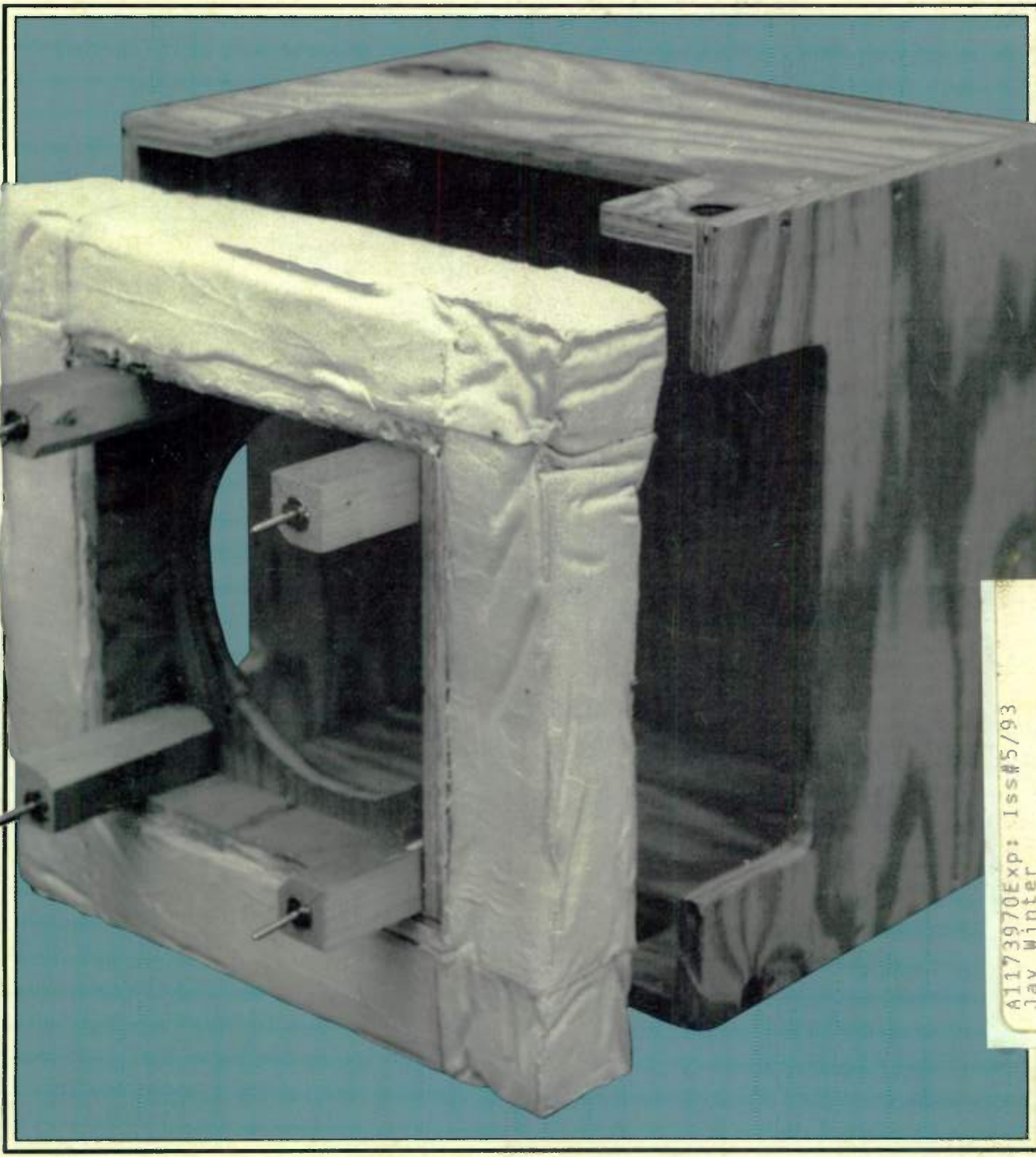
THREE/93

U.S. $7.00
CANADA $8.00

Speaker Builder
THE LOUDSPEAKER JOURNAL



Good News

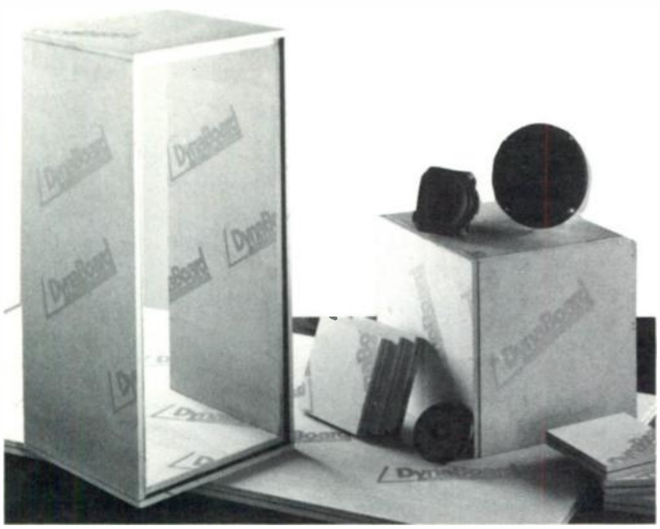
► PYLE INDUSTRIES
Multi-element automotive speaker kits are available in seven models. Component system kits come in 4″, 5¼″, and 6″ sizes. Each includes two high-performance mid-woofers, two 1″ rare earth NeoDome tweeters with multi-mount housings, and two multi-band frequency dividing passive networks. Pyle Industries, Inc., 501 Center St., Huntington, IN 46750, (219) 356-1200.
Reader Service #52

■ SCANTEK
A series of portable, rack-mounted microphone power supplies includes the Type 324, from Norsonic, a self-contained, portable, battery-operated, dual-channel unit; the Type 325 is a plug-in unit for multi-channel systems. Both versions are functionally and electrically identical. Scantek, Inc., 916 Gist Ave., Silver Spring, MD 20910, (301) 495-7738, FAX (301) 495-7739.
Reader Service #71

◄ PSB INTERNATIONAL
The 100C loudspeaker has been designed to optimize the center channel in home theater systems employing Dolby Pro Logic and compatible surround sound decoders. The driver and crossover designs provide interference-free dispersion over an area 15° to either side of the center. Suggested retail price is $179. PSB International, Inc., 633 Granite Ct., Pickering, Ontario, Canada L1W 3K1.
Reader Service #70

▼ WESTLAKE AUDIO
The BBSM-10VNF loudspeaker utilizes dual ported 10″ woofers, a 6½″ midrange driver in a sealed, nonresonant enclosure, and a 1¼″ cloth dome tweeter. Suggested system list price is $5,600. Standard finish is oiled North American walnut veneer. Westlake Audio, 2696 Lavery Ct., Unit 18, Newbury Park, CA 91320, (805) 499-3686, FAX (805) 498-2571.
Reader Service #55

■ HERNON
Adhesion Promoter 39 is a single-component material which promotes bonding of polyethylene, polypropylene, thermoplastic rubber, and most treated, low-energy plastics. Fixture time on most primed substrates is less than ten seconds (24 hours for maximum bonding). Hernon Manufacturing, Inc., 121 Tech Dr., Sanford, FL 32771, (407) 323-0545, (800) 527-0004, FAX (407) 321-9700.
Reader Service #51

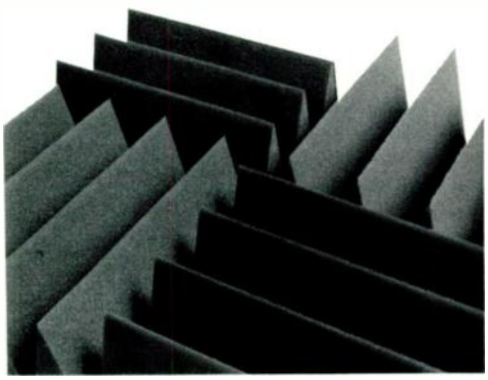


◄ DYNAMIC CONTROL
Dynaboard Enclosure Composite™ is ⅜″ thick and composed of a layer of Dynamat sound damping material sandwiched between two layers of medium density fiberboard. The resonant vibrations that interfere with loudspeaker performance are thus eliminated. It measures 0.81″ x 24″ x 48″, and costs $99 per unit. Dynamic Control, 125-B Constitution Dr., Fairfield, OH 45014, (513) 860-5094, FAX (513) 860-5095.
Reader Service #69

Good News

▼ NETWELL
SuperMAX Acoustic Foam is made of open-cell polyurethane, designed to deaden harsh noise sources in a variety of applications (sound booths, anechoic chambers, low-frequency audio recording, sound chambers, and more). The blocks are 12″ × 12″, with standard thicknesses of 6″, 8″, or greater. NetWell Noise Control, 6125 Blue Circle Dr., Minnetonka, MN 55343, (800) 638-9355, FAX (612) 939-9836.

Reader Service #65

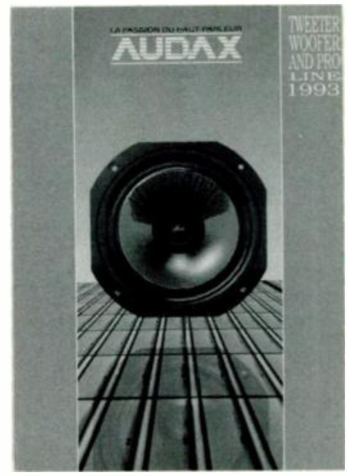


■ SITTING DUCK SOFTWARE
The companion volume to the *Sketch Book of 70 Unique DIY Loudspeaker Enclosure Ideas* is titled *More Unique DIY Loudspeaker Enclosure Ideas.* Both Vol. 1 (BKSD1) and Vol. 2 (BKSD2) are available for $16.95 each plus $3 total shipping from Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458, (603) 924-6371, FAX (603) 924-9467.

Reader Service #68

■ CARVER
The AVX-606 is a configurable six-channel THX-approved power amplifier rated at 100W/channel into 8Ω. The one-piece device is designed to be fully compatible with any Lucasfilm THX home theater system. Suggested retail price is $1,499.95. Carver Corp., PO Box 1237, Lynwood, WA 98046, (206) 775-1202, FAX (206) 778-9453.

Reader Service #67



▲ POLYDAX
The new catalog for 1993 (216 pages) includes nearly 100 new speaker components and six product lines. Detailed specifications, frequency curves, and waterfall plots for each model are included. Polydax Speaker Corporation, 10 Upton Dr., Wilmington, MA 01887, (508) 658-0700, FAX (508) 658-0703.

Reader Service #54

Reader Service #3 →

Speaker Builder

The Staff

Edward T. Dell, Jr. Editor and Publisher

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

Mary Wagner Managing Editor
Rebecca De Fusco Assistant Editor

Christine Orellana Graphics Director
Production
Glenn Galloway, Edward Roane

Katharine Gadwah Circulation Director
Circulation Assistants
Doris Hamberg, Kathie Morrocco
Diane Smith Advertising Assistant

Advertising Rates & Schedules

Maureen McHugh Advertising Director
PO Box 576, Peterborough, NH 03458-0576
Advertising Telephone: (603) 358-3756

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

Speaker Builder is published bi-monthly in the interest of the art and craft of speaker building.

Subscription Inquiries

To subscribe, renew or change address write to Circulation Department. Call (603) 924-9464 or FAX (603) 924-9467 for MC/VISA charge card orders. For gift subscriptions please include gift recipient's name and your own, with remittance. A gift card will be sent.

Send circulation and editorial correspondence to PO Box 494, Peterborough, NH 03458-0494. No responsibility is assumed for unsolicited manuscripts. All MSs must include a self-addressed envelope with return postage. The staff *will not* answer technical queries by telephone.

Speaker Builder (US ISSN 0199-7920) is published bi-monthly, at $25 per year, $45 for two years; Canada add $6 per year; overseas rates $40 one year, $70 two years; by Edward T. Dell, Jr. at 305 Union Street, PO Box 494, Peterborough, NH 03458-0494. Second class postage paid at Peterborough, NH and an additional mailing office.
POSTMASTER: Send address change to:
Speaker Builder, PO Box 494
Peterborough, NH 03458-0494

About This Issue

Dave Davenport's "A Bi-Structural Enclosure" has had a gestation period of nearly five years, if my memory serves me correctly, a time span scarcely untypical in the birth records for *Speaker Builder* articles, however. Compared to the evolutionary scales of nature's critters, though, Dave's baby is nearly supersonic. I predict the newcomer will be highly popular with many of you. Is this a topology breakout? Turn to page 10 to consider, and decide.

Embroidery for the infrastructure for your next box is what **Bruce Hermann** is up to in his "A Sixth-Order T/S Subwoofer Design," despite the title, and illustrating one of the pleasures of the fine work *SB* authors do. Subwoofing and sixth-order details are fine also, but look at the bone structure of that box (p. 16).

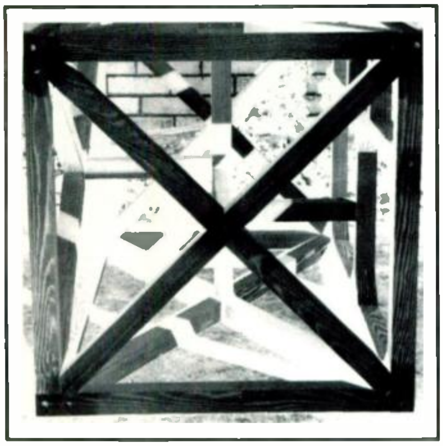
Only in *Speaker Builder* would a meeting of minds between a violin maker and a retired electronics engineer turn to the subject of screws. But wood screws, like so much else, turn out to be a highly specialized topic in these technological times. The **Bob Spear/Alex Thornhill** team bring us up to date on this vital matter starting on page 34.

Bill Waslo takes us on a tour of the fine points of running his IMP computer add-on beginning on page 36. This inexpensive speaker builder volkstool is gaining respect of both amateurs and pros alike, and spreading internationally, as well. (The Aussies love it down under.) Next time, you'll get a first glimpse of what IMP can tell you about other parts of your system.

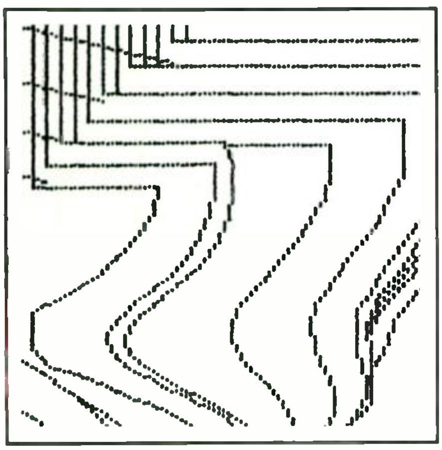
Speaker Builder
THE LOUDSPEAKER JOURNAL

VOLUME 14 NUMBER 3 MAY 1993

10



16



36

FEATURES

DEPARTMENTS

MW 114-S

Neodymium Magnet DPC Cone 4" Woofer

Specification

Overall Dimensions	Ø118mm (4.64") x 58mm(2.29")
Mounting Baffle Hole Diameter	Ø95mm (3.75")
Magnet System	Pot Type, Vented, Neodymium Magnet
Nominal Power Handling (Din)	150W
Transient Power - 10ms	800W
Voice Coil Diameter	54mm (2.125")
Voice Coil Type/Former	Hexatech Aluminium
Frequency Response	55-7000 Hz
FS - Resonant Frequency	65 Hz
Sensitivity 1W/1m	87 dB
Z - Nominal Impedance	8 ohms
RE - DC Resistance	5.6 ohms
LBM - Voice Coil Inductance @ 1kHz	0.47 mH
Magnetic Gap Width	1.25mm (0.050")
HE - Magnetic Gap Height	6mm (0.236")
Voice Coil Height	12mm (0.472")
X - Max. Linear Excursion	3mm
B - Flux Density	0.88T
BL Product (BXL)	6.75
Qms - Mechanical Q Factor	2.32
Qes - Electrical Q Factor	0.36
Q/T - Total Q Factor	0.31
Vas - Equivalent Cas Air Load	3.18 litres (0.113 cu. ft.)
MMS - Moving Mass	7.00gm
CMS	807µm/n
SD - Effective Cone/Dome Area	53cm² (20.86 sq. in.)
Cone/Dome Material	DPC (Damped Polymer Composite)
Nett Weight	0.500 kg

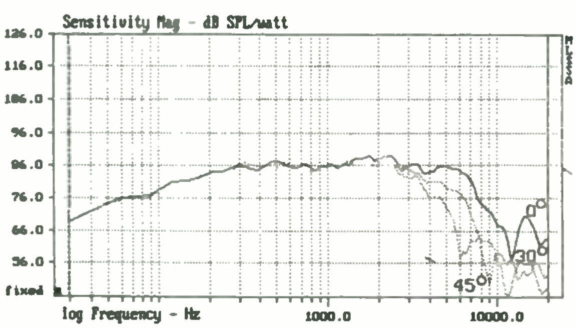
Specifications given are as after at least 45 minutes of high power, low frequency running, or 24 hours normal power operation.

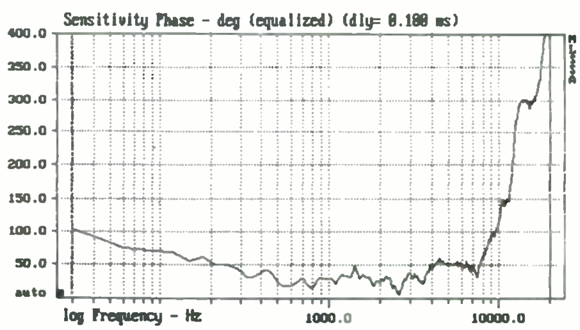
The 114-S is the first of Morel's new generation of woofers, featuring a powerful Neodymium magnet system which provides increased sensitivity, lower Qt and reduced distortion. For a 4" driver it is unique in having a large 54mm (2.125") diameter Hexatech aluminium voice coil.

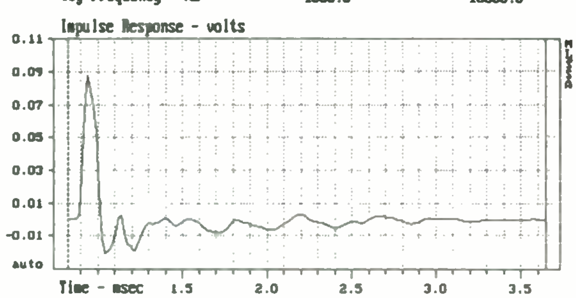
Benefits of this large voice coil diameter include a very high power handling capacity and lack of sound level compression. In addition, it allows the use of a very shallow cone profile. Coupled with the use of Damped Polymer Composite cone material and a rubber surround, this provides excellent dispersion (off-axis response), resistance to cone break-up (even at high sound pressure levels) and lack of colouration.

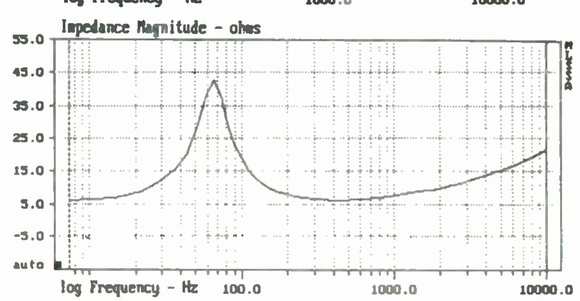
Frequency and phase response are very flat, while the roll-off is very smooth. The MW 114-S may be used either as a bass-mid range in 2-way systems, or as a mid-range in multi-way systems.

The vented magnet system is encased within a steel chassis, which improves efficiency and shields the magnet, virtually eliminating stray magnetic fields. The MW 114-S is ideal not only for high quality hi-fi, but also TV, video and surround-sound applications.









morel

high fidelit
range

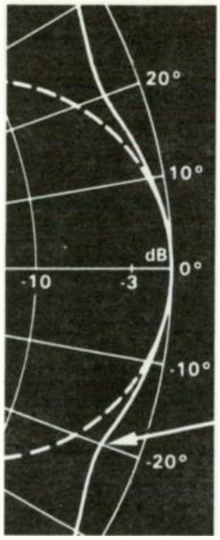
morel (U.K.) ltd.
11 Foxtail Road,
Nacton Rd. (Ransomes)
Industrial Estate,
Ipswich, IP3 9RT
England
Tel: (0473) 719212
FAX: (0473) 716206

morel acoustics USA
414 Harvard Street
Brookline, MA 02146
Tel: (617) 277-6663
FAX: (617) 277-2415

morel

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

USE THESE CARDS



Speaker Builder
THE LOUDSPEAKER JOURNAL

❑ New Subscription ❑ Renewal (Please attach your label)
❑ 1 year (6 issues) $25 ❑ 2 years (12 issues) $45

Canada add $6 postage per year. Remit in US dollars only, drawn on a US bank. **Overseas subscription and postage:** 1 year/$40; 2 years/$70.

MC/VISA NUMBER ____________ EXP. DATE ____________

NAME ____________

STREET & NO. ____________

CITY ____________ ST ______ ZIP ______

❑ Bill me (Please initial here) ________ ❑ Enclosed is my check
❑ Charge my credit card ❑ MC VISA ❑

(603) 924-9464, M-F, 9-4 EST; Answering machine 4 p.m.-8 a.m. EST daily; FAX (603)924-9467 24 hours
Please allow six weeks for delivery of first issue.

FOR Subscriptions,

FREE SHIPPING IN THE USA*

WHEN YOU ORDER RONALD WAGNER's

ELECTROSTATIC LOUDSPEAKER
DESIGN AND CONSTRUCTION (see ad this issue)

Use this card alone for your Mastercard or VISA purchase, or include card in envelope with your check or money order. **OFFER GOOD ONLY WITH THIS CARD.**

YES! Please send me ________ #BKT6 @ $19.95	=	$ ________
PLUS USA Shipping	=	00.00
OR Canada/Other Surface* shipping	=	________
TOTAL ORDER	=	$ ________

❑ Check or money order enclosed MC ❑ ❑ VISA US funds drawn on a US bank.

NAME ____________ TODAY'S DATE ____________

STREET & NO. ____________

CITY ____________ ST ______ ZIP ______

COUNTRY ____________ DAYTIME TELEPHONE ____________

MC / VISA CARD NO. ____________ EXPIRATION DATE ____________

* $2 Canada
$7 Other Surface

OLD COLONY FREE SHIPPING

What would your friends say about Speaker Builder?

Ask them and find out! Fill out the card below or call us with their name and address, we'll take it from there. They'll probably say, "Thank you" and we will too.

NAME ____________ NAME ____________

STREET & NO. ____________ STREET & NO. ____________

CITY ________ ST ____ ZIP ____ CITY ________ ST ____ ZIP ____

NAME ____________ NAME ____________

STREET & NO. ____________ STREET & NO. ____________

CITY ________ ST ____ ZIP ____ CITY ________ ST ____ ZIP ____

OR Information FOR YOUR FRIENDS

Speaker Builder PO Box 494, Peterborough, NH 03458-0494 (603) 924-9464

YOUR
STAMP
HELPS

Speaker Builder
PO Box 494
Peterborough NH 03458-0494

YOUR
STAMP
HELPS

OLD COLONY SOUND LAB
PO Box 243
Peterborough NH 03458-0243

YOUR
STAMP
HELPS

Speaker Builder
PO Box 494
Peterborough NH 03458-0494

Editorial

THOUGHT FOOD

Big topics for editorials come along fairly often, but sometimes I find I accumulate a handful of smaller topics, no one of which seems worth a page of comment, but which are interesting enough to stimulate wider consideration. I welcome your commentary, as always.

My tax consultant tossed out an idea the other day from his earlier training in TV production during the sixties. He commented on a discovery that the speed of visual access to what is on the screen was getting ahead of the abilities of pre-TV generations. Younger viewers were measured as processing what they saw on the screen faster than their parents and grandparents. It reminded me of the reports by visitors to primitive tribes in Africa and elsewhere, that the inhabitants cannot recognize themselves in a snapshot taken moments earlier. To them it appears to be only a small piece of paper with colored blobs on it.

If it is true that younger persons watching TV are "learning" to see faster, this may confirm the evolutionary theory that when survival depends upon the selectivity of a human sense it becomes more sensitive and acute. I believe it is generally accepted that our current culture has tended to make hearing and vision less sensitive since we are no longer hunters, bringing home the kill from the forests. It may well be that these senses are acting selectively in the business of driving automobiles, where acuity may have something to do with who survives, and those who are reproducing children with better driving capacities. Just what survival value the choice to listen (as opposed to mere hearing) is certainly undetermined, so far as I know. But I keep remembering Andrew Stiller's assumption that music, being universal in all cultures, must therefore be a necessity for human evolution (*TAA* 1/90, p. 38). If TV has altered our sight processing speed, perhaps something is happening to the ability of younger ears to process sound.

I have long wondered what effect the explosion of music's availability may be having on hearing. Much of what we hear is involuntary and unless some "survival factor" figures into the equation, the only change may be an enhanced ability to turn down the volume control in our brains. What a nice joke it would be on Madison Avenue whose TV ads turn up the gain as far as they legally may.

I see that the electronics magazines and newspapers have begun to speculate on whether cheap digital signal processing chips spell the end of traditional "hi-fi sound" as we know it. Doubtless the computer equipped with a sound board is edging its way into the horizon of consumer electronics. DSP has been having a profound effect on professional sound processing for some time.

To gain some perspective here, we might note that pocket radios full of transistors have now become collectibles. The rising interest in tube technology is partly fueled by the "antiquity factor," as well. Our sister publication *Glass Audio* flourishes despite the technology having been declared passé in the early sixties. So I imagine that this new development in DSP will take its place in the queue of sonic evolution and have its add-ons and upgrades and adjustments like every other technology having to do with sound. It is surely a delicious opportunity for upgrades in the current examples of computer sound where the little 2W board amps are poking 2½" drivers in and out, reproducing your 8-bit, 35 seconds of recorded music.

I have just finished reading James Gleick's biography of Richard Feynman titled *Genius* (Pantheon Books, New York, 1992). I commend it to any audiophile who wishes to understand the revolutionary changes in the way we must now regard the physical world which have come about in this century. Feynman was undoubtedly at once one of the most important contributors to the new way of thinking about matter, but also one of the most controversial. His work spanned the period from the design of the atomic bomb at Los Alamos to the hearings on the Challenger disaster in Washington.

We entered this century with several ideas firmly held by scientists that it was to be only a matter of time before the complete structure of matter would be fully described with the corollary that "control" of nature would be possible. What a surprise dawned on the scientific world following Heisenberg's reluctant announcement of the "uncertainty principle." Feynman's legendary teaching, his astonishing computational skills, and his mastery of analogy all worked together with his utter honesty, to produce a view of a physics which was, and is, humbling to say the very least.

The most intriguing feature of this account of Feynman's life (cut short by cancerous tumors whose origin can probably be traced to Los Alamos) was his ability to define what can be reliably known about the multiplicity of new particles physicists were discovering during the postwar period. But this contrasts starkly with his continuing insistence that even with our best efforts to accurately understand and predict particle behavior, he maintained that, on balance, "Nothing is certain."

Feynman was awarded the Einstein and Nobel prizes, but his legacy is so large as to be difficult to adequately assess. Despite the relatively little which he published, he is still a monumental force in the way physics is done today. The book surely sets out in fascinating detail the essence of the man. The opening quote on page one should be enough to convince you to read the book. "I was born not knowing," Feynman said, "and have only had a little time to change that here and there."—E.T.D.

A BI-STRUCTURAL ENCLOSURE

BY DAVID W. DAVENPORT
Contributing Editor

You can relax—this is not an article about another kind of enclosure. Rather, it is about a method you can incorporate in your next construction project whether sealed, transmission line, or bass reflex. As you will see, it is particularly suited for subwoofers and is aimed at reducing cabinet resonances.

BAD VIBES. In a conventional speaker, the driver is securely fastened to the enclosure so its kinetic energy is directly coupled to the enclosure walls. The result is substantial sound radiation, which you can feel by placing a hand on the enclosure while playing music with a heavy bass. This secondary radiation, not being correlated with the sound from the driver, results in a "muddy" or "smeared" sound.

Some designers attempt to solve the problem by coupling the enclosure to the floor with spikes. Although this is a step in the right direction, success dictates that the vibrations be kept out of the enclosure to begin with. Along these lines, some speaker builders isolate the driver from the enclosure with rubber grommets.

I thought this concept could be improved upon. What if the driver were mounted on a panel, and the panel then mounted on the enclosure with a layer of silicone adhesive. Better yet, what if it were isolated with a layer of sorbothane between the mounting panel and the enclosure? This, too, is only a partial solution. To achieve success, the driver must be totally isolated from the enclosure with no physical path to transport vibrations.

Since the speaker driver is vibrating, why not mount it directly onto the floor (mass-coupled to it with spikes) to absorb the vibrations and prevent them from entering the enclosure? "But isn't the driver still mounted in the enclosure wall, vibrating like crazy?" you ask. Mounting the driver on the floor is just part of the story; no connection exists between the driver and the enclosure.

The driver is mounted face down in a frame which sits on the floor. The frame has high sides, but is open on top, and constitutes the inner structure of a bi-structural enclosure. The outer structure is a five-sided box, open on the bottom and larger all-around than the inner structure. It sits over the inner structure without touching it (*Figs. 1* and *2*). The sides of the inner structure form the inner walls of a duct, and the outer structure sides form the outer walls. The space between the inner and outer structures forms a tuned port. What's unique about this design is that no connection exists between the driver and the enclosure.

PEEKING DUCT. I designed the first prototype using conventional Thiele/Small theory. The dimensions are what you might expect: an ordinary-sized enclosure with an ordinary-sized vent. When you distribute the vent all around the enclosure's periphery, however, it is spread pretty thin (in this case, 1/16"). Such a thin slot contributes high acoustic resistance and vent noise. I was also concerned about rattles and buzzes from the outer structure inadvertently contacting the inner structure. I believe the concept would have worked given the right driver—one requiring a very large enclosure and large-volume duct.

I decided to pursue an alternate design. I could increase the duct's thickness only if it didn't completely circumvent the enclosure. The concept I wanted to preserve was the acoustic separation of the outer enclosure from the driver, which doesn't require an air gap.

I decided there would be adequate isolation if the gap was sealed on three sides with foam rubber, and the duct's

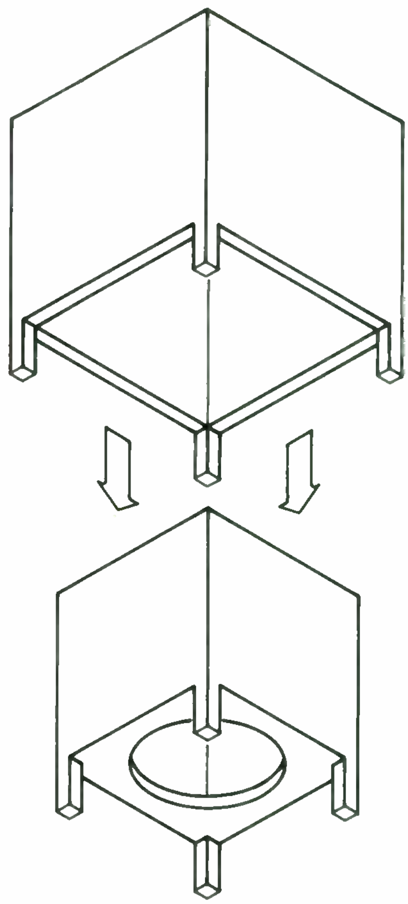


FIGURE 1: Original ported design.

ABOUT THE AUTHOR

Dave Davenport has been building audio equipment for over thirty years. Dave is employed at IBM as an engineer engaged in developing communications networking systems. He is married and has two sons. His current audio interests range from acoustics to tube electronics. He is particularly interested in methods to eliminate extraneous vibrations from loudspeaker systems.

thickness increased to ¼". To reach reasonable proportions, however, the gap would need to be increased to about 3". The duct's length would then increase beyond the enclosure's depth. In an ultimate act of duct folding, I increased the foam's thickness to 3" all around, and sculpted the duct as a spiral in the foam completely circumventing the enclosure. I was thus able to make a 42-inch long duct in the walls of the base (*Photo 1*).

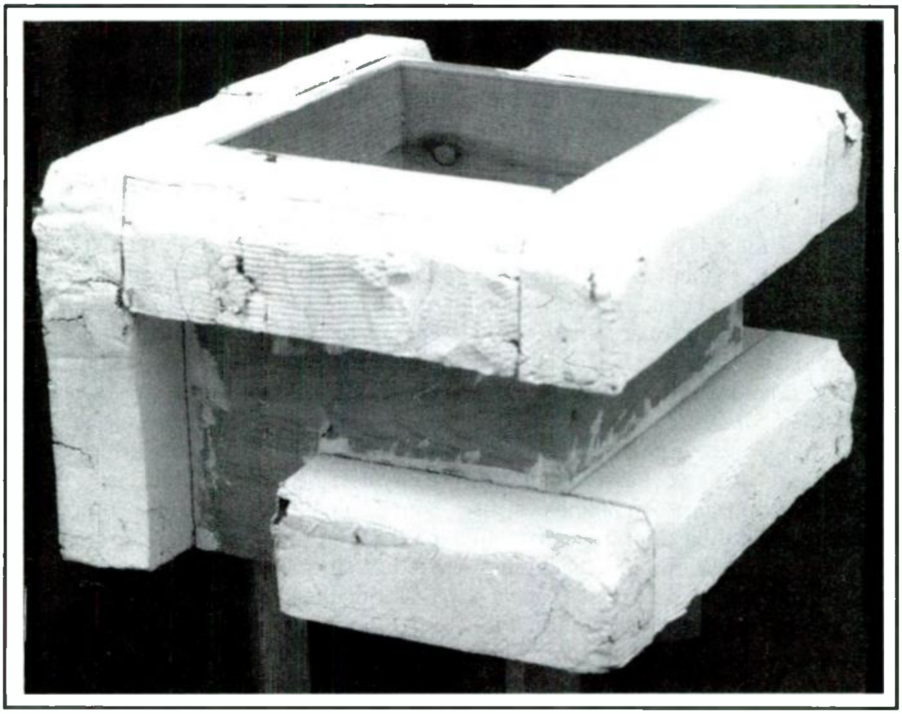


PHOTO 1: Inner structure with a 42-inch long spiral duct.

NAGGING LOSSES. The method I prefer for designing enclosures involves first calculating the optimum volume using the Thiele/Small parameters, and then building a prototype enclosure with stuffing and correct duct. I use this enclosure as a test box to refine the Thiele/Small parameters. Usually, only slight adjustments are necessary.

Surprisingly, the new measurements were vastly different from the original. Normally, a cursory check will indicate a Q_L close to an acceptable value of seven, but I got a value of 15. While not unusual, this value did not respond to the normal adjustment attempts. I went through the tedious process of calculating the total Q (Q_B) from the separate values of Q_L, Q_A, and Q_P, as outlined by Small.[1] Q_B is obtained from the formula:

$$\frac{1}{Q_B} = \frac{1}{Q_A} + \frac{1}{Q_P} + \frac{1}{Q_L}$$

Where Q_A = loss due to absorption from damping material
Q_L = losses from leakage
Q_P = the vent losses

You can imagine my consternation when I found the losses to be: $Q_A = 0.36$, $Q_P = 0.32$, and $Q_L = -0.17$. According to Small, the enclosure loss model makes some simplifying assumptions which don't matter with normal minimal losses.[2] However, when losses are excessive, the model can no longer be applied with accuracy. I was using open-cell foam, which meant that in addition to enclosure leakage there was leakage all along the vent. I tried sealing the foam with two coats of latex house paint, which resulted in losses of: $Q_A = 11$, $Q_P = 23$, and $Q_L = 6$, $Q_B = 3.3$.

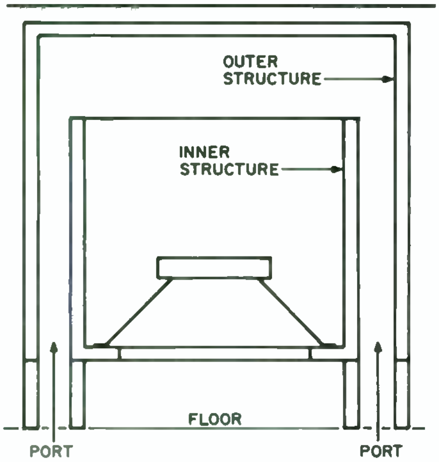


FIGURE 2: Cross-section of original ported design.

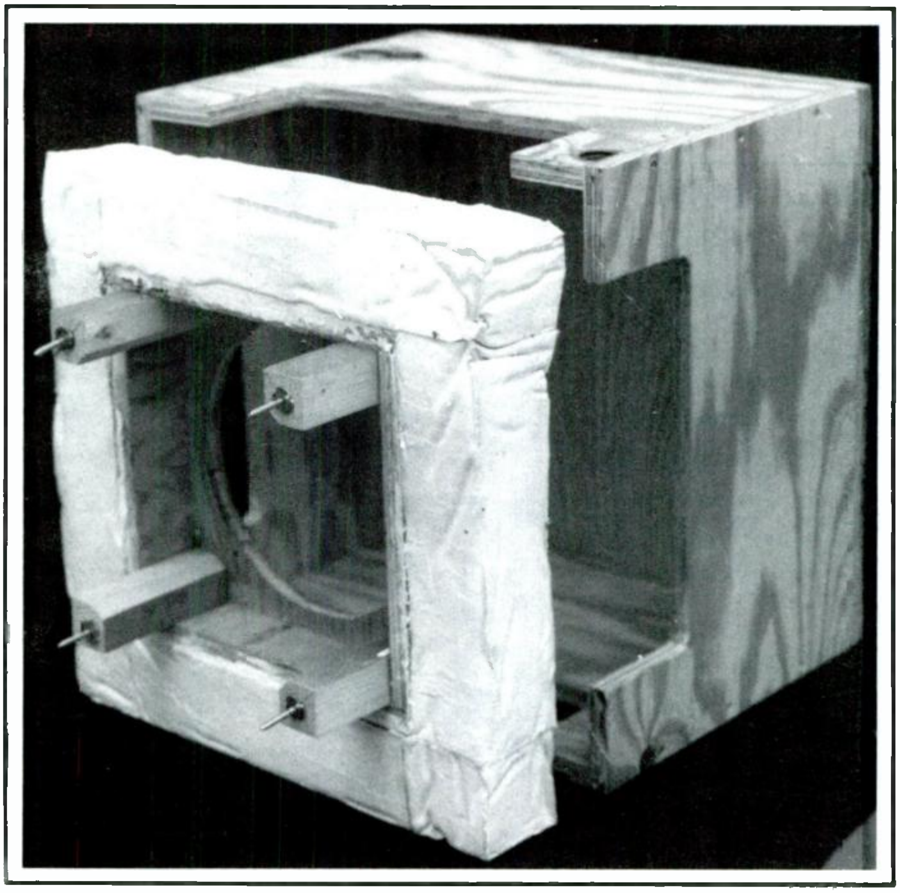


PHOTO 2: An early prototype of the bi-structural base.

LOOSE CONNECTIONS. I still wasn't happy. My design had a 42-inch long duct that exhibited excessive losses and didn't sound very good. The bass was "fat" and "boomy" and lacked control. Fortunately, the remedy is simple: if a duct is too long, use a passive radiator instead. This meant I had to completely seal the enclosure, which I did with a foam gasket. Since I haven't found a source for closed-cell foam, I improvised by using open-celled foam which I coated with a layer of silicone adhesive (*Photo 2*).

An added benefit of sealing the enclosure is that it opens up the whole range of enclosure designs. Passive-radiator, sealed-box, and transmission-line designs all use the same base, and I can swap from one to the other in less than a minute. I use the standard formulae for each version. One special consideration with a sealed enclosure is its internal pressure. Normally, with everything rigidly connected, the pressure will compress the air inside the enclosure. The bi-structural enclosure, however, has two parts which are only loosely connected. Rather than compressing the air, the immense pressure will expand the interior volume by lifting the exterior shell. I did not directly measure the pressure, but experienced its effect through grossly altered driver parameters.

Since I didn't have the tables for flexible enclosure alignments, I chose to remedy the situation. For my prototype, I set a 50 lb. bag of sand on the enclosure. For the final design, I would recommend a hollow-wall, sand-filled enclosure. You would use this special technique only for sealed enclosures; other designs may use conventional walls.

MULTIPLE PERSONALITIES. I had always wanted to directly compare sealed, vented, and transmission-line enclosures with everything else equal. Since I had built numerous versions, now was my chance. *Photo 3* shows sealed, passive-radiator, and transmission-line shells for the base. Each enclosure is correctly designed for the drivers used in the common base, a face-to-face compound pair. Each provides solid, deep base, devoid of smearing or muddiness.

During the touch test, I could feel minimal vibration on the outer shell which I believe is due to airborne vibration, as opposed to mechanical coupling. I made the shells from a single layer of ¾-inch thick plywood with no acoustical treatment or special bracing. I have no doubt the residual vibration could easily be damped using conventional techniques.

Each design has its own personality. The sealed box provides a tight, well-controlled bass which is impressive from such a small enclosure. (It did reveal one flaw: when playing recordings with large amounts of deep bass, the buildup of pressure is relieved with a gasket blow-by that sounds like a giant flatulence. I believe this could be remedied by the pressure release provided by an aperiodic vent.) I am generally pleased with this enclosure, particularly in light of its small size.

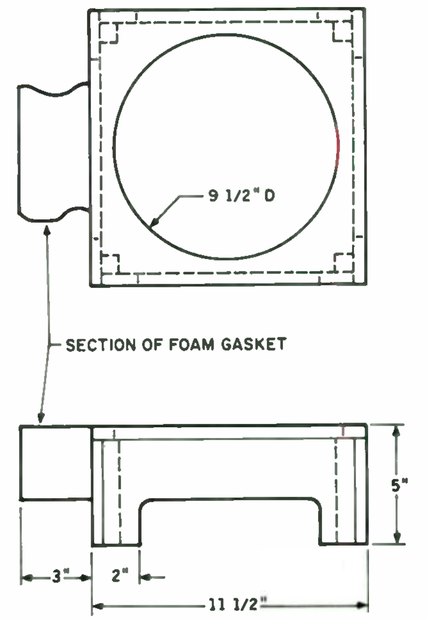


FIGURE 3: Bi-structural base. Material is ½" plywood with ¾" battens in corners.

The passive radiator provides equally deep, but not as tight, bass. It seems a little "fat" in comparison. With such indistinctiveness, I rate it below the sealed version.

Continued on page 14


PHOTO 3: Prototypes of sealed, transmission-line, and passive-radiator enclosures.

