Finding Exact Mass & Resistance For Your Driver

FOUR: 1997

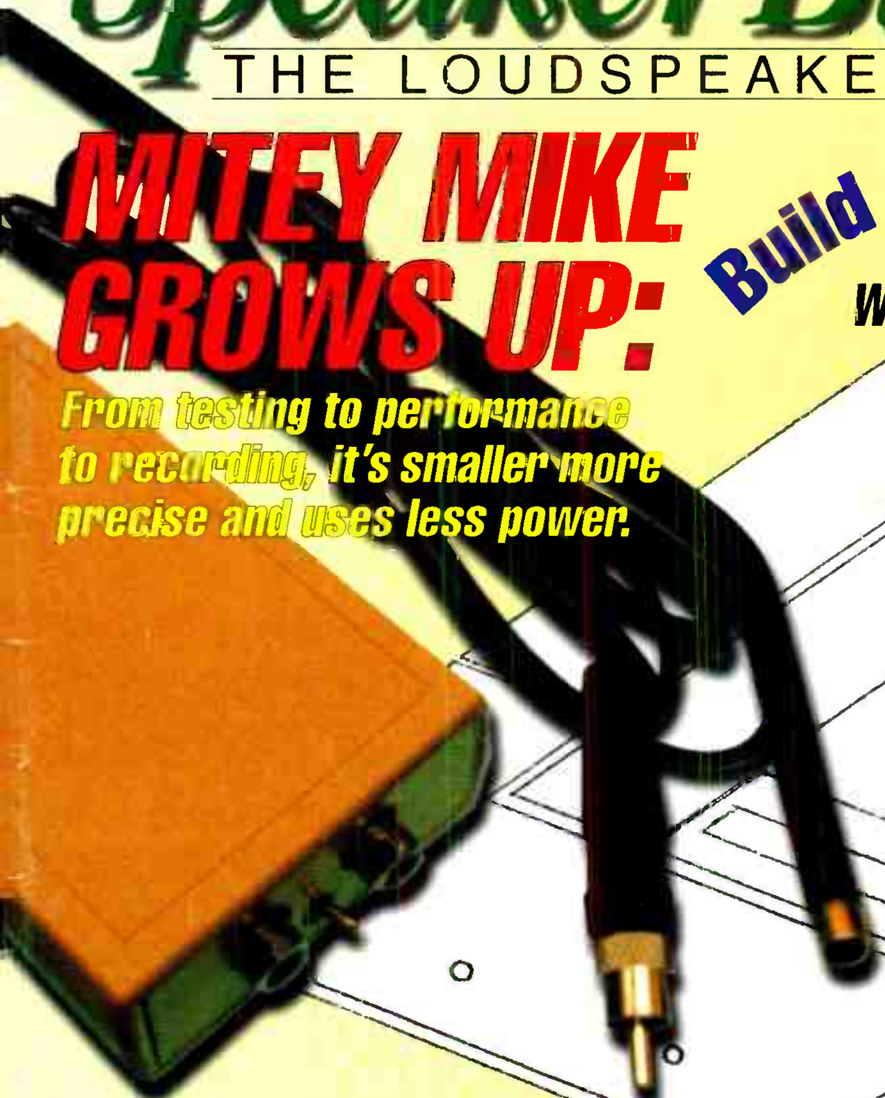
US $7.00
CANADA $8.00

Speaker Builder®

THE LOUDSPEAKER JOURNAL

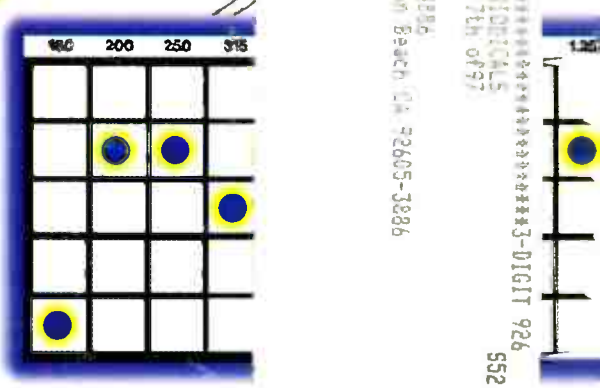
MITEY MIKE GROWS UP:

From testing to performance to recording, it's smaller more precise and uses less power.



Build An Electrost...

With Insulated ...



RULES OF THE ROAD

For Building GREAT LOUDSPEAKERS

Book Report:

Improving Sound In Your Car

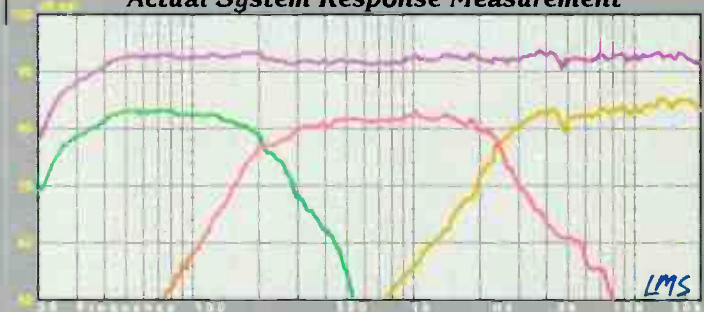
New! LEAP Version 4.5

LEAP

Precision Development Tools for Precision Loudspeaker Designs

LEAP System Response Prediction

Actual System Response Measurement

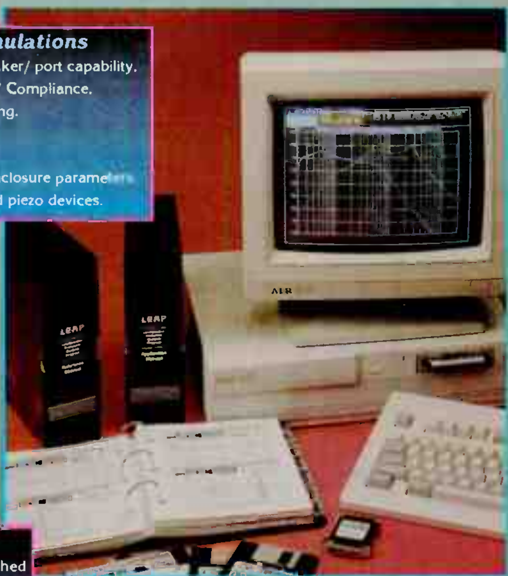


The Art and Science... of loudspeaker system development today has become more complex than ever before. Competition is tough, and to compete each design must perform to the best of its ability, and make the most out of every dollar's worth of transducer cost. The simple approach of choosing a combination of seemingly appropriate transducers coupled with ordinary networks and filters, has given way to a painstaking process of meticulously blending selected transducers in combination with carefully devised and matched crossover designs.

LEAP (Loudspeaker Enclosure Analysis Program) is a complete full range analysis package which provides virtually *all* of the tools necessary to develop precision loudspeaker systems, for today's demanding audio markets. Whether your applications are consumer audio, car stereo, professional audio, or custom esoteric marvels, LEAP provides the power, flexibility, and accuracy to investigate every possible design permutation. The open architecture and broad spectrum of features provided will dramatically reduce your development time, while improving the quality of the final result... and demonstrates why LEAP has become the #1 choice of professional loudspeaker designers world-wide!

Advanced Transducer/Enclosure Simulations

- ✔ Sealed,Vented, Bandpass, PR Simulations with multiple speaker/ port capability.
- ✔ Large signal analysis of TempVC, and Non-Linear BL/ Ports/ Compliance.
- ✔ Acoustic Parallel or Acoustic Series (Isobaric) Driver Mounting.
- ✔ Port Standing Wave resonance modeling.
- ✔ Frequency Dependent Revc and Levc modeling.
- ✔ Library storage of 36 transducer parameters, and over 24 enclosure parameters.
- ✔ Generic transducer modeling of electro-dynamic, ribbon, and piezo devices.



Advanced System Analysis Features

- ✔ Use simulation or Imported actual measured SPL/Z data.
- ✔ 5-Way crossover system modeling, and more.
- ✔ Time offset between transducers.
- ✔ Active or Passive based crossovers.
- ✔ Hilbert-Bode transform for deriving phase.
- ✔ 22 Passive components per xover section.
- ✔ 16 Active filter blocks per xover section.
- ✔ Passive Network Optimizer for single/system response.
- ✔ Active Filter Optimizer for single/system response.
- ✔ Frequency ranges from 1Hz to 100kHz.

Extensive Documentation

The two volume manual set comprises almost 1,000 pages of documentation which thoroughly covers the operation of the program- and provides numerous examples of how to maximize your use and understanding of the program's many features. The Reference Manual describes all graphs, menus, commands, and their operation. This manual explains the unique and special non-linear speaker and port models, as well as proper use of the optimizers, importing data, and the many other utilities. The Application Manual provides many exciting examples showing how to use the powerful features of the system in a combined manner to perform both simple and complex design tasks. Both novice and experienced users alike will find this information invaluable for exploiting the full power of the system. Additional information is also provided on loudspeaker measurements, design tips, filter calculations, and complete crossover system development for both passive and active based systems.

- ✔ 502 Page Reference Manual
- ✔ 436 Page Application Manual

Printer/Output Formats

When you wish to produce a hardcopy output of your finished designs and graphical data, LEAP supports a large number of printer standards, and even supports numerous desktop publishing graphic formats in both black & white and color! Portrait/Landscape orientations in any custom size and aspect ratio are user controllable.

- ✔ IBM/Epson 8 Pin Dot Matrix
- ✔ Epson 24 Pin Dot Matrix
- ✔ HP LaserJet Series Printers
- ✔ HPGL Compatible Plotters
- ✔ PostScript EPS/TIF B&W,Color
- ✔ AI-Adobe Illustrator B&W,Color
- ✔ NEC 24 Dot Matrix
- ✔ TOSHIBA 24 Dot Mat
- ✔ HP DeskJet 500C
- ✔ PostScript Printers
- ✔ DXF AutoCAD
- ✔ TIFF, BMP, PCX Plots

Call for a free Demo Disk!
TEL: (503) 620-3044

Development Utilities

- ✔ Quick Cabinet Box Designer
- ✔ Conjugate Network Designer
- ✔ Wire Table Calculator
- ✔ Multi Curve Averager
- ✔ Import Data from ASCII Files
- ✔ Crossover Network Designer
- ✔ Spkr Parameter Measurement
- ✔ Voltage/Current/Imp Calculator
- ✔ Motor Constants Calculator
- ✔ Export Data to ASCII Files

LINEARX™

LinearX Systems Inc 7556 SW Bridgeport Road Portland OR 97224 USA Tel (503) 620-3044 Fax (503) 598-9258

International Dealers: **Agentina**:Interface SRL (54 1)741 1389/**Australia**:ME Technologies 61(0)65-50 2200/**Austria**:Audiomax 49(0)71 31 162225/**Belgium**:Belram 32(0)2 736 50 00/**Canada**:Gerraudio 416 696 2779/**Denmark,Finland**:A&T Ljudproduktion 46(0)8-623 08 70/**France**:Belram 32(0)2-736 50 00/**Germany**:Audiomax 49(0)71-31-162225/**Indonesia**:Ken's Audio 62(0)21 639 5806/**Italy**:Outline snc 39-30 3581341/**Korea**:Sammi Sound:82(02)463 0394/**Luxembourg**:Belram 32(0)2 736-50-00/**Malaysia**:AUVI 65-283-2544/**New Zealand**:ME Technologies 61-65-50-2254/**Norway**:A&T Ljudproduktion 46(0)8-623 08-70/**Philippines**:Dai Ichi Denshi (63)-2631-69-80/**Poland**:Inter-Americom 48(22)43 23-34/**Singapore**: AUVI 65-283-2544/**Sweden**:A&T Ljudproduction 46(0)8-623-08 70/**Switzerland**:Audiomax 49 71-31-[illegible] **Taiwan**: Taycan Intl 886-2-786-3468/**Thailand**:AUVI 65-283-2544/**The Netherlands**:Duran Audio 31-41-80 15583/**UK(England)**:Munro Assoc 44(0)171-403-3808.

Reader Service #36

Good News

➲ WIRE 'EM UP

In-Wall Terminator Systems, from Music Interface Technologies (MIT), are high-performance speaker wiring products designed to deliver improved sound quality in custom installation applications, including home theater and whole-house sound systems. The products consist of three modules: the MITerminator In-Wall Speaker Module (for flush-mount speakers), the MITerminator On-Wall Speaker Module (for surface-mount speakers), and the MITerminator Freestanding Speaker Module (for floor-standing or shelf-mounted speakers). Each module contains MIT's patented circuitry, and is installed either in the wall cavity or in a single-gang box. Music Interface Technologies, Inc., 13620 Lincoln Way, Ste. 320, Auburn, CA 95602, (916) 888-0394, FAX (916) 888-0783.

Reader Service #102

■ PROGRAM FOR SPEAKERZ

True Audio has released WinSpeakerz 2.0, a loudspeaker program used to predict the performance of a speaker system before construction. This latest version models a speaker's response in either a listening-room or auto-cabin environment. The program also provides box calculators that support the design of passive crossovers, attenuators, and impedance compensation networks, and suggests dimensions for a specified volume, or calculates volume from specified dimensions. The company has also announced a name change, from True Image Audio to True Audio. True Audio, 349 W. Felicita Ave., Ste. 122, Escondido, CA 92025, Voice/FAX (760) 480-8961, E-mail Sharon@trueaudio.com, Website http://www.trueaudio.com.

Reader Service #101

■ HEAVY TRAFFIC

Marchand Electronics offers a free function generator you can download from its website. The program fg.exe allows any IBM PC (486 and up) with a Soundblaster soundcard and compatibles running Microsoft Windows 3.1, 95, or NT, to be used as a two-channel function generator. The frequency range is 1Hz–20kHz; waveforms are sine, square, triangle, and pulse, which are independently selectable for left and right channel. The company's website pages contain a full catalog of electronic crossover networks and power amplifiers for high-performance audio Marchand Electronics Inc., PO Box 473, Webster, NY 14580, (716) 872-0980, FAX (716) 872-1960, E-mail info@marchand-elec.com. Website http://www.marchand-elec.com.

■ PRECISION LUBRICANT

CaiLube MCL, from CAIG Laboratories, is a lubricant designed for use with conductive plastic, carbon compound faders, and switches, replenishing lubrication on surfaces cleaned with solvents or cleaning solutions. Applying CaiLube MCL will provide a barrier against oil, grease, and acids built up on the conductive membrane switches and components. Available in 5% or 100% spray, precision dispenser, and other sizes. CAIG Laboratories, Inc.. 16744 W. Bernardo Dr., San Diego, CA 92127-1904, (619) 451-1799, FAX (619) 451-2799, (800) CAIG-123,
E-mail caig123@aol.com, Website http://www.caig.com.

Reader Service #103

■ FLATLINERS

Nordost introduces the SPM Reference Series loudspeaker cables and interconnects. The cable is flat, only 44mm (1.75″) wide and 0.95mm (.038″) thick. It is made from high-quality extruded Teflon®, and consists of 32 conductors of solid 99.999999% oxygen-free copper, covered with 60μ of extruded silver. The interconnect is also flat, only 22mm (0.88″) wide and 0.95mm (.038″) thick. It is made from high-purity extruded Teflon and includes two groups of eight conductors encapsulated in a Teflon jacket (5 mils thick). Nordost Corporation, 420 Franklin St., Framingham, MA 01702, (508) 879-1242, FAX (508) 879-8197.

Reader Service # 108

■ THAT SOUNDS LOGICAL

Iasys is an easy-to-use logic-based electro-acoustic analyzer from AudioControl. This rugged, self-contained unit (no computer necessary) features high-speed analysis and portability. Its applications include system design and installation, system tuning and optimization, component research, and system servicing and reconfiguring. AudioControl Industrial™, 22410 70th Ave. W., Mountlake Terrace, WA 98043, (206) 775-8461, FAX (206) 778-3166.

Reader Service #107

■ HIGH HONORS

Ray Dolby, founder and chairman of Dolby Laboratories, Inc., has been named by President Clinton as a recipient of the 1997 National Medal of Technology, the nation's highest technology honor. The medal is awarded to individuals, teams of individuals, and companies in recognition of technological innovation and the advancement of US global competitiveness. Dolby holds 50 US patents, and has earned many technical and industry awards, including both an Oscar and an Emmy. Dolby Laboratories, Inc., 100 Portrero Ave., San Francisco, CA 94103, (415) 558-0200, FAX (415) 863-1373, E-mail info@dolby.com, Website http://www.dolby.com.

■ COMPREHENSIVE CATALOG

Parts Express releases their free 244-page 1997 catalog. This year's directory includes a selection of raw loudspeaker drivers for home and auto applications, as well as CATV and VCR repair parts, semiconductors, tools, home-theater products, alarm systems, test equipment, computer accessories. instructional books and videotapes, speaker design software, cellular phone accessories, stage lighting, pro sound equipment, and more. Parts Express, 340 E. First St., Dayton, OH, 45402-1257, (800) 338-0531, Website www.parts-express.com.

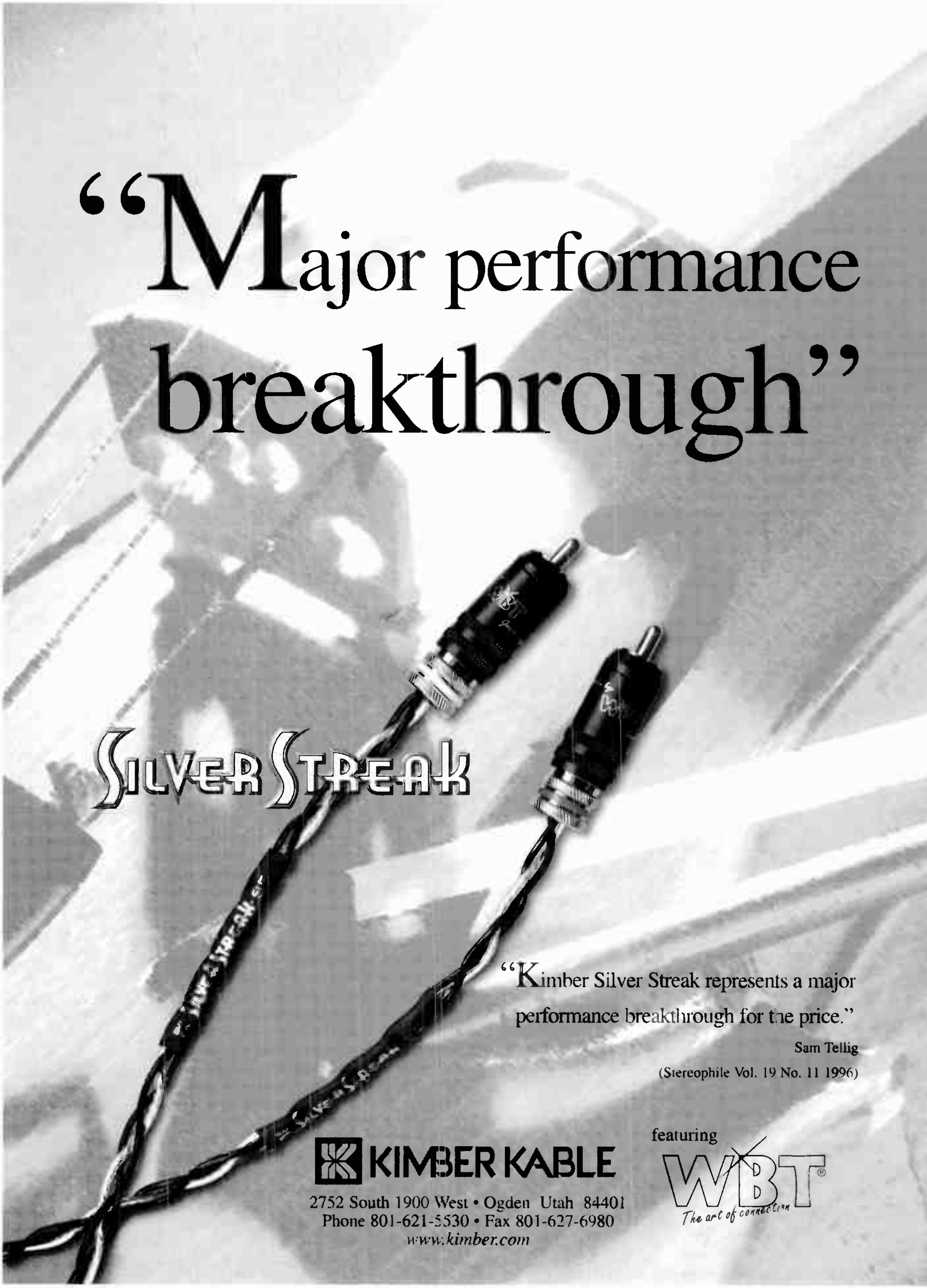
Reader Service # 105

■ ALL-SEASON SPEAKERS

The AW-700 Outdoor In-Wall Loudspeaker, from OEM Systems, is designed specifically for outside use. It features a 6½″ carbon fiber woofer with butyl rubber surround, 1″ weatherized titanium dome tweeter, a silicon-sealed crossover network, and gold-plated spring-clip terminals. The aluminum grille is rustproof, the hardware is stainless-steel, and anti-corrosive materials are included throughout. OEM Systems Co., Inc., 740 Freeport Blvd., Ste. 106, Sparks, NV 89431, (702) 355-0405, FAX (702) 355-0646.

Reader Service #106

Reader Service #65 →


"Major performance breakthrough"
SILVER STREAK
"Kimber Silver Streak represents a major performance breakthrough for the price."
Sam Tellig
(Stereophile Vol. 19 No. 11 1996)
KIMBER KABLE
2752 South 1900 West • Ogden Utah 84401
Phone 801-621-5530 • Fax 801-627-6980
www.kimber.com
featuring
WBT®
The art of connection

About This Issue

Mitey Mike has grown up. The popular, high-performance, low-cost mike system for loudspeaker and acoustic measurements now has expanded capabilities. Not just for testing, the latest version can also be used for recording and performance. The Mitey Mike II design is smaller, lighter, quieter, costs less, and uses less power. For more on how to use MMII—available in kit or assembled form—see the article by **Joe D'Appolito** and **Dick Campbell** beginning on p. 10.

As someone who has been in the speaker business, **Marc Bacon** knows what it takes to market a quality speaker. In "A Speaker Builder's Travel Guide" (p. 18), he provides some insights on how to build world-class speakers at home and offers some helpful directions and travel tips to those on the road to Speakerdom.

For all its added sound-performance benefits, electrostatic speakers require special care to build. **Matthew Lattis**'s interesting electrostatic loudspeaker design offers several advantages—including higher efficiency and lower cost—over most DIY designs. The author's solution to the problems associated with building such a device is a self-insulating diaphragm design ("An Insulated Diaphragm Electrostatic," p. 26).

In the course of designing a subwoofer, **Ahmet Deniz** devised equations to determine how much mass and/or resistance to add to achieve optimum sensitivity. "Of Mass and Resistance" (p. 36) shows how added mass affects other T/S equations governing driver behavior.

