EXPLORE THE INS & OUTS OF A MINISUB

ONE: 1995
US$7.00
CANADA $8.00

SpeakerBuilder
THE LOUDSPEAKER JOURNAL

UNDERFOOT TRUCK T-LINE

TAMING X-OVER PHASE BUGS

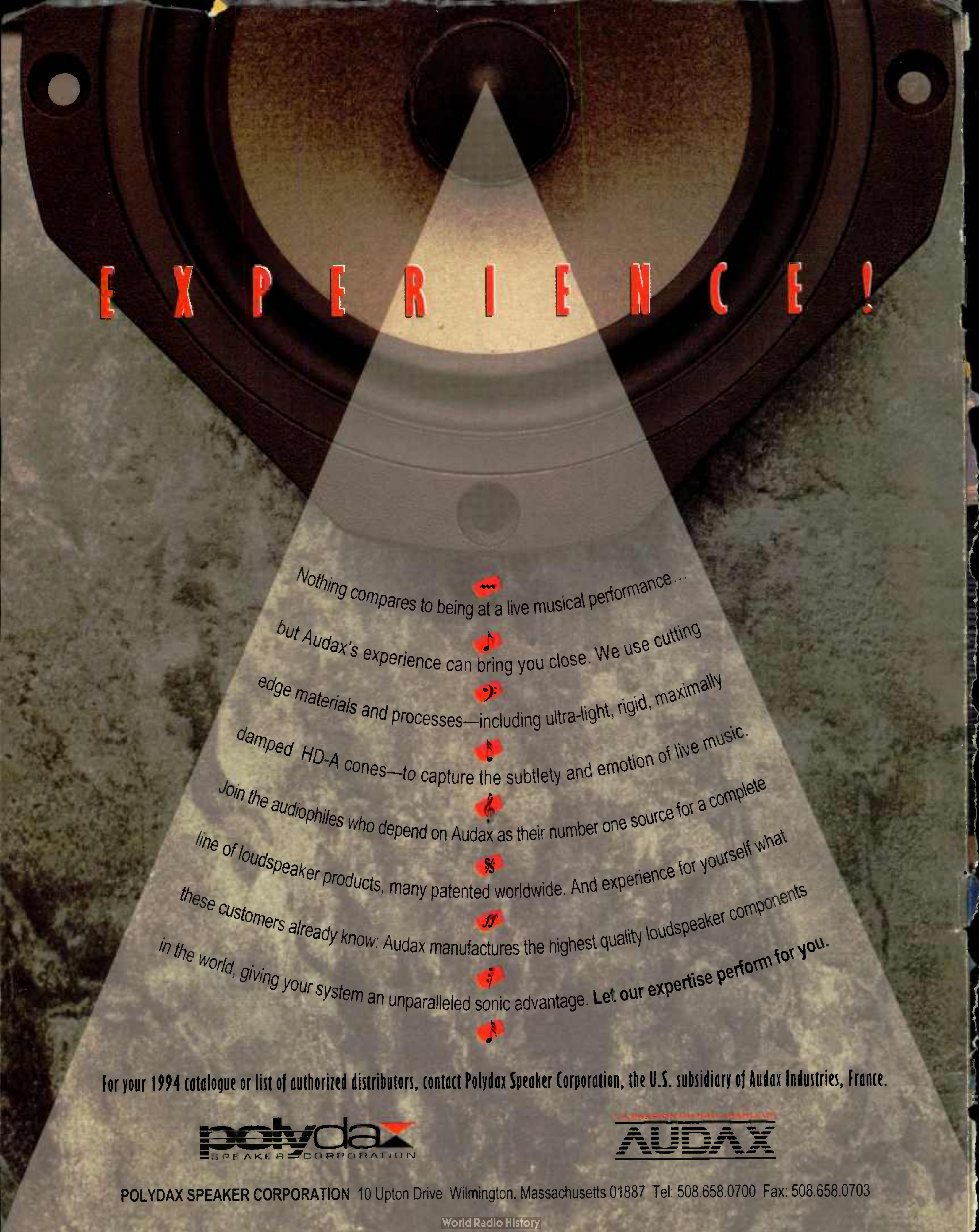
WRESTLING GOOD STUFF FROM PIEZO DRIVERS

MEASURE SIXTY CHANNELS IN THE ROOM

D'Appolito & Pierce
ON VOLTAGE, POWER & EFFICIENCY PUZZLES

01 >
0 74470 84699 4

DRESSING UP THE GRILLE FRAME


EXPERIENCE!

Good News

■ DESIGN SOFTWARE

Pyle's Pro Designer™ speaker enclosure design software installs with any DOS-based platform. The specifications range from single chamber sealed to Isobaric tri-chamber vented bandpass systems. Twelve core designs are included; optimum sizes and tuning are automatically calculated. The IBM-compatible software runs on VGA or SVGA monitors. Pyle Industries, Inc., PO Box 620, Huntington, IN 46750, (219) 356-1200, FAX (219) 356-2830.

Reader Service #105

■ CONDUCTIVE GREASES

Two new greases have been developed by Planned Products for applications requiring electrical conductivity, lubrication, and protection from moisture, oxidation, radiation, corrosion, and corrosive atmospheres. Available in silver and carbon formulations, Circuit Works Conductive Greases can be used on metal, rubber, and plastic to lubricate assemblies while forming electrical contacts, connections, static drains, and grounding. The silver grease is thermally conductive and can be used as a heatsink in thermal management applications. Planned Products, 303 Potrero St., Suite 53, Santa Cruz, CA 95060-2760, (408) 459-8088, FAX (408) 459-0426.

Reader Service #106

■ IRON SUPPLEMENTS

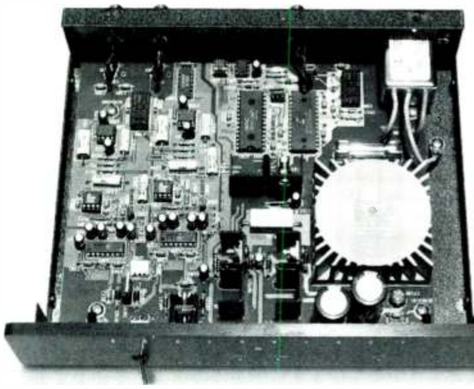
Antex standard-size and miniature soldering irons boast quick cycle times and a wide range of replaceable tips. The devices heat within 45 seconds and recover instantly, because the heating elements are located directly under the tips for optimum thermal efficiency. Model XS (25W) heats to 800°F; the miniature G/3U (18W) reaches 750°F. M.M. Newman Corp., PO Box 615, Marblehead, MA 01945, (617) 631-7100, FAX (617) 631-8887.

Reader Service #108

SUPPORT SYSTEM

The Euro Foundation series has been added to Sanus Systems' Sound Foundation® line of loudspeaker supports. The design incorporates adjustable steel floor spikes, rubber isolation pads, and a concealed speaker wire path. Bases can be filled with sand or shot to enhance stability and damp resonances. Three models are available. Sanus Systems, 1973 W. County Rd. C2, St. Paul, MN 55113, (800) 359-5520, (612) 636-0330, FAX (612) 636-0367.

Reader Service #118



DAC DIY

The Assemblage DAC-1 digital processor is a complete DIY kit. Designed for beginners, the small chassis (9.5″ × 2″ × 7″) typically takes one hour to build. The assembled and tested board implements Burr-Brown's 1702 DAC, Crystal 8412 input receiver, NPC 5813 digital filter, Analog Devices AD844 and 847 op amps, and custom-potted toroidal power transformer. The Parts Connection, 2790 Brighton Rd., Oakville, ON L6H 5T4, Canada, (905) 829-5858, (800) 769-0747, FAX (905) 829-5388.

Reader Service #101

■ MLS OPTION

Scantek now implements a maximum length sequence (MLS) option in its real-time analyzer. The Type 840 uses MLS and a Fast Hadamard Transform to reduce the need for a high signal-to-noise ratio and high-powered noise source. The MLS technique is insensitive to extraneous noise, and can be used for both reverberation time and transmission loss measurements in adverse conditions. Scantek, Inc., 916 Gist Ave., Silver Spring, MD 20910, (301) 495-7738, FAX (301) 495-7739.

Reader Service #102

■ HORNS WORKSHOP

A Horns II Workshop will be held on March 29-31, 1995, in Columbus, OH. This follow-up to last November's workshop will continue to explore constant-coverage horn parameters and their behavior in various multiple-unit arrays. Also discussed and demonstrated will be arrayed boxed loudspeaker systems and array design for broadband directivity control. For further information, contact Synergetic Audio Concepts, 12370 W CR 100 N, Norman, IN 47264, (812) 995-8212, FAX (812) 995-2110.

Speaker Builder (US USSN 0199-7929) is published every six weeks (eight times a year), at **$32** per year, **$58** for two years; Canada add $8 per year; overseas rates **$50** one year, **$90** two years; by Audio Amateur Publications, Inc., Edward T. Dell, Jr., President, 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

← Reader Service #21

Good News

■ W.A.R. MONGERS
W.A.R. Audio in Perth, Western Australia, has been appointed Australasian agent for Orca's complete line of products. The company will handle speaker kits, raw drivers, Accuton, Cabasse, Focal, Focal Audiomobile, Blackhole, SCR and Axion caps, accessories, and cables, as well as the new Clio measuring system. W.A.R. Audio, Westpoint Commercial Centre, Unit 203/396, Scarborough Beach Rd., Osborne Park 6017, Western Australia, (011) 61-9-242-5538, FAX (011) 61-9-445-2579.

■ A/V RECEIVER
NAD's new remote-controlled AV716 Surround Sound Receiver utilizes video inputs and switching, Dolby Pro Logic Surround decoding and Hall surround modes, five-channel amplification, and AM/FM tuning. All-discrete transistor power amplifiers are employed throughout. The AV716 produces 55W for each front channel, with two 20W outputs for the surround channel (8Ω); stereo mode operation delivers 80W/channel (8Ω) and 115W at 4Ω. Contact Lenbrook Industries, 633 Granite Ct., Pickering, ON L1W 3K1, Canada, (800) 263-4641, FAX (416) 831-6936.

Reader Service #109

■ OCTAVE EQUALIZER
AudioControl's new version of its C-101 home octave equalizer is the Series III, with built-in digital pink-noise generator and real-time audio spectrum analyzer. The unit can be connected to any home stereo, from single receiver to multiple systems, and comes with a calibrated microphone. Other features include octave-spaced sound controls and an 18dB/octave Chebyshev alignment subsonic filter. AudioControl, 22410 70th Ave. W., Mountlake Terrace, WA 98043, (206) 775-8461, FAX (206) 778-3166.

Reader Service #107

➲ POWER AMPLIFIER
The PS24 is a combination toroidal power transformer and linear rectifier unit mounted in an aluminum chassis, with one or more power amplifier modules. Each module has differential inputs with selectable DC/AC coupling and DC-coupled output. The unit's open-frame construction offers thermal protection against overheating and output current protection against short circuits and other overloads. Its 100VA transformer is available with several secondary voltages. Marchand Electronics, Inc., PO Box 473, Webster, NY 14580, (716) 872-0980, FAX (716) 872-1960.

Reader Service #104

➲ AUDIOPHILE TURNTABLE
The BES-2 from Esoteric Sound is designed to play virtually all electrically recorded 78s. The belt-drive turntable incorporates a fixed cartridge-mount arm, two speeds (33 and 78 rpm), a dust cover, and fully manual operation. Esoteric Sound, 4813 Wallbank Ave., Downers Grove, IL 60515.

Reader Service #103

Speaker Builder

The Staff

Editor and Publisher
Edward T. Dell, Jr.

Contributing Editors
Joseph D'Appolito **Robert Bullock**
Richard Campbell **John Cockroft**
David Davenport **Vance Dickason**
Bruce Edgar **Gary Galo**
G.R. Koonce **Richard Pierce**

Assistant Publisher
Karen Hebert

Dennis Brisson Managing Editor
Mary Wagner Associate Editor

Glenn Galloway Graphics Director
Production Assistants
Brian Jenkins **Diane Luopa**

Laurel Humphrey Circulation Director
Circulation Assistants
Robyn Lasanen **Angela Swett**

Advertising Rates & Schedules
Martha L. Povey National Advertising Director
Laura Brown Advertising Assistant
(603) 924-9464 **FAX (603) 924-9467**

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

∽ JOHN STUART MILL

Speaker Builder is published eight times a year in the interest of high-quality audio reproduction.

No material in *Speaker Builder* may be used in any form without the written permission of the publisher.

Subscription Inquiries

A one year subscription to *Speaker Builder* is $32. Canada please add $8. Overseas rate is $50 per year.

To subscribe, renew or change address write to Circulation Department or call (603) 924-9464 or FAX (603) 924-9467 for MC/Visa/Discover 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 *Speaker Builder*, PO Box 494, Peterborough, NH 03458-0494. No responsibility is assumed for unsolicited manuscripts. All manuscripts must include a self-addressed envelope with return postage. The staff ***will not*** answer technical queries by telephone.

About This Issue

You don't need to be a paleontologist, or even a *Jurassic Park* fan, to appreciate **Richard Carlson's** T-Rex construction project. He unearths a bandpass subwoofer design and proves that even small drivers can produce deep, powerful bass in an autosound environment ("The T-Rex Minisubwoofer," p. 10).

Industry consultant and Motorola insider, **Mike Klasco**, explains how to achieve high-quality sound from the Motorola compression driver and shares some secrets for their best use in horn designs ("High Quality Use of Motorola's Piezo Driver," p. 18).

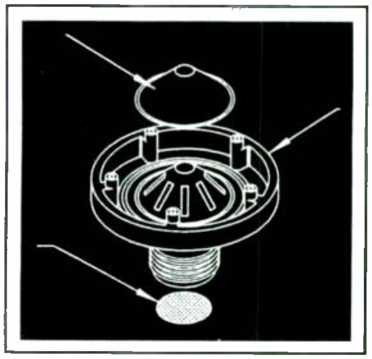
Ken Ketler, a battle-scarred veteran of Northeast roadways, outfits his vehicle with an audio system that takes the edge off the hassles of big-city traffic. His cleverly titled speaker design ("The Achilles," p. 22) is an automotive transmission line project. You're guaranteed a safe, enjoyable ride.

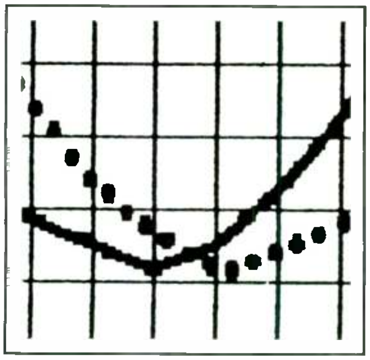
Speaker builders who have agonized over the process of designing a crossover will benefit greatly from reading "Driver-Offset-Related Phase Shifts," Part 1, p. 26. **Bruno Carlsson's** extensive study, which includes quite a number of different filter types, demonstrates the influence of phase shift on crossover behavior and promises some welcome relief.

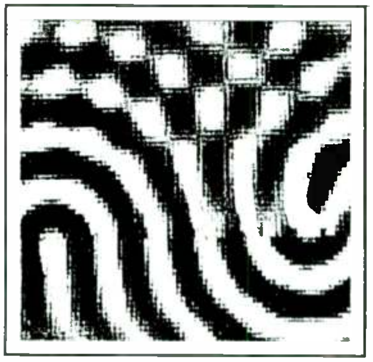
Philip Witham's incessant tweaking and adjustment of his linear-array setup has produced some interesting sound pressure plots, as "The Linear-Array Chronicles" (Part 3, p. 40) continues.

In this 1995 debut issue, we are pleased to bring you familiar names—**D'Appolito, Campbell, Pierce, Wayland**—with their sage advice and helpful insights to kick off the new year on the right note. *SB* resolves to offer the best contributions from seasoned veterans as well as promising newcomers to help make this your best speaker-building year ever.

Speaker Builder
THE LOUDSPEAKER JOURNAL
VOLUME 16 NUMBER 1 JANUARY 1995


18


26


40

DEPARTMENTS

Good News

■ SUPER SONICS

The Subsonic III subwoofer is housed in a 16 in^3 cabinet. Features include: a 12″ low-frequency transducer; super-long-throw, poly-coated compressed diaphragm; high-linearity butyl rubber surround; and a motor incorporating a high-temperature, 2″ voice coil and 40 oz magnet structure. The 15.5″ × 20″ × 17″ Alpha Subsonic passive subwoofer utilizes a twin-chambered "bandpass" enclosure and dual 6.5″ out-of-phase drivers with dynamic damping. PSB International, Inc., 633 Granite Ct., Pickering, ON L1W 3K1, Canada.

Reader Service #115

■ NOISE NEGATERS

MAX Acoustic Sound Blocks are 12″ × 12″ squares of open-cell, polyurethane foam. Standard panel thicknesses are 6″ and 8″, but custom panels up to 3′ thick are also available. Appropriate applications include dynonameter rooms, anechoic chambers, sound testing booths, recording studios, microphone calibration, and more. NetWell Noise Control, 6125 Blue Circle Dr., Minnetonka, MN 55343, (612) 939-9845, (800) 638-9355, FAX (612) 939-9836.

Reader Service #111

■ LOADED CANON

Canon's S-C10 center-channel loudspeaker incorporates a two-way, Grille Tweeter design for extended high-frequency response. The wedge-shaped cabinet offers dual-position capability for optimum placement, and the drive units are magnetically shielded to prevent TV image distortion. The S-C10 can be used in conjunction with surround sound receivers or processors, and will work directly with television systems equipped with center-channel output. Canon USA, Inc., One Canon Plaza, Lake Success, NY 11042.

Reader Service #114

■ MEASUREMENT MIKE

Scantek has released a new environmental microphone system, the Type 41AL. Manufactured by G.R.A.S. Sound & Vibration, the unit complies with ANSI and IEC Type 1 measurement requirements. Designed for community noise monitoring, with 90° incidence for a reference, the 41AL also includes a Phantom Calibration© system, a windscreen with anti-bird spikes, and an integral rain cap. Scantek, Inc., 916 Gist Ave., Silver Spring, MD 20910, (301) 495-7738, FAX (301) 495-7739.

Reader Service #110

■ STEEP SLOPES

Sussex Technical's new steep-slope electronic crossovers enable driver operation exclusively in the piston mode. Slopes of up to 66dB/octave sharply attenuate frequencies that excite driver breakup modes. All units have level controls for each frequency band, differential inputs, stereo/mono bass outputs, and accept either 120V AC or 12V DC input power. Sussex Technical Corp., 6114 Turnberry Dr., Garland, TX 75044, (214) 495-9293, FAX (214) 495-6434.

Reader Service #117

■ COMPACT SPEAKER

The LS5HC 15″ two-way speaker with cast-frame woofer is the latest addition to SoundTech's Live Series line. The speaker has a poly-coated cone material to minimize ripple distortion. Its high-frequency horn is a 90° × 90° dual-axis radial with a 1″ exit driver. System response is 102dB SPL, with 340W RMS rating. SoundTech, 255 Corporate Woods Parkway, Vernon Hills, IL 60061, (708) 913-5511, (800) 877-6863, FAX (708) 913-7772.

Reader Service #116

⏻ POWERED SUBWOOFER

M&K Sound's V-125 powered subwoofer has an Active Headroom Maximizer amplifier circuit that delivers 125W RMS. A magnetically shielded long-throw driver, a two-position phase switch, and an internal 100Hz, high-level high-pass filter with bypass capacitors are also included. The V-125's 36dB/octave low-pass cutoff above 125Hz fosters nondirectionality, and a "filter" control allows setting the upper rolloff to any frequency between 50-125Hz. Miller & Kreisel Sound Corp., 10391 Jefferson Blvd., Culver City, CA 90232, (310) 204-2854, FAX (310) 202-8782.

Reader Service #112

■ VIBRATION CONTROL

Three new products from System Analysis are designed to handle absorption, diffusion, and reflection in the listening room environment. W.A.L.S. (Wavelength Absorbing Linear Structure) utilizes nine layers of different density materials, plus an airtight seal, for linear absorption from 20Hz to 20kHz. Q.T.R.D. (Quadratic Theory Residue Diffusor) diffuses sound to 180°. W.A.P. (Wavelength Absorbing Panel) controls the first reflection point off the side walls, with absorption rates and levels varied to accommodate different room sizes. System Analysis, 9009 S. 47th Pl., Phoenix, AZ 85044, (602) 438-8012, FAX (602) 431-8824.

Reader Service #113

Editorial

Perspectives 1995

Two diverse meetings I had the privilege of attending recently are a basis for some thoughts about loudspeakers in America. The first was the 40th anniversary of the founding of Acoustic Research; the second was the Winter Consumer Electronics Show. These two gatherings took place in widely divergent settings. The first on the balcony of New York's Grand Central Concourse, and the latter in America's version of Sodom and Gomorrah, Las Vegas, Nevada.

The AR party was relatively small, probably less than 200 notables in attendance. Some 94,000+ clogged most public transport services in, and to and from, the desert city. I find it bemusing that Las Vegas was scarcely more than a crossroads when AR was launched by Edgar Villchur and Henry Kloss in 1954.

The AR celebration included not only many audio industry notables, including AR's founders, but a fascinating collection of AR's products, looking just a bit dated, if not downright dowdy. They were certainly the pacesetters of their day, however. No other single audio development popularized and spread the idea of high-quality sound in the world's living rooms more than the acoustic suspension loudspeaker. The products which followed all implemented the penetration of good sound into America's homes.

The most striking fact evident in Las Vegas is the continuing penetration of electronics into more and more parts of every person's life. Audio is no exception. The spread of audio continues, becoming ever more evident, and earlier, in home construction, in all types of public buildings, and most especially in automobiles, as well as public transport, not to mention computers.

The moving coil driver is still the predominant motor for reproducing sound in all venues. What is most startling is the degree of specialization and adaptation manufacturers are producing to meet the technical problems of reproduction as well as the demands of new environments where sound is being delivered. Even with such evident effort and displays of great ingenuity, the overall quality of sound in most environments is exceptionally primitive.

I suppose this should not be surprising considering that our technical capability has been outrunning our ability to evolve our environment for most of the last four decades. It occurred to me in wandering from room to room in the Sahara that had anyone been able to be transported from 1954 to 1994 to see what has happened to loudspeaker transducers, he or she would simply be unable to comprehend or possibly to believe that such miracles of power, size, complexity, or adaptiveness would be possible.

The loudspeaker interface is at once the most demanding and interesting of all our audio problems. Perhaps adapting to the space in which it is installed runs a very close second. The range of innovation in loudspeakers is far larger, I believe, than almost any other audio design discipline. This latter is very probably a corollary of, and a tribute to, the challenge of converting electrical signals back into modulated air.

The designers and vendors I managed to talk with on my visit to Las Vegas reminded me again that something more than competitiveness and the profit motive are part of what drives the audio business. Audio is a dream machine in more ways than one. The illusion of reproduced sound has within it a lure to invent, to found tiny companies, to make a special and unique product. I do not see this motive in other parts of the electronics industry. I have not done comprehensive surveys, you understand, but the entrepreneurial urge seems more than latent in a large proportion of audiophiles.

I would like to believe that *Speaker Builder* has offered an important point of interchange for ideas and stimuli which have contributed to the wealth of choice we find available to us today. I am happy to see that a large percentage of those products are open to speaker builders for experiment and hands-on experience.

I believe speaker builders continue to have an interactive role in what becomes possible in loudspeaker technology. The tools are migrating downward to within reach of the hobbyist. The exploration of sound in public places, living rooms, automobiles, and entertainment venues is a very large undertaking. Our knowledge, although it grows almost daily, is still quite modest.

This is a fine time for all of us who care about sound's quality. Our tools, the hardware, the information, and the sound sources are quite unprecedented in their richness, power, and variety. At the threshold of this new year, it is appropriate to look back and to look ahead. This is certainly a great time to be a speaker builder. As we commence the sixteenth year for *Speaker Builder*, I invite you to join me in this fascinating quest on which we are embarked together, to find even better, more clever, and more satisfying ways to reproduce the sounds we love.—E.T.D.

THE T-REX MINISUBWOOFER

By Richard G. Carlson

[Important Notice: The Bose Corporation of Framingham, MA, owns a patent (US Patent 4,549,631, issued 29-Oct-85) that covers bandpass enclosures which couple both sides of the enclosure to the outside (like many sixth-order bandpass enclosures). Any competitive or commercial production of these enclosures will infringe their patent rights.]

[Author's Note: The intent of this article is to share a speaker building experience with this magazine's enthusiastic readership in the interest of promoting the enjoyable hobby of speaker building.]

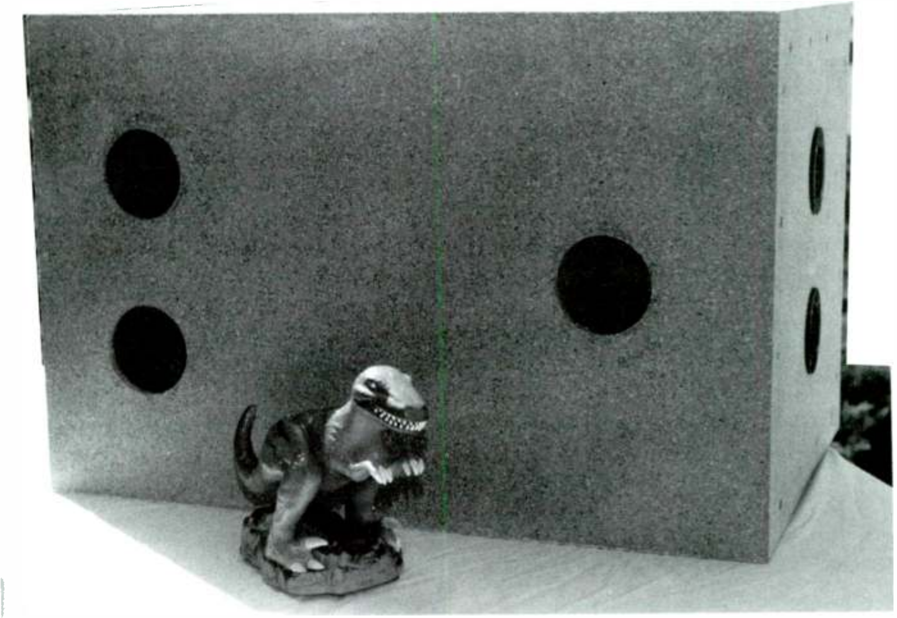


PHOTO 1: The T-Rex minisubwoofer constructed by the author (not pictured).

One of the most rewarding moments in a speaker builder's life is the thrill of experiencing the speaker construction project come to life. The moment just before you attach wires to the input terminals of a newly built speaker is quite exhilarating. You haul the hulk of a box, usually unpainted or unstained and smelling like freshly cut lumber, into your house from the garage, connect to the amplifier, and "fire up" for some preliminary testing (playing around). This moment is charged with your profound hope that performance will be nothing short of astonishing.

When you test subwoofers, setting up is usually more elaborate because a subwoofer is limited to the production of bass and must operate with full-range speakers to achieve its potential. This lengthy involvement usually causes anxiety and tension. But when all has been tested and heard, a tremendous calm permeates the environment and everyone involved. The anxiety that was the dominant emotion a few moments ago is washed away by the satisfaction and relief that the project was successful, at least in the preliminary sense.

I love bass, so experimenting with subwoofers has been an enjoyable experience for me for many years. My previous subwoofer research projects include a variety of sealed and vented subwoofers using 18", 15", 12", 10", and 8" drivers. I have never built a subwoofer using drivers smaller than 8", and I have never built a bandpass subwoofer. The term subwoofer becomes a little nebulous with smaller-than-12" drivers, because to produce true "gut-wrenching bass," subwoofers are normally configured with 12", or larger, drivers.

HOLD THAT THOUGHT

In a recent article (*Car Audio*, March 1994), nine high-quality 10" subwoofers ($150 and up, each) were tested in enclosures of 2 ft^2 or less. The test results revealed some very impressive measurements, most notably, the subjective SPL limits of five of the woofers tested which produced 20Hz at 107–111dB.

The speaker tests occurred in factory-furnished (sealed and/or vented) enclosures in the author's car, but had the speakers been tested in a living room, these measurement extremes may not have been possible. The point is that deep and powerful bass output from speakers smaller than 12" is quite possible, especially in autosound environments.

What about the flood of production (mini) subwoofers that use 6.5" (and smaller) dri-

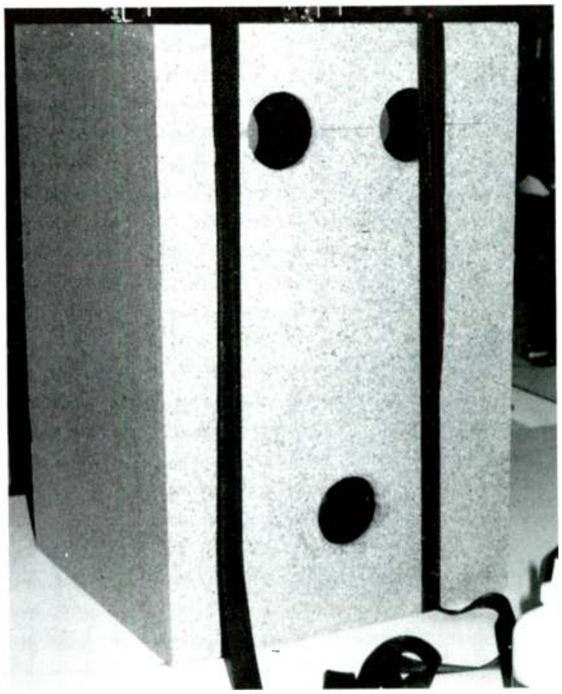


PHOTO 2: The T-Rex assembly taking shape, after gluing and clamping.

ABOUT THE AUTHOR

Richard Carlson has a bachelor's degree from the University of Maryland and has been an audio enthusiast for most of his life. He has written several *SB* articles and enjoys woodworking as a hobby. Dick is very interested in sharing ideas and experiences in speaker building and can be contacted through *Speaker Builder.*

vers? Are these subwoofers for real? Some produce good sound, and, let's face it, most of us do not wish to spend $400–500 for a car subwoofer. Besides, minisubs do not have a reputation for peeling the paint off walls, causing structural damage, or emulating an 8.5 earthquake two blocks away, but they do add impressive low end to any modest home audio or autosound system. So what is the alternative? Is an inexpensive "kick butt" subwoofer possible?

MODELING THE DRIVER

While looking through my cache of loudspeaker candidates, I found a pair of Madisound 6.5″ mid-bass drivers. I have had great success with these in the past and decided to do some modeling to see how suitable they would be for this project. Madisound predicts an f_3 of 41Hz from this driver. I entered the Madisound data using BassBox™, a Microsoft® Windows™-based computer program that can produce speaker box designs.

BassBox has been my main speaker modeling tool for more than two years. I enjoy its user friendliness, graphics, great user support, price, and other amiable features, including the ability to change from metric to English units at the click of the mouse and the box dimension calculator with 18 different enclosure volume shapes. BassBox even includes built-in procedures for testing speaker parameters and other features, plus a database containing more than 1,000 drivers for modeling.

The BassBox output report revealed some very interesting statistics. *Table 1* shows the parameters for the drivers in a parallel configuration. [*Note: The net computations under Multiple Drivers do not apply to the T-Rex subwoofer because the speakers are fed by the right and left outputs of the amplifier and are not in parallel as reported.*] The speakers function in the cabinet as parallel drivers only to support box parameters and to determine the internal box dimensions (*Table 2*).

Also notice in *Table 2* the prediction of output at 40.3Hz for the rear enclosure (hence the claim as a 40Hz subwoofer) to 100.8Hz for the front enclosure. Anticipated output graphs are shown in *Fig. 1*. This is not the best model for a bandpass subwoofer, but it works, as you will see later. If the predicted rise in lower midrange becomes a problem, you can manage it with low-pass filtering.

PLANNING THE BOX

Now that all the preliminaries are out of the way, let's do a run-through on the beast as if we were going to build it. You'd have to own or have access to certain woodworking tools for panel cutting, hole cutting, and wood clamping tasks. If you didn't have access to the appropriate woodworking tools, you'd have to make friends with someone who does.

Although I chose particleboard for the T-Rex (*Photo 1*), I strongly recommend ¾″ MDF (medium density fiberboard), which costs a little more, has superior sound characteristics, and provides a smoother surface for finishing. If you wanted a lighter box, consider a high-grade marine plywood, which increases the costs approximately 30%.

TABLE 1

LOUDSPEAKER PARAMETERS

General Information
Company: Madisound
Model: 6102-4
Ser.No.:
Multiple Drivers
Number = 2
Mech. Config: STANDARD
Elec. Config: PARALLEL
NetZ = 2.0Ω
NetRe = 1.7Ω
NetSens = 93.0dB SPL
Mechanical Parameters
f_S = 30.0Hz
Q_{MS} = 6.600
V_{AS} = 1.377 ft³
C_{MS} = 0.300 in./lb
M_{MS} = 0.511 oz.
R_{MS} = 1.036 lbs/sec.
X_{MAX} = 0.138 in.
Sd = 19.6 in²
Dia = 5.0 in.
Electrical Parameters
Q_{ES} = 0.350
R_E = 3.3Ω
L_E = 0.1mH
Z = 4.0Ω
B_L = 5.1 N/A
P_E = 50.0W
Combination Parameters
Q_{TS} = 0.330
no = 0.126%
Sens = 87.00dB SPL 2.83V)

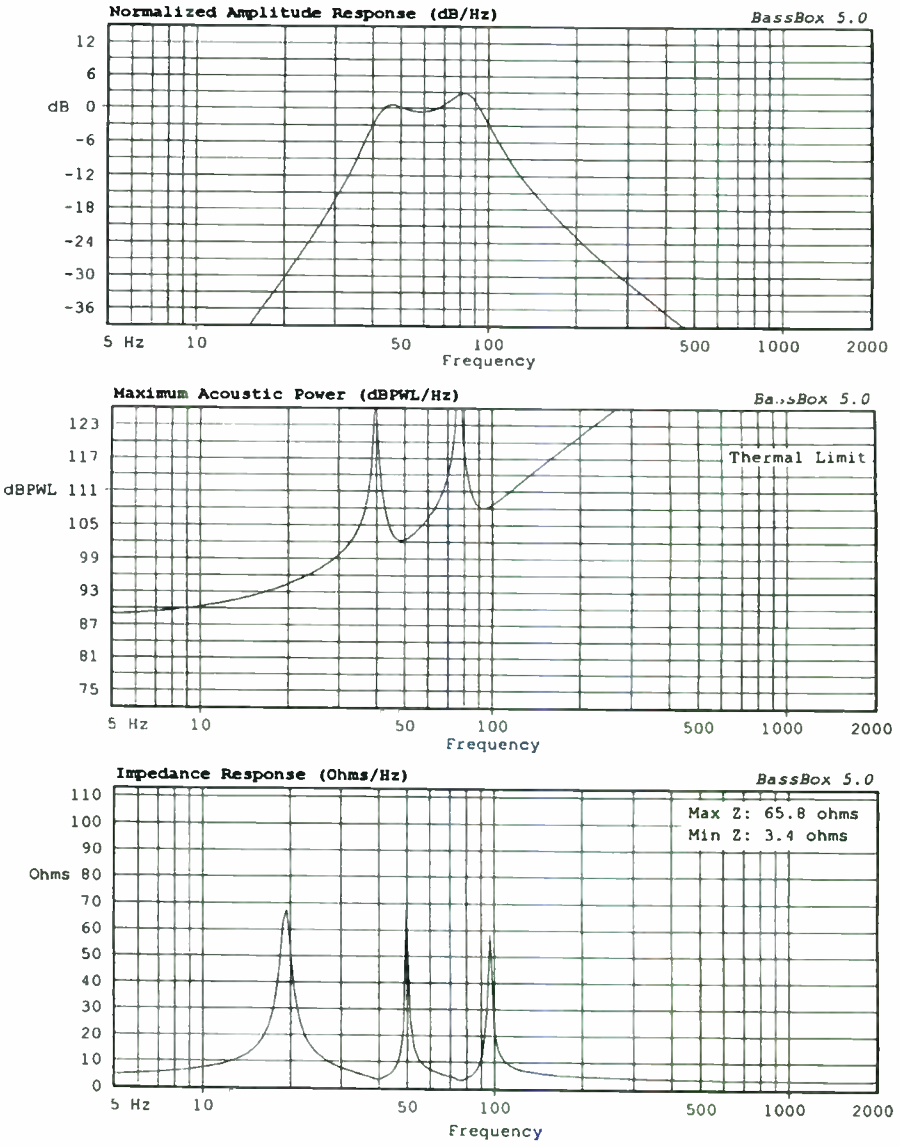


FIGURE 1: Model's output predictions.

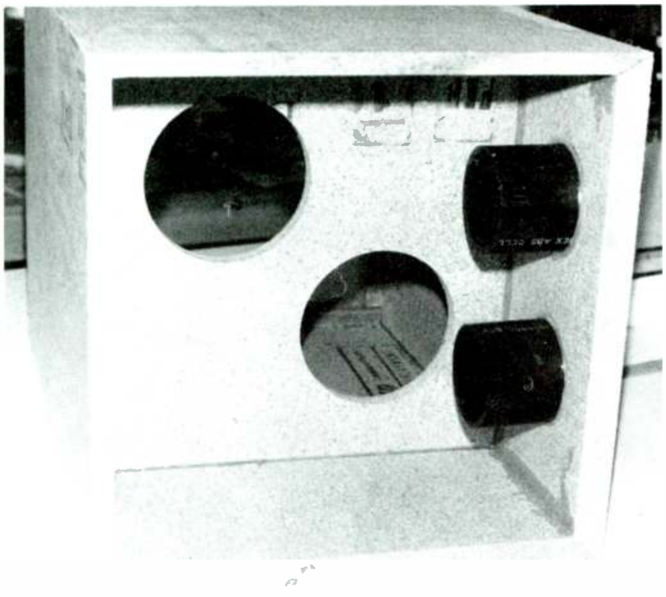


PHOTO 3: T-Rex shell after securing ABS tubes and caulking inside wood joints to prevent air leakage.

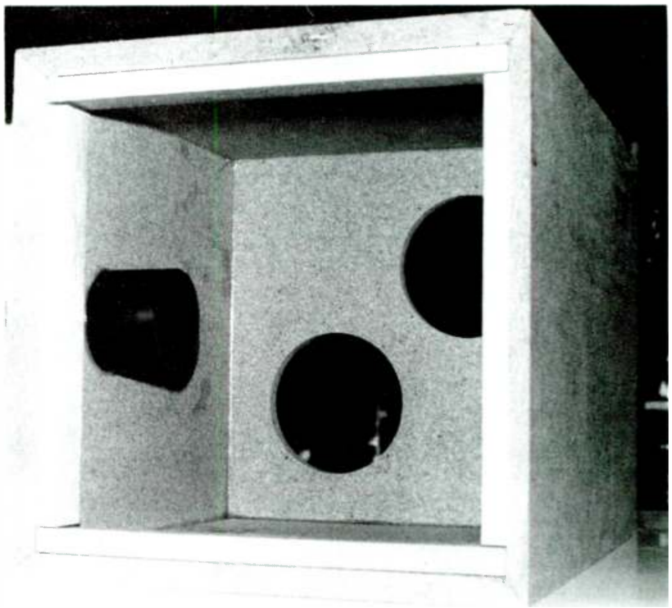


PHOTO 4: Cleats in place to accommodate cabinet end piece.

CONSTRUCTION TIPS

Please read through the following steps several times until you understand the procedure. If you were actually going to build the T-Rex, you would:

1. Cut two 8′ × 16½″ pieces from the particleboard sheet.

2. Cut three 25 3/16″ pieces from one of the 8′ lengths (*Fig. 2,* #1-3), another 25 3/16″ length (#4) from the other 8′ piece, and two 16½″ sections (#5 and 6).

3. Make 45° miter cuts on all sides of each of your six cutouts. To set miter cuts properly without cutting excess wood stock, you would need to set the table saw fence at the width of the piece to be cut, then subtract 7/8″ to compensate for the miter angle of the saw blade. [*Note: If you preferred to butt the ends of the sides, the dimensions of some of the sides would vary slightly. In making your calculations, you would want to refer to the internal box dimensions in* Table 2 *and remember to add the thickness of the wood on both ends and consider the thickness of the speaker baffle inside the box.*]

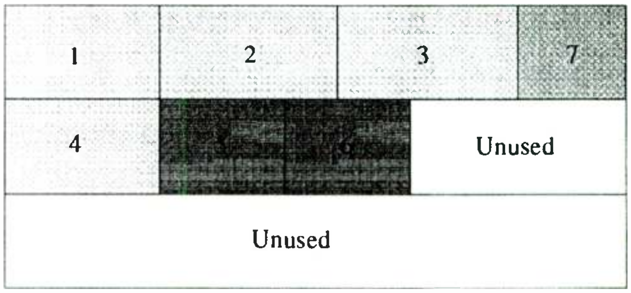


FIGURE 2: Cutting plans from 4′ × 8′ panel.

