Qms	2.76

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Fast Reply #FC683

Good News

ALTEC LANSING has developed a unique stereo design, the new model 550 Amplified Loudspeaker System, which will be on the market in Spring 1988.

Each loudspeaker delivers a total of 700W from five amplifiers. The two subwoofers and each woofer, mid-bass, midrange and tweeter has a separate amplifier. A remote control allows the levels of the system's 10 amps to be adjusted for individual preference and the acoustics of the listening room. A center cabinet containing the drivers from upper bass to tweeter range, swivels 15° from side-to-side to improve imaging and dispersion, without moving the master cabinet. Cabinet vibrations are controlled by Altec's double cabinet construction. Cabinet size is 72 by 19 by 24 inches and weighs 437 pounds.

The drivers consist of two 10-inch carbon fiber subwoofers, one carbon fiber 8-inch bass, and a 6½-inch mid-bass, and a diamond-coated Polyimide 2-inch midrange and 1-inch tweeter. Active electronic crossovers are used for optimum performance. Discrete transistor outputs are said to minimize distortion. Frequency response is 20Hz–20kHz.

Also available this Spring is Altec's amplified subwoofer that produces 250W and offers adjustable crossover points, dynamic equalizer and volume control. The PSW-10 also features overdrive protection, subsonic filter, auto on/off and reverse phase switch.

The subwoofer has variable crossover points of 50, 80, 100, and 150Hz, with a choice of 18dB or 24dB per octave slope. A volume control balances the subwoofer to the rest of the speaker system's efficiency rating. Frequency response is 26–180Hz, ±3dB. The cabinet is a cube design of 17½ inches. Suggested retail price is $800.

Suggested retail price for the model 550 Loudspeaker is $12,000 per pair. For additional information contact Altec Lansing

Consumer Products, Milford, PA 18337, 1-800-ALTEC 88.

Fast Reply #FC328

PRECISION LOUDSPEAKERS is offering two new woofer-midrange drivers. Both the TO165R 6.5″ and the TX205R 8″ have Precision's proprietary mineral filled co-polymer polypropylene cones and butydene-styrene surround. The smaller unit, with a high-temp, aluminum-former voice coil with a 9-oz. motor, is optimized for bookshelf closed box systems. The larger driver, with a 20-oz. motor, is suited for both bass reflex and closed box systems. Precision Loudspeakers Inc., 2-B Columbia Dr., Amherst NH 03031, (603) 883-7050.

Fast Reply #FC46

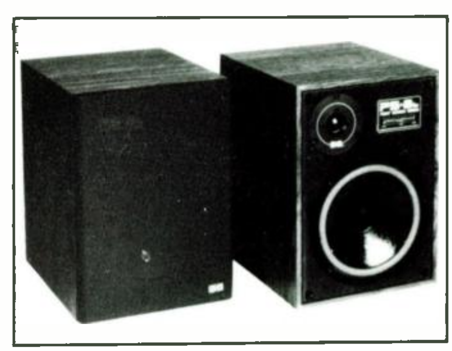
DESIGN ACOUSTICS has introduced a two-way bookshelf loudspeaker system, that utilizes a newly designed woofer to achieve a more accurate and richer sound. The new model PS-8b is also less expensive than the PS-8a which it replaces.

The system employs an 8-inch long-throw woofer and 1-inch soft dome tweeter with a crossover at 2000Hz. The newly designed woofer uses a polyvinyl acetate coated paper cone which maintains low mass and high rigidity.

Like other loudspeakers in Design Acoustics' line, the new PS-8b images well because it minimizes baffle area and the diffraction that cause distortion. The reduced baffle area is covered with a thin layer of natural rubber which further reduces diffraction.

The tweeter is asymmetrically mounted so that the two systems are mirror images of each other.

Back panel cable terminals are heavy duty push-type connectors which accept all cable diameters including the new wide



diameter "audiophile" cable and banana plugs. The PS-8b is finished in walnut grain vinyl and measures 11¾D x 9¾W x 13½-inches high. The unit carries the Design Acoustics limited five year warranty.

Suggested retail price is $179.95 each. Contact Tom Milan for information: Design Acoustics, 1225 Commerce Dr., Stow, OH 44224, (212) 986-6668.

Fast Reply #FC345

April 8-10 **STEREOPHILE** will produce another High End Hi-Fi Show, this one on the West Coast. Showgoers can attend exhibitors' seminars, speak with product designers and reviewers, and hear some of the best sound production equipment. *Audio Amateur Publications* will share an exhibitor's booth with *Madisound Speaker Components* (Room 505).

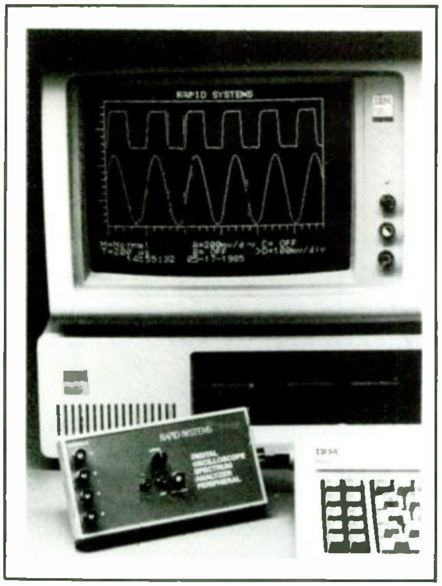
The show takes place in Santa Monica, California, at the Bayview Plaza Holiday Inn, West Pico and Third. Ticket price: $10 at the door, $7.50 advance—send check or credit card number to High End Hi-Fi Show, PO Box 5529, Santa Fe, NM 87502, or call Laurie Evans, (505) 982-2366.

STOP PRESS: Henry Kloss, co-founder of AR, KLH and Advent has designed a new speaker system, the Ensemble, for his **CAMBRIDGE VIDEO CORP.** It will be on view in New York for the first time at the end of March. For more on the Ensemble, contact Cambridge Video Corp., One Kendall Square, Suite 2200, Cambridge MA 02139, (617) 577-8481.

Fast Reply #FC44

AUDIO CONCEPTS' 1988 catalog includes a large inventory of drivers, kits, cabinets, coils, capacitors and accessories. Two new woofers designed by Audio Concepts, the AC7 and AC8, will be available this Spring to complement the AC10 and AC12.

For technical assistance, quotes and pricing contact: Audio Concepts, 1631 Caledonia St., La Crosse, WI 54602, (608) 781-2110; 1-800-346-9183 (orders only).



RAPID SYSTEMS announces the R15 multiple instrument system that turns your PC, XT, or AT computer into a variety of electronic test equipment. The R15 includes an 8-bit 500KHz digitizer and five different software packages that allow you to do digital oscilloscope displays, FFT spectrum analysis, datalogging, data transfer and data acquisition directly into your own BASIC, Turbo Pascal and C programs. Ideal for anyone needing to measure or analyze DC to 250KHz signals.

Price is $995.

Contact Rapid Systems, 433 N. 34th St., Seattle, WA 98103, (206) 547-8311.

Fast Reply #FC948

SYNERGETIC AUDIO CONCEPTS (Syn-Aud-Con), now in its 15th year of training audio professionals, will hold a Loudspeaker Designers Workshop in Atlanta, Georgia, April 15-17, 1988.

The workshop offers participants an opportunity to work with three noted loudspeaker designers in the audio industry: Edward M. Long, known for alignment by time, PZM and ELF; Don Keele, the developer of the constant directivity horn, loudspeaker reviewer for *Audio* magazine, and a key program developer for the TEF analyzer at Techron; and Dr. Eugene Patronis, the Workshop Chairman of the physics department at Georgia Tech.

The workshop will explore the dual enclosure, room acoustics, and TEF measurements will be made on high fidelity and professional loudspeaker systems to correlate what the ear/brain sees and hears. Participants will be able to hear the loudspeaker systems under test with both their own ears and those of the other participants through the use of pinnae transform recording system.

For more information, contact Synergetic Audio Concepts, PO Box 1239, Bedford, IN 47421, (812) 275-3853.

Fast Reply #FC41

SPEAKER BUILDER

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Post Office Box 494
Peterborough, New Hampshire 03458

Speaker Builder is published six times a year by Edward T. Dell, Jr., PO Box 494, Peterborough, NH 03458.

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

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

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Speaker Builder (US ISSN 0199-7920) is published six times a year at $20 per year; $35 for two years, by Edward T. Dell, Jr. at 5 Old Jaffrey Rd., Peterborough, NH 03458 USA. Second class postage paid at Peterborough, NH and additional mailing office.

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

About This Issue

By a series of coincidences, this issue turns out to be mostly about basics.

John Levreault leads off (p. 9) with a sequel to his earlier opus (*SB* 2/87), with a mid/dome array. As usual, his antipathy to woodwork is evident in the more-than-adequate simplicity of the enclosure, and lots of performance documentation.

The remainder of the issue is a glorious seminar on many of this avocation's basics, beginning with a landmark article by this magazine's newest Contributing Editor, **Vance Dickason**. Nagged for years by the seeming impenetrable complexity of the complex impedance plot, Vance finally sat down to bull through the theory with hints from the late Richard Heyser. You'll see his elegant tour of the matter beginning on page 15.

Perry Sink believes we all need a review of driver basics. On first reading I thought his ABCs on the matter too elementary for *SB*. But the longer I looked at his survey (p. 19), the better I liked it. I believe you will as well. Joining Perry on our faculty is **Peter Muxlow** from New Zealand. Peter, who writes our occasional *Technology Watch* feature, here (p. 24) surveys thoroughly good enclosure principles.

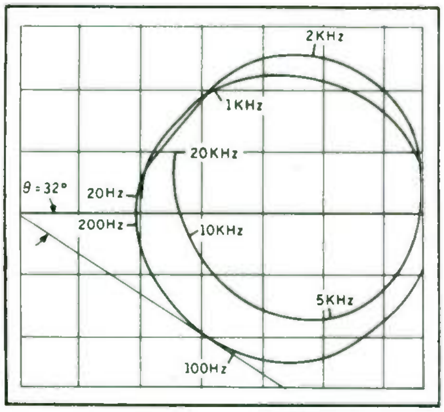
To top off the offerings, **John Buschmann** details the quality considerations for upgrading speaker systems and placing them in a room.

We have reviews of several kinds from **Bill Ruck** and **Gary Galo**, including some of software, which we think will be useful to speaker builders. **Dave Davenport** does a fine review of a new Jordan USA kit (p. 39) and we offer the second in a new series on *Vintage Designs*. Your letters, as usual, fill a provocative and informative segment (p. 45).

We'll be looking for all our Southern California speaker builder friends in booth 505 at *Stereophile*'s High End Hi-Fi Show, April 8-10 at Santa Monica, CA. Editors **Bruce Edgar** and **Vance Dickason** will also be on hand.

SpeakerBuilder
THE LOUDSPEAKER JOURNAL

VOLUME 9 NUMBER 2 APRIL 1988



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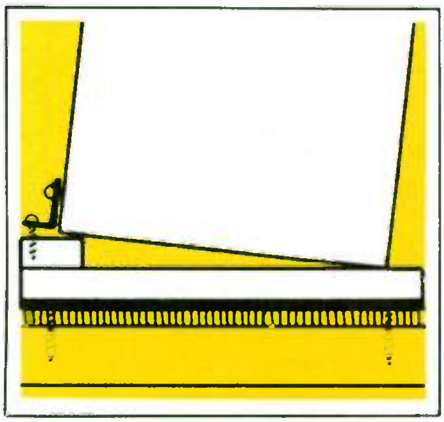

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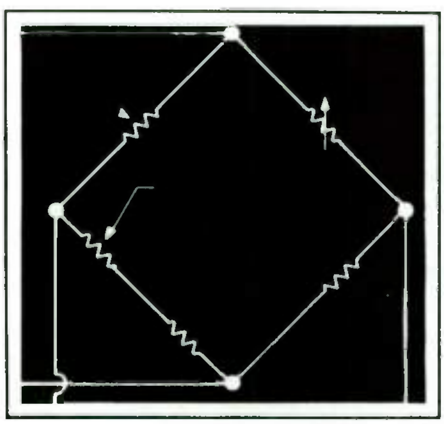

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Editorial

Copy Code: R.I.P. for a RIPoff?

The CBS engineering department could have made good use of a newly patented Japanese bubble gum. The audio industry and music lovers would have been spared a lot of wasted time, headaches, and anguish.

Like ordinary gum, this new Japanese version is pink—but unlike most gum it is interactive. It checks your body's *ph* factor. Pop this new stuff into your mouth and chew for three minutes. If you are in good shape it remains a healthy pink. If you need rest and rehab—it turns green.

Green would have been a singularly appropriate color response to the conditions in the CBS research establishment as they contemplated, undoubtedly with fear and loathing, the onset of the digital audio tape menace. They rushed from the drawing boards, we may presume prematurely, to propose the dreaded signal notch and anti-taping chip they demanded for every DAT machine.

CBS corporate management took Copy Code to the lobbyists, roused support among musicians who didn't want their art pirated, commandeered the resources of much of the world's recording industry and besieged assorted Congressmen to stop the new Japanese technical menace.

Last October when I cancelled my membership in the CBS Record Club over the Copy Code issue I received a reply which said in part, "This system has been exhaustively tested and endorsed by a special engineering committee of the Recording Industry Association of America (RIAA). In addition, the International Federation of Phonographic Industries (the European equivalent of the RIAA) has endorsed Copy Code. Copy Code encoding does not degrade the sound of recorded product, and the notch cannot be heard by listening to the recording."

Cooler heads in Congress prevailed, asking that the whole proposal be tested independently by the National Bureau of Standards. In a fashion uncharacteristic for a bureaucracy, the NBS promptly set up three tests for the Copy Code proposal: does it ever malfunction, can it be bypassed and can anyone hear the notch? The tests were funded by the Home Recording Rights Coalition, which was supported largely by the Electronics Industries Association (EIA).

By now we have all heard about the result. Copy Code flunked all three tests. As predicted by better informed technical experts before the tests, the notch did not always trip the chip, sometimes the chip functioned without the notch being present, and a very high percentage of listeners in many double-blind listening tests spotted the notch.

This is not a partial failure. This is a total bomb.

It is interesting to reflect on whether those who had purchased the CBS assets before all this tomfoolery began knew that the quality of the engineering at the CBS Labs was somewhat lacking and dismantled it summarily, or whether they were just trying to cut costs. In any case it is doubtful whether anyone remains on the current CBS roster who could stand up and cry "mea culpa."

One can also wonder whether, in the Sony boardroom, anyone is contemplating hara-kiri over having spent two billion to stop Copy Code by buying CBS Records. Ah well, gentlemen, put the daggers away. Sony can probably improve considerably on the quality of the CBS product. Maybe they can do something to get rid of that characteristic high end screech.

I believe the minimum we ought now to expect from the CBS corporate management is an apology. The longer I think about what everybody went through during this caper the more disturbed I become.

Did no one at CBS bother to test Copy Code? The proponents claimed that they were protecting proprietary information and could not allow anyone else (other than the RIAA or the IFPI) to test what they were suggesting. They gave testimony before a congressional committee about Copy Code's viability and cast grave doubt on contrary testimony by others. If they did all this without conclusive test results to back their claims, their action should now be cause for some serious questions. The whole thing sounds more than a little like the Iran/Contra affair.

Did the RIAA's special engineering committee do its homework? Did the Europeans make their own tests or just go along with the Americans? Perhaps the RIAA will favor us now by publishing some accounts of their tests and how they arrived at so positive a conclusion that Copy Code "does not degrade the sound" and "cannot be heard by listening."

Perhaps some smart lawyers for those firms who make DAT recorders are mulling over the legal possibilities in this matter. If the Bureau of Standards test results had come out as one out of three or two of three we might reasonably say that CBS had proposed something technically difficult that was not quite ready to fly. But the total failure of the system and the secretiveness about it beforehand certainly raises a lot of questions now.

Why not pen a postcard to CBS and ask for an explanation? Direct it to: CBS, Inc., Public Relations for Copy Code, 51 West 52nd St., New York, NY 10019.

And now that the coast is clear, shouldn't we all give a rousing, warm welcome to DAT with the hope that its prospects have not been irretrievably damaged by the Copy Code fiasco? Now we can get on, untrammeled by silly roadblocks, with our continuing search for the best sound which technology can make possible.—E.T.D.

A HIGH QUALITY DOME MIDRANGE/TWEETER ARRAY

BY JOHN E. LEVREAULT, JR.

As a long-time designer/builder of loudspeaker systems for use in my home, I am continually on the lookout for innovative or unusual designs. I prefer using readily available, conventional moving-coil driver elements in designs that avoid the expense of esoteric drivers. These designs can be easily built by interested amateurs at reasonable cost and in a minimum amount of time. I have built a variety of systems using drivers from Audax, Dalesford, Dynaudio, SEAS and Strathearn. I firmly believe that speaker design has no magic in it and design performance can be predicted, assuming the best possible execution techniques are employed.

For the past two years I used a midrange/tweeter array based on the Strathearn ribbons, briefly described in an earlier article (*SB* 2/87). Although these devices are capable of extremely good performance, I found the treble to be somewhat ragged, even though I modified them following the article by Spangler and McKenzie, *SB* 3/85. Furthermore, I found their imaging characteristics inferior to other driver configurations. I will describe one such configuration that solves both problems.

I believe the basic limitations of the Strathearns is their size and need for a large support structure. Two drivers per side are necessary to maintain a low and unobtrusive crossover point to a woofer (200–300Hz), but this necessitates a structure nearly five feet tall. As explained in my earlier article, I haven't the interest in building a baffling arrangement of sufficient rigidity to bring out the best in these drivers.

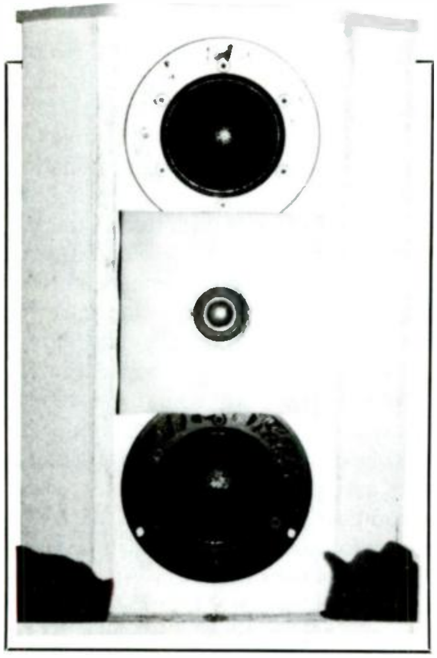

PHOTO 1: MTM array in an "open-backed" baffle.

Furthermore, the Strathearns are very sensitive to room placement. I have never been able to achieve very good imaging with this dipolar line source array. Earlier designs using a point source approximation consistently displayed better imaging and soundstage characteristics. I managed to live with this ribbon design for over two years and these effects are rather subtle. However, the time has come to try something different, combining successful design methodologies I have developed and the latest in driver technology.

THE M-T-M ARRAY. I have been impressed with the "mid-tweeter-mid" (MTM) driver configuration since first hearing a powered loudspeaker system from Meridian, a British manufacturer, over five years ago. As I recall, this two-way design used two KEF B110-style woofer/midrange drivers with a KEF T15 tweeter mounted exactly midway between the two B110s. The system was built in an equalized vented box enclosure no more than 8″ wide, containing its own amplifiers.

I was immediately struck by the elegance of this design, which approximates a true point source acoustic radiator. This design has come to be known as the "D'Appolito configuration." Joe D'Appolito has rigorously described and analyzed this design in the pages of *Speaker Builder*, and has constructed a high quality system based on this technique. See *SB* 4/84 and 4/87 for details.

I built my first MTM array nearly five years ago using a pair of Dalesford D153 woofer/midrange drivers flanking a Dynaudio D28 tweeter. I tried both third- and first-order crossovers, but preferred the first-order network. I found the improvement in coherency outweighed the irregular response just below the 3000Hz crossover point. I further modified the system by removing the horn from the D28, an improvement now conceded by Dynaudio with their D28af. Although this change cost a few dB in driver efficiency, it added to the overall smoothness of the tweeter's sound. I lived happily with this system until I opted for the "latest and greatest" Strathearns in 1984.

Based on the above considerations, I will now describe the design of a new MTM module to sit on top of my equalized vented box woofers which appeared in *SB* 2/87.

DRIVER SELECTION. Except for the Strathearns, my midrange designs have always used cone-type drivers. I tried using midrange domes to augment the upper midrange output of cone drivers, but

ABOUT THE AUTHOR

John Levreault is Marketing Manager for the Microelectronics Division of Analog Devices. He and his wife, Lorraine, live in Boxford, MA with their two teenage sons. He enjoys acoustic guitar, astronomy and building hi-fi equipment in what little spare time is available.

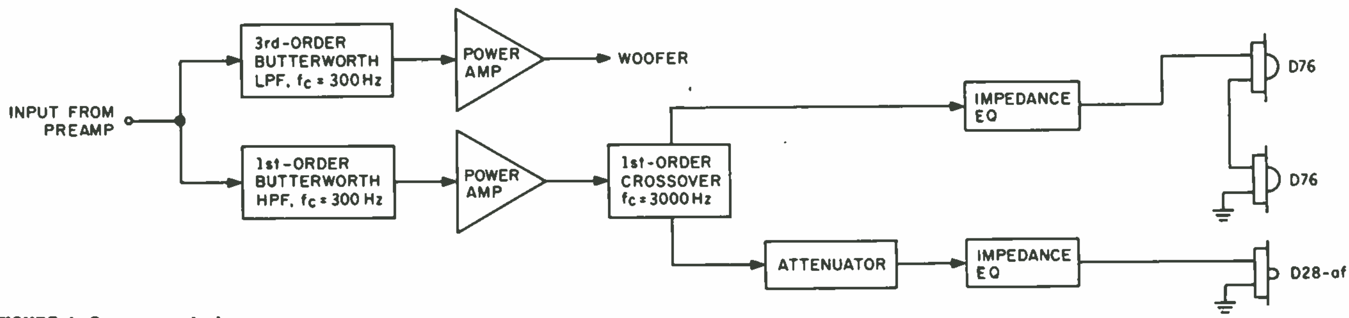

FIGURE 1: Crossover strategy.

the additional crossover complications proved disastrous to system coherency. Attempts at four- and five-way designs never equalled the performance of simpler three-way units.

Furthermore, woofer-to-midrange crossovers at frequencies above 300Hz caused difficulties with many types of source material, especially with male vocals or acoustic guitars. I consequently adopted the "woofer plus satellite" technique, which works well with active crossovers and biamping. Upgrading of either unit can be accomplished independently of the other.

I focused my new driver search on moving-coil midranges capable of spanning the critical 300–3000Hz range, drivers capable of good power response and bandwidth. I also favored drivers which could use a first-order crossover. The use of the Dynaudio D28af is a foregone conclusion based upon my past experiences. This 28mm dome tweeter has the frequency extension, power handling and smoothness I rely on.

My positive experiences with Dynaudio include the 21W54s, and just about anything I've seen from them. I was impressed by Gary Galo's enthusiastic comments on the new Dynaudio D76 dome midrange (*SB* 2/86), so I thought a pair of these drivers in an MTM configuration might do the job. Although these are expensive drivers, I believe they represent a genuine value for the home builder.

CROSSOVER DESIGN. Based on my choice of drivers and their capabilities, I chose a 3kHz first-order passive crossover between midrange and tweeter and a modified 300Hz first-order/third-order active design between the D76s and my 21W54 woofers. My overall crossover network strategy is shown in *Fig. 1*. First I'll describe the passive unit.

Passive crossover design has been the subject of endless controversy. I believe the shortcomings of passive crossovers can be overcome by solid circuit design (theory) and good components (execution). Few commercial designs include the best of both.

Design tables and computer-aided design have done little to mitigate the confusion. No matter what the desired crossover order or type, all design tables or equations require a constant termination resistance. Unfortunately, all moving-coil drivers are afflicted with two characteristics that make their voice coil impedances vary: an electro-mechanical resonance and a voice coil inductance. Ferrofluid damping can help alleviate (damp) the resonant frequency impedance buildup of the driver, but the inductance will always be present for any coil immersed in a magnetic field. However, we can deal with both problems effectively by using a compensation network to allow the driver to present a constant impedance to the crossover network. We can then use textbook design equations to calculate the crossover component values.

The well publicized Zobel network, which places a series connected resistor R and capacitor C in parallel with the voice coil, effectively compensates for the rise in driver impedance due to the voice coil inductance (see *SB* 4/82, p. 14). The values of this network can be easily approximated by measuring the voice coil impedance curve exactly as you would for a woofer. Find the minimum impedance frequency F_{min} (see *Fig. 2*) and then find the frequency F_2 where the voice coil impedance rises to 1.414 times the impedance at F_{min}. If R equals the voice coil impedance at F_{min}:

$$C = \frac{1}{2\pi \times F_2 \times R}$$

In practice, I find the following values give the best performance: R—about 10% larger than the measured voice coil resistance and C—about 20–50% larger than that calculated above.

The actual value of the constant impedance obtained, which will be slightly different than the value R, shown earlier, is of far less importance than the flatness, assuming the impedance obtained is not more than 10–20% different than the voice coil resistance. Deviations of less than ±5% in the equalized impedance can be easily obtained experimentally, using the calculated values as starting points.

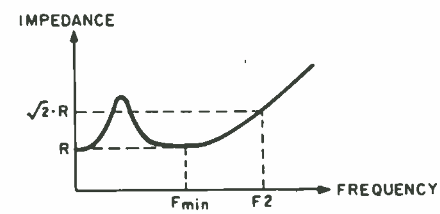

FIGURE 2: The design of a Zobel network starts by finding the frequency F_2 where the voice coil resistance rises to 1.414 times its midband range.

Our objective is to obtain the broadest range of constant impedance either side of the crossover point, since (assuming a low-pass crossover function) the crossover doesn't do anything at frequencies well below the crossover point and the signal to the driver will be severely attenuated at frequencies well above the crossover point. However, what goes on in the region two or three octaves either side of the crossover is of vital importance to the coherency and smoothness of the system, especially when using a first-order crossover design.

I choose to ignore the resonant-frequency impedance rise of the two driver types. The resonances of the D76 and D28af are effectively damped by the aforementioned ferrofluid approach. The 300Hz resonance impedance rise of the D76 is only about 15% and occurs a full decade (factor of ten) lower in frequency than the intended 3kHz crossover point. The D28af resonance occurs two octaves (factor of four) below the crossover point and is only in the 10% range, so I think this simplification is justified as well.

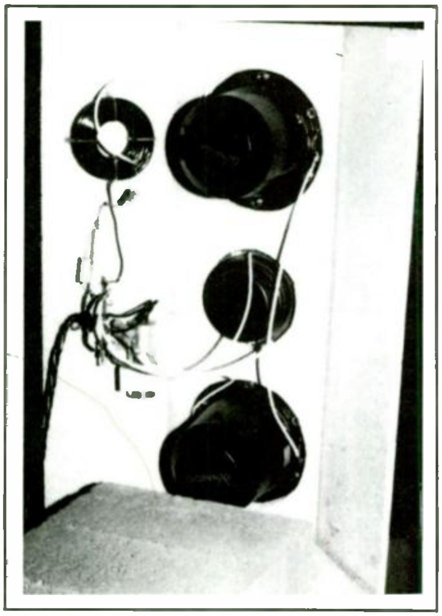

PHOTO 2: Back of the baffle, showing crossover.

Once the voice coil impedance has been made as flat as possible around the desired crossover point, the crossover components can be calculated. A first-order crossover has two basic components, an inductor L in series with the midrange driver (in this case the two D76s wired in series) and a capacitor C in series with the D28af tweeter. The values can be calculated by:

$$L = \frac{R_0}{2\pi F}$$

$$C = \frac{1}{2\pi F \times R_0}$$

where
- L = inductor value in henries,
- C = capacitor value in farads,
- R_0 = equalized impedance value of driver(s), and
- F = crossover frequency.

Generally, the voice coil impedance with the Zobel installed will be slightly different from the value R shown in *Fig. 2*, hence the use of R_0.

The final problem the crossover must address is differing driver efficiencies. We must attenuate the drive voltage to the more efficient driver, the D28af tweeter, to achieve a flat frequency response. Manufacturers typically specify the efficiency of a driver in dB (SPL) per watt of input at some nominal frequency in the driver's operating frequency range. However, 1W generally assumes 2.83V, which further assumes an 8Ω driver. As long as the efficiency is based on drive voltage, you can easily design a suitable attenuator.

The specified efficiencies of the D76 and D28af for a drive voltage of 2.83V are 88dB and 91dB, respectively. Wiring two drivers in series, as with the pair of D76s per side, has no effect on the efficiency (their impedance will increase, however). Therefore the drive voltage to the D28af must be attenuated by 3dB relative to the D76s, or the tweeter level will be higher than the midrange. The simplest form of attenuator is the L-pad shown in *Fig. 3*. The values of R_1 and R_2 can be found from:

$$R_1 = (1 - 10^{-A/20}) \times R_0 \text{ and}$$

$$R_2 = \left(\frac{R_0}{R_1}\right) - R_0$$

where R_0 is the equalized voice coil impedance and A is the desired attenuation in dB.