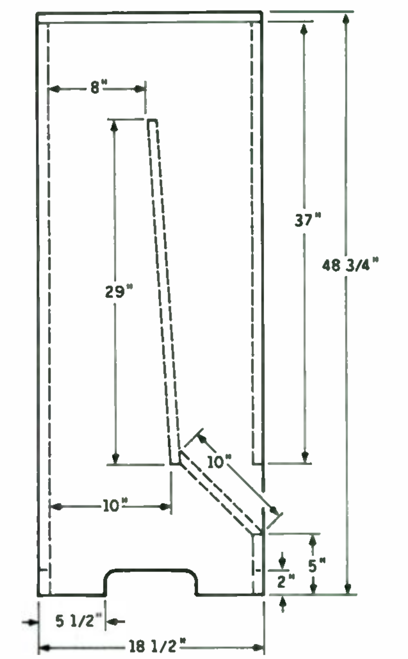


FIGURE 4: Bi-structural enclosure. Material is ¾" plywood or MDF.

ZALYTRON

YOUR ONE STOP SHOPPING CENTER

FOCAL VIETA Cabasse LA REFERENCE EN HAUTE FIDELITE SCR

seas morel ZALYTRON CUSTOM WOOFERS PHILIPS

Polydax speaker corporation l'atelier audio F R A N C E ACCUTON

In Our Efforts To Bring You the Best Equipment at the Best Price. . .

We Now Proudly Offer

ARIA 5
With new focal Titanium Tweeter $399

ARIA 5
With Accuton Tweeter
Due to an importer Authorized Sale
we are reducing the price to $599

ARIA 3 .... $999

A-3 CABASSE $1199

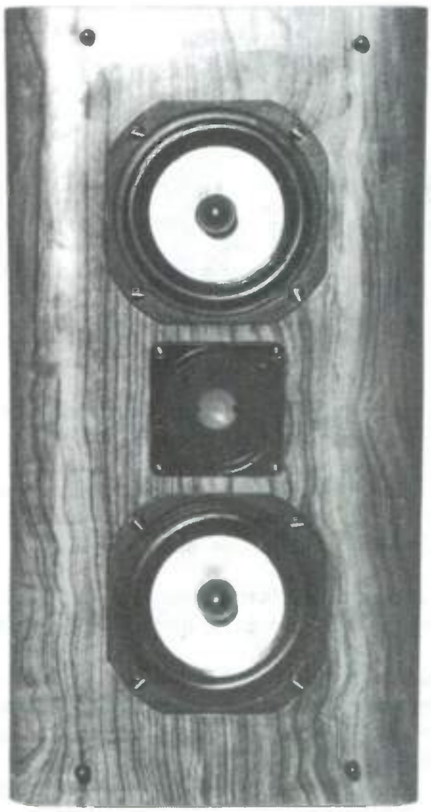
IMPORTER AUTHORIZED SALE ACCUTON REDUCED!!

C 211 .... Each $125

C 222 .... Each $150

C 277 .... Each $185

Now is the time to get the finest drivers on the planet at out of this world discounts.



ORDER YOUR BRAND NEW 1993 SPRING SPEAKER CATALOG

ZALYTRON INDUSTRIES CORP.
469 JERICHO TURNPIKE, MINEOLA, N.Y. 11501
TEL. (516) 747-3515 FAX (516) 294-1943

Our warehouse is open for pick-up 10AM to 6 PM daily, Monday thru Saturday
UPS orders shipped same day • Minimum order $50.00
WRITE OR CALL FOR ALL YOUR SPEAKER NEEDS OR INQUIRIES

Continued from page 12

While I am not a big fan of the transmission-line enclosure, I have built several full-range speakers which use it, but never a subwoofer. Perhaps the problem is the lack of rigorous theory on which to base a design. I decided to include one in this project, and am I glad I did! Sonically, it is the clear winner. I don't think the bass is any deeper, rather it is the quality (relaxed and natural) which impresses me. Its only down-side is size, which I suspect could be pared down.

REFERENCES

1. Small, R.H., "Vented-Box Loudspeaker Systems, Part IV: Appendices," *JAES*, October 1973, pp. 635–639.
2. Small, R.H., Personal Communication, November 13, 1988.

CAREFUL COMPRESSION. Plans for the base and transmission-line versions are shown in *Figs. 3–5.* The design of the base assumes a pair of Focal 10K515s mounted face-to-face in a push/pull configuration. I have used this configuration for both single-channel with two drivers wired in parallel, and for stereo with each channel driving one of the speakers. In either case, the driver which is mounted on the outside is wired out-of-phase.

I like the push/pull configuration because the resultant sound is cleaner, but you can also use a single driver. If you eliminate the external driver, the base can be shortened, but don't go much less than 2″ or you will experience slot-loading effects. No passive crossover is shown because my system uses an electronic crossover.

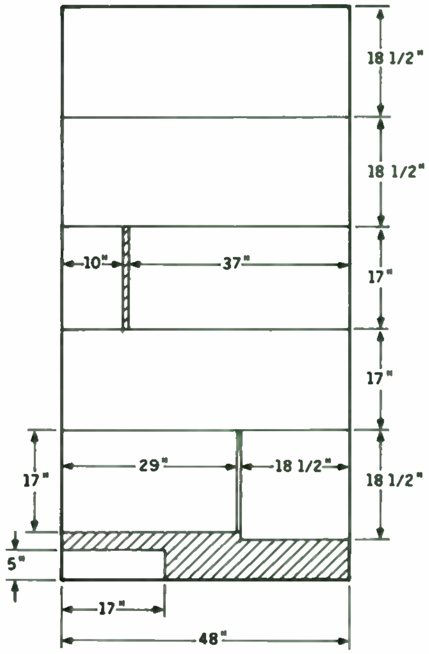


FIGURE 5: Cutting guide for a bi-structural enclosure.

I used a 3-inch thick foam gasket, simply because it was what I had on hand. Feel free to improvise, but take care not to excessively compress the gasket. I compressed the 6″ (total for the two sides) of foam 1″, but I believe ½″ would have worked better. With the 1″ compression, I needed to ensure there were no folds in the foam's surface which could create a gap and resultant leak.

I used a relatively firm, ordinary open-cell foam found in seat cushions. I glued it in place with silicone adhesive, then spread another thin adhesive coat over the entire surface to seal it. I found that stuffing the transmission line with 3.5 lbs. (½ lb./ft.[3]) of well-teased Acousta-Stuf works fine. Spikes are optional: I normally would recommend them, but listening reveals little if any difference. I suspect this is because relatively few resonances need to be damped in this enclosure.

All in all, the bi-structural enclosure is

Continued on page 70

A SIXTH-ORDER T/S SUBWOOFER DESIGN

BY BRUCE R. HERMANN

I have long been intrigued by the woofer construction projects appearing in *Speaker Builder* and other publications. I eventually developed a system which can be customized in various ways by either changing the enclosure port length or eliminating it altogether, or by adjusting the electronic equalization.

Since choosing the final system parameters is really a matter of taste, I have not included detailed design plans, however, I have provided enough information for you to get started. To realize your goals, you must have access to some test equipment, such as an audio signal generator, a frequency counter, a multimeter or two, some resistors, and an oscilloscope (Richard Saffran, "Build a Widget Box to Measure Loudspeaker Parameters," *SB* 1/81, p. 7).

THE MISTY PAST. I have been a sporadic builder of audio equipment and speaker systems since I was a high school student in the early 1960s. At that time, I knew little about electronics and even less about the theory of ported-box speaker system design. Prior to the publication of A.N. Thiele's two papers, no coherent theory was available.[1,2]

At the time, all I really knew about bass-reflex theory was that the speaker's free-air resonance was important, and the enclosure and speaker had to interact constructively for a successful design. Enclosure design was a black art practiced only by professionals with superior intuition, years of experience, and some degree of luck.[3]

As is evident in the popular literature,

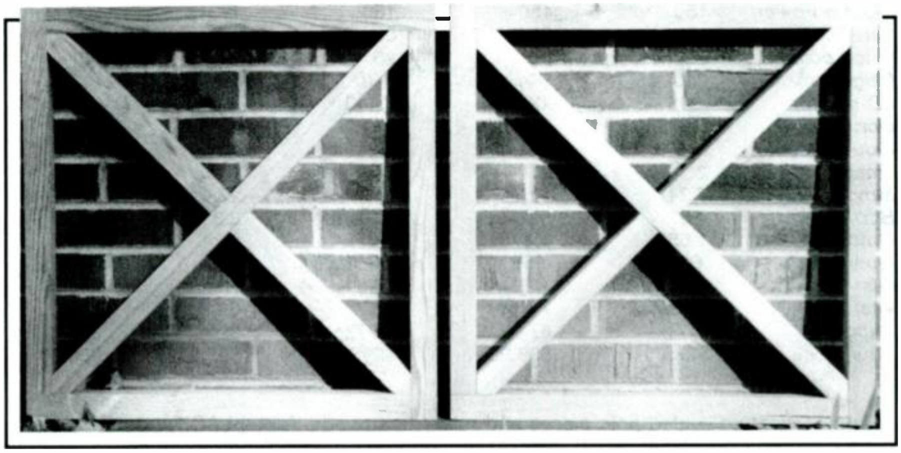


PHOTO 1: Top and bottom frame sections.

even as late as the mid-1970s, enclosure design was practiced through the implementation of several principles that yielded good results.[4] Compare this approach to the Thiele/Small (T/S) model described in a 1980 article.[5]

DESIGN STRATEGY. My goal was to make a subwoofer with a −3dB point at about 20Hz. The design option I prefer is a sixth-order system (ported box with electronic equalizer) with two drivers operating in parallel to achieve a sizable radiating area.[6] (See also Duke Le Jeune, "A Gold Ribbon System," *SB* 4/86, p. 14; John E. Levreault, Jr., "A Sixth Order Vented Woofer System," *SB* 2/87, p. 9; Craftsman's Corner, *SB* 4/87, p. 39; Joseph A. D'Appolito and James W. Bock, "The Swan IV Speaker System," *SB* 4/88, p. 9.) In 1978, I constructed a sixth-order system using a single driver, which was in service as a subwoofer for my stereo. This old design's −3dB point was at about 31Hz, and it had a Q_L of just barely 3.

I suspect that the Q_L was low because of the box. All the surfaces were ¾″ interior plywood, screwed and glued to a frame made from two-by-fours, but the back panel was removable. The back was sealed with weather stripping and attached with ten banister bolts, but because it was removable, it was not braced and probably dissipated some energy through vibration. Air leaks also may have contributed to the low Q_L.

I thought I could do better, and wanted to use two 12″ drivers in a sixth-order system with a low cutoff frequency. I used the Type I sixth-order alignment tables presented by Robert Bullock in "Thiele, Small and Vented Loudspeaker Design, Part V: Sixth Order Alignments" (*SB* 1/82, p. 20) to determine my preferred free-air speaker parameters. My previous design experience suggested I shouldn't expect a Q_L much greater than 5.

I used the Q_L = 3 table just to be conservative, leading me to limit the free air Q_{TS} to between 0.3 and 0.4, with as low an f_S as I could find. I decided not to worry too much about the published equivalent-volume V_{AS} specification for the speaker, and would fudge this if necessary.

Woofer price was a consideration, but

ABOUT THE AUTHOR

Bruce Hermann is employed as an engineer at the Naval Surface Warfare Center, Dahlgren Division, in Dahlgren, Virginia.

I was willing to spend about $300 or slightly more. I sent away for a couple of catalogs and eagerly scanned them for likely 12″ candidates.

CONSIDER THIS. I spent odd moments considering various options, and the possibility that the specifications given in the catalogs might be in error. The speaker manufacturer also might have changed the design without letting the distributor, and subsequently the buyer, know. I decided that it would be wise not to depend too much on the published specifications.

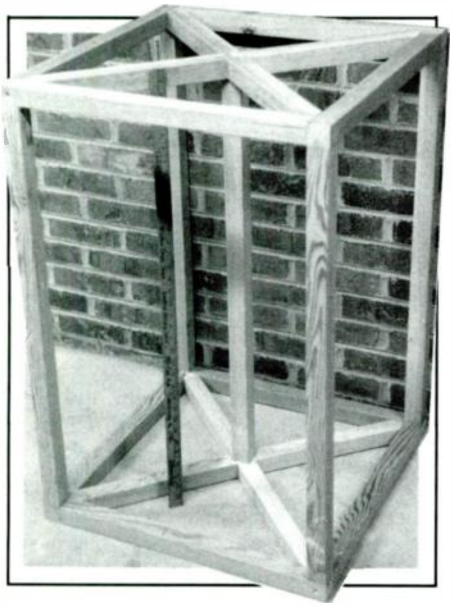


PHOTO 2: Basic frame defining the box volume.

I also considered the problem of quality control. I concluded that since no information about sample variations was available, I could get two widely disparate versions of the same driver. This could happen even if the T/S specifications listed were the correct mean values. For example, if the mean free-air resonance was f_S, what was the allowed range in f_S for this design? Could the observed variation be characterized by a standard deviation of f_S about the mean? I have seen comments to the effect that ±10% is not unusual (Robert M. Bullock III, "How You Can Determine Design Parameters for Your Loudspeaker," *SB* 1/81, p.12; Rusty Lewellen and John Cockroft, "Isobariks," *SB* 4/88, p. 52; Bill Schwefel and John Cockroft, "Radio Shack 40-1022A," *SB* 1/90, p. 3). It has been my experience that larger variations do happen.

One further consideration concerned the design as a whole. A system's response is modeled by the T/S parameters, which are functions of other electrical, magnetic, and mechanical parameters. This can be seen by studying the mathematical model.[7-15] So it is important to know how a variation in one parameter can affect the response.

The driver purchase price also concerned me. I assumed that the lower a driver's price relative to others of similar design, the less predictable would be its characteristics. If the buyer pays a premium for workmanship, the product is probably under tighter control by the manufacturer. In the case of the T/S parameters, this may translate into a smaller variation about the mean.

I believed I should choose a system design that allowed a wide range of possibilities. I didn't want to pick the T/S parameters in a way that would paint me into a corner. Also, I didn't want to make a big investment in drivers, only to be disappointed by some unforeseen quirk. So I chose the design parameters noted above and moderately-priced speakers (under $100 in 1989) to match them.

The speakers were JC12s from Audio Concepts. Each has two voice coils, which was a plus because I wanted to use the extra versatility to achieve my desired system design. I soon found this would not be necessary. When I wired the speakers in the conventional manner, with the two coils in series, I found that the initial free-air measurements of f_S, Q_{ES}, and Q_{MS} were close to what I needed. Also, the measured differences between the two drivers was small. I was off to a good start.

BOX CONSTRUCTION. A year passed before I began construction of the enclosures. In the meantime, I amused myself by occasionally repeating the free-air measurements, while putting together some computer code to help me find a final alignment (Bruce R. Hermann, "Sensitivity of Vented Box Design to Errors in the Thiele-Small Parameters," *SB* 6/91, p. 10).

Compliance is an important speaker characteristic, which is quantified by measuring the volume of air having the same acoustic compliance as the driver suspension: V_{AS}. Generally, it is recommended that this be found by building a test box of known volume and noting how the speaker parameters change in this different environment (Bullock, *SB* 1/81, p. 12; G.R. Koonce, "A Quick Opening, Variable Volume Test Box," *SB* 1/81, p. 10). This allows V_{AS} to be computed from α (Equation 1) and the physical volume of the test box: $V_{AS} = \alpha V_{BOX}$.

I didn't have a test box lying around, and I wasn't about to build one just for this purpose. Adding mass to the woofer cone and repeating the free-air measurements is another way of finding α, but that scheme did not appeal to me, either. (Joseph D'Appolito, "More Driver Tests," *SB* 4/82, p. 41; and "D'Appolito Correction," *SB* 1/83, p. 41.)

I decided to use the value for V_{AS} listed in the catalog. Since the value changed from one catalog to the next, I didn't put much faith in either published number. I decided to be conservative and use the larger value. Depending on α in the final design, I would need a big box, because

PHOTO 3: Finished frame viewed from the front.

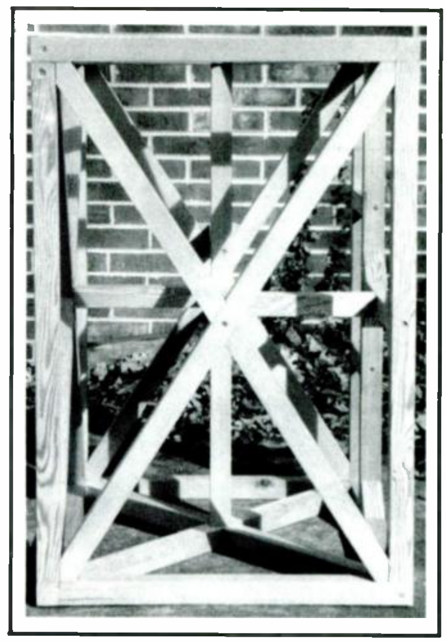


PHOTO 4: Finished frame viewed from the left side.

using two drivers in parallel doubles V_{AS} (Paul W. Graham, "V_{AS} Clarified," *SB* 1/89, p. 55).

I started thinking about the box. Suppose, instead of letting V_{AS} drive my design, I arbitrarily chose the box dimensions and then, with the help of my computer program, did the best I cou within that constraint. This seemed to be a good alternative, since I happened to have a 4′ × 8′ sheet of 1⅟₁₆″ birch plywood on hand.

With the material identified, the question of box size came down to a practical consideration: how large a volume can a 4′ × 8′ sheet of plywood enclose without any waste? Through trial and error, I found that 2′ × 2′ × 3′ used all the plywood and produced the largest volume. I realize that building a box with two identical dimensions is not recommended because of resonance effects, but I believe I have a good excuse (Lubos R. Palounek, "Enclosure Shapes and Volumes," *SB* 3/88, p.22; Peter Muxlow, "Loudspeaker Cabinets," *SB* 2/88, p. 24). The largest dimension is 3′, and the frequency that corresponds to a one-half wavelength is about 183Hz. This frequency is more than an octave above the 70Hz upper cutoff frequency that I was considering, so I assumed it would not cause a problem.

The large 2′ × 3′ area of the side panels might result in vibration, however, especially if they were fastened together only at the edges. I decided to cross-brace the frame on all sides to break up the area into smaller sections and thus raise the resonances. I also decided to add internal stiffeners front to back, side to side, and top to bottom, all joined near the center of the enclosed volume (Robert W. Schmidt and Joseph D'Appolito, "Swan Amp?," *SB* 1/89, p. 56).

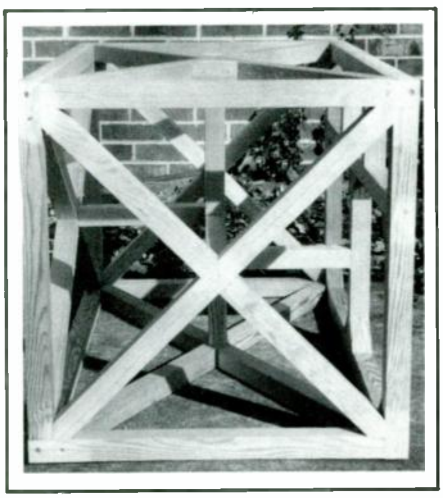


PHOTO 5: Finished frame viewed from the top, front to the right.

TABLE 1. SPEAKER "A", FREE AIR PARAMETERS

Day	f_S	f_1	f_2	$\sqrt{f_1 f_2}$	Q_{MS}	Q_{ES}	Q_{TS}
1	18.5	14.0	22.6	17.8	15.2	0.31	0.30
2	18.6	13.8	22.6	17.7	14.6	0.31	0.30
3	18.3	13.8	22.5	17.6	14.9	0.30	0.29
4	18.4	14.0	22.7	17.8	15.0	0.30	0.29
5	18.4	14.1	22.6	17.9	15.2	0.31	0.31
6	18.4	13.9	22.6	17.7	15.0	0.30	0.29
Avg	18.4	13.9	22.6	17.8	15.0	0.31	0.30

TABLE 2. SPEAKER "B", FREE AIR PARAMETERS

Day	f_S	f_1	f_2	$\sqrt{f_1 f_2}$	Q_{MS}	Q_{ES}	Q_{TS}
1	19.9	15.2	24.3	19.2	14.3	0.34	0.33
2	20.0	15.1	24.4	19.2	14.1	0.34	0.33
3	20.0	15.1	24.4	19.2	14.1	0.34	0.33
4	20.1	15.3	24.5	19.4	14.3	0.34	0.33
5	20.3	15.2	24.6	19.3	13.8	0.35	0.34
6	19.9	15.1	24.4	19.2	14.1	0.33	0.32
Avg	20.0	15.2	24.4	19.3	14.1	0.34	0.33

This construction philosophy does not allow for any removable panels. The only access to the inside would be through the speaker and port holes cut in the front panel. I would need to ensure that once the last side panel was attached, I would never need access to anything inside.

THE FRAME. For the frame material, I selected 2″ × 2″ pine, with true dimensions of 1½″ × 1½″. I cut all the pieces with a power miter saw. First, I constructed the top and bottom frame members with cross-bracing, glued each joint with yellow glue, and then fastened it with a wood screw. I used butt joints at the corners to form the square frame.

I cut the eight pieces to the same 22½″ length, so this dimension plus the thickness of the perpendicular member equaled 24″. I used right-angle picture frame clamps to hold together the four pieces making up the two square frames while I drove the screws. Then I laid the finished frames, still clamped, on my bench with weights on top to keep them flat while the glue dried overnight.

Next, I cut the pieces for the "X" cross-bracing, and the miter saw was ideal for the task. With the saw blade adjusted to perpendicular postition, I cut each cross-piece square with respect to the faces and with the correct angle at the end. I purposely cut each length a trifle long so I could shave off a small amount with the miter saw.

All the cross-bracing fit snugly. I then joined the cross-pieces with glue and one screw to hold them tight. *Photo 1* shows the top and bottom frames.

Next, I cut the four vertical pieces which join the top and bottom frames to 33″. This length, plus the 1½″ thickness of the top and bottom, makes the box 36″ high. Again, I used right-angle clamps to hold the vertical pieces perpendicular to the top and bottom frames while the glue dried. I used one screw at each joint, driving it from the top and bottom into the vertical member, to make a tight fit. I cut an additional 33″ piece and inserted it at the center of the cross-braces to join the top and bottom.

The basic frame was now complete (*Photo 2*). Only the cross-bracing on the four faces needed to be added, and I made these pieces in the same way as the top and bottom subassemblies. I used the same "X" cross-bracing on the back and two sides, but different bracing on the front. To accommodate the two speakers and the port, I divided the bracing into five smaller rectangles, with 2″ × 2″ pieces added internally to connect the middle of the side panel cross-braces to the center upright. In a similar fashion, I joined the front and back braces through the center upright.

This scheme supposedly discourages each of the faces from vibrating as one piece. *Photo 3* shows the finished frame from the front, with a view of the left side in *Photo 4*. *Photo 5* is a view from the top.

MAKING FACES. Next, I cut six faces from the 4′ × 8′ sheet of plywood. A table saw would have been helpful, but I used a power hand saw with a sharp blade for cutting plywood. I drew the cuts with a pencil, counting to make sure I would get all the pieces I needed.

I first cut down the center of the long dimension to get two 2′ × 8′ pieces. Next, I stacked the two sheets on top of one another, squared them, and clamped them together with C-clamps. I then made two cuts perpendicular to the long dimension at 3′ intervals for the four 2′ × 3′ sides. The stacked pieces remaining after the previous cut were the 2′ × 2′ pieces for the top and bottom.

The next step was sanding, for which I used a power drill with a sanding attachment. The edges and the outside faces needed to be smoothed. I also made split wood repairs and cleaned any accumulated dirt or mold. I sanded the outside facing surfaces with a coarse grit to level off all the high spots, and ensured that the plywood could be attached to the frame with no gaps around the edges.

After I had cut and sanded everything, I began selecting which piece should go where. Although there were slight differences in size, I attempted to select where each piece would fit best on the frame. When I was satisfied, I marked each of the six faces for location and top and bottom edges.

Then I drew circles on the front face in preparation for cutting the three holes. Since the general locations had already been set by the bracing, all I did was to find reasonable centers and draw the circles. A pencil compass worked for the port, as its diameter is only about 4″. I used the fiber gasket that accompanied each speaker as a guide for the two larger holes.

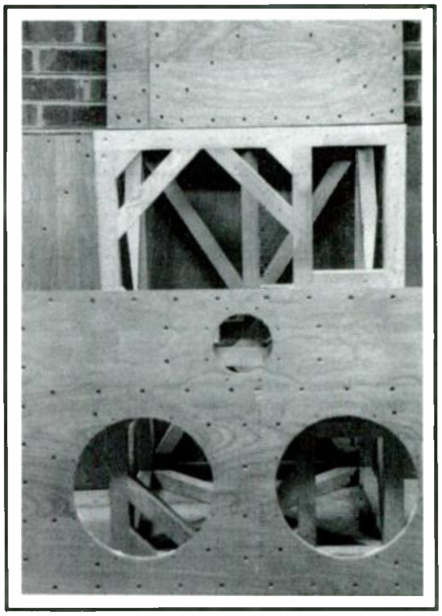


PHOTO 6: Front panel on its side leaning against the frame.

I made the cuts with a saber saw. Perfect circles were unnecessary as they would never show after the speakers and removable port were mounted. I undercut the diameter slightly, sanded the rough cuts by hand, and fixed the out-of-round spots. I tried the drivers in the holes for size and sanded until they fit.

With the drivers in position, I marked the locations of the mounting holes for eight screws. I made the holes through the front panel on a drill press to ensure they were vertical and parallel to each other, which is especially important in the case of the port. The screws mated with the T-nuts, which were mounted from the back, without cross-threading.

I used #10-24 machine screws with washers on the outside to adjust the length so the screws did not poke all the way through the T-nut. I intended to cover the screw holes from the inside with caulk to prevent any air from leaking through the threads. *(Machine screws may be shortened with a hacksaw by threading two nuts on the screw and clamping the nuts and screw in a vise.—Ed.)*

LOOSE SCREWS. With the front panel cutouts completed, it was time to drill the holes for the screws that attach the six faces to the frame. I worked on each face separately and clamped the panel to the frame with C-clamps. I drilled holes every 3″ around the perimeter of each face and wherever there was a cross-brace underneath. I used a hand-held power drill to make the pilot holes for the #8 wood screws. After completing the circuit, I changed to a larger-diameter drill to make a snug hole through the plywood

TABLE 3. CLOSED BOX SYSTEM PARAMETERS

Day	f_C	f_1	f_2	$\sqrt{f_1 f_2}$	Q_{MC}	Q_{EC}	Q_{TC}
1	33.4	30.2	36.9	33.4	34.1	0.76	0.74
2	34.0	30.4	36.8	34.0	43.3	0.64	0.63
3	33.1	30.6	36.6	33.1	44.4	0.72	0.70
Avg	33.5	30.4	36.8	33.5	40.6	0.71	0.69

TABLE 4. BOXRESPONSE'S PREDICTED OUTPUT FOR THE CLOSED BOX DESIGN PLOTTED IN FIGURE 1

Frequency Hz	System Response db	Maximum Power Input watts	Maximum Infinite Baffle Output db
5	-34.90	36.08	75.26
10	-23.01	37.34	87.31
15	-16.25	39.91	94.35
20	-11.75	44.49	99.35
25	-8.53	52.06	103.22
30	-6.25	63.87	106.39
35	-4.63	81.48	109.07
40	-3.48	106.71	111.39
50	-2.08	188.68	115.26
60	-1.34	300.00	118.02
70	-0.93	300.00	118.44
80	-0.67	300.00	118.69
100	-0.40	300.00	118.96
120	-0.27	300.00	119.10
150	-0.16	300.00	119.20
200	-0.09	300.00	119.27

TABLE 5. BOXRESPONSE'S PREDICTED OUTPUT FOR THE EQUALIZED CLOSED BOX DESIGN PLOTTED IN FIGURE 2			
Frequency Hz	System Response db	Maximum Power Input watts	Maximum Infinite Baffle Output db
5	-63.99	29293.45	75.26
10	-39.30	1590.31	87.31
15	-24.19	248.30	94.35
20	-12.95	58.99	99.35
25	-4.92	22.66	103.22
30	-1.25	20.19	106.39
35	-0.29	30.00	109.07
40	-0.04	48.24	111.39
50	0.13	113.40	115.26
60	0.18	211.40	118.02
70	0.18	232.48	118.44
80	0.17	247.10	118.69
100	0.13	265.24	118.96
120	0.10	275.52	119.10
150	0.07	284.15	119.20
200	0.04	291.01	119.27

TABLE 6. VENTED BOX MEASUREMENTS										
Duct	f_H	f_M	f_L	f_{SB}	Q_{MSB}	Q_{ESB}	Q_{TSB}	α	h	Q_L
19.5	35.5	15.5	6.2	14.2	18.7	0.43	0.42	4.07	1.06	1.59
17.7	35.0	15.0	6.7	15.6	17.0	0.39	0.38	3.28	0.96	2.33
16.2	35.3	14.1	6.6	16.5	16.1	0.37	0.36	3.00	0.85	2.46
14.5	35.5	15.1	7.3	17.2	15.5	0.35	0.34	2.69	0.88	2.64
12.7	35.6	15.7	7.6	17.2	15.5	0.35	0.34	2.63	0.91	2.89
11.2	35.9	16.5	7.9	17.2	15.5	0.35	0.34	2.65	0.96	3.02
5.0	37.2	20.1	9.9	18.3	14.5	0.33	0.32	2.21	1.10	4.54
4.0	37.8	21.7	10.5	18.3	14.5	0.33	0.32	2.19	1.19	4.81
3.6	37.8	22.2	10.7	18.2	14.5	0.33	0.32	2.16	1.22	5.20
1.7	39.3	24.3	11.9	19.2	14.0	0.32	0.31	1.96	1.27	6.00
1.5	39.6	25.0	11.8	18.7	14.2	0.33	0.32	2.10	1.34	6.20
0.0	41.8	27.2	13.5	20.7	12.8	0.29	0.28	1.76	1.31	6.69

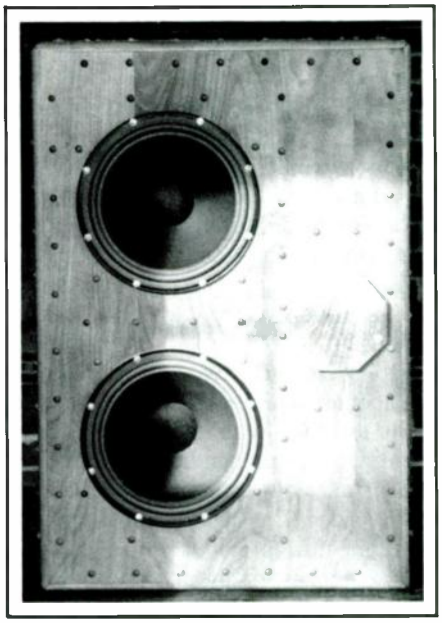


PHOTO 7: Finished system with port covered.

for the nonthreaded screw shank. Then I went around again with a ⅜″ countersinking bit. *(Page 34 begins an article on screw technology which can simplify this process.—Ed.)*

Offsetting the holes slightly on adjacent faces is helpful to avoid screws butting up against each other. After drilling the holes, I test-fitted the faces with a few screws, checking for any problems along the edges.

Since my faces and frame have the same perimeter dimensions, I filled a channel along each edge with 11/16″ quarter round. I mitered the 12 molding pieces, including eight front and back pieces, plus four 2-foot side lengths, cut square to fit them up against the mitered corners. I then rounded all the corners with a wood file and sandpaper. *Photo 6* is a view of the front panel on its side leaning against the frame.

To feed the signal to the drivers, I used an eight-terminal barrier strip, giving me access to each of the four voice coils, with each driver's two voice coils connected in series and the two drivers connected in parallel.

I substituted eight 1½″ #6-32 machine screws for one row of screws on the terminal strip, with eight holes drilled near the bottom center of the back panel to align with them. On the inside, I used a piece of perforated board to mount a washer, spade lug, and nut. Later, I attached a lug to each voice coil with 18-gauge zip cord.

ROUND PEG, SQUARE HOLE. The port cover is a wood panel fastened with eight machine screws in the same manner as the drivers to T-nuts inside. With this in place, the box could be used to find α. I designed the port cover and rings to be removable to allow me to adjust the duct length.

I cut one cover and two rings from a length of 8-inch wide, ¾-inch thick hardwood. I then trimmed the square pieces into octagonal shapes by cutting off the corners with the miter saw. I cut the 4½″ hole in the two rings undersize with a saber saw, then used a wood file and sandpaper to remove excess material until the plastic pipe for the duct fit snugly in the hole.

I screwed the ring to the outside of the front panel, with the pipe fitting through the oversize hole. A thin piece of weatherstripping served as a gasket between the ring and the front panel. I covered the screw holes in the T-nuts with caulk to prevent air leaks. For testing purposes, I filled the joint between the pipe and the ring with flexible rope caulk. For the final seal, I used silicone bathtub caulk.

Continued on page 22

TABLE 7. BOXRESPONSE'S PREDICTED OUTPUT FOR THE FOURTH/SIXTH ORDER SYSTEM WITH A 3.6" DUCT					
Frequency Hz	Unequalized System Response db	Unequalized Maximum Power Input watts	Equalized System Response db	Equalized Maximum Power Input watts	Maximum Infinite Baffle Output db
5	-49.33	4.26	-69.24	416.96	49.81
10	-27.30	9.59	-32.91	34.93	75.37
15	-15.43	32.89	-11.42	13.08	92.59
20	-7.99	282.13	-2.92	87.83	109.36
25	-3.72	300.00	-0.31	136.67	113.89
30	-1.72	149.71	0.62	87.26	112.87
35	-0.88	138.10	0.82	93.38	113.36
40	-0.52	164.36	0.77	122.20	114.49
50	-0.25	283.45	0.57	235.08	117.12
60	-0.15	300.00	0.41	263.71	117.46
70	-0.11	300.00	0.30	273.01	117.51
80	-0.08	300.00	0.23	273.01	117.51
100	-0.05	300.00	0.15	286.55	117.57
120	-0.04	300.00	0.10	290.62	117.58
150	-0.02	300.00	0.07	293.97	117.59
200	-0.01	300.00	0.04	296.60	117.60

Continued from page 20

BUTTON UP. All the pieces were now ready for finishing. When I weighed everything, the total weight was 122 lbs.

I finished the outside faces of the six plywood panels before final assembly. I primed each piece with wood conditioner, then darkened the birch plywood with a light stain. For the finish, I used three coats of polyurethane clear gloss varnish. I allowed each coat to dry for at least 24 hours, then rubbed the surfaces with steel wool to remove irregularities, which produced a matte finish.

The panels are fastened to the frame with more than 320 #8 screws, each covered with a ⅜" wooden button.

ACCESS DENIED. I was now ready to begin the final assembly of the plywood faces to the frame. In order to easily make the electrical connections to the terminal strip from the inside, I began with the back panel. I included a plug and socket in the electrical path between it and the driver. In that way, I could make permanent connections to the back panel, but still allow for the drivers to be removed by simply pulling the plug at the speaker end.

Since I had to test-fit all the panels before finishing, they went together without incident. To ensure an airtight seal, I used glue and caulk on each frame member, wiping any excess glue and caulk with a wet paper towel.

The last panel was the front. Once it was glued, there was no access to the inside except through the driver and port cutouts. I then nailed the molding in place using pilot holes for easy nailing. I also used a little glue, which helped the fit of the sharp right angle of the quarter round. The molding fit snugly in place without any gaps.

I nailed four furniture feet with large, smooth metal slides into the bottom panel, and found that I could move the box on the wood floor without leaving marks or scratches.

DRIVER INSTALLATION. The final step was installing the two drivers and making the electrical connections. I fastened the units with eight #10-24 ¾" screws, with thin foam weather stripping around the circular cutouts. The finished closed-box system is shown in *Photo 7* with the port covered.

I was concerned that the foam surrounds might be porous enough to leak air. With the drivers mounted and the port covered, I manually depressed one speaker cone and watched the other. It moved in the opposite direction and stayed displaced for a few seconds, or until the first returned to equilibrium. This proved the box was sufficiently airtight.

FREE-AIR TESTS. I used the constant-voltage method described by Robert Bullock to make the necessary measurements for computing the drivers' free-air resonance (f_S) and the electrical and mechanical Qs (*SB* 1/81, p. 12). Find the frequency at which the electrical impedance peaks, and determine the frequencies f_1 and f_2 ($f_1 < f_S$ and $f_2 > f_S$) where the impedance equals the voice coil resistance (i.e., the voice coil impedance at zero frequency) times the square root of parameter r_0. If r_0 is chosen as the ratio of the peak impedance to the voice coil resistance, the calculation is simplified and $f_S = \sqrt{f_1 f_2}$.[16]

The measurements require a low-distortion sine-wave signal generator, a frequency counter, a current and voltage meter, an ohmmeter, and a noninductive resistor of about 10Ω. I used a digital multimeter for the current meter and ohmmeter, but since the voice coil's current and voltage must be monitored at the same time, I couldn't use it as the voltmeter. Instead, I used my oscilloscope as the voltmeter and read the current from the digital multimeter. This worked well, but two items needed attention.

The first is the obvious fact that the driver voice coil impedance varies with frequency. As one searches for the maximum impedance, the voltage across the voice coil changes and requires continuous signal generator adjustment to keep the level constant. I may have been better able to keep the voltage constant if

PHOTO 8: Finished system with port and duct.

I had had a digital AC voltmeter rather than using the oscilloscope trace to eyeball a constant voice coil voltage.

The second item was changing current ranges on the multimeter changing the circuit series resistance. Thus, I made adjustment so I could make all measurements on the same current range.

For my reference impedance, I tested the frequency sensitivity of some resistors and picked one that stayed constant; it measured about 10Ω. I also tested the AC current range on the multimeter and found that it was pretty accurate between 10 and 100Hz, so I tried to keep all test frequencies within that range. I also used the multimeter to find the voice coil resistances. I wired the dual coils in series, giving a total resistance of 11.94Ω for speaker A and 11.88Ω for B.

I performed the measurements over a period of six days, with a temperature variation of 64–67°F. I hung the two drivers with twine from the floor joists and connected them to my test equipment with clip leads. I measured each driver once a day to see how repeatable the measurements were. The results are shown in *Tables 1* and *2*.

I was gratified to see that the data sets from each driver were consistent from day to day. This driver pair had a particularly sharp resonance with a maximum impedance over 500Ω, which made the determination of f_S unambiguous. In the case of drivers with a low Q, the impedance may vary only slightly around the resonant frequency, making it difficult to determine the peak's location.

The match between drivers is good enough for them to be used together in the same box. The Q_{TS} figures were within 10%, as were the resonant frequencies. The numbers also looked good for a sixth-order Class 1 system. The actual equivalent volume was still unknown, but from Bullock's *Tables 1–6*, a Class 1 sixth-order system with a driver having a Q_{TS} around 0.31 requires an α between 2.1 and 2.5 depending on Q_L (Bullock, *SB* 1/82, p. 21). Therefore, each driver could have a V_{AS} equal to the box volume. This information suggested that the 12 ft.³ box should be adequate.

CLOSED-BOX TESTS. My illusions about the adequacy of 12 ft.³ were seemingly dashed after the first closed-box measurement. With the drivers mounted and all the test equipment transported to my living room, I began the closed-box test which would give me the necessary information to compute α.

At the terminal strip on the back of the box, I used jumper wires to connect each driver's two voice coils in series and then the two drivers in parallel. The resistance was 6.01Ω measured with my multimeter, a value high enough to allow any reasonable amplifier to drive the system.

I used a similar procedure for the closed-box as for the free-air measurements on three consecutive days (*Table 3*). This time, I performed the calculations with a least squares estimation algorithm I had coded.

The least squares method doesn't require the actual measurement of f_C, f_1, or f_2. Instead, any frequencies around the peak impedance can be used. The algorithm adjusts the parameters f_C, Q_{EC}, and Q_{MC} to find the impedance curve that best fits the data. Consequently, the values listed for the parameters in *Table 3* are computed, not measured. This explains why there is exact agreement between f_C and $\sqrt{f_1 f_2}$ in the table.

reduced slightly to raise Q_{TC} and lower the 3dB frequency.

$$\alpha = \left[\frac{f_C\, Q_{EC}}{f_S\, Q_{ES}}\right] - 1 \qquad (1)$$

I could now find the value for α from Equation 1, derived by Small.[18] The average values for f_S, Q_{ES}, and Q_{MS} from *Tables 1* and *2* are 19.2Hz, 0.33, and 14.6, respectively. The closed-box values from *Table 3* are 33.5Hz, 0.71, and 40.6. Substituting these into the equation gives 2.75 for α. This was a little high for my sixth-order design goal, implying that the box was too small.