To improve the sound quality in your car, you might consider Dan Ferguson's latest book, *Ultimate Auto Sound*. **Mark Florian** reviews this handbook for those who wish to install and/or upgrade their present car sound system (p. 44).

Speaker Builder®

The Staff

Editor and Publisher
Edward T. Dell, Jr.

Regular Contributors
Joseph D'Appolito, Robert Bullock, Richard Campbell, John Cockroft, David Davenport, Vance Dickason, Bruce Edgar, Gary Galo, G.R. Koonce, Richard Pierce, Bill Waslo

Vice President
Karen Hebert

Dennis Brisson Assistant Publisher
Swain Pratt Associate Editor
Courtney E. Howard Assistant Editor
Karen Chivallati Editorial Assistant
Tina Hoppock Graphics Director
Diane Luopa Assistant Graphics Director
Joan Ahern Production Assistant
Joannie Berriman Production Assistant
Laurel Humphrey Marketing Director
Misty L'Ecuyer Marketing Assistant
JoAnne Leclair Customer Service Supervisor
Robyn Lasanen Circulation Manager
Kelly Bennett Customer Service
Peter B. Wostrel National Advertising Director
Lisa DiRusso Advertising Sales
Ann Avery Advertising Coordinator

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.

LEGAL NOTICE

Each design published in Speaker Builder is the intellectual property of its author and is offered to readers for their personal use only. Any commercial use of such ideas or designs without prior written permission is an infringement of the copyright protection of the work of each contributing author.

SUBSCRIPTION/CUSTOMER SERVICE INQUIRIES

A one year subscription costs $32. Canada please add $8. Overseas rate is $50 per year.

To subscribe, renew or change address write to the Circulation Department (PO Box 494, Peterborough, NH 03458-0494) or telephone (603) 924-9464 or FAX (603) 924-9467 for MC/Visa/Discover charge card orders. E-mail: **audiotech@top.monad.net.**

For gift subscriptions please include gift recipient's name and your own, with remittance. A gift card will be sent.

EDITORIAL INQUIRIES

Send editorial correspondence and manuscripts to *Speaker Builder*, Editorial Dept., PO Box 494, Peterborough, NH 03458-0494. **E-mail: audiodiy@top.monad.net.** No responsibility is assumed for unsolicited manuscripts. Include a self-addressed envelope with return postage. The staff ***will not*** answer technical queries by telephone.

ADVERTISING RATES & SCHEDULES

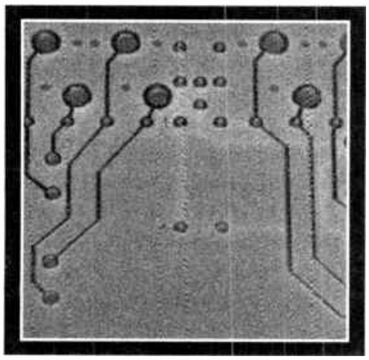
Contact Advertising Department, Speaker Builder, PO Box 494, Peterborough, NH 03458, 603-924-7292, FAX 603-924-9467, E-mail audiotech@top.monad.net.

Speaker Builder (US USSN 0199-7920) 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 Corporation, Edward T. Dell, Jr., President, at 305 Union Street, PO Box 494, Peterborough, NH 03458-0494. Periodicals postage paid at Peterborough, NH and an additional mailing office.

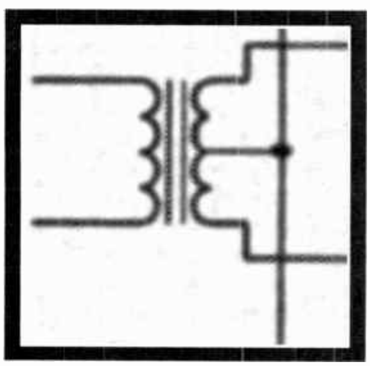
POSTMASTER:
Send address change to:
Speaker Builder, PO Box 494

Speaker Builder
THE LOUDSPEAKER JOURNAL

VOLUME 18 NUMBER 4 JUNE 1997



10



26

DEPARTMENTS

KEEP IN TOUCH

EDITORIAL — Send letters, questions, and comments to: Speaker Builder, Editorial Dept., PO Box 494, Peterborough, NH 03458 USA, FAX (603) 924-9467, E-mail: audiodiy@top.monad.net.

Be sure to reference the issue, title, author, and page number of the article or letter in question; and if you request an answer from an author, please include a self-addressed envelope (and your FAX number and/or E-mail address, if applicable), with a loose stamp or postal coupon.

Due to the volume of correspondence, we cannot personally acknowledge or respond to each letter or query. All letters to the editor will be considered for publication unless you indicate otherwise. *Speaker Builder* reserves the right to edit your letters or technical queries for length and clarity.

Author guidelines are available by sending a self-addressed envelope with loose postage to the above address.

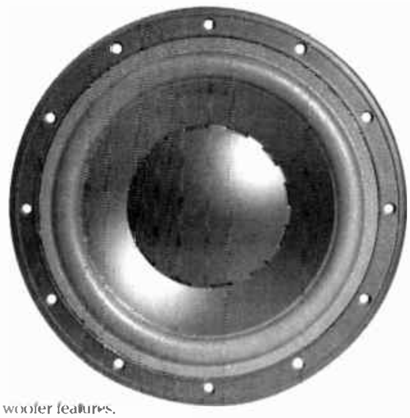
CIRCULATION — For subscriptions, renewals, back issues, or address changes, write to the Circulation Department (PO Box 494, Peterborough, NH 03458) or call (603) 924-9464 or FAX (603) 924-9467. E-mail: audiotech@top.monad.net.

ADVERTISING — Address advertising inquiries and information requests to the Advertising Department, Audio Amateur Corporation, PO Box 494, Peterborough, NH 03458-0494, voice (603) 924-7292, FAX (603) 924-9467.

OLD COLONY SOUND LAB — For product information and ordering, contact Old Colony Sound Laboratory, PO Box 243, Peterborough, NH 03458-0243, voice (603) 924-6371 and (603) 924-6526, FAX (603) 924-9467.

It could be your solution for **Perfect** LOW frequency

reproduction



D8 woofer features:
- shallow mineral filled polypropylene cone;
- high density foam surround;
- self-enclosed vented Neodymium magnet system ;
- undercut magnetic poles;
- long-throw voice coil ø100 mm with black anodized aluminum former;
- die-cast frame;
- flat linear spider with decompressed rear volume.

D8 represents a design where Neodymium magnet and undercut central pole are placed inside 100 mm voice coil. A specially shaped, CNC machined steel cup completes the magnetic structure from the outside creating a shielded magnet system with symmetrical flux density distribution along the gap. Thus a long-throw voice coil experiences symmetric driving force and substantial decrease of inductance and back electromotive force modulations. The whole magnet structure is optimized using Finite Element Analysis technique. For effective use of large excursion capability of D8, a flat linear spider is used together with an open volume under the spider.
This approach resulted in radical quality improvement of sound reproduction.

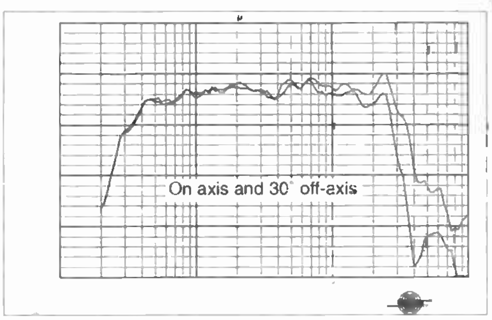
Vented design, effective heat transfer to the die-cast frame and a very large, high temperature rated voice coil, dramatically increase power handling of the driver.
A shallow high integrity cone and a large circumference of cone excitation improve phase and transient characteristics, resulting in clear and accurate sound.
D8 is excellent as a woofer for high power audiophile systems. It also may be used as a subwoofer in various configurations.

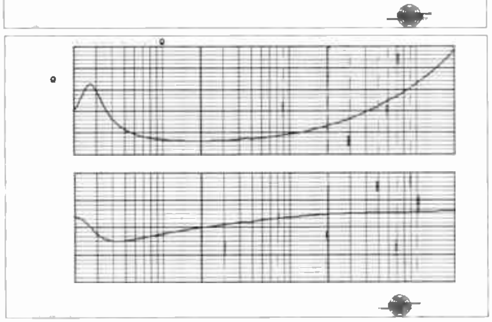
SPECIFICATIONS

Characteristics	Symbol	Value	Units
PRIMARY APPLICATION			
Nominal Impedance	Z	6	Ω
Resonance Frequency	Fs	27	Hz
Nominal Power Handling	Pnom	250	W
Max Power Handling	Pmax	400	W
Sensitivity (1w/1m)		87.5	dB
VOICE COIL			
Diameter	ø	100	mm
DC Resistance	Re	4.5	Ω
Inductance	Lbm	0.81	mH
Length	H	17	mm
Former		anodized aluminum	
Layers		2	
MAGNET			
Magnet System		self-enclosed vented neodymium	
Force Factor	BL	8.9	T•m
Gap Height	He	7	mm
Linear Excursion	Xmax	5	mm
PARAMETERS			
Suspension Compliance	Cms	947	µM/N
Mechanical Q	Qms	2.06	-
Electrical Q	Qes	0.36	-
Total Q	Qts	0.31	-
Moving Mass	Mms	35.7	g
Effective Pistone Area	Sd	227	cm^2
Equivalent Air Volume	Vas	69	L
Weight	M	3.2	kg

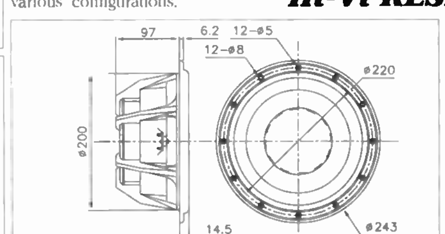
RECOMMENDED ACOUSTICAL ALIGNMEMT

DESCRIPTION	VB,L	FB,Hz	F-3,Hz
Compact Vented Box	25	36	41.6
Medium Vented Box	40	33	33.7
Large Vented Box	60	30	27.8





woofer **D8** from *Hi-Vi RESEARCH®*



for more info please

Call: (905)-475-3100

ACOUSTIC TECHNOLOGY INTERNATIONAL INC.
100 SPY COURT, MARKHAM, ONTARIO
L3R 5H6 CANADA
Tel: (905)-475-3100 Fax: (905)-475-8226

Due to constant product improvement Hi-Vi Research may modify specifications without prior notice

Postage
Required
Post Office will
not deliver
without proper
postage.

SpeakerBuilder
THE LOUDSPEAKER JOURNAL
PO Box 494 Dept RDS7
Peterborough, NH 03458-0494

Postage
Required
Post Office will
not deliver
without proper
postage.

SpeakerBuilder
THE LOUDSPEAKER JOURNAL
PO Box 494 Dept RDS7
Peterborough, NH 03458-0494

SpeakerBuilder THE LOUDSPEAKER JOURNAL

SAVE UP TO 42% off the cover price with A SUBSCRIPTION

Subscribe now and save at least 42% off the cost of buying *Speaker Builder* on the newsstand. And, get home delivery. **This card is from issue number 1 2 3 4 5 6 7 8 (circle one)**

YES! I want every issue of *Speaker Builder* delivered to me, sign me up for:

- ☐ 2 years (16 issues) at $58.00 (SAVE $54 OFF THE COVER PRICE)
- ☐ 1 year (8 issues) at $32.00 (SAVE 24%)

Canada/Mexico add $8 per year. **Overseas rates:** 1 year-$50; 2 years-$90. Remit in US $ drawn on a US bank only.

NAME

ADDRESS

CITY/STATE/ZIP

COUNTRY

PHONE *Allow 6-8 weeks for delivery of first issue Rates subject to change*

METHOD OF PAYMENT

☐ Check or money order ☐ Mastercard ☐ VISA ☐ Discover ☐ American Express

CARD NO EXP DATE

SIGNATURE

Editorial

TOYING WITH THE FUTURE

I once heard a sad tale of a small village whose inhabitants were living through a very long, bitter winter. As time passed their food supplies dwindled lower and lower. Eventually, people faced starvation and decided to open the stores of grain reserved for spring planting, hoping that the winter would soon end. Alas, it did not. When spring arrived, their seed corn was gone.

Since WWII we have been, so to speak, consuming our electronics know-how seed corn. Today there is a 17% shortage of engineers. The need is acute and few candidates are available, especially those equipped to design loudspeaker drivers. One change that came about in both the United States and Great Britain when the war ended was the dismantling of the apprentice system. On the continent, apprentice programs remained intact in most industries, and are in place today. The education of engineer candidates in the US and the UK became more "book-oriented" and far less "hands on." Engineers have come to depend upon the technicians to know how to build the designed device, with little practical understanding of how this happens. It is a truism that the technician's job is not only to build the device but then to "make it work," a polite term for re-engineering it so that it will work.

I talked at length the other day with one author who observed that he finally retired from one of America's largest manufacturing companies when his boss, a 30-year-old manager, asked whether a 62% error in a project result was a problem.

A year ago I had the pleasure of visiting three loudspeaker manufacturing firms in Denmark. All of them have programs for apprentices at most levels of the business. They maintain strong ties with the large technical universities in Denmark, as well. The production manager of Dynaudio in Skanderborg explained that the company offers a series of hobbyist kits, which seems a bit of an anomaly when you consider the rather "high-end" character of the company's product line. When I asked about this he said Dynaudio noticed that its OEM customers were almost always founded or managed, or both, by people who had developed a passion for loudspeakers in their teens, or even earlier. Thus, Dynaudio regards its kits as business incubators for the future.

When I talk with people in this business, including the authors, I generally ask how they got started in electronics. Almost invariably it will be a kit they built, sometimes very early in life. For some others it is a father, an uncle, or a friend who shared an interest in the avocation. In my own case I was introduced to ham radio by building a single-tube code-practice oscillator, guided by an older friend. When I discovered Heathkits later on, I had the confidence to tackle an amplifier.

If we are to be dependent upon kits for planting a passion for electronics innovation in young people, the future could have looked quite bleak until recently. If you look through the pages of this periodical and *Glass Audio*, you will notice that kit offerings are growing plentiful again. I am glad to say I am launching a new program aimed at reviewing the fresh new crop of speaker kits available from our advertisers. Authors are already at work building the kits which will be auditioned and then sent to Joseph D'Appolito for performance measurements. These should appear in each issue before the end of this year.

The President and General Powell recently called on the citizens of this nation to consider giving time to mentoring young people in many skill areas. Certainly, this is an important and promising enterprise. I know of few projects that would be of greater interest to teenagers than building their own loudspeakers. Have you considered offering to share your skills with a younger friend, or perhaps to the technical college or high school in your area? If you belong to one of the many audio clubs scattered across the US, wouldn't sharing your knowledge with a group of interested teenagers be a worthwhile club project? I am sure you would find vendors among our advertisers who would be glad to cooperate on group-rate pricing of supplies for such undertakings.

Which brings me to toy soldering irons. I hope those of you who wrote irate letters, and those of you who didn't but wanted to, will reconsider your ideas about what is appropriate for these pages. There is no future for those of us who are merely ready to consume every resource in our own time, with no thought for tomorrow. I believed, and still believe, that a few pages about a toy that might turn a growing boy into tomorrow's speaker builder is space well spent.—E.T.D.

MITEY MIKE II

By Joseph D'Appolito and Richard H. Campbell

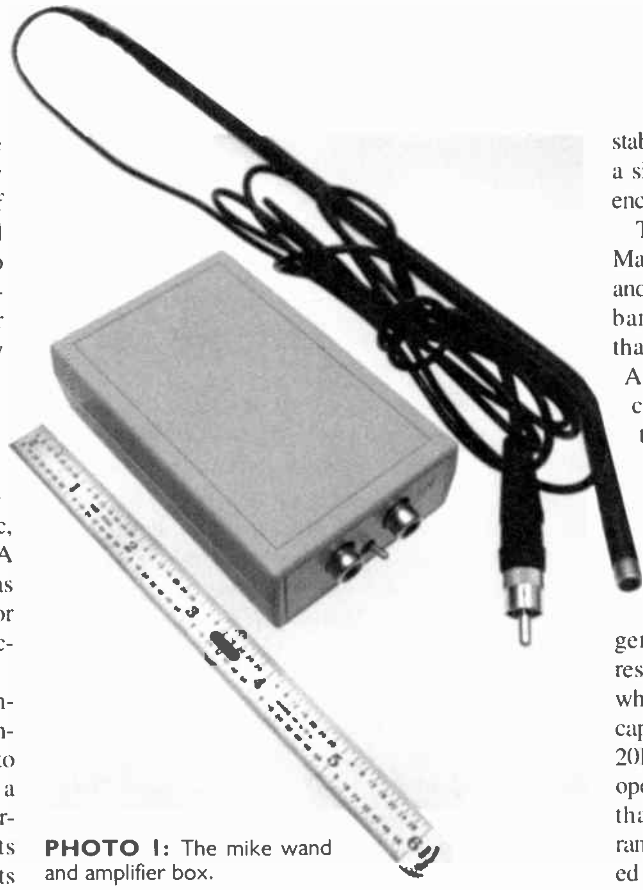


PHOTO 1: The mike wand and amplifier box.

It has been more than six years since the article that first described Mitey Mike appeared in the 6/90 issue of *Speaker Builder*. In that time, several hundred Mitey Mikes have come into existence, either through home construction following the plans in the article or through the kit supplied by Old Colony Sound Lab.

We were quite surprised by the popularity of Mitey Mike. Originally intended only for loudspeaker testing, it has become widely used by technicians and other professionals in music, sound reinforcement, and acoustics. DRA Laboratories has chosen Mitey Mike as one of its recommended accessories for use with its PC-based MLSSA acoustic-analysis system.

As good as Mitey Mike is, semiconductor technology and construction techniques have advanced in recent years to the point where it is possible to make a significant upgrade in Mitey Mike's performance while greatly reducing its power consumption and the size of its electronics package. In discussing the original and new versions of Mitey Mike, we will refer to them as MMI and MMII, respectively.

MMI: THE PAST

The design goals for MMI were to produce a stable, accurate, low-power, self-powered microphone for loudspeaker testing, with a buffered output capable of driving long shielded cables. The heart of the microphone was the Panasonic WM-063T back electret microphone capsule. This $2.25 wonder had a frequency response of 20Hz–20kHz, with a typical tolerance of ±2dB over that range. Below 4kHz, response was typically better than ±1dB. The capsule had two shortcomings, however: high output impedance and a sensitivity that changed significantly with changes in supply voltage.

The MMI electronics contained a stable voltage reference to power the capsule and a low-power op amp to buffer the mike output for long, shielded-cable drive. The op amp also supplied enough gain to allow a typical wideband AC voltmeter to read MMI's output directly without additional amplification.

The electronics package occupied about 20 in^3. The circuit was laid out on a conventional one-sided PC board, with 8-pin DIP ICs and discrete capacitors and resistors. The electronics drew about 500–550µA, and at that current level, a 9V alkaline battery gave about 500 hours of useful life. In the middle 80s when MMI was first designed, that was the lowest total power consumption we could get with readily available ICs.

ENTER MMII

Photo 1 shows the MMII electronics package and microphone wand. In contrast to MMI, the electronics now fit into a 9 in^3 pager box. Double-sided surface-mount technology replaces the conventional PC construction used in MMI. All ICs are surface mount, and chip capacitors and resistors replace the discrete parts in MMI. MMII also replaces MMI's 50µA stable-voltage reference circuit with a single precision IC voltage reference requiring only 15µA.

The new output-buffer op amp, a Maxim MAX402, draws only 60µA and yet has lower distortion, wider bandwidth, and higher slew rate than the 180µA Analog Devices' AD548 used in MMI. The total current draw of the MMII electronics is now only 200–220µA with a 9V alkaline battery, the life of which extends to more than 1,000 hours.

Finally, the WM-060AY capsule replaces the discontinued WM-063T. The new capsule is generally superior, having tighter response characteristics and somewhat lower noise. Many of the new capsules test out at ±1dB over the 20Hz–20kHz range. We have developed a modification to the capsule that greatly extends its dynamic range and linearity. While not needed for loudspeaker testing, we recommend this mod for voice and music sound reinforcement in close-miked PA applications.

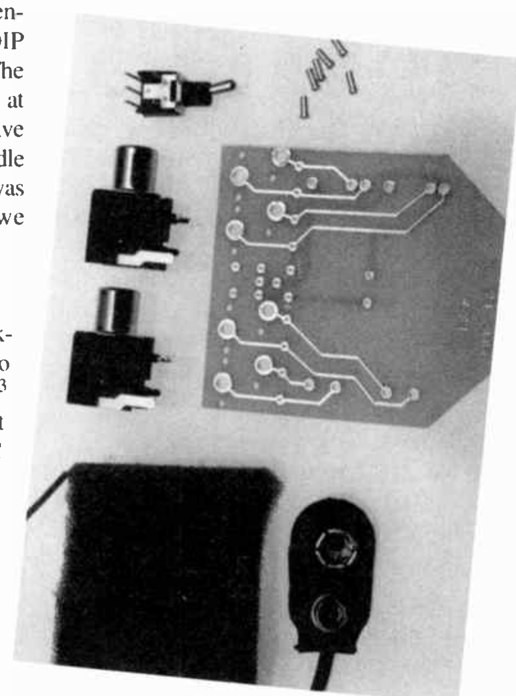


PHOTO 2: Laid-out kit of parts for the MMII box.

MMII SPECIFICATIONS

The typical MMII frequency response (*Fig. 1a*) is comparable to a good instrumentation mike. We obtained this curve by a direct comparison of MMII with a laboratory-grade microphone that is flat within ±0.5dB over 20Hz–20kHz and down only 2dB at 40kHz.

Figure 1b shows the phase shift of MMII relative to the lab mike. That MMII's phase shift is only 20° more at 20kHz is due solely to its lower frequency rolloff. No data below 400Hz is shown, since the MMII capsule is essentially flat below this frequency.

Table 1 shows the MMII's specifications. The abbreviation "Pa" stands for the Pascal, a measure of pressure in SI units equal to one Newton per square meter. One Pascal corresponds to 94dB at sound pressure level (SPL). So our specification means that MMII will output 25mV at 94dB SPL. Maximum SPL capability is commonly quoted as the SPL level that produces 3% total harmonic distortion (THD).

Maximum SPL capability for $3,000–$5,000 lab mikes is typically 150–160dB. For MMII, the maximum SPL is limited by supply voltage and the higher sensitivity we have built into it. The 130dB spec is more than adequate for loudspeaker testing, however, since the testing is conducted typically in the 80–100dB range.

MMII's total noise power is quite good—comparable to many lab-grade mikes. *Figure 2* shows the total noise-power spectrum for MMII. We made this measurement by wrapping the mike wand in a large roll of fiberglass insulation and placing the roll inside an old refrigerator. Above 1kHz, MMII noise was equivalent to 5dB SPL or less! Subtracting this number from the maximum SPL capability, we got a dynamic range of 125dB.