TABLE 2

BOX PARAMETERS AND PREDICTED OUTPUT

Box Type: Bandpass Vented	
Rear enclosure	
V_B1 =	2.000 ft^3
f_B =	40.0Hz
f_3 =	40.3Hz
Ports =	1
D_V =	3.00 in.
L_V =	3.38 in.
Front enclosure	
V_B2 =	1.000 ft^3
f_B =	77.0Hz
f_3 =	100.8Hz
Ports =	2
D_V =	3.00 in.
L_V =	3.32 in.
Fill =	none
Internal Box Dimensions	
Subwoofer	
Vol1 =	2.000 ft^3
Vol2 =	1.000 ft^3
Shape =	Bandpass prism
h =	15.00 in.
w1 =	15.36 in.
w2 =	7.68 in.
d =	15.00 in.

4. To ensure size consistency, you would set the table saw fence at one dimension and cut all pieces at that width, then set the fence to the dimension of the remaining pieces before cutting.

5. Measure and cut a 15½″ × 15½″ square for the speaker baffle (#7). These dimensions are important for the dado cuts you would make later in the longer sides to accommodate the baffle.

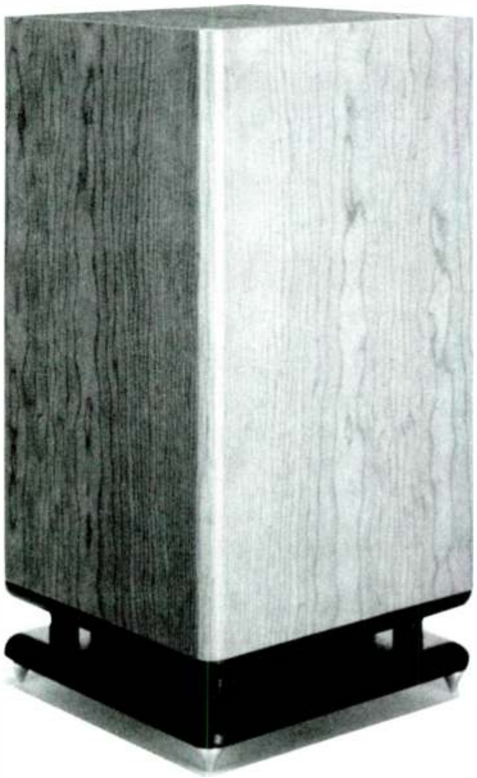
6. You'd cut two speaker holes 5 11/16″ in diameter on the baffle and, placing the speakers over each cutout, use a small bit to drill a pilot hole for the speaker mounting screws (use 1″ particleboard screws). (I aligned the woofers diagonally for baffle strength and mounted them from the rear of the baffle (gasket side down) to prevent air leaks.)

7. The next step in this exercise would be to select one of the long sides to make the holes for the three bass-reflex ports. (See my *SB* 2/92 article, "Building the Model 249 Loudspeaker," p. 22, for details on how to make professional-looking cabinet vents.) Two ports are required for the front chamber. I measured 5¼″ from each side and 4 1/8″ from the (closest) end, which centered the vents in the front chamber. For the rear chamber, I measured 5¼″ from the end and centered it for the single vent. I calculated 3/8″ for the depth of the ABS vent for firm mounting. [*Note: The calculated length of the vent must include the remaining 3/8″ of the side for proper vent length.*]

8. You would then need to cut the three vent holes at the marked locations *from the inside of the side piece first,* turn the piece over, reset the hole cutter for 3″ (inside diameter of the ABS), and finish the three port hole cuts.

9. Location of the speaker input terminals is a matter of preference, but for this project, I put the terminals at the end of the cabinet (large chamber end). Since this subwoofer is primarily for autosound, the end is the best location for the input terminals. If you were to build this subwoofer and place it in your home and on end, you would need to simply

We'll tell you no lies...



Titan Powered Subwoofer

The most reasonably priced, high-performance powered subwoofer available today. Titan's dynamic range and clarity improves any stereo or home theater system.

- Flat response from 20-150Hz, ∓3db
- Adjustable crossover frequency of 50-150Hz 12 db/octave
- Amplifier delivers 250 watts RMS with less than .5% distortion
- Long Excursion Proprietary 12" woofer
- Current sensing feedback reduces distortion; prevents driver damage
- Protection circuit senses and limits excessive input levels
- Height: 26 1/2", Width: 13 1/2", Depth: 15 1/2"

(plus shipping and handling, and 5% sales tax in WI only.) Call for finish availabilities.

ACI (Audio Concepts, Inc.)
901 South Fourth Street, La Crosse, WI 54601 (608) 784-4579 Fax (608) 784-6367

Reader Service #6

fabricate a ¾" base to keep the speaker wires from binding.

10. The plans for this project would next instruct you to make ¾" × 5/16" deep dado cuts in each of the four long sides on the inside (to accommodate the speaker baffle), measuring 7 11/16" from the inside of the miter to ensure proper depth of the smaller chamber. [*Note: To cut a dado, use a dado blade or make several passes across the table saw cutting blade until a ¾" dado results. A little practice of this procedure will make you an expert.*]

11. You would then cut three ABS pieces at the prescribed length (*Fig. 2*) and secure (using wood glue) in the previously cut holes. I tapped the ABS tubes lightly into each slot using a mallet. When the tubes were seated, I rotated each one a half turn to ensure a uniform glue application and applied a solid bead of glue around the base of each tube where it meets the wood to ensure it is secured in the slot. I let this set overnight.

12. You would next need to apply glue to the longer miter sides of the cabinet pieces and in the dado trench with your finger for a uniform glue application. Assemble all four sides *and* the speaker baffle, making certain the predrilled speaker mounting holes face the long chamber end of the cabinet (the end from which the speakers are mounted). Clamp and let set overnight (*Photo 2*). Generously glue the inside joints of the cabinet. After the glue dries, caulk all internal wood joints against possible air leaks (*Photo 3*).

13. The next day, you would glue the top end (small chamber) of the cabinet, clamp, and let set overnight.

14. You would also need to make four wood cleats for the remaining end piece (*Photo 4*). Glue and nail (or staple) the cleats, which provide a backing for wood screws to secure the remaining end piece to the cabinet. Use at least four screws per side and apply window insulation foam for an airtight seal.

15. If you were to complete cabinet assembly, you would want to sand it using #220 sandpaper and apply primer and paint, or, if you prefer, glue and wrap the cabinet with speaker carpeting, being careful not to block any of the three vent openings.

TEST EQUIPMENT

My test setup includes a Rane RE14 2/3-octave equalizer and spectrum analyzer, Marantz Model 3250B preamplifier, Carver PM-1.5 power amplifier, and a Radio Shack SPL meter (*Photo 5*). I conducted low-frequency testing using track 16 (bass decade (200Hz–20Hz), 1/3-octave warble tones @ -20dB f_S) of *Stereophile*'s Test CD2, STPH 004-2. Low-frequency test points on the CD are 200, 160, 125, 100, 80, 63, 50, 40, 31.5, 25, and 20Hz. I performed initial testing in my garage, and subsequent testing in an auto interior using the same test equipment.

A baseline sensitivity level of 90dB at 1m was established using the Rane's built-in pink noise generator. Sound pressure measurements were recorded with the SPL meter 1m from the center of the speaker-port side. I conducted the recording level of each test point three times to ensure consistent output readings, with the microphone 1m directly in front of the three ports.

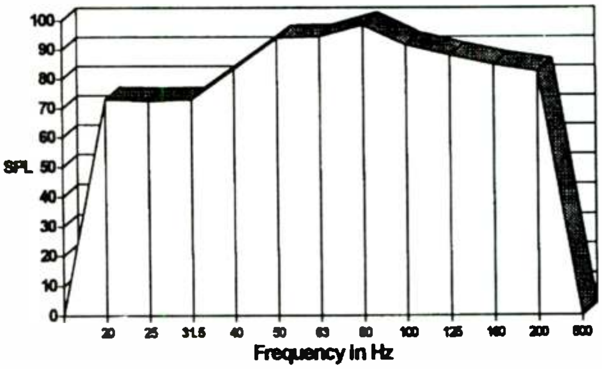


FIGURE 3: Low-frequency test results.

PERFORMANCE

The most exciting part of testing is listening to the speaker for the first time. Pretesting (which is the enjoyable part for normal people) usually involves listening to music. During pretesting I noticed the very strong (loud) bass output (note the NetSens prediction in *Table 1*) and a hollow midrange output. The latter was annoying, but I proceeded with "formal" testing in spite of the annoyance. I averaged and recorded the test results (*Fig. 3*). The ports produced some noticeable noise or chuffing sounds when driven very hard. I did not attempt to reduce this noise during this project.

A comparison of the predicted output (*Fig. 1*) versus the actual output (*Fig. 3*) reveals significant differences. This is normal, since the prediction portrays a "perfect" world, where both drivers are identical in electrical and physical characteristics. I did not test the two drivers to verify their specifications, but you can be sure they are not the same. Their specs are certain to be at least "a tad" more or less than the Madisound spec sheet.

Figure 3 verifies their performance in the "real" world, where stuff happens, including differing driver specifications. The possibility of these drivers being the same is very remote, so their specs are used to establish a baseline prediction. The closer the drivers are to the published specifications, the closer (not necessarily better) their performance will be to the predicted output. The actual output is a mixture of performances by each of the (dissimilar) drivers and the effects of the combination in the boxes, ports, and listening environment.

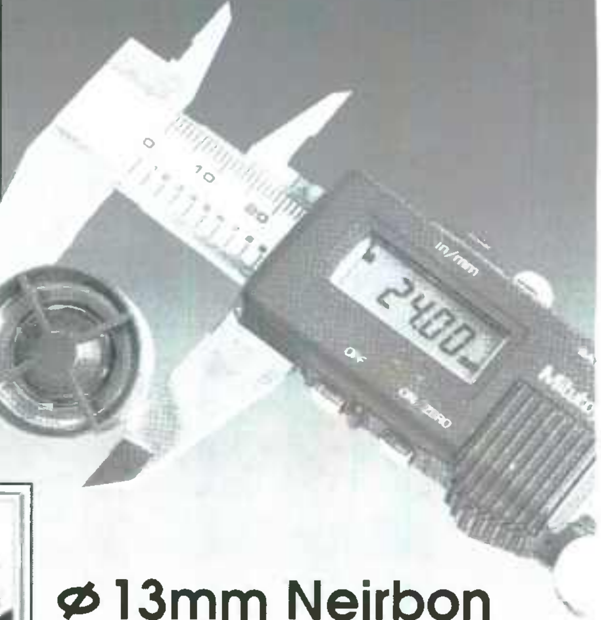
In any speaker project, if you seek flawless performance, you must spend extra time changing the physical variables (box size, vent length, damping material, low-pass filtering, and so forth). Each time any of these variables is changed, you must conduct another round of testing to measure (and record) the output results. This process is

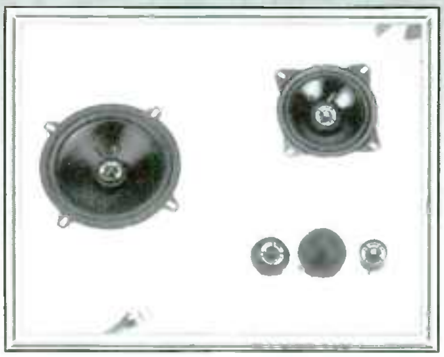
PHOTO 5: The author with completed T-Rex and test equipment.

Forgings TWEETER / SYNCHRONOUS SPEAKER

HUNDREDS OF OUTSTANDING TWEETERS ARE AVAILABLE FOR EVERY OF YOUR PROJECT

Newest Tweeter with one-piece diaphragm in Super Duralumin, Titanium ... material.





DOME TWEETER : @USD 0.79

⌀13mm Neirbon Super-Tweeter

- ☐ Supreme know-how and continuous research
- ☐ Hi-quality products at the most competitive pricing
- ☐ Available for OEM design and free catalogues

You'll be surprised to find we're the one you've been looking for !

FORGINGS IND. CO., LTD. / P.O. BOX 1823, TAIPEI, TAIWAN, R.O.C.
TEL: 886-2-585-3316/7 FAX : 886-2-594-2708 ATTN: MS. LU CHI YING

called analysis, which is the secret ingredient in many of the high-quality production and custom audiophile speakers.

COSTS

I did not realize how affordable this project was until I calculated the costs for materials. My total investment was:

$48	Two Madisound 6102-4
13	4′ × 8′ × ¾″ particleboard*
3	Two input cups
20	Miscellaneous (wire, glue, screws, ABS, paint, etc.)
$84	**Total**
	*Add $8 for MDF

[Note: Madisound charges extra for shipping, but not handling. Although they recommend adding 20% to the total for any order, I cannot remember being charged more than 10% for any order to my West Coast address. Any excess is refunded to you with the order. These folks are very pleasant and helpful.]

SOURCES

Madisound Speaker Components
Box 44283, 8608 University Green
Madison, WI 53744-4283
(608) 831-3433
Drivers, accessories

Harris Technologies
PO Box 622
Edwardsburg, MI 44112-0622
(616) 641-5924
Design software

CONCLUSION

I named the T-Rex for its size, small drivers, and performance attitude as an economical "killer" subwoofer. In the car, it lived up to its name as an awesome performer. Low-frequency output is profound and robust.

Make no mistake, this is a very effective, efficient, powerful, and inexpensive speaker. It also moves a lot of air. During testing, I felt strong puffs of air from the ports from 6′ away. Low-frequency output caused chest irritation and a tingling on the surface of my face during cut #3, "Bye Bye Baby" of Madonna's "Erotica" CD (Maverick/Sire, 945031-2). The hollow midrange was not noticeable (probably because high frequencies are naturally attenuated or filtered when operating from a trunk isolated from the passenger compartment). Instead, there was only strong bass, which was my primary objective with this project.

In retrospect, I had wished for a minisubwoofer, but as it turned out, this speaker is heavy, cumbersome, and too large for many of today's popular small cars. The box should be smaller or reconfigured for autosound applications. However, it performs well in a car environment. Some tweaking of internal cabinet dimensions could produce a box configuration more conducive to a small car environment.

Should you prefer the large internal volume of the T-Rex, be sure to maintain the specified volumes for the front and rear boxes. For example, a dual-chambered box measuring (internally) 9″ × 18″ × 10.67″ for the front and 9″ × 18″ × 21.33″ for the rear offers a configuration that will fit in most small and mid-size cars. This subwoofer has abundant bass output for drivers of this size and price.

PREVIEW
Glass Audio

Issue 1, 1995

- Vacuum Tube Op Amp
- Quality Preamp Power Supply
- More Phase Splitters
- Making Contact With Your Tubes
- Quick, Simple Output Transformer Tests

SOUND PERFORMANCE.

Brought to You by Speaker Materials of DuPont KAPTON®.

Everything — from Louis Armstrong to Led Zeppelin — sounds better coming out of loudspeakers designed with DuPont KAPTON. A truly sensational speaker material, KAPTON improves acoustics and stands up to high wattages and harsh environments better than any other.

You've probably heard about the success of KAPTON in voice coils...and now it's available for other speaker parts, too.

VOICE COILS OF KAPTON

SPIDERS OF KAPTON

Precision-formed parts of KAPTON exhibit a high stiffness-to-weight ratio — better than conventional speaker materials. Voice coils of KAPTON are non-conductive and non-magnetic, with a broader frequency response than aluminum in both high and low ranges. No matter where it's found in the speaker, KAPTON enhances acoustical performance.

And unlike aluminum and paper, KAPTON resists heat damage to glue joints. It stays cool and dry when the power, heat and humidity are turned up. So not only do your speakers generate better sound — even under environmental extremes — they last longer, too.

DOMES OF KAPTON

Available as flat film for voice coils or as precision-formed spiders, cones, surrounds and domes, KAPTON is extremely lightweight and stiff. And it won't dent, tear or crease, for added durability and easier speaker manufacturing.

Sound Good?

Want to hear more about how KAPTON can improve the acoustics and durability of speakers you design? Just call 1-800-356-6714. We'll put you in touch with our applications engineers. We'll also send you sample film and technical information on designing speakers using KAPTON parts. We're sure that once you evaluate DuPont KAPTON for yourself, you'll be impressed with its sound performance.

CONES OF KAPTON

DU PONT

Part 1

HIGH QUALITY USE OF MOTOROLA'S PIEZO DRIVER

By Mike Klasco

In 1984 Motorola introduced its first large piezo element compression driver. When used with an optimum horn, the KSN1086A featured a response extending from 700Hz to over 20kHz, with dispersion, efficiency, and power handling well beyond conventional midranges and tweeters. It cost far less than other compression drivers with such an extended bandwidth, yet it achieved very limited acceptance with designers and end-users.

UPGRADE NEEDED

Physically, the Motorola compression driver appears to be a direct "drop-in" alternative for a conventional compression driver. However, many of the techniques that wring the best performance from this piezoelectric transducer are a bit different from those applied to electrodynamic drivers. Design rules, wisdom, and witchcraft for the KSN1086A were never published, and, not surprisingly, the product racked up few "design wins."

In light of the limited product orders from preproduction samples, Motorola could see that "hard" tooling for large production runs did not make sense. The company continued to produce modest quantities from short-run molds, although this resulted in wider than desirable frequency response tolerances.

Last year Motorola finally bit the bullet and completely retooled its compression driver with precision tooling and reintroduced the product as the KSN1188A (*Photo 1*). Still, the problems of correctly matching the driver to the right horn, obtaining the desired sensitivity and acoustic output, handling crossover network for piezo elements, overload protection, amplifier stabilization, and various other chef's secret sauce techniques for getting the best out of the 1188A need to be revealed for designers working with this device to attain optimum results.

I have worked closely with Motorola's design team on this driver, and include in this article recommendations that have either been initiated or approved by Motorola. I would also like to thank Donald Richardson for his comments and review of the article.

PHOTO 1: The Motorola KSN1188A compression driver.

ABOUT THE AUTHOR

Mike Klasco started his first speaker projects as a teenager in the mid-'60s and has been out of control ever since. In the '70s Mike owned GLI, a popular disco speaker manufacturer, and many of his designs used unique methods to get the best out of the piezo tweeters. For the last ten years his company, Menlo Scientific, Ltd., has served as consultants to the speaker industry.

PIEZO OVERVIEW

Piezoelectricity can be defined as the ability of some materials to alter their shape under the influence of an electrical field. If the shape change can be used to provide back and forth motion, and a diaphragm is attached to the element that is moving, then this arrangement will yield acoustic output.

Piezoelectric materials appeared in practical transducers during World War II as sonar devices (still a major application), followed by commercial devices such as microphones and phonograph cartridges. Before the 1960s piezo speakers were not considered viable, because the ceramic elements lacked adequate excursion to produce enough sound level, and the response range of most practical elements barely extended down to the audio range.

Piezo transducers offer power conversion efficiencies approaching 50%, over 10× that of conventional speakers. Motorola scientists wished to develop a high-performance hi-fi tweeter and found the piezo element's extended top-end response, light weight, and potentially low-cost materials all quite alluring.

Motorola introduced its first commercial product in 1965: a piezo horn tweeter of quite a bit different construction than the piezo tweeters of today. Aside from being a somewhat fragile assembly, it required an outboard transformer, which was expensive, heavy, and defeated the goal of achieving an inexpensive and light device.

MOTOROLA HORNS

By 1970 Motorola developed the first tweeter horns that did not require a step-up transformer, but used instead a unique push-pull "momentum drive" scheme. Two piezo ceramic disks were charged with opposite polarity, and then one flipped and both used together. This push-pull arrangement (both going in the same direction at the same time) resulted in greater excursion and a "motor" capable of very high force.

Keep in mind that "high excursion" for a piezo element is miniscule when compared to any electrodynamic speaker. High-force piezo drivers are ideal for horn loading since excursion requirements are minimal, while the piezo motor has the "push" to easily drive the air column in the horn. A horn is an acoustic transformer, which the piezo element needs to match its intrinsic characteristics to do the job.

A typical system using the 1188A compression driver features a horn on the driver, a crossover network, and a woofer to provide the low-end response. Let's take a look at all these elements and how they fit together.

MATCHING DRIVER TO HORN

The KSN1188A driver (*Fig. 1*) will fit any standard 1 3/8"-18-thread horn. Physically, a piezo ceramic compression driver differs most dramatically from conventional voice coil/ceramic magnetic structure compression drivers in terms of weight. The driver weighs only a fraction of a pound, while the conventional driver weighs five or more. The original KSN1086 weighed even less. Its current enhanced version includes much thicker and denser wall construction to prevent any interference between the woofer and the compression driver when both are used within the same enclosure.

The horn requires only the thinnest plastic wall construction to support the weight of the 1188A driver. But for the same reasons that reinforced engineering plastic is used on the 1188A, care must be taken to prevent the horn walls from being modulated and flexed by the woofer's operation.

When the driver and woofer share the same enclosure, the positive/negative pressure within this space will modulate anything that is more flexible than the cabinet's panels. The horn walls will be "driven" by the woofer from within the enclosure, and this spurious energy will re-radiate into the room. This noisy modulation emanates from the horn, but the innocent piezo driver is blamed for this distortion.

This common problem with any horn of thin wall construction is not specifically related to piezo element horns. You can still use lightweight horns of medium density plastic foam construction, or even thin wall plastic devices coated with epoxy/damping compounds (available from SoundCoat and others). High-grade fiberglass construction horns often encapsulate balsa wood within the wall structure to dampen large panel areas.

BANDWIDTH

The response range of the KSN1188A extends down to 500Hz before it rapidly cuts off. Usable range is 800Hz to beyond 20kHz, which is an extremely wide bandwidth for a relatively inexpensive compression driver. Finding a horn that works well over this range is no easy task (Part 2 of this article will present an almost ideal solution that may surprise many readers).

Selecting a horn which performs well over the desired bandwidth involves many design decisions. I will briefly discuss these issues in using the 1188A.

The family of horns comes in a range of flavors, from the slowly expanding hyperbolic, to the popular and well-balanced trade-offs of the exponential, to the straight-sided conical. The hyperbolic horn provides great low-end loading down to the lowest usable horn response. But this benefit comes with a price: only slightly more than two octaves of really clean response. Harmonic distortion can become serious in the upper octaves.

The effect on sound quality of a long and slowly expanding column can be heard by cupping your hands in front of your mouth and talking. By slowing widening the angle of your hands, the noisy "horn sound" fades. Too much of anything can be...just too much.

HORN CHOICES

The exponential expansion rate is a very good compromise of loading, distortion, and bandwidth. A carefully selected exponential horn can perform well over four octaves. If you cross over from the woofer at 800Hz, then you will have response to beyond 12kHz before the horn's distortion creeps in. Since the horn's first harmonic distortion would only start to occur at 24kHz, maybe this would offend only passing bats.

One configuration to consider is a pair of vertically oriented 8" woofers with the horn between them. As many *SB* readers are aware, Joseph D'Appolito has suggested an excellent crossover scheme that would work really well with this arrangement. A crossover of 1.2kHz should be fine for an extended range 8", and, with an optimum horn, the horn's fourth octave distortion would not hit until it is almost beyond human hearing range.

Conical horns can have even lower midrange and high-frequency distortion over wider bandwidths than exponential horns, but their poor low-end loading can result in excessive driver distortion, subjectively worse (nasal sounding) to most listeners than the hyperbolic horn's rising harmonic distortion at the top end.

Hybrid approaches that combine some of the above horn expansion rates are especially appealing with the 1188A. For example, since the piezo drive has especially high force, a horn designer can take advantage of the excellent low-end loading of the hyperbolic taper rate. By simply slowing the expansion rate from exponential, yet opening faster than hyperbolic, the top-end distortion arises more slowly (than a pure hyperbolic taper). Conical mid-horn flare can help maintain constant directivity. A final tractrix rapid flare-out at the mouth improves both transient response and aids directivity control at the low-end due to the larger mouth area.

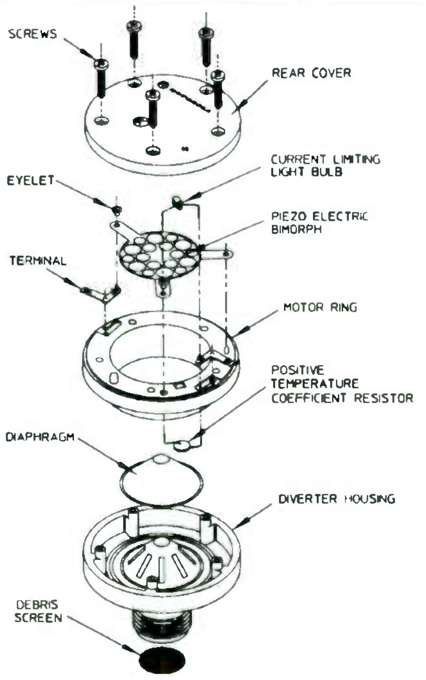


FIGURE 1: KSN1188A components.

SENSITIVITY

While the sensitivity of a compression driver will vary with the horn used, you can expect about 93dB @ 1m with 2.83V input from the 1188A. The apparent sensitivity of the piezo compression driver is quite a bit lower than conventional electrodynamic compression drivers—almost 10dB. The real conversion efficiency of piezo speakers is quite high, but their impedance is also high, from about 100Ω at 1kHz, dropping to about 20Ω at 20kHz. With such high impedance, very little real power is drawn from the amplifier. In fact, voltage, not power, controls piezo sound levels (I'll discuss voltage step-up transformers later in this article).

Aside from presenting the speaker designer with something different from what he is used to, the difference in apparent sensitivity is not too much of a problem. Actually, the piezo compression driver's level is much closer to the woofer's, and therefore the piezo does not need to be padded down as is required with electrodynamic compression drivers. Using resistors with these drivers to match the woofer's sensitivity generates heat and represents a failure mode and a waste of amplifier power.

Conventional compression drivers exhibit a drooping top-end response, starting typically at a point before 5kHz. Although midrange sensitivity of 105dB at 1kHz is common, very few drivers can maintain sensitivities over 100dB at 10kHz, with response usually falling to 95dB or less at 15kHz. In contrast, the falling impedance of the piezo compression driver compensates for this effect, and output remains fairly linear and strong to 18kHz.

OTHER FACTORS

Both the sensitivity and the maximum acoustic output of the KSN1188A is comparable to that of most medium-efficiency direct radiator 8–12" woofers. With an E-V 8HD horn, the 1188A will reach 113dB maximum output (1W/1m) for extended periods of time. Above this level a built-in protection circuit unobtrusively protects the driver and limits output.

If you use a very wide coverage horn, such as a 120° horizontal by 60° vertical, then the on-axis output will drop (the same overall sound energy is simply projected over a wider area). If you use a 40 × 20 long throw horn, expect sensitivity closer to 100dB/1m with 2.83V input.

Since most speaker designers will have other significant reasons to select the coverage of the horn (aside from matching the sensitivity of the compression driver to the horn), I will address the various techniques to attain the desired sensitivity, power handling, compensation of a couple of sharp frequency irregularities, and acoustic output.

CROSSOVER NETWORK

Piezo speakers don't require crossover networks to protect the ceramic element from overexcursion and damage. As the lower frequency limit of the driver is approached, the inherent rising impedance of the piezo drive element takes the transducer out of the circuit naturally. In designs with extreme cost constraints, the expense of a crossover network is thus avoided. Perhaps speaker design engineers know this all too well, and historically Motorola's piezo speakers have been used most often without a crossover network.

But crossover networks are used for many reasons, aside from simply controlling diaphragm excursion. It is always good practice to use mid- and high-frequency speakers above their resonance frequency. At and near resonance, transient response suffers, phase response undergoes rapid shifts, and intermodulation distortion increases. These conditions certainly do not contribute to smooth transitions between woofers and midranges, and degrade the clarity and definition of sound reproduction. These problems are universal for any type of speaker, but because the piezo element can withstand operation without any crossover, they have taken a bum rap for the sonic results of "running bare."

Still another compelling reason to use a crossover is to minimize the overlap between woofer and tweeter. Interference effects between drivers, both in coverage pattern and frequency response, are exacerbated when the woofer and midrange are both operating beyond their optimum transition points.

Finally, the optimum horn mouth size to accommodate the KSN1188A's 500Hz low-end cutoff is close to $3ft^2$. If the designer ignores this limitation, then standing wave reflections at the mouth will result in comb filter dips and peaks in the response near cutoff, degrading the critical voice range. Of course, the design rules for horn mouth size and low-frequency performance are the same for all transducers.

ACTIVE OR PASSIVE?

You can use traditional passive crossover networks with the KSN1188A, requiring only a 10–20Ω 10W resistor across the speaker terminals. Because the piezo driver acts more like a lossy capacitor than the inductive/resistor model of electrodynamic speakers, you can implement some unique techniques in piezo passive crossover designs. To move the crossover point upward, use a series cap along with a resistor in parallel (in the 5–10Ω range). The higher-value resistor will shift the crossover point upward.

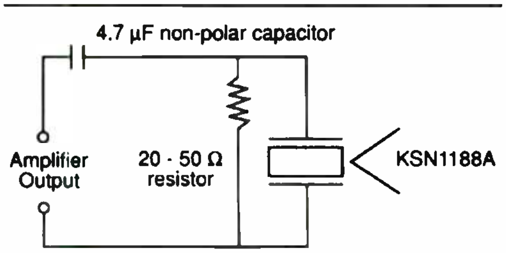


FIGURE 2: Resistor placement for amplifier stability.

Most musical instrument, vocal PA, club, and hi-fi applications use passive crossover networks after the power amplifier. Electronic crossovers offer various benefits, but require the expense and bulk of an additional amplifier. Also, we must address the additional issue of attaining the smoothest possible response.

The KSN1188A's predecessor tended to have a number of sharp peaks and dips, especially in the upper midrange. The center frequency for these gremlins shifted from unit to unit, so the solution was elusive, short of custom-building a parametric equalizer correction circuit for each device. The KSN1188A still has a few narrow dips, which are consistent from device to device and can be equalized out by a three-band parametric. I have seen a parametric kit or two using a few op amps solve this problem. Combining both the electronic crossover and the parametric in the same chassis and providing a common power supply would save a little money.

PIEZO PARAMETERS

Electrically, the 1188 driver appears as a lossy 1.5μF capacitor. The driver impedance decreases with frequency, and the bandwidth of many amplifiers extends to 100kHz and beyond. At those frequencies, ultrasonic resonances may occur between the amplifier and the driver, causing damage to one or the other, or both. You should use a 20Ω 10W resistor with extended range amplifiers to prevent these ultrasonic resonances (*Fig. 2*).

The KSN1188 uses Motorola's Powerline Internal protection circuit. Neither additional protection nor crossover is required. The threshold of the protection circuit is at 100W continuous and 400W peak levels.

Above this power, a positive temperature coefficient (PTC) thermistor, in parallel with a bulb, begins to limit high-frequency power. If continuous power remains above 100W, the PTC opens, and all power passes through the lamp. The level slowly drops 1dB at 800Hz, but 16dB at 10kHz. The lamp limits peaks above 400W. Normal operation resumes after the speaker cools.

Adding piezo driver/horns together, wired in parallel, increases sensitivity. The high electrical impedance of the KSN1188A (never falling below 15W in the audio range) allows several units to be connected in parallel without amplifier loading problems. Each time the number of driver/horns is doubled, the average sensitivity of the array increases by 3–6dB.

The actual increase depends on several factors such as off-axis angle, frequency, and physical configuration of the array. Part of the increase is due to the higher Q of the directivity (tighter pattern and attendant increase on-axis, at the expense of off-axis output). Vertical arrays can maintain good horizontal dispersion and tight vertical coverage, minimizing floor and ceiling reflections, which is ideal for home theater applications.

STEP-UP TRANSFORMERS

Another way to increase sensitivity is by using a step-up transformer, which is useful when the cost of multiple drivers is prohibitive or when the higher acoustic output of multiple drivers is not required. Since the piezo driver's output responds to voltage, a 1:4 turns ratio will yield +6dB increased apparent sensitivity with a conventional power amplifier. You may specify smaller step-up ratios. Beyond 1:4 loss of top-end response, higher distortion, and amplifier stability become more severe.

Remember, the voltage capacity and maximum acoustic output of the piezo compression driver have not changed, so 25W continuous into a 1:4 step-up transformer results in the 100W maximum input level of the driver before the internal protection circuit begins operation. Of course, we are not increasing wattage, just the voltage. The step-up transformer can enable you to match sensitivity to very efficient woofers, or simply compensate for the lower on-axis response when the 1188A is used with a wide coverage horn.

WOOFER SELECTION

The sensitivity and acoustic output of the KSN1188A is comparable to many 10–15″ woofers. Obviously, woofer sensitivity and power handling vary with magnetic system strength, moving mass, cone size, and many other variables. Since the KSN1188A has a usable range down to 800Hz, the woofer must at least have a good response up to this

Continued on page 65

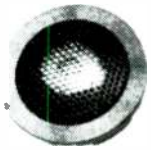
VERSA-TRONICS INC.

P.O. Box 87, Amherst, N.H. 03031
(603) 883-1960
FAX (603) 886-1592

NEODYMIUM

RARE EARTH MAGNET TWEETERS


66-25Neo/8F

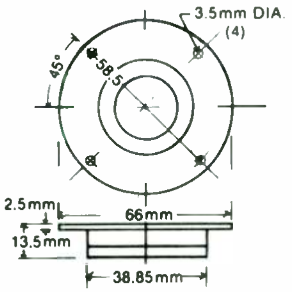

49-25Neo/8F

WITH REPLACEABLE DOME/VOICE COIL

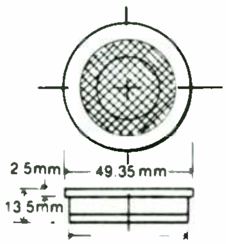
Specifications

Impedance:	8 Ohm
Resonance Freq: Fs.	1500 Hz
Frequency Response:	20,000 Hz
Dome Material:	Drawn Titanium
Suspension:	Supronyl
Voice Coil:	25,4 mm
Layers:	2
Winding Length:	2.0 mm
Former:	Titanium
Magnet:	Rare Earth Neodymium
SPL:	90dB 1/W/1M
Rated Power:	*100 W

*Music Power



66-25Neo/8F



49-25Neo/8F

The introduction and utilization of the new rare earth Neodymium magnet allows for the production of much smaller drivers without any compromise in quality. The Neodymium material produces a magnet at least ten times the strength of the conventional ferrites and also does not require the top and rear plates.

Now and only now can the tweeter be brought in close proximity to the woofer and if necessary be placed in the cabinet corner for those desiring this type of design.

The Versa-Tronics Neodymium is constructed of a one piece drawn Titanium voice coil-former combination. This allows us to bypass the normal glue joint between the voice coil and the dome. There are 3 versions so as to provide the necessary configuration as required by the various system designs. All are Ferrofluid cooled.

DISTRIBUTED BY

Speaker City
115 S. Victory • Burbank, CA 91502
Tel. (818) 846-9921 • Fax (818) 846-1009

The Speaker Works
1021 E. Camelback • Phoenix, AZ 85014
Tel. (602) 230-0344 • Fax (602) 230-8533

Toutant Electronics
246 E. 131st Street • Cleveland, OH 44108
Tel. (216) 451-6325 • Fax (216) 451-0226

THE ACHILLES: A TWO-WAY AUTOMOTIVE TRANSMISSION LINE

By Kenneth W. Ketler

In the endless pursuit of a *musical*-sounding car stereo system, I decided to replace the speakers in my 1986 Mazda B2000 pickup. One obvious problem with many cars, and especially small trucks, is the dismal lack of space in which to mount speakers. I've tried those in-wall pods...but my folks raised me to say nothing at all if I couldn't say something nice.

There seemed to be enough room on the floor—just behind the driver/passenger's feet—to mount a pair of small enclosures without getting in anyone's way. The units could also be moveable to accommodate people of different heights. A 4″ woofer would fit just fine, but what kind of low-end response could I expect?

After sorting through endless catalogs, I found the Audax HT100FO 4″ fiberglass woofer, with a 60Hz f_S and a reported range of 60Hz–8kHz. Because of the intended location, the woofers would need to be spill-resistant, which these are. And, at $30 per driver, they were the right choice. Following the steps in Vance Dickason's *Loudspeaker Design Cookbook*,[1] I measured all necessary Thiele/Small parameters to within a decimal place or two of those specified in the 1994 Polydax catalog.

For high frequencies I chose the Audax TIW60A dome tweeter, because of its advertised dispersion and transient response. Its lower response overlapped the woofer's high response enough that I could use a fairly low-order crossover. And, once again, the price was right!

WHY A TL?

Transmission-line theory afforded me great leeway in folding and tapering the waveguide to squeeze the enclosure into such a tight space. Of course, the response of a sealed or vented enclosure depends substantially on the volume and dimension ratios of the box. The answer was obvious. Having recently purchased Larry D. Sharp's *Quick & Easy Transmission Line Speaker Design*, I decided to run some numbers to get a clear picture of my possibilities.[2]

As Vance Dickason states in his book, with higher ratios of area tapering "the emphasis is placed more on the low bass area, and a better sounding midbass." After many trial calculations I settled on a taper ratio of 2.5:1 (times the driver S_D). This resulted in a transmission line that was 15.5″ long with 1.23 oz of wool stuffing. Folded into a 14″× 6″× 5″ box, it was thin and shallow enough for a pickup's limited legroom.

This design would yield an f_3 of 60-66Hz. Strictly in terms of available volume ("golden ratio" notwithstanding), an air-suspension version would yield a lower cutoff of about 117Hz, with an f_B of 135.5Hz. A similar vented box design (B4 alignment) would have an f_3 of 119Hz and an f_B of 96Hz.

As if this weren't enough, I found even more practical advantages to this type of enclosure. The waveguide provides a small compartment to house the crossover, tweeter, and L-pad. It creates a "dual-chamber" effect to help isolate the low-frequency energy from the outside of the cabinet, and it does an extremely good job of bracing three sides of the box against "cabinet talk."

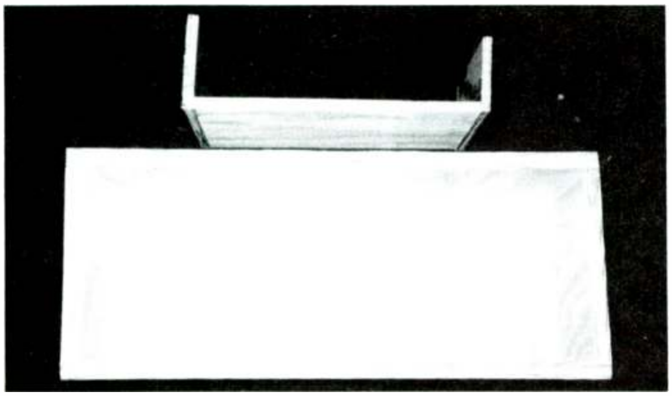


PHOTO 1: Empty box with waveguide.

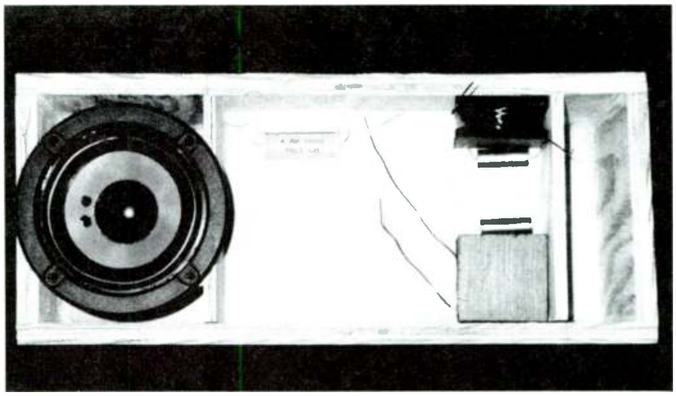


PHOTO 2: Driver and crossover components dry-fitted.

LET'S BUILD IT

I was trying for an innovative and seamless look to set this design apart from any currently on the market. The enclosure walls are ½″ plywood with butt joints; the internal parts of the waveguide are ¼″ plywood. I joined the pieces with Elmer's Carpenter's Wood Glue and clamps; because of the small size of these enclosures, screws weren't necessary. In addition, I sealed all joints with silicone. To avoid shifting, I evenly separated the 1.23 oz of long-fiber wool and secured it to the inside of the enclosure by painting some wood glue on all inner surfaces and simultaneously stuffing and gluing.

The grilles were a bit different. I siliconed pieces of Radio Shack grille cloth directly onto the speaker frame and in the port end. To prevent the woofer surround

ABOUT THE AUTHOR

Ken Ketler is a 25-year-old student of electrical engineering technology, now in his senior year at the University of Massachusetts at Dartmouth. He has an associate's degree in audio recording technology from Five Towns College, Long Island, NY. Although audio has always been his hobby, Ken has been building speakers for a little more than a year. He hopes to find employment in the speaker industry upon graduation from college.