I used the BOXRESPONSE program as an aid to evaluate system performance (Robert M. Bullock and Bob White, "Boxresponse, An Apple Program for the Thiele-Small Models," *SB* 1/84, p. 13). My version was derived from the basic code that appeared in *SB* 1/84 and subsequently modified.[19-22] The entry called "damping" required by BOXRESPONSE when you're using electronic equalization caused me some consternation. A parameter called "damping ratio" (zeta or d) can be shown to be equal to 1/2Q.[23, 24] Careful reading of the original

Continued on page 28

TABLE 8. BOXRESPONSE'S PREDICTED OUTPUT FOR THE FOURTH/SIXTH ORDER SYSTEM WITH A 1.5" DUCT

Frequency Hz	Unequalized System Response db	Unequalized Maximum Power Input watts	Equalized System Response db	Equalized Maximum Power Input watts	Maximum Infinite Baffle Output db
5	-52.03	4.53	-79.92	2790.73	47.61
10	-30.05	9.56	-45.65	347.21	72.83
15	-17.85	24.93	-26.28	173.57	89.19
20	-9.48	102.75	-13.34	250.39	103.72
25	-3.82	300.00	-5.13	405.56	114.02
30	-0.93	242.65	-1.06	249.97	115.99
35	0.05	156.47	0.38	145.09	115.07
40	0.28	167.65	0.75	150.41	115.60
50	0.24	275.88	0.71	247.94	117.73
60	0.16	300.00	0.54	274.88	118.01
70	0.10	300.00	0.41	279.77	117.95
80	0.07	300.00	0.31	283.63	117.92
100	0.04	300.00	0.20	288.86	117.88
120	0.02	300.00	0.14	292.01	117.87
150	0.01	300.00	0.09	294.75	117.86
200	0.01	300.00	0.05	296.99	117.85

I was delighted to find I had stumbled upon a nearly perfectly aligned closed-box system. The average Q_{TC} of 0.69 is almost equal to one-half the square root of two, which is the Q for a second-order Butterworth high-pass filter.[17] The closed-box resonance of f_C = 33.5Hz would make this a respectable closed-box design. In fact, the box volume could be

19P

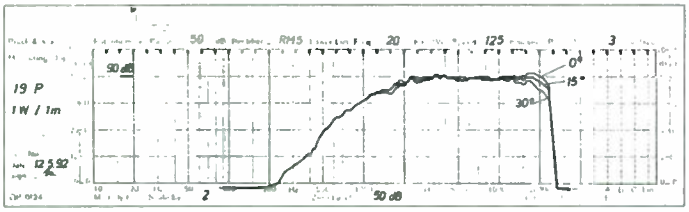
3/4" dome tweeter

Price $13.00

19 mm polymide soft dome tweeter with smooth and extended frequency response and wide dispersion

- polymide soft dome
- glassfibre reinforced black plastic front plate
- grill frame available

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	6.0	Ω
Resonant Frequency	f_r	2000	Hz
Rated Power		80	W
SPL 1W/1m		89	db
Compliance	C_{ms}	-	m/N
Mechanical Q Factor	Q_{ms}	-	
Electrical Q Factor	Q_{es}	-	
Total Q Factor	Q_{ts}	-	
Mechanical Resistance	R_{ms}	-	kg/s
Total Moving Mass	M_{MS}	0.18	g
Effective Piston Area	S_D	3.9	cm^2
Equivalent Air Volume	V_{AS}	-	L
Voice Coil Diameter		19	mm
Voice Coil Former		Aluminium	
Voice Coil Length		1.5	mm
Voice Coil Layers		2	
Flux Density	B	1.38	Tesla
Force Factor	B_L	2.3	Tm
Gap Height		3	mm
Magnet Diameter		55	mm
Magnet Height		12	mm
Magnet Weight		0.12	kg
Mass of Speaker		0.3	kg



Frequency Response

20T

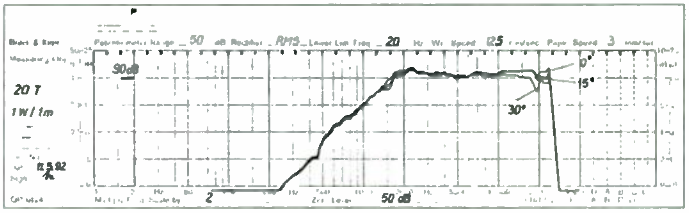
3/4" dome tweeter

Price $16.00

19 mm titanium dome tweeter with high efficiency and excellent sound quality

- titanium dome
- black aluminum front plate
- diffusor with improved acoustic design

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	6.0	Ω
Resonant Frequency	f_r	1700	Hz
Rated Power		80	W
SPL 1W/1m		90	db
Compliance	C_{ms}	-	m/N
Mechanical Q Factor	Q_{ms}	-	
Electrical Q Factor	Q_{es}	-	
Total Q Factor	Q_{ts}	-	
Mechanical Resistance	R_{ms}	-	kg/s
Total Moving Mass	M_{MS}	0.19	g
Effective Piston Area	S_D	4.9	cm^2
Equivalent Air Volume	V_{AS}	-	L
Voice Coil Diameter		19	mm
Voice Coil Former		Aluminium	
Voice Coil Length		1.5	mm
Voice Coil Layers		2	
Flux Density	B	1.4	Tesla
Force Factor	B_L	2.3	Tm
Gap Height		2.5	mm
Magnet Diameter		55	mm
Magnet Height		12	mm
Magnet Weight		0.12	kg
Mass of Speaker		0.3	kg



Frequency Response

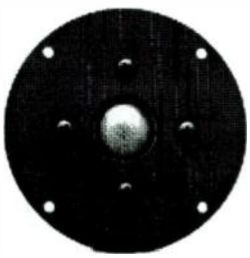
25FA

1" dome tweeter

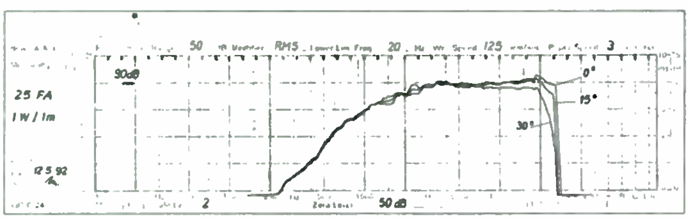
Price $19.00

25 mm soft dome tweeter with extraodinarily wide frequency response and excellent sound quality

- precoated textile dome
- black aluminum front plate
- magnetic fluid
- grill frame available



Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	6.8	Ω
Resonant Frequency	f_r	1800	Hz
Rated Power		100	W
SPL 1W/1m		90	db
Compliance	C_{ms}	-	m/N
Mechanical Q Factor	Q_{ms}	-	
Electrical Q Factor	Q_{es}	-	
Total Q Factor	Q_{ts}	-	
Mechanical Resistance	R_{ms}	-	kg/s
Total Moving Mass	M_{MS}	0.22	g
Effective Piston Area	S_D	6.5	cm^2
Equivalent Air Volume	V_{AS}	-	L
Voice Coil Diameter		25	mm
Voice Coil Former		Aluminium	
Voice Coil Length		1.5	mm
Voice Coil Layers		2	
Flux Density	B	1.6	Tesla
Force Factor	B_L	2.9	Tm
Gap Height		3	mm
Magnet Diameter		72	mm
Magnet Height		15	mm
Magnet Weight		0.25	kg
Mass of Speaker		0.5	kg



Frequency Response

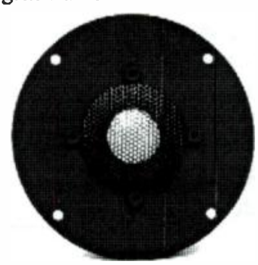
26T

1" dome tweeter

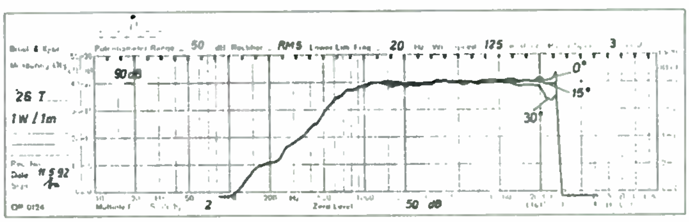
Price $30.00

25 mm titanium dome tweeter with high efficiency and wide frequency response

- titanium dome with rubber surround
- black aluminum front plate
- double magnet
- vented polepiece
- grill frame



Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	6.8	Ω
Resonant Frequency	f_r	730	Hz
Rated Power		100	W
SPL 1W/1m		90	db
Compliance	C_{ms}	-	m/N
Mechanical Q Factor	Q_{ms}	-	
Electrical Q Factor	Q_{es}	-	
Total Q Factor	Q_{ts}	-	
Mechanical Resistance	R_{ms}	-	kg/s
Total Moving Mass	M_{MS}	0.28	g
Effective Piston Area	S_D	6.8	cm^2
Equivalent Air Volume	V_{AS}	-	L
Voice Coil Diameter		25	mm
Voice Coil Former		Aluminium	
Voice Coil Length		1.5	mm
Voice Coil Layers		2	
Flux Density	B	1.8	Tesla
Force Factor	B_L	3.2	Tm
Gap Height		1.5	mm
Magnet Diameter		72	mm
Magnet Height		2 x 15	mm
Magnet Weight		2 x .25	kg
Mass of Speaker		0.75	kg



Frequency Response

38T

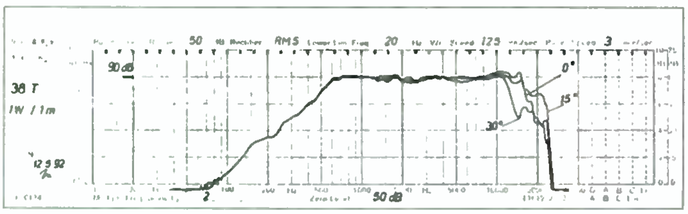
1 1/2" midrange dome

Price $35.00

37 mm titanium dome with smooth and extended frequency response and sound reproduction without any coloration

- titanium dome, rubber surround
- black aluminum front plate
- rear chamber
- vented pole piece
- grill frame

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	5.7	Ω
Resonant Frequency	f_r	490	Hz
Rated Power		70	W
SPL 1W/1m		91	db
Compliance	C_{ms}		m/N
Mechanical Q Factor	Q_{ms}		
Electrical Q Factor	Q_{es}		
Total Q Factor	Q_{ts}		
Mechanical Resistance	R_{ms}		kg/s
Total Moving Mass	M_{MS}	0.78	g
Effective Piston Area	S_D	15	cm²
Equivalent Air Volume	V_{AS}		L
Voice Coil Diameter		37	mm
Voice Coil Former		Aluminium	
Voice Coil Length		38	mm
Voice Coil Layers		1	
Flux Density	B	1.5	Tesla
Force Factor	B_L	3.3	Tm
Gap Height		3	mm
Magnet Diameter		84	mm
Magnet Height		18	mm
Magnet Weight		0.38	kg
Mass of Speaker		0.8	kg



Frequency Response

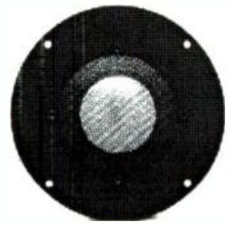
51AT

2" midrange dome

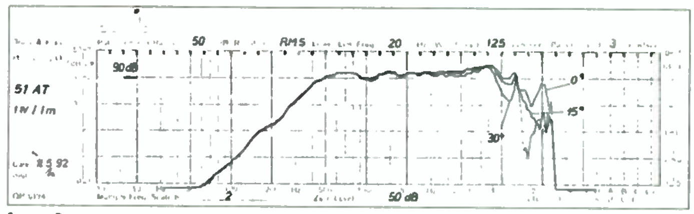
Price $45.00

50 mm metal midrange dome with high efficiency and extraordinarily wide frequency response

- aluminum / titanium alloy dome
- rubber surround
- black aluminum front plate
- rear chamber
- vented pole piece
- grill frame



Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	5.7	Ω
Resonant Frequency	f_r	480	Hz
Rated Power		100	W
SPL 1W/1m		93	db
Compliance	C_{ms}		m/N
Mechanical Q Factor	Q_{ms}		
Electrical Q Factor	Q_{es}		
Total Q Factor	Q_{ts}		
Mechanical Resistance	R_{ms}		kg/s
Total Moving Mass	M_{MS}	1.27	g
Effective Piston Area	S_D	26	cm²
Equivalent Air Volume	V_{AS}		L
Voice Coil Diameter		50	mm
Voice Coil Former		Aluminium	
Voice Coil Length		4.3	mm
Voice Coil Layers		1	
Flux Density	B	1.3	Tesla
Force Factor	B_L	3.7	Tm
Gap Height		3	mm
Magnet Diameter		102	mm
Magnet Height		17	mm
Magnet Weight		0.47	kg
Mass of Speaker		1.2	kg



Frequency Response

100HMS

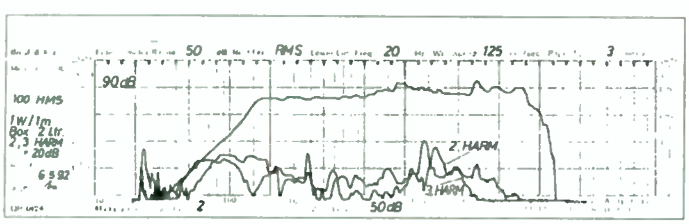
4" midrange cone

Price $25.00

High performance midrange unit with wide and very smooth response and excelent sound quality

- coated paper cone
- rubber surround
- epoxy resin coated steel basket
- high temperature voice coil for high power handling

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	6.0	Ω
Resonant Frequency	f_r	96	Hz
Rated Power		30	W
SPL 1W/1m		88	db
Compliance	C_{ms}	.00062	m/N
Mechanical Q Factor	Q_{ms}	2.34	
Electrical Q Factor	Q_{es}	0.79	
Total Q Factor	Q_{ts}	0.59	
Mechanical Resistance	R_{ms}	1.1	kg/s
Total Moving Mass	M_{MS}	4.4	g
Effective Piston Area	S_D	53	cm²
Equivalent Air Volume	V_{AS}	4.5	L
Voice Coil Diameter		19	mm
Voice Coil Former		Aluminium	
Voice Coil Length		6.1	mm
Voice Coil Layers		2	
Flux Density	B	1.4	Tesla
Force Factor	B_L	4.5	Tm
Gap Height		4	mm
Magnet Diameter		72	mm
Magnet Height		15	mm
Magnet Weight		0.25	kg
Mass of Speaker		0.5	kg



Frequency Response/Distortion

130HMS

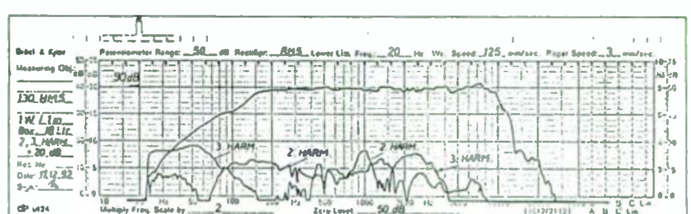
5" midrange cone

Price $28.00

High performance midrange unit with wide and very smooth response, low distortion and high power handling

- paper cone
- rubber surround
- epoxy resin coated steel basket
- high temperature voice coil for

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	5.3	Ω
Resonant Frequency	f_r	40	Hz
Rated Power		50	W
SPL 1W/1m		90	db
Compliance	C_{ms}	.0019	m/N
Mechanical Q Factor	Q_{ms}	1.32	
Electrical Q Factor	Q_{es}	0.25	
Total Q Factor	Q_{ts}	0.21	
Mechanical Resistance	R_{ms}	1.5	kg/s
Total Moving Mass	M_{MS}	7.7	g
Effective Piston Area	S_D	78.5	cm²
Equivalent Air Volume	V_{AS}	18	L
Voice Coil Diameter		25	mm
Voice Coil Former		Aluminium	
Voice Coil Length		9	mm
Voice Coil Layers		2	
Flux Density	B	1.1	Tesla
Force Factor	B_L	5.5	Tm
Gap Height		6	mm
Magnet Diameter		84	mm
Magnet Height		15	mm
Magnet Weight		0.35	kg
Mass of Speaker		1.0	kg



Madisound Speaker Components; P.O. Box 44283, Madison WI 53744-4283 Tel: 608-831-3433 Fax: 608-831-3771

LPG 130HWS

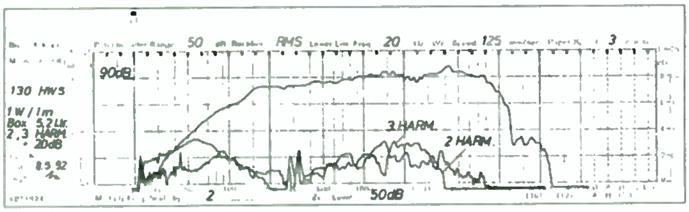
5" woofer

Price $32.00

High efficiency bass/midrange unit with excelent sound quality and high power handling

- black polypropylene cone
- rubber surround
- epoxy resin coated steel basket
- high temperature voice coil
- vented pole piece

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	5.3	Ω
Resonant Frequency	f_r	56	Hz
Rated Power		50	W
SPL 1W/1m		89	db
Compliance	C_{ms}	.00114	m/N
Mechanical Q Factor	Q_{ms}	1.74	
Electrical Q Factor	Q_{es}	0.42	
Total Q Factor	Q_{ts}	0.34	
Mechanical Resistance	R_{ms}	1.43	kg/s
Total Moving Mass	M_{MS}	7.1	g
Effective Piston Area	S_D	83	cm^2
Equivalent Air Volume	V_{AS}	12	L
Voice Coil Diameter		25	mm
Voice Coil Former		Aluminium	
Voice Coil Length		9	mm
Voice Coil Layers		2	
Flux Density	B	1.1	Tesla
Force Factor	B_L	5.6	Tm
Gap Height		6	mm
Magnet Diameter		84	mm
Magnet Height		15	mm
Magnet Weight		0.35	kg
Mass of Speaker		0.95	kg



Frequency Response/Distortion

LPG 160HWS

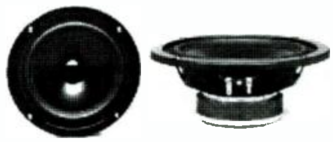
6 1/2" woofer

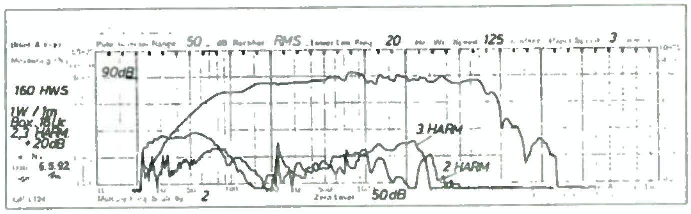
Price $37.00

High efficiency bass unit with very smooth response and low distortion

- black polypropylene cone
- rubber surround
- epoxy resin coated steel basket
- high temperature voice coil
- vented pole piece

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	5.7	Ω
Resonant Frequency	f_r	44	Hz
Rated Power		60	W
SPL 1W/1m		89	db
Compliance	C_{ms}	.00108	m/N
Mechanical Q Factor	Q_{ms}	1.61	
Electrical Q Factor	Q_{es}	0.57	
Total Q Factor	Q_{ts}	0.42	
Mechanical Resistance	R_{ms}	2.07	kg/s
Total Moving Mass	M_{MS}	12.1	g
Effective Piston Area	S_D	137	cm^2
Equivalent Air Volume	V_{AS}	30.5	L
Voice Coil Diameter		25	mm
Voice Coil Former		Aluminium	
Voice Coil Length		10	mm
Voice Coil Layers		2	
Flux Density	B	1.15	Tesla
Force Factor	B_L	5.8	Tm
Gap Height		6	mm
Magnet Diameter		90	mm
Magnet Height		17	mm
Magnet Weight		0.43	kg
Mass of Speaker		1.25	kg





Frequency Response/Distortion

LPG 245HWD

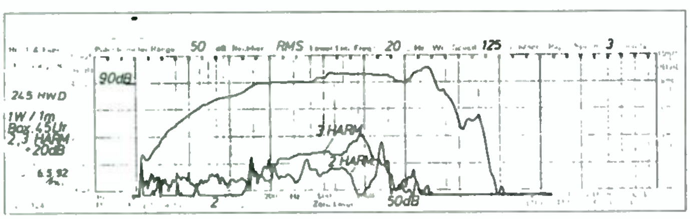
10" woofer

Price $137.00

High performance bass unit with a double magnet system for high efficiency and a long throw voice coil

- coated paper cone
- rubber surround
- diecast basket
- high temperature voic coil
- double magnet, vented pole piece

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	7.2	Ω
Resonant Frequency	f_r	22	Hz
Rated Power		150	W
SPL 1W/1m		90	db
Compliance	C_{ms}	.00135	m/N
Mechanical Q Factor	Q_{ms}	1.58	
Electrical Q Factor	Q_{es}	0.21	
Total Q Factor	Q_{ts}	0.19	
Mechanical Resistance	R_{ms}	3.5	kg/s
Total Moving Mass	M_{MS}	40	g
Effective Piston Area	S_D	314	cm^2
Equivalent Air Volume	V_{AS}	200	L
Voice Coil Diameter		50	mm
Voice Coil Former		Aluminium	
Voice Coil Length		27	mm
Voice Coil Layers		2	
Flux Density	B	1.1	Tesla
Force Factor	B_L	6.1	Tm
Gap Height		8	mm
Magnet Diameter		134	mm
Magnet Height		40	mm
Magnet Weight		2.35	kg
Mass of Speaker		5.3	kg



Frequency Response/Distortion

LPG 310HWD

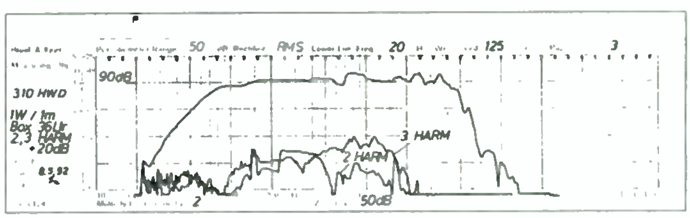
12" woofer

Price $195.00

High performance bass unit with double magnet system and long throw voice coil

- coated paper cone
- rubber suround
- diecast basket
- high temperature voice coil
- double magnet, vented pole piece

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	8	Ω
DC Resistance	R_{dc}	7.2	Ω
Resonant Frequency	f_r	25	Hz
Rated Power		150	W
SPL 1W/1m		91	db
Compliance	C_{ms}	.00063	m/N
Mechanical Q Factor	Q_{ms}	1.97	
Electrical Q Factor	Q_{es}	0.31	
Total Q Factor	Q_{ts}	0.27	
Mechanical Resistance	R_{ms}	4.9	kg/s
Total Moving Mass	M_{MS}	62	g
Effective Piston Area	S_D	515	cm^2
Equivalent Air Volume	V_{AS}	180	L
Voice Coil Diameter		50	mm
Voice Coil Former		Aluminium	
Voice Coil Length		27	mm
Voice Coil Layers		2	
Flux Density	B	1.1	Tesla
Force Factor	B_L	6.1	Tm
Gap Height		8	mm
Magnet Diameter		134	mm
Magnet Height		40	mm
Magnet Weight		2.35	kg
Mass of Speaker		5.7	kg



Frequency Response/Distortion

Madisound Speaker Components; P.O. Box 44283, Madison WI 53744-4283 Tel: 608-831-3433 Fax: 608-831-3771

LPG 160CWD

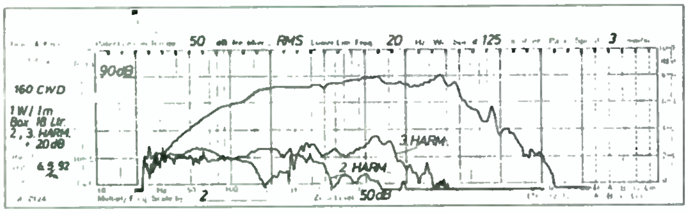
6 1/2" 4Ω woofer

Price $61.00

High performance woofer with high power handling and smooth frequency response, specially designed for car audio applications

- black polypropylene cone
- rubber surround
- diecast basket
- high temperature voice coil
- large magnet and vented polepiece
- grill frame available

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	4	Ω
DC Resistance	R_{dc}	3.2	Ω
Resonant Frequency	f_r	48	Hz
Rated Power		100	W
SPL 1W/1m		88	db
Compliance	C_{ms}	.00057	m/N
Mechanical Q Factor	Q_{ms}	1.77	
Electrical Q Factor	Q_{es}	0.35	
Total Q Factor	Q_{ts}	0.29	
Mechanical Resistance	R_{ms}	3.28	kg/s
Total Moving Mass	M_{MS}	19.3	g
Effective Piston Area	S_D	137	cm^2
Equivalent Air Volume	V_{AS}	14	L
Voice Coil Diameter		37	mm
Voice Coil Former		Aluminium	
Voice Coil Length		15	mm
Voice Coil Layers		2	
Flux Density	B	1	Tesla
Force Factor	B_L	7	Tm
Gap Height		8	mm
Magnet Diameter		102	mm
Magnet Height		20	mm
Magnet Weight		0.6	kg
Mass of Speaker		1.9	kg



Frequency Response/Distortion

LPG 205CWD

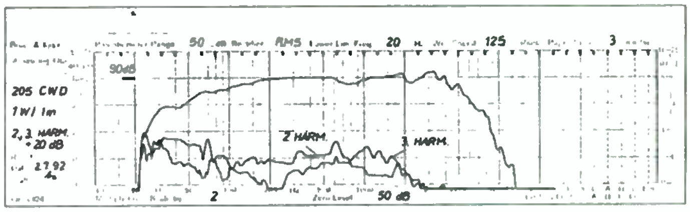
8" 4Ω woofer

Price $75.00

High efficiency woofer with excellent bass reproduction, designed for car audio applications

- black polypropylene cone
- ruber surround
- diecast basket
- high temperature voice coil
- large magnet and vented polepiece
- grill frame available

Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	4	Ω
DC Resistance	R_{dc}	3.2	Ω
Resonant Frequency	f_r	42	Hz
Rated Power		120	W
SPL 1W/1m		89	db
Compliance	C_{ms}	.00065	m/N
Mechanical Q Factor	Q_{ms}	2.04	
Electrical Q Factor	Q_{es}	0.57	
Total Q Factor	Q_{ts}	0.45	
Mechanical Resistance	R_{ms}	2.86	kg/s
Total Moving Mass	M_{MS}	22.1	g
Effective Piston Area	S_D	240	cm^2
Equivalent Air Volume	V_{AS}	40	L
Voice Coil Diameter		37	mm
Voice Coil Former		Aluminium	
Voice Coil Length		14	mm
Voice Coil Layers		2	
Flux Density	B	1.25	Tesla
Force Factor	B_L	5.4	Tm
Gap Height		6	mm
Magnet Diameter		121	mm
Magnet Height		20	mm
Magnet Weight		0.9	kg
Mass of Speaker		2.5	kg



Frequency Response/Distortion

LPG 245CWD

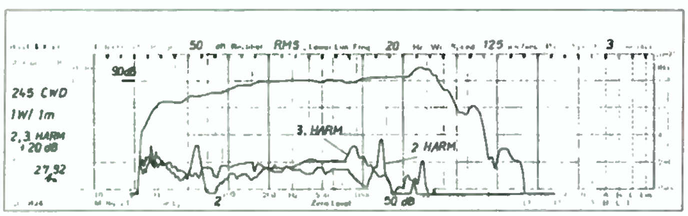
10" 4Ω woofer

Price $96.00

High efficiency woofer with excellent bass reproduction and high power handling, designed for car audio

- coated paper cone
- rubber surround
- diecast basket
- high temperature voice coil
- large magnet with vented polepiece
- grill frame available

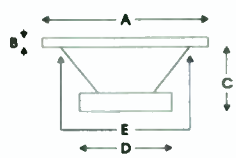
Technical Data	Symbol	Value	Unit
Nominal Impedance	Z_e	4	Ω
DC Resistance	R_{dc}	3.25	Ω
Resonant Frequency	f_r	24	Hz
Rated Power		130	W
SPL 1W/1m		90	db
Compliance	C_{ms}	.00157	m/N
Mechanical Q Factor	Q_{ms}	2.41	
Electrical Q Factor	Q_{es}	0.3	
Total Q Factor	Q_{ts}	0.27	
Mechanical Resistance	R_{ms}	1.75	kg/s
Total Moving Mass	M_{MS}	28	g
Effective Piston Area	S_D	326	cm^2
Equivalent Air Volume	V_{AS}	214	L
Voice Coil Diameter		50	mm
Voice Coil Former		Aluminium	
Voice Coil Length		14.5	mm
Voice Coil Layers		2	
Flux Density	B	0.9	Tesla
Force Factor	B_L	7.1	Tm
Gap Height		8	mm
Magnet Diameter		121	mm
Magnet Height		20	mm
Magnet Weight		0.9	kg
Mass of Speaker		3.0	kg



Frequency Response/Distortion

Unit	A	B	C	D	E	V_b liter	F_b Hz	F_3 Hz	Vent D"Ø	Vent L"	Vb liter	F_3 Hz
19P	100	3	21	55	67							
20T	96	2	21	57	57							
25FA	110	2	24	74	74							
26T	110	2	41	74	74							
38T	124	2	46	86	86							
51AT	140	2.5	46	105	105	Vented Alignments					Sealed	
100HMS	125	4	48	74	92						5-10	115
130HMS	155	4	61	84	113	3	74	90	1	3.5	3	115
130HWS	155	4	61	87	113	6	67	75	1.5	4.25	3.7	115
160HWS	186	7.5	67	92	148						9-17	75
245HWD	272	8.5	127	138	240	28	48	55	3	4	15	80
310HWD	332	8.5	147	138	295	45	38	45	3	6.3	30	65
160CWD	186	7.5	76	107	176	4.5	65	75	1.5	6	3	115
205CWD	229	8	85	127	203	35	39	43	2	3	28	65
245CWD	272	8.5	104	127	240	51	36	45	3	5.8	36	60
130 2-way	173	24	67	75	112						8	90
160 2-way	182	25	73	87	142						14	75
26NA	48	8	10	47	47							
Wedge	50	25										

Speaker measurements are in mm (25.4mm = 1"). Suggested box sizes are mostly QB3 alignments, but many other box sizes are useful for these drivers. If you have an existing box or if you want another alignment, please call and we can quickly give you another alignment over the phone. (28.31 = 1ft^3)



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. Add 10% for shipping charges. Residents of Alaska, Canada and Hawaii, and those who require Blue Label air service, please add 25%. There is no fee for packaging or handling, and we will refund or bill you to the exact shipping charge. We accept Mastercard or Visa on mail and phone orders.

Madisound Speaker Components; P.O. Box 44283, Madison WI 53744-4283 Tel: 608-831-3433 Fax: 608-831-3771

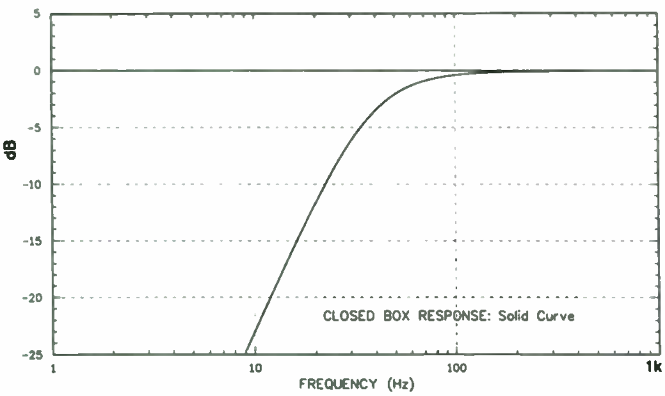


FIGURE 1: Closed-box alignment without equalization.

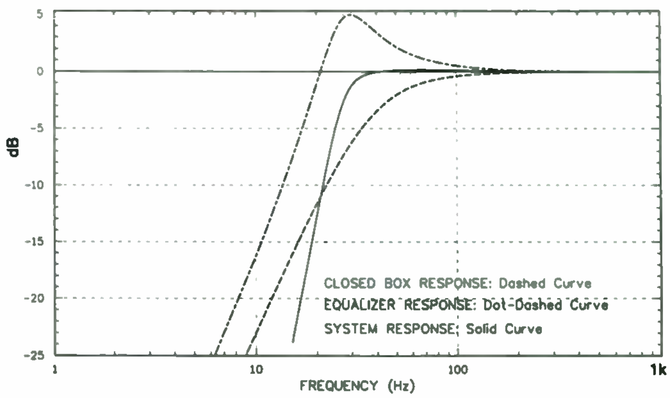


FIGURE 2: Closed-box alignment with equalization.

Continued from page 23
BOXRESPONSE article indicates that the authors intended their damping (D) to equal $1/Q_E$. I mention this to emphasize that Q_E, in the following discussion, is the same as D's reciprocal in BOXRESPONSE.

The frequency response for this closed-box system is plotted in *Fig. 1*. I used BOXRESPONSE to compute the delivered theoretical acoustic power, using the catalog specifications for electrical power input and cone displacement. The RMS power rating is 150W/unit, and the maximum one-way excursion is listed as 8 mm (0.3″).

The sound levels predicted by BOXRESPONSE are presented in *Table 4*: the first column lists the frequency; the second gives the system response in the operating region where the thermal and linearity constraints are not factors; the third indicates the maximum power the system can absorb at each frequency and remain within the thermal and linearity constraints.[25] The last column is an estimate of the sound level attainable at the third column limits.

The sound level is a function of many parameters, including temperature and atmospheric pressure. Nominal values of 70°F and 29.485″ of mercury were chosen to generate the tables. The acoustic output is also a function of V_{AS}. I estimated the actual box volume to be about 11 ft.^{3} with 1 ft.^{3} occupied by the internal bracing. Using α computed from Equation 1, V_{AS} = 30.25 ft.^{3} With this information, BOXRESPONSE predicted that the closed-box system would be thermally limited above 60Hz and excursion limited at lower frequencies.

By adding electronic equalization, the small-signal bandwidth can be extended so the 3dB point is below 30Hz. A second-order equalizer with f_E = 27Hz and Q_E = 1.7 (damping parameter = 0.558) resulted in a good looking curve, the solid line in *Fig. 2*. The dashed line in this figure is the unequalized response, and the long-short dashed line is the equalizer response. The BOXRESPONSE results are presented in *Table 5*.

Notice that the maximum output is the same as in *Table 4*. Even though I added electronic equalization, the maximum ratings of the speaker parameters entered into BOXRESPONSE did not change. You can better understand the maximum power input column if you consider it to refer to the power into the equalizer, and then regard the equalizer as a power booster connected directly to the speaker terminals.

At 30Hz, the system response (column two) differs by 5dB between the equalized and unequalized designs. Since the unequalized response (*Table 4*) is more negative, the equalizer must be adding the difference (check *Fig. 2*). According to the way BOXRESPONSE works, less power into the equalizer is required at 30Hz, and this appears as a smaller number in column three of *Table 5*. The ratio of the powers proves this to be the case. In decibels, the ratio of 63.87W (from *Table 4*) to 20.19W (from *Table 5*) is the missing 5.00dB.

VENTED-BOX MEASUREMENTS.

I removed the port cover and made measurements with ducts of varying lengths (Bullock, *SB* 1/81, p. 12). The 4½″ outside diameter plastic pipe was fitted in one of the port rings (*Photo 8*). I pressed the rope caulk all around the joint from inside the ring. I started with a duct length certainly too long: 19½″. Then I cut about 1½″ off the pipe to prepare for the next session.

Table 6 lists the results of many measurements, with the duct length in inches listed in the first column. The second, third, and fourth columns list f_H, f_M, and f_L, the measurements from which all the other parameters are computed. The value for f_L was sometimes difficult to locate, especially when it was below 10Hz, because I was using my oscilloscope as an AC voltmeter. The strobe effect caused by the slow sweep at these frequencies made it hard to accurately find the maximum. The results listed in the table seem to show systematic trends, however, so I believe the measurements are reasonably correct.

As I shortened the duct, α decreased. This result seems to say that as the box resonance (f_{SB}) increased, the compliance of the air in the box also increased. Or, as the box resonance increased, the speaker suspension compliance decreased. What is interesting is that α is a moving target that depends on the interaction of the system parameters.

Also, as I shortened the duct, Q_L increased. This might be explained (but by no means proved) by hypothesizing that the box construction "appears" stiffer to one's acoustic eye as the box resonance increases. Therefore, the losses resulting from flexing decrease and Q_L reflects this by increasing. The overall change in f_{SB} was only a little more than 6Hz from minimum to maximum.

ALIGNMENT.

Some of the results from *Table 6* are plotted in *Fig. 3*. Starting with the 11.2″ duct and working to shorter lengths flattens the response curves until at 1½″ there is a small peak. It seemed that a little bit of electronic boost could flatten these and extend the response to below 30Hz. My first choice for the alignment was the one with the 3.6″ duct, which had the potential for a low cutoff frequency and a respectable Q_L of 5.2.

A frequency response curve with electronic equalization is shown in *Fig. 4*, with corresponding BOXRESPONSE data in *Table 7*. Note, however, that about 5dB of equalization boost was required to extend the 3dB point to 20Hz. I used a Q_E of 1.82 and an f_E of 16.4Hz.

Table 7 lists both the equalized and unequalized response at each frequency. As mentioned previously, the maximum acoustic output was the same regardless of whether or not equalization was used. I also discovered that low-frequency boost has its down side: it may introduce harmonic distortion.

As I was performing the free-air tests, I noticed the speakers were not totally silent when driven at low frequencies. Because there is no baffle during the tests, the forward and backward waves cancel. When the speakers are driven at low frequencies, no sound should be heard, although the speaker cones are moving a significant amount. During these tests, I heard a soft hum, but I dismissed it because I didn't understand its source.

While auditioning the 3.6″ duct, I again heard the hum at frequencies below about 25Hz. Determined to find the cause, I hooked up a small microphone to one of the vertical channels of my oscilloscope to view the reproduced waveform.[26, 27] I then connected the other channel in parallel with the electrical input to the speakers.

On the dual-trace oscilloscope, I was able to compare the waveform of the electrical input to the acoustic output as received by the microphone. With the system being driven at a low-level 20Hz and the microphone placed a few inches in front of either driver, the trace showed a misshapen waveform compared to the electrical input. The original sine wave had become almost triangular.

As I increased the input frequency, the hum diminished and the shape of the signal from the microphone improved. As I decreased the input frequency, the hum grew louder and the signal more triangular. Apparently, I was witnessing the onset of harmonic distortion produced by the speakers at low frequencies.

I immediately thought this triangular waveform was some sort of microphone artifact. But I was able to eliminate the microphone response as the signal's source by moving the microphone to the port. At this location, the acoustic signal was a sinusoid at all frequencies, even below the box resonance of 19Hz. By placing my ear close to the port, I was able to verify that the signal sounded like a clean fundamental. I could draw only one conclusion: the speakers themselves were producing the extraneous sound.

This unexpected noise forced me to conclude that any alignment with a significant amount of boost below 25Hz was undesirable. In that sixth-order system, the electronic boost required at 16Hz for a more or less flat response would only aggravate the production of harmonics.

Since the distortion level was acceptably low at 25Hz and diminished at higher frequencies, I decided to adopt a port length of 1½″. Also, to quickly roll

TABLE 9. BOXRESPONSE'S PREDICTED OUTPUT FOR THE FOURTH/SIXTH ORDER SYSTEM WITH A 5.0" DUCT

Frequency Hz	Unequalized System Response db	Unequalized Maximum Power Input watts	Equalized System Response db	Equalized Maximum Power Input watts	Maximum Infinite Baffle Output db
5	-47.47	4.04	-68.70	536.02	51.61
10	-25.37	9.72	-33.52	63.55	77.52
15	-14.18	48.85	-15.00	58.91	95.72
20	-7.89	300.00	-6.17	201.53	109.89
25	-4.47	189.36	-2.66	124.67	111.32
30	-2.68	124.43	-1.21	88.74	111.28
35	-1.73	129.30	-0.58	99.21	112.40
40	-1.19	158.63	-0.28	128.64	113.83
50	-0.66	275.04	-0.06	239.49	116.75
60	-0.42	300.00	0.01	272.14	117.37
70	-0.29	300.00	0.02	279.12	117.50
80	-0.21	300.00	0.03	283.81	117.57
100	-0.13	300.00	0.02	289.48	177.66
120	-0.09	300.00	0.02	292.64	117.70
150	-0.06	300.00	0.01	295.26	117.73
200	-0.03	300.00	0.01	297.32	117.76

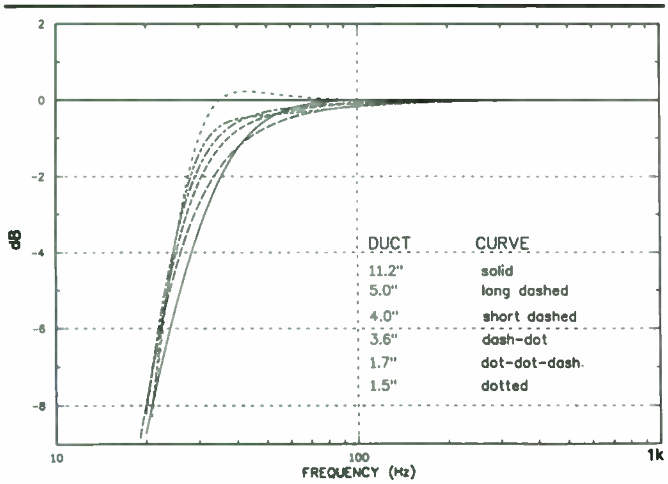


FIGURE 3: Ported-box response with six duct lengths.

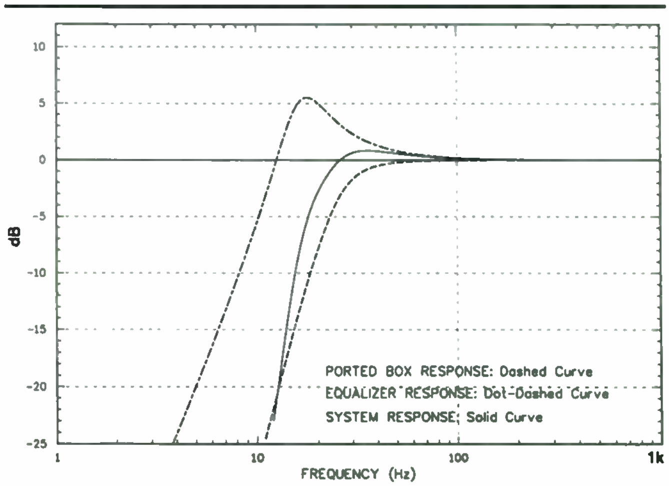


FIGURE 4: Sixth-order system with 3.6″ duct.

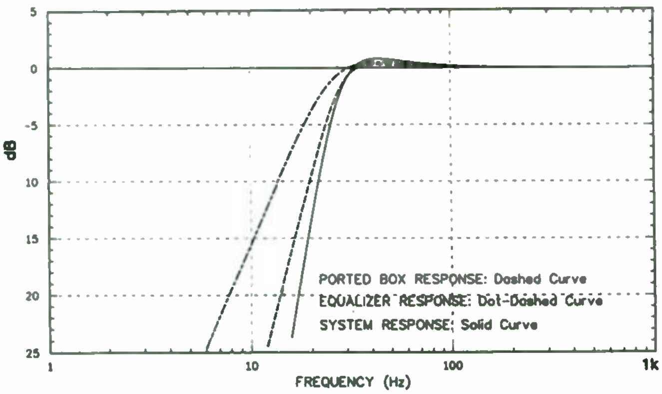


FIGURE 5: Sixth-order system with 1½″ duct.

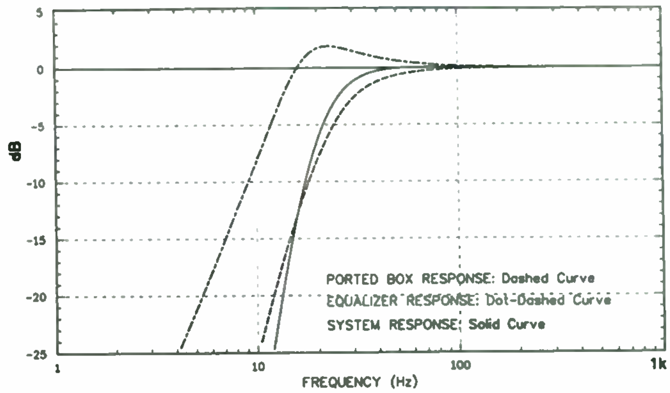


FIGURE 6: Sixth-order system with 5″ duct.

off the response, I used an equalizer with a Q_E of 0.86 and an f_E of 25Hz. According to the BOXRESPONSE data presented in *Table 8*, the box resonance was near 27Hz and the sixth-order system response was −5.13dB at 25Hz. As *Fig. 5* illustrates, the electronic equalization (long-short dashed curve) caused the system response (solid curve) to roll off faster than the unequalized response (dashed curve). Consequently, the drivers would never be called upon to produce large excursions at frequencies much below 25Hz, thus minimizing the production of harmonics.