As is typical of all mikes, the noise level rises at lower frequencies. Even at 20Hz, where the noise level is 35dB, we get a dynamic range of 95dB. This is more than adequate for loudspeaker testing, where distortion products are rarely more than 40dB below test levels. The broad-band electronics noise level is 26dB below the MMII total.

So electronics noise does not limit MMII's performance. MMII's noise is so low that MLSSA is operating at maximum gain with a full-scale sensitivity of only 10μV to measure it. At this gain setting, we also see a spike in the spectrum at 8kHz due to leakage into the measurement from an on-board oscillator.

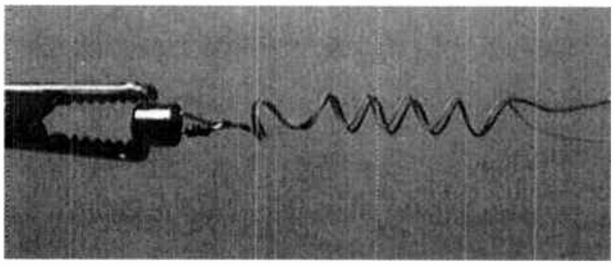


PHOTO 3: Capsule with resistor and leads soldered to it.

MMII ELECTRONICS

Figure 3 is a functional diagram of the MMII electronics. The mike is battery powered to avoid problems and circuit complications associated with phantom or remote powering. We placed great emphasis on an ultra-low-power design to extend battery life. The electronics consist of a micropower voltage reference providing a stable supply voltage to the mike capsule, the capsule itself, and a micropower op-amp buffer/gain block. As stated above, the combination draws no more than 200–220μA, and it can drive 50′ of shielded cable with no loss in frequency response.

Figure 4 is a schematic diagram of the microphone electronics. IC1, a Maxim MAX874, is a very stable micropower voltage reference, providing a constant 4.096V. It draws only 15μA to power its internal circuitry, but can source up to 500μA. Drop-out voltage is 200mV, so it has no trouble regulating capsule voltage as battery voltage falls over several hundred hours from 9V to its useful lower limit of 6V.

Unfortunately, micropower voltage references tend to be noisy. R1, C1, and C1A form a low-pass filter to filter out this noise. C1A is a high-frequency bypass for C1. R2 is the load resistor for the WM-060AY mike capsule. With the modified mike capsule, the optimum value of R2 is 10k.

C3 serves as a DC blocking capacitor while also coupling the AC mike capsule output to IC2. L1, formed with a ferrite bead, and C2 make up a high-frequency low-pass filter to block RF noise that may appear on the cable connecting the microphone wand to the electronics package.

IC2 is a Maxim MAX402. In this application, the 402 has a full-power bandwidth of over 100kHz, while drawing only 60μA. Resistors R4 and R5 set the DC operating point for IC2 midway between the supply voltage and ground to provide symmetric clipping. C4 filters the bias voltage, shorting to ground any noise voltage on the power supply. R6 and R7 set the AC gain to 2, while C7 returns IC2's gain to unity at DC so that the DC operating point is solely a function of R4 and R5.

C8 provides high-frequency compensation for IC2, while R8 buffers the op amp against capacitive cable loads. Because pin 6 of IC2 sits at one-half the supply voltage with no signal, C9 is required to block DC from any meter or other measurement device placed on MMII's output. Finally, R9 provides a DC return path to charge C9 at turn-on.

ASSEMBLING THE ELECTRONICS

We assumed that the majority of readers would not have the equipment needed to assemble a double-sided PC board with surface-mount components. A fully assembled and tested circuit board is available from Old Colony Sound Lab as one element in a complete kit of parts for the MMII electronics, but is also available separately. The kit is shown in *Photo 2*. *Table 2* is the parts list.

Following is an extract from the instructions for assembling an MMII electronics kit.

Solder the pin receptacles, switch, and jacks onto the PC board. As an alignment aid, slip on the end panel before soldering the switch and jacks. Now solder the 9V battery clip wires to the correct PC-board

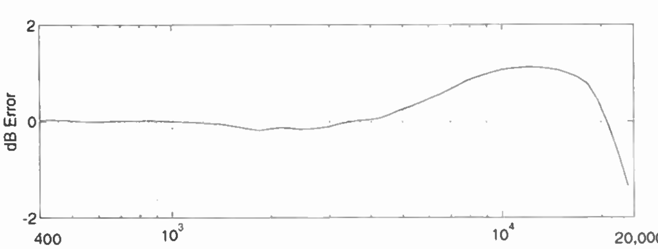


FIGURE 1A: Typical calibration curve for MMII.

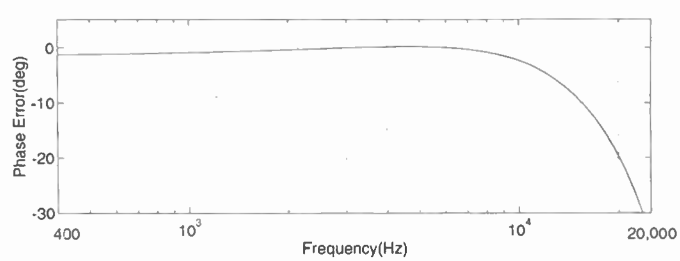


FIGURE 1B: Phase response of MMII relative to lab mike.

terminals, with the red wire soldered to the pad marked +. Slide the case-end panel over the switch and jacks (with the nomenclature facing out), taking care not to force the panel over the jacks or the switch bushing.

Now fit the assembly into the box, carefully guiding the end panel into the slots. Align the MMII amplifier pins with the PC board receptacles, getting all pin tips into place before pushing on the MMII. Press the MMII amplifier very gently into place, taking great care not to bend the solid brass pins, or they will surely break. Then place the foam piece on top of the PC board—it goes only over the amplifier, not over the jacks—and fit the cover, attaching it with two screws and a very small Phillips screwdriver. Finally, connect the battery and switch on and test the microphone preamp (accidentally touching the battery backward will do no harm).

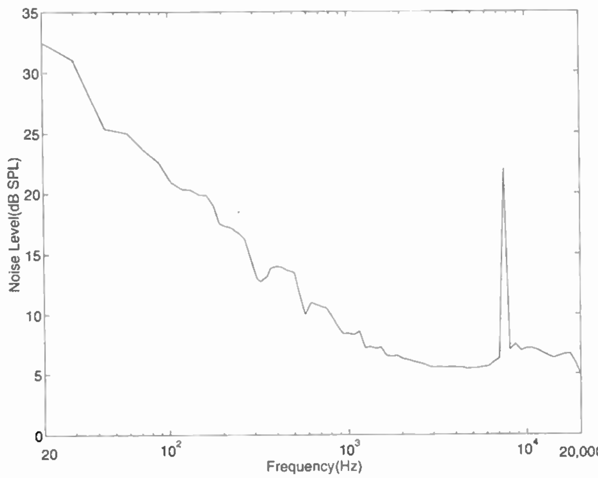


FIGURE 2: Plot of MMII's total noise spectrum.

MODIFYING THE WM-060AY CAPSULE

The Panasonic WM-060AY microphone capsule has a built-in FET with an integrated source resistance to ground. It is not possible to get at the connection between this internal resistor and the FET source terminal. The internal source resistance, about 75Ω, works well in applications for which the capsule was designed originally, such as tiny portable tape recorders and telephones where the SPL is from normal speech.

PHOTO 4: Cutting modification on the WM-060AY capsule.

However, even when the capsule is operated at higher supply voltages, with SPLs above 110dB, the distortion at the drain connection is apparent when using the recommended 2.7k drain resistor. At the higher SPLs, the distortion is unacceptable. In the end, it boils down to insufficient gate bias for high-input signal levels from the microphone diaphragm. The only solution is to increase the gate bias by increasing the external source resistance.

The diaphragm is grounded to the case and the free end of the internal source resistance is connected to solder pad A on the back of the capsule, as seen in *Photo 3*. The other solder pad, B, is the drain. The internal source resistor is grounded to the case through a printed circuit trace visible on the back side of the capsule. It is possible to cut this trace thereby disconnecting the internal source resistor from case ground. We then add another external resistor to the source circuit and ground *it* to the case. The electric transducer diaphragm is grounded to the case, thus completing the circuit (*Photo 4*).

DRAMATIC CHANGE

Adding 150Ω to the FET source and changing the drain resistor to 10k has a dramatic effect on capsule performance. The distortion at 100dB drops by a factor of 10 to about 0.2%, in part due to higher source degeneration. The sound level can be in excess of 125dB before the distortion becomes significant. The audio signal at the coupling capacitor increases by about 10dB, so the amplifier gain can decrease to 6dB, thereby improving its performance due to increased feedback.

Tests have shown that an unmodified capsule will work well even with the 10k drain resistor for most loudspeaker-measurement applications. A modified capsule might be in order for close-miked sound reinforcement, musical-instrument pickup, recording applications, or THD evaluation at very high SPLs.

We mention that the diaphragm is grounded, which may sound strange to those who think of electret diaphragms as things you must carefully insulate *from* ground. The WM-060AY is a "back-electret" design, as are most modern capacitor microphones. The surface-charged electret film is not on the diaphragm but on the fixed backplate, which is carefully insulated from ground and connected directly to the FET gate.

The diaphragm is, in effect, a moving ground relative to the backplate, causing the backplate voltage to vary as the capsule capacitance varies with sound pressure. The beauty of this design is that the entire transducer is shielded inside of a grounded conductive enclosure, a portion of which is the diaphragm itself.

MICROPHONE CAPSULE PREPARATION

If you are not a watchmaker, perhaps you should not try this. The first step is to slightly rough up the outside of the capsule with a very small file, because you will attach it to the wand using conductive epoxy. The aluminum capsule case is extremely thin, so you must handle it with great care.

Hold the capsule in some kind of fixture. One approach is to drill a ¼″ hole ¼″ deep in a hardwood block and insert the capsule, contacts up, into the hole. On the back side, locate the printed-circuit trace that runs from one pad to the underside of the case-

TABLE 1

MMII SPECIFICATIONS

Response (rel. 1kHz)	±1dB, 20Hz–10kHz ±2dB, 10kHz–20kHz
Sensitivity @ 1kHz	25mV/Pa, ±2dB
Max. SPL (at 3% THD)	130dB
Wideband noise level	
Flat weighting	≤40dB
"A" weighted	≤36dB
Mid-band dynamic range	≥120dB

TABLE 2

KIT PARTS LIST

Case (bottom, top, end panel, two screws)
9V battery connector with red and black leads
PC board MMII-6214
Two PC-mount RCA jacks
One PC-mount miniature toggle switch
Six (one extra) PC-mount gold pin receptacles
One MMII amplifier assembly
Foam piece

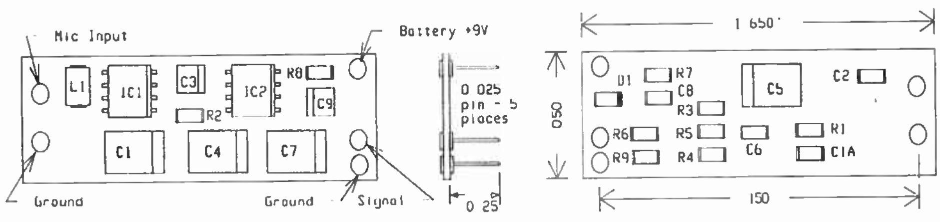


FIGURE 3: Parts placement for both sides of the MMII board.

edge roll. Using a very sharp, fine knife, cut through and remove a portion of the trace to break the circuit.

Prepare a 1/10W 150Ω film resistor by bending the leads 90° close to the body. Cut each bend to about 0.050″, making, in effect, a tiny hook in the ends of both leads. Using the lowest-powered, smallest-tipped soldering iron available, solder one end of the resistor to the pad from which you cut the trace. The resistor should be standing straight up from the back of the capsule. Apply only enough heat to achieve a proper solder joint.

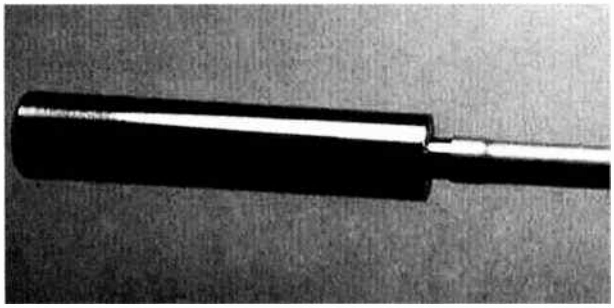


PHOTO 5: Use swaging tool to enlarge capsule end of wand.

Prepare one 6″ and one 5″ piece of #30 wire-wrap (silver-plated, Kapton®-insulated) wire of different colors by stripping the ends about 1/8″. Hook one end of the 5″ piece to the 150Ω resistor and solder. Hook one end of the six-inch piece to the remaining pad on the capsule and solder.

WAND PREPARATION

Fabricate the wand from a 12″ length of 0.25″ OD brass tubing with a wall thickness of 0.014″. The outside diameter of the WM-060AY is larger than the inner diameter of the tube, so you must swage the tube to enlarge it (*Photo 5*). You do the swaging by holding one end of the tube against a forgiving surface, such as wood, inserting the swaging tool into the other end and beating on it with a soft hammer until the tool shoulder touches the tube. The capsule will then fit snugly into the enlarged end.

Cross-drill the opposite end of the tube in two 90° passes with a 1/16 drill, making four holes for the strain-relief cables. Drill these four holes 0.15″ from the end of the tube. Then brighten both inside ends of the tube with a tiny ball cutting wheel mounted in a hand-held grinder to make good electrical-bonding surfaces. Also, it is important to thoroughly deburr the cross-drilled holes inside and outside one tube.

Now bend the wand 45° at a point three inches from the swaged end. The reason for this is to get the bulk of the assembly away from the capsule's main axis. It is extremely bad measurement practice to have any normal reflecting surfaces behind the microphone on its main axis. Usually the wand will be clamped in a mike stand, which can cause diffraction and reflection at the short wavelengths associated with tweeter measurements. With a bent wand, the clamping device is far off axis and can be covered with absorptive material.

GROUNDING-WIRE INSTALLATION

The next step is to prepare the drilled end of the tube for the grounding wire by tinning the inside where the cross-drilled holes are located. Cut a 4″ piece of #28 stranded hookup wire and strip each end about ¼″. Fold the wire sharply at a point 1.5″ from one end. Insert the fold into the tube so that the shorter stripped end is even with the end of the tube. After a bit of monkeying around, you can make the stripped end lie against the tinned inside wall of the tube. Solder it there. This leaves about 1″ of ground wire sticking out of the end of the tube.

Now cut two 12″ pieces of fishing-leader wire for the cable strain relief. Use 30 lb-

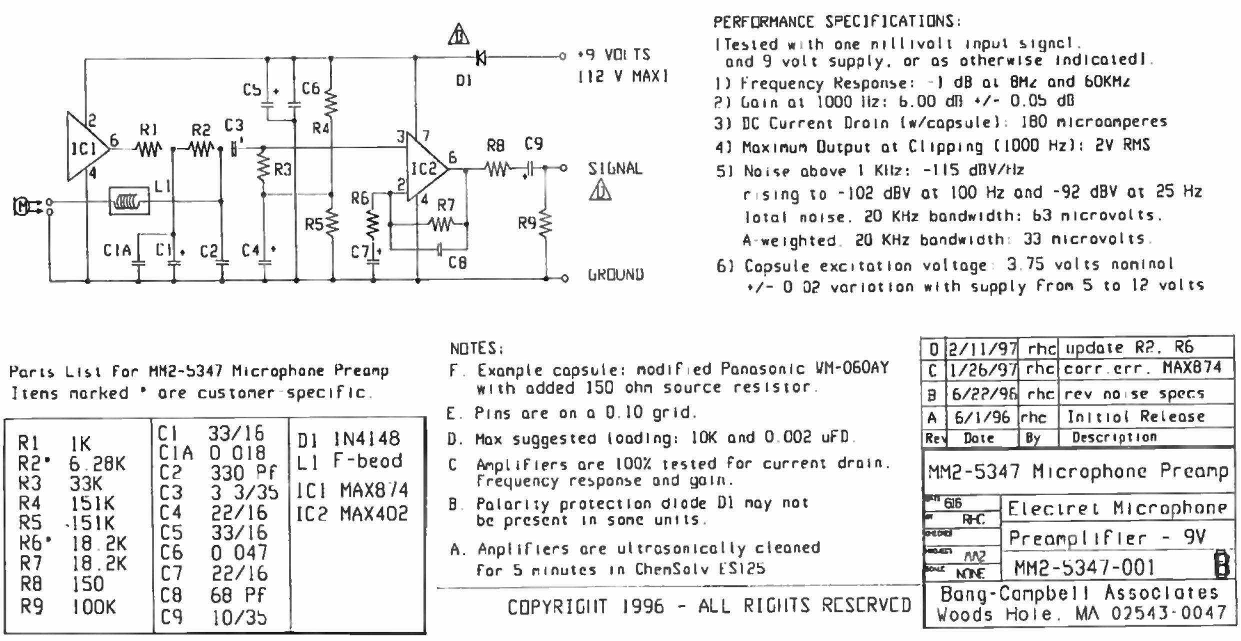


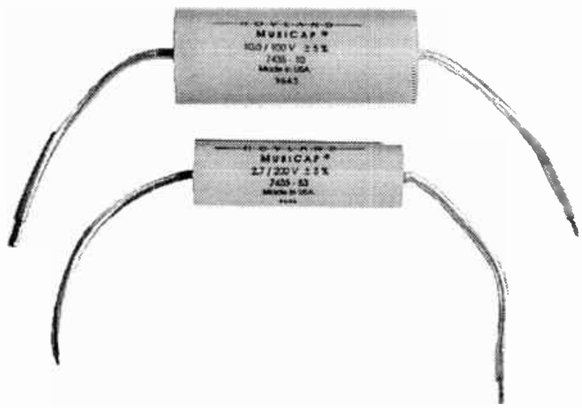
FIGURE 4: MMII electronics schematic.

MUSICAP by H O V L A N D

Madisound is pleased to offer Hovland MusiCaps, film and foil polypropylene capacitors, for the speaker builder who can settle for nothing but the best in sound reproduction. MusiCaps have quickly become the the standard for extremely high end audio systems, allowing a speakers to achieve their ultimate level of performance. MusiCaps provide a dramatic improvement in clarity, focus and dynamics. Although MusiCaps are expensive, the degree of improvement is a value compared to the cost of high end cables and interconnects. Hovland MusiCaps are the component of choice when musical realism is your goal.

FEATURES

- Separate layers of polypropylene film & conductive foil, deliver superior clarity of reproduction
- Custom stranded 16 gauge silver-plated copper leads - no copper oxidation to ever degrade the sound
- Lead-free silver-bearing solder used in tinning and attachment of leads
- Tight ± 5% tolerances
- Hand Soldered lead termination
- Extremely low DA, DF and ESR
- 100% pre-testing for absolute quality assurance
- Consistent even winding tension assures freedom from microphonics
- A single capacitor = a singular sound – no time smear from multiple sections
- Blue striped lead to indicates lead connected to foil inner edge. (In a series connection the blue lead should be closer to the speaker, in parallel the blue lead should be closer to ground.)



What the reviewers say...

"After auditioning a wide variety of caps, I find these film-and-foil capacitors to be the most musical performers—and by a large margin. The MusiCap specializes in textural liquidity (lack of grain) and delicacy of treble nuances."

Dick Olsher, **Reviewer and Designer for Samadhi Acoustics**, *November 1996 white paper*

"...the extra ambiance, combined with a very clean treble delivery that seemed far less prone to ringing or sibilance than the other types does make them really quite special."

Domini Baker, **HI-FI WORLD SUPPLEMENT**, *August 1996*

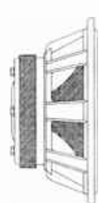
"If you want see-thru, high definition, detail *and* listenability, try the MusiCaps."

Joe Roberts, Editor, **SOUND PRACTICES**, *Issue 6 1994*

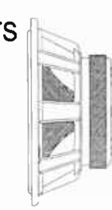
"The improved signal transmission of the Hovland foil capacitors elevated the [Arial] speakers to a new level of naturalness, clarity, and immediacy."

Lynn Olson, **POSITIVE FEEDBACK**, *Vol. 5, No. 4*

Value	WVDC	Dimensions (D x L)(Inches)	Price Each
1.0 µf	100V	0.55 x 2.00	$14.20
1.5 µf	100V	0.70 x 2.00	$17.00
2.0 µf	100V	0.70 x 2.25	$19.30
2.7 µf	100V	0.80 x 2.25	$20.50
3.3 µf	100V	0.82 x 2.88	$21.20
4.0 µf	100V	0.85 x 2.88	$23.80
5.0 µf	100V	0.95 x 2.88	$26.30
6.0 µf	100V	0.94 x 2.88	$29.40
7.0 µf	100V	1.05 x 3.25	$33.70
8.0 µf	100V	1.10 x 3.25	$35.70
9.0 µf	100V	1.20 x 3.25	$38.60
10.0 µf	100V	1.35 x 3.25	$42.30



MADISOUND SPEAKER COMPONENTS
8608 UNIVERSITY GREEN
P.O. BOX 44283
MADISON, WI 53744-4283 U.S.A.
TEL: 608-831-3433 FAX: 608-831-3771
e-mail: madisound@itis.com
Web Page: http:/www.itis.com/madisound



test plastic-covered stainless leader, which has an outer diameter of about 0.025. Fold the pieces in half, pass each end of each piece through adjacent holes, and pull them up tightly to form four strands of wire streaming from the inside of the tube end.

If you wish to cover the wand with shrink tubing (mainly for appearance), you should do this now. Spray a small amount of "slide" or "mold release" on the wand to facilitate placement of the shrink tubing. It is difficult to get the stuff to shrink smoothly at the inside of the bend, so be sure to pull the strain-relief cables tightly so that the folds are hard against the outside wand wall.

At the microphone end, trim the shrink tubing carefully just behind the swage. At the other end, trim it right at the end of the wand so that the strain-relief cables are trapped under it.

Prepare 6′ (or more) of single-conductor shielded microphone cable having a diameter of less than 1/8″. We use a .11″-diameter cable from France that has a conductive plastic shield (with drain wire) for very low cable microphonics (Farnell P/N 218-091). Strip and tin one end only in the conventional way, so that the center conductor has at least ¼″ of insulation on it.

Cut a 14″ piece of #24 hookup wire, solder one end to the shield drain wire, and lead it back along the cable. It is wise to apply a very small piece of tape at the loose end of this ground wire to keep it attached to the outside of the shielded cable and stretched out along it.