The completed crossover design is shown in *Fig. 4*. As an exercise for readers familiar with the calculation of resistive divider networks, it is possible to remove the constraint that the L-pad maintain the impedance of the equalized driver voice coil, thus allowing more convenient crossover values. I have done this in the completed design shown in *Fig. 4*. The back of the array and the crossover components are shown in *Photo 2*.

To guarantee the crossover works exactly as designed, the highest quality components must be used. Inductors must have as low a DC resistance as possible; I obtained acceptable results with "Perfect-Lay" inductors purchased from Madisound. Similar air-core inductors made with large wire should prove satisfactory.

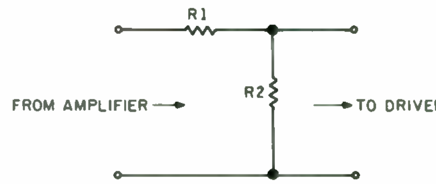

FIGURE 3: L-pad used to attenuate drive to more efficient driver, in this case the D28af tweeter.

Capacitors should have polypropylene dielectric to maintain dynamic contrasts and minimize coloration and temperature drift. Siderealkaps,® Wondercaps® or Chateauroux products should perform acceptably. Teflon or polystyrene capacitors will work well but may be difficult and/or expensive to obtain. (Adding a small .01μF to 0.1μF polystyrene or polypropylene capacitor across a larger value may offer an improved sense of high frequency extension.)

Finally, resistors should be temperature stable, metal film types, 2W minimum rating. Resistors used for tweeter attenuators dissipate surprisingly little power, but if your resistors seem to get hot under actual operation, increase their power handling capacity by paralleling devices.

High quality interconnect wiring is vital to crossover operation. The list of possibilities seems endless. I recommend

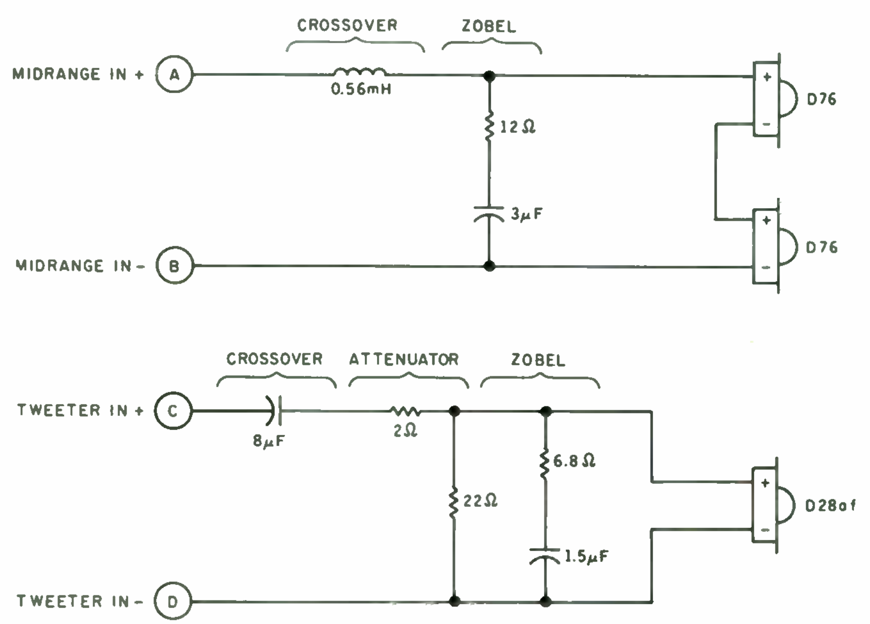

FIGURE 4: Completed passive crossover design. If bi-wiring is not used, connect point A to point C, and connect point B to point D.

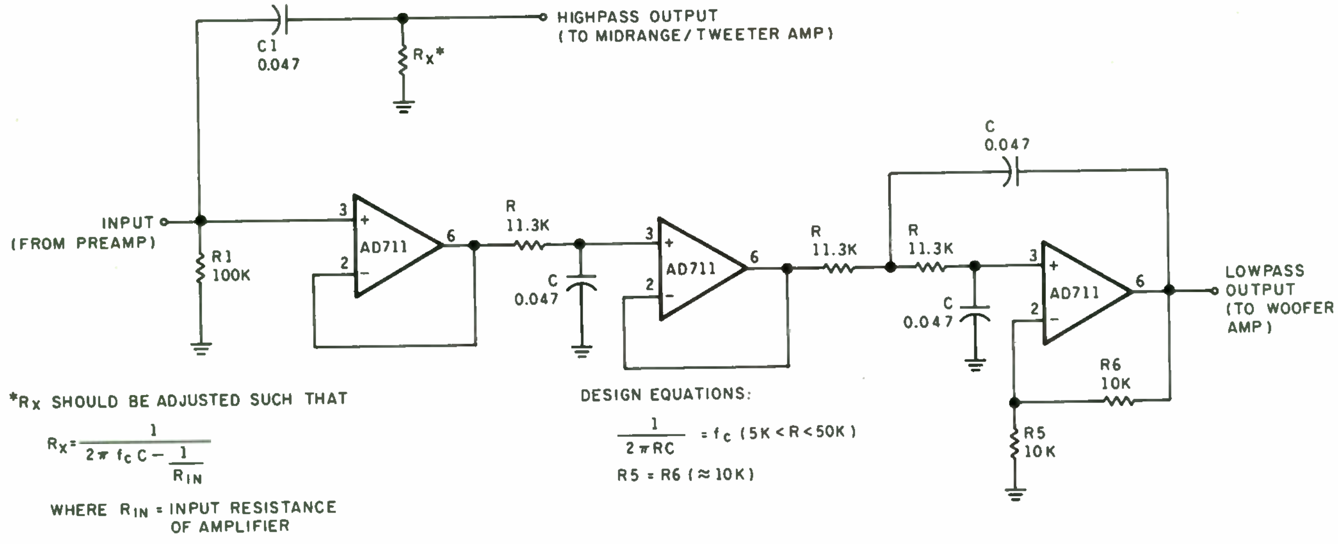

FIGURE 5: Active/passive crossover network detail.

PARTS LIST

Resistors	
R1	100k
R2-R4	11.3k
R5,R6	10k
Capacitors	
C1-C4	0.047
ICs	
AD711 (3)	

as a minimum that Teflon-insulated, silver-plated stranded copper wire be used. Litz construction may prove advantageous. Surprising though it may seem, wire is the "other" component that may sabotage an otherwise high-quality crossover network.

Your choice of passive component types can significantly alter the tonal balance and dynamic range of a loudspeaker system. With the necessary financial means, you may fine-tune the sonic attributes of your system by using any of the wide array of products available. I do suggest, as a minimum, AWG16 wire for the inductors, polypropylene for the capacitors, metal film resistors and teflon/copper/silver wire. Beyond that, one can become lost in a labyrinth of confusion, hype and opinionated babblings. As my grandfather once told me (as paraphrased by yours truly), "Fi is hi in the ears of the listener." Let your ears be the final arbiter of system sound.

The active crossover between the MTM array and the woofer is designed for maximum simplicity and minimum sonic penalty. I have found over the years that all active components have their sonic signature, so I try to use as few transistors and ICs as possible. This is especially true at midrange and treble frequencies but less so in the bass region. Consequently, I favor a design first used in the Dahlquist DQLP1 active/passive crossover.

This design uses a third-order Butterworth, low-pass active filter between the preamp and the woofer power amplifier, but uses only a series capacitor at the input to the midrange/tweeter amplifier for a high pass filter. See *Fig. 5*. Although this appears to create a mismatch in the response functions between high- and low-pass channels, such is not the case. I chose the crossover point to coincide with the low frequency cutoff point of the midrange driver. Since moving-coil drivers roll off at 12dB per octave, this results in a third-order acoustic high-pass response.

This technique works ideally when the midrange device is a cone-type driver in a closed box, tuned for a Q_{tc} equal to 1.0. The series capacitor to the midrange amplifier is tuned to the resonant frequen-

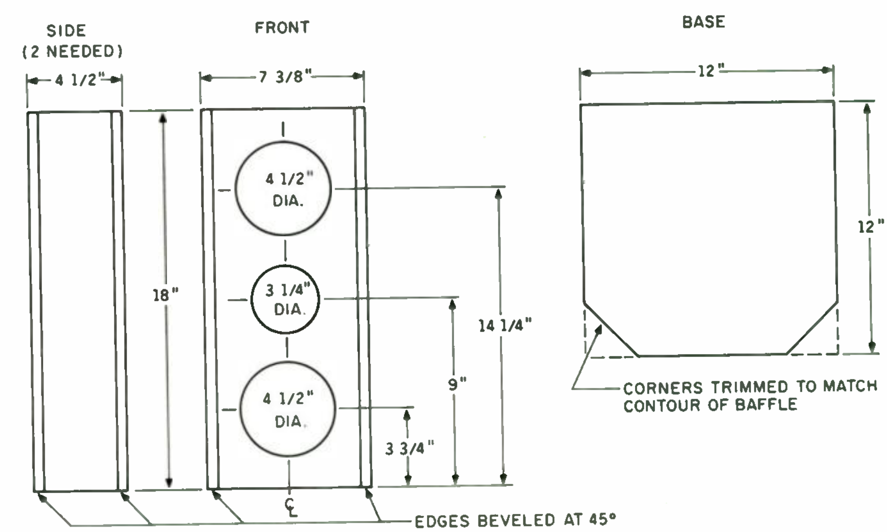

FIGURE 6: Panel dimensions. All material is ¾" particle board.

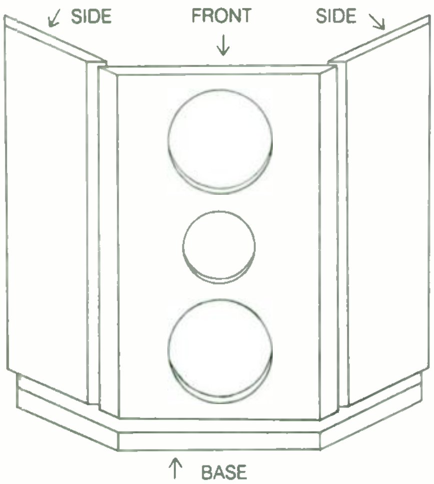

FIGURE 7: Putting the pieces together. Glue side pieces, one at a time, to front. The author glued this assembly to the base.

cy of the driver, resulting in an "acoustic Butterworth" response.

The active/passive crossover design as shown in *Fig. 5* includes design equations, if you wish to modify either the frequency or the component values. The values I chose were on hand and may be changed within reason.

As with passive crossovers, component quality has a direct bearing on system performance. I suggest only polystyrene or polypropylene capacitors and metal film resistors to maintain the clarity and dynamic range of the system. I am most enthusiastic about the AD711 IC op amps, and not just because I work for Analog Devices. They offer transparency I have never experienced from another op amp. The use of high quality gold-plated connectors and interconnects is strongly recommended.

MOUNTING BAFFLE. The drivers used are "closed-back," that is they each have a plastic cup-like device fitted to their rear. This cup is filled with a fibrous damping material to eliminate the backwave off the dome. Consequently, an open-back baffle can be used to support the drivers. I used a "flat front with sloping sides" arrangement as shown in the photographs. *Figure 7* shows the baffle construction. Since I planned on mounting the array directly atop my twin-Dynaudio 21W54 equalized vented woofer system, I made the baffle 12" wide. The width is not critical, but I made it the same as the top of my woofer, to minimize diffraction. Notice in the finished system (*Photo 1*) that I use foam damping triangles on the exposed corners of the woofer cabinets to further reduce diffraction effects.

I highly recommend mechanically isolating the woofer from the mid/tweeter array using "Tip Toes" or other such techniques. This helps protect the mid/tweeter array from being modulated by any woofer cabinet vibrations.

I constructed a set of spikes for the bottom of the array that work quite well. First, drill three ¼" holes in the bottom of the baffle, and insert #10 tee-nuts in the holes. Take some #10 brass screws and cut the heads off. File the ends to a point by clamping the headless screw into a drill chuck, turning on the drill, and turning the screw against a flat file. A hex-nut secures the screw in the tee-nut. See *Fig. 8*.

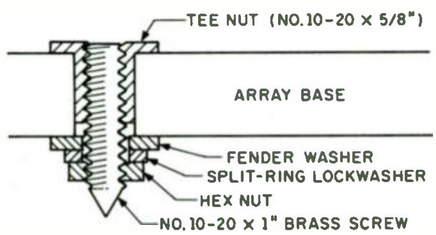

FIGURE 8: Detail of "spike" design used to acoustically decouple array from mounting platform, in this case, the author's woofer system. Cut off head of brass screw and grind end to a point.

The isolation of the array may be further improved by increasing its mass. A couple of bricks placed on the base of the array noticeably stabilizes the image. These are visible in *Photo 2*. See *Photo 3* for the finished job.

CONCLUSION. The completed design exceeds all my expectations. Imaging, detail and transparency are excellent. Dynamic range is awesome and the efficiency is quite good. A 100W amplifier makes the system capable of painful sound levels. The critical lower midrange is especially good, allowing me to enjoy male vocalists and acoustic guitars as never before. Female vocals are significantly improved relative to the Strathearns, due to the smooth response of the Dynaudio domes. These units have exposed several weaknesses in my electronics, motivating me to update my active components. In particular, the sonic superiority of the AD711 op amp is readily apparent, something I couldn't hear with the Strathearns.

I have attempted to outline a simple design with readily available components which leaves room for individual choice and experimentation. The component philosophies espoused contain my strongest recommendation, that "passive" devices really aren't. The ear is extremely sensitive to component-induced errors, and the attendant loss in timbre, transparency, and dynamic range by the use of sub-standard parts is not worth the modest savings.

This design leaves room for improvement and I welcome any further discussion. I plan to remove the plastic enclosures on the rear of the drivers and load the rear wave into damped transmission lines. Due to the high cutoff frequency, these lines could be quite short and be either open or closed. Also, the low frequency characteristics of the damping would be less critical, possibly allowing the use of polyester or fiberglass. I believe a curved baffle might prove superior to the slanted one.

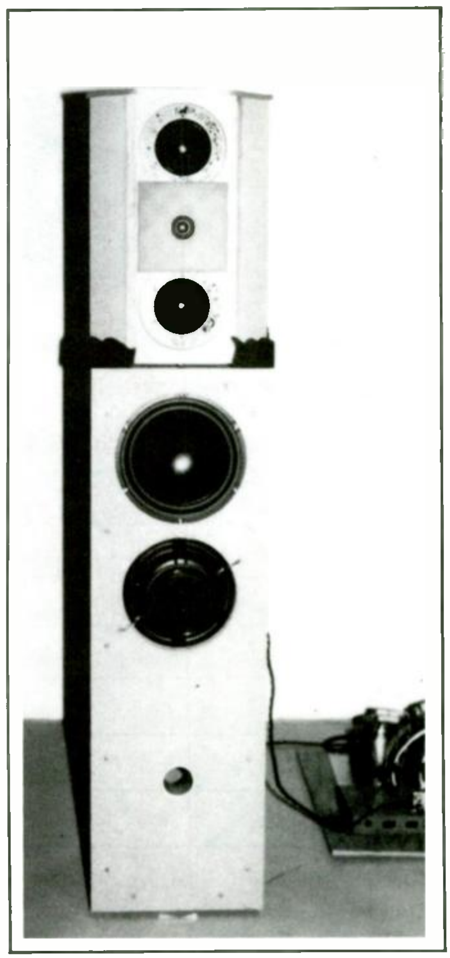
PHOTO 3: The finished system sits atop the author's vented box woofers.

HOW TO PLOT AND UNDERSTAND COMPLEX IMPEDANCE

BY VANCE DICKASON
Contributing Editor

It is of critical importance to any speaker designer, amateur or professional, to understand the exact nature of the resistive load a loudspeaker presents to the terminals of an amplifier. Yet, generating its most illuminating presentation, the complex impedance plot, seems to be understood by only a few individuals in the industry. Even the late Richard Heyser described the complex impedance plot as "sufficiently difficult to perform that the vast majority of loudspeaker manufacturers do not, themselves, know what the complex load properties of their products are."[1]

But, sufficiently difficult is certainly not impossible, and I think Mr. Heyser's comment was to a large part meant to admonish that "vast majority" of hi-tech neophytes masquerading as loudspeaker manufacturers. A complex impedance plot is not all that difficult to produce, and it is something which all *SB* readers should be able to understand and apply.

We can think of impedance, in any electrical circuit, as AC resistance. AC resistance is more complex than simple DC resistance, and contains two components, resistance and reactance. Because of the nature of reactance, we can't measure impedance with an ohmmeter in the same manner as we measure resistance; it requires different techniques. With a loudspeaker, the impedance magnitude is indirectly measured by determining the amount of voltage required to pass a fixed amount of current through a loudspeaker at different frequencies. This test procedure, referred to as the constant current method,[2] likewise produces a composite result which is made up of both resistance and reactance; mathematically expressed as:

$$Z = \sqrt{R^2 + X^2}$$

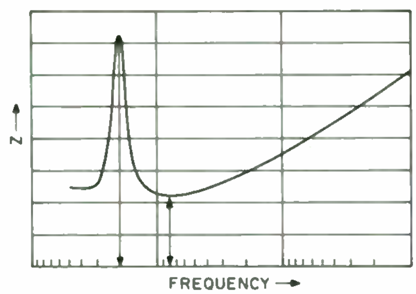

FIGURE 1: Impedance plot.

where Z is the impedance magnitude, R is the resistive component, and X is the reactive component.

SLEUTHING ELEMENTS. The resistive portion of impedance can to some extent be observed in an impedance magnitude plot (*Fig. 1*). The lowest point in the trough just following the resonance peak is purely resistive, and generally equal to the DC resistance of the speaker. Also, from the definition of resonance, the impedance at the resonance frequency point is also purely resistive. Understanding which part of the impedance magnitude curve is reactive, however, is not so readily apparent and requires further computation and analysis.

The reactance portion of the loudspeaker impedance (or in any electrical circuit), can be either capacitive or inductive. These two types of reactances behave differently and have exactly opposite effects on the voltage and current of the circuit. Capacitive reactance causes the voltage to lag the current waveform (current lead), while inductive reactance causes the voltage to lead the current waveform (current lag).

Since it's this lead or lag in voltage at different frequencies which determines how happy (or unhappy) a particular amplifier will be when driving a particular speaker, finding a way to depict this information would be invaluable.

WHERE'S THE IMAGINARY? Because the impedance magnitude curve lumps together both resistance and reactance components, about all we can establish from the curve is whether or not the total load picture drops below the minimum impedance most amplifiers will accept. The complex impedance curve, moreover, solves this problem by graphically depicting the relationship between both elements, resistance and reactance, in a way that makes the interpretation of the speaker load profile much more understandable. Mathematically, this is not difficult, but it does involve complex algebra and a little trigonometry.

We can separate impedance magnitude into its resistive and reactive component parts by using impedance magnitude and impedance phase information to generate both the "real" and "imaginary" elements for each measurement point. For a loudspeaker impedance, the real part is the resistive component and the imaginary part is the reactive component.

Since the mathematical terms "real" and "imaginary" are probably not overly familiar to everyone, a short explanation of this and the "j" operator will be useful.

1. Dickason, V., *Loudspeaker Design Cookbook*, 1977, 1978 and 1987, Marshall Jones Co.
2. Heyser, R., "Speaker Impedance—More Complicated Than One Number," *Audio*, June 1984.

Much of our analysis in electrical engineering is done from the standpoint of the sine wave. Sine waves can be represented graphically using the cartesian coordinate system as shown in *Fig. 2*. The vector, rotating around the point of origin, describes the changing voltage (or current) of the sine wave. Starting at zero, the vector rotates counterclockwise, increasing to a positive maximum, then decreasing to zero, increasing to a negative maximum, and finally decreasing to zero again to restart the cycle. Mathematically, this rotation is accomplished by simple multiplication.

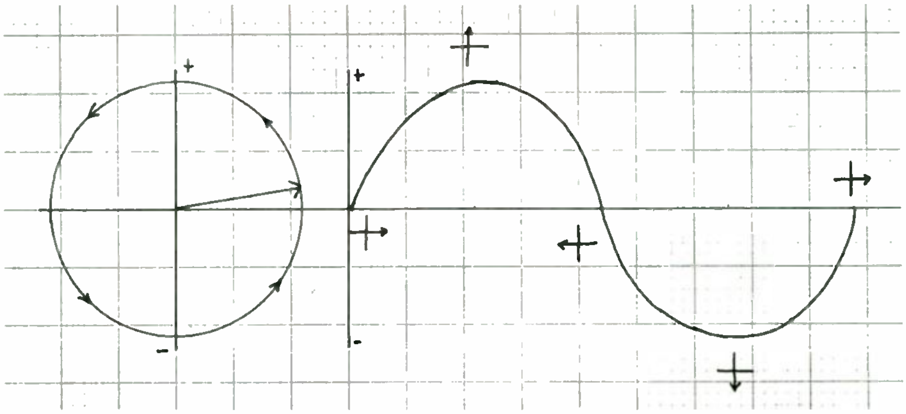

FIGURE 2: Sine wave generation.

ROTATION BY MINUS. From *Fig. 3*, we can see that it's possible to think of a number as being rotated 180° by multiplying (or dividing) it by a minus one (-1). If we take the number 6, for example, multiply by -1, the answer,

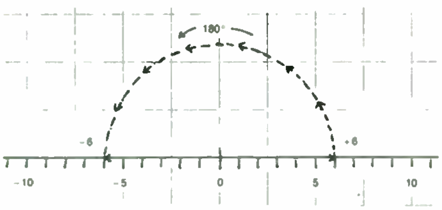

FIGURE 3: Rotation by multiplication.

-6, has rotated 180° on the number line. If we multiply the same number by -1 twice (which is the same as multiplying by $+1$), it would be rotated 360° degrees. Since $\sqrt{-1}$ times $\sqrt{-1}$ equals -1, we can assume that multiplying a number by $\sqrt{-1}$ rotates that number (or vector) by only half as much, or 90°. If we rotate the vector 270° it would be $\sqrt{-1}$ times $\sqrt{-1}$ times $\sqrt{-1}$, or $-1\sqrt{-1}$.

In math, the $\sqrt{-1}$ has no rational solution of its own, and is a special number which is represented by the letter i, and referred to as an imaginary number. Numbers which do have a rational solution to their square root, are referred to as "real" numbers. Real numbers which include i as a coefficient are also called imaginary numbers (this is a very unfortunate choice of terminology, because the word "imaginary" sounds contrary to reality, and seems to imply that an imaginary number has no existence, when in fact it does).

In electronics we use the letter i to represent current in a circuit, so electrical engineers decided to rename the imaginary number, using the letter j to distinguish it from the symbol for current. Thus we use the j operator as the imaginary symbol for numerical rotation in circuit analysis.

PHASE DETECTION. Looking at the complex impedance plot in *Fig. 4*, notice that the vertical axis is labelled inductive reactance at the top, and capacitive reactance at the bottom, and is graduated in $+j\Omega$ and $-j\Omega$ respectively. The j operator in this case represents the vector rotation of the reactive component which describes either a lead or a lag in the circuit voltage. The measurement of this rotational distance, which determines exactly how far the voltage component was rotated in respect to the current component, is known as phase.

When voltage and current do not rise and fall in unison, we refer to them as being out of phase and, conversely, when they do occur concurrently, we say they are in phase. Phase difference between voltage and current is measured in degrees, and is referred to as the phase angle. Looking at *Fig. 5*, the phase angle is the measured difference in the lead (or lag) one vector has over the other. Fortunately, there is an easy way to measure phase angle so as to discern this lead-lag situation. For that we use a phase meter.

A phase meter is not a particularly common piece of gear and if you don't have access to one, I suggest reading G. R. Koonce's outstanding article "Build Your Own Phase Meter" (*SB* 1/84). It describes accurately the setup required to plot both impedance magnitude and the

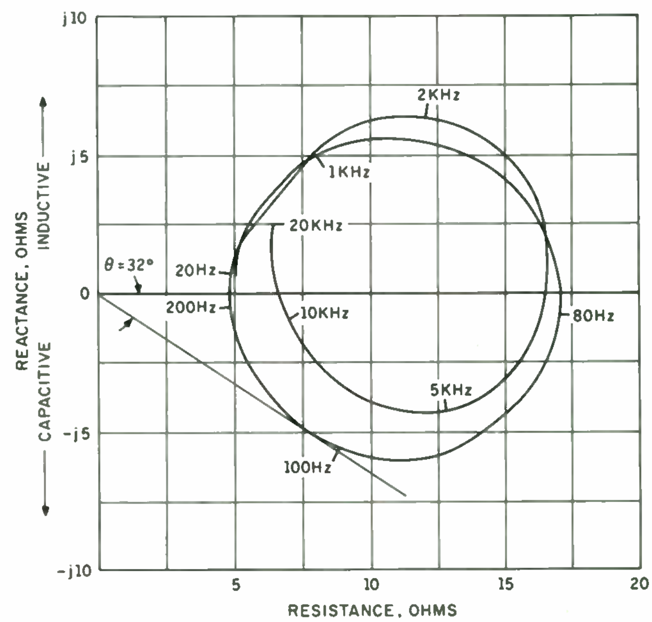

FIGURE 4: Complex impedance plot.

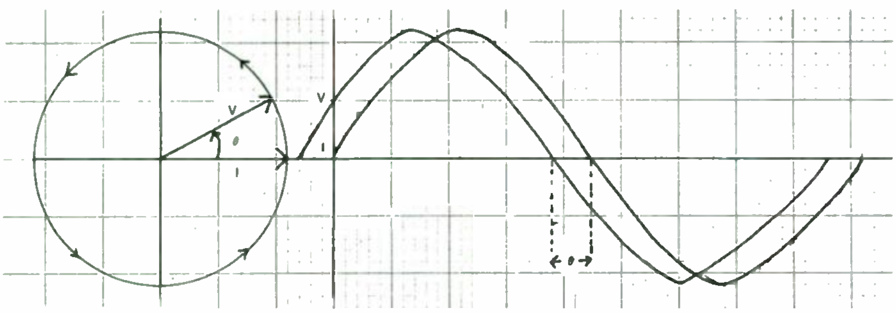

FIGURE 5: Phase angle.

phase of the impedance magnitude, so I won't repeat the procedure.

DIG WITH TRIG. As I said, we generate the complex impedance plot (also known as a Nyquist plot) by using data from both the impedance magnitude and phase angle plots. Mathematically, we can accomplish this by using the phase angle information and some trigonometric manipulation to separate the real (resistive) and imaginary (reactive) components of the impedance magnitude.

Looking at the graph in *Fig. 6*, we have another vector representation, this time for impedance, with the vertical axis graduated in $\pm j\Omega$ for reactance and the horizontal axis graduated in pure resistive ohms. I have drawn three vectors on this graph: Z, X_L, and R which represent impedance magnitude, reactance (in this case inductive), and resistance. The Z vector is in a rotated position, 40° from the horizontal plane, which represents

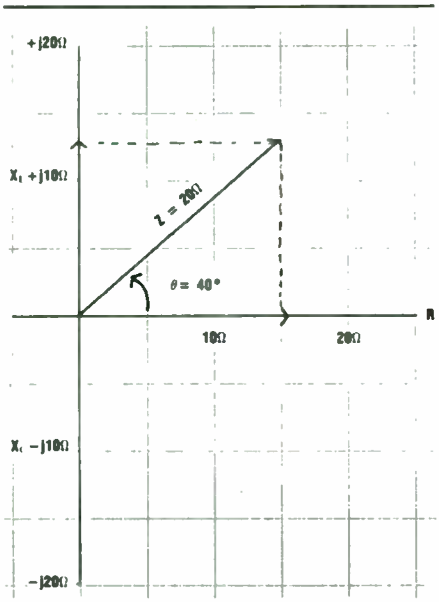

FIGURE 6: Impedance magnitude, reactance and resistance.

the measured phase angle. If the phase angle at this impedance magnitude point is zero degrees, which means it has no reactive component at all, the impedance would be strictly resistive, and would appear as a positive point on the horizontal axis:

using the formula for impedance

$$Z = \sqrt{X^2 + R^2} = \sqrt{0^2 + R^2} = R$$

If the impedance includes a reactive factor, as this example does, its vector would be rotated by the amount indicated by the measured phase angle, and we can determine by simple trigonometry what the resistive (real) and reactive (imaginary) portions would be.