This lesson must be considered in any design. Even if the T/S parameters for a particular driver predict that a certain system response is possible, that does not guarantee that the selected driver will be capable of producing clean output at those frequencies. The nonlinearities of the particular driver are not accounted for in the T/S model. Martin Colloms discussed the sources of distortion in loudspeaker systems in a chapter titled "Loudspeaker Assessment."[28]

FOURTH-ORDER FEVER. If a sixth-order system is not your choice, this box and driver combination in a second-order closed-box alignment, with or without electronic equalization, looks attractive. Various fourth-order systems (vented boxes without equalization) can be investigated with the data presented in *Table 6* and a computer program such as BOXRESPONSE.

Examples of unequalized fourth-order responses with the 3.6″ and 1½″ ducts are given in *Figs. 4* and *5* by the dashed curves. An additional response using a 5″ duct is presented in *Fig. 6*, with the corresponding BOXRESPONSE data listed in *Table 9*. A sixth-order version of the 5″ duct system, with a Q_E of 1.11 and an f_E of 17.4Hz, is also included. None of these responses is ideally flat, and they may be troubled by harmonic generation.

The recent article by Mark Rumreich defines four relative performance parameters (RPPs) that can be computed for any driver if the T/S parameters are known.[29, 30] In the present case, two are of particular interest for predicting the system performance: f_{OB}, the relative cutoff frequency in an optimum volume box, and VOF, the relative box volume for the optimum cutoff frequency.

Using the average values from *Tables 1* and *2* for f_S and Q_{TS}, with the equivalent-volume V_{AS} determined from the closed-box measurements, the values for the two parameters are f_{OB} = 60.9Hz and V_{OF} = 3 ft.[3] As Rumreich points out, f_{OB} is almost the same as Small's efficiency bandwidth product. Values less than 50 favor using the closed box; values greater than 100 favor a ported box. A value of 60.9 puts this speaker in the gray area, and it could be used in either a closed or a ported box.

V_{OF} is useful for selecting the box volume for a desired frequency response curve. Rumreich supplies several frequency response plots corresponding to specific Q_{TS} values. In this case, the actual box volume is about 3.7 × V_{OF}, and Q_{TS} is 0.31. Placing these values on his *Fig. 4* (p. 12) suggests that the 3dB point will be at about 0.4 × f_{OB}, or 24.4Hz. This prediction agrees with my measurements, plotted in *Fig. 3*. Rumreich's *Fig. 4* also suggests that the 3dB point can be lowered if the box volume is increased to 5 × V_{OF} or greater.

Substituting different drivers for the current pair with the goal of lowering the

Continued on page 32

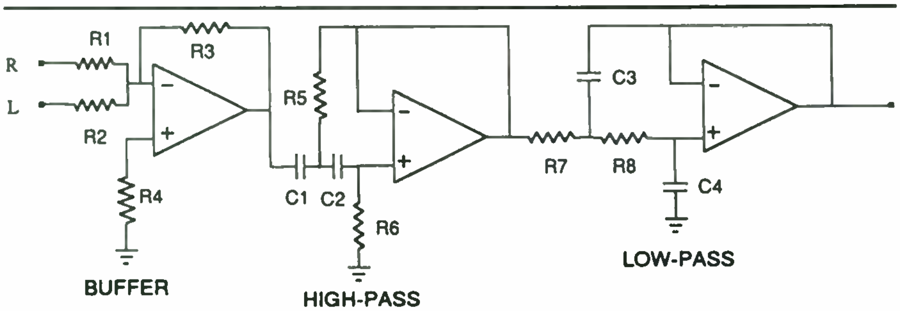


FIGURE 7: Electronic equalizer. A parts list with component values appears in *Table 10*. Strict adherence to my preferences is not necessary for a successful project; a wide latitude of designs is possible which will perform satisfactorily.

TABLE 10

EQUALIZER PARTS LIST

ITEM	DESCRIPTION
Capacitors	
C1–3	0.1μF
C4	0.05μF
Resistors	
R1, 2	120k
R3	330k
R4	51k
R5	36k
R6	110k
R7, 8	33k

Note: These values will give a gain of −2.75 for the buffer input stage. The high-pass stage has a Q_E of 0.86 and an f_E of 35Hz. The final low-pass stage has a Q_{LP} of 0.707 and an f_{LP} of 70Hz. Strict adherence to component values is not necessary.

Continued from page 30

3dB point, but retaining the same box volume, can be investigated through these two RPPs. The product of V_{AS} and Q_{TS}^2 equals V_{OF}, while f_{OB} equals f_S/Q_{TS}. Generally, to lower the 3dB point, decrease f_{OB}. This can be done by finding drivers with lower values for f_S and higher values for Q_{TS}. Also, to keep V_{OF} constant, V_{AS} must roughly compensate inversely to any changes in Q_{TS}^2.

THE GREAT EQUALIZER. My electronic equalization circuit consists of a buffer amplifier with gain feeding a low-pass filter, which in turn feeds a high-pass filter. The equalizer receives its input by tapping the signal from the preamplifier output cables to the left- and right-channel stereo power amplifier inputs. The output goes to a single-channel power amplifier that drives the woofer.

In the circuit in *Fig. 7*, the left- and right-channel inputs are summed in the buffer stage, and the high- and low-pass functions are implemented with Sallen and Key active filters.[31] Using LM318s as operational amplifiers has been successful.

The buffer gain stage is set by the ratio of feedback resistor R3 to input resistor R1 or R2. To keep the input balanced, I selected R4 to be approximately equal to the parallel combination of R1, R2, and R3. For a gain of 2.75, R3 = 330kΩ, and R1 = R2 = 120kΩ. R4's computed value is 51kΩ, which is available in a 5% tolerance. Alternatively, a ±10% 47kΩ could be used.

The unit gain high-pass stage is next. If capacitors C1 and C2 are chosen to be the same value ($C1 = C2 = C_E$), then the two resistor values must be computed to achieve the desired Q_E and f_E. Where $f_E = 25\text{Hz}$, $Q_E = 0.86$, and $C_E = 10^{-7}\text{F}$, then R6 = 109.5kΩ and R5 = 37kΩ.

$$R6 = \frac{Q_E}{\pi f_E\, C_E} \qquad R5 = \frac{1}{4\pi f_E\, Q_E\, C_E} \tag{2}$$

The last stage is the unit gain low-pass filter, where the two resistors are chosen to be the same value ($R7 = R8 = R_{LP}$). In the case of a Butterworth filter where $Q_{LP} = 0.707$, the two capacitor values should differ precisely by a factor of 2: C3 = 2C4. If C3 is selected as some convenient value, then with f_{LP} being the desired high-frequency cutoff, the value for R_{LP} can be computed from the following equation:

$$R_{LP} = \frac{1}{\sqrt{2}\pi f_{LP}\, C3} \tag{3}$$

For the Butterworth, where $C3 = 10^{-7}\text{F}$, $C4 = 5 \times 10^{-8}\text{F}$, and $f_{LP} = 70\text{Hz}$, $R_{LP} = 32{,}154\Omega$. If some other Q_{LP} is desired, the following two equations apply:

$$R_{LP} = \frac{Q_{LP}}{\pi f_{LP}\, C3} \qquad C4 = \frac{C3}{4Q^2_{LP}} \tag{4}$$

LISTENING TESTS. High-fidelity component listening tests are unavoidably subjective.[32] When attempts have been made to eliminate biases through the use of double-blind "A-B" experiments with electronic components, the results indicate little actual difference in performance.[33,34] With speakers, such controlled testing is more difficult to arrange, since the listening room and the listener's position contribute a great deal to the perceived sound.[35-37]

In this case, with a single speaker system, limited test equipment, and no standard reference for comparison, a thoroughly subjective evaluation was all that was possible. I looked at the CD recordings suggested by D'Appolito and Bock for deep bass.[38] Then I rummaged through my CD library, listening for low-frequency passages that might help describe the woofer performance.

I listened with the main speakers off and the subwoofer on, with the main speakers alone, and with both the speakers and the subwoofer on. My main full-

REFERENCES

1. Thiele, A.N., "Loudspeakers in Vented Boxes: Part I," *Proceedings of The Institute of Radio Engineers*, Australia, August 1961.
2. Thiele, A.N., "Loudspeakers in Vented Boxes: Part II," *Proceedings of The Institute of Radio Engineers*, Australia, August 1961.
3. Augspurger, George L., "Theory, Ingenuity, and Wizardry in Speaker Design," *Audio*, April 1987.
4. Weems, David B., "Taming the Bass Reflex," *Radio-Electronics*, February 1976.
5. Weems, David B., "A Second Life for Vented Speakers," *Popular Electronics*, January 1980.
6. Stuart, Bob, "The Case for Active Speaker Systems," *Audio*, September 1987.
7. Small, R.H., "Direct-Radiator Loudspeaker Systems Analysis," *JAES*, June 1972.
8. Thiele, A.N., "Loudspeakers in Vented Boxes: Part I," *JAES*, May 1971.
9. Thiele, A.N., "Loudspeakers in Vented Boxes: Part II," *JAES*, June 1971.
10. Small, R.H., "Closed-Box Loudspeaker Systems, Part I: Analysis," *JAES*, December 1972.
11. Small, R.H., "Closed-Box Loudspeaker Systems, Part II: Synthesis," *JAES*, January/February 1973.
12. Small, R.H., "Vented-Box Loudspeaker Systems, Part I: Small-Signal Analysis," *JAES*, June 1973.
13. Small, R.H., "Vented-Box Loudspeaker Systems, Part II: Large-Signal Analysis," *JAES*, July/August 1973.
14. Small, R.H., "Vented-Box Loudspeaker Systems, Part III: Synthesis," *JAES*, September 1973.
15. Small, R.H., "Vented-Box Loudspeaker Systems, Part IV: Appendices," *JAES*, October 1973.
16. Small, "Direct-Radiator Loudspeaker Systems Analysis," Appendix.
17. Small, "Closed-Box Loudspeaker Systems, Part I: Analysis."
18. Small, "Direct-Radiator Loudspeaker Systems Analysis," Appendix.
19. White, Bob, "Realizing the Potential of Boxresponse," *SB* 1/85, p. 28.
20. Bullock, Robert, M., "Correction: Boxresponse," *SB* 1/86, p. 42.
21. Luz, David and Robert M. Bullock, "Elevated Boxresponse," *SB* 1/86, p. 42.
22. Edmundson, Chris and Bob White, "Boxresponse Update," *SB* 4/88, p. 66.
23. Gonzales, Ralph, "An Introduction to Frequency Response and LMP, Part I," *SB* 1/87, p. 18.
24. Graeme, Jerald G., Gene E. Tobey, and Lawrence P. Huelsman, eds., *Operational Amplifiers, Design and Applications*, McGraw-Hill, 1971, p. 194.
25. White, Bob, "Realizing the Potential of Box Response," *SB* 1/85, p. 28.
26. Ballard, Robert, "An Active Crossover With Phase Connectors: Part II," *SB* 4/82, p. 26.
27. D'Appolito, Joseph, "Mighty Mike: For Loudspeaker Testing," *SB* 6/90, p. 10.
28. Colloms, Martin, *High Performance Loudspeakers*, Halsted Press, 1978.
29. Rumreich, Mark, "The Box Design and Woofer Selection: A New Approach," *SB* 1/92, p. 9.
30. Tedeschi, Frank P., *The Active Filter Handbook*, Tab Books No. 1133, 1979.
31. Viesca, Fernando Garcia, and Marco E. Perez, "Active Filter Design With Crossover Calc," *SB* 4/88, p. 34.
32. Hirsch, Julian D., "Technical Talk: Do You Hear What I Hear?" *Stereo Review*, February 1983.
33. Masters, Ian G., "Do All CD Players Sound the Same?" *Stereo Review*, January 1986.
34. Masters, Ian G., "Do All Amplifiers Sound the Same?" *Stereo Review*, January 1987.
35. Hoffman, William R., "Build a Live End/Dead End Listening Room: Part I," *Audio*, December 1986.
36. Hoffman, William R., "Build a Live End/Dead End Listening Room: Part II," *Audio*, January 1987.
37. Pisha, B.V., and Charles Bilello, "Designing a Home Listening Room," *Audio*, September 1987.
38. D'Appolito, Joseph and James Bock, "The Swan IV Speaker System," *SB* 5/88, p. 34.

range speakers are a pair of closed-box Klipsch Heresys, vintage early 1970's, modified by stuffing the boxes. The stuffing lowered the Q_{TC} to 0.7 and moved the −3dB point to about 70Hz. Because of this relatively high rolloff frequency, the subwoofer is a welcome addition.

I found that the musical selections I used benefitted from the addition of the subwoofer. The impact was greater, and the spaciousness or ambience of the performance increased. Also, to my ears, the lack of stereo at the very low frequencies was not a detriment. The single, summed center-channel woofer seemed to work well with the main speakers.

SUMMARY. This project was instructive in several ways. It demonstrated that choosing a box volume (albeit a large one) and designing a system to accommodate it can be a successful design technique. The box construction with internal cross-bracing for rigidity at low frequencies seemed to be a reasonable approach, even though two of the box dimensions were identical. *Table 6* illustrates that Q_L was a respectable 5 when the box resonance ($f_B = h \times f_{SB}$) was near 18Hz. Although the box supported operation at this low frequency, the speakers produced an unacceptable amount of harmonic distortion in this range. I gave up 7Hz of low-frequency response in exchange for lower harmonic distortion.

SPEAKER ENCLOSURE SCREWS

BY ROBERT J. SPEAR and ALEX THORNHILL

Man-made boards come in a bewildering number of types. Particleboard and fiberboard (in low, medium and high densities) are the most commonly used for speaker enclosures. In addition, there's chip board, oriented strand board, wafer board, hard board, and flake board, just to name a few. For each type of board, a corresponding screw type will give you the best results.

Alex and I often use inexpensive shelving board for constructing prototypes of our TL designs. The mushy and inconsistent quality of these boards makes them an excellent worst-case test for fasteners. Through our experiments, which require repeated removal of various panels, we have gained quite a bit of experience with screws.

WOOD SCREWS. The common soft steel, zinc-chromate wood screw isn't a good choice for particleboard because its body tapers toward the tip. To ensure a proper fit, the bit used to bore the screw hole must have the same taper, but tapered drill bits have virtually disappeared from the average hardware store. A few specialty shops which cater to craftsmen woodworkers still carry them, although finding them is probably not worth the effort and better screws are available for our purposes.

You might be surprised to learn that the common twist bit sold in most hardware stores is actually a metal-drilling bit. A similar bit for wood, the brad-point or centering bit, is a great improvement. Like the twist bit, it drills a hole with straight sides. If you put a tapered screw into an untapered hole, the screw threads at the bottom don't grip the wood. The fit feels snug at the top, but since there are no threads at the top of a wood screw, the grip is not tight.

Other drawbacks to the wood screw include a slotted head which is a poor choice for powered screwdriving. The driver blade can easily slip out under pressure and damage the cabinet, or puncture a speaker cone. In mushy artificial boards, burst or swollen walls and spun-out screws are common. Holes for wood screws are also a pain to drill using straight bits. First, you must bore the screw hole, then counter bore for the thicker, threadless part of the shaft, then countersink the hole. Special bits are available which do all three at once, but one bit is needed for each screw size and length.

DRYWALL SCREWS. Some years ago, a new screw appeared on the market. It had a straight, hardened-steel body, a cross-shaped screw slot (Phillips head), a thin, pointed screw tip, and a bugle head. This screw is commonly known as a drywall or sheetrock screw, and it has a tenacious grip in wood. Driven hard, drywall screws can pull themselves almost completely through a two-by-four. We have found them in building supply stores in lengths up to 6", so they may be your only choice when you need a long screw.

Drywall screws are good for particleboard work, depending on the thread. Normally, the thread is fine and, like the wood screw, rather closely spaced and shallow. However, fine-thread screws will strip out of a soft board if overdriven. Coarse-thread sheetrock screws are becoming more readily available. They have a strong grip in artificial boards, and can be used interchangeably with particleboard types because the threads are identical.

The Phillips slot makes the screw much easier to drive with power tools, and since the shank is straight, a bored hole needs only to be countersunk. I used "Super Streakers" from the John Wagner Co. for many years because they were readily available. Most screws of this type are treated with a black finish to prevent them from rusting in the drywall compound. Rust isn't usually a problem for speaker builders, but black screws present a nice, finished appearance in places where the screw head may be exposed, such as rear panels.

EXTERIOR DECK SCREW. This type of fastener has many good features to recommend it. Available from Osmose and VSI, among others, it has a hardened steel shank and a bugle head with a Phillips slot. The deck screw's coarse thread is even coarser than a particleboard screw, so the two are not interchangeable. However, the coarse thread means the screw can be driven very fast and its rough texture, imparted by the galvanized-zinc coating, produces a fantastic grip. The deck screw is usually light to medium gray depending on the galvanizing process used, with a dull to semi-bright finish. You might not want to use it where the head will be visible.

A nice feature of the Osmose screw is its thinner shank per length than with other screws. I rarely see a particleboard screw thinner than a 1¾" #8, but the Osmose is available in a 2" #6. (A smaller number indicates a thinner shank.) With the greater shaft length, you can get a deep grip in the butt edge of a soft board, but the smaller diameter reduces the possibility of bursting the board. The screws from VSI can sometimes be purchased in quantities of 500; they come in a small plastic pail with a snap lid and carrying handle which is very convenient, and the pail is useful in the workshop once the screws are gone.

PARTICLEBOARD SCREWS. Like a drywall screw, a particleboard screw is made of hardened steel with a Phillips head and a shank of constant diameter. This screw has a coarse thread and a "V" head taper. Since it normally doesn't have to contend with moisture from green wood or drywall compounds, it has no protective chemical blackening. Some brands feature a fluted tip which improves chip clearing, and also provides a cleaner bore when used as a self-drilling screw.

Perhaps the best particleboard screw we have yet found is Equality Screw Company's Super Sinker 17, which has just about everything you could want in a fastener. Like any good particleboard screw, it has a deep, aggressive thread for a fast drive and excellent grip. A long portion of the upper shank is not threaded, reducing the possibility that the boards will end up screwed apart.

The tip of the Super Sinker is called a Type 17. It features a single-flute "auger" for boring and chip clearing when used as a self-drilling screw. The head's underside is the preferred straight "V" type. The head is cleverly designed to accept both Phillips and square drives.

SQUARE-DRIVE SCREWS. The square-drive (Robertson) screw is the most jump-resistant of all. Although it has been used in commercial production for close to 90 years, it is only recently gaining favor among home wood workers. The screw gets its name from the recessed square in the head in place of the familiar wood-screw slot or the cross-shaped Phillips-head slot. You'll need a #1 or #2 square bit, but they are inexpensive and last almost forever. We tried a box of 1¾" #8 prelubricated flat heads with nibs from McFeely's, and they quickly became our favorite fastener. The fit between bit and recess is so snug that you can load a screw on the bit and it won't fall off, which is a great feature when you need to drive a screw into a place where you can't get two hands.

The McFeely screws were crooked, which caused them to wobble a bit as they were driven in. To our surprise, the misshapen shank coupled with the deep thread produced an unbreakable grip. Using a drill with a clutch, we drove and withdrew these screws dozens of times without a single "spinner," as we modified a large transmission-line enclosure. Only this screw performed so well. Square-drive bits also lasted much longer than Phillips bits. The dark brown, dry lubricant finish, and the square drive head impart a professional appearance to any job.

THAT SINKING FEELING. With particleboard, predrilling is highly recommended, even if a screw is advertised as self-drilling. You need to avoid splitting the material, especially if you are fastening near the board's ends or in the butt edges. A good idea is to slightly countersink the hole. Most available countersinks adhere to the old wood screw standard of a conical bore. When you drive a bugle-head screw into such a hole, the rim is the first part of the head to make contact with the board. This concentrates pressure on a very narrow ring under the head and causes the material beneath the rim to splinter and lift, and the screw sinks much deeper into the hole than you had intended.

As the screw head sinks, it deforms and pushes away the board material. After the head has passed by, the wall edges spring back and trap the screw. If the screw needs to be withdrawn, the embedded head will push the material above it out ahead of it, causing the area around the hole to rupture. This can ruin the surface of a veneered plywood board. In any case, it means patching the hole (or, in some cases, quite a few holes).

A "V"-shaped head with a flat taper makes full contact with the board, so the stress is distributed evenly. Screws from Equality and McFeely's have four small nibs under the head which let the screw countersink itself. The nibs are offset so the hole is just a bit wider than the head. If the screw is withdrawn, the head exits the hole without causing damage. In practice, however, we found that some countersinking was still needed. We also realized that designing a new screw is not as simple as it first appears.

The ability to repeatedly drive and remove screws without damaging the panel's surface is a great feature. The only drawback to Equality's Super Sinkers is that they are only available in #8 and #9 diameters, but with 1-3" lengths you should find one adequate for all but the thinnest boards. We use the 1⅝" flat head in ¾" MDF with excellent results. The selection of nibbed designs from McFeely's is even more limited: #8 only in four lengths from 1¼ to 2". We found that the 1¾" length is a great performer in ¾" particleboard, and on only a few occasions wished for a longer screw.

Osmose, VSI, Wagner and other screws are available at many hardware and lumber outlets, while Equality and McFeely's sell direct. Equality requires a minimum order of $35 and charges an extra $5 for shipping. For further information, use the fast reply number from the Equality ad in *SB*. McFeely's service is unusually friendly and efficient, and there is no minimum order. Their catalog is worth having for the explanations and drawings showing how a modern screw is made. Incidentally, most of McFeely's products are made in the USA or Canada.

SUPPLIERS

Equality Screw Co.
1850 John Towers Ave.
El Cajon, CA 92020
(800) 854-2886
("Super Sinker 17" and others)

McFeely's
712 12th St.
PO Box 3
Lynchburg, VA 24505-0003
(800) 443-7937
FAX (804) 847-7136

Osmose Wood Preserving Co.
980 Elliot St.
Buffalo, NY 14209
(716) 882-5905
FAX (716) 882-5139
("Osmose" Deck Screws)

VSI
12930 Bradley Ave.
Sylmar, CA 91342
("Power Drive" fasteners)

John Wagner & Sons, Inc.
900 Jacksonville Rd.
Warminster, PA 18974
(215) 674-5000
FAX (215) 674-0398

Part III

THE IMP

BY BILL WASLO

In the first two parts of this series, I described the hardware construction and software operation of the IMP analyzer system. This beast is a versatile but complex device, so this part provides some step-by-step examples of measurement procedures using it. If you have the software program but not an IMP module, you'll be able to follow along by loading the IMP data files from the distribution disk.

OPERATING THE IMP. These examples are far from exhaustive. Variations such as near versus far field, fast versus slow sample rate, **SIZE** changes, and selective echo inclusion are left to your own ingenuity and possible future articles on measurement techniques.

All the procedures follow a somewhat common form. First, adjust the sensitivity of the probe #1 input for the best use of the IMP's dynamic range. Then, the amplifier delivers a copy of the test impulse via the IMP to the computer, where it is transformed for use as Cal, or correction, data.

If the measurement uses the mike input, its sensitivity is then adjusted (probe #2 shares a sensitivity control with probe #1 and usually need not be set separately). The desired data is then acquired from either the mike or probe #2, possibly edited, and transformed with the use of Cal data into the appropriate form for display.

POWER CHECK. When you first fire up the IMP module with the software, plug the microphone into its jack and select [**Acquire, Repeat**]. The program will likely display a line near the top of the plot window the first couple of times the screen is drawn, while the electrolytic capacitors in the circuit settle down. In about a minute, the plotted trace should come to near the center of the window. If you turn up the mike level control (V1), you should be able to "see" your voice as you talk near it.

If the screen does not repeatedly plot a trace, if the program complains "module doesn't respond," or if the plot does not resemble a typical oscilloscope plot, something is probably wrong. Be sure the module's power supply is plugged in. The circuit can almost, but not quite, operate off the power coming from the computer via the printer port line, and will produce a bizarre trace if you try to operate it this way. Also, check for solder bridges on the board and that all ICs are properly installed.

ANECHOIC ARRANGING. Measurement of anechoic acoustic frequency response was what initially prompted me to design the IMP. The equipment configuration for this measurement is shown in *Fig. 1*. Hook up everything before applying power, and start out with the preamp/amp volume control set to minimum.

If possible and practical, place the speaker so that its tweeter/midrange radiation center is about equally spaced between the floor and the ceiling, and is as far as possible from the side walls and furniture. You want the longest possible time lag between the direct path to the microphone and the first reflection off anything else. Set the microphone at some distance from the speaker (a little over 3′ is commonly used) and on the tweeter axis. The variation in frequency response with microphone (i.e., listener) position is something you will want to investigate after you get the hang of the measurement process.

Connect the probe to the speaker terminals. Make sure the hot probe lead is connected to the hot amplifier lead, and the ground probe lead is connected to the amplifier output ground. Do not use amplifiers with either output lead at ground potential, such as bridged amps. Amplifiers sometimes respond unpleasantly to their outputs being shorted, so be careful.

The plots illustrating this example are measurements of an unmodified Dynaco A25 loudspeaker. If you will be measuring biamped, triamped, or higher-amped

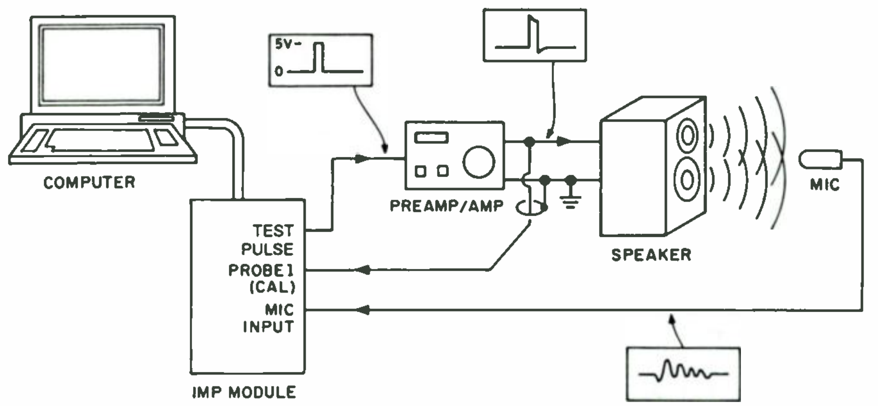


FIGURE 1: IMP configuration for measuring anechoic acoustic impulse response.

systems, just connect the probe leads to the output pulse signal from the IMP, as it feeds the preamp input.

TICK, TICK, TICK. When the equipment is ready, turn on the power switches. Get the IMP software up and running, and verify that the **RATE** (second screen line, second column) is set to 61.2kHz. Press [F4] until the **INPUT** is set to **PROBE1**, which is the Cal probe. From the top level menu, choose [**Setup**], then [**Cpu_speed**] (in case you've forgotten, you do this by pressing the capitalized letters in the desired selections—in this case, S and then C). You will be asked your computer's speed in megahertz. Type in your computer's clock speed and press [Enter]. Don't worry about overestimating, as doing so only affects data transfer time to and from the IMP module.

Get back to the top menu by pressing [*], then select [**Acquire, Repeat**]. The bottom plot will be repeatedly drawn on the screen. All the while, test pulses are being sent to the amplifier. Turn up the volume control until you can hear the "tick. . .tick. . ." sound of the impulse from the speaker.

The choice of volume level is up to you; too low and you will be covered under noise, too loud and you may clip the amp (or even arc the speaker, in the case of electrostatics). I set the volume so the impulses sound about as loud as a pebble being dropped into a ceramic cup.

LOADING CAL. If you turn up the probe level control (V2), the impulse from the amplifier output should appear on the left side of the plot in the lower half of the screen. Adjust the probe level control so the peak of the impulse is at about 75-85% of the plot window height (see *Fig. 2*; if the peak is negative, it should be in the 15-25% range). The control can move fast, so use slight adjustments. When you have it set, press [Esc] to end the repeat cycle.

To get a Cal sample, choose [*, **Acquire, Collect**]. The system will collect and average five impulse responses. When the process ends, press [F2] until **SIZE** is changed to 2,048 (for a high-resolution Cal). You can save this reponse by choosing the sequence [*, **File, Save, Timeresp**] from the top menu.

The Cal impulse for the A25 measurement is on the IMP software distribution disk under the name DYNACAL.IMP. If you want to follow along with the IMP software on your computer and don't have a completed IMP module, you can load this Cal (and other example files re-

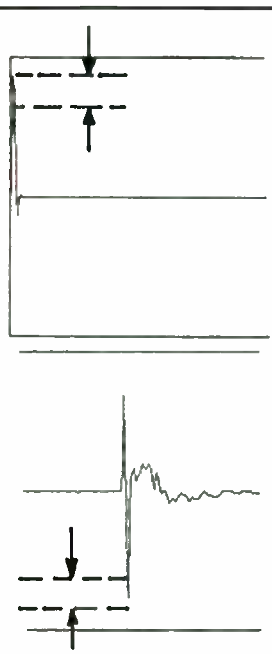


FIGURE 2: Target ranges for IMP input level adjustments.

erred to hereafter) by using the sequence [*, **File, Retrieve**] and answering DYNACAL (or the indicated name) when prompted for a file name.

PERTURBATION PEAKER. The Cal impulse response data must be transformed to Cal frequency response data. To transform all the data, make sure that **MKR1**, as shown on the second screen line, is set to sample number 1, and **MKR2** is set to the same value as **SIZE** (2,048 in this example). Use [F5] and [F6] to set these values. Press [*] to get back to the top menu (if you're not already there) and select [**Transform, Fft**].

After the little dial has finished going around, the program traces a rather tame frequency response plot at the bottom of the screen. This is your Cal response. To so declare it, select [**Set_cal**] and answer "Y" to the neurotic question ("Are you sure?") that the program will ask. A small "c" will appear to the left of the IMP logo in the top screen line to indicate that Cal data is in memory.

To take a speaker measurement, press [F4] until the **INPUT** selected is **MIC**. Leave the amp volume control alone and select [**Acquire, Repeat**]. Adjust the mike level control (V1) until the displayed perturbation peaks near 75-85% (or 15-25%) of the lower window, and then press [Esc].

SPEED & MARKS. Because of the finite speed of sound as the impulse travels from speaker to microphone, this peak will not be at the far left side of the screen. The wiggle you see is how the speaker renders that pulse you saw earlier in the acquired Cal. To get a cleaner, averaged copy, now select [**Acquire, Collect**].

After the 15 or so samples have been taken and the tick sounds have stopped, you may wish to save this data to disk. Press [F2] until **SIZE** is 1,024 (or however many points you wish to save), then select the sequence [*, **File, Save, Time_file**]. Press [F1] to redraw the display with any new size setting. My data for the A25 at this point is in the file named DYNACOUS.IMP.

Press [F5] once and use the left/right

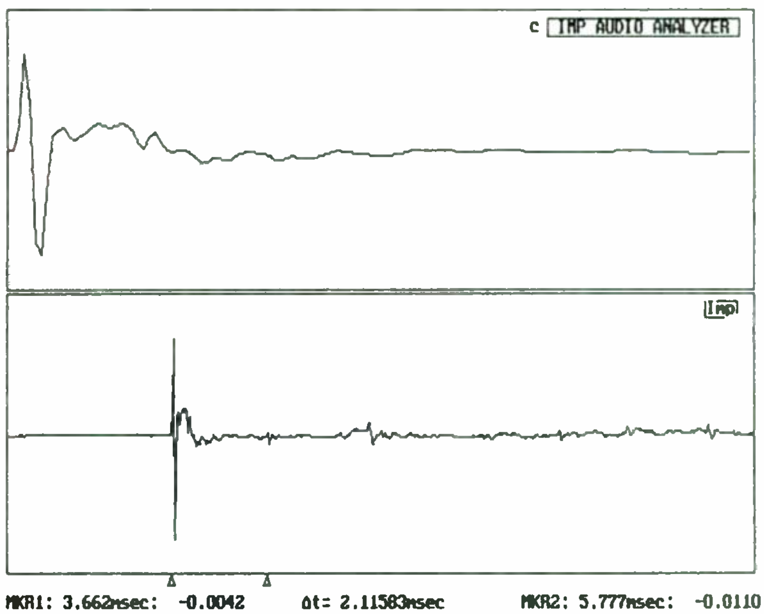


FIGURE 3: Impulse response of the Dynaco A25, with the anechoic region marked.

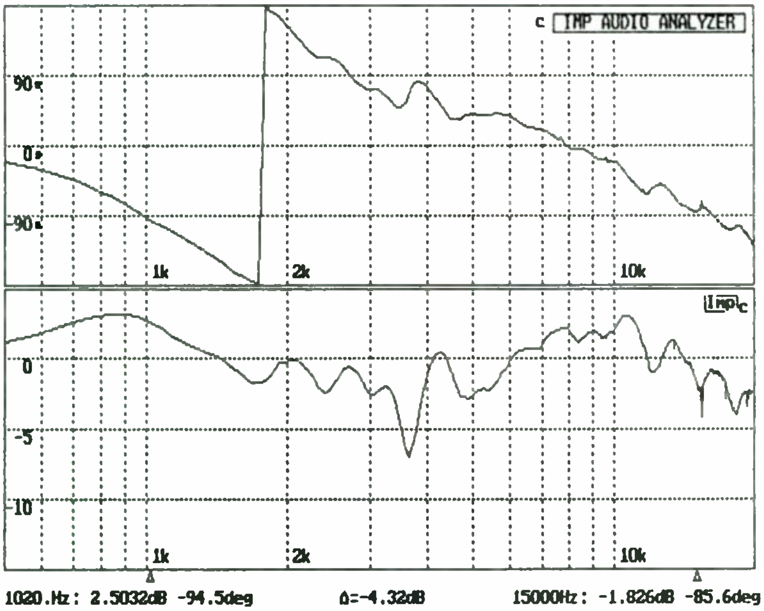


FIGURE 4: The Dynaco A25's upper-range frequency response as measured with the IMP.

arrow keys to move **MKR1** just to the left of the beginning of the perturbation. Holding down the control key makes the marker move faster if you have a long way to go. When you have **MKR1** where you want, press [Enter] to seal it. Notice that the top display is updated.

SCALES & MARKS. Press [F6] and likewise move **MKR2** just before the first echo reflection wiggle. This condition is shown for my A25 data in *Fig. 3.*

To turn this edited impulse response into a frequency response, select [*, **Transform**, **Fft**]. After a short time, a curve should appear. This is the raw frequency response—it is still affected by the amplifier and IMP filter responses. Select [**Cal**] to remove these influences, and the high end should rise a bit. The overall level also will generally change.

Let's spend some time on the presentation of this plot. If you move the markers around, you will notice that the frequencies and decibel values are read out on the screen. Put **MKR1** at 1kHz (press [F5], type in "1K" and press [Enter]) and **MKR2** at 15kHz. By the way, don't take all those significant digits in the readouts seriously. You probably won't find anything like 0.001dB precision very repeatable.

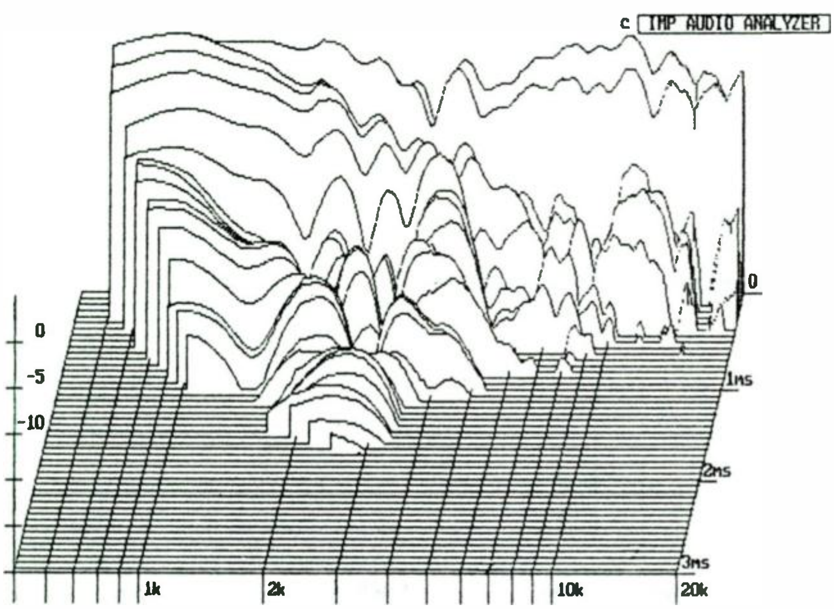


FIGURE 5: A waterfall plot of the Dynaco A25.

The starting frequency of the plot probably isn't optimal. Press [Shift F5], then type in 500 when prompted for the starting frequency. [F8] can be used to raise or lower the curve on the grid (negative values make it go down). Pressing [Shift F8] will allow change of the decibel scale. A 20dB/division scale will make any speaker look great!

MOVING TIME. Lastly, you may want to see phase response along with the magnitude. Just press [F10], then select [**Freq_resp**]. Note that the phase is relative to the reference plane determined by the original time-domain **MKR1** setting. You can modify this curve by using the [F9] delay adjustment key. A reasonably formatted picture of the A25's response is shown in *Fig. 4.*

All of this may seem like a lot of effort, but before long you'll be able to go through the setup in minutes without even thinking about it. And after you have it all set up, making each measurement will take hardly any time at all.

Remember the **auto_Measure** facility? To get another response after, say, making a crossover tweak or changing the microphone height, just use the sequence [*, **auto_Measure**, **Acoustic**] and let the computer run through the collection, calibrating and transforming itself while you consider your next move. Use [*, **auto_Measure**, **Setup**] to specify whether the IMP should use a Cal, and whether it should obtain a new one each time. Note that the time marker positions may need moving if the effective microphone distance changes much. Use [F1] to get to the proper display in which to move them. For transformations of near field measurements, use the time markers set at 1 and **SIZE**.

NYQUIST TWIST. Waterfall plots are easy to do. If the gain, scale, and frequency range are set to your liking, just select [*, **Transform**, **Waterfall**]. You will be asked whether you want to include Cal data (usually the answer will be "1" for yes). A waterfall plot made for the A25 is shown in *Fig. 5.* If your computer is slow or you are impatient, you may want to set **SIZE** to a smaller value before doing a waterfall plot. These can take quite a while on a 5MHz PC.

You can transform the "Cal'd" anechoic frequency response data back to corrected time-domain impulse response data. If you just plotted a waterfall, you need to retrieve frequency response data. Select [*, **Transform**, **Fft**, **Cal**]. Be sure to set the delay (via [F9]) back to

Continued on page 45

- Industry Standard
- Fast Measurements
- High Noise Immunity
- Measurement Bandwidth to 40 kHz
- Time-Bandwidth Product to 20,000
- Loudspeaker Measurements
- Room Acoustics Measurements
- Room Equalization Adjustments
- Speech Intelligibility

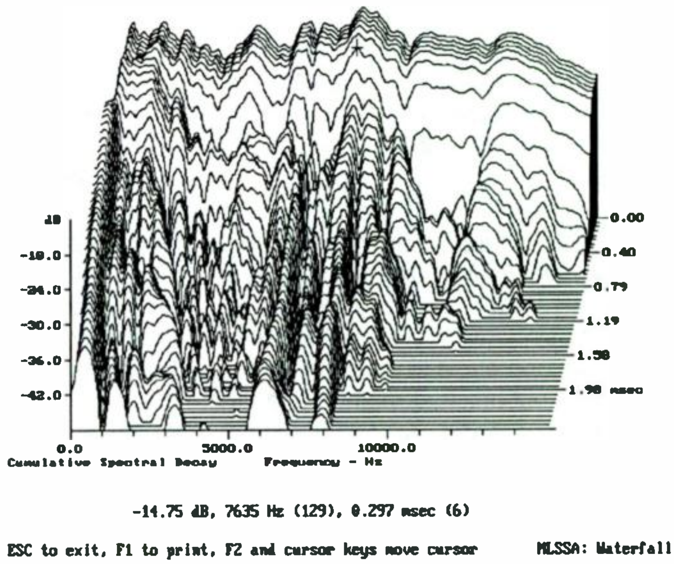
Industry Standard

Since its introduction in 1987, *MLSSA* (pronounced "Melissa") has become the loudspeaker industry's standard measuring tool as recognized by the world's leading loudspeaker designers and manufacturers. *MLSSA* is also the system chosen by auto makers, academicians, recording studios and government agencies for many other applications including room acoustics and speech intelligibility measurements.

MLSSA pioneered the maximum-length sequence (MLS) method of system analysis which offers an unsurpassed combination of speed and noise immunity with an enormous time-bandwidth product. Nonetheless, without the powerful and comprehensive post-processing functions offered by the *MLSSA* software, the full potential of MLS techniques cannot be realized. The easy-to-use *MLSSA* software undergoes constant improvement with at least one new software upgrade released each year.

Noise Immunity

Most acoustical measurements are made in environments subject to significant levels of interfering background noise. Nonstationary noise, such as impulse noise due to doors closing or, sporadic noise due to local traffic can result in severe errors with some other measuring systems. A significant advantage of *MLSSA* is that all nonstationary interfering noise, whatever its source, is automatically converted to stationary noise during the measurement process. Stationary noise is much more benign than nonstationary noise because it is spread out evenly over time and is largely windowed away in loudspeaker frequency response measurements. In some room acoustics measurements, *MLSSA* provides post-processing algorithms capable of removing even the residual stationary noise.



Fast Measurements

Although *MLSSA* contains no DSP chip, it is actually faster than some more costly DSP-based systems when running on the faster personal computers. Eschewing an integrated DSP chip not only lowers hardware costs but also forestalls obsolescence by allowing *MLSSA*'s performance to improve in step with improvements in PCs. Running on a 33 MHz 486, for example, anechoic loudspeaker frequency response measurements including acquisition, computation and display require only 3.1 seconds using a full-length 64K-point MLS stimulus or, just 1.6 seconds using a shorter 32K-point sequence. Altogether, four distinct sequence lengths of 4K, 16K, 32K and 64K-points are provided in hardware for high precision, low jitter MLS generation.