FINAL ASSEMBLY

Now attach the capsule assembly to the shielded cable. Stretch out the pair of #30 leads, but do not twist them together. Using a small-diameter (0.10″) mandrel, form the two leads into a tight coil-spring. The purpose of this is to provide, for final assembly, a lot of motion relief between the capsule and the cable. Solder the free ends of the #30 wire to the cable by attaching the lead from the resistor to the shield connection, and the one from the pad to the center conductor. The result is shown in *Photo 6.*

Push the cable through the wand from the swaged end and carefully work it past the fold in the ground wire at the other end. Patience is required to avoid pushing the folded ground lead out of the wand. A squirt of "slide" goes a long way. Eventually, the capsule ends up positioned just outside the swaged end of the wand, and the end of the cable's extra ground wire appears sticking out of the opposite end of one wand.

Cut and strip the ground wire that is sticking out of the wand so that it is the same length as the folded ground wire previously installed. Twist them together and solder. This connects the cable shield to the wand.

CABLE PROTECTION

Sort out the four strain-relief cords and temporarily tape them back along the wand to get them out of the way. Cut a 1.5″ piece of plastic insulating tubing that fits snugly over the shielded cable and push it up into the end of the wand about ½″. This provides additional bend protection for the shielded cable. Cut a 4″ piece of 5/16″-diameter shrink tubing, slip it up over the insulating tubing and over the ground-wire joint, and shrink it.

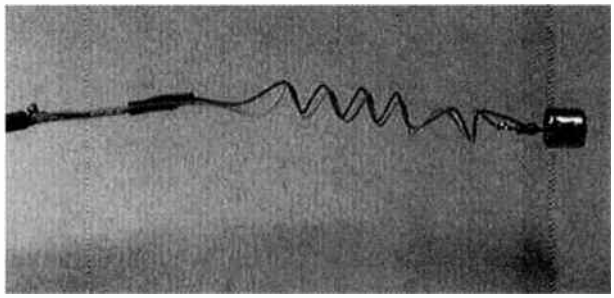


PHOTO 6: Coiled wire leads attached to capsule just prior to inserting capsule and leads into the wand.

Remember that the cable/microphone assembly is still free to move inside the tube, so be extremely careful about disturbing the capsule connections.

Neatly gather and position the four strain-relief cords along the shielded cable. Cut a 2″ piece of shrink tubing with a diameter just large enough to slip over the cable-end of the wand assembly and push it up onto the wand.

Starting with two adjacent strain-relief cords, weave them around the shielded cable by crossing them on top, then under, then on top, then under, with a pitch of about ½″, until the end of the cords is reached. Tape them down temporarily. Roll the wand over 180° and repeat with the other two strain-relief cords.

The result should have the appearance of a "Chinese finger" for about two inches over the shielded cable from the end of the wand. Pull the piece of shrink tubing down over the weave and fix it in place. Cut off any excess of the strain-relief cords sticking out from under the shrink tubing.

Prepare an extremely small amount of conductive epoxy or equivalent material. Apply it in only a few tiny spots around the outside of the capsule case. Obviously, it must never get to the electrical connections, and it must not spread onto the fuzzy material on top of the capsule. Push the capsule into the wand and hold it until the conductive adhesive cures.

At this point the microphone wand is strong and durable, with plenty of protection for the cable when it is pulled, bent, or rotated. Apply more shrink tubing to suit for a final neat appearance. Lastly, attach an RCA plug to the end of the shielded cable.

CONCLUSION

Although Mitey Mike was originally intended for use by readers in loudspeaker testing, it is being used in a wide range of interesting and unexpected applications. The motherboard actually supports two amplifier daughterboards. In this configuration, MMII has been used for on-site stereo recording, and we have found it especially suited to piano recording.

A single-channel version of MMII is currently being used by a vocalist in a live night-club show.

A prominent manufacturer of sound-reinforcement speakers is using a large array of MMIIs to test for total power response and to obtain very detailed polar response plots. We are sure readers will find many more interesting applications for MMII. We would appreciate hearing about them from you.

Old Colony Sound Lab (305 Union St., PO Box 576, Peterborough, NH 03458, 603-924-6371, FAX 603-924-9467) will offer the following alternatives for Mitey Mike II:

KD-4: Mitey Mike II one-channel unassembled kit. Includes motherboard, one mike preamp board, mounting pins, box with 2-jack front plate, switch, battery leads, foam padding, two RCA jacks, and other necessary hardware.

KD-42B: Mitey Mike II two-channel upgrade unassembled kit. Includes one additional mike preamp board, additional mounting pins, two additional RCA jacks and a replacement front plate with 4-jack holes drilled.

KD-4A: Mitey Mike II one-channel assembled unit. Includes assembled KD-4.

KD-42BA: Mitey Mike II two-channel assembled unit. Includes assembled KD-4 plus KD-42B (using replacement face plate).

KD-4M: Mitey Mike II microphone capsule and wand unassembled kit. Exact configuration of kit is to be determined.

KD-4MCA: Mitey Mike II modified microphone capsule and wand, assembled and calibrated.

KD-MUA: Mitey Mike II modified microphone capsule and wand, assembled and uncalibrated.

A SPEAKER BUILDER'S TRAVEL GUIDE

By Marc Bacon

Many audiophiles get bitten with the do-it-yourself bug and decide to construct their own home speakers. Most are successful—a few wildly so. Their audio nirvana is delectable until their best friend, the one with more common sense than golden ears, arrives. After listening to their idea of paradise, he remarks, "not bad, considering you made it yourself" (rough translation—"were I not your friend I'd think you're nuts!"). Add to this his/her spouse's remarks as to size, finish, and, of course, the incredible drain on the budget, and you can understand why the results of an otherwise fantastic hobby end up in one end of the rec room.

What follows is not a prescription for the *ne plus ultra* of speakerdom. It is a prescription for success on the first try, broken down into rules and suggestions. Some are common sense; others may not be as evident.

THE BASICS

1. ***Establish budget and time constraints.*** I don't own a Mercedes or Aston-Martin, even though both are extremely good automobiles. I don't drive a semi-trailer to work, although it would have lots of room for picking up a quart of milk on the way home. Likewise, you must decide on your budget and time constraints. Do you have the time and money for your dream system, or must you settle on something you can afford?

2. ***The KISS (acronym for Keep it Simple, Stupid) principle.*** Don't build horns, quarter wave lines, transmission lines, dipoles, bipolar speakers, or anything with more than a 3-way crossover unless you have the knowledge and measuring equipment to make it work, or a very good kit designed by a competent person. Complex speakers don't sound right unless they're designed and built right.

3. ***Pay attention to detail.*** Detail takes time and patience. It is also one reason why home-builders can produce outstanding speaker systems, since their commercial rivals would be too costly to build.

4. ***Get back to basics, i.e., read, plan, build, measure....*** Don't use a pyramid-shaped speaker just because you saw one highly reviewed in the technical literature. Likewise, don't try to imitate a Focal egg, a Wilson SLAMM, or a Spica TC050 unless you are extremely competent.

Amateurs rarely lack in enthusiasm and audacity on their first try, but can waste loads of money with disappointing results. Applied physics is the reason speakers sound good. It's not rocket science or voodoo, just a few basic concepts with innumerable small details.

5. ***Buy the fewest, but highest-quality components you can afford.*** I like the minimalist approach. For example, an excellent two-way system made from a single Focal 5N412DB mid-woofer and a Cabasse DOM 2 tweeter with a simple high-quality crossover in a 10-ltr box will produce much more satisfying results than a similarly priced 60-ltr 4-way system with a Radio Shack 12″ woofer, 6″ mid-woofer, soft-dome midrange, and supertweeter using electrolytic caps and small-gauge inductors.

Likewise, I have moved away from designing extremely complex crossovers *à la* Dynaudio and Thiele to using the minimum number of components required to achieve a good transfer function. I find that complex crossovers tend to smear sound detail, even though they produce more linear predictions. The secret to minimalist crossovers is to use very well-behaved (i.e., smooth rolloff) drivers.

LISTENING ROOMS

1. ***Evaluate your listening room.*** This is the area probably most overlooked by audio enthusiasts. Since changing your listening room may not be possible due to the spouse acceptance factor, your budget, or your landlord, you must match the speakers to the room. Minimus-7 speakers won't work in the Taj Mahal, nor will

ABOUT THE AUTHOR

Marc Bacon is a US citizen, making his home near Montreal, Quebec, with his wife and two children. A professional engineer with training and experience in both science and electronics, he finds speaker building an extremely rewarding avocation. He turned his hobby into a small distribution business, *Technologie MDB*, which he unfortunately had to close earlier this year. He remains president of a consulting engineering company, and is extremely interested in music reproduciton.

TABLE 1

LISTENING ROOM EVALUATION CHART

LISTENING ROOM	SPEAKER INTERNAL VOLUME (LITERS)	LOWEST FREQUENCY	2- OR 3-WAY	SPOUSE ACCEPTANCE FACTOR
Small–medium	15 liters or less	50Hz	2-way	Excellent. Don't forget that speaker stands may be required, and may not fit well into a home decor.
Small–medium	15–40 ltr	40Hz	2-way is simpler, probably better quality for the money	Good. This is the most common speaker size in the 1990s. Speaker stands may be required.
Medium–large	40–80 ltr	Down to 25Hz if you want it that way	2-way is simpler, but larger volume allows for 3-way with 8–10″ woofer	Requires a good heart-to-heart discussion. If you keep the footprint small, the SAF will increase substantially.
Large	over 80 ltr	30Hz if so designed	Definitely a 3-way	Poor, unless your spouse is blind or has the patience of Job.

Wilson SLAMMs in a single-bedroom apartment.

As a general rule, if the speaker looks tiny in the room, it probably will sound that way. If it is overwhelmingly large, you may love the sound and enjoy showing it off, but you'll be alone in appreciating it. Use *Table 1* as a guide.

2. Plan ahead for proper speaker placement in the listening room. Use Roy Allison's equations (available from many sources, including the Madisound BBS, the Internet, and the Room Design Powersheet by Old Colony Sound Lab) to predict the effect of the room on midbass power response. Normally, the solution for this is to mount small 2-ways flush with bookshelves or a wall, or to move them well out into the room on stands.

For 3-ways, I prefer an arrangement with the woofer near a known room boundary, such as the floor or rear wall, and a steep crossover to the midrange at around 350Hz. Line arrays, *à la* Infinity Reference Standard, where the listener is located in the near-field, reduce most room problems, but cannot deliver pinpoint imaging.

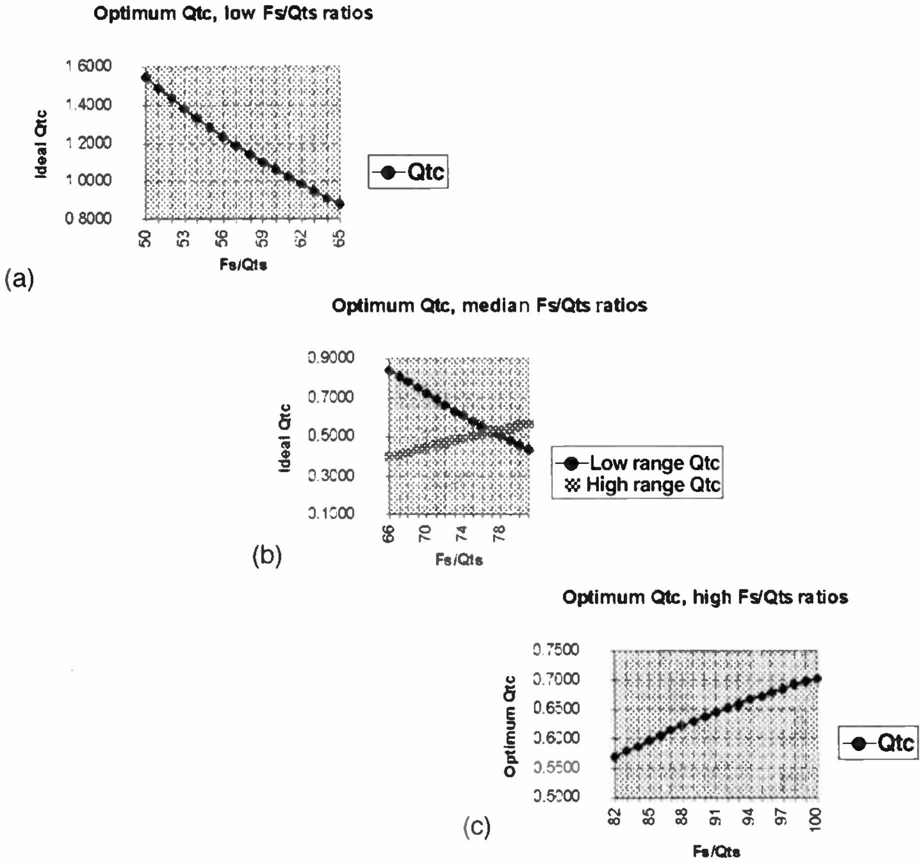


FIGURE 1: Optimum Q_{tc}, with low F_s/Q_{ts} ratios (a), median F_s/Q_{ts} ratios (b), and high F_s/Q_{ts} ratios (c).

DRIVERS

1. Buy a woofer with sufficient displacement for the box tuning. For details, see Vance Dickason's *Loudspeaker Design Cookbook* (Old Colony Sound Laboratory, PO Box 243, Dept. B97, Peterborough, NH 03458, 603-924-6371, FAX 603-924-9467). Insufficient excursion causes a very displeasing form of distortion as woofer movement becomes nonlinear. Be careful when reading manufacturer's literature—some list X_{MAX} as total excursion, others as total one-way excursion, still others as one-way excursion + 15%! Alternatively, use a D'Appolito arrangement to halve the volume displacement while retaining a narrow baffle (good for diffraction), the ability to compensate for diffraction loss, and the high acceleration and good midrange definition inherent in small woofers.

2. Use a tweeter with sufficient power handling. Many amateurs burn out tweeters, the principal causes being:

- Using too small an amplifier. When it distorts, it burns out the tweeter.
- Using too low a crossover point or too low an order. There is an almost mythical belief among audiophiles that first-order crossovers are the best. Since tweeter rolloff is generally second-order, even a first-order crossover will often generate a quasi-second- or third-order response.

Thus, the belief in the first-order crossover is just a myth unless you cross over the tweeter at least two octaves above the beginning of its rolloff. A more sensible tweeter crossover is an acoustic fourth-order Linkwitz-Riley response, which normally uses a second- or third-order electrical crossover, resulting in better tweeter protection.

- Listening to raw tweeters with no protective circuit. Especially in ribbon tweeters, this is sure death.
- Measuring raw tweeters with tone generators and computer programs with no protective circuit and too much input power.

3. ***Buy drivers with smooth rolloffs.*** It is very difficult to design a crossover for a driver (such as some of the newer metal-cone woofers or some older Kevlar® models) that exhibits a ragged upper rolloff. Ideally, you would cross over drivers at least an octave above their fundamental resonance and one-half of an octave below their high-frequency −3dB point. A smooth rolloff means a minimal number of crossover parts, allowing you to purchase higher-quality components and thus minimize crossover-induced problems.

TABLE 2

SAMPLE F_S/Q_{TS} RATIOS

DRIVER 1		**DRIVER 2**		**DRIVER 3**		**DRIVER 4**	
F_s	45Hz	F_s	35Hz	F_s	21Hz	F_s	25Hz
Q_{ts}	0.38	Q_{ts}	0.40	Q_{ts}	0.304	Q_{ts}	0.446
V_{as}	30 ltr	V_{as}	30 ltr	V_{as}	30 ltr	V_{as}	80 ltr
F_s/Q_{ts}	118.4	F_s/Q_{ts}	88	F_s/Q_{ts}	69	F_s/Q_{ts}	56
Vented box		Either vented or sealed		Two sizes of sealed boxes		Sealed box	
Ideal V_b:	28 ltr	V_b, vented box:	32 ltr	V_b, box 1:	5.7 ltr	V_b:	12 ltr
		V_b, sealed box:	20.3 ltr	Q_{tc}, box 1:	0.75	Q_{tc}:	1.23
		Q_{tc}, sealed box:	0.63	V_b, box 2:	28.5 ltr		
				Q_{tc}, box 2:	0.43		

4. ***Listen to the driver outside the box with no crossover, if possible.*** Although bass and midrange drivers sound like fish out of water outside of a box, you will learn much about timbral balance by listening to them "stark naked." Likewise, listen to the tweeter you wish to use by playing it with a single polypropylene or polystyrene capacitor of 4.7–10µF in series.

BASS TUNING

1. ***Use a closed box if the F_s/Q_{ts} ratio is lower than 82, a vented box if it is over 100, either one if it is between 82 and 100.*** For closed boxes, Martin Colloms recommends using a higher Q_{tc} with higher F_c for an apparent increase in bass, and a lower tuning for tighter bass with lower Q_{tc}. This takes advantage of the room lift available at lower frequencies. I have developed a method that allows for just such optimization. To use it, find the F_s/Q_{ts} of the speaker you intend to use, taking into account all series resistances. The formulae are as follows:

- $Q_e' = Q_e \times$ (DC resistance of driver + resistance of crossover and cabling)/(DC resistance of driver).
- $Q_{ts} = 1/(1/Q_e' + 1/Q_{ms})$.

For drivers with an F_s/Q_{ts} of less than 62, expect a rather high box Q, as shown on the first graph of *Fig. 1*. There are two optimum tuning points for the speaker between the F_s/Q_{ts} ratios of 66 and 81, as shown on the second graph, one with a lower Q_{tc}, bigger box, and higher efficiency, and another that is subjectively more plump and less efficient, but uses a much smaller box. For 82 to 100, there is one point that satisfies the requirements. *Table 2* lists several examples of F_s/Q_{ts} ratios.

2. ***Don't stretch out vented-box tuning for maximum bass extension.*** I personally prefer a quasi-third-order, rather than a fourth-order, rolloff for vented boxes. There are several reasons for such a tuning scheme:

- The room response helps to lift the response. It is therefore more appropriate to roll off gradually, allowing the room to lift very low bass, rather than to try for maximum extension, with resulting boominess.
- Transient response is improved by lower-order rolloff.
- Third-order rolloff is less sensitive to variations in driver parameters. While actively assisted sixth-order vented boxes are fun to design on paper, they are extremely difficult to achieve in reality.

3. ***To increase bass response from a speaker without changing box tuning:***

- Position the port towards the rear wall or the floor.
- Place the speaker near room boundaries.

4. ***To improve bass transient response and reduce distortion:***

- Use a port with the inner end cut at a 45° angle and its average length equal to the calculated length.
- Fix a boom port by putting straws in it.
- Reduce distortion by mounting woofers face to face (only for 150Hz or less), using a box volume one-half of that predicted, and wiring the woofers in parallel. The sensitivity of the system is equal to that of a single woofer.

CROSSOVERS

1. ***Compensate for baffle diffraction.*** This is one of the single most common failings of amateur crossover designers. You must provide a crossover shaping that emphasizes the lower part of the frequency range where baffle diffraction provides a bass rolloff. There are at least three easy ways to do this:

- Use a dual voice-coil design, with the lower voice coil acting only in the low bass. To model this on CALSOD, input the driver as two separate drivers acting on the baffle width, with a coincident origin. Optimize the crossover between one of the coils and the tweeter; then add the effect of the second coil to achieve bass boost.

- Use a second driver in a D'Appolito arrangement, such as the Aria 5 design, where the two bass-midrange drivers act in parallel over the lower range, and then are crossed over to the tweeter. This makes for very linear phase as well. The box size is greater than that of a dual voice-coil driver, but the bass excursion is halved, resulting in less distortion.
- Use very high-efficiency midbass and shape the crossover so that the midband and tweeter response is down approximately 6dB. For example, using a Cabasse 21M18 (93dB) woofer-midrange, it is possible to get greater apparent bass, albeit at around 87dB, by shaping the crossover to tone down the tweeter and midband. The disadvantage of this arrangement is lower sensitivity of the entire system. The bonus is the extra tweeter protection afforded by the series resistance.

2. *Don't use a crossover to extend a driver's response by peaking it, then falling off.*

Crossover optimization programs are notorious for doing this as they attempt to generate a flat response. After optimization, look at each driver's crossover/driver response and the crossover transfer function to ensure that they follow smooth curves without undue peaking. Ideally, the combined driver/crossover response will be an established crossover type, such as Butterworth, Linkwitz-Riley, Chebyshev, and so on, since these allow you to accurately predict polar tilt and phase response. Then reverse the connections of one of the drivers and make sure the resulting null is symmetrical and at least 20dB, in order to ensure good phase response.

3. *When developing a crossover using an optimization program, design for a smooth response (±2dB from target across the front 60° and ±3dB from target between the standing and sitting listening positions).*

TABLE 3

EFFECT OF PARALLELED COMPONENTS ON TOLERANCE

NUMBER OF PARALLELED COMPONENTS	SPECIFIED TOLERANCE	RESULTING TOLERANCE
2	10%	6.4%
	5%	3.2%
	1%	0.64%
3	10%	5.2%
	5%	2.6%
	1%	0.52%
4	10%	4.6%
	5%	2.6%
	1%	0.46%
5	10%	4%
	5%	2%
	1%	0.4%

Many computer-generated crossover optimizations are extremely sensitive to interdriver separation and listening position. Generally, ways of improving the response over the range are to:

- Minimize interdriver separation by using small-diameter drivers close to each other. A D'Appolito arrangement with two 3½"-diameter Ceratec drivers and a 1"-diameter tweeter mounted closely together will behave much better than one with two 6½" drivers and a very large tweeter. I have yet to realize a good D'Appolito speaker with 8" drivers.
- Use a fourth-order L-R crossover function between the midrange and tweeter. Normally this requires only a second- or third-order electrical crossover.
- Use midranges only up to the point where the off-axis response begins to fall off.
- Aim the array at a point midway between seated ear height and standing height.

4. *Use impedance equalization on woofers and woofer-midranges.*

It is rarely possible to design as good a system with nonequalized drivers as with equalized ones. An added advantage is that when fine-tuning the system, you may vary somewhat the component values of the zobel, achieving a more subtle effect than that of varying series or parallel components.

5. *Use active crossovers for all crossovers below 150Hz.*

This is expensive, but justified by the fact that the woofer and midrange impedances vary wildly in the bass, often by a factor of 5–10. The amount of capacitance and inductance required to equalize these impedances is very costly and introduces a substantial amount of distortion. The alternative is to use hybrid passive networks with minimal equalization and resulting phase problems.

Active crossovers are not easy to design. For a first try, you might use some from Marchand Electronics (which advertises frequently in *SB*). The cost of two amplifiers and an active crossover is often not much more than that of a single amplifier driving a passive circuit. The *Loudspeaker Design Cookbook* lists several benefits and several sources for active crossover design.

6. *As a starting point, try the following crossover points*:

- 2-way with 4" or 5" woofer, 3.54kHz.
- 2-way with 6" woofer, 3.5kHz.
- 2-way with 8" woofer, 2kHz (requires a tweeter that can handle the power and excursion). The ear is sensitive to problems in the crossover at this range, so be careful.
- 2-way plus subwoofer. Active crossover below 150Hz, passive crossover as above.
- 3-way. Passive crossover at 350Hz–3.5kHz.