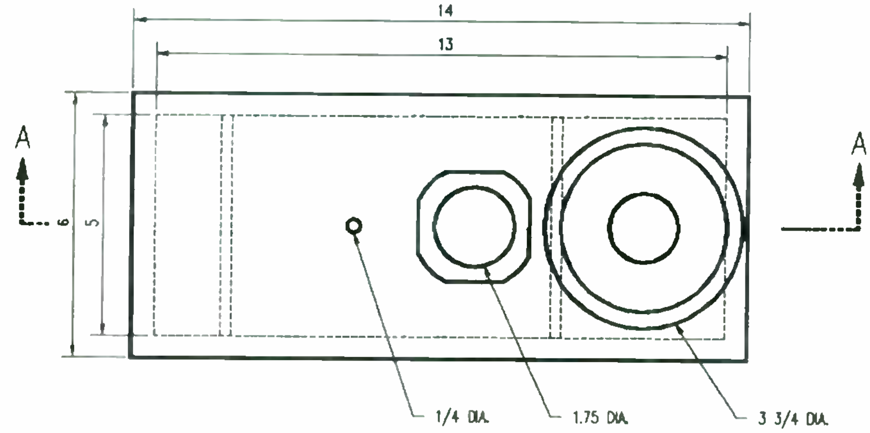


FIGURE 1: Automotive two-way transmission line speaker, plan view.

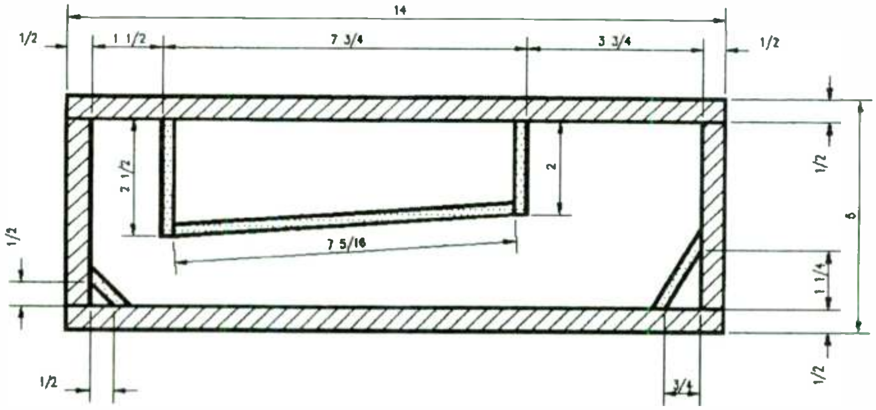


FIGURE 2: Automotive two-way transmission line speaker, cross-section.

from hitting the grille, I spread a thick bead of black silicone around the outside of the driver frame.

I let it set for one hour to ensure it would dry evenly, and then turned the woofer face down so its weight would flatten out any inconsistencies. Then it was easy to stretch the cloth over the driver and secure it underneath with elastic bands and more silicone.

Instead of screws, I used DAP Acrylic Latex Caulk Plus Silicone and a large clamp to attach the woofer to the enclosure. The latex is much stiffer than pure silicone, and since there isn't much air resistance behind the driver, it doesn't tend to "bounce" as it flexes. The latex also acts as a great sealant and gasket coupled with the grille fabric. If the woofer must ever be removed, a razor blade will do the trick.

THE CROSSOVER

I chose an impedance-compensated, 12dB/octave Linkwitz-Riley (LR), because of its inherently flat magnitude response and low offset sensitivity. Polydax recommends crossing over the TIW60A tweeter at 5kHz (assuming a minimum of 6dB/octave).

The calculated component values resulted in a crossover point closer to 4.5kHz, or roughly one-half octave from its 2.9kHz resonant frequency. Since the LR filter is down 6dB at this point, this seemed to satisfy the minimum requirements. All capacitors are high-quality Mylar®, and the resistor in the impedance equalizer is noninductive. Although these components are rated for accuracy within 10%, the worst case is actually within 4% of the specified values.

After reading *Designing, Building, and Testing Your Own Speaker System*, I felt inspired to wind my own inductors.[3] So I made the coil forms out of 1" diameter dowel and scrap wood, and obtained a large roll of #20 magnet wire. The thought of winding by hand and counting the turns was quite discouraging! Instead, I estimated the length of wire needed using the charts in the book. I measured the correct length plus about 1' and wound it tightly with a variable-speed drill.

CIRCUIT CONSTRUCTION

The values of each choke are easily fine-tuned with a modest set of test equipment by following these steps:

1. I built a simple series circuit with a sine-wave oscillator, a known resistance (R_{TEST}), and the inductor.
2. I set the oscillator to the intended crossover frequency (f), and measured the voltage (V_{TEST}) across R_{TEST} with a DVM.

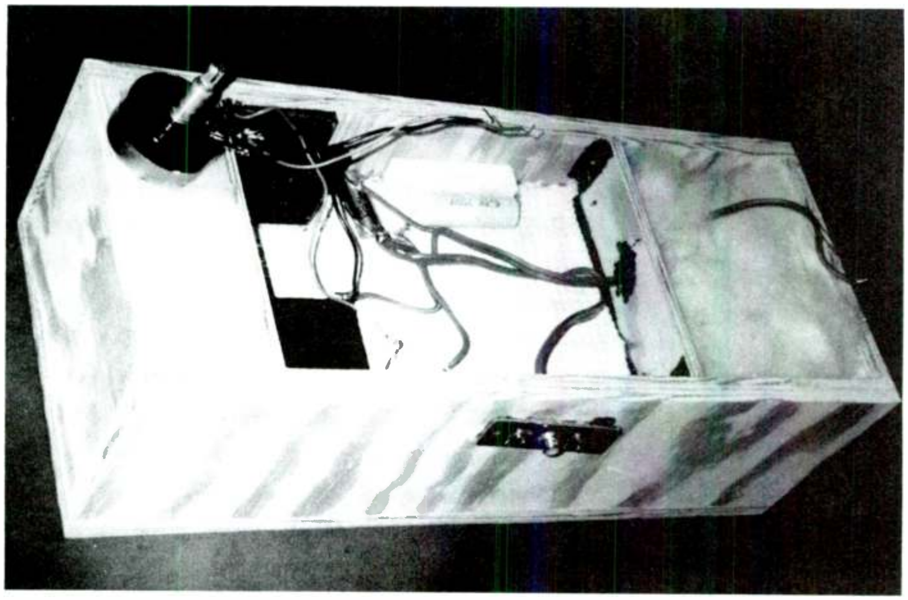


PHOTO 3: Stuffed box with crossover. Stuffed T-line, the finished crossover with L-pad for the tweeter. Note the upside-down piece of carpet to damp the compartment against vibration.

REFERENCES

1. V. Dickason, *The Loudspeaker Design Cookbook*, 4th ed., (Audio Amateur Press, 1991): 125, 132–133.

2. L.D. Sharp, *Quick & Easy Transmission Line Speaker Design*, (Mahogany Sound): 6–9.

3. D.B. Weems, *Designing, Building and Testing Your Own Speaker System*, 3rd ed., (TAB Books, 1990): 128–131, Appendix B.

RECOMMENDED READING

G.A. Briggs, *Loudspeakers: The Why & How of Good Reproduction*, 4th ed., (Audio Amateur Press, 1990).

G. McComb, *Building Speaker Systems*, (Master Publishing Inc., 1988).

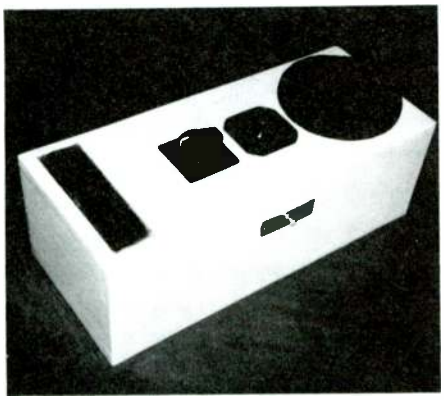


PHOTO 4: Single completed speaker.

Next, I calculated the series current (I) using Ohm's Law:

$$I = \frac{V_{TEST}}{R_{TEST}}$$

3. I read the voltage (V_L) across the inductor and found its complex impedance using:

$$Z = \frac{V_L}{I}$$

4. To separate the reactive and resistive components of the impedance (Z), I first measured the inductor's DC resistance (dcr) and then removed the reactive portion by calculating:

$$X_L = \sqrt{Z^2 - dcr^2}$$

5. The present inductance (L) of the coil is easily calculated by:

$$L = \frac{X_L}{2\pi f}$$

6. Use the following equation to predict the correct X_L for the desired inductance value (L_{FINAL}):

$$X_L = 2\pi f L_{FINAL}$$

7. Assuming that small changes in wire length would not significantly change the dcr, I calculated the appropriate complex Z, where:

$$Z = \sqrt{X_L^2 + dcr^2}$$

8. Making sure that the current in the circuit remained constant, I calculated the proper voltage (V) for the inductor at the predicted Z:

$$V = ZI$$

9. Finally, I unwound turn by turn from the coil until the voltmeter showed the predicted voltage. And the result—an accurate inductance!

I wired the final circuit as in Fig. 7.80 of *The Loudspeaker Design Cookbook*, using 2.2µF capacitors and 563µH inductors, with the tweeter reverse-polarized and an 8Ω/6.8µF impedance equalizer in parallel with the woofer.

FINAL RESULTS

After the glue, paint, and polyurethane had dried, I was ready to put the Achilles to the big test. I set them up in my test laboratory (aka my bedroom), surrounded by a cluster of pillows, and listened to a variety of CDs. To be honest, the lack of low-frequency response was disappointing. I immediately set up the sine-wave generator and a Radio Shack sound level meter, and found a fairly smooth rolloff which began at about 100Hz—nearly an octave higher than expected! But why was this so?

I then decided to compare my system response plot against the manufacturer's curve for the HT100FO driver. Much to my surprise they were remarkably similar. The main difference was that my measurements were a bit more "peaky" than the factory specs, probably due to the 90° phase shift between driver and terminus, not to mention room response.

In fact, the distributor had specified a frequency response of 60Hz–8kHz. Although there was a significant amount of energy down to about 60Hz, the frequency specs should be the -3dB points. Let the buyer beware! Luckily, my car stereo's bass control has a shelving response with a corner frequency of 100Hz. Since the enclosure is not really a contributing factor to the deficient low end, a slight turn of the bass knob alters the driver's natural response and resurrects the low end between 60-100Hz quite smoothly. A little judicious EQ can actually be part of the design for some commercial small woofer systems. In the case of the Achilles, I got lucky!

Measuring the exact response inside the truck didn't seem to make much sense, since I couldn't obtain accurate numbers due to the close quarters, the different numbers and sizes of passengers, and so on. Also, you'll recall that these enclosures had to be easily moveable, but they couldn't be free to slide around. Each unit weighs about 7 lbs and the truck interior is carpeted. As a result, I have not noticed them shifting even in some of the worst Boston traffic. I still plan to install a few strips of Velcro® under each enclosure just to be safe.

AUTHOR'S NOTE

After I had completed this project, a friend pointed out that there is significant space behind the seats in which to mount speakers. Actually, I was a bit stunned (not to mention embarrassed) that I hadn't thought of it. But my butterfly lug wrench, jack, sun shade, and jumper cables occupy that space, so I guess it just didn't occur to me. While I have started a new project to redistribute this space to make room for more speakers, for now it's a secret.

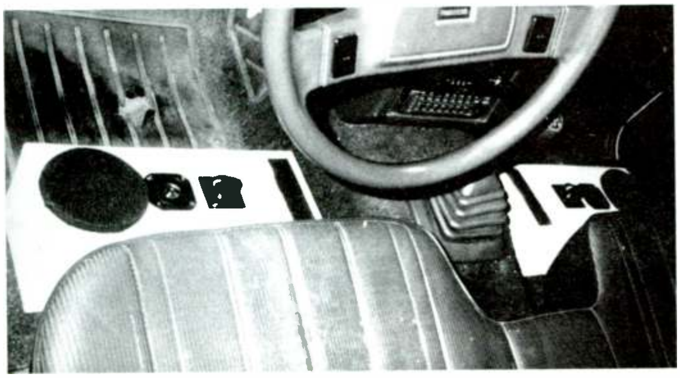


PHOTO 5: Speaker placement inside truck (driver's side view).

PHOTO 6: Passenger's side view.

HOME AUTO

THE SPEAKER WORKS, INC.

1021 E. Camelback Rd.
Phoenix, AZ 85014
(602) 230-0344 FAX (602) 230-8533

VERSA-TRONICS INC. QUALITY SPEAKERS

Woven Carbon

DOB100R-WCC/8 4"

- Woven Carbon Cone
- Rubber Surround
- Kapton Voice Coil
- Cast Allumalloy Basket

Specifications

Impedance	8 Ohm
Resonance	65 Hz
Upper Frequency	12,000 Hz
SPL 1/W/1M	83 dB
Power Handling	50 W
Qts	0.45
Vas	3.75 L
Voice Coil	25,5 mm
Magnet	10 Oz.

$24.17 EA

EOB130R-WCC/8 5-1/4"

- Woven Carbon Cone
- Rubber Surround
- Kapton Voice Coil
- Cast Allumalloy Basket

Specifications

Impedance	8 Ohm
Resonance	40 Hz
Upper Frequency	7,000 Hz
SPL 1W/1M	88 dB
Power Handling	60 W
Qts	0.21
Vas	21.55L
Voice Coil	25,5 mm
Magnet	13.3 Oz.

$29.62 EA

FQB165R-WCC/8 6-1/2"

- Woven Carbon Cone
- Rubber Surround
- Excellent Damping
- Cast Allumalloy Basket

Specifications

Impedance	8 Ohm
Resonance	36 Hz
Upper Frequency	5,500 Hz
SPL 1W/1M	88 dB
Power Handling	80 W
Qts	0.24
Vas	27.83 L
Voice Coil	35,5 mm
Magnet	18 Oz.

$41.38 EA

GQB210R-WCC/8 8"

- Woven Carbon Cone
- Rubber Surround
- High Power Handling
- Cast Allumalloy Basket

Specifications

Impedance	8 Ohm
Resonance	33 Hz
Upper Frequency	5,000 Hz
SPL 1W/1M	90 dB
Power Handling	100 W
Qts	0.20
Vas	54.15 L
Voice Coil	35,5 mm
Magnet	30 Oz.

$55.95 EA

NEODYMIUM

RARE EARTH MAGNET TWEETERS WITH

REPLACEABLE DOME/VOICE COIL

Specifications

Impedance	8 Ohm
Resonance FREQ: Fs	1500 Hz
Frequency Response:	20,000 Hz
Dome Material:	Drawn Titanium
Suspension:	Supronyl
Voice Coil:	25,4mm
Layers:	2
Winding Length:	2.0 mm
Former:	Titanium
Magnet:	Rare Earth neodymium
SPL:	90dB 1/W/1M
Rated Power:	*100W

*Music Power

66-25Neo/8F

$20.22 EA

49-25Neo/8F

$19.91 EA

SPECIAL - SPECIAL - SPECIAL

- While They Last -

3/4" and 1" Soft Dome and Metal Dome Tweeters

Take Your Pick **$7.95 EA**

ANY QUESTIONS? — CALL US

We accept VISA - Mastercard - Check — No C.O.D.

195 PAGE CATALOG $10.00

Part 1

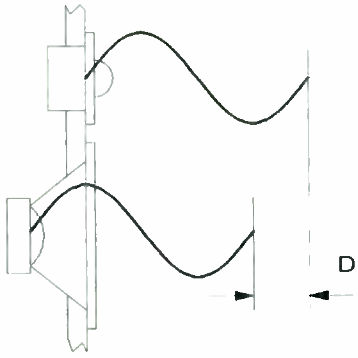
DRIVER-OFFSET-RELATED PHASE SHIFTS IN CROSSOVER DESIGN

By Bruno Carlsson

Ask speaker builders which part of a speaker project with which they are the least comfortable, and chances are many will choose crossover design. Analyzing and designing speaker crossovers requires fairly advanced math, and, to make matters worse, most drivers refuse to behave like the resistors which are used as the load in textbook formulas. Designing a crossover is also complicated by the response of the different drivers, which will almost certainly add amplitude and phase errors to the response of the crossover filters. Finally, *driver offset* is one more factor affecting the operation of the crossover filters.

In a typical speaker system, the woofer's voice coil is obviously much deeper than the tweeter. When speakers are mounted on a common baffle (*Fig. 1*), the offset due to the difference in depth causes the sound waves from the woofer to start behind the sound waves from the tweeter. Since the waves from both drivers travel at the same speed, the waves from the tweeter arrive at the listener before the ones from the woofer. The time difference between signals translates into a phase shift, which increases in a linear fashion with frequency, and, added to the phase shifts from the crossover network, introduces errors in the signal summation.

I will show you how different types of crossover filters perform when driver-offset-related phase shift is added to the woofer. I will also cover some methods to minimize these errors, as well as some practical ways of estimating driver offset in a given speaker system.



$$\text{PH. ANGLE} = \frac{D*F*360}{13500}$$

FIGURE 1: Typical speaker arrangement with woofer (bottom) set back from tweeter (top).

SPEAKER SETUP

Before we study the performance of various crossover networks, it may be useful to establish the relationship between speaker offset and the resulting phase shift. In *Fig. 1* the top speaker is the tweeter and the bottom one is the woofer. As usual, the tweeter coil has shallower depth behind the baffle than the woofer, with the difference in depth designated by "D" in the figure. When a signal is applied to both drivers, the resulting sound wave from the tweeter has a shorter distance to travel before reaching the listener and arrives before the sound from the woofer.

For example, if the offset D is one-fourth of a wavelength (as in *Fig. 1*), then the signal from the woofer will have a negative phase shift of 90° relative to the signal from the tweeter. (Remember that a full cycle of a signal represents a change in phase of 360°, so one-fourth of a cycle is 90°.)

Figure 1 includes the proper formula for calculating the phase shift when the distance D and the frequency F are known. The speed of sound is around 13,500″/sec., so when using this formula, calculate D in inches. If you prefer metric units, simply substitute 340 for 13,500 and enter D in meters. In either case, enter F in hertz. For example, with a frequency of 2kHz and an offset of 1.25″, use the formula to get a phase shift of 67°.

The higher the frequency of the signal, the shorter the wavelength, and the less offset is necessary for a given phase shift. Phase shifts resulting from driver offset are much more troublesome at high crossover frequencies. For example, an offset of 1″ represents a negligible phase shift of about 13° at 500Hz, but a very significant 135° at 5kHz. Consequently, driver offset is typically a concern in two-way speakers, and for the midrange-to-tweeter crossover in multi-driver systems.

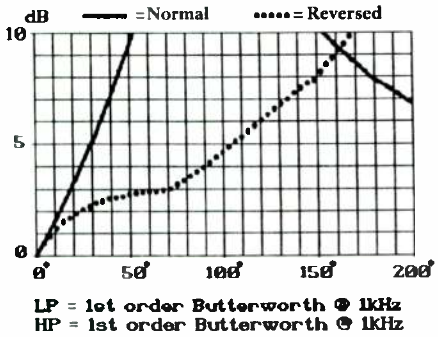


FIGURE 2: First-order Butterworth filters.

PC GRAPHS

To investigate the influence of driver offset for various crossover filter types, I used computer simulation rather than measurements of real speakers. The most obvious advantages of this approach are the ability to use "ideal" drivers and savings in time, effort, and money. In the computer simulation, the response of a low-pass (LP) filter and a high-pass (HP) filter were mathematically summed, with a time delay added to the LP filter. If properly chosen, the time delay will simulate the phase shift introduced by driver offset.

For all computer runs, I used a crossover frequency of 1kHz and added to the LP filter a delay which was a multiple of 27.8μs. I did this for delays ranging from 0-556μs. At 1kHz this corresponds to phase shifts from 0° to 200°, with steps of 10°.

The computer plotted the combined response of the two filters for each 10° step, and the response was scanned from 200Hz to 5kHz for the maximum deviation or error from a flat response. The computer then plotted the absolute value of this error against the corresponding phase shift. By using different types of crossover filters, I was able to evaluate the performance of various filter configurations when a phase shift related to driver offset was present.

FIRST-ORDER FILTERS

The resulting graph (*Fig. 2*) shows the results when using first-order Butterworth filters for both HP and LP filters. As you may know, first-order Butterworth filters

ABOUT THE AUTHOR

Bruno Carlsson is an electronics engineer who was born and educated in Sweden. He moved to the US in 1984 and settled in the Cincinnati area. His interests outside of audio include traveling with his family, photography, cooking, and reading detective novels.

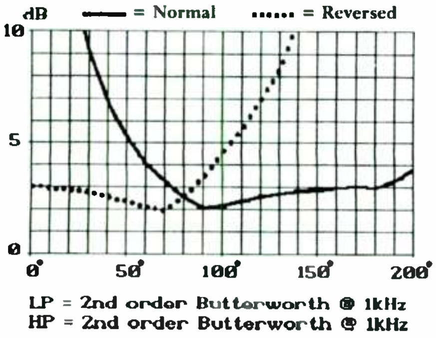


FIGURE 3: Second-order Butterworth.

sum flat for both an in-phase and an out-of-phase connection. Or, to be more correct, they will sum flat if no driver-offset-related phase shift occurs. *Figure 2* shows the maximum response error in decibels which will result from a certain phase shift at the crossover frequency.

You should note that the maximum error for a given phase shift is not limited to the crossover frequency, but to the entire speaker frequency range. The graph does not show whether the error is positive or negative, since this would add to the graph's complexity without providing much additional information. Since an error of 10dB is more than most designers are willing to live with, I decided to cut off the graph at that point, simply letting a response which jumps off the scale indicate an error above 10dB.

As you can see, the graph shows the response error for phase shifts between 0° and 200°, for both an in-phase (normal) and an out-of-phase (reversed) connection, as well as the type of filter used and the cut-off frequency for each filter.

Based on *Fig. 2*, it is evident that first-order filters require careful attention to phase shifts if the result is going to be even close to flat. The reversed connection is somewhat better than the normal connection, but both show much vulnerability to offset-related phase shifts.

To give you an example of how to read the graph, suppose you have a phase shift of 60° at your crossover frequency. If you use the normal (or in-phase) connection, you will have an error in the speaker response greater than 10dB. On the other hand, if you use the reversed (out-of-phase) connection, the error will be approximately 2.9dB. While neither connection is flat, most designers would prefer the reversed connection in this case.

STANDARD CROSSOVER FILTERS

In the real world, the filter response is a combination of the crossover network and the driver's amplitude and phase response. Therefore, when we study the performance of a particular filter type, we are considering

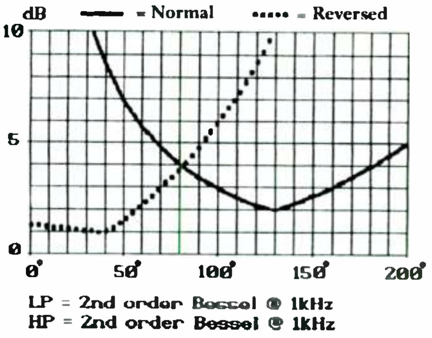


FIGURE 4: Second-order Bessel filters.

combined response. For example, it is possible for a second-order crossover filter to interact with the driver response to produce a fourth-order filter response.

In analyzing the performance of the different filters, I have rather arbitrarily chosen any error below approximately 2dB as acceptable. If you are willing to accept a greater error, or have even more stringent criteria, use the graphs to draw your own conclusions. Let's examine some standard filter types of second-, third-, and fourth-order.

SECOND-ORDER FILTERS

Second-order filters have a 90° phase angle at the crossover frequency, with the LP section showing a positive phase angle and the HP section a negative phase angle. At the crossover frequency, Butterworth filters are –3dB, Bessel filters are –4.8dB, and Linkwitz-Riley filters are –6dB. The 90° phase angle of two sections means that for the normal connection the LP and HP sections will be 180° out-of-phase, producing a null in the response at the crossover frequency.

The reversed connection produces a 0° phase angle between sections at the crossover frequency (180° + 180° = 360° = 0°). Consequently, the reversed connection is typically used with these filters.

The second-order Butterworth filter (*Fig. 3*) is not flat for a 0° phase shift. With each filter section down by 3dB at the crossover frequency, the 0° phase angle between sections produced by the reversed connection gives a 3dB "hump" in the response. As expected, a null occurs at 0° for the normal connection. To produce a flat response with each section at -3dB, the phase angle between LP and HP filters should be 90° at the crossover frequency. If we add 90° of negative phase shift to the LP filter, we will have a 90° phase angle between the two sections for both the normal and the reversed connection.

This is clearly evident in *Fig. 3*, where the normal and reversed responses are mirrored around 80°, showing the least error close to 90° for each connection. We might have expected a flat response when the phase shift is 90°, and if we had looked at the crossover frequency only, this would have been the case. Errors at frequencies other than the crossover frequency are responsible for the 2dB minimum error in *Fig 3.*

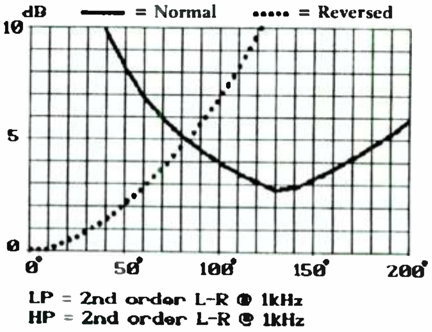


FIGURE 5: Second-order Linkwitz-Riley filters.

The lesson to be learned here is that even though it may be possible to eliminate errors at the crossover frequency, response problems are likely at other frequencies. While it is possible to achieve a reasonably constant error over a wide range of phase shifts by reversing polarity at a phase angle of 80°, the absolute value of this error may be unacceptable.

The second-order Bessel filter (*Fig. 4*) is almost flat at a 0° phase shift. Again, the two responses appear to be mirrored around 80°, but this is not the lowest error for this filter type. With the response 4.8dB down at the crossover frequency, we would need a phase angle of around 60° between sections for a flat response. When the reversed connection is used, this is equivalent to adding a negative phase shift of 60°. In fact, the minimum error does occur close to 60°.

For the normal connection, the phase angle between sections is 180°, and adding –120° will produce the required 60° angle. As expected, *Fig. 4* shows the minimum error for the normal connection close to 120°. This filter type provides acceptable performance between 0° and 60°.

In the second-order Linkwitz-Riley filter (*Fig. 5*), with each section 6dB down at the

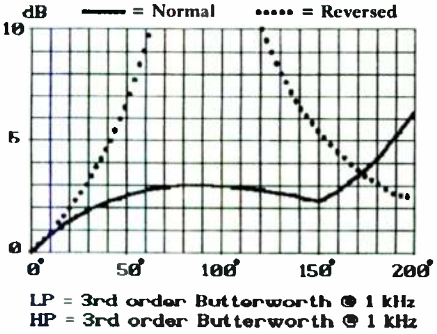


FIGURE 6: Third-order Butterworth.

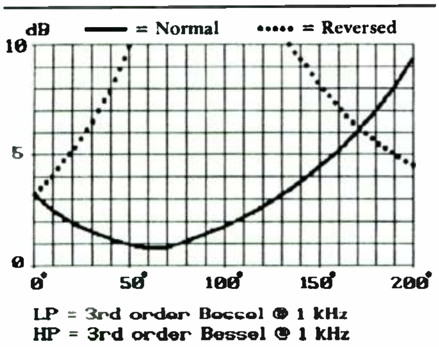


FIGURE 7: Third-order Bessel.

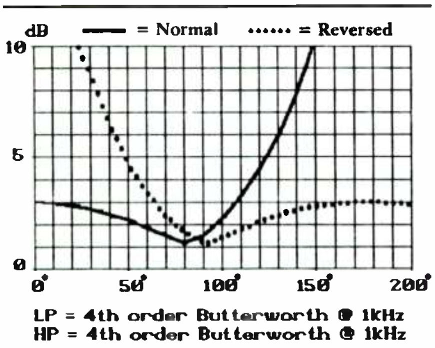


FIGURE 8: Fourth-order Butterworth.

crossover frequency, a flat response is produced with 0° phase angle between sections. As the graph shows, this filter type does indeed sum flat for the reversed connection when the phase shift is 0°. With this type of filter, we get acceptable performance between 0° and about 50°. While we might have expected the normal connection to show a flat response for a 180° phase shift, the minimum error is at a somewhat lower 130°.

THE LESSON

Intuitively, we may think that if the driver-offset-related phase shift is 180°, simply reversing the polarity of one driver will produce a flat response. This is most definitely not so, as you can see by comparing the error at 0° for the reversed connection with the error at 180° for the normal connection. While the reversed connection sums flat at 0°, a substantial error of almost 5dB occurs at 180° with the normal connection.

The reason is fairly simple: even though a 0° phase shift with the drivers in-phase is the same as a 180° phase shift with drivers out-of-phase *at the crossover frequency*, a phase shift less than 180° will occur below the crossover frequency, and a phase shift greater than 180° will occur above the crossover frequency. Simply reversing the speaker polarity cannot compensate for the phase shifts above and below the crossover frequency, and errors in the response result.

Based on these graphs, the Linkwitz-Riley filter is the choice for phase shifts of less than 30°, the Bessel filter is better between 30° and 60°, and the Butterworth filter shows less error for phase shifts above 60°. Finally, if the phase shift is between 120° and 160°, the Bessel filter will be better than the Butterworth filter. However, it is quite evident that second-order filters perform best with relatively small phase shifts.

THIRD-ORDER

Third-order types have a phase angle of 135° at the crossover frequency, with the LP section showing a positive phase angle and the HP section a negative one. At the crossover frequency, Butterworth filters are -3dB and Bessel types are -6.3dB. It is not possible to build a third-order Linkwitz-Riley-type filter. With each filter section contributing a 135° phase angle, a phase angle of 90° occurs between sections at crossover. To produce a flat response with this phase angle, each section should be 3dB down, which is exactly the case for the Butterworth.

As expected, the third-order Butterworth filter (*Fig. 6*) has no error for a phase shift of 0°. With a third-order filter, a 90° phase angle will occur at crossover between sections for both the normal and the reversed connection. Consequently, both connections are flat at 0°.

As the phase shift increases, so does the error. If the normal connection is used, the error will stop increasing and remain below 3dB from 0° to 160°, where it will again increase. As we add negative phase shift to the LP filter, the phase angle between sections is reduced, and when the added phase shift is -90°, the phase angle between sections is 0°, producing a +3dB peak.

When the reversed connection is used, the LP section is at -135° and the HP section is at -45° (+135° - 180° = -45°), assuming tweeter polarity is reversed. When we add negative phase shift to the LP filter, the phase angle between sections grows and reaches 180° when 90° is added. This explains the null in the reversed connection at around 90°.

Despite the wide range over which the error stays relatively constant for this filter type, the acceptable performance is limited to between 0° and 30°. However, if we are willing to accept a slightly higher error, the normally connected third-order Butterworth filter can be a good choice with an unknown phase shift.

THIRD-ORDER BESSEL

The third-order Bessel filter response is shown in *Fig. 7*. With each section about 6dB down at crossover, a flat response requires a 0° phase angle between sections. Adding an extra –90° of phase shift to the existing 90° phase angle between sections produces a 0° angle for the normal connection. In fact, the minimum error for the normal connection is at a phase shift close to 90°.

The acceptable range for this error is a wide 20-110° when the normal connection is used. With the reversed connection, adding a –90° phase shift to the LP filter produces a phase angle of 180° between sections and a resultant null. *Figure 7* confirms this at a phase shift of around 90°.

Both third-order filter types perform well in the presence of phase shift. The Butterworth filter maintains a reasonable error over a wide range of phase shifts, while the Bessel filter shows a lower error between 30° and 120°.

FOURTH-ORDER

Fourth-order filters have a 180° phase angle at the crossover frequency, with the LP section showing a positive phase angle and the HP section a negative one. Butterworth filters are –3dB, Bessel filters are –7.8dB, and Linkwitz-Riley filters are –6dB at crossover.

Given a 180° phase angle at crossover, fourth-order filters, like second-order filters, have a phase angle between sections of either 0° or 180°. However, fourth-order filters have a 0° phase angle between sections when the normal connection is used. As a result, you might assume that fourth-order filter performance will be fairly similar to that of second-order filters, with the connection reversed.

As was the case for its second-order counterpart, the fourth-order Butterworth filter (*Fig. 8*) achieves minimum error when the phase shift is close to 90°. Because of the steeper slope of the fourth-order filter, errors away from the crossover frequency are more attenuated than for the second-order filter,

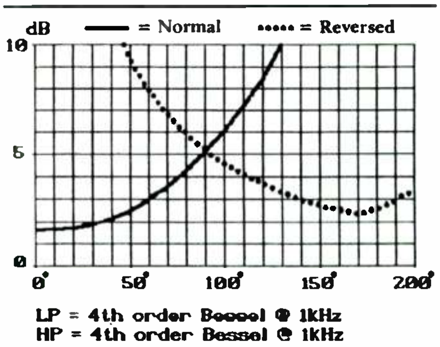


FIGURE 9: Fourth-order Bessel.

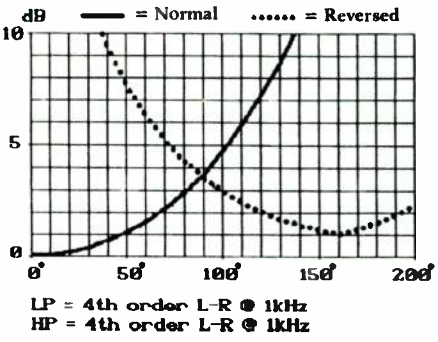


FIGURE 10: Fourth-order Linkwitz-Riley.

AΞON 250 VDC 5% FINE CAP

Metallized polypropylene capacitors for loudspeaker passive network.

Another brand of metallized polypropylene capacitors ? Well, not exactly ... At Orca we have been thinking for a while about how to make polypro caps more affordable for a larger number of speaker builders, people who use caps only for speaker passive X-over network. We thought that it would be tremendous if we could offer a line of polypro caps that would be so affordable that people would have no reason to use cheap mylar, as they would be able to get for not much more money a much much better cap. As you know, even extremely powerful solid state amps (we are talking KW here) can barely produce rail voltage higher than 60 V. So it is safe to assume that a 100 VDC cap would be a pretty robust cap to use in a passive loudspeaker network. So to be really safe, we decided to make all the AXON cap of our FINE CAP basic line 250 VDC. Now that's about where the compromises start and stop. On the other hand for example, you may or may not know that when a cap value is said to be 10.0 µF with 5% precision, it means that the manufacturer of caps sets its winding machine to 9.7 µF and then produces this series with 2% tolerance (not very difficult with numeric controlled winding machines). The result: the manufacturer saves more than 3% in material, the precision is respected, but chances are all your caps will measure on the low side ! Orca made the special arrangement that all the AXON caps were to be wound with 5% precision with the target value set at exactly the nominal value. That means now, as most of you do, and rightly so, expect, that you should find a much greater proportion of caps very close to exactly 10.0 µF, if not 10.0 µF exactly! As for the rest, we could display here all sorts of figures and graphs that would only makes sense to 1% of our customers, but what for ? We can simply tell you this is the first polypro cap at a price closing on mylar caps. It is made by the same company that makes all our high voltage and very high voltage SCR caps, as well as our film and foil caps. Some of the best loudspeaker manufacturers have already made that easy choice. Now see for yourself and ... let your ears make the call.

Value µF	Diameter mm	Length mm	SRP US$
1.0	11	21	1.23
1.5	12	22	1.44
1.8	13	22	1.49
2.2	15	22	1.58
2.7	14	25	1.67
3.0	15	25	1.73
3.3	16	25	1.78
3.9	16	25	1.83
4.7	18	27	1.96
5.6	18	30	2.10
6.0	19	30	2.20
6.8	20	30	2.33
8.0	20	33	2.91
8.2	21	33	2.97
9.1	22	33	3.08
10.0	23	33	3.23
11.0	24	33	3.38
12.0	25	33	3.56
15.0	25	38	4.18
20.0	29	38	5.16
24.0	29	43	5.98
30.0	32	43	7.30
33.0	32	48	7.74
41.0	35	48	9.32
50.0	37	53	10.96
51.0	37	53	11.16
56.0	39	53	12.00
62.0	39	53	12.98
75.0	43	58	15.12
82.0	45	58	16.28
91.0	47	58	17.50
100.0	49	58	18.76
120.0	51	63	21.98
130.0	54	63	23.38

STOCKING DISTRIBUTORS:
BIG COVE RESEARCH
tel: (205) 722 9867 fax: (205) 430 3961
SPEAKERS ETC...
tel: (602) 944 1878 fax: (602) 371 0605
TECHNOLOGIE MDB
tel: (514) 526 8851 fax: (514) 443 5485
ZALYTRON INDUSTRIES
tel: (516) 747 3515 fax: (516) 294 1943

OEMs & EXPORT
Contact Kimon Bellas
or John Sangalli
tel: (818) 707 1629
fax: (818) 991 3072
ORCA
1531 Lookout Drive
Agoura, CA 91301
USA

COMING SOON:
FILM / FOIL 630 VDC CAPS for electronics and bypass from 0.1 µF to 1.0 µF.
POLYPRO ULTRA HIGH VOLTAGE
1200 VDC 20 µF
for power supply & tube electronics.

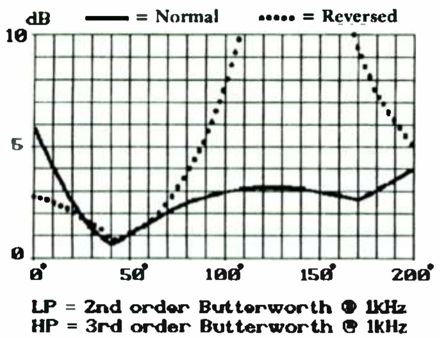


FIGURE 11: Second- and third-order Butterworth filters.

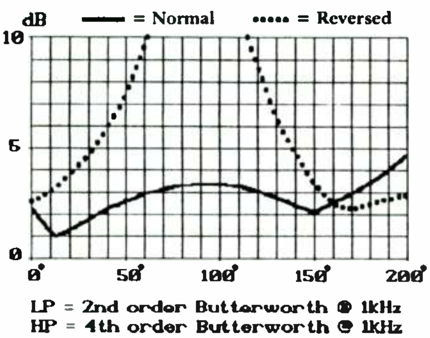


FIGURE 12: Second- and fourth-order Butterworth.

and the maximum error close to 90° is lower. If we reverse connections at around 90°, we'll get acceptable performance between 60° and 120°.

The fourth-order Bessel (*Fig. 9*) has a response very similar to the second-order. However, because the fourth-order filter is down by as much as 7.8dB at the crossover frequency, the performance is not as good as that of the second-order and is acceptable only between 0° and 30°. In fact, if a filter is down by more than 6dB at crossover, it cannot be made to sum flat regardless of the phase angle between sections. The best we can do is reduce the phase angle to 0°, which produces a flat response if the filter sections are at exactly -6dB.

The fourth-order Linkwitz-Riley filter (*Fig. 10*) is a very popular filter type. With the proper connection, it achieves acceptable performance between 0° and 70°, as well as between 120° and 200°. The overall shape of the error shown in the graph is similar to the second-order Linkwitz-Riley filter, but because of the steeper slope the magnitude of the error is smaller.

If you are using a fourth-order filter, the Linkwitz-Riley will be your best choice, except when the phase shift is between 70° and 120°, where the Butterworth type offers better performance.

MINIMIZING ERRORS

As we have seen, substantial filter response errors can occur when driver-offset-related phase shifts are introduced. Let's look at a way to reduce the sensitivity of crossover filters to phase shifts by using filters with asymmetrical slopes.

ASYMMETRICAL SLOPES

One aspect of the performance of a crossover filter is the phase angle (a multiple of 45°) at the crossover frequency. Each time the order of the filter is increased, another 45° of phase angle is added at the crossover frequency. We can take advantage of this by using the difference in phase angle between LP and HP sections of different orders to compensate for phase shifts due to driver offset.

For example, suppose we are trying to compensate for a 45° phase shift. If we use a second-order Butterworth filter for the LP section, the angle will be −90° at the crossover frequency, with an amplitude of −3dB. By selecting a third-order Butterworth filter for the HP section, the phase angle will be +135° at the crossover frequency, with an amplitude of −3dB. By adding the extra − 45° of phase shift due to driver offset to the LP filter, the phase angle of this filter section becomes −135°.

The two filter sections are now 90° apart at the crossover frequency, and they will sum flat. Since the slopes of the two filters are different, or *asymmetrical*, some errors will occur at frequencies other than the crossover frequency. By using various filter types and orders in combination, you can compensate for some of the phase shifts introduced by driver offset.

ASYMMETRICAL BUTTERWORTH

Figure 11 shows the performance of a second-order Butterworth filter, when combined with a third-order Butterworth filter. We saw this same combination in the example above, and the minimum error for the normal connection is very close to the expected 45°. If we use the reversed connection, the two will be 45° apart when the phase shift is 0°, and the phase angle between sections will expand with an increase in phase shift.

As the phase shift approaches -45°, we again have 90° between sections and a nearly flat summation. At a 135° shift, a null occurs at the crossover frequency due to a 180° phase angle between sections. For most phase shifts, the performance of this filter combination is no better than that of several symmetrical filter types, but between 30° and 50° the performance is very good.