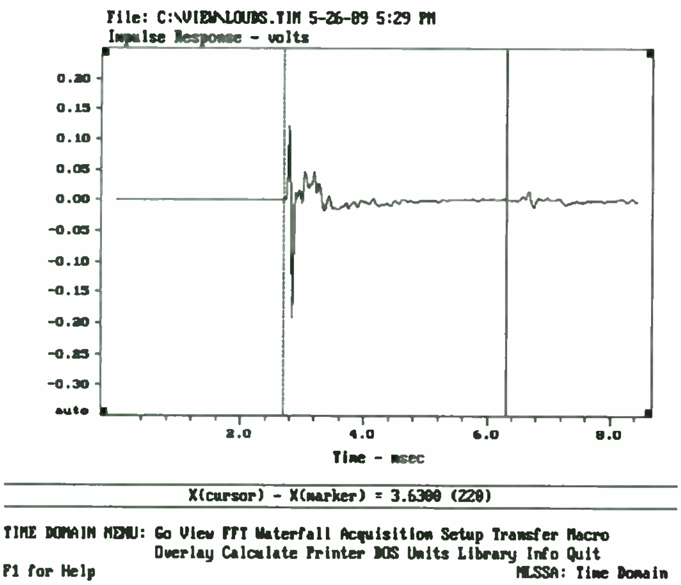
Enormous Time-Bandwidth Product

A third fundamental advantage of *MLSSA* is its enormous time-bandwidth product. This feature is especially useful in room acoustics and speech intelligibility applications because it allows you to measure a long impulse response over a wide bandwidth quickly and store the results to disk. Then, through its powerful post-processing functions, software can perform detailed narrowband analysis later from stored time-domain measurements. But this feature is equally useful in impedance measurements of drivers or loudspeaker systems. A time-bandwidth product of 20,000 allows you, for example, to measure impedance over a 1 kHz bandwidth with 0.06 Hz resolution or, over a 20 kHz bandwidth with 1 Hz resolution.

DRA Laboratories · 24 Halifax CT · Sterling, VA 20165 · Tel (703) 430-2761 · Fax (703) 430-0765

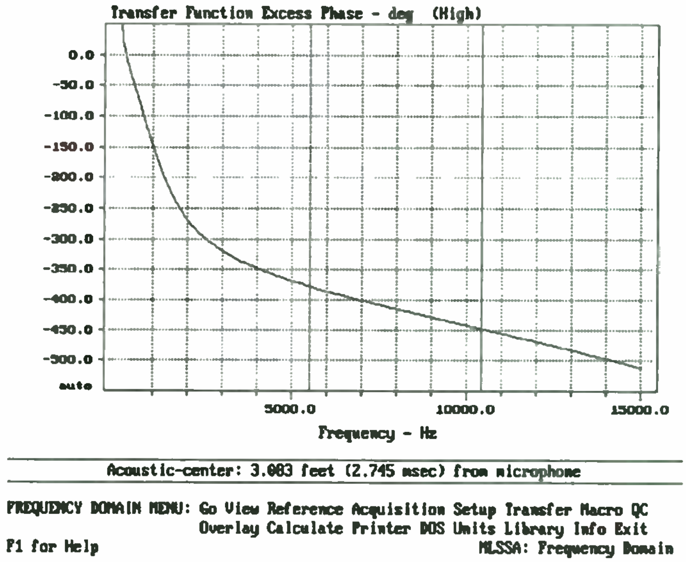
Anechoic Frequency Response

A primary application of *MLSSA* is measuring the anechoic frequency response of loudspeakers without need of an anechoic chamber. To measure the direct or "anechoic" response of a loudspeaker *MLSSA* uses cursors to select only the initial portion of the impulse response before the arrival of room reflections (see figure below). *MLSSA* then applies an FFT to the selected segment to yield the true anechoic response the loudspeaker. Because *MLSSA* measures directly in the time domain, it is a simple matter to discover any room reflections that might contaminate the measurement and then window them out of the final results. Methods that measure directly in the frequency domain, such as TDS and gated-sinewave, require more complicated procedures for insuring that room reflections are excluded from the results. Moreover, unlike gated-sinewave analyzers, *MLSSA* also correctly measures loudspeaker phase response.



Near-field Low Frequency Response

Unfortunately, in typical rooms, such windowed anechoic measurements are valid only down to about 200 Hz using any method. *MLSSA*, however, allows you to measure loudspeaker low frequency response using a near-field method and then splice this result to the anechoic high frequency response to cover the full audio range. This near-field method combined with sophisticated post-processing functions allows you to determine the full-range frequency response of even the most complex loudspeaker systems having any number of low frequency drivers, ports or passive radiators.



Time Coherence and Acoustic Centers

MLSSA measures loudspeaker time coherence both in the time domain and in the frequency domain. In the time domain, the step response can be used, however, a much better measure of time coherence is the excess phase curve. Excess phase is the difference between a loudspeaker's actual measured phase response and its theoretical minimum phase as calculated from the magnitude response. Excess phase also allows you to determine the precise acoustic centers of drivers either individually or in situ, that is, after they are already installed in completed loudspeaker systems. The acoustic center of a driver is that point in space from which its sound appears to originate which is very useful information to know when designing time-aligned loudspeaker systems.

Sound Power Response and Directivity

MLSSA allows convenient measurements of loudspeaker sound power response and directivity from free-field polar measurements. The sound power response of a loudspeaker is the power average of its frequency response measured in all directions. *MLSSA* correctly determines sound power response from polar measurements taken in just two orientations: one with the loudspeaker in its normal orientation (standing up) and the second with the loudspeaker lying on its side. Loudspeaker directivity index and directivity Q are also measured and plotted as a function of frequency. *MLSSA* will completely automate the polar response measurement procedures when used in conjunction with currently available motorized turntables.

QC PASS/FAIL Functions

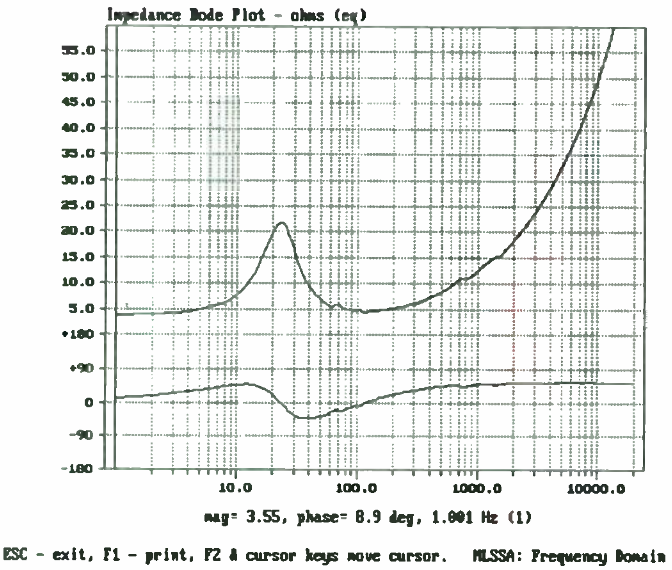
In the frequency domain, *MLSSA* provides for comprehensive automated QC PASS/FAIL testing. An unlimited number of arbitrary upper and lower QC limits curves can be defined and stored on disk. Both fixed and floating limit curves are supported. A third optional limit curve for incoherency provides distortion and/or buzz testing. You can also store a reference measurement of a "sweet" loudspeaker or driver. Thereafter, *MLSSA* will display the decibel difference between the reference driver and the driver under test. The QC PASS/FAIL functions can then be applied to this difference curve instead of the measured curve. *MLSSA* also automatically checks for correct polarity.

Cumulative Spectral Decay Plots

A generalization of the anechoic transfer function is the cumulative spectral decay plot. This 3D waterfall plot is formed by applying the FFT to successively time-shifted versions of the anechoic impulse response. The resulting surface often resembles a waterfall and shows how the acoustic energy is dissipated in both time and frequency. A cumulative spectral decay waterfall plot is illustrated on the front cover of this brochure.

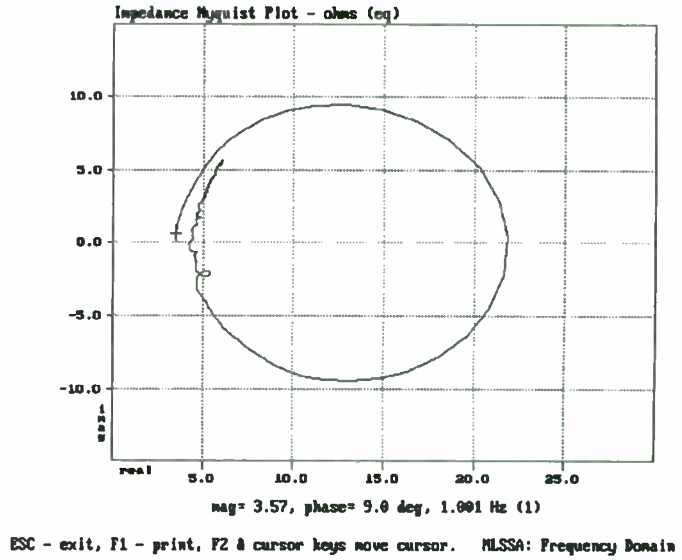
Impedance

MLSSA measures impedance magnitude and phase of any driver or loudspeaker system directly, that is, without need of an external power amplifier or test resistor. Display complex impedance to 1 Hz resolution over 20 kHz bandwidth with Bode and Nyquist plots.



Distortion Measurements

MLSSA determines intermodulation distortion vs. frequency from near-field or anechoic measurements of incoherency. MLS incoherency measurements are much more comprehensive than either harmonic distortion or conventional IM distortion tests because the MLS excites the loudspeaker with thousands of pure tones which can all interact in a myriad of ways much like music.



Accelerometer Measurements

MLSSA provides both single and double integration for computing velocity and displacement respectively from measurements taken with an accelerometer.

Other Post-processing Functions

MLSSA offers a comprehensive set of other post-processing functions. In addition to cumulative spectral decay, you can also plot Wigner distributions or the energy-time-frequency distributions as 3D waterfalls. In the time domain, *MLSSA* will compute loudspeaker step response and energy-time curves from the measured impulse response. In the frequency domain, you can smooth any magnitude curve from 0.01 to 1.0 octave. Phase can be displayed either wrapped or unwrapped and you can also display minimum phase, excess phase, group delay or even the real and imaginary parts of the complex frequency response. A special command computes true even, odd and total harmonic distortion from power spectrum measurements made with an external sinewave source.

Microphone Calibration and Correction

You can enter and store microphone sensitivity data on up to 10 microphone/preamp combinations. For higher accuracy, *MLSSA* will optionally calibrate your microphones using an external microphone calibrator. *MLSSA* will also correct out minor deviations from flat response by importing microphone frequency response data taken from its calibration curve.

Autorange and Programmable Bandwidth

MLSSA automatically adjusts its input gain on each measurement for maximum dynamic range. Input levels from 10 millivolts to 20 volts RMS are easily accommodated. Autorange can also be disabled and the input gain set manually if desired. Measurement bandwidth can also be programmed anywhere from 1 kHz to 40 kHz through *MLSSA*'s high-quality 8th-order on-board antialiasing filter.

Logarithmic or Linear Data Export and Import

MLSSA will export data in a standard text file format for use by loudspeaker CAD packages such as *CALSOD, LEAP* or *XOPT*. Exports frequency domain data in either linear format or, in logarithmic format for reduced file size. In the frequency domain, you can import both text and binary data files. The imported data is automatically interpolated by cubic splines to match the frequency spacing of the currently displayed curve allowing you to overlay curves having different frequency spacings.

Integrated Macro Processor

MLSSA contains an integrated macro processor. A complex series of *MLSSA* commands can be recorded as a macro and then played back later through the action of one or two keystrokes. No programming skills are required to create macros. Special macro commands permit remote initiation of measurement cycles or, they can be used to synchronize *MLSSA* with a motorized turntable for automated polar response measurements.

Autonamed Filenames

MLSSA provides a automatic filename system to keep your measurement data organized. Whenever you save data to a file, *MLSSA* will optionally create a new numbered filename and save that file to any preselected drive and directory. *MLSSA* also maintains an audit trail for all measurements saved to disk files because all measurement setup parameters are automatically stored along with the measurement data.

Built-in Screen Capture

A integrated utility captures any graphics screen in full color to a PCX file. Used for importing graphics into desk-top publishing (DTP) packages or for future re-display by *MLSSA*. Text screens are captured to plain text files for exporting STI, RASTI or the tabular acoustics screen.

Printer Support

MLSSA offers direct support for HP LaserJet, IBM Graphics, Epson and Okidata printers. You can also redirect printer output to a file when a printer is not available. Later, *MLSSA* can print the contents of the file. An optional header or footer file can also be attached to all graphics printouts, including waterfall plots. These files can contain anything including company logos or product information.

Computer Requirements

MLSSA consists of a full-length card and software designed to run on standard personal computers running the MS-DOS operating system versions 2.1 and above. The card is compatible with all XT (8-bit), AT (16-bit) and EISA (32-bit) full-length expansion slots.

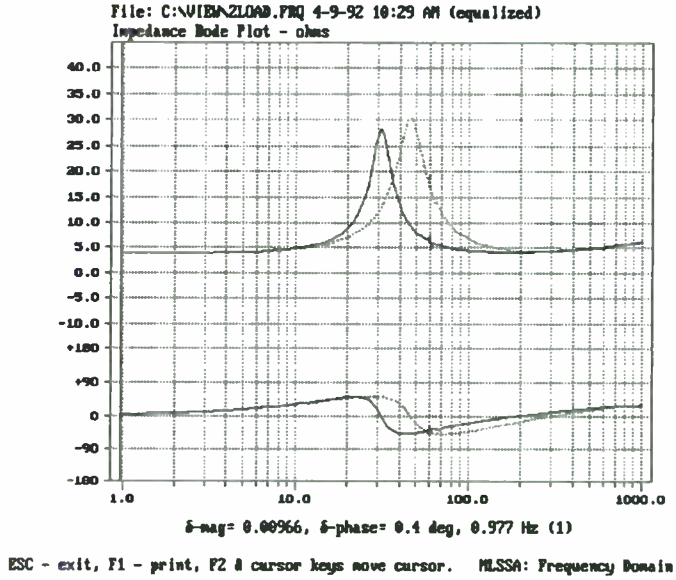
Your computer must contain a math coprocessor chip except on 486DX machines which already include the math coprocessor on the main CPU chip. Your computer must also include CGA, EGA or VGA graphics, a hard disk and, at least 640 kilobytes of memory. For optimum performance a 386SX computer or better is recommended having at least 2 megabytes of memory, VGA color graphics, MS-DOS version 5.0 or better and, an HP LaserJet or compatible printer.

Ordering Information

A complete *MLSSA* system includes a 1 year hardware warranty and free software updates for the first year after purchase. For a demo disk, current prices or, a list of authorized overseas distributors contact:

DRA Laboratories
24 Halifax CT
Sterling, VA 20165
USA
Tel (703) 430-2761
Fax (703) 430-0765

- Thiele-Small Driver Parameters
- Innovative Analysis Method
- Fast Accurate Measurements
- High Noise Immunity
- Automated QC PASS/FAIL
- Woofers, Midrange and Tweeters
- High Inductance Drivers
- Rub Detection Parameter
- Parameter Statistics



Thiele-Small Parameter Option

The *MLSSA Speaker Parameter Option* (*SPO*) is an optional software package for *MLSSA* software versions 7.0 and above.

Innovative Analysis Technique

Driver impedance comprises both magnitude and phase (see Bode plot opposite) and can be envisioned as a curve in 3D space where the X axis represents the real part of the impedance, the Y axis the imaginary part and the Z axis represents frequency. The *MLSSA SPO* quickly finds the unique set of driver parameters which best fits this 3D impedance curve over any selected frequency range. The results are optimum in a least squared error sense, that is, no other set of parameters will yield a better fit between the Thiele-Small parameter model and the measured complex impedance. This new method is vastly superior to the conventional 3-point method in terms of speed, accuracy as well as noise immunity. It should not be confused with conventional curve fitting techniques which consider impedance magnitude only.

Fast Measurements

The new method does not rely on locating special impedance points and therefore does not require ultra-fine frequency resolution. The *MLSSA SPO* uses a relatively short maximum-length sequence for fast impedance measurements with no loss in accuracy. It is much faster than conventional swept-sinewave parameter measurement methods. Running on a 33 MHz 486 computer, the *MLSSA SPO* requires just 6 seconds to measure and display all the parameters using the added-mass method. This benchmark does not include the time required to attach the test mass.

Improved Added-mass Method

In the added mass method, the driver's effective moving mass is intentionally changed by adding a known test mass and observing the shift in the resonant frequency. The conventional added-mass method also assumes driver compliance is the same both before and after attaching the test mass. Unfortunately, compliance shifts often occur when the suspension is disturbed in the process of attaching or removing the test mass. Unintended compliance shifts can result in significant errors in the measured parameters, especially Bl, when using the conventional added-mass method. The *MLSSA SPO* eliminates this problem through an improved added-mass algorithm that is immune to unintended driver compliance shifts. The result is greater accuracy and repeatability of all parameters but especially of Bl.

Three Vas Methods

In addition to the improved added-mass method, the traditional closed-box method is also provided for determining driver compliance or Vas. Additionally, a third method called Fixed-Mmd requires only one impedance measurement when the driver's moving mass, Mmd, is known. Measured parameters include Fs, Re, Res, Qms, Qes, Qts, Vas, Cms, Mms and the Bl product. In addition, other parameters describing the driver's motor impedance are also measured and displayed.

DRA Laboratories · 24 Halifax CT · Sterling, VA 20165 · Tel (703) 430-2761 · Fax (703) 430-0765

Three DCR Methods

The voice coil DC resistance (DCR) can optionally be a) measured automatically by *MLSSA* when the signal path is DC coupled, b) obtained from an ohmmeter and entered manually or, c) estimated from the AC impedance data when the signal path is AC coupled.

Rub Detection Parameter

In addition to the Thiele-Small parameters, the *MLSSA SPO* also includes a proprietary rub detection parameter. This parameter is a very sensitive indicator of driver rub problems caused by mechanical misalignment of the voice coil or, by the presence of chips or other foreign matter lodged in the air gap. The rub parameter is used to automatically reject defective drivers with no increase in the total measurement time.

Automated QC PASS/FAIL Functions

QC PASS/FAIL testing is directly supported and QC acceptance limits can be individually programmed for each parameter (see sample *SPO* screen below). Additionally, all parameter data is automatically logged to a text file for driver matching purposes or, for later statistical analysis by the *MLSSA SPO*. Both automatic and manual serialization is supported. The normal *SPO* screen can also be blanked and a simple PASS/FAIL message displayed for production-line operators.

MLSSA SPO 2.2 #930126-1033-1034 for DRA Laboratories

Measured Data C:\VIEW\DEMO.PLM

Line	Parameter	Value	Units	Nominal	Min	Max	Result
1	RMSE-free	0.20	Ohms	0.00	0.00	0.50	PASSED
2	Fs	45.90	Hz	45.00	42.00	48.00	PASSED
3	Re	3.80	Ohms	4.00	3.50	3.90	PASSED
4	Res	26.41	Ohms	25.00	23.00	27.00	PASSED
5	Qms	2.87		2.85	2.75	3.00	PASSED
6	Qes	0.41		0.40	0.38	0.43	PASSED
7	Qts	0.36		0.35	0.33	0.37	PASSED
8	L1	0.22	mH	0.25	0.20	0.30	PASSED
9	L2	0.53	mH	0.50	0.45	0.55	PASSED
10	R2	3.00	Ohms	3.00	2.75	3.25	PASSED
11	RMSE-load	0.14	Ohms	0.00	0.00	0.50	PASSED
12	Vas(Sd)	34.15	liters	35.00	33.00	38.00	PASSED
13	Mms	8.68	grams	8.60	8.50	8.75	PASSED
14	Cms	1381	µM/Newton	1380.00	1375.00	1400.00	PASSED
15	Bl	4.80	Tesla-M	5.00	4.75	5.25	PASSED
16	SPLref(Sd)	90.9	dB	90.00	87.00	95.00	PASSED
17	Rub-index	0.18		0.00	0.00	0.00	

Method: Mass-loaded (10.00 grams) Area (Sd): 132.70 sq cm

DCR mode: Measure QC file: CLOSED

Analysis successful. Shift in Fs = -32.1% (-20% to -50% is recommended).

LIB PARAMETERS: Go Calculate Method DCR-mode Area Synthesize QC Export Print

F1 for Help or ESC to exit MLSSA: Parameters

Built-in Statistics Functions

Statistics functions include mean, standard deviation, minimum and maximum for each parameter. The number of failures for each parameter and total yield are also computed based on any QC acceptance limits. This allows what-if comparisons between tighter or looser QC acceptance limits without the need to repeat the parameter measurements.

MLSSA SPO QC Statistics Summary

Line	Parameter	Units	Mean	STD	Low	High	Failures
1	RMSE-free	Ohms	0	0	0	0	0
2	Fs	Hz	0	0	0	0	0
3	Re	Ohms	0	0	0	0	0
4	Res	Ohms	0	0	0	0	0
5	Qms		0	0	0	0	0
6	Qes		0	0	0	0	0
7	Qts		0	0	0	0	0
8	L1	mH	0	0	0	0	0
9	L2	mH	0	0	0	0	0
10	R2	Ohms	0	0	0	0	0
11	RMSE-load	Ohms	0	0	0	0	0
12	Vas	liters	0	0	0	0	0
13	Mms	grams	0	0	0	0	0
14	Cms	µM/Newton	0	0	0	0	0
15	Bl	Tesla-M	0	0	0	0	0
16	SPLref	dB	0	0	0	0	0
17	Rub-index		0	0	0	0	0

Total: 7 units QC file: C:\VIEW\TEST3.PQC

Yield: 0 units (0.00%) Limits file: C:\VIEW\DEMO.PLM

LIB PARAMETERS QC STATISTICS: Calculate QC-file Limits-file Print

F1 for Help or ESC to exit MLSSA: Parameters

Tweeters and High Inductance Drivers

Setup files and procedures are included for measuring tweeters as well as woofers and midrange drivers. Due to the new analysis technique, even highly damped or highly inductive drivers can often be measured, drivers that previously were impossible to characterize using traditional techniques.

Impedance Synthesis

The *MLSSA SPO* can also synthesize the ideal impedance of a driver based on measured or manually entered parameters. This synthetic impedance can then be compared to measured impedance to spot driver or model imperfections. A complex (magnitude and phase) impedance error curve can also be computed and displayed.

Macros and Export Support

Complete parameter measurements can be performed without macros but all the standard *MLSSA* macro functions are also accessible from the *MLSSA SPO* menu. Measured parameters can also be exported to standard text files for importing into CAD packages.

Ordering Information

The *MLSSA SPO* includes a separate manual and free software upgrades for the first year after purchase. Additionally, *MLSSA SPO* owners automatically receive the latest standard *MLSSA* software upgrade with their *SPO* upgrade at no additional charge. Contact DRA Labs for current prices.

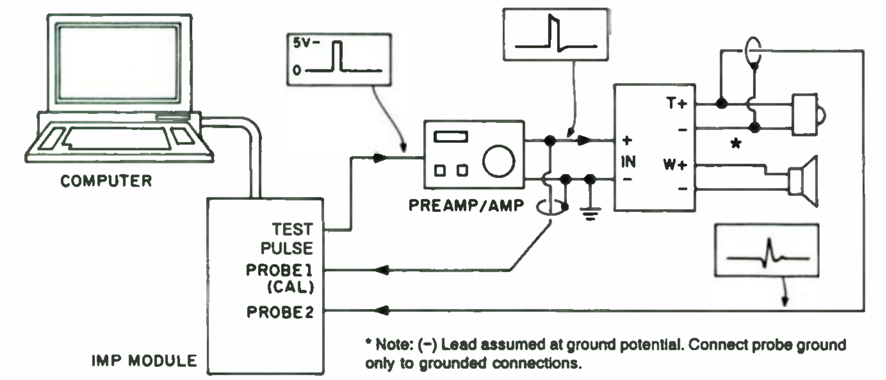


FIGURE 6: Setup for measuring crossover characteristics.

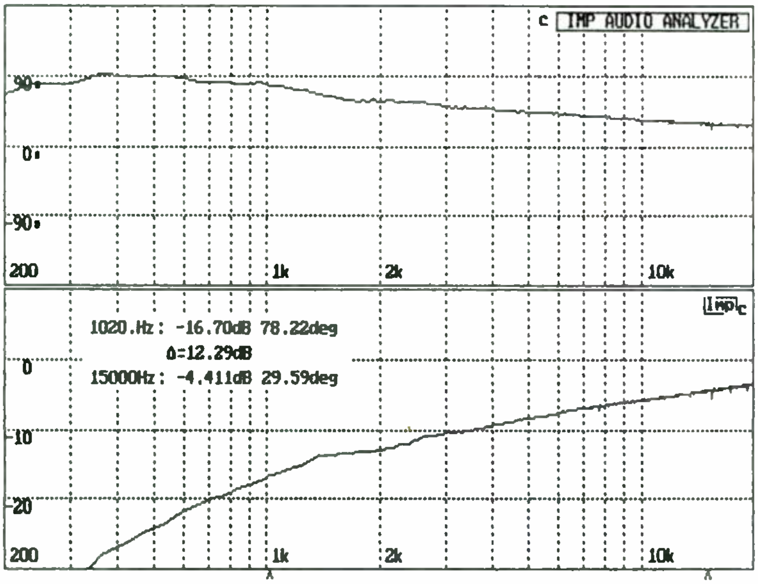


FIGURE 7: Frequency response of the Dynaco A25 tweeter crossover.

Continued from page 38

zero. Then select [*, **Transform**, **Ifft**], and the time response data will be corrected for the amplifier and IMP filters. I have noticed some fuzziness on many "**Ifft**'d" curves, which seems to have something to do with a response of zero in the Cal data near 31kHz at the Nyquist frequency.

CROSSOVER ACQUISITIONS.

Figure 6 shows the equipment setup for measuring the electrical frequency response of a crossover—in this example, for the Dynaco A25's tweeter. This is a rather unexciting first-order network, but the procedure is the same for more exotic circuits. I used 61.2kHz as the sample rate here.

Acquire the Cal as you did for the acoustic measurement. Be sure it is transformed from data of **SIZE** at least as large as that desired from the tweeter probe, or the software will complain that the Cal is not compatible. Use the file DYNACAL.IMP for this example.

When you have set the probe level, acquired and transformed the Cal, and selected [**Set_cal**], just press [F4] until **PROBE2** is selected as **INPUT**. Do *not* readjust the probe level control (V2). Select the sequence [*, **Acquire**, **Collect**] and wait for the acquisition to be complete (example data is in the file named DYNATWEE.IMP). Make sure that the markers are placed at the beginning and end of the data window, then select [*, **Transform**, **Fft**, **Cal**].

When the calculations are done, the crossover response curve will appear on the screen. You can format the display as described previously, but if you have the **GAIN** set to 0dB, you will have a plot of actual rather than relative loss of the network. Phase data can be displayed via [F10] followed by [**Freq_resp**]. The A25's tweeter crossover curve is shown in *Fig. 7*.

If you look in the **auto_Measure** submenu, you will find an automated procedure for electrical response measurement, which will be useful when you're tweaking a network.

POP KNOCK. For this example, refer to *Fig. 8*. The resistor (R) is selected to provide a known value of resistance near the nominal impedance of the speaker. For determining Thiele/Small parameters of woofers, a value of twice the nominal impedance seems to work best. Results will be most accurate for measured data with a value close to the value of R. A 10Ω resistor is easy to come by. Radio Shack sells 8Ω, 5% power resistors which work well.

My example is for the impedance of a woofer in a homemade ported system. We are interested in data ranging from a few hertz to under 500Hz, so the rate should be set (via [F3]) to 1.92kHz. You must tell the computer what value of resistor you are using by executing the sequence [*, **Display**, **Format**, **Scale**, **Ref_resistor**] and answering the prompt. The best resolution will result if you use a **SIZE** of 4,096, but this is usually needed only if you're investigating very low frequency behavior.

Set the **INPUT** to **PROBE1** via [F4]. Turn on the amplifier and select [*, **Acquire**, **Repeat**]. Turn the preamp volume control up until you hear a pop about as loud as a moderate knock at the door. Adjust the probe level control for the usual 75-85% (or 15-25%) of full-

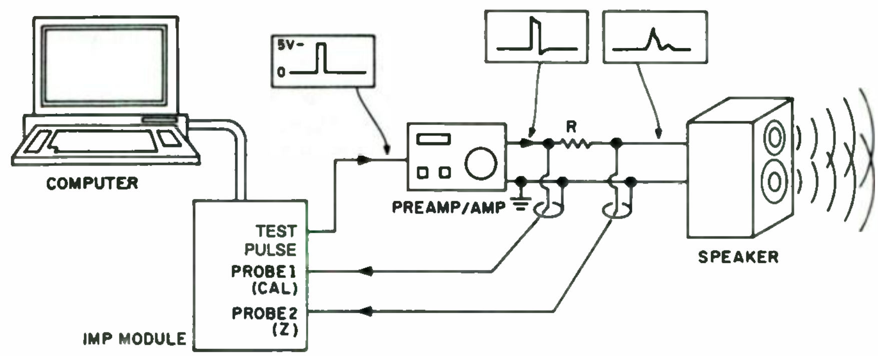


FIGURE 8: Setup for measuring complex impedances.

scale display for the peak impulse. This can be confusing, as each sample is several seconds long, and the display lags significantly behind the adjustment. Go slowly and be patient. When you have it right, press [ESC].

IMPEDANCE TRAPPING. Now make sure **MKR1** is set to 1 (use [F5] if it isn't) and that **MKR2** is at **SIZE** (use [F6] to set it to the same value as shown under **SIZE**—4,096 for this example). Select [*, **Acquire, Collect**] and wait for the Cal run to complete. If you wish to look at or print the impedance plot in a later session, save this time response data to disk. Cal data for the example can be retrieved from the file named TWWCAL.IMP. Finish the Cal process by transforming and declaring the Cal: [*, **Transform, Fft, Set_cal**].

You can set the frequency range now. To match the example, use [Shift F5] and [Shift F6] to set the lower value to 10Hz and the upper value to 700Hz. Set **INPUT** to **PROBE2** using [F4], and without disturbing any controls, execute [*, **Acquire, Collect**] to get the data from the speaker side of the resistor. The example data for this is in the file named TWWZ.IMP.

Readers wishing to purchase an *assembled* IMP unit, with software, may indicate their nonbinding interest by writing #76 on their Reader Service card.

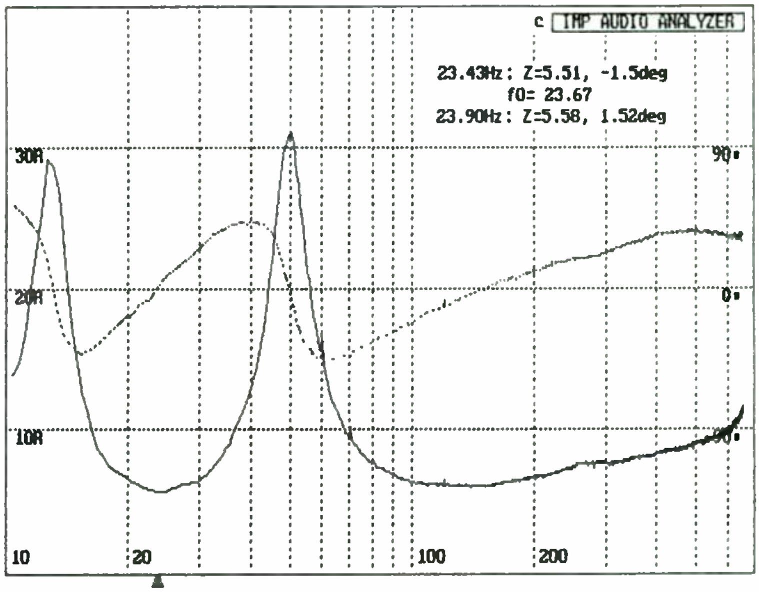


FIGURE 9: Impedance curves of a ported bass unit.

To compute these two data sets into a complex impedance curve, use [*, **Transform, calcZ**]. Results using the example files are shown in *Fig. 9*. The markers are set to pinpoint the box resonance. You can adjust the **Scale** by using [*, **Display, Format, Scale, Ohms/div**]. An automatic routine for impedance measurement also exists under the **auto_Measure** submenu. If you want to repeat the impedance plot later from disk storage, however, you'll have to collect and save the Cal data the slower way.

IMPULSE & POINTS. If you load one of the ?.IMP data files into an ASCII text editor, you'll see it is only a list of numbers saved one to a line. If you wish to generate your own artificial impulse responses to analyze with the IMP software or use the IMP data in other graphing programs, here is a quick rundown on the format.

The first number is the **SIZE** of the data, as was current when the data was saved. The second value is the number of valid data points, which may be less than **SIZE** if the data was from an Inverse Fast Fourier Transform (IFFT) operation. After this comes the sample rate, which the IMP program will round to the nearest of 1.9kHz or 66.2kHz. Next comes either the value one or zero. One means the data is corrected (via an IFFT of a "Cal'd" response); zero means it isn't. The data points come next with the number of them being equal to **SIZE**. And that's it.

ACKNOWLEDGMENTS
I thank Carol Stewart, my wife, who proofed the early drafts, did camera work, corrected and clarified the sentences, put up with a project that grew (in involvement) far beyond anything I expected or had led her to expect, and provided much-needed support. My three children deserve thanks for putting up with my long hours at the keyboard. Tom Alverson was most helpful in all matters relating to computer systems. Gary Smith transferred the laser plots of the PC board patterns. Ray Andrews provided speakers and drivers to test, as well as general inspiration in the art of speaker building and audio.

Product Review

PSB Stratus Mini

By Vance Dickason
Contributing Editor

Stratus Mini, PSB International, Inc., 633 Granite Court, Pickering, ON, Canada L1W 3K1, (800) 263-4641

The last review I did for *Speaker Builder* was of a Precise Model 10, which appeared in the 1/91 issue (p. 50). The review's primary purpose was to examine the design technology used to create the Model 10, and to a lesser extent offer subjective criticism. The intent was to provide the loudspeaker hobbyist with professional examples of what to do with their own designs or, as was the case with the Model 10, what not to do. This time, I was hoping for a speaker which would provide some creative insight into the "what to do" category. Which brings us to the PSB Stratus Mini.

The PSB Stratus Mini is a classic case study in the design methodology required for producing a good sounding, anechoically-flat loudspeaker, which makes it an ideal subject for an *SB* review. Before discussing the engineering details, however, I'd like to introduce the speaker's designer, Paul Barton.

Barton has been a major force in the growing number of Canadian loudspeakers in the US market. The first Canadian manufacturers to use the NRC (Canadian National Research Council) anechoic chamber for design work, he was also one of the first to use computer-aided loudspeaker design software. His early choice was Peter Schuck's XOPT.[1]

Overview

The Stratus Mini, part of the PSB family, is the smallest in the series. It is a compact two-way design using a 6.5″ woofer and ¾″ aluminum dome tweeter, and is priced at $1,000/pair, including stands. The stand's construction is similar to that of the speaker, with extruded aluminum corners to join the four sides of the vertical portion. For mechanical stability, the user may fill the vertical member with sand or lead shot. Both drivers are mounted on a flat baffle: the woofer at the top and the tweeter below. The enclosure vent is located beneath the tweeter.

Low End

The woofer is a variant of Vifa's classic P17WJ-00-08. This driver, which in various incarnations has been used by companies such as Thiel, conrad-johnson, Synthesis, Unity Audio, and Triad, is not only one of the best 6.5″ woofers available but one of the oldest (1988) and most popular Vifa designs.

Using a cast basket, poly cone, rubber surround, and soft poly dustcap, the PSB P17WJ variation has several obvious modifications. Most evident is the bump-out on the magnet assembly back plate, which allows for longer voice coil travel.

The best way to assess the woofer's performance is to measure the parameters and do a computer simulation of its low-end response. Using the LMS analyzer, I measured the woofer's impedance as

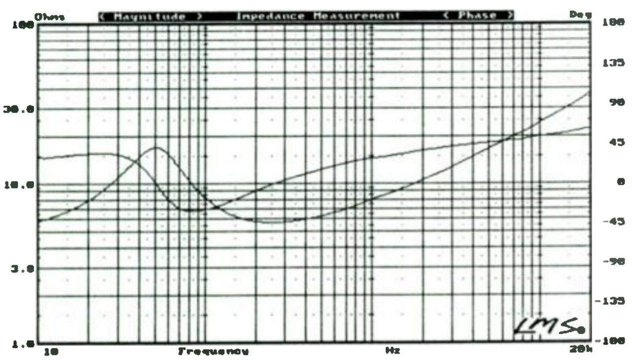


FIGURE 1: Woofer impedance magnitude and phase.

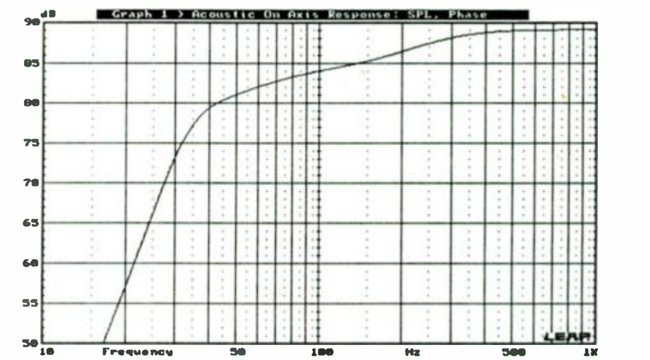


FIGURE 2: Woofer anechoic low-frequency simulation.

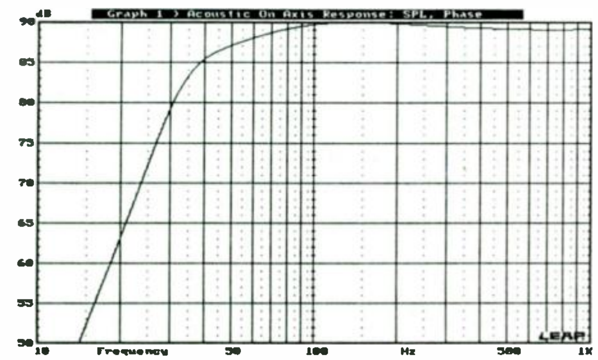


FIGURE 3: Woofer half-space low-frequency simulation.

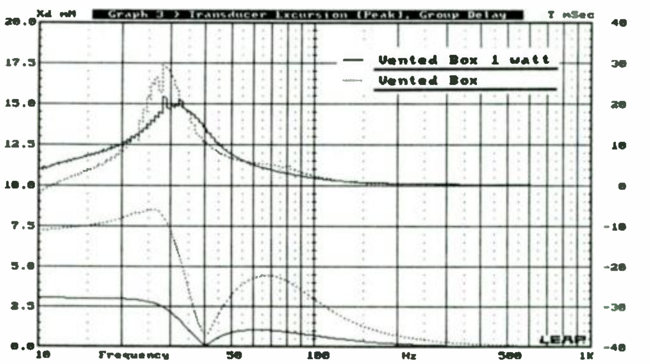


FIGURE 4: Woofer cone excursion and group delay simulation.

FIGURE 5: Woofer full-range anechoic frequency response (no network).

FIGURE 6: Woofer polar frequency response 0–45° (no network).

shown in *Fig. 1*, and exported the data into LEAP 4.5 to calculate the parameters. Using the measured enclosure volume of 0.6 ft.^{3}, about 40% enclosure fill (a white Dacron-type material), and a 2″ ID 5.75″ vent, I did a vented-box simulation at 1W (2.83V) and at 45W (15V). *Figure 2* is the 1W anechoic response curve. Since it is difficult to calculate the f_3 from the anechoic response (it includes the baffle step response), the half-space woofer response is given in *Fig. 3*. The f_3 for this simulation is about 49Hz, with the speaker down only 6dB at about 36Hz.

This vented alignment is not one of the critically damped types (such as a QB3), and is roughly a damped Chebychev/Bessel. *Figure 4* shows the group delay for this type of alignment at 1 and 15W. This alignment provides a reasonably satisfactory subjective bass quality, while at the same time producing much deeper bass than would be possible with a better damped QB3 type. As loudspeaker tradeoffs go, this a fairly good one.

The cone excursion curves in *Fig. 4* show a maximum excursion of 4.6 mm at 65Hz with an SPL of 95dB. For the stock version of the P17WJ, this would be X_{MAX} plus 15%, indicating that the driver is still operating in a linear range. Since I know the PSB version has a longer coil, I presume it will remain in its linear operating range well up to 100dB, which is good for a 6.5″ woofer.

Response Respectability

Figure 5 shows the woofer's full-range frequency response taken at 2.83V. To capture this, I spliced a ground plane sinewave measurement done outdoors with a gated sine-wave measurement, also done outdoors but positioned on a 5.5′ tower. The gated measurement was good down to about 300Hz, which is about where the splice to the ground plane was made. Once completed, this is effectively a full-range anechoic chamber measurement.

This driver, like the stock Vifa P17WJ measured on a small baffle, has a 6–7dB rise from 100Hz to 1kHz, and has no objectionable spikes in the upper range due to unattended cone breakup. The LEAP simulation of *Fig. 2* was very close to the measured data showing an SPL of 80dB at 40Hz and 84dB at 100Hz, which is identical to *Fig. 5*.

Off-axis response is also quite good, as illustrated in *Fig. 6*. The 30° curve is about 3dB down from the on-axis curve at 2kHz, and 9dB down at 3kHz. This indicates that the probable choice for the crossover would be in the 2kHz region if the criterion were to maximize the smoothness of the power response.

The 2″ ID port is a reasonable choice for a 0.6 ft.^{3} box tuned to 49Hz. While a larger diameter would be preferable, the vent would be too long. *Figure 7* shows the impedance of the completed speaker at 0.9, 2.83, and 6.33V. The decreasing amplitude of the lower impedance peak as voltage increases demonstrates the nonlinearity of the 2″ ID port in this size box. However, it is only fair to point out that practically no realizable port is linear, and virtually every vented box exhibits the same behavior. The consequence is a subjective impression of some compression in the bass at higher volumes, but this is not particularly distracting to most listeners (in fact, unless I pointed it out, very few listeners would be aware of it).

Woofer Crossover

Figure 8 is the Stratus Mini network topography. As mentioned above, a good crossover frequency which would maintain a well-behaved power response would be in the vicinity of 2kHz. Paul Barton chose to use 2.2kHz as his target frequency. The network required to do this is a second-order with an added LCR conjugate. Final response of this network, compared with the response without the network, is shown in *Fig. 9*. The rising response is contoured starting at about 250Hz, and is 6dB down at 2.2kHz with a slope of about 16dB/octave (measured in the first octave above the low-pass crossover frequency). This requires using a network transfer function which is more than the simple classic filter function, such as a Butterworth or Linkwitz-Riley, because it has two break points rather than one, visible in *Fig. 10*.