CAPACITIVE TOO. In *Fig. 6*, the XL vector equals the height of the third leg of the right triangle whose second angle, the phase angle, is known. Using the usual trigonometric relationships of a right triangle:

$$R = Z\ (\cos\theta)$$
$$X_L = Z\ (\sin\theta)$$
$$X_C = Z\ (\sin\theta)$$

For the example in *Fig. 6*, R = 20 (Cos 40°) = 15.32Ω, while X_L = 20 (Sin 40°) = 12.85Ω (never mind using trig tables, punch it up on your scientific calculator). X_L is an imaginary quantity (i.e., it is an out-of-phase voltage lead situation which has caused the Z vector to be rotated counterclockwise) and is written as +j 15.32Ω.

DOING ONE. *Figure 7* shows the same situation for a capacitive reactance, with a negative phase angle, rotating the Z vector clockwise, for a voltage lag situation, with Z = 15Ω. Again, R = 15 (Cos −45°) = 10.61Ω, and X_C = 15 (Sin −45°) = 10.61Ω, appropriately written as −j 10.61Ω. With capacitive reactance, the scale on the vertical axis is labelled −j rather than +j. This has to do with the amount of rotation at that axis point (see above) and the direction of rotation. You may check the validity of these calculations by going back to our original equation for impedance. For the *Fig. 6* example:

$$Z = \sqrt{15.32^2 + 12.85^2} = 20$$

for the *Fig. 7* example:

$$Z = \sqrt{10.61^2 + 10.61^2} = 15$$

The best way to compute a complex impedance plot is to start by using the data from your impedance magnitude and

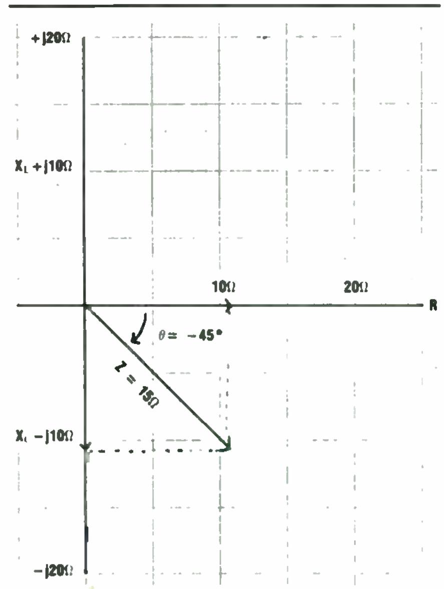

FIGURE 7: Capacitive reactance.

phase measurements to set up a table. This table should contain one line for each frequency point with separate columns labelled Z, θ (Phase Angle), X_C, X_L, and R. *Table 1* contains the data for a complex impedance plot of a two-way acoustic suspension speaker. *Figures 8* and *9* give the impedance magnitude and

TABLE 1

DATA FOR COMPLEX IMPEDANCE PLOT

f (Hz)	Z(Ω)	θ(°)	X_C(−jΩ)	X_L(+jΩ)	R(Ω)
20	5.0	6.8	—	.6	5.0
80	17.3	− 2.7	.8	—	17.2
100	9.5	−32.5	5.1	—	8.0
200	4.9	− 5.8	.5	—	4.9
1000	8.4	32.0	—	4.5	7.1
2000	13.7	27.9	—	6.4	12.1
5000	12.6	−20.0	4.3	—	11.8
10K	7.1	−20.6	1.0	—	7.0
20K	7.0	21.0	—	2.5	6.5

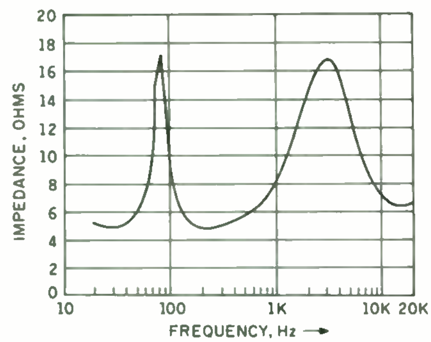

FIGURE 8: Impedance magnitude plot.

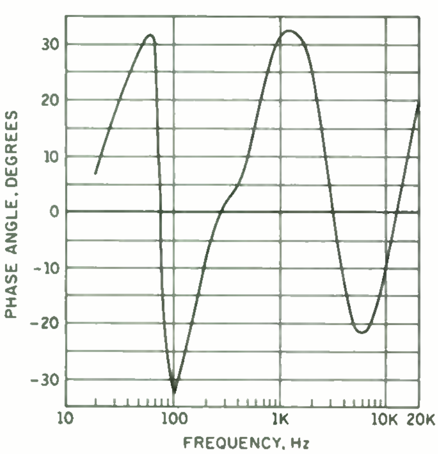

FIGURE 9: Phase angle plot.

phase plots for the speaker, which supplied the data for the table.

For this example, *Table 1* shows only the data for the marked frequencies, but enough so you can get an idea of how this process works. Because some events happen in a relatively short frequency span, quite a large number of data points are needed in order to achieve a reasonable degree of resolution. Ideally, one could use a digitizer to read the magnitude and phase curves from swept measurements into a computer and run a simple program that would output to a X Y plotter, but since that is more hardware than most of us have available, the hand-plotted method works just fine. Start by plotting every 5Hz from 20Hz to 100Hz, every 50Hz from 100Hz to 1kHz, and every 100Hz from 1kHz up.

Figure 4 gives the complex impedance plot for the two-way sealed box example. The points on the curve are plotted from R and X values and joined together to produce the familiar clockwise spiral curve. At appropriate intervals, the frequency of that plotted point is marked with a slash and labelled. The horizontal and vertical axis are both scaled in the same units and marked appropriately, resistance in ohms for the horizontal scale, and reactance, +jΩ and −jΩ, for the vertical scale. End of mystery.

WHAT IT MEANS. Now that you know how to generate the data for plotting a complex impedance curve, here are some of the things to look for in interpreting it. To begin to gain an understanding of the evaluation, go back through the last several years of *Audio* magazine's speaker reviews, particularly Heyser's, (make copies so you can refer to them without having to thumb through all that bulk).

A lot can be learned by just reading what Heyser interprets from complex impedance. Beyond that, a number of basics, most of which are covered in Richard Heyser's excellent article in *Audio*, June 1984, "Speaker Impedance—More Complicated Than One Number," are readily apparent.

First, most speakers start out at 20Hz with a large resonance circle, like the example in *Fig. 4*. One circle will appear for each resonance peak. As you would expect, a sealed box has one complete circle for the bass resonance, while a vented enclosure would have two complete circles. If the box is supposed to be sealed, but has some prominent air leaks, these will show up as an unexpected circle (like a vent).

BREATHING AND PIGS. Box resonances, and other unwanted acoustic resonances will be revealed as small loops or "pigtails" in the curve (because these anomalies occur over small frequency spans, high resolution in your measurements is the only way to reveal them. This means more data points, especially at frequencies which exhibit rapid phase or magnitude changes). The second large resonance circle in the two-way example represents the tweeter resonance. The circle crosses the horizontal axis at the tweeter resonance close to 3kHz, curls to the left as a capacitive reactance and again crosses the horizontal axis coincident with the trough of the magnitude curve, somewhat over 10kHz.

Three-way speakers usually produce an additional large resonance circle, which indicates the presence of the midrange resonance peak. All resonances start on the left side of the graph, curl upward, as an inductive reactance, toward the right hand side and cross the horizontal axis at their resonance point, which is at zero phase angle and purely resistive. The curve then continues on to curl downward as a capacitive reactance, and finally upward—crossing the horizontal axis, coincident with the magnitude curve trough point, which is again at zero phase angle and purely resistive.

If the woofer enclosure is well braced and doesn't "breathe" as a result of cone activity, the circle will be round and symmetrical. If not, it will show distinct deformation (this will depend somewhat on the drive level used in measurement). Also, other small loops or "pigtails" may show up in the mid to high frequencies as acoustic coupling between drivers, caused by the excessive overlap of driver operating ranges.

BAD LOADS. Heyser always took special note of the angle of maximum capacitive reactance and at what frequency it occurred, the idea being that most amplifiers handle inductive loads better than they do capacitive loads. Since the complex impedance plot graphically depicts the "motion" of the impedance magnitude vector as frequency changes in respect to phase, the phase angle can be physically measured with a protractor (from the point of origin) for any point on the spiral curve.

In *Fig. 4*, the line tangent to the capacitive side of the bass resonance circle depicts the highest phase angle which occurs at any frequency. For this speaker, maximum capacitive phase angle occurs at around 100Hz, with an angle of about 32°.

Heyser usually noted a speaker with a maximum capacitive phase angle approaching or exceeding 40° as requiring a " high quality" amp. If this large phase angle occurred at lower frequencies, in the region of high musical energy content, he would suggest possible problems in the reproduction of loud "thundering" bass passages. If a high capacitive phase angle occurs at higher frequencies, over 1 or 2kHz, where amplifier slew rates become important, Heyser would also point out the difficulty in driving such a load for some amplifiers.

In conjunction with this, it is important to also note the place of lowest resistance (crossing the horizontal axis) at the highest frequency. A low resistive load at 10kHz and above represents yet another difficult drive situation (such as that presented by the old AR LST). It is a foregone conclusion that Richard Heyser did this industry a great service by constantly pointing out for amplifier designers, exactly, and in detail, what kind of load a particular speaker would present. He will be missed.

A PRIMER ON DRIVER DESIGNS

BY PERRY SINK

Speaker builders may often wonder what it is about their drivers that cause them to behave the way they do. To fully understand the implications of his choices, a speaker builder must have a basic knowledge of the variables involved in driver design. My purpose here is to examine the many trade-offs and compromises in driver design, and to clear up some misconceptions about speaker design in general.

PURPOSE OF A LOUDSPEAKER. To explain the theory behind driver design, we must understand what a speaker is intended to do. I will define this as "to perfectly match the output of the amplifier to the radiation resistance of the air." This is essentially as Jordan[1] has defined it.

A loudspeaker which is able to do this would be 100% efficient, have no residual distortions, and no frequency response or transient errors. So far, no loudspeaker has ever been made which met any of these requirements. As a matter of fact, a loudspeaker which is 100% efficient could probably be perfect in all other areas of performance as well.

No loudspeaker is 100% efficient. A few horn designs reach 50% or so at certain frequencies, but most systems are only about 1%. No loudspeaker is completely free of distortion, either. Nothing in nature is known to be able to oscillate at a single frequency without any harmonics whatsoever. Distortion figures range from 0.1% for some high quality horns and direct radiators, to 10% or more for some poorly designed speakers, especially at low frequencies. Finally, no speaker has infinite bandwidth or is completely free from transient errors. Now let's look at some of the reasons for these limitations.

THE MOVING-COIL DRIVER. The type of driver which is in the widest use today is the dynamic moving-coil type, invented by Rice and Kellog in the 1920s. It consists of a circular magnet system, a voice coil, cone, rear suspension, and surround, supported by a basket which holds the assembly together. These five relatively simple parts are common to almost all dynamic cone drivers and the care with which these parts are implemented together means the difference between barely adequate and excellent. We will examine the functions of these parts and see how driver performance changes as the characteristics of these parts are changed.

MAGNET AND VOICE COIL. In a driver, the cone is driven by a linear motor which uses magnetism to push it in and out according to the electrical input.

A voice coil is a circular, cylindrical assembly which is usually made of metal. It is thin and tubular, being hollow through the center. It has wire wound around the lower half, usually in several layers. It is made to tight tolerances, with good adhesives for high temperature and reliability.

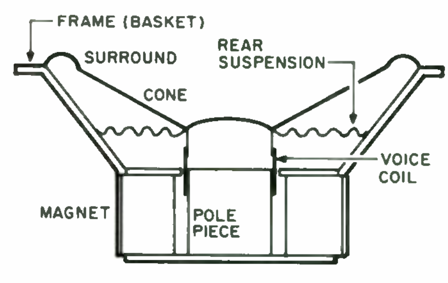

FIGURE 1: Cutaway view of a cone speaker.

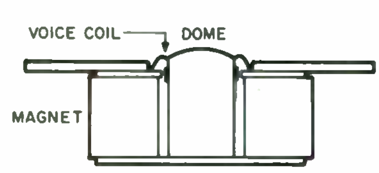

FIGURE 2: Cutaway view of a dome speaker.

The voice coil is suspended in a magnet gap (*Figs. 1* and *2*) where a magnetic field is focused on the winding. The magnetic circuit flows from the magnet through the top plate, across the gap and through the windings, to the pole piece and down the back plate, and to the other side of the magnet. The pole piece and front and back plates are made of metals which do not hold a permanent magnetic field, but only conduct the magnetic field. The whole circuit is energized by a donut-shaped, permanent magnet, usually made of ferrite.

When we feed a voltage to the voice coil, its flux lines travel in a circular pattern around the coil. The permanent magnet's flux lines are moving at a right angle to the voice coil, through the gap. The nature of magnetism is such that mechanical motion will always be at a right angle to the two magnetic fields. Alternating current causes the voice coil's magnetic field to reverse peri-

ABOUT THE AUTHOR

Perry Sink has been designing and building speaker systems since he was in junior high, and is now at the Universiy of Nebraska at Lincoln, majoring in electrical engineering.

1. Jordan, E.J., *Loudspeakers*, Focal Press, London, 1963.

odically, and this in turn causes the voice coil to move back and forth through the gap. This moves the cone and the air, and if the driver is properly designed, the relationship between power input and movement will be quite linear.

A symmetrical magnetic field is important in realizing a linear relationship between force and displacement. If the magnetic field is lopsidedly focused, then lengthy excursions of the voice coil will result in large amounts of distortion. Some manufacturers take the time to ensure the magnetic fields of their speakers are absolutely symmetrical, although satisfactory results are often obtained without a great deal of attention to this detail.

The voice coil's length in relation to the gap is also important. The voice coil will travel in a linear fashion only if the number of windings within the gap is held constant. If long excursions must be made, the voice coil must be long so that the windings will not travel outside of the gap, but lengthening the voice coil increases the moving system's mass, reducing efficiency.

Magnet weight is an important but overrated variable in speaker design. Some assume that the bigger the magnet, the better the speaker, but this is not so.

When this alternating current is fed to the voice coil, its magnetic field reacts with the magnetic field of the magnet, causing the voice coil and cone to move. It may seem logical that if the magnet is bigger, the cone will be moved more effectively, but another consideration, resonance, comes into play.

The magnet electrically damps the resonant motion of the cone and voice coil. At the driver's resonant frequency, the speaker impedance rises. This rise rejects current flow through the voice coil, and reduces the amount of power delivered to the driver. The larger the magnet, the more pronounced this impedance rise becomes. The effect of a large magnet, then, is to weaken the driver's bass response. Large magnets are useful in the midband, where efficiency rises.

We see now that the magnet size affects the "tilt" of the response curve, but it is not possible to improve a driver by merely putting a larger magnet on it. Magnet size must be optimized for the speaker's intended purpose, relating to its Q and efficiency.

The resonance, Q factor, and frequency response of a speaker are demonstrably related to each other. An excellent way to observe this is to look in the Audax master catalog, which includes complete specifications and response curves for over 200 drivers.

Audax measures their units in an anechoic chamber where the only effects upon the response curves are the inherent characteristics of the drivers themselves. Woofers function as if mounted in an infinitely large enclosure, and response curves correspond closely to the Thiele/Small parameters. For example, if a driver has a Q_t of 0.31 at 25Hz, it will be 10.2dB down at that frequency, because 0.31 log × 20 is −10.2. The response curve shows this quite accurately.

Another useful variable for the designer is the number of layers in the voice coil. Increasing the number of coil windings raises the intensity of the magnetic field. However, this also adds mass to the voice coil, and requires that the gap be made wider.

A number of things change when we increase the number of windings in the coil. More turns may reduce high frequency response by increasing the inductance of the coil. The Q may go up or down, and the force factor (BL product) may also go up or down, depending on the length of the coil, size of the magnet, and so on.

THE REAR SUSPENSION. The rear suspension's most important job is keeping the voice coil centered in the gap, but it also plays a critical part in determining the low frequency response of the driver. If a driver is mounted in an infinitely large enclosure, the low frequency response is determined exclusively by the compliance of the rear suspension, and could extend indefinitely if the suspension was infinitely compliant. Such a driver, for example, might be best used in a transmission line type enclosure, which does not function as an air spring.

Another characteristic of the rear suspension is the nonlinear relationship between force and displacement. As the assembly moves toward its limits, the suspension will become increasingly more difficult to work against, and distortion will occur. Joe D'Appolito ("More Driver Tests," *SB* 4/82, p. 43) explains why drivers measured at high power levels have higher resonances and higher Qs than when measured at low power levels.

In acoustic suspension designs, the air spring is intended to have a much greater effect on the cone motion than the suspension. In reflex designs, the high impedance of the box at resonance keeps cone motion to a minimum. The horn presents such a high radiation load impedance that the suspension stiffness is small in comparison. The majority of the energy is channeled into the surrounding air instead of the nonlinearities of the suspension parts. In a transmission line, the air resistance presented by the absorptive materials constitutes a greater effect upon cone movement than the suspension.

Rear suspensions are usually made rather stiff as this prevents potentially damaging excursions. This increases the power rating, at the expense of low frequency efficiency. Maximum acoustic output will probably be less than that of a speaker with a more compliant suspension, due to the nonlinearities discussed earlier. Perhaps a better way to prevent excursion-induced damage is to condition the signal before it reaches the amplifier.

Because resonance is determined by mass and compliance, the free air resonance is a result of the mass of the cone and the compliance of the rear suspension. If the suspension is made twice as stiff, the resonance frequency will be multiplied by the square root of 2. The Q will also rise in a similar fashion.

Thus we can see that proper suspension design is critical to determining the performance of the speaker.

THE CONE. The cone is connected to the voice coil so voice coil movement in turn moves air. The cone is extremely critical in terms of frequency response and efficiency, and must be designed very carefully.

Many cones are made of paper and sometimes treated with other materials. Plastic cones are also common, including polypropylene, Bextrene, Neoflex, TPX, polysulfates and others. Sometimes layers of different materials are used, and occasionally metals like aluminum, titanium and certain alloys.

The cone's diameter and mass are its two most important parameters. The first of these, the diameter, determines the high frequency cutoff. When the wavelength is shorter than the cone's diameter, the cone is unable to effectively reproduce that frequency. A cone cannot have a natural mechanical cutoff below a frequency whose wavelength is equal to the cone diameter.

If a cone could be a rigid piston, its response would be flat to cutoff, and its power response would fall above this frequency, due to cancellation effects. However, no cone is infinitely rigid and this is advantageous because the cone will flex, and only the center portion will move at high frequencies. This allows the cone to reproduce wavelengths much smaller than the cone itself. If the flexure characteristics are carefully controlled, the cone may have smooth frequency response to an octave or two beyond that of a rigid piston of equivalent size.

Cone mass is extremely important, since it relates directly to efficiency and reason and behavior. A common misconception is that it is also directly related to high frequency response and transient response, but this is not necessarily true.

A perfect piston is mass controlled in terms of excursion. A given voltage applied to the voice coil will result in a corresponding force applied to the cone, and the distance that the cone travels is determined by the mass of the cone and the duration of the signal.

The excursion diminishes with the square of the frequency. In a mass-controlled system, acceleration is entirely independent of frequency. Therefore, since acceleration is proportional to mass, then frequency is also independent of mass. When you turn up the volume on your amplifier, you're simply causing the voice coil to accelerate faster. This means that higher SPLs are achieved by allowing the acceleration to rise, either by applying more force to the cone or by reducing the cone's mass.

Mass determines low frequency response because it determines resonance. In a typical driver, doubling the mass will raise the Q and lower the resonance by the square root of 2, and extend the frequency response by about an octave. It will also reduce the sensitivity of the speaker by 6dB.

Even though excursion decreases significantly as frequency goes up, a mass-controlled system will have flat frequency response because the impedance of the air rises correspondingly, and these two factors cancel each other out.

Cone material choice depends on the application and has been debated for many years. Basically, there are two approaches.

The most common method is to use stiff but lossy cone materials which do not transmit waves very well. When a pulse originates from the voice coil, the wave travels from the center to the edge, where it should be absorbed by the surround. Soft cone materials absorb this wave as it travels, but they tend to dissipate it rather slowly.

The second approach is to use a low-loss material, such a metal, which transmits waves at extremely high speed, so the wave travels quickly to the surround where it is immediately absorbed (if the surround is properly designed).

There are excellent examples of speakers using either technique, and even hybrid designs utilizing both techniques.

DOMES. Dome speakers are used for high frequencies, because a small diaphragm is necessary for short wavelengths. In a dome speaker, the diaphragm need not be any larger than the voice coil. In a cone speaker, the voice coil is always smaller than the cone, and a larger voice coil may be needed to accomodate the power being applied to the system.

As its name implies, a dome speaker has a dome-shaped diaphragm the same size as the voice coil, and it is suspended by a small surround on the outside edge. Domes are usually made of cloth which is treated for damping, or soft, lossy plastics.

While a cone becomes smaller as it flexes, a dome turns from a ball into a ring transducer. Because of this, it is more difficult to make a dome reproduce wavelengths which are smaller than the diaphragm, than it is with a cone. Most domes, when measured off axis, exhibit sharp cancellations, although carefully designed domes don't have as many problems in this area.

Perhaps the most significant difference between a cone and a dome is that in a cone, vibrations are absorbed by the surround, but in a dome, they must be lost within the diaphragm itself. This usually necessitates lossy materials, which may not always suit other purposes.It is extremely difficult to make domes work effectively at low frequencies.

THE SURROUND. The surround is a critical part of the driver. It must be flexible enough to allow large cone excursions and lightweight to prevent distortion problems. It must also be unaffected by pressures inside the cabinet, and be viscous to absorb sound waves from the cone edge. This last capability is the most important.

When the voice coil moves, a flexure wave travels from the center of the cone to the edge, where it must be absorbed by the surround. If these waves are not absorbed, they will be reflected back to the center of the cone, and standing waves will develop. A properly designed surround will absorb these waves and prevent extraneous peaks and dips in the driver's frequency response.

The viscosity, mass, and compliance of the surround must be carefully optimized to correctly damp the cone vibration. These characteristics determine the termination impedance, a variable which changes with different cone characteristics.

The most commonly used materials in the surround are treated cloth, foam, or soft rubber.

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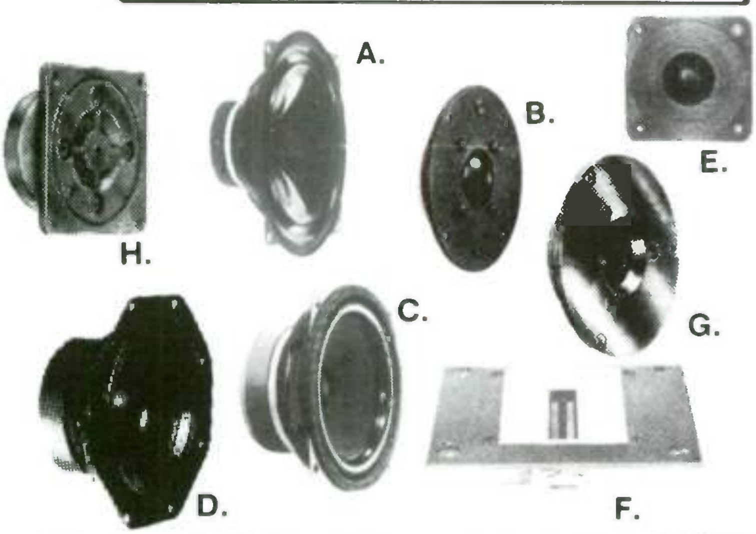

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LOUDSPEAKER CABINETS

BY PETER MUXLOW

Thoughts and tests on the ideal speaker cabinet have included:

"Mechanical resonances in LSs (loudspeakers) are probably creating one of the most audible effects in today's audio systems."[1]

"There is little doubt that the secondary sound output due to transmission through and vibration of the enclosure structure changes the characteristics of the loudspeaker quite noticeably and perhaps goes some way to explain why similar cabinets with identical drive units can sound so different."[2]

The cabinet's or enclosure's function is to control the sound from the back of the loudspeaker (LS). These sound pressure variations inside the cabinet, however can cause the walls to flex or vibrate. This wall vibration acts as another speaker and creates what is called secondary radiation—not exactly what you want.

To give you an idea how little the walls must vibrate to equal the sound output from the loudspeaker cone, let's take a typical cabinet with a surface area 50 times the driver's cone area. For the same sound output, the cabinet walls only have to vibrate 1/50th the displacement of the cone. For example, at 50Hz, for a 10″ loudspeaker to radiate a sound level of 1 acoustic watt, the cone must move 1″. The equivalent cabinet wall movement for the *same* sound output is .02″.

To make matters worse, the walls do not flex simply. They have their own resonances which "store" sound energy in the cabinet walls. Once the music has stopped, the walls keep on "playing." In other words, any form of resonance is

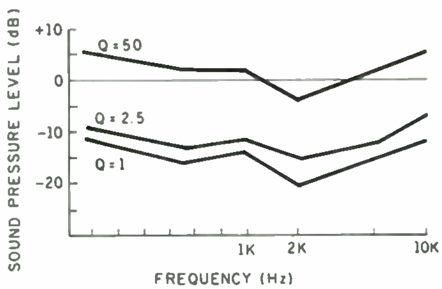


FIGURE 1: Detectability of resonances with classical music, 0dB program level. At Q=1 at 1kHz: audible resonance is −15dB below the program level. At Q=50 at 1kHz: audible resonance is 2.5dB above the program level.

a form of time delay:

$$R_r = \frac{2.2Q}{F_r}$$

where F_r = freq. of resonance

R_r, the delay time or reverberation time, is the time it takes for the energy stored to decay 60dB. This form of distortion is called delayed resonance and was first identified in 1946 by Shorter of the BBC.[3] You might still think this internal sound pressure inside the LS cabinet walls of, say, ½-inch chipboard, wouldn't have much audible effect. Let's look at how much of this wall vibration you can tolerate before you hear a coloration of the original sound.

PSYCHOACOUSTICS. This is what we hear, not always what we measure. In England, a series of tests were carried out where this delayed resonance was introduced artificially, via electronics, into a signal. The result was clearly audible (*Fig. 1*). The surprise was the high Q resonances were not the problem; what was clearly audible was the medium to low Q resonances[4].

There appear to be several reasons for this.[5] Musical transients, according to statistics, have less chance in exciting high Q resonances fully. A Q of 1000 at 1Hz would have to be within 0.1Hz and continue for ten seconds to fully excite the resonance. A low Q resonance doesn't require that much time to come to its maximum. These resonances are forced, and once the music signal exciting them is removed, the resonant system goes back to its own natural frequency.

This natural frequency in low Q resonant systems can be substantially different from the frequencies in the original music. With high Q resonances, the forced and natural resonances are much the same, making the resonant overhang more difficult to detect within the music.

Harwood of the BBC also conducted a series of controlled listening tests to determine the audibility level of this secondary radiation (*Fig. 2*) from a cabinet. He notes this curve has no theoretical backing whatsoever, and is based solely on experimental listening data.

How do you go about controlling this secondary radiation? Several schools of thought exist, but let's start with the air volume inside the cabinet.

1. Moller, H., "Multidimensional Audio," *JAES*, May 1979.
2. Stevens, W., "The Sound Radiated from Loudspeaker Cabinets," *Proceedings of the AES 50th Convention*, March 1975.
3. Shorter, D., "Loudspeaker Transient Response," *BBC Quarterly*, 1946.
4. Fryer, P., "Loudspeaker Distortions," *Hi-Fi News & Record Review*, July 1977.
5. Toole, F.E., "Loudspeaker Measurements and Their Relationship to Listener Preference," *JAES*, April 1986.

CAVITY RESONANCES. Inside every cabinet, a volume of air is determined by the size of the cabinet. This trapped air, with its own mass and stiffness, has a number of what are called resonant modes—frequencies where the air resonates. These resonances are developed from the standing waves inside the cabinet which reinforce and cancel at specific frequencies and are dependent on the cabinet's dimensions:

$$F_r = \frac{C}{2}\sqrt{\left(\frac{A}{H}\right)^2 + \left(\frac{B}{W}\right)^2 + \left(\frac{C}{D}\right)^2}$$

where F_r = frequency of resonances
C = velocity of sound (meters per second)
H, W, D = cabinet dimensions in meters
A, B, C = mode order

These air resonances create amplification of air pressures—around 15–30dB. Such excessive pressure variations inside the cabinet cause additional problems with cabinet wall vibration. In addition, they present a variation in acoustic load to the back of the loudspeaker cone, thereby affecting its motion. You can choose to design an enclosure where the cabinet's cavity resonances are higher than those the driver will operate. This is called making the cabinet acoustically small.

The maximum dimensions for an enclosure to be acoustically small is:

$$D = \frac{C}{2F}$$

where D = largest dimension of the enclosure in meters
C = velocity of sound (334 meters per second)
F = lowest frequency of operation (Hz).