If we combine a second-order Butterworth with a fourth-order Butterworth (*Fig. 12*), the LP section will have a phase angle of -90° at the crossover frequency and a +180° phase angle of the HP section. Since the two sections are 90° apart, we would expect the minimum error to occur at a phase shift of 0°. *Figure 12* shows this error at 10°, which is very close. While better choices probably exist, if you wish to combine a relatively steep fourth-order slope with a more gradual second-order slope, with the phase shift between 0° and 30°, this filter type might be worth considering.

The final Butterworth combination is a third-order in conjunction with a fourth-order (*Fig. 13*). The LP section is at -135°, while the HP section is at +180°, creating a 45° phase angle between them. Since the driver-offset-related phase shift is negative and added to the LP section, we need to add 135° of phase shift to reach the desired 90° phase angle between sections (LP at −270° and HP at +180°).

As we add phase shift, the phase angle between sections is 0° for a 45° phase shift, producing a +3dB hump. Performance is much as expected, with minimum error at 120° for the normal connection and 130° for the reversed connection. The hump at 45° is also evident (as is the null in the reversed response). By using the proper connection, this filter shows acceptable performance between 100° and 150°.

ASYMMETRICAL BESSEL

When comparing Bessel with Butterworth filters, remember that while the phase angle at crossover is the same, the Bessel filter amplitude is lower. If we combine second- and third-order Bessel filters, the LP section

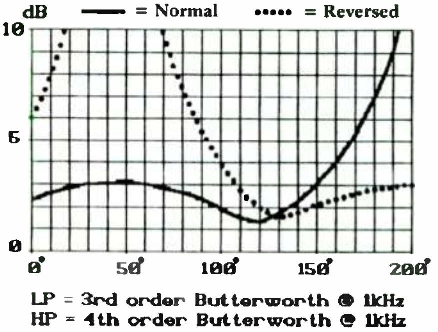


FIGURE 13: Third- and fourth-order Butterworth.

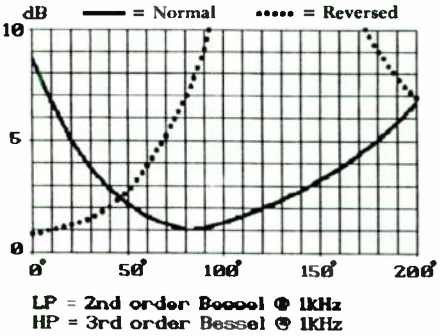


FIGURE 14: Second- and third-order Bessel filters.

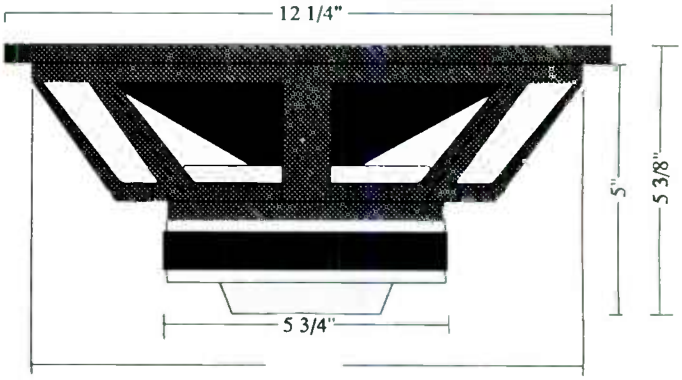
NHT 1259

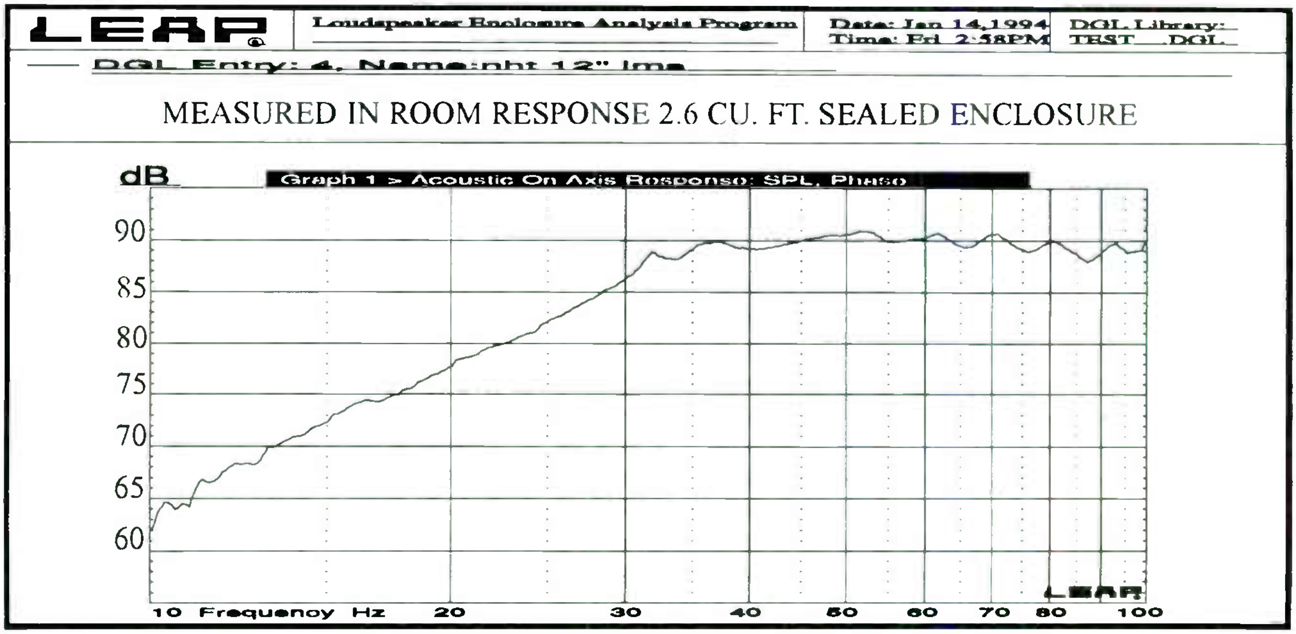
NOMINAL IMPEDANCE	4 ohm
MUSIC POWER	300 W
FREQUENCY RANGE	19-1000 Hz
SENSITIVITY (2.83 V)	90 dB
EFFECTIVE CONE AREA	507 cm2
VOICE COIL RESISTANCE	3.4 ohm
VOICE COIL INDUCTANCE	1.2 mH
VOICE COIL DIAMETER	50 mm
VOICE COIL HEIGHT	34 mm
AIR GAP HEIGHT	8 mm
XMAX	13 mm
FREE AIR RESONANCE	19 Hz
MOVING MASS (MMS)	121 g
FORCE FACTOR (BI)	9.6 TM
MAGNET WEIGHT	59 oz
QMS	2.6
QES	.56
QTS	.46
VAS	190 LTRS
KRM	28.89

A&S Speakers is pleased to be able to offer this custom made, high performance woofer from Now Hear This (NHT). This is the cost no object woofer used in the highly acclaimed NHT 3.3 system. Unlike almost all other woofers, the NHT1259, with its low resonance and exceptionally long voice coil is designed to produce deep bass in a small sealed enclosure when positioned within two feet of the rear wall. This design results in superior transients and minimal phase shift and group delay. Every construction feature contributes to the outstanding performance of this driver: the 50mm diameter, 34mm long, 2 layer voice coil allows long excursion, high thermal capabilities and tremendous output; the large bumped backplate and raised spider prevent bottoming at maximum excursions; the heavy cast frame minimizes energy transfer to the enclosure; and the rubber surround and polypropylene cone promise long term durability in every environment.

Price: $149.00/each

***Cabinets and plans for our computer designed enclosure utilizing 14 internal braces are now available upon request.**




LEAP Loudspeaker Enclosure Analysis Program
Date: Jan 14,1994 Time: Fri 2:58PM
DGL Library: TEST .DGL
DGL Entry: 4, Name:nht 12" lms

MEASURED IN ROOM RESPONSE 2.6 CU. FT. SEALED ENCLOSURE

A&S speakers

3170 23rd Street; San Francisco, CA 94110
Telephone: (415) 641-4573 Fax: (415) 648-5306

Reader Service #31

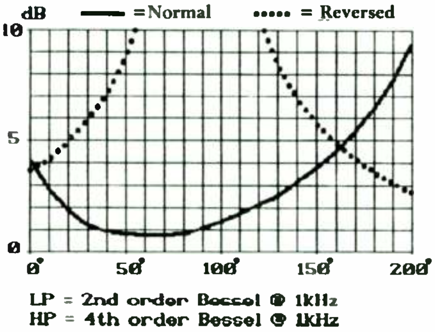


FIGURE 15: Second- and fourth-order Bessel.

will be –90° and –4.8dB, while the HP section will be + 135° and –6.3dB. Given the –4.8dB and –6.3dB amplitudes, a phase angle of around 40° between sections produces a flat response. Since the phase angle is 135° without any phase shift, we must add an extra 95° of phase shift from driver offset to get a flat response at crossover.

The minimum error for the normal connection occurs around 85°, which is very close to the expected 95° (*Fig. 14*). When we use the reversed connection, a 45° phase angle between sections will occur if the phase shift is 0°. Adding a negative phase shift to the LP filter increases this phase angle, and we must add 275° (315° – 40°) before the angle between sections is 40°. By changing from the reversed connection to the normal one when the phase shift is above 45°, this combination shows acceptable performance between 0° and 120°.

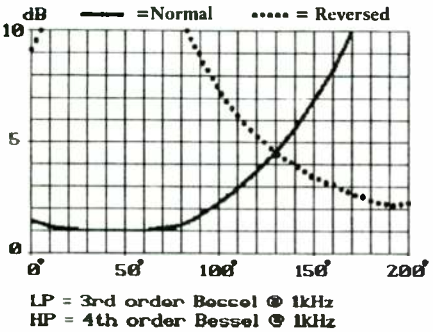


FIGURE 16: Third- and fourth-order Bessel.

OTHER BESSEL COMBOS

In the second- and fourth-order Bessel combination (*Fig. 15*), the LP section is down by 4.8dB with a phase angle of –90°, and the HP section is down by 7.8dB with a phase angle of +180°. Adding two signals, at –4.8dB and at –7.8dB, fails to produce a flat result regardless of the phase angle, but with an angle of 0° we will approach a flat signal. Since the phase angle between sections is 90° without extra phase shift, we need to add 90° to achieve the most nearly flat response.

As *Fig. 15* shows, the error at 90° is close to the minimum (the null in the reversed connection, which is symmetrical around 90°, also shows this). This combination demonstrates acceptable error between 20° and 120°, with exceptional performance between 40° and 90°.

If we substitute a third-order Bessel filter for the second-order, we will obtain the response in *Fig. 16*. Here the LP section is down 6.3dB with a phase angle of -135°, and the HP section is –7.8dB with a + 180° phase angle. Adding two signals, both lower than –6dB, can never produce a flat response, but using a phase angle of 0° between sections produces an as-near-flat-as-possible result. With a 45° phase angle between filter sections, we need to add an extra 45° of phase shift, and the minimum error occurs near 45°.

As with the previous combination, a wide range of phase shifts shows good to very good performance. This filter combination is shifted towards 0° relative to the second-order/fourth-order combination, and is a better choice between 0° and 40°. It will also be worth considering all the way to 100° if the steeper slope of a third-order filter is important.

ASYMMETRICAL LINKWITZ-RILEY

Figure 17 shows the response of a second- and fourth-order Linkwitz-Riley filter combination. When the normal connection is used, the phase angle between sections is 90° (-90° for the LP and +180° for the HP), and since Linkwitz-Riley filters are -6dB at crossover, they require a 0° phase angle for a flat response. We must add 90° of phase shift, and, as the figure shows, the minimum error occurs around 90°. This combination is exceptionally insensitive to driver-offset-related phase shift and is usable from 15° to 145°. If the exact phase shift is unknown, this is a good filter choice.

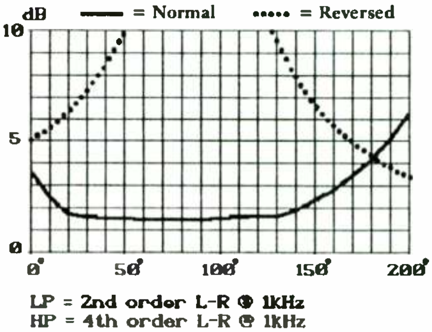


FIGURE 17: Second- and fourth-order Linkwitz-Riley filters.

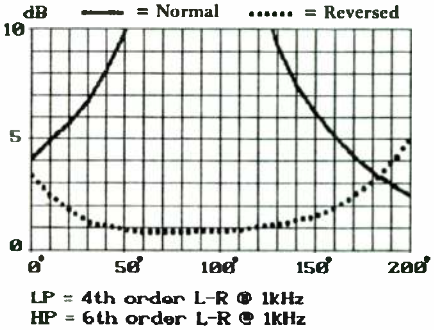


FIGURE 18: Fourth- and sixth-order Linkwitz-Riley.

The same can be said for the fourth- and sixth-order Linkwitz-Riley combination, which shows even lower error over a wider range, from 20° to 160° (*Fig. 18*). The LP section is at -180° and the HP section is at +270°, with a 90° phase angle between sections. However, since the negative phase shift is added to the LP section, you need to add -270° before there is a phase angle of 0° between filter sections. By using the reversed connection, an additional -90° of phase shift will achieve a phase angle of 0° between sections.

As expected, minimum error (this time in the reversed response) occurs close to a 90° phase shift. Again, this is a nearly ideal filter combination when the phase shift is unknown.

In Part 2, we will consider two other ways to minimize errors due to driver offset: adjusting the filter overlap and using phase shift networks. ▶

ZALYTRON

PRESENTS A NEW LINE OF HIGH QUALITY, PROFESSIONAL ,CROSSOVER ,COILS
MANUFACTURED BY:

ERSE Electronics Co,Inc.

ERSE is an audio manufacturer supplying high quality components to professional loudspeaker manufacturers throughout the world. These high quality components are now available to you from ***ZALYTRON.*** **Made in the USA.**

14ga Perfect Lay Winding

ERSE's 14ga perfect layer audio air core coils are the highest quality of its kind. These coils are excellent for those who do not want any saturation distortion, but still want a low d.c. resistance. **Precision quality made in the USA.**

INDUCTANCE	DCR	PRICE
6.20mh	0.687	$24.84
5.60mh	0.630	$23.28
4.70mh	0.560	$20.76
3.90mh	0.490	$18.36
3.30mh	0.451	$16.90
3.00mh	0.433	$15.74
2.70mh	0.386	$14.82
2.20mh	0.330	$12.60
1.80mh	0.301	$11.50
1.50mh	0.286	$11.25
1.20mh	0.240	$9.54
1.00mh	0.227	$8.32
0.82mh	0.191	$7.56
0.68mh	0.170	$6.86
.056mh	0.150	$6.10
0.47mh	0.131	$5.46
0.39mh	0.117	$4.94
0.33mh	0.100	$4.30
0.27mh	0.092	$3.98
0.22mh	0.082	$3.74
0.18mh	0.078	$3.48
0.15mh	0.065	$3.08
0.12mh	0.058	$3.02
0.10mh	0.056	$2.98

FERON Bobbin Inductors

***ERSE*'s** *FERON* Bobbin Inductors have many qualities important to loudspeakers builders. *FERON* is a higher quality alternative to ferrite.

- Very high saturation levels
- Low total harmonic distortion
- Low hysteresis distortion
- Low d.c. resistance
- Very high quality factor
- Unique 8/32 mounting system

PRECISION QUALITY
MADE IN THE USA

NEW LOWER DISTORTION

INDUCTANCE	DCR	PRICE
2.20mh	.141	$6.99
2.70mh	.174	$7.36
3.00mh	.191	$7.57
3.30mh	.191	$7.88
3.90mh	.210	$8.32
4.70mh	.241	$8.92
5.60mh	.270	$10.17
6.80mh	.281	$10.77
8.20mh	.321	$11.44
10.0mh	.370	$12.33
12.0mh	.417	$13.29
15.0mh	.456	$14.54
18.0mh	.519	$15.07
21.0mh	.580	$16.87

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 10A.M. to 6 P.M. daily, Monday thru Saturday
UPS orders shipped same day. Minumum order $50.00

WRITE OR CALL FOR ALL YOUR SPEAKER NEEDS OR INQUIRIES

Reader Service #45

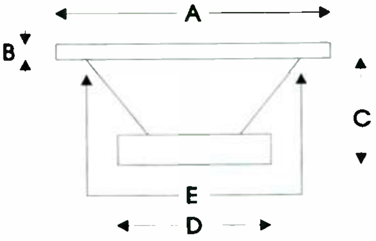
seas

Audiophile
Price List
June 1994

Madisound Speaker Components
(8608 University Green)
P.O. Box 44283
Madison, WI 53744-4283 U.S.A
Voice: 608-831-3433
Fax: 608-831-3771

Model	Size Description	Imp. Ω	Fs Hz	Qts	Vas Liters	X-Max mm Peak	Power Watts	Rating db @Freq	Sens. 1W/1M db	Cost Per Unit
Tweeters										
19TFF (H586)	19mm textile dome tweeter	8	1700				80	12@5K	87	**$15.50**
25TAF/G (H398)	25mm aluminum dome tweeter with grill	8	1400				100	12@3.5K	90	**$19.60**
25TAC/G (H400)	25mm aluminum dome tweeter with chambered back & grill	6	660				55	12@3K	91	**$23.50**
Midranges										
MCA11RC (H143)	4.5" treated paper cone mid with cast magnesium basket	8	140	.72	1.3	.9	110	6@800	89	**$30.85**
K2852	Chamber for MCA11RC	-	-	-	-	-	-	-	-	**$1.50**
Woofers										
CA11RCY (H149)	4.5" treated paper cone woofer with cast magnesium and rubber surround	8	58	.24	5.4	3	60		86	**$34.80**
P11RC (H454)	4.5" poly cone woofer with cast magnesium basket and rubber surround	8	55	.34	5.3	3	60		84.5	**$30.25**
P14RC (H395)	5" poly cone woofer with cast magnesium frame and rubber surround	8	40	.28	18.9	3	60		89	**$29.65**
P17REX (H416)	6.5" poly cone woofer with cast magnesium frame, rubber surround, large VC	8	34	.24	30.5	3	80		89	**$42.20**
P17RE (H419)	6.5" poly cone woofer with cast magnesium frame and rubber surround.	8	34	.33	30.5	3	80		87.5	**$39.00**
P17RC (H353)	6.5" poly cone rubber surround, cast magnesium frame for sealed enclosures.	8	35	.32	40.8	3	60		89	**$32.50**
P21REX (H282)	8" poly cone rubber surround, cast magnesium frame woofer with 1.5" VC	8	33	.37	68.9	3	80		91	**$48.50**
P21RF/P (H511)	As above with phase plug and 2" diameter voice coil	8	34	.34	48.3	4	125		88	**$54.40**
P21RE4X/DC (H442)	Dual VC 8" woofer with poly cone, rubber surround, cast magnesium.	8/8	31	.30	66.4	3	90		90	**$55.30**
P25REX (H283)	10" poly cone woofer with rubber surround and cast magnesium frame.	8	27	.44	156.8	3	80		93	**$54.30**
CA25RE4X/DC (H372)	10" treated paper cone woofer with rubber surround, cast magnesium frame	8/8	25	.31	187.9	4	90		91	**$59.00**
Coincidental Coaxial Driver										+
P17REX COAX/F (H489)	6.5" coaxial P17REX/25TFFN/G in a coincidental configuration.	T6 W8	T1.8K W35	W .25	W 26.9	W 3	T90 W100		T89 W89	**$82.00**

Unit	A mm	B mm	C mm	D mm	E mm	Vented Box QB3 alignment					Sealed Box	
						V_b liter	F_b Hz	F_3 Hz	Vent Ø"	Vent L"	V_b liter	F_3 Hz
19TFF (H586)	93.8	3.1	18.4	66.5	66.5							
25TAF/G (H398)	103.8	3.6	24.4	74.8	74.8							
25TAC/G (H400)	103.8	3.6	37.9	74.8	74.8	No Rg values are used in these alignments.						
MCA11RC (H143)	109.4	4.4	49.1	72	95.8						3 to 5	145
CA11RCY (H149)	109.4	4.4	55.1	93	95.8	1	59	135	1	5.7	1 to 2	175
P11RC (H454)	109.4	4.4	49.1	72	95.8	3	64.4	75	1	4.6	1.7	114
P14RC (H395)	133.2	3.7	62.3	72	112.8	5.5	56	70	1	2.7	3.7	100
P17REX (H416)	170.4	3.8	67.7	110	145.3	6	55	70	1.5	6.2	4.3	97
P17RE (H419)	170.4	3.8	67.7	93	145.3	13	42	50	1.5	4.8	8.6	73
P17RC (H353)	170.4	3.8	64.7	72	145.3	15.7	44.6	52	2	6.2	11	78
P21REX (H282)	215.4	4.7	75.3	110	186.8	46	36	39	2	2.6	27	63
P21RF/P (H511)	215.4	4.7	75.3	110	186.8	22.4	41	45	2	4.9	14.5	71
P21RE4X/DC (H442)	215.4	4.7	75.3	110	186.8	25.6	39.5	45	2	4.5	16	70
P25REX (H283)	261.2	4.2	82.8	110	229						70	44
CA25RE4X/DC (H372)	261.2	4.2	82.8	110	229	72	32	38	3	5.2	46	57
P17REX COAX/F (H489)	170.4	3.8	67.7	110	145.3	5.5	57	70	1.5	6.7	4	100



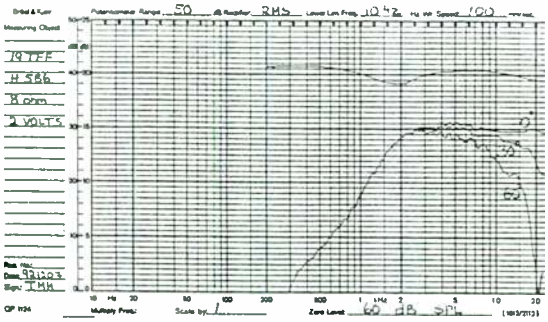
Call for more specific alignments and assistance with your application. Our staff is very experienced and most helpful.

Seas 19TFF **H586**

This 19mm textile dome tweeter offers an extremely smooth response from 4K to over 20KHz. The textile dome is made from a precoated fabric for very tight production tolerances. The dome is suspended by a soft polyamide surround. The frame is a glass fiber reinforced plastic. The voice coil is wound on a perforated aluminum former and immersed in magnetic fluid to reduce problems with resonance and increase short term power handling and decrease compression at high power levels.

Should be a good choice for any system requiring a tweeter above 4KHz.

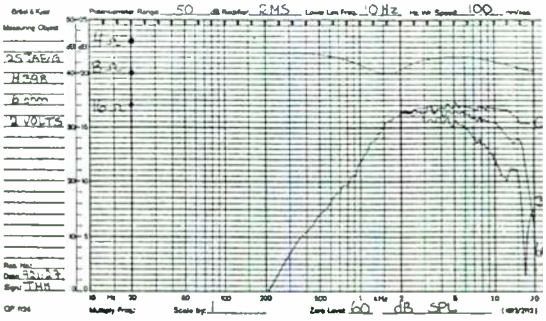
Nominal Impedance	8	Ohms	Voice coil resistance	6.2	Ohms
Recom. frequency range	4000-20000	Hz	Voice coil inductance	0.05	mH
Short term max. power	200	W	Force factor	2.6	N A
Long term max. power	80	W	Free air resonance	1700	Hz
Sensitivity (1W/1m)	87	dB	Moving mass	0.22	g
			Suspension compliance	-	mm/N
Voice Coil Diameter	19.5	mm	Suspension mech. resistance	-	Ns/m
Voice coil height	1.5	mm	Effective piston area	4.0	sq. cm
Air gap height	2.0	mm			
Linear coil travel (p-p)	0.5	mm	Vas	-	Liters
Max. coil travel (p-p)	-	mm	Qms	-	
Magnet weight	0.12	Kg	Qes	-	
Total weight	0.30	Kg	Qts	-	



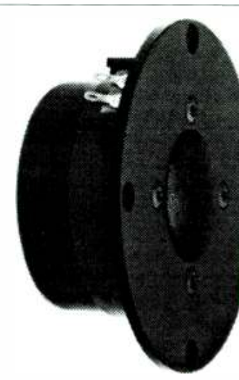
Seas 25TAF/G **H398**

This 25mm aluminum dome tweeter features high efficiency and a smooth extended response, resulting in good dispersion above 10KHz. Its aluminum diaphragm with critically designed shape and thickness is protected by a fine mesh grill, which also supports a phase plate which compensates for a slight axial roll off at 20KHz. A specially designed soft surround allows for a low fundamental frequency and excellent mechanical linearity. The voice coil is immersed in magnetic fluid, allowing high power handling and simplified crossover design.

Nominal Impedance	6	Ohms	Voice coil resistance	4.8	Ohms
Recom. frequency range	3000-25000	Hz	Voice coil inductance	0.05	mH
Short term max. power	240	W	Force factor	3.5	N/A
Long term max. power	100	W	Free air resonance	1400	Hz
Sensitivity (1W/1m)	90	dB	Moving mass	0.33	g
			Suspension compliance	-	mm/N
Voice Coil Diameter	26	mm	Suspension mech. resistance	-	Ns/m
Voice coil height	1.5	mm	Effective piston area	7.0	sq. cm
Air gap height	2.0	mm			
Linear coil travel (p-p)	0.5	mm	Vas	-	Liters
Max. coil travel (p-p)	-	mm	Qms	-	
Magnet weight	0.25	Kg	Qes	-	
Total weight	0.55	Kg	Qts	-	

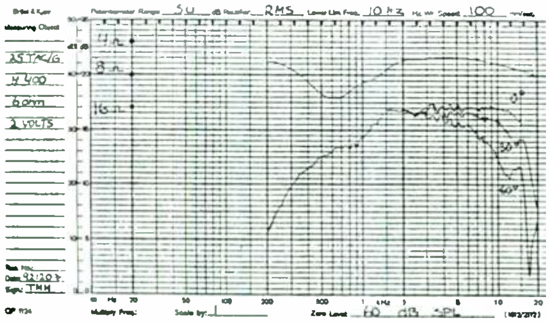


Seas 25TAC/G **H400**



This is a chambered back version of the H398 tweeter. It features the same aluminum voice coil, magnet and metal mesh grill of the H398. The hole in the pole piece and tuned chambered back behind the magnet result in al low resonance frequency. The lower resonance allows this driver to achieve a lower crossover frequency. This tweeter has a smooth response and good off axis response.

Nominal Impedance	6	Ohms	Voice coil resistance	4.8	Ohms
Recom. frequency range	2000-25000	Hz	Voice coil inductance	0.05	mH
Short term max. power	150	W	Force factor	3.5	N/A
Long term max. power	55	W	Free air resonance	660	Hz
Sensitivity (1W/1m)	91	dB	Moving mass	0.33	g
			Suspension compliance	-	mm/N
Voice Coil Diameter	26	mm	Suspension mech. resistance	-	Ns/m
Voice coil height	1.5	mm	Effective piston area	7.0	sq. cm
Air gap height	2.0	mm			
Linear coil travel (p-p)	0.5	mm	Vas	-	Liters
Max. coil travel (p-p)	-	mm	Qms	-	
Magnet weight	0.25	Kg	Qes	-	
Total weight	0.50	Kg	Qts	-	



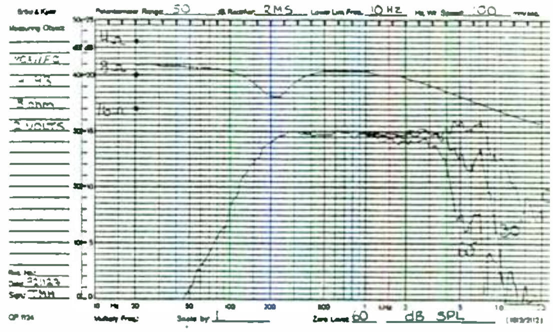
Seas MCA11RC **H143**

This 4.5" treated paper cone midrange provides an extremely smooth response to 4,000 Hz. The paper cone is a specially treated paper with a mechanically matching foam surround. The frame is a stable injection molded magnesium. A 1" high temperature voice coil is wound on an aluminum voice coil former for high power capacity.

A rear chamber with optimized shape and volume is available (K2852).

Flat response at 60° off axis to 3,000 Hz!

Nominal Impedance	8	Ohms	Voice coil resistance	6.5	Ohms
Recom. frequency range	400-5000	Hz	Voice coil inductance	0.35	mH
Short term max. power	400	W	Force factor	4.7	N/A
Long term max. power	110	W	Free air resonance	140	Hz
Sensitivity (1W/1m)	89	dB	Moving mass	4.0	g
			Suspension compliance	0.3	mm/N
Voice Coil Diameter	26	mm	Suspension mech. resistance	1.7	Ns/m
Voice coil height	5.8	mm	Effective piston area	55	sq. cm
Air gap height	4.0	mm			
Linear coil travel (p-p)	1.8	mm	Vas	1.3	Liters
Max. coil travel (p-p)	-	mm	Qms	2.17	
Magnet weight	0.25	Kg	Qes	1.09	
Total weight	0.55	Kg	Qts	0.72	

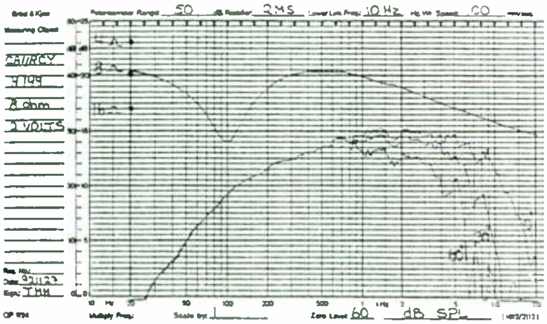


Seas CA11RCY **H149**

This 4.5" mini woofer features a hand coated paper cone with a natural rubber surround and coated fabric dust cap. The frame is made of injected molded magnesium to reduce resonance and distortion. Excellent linearity is achieved with a large magnet system and a symmetrical driving force accomplished with a special winding technique for the voice coil.

The large magnet system provides a usable efficiency. This driver has a smooth response to 5KHz.

Nominal Impedance	8	Ohms	Voice coil resistance	6.4	Ohms
Recom. frequency range	45-5000	Hz	Voice coil inductance	0.55	mH
Short term max. power	200	W	Force factor	7.0	N/A
Long term max. power	60	W	Free air resonance	58	Hz
Sensitivity (1W/1m)	86	dB	Moving mass	5.7	g
			Suspension compliance	1.3	mm/N
Voice Coil Diameter	26	mm	Suspension mech. resistance	1.4	Ns/m
Voice coil height	12	mm	Effective piston area	55	sq. cm
Air gap height	6.0	mm			
Linear coil travel (p-p)	6.0	mm	Vas	5.4	Liters
Max. coil travel (p-p)	9.0	mm	Qms	1.54	
Magnet weight	0.42	Kg	Qes	0.28	
Total weight	1.1	Kg	Qts	0.24	

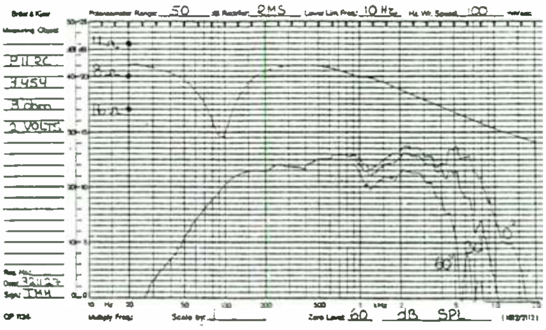


Seas P11RC **H454**

This 4.5" mini woofer features a polypropylene cone, a natural rubber surround and a soft PVC dust cap which results in a woofer of high quality and consistency. The frame is made of injection molded magnesium for stability. The high temperature voice coil is wound on an aluminum former for high power handling.

This driver could provide deep bass in a small two way system, as well as provide neutral midrange. You could also use this driver where a low resonance midrange is needed.

Nominal Impedance	8	Ohms	Voice coil resistance	5.7	Ohms
Recom. frequency range	45-4000	Hz	Voice coil inductance	0.65	mH
Short term max. power	200	W	Force factor	5.5	N/A
Long term max. power	60	W	Free air resonance	55	Hz
Sensitivity (1W/1m)	84.5	dB	Moving mass	6.5	g
			Suspension compliance	1.3	mm/N
Voice Coil Diameter	26	mm	Suspension mech. resistance	1.5	Ns/m
Voice coil height	12	mm	Effective piston area	55	sq. cm
Air gap height	6.0	mm			
Linear coil travel (p-p)	6.0	mm	Vas	5.3	Liters
Max. coil travel (p-p)	9.0	mm	Qms	1.54	
Magnet weight	0.25	Kg	Qes	0.44	
Total weight	0.65	Kg	Qts	0.34	

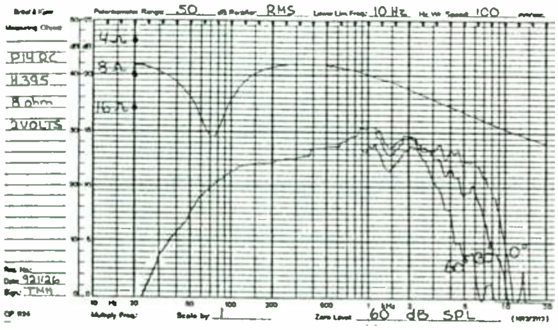


Seas P14RC **H395**

This 5" polypropylene cone woofer will provide good bass as well as uncolored midrange in a small 2-way system. An injection molded magnesium frame is used for minimum resonance and lower distortion. The poly cone is suspended by a natural rubber surround and has a soft PVC dust cap. The high temperature voice coil is wound on an aluminum former for higher power handling.

This driver will perform well as a woofer in a vented enclosure, or as a midrange in a sealed enclosure.

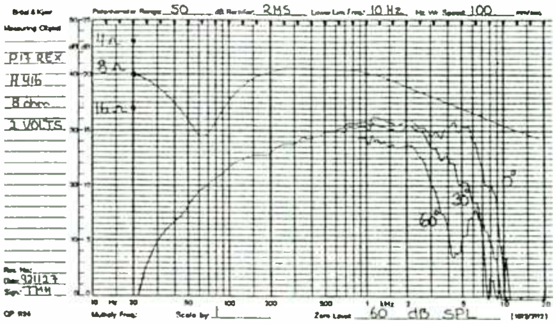
Nominal Impedance	8	Ohms	Voice coil resistance	5.7	Ohms
Recom. frequency range	45-4000	Hz	Voice coil inductance	0.65	mH
Short term max. power	250	W	Force factor	5.5	N/A
Long term max. power	60	W	Free air resonance	40	Hz
Sensitivity (1W/1m)	89	dB	Moving mass	7.0	g
			Suspension compliance	2.2	mm/N
Voice Coil Diameter	26	mm	Suspension mech. resistance	1.4	Ns/m
Voice coil height	12	mm	Effective piston area	80	sq. cm
Air gap height	6.0	mm			
Linear coil travel (p-p)	6.0	mm	Vas	18.9	Liters
Max. coil travel (p-p)	14	mm	Qms	1.35	
Magnet weight	0.25	Kg	Qes	0.36	
Total weight	1.65	Kg	Qts	0.28	



Seas P17REX **H416**

This 6.5" woofer has a polypropylene based cone with a soft PVC dust cap and high loss rubber surround. These three components have been carefully matched to each other, resulting in outstandingly smooth response. The frame is made of injection molded magnesium for reduced resonance. The magnet system has a T-shaped cross section of the pole piece for low modulation distortion. A large magnet system provides high efficiency and a low Q. This driver has good off axis response to 3,000 Hz. Exceptional driver for a 2-way system.

Nominal Impedance	8	Ohms	Voice coil resistance	6.1	Ohms
Recom. frequency range	40-3000	Hz	Voice coil inductance	0.6	mH
Short term max. power	250	W	Force factor	8.5	N/A
Long term max. power	80	W	Free air resonance	34	Hz
Sensitivity (1W/1m)	89	dB	Moving mass	16	g
			Suspension compliance	1.4	mm/N
Voice Coil Diameter	39	mm	Suspension mech. resistance	3.0	Ns/m
Voice coil height	12	mm	Effective piston area	130	sq. cm
Air gap height	6.0	mm			
Linear coil travel (p-p)	6.0	mm	Vas	30.5	Liters
Max. coil travel (p-p)	19	mm	Qms	1.21	
Magnet weight	0.64	Kg	Qes	0.31	
Total weight	1.60	Kg	Qts	0.24	

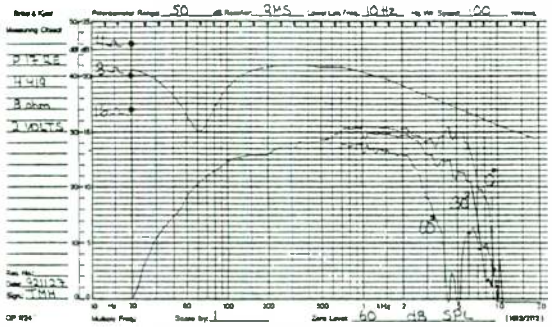


Seas P17RE **H419**

This 6.5" woofer has similar features to the P17REX, with the magnesium frame, polypropylene cone, soft PVC dust cap, and high loss rubber surround. The relatively large voice coil provides good power handling. The magnet system with T-shaped cross section of the pole piece provides low modulation distortion.

The small magnet of this driver gives it a higher Qts, allowing this driver to be used in a either a sealed or vented enclosure. Vented response to 50Hz or Sealed response to 70Hz. Smooth response to 3,500 Hz with good off axis response to 2,500 Hz.

Nominal Impedance	8	Ohms	Voice coil resistance	6.1	Ohms
Recom. frequency range	40-3000	Hz	Voice coil inductance	0.6	mH
Short term max. power	250	W	Force factor	7.0	N/A
Long term max. power	80	W	Free air resonance	34	Hz
Sensitivity (1W/1m)	87.5	dB	Moving mass	16	g
			Suspension compliance	1.4	mm/N
Voice Coil Diameter	39	mm	Suspension mech. resistance	3.0	Ns/m
Voice coil height	12	mm	Effective piston area	130	sq. cm
Air gap height	6.0	mm			
Linear coil travel (p-p)	6.0	mm	Vas	30.5	Liters
Max. coil travel (p-p)	19	mm	Qms	1.21	
Magnet weight	0.42	Kg	Qes	0.45	
Total weight	1.20	Kg	Qts	0.33	

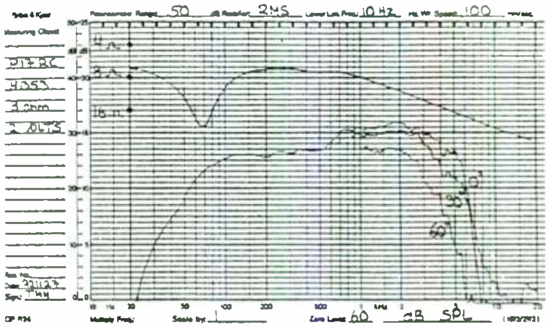


Seas P17RC H353

This 6.5" woofer is suitable for either sealed or vented enclosures. The cone material is a specially compounded polypropylene with a soft PVC dust cap and a high loss rubber surround. The result is a smooth uncolored response. The high temperature voice coil is wound on an aluminum former for high power handling.

A F3 of 50 Hz can be achieved in 1/2 ft^3 or 78 Hz in 1/3 ft^3.

Nominal Impedance	8	Ohms	Voice coil resistance	5.7	Ohms
Recom. frequency range	40-4000	Hz	Voice coil inductance	0.65	mH
Short term max. power	250	W	Force factor	5.5	N/A
Long term max. power	60	W	Free air resonance	35	Hz
Sensitivity (1W/1m)	89	dB	Moving mass	11	g
			Suspension compliance	1.8	mm/N
Voice Coil Diameter	26	mm	Suspension mech. resistance	3.0	Ns/m
Voice coil height	12	mm	Effective piston area	130	sq. cm
Air gap height	6.0	mm			
Linear coil travel (p-p)	6.0	mm	Vas	40.8	Liters
Max. coil travel (p-p)	16	mm	Qms	0.88	
Magnet weight	0.25	Kg	Qes	0.50	
Total weight	0.70	Kg	Qts	0.32	

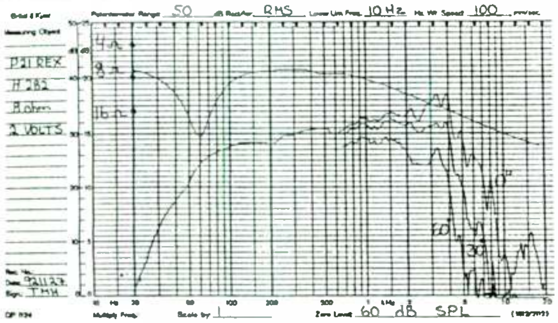


Seas P21REX **H282**

This 8" woofer has an injection molded magnesium chassis. Careful matching between a polypropylene cone, a polypropylene dust cap, and a low loss rubber surround yields a smooth frequency response with a well behaved roll off. The magnet system has a T-shaped cross section of the pole piece for low modulation distortion. A relatively large voice coil provides good power handling capacity.