Figure 10 represents the measured (not simulated) transfer function of the woofer and tweeter networks. This measurement is accessible by performing one VdBm sweep with LMS at the network input and another at the output, and dividing the two to get the transfer function. The second-order network begins attenuating the woofer response at about 250Hz, sloping down at 3-4dB/octave, and then changing slope at 2kHz to about 15-16dB/octave; this is typical of the low-pass transfer function for a two-way speaker. An additional LCR network flattens the response in the 100–400Hz region by a few decibels. Both circuits combined will bring the overall low-end efficiency into the 85–86dB region, which is in accordance with PSB specifications.

Figure 11 shows the resulting off-axis re-

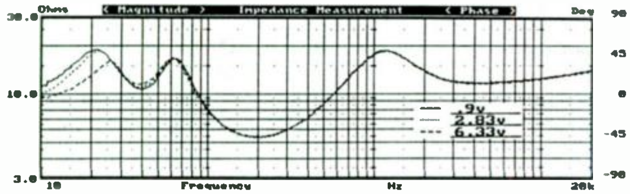


FIGURE 7: Dynamic woofer impedance (0.9, 2.83, 6.33V).

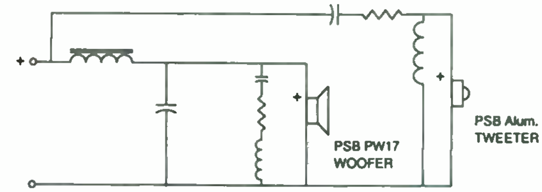


FIGURE 8: Stratus Mini crossover diagram.

FIGURE 9: Comparison of woofer response with and without network.

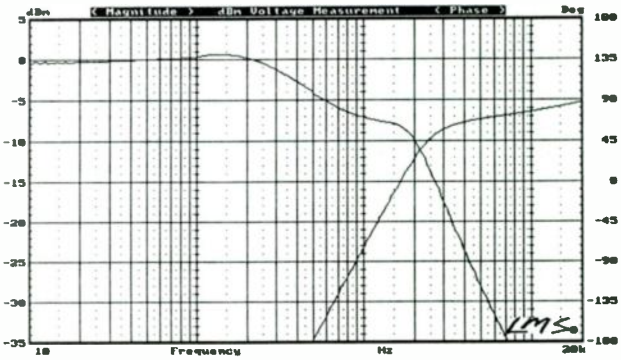


FIGURE 10: Crossover transfer functions.

FIGURE 11: Woofer polar frequency response with network.

FIGURE 12: Tweeter frequency response (no network).

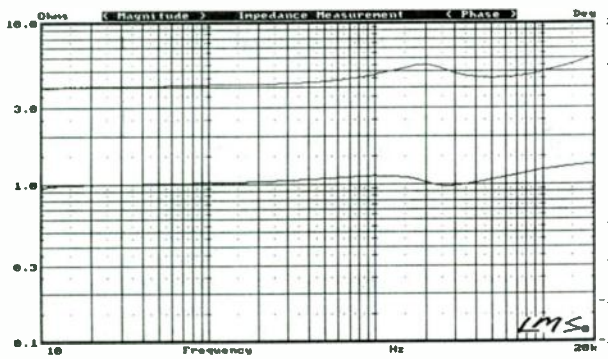


FIGURE 13: Tweeter impedance magnitude and phase.

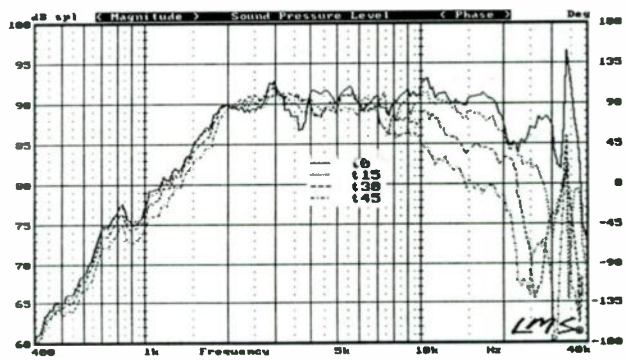


FIGURE 14: Tweeter full-range anechoic frequency response 0–45° (no network).

sponse with the network, which is very smooth out to 45°. Herein lies the secret to getting an appropriately smooth power response from the completed speaker. The subjective importance of maintaining a smooth power response has been emphasized many times by Dr. Floyd Toole at NRC.[2]

Network components include a silicone iron-laminate core inductor for the series inductor, an air core for the LCR inductor, and two nonpolar electrolytics. The transformer laminate core inductor has become highly popular in recent years. The core used in the Stratus Mini is a high-Q coil with the laminate "I" extending at least the height of the core over the bobbin ends. I used a similar configuration in a subwoofer crossover inductor in one of my SRA (Speaker Research Associates) loudspeakers in 1978. The combination of a high-Q coil and the extended "I" core works very well, and handles substantial amounts of current without annoying saturation problems.

Nice Knees

Like the woofer, the tweeter is also from Vifa. However, this unit is a 0.75″ aluminum dome with a custom phase plug and flange, and has no counterpart in the Vifa catalog. Frequency response and impedance magnitude and phase are shown in *Figs. 12* and *13*. From the impedance plot, it is apparent that the voice coil gap is filled with ferrofluid, leaving a very damped resonance at 2kHz with barely a 1Ω rise. The dip at 3.75kHz is a diffraction artifact and will be discussed later. Off-axis response is depicted in *Fig. 14*. Since this plot goes out to 40kHz, the aluminum dome breakup mode at 35kHz is visible. Other than that, the response is quite smooth out to 20kHz, and is only 3dB down at 30° off-axis at 20kHz.

Looking at the crossover in *Fig. 8*, the tweeter network also uses a second-order topography with a series attenuation resistor positioned between the two filter elements. Network and tweeter response is illustrated in *Fig. 15*. The decibel SPL (*Fig. 14*) without the network is about 90dB, and since the woofer was about 86dB after it was contoured flat, the tweeter needed about 5dB of attenuation. Depending on where it is located, the attenuation resistor can have a variety of influences on the circuit. It can affect the total impedance or directly influence the network's transfer function. Looking at the transfer function in *Fig. 10*, the curve exhibits a nice low-Q knee. If the resistor were on the tweeter side of the circuit, the network transfer function would have likely had a much sharper and less damped knee at 2–3kHz.

The off-axis response of the tweeter with the network is shown in *Fig. 16*. The response is rendered reasonably flat and

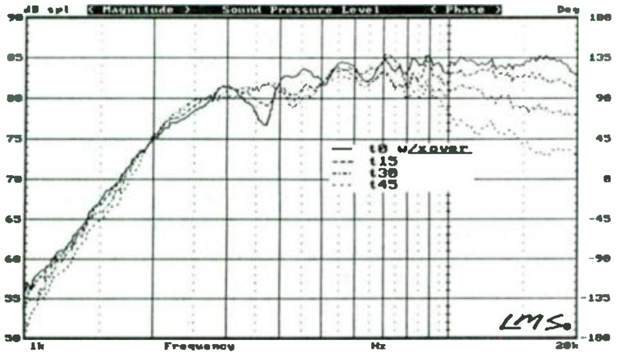


FIGURE 15: Tweeter frequency response with network 0–45°.

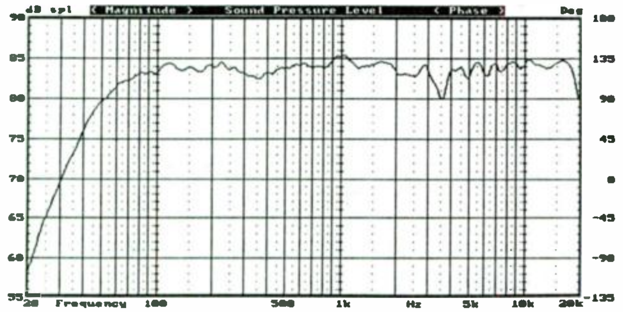


FIGURE 16: Stratus Mini full-range system response.

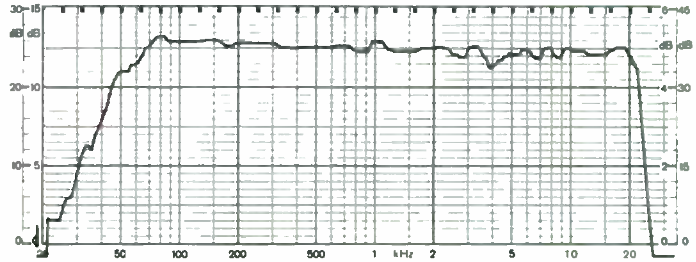


FIGURE 17: Frequency response (NRC anechoic chamber).

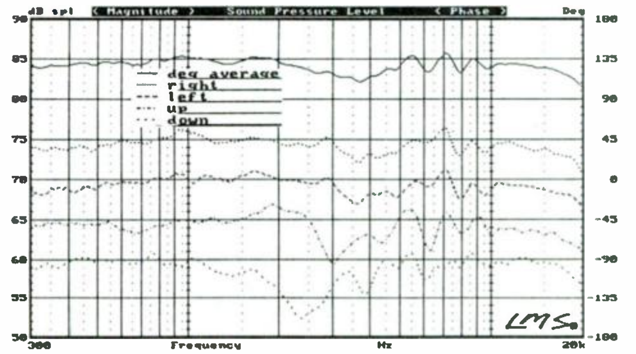


FIGURE 18: Average of frequency response (left, right, up, down 15°). The solid plot is the averaged response; the others were scaled 5dB for viewing ease.

rolls off to about 6dB down at 2.2kHz, the crossover frequency. The roll-off is about 19dB down in the first octave below the high-pass crossover frequency, which is the target response for a fourth-order Linkwitz-Riley network.

The tweeter network components are an air core inductor and an NP electrolytic capacitor, which will undoubtedly horrify those of you who believe that high-cost polypropylenes are essential for good results. Quite the contrary: many of the high

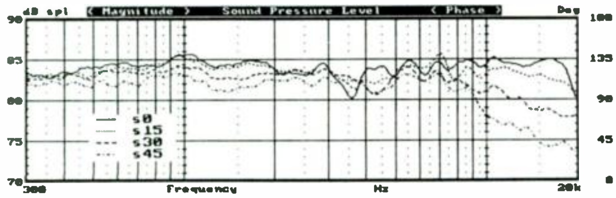


FIGURE 19: System horizontal frequency response 0–45°.

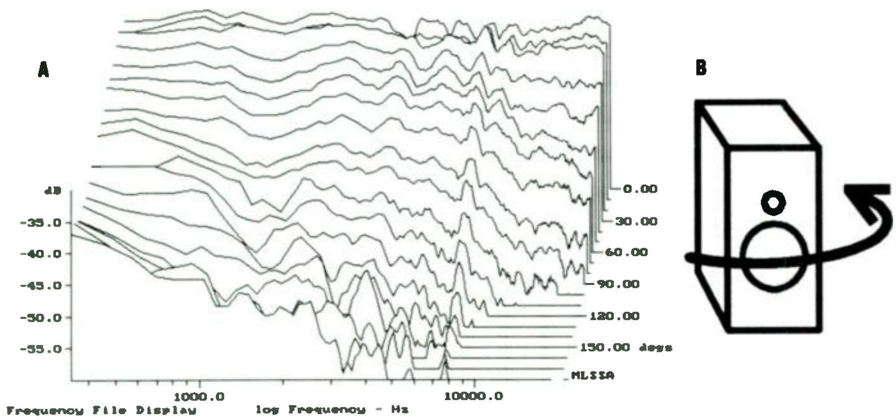


FIGURE 20: a. System horizontal frequency response 0–180°; b. direction of the polar plots.

quality NP electrolytics, such as those from InterTechnik, sound very good and are sometimes employed in high quality speakers with excellent results.

Diffraction Dip

The speaker's complete full-range response is depicted in *Fig. 16*, showing ±2.5dB from 50Hz to 20kHz. *Figure 17* is the NRC chamber response plot of one of the sample pair provided for this review. Measuring the response with LMS compares well with the NRC plots, however, it is difficult to compare the resolution without knowing the write speed of the Brüel & Kjaer chart recorder used at the chamber (the LMS plots used 200 points 20Hz–20kHz). PSB quotes ±1.5dB, which is slightly better than my measure. However, the biggest difference between the two is the dip at 3.75kHz.

When I first discussed this review with Paul Barton, he mentioned that the dip was a diffraction artifact caused by the 0.75″ overlap of the box (top and bottom) over the front baffle. Cosmetically, it looks quite nice, and the diffraction dip is minimal. Paul suggested that if I averaged the response off-axis, this would disappear. When I averaged the left, right, up and down 15° off-axis measurements, the results proved the dip was definitely the result of box cosmetic (*Fig. 18*). Ignoring this diffraction anomaly, the speaker is easily flat to ±1dB.

Figure 19 is the 0–45° off-axis response, showing the speaker to have an excellent response in the horizontal plane. *Figure 20* is the off-axis response done with the MLSSA FFT analyzer out to 180° off-axis.

The same measurement on the vertical axis, depicted in *Fig. 21*, illustrates the off-axis lobing at the crossover frequency you would expect for noncoincident drivers using a fourth-order Linkwitz-Riley response. This measurement was made starting at the on-axis point, and up over the top of the speaker. *Figure 22* shows the same polar response in the vertical plane out to 180° using MLSSA.

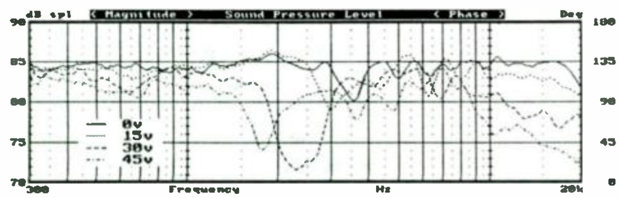


FIGURE 21: System vertical frequency response 0–45°.

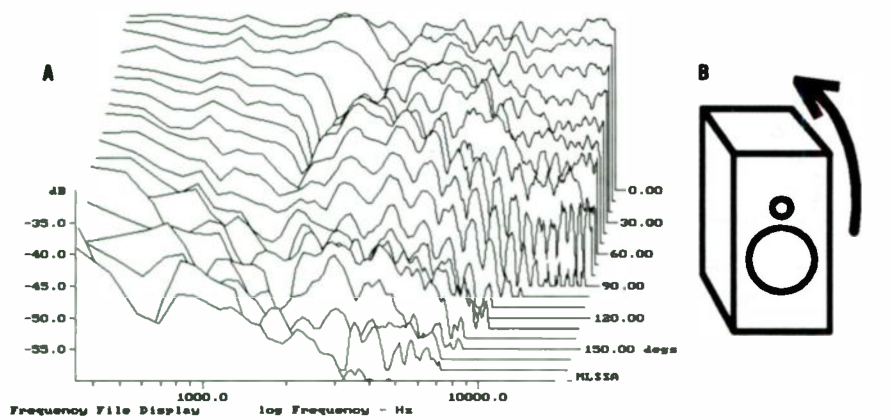


FIGURE 22: a. System vertical frequency response 0–180°; b. direction of the polar plots.

A Minor Variation

The plot in *Fig. 23* shows the woofer and tweeter response along with the system response. The crossover at 2.2kHz is exactly 6dB down from the system response, which is necessary to produce a flat magnitude curve. *Figure 24* shows the system response with the drivers electrically out of phase compared to the in-phase system response. The null is fairly deep and symmetrical, indicating the crossover is close to being in phase at that frequency.

The physical delay from the tweeter's baffle location to the woofer is about 140μs, which is the amount I used to create the phase plot in *Fig. 25*. I added the appropriate amount of delay to the low-pass section before mathematically summing the high- and low-pass sections in the LMS software. Also, the 140μs delay explains woofer slope is less than the tweeter's crossover slope, a procedure which can be used to produce a flat response with both drivers mounted on the same baffle. Mounting the tweeter below the woofer also helps, if the measurement axis is at ear level.

Besides a smooth amplitude response, the Stratus Mini also produces a clean spectral decay curve, done with the MLSSA FFT analyzer (*Fig. 26*). The midrange and high-frequency areas are free from any major resonance modes and show minimal activity after the first 2ms.

REFERENCES

1. Dickason, Vance, *Voice Coil*, October/November 1988.

2. Toole, Floyd E., "Subjective and Objective Measurements of Loudspeaker Performance," NRC, Canada, or *JAES* June 1982, January/February 1985, April and May 1986.

3. Dickason, Vance, *Voice Coil*, November 1991.

The review pair had well-matched amplitude response showing barely 0.5dB variation, as depicted in *Fig. 27*. The difference curve is shown in *Fig. 28*.

Grille frames always cause some deterioration in the amplitude response, and the grilles on this speaker are no exception. *Figure 29* shows the response of the Stratus Mini with and without the grilles, while the plot in *Fig. 30* shows the difference curve. The effect of the grille frame and cloth are mostly in the 2kHz and above region, where deviations reach a maximum of 3dB.

The impedance magnitude and phase are shown in *Fig. 31*, with the complex impedance curve in *Fig. 32*. Minimum impedance was 4.7Ω at 200Hz with a range of 4.7–12Ω maximum, indicating the voltage dividing effect caused by speaker cable resistance to be minimal. The maximum capacitive load comes at a phase angle of −36.85° at 96.68Hz, while the maximum inductive load occurs at a phase angle of 36.6° at 661.57Hz, making this speaker an easy load for almost any amplifier. Two paralleled together probably wouldn't be a good idea on low quality amps, however, as minimum impedance would be 2.35Ω.

The dynamic range of any two-way 6.5″ speaker is somewhat limited, with a few exceptions such as the $12,500/pair Sonus Faber Extrema. The Stratus Mini does a good job, however, of staying linear up to at least 95+dB. This represents a sine-wave input of 10V, which is where I stopped the test. Looking at the full-range ground plane plots in *Fig. 33* and the difference graph in *Fig. 34* (comparing the output at 0.9V to 10V), the Stratus Mini produced minor variations (1.6dB in the crossover region) up to the 95dB SPL level.

FIGURE 23: Woofer, tweeter, and system response.

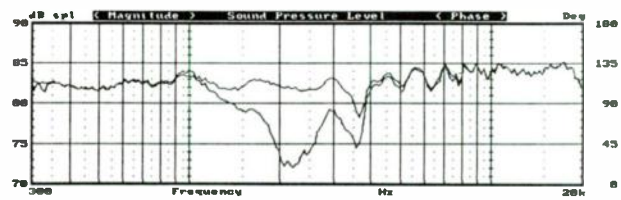


FIGURE 24: System response with tweeter in phase and phase reversed.

Extrusion Inclusion

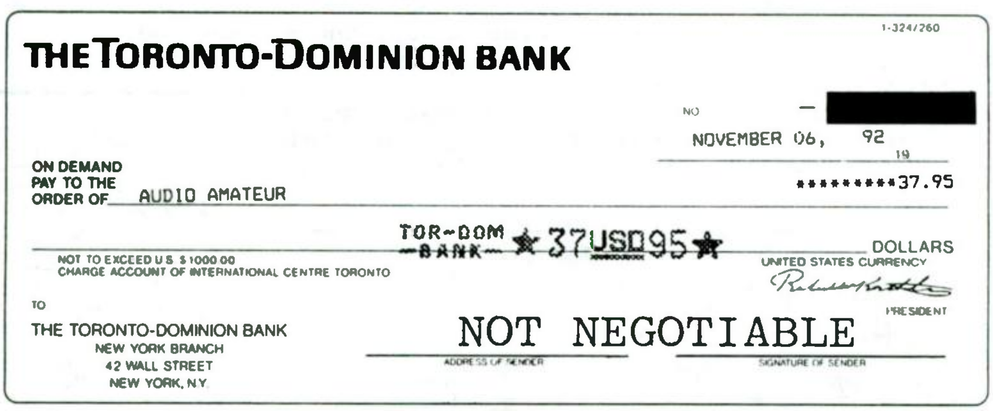
The Stratus Mini cabinet construction is very solid, a feature that goes a long way

Dear Canadian Subscriber,

Maybe it's because we are in a small town, but our bank just cannot seem to make a decision regarding Canadian remittances. We are being charged exorbitant fees for processing all but the most clearly defined checks. The details of acceptable checks are below, please help us out by making every effort to follow these guidelines to aid in our quick processing of your orders.

Thank you.

- **All checks must be drawn in US dollars and must list a corresponding bank in the United States. This service is available at your bank.**



1-324/260

THE TORONTO-DOMINION BANK

NO — [redacted]

NOVEMBER 06, 19 92

ON DEMAND PAY TO THE ORDER OF AUDIO AMATEUR

*********37.95

TOR-DOM BANK ★37USD95★ DOLLARS

UNITED STATES CURRENCY

NOT TO EXCEED U.S. $1000.00
CHARGE ACCOUNT OF INTERNATIONAL CENTRE TORONTO

PRESIDENT

TO
THE TORONTO-DOMINION BANK
NEW YORK BRANCH
42 WALL STREET
NEW YORK, N.Y.

NOT NEGOTIABLE

ADDRESS OF SENDER — SIGNATURE OF SENDER

- **If you use a Canadian Postal Money Order, have it written in US$.**
- **If you have access to a Mastercard or Visa, this is the fastest and easiest method of payment.**

FIGURE 25: System magnitude and phase response.

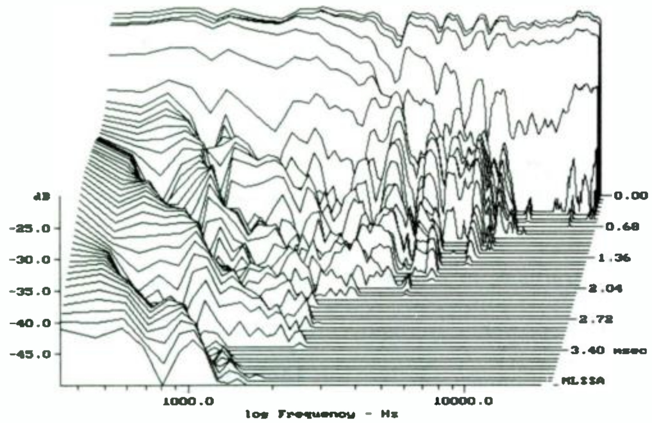


FIGURE 26: System cumulative spectral decay plot.

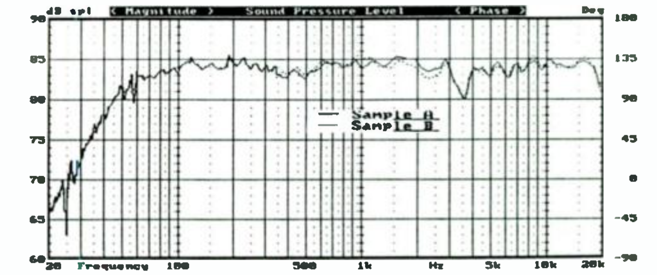


FIGURE 27: Comparison of left and right speaker response.

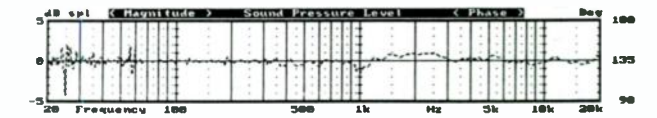


FIGURE 28: Left/right difference curve.

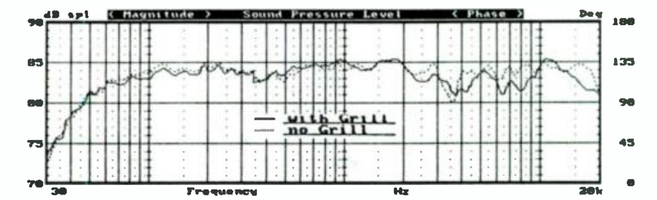


FIGURE 29: System response with and without grille.

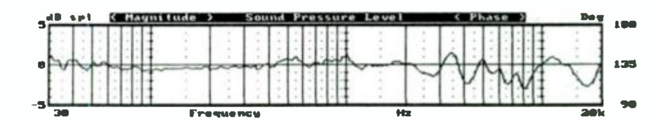


FIGURE 30: Grille frame difference curve.

to limit unwanted colorations. The enclosure is unusual in that extruded aluminum is used to join the four side walls at the corners rather than the usual glue and staples, which effectively isolates the baffles and side walls. Construction is from standard ¾″ MDF, with a horizontal girth brace at the center of the box between the woofer and tweeter. The drivers are mounted using Well Nuts, which not only makes removing the drivers easy without the risk of stripping out the wood, but also provides a degree of vibration isolation for the driver. This technique works well with typical ¾-1″ material cabinets. The alternative is to use very massive 2-4″ front baffles with the driver rigidly mounted without isolation.

The extruded aluminum produces a solid cabinet, also providing a unique and good-looking appearance. I used a polyvinylidene fluoride (PVDF) accelerometer to evaluate the effectiveness of this construction technique.[3] Although the low-cost accelerometer's performance is quite good and more resonance-free than its expensive counterparts, it is not a calibrated device and is useful only for relative comparisons.

Figure 35 shows the spectral decay plot using MLSSA with the accelerometer mounted on the Stratus Mini side panel. The low end looks fairly damped with higher frequency peaks at 400Hz, 650Hz, and 1.8kHz. (These curves do not represent excursion, but only useful velocity, which is why the peaks at higher frequencies appear to have higher amplitude than at lower frequencies.)

By comparison, the speaker I designed in *Fig. 36* is definitely an improvement. However, it is important to point out that the cabinets I constructed for this particular speaker, which also uses a Vifa P17WJ, were very elaborate compared to the Stratus Mini. The walls are 1″ MDF with 1.75″ front baffles, featuring an internal cardboard semi-cylinder rear baffle with sand filled in behind, plus a cross-brace from the center of the front baffle to the rear and another joining the side walls. In other words, this is a very heavy (35 lbs. without crossovers, which are in the stands) and rigid speaker, which would cost considerably more to put into production than the Stratus Mini. Also, both speakers were measured on their own stands.

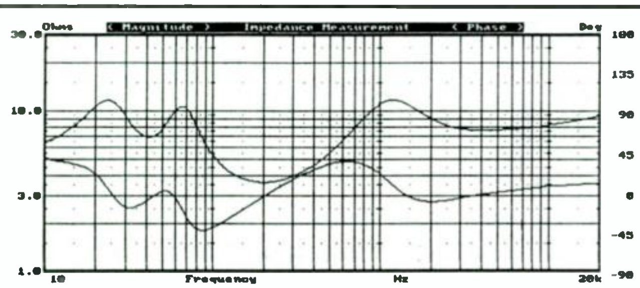


FIGURE 31: System impedance magnitude and phase.

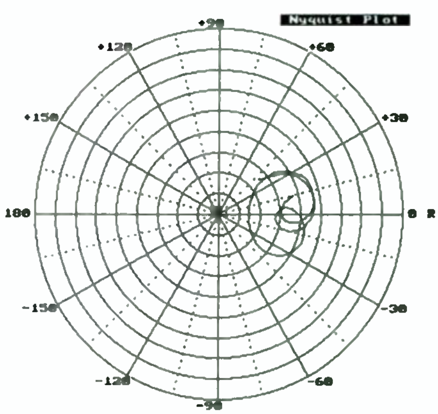


FIGURE 32: Complex impedance.

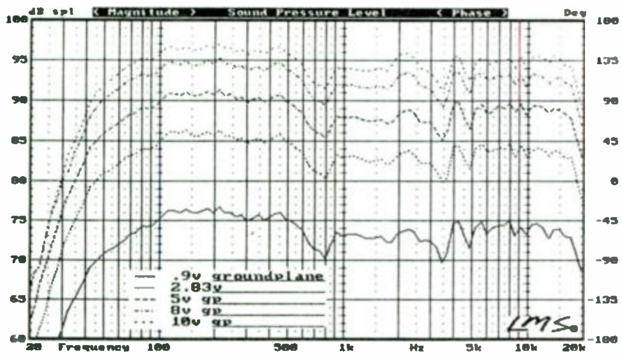


FIGURE 33: System dynamic frequency response (0.9, 2.83, 5, 8, 10V).

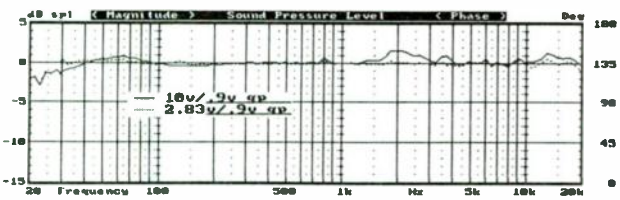


FIGURE 34: Dynamic frequency response difference curve.

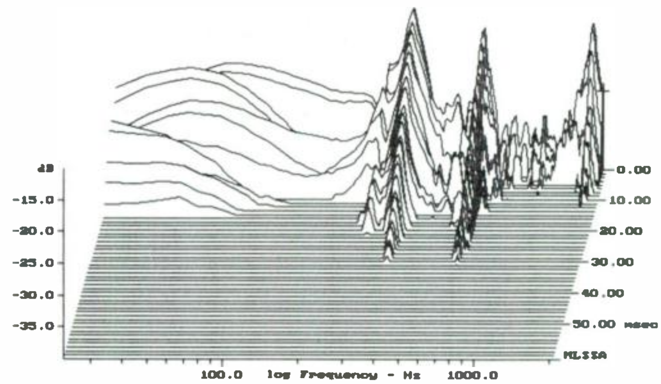


FIGURE 35: Stratus Mini enclosure accelerometer decay curve.

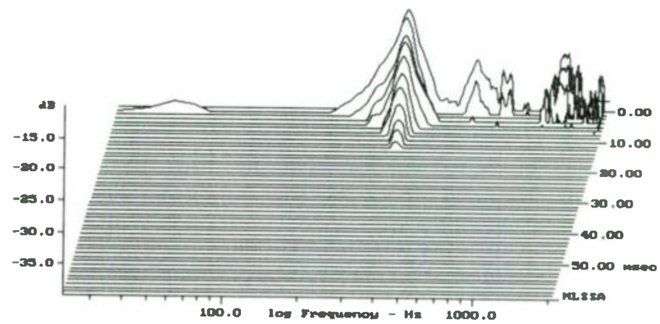


FIGURE 36: Author's enclosure accelerometer decay curve.

To measure the PSB stands, I did not fill the extrusions as the end user may do. My speaker stands are not sand- or lead-shot filled either, since they contain the crossover, but they do make some provision for isolation which the PSB stands do not. For a $1,000/pair speakers weighing 25 lbs., the PSB curve in *Fig. 35* seems very respectable.

Bottom Line

I admire the design and construction of the Stratus Mini very much. The excellent off-axis response and closely-matched drivers produce a good image character with a reasonable amount of depth. The dynamic range is really quite good, and seemed better to me than some of the comparably-priced competition which use shallow-sloped crossover techniques. The Stratus midrange is neutral sounding; the high frequencies are clean and free of harshness or excessive sibilance. The bass is well-defined and well-balanced, with good extension for a 6.5″ woofer. Using this speaker with the right subwoofer would give the bottom end the authority lacking in all 6.5″ drivers.

Compared to some of my current work, which uses very expensive 12-gauge air core inductors and beautiful poly caps in similar two-way design formats, the PSB Stratus Mini sounds embarrassingly good, cored inductors and NP electrolytics notwithstanding. If I were asked to recommend speakers in the $1,000/pair category, I would definitely include the Stratus Mini.

Wayland's Wood World

BUILDING MATERIALS FOR SPEAKER CABINETS

By Bob Wayland

We have all faced the same problem. You've carefully worked your way through a speaker design, and chosen the best, most affordable components. You are now ready to build the cabinet, but you don't know what construction materials to choose. This step can often be confusing if you lack familiarity with what is available. This time, I will discuss the different materials and offer a few suggestions and observations.

The basic cabinet requirement is that it doesn't become a secondary source of sound, which places some interesting restrictions on what material should be used. We have all heard about two-ton, reinforced-concrete enclosures, but are restricted to using more mundane materials such as solid wood, plywood, hardboard, or particleboard.

Solid wood is perhaps the most aesthetically pleasing, but it presents some problems. *Plywood* has long been a favorite, although great care must be exercised in its selection. *Hardboard* has good strength and water resistance, and it can be tempered to improve stiffness, hardness, and finishing properties. Because hardboards are normally less than ⅜" in thickness, they have limited usefulness in speaker building. *Particleboard* uses wood particles such as chips, splinters, shavings, flakes and other sawmill waste, which are glued together with a thermosetting, formaldehyde-based, synthetic resin, or equivalent binder. When you choose a material, you should always consider both its mechanical and acoustical properties.

Wooden It Be Grand?

Factors to consider when choosing solid wood include how the wood was sawed, defects, species, grade, cost, stability, durability, availability, ease of working, and suitability. For speaker cabinets, the acoustical properties must be acceptable. The wood should be clean cut and free of defects. Avoid knots, unless they are intergrown (grown together with the fiber of the surrounding wood). Watch for decay and pitch pockets, especially those which have dried out or contain loose pitch. Insect damage can result in whistle-producing holes.

When wood is cut, the sawing angle relative to the tree's structure can affect its acoustical and mechanical usefulness. Trees grow in a series of concentric rings caused by the annual variance of the growth cycle. The newer, outer-growing part (sapwood) carries the sap from the roots. The inner rings (heartwood) are sapwood which has become inactive. In general, heartwood is preferred for building speakers because of its stability and general lack of pitch. If a log is sawed at a tangent to the annual rings, the wood produced is termed either *plain sawed* for hardwood or *flat grained* for softwood (*Fig. 1* and *Photo 1*). Be careful: a hardwood comes from a deciduous (broadleaf) tree but its wood may be very soft, for example basswood.

Another method involves sawing the log into quarters (*quarter sawed*). Each quarter is cut so the angle between the cut and the growth rings varies from 90° to about 60° (*Fig. 1* and *Photo 2*). Wood expands and shrinks as its moisture content increases or decreases. Plain-sawed wood suffers from considerable changes in width, and it tends to warp (crook, bow, cup, and twist). Quarter-sawed wood has the advantage of less change in width, and it warps less. However, it is also harder to find and more expensive.

A rule of thumb: negligible dimension changes will occur in the longitudinal direction, and changes in the tangential direction will be about twice those in the radial direction. (All directions are relative to the growth rings.) If your application demands highly stable dimensions, you can use a polyethylene glycol (PEG) treatment to stabilize the wood. For the average speaker builder, however, this is an unnecessary complication.

Hardwood Hegemony

Of the more readily available woods which are most useful for speaker building, the softer woods, such as the pines, are not a good choice. You will probably be happier using the hardwoods, such as walnut, cherry, maple, oak, and perhaps mahogany. If you have the equipment and patience, exotic woods such as teak, rosewood, wenge, and purpleheart are wonderful to work with.

American black walnut heartwood varies in color from light gray-brown to purplish brown. Its small shrinkage factor makes it desirable for exposure to varying climatic conditions. With a medium hardness and texture, and a straight to irregular grain, it is moderately easy to work

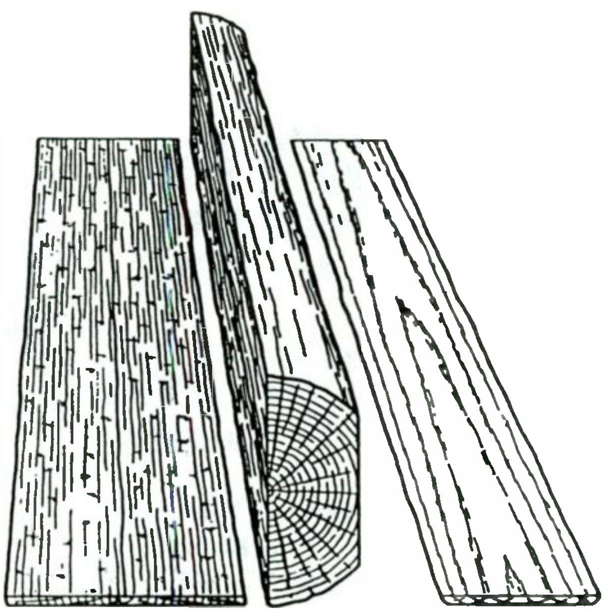


FIGURE 1: Quarter-sawed (left) and plain-sawed (right) boards.

and exceptionally durable. However, it can be quite expensive. If you wish to create a striking pattern, consider combining small segments of nearly white sapwood into your design.

Wild black cherry is a strong, stiff, moderately hard wood which is easy to find at hardwood suppliers. Although unfinished cherry's normal color is a medium reddish-brown, it often has a distinctive grayish tint which can vary all the way to a light straw color. Cherry is a medium-density wood with fine texture and straight grain, stable and moderately easy to work. While not as durable as walnut, it makes a good enclosure wood and is available at medium to high prices.

You might consider *sugar* or *hard maple*, a hard, heavy wood of fine and even texture. Normally, the grain is straight, but some beautiful variations include a bird's eye figure or wavy, curly grain (fiddle back). The heartwood is pinkish-brown, with reddish-brown growth rings. Its lack of open pores can cause some trouble with older types of glues. While moderately easy to work, using maple can mean frequent tool sharpening. Although about as stable as cherry, it is usually more durable. For a light color or tone in a naturally finished wood, maple is a good choice.

More than 200 species of *oak* are available, about 50 of which are native to the United States. Red oak (amber with a reddish tinge) is found at any well-stocked lumber yard at medium prices. It is coarse-textured, hard and very durable. Oak works well by machine, but can be hard on sharpened edges. The alternating open and closed grains provide a strong and interesting figure which can be toned down by filling the open pores prior to staining and finishing. Like maple, oak can be finished for a light-colored enclosure. White oak is much like red oak, with pale tan the dominant color.

Mahogany has moderate density and hardness, with excellent working and finishing properties. However, it is very porous, and most people use a filler during finishing. The figure is not striking, although it can be very pleasing. Its low shrinkage and relative ease of working make it a useful enclosure wood. The heartwood varies in color from pale to deep reddish-brown which deepens on exposure to sunlight. Genuine mahogany comes from Mexico and northern South America, and tends to be expensive. Other species from the Philippines (lauan) and Africa have similar properties, but are not quite as beautiful or useful.

Board Rules

Knowing some common lumber terms and abbreviations will prove useful when buying hardwoods. Thickness is given in fourths of an inch of the rough-cut wood, not the finished dimension. For example, 5/4 (spoken as five quarters) is 1.25". The finished dimension is smaller: a 4/4 rough

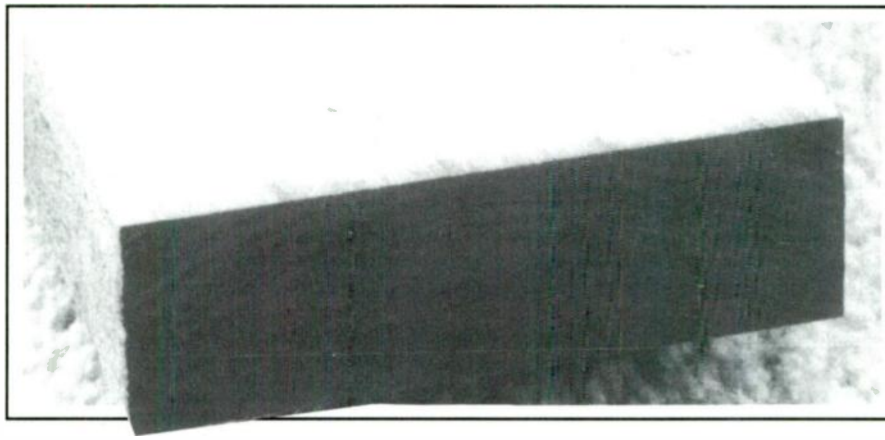


PHOTO 1: Plain-sawed board.

is usually surfaced on two sides (S2S) to a finished dimension of 25/32″ green or ¾″ dry. The unit of volume is the board foot, equivalent to 1′ × 1′ × 1″, or 144 in.[3]

Hardwood lumber is usually sold on a random width and length basis, so board footage is based on actual surface area and nominal thickness. Normally, the board edges are not finished, and you will pay extra for this service.

Hardwood grade is based on the percentage of the board that is clear of defects. For finished lumber, the grade is determined by the better face. The top and most expensive grade, "first-and-seconds" (FAS), is for 6″ and wider, and 8′ and longer, with about 83% (10/12s) yield (free of defects). The next grade down is select. It is the same as FAS, except the size limits are 4″ and wider, and 6′ and longer. The lowest grade, number one common (the thrift grade), can offer substantial savings. The yield is about 67% (8/12s) of 3″ and wider, 4′ and longer. It often has a more interesting grain pattern than the higher grades. Lumber yards usually sell kiln-dried wood of about 7% moisture content. Air-dried lumber often has a higher moisture content which can sometimes create gluing problems.

Core Curriculum

Plywood has several advantages over solid wood for speaker building. The grain of adjoining plies runs in opposite directions, so it has greater dimension and strength stability. Depending upon the cut of the veneers, the grain pattern of the exposed ply can enhance the wood's beauty. A wide range of sizes and thicknesses, along with special shapes, contribute to added flexibility in enclosure design. The outermost veneers are referred to as faces: the better of the two is called "the face"; the poorer is "the back." The center ply is "the core," and when there are more than three plies, the intermediate veneers are referred to as "crossbands."

Veneer-core is the conventional method of making plywood by gluing three, five, seven, or nine plies of thin veneers in a balanced construction. A greater number of plies reduces the tendency to twist. The plies are arranged in matched pairs on each side of the core, with each ply's grain at right angles to adjacent ones. You can sometimes buy lumber-core plywood which is made with a core of narrow, sawed strips as the central member. This plywood is especially useful for applications where there will be doweling, splines, dovetail joints, and exposed edges; however, it is often difficult to find.

Plywood grading is different for softwoods and hardwoods. If you are considering using a softwood, be aware that

Continued on page 60

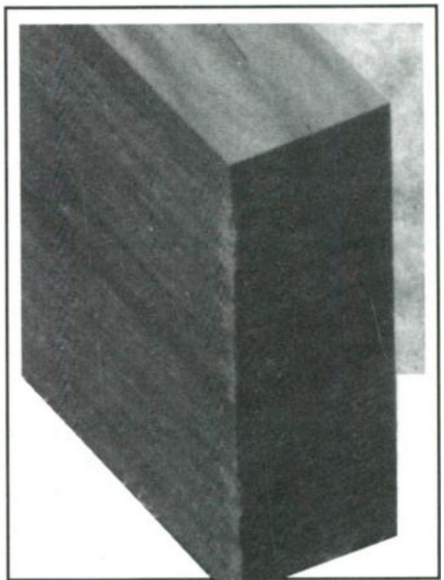


PHOTO 2: Quarter-sawed board.