7. *Use polypropylene or polystyrene capacitors for all caps in crossovers, except for those used in Zobel impedance compensation networks. Bypass all electrolytics with at least 10% polypropylene.*

Note that despite many manufacturers' claims about the performance of their caps, I have yet to see documented proof that any poly cap is measurably better than any other in the audio range of frequencies, unless you require extremely high voltage ratings. (I'm already ducking the rotten tomatoes on this statement!) Electrolytics are notoriously nonlinear, and can degrade with time.

8. *If series resistance of an air-core is less than 10% of driver impedance, use it. For larger values, use a high-grade ferrite- or laminated-core inductor with at least 500W saturation.*

Recent publications show that laminated-core inductors have the least distortion in larger sizes, since ferrite cores are more nonlinear. CFAC and other exotics have to my knowledge been proven to be measurably different, but not necessarily better. (Another duck, this time for rotten eggs!) I'm not a great believer in exotic cables, either, as long as the wire gauge is sufficient and contacts are well-designed. Inductor saturation produces compression and distortion effects that destroy the large-signal response of many otherwise excellent systems.

9. *Use paralleled components to achieve single values with substantially lower tolerances.*

The range of tolerance is narrowed by the use of paralleled components (*Table 3*). It is therefore possible to achieve the following tolerances at minimum cost:

- Inductors (two larger values in parallel, 5% tolerance on winding), 3.2%
- Capacitors (two smaller values in parallel, 5% tolerance), 3.2%
- Resistors (two larger values in parallel, 1% tolerance), 0.64%

An added bonus is the reduction of the power-handling requirements of the individual components. Note that you should mount paralleled inductors orthogonally to each other to avoid coupling.

Also note that resistors used to reduce sensitivity in the signal path should be of a very high quality and have no more than 1% tolerance. Capacitors and inductors of 5% tolerance are normally acceptable in all but the most expensive systems.

BUILDING DETAILS

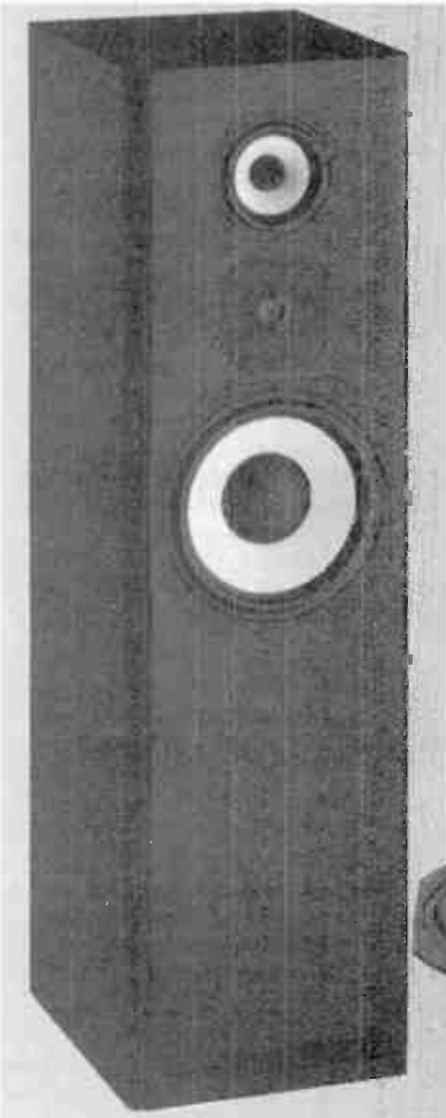
1. *Build the stiffest box you can afford within constraints of time, budget, space, and weight, and seal it well.*

See the *Loudspeaker Design Cookbook* for suggestions. Try these hints as well:

ZALYTRON

Focus on Focal!

COSMETICS ON SALE



5K413S	$79.00
TC120TDX/T	$65.00
5N411L	$45.00
10K611 (Similar to 10K617)	$139.00
12V726S	$175.00
TC90TDX/T	$36.00
4K211	$55.00

Brand new Focal drivers have come to us at a special price because of a slight imperfection in cosmetics.
Some of these are so slight you can't even see them. Use these drivers to build a great looking and great sounding Focal system.

ZALYTRON INDUSTRIES CORP.
469 JERICHO TURNPIKE, MINEOLA, N.Y. 11501
TEL. (516) 747-3515 FAX (516) 294-1943
Our warehouse is open for pick-up 10AM to 6 PM daily, Saturday 10 AM to 5 PM
UPS orders shipped same day • Minimum order $50.00
Call or Write for your Latest Catalog mailed FREE in USA. Canada $5 P&H, Worldwide $10 P&H

Reader Service #45

- Rounded shapes can be many times stiffer than boxes, since radial stiffness, not bending modes, are involved.
- Bracing is extremely important. An effective means of bracing and damping cabinets is to insert a hardwood dowel between the woofer magnet and the back panel, using a bit of silicon at each end.
- All corners should be braced, glued, and lined with silicon.
- Crossovers should be secured in such a way as to minimize rattles and buzzing. Try silicone or hot glue.
- If you can, measure cabinet vibrations and displacements with an accelerometer.

2. ***You should damp all panels to prevent ringing by:***

- Using roofing compounds or other proprietary mixes (make sure they don't dissolve driver surrounds); coat at least the center 50% of the area of each panel.
- Using a damping self-adhesive mastic, such as Black Hole, to do the same as with the roofing compound, with less mess and risk.
- Using a double-wall, sand-filled panel. Sand is heavy and only stiff in compression, making it an excellent damping material. Alternatively, use a mass-loaded boundary layer system, such as Black Hole 5. This "constrained layer" construction is quite effective.
- Making cabinet walls from a mixture of ground-up rubber, sand, and epoxy resin. This is extremely effective, but is a patented process and so cannot be used commercially.
- Attaching screw-eyes to numerous points on the largest panels, then stringing small cables between the screw-eyes. The cable serves to pre-tension the panels, but has no stiffness in compression, making it an effective damping mechanism.

3. ***Line all cabinet walls with a suitable lining to minimize midrange reflections.***
There are several schools of thought on this matter. Dickason gives results of measurements in the *Loudspeaker Design Cookbook*. I have used wool (watch out for bugs), Black Hole 5 (predictable, but expensive), fiberglass, and "egg-crate" open-cell foam with success. Note that the internal volume *increases* in Thiele/Small equations by approximately 20–25% of the volume of the lining.

4. ***When designing your cabinets, allow for speaker-driver volume, port volume, bracing volume, and lining volume.***

5. ***Use cabinet dimensions that are prime numbers, Avogadro series, or the Golden Ratio of 0.618, 1.000, 1.618 to minimize standing waves.***
I've gotten some *very* bizarre results from otherwise rational cabinets, especially from bandpass enclosures that behaved more like some sort of tuned pipe than a classic Helmholtz resonator. Note that although nonparallel sides do help in minimizing direct midrange reflections, they will not eliminate standing waves, although they will reduce their magnitude.

6. ***Keep the internal end of the port away from cabinet boundaries and other obstructions by a distance at least one-and-a-half times its diameter.***

7. ***Use a port diameter of at least 25% of the nominal driver diameter. Calculate the lengths of rectangular ports and multiple ports using George Augspurger's* SB *2/91 article.***

8. ***Mount drivers using appropriate damping gaskets (Norsorex or equivalent) or a very soft silicone.***
Note that scrapes and silicone will void manufacturer's warranties. Play the driver in open air before mounting it, in order to ensure that it works.

9. ***Mount crossover networks away from driver magnets.***

10. ***Rule: Solder all the connections to the drivers.***
Note that this will void the manufacturer's warranty, so you might want to test the drivers with crimp connections for a few days before soldering. Use appropriate heatsinks when soldering tweeter connections.

11. ***Rule: Mount crossover inductors orthogonally to each other, with tweeter inductors well away from other inductors.***
This will reduce distortion due to coupling between the inductors.

12. ***Rule: Isolate the speaker from its surroundings.***
There are many methods of isolating speakers, some of which are based on solid engineering, and many of which are not. For a discussion of vibration isolation, call the Fabreeka company or the makers of EAR or Sorbothane, and request their literature.

Basically, speakers should either be rigidly coupled to a rigid floor at specified points, or decoupled as much as possible. Rigid coupling is accomplished through the use of carpet-piercing points. Since three points determine a plane, I prefer to mount speakers that way. The problem is that a three-point mounting is also quite prone to tip over when cats, dogs, children, or clumsy adults bump the speakers. A better real-world solution is to use adjustable points.

Rigid coupling works well when the floor is heavy and nonresonant—otherwise it will muddy the sound by causing the floor to vibrate. The solution is to use a decoupling system, such as isolation mounts made by the companies named above or similar products available from McMaster-Carr.

It is important to use mounts made for the specified weight, for viscoelastic damping is dependent on the nonlinear behavior of the damping materials. If the speaker is too light for the mount, it will not compress the material sufficiently. Conversely, if it is too heavy, the material will be too stiff and will not experience enough hysteresis to provide good damping.

13. ***Use heavy-duty binding posts.***
Plastic cups tend to leak and be noisy.

14. ***Flush-mount all drivers that operate from 300Hz and up.***
Small projections tend to cause response irregularities.

15. ***If possible, mount the crossover outside the box in order to avoid the capacitors acting as microphones and increasing distortion.***

TABLE 4

SUGGESTIONS FOR SPEAKER BUILDERS

TECHNICAL KNOWLEDGE	MODELING TOOLS	BUDGET	SUGGESTION
Beginner	None–many	Low–high	Kits designed by D'Appolito, Dickason, and the like.
Medium	None or few	Low–high	Kits designed by D'Appolito, Dickason, and the like.
Medium–high	A minimum of CALSOD or equivalent. CLIO or equivalent desirable	Low	2-way system, Audax, Vifa, Focal, Access, Peerless drivers
		Medium	2-way system, Focal, Seas, Morel drivers
		High	2-way system, Cabasse, Scan-Speak, Dynaudio, Ceratec, Raven drivers

DESIGN AIDS

1. ***If you don't own the* Loudspeaker Design Cookbook, *or know most of what is in it, buy a copy.***
This is one of the most inexpensive and comprehensive references for success in home speaker building. The cost is less than half that of a single good woofer. (Note: I don't work for Audio Amateur Corporation and am not related to the author!)

2. ***If you have a computer available, buy a crossover optimization program. If not, build from a kit produced by a reputable designer.***

It makes no sense to buy high-quality components, fuss over binding posts, tiptoes, and cabling, and then ruin everything with a poor crossover. An excellent program, CALSOD, is available from Old Colony Sound Lab for around $70. It isn't easy to learn, but the effort will teach you quite a bit, and it works outstandingly well. For a more user-friendly program for the well-heeled or those planning to build enough systems to justify the cost, you might try LEAP.

3. ***If you're lucky (or rich) enough to measure your speaker-system response, do so.***

My personal preference is CLIO, but you might want to try MLSSA, LMP, or IMP. Each has its own price structure, advantages, and shortcomings. Here are some tips that should help:

- Measure each driver in the finished box (to allow for baffle diffraction) and design the crossover afterwards based on the response.
- Allow the drivers to break in before measuring by playing them for at least 48 hours with a moderately high drive level. (Woofers should be broken in with a large percentage of bass notes or a frequency generator, in order to allow the suspension to travel through most of its predicted X_{MAX}). Watch out for cats', dogs', kids', and spouses' ears when breaking in speakers, and don't forget to protect midranges and tweeters with appropriate capacitors to avoid burning them up.
- Once you've measured the speakers in their boxes, design the crossover, build a prototype, and measure the finished system.
- Don't expect accurate results in most rooms under 300Hz, unless you have a very large measuring room. You'll have to go with Thiele/Small predictions or close-miked responses in this range.
- Make sure you're working with a calibrated system.
- Trust your ears over your measurements. While this goes against the grain of the engineer in me, the fact is that you can design any number of crossovers that measure flat, yet sound different. The difference in timbre and phase will make one speaker musically pleasing, another lifeless. Many professionals, and most audiophiles, cannot explain what constitutes good sound. Good starting points are a flat response, low distortion, few phase problems, good impulse response, and nearly resistive impedance.

WHERE DO I START?

The above should help you get well on your way to success, keep your common-sense neighbor at bay, and not only increase the spouse acceptance factor, but actually stir some interest. (My wife, for example, does not spend much time worrying about crossover design or cabinet damping, but she loves fine music and is an excellent judge of speaker musicality.)

I deliberately have not discussed timbral nuances, driver types, and bass loading, since the type of music you listen to, your hearing, your personality, and your budget will dictate what you build. *Table 4*, however, may serve as a guide for your first home-built speakers.

SOURCES

Fabreeka International
1023 Turnpike St., PO Box 210
Stoughton, MA 02072
(800) 322-7352, (617) 341-3655, FAX (617) 341-3983

Sorbothane Incorporated
2144 State Route 59
Kent, OH 44240
(330) 678-9444, FAX (330) 678-1303

E.A.R. Specialty Composites
7911 Zionsville Rd.
Indianapolis, IN 46268

AN INSULATED DIAPHRAGM ELECTROSTATIC

By Matthew Lattis

For an electrostatic loudspeaker (ESL) to operate at its full potential, insulation is necessary. However, most do-it-yourself ESL builders forego this and build simple, uninsulated units. This article presents a cost-effective method of producing insulated ESLs. You can use this technique with all styles of construction—wire, perforated metal, perforated plastic with conductive coating, and so on.

PROS AND CONS

ESLs have two easily identifiable and significant advantages over standard moving-coil units. First, the moving mass per unit area of an ESL is very small compared to a cone or dome speaker. In an ESL with 1 mil of total diaphragm thickness, it takes 11 in^2 of diaphragm to equal the moving mass of a typical 1″ soft-dome tweeter. This low mass gives ESLs excellent transient response.

Second, an ESL's driving force is applied over the whole surface of the diaphragm, essentially eliminating breakup. Cone and dome speakers are basically driven from a central point or ring around the edge of the unit, a system that allows the cone or dome to flex and resonate. ESLs typically have much lower distortion than cones or domes.

That said, there are also two significant disadvantages to using ESLs: in general, they are notorious for their low sensitivities, and they use high voltages. The voltages involved obviously demand respect. If you build an ESL, you should familiarize yourself with high-voltage safety and take steps to minimize exposed high-voltage points in the design.

Roger Sanders and Ronald Wagner have both written excellent books on ESLs. Sanders[1] devotes a section to high-voltage safety, and also presents several hybrid designs (using conventional woofers with ESLs) and a full-range unit. Wagner's book[2] takes an in-depth look at the technical principles behind building ESLs, presents exact construction plans for a full-range segmented ESL, and contains information about commercial designs.

INSULATED PLATES

For safety and high output, insulated plates are hard to beat. In most commercial ESLs, the plates are made of powder-coated perforated metal or sheathed wires. These designs produce the highest outputs, but are impractical for most DIYers, since the types of powders suitable for ESLs are not generally used at most powder-coating facilities. Also, coating parts in small quantities is very expensive. You can build your own sheathed-wire designs, but the tedium involved keeps most people from doing so.

An insulated diaphragm gives you most of the benefits of an insulated plate, though you can't run the bias voltage as high, and the efficiency will therefore be slightly lower. Also, diaphragms in these units usually don't last as long as those in speakers with insulated plates. When using thin film for insulation, carefully ensure that no small tears or holes develop in the film during shipping or coating. From the standpoint of safety, an insulated-diaphragm design—without insulated plates—will be just as unsafe as a completely uninsulated unit, so if you build this way, take care to minimize the likelihood that anyone can touch the ESL's plates.

The bias supply has current-limiting resistors in series with its output, so it isn't an electrocution hazard (although its internal capacitors can be). The audio signal on the plates is the actual hazard. While I'm on the subject, the speaker itself is a capacitor and can therefore hold a charge and shock you after you've turned it off. Always discharge all capacitors before working on the speakers or bias supply.

The simplest way to insulate diaphragms is to place two of them with their conductive sides facing one another. Earl Peabody patented this technique in 1968 (US patent 3,389,226). The Pickering Isophase loudspeaker also used a similar style of insulation (US patents 2,934,611 and 2,934,612, from 1960).

Compared to an uninsulated ESL, those with insulated diaphragms have the following advantages:

1) higher operating voltages and therefore higher output;
2) no hissing when the bias is first turned on;
3) no hissing in high humidity or dusty conditions.

Compared to sheathed conductors or powder-coated plate designs, insulated diaphragms have the following advantages:

1) numbers 2 and 3 from the preceding list;
2) lower price;
3) faster construction time;
4) use of readily available materials.

CONSTRUCTION

Each unit I built is 5.5″ × 20.2″. See *Fig.1* for parts layout, and *Table 1* for materials list. Quantities listed are for one unit. I suggest using at least two units per channel. Except for the spacers on the contact end, the two halves of the unit are identical. One half uses a 5.5″ × 1.375″ spacer, while that of the other half is 5.5″ × 0.875″. You could make your units larger, but keeping them flat would then be more of a problem. The glues involved in this project also dry rather quickly, causing assembly problems with larger units. A breakdown of the expenses involved in this project is shown in *Table 2*.

The grid that is the main structure of the unit is styrene egg-crate-style fluorescent-light diffuser, available at home-improvement centers. Buy the flattest diffuser you can—they are all warped a little. The ribs

TABLE 1

MATERIALS LIST

NUMBER PER UNIT	SIZE (IN INCHES)	MATERIAL
3	0.875 × 5.5	.04 thick polycarbonate(PC)
4	1 × 17.875	.04 thick PC
1	1.375 × 5.5	.04 thick PC
2	.125 × 17.625	.04 thick PC
8	.375 × 1.25	.04 thick PC
2	4.5 × 19.7	styrene light diffuser
4	1.4375 × 20.75	aluminum window screen (see text and Fig. 1b for exact dimensions of screen)

that make up the grid are thicker on one side than the other. Keep in mind when you are buying your diffuser that the thick side should face the diaphragms to maximize the contact area of all joints.

The grid should be oriented so that any bowing of the middle of the diffuser is away from the diaphragm. If it bows in the other direction (with the ends bending away from the diaphragm), the diaphragms will lose some of their tension when you bolt the two halves of the speaker together.

You can easily cut the diffusers with a jig saw equipped with a blade for cutting plastic. After they are cut to the proper size, make sure no burrs are sticking up from the surface of the grid. The edges will have some burrs from the cutting procedure, and the field may have burrs from the equipment in which it was molded. Any protrusions on the surface of the grid will throw off the spacing between the plates and diaphragm, limiting your speaker's diaphragm travel and decreasing its output.

SPACERS

You cut the spacers from 0.040″ polycarbonate (PC) with sharp shears, sheet-metal snips, a table saw, or other appropriate instrument. You can also score this material and snap it off like glass. I usually cut spacers with metal snips.

You need to deburr the edges to ensure uniform spacing. I cut long strips of spacer material and deburr it before cutting it to its final length. It is also easier to strip off the masking material from the side to which you will be gluing the diffuser before cutting the spacers to their final size. You can vary the width of the spacers to accommodate your mounting frames as long as you have at least ½″ of overlap between the PC and diffuser. You also need enough PC on the sides to bolt the two halves of the unit together.

You can glue the spacers to the diffuser with many types of adhesive, since they are common types of plastic. For the money, though, it's hard to beat plastic-pipe cement. The all-purpose variety works on PVC, ABS, styrene, and CPVC. You can find it at home-improvement centers or plumbing-supply stores.

It was obvious that this type of glue would hold the styrene diffuser, but I ran a test to make sure it would work on the PC. I glued two pieces of PC together, and it produced a very strong bond. Because the contact area between the grid and PC is small, the joints aren't unbreakably strong, but they are more than adequate, and can

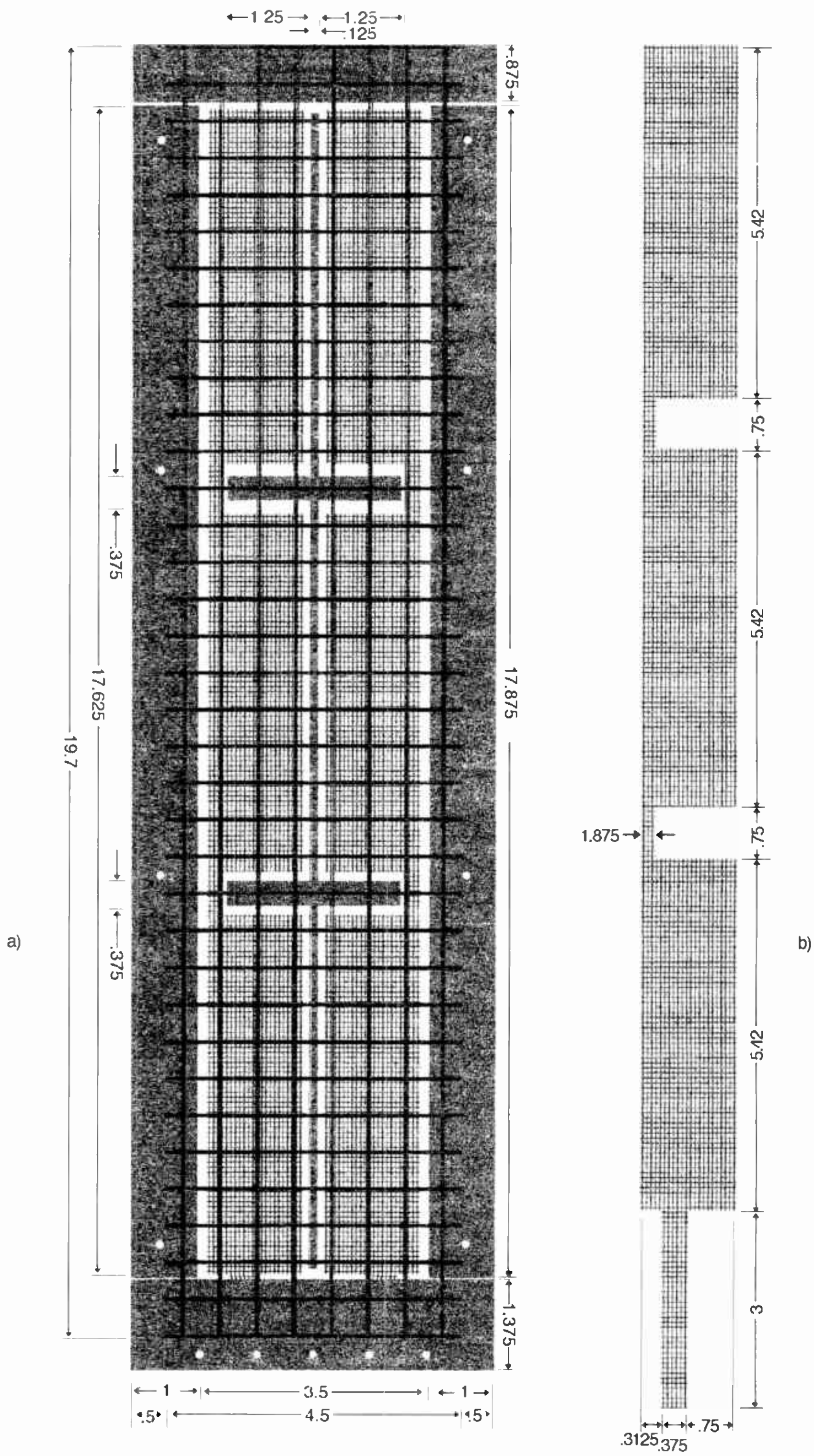


FIGURE 1: a) Layout of diffuser, spacers, and plates; b) Screen dimensions (see text for more info about screen d mensions).