This driver will provide low bass in a reasonable sized vented enclosure.

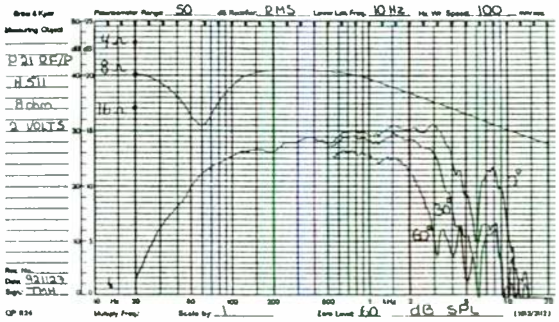
Nominal Impedance	8	Ohms	Voice coil resistance	6.1	Ohms
Recom. frequency range	35-3000	Hz	Voice coil inductance	0.6	mH
Short term max. power	250	W	Force factor	8.5	N/A
Long term max. power	80	W	Free air resonance	33	Hz
Sensitivity (1W/1m)	91	dB	Moving mass	23	g
			Suspension compliance	1.0	mm/N
Voice Coil Diameter	39	mm	Suspension mech. resistance	2.2	Ns/m
Voice coil height	12	mm	Effective piston area	230	sq. cm
Air gap height	6.0	mm			
Linear coil travel (p-p)	6.0	mm	Vas	68.9	Liters
Max. coil travel (p-p)	20	mm	Qms	2.36	
Magnet weight	0.64	Kg	Qes	0.44	
Total weight	1.60	Kg	Qts	0.37	



Seas P21RF/P **H511**

This 8" driver with phase plug has an extremely smooth response to 3,000Hz and very good 60° off axis response to 2,000Hz. The frame is made of injection molded magnesium. The cone is polypropylene with a high loss rubber surround for a smooth response and low coloration. The magnet system is designed to give excellent field symmetry, and consequently low distortion. A bullet shaped phase plug reduces compression due to temperature variations in the voice coil, avoids resonance which would occur in the volume between the dust cap and the pole piece, and increases power handling.

Nominal Impedance	8	Ohms	Voice coil resistance	6.4	Ohms
Recom. frequency range	35-3500	Hz	Voice coil inductance	0.8	mH
Short term max. power	300	W	Force factor	8.8	N/A
Long term max. power	125	W	Free air resonance	34	Hz
Sensitivity (1W/1m)	88	dB	Moving mass	22	g
			Suspension compliance	1.0	mm/N
Voice Coil Diameter	51	mm	Suspension mech. resistance	3.0	Ns/m
Voice coil height	14	mm	Effective piston area	194	sq. cm
Air gap height	6.0	mm			
Linear coil travel (p-p)	8.0	mm	Vas	48.3	Liters
Max. coil travel (p-p)	18	mm	Qms	1.70	
Magnet weight	0.57	Kg	Qes	0.42	
Total weight	1.70	Kg	Qts	0.34	

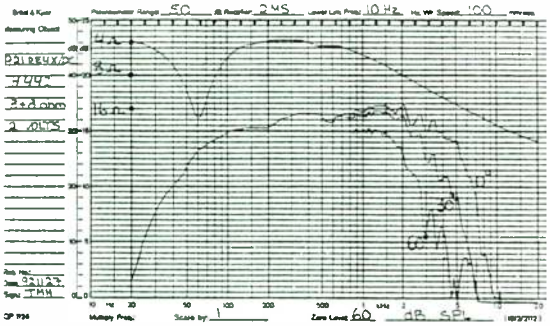


Seas P21RE4X/DC **H442**

This Dual Voice Coil 8" woofer could be used as a single woofer with a stereo pair of satellite speakers or with the voice coils in parallel as a single 4 ohm woofer. The frame is made of injection molded magnesium. The polypropylene cone has been carefully matched with a soft PVC dust cap and a low loss rubber surround for a well behaved roll off and smooth frequency response. The magnet system features the T-shaped pole piece for low modulation distortion.

This driver also offers new possibilities in response shaping by crossing over the coils at different frequencies.

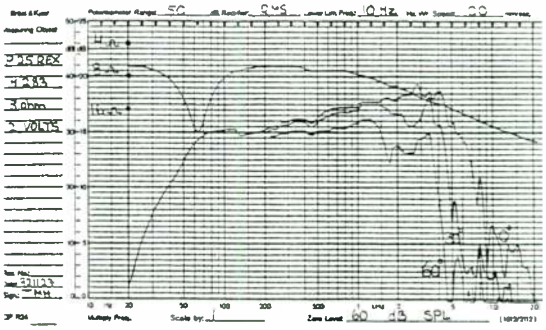
Nominal Impedance	8/8	Ohms	Voice coil resistance	2.8	Ohms
Recom. frequency range	32-2500	Hz	Voice coil inductance	0.5	mH
Short term max. power	250	W	Force factor	6.9	N/A
Long term max. power	90	W	Free air resonance	31	Hz
Sensitivity (1W/1m)	90	dB	Moving mass	27.4	g
			Suspension compliance	1.0	mm/N
Voice Coil Diameter	39	mm	Suspension mech. resistance	1.6	Ns/m
Voice coil height	12	mm	Effective piston area	230	sq. cm
Air gap height	6.0	mm	Vas	66.4	Liters
Linear coil travel (p-p)	6.0	mm	Qms	3.58	
Max. coil travel (p-p)	20	mm	Qes	0.34	
Magnet weight	0.64	Kg	Qts	0.30	
Total weight	1.60	Kg	* Measured with coils in parallel.		



Seas P25REX **H283**

This 10" woofer features a polypropylene cone, polypropylene dust cap and low loss rubber surround. These components have been carefully matched for a smooth frequency response and a well behaved roll off. The frame is made of injection molded magnesium. The magnet system has a T-shaped cross section of the pole piece for low modulation distortion. A relatively large voice coil provides high power handling.

Nominal Impedance	8	Ohms	Voice coil resistance	6.1	Ohms
Recom. frequency range	30-2500	Hz	Voice coil inductance	0.6	mH
Short term max. power	300	W	Force factor	8.5	N/A
Long term max. power	80	W	Free air resonance	27	Hz
Sensitivity (1W/1m)	93	dB	Moving mass	34	g
			Suspension compliance	1.0	mm/N
Voice Coil Diameter	39	mm	Suspension mech. resistance	2.8	Ns/m
Voice coil height	12	mm	Effective piston area	350	sq. cm
Air gap height	6.0	mm			
Linear coil travel (p-p)	6.0	mm	Vas	156.8	Liters
Max. coil travel (p-p)	20	mm	Qms	2.30	
Magnet weight	0.64	Kg	Qes	0.54	
Total weight	1.70	Kg	Qts	0.44	

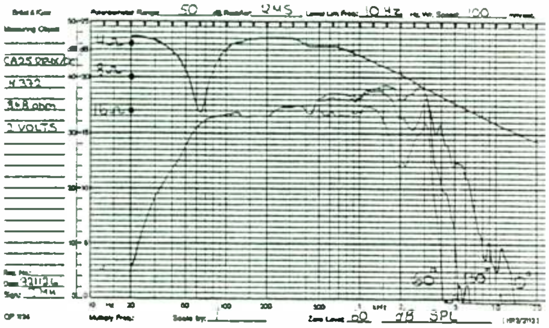


Seas CA25RE4X/DC **H372**

This 10" Dual Coil woofer features an injection molded magnesium frame. There is excellent mechanical matching between the paper cone, paper dust cap and low loss rubber surround. A special treatment of the cone produces a well behaved roll off and reduces resonance problems. The magnet system has a T-shaped cross section of the pole piece for low modulation distortion.

The double two layer voice coil allows this driver to be used as a single stereo woofer with two satellite speaker. The relatively large voice coil provides good power handling.

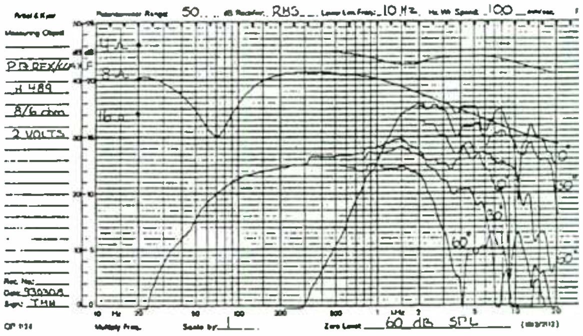
Nominal Impedance	8/8	Ohms	Voice coil resistance	2.9	Ohms
Recom. frequency range	30-1500	Hz	Voice coil inductance	0.6	mH
Short term max. power	300	W	Force factor	7.0	N/A
Long term max. power	90	W	Free air resonance	25	Hz
Sensitivity (1W/1m)	91	dB	Moving mass	33	g
			Suspension compliance	1.2	mm/N
Voice Coil Diameter	39	mm	Suspension mech. resistance	1.6	Ns/m
Voice coil height	14	mm	Effective piston area	350	sq. cm
Air gap height	6.0	mm	Vas	187.9	Liters
Linear coil travel (p-p)	8.0	mm	Qms	3.63	
Max. coil travel (p-p)	20	mm	Qes	0.34	
Magnet weight	0.64	Kg	Qts	0.31	
Total weight	1.70	Kg	* Measured with coils in parallel		



Seas P17REXCOAX/F **H489**

The H489 is a coaxial speaker with a time-coherent arrangement between woofer and tweeter tweeter is mounted at the bass of the cone where the dust cap is usually found. The cone of the woofer acts as horn loading for the tweeter. The two drive units have identical acoustic centers, and their directivities in the crossover frequency region are practically identical. Thus it is possible to build a full range Hi Fi system with a symmetrical and stable radiation pattern, combined with a smooth energy response. Sound from the woofer and tweeter reach your ear at the same time.

	Tweeter/Woofer				
			Voice coil resistance	4.8/6.1	Ohms
Nominal Impedance	6/8	Ohms	Voice coil inductance	0.05/0.6	mH
Recom. frequency range	40-25000	Hz	Force factor	2.45/8.5	N/A
Short term max. power	220/250	W	Free air resonance	1800/35	Hz
Long term max. power	90/100	W	Moving mass	0.3/14.5	g
Sensitivity (1W/1m)	89/89	dB	Suspension compliance	-/1.4	mm/N
Voice Coil Diameter	26/39	mm	Suspension mech. resistance	-/2.0	Ns/m
Voice coil height	1.5/12	mm	Effective piston area	7.0/120	sq. cm
Air gap height	2.0/6.0	mm			
Linear coil travel (p-p)	0.5/6.0	mm	Vas	-/26.9	Liters
Max. coil travel (p-p)	-/20	mm	Qms	-/1.70	
Magnet weight	-/0.64	Kg	Qes	-/0.29	
Total weight	-/1.60	Kg	Qts	-/0.25	



Reader Service #38

NOW IN STOCK!

VANCE DICKASON'S

LOUDSPEAKER RECIPES

BOOK ONE

An owner-built loudspeaker with truly dazzling performance is now within the reach of almost any reasonably intelligent constructor. Loudspeaker building, only a very few years ago, was a matter of a few hand tools and some plywood, plus some guesses as to the technical details. Our knowledge of what makes a special combination of drivers and crossover components the best possible has been growing explosively in the last decade.

◆ ◆ ◆

Vance Dickason, bestselling author of *The Loudspeaker Design Cookbook* (over 33,000 English copies sold, with German and Portuguese versions also available) brings almost twenty years of experience, research and hands-on knowledge to this new book on designing and building four tested and proven two-way loudspeaker systems.

◆ ◆ ◆

The best news, however, is that the directions, definitions and instructions for realizing these four demonstration systems, contain all the right questions and the clear paths to their answers which enable you to build excellent performing two-way systems with an almost endless combination of available woofers and tweeters.

◆ ◆ ◆

Dickason shows you how to look for the right driver characteristics to be paired successfully with the right crossover components and also how to fix any anomalies which may trouble your particular choices. Although the four two-way systems which are meticulously documented in this book, along with an outstanding general purpose subwoofer, may be built just as they are defined here, you are not limited to building these systems only.

◆ ◆ ◆

Loudspeaker Recipes, Book 1, lays a firm groundwork, both theoretical and practical, for building as many varied and successful two-way loudspeaker systems as you wish. The book benefits from the latest techniques for computer aided design, but is also rich in proven construction practices for building practical systems. Mr. Dickason is not only a published author and Editor of Voice Coil, the monthly newsletter for the loudspeaker industry, a Contributing Editor for *Speaker Builder*, but also is a professional consultant and product reviewer as well.

◆ ◆ ◆

Loudspeaker Recipes, Book 1 provides a powerful tool for any music lover who wishes to build a technically outstanding and satisfying loudspeaker system for home listening. Watch for new volumes in this series at your bookseller.

ONLY $24.95! ORDER NOW! ONLY $24.95!

☒ **YES!** PLEASE SEND ME ____ #BKAA30 @ $24.95

FOR S/H INCLUDE: ☐ $3 USA

☐ $5 OTHER SURFACE ☐ $10 OTHER AIR

TOTAL AMOUNT OF ORDER $ ____________

NAME ____________ TODAY'S DATE

STREET ____________

CITY ____________ ST ZIP

MASTERCARD / VISA / DISCOVER ____________ EXP. DATE

OLD COLONY SOUND LAB, PO BOX 243, PETERBOROUGH, NH 03458 USA
24-Hour Tels.: (603) 924-6526 (603) 924-6371 24-Hour Fax: (603) 924-9467

Part 3

THE LINEAR-ARRAY CHRONICLES

By Philip Witham

The latest scoop on my experimental project isn't earthshaking, but I'm making progress one step at a time. I have some interesting results from simulations of soundfields produced by speakers. And the plots are pretty, to boot.

I've expanded the microphone to 60 channels and corrected the individual end-to-end (mike-amp-driver) channel gains by adjusting the resistor values in each mike preamp channel. The gains were even farther out of whack than I thought, with ±3½dB variation, mostly due to the mike elements. It's now tighter than ±1dB.

The result of the increase in width (channels) is as expected: at 4′ from the speaker, you'll get an almost 90° spread of sounds. The gain adjustment has reduced or eliminated an effect noticeable when listening within inches of the speaker; that is, the sound images tended to gravitate towards the higher gain channels.

SOUND PRESSURE PLOTS

In the first "Linear-Array Chronicles" (*SB* 5/94, p. 43) I showed polar plots from simulations of arrays as well as two- and three-channel stereo. I noted that it was hard to visualize the image directions heard from a listening position given far-field polar plots. I experienced one of those "Eureka!" moments when I realized that I could use the same math to plot the pressure contours over the listening area and "see" the sound waves directly. This math is a type of "ray tracing," which, I've learned, is similar to the "Phasor sum" method that has been fairly accurate in predicting the performance of actual speaker arrays.[1]

These plots cover a 12′ × 6′ area, seen from above. They show the predicted instantaneous sound pressure produced by the speakers over an anechoic space given a constant sine-wave source. For the plots here, the mikes and drivers are assumed to be omnidirectional. The speaker array is on the left side: 60 channels covering 8′.

The pressure at each point on the plot (represented by a gray scale) is calculated by adding the individual pressure contributions from each speaker channel. First, the phase and amplitude of each microphone array signal is calculated from the distance between the source and that mike element, given the source position, frequency, and the speed of sound. Then for each point on the plot the distance to each speaker driver is calculated, and the phase and amplitude contributed by that channel results. This is repeated for each driver and added up to a total pressure sum.

The process is repeated for each of the thousands of points on the plot. You can imagine this takes a bit of number crunching by my poor, overworked PC. It gets worse as the frequency approaches the upper treble, where the directional characteristics of the drivers must be accounted for. This requires up to 100,000,000 ray tracings and eight hours per plot. Eventually, I needed to code the number crunching guts as a C program, rather than wait all week for a single plot from my MathCad sheet.

EXAMPLES

The first group (*Figs. 1–4*) includes a 2kHz source. *Figure 1* has the source centered at 0°, 10′ from the mike. A typical listening position is somewhere between the center of the plot to the far right center. Imagine listening from there. *Figure 2* features the source moved up to 3′ from the mike. In *Fig. 3* the

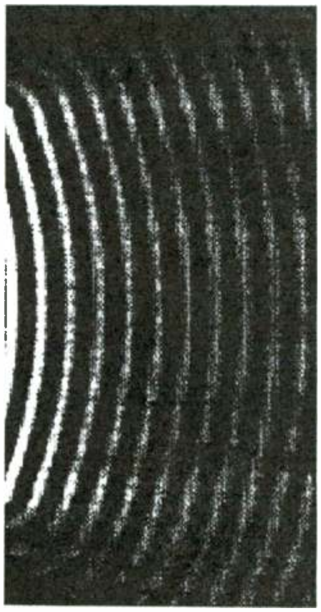


FIGURE 1: Various source centers (1-4): 2kHz, 10′ behind mike.

FIGURE 2: 3′ behind mike.

FIGURE 3: 1′ behind mike, near right end.

FIGURE 4: "End-fire," 90° from left.

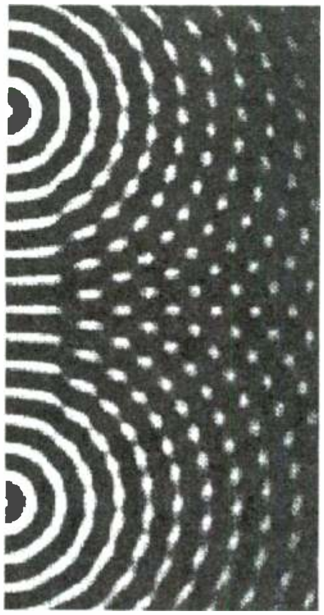


FIGURE 5: Plots with same source but increasing number of channels (5-13): two channels.

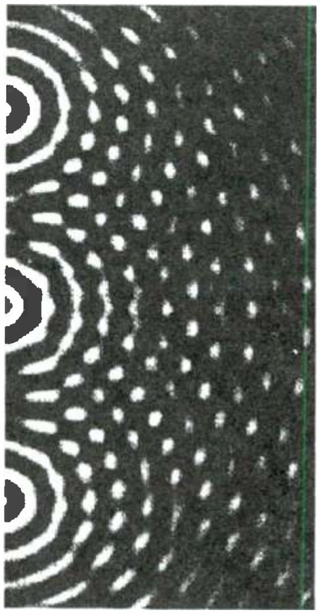


FIGURE 6: Three channels.

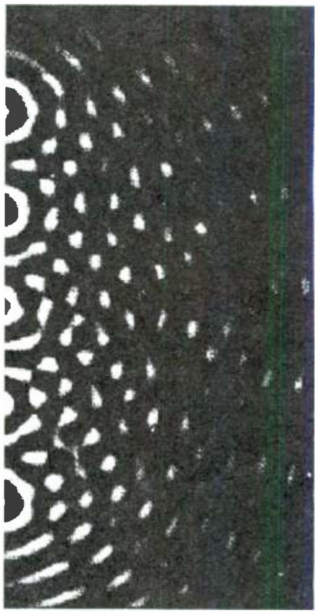


FIGURE 7: Five channels.

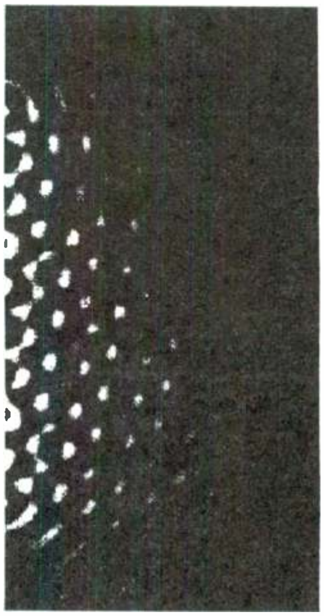


FIGURE 8: Ten channels.

source is 1′ behind the mike, 1′ inside the right end of the mike array.

Figure 4 is an "end-fire" situation, with a distant source at 90° off to the left. This is a good illustration of the array's ability to direct sounds, even off at the side walls of the room. A waste of signal, you say? Maybe, but when this bounces off the wall and back at the listening area, it is coming from the extreme right or left, which could be useful for reproducing hall reverb. And in a more typical situation, such as *Fig. 1*, the array directs far less of the sound at the side walls than a stereo system does. A little more control over room acoustics, anyone?

Figures 5-13 all have the same test situation: a distant source (plane waves) 30° off to the left side, but the number of channels increases from two (*Fig. 5*) to 60 (*Fig. 13*). A minimum of 23 channels (*Fig. 11*) is needed for this case to resolve a single, correct wavefront. The true wavefront can't even be recognized until the ten-channel example (*Fig. 8*), where it is joined by (only) two alias wavefronts, equal in intensity. If you look closely, you can differentiate the three individual wavefronts. It helps to look at the plot almost on edge and rotate it.

With fewer channels, the result is an omnidirectional mess of interference. At 16 channels (*Fig. 9*), there is only one (significant) alias, which, at 22 channels (*Fig. 10*), has moved around until it is heading directly towards the left (bottom of the plot) into the side of the listening room. This probably will not greatly affect what you would hear from

REFERENCE

1. K.D. Jacob and T.K. Birkle, "Accurate Prediction of the Three Dimensional Dispersion Characteristics of Loudspeaker Arrays Composed of Real or Theoretical Sound Sources," AES preprint #2823, 1989.

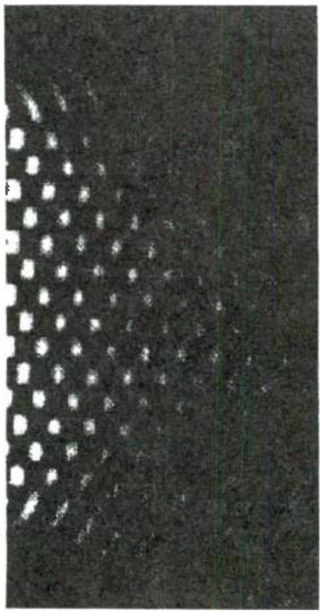


FIGURE 9: Sixteen channels.

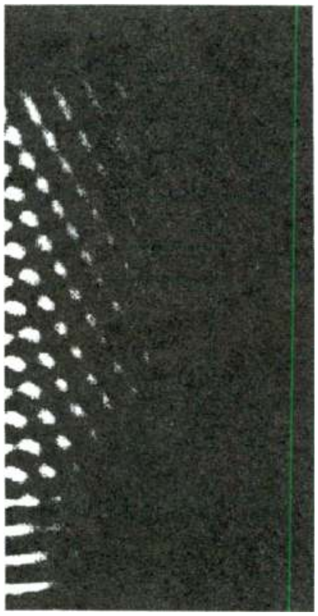


FIGURE 10: Twenty-two channels.

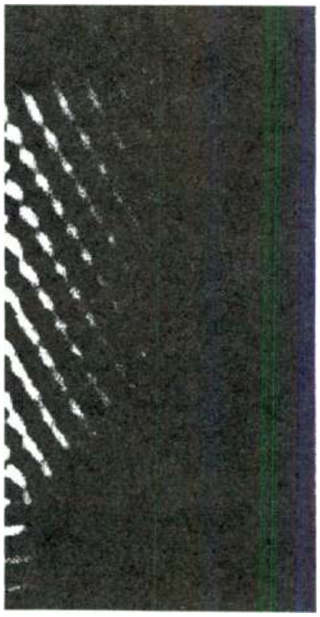


FIGURE 11: Twenty-three channels.

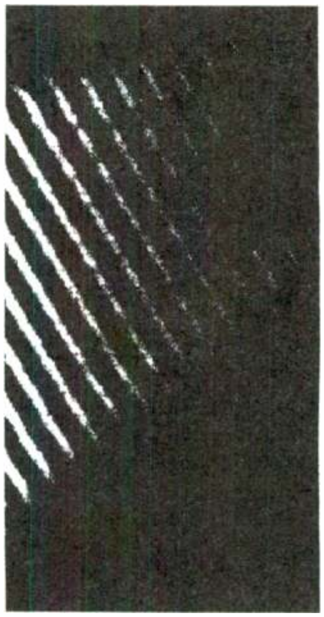


FIGURE 12: Thirty channels.

a typical listening position. With the addition of one more channel (*Fig. 11*), the alias is reduced almost to insignificance.

Adding more past this point (*Figs. 12* and *13*) "purifies" the imaging, but is probably not especially (audibly) better. However, this is just one test case. Thirty or more channels are needed to handle an end-fire sound at 2kHz, to say nothing of higher frequencies.

APERTURE DIFFRACTION

Also notice from the plots how the wavefront is bent around the ends of the array. This causes the apparent source to be near one of the ends if you are listening from a spot outside the main "beam" area. This diffraction happens to sound coming through any window or "aperture." You can try an experiment: listen to outdoor sound (from a bird, for example) through a window and move to where you no longer have a "line of sight" to both ears. You should notice the apparent sound source direction is usually at the near end of the opening.

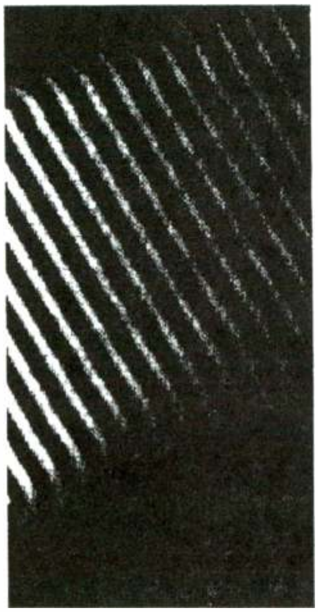


FIGURE 13: Sixty channels.

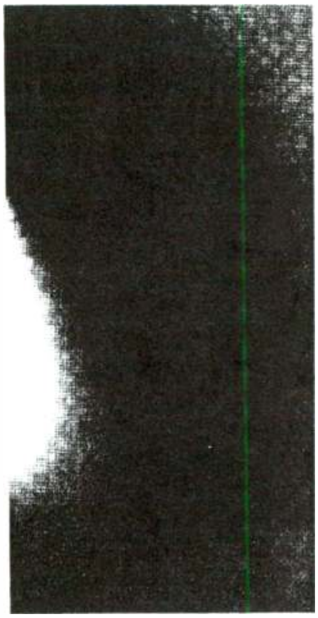


FIGURE 14: At 100Hz, covering a 16′ × 8′ plot area.

FIGURE 15: At 400Hz in a 16′ × 8′ area.

The aperture width becomes another limitation on what the array can do, at a low enough frequency, turning the whole contrivance into an omnidirectional transducer despite all those channels. The 8′ width used here is a practical upper limit on what many people would put up with in their homes. *Figures 14* and *15* are the result at 100Hz and 400Hz, with a distant source off 30° to the left. These two plots cover a 16′ × 8′ area.

That's all for now.

Ultrawide Radiation ...Without Fallout

Get the only tweeter that delivers on its promise to recreate the feeling of a live performance.

Designing a tweeter that can reproduce the spacious sound of a concert hall without the fallout from design compromises...takes years of experience. Designed by audio legend Roy Allison, the RDL pulsating dome tweeter performs unlike any tweeter in the world. It delivers an extremely wide dispersion at all sound frequencies, including the full treble range, so as to simulate the rich reverberant field of a live performance.

The spacious sound is so incredible–it has to be heard to be believed. Don't just take our word–listen to what the critics have to say...

According to David R. Moran of The Boston Audio Society Speaker Newsletter: "...*Allison's unsurpassed, strangely unimitated convex tweeter...its ultrawide radiation and airy imaging may be even more uniform than previous implementations...in over a dozen measurements, the tweeter consistently ran ±2dB from 1-2 kHz to around 18kHz*"

RDL
ROOM ACOUSTICS
DESIGNED
LOUDSPEAKERS

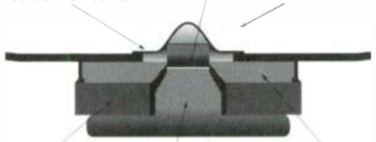
26 Pearl Street #15 Bellingham, MA 02019

Order The Ultimate Tweeter for Your Next Speaker Project. Call

1-800-227-0390

VISA MasterCard DISCOVER NOVUS

Be sure to ask for our free 32 page catalog



SPECIFICATIONS

Frequency Response	2,000 to 20,000 Hz ±3 dB
Sensitivity	87dB SPL 1w/1m
Overall Dimensions	4" Diameter x 1 3/4" thick
Face Plate Thickness	1/8"
Voice Coil Diameter	1/2"
Voice Coil Length	0.115"
DC Resistance	4.7 Ohms
Nominal Impedance	8 Ohms
Nominal Power Handling	15W Cont. or Avg. 150W Peaks
Cone	Treated paper
Net Weight	1 lb. 5 oz.
Price	**$41.00ea.**

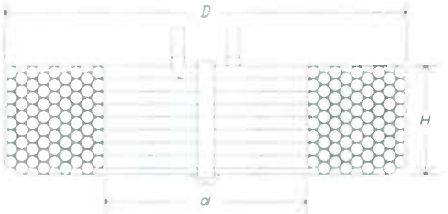
Reader Service #39

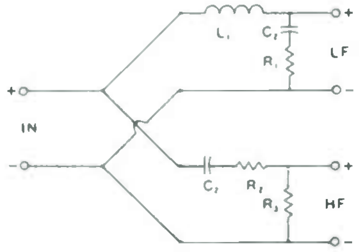
World Radio History

SOLEN SPEAKER COMPONENTS

DAVIS
scan·speak
vifa
DYNAUDIO
LA PASSION DU HAUT-PARLEUR
AUDAX
morel
seas
Peerless
AIRBORNE
CERATEC
MADE BY CERATEC-THIEL
ETON
LPG

CROSSOVER, SPEAKER COMPONENTS





FAST CAPACITORS
Metallized Polypropylene (Non-Polarized)
Values from 1.0 mfd to 200 mfd.
Voltage Rating: 250 VDC / 150 VAC

SOLEN INDUCTORS
Perfect Lay Hexagonal Winding Air Cored
Values from .10 mH to 30 mH
Wire sizes from #20 AWG to #10 AWG

HEPTA-LITZ INDUCTORS
Seven Strands Litz-Wire Constructions
Values from .10 mH to 30 mH
Wire sizes from #16 AWG to #12 AWG

SOLEN CROSSOVERS
Custom Computer Design
Passive Crossover for Professional, Hi-Fi and Car Hi-Fi, Power up to 1000 Watt

CROSSOVER, SPEAKER PARTS
Gold Speaker Terminals, Gold Banana Plugs
Gold Binding Posts, Crossover Terminals
Power Resistors, Mylar Capacitors,
Bi-Polar Capacitors, Plastic Grille Fasteners,
Nylon Ties, Car Speaker Grilles, Speaker Books,
Speaker Kit Brochure, Miscellaneous Parts

SOLEN INC.
4470 Thibault Ave.
St-Hubert, QC J3Y 7T9
Canada
Tel.: (514) 656-2759
Fax: (514) 443-4949

COMPUTER AIDED DESIGN FOR ENCLOSURE AND CROSSOVER AVAILABLE TO CUSTOMER

Catalog $6.00 refundable.

Reader Service #24

Wayland's Wood World

DRESSING UP THE GRILLE

By Bob Wayland

The grille frame described last time (*SB* 8/94, p. 47) is the plain, stripped-down version. Although that is almost a contradiction, because the whole reason for this piece is to dress up your speaker. So let's discuss a few accessories—utilitarian and decorative—to make your grille frame a bit more flamboyant. (Please read the entire article before starting, as some steps must be taken before you're too far along.)

UTILITARIAN DRESS

The construction of last issue's frame depended upon a jig to ensure that accurate corner angles were cut. If you made a frame using one, you were probably very dependent upon its accuracy. Perhaps you also discovered that your frame was not very strong. The corner joints, especially for larger frames, can experience sufficient stress to break the unreinforced joint. Clearly, this weak link must be strengthened.

The simplest solution is to place a dowel across the joint. The Dowel-It jig (available from Woodworker's Supply, #120-001, for $39.95 plus S&H) allows you to quickly drill the dowel hole exactly where you wish and ensure that it's perpendicular to the side of the frame (*Photo 1*). I normally choose a dowel diameter that is one-third to one-half the thickness of the frame. To hide the dowel, use the same wood as the frame and line up the grain patterns if possible.

You can let the end of the dowel protrude about ¼", then cut it off after the glue has dried and sand it flush. For a more decorative touch, try using a dowel made of contrasting wood. Many different options are available from most woodworker supply houses. All sorts of variations are possible, such as using two small dowels instead of one larger one. I have even seen frames with brass or copper dowels.

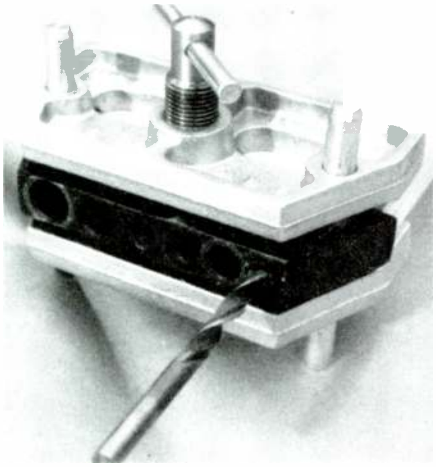


PHOTO 1: Using the Dowel-It jig for reinforcing the grille frame.

If your frame has wide pieces, you can use biscuit-joining techniques (*SB* 5/94, p. 50). Remember that the width of the two pieces to be joined should be greater than the biscuit's long dimension.

Another approach is to make an exposed corner spline, which is easy with a simple jig.

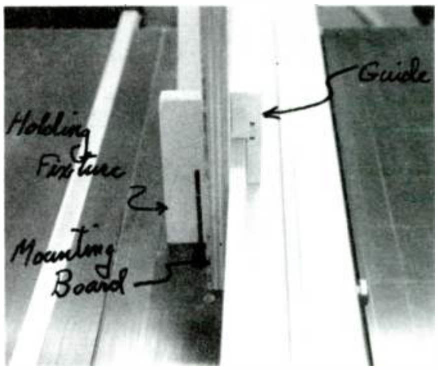


PHOTO 2: Arrangement of guide, holding fixture, and mounting board for corner spline jig.

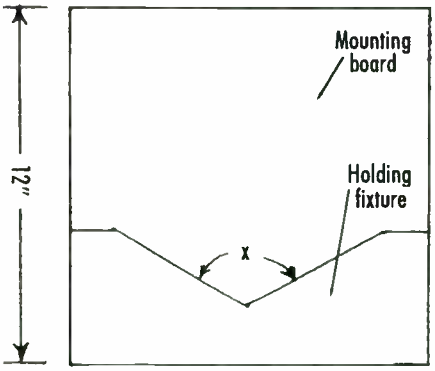


FIGURE 1: Holding fixture cutting guide.

Start with a piece of ¾" plywood (any flat board will do) about 12" × 12" to serve as a mounting board. Affix a guide that will fit snugly over your saw's fence, while position-

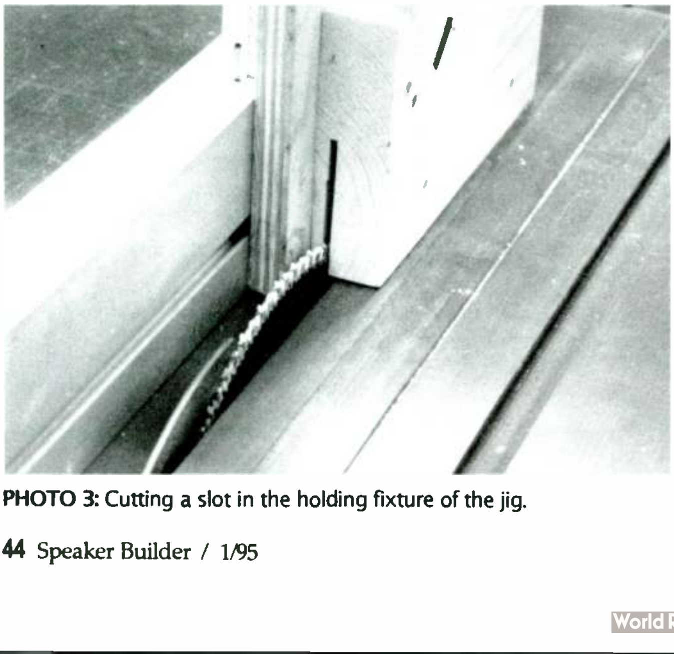


PHOTO 3: Cutting a slot in the holding fixture of the jig.

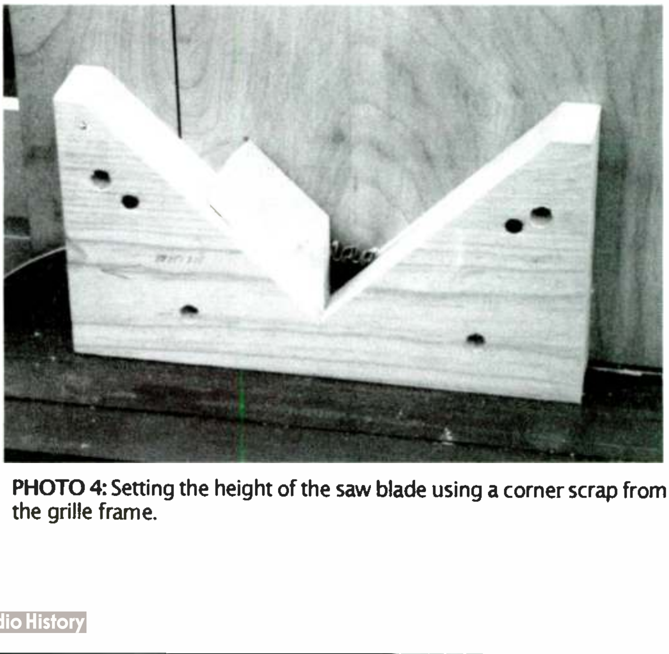


PHOTO 4: Setting the height of the saw blade using a corner scrap from the grille frame.

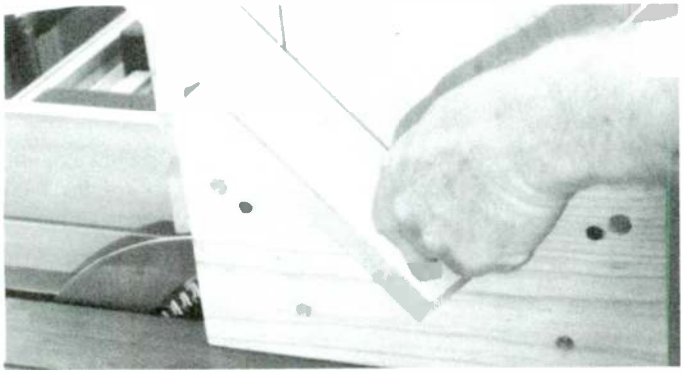


PHOTO 5: Holding the frame while making the spline cut. This is not a good idea—use clamps!

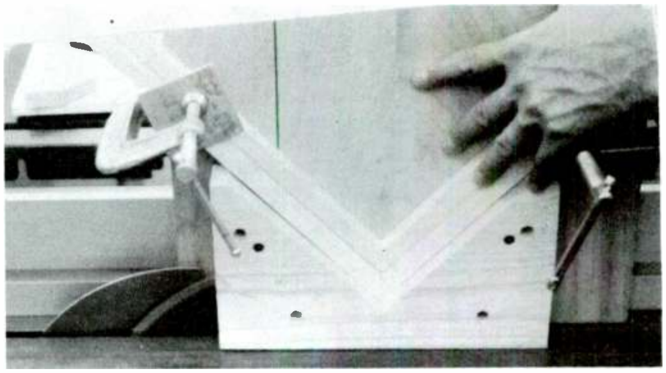


PHOTO 6: Cutting the spline slot with the grille frame clamped to the jig.

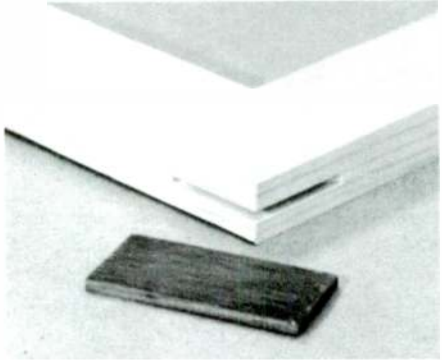


PHOTO 7: Spline prepared for the corner. Note the direction of the wood grain.

ing the board perpendicular to the saw table (*Photo 2*).

To this mounting board construction attach a holding fixture made of 2″ × 10″ or 2″ × 12″ scrap wood. Cut it as shown in *Fig. 1*. The reference angle is the one at the corner you wish to reinforce: 90° for a square or rectangular frame. I have a series of holding fixtures for the different reference angles I most often use. Don't worry about accuracy; freehand cutting with a hand or band saw is fine.