PREVIEW
Audio Amateur

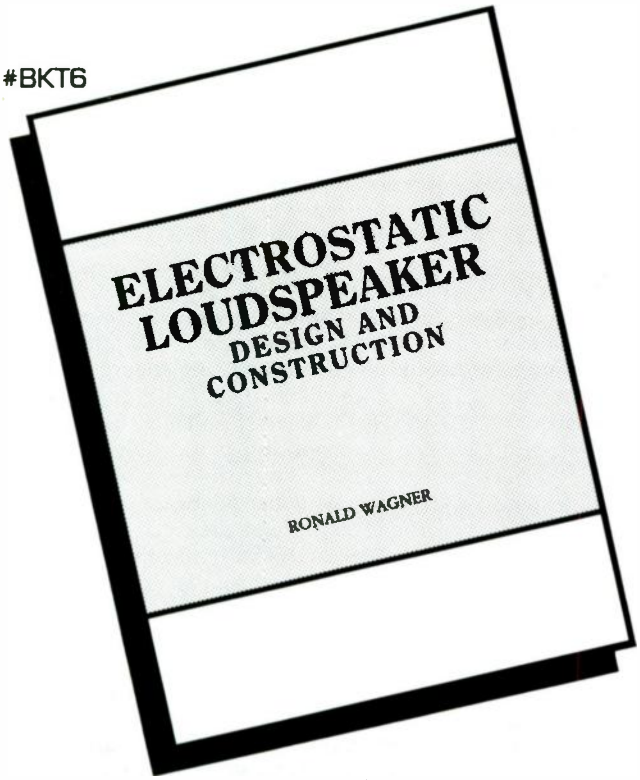
Issue 1, 1993

- Line-Level Preamp, Part I
- Continuous-Time Monolithic Filter
- A75 Power Amp, Part II

THE BOOK IS BACK!

$19.95

#BKT6



Second Edition, 1993. 7" x 9⅝", 256 pp.

ELECTROSTATIC LOUDSPEAKER
DESIGN AND CONSTRUCTION
by Ronald Wagner

NOW BACK IN PRINT BY POPULAR DEMAND AND SPECIAL ARRANGEMENT!

This classic, one of the most hard-to-find volumes in the loudspeaker field, is a slightly abbreviated version of that first published by TAB Books in 1987. Well known as both a "how-to" book and an informative text on electrostatic speakers, it will provide you with step-by-step sequences for building full-range electrostatics as well as acquaint you with their basic operating principles. Author Wagner also explains here the important parameters of an electrostatic speaker and indicates how each affects its performance.

Intended for the audio amateur, musician, or craftsman, this book is also a classic acquisition for anyone who is interested in this type of speaker and searching for the very best in sound reproduction. In addition, it provides a rich source of information for everyone involved in electrostatic loudspeaker research, repair, or restoration.

YES! Please send me ___#BKT6 @ $19.95 = $____.____

Plus shipping @ ___$3 USA ___$10 Other Surface

___$5 Canada ___$20 Other Air = $____.____

TOTAL ORDER = $____.____

☐ Check/money order enclosed. US funds drawn on a US bank. ☐ Mastercard MasterCard VISA Visa ☐

NAME ____ TODAY'S DATE ____

STREET ____

CITY ____ STATE ____ ZIP ____

COUNTRY ____ DAYTIME TELEPHONE ____

MC/VISA CARD NO. ____ EXPIRE DATE ____

OLD COLONY SOUND LAB
PO Box 243, Dept. B93
Peterborough, NH 03458 USA
24-Hour Lines:
Phone: (603) 924-6371
(603) 924-6526
FAX: (603) 924-9467

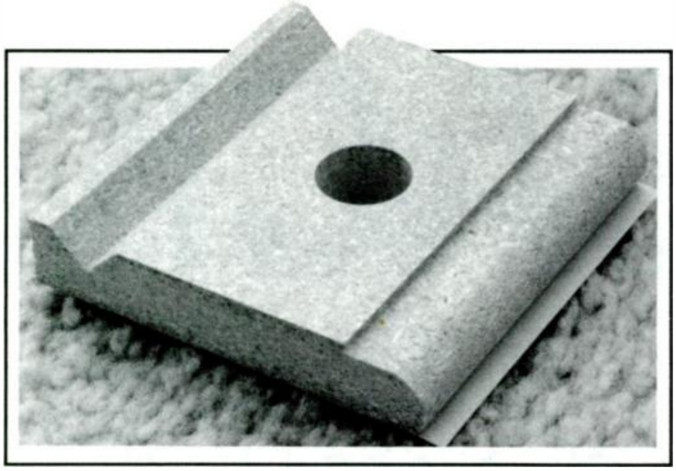


PHOTO 3: Boise-Cascade MDF.

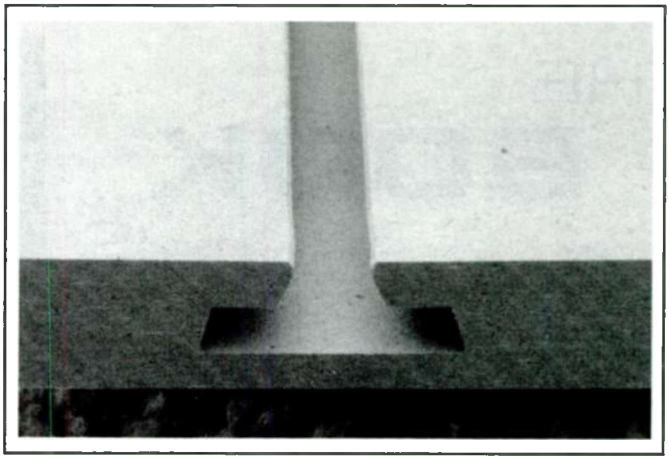


PHOTO 4: Norbord MDF.

Continued from page 58

there are often problems. The interior plies may have voids which will produce some unusual sound coloration, most often a buzzing at certain frequencies. Face grades are shown in *Table 1* with notations indicating the type of surface on each side. For example, A-B grade indicates that one side is grade A and the other is grade B. The core may be grade C or D, however, making the panel useless for speaker construction.

You will save yourself a great deal of pain by avoiding softwood plywood and restricting yourself to the hardwoods, sometimes referred to as furniture grade. These are graded by their face veneer status. Premium (A) is a clear-face veneer; all splices are tight and sound, although there may be occasional small burls and tiny pin knots. Most species are book or slip matched. This grade always has a Good Back veneer on the rear face.

The next grade downward is Good Face (B), which has poor face veneer matching. Smooth Back, or 2, is the third-level grade. The backside veneer is the same as the face veneers, with no open defects. Open holes and other objectionable defects are found in the Reject Back grade. Shop grade sometimes consists of downgraded A-2 panels, but can also be 2-2 panels. Avoid this grade.

Hardwood plywood panels typically have one A-Premium side; the other is a lower grade, such as A-1 or A-2. Be very careful when buying these, as A-2 sheets can contain drastic differences. The Premium A-2 will have a back which is very nearly Good (1), not a paint-grade with visible filler paste. Also, the Premium A-2 never has different species on the back side. Foreign manufacturers produce face veneers which are so thin that you will go right through the surface if you sand them. This seems especially true of the exotic hardwoods, but I have also encountered the problem in red oak.

If you are buying ¾″ plywood, be certain it is at least a seven-ply panel. A-2 is the most common grade, and a good supplier will have face veneers in ash, birch, cherry, genuine and Philippine mahogany, maple, red and white oak, teak, and walnut. The standard thicknesses are ⅛″, ¼″, ⅜″, ½″, and ¾″, with up to 2″ or thicker possible on special orders. Plywood edgings made of genuine wood, with precoated hot-melt glue backing, are a quick way of adding a nice surface to exposed edges with a hot iron. You can purchase preformed geometric shapes in customary cylindrical, quarter-rounds, half-rounds, or custom shapes.

Composite School

Particleboard's advantage is its uniformity in both surfaces and throughout the total volume, freeing it from internal voids and improving its acoustical properties. Its lack of grain simplifies many of the normal woodworking operations. However, it dulls tools quickly. A higher grade of composite board came into widespread use in the late '70s and early '80s. Particleboards are classified into low and medium densities; high-density categories are described in *Table 2*.

Most available sources will offer medium-density fiberboard (MDF). Flake board is high quality particleboard made from flakes which are cut with the grain to precise thicknesses and lengths; it has better woodworking qualities than most particleboard. You can buy plywood, hardboard, and particleboard with veneers and plastic laminate surfaces, or you can apply the surfacing yourself. For mat-formed, flat-pressed boards, you will find composite boards with MDF centers and high-density surfaces. Top-end producers try to limit the panel's density variation to 8% or less. While this may appear attractive at first, it can cause real trouble if you are making the joints for your speaker box using a cheaper grade of MDF, with a density variation which exceeds 25%. Each density group has two strength classes, with Class 2 being stronger than Class 1.

Many of particleboard's woodworking properties make it ideal for speaker enclosures. When screws and nails are driven perpendicular to the surface, they hold well if a suitable pilot is drilled. Random particle orientation means very little splitting. Particleboard is normally made so its center is less dense than near the surface, which causes fasteners driven into the center of panel edges to hold

TABLE 1

PLYWOOD FACE GRADES

GRADE	ALLOWED DEFECTS
A	*Football* or *Strip* Patches
B	*Football, Strip,* or Round Patches
C	Limited open defects
D	Open knotholes and splits

TABLE 2

PARTICLEBOARD DENSITIES

	DENSITY	
	PER. FT.³	GRAMS/Cm³
Low	< 37	< 0.59
Medium (MDF)	37 to 50	0.59 to 0.80
High	> 50	> 0.80

poorly. You can overcome this problem by gluing a solid wood strip to the troublesome edge. To illustrate the machining possible with high-grade MDF, consider the edge shaping in *Photo 3*. You can even rout out intricate shapes (*Photo 4*).

If you are using a high-grade MDF, it is unnecessary to apply crossbands before veneers. However, take care that both the veneer and the particleboard have approximately 6-8% moisture content. Also, to protect against moisture and increase dimensional stability, you should seal both MDF sides and edges. Use contact cement when applying veneers and plastic laminates; special screws are available for particleboard.

MDF-core plywood has the advantages of both plywood and MDF. Available thicknesses are ½" and ¾". The selection is not as wide as for veneer core plywood, but you should be able to find ash, birch, genuine mahogany, and red/white oak.

TABLE 3

MECHANICAL PROPERTIES OF MATERIALS

PRODUCT	MODULI OF ELASTICITY	POISSON'S RATIO
Walnut	1.4 to 1.7 × 10^6	0.035 to 0.72
Plywood	1.8 × 10^6	0.02 to 0.4
MDF, Class 1	250,000	0.3
MDF, Class 2	350,000	0.3
High Density	500,000	0.3

Property Values

Speaker builders should be aware of a material's acoustical characteristics, which largely reduces to consideration of vibrational properties. We can develop a few rules of thumb from studying the vibration of a board simply supported along its edges. The frequency of the fundamental mode of vibration of a perfectly elastic, homogeneous, isotropic material of uniform thickness (h), width (a), and depth (b) is given by:

$$f = \frac{\pi}{2}\sqrt{\frac{gD}{hd}}\left(\frac{1}{a^2} + \frac{1}{b^2}\right)$$

where:
d = weight/unit volume
g = acceleration of gravity

$$D = \frac{Eh^3}{12\,(1 - u^2)}$$ = flexural rigidity of plate (u is Poisson's ratio)

E = moduli of elasticity (psi)

A number of uncertainties exist. For example, "u" changes with boards cut for solid wood, but is approximately constant for MDF, and relatively constant for plywood. Typical values for building products are shown in *Table 3*.

For the same size, solid wood nominally vibrates at about twice the frequency of particleboard, with plywood a few percent higher than solid wood. These values will enable you to estimate whether a particular enclosure side might cause problems for your desired frequency range. At best, this is an approximation and you should test your enclosure. Solid wood properties vary considerably with moisture and sawing orientation, while particleboard and plywood tend to be more uniform and stable. For this reason, many speaker builders use MDF.

Conclusion

For different perspectives on these issues, I refer interested readers to several titles. The most useful of the currently available books is R. Bruce Hoadley's *Understanding Wood* from Tanon Press (52 Church Hill Rd., Box 355, Newtown, CT 06470). Another handy booklet is *Beautiful Woods* by Frank Paxton Lumber Co. (5719 W. 65th St., Chicago, IL 60638). The granddaddy of them all is the *Wood Engineering Handbook* by the U.S. Forest Products Laboratory, published by Prentice Hall. Even more useful is the specific literature available from manufacturers.

Personally, I choose solid wood whenever possible, mainly for aesthetic reasons. If you are buliding satellite speakers, this is a reasonable choice. When expense and uniformity of material are important, however, stick to MDF or the high-density fiberboard. You should also use materials at least ¾-inch thick. Veneered MDF offers a compromise which just might meet all of your requirements.

SOURCES

Educational Lumber Co.
PO Box 5373
Asheville, NC 28813
(704) 255-8765
(Mail-order supplier)

Eisenbrand, Inc.
4100 Spencer St.
Torrance, CA 90503
(213) 542-3576
(Mail-order supplier)

Northeastern Hardwoods
25 Morningside Ave.
Salamamca, NY 14779
(800) 235-8317
(Mail-order supplier)

Roberts Plywood Co.
150 Rodeo Dr.
Brentwood NY 11717
(800) 422-4944
(Will sell one-of-a-kind items)

IMP Audio Analyzer

Loudspeaker and crossover building is a whole new world when you can see what you are doing as well as hear the effects. The IMP (Impulse response Measurement and Processing) system works with your IBM-compatible computer and existing stereo amplification chain to go beyond simulation and provide sophisticated real-world measurements of impulse response, quasi- anechoic and live-room frequency response including phase, complex impedance curves, spectrum analysis, and even Thiele/Small parameters. Measurements can be made from frequencies as low as 2Hz or as high as 21kHz, at over 600 frequency points in a measurement!

The IMP module provides a test pulse and performs analog-to-digital conversion of your project's response from one of two probes or a microphone. The digitized data is transferred to your computer into its parallel port using the standard Centronics printer cable, so hardware installation of the IMP inside the computer case is not required.

The IMP software controls the IMP module for data collection and provides the extensive digital processing facilities. Features are truly too numerous to detail, but are illuminated in *SB* 1-3/93. Whether raw data is obtained from the module directly or from disk storage, the IMP program provides easily scaled and formatted views of frequency, time, or even 3-D waterfall responses, and can print the high-quality graphics on your Epson- or LaserJet-compatible printer. Requires 640K RAM plus Hercules, EGA, or VGA. Coprocessor not needed. Case, knobs, microphone housing, cables, and probe components *not* included. Hardware requires somewhat skilled assembly. Designed by Bill Waslo. Purchasing options available:

SOF-IMP1B5GD	IMP Software Demo 1 x 5¼" DS/DD	$ 5.00
SOF-IMP1B3GD	IMP Software Demo 1 x 3½" DS/DD	5.00

Note: Software demo cost is deductible from later purchase of full package.

SOF-IMP1B5G	IMP Software 1 x 5¼" DS/DD	49.95
SOF-IMP1B3G	IMP Software 1 x 3½" DS/DD	49.95
PCBW-4	IMP Double-sided PC board, unpopulated	39.95
KW-4	Unassembled IMP Kit, including software (please specify disk size), PC board, ICs, passive components, connectors, power supply, controls, microphone capsule	249.00
KD-2	Unassembled Old Colony Mitey Mike Test Microphone Kit	149.00
KD-2AMM	Assembled Old Colony Mitey Mike Test Microphone, with IMP calibration files on disk	209.00
KMW-4	Unassembled IMP Kit (as above) plus Unassembled Mitey Mike Test Microphone	389.00

P-FILTER Software — SOF-PFL1BXG — $25.00

P-FILTER is a passive crossover design program for 2- and 3-way second-, third-, and fourth-order allpass (APC) and constant power (CPC) networks. For the bandpass section of 3-way systems, the C or T topologies may be selected. Wiring diagrams, parts values, and response/phase curves are generated, and crossover designs may be saved into a disk file in the proper format for importing into the Loudspeaker Modeling Program (LMP). The network design values provided with P-FILTER are based on a resistive load at the output of the network and impedance correction networks are assumed to be in place for reactive loads. The use of P-FILTER requires some familiarity with crossover network design. By Sitting Duck. IBM PC or compatible; Hercules, CGA, EGA, VGA; dot matrix, LaserJet-compatible printers; 3½" and 5¼" DS/DD supplied. *Because P-FILTER is already supplied with LMP, owners of LMP should not purchase this package.*

SPEAKER SYSTEM DESIGNER Software

NEW FOR '93

New from Australia, SSD is menu-driven software that takes advantage of the VGA graphics capabilities of your computer. The program enables the designer to create and then evaluate and optimize 2- or 3-way loudspeaker systems prior to starting any assembly or building activities. Most errors or problems can be intercepted and corrected at a very early stage of the design with no cost penalties. Functions performed include driver reference library creation, loudspeaker enclosure design and optimization, compensation of driver impedance or amplitude irregularities, ladder network analyzer, crossover filter design and optimization, system frequency response evaluation and optimization, and frequency response estimate based on different enclosure placements. Also included are calculators for inductors, L-pads, round vents, series LRC, zobel networks, and impedance peak suppressors. By Bodzio. MS-DOS; 286+; 1Mb RAM required, 1.5Mb RAM recommended; VGA 640 x 480; LPT1: printer. 50-page manual. Purchasing options available:

SOF-SSD1B5GD	Speaker System Designer Demo 1 x 5¼" DS/DD	$ 5.00
SOF-SSD1B3GD	Speaker System Designer Demo 1 x 3½" DS/DD	5.00

Note: Software demo cost is deductible from later purchase of full package.

SOF-SSD1B5G	Speaker System Designer 5¼" DS/specify DD or HD	99.00
SOF-SSD1B3G	Speaker System Designer 3½" DS/specify DD or HD	99.00

MODES FOR YOUR ABODES Software — SOF-ABO1B5 — $25.00

This unique program helps acousticians and audiophiles in designing listening rooms or better understanding a room's sonic character. MODES is a menu-driven, user-friendly program that rapidly generates and prints out axial, tangential, and oblique modes, as well as predicts axial coincidences. Its database summary screen provides a convenient, rapid means of running multiple calculations and comparing many room sets. Supports standard text printing. By Joseph Saluzzi. IBM PC or compatible, MS-DOS 5.0+, 640K RAM, 1Mb free disk space. 1 x 5¼" DS/DD. From *SB* 6/92, 1-2/93. Article reprints included.

ALPAS-X ALLPASS CROSSOVERS DELUXE Software

ALPAS-X provides for the design of allpass in-phase (Linkwitz- Riley) crossovers for 2-, 3-, 4-, and 5-way systems for any choice of crossover frequencies. The bandpass natural response of the drivers can then be entered and its effect assessed, thus assisting in the correct selection of speakers. 2-ways are of order 2, 4, 6, or 8; 3-ways, of order 4 or 8; 4-ways, of order 6; and 5-ways, of order 8. Bandpass filters can be designed for different topologies, allowing a degree of level and input impedance adjustment. For each filter, voltage response in magnitude and phase is displayed, as well as input and output impedance magnitude. For air-cored coils, physical parameters for chosen wire gauges are shown, allowing immediate construction. The distorting effect of the inductor resistive losses can be corrected, allowing the design of accurate filters and the prediction of their flat losses. Filter design for Butterworth, Chebychev, and Bessel filters is also possible, with all the features listed above, including inductor loss correction. LP and HP filters are available of orders 1 to 8, and BP filters of orders 1 to 4. By Plinio Tissi. IBM PC or compatible; MSDOS; 512K memory; no mouse or coprocessor required. Purchasing options available:

SOF-ALP1B5G	ALPAS-X Allpass Crossovers Deluxe 2 x 5¼" DS/DD	$99.00
SOF-ALP1N3G	ALPAS-X Allpass Crossovers Deluxe 1 x 3½" DS/DD	99.00

OLD COLONY SOUND LAB
PO Box 243, Department B93
Peterborough, NH 03458-0243 USA
24-Hour Lines:
Telephone: (603) 924-6371 or
(603) 924-6526 FAX: (603) 924-9467

OUR DISCOUNT POLICY

Order Value	Discount
<$50.00	0%
$50.00–$99.99	5%
$100.00–$199.99	10%
>$200.00	15%

Mastercard, Visa, Check or Money Order in US funds drawn on US bank.

PLEASE BE SURE TO ADD SHIPPING CHARGES
Shipping Charge According to Destination and Method Desired ($)

	United States		Canada		Other	
Order Value	Surface	Air	Surface	Air	Surface	Air
< $50.00	3.00	7.50	5.00	7.50	10.00	20.00
$50.00–99.99	4.00	15.00	7.50	15.00	20.00	30.00
$100.00–199.99	5.00	20.00	15.00	20.00	30.00	40.00
> $200.00	6.00	30.00	25.00	30.00	40.00	50.00

NEW FOR '93

PROJECT TRACKER Software — SOF-PJT1BX — $34.95

Also sometimes known as G'DAY MATE, this package is a daily diary and freeform text notebook for keeping track of things around the home, shop, and office. The diary portion allows for making daily entries, reading past entries, and searching past entries for key words and phrases. Of the 54 freeform, 300-line text files available, 4 may be password-encrypted. One of these, entitled DATA, may be where you choose to record key numbers, serial numbers, account numbers, and other things of a sensitive nature. One text file is dedicated for use as a Rolodex. In addition, there are an unlimited number of other freeform files which can perform elementary math calculations. These can be used for expense tracking, as a duplicate check register, a household inventory, and so forth. Batch files can be launched from within PROJECT TRACKER so that you can run other programs, such as your word processor, and then return. Also provided are a timer, an alarm, an appointment book, and a tickler file. By Sitting Duck. IBM PC or compatible; hard drive recommended; 3½" and 5¼" DS/DD supplied.

ELEKTOR ITEM TRACER Software — SOF-EIT2B5 — $7.95

Elektor project builders can now use this special software downloaded from the Dutch *Elektuur*'s internal files. Although WRITTEN IN DUTCH, EIT provides the manufacturer (name only) for more than 2700 hard-to-find European parts used in *Elektor* projects from 1982-1991. Menu-driven and including a short list of translations for key words and phrases, this detailed index is cross-referenced by ten different parameters, including part number and article title, and requires 4Mb of hard drive memory. Despite the language gap, EIT is fun to use and easily mastered in less than an hour--to provide a lifetime of reference value for anyone involved with electronics. By Paul Hogenboom/*Elektuur*. IBM PC or compatible; 2 x 5¼" DS/DD.

NON-OPTIMUM VENTED-BOX SPREADSHEET Software — SOF-NOS1B5 — $25.00

This spreadsheet calculates an optimum vented-box alignment based on Q_{TS}, V_{AS}, and f_S, and a non-optimum alignment based on f_S, V_{AS}, and V_{Box}. The results of these calculations are quite accurate, even though they are only approximations, and both sets appear on the screen at the same time to allow for comparison. The program runs in the protected mode, which means that you can enter data only into certain cells, thus protecting the spreadsheet formulas. Input is broken into three groups: Thiele/Small parameters, electrically adjusted Q_{TS}, and the known driver/enclosure combination parameters. Output includes the parameters for both optimum and non-optimum enclosures, ducted port calculations, and a vented response sensitivity table. By Paul E. Rahnfeld. Written with Quattro; Lotus 1-2-3 1A and 2.0 translation files included. IBM PC or compatible; 1 x 5¼" DS/DD. From *SB* 5/92; article reprint included. PLEASE NOTE THAT SPREADSHEET SOFTWARE SUCH AS QUATTRO OR LOTUS 1-2-3 IS REQUIRED AND NOT SUPPLIED WITH THIS PACKAGE.

FITDUCT Software — SOF-DCT1B5 — $25.00

This interesting timesaver provides for computer-assisted vented-box tuning by utilizing a new, more accurate duct-length calculation method, thereby eliminating the customary "cut and try" procedures. The program also can plot the box fitting curve and measured points. By Homero Sette Silva. IBM PC or compatible; 1 x 5¼" DS/DD. Appearing in *SB* 4/93; article reprint included.

MEPEG Audio Response Measuring System

Now available in North America for the first time, this system is a classic example of fine German engineering. With the help of a 286 or higher PC, MEPEG performs its measurements using the computer's parallel port and sound generator. Functions include SPL measurement (loudspeaker amplitude response); automatic Thiele/Small measurement and evaluation; impedance measurement; level measurement (*e.g.*, to evaluate signal-to-noise ratio); voltmeter; and function generator.

The hardware includes a 5W power amp to directly drive a speaker, as well as an individually calibrated and compensated measuring microphone to give linear response. The IBM-compatible software allows extensive curve processing and user functions such as curve smoothing; octave smoothing; average/difference evaluation of up to 30 curves; presentation of up to 30 curves in one diagram; and much more. Output to color screen or hard copy.

Technical data: frequency range, 20Hz-20kHz; voltage range, 0-7000mV; resolution, 13.8 bit (83dB); overall accuracy, 0.2dB. From *ETI Electronics Today International* (UK) 11-12/92. Article reprints included with purchase or available for 8½ x 11 self-addressed envelope plus $1. Designed by Ralph Mantel. Purchasing options available:

SOF-MEP1B5G	MEPEG Audio Response Measuring System Software 5¼" DS/DD	$ 89.95
SOF-MEP1B3G	MEPEG Audio Response Measuring System Software 3½" DS/DD	89.95
HDMCM-13	MEPEG Calibrated Microphone	99.95
PCBM-13	MEPEG PC Board, unpopulated	24.95
KM-13M	Unassembled MEPEG Kit, including software (please specify disk size), PC board, components, WITH microphone	399.00
KM-13	Unassembled MEPEG Kit, including software (please specify disk size), PC board, components, WITHOUT microphone	329.00
KM-13A	Assembled MEPEG Audio Response Measuring System, complete	599.00

OLD COLONY EASY ORDER FORM

QTY.	ITEM NO.	PRICE EACH	TOTAL
			$
			$
			$
			$

❑ FREE CATALOG

SUBTOTAL $

Less Discount $

SUBTOTAL $

PLUS SHIPPING from chart $

TOTAL ORDER $

PLEASE BE SURE TO ADD SHIPPING CHARGES. PLEASE REMIT IN US DOLLARS ONLY, DRAWN ON US BANK. PAYMENT BY: ❑ CHECK/MONEY ORDER ❑ MASTERCARD ❑ VISA

NAME TODAY'S DATE

COMPANY

STREET

CITY ST ZIP

COUNTRY DAYTIME TELEPHONE

MC OR VISA EXP.

OLD COLONY SOUND LAB
PO Box 243, Department B93
Peterborough, NH 03458-0243 USA
24-Hour Telephone: (603) 924-6371 or (603) 924-6526
24-Hour FAX: (603) 924-9467

Craftsman's Corner

Marchand Crossovers

A neighbor bequeathed me a pair of AR-3a speakers. After replacing the decayed foam surrounds, I decided they could be used to supplement my modified Dynaco A-25's bass performance. The Dynacos stop dead at around 45Hz, while the ARs go down to 30 or so.

My neighbor also gave me an old Harman-Kardon 730 receiver with a very nice amplifier section: separate power supplies for each channel, decent components, and the ability to disconnect the preamp/tuner and directly feed the amplifiers. It sent 60W into the AR-3a's 4Ω, nicely matching my Adcom GFA-535's 60W into the Dynacos' nominal 8Ω.

I needed a pair of active crossovers to bi-amp my recycled subwoofers. Marchand Electronics (1334 Robin Hood Lane, Webster, NY 14580, (716) 872-5578) offers a very well reviewed and reasonably priced line of crossovers. I ordered a pair of XM-1 24dB/octave kits and a handful of different frequency modules, and received them in less than a week.

Each crossover channel is on a 2″ × 3″ single-sided silkscreened circuit board, and holds three small integrated circuits, four film capacitors, a pot, two power supply electrolytic capacitors, several metal film resistors, and two connectors. It took about an hour to assemble both boards.

I started out with the 60Hz frequency module, mounting and wiring the boards to a pizza-sized enclosure with a dual +15/−15V supply. Total build time was no more than three or four hours.

When I hooked up the new crossovers, amp and subwoofers, they unquestionably worked. The Dynacos sounded the same, but with a palpable presence, where before there had been silence. Now I could sense the size of the hall, and feel the space and pressure of the low-register instruments. Live recordings took on a reality I'd never heard before.

Problems remained, however: a 60Hz hum in one channel disappeared only when I grounded all the input and output grounds to the chassis ground; the H-K amplifier's speaker selector switch was corroded and had to be cleaned; and one of the AR-3as had an intermittent, which has yet to be tracked down and corrected. Otherwise, the adventure went smoothly.

I now want to know how bass response down to 15Hz would sound. Quick, hide my checkbook!

Len Moskowitz
Teaneck, NJ 07666

SB Mailbox

THE FARAD FAMILY

The picofarad (pF, 10^{-12}) is the unit of lowest capacitance. The nanofarad (nF, 10^{-9}) is a unit of medium capacitance. Stated another way, 1,000,000pF = $1\mu F$ (miocrofarad, 10^{-6}); 1,000pF = 1nF; 1,000nF = $1\mu F$.

micro nano pico

1.000,000

ERRONEOUS EXTRACT

(John Cockroft's article, "The Simpline" [SB 2/93, p. 14], contains a text misprint affecting several paragraphs. Under the heading "Assembling the Enclosure" [p. 16], the following is the text as it should have appeared, beginning with the last paragraph in column two. We apologize for the confusion.—Ed.)

Before assembly, drive the nails partway into the wood. It's a good idea to line up one of the other sides along the nail line. Hold the nail to be driven against the edge of this board to ensure that it will be driven vertically. Drive the nails at the ends of the boards so that their points are just showing. The other nails need not be driven quite that deep.

Take one of the 5″ boards which has been preglued, and place it on edge on a hard, flat surface such as the garage floor. Take another 5″ board and stand it on edge against the first one so it forms a "T." Run a healthy bead of white glue along the top edge of the first board. Then place one of the wider boards with the nails (also preglued) on top of the first board so their edges and ends align. The board should rest on the other leg of the "T" and be square in all directions.

Carefully drive the end nail as straight as possible partway into the 5″ board. Then line up the boards along their entire lengths, and drive the nail at the other end all the way into the 5″ board, taking care that everything stays square. Finish driving the first nail, then drive the remaining ones.

Wipe any excess glue from the outside of the joint with a damp rag or paper towel. Using a paste brush, an acid brush, a cotton swab, or your finger, smooth out the excess glue at the seam. Let it dry enough so it won't run when the boards are turned over.

Attach the other 5″ board the same way. It is important that all the ends line up so the baffle will have a level surface on which to rest.

WONDER MODS

Bill Schwefel's "Korean Wonder" ("The Wonder of a Symmetrical Isobarik," *SB* 5/90, p. 10) inspired me when I needed small speakers for my daughter's dorm room. I built an Isobarik using a single pair of Radio Shack woofers instead of two, and a Dynaudio D-28 AF instead of the Morel.

I made the enclosures from ⅞″ solid cherry; finished dimensions are 6″ wide, 1′ high, and 9″ deep at the base. The front slopes 10° from base to top. Instead of making a tunnel, as in the original, I found that a section of 4″ poly sewer pipe 2¾″ long was exactly the right size. I mounted it in a hole in the front baffle, lined it with felt, and epoxied the rear speaker in place.

The woofers are in parallel (4Ω instead of the eight in Schwefel's design), so the series inductance is halved and the capacitor doubled in size. The zobel is comparably adjusted to a 4Ω resistor in series with a $50\mu F$ np electrolytic. I raised the series resistor in the tweeter leg from 3-6.5Ω to compensate for the lower output from the single woofer pair.

Instead of Acoustical Magic, I used NDM "Noise and Vibration Damping Material," which seems to have the same properties. Two coats built up to more than ⅛″, and left a stone-like coating on the cabinet's interior walls. I rounded the cabinet's front vertical edges, and the contrast of black speakers with cherry enclosures is very pleasing. I didn't use a grille cloth, but put a foam ring around the tweeter and glued some fiberglass screening over the hole.

I haven't run tests, because the customer in Chicago is waiting eagerly for them. But I listened to them in a 20′ × 22′ room with a cathedral ceiling and was amazed at their sound clarity, smoothness of reproduction, and excellent three-dimensional soundfield. I recommend this modification to anyone looking for very small speakers whose performance won't embarrass you, wherever you use them. Thank you *SB* and Mr. Schwefel.

Alan P. Towbin
Bethany, CT 06525

Bill Schwefel responds:

I'm glad to hear of your favorable experience with the Isobarik approach. My "Wonders" continue to impress me as the least colored speakers I have ever built.

Using Ralph Gonzalez's LMP program, I ran a model on your modified crossover and cabinet. *Figure 1* is the predicted phase and magnitude response assuming normal tweeter polarity (in phase). *Figure 2* is a reversed tweeter connection (180° out of phase). *Table 1* shows the LMP values. I did not use a step response adjustment, because I accounted for this in the model.

You might try reversing the tweeter polarity to see which connection sounds best. As you can see, the main effect is in the phase plot. The magnitude plot remains somewhat stable due to the 10° baffle slope from top to bottom.

Your letter started me thinking about why some Isobarik speakers sound better than the same single speaker in a cabinet of double volume. From what I can gather, the only difference should be a 50%

Glad you asked that!

Good Idea!

You really have some great ideas, so why not share them with your fellow readers? We love to receive typed letters (or even better, a word processor file or output) including clearly written comments and questions. Not everyone's penmanship is easily discernible—please don't make us guess.

If you are responding to a previously published letter or article, please identify it by author; it helps us research and get the answers or comments you seek. In addition, please include your full name and address on your letter in case we need to contact you (and your envelope goes south).

Direct your comments, questions, and concerns to *Speaker Builder*, PO Box 494, Peterborough, NH 03458-0494.

One more thing . . . a SASE always puts your letter on the top of the pile.

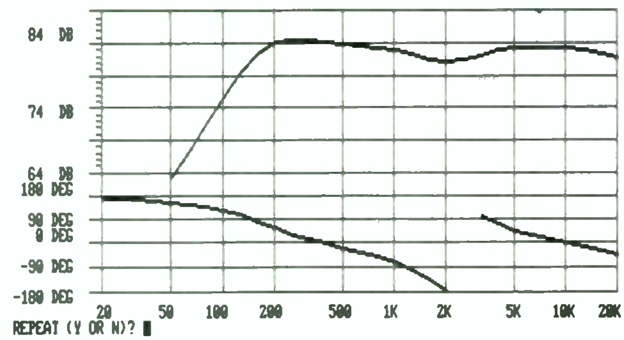


FIGURE 1: Normal tweeter polarity.

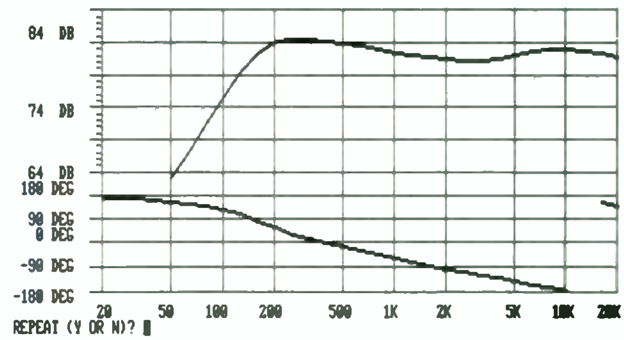


FIGURE 2: Tweeter polarity inverted.

reduction in V_{AS}. If you double the cabinet size, you can use one less speaker and still have the same sound characteristics at lower frequencies.

The above assessment, however, does not account for the differences I hear. During the initial design, I conducted lengthy listening tests of the single sealed box (double cabinet size) versus the Isobarik sealed box (one-half cabinet size). The Isobarik was much less colored and boxy than the single speaker.

TABLE 1

TOWBIN MODIFICATION LMP VALUES

Driver Number 1	
Corner frequency of low-frequency roll-off	170
Low-frequency roll-off damping ratio	0.55
Corner frequency of high-frequency roll-off	4.5k
High-frequency roll-off damping ratio	1.2
Order of high-frequency roll-off	2
Polarity inversion (yes or no)	N
Sensitivity of driver (decibels)	84
Depth displacement (inches)	−0.3
Frequency of response step	0
Height of response step	0
Identification number of crossover	5
Value of component K0	3.5
Value of component K1	10E-6
Value of component K2	3.5E-4
Value of component K3	−1
Driver Number 2	
Corner frequency of low-frequency roll-off	1.2k
Low-frequency roll-off damping ratio	0.85
Corner frequency high-frequency roll-off	40k
High-frequency roll-off damping ratio	1
Order of high-frequency roll-off	2
Polarity inversion (yes or no)	**
Sensitivity of driver (decibels)	84
Depth displacement (inches)	0
Frequency of response step	0
Height of response step	0
Identification number of crossover	6
Value of component K0	6.7
Value of component K1	1.25E-3
Value of component K2	7E-6
Value of component K3	−1

**N (*Fig. 1*), Y (*Fig. 2*)

In his initial article on the Isobarik system ("An Isobarik System," *SB* 3/85, p. 7), John Cockroft came to much the same conclusion.

I reasoned then, as now, that the Isobarik's rear speaker partially isolates the forward-facing speaker from the reverberant field inside the box. It sounds cleaner with tighter bass, not because of greater power handling or better transient response, but because the speaker cone is not subject to the same degree to box-induced coloration caused by internal sound waves reflecting back and striking the rear of the cone.

We spend lots of time and energy building solid cabinets for our speakers, which may be 2 or 3″ thick. We do this to prevent unwanted cabinet vibrations from coloring the sound. But isn't the speaker cone usually paper thin? If you were an out-of-phase sound wave and wanted to escape from the box, would you not go through the cone instead of a 3-inch-thick side wall? I know I would!

Try the following experiment. Take three small woofers and build two cheap test boxes, with one box double the size. Mount a single speaker in the larger box and the other two speakers face to face in the smaller box, then reverse the polarity to bring them back into phase. Do not put damping material in either box. Put on an album or CD, listen and compare. The difference in sound will shock you.

Good luck with future projects. If you try the above experiment, let me know what you think.

MATTERS OF IMPORT

I would like to offer a few comments on Bill Waslo's very interesting IMP article in *SB* 1/93 (p. 10). First, not having to open the computer to install it is a great advantage. Also, a club can build one and let members borrow it (or does that present a software license problem?). I think the market goes up if the software license is the same as Borland's, or at least it did when last I bought from them. You can use the software with as many computers as you wish, but only one at a time. Is the IMP rigged so software runs only when it is attached?

My biggest concern is assembling the Insulation Displacement cable. I have all the necessary tools, but recall the intermittent problems of those who have tried it via other approaches. I for one would pay extra for the assembled cable. (Has Old Colony given any thought to an assembled cable option?) Also, the article states that you can use discrete wiring with a single ground wire. I hope this has been checked out, as it violates all the concepts of high-frequency data communication.

Good data cables have every other wire grounded, which gives the wires a controlled impedance to minimize reflection problems and reduces crosstalk. For maximum EMI rejection, all the grounds should be tied together at both cable ends. I would never pass a design with a bundle of individual wires and a single ground, but perhaps the data rates and edges are slow enough so no problem will develop. I just hope it has been tested.

My other concern is the test pulse shape. When unit impulse testing first appeared, everyone thought it was the answer, and it was examined for Sonar transducer testing. However, it violates two important principles of good testing:

1. Never test with a signal that the unit will not handle linearly.

2. Always test with a signal that is contained in the measuring receiver's bandwidth. When you test with a wide-band signal, anything outside one FFT filter cell represents noise to that test bandwidth. A single driver's response fall-off may not be accurately displayed if the filter slopes are not steep enough.

I thought it was accepted that impulse testing does not yield results which agree with other classical approaches. Even *Stereophile* went back to testing Sonar transducers with a shaped burst of sinusoid (not unlike the Linkwitz shaped-pulse) and time-gated receivers. Most of the newer computer-oriented approaches seem to have strayed from testing with a single wide-band pulse.

The IMP appears to use a rectangular pulse, which is much milder than a unit impulse, but still of rather wide bandwidth. The amplifier may distort the pulse (slew limiting) which the IMP corrects for, but the speaker system (drivers or crossover components) may behave in some nonlinear fashion which is not corrected for. Do the FFT filter cells have the needed slopes with 12-bit data input? To date the article leaves some unanswered questions.

The IMP also brings in a single-ended cal signal from the amp output. Many amplifiers do not have the low speaker output terminal at ground. The cal probe hot lead has a protection resistor, but if the ground lead is hooked to an amp with a "hot" speaker low terminal, large currents could flow, as the IMP is tied to amplifier ground via the test signal input. *Figure 3* shows the amplifier output pulse with the same polarity as the input pulse. If the test amplifier is inverting, does this mess up the measurement's phase shift curve, or does the software correct for it?

G.R. Koonce
Liverpool, NY 13088

Bill Waslo responds:

Mr. Koonce has addressed some important issues about the IMP project, which should be clarified.

I should have included in Part One the caveat that power amplifiers with one output lead grounded should be connected only to an actual ground connection (or left unconnected), and the probe hot lead should connect only to a ground reference signal. This rules out using bridged (and many tube) amplifiers and certain switching designs. Please check amplifier documentation carefully before connecting the IMP probes to its output.

A second issue concerns the rise time of the square pulse the IMP uses as a test signal. Its fast slopes can cause nonlinear effects in some amplifiers, and even some passive components. When measuring speaker systems, amplifier behavior will usually be normalized by the cal process, but accuracy may be adversely affected in other situations. Measurements of active crossovers, equalizers, and some iron-cored inductors may give misleading results when measured using the IMP raw pulse. A simple bandlimiting filter, as shown in *Figure 1*, can do much to avoid this possibility.

I should emphasize that the circuit's test pulse output signal level is 5V peak. Many active circuits, such as equalizers, cannot linearly handle a signal of this magnitude. If U7 is an "HC" CMOS type, the pulse output can be easily attenuated to a more manageable 1.5V by soldering a 1kΩ resistor from the IMP pulse output connector hot lead to ground. If a film capacitor of approximately 5nF (0.005μF) is also soldered in parallel across the 1kΩ resistor, first-order bandlimiting of the test pulse is achieved as well. These parts are easily obtained, and can be installed across J4 from either side of the board.

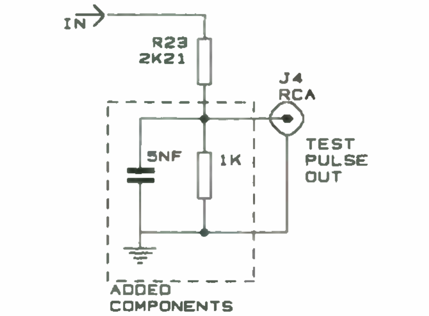


FIGURE 1: Output attenuation and bandlimiting.