TABLE 2

COST FOR FOUR UNITS AND ASSOCIATED ELECTRONICS

2 transformers	$120
1 bias supply	40
1 diffuser, 24″ × 48″	10
polycarbonate sheet (most plastic-supply houses have $10 orders, so you'll get a piece about 24″ × 48″)	10 minimum
1 pint of pipe cement	5
1 quart of contact adhesive or one can of 3M super 77	8
screen	5
wire	9
½″ × 60 yd. roll of 3M 9485PC tape	10
Mylar	10
Total cost	$227

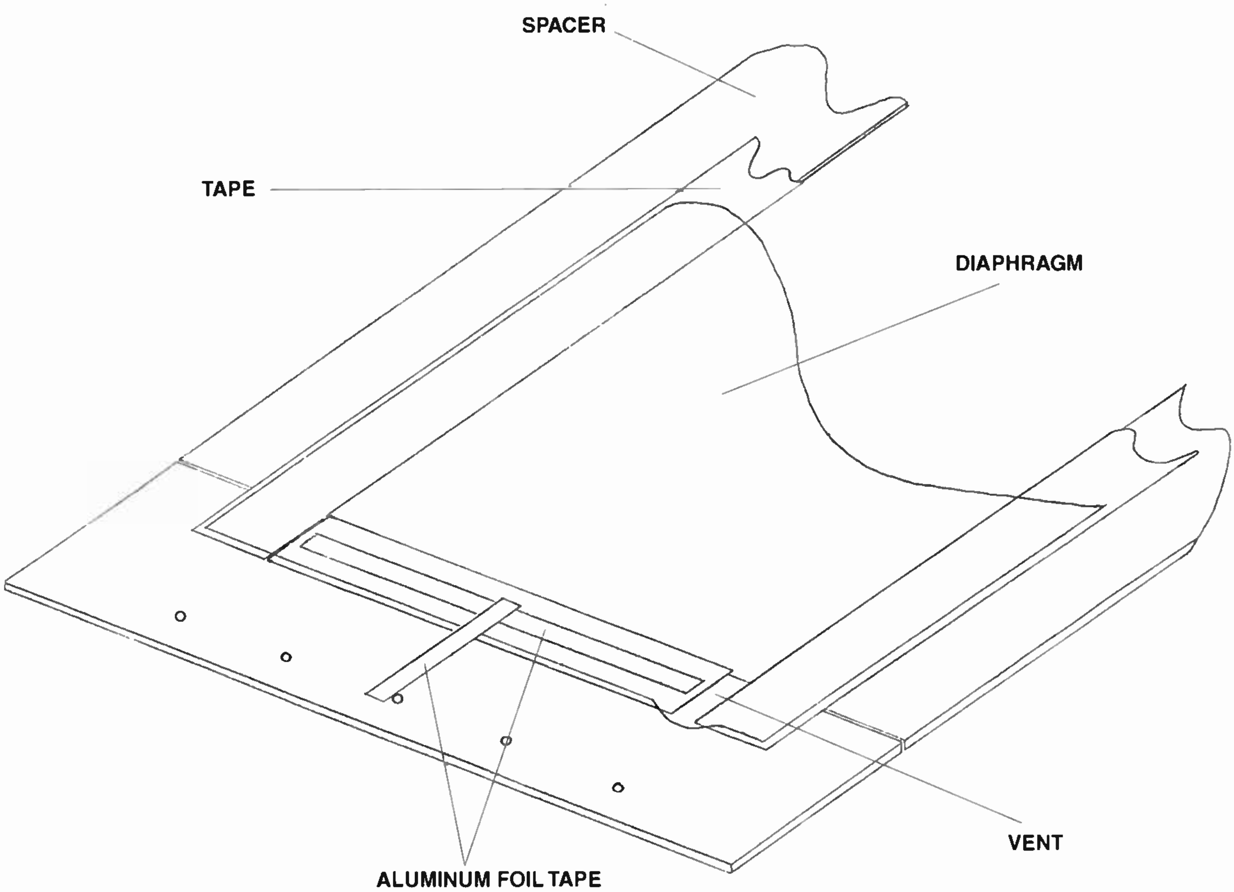


FIGURE 2: Detail of contact end and vent.

stand tear-aparts, rebuilds, and moderate torsional stress.

GLUING TIPS

You should work on a flat surface when gluing the spacers. The glue dries pretty quickly, so you can glue only one spacer at a time. Both the spacer and the area of the diffuser it will adhere to should receive a liberal coat of glue, and both surfaces should be wet when brought together. Press the pieces together with moderate pressure for 10 to 15 seconds until the glue starts to set up. Take care, for the spacers tend to slide around a little when being glued.

Though their placement need not be extremely precise, try to keep the spacers close to the suggested positions. If one gets out of alignment on the first half of a speaker, try to duplicate the misalignment on the second. The order in which I glue the spacers is: 1) one short end, 2) the long sides, 3) the remaining short end, 4) the strip running up the center, and 5) the four short spacers. Repeat the gluing procedure for all halves of your units.

After the glue sets up for a few minutes, you can gently handle the buildup. Cut the screen, which will be the plate in this design, with scissors or metal snips to fit between the spacers. Make your cuts between the wires to keep stray wires to a minimum.

Because the spacers may have slid around somewhat during gluing, you may need to cut your screen to a different size than that shown in *Fig. 1*. Make sure it is flat when you check its fit. In the area between the perimeter spacers and the short internal spacers, there remain only three wires from the screen's grid, so handle the screen gently.

Before gluing the screen to the diffuser, you should mask off the spacers to keep glue off them. Overlap the edges of the spacers with tape by about 0.0625″ to keep the adhesive from building up on the edges and throwing off the spacing.

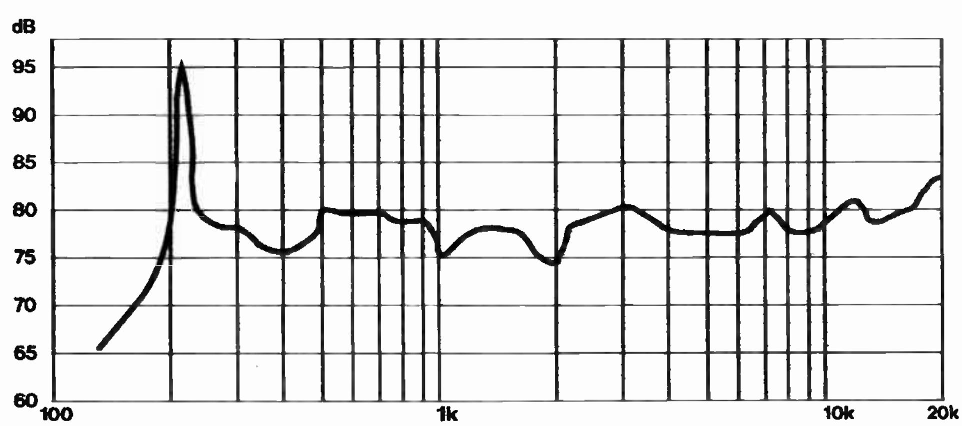


FIGURE 3: Frequency response, 2.83V RMS at 1 meter.

THE TRICKY PART

Gluing the screen to the diffuser is the only tricky part of the building process. The only spray contact adhesive I have found with significant strength and a sufficiently fine spray pattern to avoid clogging up the screen is 3M Super 77 spray adhesive. This glue has one drawback, though. Its maximum continuous-service temperature is 110°F. If you are sure your speakers will not be exposed to temperatures higher than this, Super 77 will probably work fine.

You should glue only one strip of screen at a time. Coat both the diffuser and the screen with the adhesive, being careful not to clog the screen. Within about 30 seconds the adhesive is usually dry enough to join the two pieces. Carefully align the pieces before allowing them to touch, while feeding the contact strip of screen through the grid. When you are satisfied with their alignment, press the screen down on the diffuser. The diffuser and screen will instantly bond and you won't get a second chance to align them. Roll a wallpaper-seam roller along the ribs, applying moderate pressure to ensure good contact between the screen and the diffuser.

If you are concerned about higher temperatures, you can use liquid contact adhesive to bond the screen to the diffuser. I have used Lock Bond multipurpose contact adhesive and Parabond M206 successfully. The application is messy, but the results are good if you apply the screen at the right point in the glue's drying cycle. You should practice on a scrap piece of diffuser to get your timing right.

Keep in mind that temperature and humidity can significantly change the glue's drying time. With the liquid adhesive, you cannot apply glue to the screen, so you must put an extra heavy coat on the diffuser. Brushes and rollers are almost impossible to clean after they have been dipped in contact adhesive. The cheap, throw-away solution is to use wadded paper towels to apply the glue.

If you are getting enough glue on the diffuser, it will drip out the other side, making a moderate mess. Make sure you get good coverage around the edges and between the perimeter and internal spacers. When you are sure the area the screen will touch is sufficiently covered with glue, remove the masking tape from the spacers on the half of the buildup you are currently working on. If you leave the tape on, the solvents in the adhesive can damage the PC.

FINAL GLUING TOUCHES

The adhesive should be dry on the surface but semiliquid inside when you apply the screen. Align the screen within the spacers, while feeding the contact strip through the grid, and press it into the adhesive. Roll along the ribs with the wallpaper-seam roller to ensure good contact.

If the glue is too liquid and squirts through the screen, remove any that prodrudes, so as not to interfere with diaphragm travel. If the glue is a little too dry and there are a few small areas where the screen isn't sticking, you may be able to reactivate the glue by heating it with a heat gun. The styrene melts at quite a low temperature, though, so be careful.

If the area that isn't sticking is small and unimportant (the diaphragm's travel is very restricted close to the spacers), you may be able to apply some contact adhesive over the screen and stick it back down. Repeat the above steps for the second strip of screen that goes with the buildup you are working on. You can now remove the masking material from the spacers on this half of the unit. Repeat for all halves of units. Before proceeding any further, let the adhesives dry for 24 hours.

At this stage, you should check the screen for loose spots and wires that are sticking up. You can fix any loose spots with contact adhesive or the 3M tape described later. You should push down any protruding wires and check the edges carefully.

DRILLING THE HOLES

You should now drill all the holes in the spacers. The holes shown in *Fig. 1* are 0.125″ in diameter and will accept 4–40 bolts. *Figure 1* shows only the holes for contacts and for holding the two halves of the speaker together. At this time, you should also drill the holes for mounting the units, but these will depend on your mounting frames. The inside edges of any holes should be at least ½″ from the inner edge of the perimeter spacers in order to keep the bolts from contacting the diaphragm and becoming charged with the bias.

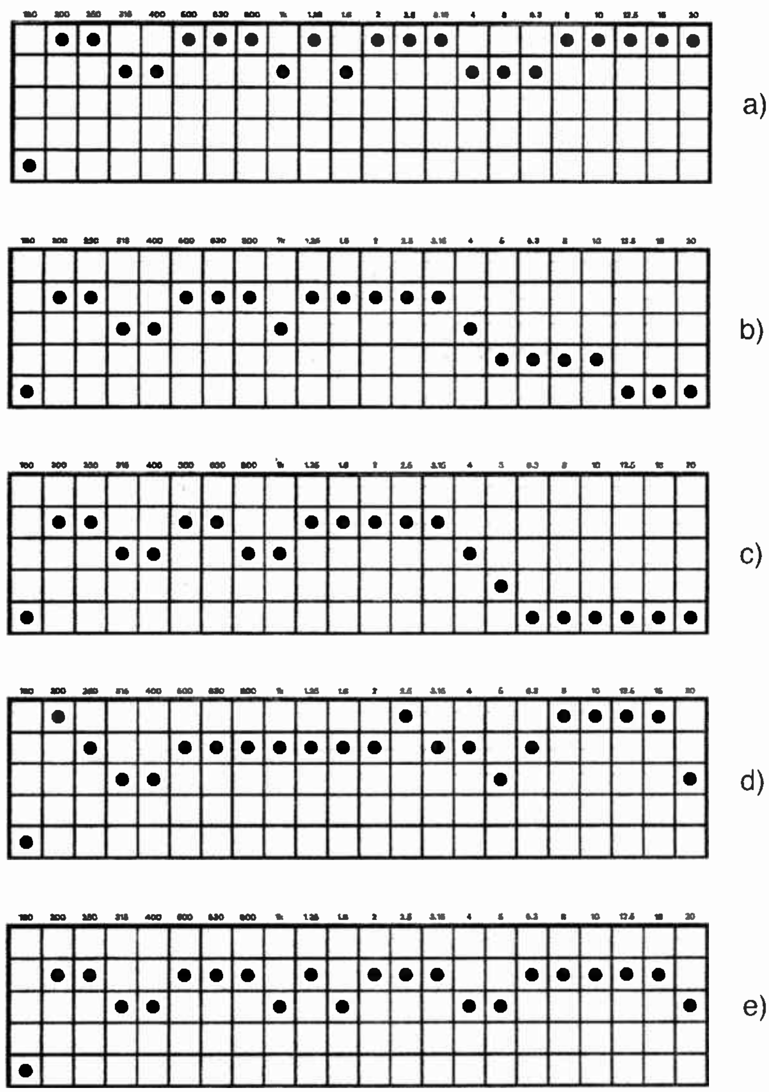


FIGURE 4: Frequency response measured at 72″ with 1/3-octave pink noise; 4dB per step; a) low turns ratio on axis; b) low turns ratio 12° off axis; c) low turns ratio 25° off axis; d) medium turns ratio on axis; e) high turns ratio on axis.

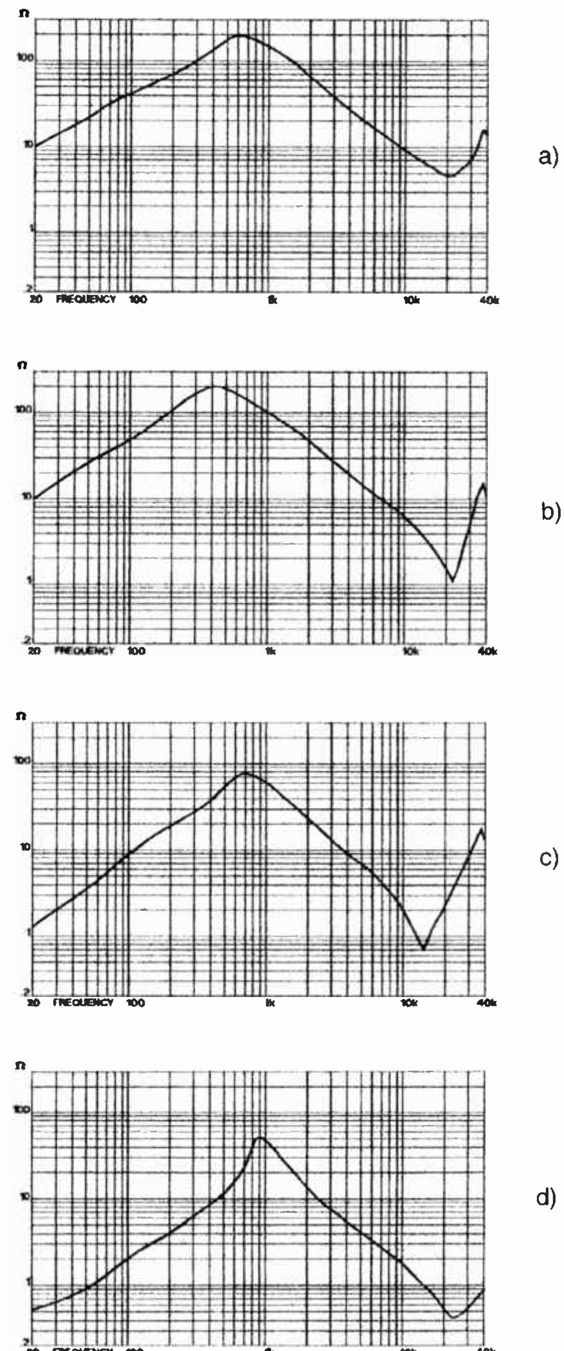


FIGURE 5: Impedance: a) two units with 4Ω and common taps used as primary, b) four units with 4Ω and common taps used as primary, c) two units with 8Ω and 16Ω taps used as primary, d) two units with 4Ω and 8Ω taps used as primary.

Drill all the holes in one half of the unit from the diaphragm side, to minimize the stress placed on the joints between the spacers and the diffuser. Now put the two halves of the speaker together, spacer to spacer, and hold them together with rubber bands. Drill through the existing holes and into the second half of the unit. Repeat for all units.

DIAPHRAGM PREPARATION

Preparation of the diaphragms is the next step. Mylar® (0.5 mil) is the best material, and the genuine DuPont brand is different from the generic varieties of polyester film on the market. Mylar shrinks more and at lower temperatures than the generics, and also seems to retain more of its tension over time. I will supply 33″-wide Mylar to those interested for 75¢ per linear foot plus $3 for shipping.

The diaphragms need a high-resistance conductive coating to carry the bias voltage. The most effective way to coat your diaphragms is with powdered graphite. Theoretically, the diaphragms' resistance (measured with probes 1″ apart) should be in the range of 10–100MΩ, but the exact value isn't very critical in practice, as long as it isn't too low. I have built units that function normally with diaphragm resistances in the range of 500kΩ.

GRAPHITE APPLICATION

With an extremely sharp utility knife or razor blade, cut a piece of Mylar about 4″ longer and wider than the outer edges of your unit. Remove any obvious pieces of dust from its surface and lay the film down on white paper towels. With masking tape, fasten down one corner of the film. Stretch the film to remove any wrinkles, and tape down the opposite corner. Then stretch and tape the other two corners.

Sprinkle a small amount of graphite on the film. The exact amount needed will depend on the type of graphite you use, but a ¼″-diameter pile is a good starting point. With a paper towel, spread the graphite around on the surface of the film, then rub it into the surface of the Mylar. I estimate that I use around ten pounds of force when rubbing the graphite in. The time, pressure, and amount of graphite required to achieve resistance in the right range will depend on your Mylar (DuPont makes several different types with various surface qualities), the type of graphite used, and what you use to apply the graphite.

If you don't get consistent coverage with the paper towel, try a piece of cotton or dacron. The more your applicator is used, the more consistently it will coat the film, so it helps to break in your applicator on a scrap piece of Mylar. Coat an area about the size of the whole unit, including spacers, to make sure all the edges of the speaker will be playing. Also, make sure to cover the area of the diaphragm contact thoroughly. When you are satisfied with the coating, wipe off any excess graphite. You will need two diaphragms per unit.

ATTACHING THE DIAPHRAGMS

Many builders like to use epoxy to attach the diaphragms to the spacers. Epoxy makes rebuilds very easy, but it has a few drawbacks: 1) It doesn't withstand torsional stress within the speaker very well. If you twist the unit after the diaphragm has shrunk, it may lose tension. 2) It's difficult to get a uniform coating of epoxy. 3) Drying time can add up when you are building multiple units. 4) Harold Beveridge's US patent 4,533,794 (1985) warns that a rigid bond between diaphragms and spacers creates stress in the diaphragms, making them prone to tearing.

I like to use ½″-wide 3M tape #9485PC. It is a two-sided, 5 mil-thick, acrylic-adhe-

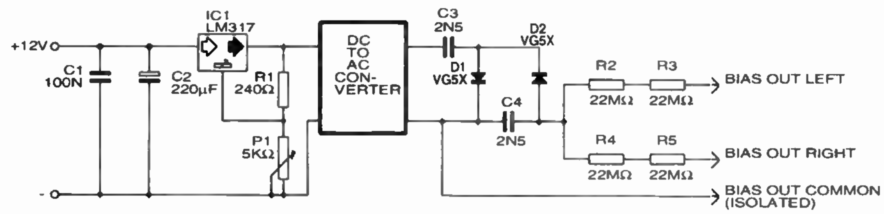


FIGURE 6: Wiring diagram for two transformers and one bias supply.

TABLE 3

COMPONENTS PARTS LIST

NO.	UNIT	VALUE/DESCRIPTION
1	C1	0.1µF 50V ceramic disc
1	C2	220µF 35V electrolytic
2	C3, C4	2,500pF 6kV
1	R1	240Ω ½W
4	R2–R5	22MΩ 1W
2	D1, D2	5kV PIV
1	P1	5kΩ ¾W pot
1	IC1	LM 317T 1.5A adjustable voltage regulator

sive transfer tape. It gives a bond of consistent thickness and more than adequate strength, and it stays flexible. Before applying the tape, make sure the surfaces to which you're applying it are clean and dry.

Apply a strip of tape down each side of the unit, overlapping the inside edge of the spacer by approximately .032″ to ensure a cushioned bond between the diaphragm and the spacers. In three of the four corners, you should butt the two pieces of tape against each other. In the fourth corner, there should be a gap of about 0.125″ (*Fig. 2*); its mirror image on the other half of the unit should have the same gap. This gap allows release of pressure between the diaphragms as temperature and atmospheric pressure vary.

For the center spacer, you need to cut a strip of tape in half. Remove the release liner from a piece of tape that runs the length of the speaker and put it on the sticky side of the tape strip. You can then easily cut the tape with scissors or a sharp knife. The edges of the center spacer should also be overlapped. You can tape the short horizontal spacers with ½″-wide tape, allowing the edges to overlap. Using medium pressure (3M recommends 15 psi), roll over the tape with your seam roller.

Now lay out the diaphragm, conductive side down, on a flat surface. Stretch it tight with tape as previously described. Remove the release liner from all of the tape on one half of a unit. Making sure of proper alignment between the diaphragm's conductive area and the speaker's plates and contact area, place the assembly, tape side down, on the Mylar. Push down, with moderate pressure, around the speaker's edges. Untape the diaphragm and turn the unit over, and run the roller over all taped areas again.

Trim the diaphragm 0.0625″ inside the outer edge of the tape, except in the area of the vent. Allow the Mylar to overlap the tape completely in this area. When you peel off the excess Mylar, there should be a 0.0625″ strip of bare adhesive outside the edge of the diaphragm. This small strip helps to seal in the volume of air between the diaphragms and maximize coupling of the two during travel. This strip should not be too wide, however, or you will have extreme difficulty getting the unit apart if the need arises. Repeat for the other half of the unit and all others.

HEAT-SHRINKING

It is now time to heat-shrink the diaphragms. As long as you use genuine Mylar and don't have any big wrinkles in the diaphragms, this will be a quick and painless procedure. I use an inexpensive, dual-temperature heat gun to shrink them. Its stated output at the setting I use is 8.8 CFM and approximately 550°F. Practice on some scrap Mylar if you have an adjustable heat gun or one that varies significantly from the aforementioned specifications.