Screw the holding fixture to the mounting board (*Photos 2-4*). With your saw blade raised an inch or two above the bottom of the notch, cut a slot through the holder, as shown in *Photo 3*. The centerline of the cut should be half the thickness of the frame, as measured from the mounting board. Most of the time this is one-half of ¾″, or 3/8″, but it needn't be exact.

SPLINE SLOTS

First, make the slot for the spline by positioning the piece of scrap wood (used to make the angled cuts for the frame), as shown in *Photo 4*, to set your saw blade height. This should be one-half to two-thirds of the diagonal of the frame side. With the frame in the holding fixture notch, clamp it to the mounting board. If you are working with soft wood, be sure to use clamping pads to protect the frame. Then push the jig through the saw blade, cutting the slot.

You will often see woodworkers just holding the frame in place during this procedure (*Photo 5*), but this is not a good idea. If you feel compelled to do this, at least clamp the first cut to ensure there are no problems (*Photo 6*). Cut slots in all corners by rotating the frame and clamping accordingly. Be sure the same side always faces outward.

As with the dowels, you may decide you wish a contrasting wood spline. Personally, I prefer a dark spline in a light frame rather than the opposite, but this is your choice.

To make the splines, first cut a piece the same thickness as the slot and about ¼″ wider than its depth (*SB* 6/94, p. 42). The grain should be perpendicular to the plane of the joint that is the mating surface. Flatten the bottom of the slot with a thin chisel, if you have one, or a file. Cut the splines about ½″ longer than the slot's longest dimension (*Photo 7*).

Apply glue along the slot's outer edges, so it will spread smoothly onto the faces when you push in the spline. When you place the spline in the slot, be certain it is completely seated against the bottom. Then attach a C-clamp, as shown in *Photo 8*.

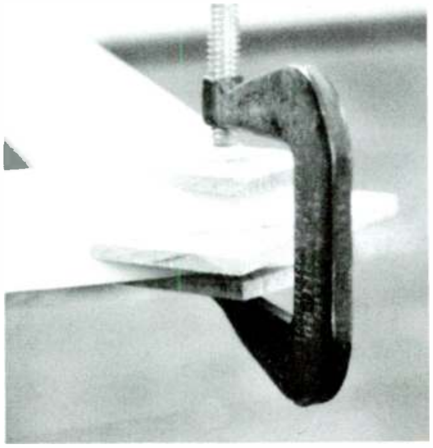


PHOTO 8: Clamping the spline for gluing.

After the glue has dried, use a hand saw to cut off the excess spline and sand it flush (*Photo 9*). The finished corner will look like *Photo 10* if you have used contrasting wood. Otherwise, it will take a practiced eye to notice that a spline is present—if you were attentive to the grain patterns. Again, this is a design decision.

DRESSING UP

With the weak corners reinforced, you can turn your attention to dressing up the frame. The obvious step is to eliminate the boxlike, sharp outer edges. (Don't overlook the possibility of also doing the inside edges.) A quarter-round routing bit offers several choices fo

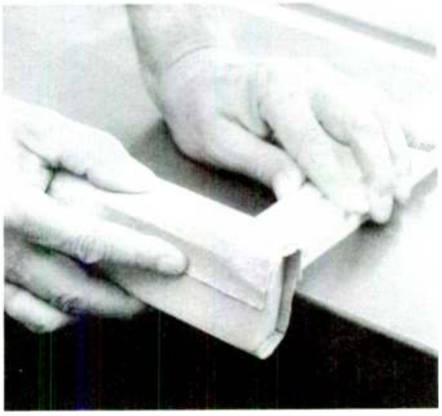


PHOTO 9: Smoothing the spline flush with the frame.

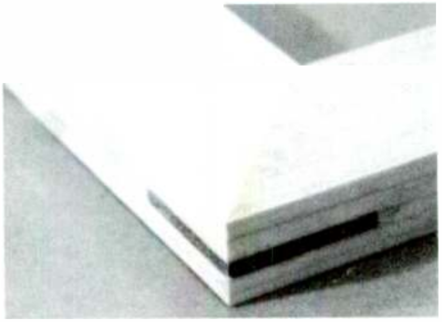


PHOTO 10: Complete spline corner joint.

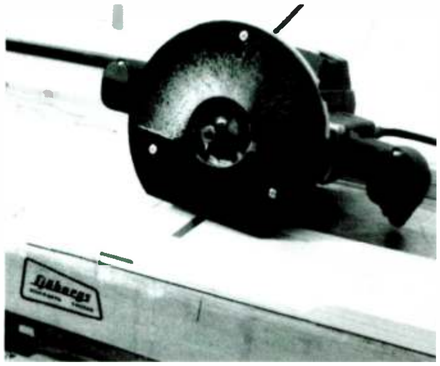


PHOTO 11: Routing the edge of the grille frame for effect. Note the use of scrap wood to provide good support for the router.

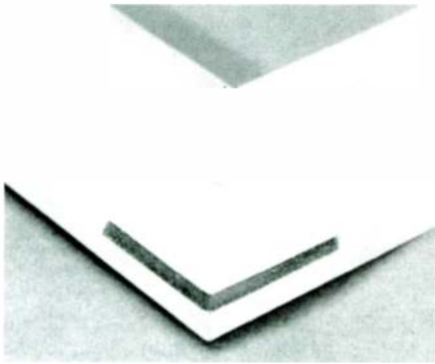


PHOTO 12: Soft rounded edge for the grille frame.

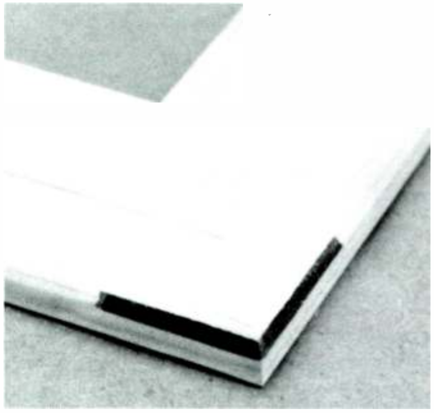


PHOTO 13: Soft-to-hard edge, made by lowering the roundover router bit so the upper edge cuts into the frame.

softening the frame's lines. I have ¼″ and ½″ radius bits with guide bearings. If you wish to remove only the harsh edges, the ¼″ will do the job. You can, in fact, achieve the same results with sandpaper. For a more pronounced effect, you should consider the ½″ radius bit.

Of course, there is no reason to restrict yourself to a simple round overcut. Any decent woodworkers' supply or hardware store tool section will have a number of different profiles. The only limitations are your personal preferences and the frame's thickness.

Regardless of which profile you choose, some pitfalls can cause trouble when you rout the edge of the frame. The dominant one is the width of the frame sides being insufficient to adequately support your router, resulting in a wavy edge. You can easily avoid this by providing a firm extended support for the router's base. I usually lay scrap pieces inside and outside the frame (*Photo 11*).

Take care that the scrap is the same thickness as your frame. If you examine the photos, you will see substantial gouges in my work table. These are the result of using an old-style collet and router. Regardless of the amount of torque I applied to tighten the collet, it was never enough. The bit would creep and produce a big gouge. Happily, newer routers have eliminated this problem.

Simple changes in the way you rout your edge can make rather strong statements. If you just round over the frame, the smooth edge will give your speaker a soft appearance (*Photo 12*). By lowering the cutting, you can completely change this effect, with the soft edge leading into a hard edge, as in *Photo 13*. This leads the eye to the front of the speaker and says "here is where all the work is done."

INLAYS

Another way to dress up the frame is with an inlay, but you must plan ahead. After you have cut the sides, you should decide upon the design. I will explain how to create a very simple frame-within-a-frame pattern, although you can be as elaborate as you wish; the only limitations are time, patience, and the space on your frame.

For this example, simply insert a strip of wood into the face of the grille frame. As with the spline, I like a dark insert in a light wood. To be a bit more expansive, use two or more woods. Some of the more interesting are padauk (dark red), ebony (black), and yellow pine. I chose a cherry inlay for my pine frame.

First, make a groove with a router or your table saw. If you use a router, a high-speed spiral cutting bit (instead of the conventional two-flute mortising bit) will produce an exceptionally smooth groove. Using a table saw is faster but requires some cleanup. Set the depth of cut at ¼″ (this dimension is not critical as long as you are consistent), and space the rip fence so you will cut the groove where you wish on the frame face (*Photo 14*).

Being careful to always have the same edge next to the fence, and the same face down on the table, cut a groove into each of the frame's four pieces. For a wider inlay, reset the fence and make a second round of cuts. Continue until you have the desired pattern. A combination saw blade (such as the Freud LU84) with a square raker tooth will produce flatter-bottomed grooves. You can also use a saw from a dado set. Most of the time you will need to flatten the groove with a chisel or file.

After you have cut the grooves, make the inlay strip. Set the depth of cut of your saw blade about 1/32″ taller than the groove depth, and, from the saw blade edge, set the rip fence exactly as wide as the groove. (An interesting variation is to make the inlay strip thicker than the groove depth for a three-dimensional surface.) Cut slots in four corners of a piece of inlay stock. Make a catch using masking tape, as shown in *Photo 15*.

Set your saw so the inlay strip will be a hair thicker than the depth of the groove (*Photo 15*). The masking tape will "catch"

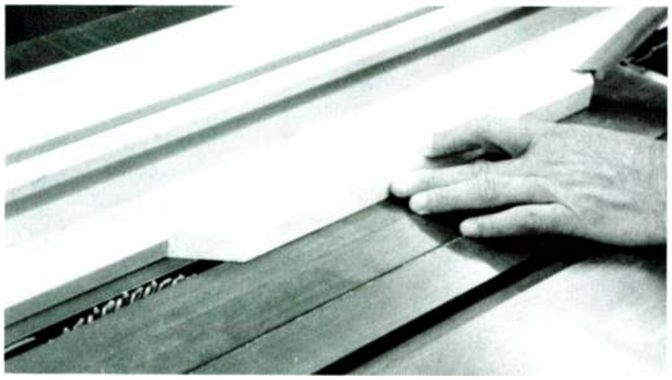


PHOTO 14: Cutting the groove for the inlay strip on a side of the grille frame. This should be done before you assemble the frame.

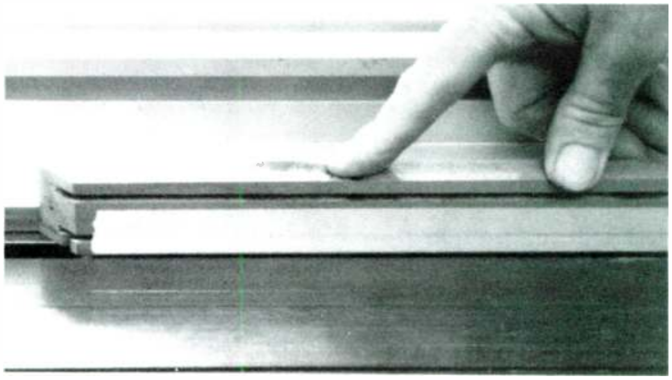


PHOTO 15: Cutting off the inlay strip.

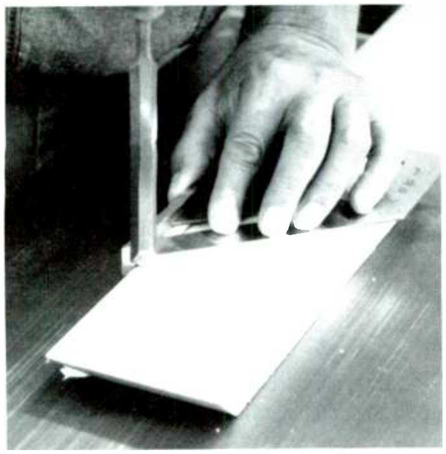


PHOTO 16: Making the first cut for an inlay strip.

PHOTO 17: Marking the other end of an inlay strip. Remove the strip and cut off the excess, as shown in Photo 16.

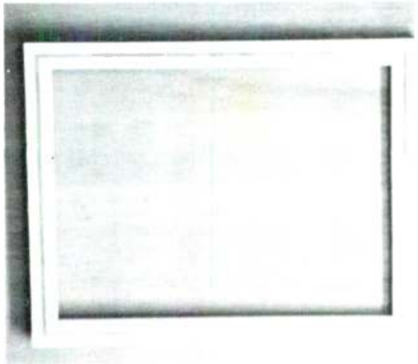


PHOTO 18: Completed grille frame with centered inlay strip.

the strip without exposing your fingers to the blade. You could also use the rip fence as a guide and catcher by setting the strip thickness as the space between the blade and the fence, and cutting the strip next to the fence. However, this is tricky because the cut piece can easily become a projectile.

The first step in fitting the strip into its groove is to cut its end at the frame's corner joint angle. For a rectangular frame this is 45°, and you can use a try square, as in *Photo 16*. Temporarily place the strip into its groove, and, with a chisel, mark where the other end needs to be cut (*Photo 17*). Cut off this end and repeat until you have cut all of the strips.

Finally, glue the strips into their grooves. Be careful not to use too much glue. Place wax paper and a piece of scrap wood over the insert and attach C-clamps every few inches for adequate pressure. After the glue has set, but before it has hardened, scrape off any excess. Then sand the strip flush with the frame, unless it is meant to extend beyond the surface. Our finished frame is shown in *Photo 18*.

As you read these procedures, you no doubt realize that grille frames offer opportunities to make each enclosure uniquely yours. The same techniques can also be used to make picture frames.

SOURCE

Woodworker's Supply
5604 Alameda Place NE
Albuquerque, NM 87113-2100
(800) 645-9292

HIGH PERFORMANCE ELECTRONIC CROSSOVER NETWORKS
THESE COMPONENTS AVAILABLE FULLY ASSEMBLED OR AS KITS

XM9 Crossover Network • 24 dB/octave slope • fourth-order constant-voltage design • Outputs in phase • Low noise • Controls on circuit board or panel • Settable crossover frequency from 20–5,000 Hz.

XM16 Crossover Network • 48 dB/octave slope • Eighth-order constant-voltage design • Outputs in phase • Low noise • Controls on circuit board or panel • Settable crossover frequency from 20–5,000 Hz.

XM9-C and XM16-C Custom Cabinets (for home use) Accommodates 2 or 4 XM9 or XM16 Crossovers and PS10 (or PS15) power supply to make either 2-way or 3-way system. • Buy cabinet only, kit, or fully assembled with circuit boards.

XM9-CA2 and XM9-CA3 Custom Cabinet (for automotive use) Accommodates 2 or 4 XM9 or XM16 Crossovers and PS15 (or PS10) power supply to make either 2-way or 3-way system. • Buy cabinet only, kit, or fully assembled with circuit boards.

PS10 Power Supply (for home use) converts 120 VAC to dual 15 VDC supply • Regulated • Can support 8 crossover networks.

PS15 Power Supply (for automotive use) converts 12 VDC to dual 15 VDC supply • Can support 4 crossover networks.

WM8 "BASSIS" Bass Correction Equalizer extends bass response by 1 to 2 octaves • Adjustable bass boost and damping • Rumble filter • 20 Hz subsonic filter.

PM2 and PM22 Power Amplifier Modules provide 75 watts RMS into 8 ohms • Complementary Darlington output stage • Integrated-circuit driver circuit • Over-current and over-temperature protection • Class A or Class AB operation.

WRITE NOW FOR FREE LITERATURE ABOUT THESE AND OTHER MARCHAND PRODUCTS
SEND YOUR NAME AND ADDRESS TO: MARCHAND ELECTRONICS, INC.
P.O. Box 473 • WEBSTER, NY 14580 • PHONE (716) 872-0980 • FAX (716) 872-1960

Reader Service #28

World Radio History

Ask SB

Joseph D'Appolito
Dick Pierce

SPEAKER SYNERGY

Over the years in *SB* Mailbox (2/85, 4/85, 1/86, 2/86, 3/86, 4/86, and 1/87), Joe D'Appolito has patiently explained how to calculate the performance of double drivers, whether side-by-side or in compound, or connected in series or parallel. Would Mr. D'Appolito entertain perhaps a final question concerning such systems?

Side-by-side, parallel-connected drivers produce twice the SPL that a single driver produces. This is quite understandable: two drivers equal double the SPL of one. This two-driver system, however, also (remarkably) exhibits twice the efficiency (acoustic output power divided by the electrical power) of a single driver. Its acoustic output is four times that of a single driver. Half of this gain comes about because the input power has doubled; the other half occurs because system efficiency has doubled.

This doubling of efficiency was explained in two ways. Small's efficiency equation contains V_{AS} in the numerator. The side-by-side drivers have twice the V_{AS} of one; therefore, the calculated efficiency is doubled. The second explanation cites the fact that two such drivers exhibit not twice, but four times, the radiation resistance of one, which translates into a doubling of efficiency. It's hard to understand how the value of V_{AS} can affect efficiency, whereas it's easy to understand how changes in radiation resistance can. It's clear, however, that these influences are not additive, but are merely a reflection of the same phenomenon. Could Mr. D'Appolito clarify this?

My second question concerns the correct way of combining individual SPLs to get the acoustic sum. The square of SPL is proportional to the acoustic output. It would seem to follow an electrical analogy to first square the individual SPLs and then perform the summation. This order of calculation, however, does not yield an answer consistent with the rest of dual driver performance theory because it shows acoustic power to be only twice that of one. To obtain the correct result, it is necessary to first sum the individual SPLs, and then to square the sum. Could Mr. D'Appolito explain why the second calculation is the correct one?

David J. Meraner
Scotia, NY 12302

P.S. If my calculations are correct, the series and parallel connections offer the same 3dB improvement in efficiency. The parallel connection offers a 6dB improvement in voltage sensitivity, but no improvement in power sensitivity; the series connection offers no improvement in voltage sensitivity, but a 6dB improvement in power sensitivity. From this it would seem that the parallel connection is best in systems with passive filters, whereas the series connection is best in systems with active filters.

Contributing Editor Joseph D'Appolito responds:

Before replying to Mr. Meraner's questions, I'll review the difference between loudspeaker voltage sensitivity, power sensitivity, and efficiency. Loudspeaker voltage sensitivity *is the measure of the sound pressure level (SPL) produced by a loudspeaker in response to an applied* voltage *at the voice coil terminals. It is commonly measured at a distance of 1m with an applied voltage of 2.83V (thus, a typical sensitivity rating is 90dB SPL/2.83V/1m). Voltage sensitivity is independent of loudspeaker impedance.*

Loudspeaker efficiency *is the ratio of acoustic output power to electrical input power. Total acoustic output power is rather tedious to measure. Instead of measuring efficiency directly, a third measure of speaker performance,* power sensitivity, *is normally used. In this method the loudspeaker impedance is assumed to be a pure resis-*

tance equal to the nominal impedance of the speaker or system. Input voltage is then adjusted to the value which would put 1W into this resistor.

Finally, with this input voltage, the SPL at 1m is measured to arrive at a power sensitivity expressed in dB SPL / 1W/1m. Although it is called power sensitivity, this measure is actually a voltage sensitivity normalized to a particular nominal impedance value.

Now we arrive at the first point of confusion. Doubling the input voltage to a loudspeaker doubles the output SPL. Output power is proportional to the square of the output pressure, so output power is quadrupled (the input power has also been quadrupled with a single driver). Both the output power and output pressure, however, increase by 6dB. (Remember, decibels go as 10× log power ratio or 20× log pressure ratio.)

If, on the other hand, we double input power, input voltage increases by only $\sqrt{2}$. *Output pressure goes up by* $\sqrt{2}$, *output power doubles, and both go up by 3dB. To avoid confusion, we must, at all times, keep track of whether we are talking about power or voltage sensitivity.*

Design information, such as alignment charts, for loudspeaker systems assume a single driver. The performance of multiple drivers in a single enclosure is best determined by a careful analysis of the complete electroacoustical system. The purpose of my many earlier letters to which Mr. Meraner refers was to provide SB *readers with simple rules for finding a single "equivalent" driver to represent multiple drivers in the design process. As with all such rules, it is possible to misapply them. Let's examine the many variations of the multiple driver problem and draw some connections between them.*

In terms of fundamental electromechanical parameters, the expression for the half-plane midband efficiency for a single driver is:

$$\eta_o = \frac{\rho_o B^2 l^2 S_D^2}{2\pi c R_E M_{MS}^2} \qquad (1)$$

where:

η_0 = *loudspeaker efficiency (watts out per watt in)*

B = *magnetic flux density in the driver air gap*

l = *length of voice-coil wire in the magnetic field*

R_E = *voice-coil resistance*

S_D = *effective surface area of driver diaphragm*

M_{MS} = *mechanical mass of diaphragm assembly*

ρ_0 = *density of air*

c = *speed of sound in air*

η_o *is dimensionless and normally quoted in percent. Also, driver input impedance is assumed to be resistive and equal to* R_E. Equation (1) *has some intuitive appeal. For example, you would expect a stronger magnetic field to produce more output. You would also expect a heavier cone to be less efficient. Similarly, all things being equal, a larger cone area should radiate more power. I'll say more about* Equation (1) *later.*

Small has shown that the expression for efficiency can be rewritten in terms of the driver resonant frequency, f_S, *driver electrical* Q_{ES}, *and* V_{AS}:

$$\eta_o = \frac{4\pi^2 f_S^3 V_{AS}}{c^3 Q_{ES}} \qquad (2)$$

At first glance, it appears Equation (2) *does not have the intuitive appeal of* Equation (1). V_{AS} *is not a fundamental physical parameter and is certainly not intuitively related to loudspeaker efficiency or sensitivity. It represents the enclosed volume of air which has the same compliance as the driver's suspension system when that air volume is compressed by a piston of the same area as the driver diaphragm.* V_{AS} *is a useful concept because it helps us visualize the range of enclosure volumes in which a particular driver will work well.*

Equation (2) *is very useful because it is written in terms of derived parameters easily obtained with simple electrical measure-*

ments at the voice coil terminals. Both equations are correct, but they represent different views of efficiency. Either equation can explain the operation of multiple drivers, but as Mr. Meraner points out, you cannot double-count by using both.

What about power sensitivity? For typical listening environments a direct relationship exists between radiated acoustic power and SPL. This allows us to express power sensitivity in terms of efficiency:

$$\text{dB SPL}/1\text{W}/1\text{m} = 112.2 + 10\log(\eta_o) \qquad (3)$$

Now we finally get to Mr. Meraner's questions. Two side-by-side drivers mounted on an infinite baffle do *display twice the efficiency of a single driver. Furthermore, if the drivers are identical and we ignore the generally small mutual coupling, their resonant frequencies and electrical Qs are unchanged. These are experimentally observed facts, which can also be demonstrated by a physics-based analysis of the electroacoustical system. It would be convenient if the explanations for this behavior were more simply expressed in terms of the Thiele/Small analysis, with which we are all comfortable.*

In terms of Equation (2), *these facts can only be explained by assuming the equivalent driver has double the* V_{AS} *of a single driver. This assumption comes from the acoustic side of the driver characteristics (*V_{AS} *is an acoustic parameter) and allows us, for example, to correctly compute the resonant frequency of the driver pair in a given enclosure.*

We have two drivers and two diaphragms, so it seems reasonable to assume that the equivalent single driver has twice the cone area and twice the mass. The ratio S_D / M_{MS} *in* Equation (1) *is thus unchanged and we must look to the driver's electrical side when interpreting* Equation (1). *Here we have two options: parallel voice coils or series voice coils.*

I proved the following in a previously published SB *letter (2/86, p. 48): (1) with parallel VCs,* R_E *halves, and Bl is unchanged; (2) with series-connected VCs,* R_E *and Bl both double; and (3)* Q_E *is the same for both connections and the same as that of a single driver. In either case, efficiency is doubled. According to* Equation (1), *efficiency has doubled because motor efficiency,* B^2l^2/R_E, *has doubled either by doubling Bl and* R_E *or halving* R_E, *depending upon the voice coil connection used.*

How do we make Equations (1) *and* (2) *jibe? They seem like very different views of the same phenomenon. The connection is made through the mechanoacoustic transformation between driver mechanical and acoustic parameters. Acoustic parameters are somewhat abstract, but please bear with me. Three equations are needed:*

$$f_S = \tfrac{1}{2}\pi\sqrt{(M_{MS}C_{MS})} \qquad (4)$$

$$C_{AS} = C_{MS}S_D{}^2 \qquad (5)$$

$$V_{AS} = \rho_o c^2 C_{AS} \qquad (6)$$

where:

C_{MS} = *mechanical compliance of suspension*

C_{AS} = *acoustic compliance of suspension*

Now let's try to follow the logic. Equation (4) *indicates that* f_S *is proportional to the inverse square root of the product of mechanical mass and mechanical compliance. If* M_{MS} *has doubled, then* C_{MS} *must halve because* f_S *is unchanged and therefore the product* $M_{MS}C_{MS}$ *cannot change. Now even though* C_{MS} *is halved, the area,* S_D, *is doubled, so by* Equation (5), *the acoustic compliance,* C_{AS}, *must double. Finally,* Equation (6) *reveals that doubling* C_{AS} *doubles* V_{AS}, *and we are back to the conclusion derived from* Equation (2).

Does this result make sense physically? Remember that compliance is the opposite (mathematically, the inverse) of stiffness. If

the mechanical compliance is halved, the stiffness is doubled. This should be clear since two identical cones moving the same distance in the same enclosed volume will compress twice as much air and experience twice the restoring force of a single diaphragm.

Now let's look at sensitivity. The equation for midband sensitivity, S_0, at 1m is:

$$S_o = \frac{\rho_o B l S_D}{2_\pi R_E M_{MS}} \qquad (7)$$

The unit of measurement for S_0 is pressure per volt. Notice that the Bl product is not squared. This ultimately explains why voltage sensitivity and efficiency behave differently. Unfortunately, no useful expression for sensitivity exists exclusively in terms of derived parameters such as Q_{ES}, f_S, and V_{AS}. That is, these parameters are neither needed nor useful in the discussion of voltage sensitivity.

From our earlier discussion, the ratio S_D / M_{MS} is unchanged. In the parallel connection, Bl is constant and R_E halves, so voltage sensitivity doubles (6dB). In the series connection both Bl and R_E double so that S_0 is unchanged. Again, this should make sense physically. If we place two drivers on a baffle and apply the same voltage to each voice coil, i.e., parallel them, we should expect twice the output pressure. Likewise, if we apply the same voltage to the coils in series, each coil receives half the voltage and each driver puts out half the SPL, and the sum is back to the original SPL of a single driver.

Still confused? When measuring voltage sensitivity we apply the same voltage to the voice coil combinations. When measuring power sensitivity we input the same power to each voice coil combination. This means the applied voltage must change by a factor of two between parallel and series connections.

Now we begin to see why the subject is so confusing. A loudspeaker is a complex electro-mechano-acoustic transducer. We can examine it in terms of parameters from three different worlds. We can also examine it in terms of voltage or power response. They can each be made to give the right answer, and we choose the most useful answer or answers for design purposes. All explanations are just different views of the same phenomenon.

Summarizing our results, both the parallel and series connection offer a 3dB improvement in power efficiency and power sensitivity. That is, they both offer 3dB more output with 1W input. But the input voltages for 1W differ by a factor of two because of impedance differences. The parallel connection also offers a 6dB improvement in voltage sensitivity, while in the series connection voltage sensitivity is unchanged.

I have always maintained that loudspeaker voltage sensitivity is the more meaningful specification, since loudspeaker response curves are always run with a constant voltage input. Furthermore, modern amplifiers are voltage sources, so driver voltage sensitivities in multidriver systems must match if the system is to have flat on-axis frequency response. As long as the amplifier can supply the required current, driver impedance is not important and driver input power is not controlled.

Let's now look at Mr. Meraner's question on summing pressure versus summing power. To get the right answer, of course, you must sum the individual pressure contributions from each source first and then square the resulting pressure to get net power. This is true because pressure, like electrical voltage, has both amplitude and phase. A simple example makes this clear.

Suppose we have two drivers on a common baffle. If the voice coils are driven in phase, the pressure from each driver will add to twice the pressure and four times the acoustic power of a single driver. This is a result we have already seen. If we reverse the phase of one driver VC, the net pressure will drop to zero. But if we square and sum the two individual contributions to the total pres-

sure, we will arrive at the erroneous conclusion that acoustic power has been doubled.

No simple physical argument relating radiation resistance to V_{AS} exists. Examining the relationship between efficiency and radiation resistance goes well beyond the Thiele/Small lumped parameter circuit analysis approach to loudspeaker design, and I think I've already bored everyone with too much math so I've chosen not to answer that question.

In his footnote, Mr. Meraner discusses power sensitivity and reaches some surprising conclusions. Since power sensitivity is simply an alternate expression for efficiency, all the conclusions regarding efficiency apply directly to power sensitivity. As stated above, both connections offer a 3dB improvement in power efficiency and, by Equation (3), *a 3dB improvement in power sensitivity, but a 6dB difference in voltage sensitivities. I do not necessarily agree with the conclusions he draws here. Many additional factors enter into the choice of series/parallel connections.*

ONE TEN vs. TWO SIXES

In the Usenet newsgroup *rec.audio.tech*, Farul Ghazali wrote: "What are the advantages of one large woofer versus two smaller ones, for example, a 10" versus two 6½" woofers in a sub? Efficiency? Economics? Space?" Well, the correct answer is: it depends.

The common, simple answer is that since the effective areas of two 6½" woofers are about the same as a single 10" woofer (S_D is about $3.1 \times 10^{-2}m^2$ for the former as opposed to $3.6 \times 10^{-2}m^2$ for the latter, with the 10" being larger by about 20%), they are closely equivalent. But that ignores many other factors. Depending upon those factors and your application, the answer could easily be: "No, they are not the same."

For example, if you designed a cabinet based on a 10" woofer that has a certain compliance, resonant frequency, and Q_T, it is *very* unlikely you'll find a pair of 6½" woofers that even come close to the same V_{AS}, F_S, and Q_{TS}. For example, typical 10" polybutadene surround woofers have an F_S of 20–27Hz, V_{AS} around 100 liters, and a plausible Q_{TS} of about 0.35 (depending upon magnet, voice coil, and so on), whereas a typical 6½" woofer has an F_S of 32–45Hz, a V_{AS} around 28 liters, and a Q_{TS} also around 0.35. So the combined V_{AS} of the two, smaller woofers will, at most, be about half that of a similarly constructed larger model.

A 10" woofer's suspension parts, along with the magnet and voice coil design, usually allow it to move farther linearly, sometimes by 50% or more. That means the excursion limited output of a 10" type at any given frequency can be significantly greater. Also, its heat dissipation properties with its larger voice coil, magnet, wire, and so on, are usually substantially greater than the combined capabilities of two 6½" models.

On the other hand, it's almost always true that the response of a smaller type will be somewhat more extended and smoother at high frequencies. However, that is counterbalanced by the fact that two 6½" woofers subtend a larger effective radiating area, so dispersion along the axis between the two driver centers will be somewhat worse due to interference, and the radiation pattern will not be rotationally symmetric (assuming that's important).

Two 6½" units will fit on a baffle only about 8" wide (including internal bracing, cabinet walls, and the like); a 10" woofer will not, and that may be important. Depending upon panel configuration, 6" holes may or may not result in greater weakening of the baffle than a single 9" hole.

But I can reduce all of this to some simple answers (but not one answer): for many applications, these two types could be equivalent. For raw power output and low-frequency extension, a well-designed 10" model usually beats out two well-designed 6½" woofers by a noticeable margin, assuming you design the cabinet accordingly. For small cabinets, two smaller units would probably work better than a single larger one.

As far as your other considerations are concerned, there are no clear-cut answers. Generally, the economics of a single 10" woofer (all other things being as equal as possible) are less favorable, but usually not by much. Typically, you can expect to pay roughly as the square of the diameter, but many other factors can come into play, and trying to make an economic comparison between the two choices includes completely nontechnical factors such as manufacturing overhead, cost and profit structure, advertising, import duty and shipping, and so on. More variables contribute to efficiency than simple diameter, so again a direct comparison is not possible.

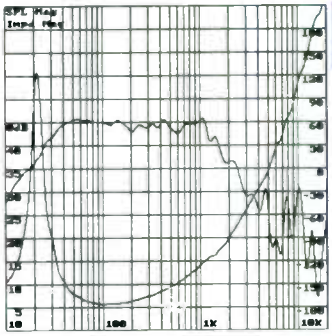
All this is not to say that a given manufacturer made a bad decision by choosing one implementation over another. Many factors—technical, economic, philosophical, and so on—lead to one decision or another. It's also possible for a manufacturer to have a woofer custom-designed, which can relieve some of the constraints many of us have when dealing with off-the-shelf components.

But the answer *still* is: it depends.

Dick Pierce
Contributing Editor

PC AudioLab

...Finally, a complete low cost PC based measurement solution for all of your loudspeaker and audio measurements. Use your home/office computer and the CD quality 16 bit sound cards from Media Vision or Soundblaster to actually measure the performance of your loudspeakers, electronics and crossovers. VERSION 2.0 now available!



PRODUCT HIGHLIGHTS

- OSCILLOSCOPE
- SPECTRUM ANALYZER
- NETWORK ANALYZER
- DISTORTION ANALYZER
- LOUDSPEAKER ANALYZER
- IMPULSE ANALYZER
- ROOM ACOUSTICS ANALYZER

SYSTEM REQUIREMENTS:
- 386/486 IBM AT compatible
- 4 Mb RAM memory
- Math Coprocessor
- VGA Graphics Display
- Media Vision or SoundBlaster 16 bit sound card

- DETAILED MANUAL
- TEST CABLES
- GRAPHICAL USER INTERFACE
- PRINTER OUTPUT SUPPORT
- MOUSE SUPPORT
- EXPORT/IMPORT FILES
- $300 VISA/MC/MONEY ORDER

MICROACOUSTICS
AUDIO SOFTWARE PRODUCTS

2553 CARPENTER ST, THOUSAND OAKS, CA. 91362 (805) 495-8945 PHONE/FAX

Reader Service #20

MCM AUDIO SELECT™

High Performance Plus, Attractive Price

FREE CATALOG

MCM ELECTRONICS®

Rubber Surround Poly Woofer Series

MCM Audio Select's Rubber Surround Poly Woofer Series offers the most asked for features at a price that is truly unbeatable. Their unique design offers tight, punchy bass along with excellent moisture and humidity resistance. This design is great for band pass and closed box enclosures.

Get complete details, call MCM Electronics today. Whether you are speaker building or upgrading, our free catalog is an indispensable tool. It's packed with hundreds of accessories from names you know: AMS, Pyle, Eminence, Pioneer, Electrovoice, MCM Audio Select and others. In addition, there's MCM's complete line of electronic components, repair parts, tools, test equipment and more. Over 21,000 products in all, are in stock and ready to ship. Call for your free catalog today.

For a FREE Catalog, Call...
1-800-543-4330
Product Questions 1-800-824-TECH(8324)
New hours: M-F 7 a.m.- 9 p.m., Sat. 9 a.m.- 6 p.m. EST.

mcm
MCM ELECTRONICS℠
650 CONGRESS PARK DR.
CENTERVILLE, OH 45459-4072
A PREMIER Company

Serving you coast to coast! Distribution Facilities in Dayton, OH and Reno, NV! SB 20

Reader Service #11

World Radio History

SB *Mailbox*

RECIPE REMARKS

I would like to comment on Richard Campbell's review of *Loudspeaker Recipes, Book One*, which appeared in *SB* 5/94 (p. 53). First, my thanks to Mr. Campbell for his many kind remarks concerning my latest effort. The book was several years in production, and, as he noted, profusely illustrated with nearly 400 graphs explaining four loudspeaker designs. It was conceived, however, as two books in one.

While it is without question a kit book, with four professionally executed designs for the home builder to duplicate, *Recipes* is also a collection of exercises to demonstrate some of the finer points of computer-aided loudspeaker system design. Each design purposely represents a very different set of problems relating to interdriver time delay. As such, each presents a different solution in which the crossover and overall system design are manipulated to compensate for this factor and still achieve a flat-summed response on- and off-axis. I agree with Mr. Campbell's dislike of misinformation and misleading statements in print, and for this reason I wish to clarify some apparent confusion about certain statements made in the book.

1. Radians versus hertz for creating excursion curves. Mr. Campbell aptly points out that to correctly scale a calibrated accelerometer when mathematically converting acceleration to excursion, the data should be divided by radian frequency. I state in the book that dividing by frequency twice will produce the conversion.

Since the accelerometer in my example is not calibrated, the choice of dividing twice by hertz or radians isn't relevant, and I don't bother explaining the difference. If we wish to nitpick, however, the data is indeed divided by radians twice. With an uncalibrated device, though, the result will look the same with either hertz or radians—just scaled differently.

2. Measured versus calculated phase. Because the book's underlying theme is real-world computer-aided design application, I must qualify certain aspects of the required data collection. Although Mr. Campbell does not mention it, the computer simulations are within approximately 0.5–1dB of the actual measured prototypes. For this to occur, the LEAP software requires accuracy not only of frequency response and impedance magnitude data but of interdriver delay and phase information as well. These elements are equally important for accurate predictions of high- and low-pass summations.

The issue of whether calculated phase is as accurate (or, as I have implied, more so) than measured phase from FFT analyzers used in nonanechoic environments is not "nonsense." LEAP/LMS calculated phase is as correct as measured phase generated from whatever type of test instrument, FFT, or sine wave in whatever measurement environment. The reason for this is entirely pragmatic, and the conclusion is the result of empirical evidence.

Figure 1 shows the comparison between the measured system response of a fairly complex three-way speaker crossed over at 300Hz and 3kHz and the computer simulation using the LEAP calculated phase. The simulation summations in the two crossover regions agree within less than 1dB with the measured prototype. Obviously, if the calculated phase were even slightly inaccurate (even if it were not identical to a measured phase response), the comparison would not be as close or the crossover simulation process possible.

In fact, this point is made repeatedly, as all of the computer simulations—each using calculated phase—show the same close correlation with the measured prototype. Without question, the "phony" phase data generated by LEAP/LMS (which, as I stated in the book, is not simply a Hilbert transform) would by implication be as accurate and useful as measured phase.

Is calculated phase better than measured phase? My concern with accuracy applies mostly to computer simulations of loudspeaker crossovers, which I use frequently in connection with my books and my consulting business. It was not the purpose of *Recipes* to discuss the various application details of different analyzers for computer-aided crossover design, so I considered it beyond the scope of what I intended to cover and devoted only about a paragraph to the subject. In retrospect, I should have used the word "difficult" rather than "semi-accurate."

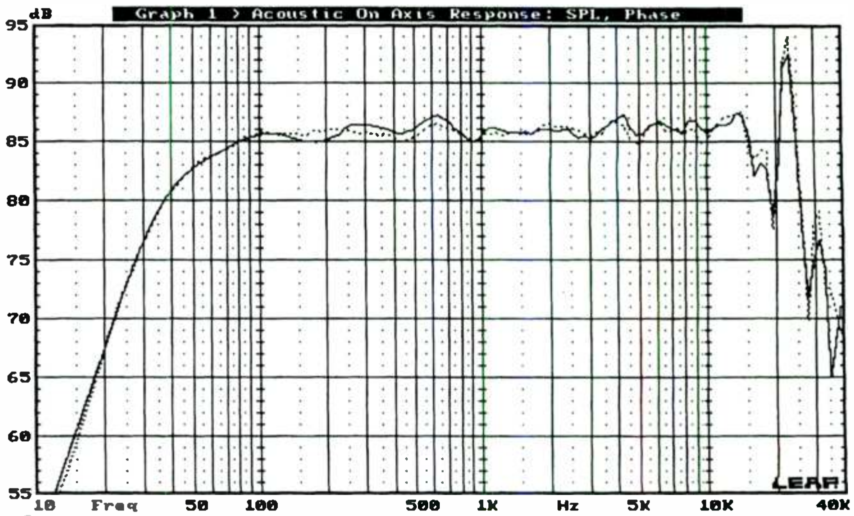


FIGURE 1: Comparison of three-way simulation using calculated phase (dot) and measured prototype response (solid).

For example, a test comparison at the 1992 AES Convention in San Francisco conducted by the Technical Committee on Transducers used several different types of analyzers (the DRA Labs MLSSA, the Techron TEF 20, the Brüel and Kjaer 2012, and the LMS) to measure the same speaker and microphone in the same limited acoustic environment, comparing frequency SPL and phase and impedance magnitude and phase. I published the results in the November 1992 issue of *Voice Coil.*

The measured system phase generated by the three FFT analyzers (MLSSA, TEF 20, and B&K 2012) was literally all over the map and showed no agreement whatsoever. In fact, the only appropriate system phase appeared to be the "phony" one generated by the LMS analyzer software. Having consider-

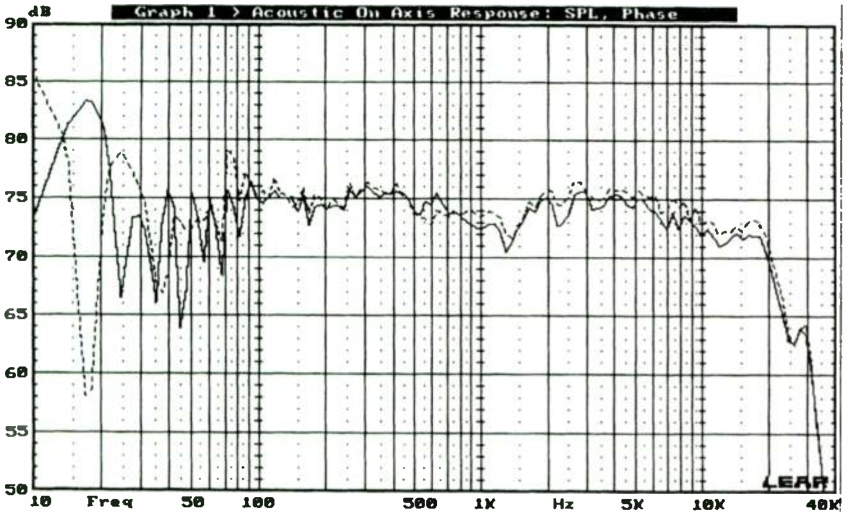


FIGURE 2: Comparison of two-way simulation using measured phase (dot) and measured prototype response (solid).

able faith in the abilities of the equipment testers, I cannot write off the results as operator error. I believe that phase measurement, while not particularly easy to obtain with FFT analyzers, is not impossible.