Mr. Koonce points out that the IMP may inaccurately portray measurement of drivers or networks with very steep response slopes, and there may indeed be limitations. His concern, as I understand it, is as follows: the finite extent of an acquired time sample limits the steepness of a frequency response transition which can be resolved. An infinite slope "brick wall" characteristic, for instance, would have an impulse response that rings forever. Transformation of a finite time period of this eternal signal, such as would be acquired by IMP (or MLSSA or LMS), into a frequency response curve would result in spillover as noise and an inaccurate measurement.

I haven't noticed any problems attributable to this effect, but the comment seems valid. In other words, very abrupt frequency response magnitude behavior should probably be double checked for ultimate accuracy using sine-wave techniques (although even these tests must necessarily be time limited). Perhaps some theoreticians out there will elaborate on this?

You may encounter difficulties with very long parallel port cables, especially if you use a discrete wiring connector for J5, and connect it to the board with a signal common ground lead. I have successfully used a 15′ cable, but haven't tried longer ones. Fifty-foot runs are not recommended. The Insulation Displacement cable assembly for J5 (supplied assembled in the kits) reduces EMI radiation and pickup. When using a discrete-wire type connector for J5, keep the lead lengths down to a few inches, or run twisted pairs with individual grounds for each signal line. If interface problems occur, you might try a shorter parallel port cable or a non-shielded type.

In addition to Mr. Koonce's highly valid comments, other errors or advisable changes regarding the IMP have come to light. I include them here for your edification.

Figures 10 (p. 16) and *13* (p. 22) show Pin 32 of J5 unconnected. This pin *must* connect to the signal "go" (Pin 5 of U14), or the system will not operate. If you are building with a PC board, and are using an IDC connector to J5, this will be done automatically and only the documentation will need to be changed. In addition, change Pin 35 in *Fig. 13* to "unused."

In some parallel port cables, crosstalk and noise between lines can scramble the computer's control signals and cause the IMP to acquire only noise, "hiccup," and seemingly repetitive sections of the same response. It can even cause the software to time out and not recognize the IMP module. This seems to be related to the type of computer and cable being used, and perhaps radio-frequency interference near the system.

To fix this problem, add three 1nF (0.001μF) capacitors rated at 25V or more to input buffers U11 and U12, which will prevent false triggering. The capacitors can be virtually any type, although ceramic disks are preferred. They should be mounted on the board's solder side with short lead lengths as follows:

- One capacitor from U11 Pin 13 to U11 Pin 7
- One capacitor from U11 Pin 9 to U11 Pin 7
- One capacitor from U12 Pin 9 to U12 Pin 7

You can extend the positive output voltage range of the TLC274 CMOS quad op amp by adding a 10k (5%) resistor from U17 Pin 14 to U17 Pin 4. This will allow use of almost all the MAX190's input range, rather than only about 90%.

The following part substitutions are acceptable:

- U17: TLC2274 (any suffix) or TLC274A. (The TLC2274 doesn't need modification #5, above.)
- U18: MAX191BCNG (new part).

The IMP was intended to maximize performance using minimum hardware and expense. I believe this has been achieved, and the response so far has been gratifying. As with any tool, however, limitations should be recognized and taken into account. Reader comments, questions, suggestions, or criticisms are encouraged.

BASS RELIEF

Alex and I would like to offer a few additional insights about the Brother Jon which have arisen since publication of our construction articles (*SB* 4/92, p. 10; 5/92, p. 22; 1/93, p. 44). They stem from several comments that the midrange and tweeter units are too bright, which we have concluded is the result of an overly-attenuated bass.

While this may seem like heresy in view of the TL's reputation for bass, the problem probably arose because our workroom is very small. When we tested the speakers, we placed them near the room's corners, and the balance across the three drivers sounded about right to us. When we later played them in a larger room, with the enclosures away from walls and corners, bass output fell off. One of amateur speaker building's perils is being unable to test drivers without room reflections throwing you off track. Our experience is a good reason why Bill Waslo's IMP articles (1/93, p. 10; 2/93, p. 30) should be seriously considered by all *SB* readers.

If you are thinking of using the speakers in a large room, we suggest that midrange and tweeter output be attenuated 3-6dB relative to the woofer. You can make a 6dB L-pad by using a 4Ω resistor in series with, and an 8Ω resistor across, the driver to be attenuated. Alternatively, use a variable L-pad (available from Radio Shack or MCM Electronics) and find the adjustment point that sounds best to you. If you don't care to leave the variable type in the circuit, you can then compute the required fixed resistor values using the formulas in Vance Dickason's *Loudspeaker Design Cookbook*, and use the L-pads again in your next project.

Robert J. Spear
Alex F. Thornhill
Accokeek MD, 20607

(The Loudspeaker Design Cookbook *is available from Old Colony Sound Lab.—Ed.)*

INFINITY HUES

I have a Zenith/Bose 27″ color console TV in my living room. On either side are a pair of Infinity three-way speakers on 8″ stands. The drivers roughly align with the TV screen (tweeter on top, mid-range in the middle, woofer at bottom). The speakers are roughly 8–10″ from the sides of the TV.

As you have probably guessed, the drivers' magnetic field(s) are causing disruption to the picture tube's color purity. Because of a doorway on one side of the TV and the opening to my dining room on the other side, I am unable to move the speakers any further from the TV. At the distance I currently have the speakers, the problem only affects the four corners of the screen: two are blue and two are yellow.

Is there a way to "isolate" or "disrupt" the magnetic fields of the Infinity drivers? Perhaps other magnets placed inside the cabinets or around the driver magents? Complete isolation is not needed.

These are the speakers I had before I got interested in building my own. My wife is very fond of them, and there is really no other practical place in the room to put them. Any help you can give me will be greatly appreciated.

Charles Pelosi
Piscataway, NJ 08854

CALSOD CROSSOVERS

I just received my updated version (1.30) of CALSOD, and would like to pass along my first impressions.

CALSOD has improved with such additions as bandpass boxes, modeling diffraction loss, easily removed circuit elements without renumbered nodes, and many different module and submodule descriptions. Both video and printer control is enhanced; screen dumps may now be written to files for exporting to other programs; optimization is faster, and so on. Rarely have I seen such well-managed product evolution. My remarks in "The Danielle" (*SB* 4/92, p. 22, and 5/92, p. 34) are even more true today.

The program contains an impressive amount of error-free code for the price, and a 250-page instruction manual. If you have access to a computer, this program is definitely a more cost efficient means of producing good sound than fancy cabling or exotic spiked feet. Used wisely, it will give you a very good crossover. In my experience, the crossover design is the single greatest determining factor for success or failure of home-built speakers, once you've learned the basics.

Marc Bacon
Ascot Corner, Quebec JOB 1AO

Enclosure

continued from page 14

a success when used in a subwoofer, although I can't say how it would fare in a full-range system. I wouldn't hesitate to try it, however, if I had a design that incorporated a downward-facing woofer. Things rarely turn out the way they are originally conceived, and this project was no exception. But I learned a lot, and had fun doing it. Isn't that what it's all about?

Classified

TRADE

BANDOR 50 mm aluminum cone-drive units, made in England and built with exceptional quality. Response 100–22kHz ± 1.5db, 35W rms, fs = 75Hz with unbelievable low distortion and electrostatic like transparency. Four models in stock. Call for reviews and more information. ***EN INNOVATION*** (916) 421-8935. T4/93

ROOM ACOUSTICS HANDBOOK *Get the Most Out of Your Room*, $14.95. Vibration isolation feet, improves imaging and bass, for equipment and speakers. ***MACH 1 ACOUSTICS***, RR2 Box 334A, Wilton, NH 03086, (603) 654-9826. T1/94

EXCITING NEW COMPANY! *SPEAKER-SCULPTURE.* Transmission lines. Remarkable designs, look like scupltures, not speakers. Extraordinary sound. Satisfaction guaranteed. For a brochure call; (914) 516-2896, write; Speaker-Sculpture, 2 Division St., New Rochelle, NY 10801. Buy Direct/Save! American made. T3/93

OMNIDIRECTIONAL ADD-ON SUPERTWEETER 7 to beyond 20K. Extremely Smooth. Call/write G. Mueller, R.R. 3, Box 541, Glen Gardner, NJ 08826, (908) 537-6245. T3/93

DUO-TECH cable enhancer ($150) $125, ADS model 10 time delay system $130, Signet/MK10t step up transformer $30, Simply Physics standard isodrive/new $95, Vifa D19TD-03-8 new $18 pr., LASER ILLUSION aperture for PHILIPS ROTEL MOD SQUAD type players $65, four black Echotunes $65, four black Cornerturnes $65, two grey Roomtunes $190, Magnavox CDB 614, $225 new, Philips FR50 $250, Terk P12 $60, Terk wedge $50, QED Digit D/A modified $300. Mike, (708) 587-4134 before 2 p.m. T3/93

SPEAKER COMPONENTS IN WESTERN CANADA. Inter Technik Quality Crossover components, Hart Professional Loudspeakers, Orevox Loudspeaker. Call or write for our free catalog to; ***RIGG AUDIO DISTRIBUTORS***, PO Box 787, Kelowna, B.C. CANADA V1Y 7P4 or call (604) 862-9399.T6/93

COMPLETE SPEAKER SYSTEMS AND KITS from 5″ two-way to 12″ three-way, sub-woofers, high-definition systems. Oak, black piano, and texturelac finishes. FACTORY DIRECT PRICING. ***SPEAKER-WORLD TECHNOLOGY*** (510) 490-5842, FAX (510) 490-1961. T1/94

PUT MORE WHAM! in your low end with our twelve-gauge Music Coils. Please call or write for our complementary catalog. ***NORTH CREEK MUSIC SYSTEMS***, Route 8, PO Box 500, Speculator, NY 12164. (518) 548-3623. T3/93

FOR SALE

New focal 8V416 $50, plus shipping. Chet Parkinson, Los Angeles (310) 823-0124.

Three-way truncated pyramids, acoustic suspension, 8″ treated paper woofer midrange chamber, superior composite construction, formica (black) shell, grey fleckstone baffle, 33″ tall, great sound, designed sans grill, striking looks, custom built, just broken in, $600. Also mini pyramids double 4″ woofers, tweeter top mounted same finsh $250. Derek (914) 576-2896.

SPEAKER BUILDER CLASSIFIED ORDER FORM

PLEASE FILL OUT IN CLEAR BLOCK LETTERS OR TYPE. PLEASE SPELL OUT ENTIRE WORD.

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50

☐ Private For Sale ☐ Private Wanted ☐ If Trade, please indicate # of insertions ______
$10 minimum per insertion

Private For Sale ads are for *non-profit* use. Individuals selling items for retail/profit should be using **Trade** ads. **Private For Sale** and **Private Wanted** ads are on a one-time insertion basis. Ads **must** be resubmitted for renewal. **Ads will not be taken over the phone. ILLEGIBLE ADS WILL BE DISCARDED.**

Definition of a word: A series of letters with a space before and after. Count words, not letters. Any words over 50, 20¢ per word. Trade ads are $1.00 per word and indicate number of insertions. Deduct 5% for a 6x contract in *Speaker Builder*. **Payment MUST accompany ad. No billing.**

Please remember to include your name, address and telephone number. In order for Private For Sale and Want ads to be **free**, you must be a current subscriber.

Please charge to my MasterCard/Visa:
Ten dollar minimum for charge card orders.

CARD NUMBER EXP. DATE

☐ *Check/Money Order Enclosed* ☐☐☐☐☐☐
Account Number

NAME

PHONE

COMPANY

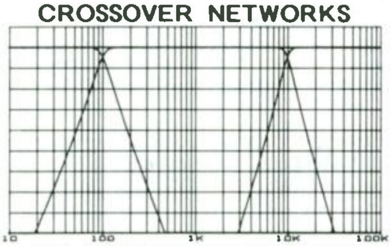
STREET & NO.

CITY ST ZIP

ULTRA CAP—8mfd 200V ± 10% polypropylene, 1,200 available. Axial lead 2" × 1", 10 for $15, plus shipping. 4.75mh steel transformer type choke coil, $1.50/ea. Steve Slater (818) 248-0416.

Nice rigid walnut speaker cabinets I.D. 22½" × 14½" × 9⅛", 8" speaker cutout, black grills, $80/pr., 8" 8Ω polypropylene 40oz magnet speakers $60/pr., Realistic 2" × 6" #40-1379 horn piezo tweeters $20/pr., Jerry Feldstein, 705 E. 189 St., Bronx, NY 10458, (718) 364-3485, 7–10p.m. EST. No machine.

Adcom GCD-575 CD player, brand new, factory sealed. Full warranty, $400. Larry (201) 785-5132. Leave message.



Dynaudio D76 $65/pr., D28AF $45/pr., 21W54 (new) $100/pr., Focal 8P511 $40/pr, Foster E110-108 Ribbon Tweeter (new) $50/pr. You pay shipping. Carl (916) 967-1065

Paradigm IlseMKII speaker system. Each speaker includes; one 1" dome textile tweeter, two 8" poly mid/woofer. Floor standing, black, 3¾"H × 11¾"W × 14¼"D. Awarded sound and vision's critic's choice award. Max input power: 160W, $600/pr., or BO. Paul, (814) 862-7865

Dynaco PAT-4 preamp, factory built, working condition $40 plus shipping. Bob (609) 953-5519.

Audio research SP-11 MARKII Silver, $2,500; conrad johnson Premeire 5 200W Mono Tube Amps, $1,000; Star Sapphire Koa turntable, $800; Sequarra T-1 ribbon tweeter, $400/pr. Douglas S. Robinson, 20735 Timberlane Dr., Elkhorn, NE 68022. H (402) 289-0886. W 8–5, (402) 779-2531.

Test Equipment, B&K beat frequency oscillator #1022 $75; level recorder #2305 $50; audio frequency spectrometer #2112 $75; microphone amplifier #2603, #2604, #2605 $50; distortion bridge #1607 $100. Ken Kopper (201) 599-0499.

Dahlquist DQ-LP1 upgraded with wonder caps, 1% resistors and gold RCA jacks. Sonics excellent, cosmetics very good with manual and schematic $150. Direct Disc albums, Dave Gruzin "Discovered Again" mint $50; Lincolm Mayorga "Vol. III" sealed $50; Lew Tabakin "Trackin" mint $25. Shipping paid. Dan (716) 627-4430, 4–10 p.m., NY.

Essence Gem high resolution monitor in Zebrawood. 40–19kHz ±2, 20"H × 10"W × 13"D ($1,000 cost) $800 mint condition, awesome bass. California Audio Delta Drive and Sigma D/A Super mint, low hours $1,200 vs $1,500. New original boxes plus shipping. Mr. Willes (800) 227-6121, weekdays.

Sony TC880-2 professional reel to reel with many accessories, their best, originally $3,000+, asking $1,000, never used; Q.E.D. headphone amp, real nice, paid $170, make an offer; McIntosh MC2500 advertising poster 31" × 24", new, $9 shipped, Walt Fleming, 182 Plain Hill Rd., Norwich, CT 06360, (203) 889-5018.

JBL 2425H Drivers $125/ea. Four JBL 2370A Biradial horns $60/ea. Rane AC22 crossovers $165. Biamp systems EQ220 $90. JBL SR4722's New in box, warranty, $595/ea. Jim, (516) 244-0214.

JBL 2213H $125/pr.; 104H3 mids $50/pr.; 035Ti tweeters $50/pr.; LE5-2 mids $100/pr.; LE-25 tweeters $50/pr.; Jordan modules $100/pr.; AR 3a 12" drivers (new) $125/pr.; AR 10pi $400/pr.; AR 5 $300/pr.; Advent bass drivers $180/pr.; Tweeter $40/pr.; all plus shipping. All drivers and speakers in good shape. Dean Christie (210) 497-7453.

Jantzen U-130 Electrostatic modules, 4–5" square panels/unit, including schematic and origianl brochures, $75/ea. One pair Dynaudio 30-W100, 4Ω, 4" V/C, excellent condition, $150/ea. Prices firm, split shipping. Paul Champlin, 1016 Quail Gardens Ct., Encinitas, CA 92024, (619) 632-7463.

WANTED

Information on experience with Dipole Cone Woofers and Subwoofers. Contact Bob Reimer, (519) 886-9044 FAX (519) 747-9922, or write; 469 Parkwood Ct., Waterloo, ON N2L4A7.

Dynaco FM-3 maual or copy, will pay for copying and postage. Send postcard to: Bob, 322 Tavistock Dr., Medford, NJ 08055. (609) 953-5519.

Heil (ESS) 21.5 in² midrange/tweeters air motion transformer or Heil Elite Speaker. Steven Williams (212) 781-0585, or write PO Box 1953, Cathedral Sta., New York, NY 10025.

Pair AC10R, four focal 8V416J, two Tonegen 16K65, two Tonegen 94C70, Adcom 500-11, or Rotel RTC950, Rotel 965BX CD Player. Parasound C/PT-1000R, one 10V516. Jim (708) 425-6719

McIntosh tuners, any model; early Mac non-panloc cabinet; McIntosh MR-2, MR-6 or similar quality MPX unit such as Scott or Fisher; mint or new Dynaudio D28AF or Esotar tweeters, must be reasonable. Walt Fleming, 182 Plain Hill Rd., Norwich, CT 06360, (203) 889-5018.

Service manual for Pioneer TVX-9500 TV Audio Tuner. (Need help on how to make it's fine tuning less fussy and more stable.) Trade (copy of) manual for collectable Hi-Fi books; ask for list. Also see *SB* 1/93, p. 71 for items for sale. Andy Keller, 1455 Twinsisters, Longmont, CO 80501 (303) 772-4801.

Old Klipsch catalogs, manuals, crossover components: old JBL catalogs, literature; books: Shockley, *Electrons and Holes in Semiconductors*, R.C. Schaller, *Throne of Merlin* Altec N500D crossover; Marantz 7T with case. D.R. Schaller, 6704 Schroeder Rd., Suite 6, Madison, WI 53711.

Laserdisc movies and music. Mike (708) 587-4134 before 2 p.m.

EV Speakers: SP15 or SP15B also SP8B. State price and condition. Fred Sutton, (310) 316-4406.

CLUBS

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

AUDIOPHILES IN THE DAYTON/SPRINGFIELD, OHIO AREA: We are forming an audio club. Please contact me if you're interested in construction, modifications, testing, recording or just plain listening to music. Ken Beers, 1756 Hilt Rd., Yellow Springs, OH 45387, (513) 767-1457.

ARIZONA AUDIOPHILE SOCIETY Located in Metropolitan Phoenix is a growing and active club in the pursuit and reproduction of recorded music. New members are welcome. Meetings are last Tuesday of each month. Receive monthly newsletter and bi-annual journal. Club discounts with local high-end audio dealers. Send inquiry to Arizona Audiophile Society, PO Box 13058, Scottsdale, AZ 85267, or call Bob Williams, (602) 944-5929.

AUDIO SOCIETY OF MINNESOTA Now in its 15th consecutive year! Serving the many and varied interests of audiophiles in the upper midwest. Monthly meetings, tours, audiophile concerts, special guests. For information and a sample of our latest newsletter, write ASM, PO Box 32293, Fridley, MN 55432 or call our 24 hour "Audio Hotline," (612) 825-6806.

THE ATLANTA AUDIO SOCIETY is dedicated to furnishing pleasure and education for people with a common interest in fine music and audio equipment. Monthly meetings often feature guest speakers from the audio manufacturing and recording industry. Members receive a monthly newsletter. Call: Chuck Bruce, (404) 876-5659, or Eddie Carter, (404) 847-9296, or write: A.A.S., 4266 Roswell Rd. N.E., K-4, Atlanta, GA 30342-3738.

THE BOSTON AUDIO SOCIETY the nation's oldest (founded 1972), seeks new members. Dues includes the monthly meeting notice and our newsletter, the *BAS Speaker* (6 times/year). Recent issues cover Carver, a/d/s; the founder of Tech Hi-Fi; Photo CD; plus visits from famous speaker designers; listening tests; measurement clinics; research investigations; and more. Back volumes available. Membership includes engineers, journalists, consultants, and music-loving audiophiles like yourself. For information write to PO Box 211, Boston, MA 02126-0002, USA.

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 bi-monthly newsletters, plus participation in meetings and lectures. For more information, send SASE to: CAS, 11685 W 22nd St., Lakewood, CO 80215, (303) 231-9978.

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

SOUTHEASTERN MICHIGAN WOOFER AND TWEETER MARCHING SOCIETY (SMWTMS). Detroit area audio construction club. Meetings every two months featuring serious lectures, design analyses, digital audio, A-B listening tests, equipment clinics, recording studio visits, and audio fun. The club journal is *LC, The SMWTMS Network.* Corresponding member's subscription available. Call (313) 544-8453 or write David Carlstrom, SMWTMS, PO Box 721464, Berkley, MI 48072-0464.

DO YOU LIVE NEAR LAWRENCE KANSAS? I am a student at the University of Kansas looking for other speaker builders within driving distance. I would like to exchange ideas and listen to other homebrew systems. Michael Marmor, 1520 Lynch Court #2, Lawrence, KS 66044, (913) 843-8993

ESL BUILDERS GROUP is a new address for people who have built or want to build ELECTROSTATIC LOUDSPEAKERS and ASSOCIATED (TUBE) DRIVERS, or are just interested. We will concentrate on ESL-related building projects but also look at the theoretical aspects of acoustics and electronics. Interested? An answer is ensured, if you include some kind of compensation for postage and handling. Write to: Gunter Roehricht, Buhler STR.21, 7030 Boblingen, Germany.

LONDON LIVE D.I.Y. HI-FI CIRCLE meets quarterly in London, England. Our overall agenda is a broad one, having anything to do with any aspect of audio design and construction. We welcome everyone, from novice to expert. For information contact Brian Stenning, 081-748-7489.

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 Frank J. Alles, (908) 424-0463, 209 Second St., Middlesex, NJ 08846; or contact Bob Young, (908) 381-6269, or Bob Clark, (908) 647-0194.

PACIFICNORTHWEST AUDIO SOCIETY (PAS) consists of 60 audio enthusiasts meeting monthly, second Wednesdays, 7:30–9:30 p.m. at 4545 Island Crest Way, Mercer Island, WA. Be our guest, write Box 435, Mercer Island, WA 98040 or call Bob McDonald, (206) 232-8130 or Nick Daniggelis, (206) 323-6196.

PIEDMONT AUDIO SOCIETY Audio club in the Raleigh, Durham, and Chapel Hill area is meeting monthly to listen to music, demonstrate owner-built and modified equipment, and exchange views and ideas on electronics and speaker construction. Tube and solid state electronics are of interest and all levels of experience are welcome. Kevin Carter, 1004 Olive Chapel Rd., Apex, NC 27502, (919) 387-0911.

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

IF YOU ARE an "Organ Music Lover" and like to test your audio system, **SFORZANDO** has room for a few more members. We have about three thousand "Live," on-the-spot, cassette tapes that are not available in the stores. We are happy to lend them to you via the mail. Just ask EA Rawlings, 5411 Bocage St., Montreal, Canada, H4J 1A2.

ELECTROSTATIC LOUDSPEAKER USERS GROUP is now a world-wide network for those interested in sharing valuable theory, design, construction, and parts source information. If you are interested in building, or have built, your own SOTA ESL we invite you to join our loose-knit organization. For information, send a SASE to: Barry Waldron, 1847 Country Club Dr., Placerville, CA 95667.

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

THE CATSKILL AND ADIRONDACK AUDIO SOCIETY invites you to our informal meeting. Join our friendly group of audio enthusiasts as we discuss life, the universe and everything! Tubers, transistors, vinyl canyons or digital dots. No matter what your level of interest, experience, or preferences, you are welcome. Contact CAAS at (518) 756-9894 (leave message), or write CAAS, PO Box 144, Hannacroix, NY 12087. See you soon!

WASHINGTON AREA AUDIO SOCIETY Meetings are held every two weeks, on Fridays from 19:00 hours to 21:30 hours at the Charles Barrett Elementary School in the city of Alexandria, Va. Prospective members are welcome but must register in advance in order to be admitted to the meetings. No exceptions please. If interested please call Horace Vignale, (703) 578-4929.

LOS ANGELES AREA ARIA AND SWAN Loudspeakers Users Group. If you have built or plan to build any of the Aria or Swan loudspeakers and would like to meet for listening sessions or have any questions or modifications that you would like to share, please call Geoffrey, (213) 965-9173 or Edward, (310) 395-5196.

THE PRAIRIE STATE AUDIO CONSTRUCTION SOCIETY. (PSACS) meets every other month. Meetings feature audio construction, design, and analyses, blind listening tests, equipment clinics, autosound, lectures from manufacturers and reviewers. PSACS, PO Box 482, Cary, IL 60013, call Tom, (708) 248-3377 days, (708) 516-0170 eves.

HI-FI COLLECTOR/HOBBYIST seeks "living letters"/audio pen pals from other states to correspond via reel-to-reel tape. Non-commercial strictly; make up short monologues on subjects from vintage technology, with regional FM excerpts for background or equipment samples, from personal tales of yard sales scavaging success, repair/restoration tactics and strategies, favorite service centers, general ways to handle the burgeoning obsession with arcane hi-fi gear. All correspondence on 3", 5", 7" reels (¼" tape) will be cheerfully answered and tapes returned via parcel post. James Addison, 171 Hartford Rd., Apt. #7, New Britain, CT 06053.

MONTREAL AREA SPEAKER BUILDER looking for others interested in speaker design and construction from small to large systems. Feeling like I'm the only one. Prove me wrong! Andrew McCree, 4701 Jeanne Mance, Montreal, PQ H3V 4J5, Canada, (514) 281-7954.

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

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

THE WESTERN NEW YORK Audio Society is an active, long established club located in the Buffalo area. We issue a newsletter and hold meetings the first Tuesday of every month. Our meetings attract many prominent manufacturers of audio related equipment. We are involved in all facets of audio—from building/modifying to exposure to the newest high-end gear, and the chance to hear more types of music. For information regarding our society, please write to WNY Audio Society, PO Box 312, N. Tonawanda, NY 14120.

W A N T E D

AUDIO CLUB MEMBERS

(Good singing voice not required)

Learn about the latest equipment, techniques and recordings through group meetings, tours and newsletters. Ask questions. Share viewpoints and experiences. *Have fun!*

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

Ad Index

Moran in the Market

INSIDE RUBIK'S LISTENING ROOM

By David R. Moran

Eureka, Again

It is not uncommon in the audio business for a clever engineer to devise a novel, sometimes elegant solution to a real problem and then to found a company based on the results. (It is quite common for fake or only partly real audio engineers to devise fake or only partly real solutions to fake or misidentified problems, but that's a different chapter of the story.)

What is pretty rare is for such a new company to succeed. Velodyne is one such, and for years their superb line of powered, servo-controlled subwoofers has set the standard for extremely flat, loud, clean output in the 1–2.5 octaves above 20Hz. Only the Hsu (formerly Definitive) Research subwoofer appears to be their equal these days, at least at a reasonable price (see *SB* 3/92, p. 91).

Some years ago for *CD Review* I tested (using close-miking) a Velodyne unit and was mightily impressed by its low reach, straight-line frequency response, and high output capability. Recently, I spent some time with a new, lower-priced Velodyne model, the F-1000, priced at under $900. The F-1000 comprises a nominally 10″ driver controlled by an 80W amp (two-channel input), with everything contained within a 14″ cube handsomely finished in black woodgrain vinyl with granite-vinyl trim. The low-pass upper frequency is adjustable from 40 to 100Hz. As I will show presently, I do wish Velodyne would extend the upper-end option another octave. But other than that, the F-1000 was another splendid performer, with nothing to complain about.

Method the Second

This time, I measured the Velodyne outdoors, with the 80Hz-low-passed unit sitting on the ground as it would on a floor, and the measuring mike continuously moving and averaging, 8–10′ away and 32–40″ above the ground (at seated ear height, in other words). *Figure 1* shows the F-1000's response to healthy-level pink noise, ⅓-octave-averaged using the dbx RTA-1. (All this is my usual protocol.) The result is practically perfection itself, 20–80Hz ±1dB or so.

Twenty years ago, *Audio* magazine's current speaker tester, Don Keele Jr., explained in a *JAES* paper how close-miking a sealed-box woofer is, up to a certain frequency, equivalent to measuring its total output into half-space (2π load). Since *Fig. 1* is virtually identical to the close-miked response I obtained with a different Velodyne years ago, I suggest the results constitute an existence proof of Keele's work.

Corner That Bass

Where should one place such a woofer in a room? One often reads or hears that the corner is not a good place, is the worst place, in fact, because it makes any problems with room resonances worse (aggravates them). Feh, I say—drive those resonances! Put that low-bandwidth woofer in the corner. Let the corner maximally and smoothly augment the driver's output below 200Hz, and get some bass power you can feel in your feet.

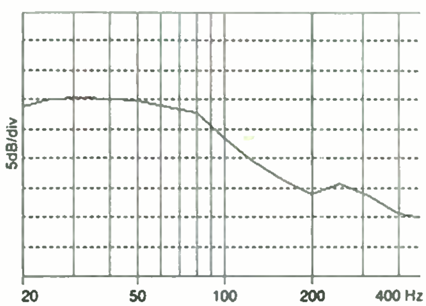


FIGURE 1: Frequency response measured 20–400Hz to pink noise (⅓ octave) in 2π space of Velodyne F-1000, low-passed at approximately 80Hz.

Basically, what corner placement does is excite room resonances to the max, making them louder overall. If it's excessive, this excitation you can control, broadband, simply by reducing the input to the woofer. Putting a stand-alone woofer out in the room, as we are advised so often, is extremely unlikely to notch out a room's worse resonances satisfactorily, even if you experiment with various third-length or quarter-length placements. Naturally, the listening (or measuring mike) position is the third variable, but in my experience it comes behind near-corner augmentation and room proportions.

The way for empirically experimenting with fullband-speaker placement, as opposed to calculating it, is to put the speaker in your listening chair, and crawl around with your head in plausible or likely woofer locations while the speaker plays broadband noise. With practice, you can home-in on some of the less boomy spots for cabinet location. It's a ridiculous feeling and looking exercise, so you'd best not let anyone see you.

Figure 2 shows the bass (20–200Hz) boundary augmentation of a good woofer in a corner. *Figure 3* shows the same for a woofer 4′ out from the corner (3′ from the walls, in other words) but still on or otherwise quite near the floor. Room resonances will combine with these responses. The top curve is what the corner does absolutely, all by itself, while the line below the top one shows what the corner does to a good-quality 8″ woofer in a reasonable-size sealed cabinet. Since the Velodyne behaves practically perfectly 20–100Hz, the top, theoretical curve can be said to plot its actual reponse, for that range anyway. Dozens of measurements which I and others have made in different rooms at typical listening positions confirm that these theoretical boundary augmentations generally correlate well with reality, provided you measure with some spatial averaging, and they correlate well with audibility, too.

Up With Stands!

Now, I know I sometimes sound in these columns like a stuck record (there's a figure of speech on its way out in the CD era) as I harp on the subject of boundary augmentation. But here's an idea for a speaker-building project. Speakers located up on a stand and out from the near corner always have a suckout in their upper-bass/lower-midrange sound, right? Rather than try to avoid it, why not embrace it, and put the problem to good use? In other words, begin the crossover from satellite to woofer at the suckout point.

Figure 4 shows boundary augmentation for a 6″ driver 27″ off the floor and 3′ out from the front and side walls. (Presumably, the tweeter in such a satellite would be around ear height.) If we highpass the 6-incher around 160Hz (no lower), and stitch it smoothly with a woofer lowpassed to the same point, we should have a really good-sounding—comparatively full-sounding—satellite/woofer system for use in such a location. With luck, its response would look like *Fig. 4* combined at 160Hz with *Fig. 2*.

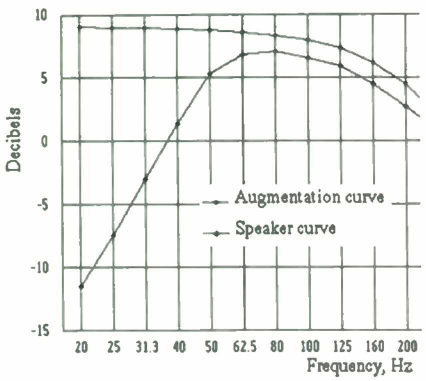


FIGURE 2: At top, theoretical augmentation below 200Hz of woofer (or response of perfect woofer) in an appropriate cabinet placed next to three surfaces of a corner. Lower curve is the same for an 8″ woofer. (Free software program by R. Allison.)

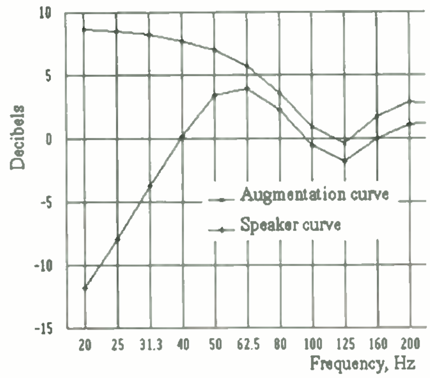


FIGURE 3: As in *Fig. 2* but for woofers placed 3′ from the front and side walls and close to the floor.

Alternatively, you could accept some suckout and put your woofer module underneath your satellite (or just use a single cabinet, conventional-style), provided you kept the woofer center down near the floor and again kept the crossover low, again around 160Hz. In this case, you would wind up with something like *Fig. 4* combined at 160Hz with *Fig. 3*—still preferable to *Fig. 4* alone.

Note that in all of these cases, if you can put your new, out-from-the-corner speaker system so it's not the exactly same 3′ from front and side walls (go for 2.5′ and 3.5′ or some such), the response around the crossover stitch will be flatter yet.

That's what I would do, anyway, if I were a speaker builder: try to design for near-worst-case boundary siting, letting the lower-midrange suckout and the crossover complement each other. If any reader actually builds such a design with the woofer close to the floor and the satellite portion well above it at seated-ear height, and you think it sounds good and measures well, let me know. Pay for shipping to and from my laboratory and I'll measure it and otherwise evaluate it. If it's audibly a success, I will write it up in a future column. Let's see if the conflicting constraints among smooth boundary augmentation, crossover points, and precise satellite-type imaging can be made to converge.

That First Reflection Set

I've been musing recently on effective visualizations for thinking about speakers playing in rooms. Let me try this out here; see if it helps.

If the room where you listen to your loudspeakers is rectangular, as is likely to be the case, picture it for the moment as being the center room buried in a large "Rubik's cube" of identical rooms. Such a structure (not actually cubic, we hope) has three rooms on a side, equaling 3 × 3, or 27 rooms in all—yours, in the middle, plus 26 others.

Let's consider what this structure looks like for a moment. There's an identical but phantom room above yours, like a second story, and also one below, basementlike. There is one directly in front of your room and one behind it. (And there are those at your sides: one to the left, and one to the right.)

There also are the above-left (one floor up/one room over, in other words) and above-right, above-front and above-back, and the same below: below-left, below-right, below-front, below-back.

Finally, there are all those phantom corner rooms on the same level as your real room. These consist of the one "L-connecting" (adjacent to) the front room and the left room, the one connecting the front room and the right room, and the same situation for the back room (directly behind) "connecting to" the left and right rooms to your sides. And last, above and below these corner rooms just noted, that is one floor up and one floor down, are the "corner-corner" rooms, forming the corners of this particular Rubik's cube. The total is 26 phantom rooms, apart from your actual own listening room.

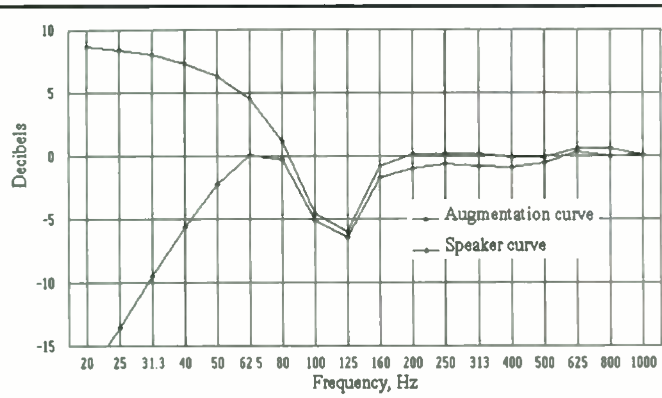


FIGURE 4: As in *Figs. 2* and *3* except showing boundary augmentation 20Hz–1kHz for driver placement 3′ from front and side walls and 27″ off the floor; lower curve is for 6″ woofer, as in a satellite loudspeaker on a stand.

Other Speakers, Other Rooms

Each of these phantom rooms contains a "set" of your loudspeakers, technically an image source, which is playing away while you are listening to your original pair. You hear all of these speakers. Fortunately, it's the same piece at the same time (which is never the case in an apartment building). Each image-source loudspeaker is reproducing the program at similar overall loudness, although usually with reduced treble.

This Rubik's-room situation as I have described it here models only the first set of loudspeaker reflections. In this first set there are six axial reflections (one-dimensional, i.e., individually from front wall and rear wall, side walls, and the floor and the ceiling), twelve tangential (two-dimensional, or involving pairs of adjacent walls), and eight oblique (three-dimensional, or involving trios of corners). If you build a model room with eight mirror tiles and a light source, as I've recently done, you can actually spot these single/double/triple (6/12/8) images with enough peering and neck-craning. (Believe me, it's another exercise which feels ridiculous.)

You also see right away that there's a virtual infinity of image-source sets. After the first set as described above, the images line up recedingly, smaller and smaller, within successively distant and smaller rooms. For this discussion, though, we'll concern ourselves with only the first, 26-room set, for it's the loudest and the most influential.

Happily for our hearing, in domestic-size listening rooms, the ear does not sense these image-source loudspeakers the way the eye does, as completely separate and discrete, readily discernible entities.

The Primacy of One?

For some reason it is widely stated that the one-wall (axial or one-reflection) image sources are the important ones, or, more verbatim, that the room resonances piled up at various predictable frequencies by the one-wall reflections "domi-

Continued on page 78

HEAR, HERE!

Our 1993 product line just arrived and there's lots to celebrate. A comprehensive array of nearly 100 drivers. Innovative technologies. Leading edge materials. Engineered to provide flexibility in your design process and clear cut sonic quality advantages at every level of performance.

You've heard about our quality for years. Now's the time to hear it for yourself.

polydax
SPEAKER CORPORATION

Subsidiary of Audax Industries, France.
For your nearest authorized distributor
please call 508.658.0700

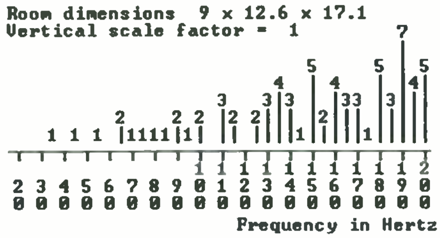


FIGURE 5: Number of single-, double-, and triple-boundary resonances 20–200Hz computed for a euphoniously proportioned high-ceilinged domestic room of dimension ratios 1/1.4/1.9.

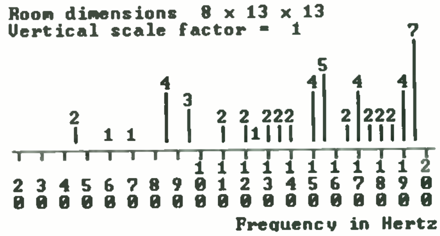


FIGURE 6: As in *Fig.* 5 but for a square room with a normal ceiling.

Continued from page 76

nate" the acoustics of a rectangular room. Articles over just the last couple of years in *Mix*, a semi-pro audio magazine; in the influential *Audio* magazine; in the subjectivist *Absolute Sound*; and in these very pages (*SB* 6/92) all have said as much. At least one loudspeaker-placement computer program makes its calculations based on the same assumption. The font of this belief apparently is one of the "master" audio handbooks of the sort that many of us sometimes rely on for reference.

Measurement and Theory

But if you put a woofer in one corner of a rectangular room (a woofer and cabinet together small enough that you can get it in nice and close, like say a 6-incher) and a mike in another corner of the room and, using either noise or tones, measure its response hertz by hertz from the infrasonic region up to, let's say, somewhere above middle c (20–300Hz, e.g.), you will see resonant peaks at the same or similar loudness levels throughout a range of frequencies—not just axial ones. (Above a point in the lower-midrange the increasingly numerous resonances bunch together so tightly that we don't register them as such, and any head movement swamps the matter in any case.)

The equation for figuring these frequencies in a rectangular room, as you may recall from these and other pages, is half the speed of sound times the square root of the sum of the squares of each dimension's reciprocals. (Anyone who sends me a diskette and an SASM will receive a simple BASIC program that makes these calculations quickly.) To wit:

$$f_{NX,\,NY,\,NZ} = 565\,[(n_X / x)^2 + (n_Y / y)^2 + (n_Z / z)^2]^{1/2}$$

where x, y, and z are the dimensions in feet of your room and n is any whole number (0, 1, 2, . . .).

(Send your diskette and SASM to: Farrar Rd., RR1, Lincoln, MA 01733.)

I recently examined resonance data of this kind which had just been collected by the leading Boston architectural-acoustics firm on a small recording studio for which the firm is specifying absorptive, damping structures and their placement. All the resonances predicted by the arithmetic showed up, most of them at close to the same SPL. The axial resonances rose up shoulder to shoulder with their tangential and oblique colleagues, in other words. By the time this column is published, I hope to have completed controlled precision measurements of exactly what happens when a rectangular enclosure acts as a resonator—the frequencies and exact energy levels of all the resonances—to settle this issue (we hope) for good.

The reason this subject is important in such detail, of course, is that near-corner speaker location, room shape, and near-corner head location really do dominate loudspeaker playback for the midrange and below. As I have harped on in column after column, asymmetry's the key—the key for the shape of the space where we listen (although most of us must live with what we have), for the three distances from each speaker to the nearest corner, and for the same from our listening head to the corner nearest us.

For those of us who can build anew, the ten best domestic-size rectangular-room proportions (after M.M. Louden, *Acustica*, Vol. 24, 1971), are 1/1.4/1.9, 1/1.3/1.9, 1/1.5/2.1 and /2.2, 1/1.2/1.5, 1/1.4/2.1, 1/1.1/1.4, 1/1.4/1.8, 1/1.6/2.1, 1/1.2/1.4. Many of these make for awfully squarish, even small listening rooms. Refer to *Figs.* 5 and 6, showing resonances (in 5Hz bundles) for one very good (even distribution) and one bad (lumpy distribution) domestic rooms. Most current listening rooms are too long, too shoeboxlike—not short enough, believe it or not. But listening in them may still be pleasurable, lumps and all: witness J. Saluzzi's (*SB* 2/93), and my own IEC-quality room of 8′ × 13′ × 24′. The keys, I suggest, are locational asymmetry of speaker and listener, and for this readership, some home-brew speakers built according to the suggestions above. Let me know your opinion of the audible differences that manipulating these variables makes.

SOURCES

Velodyne
1070 Commercial St. #101
San Jose, CA 95112
(408) 436-7270