I shrink half of one-half of a unit at a time (a 1.6″ × 18″ strip). With the heat gun warmed up, hold the nozzle approximately ½″ from the diaphragm and move it rather quickly over the strip. You should be able to shrink the strip with one five-second pass. Now shrink the other strip on the half of the unit you are working on.

If you move the heat gun too slowly, heat will begin to transfer into the spacers and warp the assembly. Though it won't damage the assembly, it will stretch the tape bonds, and when the assembly cools and unwarps, the diaphragm will lose some, or all, of its tension. If you use Super 77 spray adhesive, moving the heat gun too slowly may also break the bond between the screen and diffuser.

After you shrink half of a unit, wait ten to fifteen minutes before you shrink any other diaphragms. If the first diaphragm you shrank still has its tension, proceed with the rest of the units. If it has lost its tension, you need to modify your technique before proceeding. You may also need to replace the diaphragm that lost its tension.

For diaphragm contacts, I use an aluminum-foil tape with a conductive adhesive. If you send me a self-addressed, stamped envelope and $2, I will send you a ½″ × 1′ piece of this tape. I cut it down to 0.125″-wide strips when using it for diaphragm contacts. Cut a 3″ × 0.125″ strip and stick it to the diaphragm on the contact end (*Fig. 2*). With another piece of the same tape, make a T to overlap the piece of tape you have already laid down, and run this piece next to the diaphragm contact hole. Rolling over the tape with the seam roller finishes the contact for that diaphragm.

For the half of the speaker that has the short spacer on the contact end, just leave the second piece of conductive tape (which makes the T) hanging off the end of the

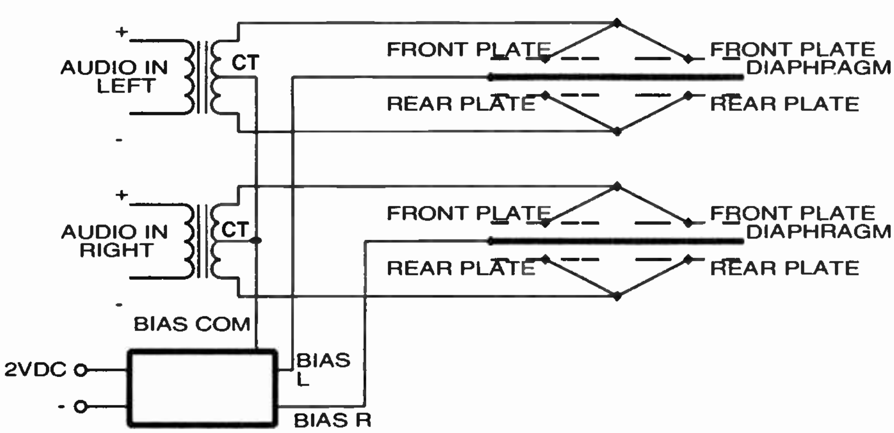


FIGURE 7: Schematic of bias supply.

speaker. Then, when you assemble the unit, fold the tape under and stick it to the foil from the other diaphragm.

JOINING THE HALVES

After making sure the diaphragms are free of debris, you can fasten the two halves of the unit together with 4–40 by ¼″ bolts. After mounting the units to your frame, wire the diaphragms and plates. The wires from the bias supply and step-up transformers to the ESLs should be high-voltage. Inexpensive test-probe wire with a 5kV rating is easy to find.

To minimize exposed high-voltage wiring, you should place the transformer for each channel in the speaker (they mount easily on top of your woofer enclosures in their own small boxes). Mounting the transformer in the speaker also decreases the amount of high-voltage wire you need. If you use only one bias supply to run both channels, you will also need enough high-voltage wire to run two wires between the two channels. You can use banana plugs on the wires running between the two speakers.

For the contact bolts, I use nickel-plated steel bolts. Use flat washers between all ring terminals and contacts, even if the terminals are tin plated. This will keep the aluminum screen from digging into the coating and coming into contact with the copper beneath. Flat washers are also necessary between the ring terminals and the foil diaphragm contacts to prevent any twisting of the terminal from tearing the foil.

ASSOCIATED ELECTRONICS

The voltage from your amplifier needs to be stepped up to the high voltage/low current that ESLs require. The MagneTek-Triad S-142A (no longer available) was the transformer of choice of DIYers for years; clones are available from Roger Sanders for $119 per pair, including shipping.

I supply transformers—not direct clones of the original—with a turns ratio of approximately 1:50, and without the multiple taps of the original S-142A. Their core size is identical, however, and they are very similar electrically to the S-142A running 1:44.7. I sell them for $60 each, including shipping.

If you use the direct S-142A clone, you have several primary winding configurations to choose from, though you always use the full secondary. The different wiring configurations produce different sensitivities, frequency responses, and impedances, so building your ESLs will involve several trade-offs.

The 1:44.7 turns ratio is about as low as you should use. You use the 4Ω and common taps as the primary in this configuration. This turns ratio presents a relatively easy load to your amplifier and has the most high-frequency output, but has fairly low sensitivity. With this ratio and two units in a 12″-wide baffle, one stacked above the other approximating a 3″ × 35″ line source, I achieved the frequency response plot shown in *Fig. 3* at 1 meter with 2.83V RMS into the transformer.

You can add more units to increase output. Each doubling of active diaphragm area yields a 6dB increase in sensitivity, assuming your amplifier is capable of delivering the extra current required to drive the higher capacity. (This is most demanding at high frequencies, and should not be a limiting factor with today's higher-current amplifiers.) You can also increase dispersion as you add more units by angling some of them off axis.

INCREASING OUTPUT

You can also increase output by using different taps for the primary winding. With pink noise as the test signal and the 1:44.7 turns ratio as a reference, using the 8Ω and 16Ω taps as the primary yielded a 5.4dB increase in sensitivity. Compared to the 1:44.7 wiring configuration, using the 4Ω and 8Ω taps as the primary yielded a 7.2dB increase in sensitivity.

With the increased turns ratio comes an increase in the transformer's leakage inductance, which forms a series resonance with the ESL's capacity. At frequencies higher than this resonance, the speaker's output is rolled off. Higher leakage inductance and speaker capacity cause this resonance to occur at lower frequencies. Luckily, with the relatively low capacity of these units (approximately 160pF per unit), this is not much of a problem.

Driving two units with the highest turns ratio produces a resonance at a high enough frequency that, on a 1/3-octave basis, the output of the 20kHz band is decreased only by 3dB, when compared to the 1:44.7 configuration. In theory, you would expect the highest turns ratio to have the greatest attenuation at high frequencies, but this honor belongs to the medium-output taps. The physical layout of the windings may be the cause of this unexpected loss.

The impedance is also quite a bit lower with the higher turns ratios, but is only extreme in the top octave. Luckily, not much power is required in this region, and the impedance isn't as hard to drive as it appears. As a test, I ran two units—connected with the highest output wiring configuration—on a low-cost, low-current 45 WPC receiver for three hours at high output levels. The receiver neither became hot nor showed any audible signs of distress. If you are worried about it, though, you will probably prefer to use the 1:44.7 wiring configuration with four units per channel.

Figures 4 and *5* show frequency response and impedance plots for various configurations. The plots were taken 72″ from two units, one above the other, in a 12″-wide baffle and with a 6dB/octave 400Hz crossover. I used an Audio Control SA-3050A for all these measurements.

BIAS SUPPLY

This design needs a bias of approximately 1.4kV DC. The tension on the diaphragms, which counteracts the tendency of the bias to pull the diaphragms into the plates, will vary depending on the precision with which you built your units. The units may handle more or less voltage. My speakers will usually take about 1.6kV DC, but I like to run them a little conservatively. When you first connect the bias, start out at about 800V DC and gradually increase the voltage. The speaker will pop when too much bias has been applied. When you hear the first pop, decrease the bias by about 100–200V.

Although you can use 120V AC line step-up transformers to obtain bias, I don't like running AC lines to my speakers with the hazards they present. I prefer to use a small, high-frequency, switching power supply that requires a 12V DC source, which anyone should be comfortable wiring. You can plug a small wall transformer into a switched outlet on your stereo and turn the bias on and off with the system. I sell the DC-to-AC converter section for $30, including shipping.

With a few surplus high-voltage parts and some common parts from any electronics-supply house, you will have a small, regulated, variable-voltage bias supply that draws relatively low current. *Figure 6* shows a schematic for the supply; the component values are in *Table 3*. With the voltage-doubler circuit, this supply puts out 1.4kV DC, with 7V DC and 60mA out of the regulator.

The relationship between input and output voltage is linear (each 1V in equals approximately 200V out), so anyone with a multimeter can check the input and output voltages at a low setting, thus gaining an accurate estimate of higher voltage outputs without a high-voltage probe. As this supply doesn't contain bleeder resistors, you should take care to discharge the HV capacitors it contains before working on the bias supply or speakers. You can use one bias supply for both speakers as shown in the diagram, or build a separate supply for each channel.

Figure 7 shows a wiring diagram with both transformers and a bias supply. You should definitely use grille cloth on both sides of your speakers, and possibly add .25 inch "acoustically transparent" foam to their backs. The grille cloth alone decreases the magnitude of the ESL's output at resonance by 3 or 4dB. With the foam—or multiple layers of grille cloth—on the back, you can decrease the output at resonance another 3dB. The grille cloth also makes it less likely that anyone will touch the ESL's plates. Covering the HV connections of the unit with PC is also a good idea.

CROSSOVER CONCERNS

These panels should be crossed over at approximately 500Hz with a 12dB/octave crossover, though the slope could be 6dB if you don't expect extreme output from them. The spacing of these speakers (approximately 30 mils from diaphragm to plate) is less than that normally recommended for DIY ESLs, but is quite generous as long as you control the diaphragm at resonance. I have built fully insulated units, with powder-coated plates and 15 mil spacing from diaphragm to plate, that can be crossed over at 500Hz. As long as you damp the diaphragm's resonance, you can run these units with 1:150 transformers without problems.

Below 500Hz, conventional woofers are a more practical choice. I advise active crossovers and biamping. Active crossovers will simplify the task of getting the balance right between your essentially omnidirectional woofers and your line-source dipole ESLs. However, if you wish to use passive crossovers, refer to Ron Wagner's book, which contains a reprint of an article covering such a design.

POWER CONSIDERATIONS

Figure 3's frequency-response plot shows that with the highest turns ratio available, two units will produce a sensitivity of approximately 84dB. Though a speaker with a sensitivity rating in this range won't run you out of the room, it will produce reasonable output. With the highest turns ratio, I suggest a maximum amplifier rating of 100 WPC at 8Ω. With the lowest turns ratio, you could use over 200 WPC.

You need to keep two things in mind when deciding on a power level. First, depending on the turns ratio you choose, you can exceed the transformer's insulation rating with relatively low power, though most transformers are rated pretty conservatively. Second, high-powered, distorted signals can produce enough high-frequency high voltage on the plates to punch a hole through both layers of Mylar. This type of puncture is caused by an arc from plate to plate, not plate to diaphragm, and is a risk in uninsulated ESLs, as well. If you respect your equipment and its limitations, neither of these issues should be a problem.

FINE SOUND

The sound of ESLs is unique. Although many reviewers regard ESLs' midrange as their most impressive frequency range, to me the most noticeable difference between them and other driver types is the ESL's effortless reproduction of high frequencies. I have never heard any other type of speaker that is as free from grain or that induces less listener fatigue. Of the speakers I have heard, ESLs come closest to disappearing when you're listening to them.

A word of warning though: for all they can bring out in a good recording, ESLs also have a habit of exposing recording errors that may not show up on other types of speakers. But this is a small price to pay when you consider how impressive they are with good recordings.

REFERENCES

1. Roger Sanders, *Electrostatic Loudspeaker Cookbook*, Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458, 603-924-6371, FAX 603-924-9467.

2. Ronald Wagner, *Electrostatic Loudspeaker Design*, also available from Old Colony.

SOURCES

Matthew Lattis, 5321 Vista John Dr., Louisville, KY 40214, E-mail electrostatic@juno.com
Mylar, transformers, bias supplies

Roger Sanders, (505) 759-3822
Mylar, transformers, general ESL parts

3M, (800) 362-3550 for locations of distributors of 9485PC

R&D Electronics, (216) 441-5577
HV diodes Varo VG5X (part #323, 10 for $5.50), HV caps 2,500pF 6kV, $0.75 each

MCM Electronics, (800) 543-4330
Inexpensive HV wire (part #24-1795, $9 for 50')

Local plastic-supply house
40 mil. polycarbonate

OF MASS AND RESISTANCE

By Ahmet Deniz

I recently set about designing a passive subwoofer for a pair of commercial minimonitors that I own. The minimonitor in question is mercilessly accurate and revealing, but like all such systems, its bass response is limited. The bass it produces is clean and, considering the tiny dimensions, surprisingly deep, but unfortunately not quite deep enough to be completely satisfying.

I decided to solve this problem the same way the original manufacturer did—by designing a dedicated passive subwoofer. The manufacturer's purpose-designed subwoofer works very well, but unfortunately it is very costly and is no longer being made. So, I figured that if I desired a quality subwoofer extension, I would need to build my own. In the process of designing the sub, I made some derivations of Thiele and Small's original equations that I thought might be of interest to some builders.

The equations I describe in this article should interest anyone who has been frustrated by being unable to find a catalog driver to meet a situation's given requirements. Although the derivations are specific to the needs I encountered in my subwoofer project, my hope is that you will be encouraged to use similar derivations for other situations you may encounter.

SENSITIVITY MATCHING

The big problem I had was finding a driver with an appropriate sensitivity. To produce a flat system response, the sensitivity of the add-on subwoofer needed to match that of the minimonitor satellites. (Remember, this was to be a passive subwoofer.) The manufacturer of my minimonitors specifies a sensitivity of 85dB for 2.83V input at 1m—a figure I verified in testing.

The subwoofer would be closely coupled to the floor of my room and so would be seeing an approximately hemispherical load. This meant that I needed a driver with a hemispherical sensitivity close to 85dB if I wanted to put it in either a closed or vented box.

If you page through the various catalogs of drivers available to home builders, you will find very few low-frequency drivers with a rated sensitivity near 85dB. Most drivers are considerably more sensitive. While insertion losses in the crossover would reduce the effective sensitivity a bit, these losses would typically be limited to about a decibel—not much of a help. Of the drivers I did find with an appropriate sensitivity, none gave me the kind of extension I wished. Now what?

One obvious course was to modify the performance of a selected off-the-shelf driver to meet my needs. *Speaker Builder* authors have previously dealt with modifying drivers by using series resistance and adding mass to driver cones.[1,2] While these articles presented some general rules of thumb for determining how a given resistance or mass will affect a driver's parameters, my project required a concise, analytical means to accurately predict outcomes. Luckily, it is not impossible to develop such a method.

By applying some basic knowledge of how loudspeakers work to the original Thiele/Small (T/S) equations that describe a driver's low-frequency behavior, I derived a set of equations that told me exactly what I needed to know, namely, how much mass and/or resistance I needed to add to a driver of known specification to achieve a given sensitivity. I also needed to know what impact that added mass or resistance would have on that driver's T/S parameters.

I will first present the analysis that leads to the equations, and then describe a design example that shows how to use them.

BACK TO BASICS

The first step in the analysis is to think about how a driver works at a fundamental level. At its core, a loudspeaker is a system consisting of a mechanically resonant diaphragm/voice-coil assembly driven by an electromagnetic motor. You can therefore view the driver as having a set of fundamental parameters (FPs) that directly reflect the above two subsystems, and it turns out that doing so simplifies the analysis quite a bit.

To that end, I have tabulated a set of fundamental mechanical parameters (*Table 1*) and a set of fundamental electromagnetic parameters (*Table 2*). These are based on the analysis of electrodynamic loudspeakers in Beranek's *Acoustics*.[3]

TABLE 1

FUNDAMENTAL MECHANICAL PARAMETERS

PARAMETER	DESCRIPTION	UNIT OF MEASUREMENT
M_{MD}	moving mass of diaphragm and voice coil	kg
C_{MS}	mechanical compliance of suspension	meter/Newton
R_{MS}	mechanical resistance of suspension	Newton sec/meter
S_D	effective diaphragm area	meter^2
M_{MI}	equivalent mass of air load on one side of diaphragm	kg
M_{MS}	total effective moving mass = $M_{MD} + 2(M_{MI})$	kg

You can characterize any simple, mechanically resonant system as having a moving mass, a compliance, and a loss factor—a measure of the energy in the mechanical system that is converted to heat from kinetic and potential energy. In a loudspeaker driver, almost all of the system's moving mass, referred to as M_{MD}, comes from the diaphragm and the voice-coil assembly.

The mechanical compliance, C_{MS}, comes from the combined effect of the driver's surround and spider. The mechanical losses (arising primarily from friction and viscous losses in the surround and spider, but also from resistance to air flow around the voice coil, and from other less obvious phenomena) are approximated by the simple mechanical resistance, R_{MS}. A driver's diaphragm has an effective surface area, S_D, the relevance of which will become clear below.

ADDING A LOAD

The parameter M_{MI} is the result of a rather subtle phenomenon that must nonetheless be accounted for. When you wave your hand in the air, you can sense something that slightly impedes your hand's motion: namely, the gazillions of air molecules that your hand displaces. The faster you wave (the greater your waving frequency), the more impedance you feel. A loudspeaker's diaphragm experiences much the same thing, and in technical literature, this is typically identified as "radiation impedance."

The nature of this impedance is rather complex—in many senses of the word. Fortunately, applying some of the approximations that acousticians routinely rely on to obtain usable analytic relations shows that at low frequencies the effect of the impedance caused by the air load on a diaphragm is almost exactly equivalent to adding a small physical mass to the cone.

This equivalent additional mass experienced by *one side* of a diaphragm mounted on an infinite baffle is represented by M_{MI}, and is equal to $8\rho_O(S_D/\pi)^{3/2}/3$—where ρ_O is the mean density of air (typically about $1.18kg/m^3$). Finally, M_{MS} represents the total effective mass of the entire moving system, and is equal to the sum of M_{MD} and two times M_{MI} (one M_{MI} for each side of the diaphragm).

A loudspeaker's electromagnetic motor essentially consists of an electrically conductive coil (the voice coil) placed within a magnetic field. The strength of the magnetic field that cuts the voice coil at a right angle is represented by B, the air-flux density. The length of the wire the magnetic field cuts across, that is, the wire in the motor system's air gap, is represented by l, and R_E represents the DC resistance of the entire coil.

Typically, the coil is connected to an amplifier that behaves as a voltage source with some small output impedance, through a cable also having some small impedance. For the present purposes, the combined influence of these two impedances is lumped together into an equivalent series resistance, represented by R_g, the generator source resistance. The total DC resistance of the system is represented by R_{dc}, which equals the sum of R_E and R_g. (The voice coil's impedance also has a complicated inductive-like component associated with it, but I have chosen to ignore it in this analysis, since the effects of this inductive-like behavior don't manifest themselves at low frequencies.)

Viewing the electromagnetic motor this way, you can see that the total force generated by the motor is f = (Bl)i, where i is the current through the length of wire l. This current equals the voltage sourced to the system divided by the total DC resistance, or $i = V_g/(R_g + R_E) = V_g/R_{dc}$. Thus, $f = (Bl)(V_g/R_{dc})$. This isn't terribly important to the present task, but it does show the relevance of the often-referred-to "Bl product" of a driver.

TABLE 2

FUNDAMENTAL ELECTROMAGNETIC PARAMETERS

PARAMETER	DESCRIPTION	UNIT OF MEASUREMENT
B	flux density in voice-coil air gap	Weber/m² or Tesla
l	length of wire in voice-coil air gap	meter
R_E	DC resistance of entire voice coil	ohm
R_g	generator DC resistance	ohm
R_{dc}	total DC resistance of system = $R_E + R_g$	ohm

TABLE 3

T/S PARAMETER TO FUNDAMENTAL PARAMETER CONVERSIONS

PARAMETER	UNIT OF MEASURMENT
$S_D = \pi a^2$ (or use specified value)	m² (note: a is the effective cone radius in meters)
$C_{MS} = \dfrac{V_{AS}}{\rho_O c^2 S_D^2} \times 10^{-3}$	meter/Newton (note: V_{AS} is measured in liters)
$M_{MS} = \dfrac{1}{(2\pi f_s)^2 C_{MS}}$	kg
$M_{M1} = 8a^3 \rho_o / 3 = 0.479 \rho_o S_D^{3/2}$	kg
$M_{MD} = M_{MS} - 2M_{M1}$ $= \dfrac{1}{(2\pi f_s)^2 C_{MS}} - 0.958 \rho_O S_D^{3/2}$	kg
$R_{MS} = \dfrac{2\pi f_s M_{MS}}{Q_{MS}}$	Newton sec/meter
R_g = the sum of the amplifier output resistance, the total crossover inductor resistance, and any additional series resistance.	ohm
R_E = measure directly or use specified value.	ohm
$R_{dc} = R_E + R_g$	ohm
$(Bl) = \left(\dfrac{R_{dc}}{Q_{ES}}\right)^{1/2} \left(\dfrac{M_{MS}}{C_{MS}}\right)^{1/4}$	Weber/meter, Tesla-meter, or Newton/ampere

PARAMETER ALTERATION

With the loudspeaker driver modeled in this way, the next step is to figure out what happens to the FPs when you add some mass to the cone or put a resistor in series with the voice coil. I think it's fairly obvious that adding mass to the cone of the driver will increase M_{MD} by exactly the amount of the added mass. Similarly, if you put a resistor in series with the voice coil, the R_g of the system will increase by an amount equal to the added resistance.

What is less clear is how the other parameters change, if at all. Since C_{MS} is a mechanical property of the surround and suspension, neither of the modifications should affect it. Also, since the properties of the suspension dominate R_{MS}, it, too, will remain unaffected. Adding mass or resistance does nothing to change S_D, so M_{MI} should also stay the same, and since M_{MI} didn't change, you can expect M_{MS} (the sum of M_{MD} and M_{MI}) to likewise increase by exactly the amount of the added mass.

On the electromagnetic side, adding a series resistor will not change the properties of the magnet, so B, the flux density in the gap, stays the same. Moreover, the added resistor doesn't change the length of the wire in the air gap or the DC resistance of the actual voice-coil, so l and R_E do not change. And since R_E stays the same, R_{dc} simply increases by the amount of the added resistance.

To summarize, adding mass to the cone of a driver increases M_{MD} and M_{MS} by the amount added; when you add a series resistance, R_g and R_{dc} increase by the amount of the added resistance. No other FPs are affected.

This simple result is one reason for basing the analysis on the FPs rather than the more familiar T/S parameters. Rest assured, I'll get around to converting between T/S parameters and FPs soon enough, but first I'll show you how to calculate the amount of mass and/or resistance to add to the driver to achieve the desired sensitivity using the FPs.