As further proof, I did a crossover simulation for a simple two-way design using MLSSA SPL and impedance data imported into LEAP, and compared the result to the measured prototype using the network values generated by that simulation. *Figure 2* shows the comparison. (The MLSSA SPL data has a 32,768 acquisition length and 32,768-point FFT.) I collected this data using the ground-plane measurement technique to obtain a full-range anechoic response. (Splicing a ground-plane for the lower frequencies and a truncated anechoic response for the upper ones can be accomplished with MLSSA, but the phase response will not be preserved.)

With 40kHz-wide bandwidths, which are normal for LEAP-generated crossover designs, MLSSA cannot provide accurate low-frequency data. This explains the unusable response profile below 100Hz. The MLS stimulus, like white noise, drops in amplitude about 10dB/decade from high to low frequencies. When wide-bandwidth measurements are attempted, the lower frequencies fall into the noise floor of the hardware and low-frequency SPL and phase data cannot be discerned.

Obviously, the measured phase throughout the crossover region is moderately accurate, since the comparison is fairly close (within 1-2dB) in the summation region centered on the 2.5kHz crossover frequency. *Figure 3* shows the comparison between LMS-calculated and MLSSA-measured phase responses of a Scan-Speak D2905 tweeter without the crossover network in place. Although the responses in the crossover region are fairly close, I would be suspicious of MLSSA phase data that shows the upper-frequency phase going to nearly 0° above 3kHz and continuing out to 30kHz at 0° accompanied by a moderately flat magnitude response. A 5kHz crossover frequency would probably not have produced as accurate a simulation.

Continued on page 59

SPICE FOR CIRCUITS AND ELECTRONICS USING PSPICE — BKPH6 — $33.95

Muhammad H. Rashid

This easy-to-read-and-follow text thoroughly and quickly introduces the reader to the SPICE simulator and its outstanding capabilities for analyzing electrical and electronic circuits. Examples of everything from passive circuits to those with active devices are provided herein. Rashid carefully describes simulation techniques and then covers the application of various SPICE commands. The circuit examples cited are those commonly used in basic circuits and electronics courses. Over 170 detailed figures. 1990, 240pp., 7 × 9¼, softbound.

TROUBLESHOOTING & REPAIRING COMPACT DISC PLAYERS — BKT20 — $24.95

Homer L. Davidson

Now updated to cover the latest compact disc player makes and models, this second edition puts at your fingertips the practical service data you need to solve even the toughest problems in today's CD players quickly and easily. Whether you're an electronics student or a practicing technician, this book will prove an invaluable hands-on guide. Beginning with basic CD player principles and ending with schematic diagrams—straight from more than eleven different manufacturers—this heavily illustrated reference shows you exactly how to remove and replace defective laser heads; troubleshoot and replace low-voltage power supply circuits; service signal circuits with a scope; repair servo systems; locate and replace defective slide, load, and disc motors; build an infrared tester; troubleshoot and replace defective audio circuits; and much more!

BENCHWORK — BKDE5 — $23.95

Robert G. Dixon

This textbook is designed to provide a basic understanding of the tools and procedures of applied benchwork related to the machine trades. Step-by-step instructions are augmented by photos, drawings, and charts, as well as safety precautions highlighted throughout the text. The book's five sections are Introduction to Practical Benchwork, including basics, materials, and fasteners; Measurement Systems, Tools, and Fitting, including units of measure, measuring tools and gages, and tolerances and fits; Layout Principles, including nonprecision, semiprecision, and precision tools; Hand Tools, including assembly tools, arbor and shop presses, chisels, files, drills, reamers, saws, taps, and dies; and Power Tools, including hand drills and grinders, saws, grinders, and special tools and procedures. 1981, 211pp., 7¾ × 10¼, softbound.

THE ULTIMATE HI-FI TEST PACK 2-CD SET — CDCAD2 — $54.95

CAD Music

NEW FROM SWEDEN! These great new "gold" CDs represent the latest effort from CAD Music, one of Scandinavia's rising stars of audio precision. Produced by Clark A. Valleystream, René Corona, and Jimmy Z. 1994; two discs; CAD Music Ref. #003/1,2; 104:58. 15-page booklet in English and Swedish. Not to be confused with *The Ultimate Test CD* by Woodford Music (not carried by Old Colony). Some extremely dynamic signals—caution advised.

Contents: CD #1—[1] Grand gong, 0:19. [2] Guitar stack in cathedral, 1:31. [3] Sopranino (recorder)/Korean song, 0:40. [4] Baroque flute, "Moon Over Ruined Castle" (Taki), 0:56. [5] Baroque flute, Japanese folksong (Sakura), 0:49. [6] Ancient Chinese folksong, 0:47. [7] Ancient Chinese folksong, 0:48. [8] Flute, "Du Går Icke Ensam" (Almqvist), 1:31. [9] Rock ballad, guitar mix, 6:13. [10]-[16] Classic guitar, stereo; mono; +6dB 125Hz, 250Hz, 500Hz, 1kHz, 3kHz; each approx. 0:49. [17]-[23] Classic vocal, stereo; +6dB 125Hz, 250Hz, 500Hz, 1kHz, 3kHz; reverse; each approx. 0:34. [24]-[27] Classic vocal 2, stereo (dummyhead); mono; L; R; each approx. 0:34. [28] Guitar stack in warehouse, 2:37. [29]-[32] Tom tom roll, stereo; mono; L; R; each approx. 0:07. [33] Tam tam tam test [tom toms], 2:12. [34]-[40] Dynamic tom toms, stereo; mono; 500Hz highpass; 500Hz lowpass; 1kHz highpass; 1kHz lowpass; reverse. [41] Autobahn, 3:40. [42] Autobahn, reverse edit, 2:17. [43] Golf swing, 0:34. [44] Stream, 1:04. [45] Airport (takeoff), 4:01. [46] Silence, 1:03. [47]-[56] 1/3-Octave band noise, left channel -20dB, right channel -16dB (On-Off); L 25Hz, 31.5Hz, 40Hz, R 31.5Hz; L 50, 63, 80, R 63; L 100, 125, 160, R 125; L 200, 250, 315, R 250; L 400, 500, 630, R 500; L 800, 1kHz, 1.25kHz, R 1kHz; L 1.6, 2, 2.5, R 2; L 3.15, 4, 5, R 4; L 6.3, 8, 10, R 8; L 12.5, 16, R 16. BONUS TRACKS from #CDCAD1, CAD Audio Reference Disc: [57] Splash in the wilderness, 1:55. [58] Splash in the wilderness (reverse), 1:55. [59] Rain and rolling thunder, 1:56. [60] Dramatic movie magic, 3:40.

CD #2—[1] The ultimate demo ("Say aaah!"), 4:31. [2] Techno blaster, 2:10. [3] Fritz intro, 2:02. [4] Deep soft slow, 4:36. [5] Reggae groove, 1:35. [6] House groove, 1:33. [7] 3-D surround power, 1:00. [8] 3-D 360-degree spin beat, 1:10. [9] Bass blip I, 0:33. [10] Bass blip II, 0:31. [11] L vs. R, 1:35. [12] Phase out, 0:59. [13] Frequency sweep (1kHz, 5Hz-22kHz), 1:12. [14] Pink noise -20dB, L 0:30, R 0:30, both 1:00. [15] White noise 0dB, 2:06. [16]-[18] Master calibration, L 0:15, R 0:15, both 1:00, 1kHz, 10kHz, 100Hz. [19] Sine wave 1000Hz L-R check, 0:34. [20] Sine wave 1000Hz reference level, 0:35. [21]-[24] Frequency check, each approx. 0:15; 20Hz, 32, 40, 64; 120, 280, 420, 640; 800, 1.2kHz, 2.8, 5.0; 7.5, 12, 15, 20kHz. [25] 1000Hz toneburst (EIJ) 0dB, 0:33. [26] 1000Hz toneburst (EIAJ) 0dB, 0:37. [27] SMPTE code 25 fps, starts at 00:59:55:00, 8:16. [28] Pulsive signal (0dB 40ms 7 sec. +/-20% × 4), 0:32. [29] Impulse I (0dB 100ms +/-20% random × 256), 0:34. [30] Impulse II (0dB 4 sec. +/-20% random × 8), 0:28.

BOOKS AND MORE!

OLD COLONY SOUND LAB

PIANO TUNING — BKD12 — $4.95

J. Cree Fischer

This is the clearest and most complete book available for beginning tuners and amateur pianists. It explains all the basic processes practically and with model clarity, and even a nonmusician can use it without too much difficulty. You will learn how upright, grand, and square actions work, and how to take care of most small repairs such as repairing stuck keys, poorly adjusted bottoms and capstans, crowded back checks, felts and leather on the hammers, hammer stems; softening damper and hammer felts; installing new bridles; and eliminating "sympathetic rattles." This book teaches a professional method of tuning based on slightly flattened fifths—where only the octave and the upward fifth intervals are used—a method especially suitable for amateurs working without a teacher. If you want to experiment with tuning a piano, there is no better book to start with, and those who want to know how pianos work will find this unique volume both clear and useful. 1907, 1975, 201pp., 5⅜ × 8, softbound.

BASSBOX 5.0 SOFTWARE FOR WINDOWS — SOF-BAS1B3G — $99.00

Harris Technologies

BassBox 5.0 is a great program that aids in the design of bass loudspeaker enclosures in two ways. First, it models how a speaker will sound in a variety of boxes. This small-signal analysis includes the amplitude (frequency response) and voice coil impedance response. Second, it models the maximum loudness of the loudspeaker/box combination. This large-signal analysis includes the displacement-limited maximum power response. Once these tools help you to decide what size and type of box to use, BassBox will then help you calculate the dimensions of its port, if the design is vented, and the box itself.

Other features include: multiple graph overlay capability for easy on-screen comparison; examination of one speaker in several different boxes or several different speakers in the same box; 1000-driver database which can be searched, edited, or added to; acceptance of both Thiele/Small (T/S) and electromechanical (E-M) parameters; allowance for damping specification; manual override of vented box tuning and QL; design capabilities for multiple-vented boxes, custom passive radiator boxes, and both "optimum" and custom closed boxes; multiple woofer designs including standard, push-pull, and compound (isobaric) acoustical parameters as well as parallel, series, and series-parallel electrical parameters; box dimension calculator accommodating many different volume shapes in a 20-volume database; English or metric units; and print capability by most printers supported under Windows 3.1 and later.

System requirements: Windows 3.1+; DOS 5.0+ recommended; IBM 386SX+ or compatible; 4Mb RAM; mouse; 4Mb hard disk space (cannot be run from floppy). Easy-to-use printed manual. Also available:

SOF-BAS1B3G/X	BassBox 5.0 plus Xover 2.0 (see next page), at a savings of $10!	**$118.00**

OLD COLONY SOUND LAB
PO Box 243, Department B95
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, Discover, 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

BOOKS AND MORE!

XOVER 2.0 SOF-XOV1B3G
SOFTWARE FOR WINDOWS $29.00

Harris Technologies

This package helps in the design of 2-way and 3-way passive dividing networks, as well as simple load-compensating circuits, and calculates the component values for many common first-, second-, third-, and fourth-order networks. Two-way designs include Bessel, Butterworth, Chebychev, Gaussian, Legendre, Linear-Phase, and Linkwitz-Riley, while 3-ways include 3- and 3.4-octave spreads between crossover frequencies. Other features include design capability for load-compensating circuits such as L-pads, series notch filters, and loudspeaker impedance equalization networks; circuit diagrams with component lists that can be displayed and/or printed; and a new filter for first-order 2-way networks, "Solen Split -6dB," in which the high-pass and low-pass halves of the network have Butterworth slopes and are set farther apart so that they cross at approximately -6dB (versus the usual -3dB).

System requirements: Windows 3.1+; DOS 5.0+ recommended; IBM 386SX+ or compatible; at least 2Mb RAM (4Mb recommended); mouse; 1.5Mb hard disk space. Easy-to-use printed manual.

THE SEARCH FOR MUSICAL ECSTASY & THE ARCHAIC AURAL REVIVAL BKIM1 $24.95

Harvey "Gizmo" Rosenberg

This is a bizarre book. Then again, it has a bizarre author. Founder of New York Audio Laboratories, gadfly, guru of all aural and musical, prolifician *sans pareil*—these are just a few of the labels that could be pinned on Harvey Rosenberg, if you could catch up with him and keep him still in the first place. This new book is hard to describe—other than to say that it will surely be a classic—but let us say that it is one very sensitive, knowledgeable, fearless, experienced audiophile's wacky yet brilliant ramblings about his life, your life, and about a thousand other things—all infused and intertwined with an iconoclastic respect and reverence for beautiful sound and beautiful sound technology.

If you like tubes, you'll love this book. If you love music, you'll treasure it. If you treasure weird, one-of-a-kind things, you'll sleep with this under your pillow. But it IS hard to describe. Parts include "My Search for the Audio Grail" and "Tweaking Ecstasy." Among the chapter titles are "Celebrating the Tribe of Audioxtasists" and "Speakering Down Untrodden Paths." One subtitle is "I Was A Teenage Mutant Audio Nerd." As Ken Kessler of *Hi-Fi News & Record Review* has written about Rosenberg's "crazed musings," "He sees music as an aphrodisiac, musical ecstasy a measure of one's development, a yardstick of maturity. Rosenberg overturns the standard values, telling us that sheer realism and total accuracy are not the final goals. The goal is musical ecstasy. Nearly all that has been written about hi-fi has been of the 'what' and 'how' variety. *The Search for Musical Ecstasy* tells us *why*."

So there you have it. This book is not for everybody, but it most certainly would be enjoyed by anybody who cares enough about quality audio to find himself reading these words. It's Julius Futterman Gets Yippie-ized. It's The Zenmeister Meets Tubezilla. Or something like that—we're still not sure. But this book should be yours—it imparts rare knowledge and makes for great fun. 1994, 350pp., 6 x 8½, spiralbound.

ELECTROACOUSTICAL REFERENCE DATA BKVN8

John M. Eargle **$59.95**

This valuable handbook offers a comprehensive collection of electroacoustical reference materials and design data—all presented in a clear and consistent graphic format that makes solving routine electroacoustical problems quick and easy. For each entry, graphical data is presented on the right-hand page, with corresponding text, examples, and references appearing on the left-hand page. Also included are sample problems with their solutions, and a convenient index that helps you to identify specific graphs and their relationships to the particular problem or project your are working on. Areas covered include: general acoustics; loudspeakers; microphones; signal transmission; psychoacoustics; musical instruments; and magnetic recording. 1994, 378pp., 8¾ x 11¼, hardbound.

BEST OF DEMONSTRATION TEST CD, VOLUME 1 CDPV5

Disques Pierre Verany **$16.95**

As the liner notes say, "These recordings were all made in natural surroundings, whether it be in the open air, in churches, or in concert halls. Our aim is to try to breathe a little human warmth into the icy indifference of electronics, and to let the sound and the music speak for themselves in all their naturalness and fullness. We shall be absolutely delighted, therefore, if the listener's initial curiosity gives way to pleasure and emotion."

Contents: [1] Nightingales, 2:51. [2] L'Epee music box, 1:56. [3] Arrival of the steam train, 1:04. [4] "Gilardenghi" barrel orchestrion, 1:03. [5] Fireworks, 3:57. [6] Indian harp and organ, 2:30. [7] Big band Charleston, 3:10. [8] Tangos for two harpsichords, 4:53. [9] Percussion, 5:50. [10] Acoustical jazz, 5:19. [11] Symphonic orchestra, 4:29. [12] Russian Orthodox choirs, 3:05. [13] Steinway classical piano, 3:29. [14] Piano and chamber orchestra, 3:28. [15] Maurice Bourgue Wind Ensemble plays Mozart, 3:20. [16] Original Instrument Orchestra, 1:59. [17] Early music, 2:17. [18] Great lyrics, Pelléas and Mélisande (DeBussy), 6:01. [19] Symphonic orchestra, 2:54. [20] Great organs, 5:22. Eight-page French/English booklet.

THE MAGIC OF INTERACTIVE ENTERTAINMENT (WITH CD ROM) BKS52 $39.95

Mike Morrison

This blockbuster package, which includes a CD ROM as well as 3-D viewing glasses, takes a close look at hardware and software developments in numerous areas—from the text-based adventures of a decade ago to today's CD games with real-time video images. Thanks to the inside scoop from developers and employees of the hottest companies in the industry, the author and his technical editor (Johnny Wilson, Editor, *Computer Gaming World*) are able to explain the entire interactive field, what's hot now, and the future in interactive television, multimedia, edutainment, and games on all systems. Also fascinating is how they follow the creation of software titles from the initial concept through testing, marketing, and final release. In addition to the complete retail versions of VistaPro 1 (IBM PC) and Distant Suns (PC/Mac) from Virtual Reality Labs (a $100+ value alone!), the CD ROM also contains more than 80 playable test flights of PC and Mac software, including Return to Zork; My First Atlas; Total Distortion; Aladdin and the Wonderful Lamp; Rock, Rap 'n' Roll; and Mech Warriors 2.

System requirements (in addition to CD ROM drive): Windows—386+, Windows 3.1+, 2Mb RAM, Windows-compatible mouse, VGA graphics minimum; 4Mb RAM, Windows-compatible sound card and speakers, SVGA (256-color) recommended. DOS—286+, 12MHz+, DOS 5.0+, 1Mb RAM, VGA minimum; 386+, 2Mb RAM, compatible sound card and speakers recommended. Mac—LC, II series, or better; 12-inch or larger color monitor; System 6+; 2Mb+ RAM minimum; System 7, 4Mb RAM recommended. 1994, 325pp., 11 x 8⅜, softbound, CD ROM included. Weighing in at more than three pounds, this is one of the best book bargains we have seen in years!

VINTAGE HI-FI VIDEO: THE GOLDEN ERA, 1947-1965 VDVHFP1 $29.95

Vintage Hi-Fi Productions

Divided into two segments, "Mono: 1947-57" and "Stereo: 1958- 65," this nostalgic masterpiece is subtitled, "The Story of Classic American Tube Hi-Fi from Post-War to the Mid-Sixties." Included are more than 65 amps, preamps, tuners, and turntables (plus one speaker, the Stephens 106AX), created by such venerable names as Altec, Fisher, McIntosh, Scott, Dynaco, and Marantz. A worthwhile addition to any video collection! 1994, VHS, NTSC, color, 34:00.

CANARE F-10 RCA PLUGS SCF10G

Canare Cable **Each $3.95**

As reviewed by Gary Galo on pages 42-43 in *Speaker Builder* 4/94, these popular new connectors are made by a performance-oriented company previously best known to audio professionals. To quote Galo: "The F-10 RCA plug is a rugged, gold-plated connector. The gold plating is extremely high quality, applied directly on brass. The best news is the insulator—pure Teflon TFE. The Canare F-10 connectors are the most economical Teflon-insulated RCA connector made, (comparing) favorably with high-end audio types costing several times as much..."

OLD COLONY SOUND LAB
PO Box 243, Department B95
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, Discover, 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

Continued from page 56

Still, this simulation using the FFT-measured phase data is definitely not as close as I normally get to the measured prototype response with the LEAP/LMS-calculated phase process (which, incidentally, can be applied to MLS data). In this case, I would definitely say that the "phony" calculated phase based on the assumption that individual transducers are minimum-phase devices, which Mr. Campbell says may not be true, is in fact more useful than the so-called real thing generated from truncated-data linear-point time/frequency measurement systems.

I have a good deal of experience with FFT analyzers and use MLSSA, TEF 20, Ariel SYSid, and Audio Precision DSP-based System 1 in my work, so I can't be accused of being a hard-core sine-wave advocate defending the old guard. Nor is it my chosen mission in life to bash FFT analyzers, especially since I find them to be valuable instruments. In my opinion, however, the LEAP/LMS calculated-phase methodology makes it considerably easier to reliably obtain accurate phase data than does measured phase from FFT analyzers. It is also preferable in nonanechoic circumstances (I don't have a chamber), for computer design of loudspeaker crossovers, or for any other purpose.

3. Box drawings and network layout dia-

Speaker Builder

BACK ISSUES

1981 A Testing Unit for Speaker Parameters • Variable-Volume Enclosure • Thiele/Small Theory, Pt 1-3 • Easy to Make Enclosure Using Concrete Blocks • The Tractrix Horn: Good Dispersion From an Old Design • Diffuser Port for Small Boxes • Mini-Speaker Made From PVC Tubes • Closed vs. Vented Box Efficiency • Interview with P.G.A.H. Voigt • Dual 8" Symmetrical Air Friction Enclosure • Thiele/Small Calculator Computation • Thiele/Small Parameters for Passive Radiators •

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

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

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

1985 OUT OF PRINT, some single issues still available at $7 each •

1986 The Edgar Midrange Horn • Sand-Filled Stands • Crossover Networks: Passive and Active • 5-sided Boxes • A 2 x 4 Transmission Line • The Free-Volume Subwoofer • Notch Filters • By-Wiring the LS3/5A • A Push/Pull Constant Pressure System • Current and Power in Crossover Components • The Unbox (Egg) • Upgrade Speakerlab's S-6 Crossover • Measure Speakers with Step Response • A Gold Ribbon System • A Visit with Ken Kantor • A Tractrix Horn Design Program • Reviews: Audio Concepts "G"; Seven TL Midranges; Focal's Model 280; the Audio Source RTA-ONE.

1987 A Compact TL Woofer • Frequency Response and Loudspeaker Modeling, Pt 1-3 • A Manual Coil Winder • The Model-One Speaker • Designing a Listening Room • A Sixth-Order Vented Woofer • Tapered Pipe Experiments • Visiting Boston Acoustics • A Vented Compound System • The Octaline • Spreadsheets for Speaker Design • In Memoriam: Richard Heyser, Pt 1-2 • Using Non-Optimum Vented Boxes • Building Speaker Stands • Evaluating Driver Impedance Compensation • Tuning Bass Reflex • Six Woofers Compared • Bullock on Passive Crossovers: Alternate Bandpass Types • Fast, Easy Filter Calculations • A Mobile Speaker • Polk 10 Mod •

1988 Electronic Turns Counter • Two-Way Design • Minimus-7 Mod • Dome/Midrange/Tweeter Array • Plotting Complex Impedances • A Driver Design Primer • A Cabinet Primer • Tuning Up Old Systems • Low-Cost AR-3 Upgrade • Electronic Time Delay • Enclosures Shapes and Volumes • Minimum-Phase Crossovers • Spot Sound Absorbers • How to Add a Subwoofer • The Swan IV System • Sub-Bass Power Boosting • The Unline: A Short TL • Active Filter Computer Design Program • Low-Cost Two-Way Ribbon • Amp-Speaker Interface Tester and Construction Plans • The QB_3 Vented Box is Best • A Pentagonal Box System • Keith Johnson Profile • Sheathed Conductor ESL • A Symmetrically Loaded System, Pt 1 • Ceramic Enclosure • Inductance Measuring Technique • Polk 10 Mods •

1989 (4 Issue Set: VERY LOW STOCK) The Audio Laboratory Speaker System • A Passively Assisted Woofer • Digital Filter Tutorial • The Listening Arc Alignment • Small IC Power Amp & Crossover • Easy Surround Sound • Building Speaker Spikes • An Isobarik in a Thunderbird • Sheetrock Cabinetry • A Picket Speaker • Servo-Controlling AR-1 • Silent, Safe Muting System • Equalizing the Klipsch Cornwall • A Test Switcher • Visiting the Klipsch Kingdom • Rehab for Kitchen Music • Spreadsheet Design • A Subwoofer/Satellite System • Impedance Measurement as a Tool • Practical Passive Radiators • A Symmetrical Dual Transmission Line, Pt 1 • The Microline • A Voice Coil Wheatstone Bridge • Tweeter Q Problems •

1990 Acceleration Feedback System • Cylindrical Symmetrical Guitar TLs • Compact Integrated Electrostatic TL, Pt 1-3 • Minimus-7 Super Mod • The Show (Bass Horn) • A Small Two-Way System • Helmholtz Spreadsheet • Heresy Upon a (Klipsch) Heresy • Beer Budget Window Rattler • Contact Basics • MDT Mini-Monitor Speaker System • Titanium + TPX + Polypropylene = Fidelity • Tom Holman, Skywalker, and THX, Pt 1-2 • Bud Box Enclosure • Klipschorn Throat Riddle • Modular Three-Way Active Speaker • CD Speaker System • SPEAKER DESIGNER Software • Symmetrical Isobarik • Novice Crossovers • Triamplified Modular System • Magnetic Crosstalk in Passive Crossovers • Mitey Mike Loudspeaker Tester • Symmetrical Loading for Auto Subwoofers • Improved Vented Box with Low Q_{TS} Drivers • BOXMODEL Woofer System Design Software • Four Eight By Twos • Dynaco A-25 Mod • Klipschorn Throat Revisited •

1991 Students Building Systems • Servo Subwoofers • An Apartment TL • L-R Crossover for the Swan IV • More or Less Power • New Guidelines for Vented Boxes • The Pipes • Macintosh's Wave and Sound Programs • Creating Professional Looking Grilles • Octaline Meets D'Appolito • Using Radar to Measure Drivers • Deep Bass for GMC • PSpice LF Response Calculating • Pipe and Ribbon Odyssey • The Delac S-10 • Infrared Remote Volume Control • Backloaded Wall Horn Speaker • Mod for the Minimus 7 • Simplifying Cabinet Assembly • Fibrous Effects on TLs • The DOALs • Loudspeaker Cable • Speaker to Ear Interface • Speaker Sensitivity to Errors in T/S Parameters • TL Speaker Evaluation • Cable and Sound • Kit Reports: Little V; Audio Concepts' Sub-1 •

There's More ☞

Please send me the following back issues of Speaker Builder

☐ 1994 $32 ☐ 1993 $25 ☐ 1992 $25 ☐ 1991 $25
☐ 1990 $25 ☐ 1989 $18 ☐ 1988 $23 ☐ 1987 $20
☐ 1986 $20 ☐ 1984 $18 ☐ 1983 $18 ☐ 1982 $18
☐ 1981 $18

SHIPPING BACK ISSUES

UPS: Domestic ground service by value of order:
Less than $60.00 - $4.50 $131.00-220.00 - $8.50
$61.00-130.00 - $6.50 $221.00+ - $10.50
Canada: Add $6.00 per year.
Foreign Air: Europe add additional 40% of total order.
Other destinations: 50% of total order.
Foreign Surface: Add additional 20% of total order.

Total Magazines ________
Postage ________
TOTAL ENCLOSED ________

Rates subject to change without notice. All remittance in US $ only drawn on a US bank.

☐ Check or Money Order ☐ Discover ☐ MC ☐ VISA

DISCOVER/MC/VISA NO. EXP. DATE
NAME ACCOUNT NO.
STREET & NO.
CITY STATE ZIP

Speaker Builder

Post Office Box 494, Dept. B95, Peterborough, NH 03458-0494
(603) 924-9464 FAX (603) 924-9467

Answering machine for credit card orders only–before 9:00 a.m., after 4:00 p.m. and weekends
Please have all information plus MC/VISA available.

grams. I am sorry Mr. Campbell takes issue with my box drawings, which were generated with the Mircrografx Designer draw program. They are identical to the ones I provide to professional manufacturers. While the elaborate CAD drawings are nice, there is no reason why anyone who has built an enclosure can't take the data I supplied and duplicate the designs. All a builder really needs for these simple butt-joint designs is the internal box dimensions—and far more than that is provided. In fact, anyone who thinks this is a problem will probably not wish to attempt such a project without more experienced help.

Regarding network layouts, all the designs locate the crossovers in custom-made stands, giving the builder much more room to lay out the network than is normally afforded small enclosures. This affectation makes the location of absolute inductors not nearly as critical as it can sometimes be. I provide schematics along with written suggestions for layout, as well as photographs.

Crossovers are relatively simple electronic circuits with few components, and coming up with a parts layout doesn't even approach the complexity of a preamp or amplifier circuit board. I give my readers some credit for being able to figure out a few simple things for themselves. I don't wish to take all the work and mystery out of the project!

Vance Dickason
Contributing Editor

FIGURE 3: Comparison of measured phase (MLSSA) and calculated phase (LMS) for tweeter response of system depicted in *Fig. 2.*

Contributing Editor Dick Campbell responds:

Mr. Dickason's comments are lengthy and contain much information for SB readers, so I am delighted the editor has seen fit to reproduce the entire letter. I will discuss a number of specific items; however, I would rather have readers judge the overall applicability of his remarks for themselves. I congratulate Mr. Dickason for getting his calculated and measured loudspeaker responses to agree to such close tolerances; I never seem to have that kind of luck.

If you consider a loudspeaker cone entering its first major circular resonance mode, a large acoustic component of the output will originate perhaps halfway between the rim and the voice-coil former attachment point. It is possible that this new and spectrally transient source, with respect to axial measure, will be minus or plus a centimeter: inside the rim or outside the former as you choose to consider the geometry of the problem. At 2kHz and 344m/s, for example, this momentary 1cm source shift represents a transient phase shift in the acoustic field of about 22°, in addition to the ±180° being fought over by each half of now-split cone. There are many of these very high Q resonances in the transducer and also associated with the enclosure. In two words, it's a phase mess.

Should we care? That question—at the root of Mr. Dickason's comments—is a damn good one. Can we hear that stuff? I am not sure. If the transitions are smooth, I think not, because these little problems are masked by the mass of musical information we are processing at any one time. In some cases undesirable resonances will respond to analytical masking analysis upon which we can declare them inaudible anyway. Some of these events produce "musical" distortions which we interpret only as an alteration in the timbre of the musical instrument.

Three examples from personal experience come to mind regarding phase sensitivity and analysis:

1. In the '50s Les Paul, the great guitarist, complained to Ampex that something was wrong with its brand new tape machine just installed in his studio. "It's not my guitar," he would say after listening to a playback. The frustrated engineers packed the unit off to the factory, and, ultimately, made a fascinating discovery: when the recorded wavelength on the tape equaled the length of the contact portion of the tape wrap on the play head, they observed a large phase shift with no accompanying amplitude change. This proved to be the source of Paul's dissatisfaction.

2. In the '60s we purchased two Leak bookshelf loudspeakers for the Worcester Polytechnic Institute acoustics lab. These acoustic suspension types had a highly advanced and innovative bass cone composite material of an aluminum foil and rigid foam sandwich. They sounded absolutely awful to me in the midrange, although not all the staff members agreed. Their amplitude response was as flat as a pancake through this frequency region. One evening I carefully measured phase response and guess what I found? Big phase shifts from somewhere. I never found out where because I could not (read: was not allowed to) open them up.

3. Two years ago I measured a Tannoy System 8 coaxial driver and was quite careful in the crossover region where the cone as a piston driver melds into the horn with its cone-cum-bell. I was astonished at the flat frequency response through this region, but I was likewise amazed to observe that the acoustic radiation plane, as frequency went from low to high, moved smoothly into the driver about 2.5cm at the crossover frequency, 2.4kHz, then back out again. At low and high frequencies the radiation plane was at the same distance, attesting to this superb design. I could observe this behavior because of the extraordinary accuracy of MLSSA when switched into "super" mode.

In all three cases, the Hilbert transform of the log amplitude response would have revealed nothing, because none of them are minimum-phase events.

OK, I probably could have picked a more genteel word than "phony" and a less provocative exclamation than "nonsense," but now you know where I'm coming from.

The real problem is that FFT analyzers are too accurate. For example, I just received the latest Tektronix catalog, which includes the ultimate FFT analyzer, Model 3054, $147,750. It has 1,024 parallel filters and claims a phase resolution of 0.01° and a phase noise of –80dBc. These instruments produce so much fine detail that, without smoothing, they could very well be regarded as useless in terms of psychoacoustics and loudspeakers. That's one reason why the latest MLSSA release has an optional adaptive sliding resolution window in the time domain to conserve computational load by dynamically altering the length of the time record fed into the FFT.

Mr. Dickason mentions low-frequency discrepancies referring to Fig. 2, *but I do not understand why anyone would use a 40kHz bandwidth to measure a 2.5kHz crossover. A second-order crossover is down 24dB at 10kHz, and I'm not interested in the response after that.*

Contrary to what Mr. Dickason says about loss of phase response in the MLSSA splice operation, here is a direct quote from the manual: "This command adjusts the decibel level and phase delay of the low frequency near-field file to smoothly connect it to the high frequency far-field file." Furthermore, you can execute an Inverse Fourier Transform (IFT) on the spliced file and obtain a perfect wideband impulse response for the entire speaker system.

Another bothersome remark is that the MLS signal loses power at low frequencies. In fact, an MLS signal has nearly constant power +0/–1dB from the first frequency line (1/sequence-length) to 0.34 × clock rate. I think what he meant to say was that if you filter the MLS signal in fractional-octave bands, the band pressure level drops at –3dB per octave. That is a filtering artifact, and not an indication of low-frequency power loss. MLS is statistical white noise.

Mr. Dickason closes his commentary on FFT analyzers by saying "...the calculated phase methodology (meaning Hilbert Transform)...makes it considerably easier to obtain accurate phase data than measured phase from FFT analyzers...." In support of my original contention, I would change the word "accurate" to "alluring." His earlier observation about the phase jumping all over the place means that the phase was jumping all over the place. If you trash all those nasty real and imaginary whirling vectors and deal with only the log magnitude response, it is alluring. It may very well be the correct thing to do with real ears and real music. Welcome to acoustic measurements!

Speaker Builder *has its strongest focus on amateurs with minimal experience. Building loudspeakers is practically the last proudful bastion of the amateur in being able to create a highly technical and useful system to live with and enjoy for years. These folks need a fair amount of handholding to guide them through the process. I decided to comment on the lack of detailed drawings and crossover layouts for that reason. All that aside, this book is a treasured possession in my library, as it should be in yours.*

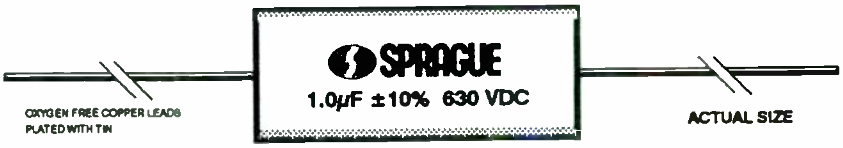
IN AGREEMENT

For the first time ever, I completely agree with Gary Galo. His response to reader Carl Roberts (*SB* 8/94, SB Mailbox, p. 63) was right on target. Diversity of subjects and viewpoints makes *SB* a great magazine. In virtually every issue at least one article doesn't appeal to me in the least, but I skip them knowing that I will someday read them—maybe in two years or so, when current wisdom has caught up with the author, or when I am zealously following a newly found (to me) subset of this wonderful hobby and pastime.

This diversity also has some not-so-obvi-

SPRAGUE *UltraCAP*

High Performance Film Capacitor



Sprague's most advanced capacitor, the UltraCAP is made from a proprietary 630 VDC/ 275 VAC high frequency, high current metallized polypropylene film that features:

- **Lowest ESR:** the combination of film geometry, conductor materials, and oxygen-free copper leads yields an ESR fully one-third lower than conventional film capacitors.
- **Lowest DA:** Due to the highly refined, non-polar nature of the film, the UltraCAP's dielectric absorption is 10% to 90% lower than conventional film capacitors at high frequencies. Low DA is the key to transparent top end reproduction.
- **Lowest DF:** Unlike conventional film capacitors, the UltraCAP's performance actually *improves* at higher frequencies. In fact, this reaches its *minimum* DF at 10 kHz.
- **Dynamic Stability:** Because of its high frequency, high voltage, high current design, the UltraCAP's internal losses are minimal even under very dynamic conditions. At 20 kHz, the UltraCAP can still withstand a ripple current of over 8.5 Amps - more than twice that of conventional film capacitors.

The Sprague UltraCAP is the most advanced metallized polypropylene film capacitor made by the largest supplier of quality film caps to the US Military. You won't believe how good your tax dollars can sound.

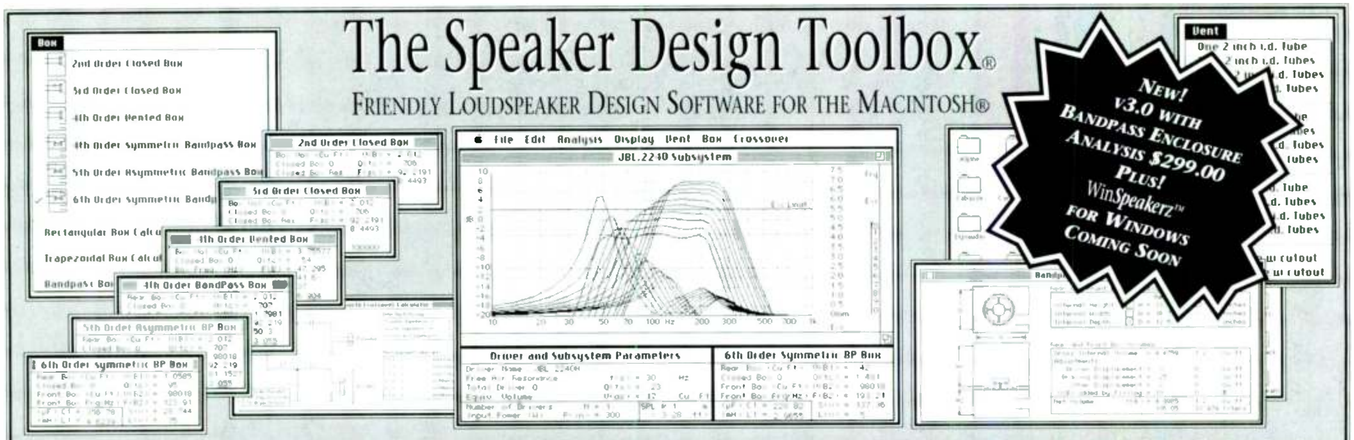
For a complimentary copy of our catalog, please give us a call or drop us a line.

North Creek Music Systems

PO Box 1120, Old Forge, NY 13420

Voice/Fax (315) 369-2500.

Reader Service #17



The Speaker Design Toolbox®

FRIENDLY LOUDSPEAKER DESIGN SOFTWARE FOR THE MACINTOSH®

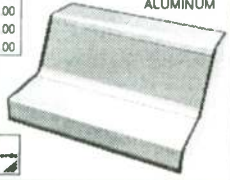
NEW! v3.0 WITH BANDPASS ENCLOSURE ANALYSIS $299.00 PLUS! WinSpeakerz™ FOR WINDOWS COMING SOON

Mac*Speakerz* v3.0 provides everything you need to stay competitive in today's loudspeaker market....*Easily, Accurately and Elegantly.* Mac*Speakerz* enables you to expertly design these enclosures: • Closed • Vented • 3rd Order Closed • 4th Order Bandpass • 5th Order Bandpass • 6th Order Bandpass • *Plus* Isobarik variations on all of these! Includes: • Crossover Calculators • Box Calculators • Sound Pressure Level • Large, Expandable Driver Library (800 drivers) • Manual (with friendly tutorial) • Free Customer Support! ***Call for a demo disk today!***

Mac*Speakerz* FROM True Image Audio® 349 WEST FELICITA AVENUE, SUITE 122, ESCONDIDO, CALIFORNIA 92025

VISA PHONE (800) 621-4411 8:00-5:00 PST, MON-FRI, FAX (619) 480-8961 24 HRS. A DAY, OUTSIDE THE U.S.A. PHONE/FAX (619) 480-8961 MasterCard

Reader Service #29



ENCLOSURES

PANELS ARE .063" ALUMINUM

- In stock for fast delivery
- Designed for small lot production
- Flat panels for easy fabrication
- Shipped unassembled
- Also available in all black for an extra charge

Rack Chassis

MODEL	W x D x H (in)	$
1RU5	19 x 5 x 1.75	34.00
1RU7	19 x 7 x 1.75	36.50
1RU10	19 x 10 x 1.75	38.75
1RU12	19 x 12 x 1.75	42.75
1RU15	19 x 15 x 1.75	45.75
1RU17	19 x 17 x 1.75	48.75
2RU5	19 x 5 x 3.5	36.50
2RU7	19 x 7 x 3.5	38.75
2RU10	19 x 10 x 3.5	41.25
2RU12	19 x 12 x 3.5	45.25
2RU15	19 x 15 x 3.5	48.25
2RU17	19 x 17 x 3.5	51.25
3RU5	19 x 5 x 5.25	46.00
3RU7	19 x 7 x 5.25	48.50
3RU10	19 x 10 x 5.25	51.00
3RU12	19 x 12 x 5.25	54.00
3RU15	19 x 15 x 5.25	57.00
3RU17	19 x 17 x 5.25	60.00

Dual Slope Cabinets

MODEL	W x D x H (in)	$
DS-1	4 x 6 x 4	40.00
DS-2	6 x 6 x 4	43.00
DS-3	8 x 6 x 4	46.00
DS-4	10 x 6 x 4	49.00
DS-5	12 x 6 x 4	52.00
DS-6	18 x 6 x 4	55.00
DS-7	4 x 8 x 6	50.00
DS-8	6 x 8 x 6	54.00
DS-9	8 x 8 x 6	58.00
DS-10	10 x 8 x 6	62.00
DS-11	12 x 8 x 6	66.00
DS-12	18 x 8 x 6	70.00

PANELS ARE .063" ALUMINUM

LOWER PRICES!
(800) 634-3457
Order Today!