For example, consider the largest dimension for a bass enclosure for operation up to 500Hz. Make the lowest cavity resonance 1kHz. The maximum dimension must be:

$$D = \frac{344}{2 \times 1000} = 0.172 \text{ meters}$$

One way to make a large cabinet acoustically small is to subdivide it into smaller volumes by internal partitioning.[7]

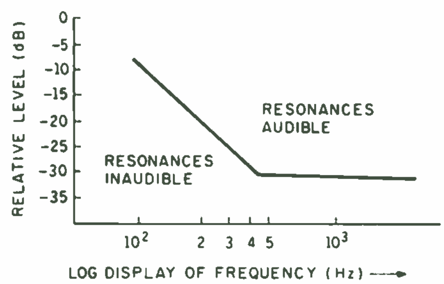


FIGURE 2: Audibility of resonances.

CAVITY RESONANCE DAMPING. You can use a filling inside the cabinet to partially absorb or dampen the sound pressure variations. The more sound energy you can absorb in the cavity with the right material, the less sound will get to the walls and the less they will vibrate. This filling will also stop sound pulses from being reflected off walls and around the cabinet, back to the loudspeaker cone. If you don't stop these reflected pulses, they will either be reradiated through the cone, or will interfere with the cone movement and cause a sound cancellation.

As to what form of filling or absorbent material you should use, being a New Zealander and sharing the land with 60 million sheep, I'm for wool. I'm not just being parochial—there are good technical reasons. The acoustic impedance for long-haired wool is close to air above 100Hz at a packing density of 8kg/cubic meter. In other words, no reflected waves will occur and all the energy will be dissipated in the wool. It has a constant attenuation rate over the audio frequency range, so it will present a constant resistive load to the back of the cone.

Fiberglass has the wrong characteristics.[8] It has an impedance which is greater than air, and its attenuation is frequency dependent, especially around 50Hz where it fluctuates badly.

In addition, most filling materials increase the cabinet's effective volume by about 20%. Wool slows down the sound's velocity by aerodynamic drag. This reduction, in the case of wool, is about half free-air value at 30Hz. Because the sound velocity is reduced, the sound behaves as though the enclosure is larger.

An interesting enclosure filling has been suggested in patent GB2146871. The patent proposes using activated charcoal, with particle diameters between 0.1 and 0.3mm, to reduce pressure variations by adsorbing the air onto the charcoal's surface. It is claimed to reduce the box volume by one-third. The finite time taken to adsorb the air makes it of no use above 80Hz, so all you subwoofer enthusiasts, get to it!

RESONANCE MEASUREMENT. With all this theory, how do you go about finding the right filling and the right amount? You can test in two ways: in the time domain, and in the frequency domain.

The time domain observes transients in real time and approximates what happens under music conditions. The frequency domain, however, is under steady-state conditions.

Cavity resonances and damping effectiveness are simple to measure. Place an omnidirectional mike inside the cabinet and apply a sweep signal to the driver. The mike's output will indicate peaks at specific frequencies where the resonances occur. Keep adding amounts of absorption (e.g., wool) until these resonances are minimized.

An alternative method is to measure what is called the loudspeaker's motional impedance. This is impedance when it is moving, and is proportional to the cone velocity. The cone motion will be affected by any cavity resonances inside the cabinet, therefore, resonances will show up as irregularities in the curve, motional impedance against frequency. *Figure 3* shows the circuit I used. This test method is valid only up to about 300Hz. Above this level, the cone normally doesn't move as a unit.[7] Incidentally, this is one way to derive a signal for motional feedback.

Finally, a method for determining the optimum amount of absorption measured in the time domain is courtesy of A.R. Bailey, who is known for transmission line speaker designs. Here, you create an acoustic pulse at the loudspeaker position—the speaker hole being blocked off—and use an oscilloscope to monitor the mike's output inside the cabinet. You will see the first pulse, followed by a series of reflected pulses, as they bounce around the cabinet's inside walls. Adjust the amount of absorption to minimize the amplitude of the reflected pulses (*Fig. 4*).

The acoustic pulse is generated by discharging a capacitor through a length of fuse wire, which causes it to vaporize. A 1000μF capacitor charged to about 250V is discharged through 1cm of 40swg tinned copper wire. This, according to Bailey, does the trick.[9]

Back to the question of secondary

6. Harwood, H. and R. Mathews, "Factors in the Design of Loudspeaker Cabinets," *BBC Report*, 1977.
7. Shorter, D., "Loudspeaker Cabinet Design," *Wireless World*, November 1950.
8. Bradbury, L., "The Use of Fibrous Materials in Loudspeaker Enclosures," *JAES*, April 1976.
9. Bailey, A.R., A Nonresonant Loudspeaker Enclosure Design," *Wireless World*, October 1965.

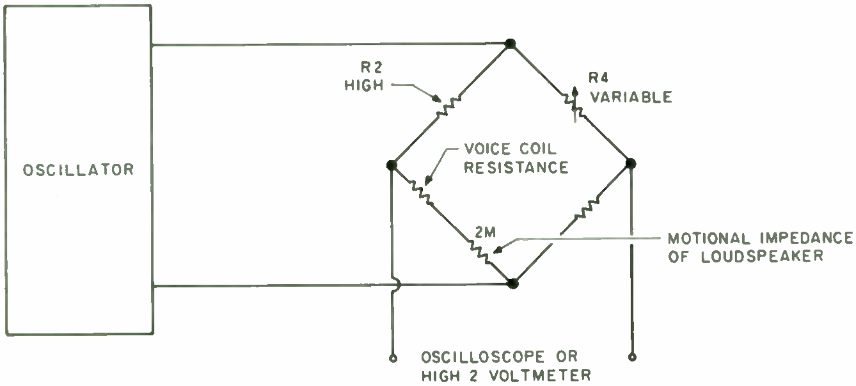


FIGURE 3: Measurement of motional impedance. R2 has to be a high resistance to feed constant current through the voice coil from the oscillator—this provides a constant force. The voltage across Zm when fed with constant current represents the back emf generated by the voice coil and that in turn represents the cone motion. To set up, the cone is prevented from moving by putting a wedge into the voice coil gap. The motional impedance Zm will now be zero. The bridge is balanced at 300Hz by adjusting R4 and the wedge is removed. The bridge output is now equal to the motional impedance. This can now be plotted against frequency and any irregularities due to cavity resonances noted.

radiation. I hope you've learned how to minimize the cavity resonance effects, so let's look at cabinet wall vibration.

WALL RESONANCES. The sound pressure variations inside the cabinet (air resonances and all) cause the walls to vibrate. These wall vibrations are not simple since they are modified by the walls' mechanical resonances. This complex wall vibration makes it impossible to design solely by theory.

What you want to do is push up the wall resonances as high as possible[10] because:

1. Sound pressure variations inside the cabinet drop off at high frequencies;
2. The panels' modes are more difficult to excite at high frequencies;
3. High frequencies are easier to damp because the vibration amplitude is less and damping materials are more effective at these frequencies.

Material properties, the dimensions and construction all determine wall resonances. Two important material properties are The Young's Modulus and the damping factor.

The Young's Modulus is the term used to describe how stiff the material is, or its stress-to-strain ratio. The damping factor, sometimes known as the loss factor, is the material's internal friction. This measures the materials' ability to dissipate energy within itself at the resonance frequencies. We'll look at this measurement later.

A clamped rectangular panel has a series of resonant frequencies:

$$F_r = \frac{12}{2\pi}\left(\frac{D}{P}\right)^{1/2}\left(\frac{7}{2}\right)\left|\frac{1}{a^4}+\frac{4}{7}-\frac{1}{a^2b^2}+\frac{1}{b^4}\right|^{1/2}$$

$$D = \frac{Et^3}{12(1-v^2)}$$

where D = bending stiffness
t = panel thickness
P = density kg/cubic meters
E = Young's Modulus
v = Poisson's Ratio
a, b = panel length and width.

Let's look at the above equation and see what you can do about increasing the wall resonant frequencies as high as possible. To maximize these frequencies, the numerator should be maximized and the denominator minimized:

- Panel material density—the lower the material density, the higher the resonant frequency.
- Poisson's Ratio—this is also a material property. When a solid is being stretched in one direction, it extends. In the other direction at right angles, it contracts. The ratio of these two strains is called Poisson's Ratio.

The panel's width and length are fixed by the cabinet dimensions. All you should keep in mind is the larger your cabinet is, the lower the resonant frequencies are going to be:

- Panel thickness—adding thickness adds mass which will push up the resonant frequencies and will also cause the panel to vibrate with a smaller amplitude for the same force. It will, however, store more energy in its resonances, which will be released later.
- The Young's Modulus—this is a material property and should be as high as possible. You can, however, increase the cabinet walls' rigidity—by bracing.

BRACING. This works by breaking up your wall into two independent panels, each having its own fundamental resonant frequency. In *Fig. 5*, you see the results of applying different forms of bracing and the corresponding different resonant frequency. Keep two things in mind here:

1. The bracing material must be stiff. Soft woods have given trouble in the past because they are not stiff enough. Perhaps you should consider a metal brace.
2. The brace should be placed slightly off-center so the two panels' resonant frequencies are different. This is so both panels don't transmit sound through at the same resonant frequency.

Ideally, no two walls should have the same shape. The reason is the same as for off-center bracing—to stagger the resonant frequencies. The cube is a bad shape because it has six identically-sized walls. The larger the cabinet walls, the lower their resonant frequencies. A large cabinet must be thicker or better braced for equivalent performance.

THE FRONT PANEL. The force driving the cone has an equal and opposite force acting on the magnet which is

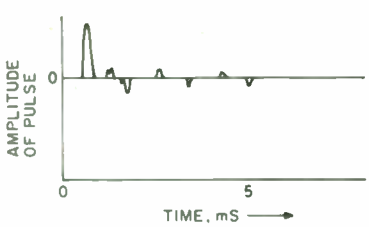


FIGURE 4a: Impulse response of ideal cabinet.

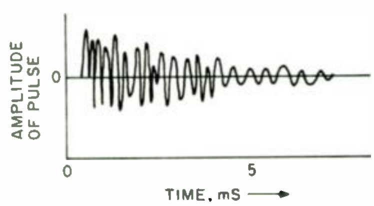


FIGURE 4b: Impulse response of cabinet with no damping.

10. Iverson, J., "The Theory of Loudspeaker Cabinet Resonances," *JAES*, April 1973.

coupled to the front panel, causing vibrations.

This is an example of Newton's law: where a force acts, there will always be an opposite and equal force. The loudspeaker driver's efficiency is low due to the large impedance mismatch between the cone and the air. This means the force applied to the magnet and to the front panel is much higher than the sound pressure generated by the cone. To minimize this vibration:

1. Use a different, stiffer material for the front panel;
2. Make the front panels' width only slightly wider than the driver's diameter;
3. Put a brace behind the magnet, and some type of damping material in between.
4. Decouple the speaker from the cabinet by compliant mountings (such as rubber bushings). The reaction force doesn't get from the driver to the baffle; it is dissipated in the mountings.

IDEAL WALL MATERIAL. A number of philosophies suggest ideal materials for a loudspeaker cabinet. One is the "concrete school," which endorses using high density materials and extensive bracing and damping to make the enclosure so inert that, it is claimed, the resonances are truly damped with no audible delayed radiation.

Another approach, pioneered by the BBC, maintains resonances are a fact of life. Since you can't get rid of them, choose a material which will have the least audible effect and damp it. This method uses only moderately-stiff, relatively light materials such as marine plywood. This is highly-damped to give a low level of mid-band coloration in the 100Hz–500Hz range (although the cabinet becomes transparent at low frequencies).

The latest philosophy is the "sandwich school," currently followed by Celestion and Wharfdale of England. They minimize the mass as much as possible by making the cabinet walls of a composite sandwich material (for example, a honeycomb aluminum material such as used on airplanes for weight reduction). These sandwiches have high rigidity and low mass, but a very high cost. Proponents maintain the cabinet should be as light and rigid as possible, because high mass in a cabinet (such as from the "concrete school") will store energy which will be released over a longer time scale. With this method, damping the sandwich will broaden the resonance area which, as we saw before, was psychoacoustically more audible.

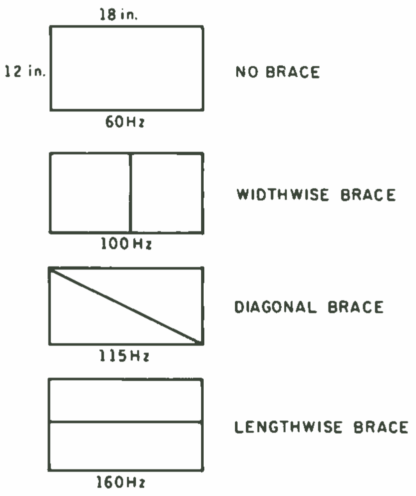


FIGURE 5: Fundamental resonance frequencies, with 0.02" sheet steel clamped at edges.

RESONANCES AND VIBRATIONS. How do you go about measuring these vibrations? If you are KEF, you attach 130 vibration pickups to the cabinet walls, place the loudspeaker in an anechoic chamber, then feed in a test signal, and process the 130 outputs from the pickups into a computer programmed to give a visual display of how the wall flexes. Not exactly the facilities you and I have at home.

Here is a simple audible method. Place two pencils (or a piece of doweling) on the cabinet wall and place a light can filled with lead shot on top of the pencils. Feed a varying frequency into the speaker. The lead shot will rattle when excess vibration occurs at specific frequencies.

If you want to know how much the panel is moving (the displacement), scatter some dry sand onto the cabinet wall and feed a signal of varying frequency and amplitude into the loudspeaker. With a magnifying glass, you will see when the grains of sand begin to dance.[11]

The amplitude of displacement is:

$$(\mathrm{mm}) = \frac{g \times 10^3}{(2\pi f)^2}$$

where g = acceleration of gravity (9.806 meters/second^2)
f = frequency

If you want to be a little more sophisticated, you could build a photoelectric vibration probe.[12] This operates by beaming light onto a vibrating surface. The light source, an LED, is focused onto the cabinet wall which reflects it back into a phototransistor. The current in the phototransistor is proportional to the cabinet wall's vibration. A phono cartridge or a contact pickup, such as is used to amplify acoustic guitars, can also be used to measure vibration.

WALL RESONANCE DAMPING. Once you have decided upon the material for the cabinet, you can help minimize the resonances and wall vibration by affixing another material with good damping properties. An ideal damping material should have high frictional losses. The vibration energy is converted into heat by alternate stretching and compressing of the damping material. It is very important that the mass per unit area for both materials, the cabinet walls and the damping material, be about the same. This gives a good mechanical match between the two stiffnesses.[13] Using an analogy in electrical terms, when the source impedance equals the load impedance, maximum power transfer takes place. The damping material's performance is measured by its loss factor.

DAMPING MEASUREMENTS. To find the right type and amount of damping material, you must first measure the cabinet walls' undamped resonances. This shows the frictional losses or the damping of the cabinet walls by themselves.

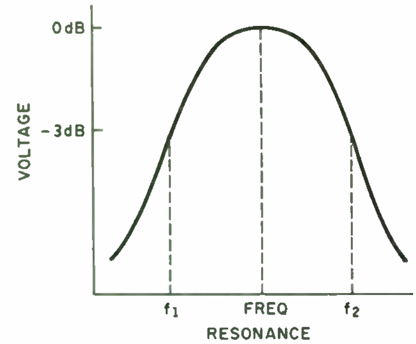
The damping factor is related to Q of the resonance curve by:

$$n = \frac{1}{Q}$$

A low value of Q indicates high internal losses, while a high value indicates low internal losses. The Q can be determined in a number of ways. In the steady-state mode, it is the ratio of the resonance frequency to the span of frequencies, which are 3dB down either side of the resonant frequency (*Fig. 6*).

For a measurement in the time domain, apply a mechanical impulse to the cabinet wall. This impulse should be a repeatable force, such as a fixed weight dropped from a fixed distance. Observe the damped oscillation via pickup on an oscilloscope (*Fig. 7*). The Q is the oscillation's rate of decay and is equal to the

11. Meyer, E. and E.G. Neuman, "Physical and Applied Acoustics," *Academic Press*, 1972.
12. Agren, "A Photoelectric Vibration Probe," *Electronic Engineering*, December 1974.
13. Linkwitz, S., " A Three-Way Enclosure Loudspeaker System," *Speaker Builder* 2/80.

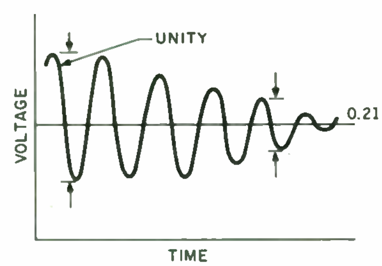


$$Q = \frac{2\pi \text{ FREQ (RESONANCE)}}{f_1 - f_2}$$

FIGURE 6: Measurement of Q, frequency domain.

number of half-cycles that occur from unity to a value of 0.21 of unity.

To evaluate your damping material, attach it to the cabinet walls and repeat the Q measurement. The difference in measurements between the damped and undamped walls will show you how effective it is. Since the cabinet wall edges are clamped, the damping in this area is inefficient. Harwood did some tests[6] and found the damping material area needed to be only 50% of the cabinet wall area.



Q = NUMBER OF 1/2 CYCLES BETWEEN UNITY AND 0.21 OF UNITY

FIGURE 7: Measurement of Q, time domain.

MATERIALS TESTS. If you want to experiment with materials for cabinet walls and damping without building a cabinet, you can build a simple jig. Clamp your sample at one end in a vise and attach a vibration transducer (e.g., a contact pickup) to it. Hit the non-clamped end with the repeatable force and measure the damped oscillations as before. You should measure the decay "across" the width and length of your sample since it might not be the same. Celestion fell into that trap when they made their prototype honeycomb cabinets. Their material had a different stiffness in different directions. They changed the way they cut their cabinet walls from the sheet honeycomb material on the production run; and a different sounding cabinet resulted.

Another test is to suspend your sample cabinet wall by four fine wires, one at each corner. Then, let a baseball (or a ball of rubber or cork) fall from a predetermined height onto your sample. Look at the shock wave on the oscilloscope as before.

A couple of new interesting materials are being used by speaker manufacturers that might be worth looking at. B&W, an English firm, uses a glass-reinforced concrete in their midrange and tweeter enclosures. Jamo, a Danish company, uses a cement mixture injection moulded between polystyrene sheets for their front panel.

ADDITIONAL EFFECTS. The loudspeaker's response is altered by reflections from the cabinet edges and other protrusions. This is known as diffraction. It is interesting that, in a previous article in *SB*,[14] it was claimed that diffraction has no audible effect under normal listening conditions. Barlow[15] proposes the following test which refutes this claim.

He mounted a single driver in a 30cm sphere which has a 30cm detachable baffle. When fed with white noise, he claimed the difference with and without the baffle was clearly audible. Kates also supports their audibility after a series of tests.[16] To minimize diffraction, avoid mouldings, all sharp boundaries on the front of the baffle, and any reflecting objects.

Cabinet width seems to be an important psychoacoustical factor. Martin Colloms reported a series of tests on 85 pairs of loudspeakers where there was a high correlation between better stereo imaging with narrow-fronted cabinets.[18] Harwood makes the same point![19]

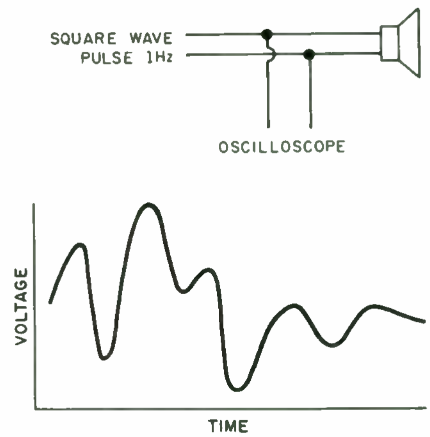


FIGURE 8: Oscillation of a poorly damped cabinet.

HOW AIRTIGHT? In the case of the infinite baffle, it is important to know whether the cabinet is airtight. A simple method is to pulse the loudspeaker with a 1Hz square-wave and observe the back emf (electromotive force) of the voice coil on a scope. If the cabinet is well-sealed, the oscillation will be nicely damped; otherwise, it will be irregular, as in *Fig. 8*. If you don't have a 1Hz generator, an old house bell with the clapper loaded to get the right frequency will do the job just as well.

Good luck with your building and let us know about your findings.

14. Kral, R., "Diffraction—The True Story," *Speaker Builder* 1/80.
15. Barlow, D., "Loudspeaker Coloration," *Wireless World*, March 1978.
16. Kates, "Loudspeaker Cabinet Reflection Effects," *JAES*, May 1979.
17. Baxandall, P., "Low-Cost, High-Quality Loudspeaker," *Wireless World*, September 1968.
18. Colloms, M., "Shattered Images," *Hi-Fi News & Record Review*, June 1979.
19. Harwood, D., "Some Factors in Loudspeaker Quality," *Wireless World*, May 1976.
20. Tappen, P., "Loudspeaker Enclosure Walls," *JAES*, July 1962.

LOUDSPEAKER TUNE UP

BY JOHN BUSCHMANN

Recent *TAA* articles have dealt with the active electronics components. The *passive* components of the loudspeaker reproduction chain can also benefit from similar work. A variety of simple modifications you can perform will optimize the performance of your stereo system. In this article I describe some techniques that can be used to "tune-up" the performance of your loudspeaker system.

My speakers are Cizek Model 1 units that are representative of many popular designs. They are a two-way acoustic suspension design using a custom built 10" woofer and a 1" soft-dome tweeter (Peerless K010 DT). Crossover is at 1.5kHz, cabinet volume is 1.4 cu. ft., impedance is 4Ω, and rated power handling capability is 150W. The power amp driving them is a Carver Model M400-t, capable of 300W per channel into 4Ω. My listening room is set up as shown in *Fig. 1*.

MODIFICATIONS. Wire and connectors are the first areas for improvements. The Cizek manual recommends the use of 12-gauge stranded wire. First I tried 12-2 Romex purchased at the local hardware store. While not stranded, it is heavy and inexpensive. I soldered short

ABOUT THE AUTHOR

Mr. Buschmann is a chemical engineer designing air pollution control equipment, whose interests have always been divided between electronics and chemistry. He built his first crystal radio kit at the age of seven and for a time held an amatuer radio license. During college Mr. Buschmann subscribed to TAA and built his stereo components from kits. After his subscription lapsed, he "moved up" to high quality commercial equipment. He has since resubscribed and rebuilt almost all his commercially-made components. Mr. Buschmann, age 35, is married and has three little girls.

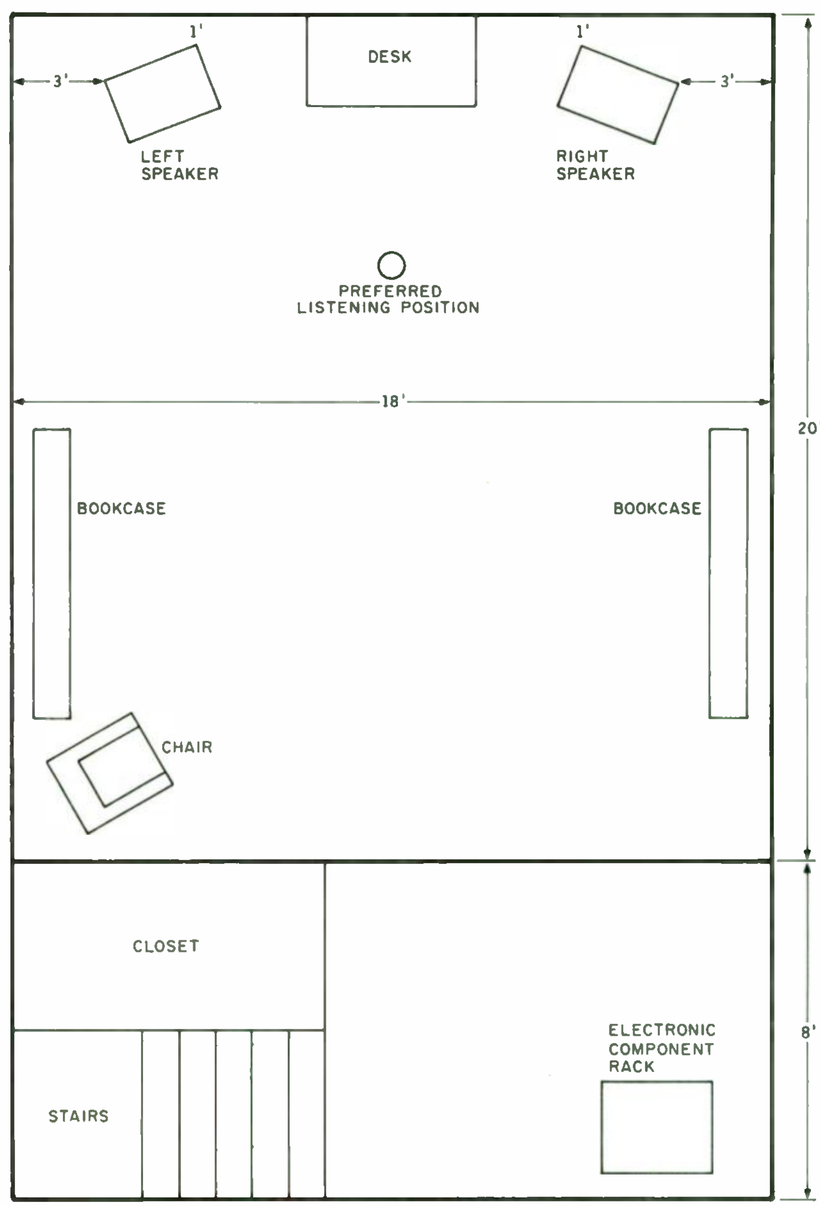


FIGURE 1: Room arrangement and preferred listening position.

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lengths of 16-gauge zip cord to each end to mate with connectors—spring-clip types at the amp and Radio Shack banana plugs at the speakers. I found that after a few weeks the sound became muddy because the connectors needed cleaning.

Switching to heavy duty, gold-plated brass banana plugs and treating all connections with Tweek contact enhancer improved the high end somewhat and increased the interval between required cleaning to a couple of months. Unfortunately, after a year or so the Tweek decomposed the nylon parts of the connector at the amp, leaving four metal tabs about ¼-inch square sticking out as the remains of the output terminals. The solution is to (carefully) solder the speaker wires directly to these terminals. I was surprised at the improved bass definition resulting from the better connection. The solder joint is much more stable over time than most mechanical connections and has not required any more attention.

In the POOGE-2 article (*TAA* 4/81), authors Jung and Marsh recommend the use of litz speaker wire, and in fact most high performance cables are now this type. I want to test this type of cable but I am discouraged by both the high cost of commercial cables and the tremendous amount of labor involved in fabricating (spinning) homemade ones.

Commercially available telephone trunk cable can be purchased on 500′ reels for 35 cents a foot. Typical construction is 20 individually insulated conductors of #24 solid copper wire with a tight fitting overall sheath. This is a very suitable alternative for speaker cables. The individual conductors do not suffer from high frequency roll off or phase shift caused by the skin effect, while the bundle has the equivalent area of a #11 solid conductor. The tight bundling of the cable tends to reduce the individual conductor's inductance. The desirable attributes of OFHC wire and low dielectric insulation are lacking, but at a fraction of the cost of high performance commercial cable, I thought it was a good compromise.

I used two of these cables, one hot and one ground, for each speaker. I stripped and twisted the ends of the conductors as recommended by Jung and Marsh. At the amp end I soldered the stiff cables to a more flexible short pigtail of #16 zip cord, which I then soldered to the amplifier output terminals. You need a high wattage gun to solder these cables.

I removed the five-way binding posts on the speakers, ran the new cables through the resulting holes and soldered them directly to the crossover circuit board inside the cabinet. The cables fit very snug in the holes and there is no apparent air leakage. You may use other methods, such as feed-through insulator or an adapter plate, to achieve the same hard-wired conection on your speakers.

I also replaced the #18 internal wiring of the speaker with this cabling, but I kept a ½-inch piece of the original wire attached to each driver spade connector, which I soldered to the stripped end of the new cable. I reinserted the spade connectors into the drivers and carefully soldered to form a permanent low impedance connection.

The resulting sound is a great improvement in midrange clarity, high frequency detail, and low frequency damping. Best of all, there is no deterioration with time.

My crossover is the next improvement area. *Figure 2* shows its circuit diagram. I was pleasantly surprised by the high quality components used, considering the age and moderate price of the speakers. The low-pass inductor (L1) was air-core wound with #17 wire and the capacitors appeared to be Mylar film types. I added 1μF Mylar bypass caps to the existing caps. A state-of-the-art design would use all polypropylene caps for the best sound. These are available but expensive. Because the switch and pots contained both ferromagnetic conductors and mechanical contacts I elected to jumper or replace them with fixed resistors and copper wire. The values of Ra, b, and c are selected to balance woofer and tweeter output level. The revised circuit is shown in *Fig. 3*.

You may find your system contains a low quality crossover with electrolytic caps or a low-pass inductor wound with small wire on an iron core. These components should be replaced as they are an absolute detriment to good sound. Madisound Speaker Components is a

PARTS LIST # 1

Resistors

R1	3Ω, 10W
R2	4.5Ω, 5W
R3	2Ω, 5W H.F. level controls
R4	10Ω, 5W H.F. contour controls
R5	2.5Ω, 5W
R6	6Ω, 5W

Capacitors

C1	50μF
C2, 3	25μF
C4	10μF

All capacitors Mylar type.

Inductors

L1	#17 wire
L2	Ferrite core, #24 wire
L3, 4	#24 wire
SW1	System "Q" selector adjust LF damping

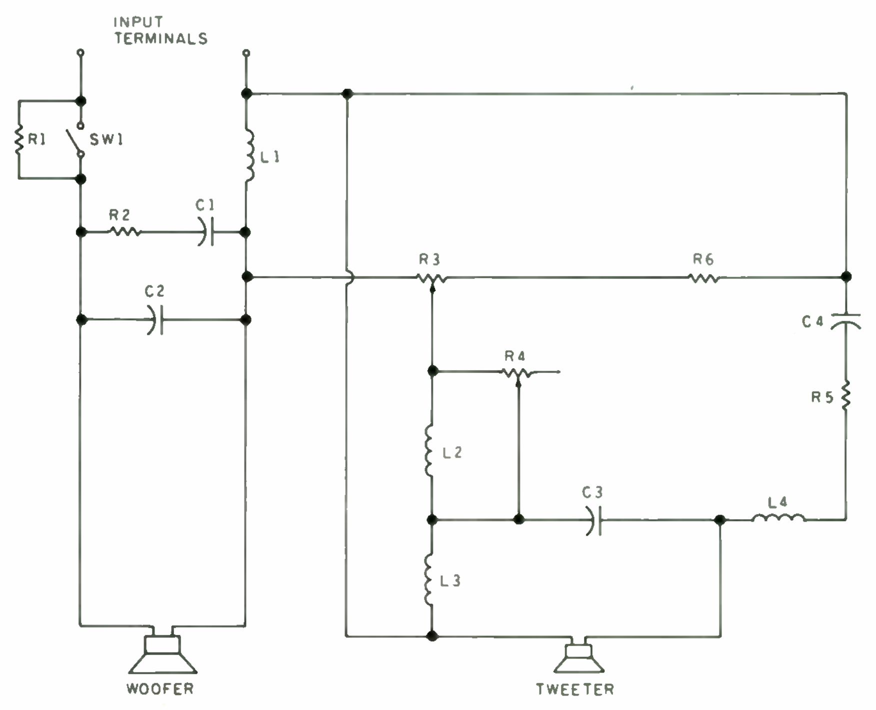


FIGURE 2: Original crossover design.

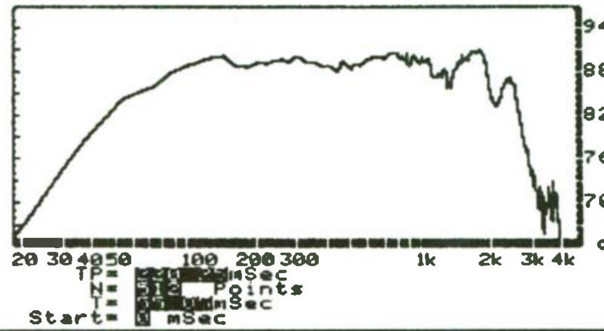
WOOFERSWOOFERSWOOFERSWOOFERSWOOFERSWOOFERS

MADISOUND 8152 – 8"
Polypropylene Woofer

FS	32 Hz +/-2 Hz
Mmd	34 Grams
Cms	1.05 X 10^{-6} CM/D
Vas	65 Liters
Rscc	5.2 Ohms
Z min	5.6 Ohms
Z max	47 Ohms
vcL	.6 mh
Qms	2.9
Qes	.39
Qts	.35
Xmax	2.4mm pk
VD	50 cm^3
Surround	Foam
Magnet:	20 Oz.. Ceramic
Voice Coil	1.5" Kapton 2 Layer 8 ohms
Cone	Clear Polypropylene
Power Handling:	75 WATTS
Frequency Response:	35-3K HZ
Efficiency:	92.5 DB 1W/1M

USES: Home, Hifi, Autosound Woofer

Price: **$25.80**

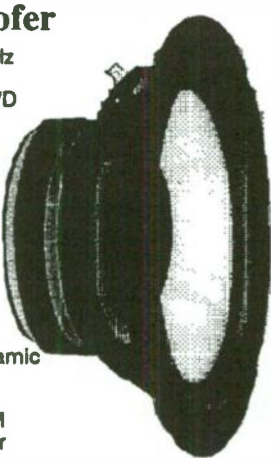


MADISOUND 8152 BASS REFLEX ALIGNMENTS

*Optimum

BOX VOLUME: VB	1.0 CUBIC FT.	1.77 CUBIC FT.	2.0 CUBIC FT.	2.5 CUBIC FT.
	28.3 LITERS	50 LITERS	56.6 LITERS	70 LITERS
BASS 1/2 PWR: F3	52 Hz	38 Hz	37 Hz	33 Hz
BOX-VENT RES FRQ: FB	44.5 Hz	36 Hz	35.6 Hz	33.3 Hz
PEAK at RES.: R	+1.8 DB	+.1 DB	-.3 DB	-.9 DB
PORT: D diameter	D 3"	D 3"	D 3"	D 3"
L length	L 7.5"	L 6"	L 5"	L 4.7"

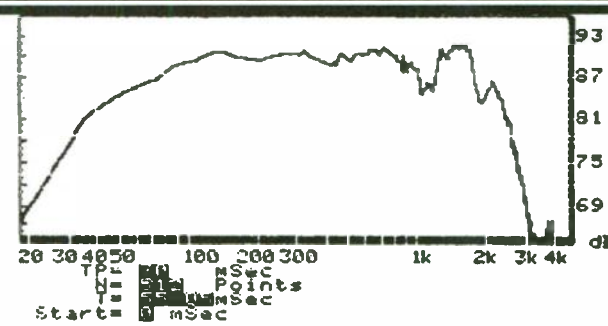
MADISOUND 81524 –
8" Polypropylene Woofer



Fs	36 Hz +/-2 Hz
Mmd	25 Grams
Cms	.8 X 10^{-6} CM/D
Vas	51 Liters
Rscc	3.7 Ohms
Z min	4.0 Ohms
Z max	32 Ohms
vcL	.6 mh
Qms	2.64
Qes	.34
Qts	.30
Xmax	2.4mm pk
VD	50 cm3
Surround:	Foam
Magnet:	20 oz. Cermamic
Power Handling:	75 WATTS
Frequency Response:	35-3K Hz
Efficiency:	92 db 1W/1M

Uses: Home Hifi, Autosound Woofer

Price: **$25.80 EACH**



MADISOUND 81524 BASS REFLEX ALIGNMENTS

*Optimum

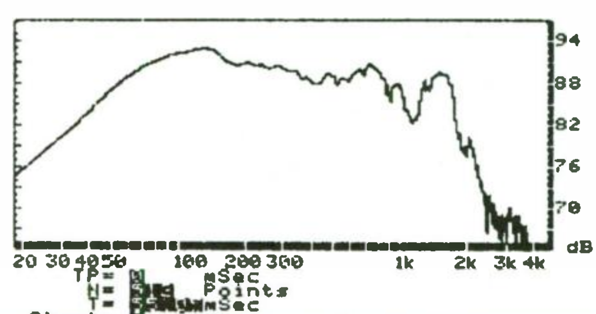
BOX VOLUME: VB	.85 CUBIC FT.	1.0 CUBIC FT.	1.5 CUBIC FT.	2.25 CUBIC FT.
	24 LITERS	28.3 LITERS	42.5 LITERS	63.7 LITERS
BASS 1/2 PWR: F3	52 Hz	48 Hz	39.5 Hz	32 Hz
BOX-VENT RES FREQ: FB	45 Hz	43 Hz	38.1 Hz	33.5 Hz
PEAK at RES.: R	+.12 Db	-.5 Db	-1.5 Db	-3.0 Db
PORT: D diameter	D 2"	D 2"	D 2"	D 2"
L length	L 3.5"	L 3.1"	L 2.4"	L 1.9"

THE MADISOUND 81524-DVC
8" Dual Voice Coil Woofer

Fs	30 Hz +/-2 Hz
Mmd	38 Grams
Cms	.7 X 10^{-6} CM/D
Vas	46 Liters
Rscc	3.6 ohms
Z min	4.3 ohms
Z max	100 ohms
vcL	1.0 mh
Qms	9.2
Qes	.32
Qts	.31
Xmax	4.7 mm pk
VD	100 cm^3
Surround:	Foam
Magnet:	20 oz. Ceramic
Power Handling:	80 Watts 40/40
Frequency Response:	30-2.3K Hz
Efficiency:	90 db 1W/1M

Uses: Audtosound, Sub-woofer

Price: **$26.80 EACH**



MADISOUND 81524 DVC BASS REFLEX ALIGNMENTS

*Optimum

BOX VOLUME: VB	.5 CUBIC FT.	.83 CUBICFOOT	1.0 CUBIC FOOT
	14 LITERS	23.5 LITERS	28 LITERS
BASS 1/2 PWR: F3	55.8 Hz	43.5 Hz	39.5 Hz
BOX-VENT RES. FREQ: FB	45.2 Hz	38.5 Hz	36.2 Hz
PEAK at RES.: R	+1.6 Db	+.1 Db	-.5 Db
PORT: D diameter	D 2"	D 2"	D 2"
L Length	L 6.8"	L 2"	L 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 Lable air service, please add 25%). There is no fee for packaging or handling, and we will refund to the exact shipping charge. We accept Master-charge or Visa on mail and phone orders.

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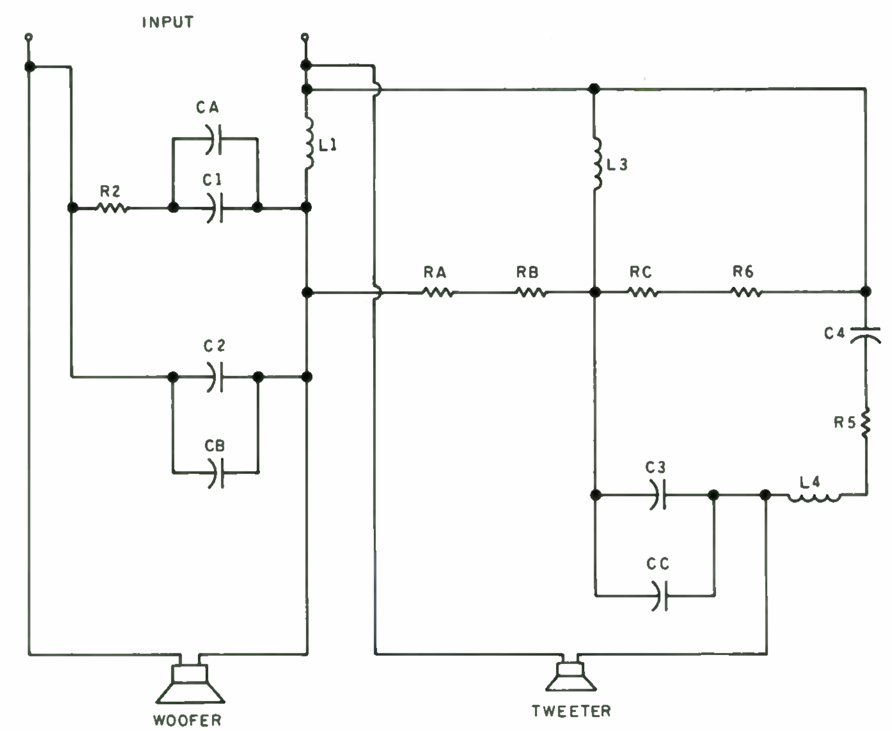

FIGURE 3: Revised crossover.

PARTS LIST # 2

Resistors

R2	4.5Ω
RA	1Ω
RB,RC	0.47Ω
R5	2.5Ω
R6	6Ω

All resistors 5W

Capacitors

C1	50μF
C2,C3	25μF
CA,CB,CC	1μF
C4	10μF

All capacitors Mylar type.

Inductors

L1	#17 wire
L3	#24 wire
L4	#24 wire

good source for both high quality components and complete crossovers.

My crossover modification extends and smooths the high end while improving the focus of the stereo image. Elimination of the mechanical contacts also corrected the long term erratic performance caused by oxidation and dirt.

I have read advertisements of the benefits of spike footed speaker stands and Tip Toes speaker feet. My version of these improvements is shown in *Fig. 4*. Adjust the dimensions to suit your speakers.

I drove four wood screws, approximately 3" long, through the carpeting into the plywood floor under each speaker. If done carefully this causes no visible damage to the carpet and won't get your wife or landlord too upset. I used bolt cutters to cut off the heads of the screws flush with the surface of the carpet. The small wooden speaker stands are hammered about ¼-inch onto the resulting sharp tips. Then I placed the speakers on the stand and clamped them, using a small bracket and another wood screw. Friction tape under the rear corners also adds stability.

Test the setup for rigidity by gently jiggling the upper front edge of the speaker. It should feel as solid as a wall. Any play is probably a result of misalignment. The position of the speaker or the stand should be slightly (millimeters often make a difference) adjusted until all components fit together tightly.

On my system this made an incredible change in the bass. The low bass was extended about an octave while both harmonic detail and transient response were improved. There is an impressive feeling of increased power and dynamic range.

SUMMARY. After completing this series of modifications the overall sound of my speakers is so much improved, it is like listening to a completely new system. For a relatively small cost you can produce excellent sound from very ordinary equipment. The design principles to be followed are:

1. Eliminate mechanical contacts wherever possible. If they cannot be eliminated, treat them with a contact cleaner/lubricant.
2. Use adequately sized multiconductor cable to achieve low impedance over a broad bandwidth and control phase shift.
3. Avoid ferromagnetic conductors. This applies equally to capacitor and resistor leads, switches, terminals, connectors, and so on.
4. Inductors in the signal path should be wound air core with heavy gauge

Continued on page 59

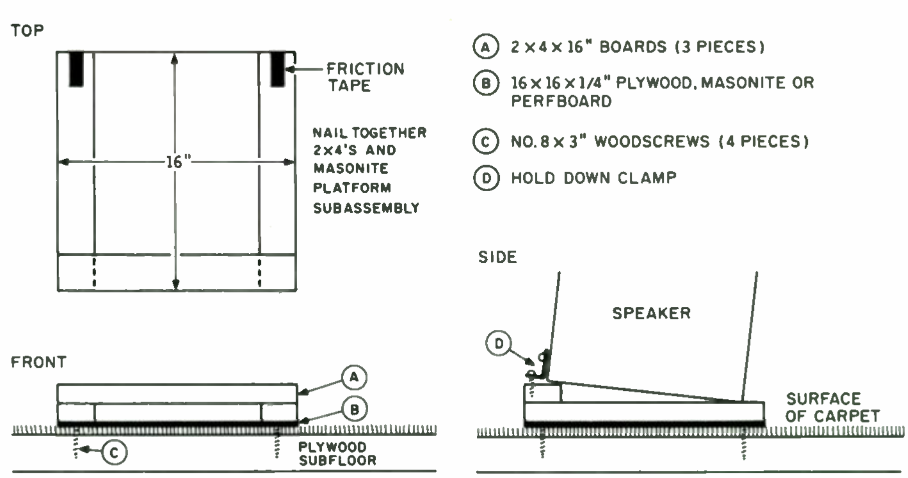

FIGURE 4: Speaker stand. Hold down clamp consists of small right angle bracket and screwed to both speaker and stand.

Book Report

From time to time I will ask various editors and authors to review books and software which I believe will be useful to Speaker Builder *readers in their work with computers. Clearly, the personal computer is becoming both less expensive and more powerful with each passing month. The PC will become the most important tool for loudspeaker development and fortunately is within the reach of even those with modest means.—E.T.D.*

Shareware

IBM PC Shareware: PC-File, PC-Write, PC-Talk and ExpressCalc *by John R. Ottensmann.* Tab Books, Blue Ridge Summit, PA 17214. First Edition, Second Printing, 1987. Softbound, 246 pp. $15.95.

Reviewed by Gary A. Galo

This book is unique in the field of third party manuals for popular applications software. For many years numerous third party books on the high-priced, industry standard business software packages, such as WordStar, D-Base III and Lotus 1-2-3, have been available. Publishers such as Que and Sybex have been the leaders in this area. The Ottensmann book is the first third party book I've seen covering programs marketed under the Shareware concept.

Shareware companies allow users to freely, and legally, make copies of programs for friends, who may use the program and determine whether it suits their requirements. The program disks normally contain a manual which can be printed, although it may be abbreviated, giving the essentials and omitting more advanced features. A few, such as ProComm, contain a complete manual on the disk. Once you have determined the program meets your needs, you are encouraged to purchase a registered copy, which normally includes a complete bound and printed manual, as well as free telephone support.

Normally, of course, you are not legally bound to purchase a registered copy, but I believe any program which is frequently used should be paid for. Many programs marketed under this concept cost a fraction of prices for commercial business software. The only way to insure that quality software of this type will continue to be available is by supporting the authors of those products. Many Shareware programs rival their commercial counterparts in performance and speed. I consistently use three Shareware programs which I find superb, including PC-Write, ProComm (one of the best communications programs, from Data-Storm Technologies) and HomeBase (a powerful and versatile desktop organizer, which makes use of expanded memory, from Brown Bag Software). I am happy to send my money to these firms, particularly when their prices are so modest in comparison to the "industry standards."

Ottensmann's book begins by introducing the Shareware concept, and discussing the differences between Shareware, Freeware and user supported software. One of my initial concerns about this book was that it might provide freeloaders with documentation for these programs and thus eliminate their need for purchasing a registered copy. I am pleased, therefore, to see Ottensmann discuss the importance of supporting the authors, and encouraging users to purchase the programs they intend to use. His approach is more a tutorial rather than a replacement for the manuals. Therefore, registered users will still find the manuals useful.

Microsoft's Disk Operating System (DOS) can be rather intimidating to the new user, so Ottensmann provides an introduction to DOS and how to use it. He discusses the most frequently used DOS commands for floppy disk systems. The author also provides instructions for preparing work disks for each of the programs covered in this book. His instructions are well written and provide clear explanations for every step of the installation processes. At least two of these programs have been updated since this book was published so these instructions may need a bit of user modification. The PC-Write version discussed here is version 2.6. Version 2.71 is the current one, which includes a spelling checker. PC-File III has been extensively updated and is now called PC-File +.

This book's lack of information on hard disks is the greatest disappointment. His only hard disk discussion consists of a few paragraphs in Appendix B, entitled "Using the Programs on Different Systems." Many serious computer users are now using hard disk systems. His coverage of DOS would be much more useful with a brief overview of PATH commands and subdirectory management. Hard disk users gain the most from knowledge of the operating system. Floppy disk users can run applications software for years without ever encountering the backslash key. He should also have discussed the installation of each of these programs on hard disk systems.

Four chapters are devoted to manuals for each of the four programs. The PC-File chapter is a good introduction to basic database concepts. As Ottensmann points out, this program is probably the easiest to use of the four discussed. Once you understand the basic concepts, the program appears on the screen in an almost self-explanatory manner. Ottensmann gives complete coverage to name and address management as well as inventory. He also discusses some of the customizing options available.

The PC-Write chapter provides an excellent alternative to the tutorial provided with the program (a rather silly story about cats who are computer hackers). PC-Write is one of my favorite programs, and one of the shining stars in the world of Shareware. Although the PC-Write Manual is one of the best pieces of computer documentation I've encountered, the text you must type for the tutorial does little to introduce you to the features of the program. Ottensmann provides a text, which you must type and edit, and which actually explains the program's features. So, you not only start using the program immediately, but you also type your own introduction to the program.

Ottensmann gives a thorough overview of many of the advanced editing features, such as marking and moving text, handling ruler lines, reformatting and the find and replace utility. He also gives a concise explanation of the formatting procedures for printing, such as header and footers, character fonts, etc. I was disappointed he did not mention PC-Write's support for the entire IBM alternate character set, including all of the foreign language and math characters. In addition, Version 2.71 supports all of the box drawing characters. [*It also supports several laser printers and is unique among Shareware word processors in supporting the Adobe Postscript language for Postscript printers.—Ed.*]

PC-Talk has been the classic communications program for the IBM compatibles. It was also the first program distributed under the Shareware concept. Ottensmann's chapter on this program is extremely informative. He gives an excellent overview of the fundamentals of personal computer communications. I recommend this section to anyone new to modems and communications software. If you have no idea what "8 data bits, no parity, 1 stop bit" means, this chapter will answer all your questions. I wish his discussion of serial ports was more complete. He correctly states that MS-DOS supports two serial ports, COM1 and COM2. He does not mention that the Intel architecture supports two additional ports, COM3 and COM4. Many internal modems can be set up as COM3 or COM4 and most of today's communications software programs provide the support for these ports that MS-DOS forgot. Beyond that, Ottensman gives good coverage of the capabilities of the program.

The ExpressCalc chapter introduces readers to spreadsheet basics. As the author points out, this program has also been distributed by Buttonware (distributors of PC-File) as PC-Calc. It is now being distributed by ExpressWare, which also sells another Shareware database called File Express. Ed Dell has considerable experience with File Express and speaks very highly of the program. Ottensmann's tutorial includes the creation of a loan amortization table. His extensive reproductions of the screens provide an excellent supplement to the text. [*ExpressCalc works well with Richard Pierce's suggestions in the* SB 3/87 *article.—Ed.*]

One of the best features of these Shareware programs is their compatibility for use as an integrated package. Ottensmann's final chapter discusses how information can be exchanged from one program to another. Appendix "A" discusses other sources for reasonably priced software, including Generic CADD, Borland's Turbo Pascal, and Mosaic Software's Lotus 1-2-3 clone called The Twin. Despite a few criticisms of the book, I do think that users of these programs will find that it provides a great deal of useful information.

SOURCES

The best single source for trial copies of these programs is PC-SIG, 1030 East Duane Ave, Sunnyvale CA, 94086 (800) 245-6717; In CA (800) 222-2996. Disks are $6 each and a catalog is available.

Beginner's DOS

Understanding MS-DOS *by Kate O'Day.* Revised by John Angermeyer. Howard W. Sams & Co. First Edition, First Printing, 1986. Softbound, 231 pp. $14.95.

Reviewed by Gary A. Galo

The MS-DOS (PC-DOS if you bought IBM's version) operating system has been notorious for the terrible documentation supplied by both IBM and Microsoft. Trying to master DOS is like trying to learn a foreign language by reading the dictionary; it's difficult to figure out how all the pieces fit together. Fortunately, several third party books are available to help both new and experienced users who need to know more. My favorite is *Using PC-DOS* by Chris DeVoney, published by Que. These books show that while DOS is rather involved at the advanced level, the poor documentation made it difficult for many users to learn.

The Sams book is another attempt to unravel MS-DOS mysteries. It begins at the most elementary level, explaining what a computer is, and illustrating the various parts of the system, including the disks. Throughout the book, the left hand column of each page contains succinct summaries of the important points discussed in the main text. Those who don't know the difference between a keyboard and a coffee maker, or the CPU and the RAM, will find this introduction most useful and not the least bit intimidating. The end of each chapter contains a short summary and list of the important facts, followed by a multiple-choice quiz.

Chapter 2 explains the function of a computer disk operating system (DOS). An analogy to air traffic control is one I have used myself, and it makes a great deal of sense to the beginner. A brief overview of operating systems gives a bit of historical perspective. Next, we are given a step-by-step tutorial on booting up for the first time, on the level of "insert disk A into slot B." Setting the system date and time and the use of the DIR and CLS commands are discussed, as well as the difference between a warm and cold boot. Of course, IBM forgot to install hardware reset buttons on their computers (including the PS/2s), making the power switch the only cold boot method possible, but this is not mentioned.

The authors stress the importance of backing up software and data and explains proper handling of disks, the FORMAT and DISKCOPY commands, as well as how to change drives. Chapter 5 covers IBM's laughable EDLIN line editor. At this stage in software history, any consideration of EDLIN is probably a waste of time. Plenty of practically free (Shareware, and others—see review this issue) ASCII full screen editors available. My advice is to acquire a copy of PC-Write and erase the EDLIN file from your working DOS disk as quickly as possible.

Chapter 6 on file management, starts with an outline of the rules for creating filenames and extensions, then how to use the absurd EDLIN as a word processor, as well as copying, renaming and erasing files, and special keys and key combinations including CAPS LOCK, ESCape and PRT SC. The authors demystify the numeric keypad, as well as the DOS switches, including /s, /v, /f, and /w, and how to use them with the DIR, CHKDSK and FORMAT commands.

Batch files, among the most powerful features of MS-DOS, are thoroughly treated in a chapter which is one of the most useful in this book, giving a concise introduction to both the simple and advanced batch file commands.

EDLIN and COPY CON are discussed as methods for creating batch files, but users will find almost any other word processor easier to use for this important task.

Chapter 9 introduces the DOS directory structure. Although devoted strictly to floppy disks, the essentials of creating, removing and moving through the directory structure are covered, as are copying files from one directory to another.

Chapter10 covers the data management commands, including SORT, FIND and MORE.

The final chapter is a disappointing discussion of hard disks. They give most of their attention to the BACKUP and RESTORE commands, with no discussion of hard disk directory management. This chapter would have been much more useful if the authors explained how to install the DOS utility files in an appropriate subdirectory, accessed by a PATH command in the AUTOEXEC.BAT file. Unfortunately they mention neither the AUTOEXEC.BAT nor the CONFIG.SYS files in the chapter. An appendix covers all of the DOS error messages.

This book will be extremely useful to the beginner, but covers only the common DOS commands and leaves out many of the more advanced ones. For others the DeVoney book mentioned above is more useful. Finally, the authors' repeated coverage of EDLIN is difficult to understand. There is no reason whatsoever for using the crude line editor, even in 1986, when this book was published. If you have never used a computer before, this book may provide the introduction you need, as long as you bear in mind its limitations. If you are technically inclined (as readers of this magazine generally are!), you can probably skip this book altogether.

Big Blue Basics

IBM PC and XT User's Reference Manual *by Gilbert Held.* Hayden Books. Second Edition, Second Printing, 1987. Softbound, 497 pp. $26.95.

Reviewed by Gary A. Galo

This book provides a great deal of information on the IBM PC and XT computers not found in the IBM DOS Manuals or the Guide to Operations. It deals exclusively with Big Blue's IBM computers, and makes no mention of clones or compatibles and very little in the way of third party hardware. The book includes an overview of the hardware in these machines with numerous photographs to show various components.

Mr. Held discusses all of the IBM expansion cards, and devotes much of his discussion to display cards and monitors. It is strictly the Big Blue party line which he tows here. He never mentions the most important graphics card prior to EGA, namely the third party Hercules Monochrome Graphics Card. This is unfortunate, since Hercules set the standard for high resolution monochrome graphics.

Held is not adverse to mentioning third party boards if there is no Big Blue competition. The AST Six Pak Multifunction Card is a case in point. If today's computer users attempted to install all the cards necessary to duplicate the third party multifunction card capabilities using only IBM's discrete cards, they would run out of expansion slots before the process was complete. And the real-time clock was never provided by IBM.

Held also mentions the Hayes modems, which set the standard for personal computer communications. Finally, the author deals with installing hard disks, wisely pointing out the potential inadequacies of the PC's 63.5W power supply. He does not mention the early PC BIOS (prior to October 28, 1982) which did not recognize the hard disk, and which must be replaced before a hard disk can be used to its full capability.

His chapter on System Setup is much more useful than the information IBM provides in its Guide to Operations. Held's first recommendation is to install a surge suppressor, and I couldn't agree more. He instructs the user on connecting the system, running the power-on self test, installing expansion cards, and also explains how to install additional memory and disk drives, as well as illustrating the correct dip switch settings.

A chapter is also devoted to storage media, beginning with a complete explanation of floppy disk tracks and sectors. The various types of drives used in the PCs are explained, as well as the use of the IBM keyboard, concentrating on the numeric function and programming assistance keys.

Chapter 4 covers the operating system, and begins by surveying the various versions of DOS. He tells you how to install DOS on both floppy and hard disk systems and explains how the functions keys operate at the system level. A DOS commands dictionary, with short function definitions is divided into two sections: one explains the resident commands and the other, the nonresident ones. The latter are those contained in program files on the DOS disks. Although this survey cannot be as comprehensive as books devoted entirely to DOS, it is concise and understandable.

Chapter 5 tells the reader how to organize hard disks, explaining the directory structure, the supporting DOS commands. His section on organizing subdirectories is especially good. Unfortunately, his hard disk illustration shows all the DOS utility files copied into the root directory. This is completely unnecessary, thanks to the

PATH command. All DOS utilities should be in their own subdirectory, accessed by an appropriate PATH command in the AUTOEXEC.BAT file. Held does not discuss batch files in this chapter, saving them for Chapter 12, which also contains information on the CONFIG.SYS file.