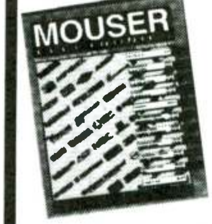
VISA MasterCard

SESCOM STOCKS ALL TYPES OF ENCLOSURES
FREE EXPANDED 1995 CONSTRUCTOR'S CATALOG

PREPAID ORDERS SHIP GROUND *FREE*
(48 STATES, CANADA & MEXICO)

SESCOM, INC.
2100 WARD DR., HENDERSON, NV 89015 USA
USA/CANADA (800) 634-3457
FAX (800) 551-2749
(702) 565-3400 FAX (702) 565-4828
TECH LINE (702) 565-3993 M-Th 8 am to 4 pm (PST)

Reader Service #23



47,114

ELECTRONIC COMPONENTS

Whether you order 1 part or all 47,114...MOUSER stocks and...*ships same day!!*

CALL...(800) 992-9943

for your FREE CATALOG

2401 Hwy 287 N.
Mansfield, TX 76063

MOUSER® ELECTRONICS
Sales & Stocking Locations Nationwide

Reader Service #30

ous benefits. For instance, I am not an electrical engineer and have no access to, nor knowledge of, the various SPICE derivatives. I know from casual observation that I could never justify purchasing it at its extremely steep price. Therefore, I have absolutely no interest in the many recent articles about modeling buffers using SPICE. What is the benefit? Those readers who have access to SPICE may, in the future, use it to develop the cookbook-type project that Mr. Roberts seems to like so much.

My basement contains every issue of *SB*, and I can tell you from experience that 1981's closed-ended designs (buy this model woofer or tweeter, and put it in a box of this volume) are now virtually useless. Most of the drivers in these designs are discontinued, and the remainder have been superseded by much improved versions. I grab one of these old issues to read articles explaining the theory behind some design aspect I wish to implement. If *SB* published only recipes, I would have tired of reading it long ago. I would probably have built one or two (or six) "projects," become bored, and canceled my subscription.

Perhaps Mr. Roberts, as a vendor of speaker components, believes he would be better served by customers who know what they want when they call him, rather than asking often frustrating questions (frustrating for him and the customer). However, consider that my basement is also clogged with drivers of every imaginable size, construction, material, and brand. Each one is waiting for that perfect bass-loading technique or crossover mod to free it from prison on my damp, dark shelves.

Meanwhile, I continue, to my family's dismay, to purchase new specimens. Were it not for *SB* and its myraid articles, I would not have bought most of them, leaving Mr. Roberts and his brethren on the supply side much poorer. To paraphrase the Bible, "Give a man a design and he'll build it, but teach a man to design and he'll build boxes (and buy drivers) forever."

Besides, I enjoy the articles on table saw basics and biscuit joinery. Keep up the good work on a fine magazine.

Rich Bartsch
Rolling Meadows, IL 60008

REPRINTS

For quality reprints in quantities
of 100 or more, contact:
REPRINT SERVICES/
SPEAKER BUILDER,
315 5th Avenue N.W., St. Paul, MN 55112,
(612) 633-1862.

THE LEGENDARY

STRATHEARN AUDIO
Pure Ribbon Driver

Mid Range - High Frequency
Perfectly made in Germany.

Spezifications:
Frequency response: 450-20000 Hz ±3 dB
Crossover point 2 units = 350 Hz
Crossover point 3 units = 250 Hz
Power handling: 100 Watts RMS
Sound pressure level:
87 dB / 1 w / 1 m / 8 Ohm transformer
90 dB / 1 w / 1 m / 4 Ohm transformer
Dimensions: 135 x 595 x 30 mm
Weight: 3,3 kg

Price: $399
incl. transformer
Payment per MasterCard
or American Express Card.
Distributor enquiries welcome.
Broschure & technical data
on request.

hifisound
EXPORT DIVISION

Jüdefelderstraße 35 + 52
D-48143 Münster

Phone: (011)-49-251-5 83 30
Fax: (011)-49-251-4 39 56

Reader Service #53

Mahogany Sound

2610 Schillingers Rd. #488
Mobile, AL 36695
(205) 633-2054

TRANSMISSION LINE SPECIALISTS

Q&ETLD

QUICK & EASY TRANSMISSION LINE SPEAKER DESIGN is a new booklet that is a must for TL fans. It offers a step-by-step design procedure that really works. All you need is a calculator with a square root key, and imagination. There is also a computer diskette for use with Lotus 123, and a 6 ½" 2-way TL project called *The Mini Monolith TL*.

Q&ETLD is $8.95 postage paid.

ACOUSTA-STUF

ACOUSTA-STUF is absolutely the best sound absorption fiber for transmission lines. You should order one pound per cubic foot of enclosure.

ACOUSTA-STUF costs $8.95 per pound, UPS paid.

WRITE OR CALL
FOR A FREE CATALOG

Reader Service #9

World Radio History

REINVENTING ADVENT?

My son Scott and I really enjoy the mag, especially the neat article "Resurrecting a Pair of AR2AXs" (*SB* 8/94, p. 20). How about an article on the old Advents, all of which died from foam surround?

Cliff & Scott Steele
Rockford, IL 61102

We encourage readers to share their experiences with these popular units.—Eds.

INPUT PROTECTION

Temporary insertion of a resistor in series with an amplifier's power transformer, as described in Mark Seymour's response to William Wallace's letter in *SB* 4/94 ("Capacitor Glut?" p. 49), is a simple and convenient approach to limit the large turn-on surge caused by increased power supply capacitance. However, you should add an additional circuit to disconnect the input signal from the amplifier while the power supply resistor is in circuit. Otherwise, an input signal large enough to drive the amplifier to full output will cause the resistor, if still in the circuit, to go up in smoke in a hurry.

Mark Swierczek
Great Mills, MD 20634

William Wallace responds:

Thank you for your suggestion to add a circuit to disconnect the input from the amplifier while it is in the "soft-start" mode, in response to my concerns about additional power supply capacitance. I control my secondary system, which has the expanded capacitance, with an AR remote control. As you probably know, this is a basic preamplifier, which I turn on only after the Hafler 120 has gone through its 90-second soft-start mode. Also, the AR control is automatically in "mute" whenever I turn it on, providing an extra layer of protection.

Although these precautions do not entirely prevent the occurrence of the problem you describe, I am willing to take the risk because I have sufficiently warned my wife and her three wayward sisters, who might use the system in my absence, by exaggerating the consequences of not following the system turn-on instructions. So far, I have had no problems.

Piezo Driver

Continued from page 20

frequency. Not only must the woofer's on-axis response reach this point, but the off-axis response should be reasonably uniform.

Although this is not an article on woofer design, it is enough to say that a woofer with a medium weight cone which has a curvilinear cross section and a dust cap glued directly to the bobbin ought to be decent up to and beyond the KSN1188A's minimum crossover point. A fabric "M" surround with a coating of elastomer should get the edge resonance well above the crossover point. Don't forget about the low-end limitations of the horn you are using with the KSN1188A, since it is more likely to restrict good performance down to 800Hz than will the woofer in reaching up to the crossover point.

Next time we will present a do-it-yourself project with a coaxial driver using the KSN1188A for mids and highs. The cone of the woofer also works as the horn for the KSN1188A, which is mounted directly behind the woofer's magnetic system and passes its output through the woofer's vented pole piece. This approach was pioneered by Tannoy, and later Radian in their studio monitors.

Readers may want to contact Motorola [4800 Alameda Blvd. NE, Albuquerque, NM 87113, (505) 822-8812] directly to receive the free application note on the KSN1188A that covers in more detail some of the topics discussed here.

Get the information you need *fast!* Use this convenient list to request the products and services that interest you in this issue. Don't forget to mention ***Speaker Builder!***

COMPANY	PRODUCT	FAX
Bohlender-Graebener Corp.	*The Acculine Series*	(702) 832-5407
Cubicon	*Paper Speaker Enclosures*	(314) 567-0046
Dupont	*KAPTON®*	(800) 879-4481
Ferrofluidics Corporation	*Ferrofluids*	(603) 883-2308
Harris Technologies	*BassBox 5.0*	(616) 641-5738
hifisound Saerbeck	*Strathearn Ribbon Drivers*	(011) 49-25143956
Image Communications	*Loudspeakers, Horns, Drivers, Parts*	(312) 585-7847
Orca Design & Manufacturing	*Focal, Axon, Cabasse, Accuton*	(818) 991-3072
Polydax Speaker Corp.	*Audax Kit Plans*	(508) 658-0703
RDL Acoustics	*Roy Allison's Convex Dome Tweeter*	(508) 966-3645
The Parts Connection	*Filters and Other Parts*	(905) 829-5388

Don't Delay FAX Today!

Classified

TRADE

AUDIO PHASE INDICATOR: hand-held tool for engineers and enthusiasts. Bi-color LED shows "IN" or "OUT" relative phase for loudspeakers, microphones, etc. For more info, write or call ***CRYSTAL LAKE DESIGNS***, PO Box 591, Crystal Lake, IL 60039, phone (815) 455-0799.

ELECTROSTATIC parts, supplies, exotic circuits. Free catalog. ***DAVID LUCAS, INC.***, 924 Hulton Rd., Oakmont, PA 15139, (412) 828-1967, FAX (412) 828-0422.

DAMPING PADS 8"x5"x¼" self-stick resonance absorbing pads, 10/$15, 50/$50. ***RICHARD***, (519) 687-2040.

ELECTROSTATIC electronics, transformers, Mylar®, information. From author ***ROGER SANDERS***, (503) 742-7640.

FOR SALE

Two 15" woofer f_s=25Hz, Q_{TS}=0.69, X_{MAX}= 11mm one way! 4Ω ideal for infinite baffle, audio, transmission line, in-wall, $150. Rich, (519) 687-2040.

Two pair Focal 5N313, matched, boxed, with curves, $80/pair; Gemini cabinets, black oak with stuffing, OFC wiring harness & cups, makes good center channel, $150. Prices include shipping. Phil, (602) 579-1446.

AudioControl SA-3050 with mike and printer output, $700; LPG38AT, $20; three LPG 51AT midranges, $30 each or $75 all. Jerry, (601) 264-6971.

Aria Cabasse kit, never built, $600 (new $1,100); Top Box IBM program, $50. Dean Carl Johnson, 370 East Tratebas Rd., Valparaiso, IN 46383-9752.

Pair Klipschorns, CES Signature, oak, new '94, $2,700 or best offer; pair JBL 4312 studio, $400. Steve, (203) 397-3888.

Get all of the "lows" with two 24" 8Ω 400W Fain speakers. They're brand new—never used! Half price, only $450 each. R. Krejci, (805) 765-5194.

Pair JBL 2235H, $325; pair Dynaudio 17W75EXT, $90; pair 15W75, $95; pair Focal 8K4155, $140; four Peerless 1758 8" woofers, $125 for all or $70 per pair. Jerry, (601) 264-6971.

Pair Vifa D25AG-05 aluminum dome tweeters, new, $10. Ray Krippner, 1329 28th St. SE, Cedar Rapids, IA 52403, (319) 363-6998.

Tape decks: ReVox A77 two-track stereo (biased for Ampex 456), $650; Teac A-2340 (right-rear treble weak), $250; Teac A-4010S (needs new forward-play head), $75; old Tandberg crossfield-head deck, $125. Prices include shipping.

Pair Altec N500G crossovers, $200; pair 511B, $100; pairs 288C, 291 diaphragms, $350; McIntosh 200, $895; two 2125, $550 each; pair Newcomb tube mono amps, 125W, $550. David, (914) 688-5024.

Pair Allison One speakers, mint condition, original owner, all new Allison woofers. No reasonable offer refused. Davis, 3702 Burrwood Terrace, Fort Wayne, IN 46815, (219) 485-6574.

Denon DP-2550 turntable, SME 3990-III arm, Shure V15 cartridge, $250; dbx 124 four-channel dbx-II processor, $150; Nakamichi 700-II three-head cassette recorder, $400; ReVox B77 open reel recorder, $500; Yamaha DSP-1 soundfield processor, $450; more equipment, video tapes, CDs. Stamp gets list. Darroch, 1807 Elm Crest, Arlington, TX 76012.

Four Focal 7N501, new, in the box, $120 all. Michael Morse, 15069 Lupin Ln., Sonora, CA 95370, (209) 536-1880, 9 a.m.-4 p.m., (209) 533-4346 after 6 p.m. (PST).

Reel-to-reel prerecorded classical tapes, mostly Barclay-Crocker Dolby encoded and a few Columbia. Send SASE for list. John Bundy, 6 Aspen St., Etna, NH 03750, (603) 643-5567.

JBL speakers, two LE15A transducers, two LE85 transducers, two H91 horns, two L91 lens, two LX5 crossovers. James, (615) 947-7607.

Pair Manley Designers' Reference Series 200W monoblock amps by VTL, like new with low hours usage, $2,950 + shipping. Lloyd, (805) 929-3545, FAX (805) 929-2043.

Pair ROR speakers, two 6½" plus tweeter, $150; pair ROR speakers, one 5" plus tweeter, $60; pair empty AR7 cabinets, $30; three Bozak pro speakers, four 4" in each, $50 each; Sherwood S2300 AM/FM, $30; empty Altec 9849 monitor cabinets, rough but solid, $50 each. David, (914) 688-5024.

12 Dynaudio 100W30 woofers, unused, $125 each; 1½"x36"x7½" oak wings & base for ribbon project (picture available), $950; 18 Infinity Emims, $75 each. Doug Robinson, home (402) 289-0886 or work (402) 779-2531.

Pair Strathearn speakers, $175; set of Marchand XM1 24dB crossovers, $25; Numark DM1850 mixer, $90; AMD 386DX-40, $20; new Shure N95HE stylus, $10; new Stanton 500/500a stylus, $5; new Stanton 681A stylus, $5; new Shure M99E cartridge. Dan Patten, 1768 N. 980 W., Orem, UT 84057, work (801) 224-8080 or home (801) 225-8577.

Theta DS Pro Prim I DAC, $750; eight Strathearn ribbon speakers, modified by Audire, CA, raw panels with no face plates, $800 takes all. All prices US dollars. Will transport to Detroit, MI vicinity. Nick Mastrobuono, 2086 Lakeshore, Sarnia, ON Canada N7T 7H6, (519) 542-0964, FAX (519) 481-2731.

Hewlett-Packard HP 180A dual trace scope, $100; Dynaco PAT-4, $40; Fisher FM-2421 tuner, $50. All + shipping. J. Curtis, PO Box 758, Stevens Point, WI 54481-0758.

Rek-O-Kut N33H turntable, S-120 arm & Shure M99E cartridge; Dynaco S120A amp; VacOrec record cleaner; ADC 3500RVC record player; Phase Linear 200 amp; Optimus Stav-3100 receiver modified to biamp, with repair contract. All manuals available. Aaron Shipow, 3408 Ramstad Dr., San Jose, CA 95127, (408) 272-6836.

Marantz EQ-10 stereo equalizer, $45; pair Audax HD12-9D25 tweeters, $20; pair Audax 1½" dome mids, $30; Jensen RP302A tweeter, $20; Radio Shack #33-1062 ultra directional electret switchable mike, $20; Micronta #22-211 analog VOM, $15; Rek-O-Kut Rondine turntable, micropoise arm, needs belt, $35. All E.C. shipping extra. Jim, (708) 425-6719, 8 a.m.-10 p.m. (CST).

Pair Cabasse 21NDC woofers, $300; IMP LMS with calibrated Mitey Mike, $500. Don Vogel, 141A 5th Ave., Ft. Knox, KY 40121, (502) 942-5039.

Hartley HQ24 driver, $225; pair KEF B-139, $70. Rion Dudley, (206) 285-7918.

Audio Research D-100 solid state amp, $325. Charles, (901) 386-1121, leave message (TN).

Strathearn ribbon speakers. Three drivers in each 6' curved oak baffle, 125Hz to 20kHz. Four extra drivers. All drivers are of the original design used in the Infinity Reference Standard. $900 takes all. You transport. Andy Catanzaro, PO Box 26143, Wauwatosa, WI 53226, (414) 466-8266, eves.

Audio Alchemy DDE 1+ digital decoder with Clearfield digital interface coax and Toslink fiber optic cable, $170; an upgrade for your CD player, brand new in carton; pair Boston Acoustics 797 car speakers, new in carton, $100. Fred, (610) 693-6167.

Pair Morel MW-224 woofers, never used, $79 ($150+ new); PS Audio 200cx amp, *Stereophile* Class B rated, 200+ wpc, $899 ($2,000 new); Bang & Olufsen Beocord 9000 tape deck, $99 (new $1,295). All prices include shipping. Art, (410) 529-7207.

Toroidal transformers: two secondary 40+40 vac, 500VA, $35 each; two 35+35 vac, 300VA, $35 each; one 35+35 vac, 625VA, $50; Ultra Analog AES-20 input receiver, asking $85; DAC-20 20-bit DAC, asking $150; Tripplite LC-1800 line stabilizer/conditioner, asking $100; Heathkit 1G-18 audio generator, asking $50; Dynaco ST-70, no power transformer, asking $150. Ashby, (305) 475-5225.

Jensen RP103 horn tweeter, $15; two LaFayette 99-0022 three-way crossover, $35. All + shipping. Stan, (216) 288-8490.

18 Audire ribbon drivers, can be used full range in quantities of four or more per side. Drive direct without transformers, high SPLs if used with dynamic drivers below 180Hz. $125 each or best offer (cost $250 new). Ken Fritz, daytime (800) 426-1828, (804) 794-4107 after 6 p.m. (VA).

Portable computer for use with LMS Leap & other speaker programs—same unit used by Vance Dickason. Mint condition 386DX40 with math coprocessor 80M-byte hard drive, 1.44 floppy drive. Selling for $750 (save $350). Jay, (801) 378-5880 days or (801) 225-7335 eves. (MST).

Ten new SEAS P21REX 8" poly cone, $30 each or $250 for all; pair SEAS 76MF 3" soft dome mids, $30; pair new Dynaudio 17W-75, $90; Dynaudio D-76AF, $50. Pat Hart, home (310) 539-0759 or work (310) 643-5300 ext. 258, 9-5 (PST).

Pair Eton 8-480, $100; pair JBL LE8T ex frame needs reconing, $50 + shipping; Dynaudio D52 (06), $75; Dyna PAS/FM3/case, $100 + shipping; Fisher 400, $75; NAK BX-2, mint with box, $165; Thorens TP-60 headshell, new in box, best offer. Rick, (509) 466-2058.

WANTED

Focal 8" mid woofers 8K515, two of each; ATC midrange, model SM 75,150S Super Dome, 16Ω; Dynaudio Esotar T330D tweeter. Charles, (901) 386-1121, leave message (TN).

Dynaudio & Scan-Speak drivers; original QUAD mid/tweeter panel; back issues of *Voice Coil*. Rich, (519) 687-2040.

Two Phillips AD0210W Sq8 mids, good condition. Gene Zesch, 3701 Iowa St., St. Louis, MO 63118, (314) 776-0567.

One or two pair Focal 5K013L. Phil, (602) 579-1446.

Focal Audio 7Ks—Wanted dead or alive! Brian, (203) 536-4421 or daytime machine (203) 535-2153.

QUAD ELS. California Institute of Technology Music Lab needs gifts of several pairs of original QUAD electrostats (not ESL-63). James Boyk, (818) 395-4590, FAX (310) 470-9140, E-mail: boyk@puck.caltech.edu.

AMPLIFIER DESIGN ENGINEER: San Diego based sub-contract manufacturer needs individual to lead new department. Must have experience designing audio power amps using discrete and I.C. technology. PCB layout skills desirable and experience with powered subwoofers and multimedia amps important. Please send your resume to: Tecate Industries, PO Box 1585, El Cajon, CA 92020-1585.

Knowledgeable speaker builder/audio entrepreneur with professional background in Quality Assurance and electronics seeks position or association with audio company in New York or southeastern states. Publio, P.M. Audio, (516) 868-8863.

Tube hi-fi, theater amps/preamps and speakers: Altec, Jensen, McIntosh, Marantz, Craftsman, Dynaco, Heath, Eico, etc. Sunshine Sounds, (405) 737-3312.

Pair AC-10 rubber surround woofers; pair 12mH ferrite or laminated steel bar inductors, Focal 10V516; pair Scan-Speak D-2905 tweeters. Jim, (708) 425-6719, 9 a.m.-9 p.m. (CST).

Great American Sound GAS 500 amp; schematic for GAS 500. Michael Morse, 15069 Lupin Ln., Sonora, CA 95370, (209) 536-1880, 9 a.m.-4 p.m., (209) 533-4346 after 6 p.m. (PST).

Altec 802-8 drivers; 311-90 horns; 416-8B drivers; EVM15L driver; JBL 2220H 15" driver; schematic/service manual for Scott 299D amp; plans for Klipschorn; would like to correspond with individuals who have built/modified horn systems, especially Klipschorn. Don W. Bible, 624 Riverbend Rd., Clinton, TN 37716, (615) 457-8391.

Wanted to thank *Speaker Builder* readers D. Delker, A. Nettlestein, C. VanDeCasteele (Italy), E. de Bode (Amsterdam), and John Wright of TDL Electronics for their generous help with my IMF speaker repair project. I couldn't have done it without the information you provided. Bob Grieb.

Pair Altec 848A Flamencos, $850; pair Altec gray VOT cabinets, $90 (pick-up only); pair Altec 511B and 808s, $250; Altec N501-8A, $50; Jensen F15LL, professionally reconed, $150; 12" Jensen field coil, $130. Dave, (216) 666-6805, 6-10 p.m. (EST).

CLUBS

THE AUDIO SYNDROME, Nassau and Suffolk county's oldest group of audiophiles is looking for new members. If you are interested, call Roy Harris, (516) 489-9576.

SPEAKER BUILDER SEEKS OTHER LONG ISLAND/WESTCHESTER COUNTY AUDIO ENTHUSIASTS for the purpose of forming a club for the exchange of ideas, advice, etc. Publio Morera, (516) 868-8863, evenings.

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. An answer is ensured, if you include some kind of compensation for postage and handling. Write to: Gunter Roehricht, Bühlerstr. 21, 71034 Böblingen, Germany.

THE NEWLY FORMED CHICAGO AUDIO SOCIETY invites all audiophiles to attend its meetings. For details and meeting location, please call Brian at (708) 382-8433 or Pat at (708) 582-3913 evenings; E-mail to sysop@nybble.com or u24129@uicvm.uic.edu. Space is limited.

WANTED: "CRADLE-TO-GRAVE" AUDIO ENTHUSIASTS. Texas doesn't have an audio club; YET! If you're interested in audio reproduction on stage and in your home, let's get together. Rick, (915) 676-7360.

WANTED: SPEAKER/TUBE GEAR BUILDERS AND AUDIO AMATEURS IN SANTIAGO, CHILE. Would like to form a club or just a friendly group of audio enthusiasts to discuss speakers/amps/preamps/crossovers and everything. Anyone interested, contact Christian Bargsted, Los Gomeros 1542, Vitacura, Santiago or call (011) 562-538-0638, office hours.

LONDON LIVE DIY HI-FI CIRCLE meets quarterly in London, England. Our agenda is a broad one, including any aspect of audio design and construction. Subscription newsletter. We welcome all, from novice to expert, in free association. Contact Brian Stenning, UK, (011) 44-81-748-7489.

WANTED: SPEAKER AND AUDIO AMATEURS IN THE BRADENTON/SARASOTA/ST. PETERSBURG/TAMPA, FL AREAS. Would like to form a club and develop a lab for testing speakers/amps/preamps and passive and active crossovers or just to discuss speaker projects and ideas. Angel Rivera, Bradenton, FL 34206, (813) 792-3870.

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

WEST VALLEY AUDIO SOCIETY is a group interested in all aspects of high-performance audio. We are located in the west San Fernando Valley, CA and look forward to hearing from interested audiophiles. Call Barry Kohan, (818) 225-1341.

SPEAKER BUILDER CLASSIFIED ORDER FORM

TRADE— for any business or private party, selling equipment, supplies, or services *FOR PROFIT*. **FOR SALE**— to sell *personal* equipment or supplies. **WANTED**— to find *personal* equipment, supplies, or services. **CLUBS**— to help readers start and maintain club membership.

PRICE: All ads are $1.50 per word. Deduct 5% for an 8X contract. $10 minimum per insertion. **Payment must accompany ad.**

FREE ADS: Subscribers receive free **For Sale**, **Wanted** and **Club** ads up to 50 words. Over 50 words .20 per word, $10 minimum. Name, address and phone number must be included with ads.

SUBMITTING COPY: A word is any collection of letters or numbers with a space on either side. Copy must be clearly typed or printed. ***Illegible ads will be discarded.*** Submit copy by mail, fax, or data transfer (ASCII, WordPerfect 5.0 or 5.1, Word for Windows, Word for DOS, Windows Write, or Word Star 3.3- 5.5 formats)

QUESTIONS? Write or fax us at the address below.

☐ For Sale ☐ Wanted ☐ Club ☐ Trade, No. of insertions_____

USE BLOCK LETTERS IF PRINTING. NO ABBREVIATIONS.

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

Please charge to my: ☐ DISCOVER ☐ MASTERCARD ☐ VISA

CARD NUMBER EXP. DATE

☐ CHECK/MONEY ORDER ENCLOSED

Subscription Account Number: A☐☐☐☐☐☐☐

NAME

COMPANY

STREET & NO.

CITY STATE ZIP

PHONE

AAP, Inc. — Classified Dept.
PO Box 494, Peterborough, NH 03458

FAX 603-924-9467
Data 603-924-6230

TUBE AUDIO ENTHUSIASTS. Northern California club meets every other month. For next meeting announcement send #10 SASE to Tim Eding, PO Box 61162, San Jose, CA 95161.

AUDIO SOCIETY OF MINNESOTA. Meeting the hobbyist needs of audiophiles in the Land of 10,000 Lakes for 16 years! Monthly meetings (Sept.-May), tours, audiophile concerts, special guests, technical assistance, etc. For information and a copy of our latest monthly Bulletin, write ASM, PO Box 32293, Fridley, MN 55432, or call our 24-hour "Audio Hotline," (612) 825-6806.

SOUTHEASTERN MICHIGAN WOOFER AND TWEETER MARCHING SOCIETY (SMWTMS). Detroit area audio construction club. Meetings every two months featuring serious lectures, design analyses, digital audio, AB listening tests, equipment clinics, and audio fun. Club publication, *LC, The SMWTMS Network*, journals the club's activities and members' thoughts on audio. For information, send name and address: E-mail aa259@detroit.freenet.org; phone (810) 544-8453 (machine); SMWTMS, PO Box 721464, Berkley, MI 48072-0464.

THE ATLANTA AUDIO SOCIETY, Inc. — Open to persons who share a common interest in the art and science of audio and music. Activities include construction projects, equipment and recording evaluations, home theater, video, film, live music and recording sessions. Monthly meetings and seminars often include prominent speakers from the industry. Newsletters and bulletins regularly published. John Morrison, Pres., (404) 491-1553, or Chuck Bruce, (404) 876-5659, 4266 Roswell Rd. N.E., K-4, Atlanta, GA 30342-3738.

WASATCH AUDIO, located in Salt Lake City. Our club is interested in construction, modifications, design, and listening to music. We are looking for members and ideas for our new club. Edward Aho, (801) 364-4204.

THE BOSTON AUDIO SOCIETY, the nation's oldest (founded 1972), seeks new members. Dues include the monthly meeting notice and our newsletter, the *BAS Speaker* (6/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.

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! Toobers, Tranzzeestors, 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 PO Box 144, Hannacroix, NY 12087.

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

THE COLORADO AUDIO SOCIETY (CAS) 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 newsletters, plus participation in meetings and lectures. For more information, send SASE to CAS, 1941 S. Grant St., Denver, CO 80210, (303) 733-1613.

VINTAGE AUDIO LISTENERS AND VALVE ENTHUSIASTS (VALVE) meets the first Sunday of every month to swap vintage audio gear, audition rare and collectible equipment, and evaluate modifications and scratchbuilt projects. Dues provide a monthly newsletter with current reviews of vintage components and modification information; vintage service data; and access to an active network of serious collectors. For information, call (206) 697-1936 or write to 1127 NW Brite Star Ln., Poulsbo, WA 98370.

GREATER SOUTH BAY AUDIOPHILE SOCIETY (Los Angeles/Orange County area) is entering its second year of existence and is welcoming new members to the more than 50 who are already enjoying its benefits. Our meetings, held every six weeks, and our newsletter, *theEarful*, cover topics on do-it-yourself tweaks and mods, music articles, equipment reviews, manufacturer's demos, and much more. Contact Larry Fisher at (310) 599-6579 or Dave Clark at (310) 427-4207.

NEW JERSEY AUDIO SOCIETY meets eight times a year. Emphasis is on extracting the best sound per dollar spent from your audio system. Dues include subscription to our newsletter, *The Source*, published four to six times yearly. Meetings focus on enjoying the hardware as well as the software. Contact Frank J. Alles, 209 Second St., Middlesex, NJ 08846, (908) 424-0463, or Valerie Kurlychek, (908) 206-0924.

WASHINGTON, D.C. AREA HORN ENTHUSIASTS GROUP now forming. If you're interested in horn loudspeakers and live in the Washington, D.C. area, we want to talk to you. Please call Dirk Wright, (703) 471-8657, or John Hanley, (703) 425-7482. Our ears are tuned to the clear dynamics of horn loudspeakers.

MONTREAL SPEAKER BUILDER CLUB. Meets when it can, BYOB, discussions range from speaker design and testing to equipment modification. All welcome. Contact Andrew McCrae, 4701 Jeanne Mance, Montreal, PQ, H2V 4J5 Canada, (514) 281-7954.

PACIFICNORTHWEST AUDIO SOCIETY (PAS) consists of 40 audio enthusiasts meeting monthly, second Wednesdays, 7:30 to 9:30 p.m., 4545 Island Crest Way, Mercer Island, WA. Write Box 435, Mercer Island, WA 98040 or call Ed Yang, (206) 232-6466, or Gill Loring, (206) 937-4705.

THE LOS ANGELES AREA LOUDSPEAKERS DESIGNERS GROUP. If you're just starting out or an experienced builder and would like to share ideas on speaker design and listen to each other's latest creations, give us a call. Geoffrey, (213) 965-0449 or Eduard, (310) 395-5196.

THE WESTERN NEW YORK AUDIO SOCIETY was established in 1984 for the purpose of offering those people interested in the hobbies of music appreciation, stereo components, etc. the opportunity to meet other individuals who share similar interests. For further information regarding our organization, please write to The Western NY Audio Society, PO Box 312, N. Tonawanda, NY 14150, Atten: Denny Fritz.

PIEDMONT AUDIO SOCIETY 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.

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 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.

Ad Index

Loudspeakers 101

EFFICIENCY, SENSITIVITY, & POWER HANDLING

By Dick Pierce

One of the Thiele/Small parameters is the *reference efficiency* or $\eta 0$ ("eta naught"). Usually expressed in percent, this number represents the amount of incoming electrical power that is converted to outgoing acoustical power. It describes the efficiency of the system well above its lower limits, typically in the midband.

System efficiency can be determined in a couple of ways. Most loudspeaker manufacturers derive this measurement by calculating $\eta 0$ from other T/S parameters. Another method involves inserting a signal adjusted to a known power level and measuring the output power. This test uses a narrow band (one octave wide) of pink noise, with a calibrated microphone and sound pressure level (SPL) meter placed at a standard distance (1m), and the loudness read.

A more understandable way of expressing efficiency is with *sensitivity.* While not strictly on the "official" list of T/S parameters, it's often specified with them.

Sensitivity is the SPL produced when 1W is applied to the input of the speaker. Again, we can mathematically convert from one to the other. A 1W sound source produces a SPL of approximately 109dB at a distance of 1m. If a driver has a reference efficiency of 10%, it's putting out 10% (1/10) of its input power or, in this case, 1/10W. This will produce a SPL of 99dB. One with an efficiency of 1% will, when driven with 1W, output 1/100W—an 89dB SPL. The sensitivities of these speakers are then 99dB and 89dB SPL (relative to 1W/1m), respectively.

Typically, high-quality drivers have efficiencies between 0.05-5% or so, with sensitivities from 86–96dB SPL. While sensitivity in and of itself is not a direct indicator of quality, these figures can be used as guidelines in matching the levels of different drivers, although radiation patterns will have some influence.

LOUDNESS LIMITATIONS

To this point, we have been discussing small-signal parameters. We will now explore those T/S parameters that determine a driver's maximum output level.

The limitations to output are mechanical and thermal. Mechanical limits determine how much air the driver is capable of moving, referred to by Small as the speaker's acoustical power limit, or P_{AR}.

Two important parameters are considered here, the first being how far the cone can move back and forth. "Maximum linear excursion"—X_{MAX} —is the maximum distance the cone can travel in one direction before either distortion rises to significant levels or mechanical damage occurs. While some manufacturers go to the trouble of determining X_{MAX} by measuring distortion, most simply specify how far the voice coil can move while remaining within the magnetic gap.

This method, although frequently used, does not include mechanical distortion in the surround, variations in the magnetic gap, and other factors which can change with different manufacturers and even from part to part. The calculated value for X_{MAX} is therefore only a rough guide for comparison.

The cone's area is the other important parameter. Impressively termed "effective emissive area" (S_D), it is simply the area of the cone that actually contributes to moving air. It also includes a portion of the surround (but only a portion because, while the inner part moves as far as the cone, the outer part is stationary, being firmly attached to the driver's frame).

If we multiply these two values, we arrive at V_D, the driver's "displacement volume." This figure is the total volume of air the driver can move, which at a given frequency determines how loudly it will play. Large drivers (with large S_D and X_{MAX}) can move more air and hence play louder—all other things being equal—than small drivers before the onset of distortion or damage.

A common belief is that with enough cone area you can produce high sound levels at low frequency, and this has resulted in speakers with multiple small woofers instead of one large one. For example, since four 6″ woofers have the same cone area as a single 12″ unit, they are thought to be equivalent. While this may be true for cone area, it's also often the case that the construction of large drivers permits large excursions, so their displacement volume may be significantly greater than that of smaller drivers.

MELTDOWN

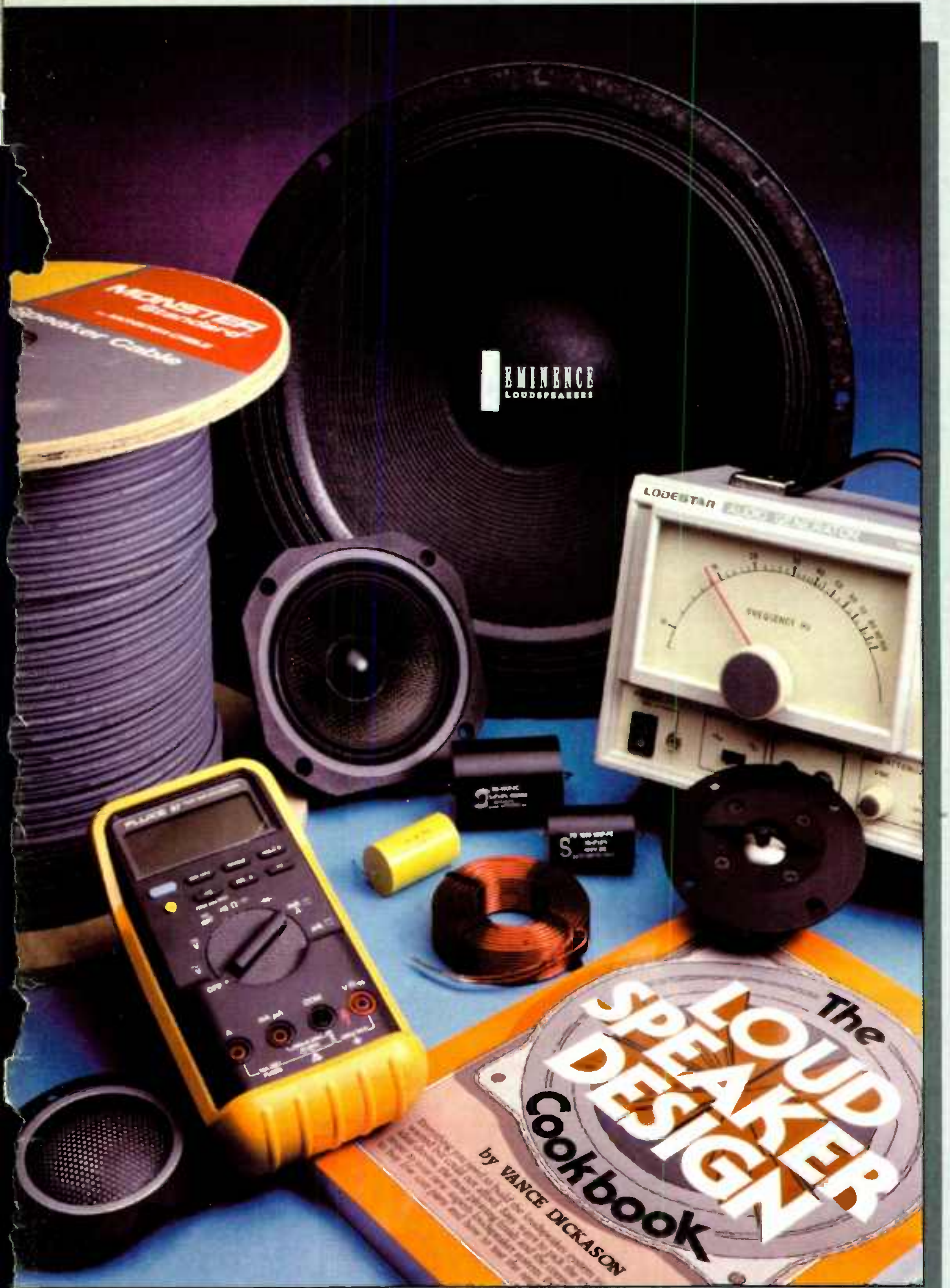
The second limitation to output is thermal or electrical. P_{ER} is the amount of sustained electrical input power a driver can withstand before temperatures rise to damage-causing levels. High temperatures can wreak all kinds of havoc, from softening adhesives and melting plastics to vaporizing fine copper voice coil windings.

In discussing sensitivity, I used an example of a driver with an efficiency of 1%, which means 1% of the input power is converted to sound. What happens to the other 99%? Almost all of it is turned into heat in the voice coil! With sustained operation at, say, 50W, the driver will produce only ½W of acoustical power, while 49½W will be dissipated as heat. Try changing a 50W light bulb that's been on for a few minutes and you'll get an idea of the amount of heat a loudspeaker voice coil might be asked to handle.

CAVEAT EMPTOR

Most manufacturers try to be diligent in specifying the T/S parameters for their products. Nevertheless, printed specifications must be taken with a grain of salt. In most cases they represent design parameters or, better yet, an average of several production runs. But because of the inevitable variations in materials (the suspension compliance is difficult to control tightly, for example), you are sure to see many unit-to-unit parameter variations as well. Given modern testing techniques, the best accuracy you can expect for these measurements is about 3%.

Also remember that, even if carefully measured, these values can change with conditions and time. For example, high-quality rubber surrounds can show large changes in compliance with temperature changes. Measurable differences in the V_{AS} of such drivers can occur even if the temperature varies from 65–85° F. ➢


MONSTER Standard Speaker Cable
EMINENCE LOUDSPEAKERS
LODESTAR
FREQUENCY Hz
FLUKE
The LOUD SPEAKER DESIGN Cookbook
by VANCE DICKASON


Parts Express

morel

High-Tech Audiophile Loudspeakers

Typical Double Magnet Woofer Cross Section

For Further Information Please Contact:

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

Reader Service #15