Five chapters are devoted to IBM BASIC programming. Unfortunately, Held seems to assume a knowledge of BASIC, and this books serves to introduce the BASIC programmer to the IBM/Microsoft format. These chapters will not teach a newcomer the workings of BASIC programming.

The chapters on display control and data communications will be useful only to programmers.

Held also provides an introduction to IBM's TopView windowing environment. Due to the popularity of Microsoft's Windows, many readers will have no need for this information. In conclusion, this book provides information useful to owners of genuine IBM PC and XT computers. I don't think owners or builders of clones will find much of interest here. The large amount of space devoted to BASIC programming may not appeal to some readers. Held seems to assume typical PC users spend most of their time programming. I'm quite sure that this is not the case, but if BASIC hacking is for you, so is this book.

Op Amps Classic

Audio IC Op-Amp Applications, Third Ed., by Walter Jung. Howard W. Sams & Co., $17.95

Reviewed by Bill Ruck

The latest edition of Walter Jung's writings on operational amplifiers is an updated volume written with audio applications in mind. Although it does not cover in great detail the basic workings and general applications of op amps, it does go into specific circuit details for common audio applications and is intended as a supplement to the author's *IC Op-Amp Cookbook*, currently in its third edition.

The first three chapters review op-amp application information and detail the important parameters for audio designs. The author not only defines the specifications and clarifies their importance, he also explains how to use published specifications in selecting an IC operational amplifier.

The fourth chapter describes useful circuitry for practical audio applications, covers basic audio amplifiers, servo-controlled stages and methods for increasing the power output of an op amp. Author Jung gives detailed instruction for microphone, tape head, and phono preamp circuits.

The fifth chapter details various types of equalized amplifiers and active filters. In the sixth and final chapter, Jung focuses on miscellaneous audio circuits including a specific section of CD D-A (Digital-to-Analog) conversion.

The book has two appendices: one contains reprints of applicable device data sheets, and the second lists manufacturers' devices—including addresses in case you need even more information.

As is the case with most books on technical subjects, reading this one does not make you a design engineer. However, Walt Jung writes in his usual excellent and clear style, and includes sufficient information to make the book a valuable addition to any audio amateur's library. If you are currently assembling or modifying your own equipment, you should have a copy at hand.

Kit Report

E.J. Jordan USA Model HRM Loudspeaker

"Come look at this!" I called my wife to see the enclosure I had just unpacked. The work I was admiring was a cabinet for the kit from E.J. Jordan USA. Their first kit, designated the High Resolution Monitor (HRM), is a two-way bookshelf system with an acoustic suspension enclosure. The Jordan 50mm module has been around for quite some time, and I wondered why so few construction articles or kits featured it. E.J. Jordan USA, the US agent for Jordan's products, is now rectifying that by offering two kits incorporating the Jordan "ACT" technology.

Kit Contents

The HRM uses an ACT 50mm module and an ACT 125-B woofer. I'm sure many are familiar with the unique Jordan ACT 50mm module. Bruce Edgar covered it nicely in his interview of E.J. Jordan in *SB* 3/84. Remember, this unit is not a tweeter—its response extends from about 100Hz–14kHz; it is almost, but not quite, a full-range driver. The ACT 125-B 7-inch woofer, is relatively new to the Jordan line and features an aluminum cone, like the 50mm module. The frame is cast aluminum, with a rather conventional rubber surround. It does, however, use the same unique suspension design as the 50mm module.

PHOTO 1: The finished E.J. Jordan USA HRM kit.

The first-order crossover shown in *Fig. 1* comes fully assembled. The capacitor is a parallel composite of three units: a 62μF polypropylene, a 6.8μF polypropylene, and a .015μF polystyrene.

Kirk Neal of Jordan USA said he experimented with many components and settled on Solen 5% units for the polypropylene and an IMB 2% unit for the polystyrene. The 1% air-core inductor is also supplied by Solen. The crossover is wired with Monster Cable, and Wonder Solder is provided for kit assembly.

The 11 x 10½ x 22-inch sealed enclosure is dense particle board, veneered on all six sides and finished with hand-rubbed lacquer (available in walnut, teak, or rosewood). The materials and workmanship, what I would expect of a piece of fine furniture, are a product of Princeton Acoustics, an affiliate of Jordan USA, specializing in custom enclosures. A snap-on, black fabric grille is included with the kit.

Dacron stuffing, diffraction rings, acoustic foam, and miscellaneous hardware are all included; all you need to provide is a tube of silicone adhesive. The kit I evaluated contained foam diffraction rings. I am told that future kits will contain felt rings.

Constructing the Kit

Assembly is straightforward, requiring no special tools or techniques. First I glued the acoustic foam panels in place inside the enclosure. Next, I installed the crossover, using adhesive and a screw.

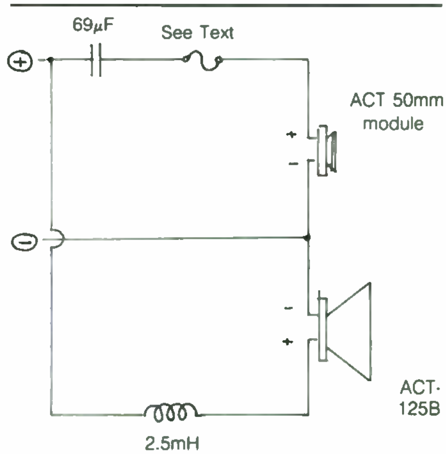

FIGURE 1: The first-order crossover network, which comes fully assembled with the kit.

The drivers are easier to install than most; rather than terminals, they have integral wire leads. The enclosure is divided into two separate chambers. I set the module on the edge of its cutout hole, fed the leads through the chamber opening in the rear, secured the leads with cable ties and sealed the hole with silicone adhesive. I let the adhesive set for a day.

I soldered the speaker leads, the crossover wires, and insulated the connections with electrical tape. After double-checking the connections, I tested the system with a low-level audio signal. Finally, I stuffed the enclosure with Dacron batten and mounted the drivers.

Four machine screws and T-nuts are included to mount the woofer. I glued the module in place with silicone adhesive, a method I do not like. I am pleased to report that future kits will have their modules secured with screws. I attached the diffraction ring around the module and snappd the grille in place.

Crossover Frequency Considerations

Even though the 50mm module has a response extending to 100Hz, Neal selected a crossover frequency of 420Hz, contend-

PHOTO 2: The kit before assembly, including acoustic foam, diffraction ring and grille.

ing this relieves the module from coping with the physical workload of lower frequencies. I think this decision is wise. Even though the unit may have a small-signal response to 100Hz, I doubt whether it can handle much power, or withstand the excursion required to move enough air at that frequency. I have heard of Jordan modules failing in the past; perhaps they were stressed beyond their capacity by being required to handle too much bass.

I am told that their suspension is so good that they will not audibly distort music until they are driven to destruction. Neal has provided a measure of circuit protection for the module as part of the kit. He experimented with many types of protection devices and found the only one that did not affect the sound in any way is an extremely accurate current regulating device—the Raychem "Polyswitch." This protection is not absolute, as with a high-speed instrumentation fuse which audibly affects the quality of the sound. The Polyswitch has one other advantage over a fuse: it does not permanently destroy itself in order to provide protection. Rather than opening the circuit, it limits the current.

With the 50mm module handling most of the audio range, crossover frequencies provided some unexpected considerations. Let me explain: whenever I evaluate a speaker that does not have impedance compensation for its woofer, I add compensation and report on its effect. I have always found that providing impedance compensation for a woofer is beneficial. Not so with this speaker—even with a first-order, low-pass filter in the crossover, the signal presented to the woofer is very low at the frequency where the inductance of the woofer starts to affect its impedance. Thus the impedance compensation has little effect.

The converse may be important in this speaker. The system could benefit from impedance compensation for the resonance of the 50mm module. This deviance from the nominal 8Ω rating is close enough to the crossover frequency to have an effect on the sound produced by the speaker. Compensating for resonance peaks is more involved than for inductive rise: requiring large capacitors and inductors that I don't have lying around in my box of spare parts; therefore, I didn't verify this conjecture.

Tilting a speaker varies the relative positions of the woofer and tweeter. This usually has a noticeable effect on the sound. The crossover frequency is so low in this speaker that the small difference in delay imposed by tilting the speaker is inaudible.

I found a third anomaly. A diffraction ring around a tweeter generally affects the definition of the treble in a subtle, but definite way. Adding a diffraction ring around the 50mm module is more noticeable—not only is the definition of the treble improved, but the focus across the whole audible range of the module improves dramatically.

I introduce the above not as criticism, pro or con, for selecting a particular crossover frequency, but rather to point out that we must consider issues other than driver parameters when choosing the crossover frequency.

Listening Evaluation

The break-in period convinced me this speaker's beauty is more than skin deep. The quality and workmanship invested in the design and materials, is evident in its sound. Although not perfect, its shortcomings are minimal.

I found that room placement is more critical than with most speakers. The HRMs like to be a little farther apart than most speakers this size. I settled on a position about eight feet apart and two feet from my listening room's long wall. With the speakers too close together, the soundstage was narrow with a small "sweet spot." With the speakers correctly positioned, there was a wide soundstage and optimal sound over a respectable listening area. Vertical placement is also important. The sound character changed dramatically as I varied the height of the speakers. The best position is with the 50mm module at, or slightly above ear level.

The speaker has a fairly neutral character, with none of the colorations generally attributed to the "West Coast," "East Coast," or "British" sound. It shares the same general character in bass, treble, and imaging with the highly regarded Spica TC-50. It is, in my opinion, a better speaker than the TC-50, producing a cleaner and more relaxed sound.

Let me elaborate. First the areas of similarity: spectral balance is very good across the audible range, although the lower bass and upper treble are rolled off. The limitation in depth of bass is comparable to that found in other speakers of similar size, and the mid and upper bass is very clean. The roll-off of the upper treble causes the music to lack both a sheen and an open-air quality. Side-to-side imaging and location is very good; however, front-to-back location of a sound source is only average. Definition of individual instruments is very good.

In two areas the HRM differs from the TC-50—one a small minus, and the other a large plus. While listening to the HRM, I detected a very slight emphasis in the 100–300Hz range. This sounded like a softening of the definition of plucked double-bass. To isolate the cause, I disconnected the 50mm module. This did not eliminate the problem so I bypassed the crossover and directly attached the woofer to the amplifier. Since the woofer now produced a wider spectrum, the problem was less audible, but it remained. I altered the amount of Dacron stuffing in the enclosure to no avail.

My next experiment would have been to reduce the volume of the enclosure. However, since the aberration is extremely subtle I decided such a major modification to the kit is outside the scope of this review.

In the second area of difference from the TC-50, the HRM's sound clearly shines. Its strong points are tonal accuracy, and extremely low distortion. The sound is cleaner than any other speaker I have heard that uses moving coil drivers. Aside from the physical concerns I expressed, many designers would balk at a crossover frequency that falls smack in the middle of the region where the fundamentals of many musical notes lie. Any aberrations in the lower midrange will noticeably affect the reproduction of human voices. I detected no problems while listening to the HRM: tonal accuracy is superb, and in everything except spatial imaging, the presentation of male voice is the most realistic I have heard from a small speaker.

The HRM favors all types of music: classical and jazz, opera and rock, solo instruments, small ensembles and large orchestras; all are reproduced equally well.

Conclusions

I strongly recommend the HRM to anyone considering buying a speaker in its price range. Although it is not perfect, its minor weaknesses are outweighed by its strengths. Specifically, I prefer the HRM to the Spica TC-50, and believe the higher price is a fair barometer of the difference in quality of these two fine loudspeakers.

You may remember from my Kit Report in *SB* 3/86 that I liked the Focal Egg very much. The choice between the Egg and HRM is not so clear-cut. The HRM has better tonal accuracy and lower distortion—a cleaner sound. The Egg has better bass and treble extension, plus superb spatial imaging. The Egg is the only inexpensive speaker that I have found that comes close to passing the "goose bump" test. It is a matter of taste: If I had to guess, I would say that someone from Sea Cliff would prefer the HRM, and someone from Santa Fe would prefer the Egg. Both are on my list of "speakers I could live with."

The complete kit for a pair of HRMs retails for $545. The ACT drivers are available separately, $156 per pair for the 50mm modules, and $120 each (ouch!) for the

125-B woofer. A second kit, the HRM-2, is a satellite/subwoofer configuration that uses two ACT 50mm modules and two ACT 125-B woofers per channel. The subwoofer is available separately as the HRM-W.

All the above are available from: E.J. Jordan USA, 301 North Harrison St., Bldg. B, Suite 252, Princeton, NJ 08540.

David W. Davenport
Raleigh, NC 27615

Kirk Neal of E.J. Jordan USA comments:

Many thanks to Dave Davenport and Speaker Builder for giving our HRM a thorough run-through. My policy has been to refuse reviews of my products but I also feel that the kit buyer is investing money and time into a product sight-unseen and therefore a review becomes almost a necessity. I genuinely thank Dave for his insight as first production run HRM systems will incorporate changes described below.

A new mounting system has the ACT-1 Treble driver adhered to a plate that is then mounted to the enclosure using screws. This eliminates the need for any gluing of the driver, making assembly even easier. We also will be using a new diffraction ring material which is a dense pre-dyed (black) self-adhering felt. We find it not only offers better spatial imaging but looks better than the foam ring.

The HRM is also available in a black gloss laminate finish ($50 additional) as well as the three stock veneers.

After a great deal of debate, the verdict is in regarding the method of protection for the drive units. The polyswitch is a tremendously accurate device but has on occasion shown tendencies to allow, under certain conditions, higher than acceptable short-burst current to the treble driver. We are now using a polyswitch in the circuit with the bass driver and will include a standard buss-type fuse for use with the treble drive. We feel this to be the most reliable method of protection and for those who must have absolute sonic virginity, the fuse may be omitted.

An additional internal brace has been inserted to compensate for cabinet resonance and should prove effective in the 100–300Hz emphasis. We are also investigating adjustment of net internal volume of the bass cavity and any improvements will be in first production systems.

The actual usable frequency response of the ACT-1 treble driver (as it is now called) is 100–21kHz, depending upon application we do not recommend the original and widely used low-pass crossover points of 100–150Hz. The advent of digital source material and input current of the average amplifiers used today apply a great deal of stress to the driver in those low frequency regions. Our systems call for crossover points of 225–550Hz unless arrays of 4 or more treble drivers are used per channel.

The HRM enclosure utilizes a very high density, very stable (important) fiber board, not particle board. As Dave stated, our fit and finish is impeccable, our enclosures are limited production and handmade in the smallest detail. All aspects and fabrication of our systems are made by us in our own facility and the HRM enclosure is built, start to finish, by one man, John G. Allen who has quietly fabricated all E.J. Jordan and Princeton Acoustics enclosures to his own standards.

We are very pleased that Dave pointed out the sonic distinctions of the HRM which is tonal and harmonic accuracy, offering the low distortion of an electrostatic and the impact of dynamic drivers. While our systems are not perfect they offer tremendous satisfaction to those seeking "resolution" and tonal accuracy. A single microphone recording of the human voice or instrument we find to be the hardest area to attain excellence in and the area the Jordan ACT drivers excel in. I have used (and still do) drivers from every major manufacturer and yet the Jordan units possess a sonic signature unlike any other driver I have used. A great deal of what we have provided in the HRM is the result of a lifetime of commitment by Mr. Ted Jordan.

Also, we are now using the absolutely wonderful Cardas Cable internal wire in all of our systems including the HRM. The benefit is a stronger sense of overall coherency and it is without a doubt made to a standard of excellence unlike any other I have seen.

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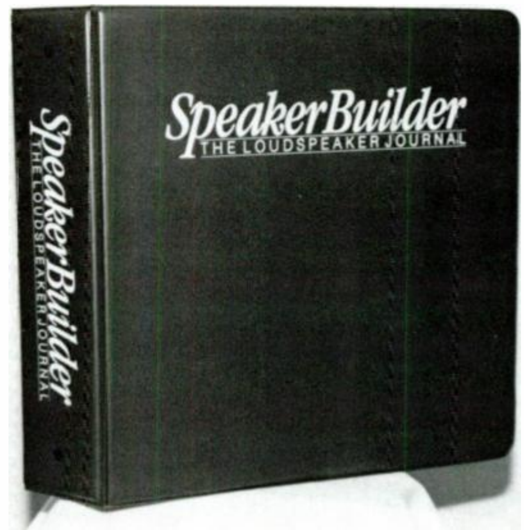

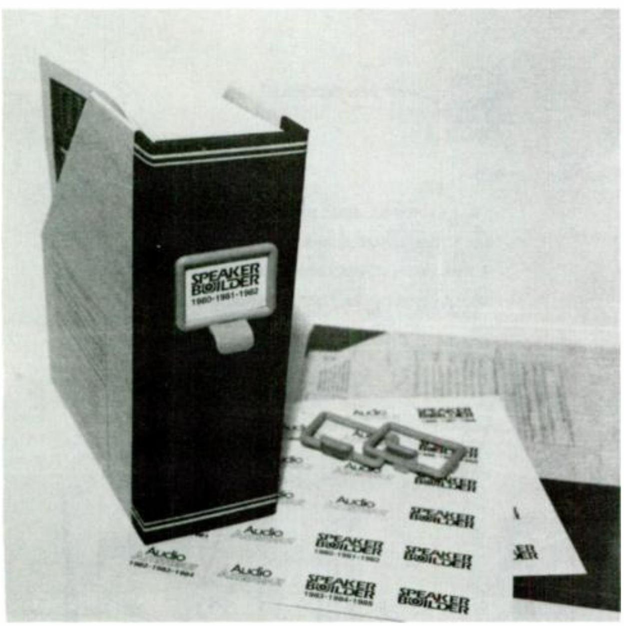

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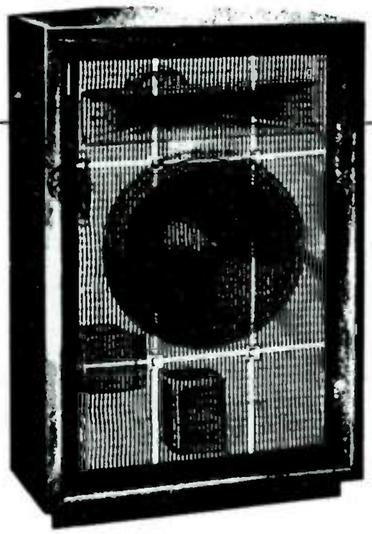
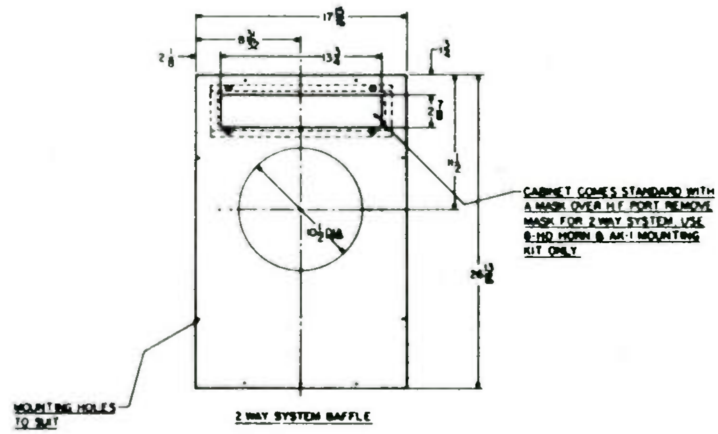
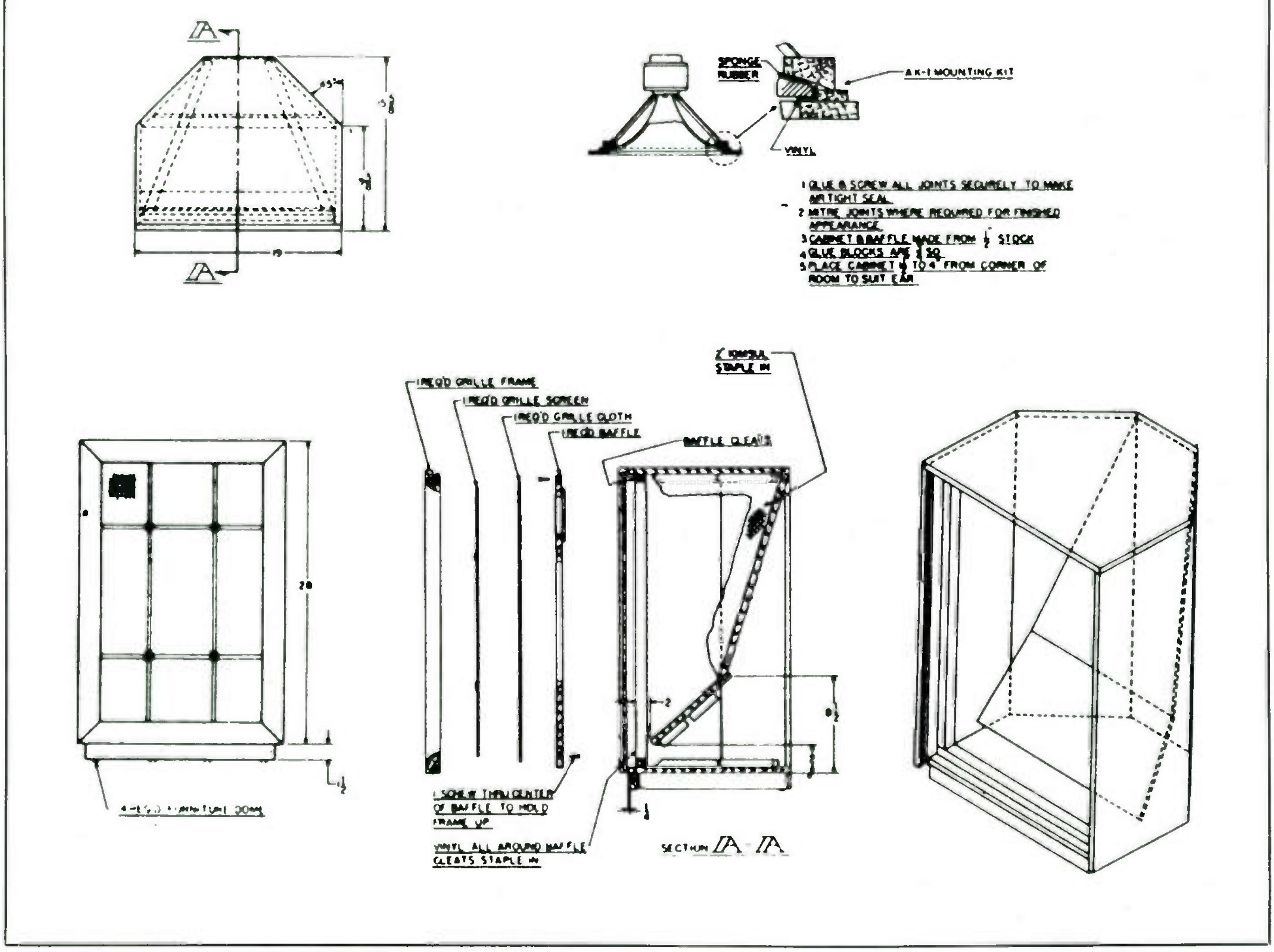


Construction Details. *Courtesy of Steve Ball, Austin, TX.*





SB Mailbox

RAPID RESULTS

With reference to the "Lowther Difficulties" letter (*SB* 4/87), for such a case Dr. Weiss should contact the resorting Chamber of Commerce and Industry; for Lowther this would be the London office.

Unlike in the US, the Chambers in European countries are all part of their Ministries of Trade and I have always experienced rapid positive results in similar disputes.

Johan van Leer
Santa Monica, CA 90405

STUFFING FOR A BEFUDDLED SUBJECT

John Cockroft's conclusions on line stuffing ("The Octaline," *SB* 3/87) are very similar to mine. My experiments with pipes of 10-12′ lengths show that Dacron increases the effective length of the pipe (approximately doubles it), but also substantially reduces the presence of the harmonics. Organ pipes owe their richness to their plentiful harmonics whereas a similarly enriched loudspeaker is an anathema. His remarks concerning quarter wavelength theory are quite correct. Speaker builders ought to understand these principles, not to apply them correctly, but to avoid them like the plague.

There is a rather persistent notion that an unstuffed TL exhibits behavior much like a covered labial organ pipe. As a matter of fact, its behavior more nearly approximates an uncovered pipe. David Weems, in discussing the harmonic structure of such pipes, is somewhat imprecise. To say the second is the fifth does not bring additional clarity to an already befuddled subject; "Zen-like" is Craig Cushing's term.

The first overtone is the second harmonic and its pitch is precisely double that of the fundamental or first harmonic. The third harmonic's frequency is three times that of the first, and so on. A frequency plot of a pipe, approximately 28′, shows clear resonant peaks at all harmonics through the fifth, whereas a 14′ stuffed pipe yields a pronounced peak at the fundamental of nearly the same pitch and a greatly reduced second. I have not yet detected the presence of the third harmonic in a stuffed pipe. All this reinforces Mr. Cockroft's contention that stuffing makes a pipe a viable speaker enclosure, although I have strong misgivings about a pipe of 6½′ or less; a pronounced resonance in the 40-50Hz range seems inconsistent with accurate sound reproduction. A short pipe modeled after a covered labial pipe is a possiblity, however there is an attendant loss of efficiency.

Vela Shirley
Jackson, MS 39212

Mr. Cockroft replies:

I am pleased to hear similar views on quarter wavelength theory as it pertains to transmission lines. All my lines have had either one or two impedance peaks, generally depending on the density of the stuffing material. The peaks have all been small to moderate in magnitude, ranging from a fraction of an ohm to a little over 22Ω. As for peaks in the sound pressure level, most people first remark on the smoothness of my short lines. No speaker has an absolutely flat response in real environments, but my short lines exhibit nothing disturbing in this area. While my lines are shorter than usual, they are loaded to a higher density than the classic line.

I consider the classic Bailey line to be an excellent basis for a transmission line system and recommend it highly to those who have the space to effectively use it. It is only the myths that grew up regarding its conception that I object to. I present my lines as alternatives to Bailey's, rather than the equivalent, to be used in places where the Bailey line is impractical. I think builders will find the overall compromises considerably less than the existing literature would have them believe.

It might be reasonable to have misgivings about lines shorter than 6½ feet in length. I presume that because of the length of the lines you are working with you have quite a large listening area to fill with sound. In spite of your misgivings, I am thoroughly enjoying music in my small listening area with my 3′ and shorter lines. One day, when enough people are aware of them, I believe they will be as common as vented or small sealed box systems and will possibly sound more natural than either.

BOX DESIGN ROADBLOCKS

I have read Bob Bullock's articles in *SB*, especially those regarding box design, with great interest. In trying to comprehend the physical relationship among several of the design parameters, however, I have come to several logic roadblocks. I could use some clarification on these items to alleviate my confusion.

The first area of confusion is compliance (V_{AS}) versus box volume (V_B). Both Small alignment tables and the formula from David Weems's book *(Designing, Building and Testing Your Own Speaker System, (1ST Edition)* indicate a direct relationship between these two parameters, but my logic (which has been known to be wrong on occasion) indicates the relationship should be indirect. For example, for a given driver, increasing the compliance also increases the damping. This should require a smaller box volume with its increased air stiffness to compensate for the increased damping and maintain optimum control over the driver diaphragm. Where am I missing the boat in this cause-and-effect description? Is my understanding of compliance wrong? Doesn't high compliance always mean high damping?

My second problem is with the computation of V_B. According to the information in Mr. Bullock's article in *SB* 4/80 (p. 7), V_B equals V_{AS}/α, where α is defined in the Small alignment tables for various values of Q_{TS}. This formula produces results that are significantly less than those achieved when using the formula from the Weems book, where V_B equals $15(Q_{TS})^{2.87}$ (V_{AS}).

For example, for the Dynaudio 21W5406, Q_{TS} equals 0.29 and V_{AS} equals 82 liters. Using Mr. Bullock's formula and the Small alignment table for $Q_L = 10$, for a Q_{TS} of 0.29, α equals 3.1843. Therefore, V_B equals 82 liters/3.1843, which equals 25.75 liters. Using the Weems method, V_B equals $15(0.29)^{2.87}$ (82 liters), which equals 35.24 liters. Since the h values from the Small alignment tables correlate exactly to the Weems tuning factor chart, I assume that both methods are based on the same mathematical concepts. Bob White used the Weems formula in the follow-up article to BOXRESPONSE in *SB* 1/85 (p. 28). Where am I going wrong here? Am I using the Small alignment tables incorrectly?

KITS

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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. **Each $62**

KF-6: 30Hz RUMBLE FILTER. [4:75] This kit implements Walt Jung's 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 Jung's article explores the use of the filter with other components in crossovers (see kits SBK-C1A, C1B, C1C). He 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 ± 15V, the KE-5 is suitable. **Each $28**

AIDS & TEST EQUIPMENT

KK-3: THE WARBLER OSCILLATOR [1:79]. This unit will produce a swept signal covering any ⅓-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 3¼" x 3⅞" circuit board, transformer, all parts and article reprint. **Each $65**

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. **Each $62**

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 250kΩ. **Each $42**

KL-6: MASTEL TIMERLESS TONE BURST GENERATOR. [2:80] All parts with circuit board. No power supply. **Each $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. **Each $26**

SBK-D2 WITTENBREDER AUDIO PULSE GENERATOR. [SB 2:83] All parts, board, pots, power cord, switches and power supply included. **Each $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. **Each $32**

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. **Each $12**

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. **Each $15**

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. **Each $58**

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. **Each $60**

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. **Each $100**

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.
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SBK-C1A: JUNG 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. **Each $30**

SBK-C1B: THREE WAY, SINGLE CHANNEL CROSSOVER. [SB 3:82] Contains 2 each SBK-C1A. Choose high & low frequency. **Each $58**

SBK-C1C: TWO CHANNEL, COMMON BASS CROSSOVER. [SB 3:82] Contains two each SBK-C1A. Choose 1 frequency. **Each $62**

SBK-C2: BALLARD ACTIVE CROSSOVER. [SB 3,4:82] three-way crossover with variable phase correction for precise alignment. Kit includes PC board (5⅜ x 9½"), precision resistors, polystyrene & polypropylene caps. Requires ± 15V DC power supply—not included. Can use KL-4A/KL-4B or KW-3. Two channel **$145**

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, 4¼" x 5½" circuit board and all board mounted components. Chassis and heatsink are not included. **Each $130** Two or more **$122**

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

KF-3: GATELY REGULATED SUPPLY. ± 18V or ± 15V @ 100mA. **Each $48**

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

KL-4B: SULZER DC RAW SUPPLY. ± 20V @ 300mA. **Each $42**

KH-8: MORREY SUPER BUFFER. [4:77] All parts, 1% metal film resistors, NE531 ICs, and PC board for two-channel output buffer. **Each $20**

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. **Each $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 ± 15V power supply @ 63 mils. Single channel. **Each $58**
Two channels. **$110** Four channels. **$198**

KW-1: MAGNAVOX CD PLAYER MODIFICATION. Improves frequency response. Includes two Signetics NE5535s, two Panasonic HF series 330μF capacitors and four 3.92k, 1% metal film resistors. **Each $10**

KW-2: MODIFICATION. As above, but with two AD-712 op amps in addition to the NE5535s. **Each $13.50**

KX-1: CD ACCESSORIES. Set of 3 Sorbothane feet, 3 Tip Toes and Mod Squad's Disc Damper with 15 centering rings. **Each Set $75**

HDHFT: HI-FI TIPS. Imported for Old Colony. Solid brass, 1" conical feet for components and loudspeakers. Includes self-adhesive pad. **Each $3.00**
10 or more **Each $2.50**

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

Finally, when determining a driver's V_{AS} using the test procedures described in Mr. Bullock's article in *SB* 1/81 (p. 12), should the volume of air trapped under the inverted driver cone in the test setup be included with the known test box volume (V_{TB}), or is it inconsequential?

Why is the formula

$$V_{AS} = V_{TB}\,[(f_C Q_{EC})/(f_S Q_{ES}) - 1]$$

better than

$$V_{AS} = V_{TB}\,[1.15(f_{cc}/f_S)^2 - 1]$$

as stated in the same article?

Robert E. Davis
Belle Mead, NJ 08502

Mr. Bullock replies:

Mr. Davis's analysis of the relationship $V_{AS}/V_B = \alpha$ is not incorrect, but it misses the point because he treats α as a constant. With this constraint, an increase in V_{AS} must be adjusted for by a decrease in V_B—i.e., an indirect relationship. But in practice, α is treated as a variable and V_{AS} as a constant. The objective is to choose V_B so that the value of α is the one specified by the target alignment. In this context, higher damping (lower Q_{TS}) is accompanied by larger α values—i.e., higher damping requires smaller box size. You can see this in the relationship between Q_{TS} and α in the alignment tables and formulas.

High compliance in and of itself does not necessarily imply high damping. Driver damping depends on several driver parameters. For example, doubling V_{AS} with no other changes will decrease Q_{TS} by a factor of $\sqrt{2}$, but doubling both V_{AS} and M_{MS} will leave Q_{TS} unchanged.

I mention the formulas found in Weems's book in my SB 4/80 article (last paragraph of Small Alignments section, p. 13), but I attribute them to Hoge. Saffran also presented them in a letter in SB 1/81 (p. 34). Alignment formulas for vented boxes are necessarily approximations to the table values, since there is really no elementary relationship between the alignment parameters. The usual procedure is to take table data and fit an elementary function to it by least squares. The accuracy of the fit depends on how many data points are used and what type of function is fitted. Using too few data points or an inappropriate function can lead to large errors. I presume this is the cause of at least part of the discrepancy Mr. Davis found. Part of it could also be due to the formulas assuming a different Q_L value than Mr. Davis used.

What you must keep in mind is that formula values are not "incorrect" in any sense; they merely produce a different alignment than the tables. To decide whether it is a good alignment, I would run it through BOXRESPONSE (SB 1/84, p. 13) and look at the response curve. Generally, I think that the table alignments should produce flatter responses, but the differences may be negligible even with a sizable difference in box volume. The excess box volume in the test box with the drivers inverted is probably insignificant, but it would not hurt to include it.

The first formula Mr. Davis gives for computing V_{AS} is exact, while the second is based on an estimate. When you mount a driver in a box, the effective moving mass increases because of an additional air load. The amount of mass increase depends on what proportion of the baffle area the driver occupies. The first formula incorporates the actual mass increase into the calculation, but the second formula assumes an "average driver" that occupies about one-third of the baffle area. Cobb gives a derivation of this approximate formula in the JAES (Volume 19, Number 1, pp. 53–55).

DRIVER DATA

In the cause of truth, I respond to Gary Galo's reply (*SB* 4/87, p. 52).

First, regarding the differences between Carbonneau drivers offered by Fried and Meniscus, and whether they are "virtually identical," or "somewhat similar," Scott Boley of Carbonneau notes:

- Different motor systems—the Fried

drivers use a 54 oz. motor system, with a different size, length, and stacked magnet approach. The Meniscus drivers use a less expensive magnetic, or motor system.

• Different dust caps—the Fried are the "duocone" versions.

• Completely different voice coil—as any who deals with drivers knows, the exact geometry and nature of the voice coil affects several operating parameters.

If Mr. Galo does contact Carbonneau (I am told he last spoke to them almost three years ago) he will find the statement to be accurate—so the phrase "somewhat similar" can *loosely* apply, but that is not what driver design is about.

I last talked to Mr. Galo over two years ago, when the C/3, SM/3 project was started. I recall some technical discussion about the differences beween Dynaudio drivers, then used in his lines (and which I had brought to the US and then used in the late 70s) and what we were now using—advanced dome units and specially designed drivers. I do not recall any cover-ups or refusals to answer technical details.

The C/3s went to Mr. Galo as he stated; later we introduced the C/3-L and I suggested that he build both and compare the results, which *SB* readers should find interesting. I did state the SM/3 kit was delayed (at one time, because of coils, i.e., chokes).

We were just about to get an SM/3 kit to Mr. Galo when the C/3 kits were returned. I apologize to all who look forward to Mr. Galo's review of a complete Fried transmision line and hope it can be arranged in the near future.

However I am troubled by the implications of Mr. Galo's statements, misleading *SB* readers—that was the reason for my first letter concerning Meniscus and Fried drivers.

Recently I found out some home builders were copying my C/3-L, using substitute drivers and domes. The basic performance of the C/3-L relies on the Fried 6½-inch driver and the specific dome unit, made for us in Denmark, which are exactly matched with the crossover and enclosure. Changing drivers and crossover will alter performance and is not recommended.

I think if Mr. Galo reviews the SM/3 kit, the design, which I have worked out over many years, will be copied by others, which brings up a question of ethics, proprietary rights, and so on. Everyone has a right to purchase one of my systems and copy it (only for private use, of course), but I do not like the notion that the copies are "virtually identical."

In closing: I generally quote other sources, as I did in my first letter, on the quality of Fried loudspeakers. I do not recall besieging Mr. Galo with claims of my own on my loudspeakers.

I trust this response will be useful; if only to keep the search for more accurate sound reproduction within the boundaries of truth, ethics and good taste. I am sure Mr. Galo and I agree on those, and perhaps we can still arrange to have him build and review the speakers, at his convenience.

Irving M. Fried
Philadelphia, PA 19151

Gary A. Galo replies:

I thank Mr. Fried for providing the specific information on the Carbonneau drivers, as per my request. It would appear that the Meniscus drivers are physically similar, but not identical.

I have never knowingly misled readers of this magazine. As our editor knows, I am prone to running up my phone bill in an attempt to get at the heart of matters I am pursuing. I do not like mysteries. The information I provided regarding the Fried/Meniscus matter was based on the best information available to me at the time the review was written.

[I am bound to remark that I believe the issue between Mr. Fried and Editor Galo is one of accuracy, not truth. Mr. Fried was not forthcoming in our long effort to get accurate information from him. But Editor Galo's descriptions were accurate, based on his available information. Mr. Fried's suggestion that truthtelling is involved here is unwelcome and highly inappropriate.—E.T.D.]

PLANAR MAGNETICS

Where might I find information on the design and construction of planar magnetic speakers?

L. Paul Monahan
Reston, VA 22091

The Editor replies:

I know of no source. Perhaps others do.

LINES & ARRAYS

I have two questions regarding my current speaker building project. Will transmission lines, which were originally calculated on the speed of sound in air (1130 ft/sec), work just as well based on ¼-wavelength and on the 400 ft/sec speed of sound through the stuffed line? Does the extra length mandated by the ¾-wavelength provide much better damping and cone control at resonant frequency along with better support of low frequencies?

People I know, who make a living building transmission lines, also say these lines must be fine-tuned regardless of what theory predicts. I suspect the theory of transmission line operation is not well understood, and that the free-air resonance of a driver may shift once it is connected to a stuffed line and also, any bends in the line are affecting the speed of sound through the line in an unpredictable way.

My second question pertains to the Jordan 50mm modules. As some readers are aware, this driver may well be without peer between 300Hz–5kHz. Nothing I have heard exceeds its clarity or transient response, and this includes the Acoustat electrostatics and the Strathearn ribbons. However, the driver does not seem to extend flat down to 150Hz as Ted Jordan claims, it needs to be stacked in vertical arrays of 4 to 8 drivers to handle power well, and there are better drivers available for the frequencies above 5kHz.

The only workable arrangement would appear to be one vertical stack of Jordans beside a vertical stack of leaf tweeters. A fourth-order crossover network would seem applicable. This still leaves the problem of a narrow radiation pattern. A D'Appolito design with a twist, using a third-order crossover with two vertical stacks of Jordans on either side of a vertical stack of leaf tweeters, might be a posssibility. Would this have an evenly distributed horizontal radiation pattern or would there be too many interference patterns from the multiple wave launch?

I would like to take the opportunity to thank *SB* and its contributors. Every issue has been thought provoking and enjoyable. In the interest of world peace, speaker building should become a universal endeavor as it leaves little energy for anything else.

One further question, does aperiodic loading work as well as Dynaudio claims?

Herbert Meyers
Longmeadow, MA 01106

Contributing Editor Galo replies:

The speed of sound in a transmission line damped with long fiber wool is 405 ft./sec. This assumes a packing density of 0.5 lb./cu. ft. (or 8kg/cu. m, as in the example on p. 38 of the Loudspeaker Design Cookbook*). A ¼-wavelength line stuffed at this density will effectively be just under ¾-wavelength. I believe that the extra length does provide better woofer control at resonance. Bailey pointed out that the ideal transmission line would be of infinite length. Since that is impossible, a shorter alternative must be found. Vance Dickason points out, as I did in my article (*SB *2/82), that the phase shift in a ¾-wavelength line is the same as in the ¼-wavelength line (90°). However, in a ¼-wavelength stuffed line the back radiation of the woofer is substantially absorbed, whereas the undamped ¼- or ¾-wavelength labyrinth will have substantial output from the end of the line.*

The evolution of transmission line theory *is still at the point where final measurements and tuning are not exactly predicted by the math. Bob Bullock has made substantial headway toward changing that, however. He has written a transmission line program for IBM compatibles which you may find both informative and useful. It is available from Madisound's Bulletin Board (TLINE.ARC). If you do not have a modem, let me know and I can send you a copy. It requires color graphics and will not run on a Hercules display card.*

I have been doing some experimentation with aperiodic loading and I can tell you that it works every bit as well as Dynaudio claims. So far, my experiments show that system resonance will be the same as a sealed (acoustic suspension) enclosure, but with a significant reduction in impedance at resonance. I believe the aperiodic enclosure is the next best thing to a transmission line for smaller enclosures. The sound quality is more open at the low end, possibly due to a reduction of internal pressure around the resonance frequency.

Kirk Neal,
President, E.J. Jordan USA, replies:

Ted Jordan and I believe the operational principles of simplicity and performance through real world conditions are the fundamental theories behind the Jordan 50mm module and all Jordan drivers.

Although the Jordan drivers are technically advanced and well designed transducers, in the final analysis the most accurate and flawless systems are achieved by trial and error, with the ear. The specifications and parameters of our drivers are a starting point for any endeavor, to find their performance potential.

Mr. Meyers is correct in his analysis of some of the 50mm module's performance potentials. We do not recommend the original crossover point of 100–150Hz for 99% of applications. This low filter point works, and was appropriate for the times and uses across the ocean, but given the US standard of higher power inputs, the advent of digital information and the ability of the Jordan module to sing beautifully until self-destruction occurs, we recommend filter points of 250–500Hz.

Mr. Meyers is also correct that to produce a system capable of "high output" an array of two to four treble drivers is mandatory. The question is, how is high output defined? The connotations of high decibel output vary dramatically from person to person. Jordan drivers are of medium efficiency and power handling capability and require careful installation and usage.

Adding leaf or other tweeter drivers above 5kHz with the Jordan unit has been done many times: most were unsuccessful and some, satisfactory. The 50mm module exhibits a frequency response glitch at about 14kHz which is only audible when listening directly on-axis. Hence, most of our designs call for a 30–45° inward toe-in.

I believe in the cleanest path from power input to driver, and 6dB or 12dB/octave, first- and second-order Butterworth filters have served well. Filter technology has advanced to such a point (not to mention the incredible source materials in Speaker Builder*) that the hobbyist can experiment at a vastly accelerated rate toward a successful system. With the experience of countless failures I can assure Mr. Meyers that an initial simple approach allowing for changes and flexibility can be the straightest path to success. Enclosure integrity and room placement are extremely important as well.*

To conclude, an apology is due to all who have patiently awaited more technical data and information from us at E.J. Jordan USA. With the advent of the E.J. Jordan Owner's Club we are finally able to offer home builders the technical backup needed.

As a veteran of hundreds of "true" transmission line systems I can assure Mr. Meyers that there is certainly a good deal of theory and comprehensible specifications to each design. There is also, however, for whatever reason, a good deal of experimentation regarding type and amount of line treatment (wool/polyfil stuffing, damping, and so on) if you are to exploit maximum results. The transmission line has all but disappeared from the public eye because they are the most *labor-intensive design to build and fine-tune. The existing theories about line lengths are accurate enough.*

My experience with aperiodic loading is somewhat limited. This method of air movement control seems to me to have a positive affect on driver speed but a negative affect on driver control and damping characteristics.

DIRECT RADIATOR ENCLOSURES

I have read with great pleasure Ralph Gonzalez' series about LMP. A wonderful work. It is a small wonder why no one has ever addressed this problem, let alone done so beautifully.

In *Part II* you asked for information about a driver's frequency response when mounted on one side of a cylinder. You may find an article by Mr. Olson, "Direct Radiator Loudspeaker Enclosures," *Audio Engineering*, Nov. 1951 interesting. A copy was given to me by my friend Siegfried Linkwitz, when I was visiting him in Santa Rosa.

Riza Nur Pacalioglu
Istanbul, Turkey

EZ CONCRETE

I have built speakers using a drywall cinder panel, used for tile walls in steam baths, compressed to ½-inch thickness, with fiberglass mesh on both sides, called Dur-A-Rock or Wonder Board.

I line the back, sides, top and bottom of my enclosures, using drywall glue and screws to hold the panels in place. The material cuts easily with a knife.

The enclosure is heavy, rigid and dead sounding.

Jim Eldridge
Frankfort, IL 60423

HIGH—FIELD MAGNETS

I am a recent subscriber, thankful that I finally found a forum where my technical questions can be answered.

My background is in high-field superconducting magnets with three-dimensional pulsed gradient fields. We lock down the coil in the field and pulse it to modify the main field. A typical speaker would utilize what we refer to as the Z-axis (or longitudinal) gradient coil and be allowed to move when pulsed rather than locked down to modify the main field. We pulse our coils at audio frequencies using standard bi-polar audio amps.

Recently, two letters raised questions in my mind about the similarities in the two technologies. First, the use of magnetic shielding and secondly, the use of copper rings between the coil and magnet assemblies.

Any sheet steel placed in close proximity to a magnetic field will "capture" flux up to the point that the material becomes permeated. Thin steel is sufficient to shield relatively small fringe fields, but the steel will become magnetized and concentrate flux. This increases the magnetic field on the side with the steel, potentially causing the coil to torque when pulsed rather than moving linearly. A product called mu metal does the same thing without affecting the main field homogeneity (available through several sources). [*And quite expensive, plus difficult to form and retain its shielding property.—Ed.*]

We use copper similarly for the purpose of decoupling eddy currents in the magnet when the coil is pulsed. I would assume that in speakers the intent would be the same. Copper sets the time constants (frequencies affected) to a fixed point thereby allowing for active equalization. This objective could also be accomplished by breaking the material carrying the eddy currents into small sections which would remove the eddy currents' path.

I would appreciate any information on the importance of these items in speaker construction. I believe speakers are affected in the same manner as high-field magnets and with higher fields it is easier to see what has an adverse effect on all magnetic fields.

Kevin S. Smith
Redondo Beach, CA 90277

ANALYZER DIVIDENDS

After much procrastination I modified my Strathearns *a la* Spangler and McKenzie (*SB* 3/85, pp. 22–30). Modifying the first unit took 45 minutes, the second, 30 minutes. The difference in sound quality is significant. I compared the sound listening to FM interstation noise. The sound of the rebuilt Strathearn was similar to a sigh, compared to a hiss for the unmodified one. It is also faster, smoother and cleaner. I have not tried the correction filter.

Clean the connectors while the driver is being modified. Brass nuts and bolts are used and they corrode easily. I also cleaned the interface between the first brass nut and the ribbon. I applied Cramolin to all contact surfaces.

Also, I fine-tuned the the audio system using a full octave spectrum analyzer. The unit, a BSR-3X, is an AC powered unit with a plug-in microphone, built-in pink noise generator and line inputs. After playing with it for a while to characterize sounds such as traffic noise, dogs barking, thunder, and my voice, I finally got down to checking out the system.

The built-in pink noise generator, when fed into the unit, was 3dB down at 30Hz. I do not use the generator since I built the *SB* pink noise generator (4/84, pp. 16–20). This unit measures flat into the analyzer, within the ±2dB resolution of the unit. I set up the microphone on a tripod at ear level in my usual listening position. The system was quite flat from 60–80kHz. There was a dropoff of −3dB at 16kHz, a 3dB peak at 8kHz and a 6dB peak at 30Hz. The 16kHz droop is the natural rolloff of the driver, the mid-peak is the metal foil resonance which is tuned out by the prefilter and the low peak is due to standing waves and a resonant floor. It was interesting to see the huge 30Hz peak when I walked across the heavily carpeted floor. So, even the best system can be undermined by a less than optimum listening room. I have seen an article on "tube traps," which might help. They are hollow fiberglass cylinders put in room corners to dampen standing waves.

I used the analyzer to adjust the relative levels between the woofers and the Strathearns. I thought the system was a little bright and the spectrum analyzer showed the Strathearn was indeed about 3dB higher. I put some resistance in line before the Strathearn crossover and matched the level to the woofer output. I plan to bi-amp the system soon and will use the analyzer to balance the two levels.

I also used the analyzer to check my cassette deck. I recorded pink noise at several levels and played it back through the analyzer. At levels where the unit should have been flat to 20kHz, it was 6dB down. I returned the deck to the dealer for repairs. It seems when they replaced the record/playback head about a year ago, they did not adjust the bias. My unit is not an auto bias machine.

So, I recommend that you buy or borrow a spectrum analyzer. It is the wisest $50 I ever spent. I also whole-heartedly recommend the Strathearn modifications. I do not think I need the prefilter, but I may try it on one loudspeaker and see if I like it.

I liked the "Mistaken Identity" editorial. Very well said and very true.

William E. Wagaman
Mertztown, PA 19562

BRAVO OCTALINE

I have been building, buying and listening to speakers for many years. I believe the Octalines (*SB* 3/87) are the best sounding speakers I have ever listened to, regardless of size or price. They offer a spaciousness, depth and clarity that I have not experienced before. Like the author, I am reluctant to turn them off.

I substituted Radio Shack's 40-1390 ribbon tweeter for the author's cone tweeter and changed the crossover to a 4µF polypropylene capacitor in series with the tweeter.

James P. Kitchen
Palm Bay, FL 32905

ESL PARTS

It is surprising that many readers of *Speaker Builder* are beginning only now to undertake construction of the electrostatic loudspeakers described in the *SB* 1980 series. I no longer supply transformers and Mylar film to home constructors because of the small quantities being requested. To assist amateurs who wish to construct these speakers, the following transformer and Mylar specifications and suppliers are suggested:

Transformers are still manufactured by Triad and are available from your local electronics parts house that handles Triad products. Although they will undoubtedly not have them in stock, they can still be ordered as part #S-142A, approximately $50 each.

One-quarter mil Mylar film is no longer available in small quantities anywhere in this country. However ½ mil is available from large plastics supply houses. My source has been Transparent Products Corp., 3410 South La Cienega Blvd., Los Angeles, CA 90016, (213) 938-3821.

Although I have moved, I am still available to answer questions or assist readers as needed and prefer phone calls at (503) 742-2122, evenings (Pacific Time).

Roger R. Sanders
Rt. 1, Box 125
Halfway, OR 97834

WOOFER GASKETS

Several writers have recommended mounting woofers in their enclosures with rubber grommets, thick foam gaskets or a deep bead of caulk. I understand the purpose is to mechanically decouple the woofer from the enclosure, to reduce sound coloration by vibrations from the cabinet.

I respectfully suggest such mounting methods are not appropriate. While a thick elastic mounting will undoubtedly dampen some vibrations, it will leave the woofer frame free to vibrate. Any movement of the frame will cause smearing of the sound due to Doppler shift.

I believe woofers should be mounted as tightly as possible. To seal the gap between the enclosure and the driver frame, use a thin rubber gasket or, instead, a thin bead of sealant. I have successfully used a product used for making engine gaskets, Permatex Aviation Form-A-Gasket. This product is a lot less messy than other gasket products.

I would welcome comments from *SB* readers.

David G. Willemain
Towson, MD 21204

LOW-END OPINION

After reading *Speaker Builder* for a year, I have several comments.

It is a very good and valuable source of entertainment and information which is badly needed in today's market.

I think it needs to give more coverage to speaker systems that are capable of reproducing the entire musical spectrum at levels approaching a live performance. The laws of physics preclude the use of low frequency drivers smaller than 12" in larger listening rooms. The use of 4–8-inch woofers in any type baffle are not capable of sounding accurate at loud levels in any room much larger than a small bedroom.

I have been building and buying speaker systems for 27 years and have found that listeners get goose bumps when they hear one that is able to perform at moderate to

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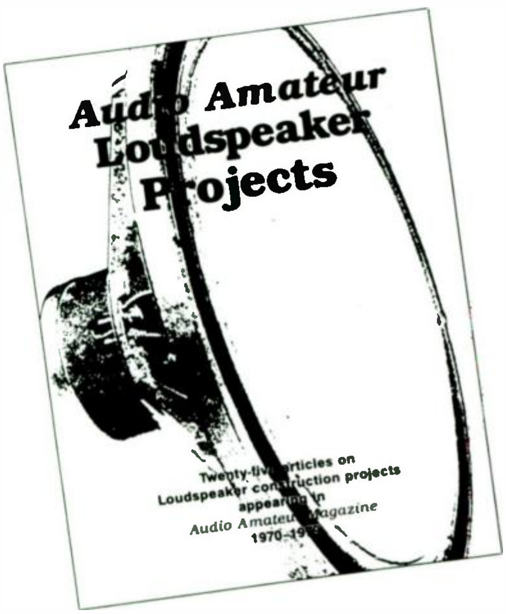
Twenty-five articles on Loudspeaker construction projects appearing in *Audio Amateur Magazine* 1970–1979



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OLD COLONY BOOKS PO BOX 243, Peterborough, NH 03458 high output, even when operated at lower levels.

I own many small systems and they have a place in many applications, but I cannot regard them as substitutes for more capable ones in a larger environment.

It seems that readers, who invest much money in the electronics part of their total systems, would be better served to remember that almost any amplifier, for example, is better then the best speaker money can buy.

Ronald B. Brantley
Westminster, MD 21157

TRANSIENT SPEED ASSOCIATIONS

Duke LeJeune's excellent project, "A Gold Ribbon System," (*SB* 4/86) is a sonically well thought-out design which acknowledges the importance of aesthetic concerns.

I have one minor correction. The author states at the end of the article that a low quality subwoofer may "detract from the system's transient speed." As I understand it, transient speed is associated with rise time, which is determined by a system's high frequency driver (see *Fig. 3* of Max Knittel's article in the same issue). As long as its frequency response extends an octave beyond its crossover frequency, I don't think a subwoofer's rise time is important.

An underdamped subwoofer may affect the system's transient response by "ringing" at its resonant frequency, which may sound like "sluggish" bass. It is also possible for cone resonances in a low quality subwoofer to color the transient response, but I think the crossover frequency is usually low enough to avoid this. It is important to note that for a minimum-phase device (which is usually a good approximation for a *single* driver), the frequency response graph provides the same information as the transient response.

Ralph Gonzalez
Philadelphia, PA 19143

Mr. LeJeune replies:

To the best of my knowledge, you are right in stating that the system transient speed (or speed with which the system can respond to a pulse) is determined by the high frequency driver, and I stand corrected.

I was trying to get across the idea that it would take a pretty good subwoofer to make a positive contribution to the bass of the Gold Ribbon System.

Several years ago I built a couple of two-way transmission line systems using the smaller KEF B110 woofers. The bass was tight, but it didn't extent very deep. I added subwoofers, using the KEF B139s, but I couldn't get the same tight bass and the music sounded more natural without the subwoofers, no matter how I adjusted them. I think I would have similar problems if I added a subwoofer to the Gold Ribbons.

Your observation that the frequency response graph provides great insight into the low frequency transient response might have helped me better identify why my subwoofers, transmission lines and Isobariks, didn't perform to my expectations, although one of the Isobariks came pretty close. At any rate, you have explained why a sealed box I built that had a calculated Q_{tc} of 0.47, didn't sound especially tight. A frequency response curve showed the low end rolloff more closely resembled a system Q_{tc} of 0.8, which is what it sounded like. The response curve far more accurately predicted the subjective bass transient response than the calculated Q_{tc} did.

REDUCE IMPEDANCE PEAKS

I have just found that if you have an L-type attenuation between your tweeter and crossover, it greatly reduces any impedance peak at resonance (*Fig. 1*).

This reduction is less effective with less attenuation, but still usefully reduces the peak.

Until now it seems no one has attempted to attenuate woofers. What if you put a resistor in parallel? You could lower an 8Ω woofer 6dB safely with an 8Ω resistor, giving 4Ω. Of course, the Q_{ts} will be lowered. This may help optimize a woofer for a smaller box. But, will this hurt the coupling to the amplifier?

Ed Light
Los Angeles, CA 90064

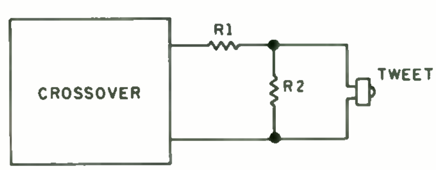

FIGURE 1: L-type attenuation between crossover and tweeter.

Joe D'Appolito replies:

L-pads do reduce the impedance peak at resonance. Any resistor paralleling the driver will do the same thing. Generally this technique is of limited use since large amounts of attenuation are required to obtain substantial reduction in the peak. L-pads are not desirable in woofers since they use up valuable amplifier power and raise Q_{ts} (not lower it) causing loss of bass control.

If the resonant peak is a problem with tweeters an RLC circuit can be placed across the voice coil terminals which exactly cancels the resonance rise and voice coil inductance effect. The same could be done for woofers but the component values become quite large. Most woofers are back to their nominal impedance value in the 200–300Hz range. Unless you are using a passive crossover at a lower frequency than this there is no need to control the peak. If you intend to cross over below this frequency, biamping is the better approach.

SONOTUBE & SAND

I have enjoyed the magazine very much. The photo shows one of my Sonotube enclosures, with Arizona sand between

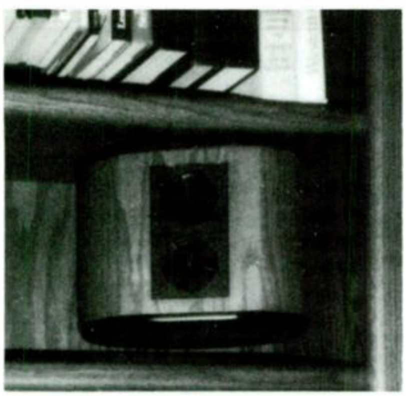

PHOTO 1: Bookshelf Sonotube.

concentric tubes, *a la* Transcendental Audio of a few years ago. Low end is 4-inch Dalesfords per Jordan. I am happy with the imaging on bookshelves where vertical placement of a tower is not possible. Crossover is now passive at 150Hz, but I will soon try an active design.

I hope to do more with Jordans in a manner acceptable to an interior designers' taste, with subwoofers hidden in an unlikely decorative cabinet.

Donald E. Lockett
Tucson, AZ 85749

SHIELDING SPEAKERS

I am writing this letter in response to Mr. Friend's question (*SB* 4/87, p. 61). I built a Heathkit TV and my own enclosure a few years ago and gained experience in this matter.

The magnetic field affects beam deflection, not color balance. You can actually see flux lines on the screen. The Heath TV is well shielded with steel and it did not help. I have not tried laminated shielding which might work, but is expensive.

A compromise is using drivers with small magnets. After trying many different drivers, I purchased some from Heath designed for video use and they worked best, especially for TV audio, but are not acceptable for hi-fi stereo. The best solution is placing the speakers away from the TV.

Al Corkins, Jr.
Battle Creek, MI 49017

VALÉ

As you know by my subscription, I have been a fan of *Speaker Builder* as well as *Audio Amateur* and have enjoyed them both through the years. Recently I had more interest in speakers than the rest of the "rig."

Being time to renew I have been thinking about it quite a bit. My retirement years have been filled more with creating stained glass windows and "sun catchers," as we call them, than to improving the sound in my home. The last time it "came first" was when we moved in over four years ago.

So I guess what I'm saying is, "Thanks for the memories." I shall skip renewing this year. All the success in the world to you and your creations.

John W. Claris, Jr.
Hendersonville, NC 28739

[*Thank you. Vale.—E.T.D.*]

ESL: THEORY OR BIAS?

I would like to comment on Mr. Sanders review of Mr. Wagners's book *Electrostatic Loudspeaker Design and Construction*. I was not in total agreement with the review. I have read this book cover to cover a couple of times and would have reviewed it more favorably.

I believe Mr. Wagner's book does not require an engineering background to understand. The math and physics are high school level. The material should be easily understood by *SB* readers. The reprinted articles by Matthys, Walker and Malme are more difficult to understand and some electronic and filter theory background would be helpful.

Mr. Sanders' remarks concerning the construction of the author's design do have merit. It is complicated and expensive and there are alternative techniques that would make it easier and cheaper to build. Mr. Wagner doesn't discount alternative methods in the book. His statements in the construction details would aid builders in developing their own ideas.

Much of the author's construction requirements are dictated by the obvious design goals. The bracing, segmentation, and diaphragm stretching are all necessary.

Some of Mr. Sanders' comments sounded biased; his design philosophies and techniques differ from the author's. For example:

Mr. Sanders doesn't use a stretcher or segmentation. Both help overcome the problem of dipole cancellation without the need for other equalization techniques. Segmentation also allows the designer to tailor the frequency response, reduce capacitative loading problems and increase dispersion properties. As Mr. Sanders points out, sensitivity will suffer as a result.

Mr. Sanders and Mr. Wagner differ in their choice of diaphragm coating material (graphite vs. Ivory soap). The goal of each is the same, to have a highly resistive diaphragm with fairly uniform conductance.

Was there some animosity on the part of Mr. Sanders? He thought it odd that Mr. Wagner neglected articles from *TAA* and *SB* which offer practical designs. The most notable and maybe only article to fit that description was written by Mr. Sanders!

Like Mr. Sanders, I would like to know more of Mr. Wagner's preferences and alternatives as he designed his speaker. As

Mr. Sanders stated, material on ESL design and construction is limited and hard to find.

William A. Harnois
Vallejo, CA 94591

Roger Sanders replies:

Thank you for your thoughtful letter. Reasonable men may disagree over details while still being in agreement with the fundamental concepts of the book. I believe that this describes our views.

I would like to make a few comments regarding specfic points you made. It has been my experience that most readers do not have an engineering background, and more importantly, do not have the desire to approach a speaker project from a mathematical direction. They are usually looking for useful, practical guidelines. I agree that a good working knowledge of high school algebra would be adequate for most of the material in this book, but that is not the point. Most readers are not inclined in this direction and would find the book to be hard reading and of little practical use. Those readers with an engineering interest would find the book a "gold mine" of information, and I credited the book and recommend it to those so inclined.

As you noted, Mr. Wagner did not discount alternative methods of construction or design in the book, but he did not discuss them. A few comments in the construction series hardly qualifies as a thorough discussion of ESL design parameters, compromises and the wide variety of possible solutions, along with their pros and cons. To those of us who are familiar with ESLs, most of his design choices are obvious. But the book will also be read by novices who will find his design choices far from obvious. I solidly stand by my opinion that the major failing of his book is that it does not clearly and concisely discuss the design parameters of ESLs and the various solutions.

I am disappointed that you feel I am biased and harbor some animosity toward Mr. Wagner simply on the basis that I am also a published author. My recommendation that Mr. Wagner's bibliography be expanded to include some more practical articles (of which there are many, not only my own), hardly represent a bias; simply a method of making the book more useful to its readers.

Incidentally, since this review was published, I have heard from two builders involved with Mr. Wagner's speaker design, who confirm my suspicions that the speakers are costly, difficult to build and have poor sensitivity with low SPLs. Additionally, they report the speakers have not been reliable, experiencing transformer failures and amplifier instability. Also, their output has decreased with time, suggesting the diaphragm coating could be failing.

[Mr. Harnois is apparently not aware that David Hermeyer also wrote a series of articles in Audio Amateur *(2 and 3/77) on an electrostatic loudspeaker. I must agree with Mr. Sanders about omitting references to his articles, particularly since Mr. Wagner knew about all that had happened in* Audio Amateur *and* Speaker Builder.

I asked Mr. Sanders to review Mr. Wagner's book because Mr. Sanders has answered scores of letters from readers who have successfully built Mr. Sanders' designs. I think his criticisms of the Wagner book are justified by thousands of hours of hands-on experience in a variety of techniques.—Ed.]

LMP DEVELOPMENTS

A diskette of LMP (*SB*, articles by Ralph Gonzalez, 1/87 and 2/87) is now available for the Commodore 64, BASIC 2.0 (or Commodore 18 in 64 mode), thanks to *SB* reader Steve Kruger. The Old Colony order no. is CSK-C5. Note that this disk does not contain the LMP2 and LMP3 versions which were intended for technically-

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***CD-5** *Discovered Again* Dave Grusin. This recording of a jazz quintet features distinguished film and television composer/pianist Dave Grusin. Songs include, *A Child Is Born, Keep Your Eye on the Sparrow,* (theme from Baretta), *Sun Song, Captain Bicardi, Cripple Creek Break-Down* and four others.

Review quotes are from original review of the direct disc editions of these CDs.
** Made from the analog master tape*
† Made from the digital master tape.

***CD-7/8** *Wagner:* Excerpts from *Die Walkurie, Tristan und Isolde, Gotterdammerung,* and *Siegfried.* Erich Leinsdorf conducting the Los Angeles Philharmonic. *"The recording is uniformly excellent: percussion, brass, strings and woodwinds are superb."*
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***CD-13** *Growing Up In Hollywood Town* Amanda McBroom & Lincoln Mayorga (pop vocals and instrumentals). Included are *The Rose, Portrait, Dusk, Growing Up In Hollywood Town,* and *Amanda* as well as four instrumentals.

†CD-15 *West Of Oz* Amanda McBroom & Lincoln Mayorga (pop vocals and instrumentals). Songs include *Dorothy, My Father Always Promised, Reynosa, I'm Not Gonna Say I'm Sorry, Gossamer, Only With You, Happy Ending,* and three instrumentals.

†CD-17 *Tower of Power Direct.* This album includes *You Know It, You're Gonna Need Me, Squib Cakes, That's Why I Sing, What Is Hip* and *Never Let Go of Love.*

‡ CD-1000 *Boxed set, CD-25, 26, 27* **$44.95**

†CD-21 *The Name Is Makowicz* Adam Makowicz. Features the pianist/composer performing with a quintet, with saxophonist Phil Woods. Songs include *Pearl Grey, Past Tense, You Do Something To Me, Moondust* and four others.

†CD-23 *James Newton Howard & Friends.* High energy rock instrumentals composed for synthesizers, drums and percussion featuring James Newton Howard, David Paich, Steve, Jeff, and Joe Porcaro. Songs include *Caesar, Gone Buttlefishn', L'Daddy, Amuseum* and three others.

†CD-24 *Stravinsky: The Firebird Suite (1910) DeBussy: Afternoon of a Faun.* Erich Leinsdorf conduting the Los Angeles Philharmonic. This recording features the expanded orchestration of the original *Firebird Suite,* complete with the finale. *"One of the very best orchestral records I have ever heard.—Hi-Fi News & Record Review*

†CD-KODO *KODO: Heartbeat Drummers of Japan.* This recording features the world's reknown KODO drummers playing a variety of wooden drums, including the massive 700-pound o-daiko drum, in addition to other traditional Japanese wind and string instruments.

***CD-14/20** *The Sheffield Track Record* and *The Sheffield Drum Record.* These albums, combined on one compact disc, were recorded for the maximum sonic impact as a component testing and evaluation tool.

‡CD-25 *The Moscow Sessions* The Moscow Philharmonic. Glinka: Russlan and Ludmilla, Tschaikowsky: Symphony No. 5 in E Minor; conducted by Lawrence Leighton Smith. Recorded in Moscow in 1986, presenting the first recording of an American conductor leading a Soviet orchestra.

‡CD-26 *The Moscow Sessions* The Moscow Philharmonic. Shostakovich: Symphony No. 1; conducted by L. Smith. Piston: The Incredible Flutist, Barber: First Essay for Orchestra; conducted by Dmitri Kitayenko. Recorded in Moscow in 1986. First recording by a Soviet orchestra of American music.

‡CD-27 *The Moscow Sessions* The Moscow Philharmonic. Shostakovich: Festive Overture, Glazunov: Valse de Concert in D; conducted by L. Smith. Copland: Appalachian Spring, Gershwin: Lullaby (for string quartet), Griffes: The White Peacock, Ives: The Unanswered Question, conducted by Dmitri Kitayenko. Recorded in Moscow in 1986.

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minded readers who can calculate their own transfer functions.

I have developed add-on subroutines for LMP which allow you to model a system using Marchand Electronics' XM1 Electronic Crossover Kit, for two-, three-, or four-way systems. This active crossover has fourth-order slopes which can be varied between Linkwitz-Riley and quasi-constant power response, and uses metal film resistors, polystyrene capacitors, and high quality op amps. You can obtain instructions and a hard copy of the subroutines from: Marchand Electronics Inc., 1334 Robin Hood Lane, Webster, NY 14580.

You can make a one-line modification to LMP to get an idea of the *reverberant response* (*SB* 2/87, p. 48) of your loudspeaker. Simply LOAD LMP with your BASIC interpreter, and retype line 3845 as follows:

```
3845 M1 = SQR (M1^2 + M2^2)
```

Also, since it doesn't affect the reverberant response, you must specify "0" for the Response Step (*SB* 2/87, p. 42) in the LMP model for your drivers. These changes will cause LMP to produce the idealized reverberant response in place of the axial (magnitude) response plot, given two assumptions:

1. Your drivers have nearly perfect dispersion up to their respective crossover frequencies;

2. The centers of the drivers are spaced *greater* than about 7000/F inches apart on the front baffle, where F is the crossover frequency. (If they are spaced much closer than this, then the reverberant response will look more like the axial response, again with the Response Step eliminated.) If you save this version, be sure to rename it, say LMPR, or you will no longer be able to use LMP to obtain the on-axis response.

Finally, I am investigating alternative drivers to the expensive Dynaudio ones I used in the Construction Example in *SB* 3/87. For starters, it looks like the Morel MDT28 or MDT30 can be substituted for the nearly identical D28af tweeter, without changing the crossover.

Ralph Gonzalez
Philadelphia, PA 19143

TUNE-UP

Continued from page 34

wire to maintain good low frequency damping and avoid core saturation.

5. Capacitors should be film types (ideally polypropylene) bypassed by small value caps.

6. The speaker cabinets should be rigidly mounted to the floor or wall. Any relative motion or vibration of the cabinet relative to the listener will blur transient response. Motion of the cabinet also frequency modulates the output of the speaker cone (similar to wow and flutter) by Doppler shifting, thus causing problems even with continuous tones.

Many of these ideas have appeared in *TAA* as part of various other articles. When applied together they produce the natural sound characteristics of a POOGEd system.

PARTS SOURCES

Newark Electronics
6500 Papermill Rd.
Knoxville, TN 37919
(615) 588-6493
Resistors, Mylar caps, multiconductor cable

Old Colony Sound Lab
PO Box 243
Peterborough, NH 03458
(603) 924-6371
Small value (< 1μF) polypropylene caps

Madisound Speaker Components
8608 University Green
Box 4283
Madison, WI 53711
(608) 831-3433
Large value (> 1μF) polypropylene caps, inductors, complete crossovers.

Radio Shack
Resistors, small value Mylar caps

Graybar Electric Company
1727 Grand Ave.
Knoxville, TN 37901
(615) 546-7550
Multiconductor cable

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FOR SALE

Heathkit 10 Meg dual trace scope, model IO-4550, mint with manual, probes, $200; VSP labs HPF 102 high pass filter, (cost $175) sell for $50; Focal 7N501 woofers, $60/pair. Bob Kuhn, (404) 475-0694.

The following pairs: Polydax midrange tweeters, 1¼-inch domes, HD-13-D-34E, $25; Polydax midrange 1½-inch domes, HD-13-D-37, $25; Oaktron 6½-inch woofer, 20 oz. magnet, foam surround, BPW-6H2, $40; Oaktron 10-inch woofers, BPW-10-X, foam surround poly, $50; Peerless 6½-inch woofer, Poly-Tac black, Butly surround, TP-165-R, $45. All excellent to new condition. Dave Kanfer, 9239 Fern Ln., Desplaines, IL 60016, (312) 298-4552 evenings.

Power supply components, high voltage high value caps, 1300µF @ 450V DC, 2000µF @ 200, 5800µF @ 100 and others, low voltage high current transformers, power zeners and transistors many others. Send SASE to Don Brassell, 112 St. James Ave., Merchantville, NJ 08109.

Tri-amp system, 40-40 and 20-20 amps (5). Crossover per Linkwitz with P-P, power supply preamp has minimal switching with l.z. phono. Pirate LS 3-5s, Speakerlab 12″ woofers. Too heavy to ship. $450. Richard Herrington, 17 Phillips St., Amsterdam, NY 12010, (518) 843-2933.

Hewlett-Packard mil spec version of model 180 oscilloscope with 1801A and 1121A plug ins. Excellent condition, $450. Also other used test equipment. Send for list. Russell Hulme, 3609 Country Club Rd., Duncan, OK 73533, (405) 255-2109.

Two Dynaudio D52AF 2″ dome midranges, 10 hours, $80 pair; (2) SEAS P 21 REX 8″ poly woofers, new, $40 pair; SEAS P 25 REX 10″ poly woofer, 50 hours, $20. Gary Griggs, 1003 Oriole Ave., Rogers, AR 72756, (501) 631-1739.

Two pairs Klipsch Hereseys. Birch or black. $450 pair; Hafler DH-200 unmodified, $260. Prices firm. Mark Williams, (717) 888-3356 evenings.

Rowland Research electronic crossover board with power supply, never used. Crossover set at 150Hz. Original price, $134, sell for $50. Rowland Research 24 position stepped attenuator switch and board for solid-state preamps and circuits, never used, $69 originally, sell for $25. Stan Foote, 11A Meriam St., Wakefield, MA 01880, (617) 246-4106.

D'Appolito satellites only, oak (prototypes for *SB* 4/87 cover) with passive 165Hz crossover, $850/pair; JansZen Z-138 eight element electrostatics with 700Hz crossover, $225/pair; Dynaudio 30W54 bass drivers, $150/pair. J.W. Bock, Box 356, Swan's Island, ME 04685, (207) 526-4368.

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Onkyo 80wpc integrated amp A7022, $175; EPI T/E320, excellent condition, little use, $290/pair; AR58Bxi, $400/pair; SAE EQ-10 three-band parametric equalizer, brand new, $175. David Willemain, 725 Morningside Dr., Towson, MD 21204, (301) 321-9063, 337-8636.

Six Bose full range speakers, blue cones, new, $25 each; Acoustilog Impulser, device for aligning speakers and speaker systems, works with triggered scope and external microphone, very accurate readings, like new, with full directions, $200; Emilar built tweeters, like JBL but smoother sounding, $120/pair. Tom Young, 518 Pleasant St., Northampton, MA 01060, (203) 274-2202.

Two pair Strathearn ribbons with transformers and solid oak baffles, barely used: two Jordan 50mm modules, unused; two JVC Dyna-Flat ribbon tweeters, HSW1101-01A, unused; two "Unbox" circular enclosures by Transcendental Audio, foamed between double walls, fits two Jordan 50mm or one Jordan/1 JVC ribbon, two Speakerlab HT 350 high power horn tweeters, original for K-horns, unused; Heathkit AD 1702, variable electronic crossover, new condition. All for $650 or best offer. George Barrett, (206) 365-9599.

Six Bose 4½" F.R. cone speakers, 24 Heppner Dhorn tweeters; (2) Emilar Bullit tweeters, $120/pair. Acoustilog Impulser device for speaker alignment measurement, etc., $200; (4) TAD 15" woofers, $125 each; (2) JBL 3105 MR to VHF crossovers, $100 pair. Tom (203) 274-2202.

WANTED

Dyna JST-120. Need not be in working condition, but power supply and transformer must be okay. State condition and price. Kenneth P. Miller, Rte. 2, Box 134, Mexico, MO 65265, (314) 581-5413.

JBL 2245 18-inch woofers. David Willemain, 725 Morningside Dr., Towson, MD 21204, (301) 321-9063, 337-8636.

Owner of Acoustat 2+2 is interested in corresponding with anyone who has experimented with designing and building high quality subwoofers for ESLs. In particular, push/pull designs like Vandersteen's or Audio Concept's "Rock" or "Pulse." Paul Champlin, 3945 Lime Ave., Long Beach, CA 90807, (213) 426-8397.

Copy of the owner's manual and/or service manual for the KLH Transient Noise Eliminator, Model TNE 7000A. David W. Dranchak, 1205 Manor Entrance, Endwell, NY 13760.

Pair of Dyna MK III amps, good working condition, with cages and bottom covers. Also, DNM speaker cable, 18 foot lengths. Herbert Reichert, Rt. 23, Box 510, Norris, NY 13808, (607) 263-5260 after 6 p.m. EST.

Jordan 50mm modules in used, good condition. Send name and asking price. I will send check, you ship. Donald Lockett, 2765 N. Placita Copan, Tucson, AZ 85749.

One or two pairs of Jordan modules and crossovers. One pair of enclosures for four Jordan modules. GSI modification literature or kit for LUX MQ68C. New stylus for Grado Signature 10. One woofer for Met 7 speaker. L.P. Wilkins, 550 Baker No. 6, San Francisco, CA 94117, (415) 563-4329.

Help! Desperately looking for design information on the old RCA "Bathtub" low frequency horns using 2-15" speakers. Used in many theaters across the nation during the 40s and 50s. The model number for the entire two-way system is PL304. Todd Wilson, Box 2475, Canoga Park, CA 91306, (818) 709-8080.

CLUBS

Space in this section is available to audio clubs and societies everywhere free of charge to aid the work of the organization. Copy must be provided by a designated officer of the club or society who will be responsible for keeping it current. Send notices to Audio Clubs in care of the magazine.

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 PO Box 346, Manchester, CT 06040 or call Mike at (203) 647-8743.

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

AUDIOPHILES IN CENTRAL PENNSYLVANIA (also eastern Pennsylvania and Delaware): Interested in forming a serious audio organization? Contact Steve Gray, 625F Willow St., Highspire, PA 17034 or phone (717) 939-4815.

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

TUBE AUDIO ENTHUSIASTS. Northern California club meets every other month. For next meeting announcement send a self-addressed, stamped no. 10 envelope to Tim Eding, 2113 Charger Dr., San Jose, CA 95131.

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

ORGAN MUSIC ENTHUSIASTS: If live recordings of fine theatre pipe organs or electronic organs are your thing, I have over two thousand of them. I lend you the music on reels or cassettes. All operation is via the mail. A refundable dollar will get you more information. E.A. Rawlings, 5411 Bocage St., Montreal, Canada H4J 1A2.

THE BOSTON AUDIO SOCIETY INVITES YOU to join and receive the monthly *B.A.S. SPEAKER* with reviews, debates, scientific analyses, and summaries of lectures by major engineers. Read about Apogee, Nytal, Conrad-Johnson, dbx digital, Snell, music criticism and other topics. Rates on request. PO Box 211, Boston, MA 02126.

PACIFIC NORTHWEST AUDIO SOCIETY (PAS) consists of 50 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.

THE ATLANTA AUDIO SOCIETY started in October 1983 and has regular meetings on the third Sunday of each month as well as special programs with leaders in the industry, such as Mr. William Conrad of Conrad-Johnson and Mr. William Johnson of Audio Research. We are currently looking for additional members in the Southeast. all members receive the minutes of each meeting and program, as well as other relevant announcements and correspondence. For full information and membership packet, write Atlanta Audio Society, PO Box 92130, Atlanta, GA 30314, or call Howard Royal in Newnan, GA, (404) 253-6419.

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

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

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

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, annual picnic 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.

SIXTIES MUSIC FANS. The first club for fans of Sixties Era music wants to meet you. Strong audio and quality recording emphasis. How-to information shared. Worldwide membership. Informative, entertaining, and provocative newsletter published bimonthly. Help the world remember when rock had real artistic merit. Free brochure: send SASE or IRC to Classic Rockers Music Club, PO Box 1043C, Stevens Point, WI 54481.

AUDIOPHILES AND EQUIPMENT BUILDERS in the Long Island area—well established club looking to expand and share out experience. Monthly meetings, record critiques, technical help. Island Audio Club, 589-4260 (Suffolk), 271-4408 (Suffolk and Nassau), 825-2102 (Nassau).

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

THE AUDIO SOCIETY OF HONOLULU cordially invites you to attend one of our monthly meetings and meet others like yourself who are interested in the hows and whys of audio. Each meeting consists of a lively discussion topic and equipment demonstrations. For information on meeting dates and location, contact Craig Tyau, 2293A Liliha St., Honolulu, HI 96817.

ESL DIY'ERS: A new electrostatic loudspeaker do-it-yourselfers 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.

SAN FRANCISCO BAY AREA AUDIOPHILES. Audio constructors society for the active, serious music lover. We are dedicated, inventive and competent. Join us in sharing energy, interest, expertise and resources. Send self-addressed, stamped envelope to S. Marovich, 300 E. O'Keefe St., East Palo Alto, CA 94303 for newsletter.

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

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.

THE INLAND AUDIO SOCIETY IN THE SAN BERNADINO-RIVERSIDE AREAS, now in its third year of existance, is inviting audiophiles and music lovers in the San Bernardino, Riverside, Orange and Los Angeles counties to join us at our bi-monthly meetings and through our quarterly publication, in the pursuit for that elusive sonic truth. We provide a forum for auditioning equipment, sampling live music for educational purposes, guest presentations, discussing recordings, and the sharing of ideas, tips, theories, opinions, experience, and new product news relating to audio systems. Additionally we cater to the hobbyist who designs, builds and/or modifies electronic components and tranducing gear. Write for information concerning membership, dues and subscription. IEAS, PO Box 77, Bryn Mawr, CA 92318, (714) 793-9209.

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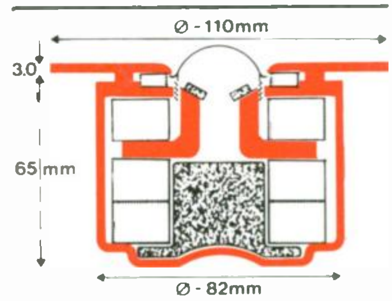
The MDT 33 is an extremely fast Tweeter, using a 28mm (1⅛") diameter voice coil and a chemically treated soft dome, and is ideally suited for two way systems with the possibility of a lower than normal crossover frequency, as well as for three and multiple way systems.

Incorporating the Morel Hexatech voice coil technique, aluminium wire wound on an aluminium former and using flexible wire termination ensures excellent high frequency performance with exceedingly high power availability. The power handling is further enhanced by using Ferrofluid in the magnetic circuit.

The magnetic system itself is an ingenious Morel double magnet design and is completely enclosed. By venting into the enlarged area of the double magnet system, a low resonant frequency of 500Hz is obtained with a remarkably smooth roll off from 1000Hz through this damped resonance area. The subsequent wide range response of 1400-20000 ± 0.6dB is obtained with a harmonic distortion of below 0.8% over the entire range. The distortion figures quoted are with an input power giving an output level of 96dB at 1 metre. The MDT 33 sensitivity is 92.5dB for 1 watt 1 metre, and a power handling capability of from 100 to 500 watt subject to crossover frequency.

With such a dome tweeter design, the acoustic qualities at lower than normal crossover frequencies are excellent with an absence of honking, and even at the more normal crossover frequencies this excellent acoustical behaviour is evident to the ear. With the lower crossover frequency available and high capability, it is ideal for consideration in two way systems using a 10" or 12" woofer.

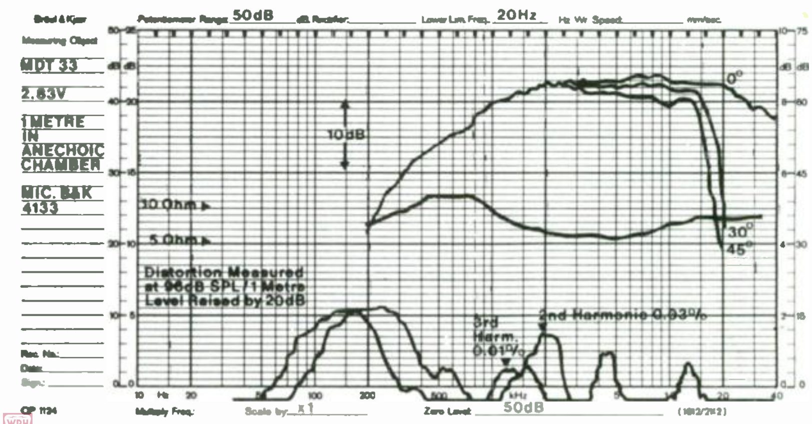
To utilise the dome at the lower than normal crossover frequency available makes it necessary to have a sharp roll off below 1400Hz of minimum 12dB per octave to protect the tweeter from mechanical damage. This makes it ideal for use with active systems.



Specification

Overall Dimensions	Ø - 110mm × 68mm	Vas	0.016 litre
Face Plate Thickness	3mm	Moving Mass including Air Load	0.44 grams
Voice Coil Diameter	28mm (1⅛") Hexatech Aluminium	Effective Dome Area	8.5 cm^2
Voice Coil Former	Aluminium	Dome Material	Treated Fabric
Number of Layers	2	Frequency Response	1400-20000 ± 0.6dB (1000-40000 – 5dB)
DC Resistance	5.2 ohms	Resonant Frequency	500 Hz
Nominal Impedance	8 ohms	Power Handling Din:	
Voice Coil Inductance @ 1 Khz	0.09mh	X-Over 1400 Hz	100W
Air Gap Width	0.75mm	X-Over 5000 Hz	500W
Air Gap Height	2.5mm	Transient Power 10ms	1500W
Voice Coil Height	2.7mm	Sensitivity	92.5dB (1W/1M)
Flux Density	1.95T	Rise Time	10μs
Force Factor (BXL)	4.76 WB/M	Intermodulation Distortion	
Rmec	2.09ns/m	for 96dB SPL	<0.2%
Qms	0.66	Harmonic Distortion	
Qes	0.38	for 96dB SPL	<0.8%
Q/T	0.24	Nett Weight	1.2 kg

Specifications given are as after 24 hours of running.



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