BASICALLY SENSITIVE

What you need now is an expression for a driver's nominal voltage sensitivity (i.e., the mid-band SPL generated by the driver when driven by a 2.83V RMS signal at 1m), given its

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.

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 •

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 •

1992 Rumreich on Box Design & Woofer Selection • MLSSA • Double-Chambered Reflex by Weems • Active Crossover and Delay • Electrical Circuit Bandpass Enclosure • A Dreadnaught System (satellite swivels) • Designing Real-World Two-Way Crossovers • 20-foot Ribbon Dipole Speaker • Biamping the Sapphire II • Capping Passive Crossovers • A High Quality Speaker Cabinet • 1/3-Octave Noise Source • Disappearing Loudspeaker • The A&S Soundoff Winner, Pt 1-2 • Alignment Jamming • Marc Bacon's "Danielle", Pt 1-2 • Double-Chambered Isobarik Bass • Ferguson's Pickup Installation • Electronic Counter for Coil Winding • Oakley on Speaker Placement • Making Your Room Hi-Fi, Pt 1 • More on Dust Caps • Spreadsheet for Nonoptimum Vented Box Design • Acoustic Resistance Tuned Enclosure •

1993 Waslo's IMP, Pt 1-3 • Quasi-Monotonic Vented Alignments • Making Your Room Hi-Fi, Pt 2-3 • A&S Soundoff Winner, Pt 3 • Flexible Dipole Woofer • The Simpline • Stalking F_3 • A Bi-Structural Enclosure • A Sixth-Order T/S Subwoofer Design • Speaker Enclosure Screws • Electric Bass Tri-Horn • Prism V Satellite/JBL Subwoofer, Pt 1-2 • Fitduct: Program for Designing Duct Software • Compact Coincidental Point Source Speaker • IMP: Measuring T/S Parameters • KIT REPORT: Rockford's Beginner Software/Driver Paks • SOFTWARE REPORT: Low Frequency Designer 3.01 • Three Affordable Measurement Microphones • Two Ways to Realize a Dream • Matching Driver Efficiencies • Two-Woofer Box System • Designing a Dual Voice Coil Subwoofer • SOFTWARE REPORT: Blaubox 1.2 • Tale of Three Speaker Projects • A&S Sound-off 1992 • Monolith Horn • Orbiting Satellites • Real-World Three-Way Crossovers • The Simplex • Living with a Speaker Builder • The IMP Goes MLS •

1994 Sanctuary Sonics • Modular Active Crossovers • A Full-Range Open-Baffle System • An Evolving Magnepan MG-1 • Low-Frequency AC-To-DC Converter • A Compact Bass Guitar Speaker • Measuring Speaker Impedance Without a Bridge • The Dynapleat • The Danielle II • The Birdhouse: A Sound-Reinforcement Subwoofer • The Linear-Array Sound System • A Revised Two-Way Minimonitor • Exploring the BUF 124 with Pspice • Signet's SL280B/U • Time Response of Crossover Filters • Converting Radio Shack's SLM To Millivolt Use • Acoustic Distortion and Balanced Speakers • Microphone Response Correction with IMP • More About the Birdhouse Bandpass • A 16Hz Subwoofer • D.H. Labs Silver Sonic Cables • The System III Loudspeaker • Exploring Loudspeaker Impedance • IMPcycling • The Linear-Array Chronicles • Book Report: Loudspeaker Recipes, Book One • The Woofer Test • A Large Ribbon You Can Build • Loudspeakers, A Short History, Pt 1-2 • Absolute SPL Sensitivity Measuring with IMP • The Damping Factor: One More Time • Cliffnotes for Loudspeaker University • Software Report: The Listening Room for Macintosh • Book Report: The Theory and Design of Loudspeaker Enclosures • A 15" Transmission Line Woofer • Inductor Coil Cross Talk • Quick Home Theater on a Budget • Silk Purses: A Two-Way Salvage Design • Audio Phase Inductor •

There's More ☞

Please send me the following back issues of Speaker Builder

❑ 1996 $32 ❑ 1995 $32 ❑ 1994 $32 ❑ 1993 $25
❑ 1992 $25 ❑ 1991 $25 ❑ 1990 $25 ❑ 1988 $23
❑ 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 $8.00 per year.	
Foreign Air:	Europe add additional 40% of total order.	**Total Magazines** ________
	Other destinations: 50% of total order.	**Postage** ________
Foreign Surface:	Add additional 20% of total order.	**TOTAL ENCLOSED** ________

Rates subject to change without notice. All remittance in US $ only drawn on a US bank.
Make checks payable to Audio Amateur Corp.

❑ Check or Money Order ❑ Discover ❑ MC ❑ VISA ❑ AMERICAN EXPRESS

CARD NO. ________ EXP. DATE ________

NAME ________ ACCOUNT NO. ________

STREET & NO. ________

CITY ________ STATE ________ ZIP ________

Speaker Builder

Post Office Box 494, Dept. B97, 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.

FPs. Beranek gives the pressure generated by a loudspeaker diaphragm at low frequencies mounted on an infinite baffle as:

[1] $$|p(r)| = \frac{V_g(Bl)S_D f \rho_0}{rR_{dc}\sqrt{R_M^2 + X_M^2}}$$

where p is the pressure, V_g the generator source voltage, r the distance from the diaphragm to the listening point, f the frequency (in Hz), and R_M and X_M the magnitudes of the real and imaginary parts of the effective load impedance seen in the analogous acoustical circuit from which Equation [1] was derived.[3] If you set r to the one-meter standard and V_g to 2.83V RMS (the equivalent of 1W into an 8Ω load), you have a relationship for a loudspeaker's normalized frequency response, S(f):

[2] $$S(f) = \frac{2.83(Bl)S_D f \rho_0}{R_{dc}\sqrt{R_M^2 + X_M^2}}$$

The parameters R_M and X_M are cause for concern, since they are rather involved frequency-dependent terms that could terminally complicate any additional analysis. Fortunately, if you're concerned only with the driver's response above its fundamental resonance, you can utilize some more of those acoustician's approximations (I exclude the details for brevity) and use [2] to derive a simple expression for the driver's midband voltage sensitivity referenced to a source voltage of 2.83V:

[3] $$S_R = \frac{2.83(Bl)S_D \rho_0}{2\pi R_{dc} M_{MS}}$$

To convert S_R to SPL (in decibels), use:

[4] $$SPL_0 = 20\log(S_R/p_{ref}) = 20\log(S_R) + 94dB$$

where p_{ref} is the standard reference pressure of 2×10^{-5} Pa.

You can see from [3] that the system's sensitivity is inversely proportional to both the total DC resistance in the system and the total effective moving mass.

You now know, thanks to Equations [3] and [4], how to determine the sensitivity of your driver, given its FPs. Next, you need to know how to calculate the amount of mass or resistance to add to bring the sensitivity down to the desired level. Call the desired sensitivity (in dB) SPL_0'. The amount that the sensitivity needs to change is $\Delta SPL = SPL_0' - SPL_0$. (Note: this will be a negative number, indicating that the sensitivity needs to come *down*.) Using the relationship given in [4],

[5a] $$\Delta SPL = SPL_0' - SPL_0 = 20\log(S_R') - 20\log(S_R) = 20\log(S_R'/S_R)$$

or

[5b] $$\frac{S_R'}{S_R} = 10^{\Delta SPL/20}$$

Using [3] and letting M_{MS}' and R_{dc}' represent the total effective mass and the total DC resistance of the modified system (i.e., after adding the mass and/or resistance), we have:

[6] $$\frac{S_R'}{S_R} = \frac{\dfrac{2.83(Bl)S_D \rho_0}{2\pi R_{dc}' M_{MS}'}}{\dfrac{2.83(Bl)S_D \rho_0}{2\pi R_{dc} M_{MS}}} = \frac{R_{dc} M_{MS}}{R_{dc}' M_{MS}'}$$

Substituting the right-hand side of [6] into [5b] and rearranging things a bit yields

[7] $$R_{dc}' M_{MS}' = \frac{R_{dc} M_{MS}}{10^{\Delta SPL/20}}$$

Equation [7] expresses a relationship between the modified parameters (on the left) and the desired change in sensitivity and the original parameters (on the right). You can use this equation directly if adding both cone mass *and* resistance. However, further simplifications are possible if you decide to add *only* mass or *only* resistance. For instance, if you let $M_{MS}' = M_{MS}$ in [7] (i.e., you don't change the cone mass), you get:

[8] $$R_{dc}' = \frac{R_{dc}}{10^{\Delta SPL/20}}$$

Similarly, if you change the cone mass, but do not add any series resistance, you get:

[9] $$M_{MS}' = \frac{M_{MS}}{10^{\Delta SPL/20}}$$

Once you have the modified values for the total effective cone mass and DC resistance (M_{MS}' and R_{dc}', respectively), you can compute the actual amount of mass or resistance to add as follows:

[10] $$\Delta M = M_{MS}' - M_{MS}$$

and

[11] $$\Delta R = R_{dc}' - R_{dc}$$

where ΔM is the added mass and ΔR is the added resistance.

MAKING IT USEFUL

Given a driver of known FPs, you now know how to modify it to produce the desired sensitivity. Unfortunately, most spec sheets and design methods are based on T/S, not the fundamental, parameters. The next step, then, is to develop some means of connecting the two sets of parameters. This turns out to be simpler than it sounds, because the T/S parameters are actually based on the FPs.

I have tabulated a series of equations you can use to get from T/S parameters to FPs (*Table 3*). *Table 4* shows the complementary set—to get from FPs back to T/S parameters. These equations are simply algebraic manipulations of the relationships published in the standard sources, so I won't belabor you with their detailed derivations.[5–8] They assume that you know how to determine—or have accurate spec sheets that specify—the following T/S parameters: V_{AS}, f_S (the free air resonance), Q_{MS}, Q_{ES}, and R_E (the voice-coil resistance—sometimes called R_{VC} or something similar).

If you are using manufacturer's data in the equation for (Bl) in *Table 3*, you should assume that R_g equals zero unless your data sheet states otherwise. In all cases, use 345 m/s for the speed of sound, and 1.18kg/m^3 for ρ_0, the mean density of air, unless you have good reason to use other values.

It may be interesting to note that the electrical damping and total system damping will change if you add either mass *or* resistance; that the free-air resonance and mechanical damping will change when you add only mass; and that V_{AS} will not change with either added mass or resistance.

DESIGN PROCESS

Given what you now know, you can define a design process as follows. Take a candidate driver's T/S specifications and convert them to the FPs using the equations in *Table 3*. Then use Equations [3] through [11] above to calculate how much mass and/or series resistance to add to produce the desired sensitivity. Having done that, compute a new set of FPs based on the added mass and resistance, and use these in the *Table 4* equations to compute a new set of T/S parameters for the modified driver. Finally, use your favorite cabinet-design tools to see what kind of performance you can achieve with the modified driver.

Given the sort of "what if" nature of the above procedure ("What if I add *this* much mass and *this* much resistance?"), as well as the tedium involved in converting parameters back and forth, you might think that this process would be a good candidate for implementation on a computer spreadsheet. Well, you're right—I have done so (see *Fig. 1*).

DESIGN EXAMPLE

To show you how to put it all together, I will now present a design example using a typical catalog driver. Say you have a driver that you have determined—either by testing or trusting the manufacturer's data sheet—to possess the following T/S specifications: V_{AS} = 30.5 ltr, Q_{MS} = 1.21, Q_{ES} = 0.31, Q_{TS} = 0.24, f_S = 34Hz, R_E = 6.1Ω, and S_D = 130cm^2. (These are actually the manufacturers' specifications for a commonly available 17cm woofer.)

The first step is to convert the T/S data to FPs. Plugging the above numbers into the equations in *Table 3* and assuming R_g is zero yields the following FPs for the unmodified driver: C_{MS} = 1.29e–3 m/N, M_{MS} = 17.1e–3 kg, M_{MI} = 0.84e–3 kg, M_{MD} = 15.4e–3 kg, R_{MS} = 3.01 Ns/m, R_{dc} = 6.1Ω, and (Bl) = 8.47 N/A.

Next, Equations [3] and [4] tell you that a driver with the above parameters will have a voltage sensitivity of 88.98dB—which is the SPL you expect the unmodified driver to produce above cutoff at 1m when excited by a 2.83V RMS signal while radiating into a hemispherical space. Normally, in a large room and at wavelengths longer than the shortest wavelength of the baffle, a driver

Unmodified T/S parameters	
Vas	30.50 liters
fs	34.00 Hz
Qms	1.21
Qes	0.31
Sd	1.30E-02 meter^2
Re (voicecoil d.c. resistance)	6.10 Ω
Amount of added mass	8.65E-03 kg
Amount of added resistance	3.00E-01 Ω
Unmodified sensitivity	*88.98 dB@2.83v*
Modified sensitivity	*85.00 dB@2.83v*
Modified T/S parameters	
Vas'	*30.50 liters*
fs'	*27.69 Hz*
Qms'	*1.49*
Qes'	*0.40*
Qts'	*0.31*
Rdc'	*6.40 Ω*

Unmodified Fundamental Parameters	
Cms	*0.00128497 m/N*
Mms	*0.01705256 kg*
Mm1	*0.00083778 kg*
Mmd	*0.01537699 kg*
Rms	*3.01066828 Ns/m*
(B l)	*8.46658376 N/A*
Rdc	*6.1 Ω*
Sr	*0.56236827 Pa*
Altered Fundamental Parameters	
Mms'	*0.02570256 kg*
Mmd'	*0.02402699 kg*
Rdc'	*6.4 Ω*
Sr'	*0.35561809 Pa*
Misc. parameters	
c	345 m/s
p0	1.18 kg/m^3
π	3.14159265
pref	2.00E-05 Pa

FIGURE 1: Mass and resistance of the SEAS P17REX driver.

effectively radiates into a spherical, rather than hemispherical, space, so the actual voltage sensitivity will be one-half (i.e., 6.02dB lower than) the value calculated with Equations [3] and [4].

However, as I mentioned in the introduction to this article, the subwoofer design I had in mind would closely couple the driver to the floor, meaning that the driver would experience boundary doubling, increasing the sensitivity by 6.02dB over the spherical value. Therefore, the sensitivity calculated using Equations [3] and [4] should directly predict the unmodified output of the example driver in its actual application. This means that to achieve a target sensitivity of 85dB, the driver's sensitivity must be brought down by 88.98 − 85 = 3.98dB.

WHICH TO ADD?

To achieve the 3.98dB attenuation using resistance alone, Equations [8] and [11] show that you'll need 3.55Ω of additional resistance. This results in a modified value for R_{dc} of 6.1 + 3.55 = 9.65Ω. Substituting this and the remaining (unchanged) parameters into the equations in *Table 4* yields the following T/S data for the modified driver: V_{AS} = 30.5 ltr, Q_{MS} = 1.21, Q_{ES} = 0.49, Q_{TS} = 0.35, and f_S = 34Hz. Finally, plugging these values into a low-frequency design program indicates that the modified driver in a ported 22-ltr box tuned to 37Hz would produce a 3dB-down point of about 39Hz. Not bad.

TABLE 4

FUNDAMENTAL PARAMETER TO T/S PARAMETER CONVERSIONS

PARAMETER	UNIT OF MEASUREMENT
$V_{AS} = C_{MS}\rho_o c^2 S_D^2 \times 10^3$	liter
$f_s = \dfrac{1}{2\pi\sqrt{M_{MS}C_{MS}}}$	Hz
$Q_{MS} = \dfrac{2\pi M_{MS} f_s}{R_{MS}}$	.
$Q_{ES} = \dfrac{2\pi M_{MS} f_s R_{dc}}{(Bl)^2}$	.
$Q_{TS} = \dfrac{1}{1/Q_{MS} + 1/Q_{ES}} = \dfrac{Q_{MS}Q_{ES}}{Q_{MS}+Q_{ES}}$	.

Now examine what happens when you add only mass to reduce the sensitivity. (In reality this is difficult to do, since crossover inductors have a non-negligible resistance that should be included as an additional series resistance. But the exercise is instructive, all the same.) Equations [9] and [10] show that 9.9g of additional mass will reduce the sensitivity of the driver by the required 3.98dB. The equations in *Table 4* then yield the new T/S parameters: V_{AS} = 30.5 ltr, Q_{MS} = 1.52, Q_{ES} = 0.39, Q_{TS} = 0.31, and f_S = 27Hz. This lets you build a 16-ltr box tuned to 33Hz, for a 3dB-down point of around 36Hz. I can live with that.

DETAILS, DETAILS

Using a lot of algebra, you can extend the above analysis to eliminate the intermediate conversions to and from FPs and derive a set of equations that directly express the changes in the T/S parameters based on the added mass and resistance. I have chosen not to do so in this article because: (1) The additional work would only marginally extend the utility of what I've presented so far, and (2) I've probably already taxed the patience of even the most dedicated *SB* reader.

Still, there are some interesting areas to explore where such an analysis can be helpful. For example, you might wonder whether it is generally better to add mass or resistance in lowering the sensitivity. Well, it turns out that from a low-frequency point of view it's almost always best to rely on added mass to achieve the desired sensitivity reduction. Doing so tends to give you the best extension in the smallest cabinet volumes for most drivers.

Having said that, a word of caution is called for. Adding a blob of mass to a driver's cone will have predictable effects at low frequencies, where the cone is moving as a piston. However, at higher frequencies, the blob you've added will have completely unpredictable, and usually undesirable, results. So if you're planning a driver crossover above a couple of hundred hertz, use series resistance alone to reduce the sensitivity.

The added resistance will itself have some effect on the driver's midrange response as it interacts with the inductive-like component of the voice-coil impedance. But the response modifications will tend to be gentle and correctable in the crossover—by adding a Zobel or a more complicated network across the voice-coil terminals, for example.

ADDING MASS

Attaching a few grams of mass to an undoped paper-cone driver should present few difficulties as long as you use a high-quality adhesive and don't get any on the surround or other moving parts. Epoxies in particular seem to be well suited for this task. The mass could be just about anything—lead shot, plastic beads, even the epoxy itself.

On the other hand, getting anything to stick to polypropylene cones is quite another matter. One knowledgeable source has suggested that cyanoacrylates (i.e., "super glues") might work in this application. Never having tried this, I can make no assurances or additional recommendations. Whatever you use, just make sure to include the mass of the adhesive in all your calculations.

Clearly, using added mass and resistance techniques can result in systems of significant extension in smallish cabinet volumes if you are designing for a low sensitivity. One often-raised concern regarding deep bass from small enclosures is the nonlinear compressibility of air. Colloms indicates that if the air compression inside a box exceeds 5% by volume, significant harmonic distortion may result.[4]

Will this be a problem for the 16-ltr box using the example driver? The driver has a peak excursion of about 1.0 cm before it bottoms out. The surface area of the cone is 130 cm^2, so the maximum volume displacement is $1.0 \times 130 = 130$ cm^3 or 0.130 ltr. This is $0.130/16 \times 100\% = 0.81\%$ of the total cabinet volume. Clearly, in this case, excursion limitations will have a much more pronounced effect on the performance of the system than the nonlinearity of air.

WHAT ABOUT THE SUBWOOFER?

So, how did the subwoofer project fare? I used the spreadsheet mentioned above to investigate many, many drivers in an attempt to find something that looked promising for my subwoofer. Despite the smallish cone area, I eventually settled on the driver used in the design examples above as offering a good compromise between extension and size—especially in view of my space limitations.

Unfortunately, after modeling the low-frequency impedance of the modified driver in its enclosure, it turned out that the cost of equalizing the low-frequency impedance peaks—necessary to avoid horrendous crossover mistermination—was irritatingly high. A few second-order systems I considered fared little better.

In the end, I opted to investigate bandpass loading techniques, and that is the subject of another article.

REFERENCES

1. John Cockroft, "The Uniline: Designing Shorter Transmission Lines," *SB* 4/88, p. 28.
2. Brian D. Smith, "Adjusting Woofers for High Performance," *SB* 6/89, pp. 22–24.
3. Leo L. Beranek, *Acoustics*, 1993 ed., Acoustical Society of America, Woodbury, New York, 1993.
4. Martin Colloms, *High Performance Loudspeakers*, 1st ed., Wiley, New York, 1978.
5. Small, R.H., "Direct Radiator Loudspeaker Analysis," JAES, June 1972.
6. Small, R.H., "Closed-Box Loudspeaker Systems, Parts I and II," JAES, December 1972 and January 1973.
7. Small, R.H., "Vented-Box Loudspeaker Systems, Parts I–IV," JAES, June–October 1973.
8. Thiele, A.N., "Loudspeakers in Vented Boxes," JAES, May and June 1971.

ACKNOWLEDGMENT

I would like to thank His Supreme Omniscience, the venerable Richard Pierce, for filling in some gaps in my knowledge in the preceding analysis and for being a general and amusing source of encouragement.

HOW TO CONTACT US

Speaker Builder encourages reader feedback in the form of letters, queries, and comments. Send your correspondence to:

Speaker Builder
Editorial Dept.
PO Box 494, Peterborough, NH 03458
FAX (603) 924-9467,
E-mail audiodiy@top.monad.net.

Letters/inquiries: Be sure to reference the issue, title, author, and page number of the article or letter in question; write clearly; and if you request an answer from an author, please include a self-addressed envelope (and your FAX number and/or E-mail address, if applicable), with a loose stamp or postal coupon.

Due to the volume of correspondence, we cannot personally acknowledge or respond to each letter or query. All letters to the editor will be considered for publication unless you indicate otherwise. **Speaker Builder** reserves the right to edit your letters or technical queries for length and clarity.

Submissions: Author guidelines to help you prepare your manuscript submission are available by sending a self-addressed envelope with loose postage. We encourage writers to query us before submitting an article. We acknowledge submissions upon receipt, then respond with acceptance or rejection within six weeks.

Audio Amateur Loudspeaker Projects

compiled from *Audio Amateur* Magazine

A collection of the 25 best speaker articles published in *Audio Amateur* throughout the 1970's, this popular book is proof that great designs are never out-of-date, and can be as challenging and rewarding as when they first appeared in print. The electrostatic and transmission-line articles are particularly interesting and useful. Profusely illustrated. 1985, 135 pp., 8-1/2″ × 11″, softbound. ISBN 0-8338-0193-7. Shipping wt: 1 lb. FOT # 2101

BKAA1 $20.00

The Electrostatic Loudspeaker Design Cookbook

by Roger R. Sanders, with Barry McClune

This volume is an encyclopedic exploration of the important issues, tradeoffs, and technical questions involved in building the radiating, electrostatically charged panel surfaces which make up the electrostatic loudspeaker. Construction advice for both flat and curved panels is offered, along with plans for the necessary interfaces and drive requirements, and power supply and crossover suggestions. Roger Sanders has been building electrostatics for nearly 25 years, and has consulted with and advised hundreds of fellow enthusiasts worldwide. 1995, 202pp., 8-1/2″ × 11″, softbound, ISBN 1-8825-8000-1. Shipping wt: l lb. FOT #2119

BKAA20 $34.95

Designing, Building and Testing Your Own Speaker System 4th Edition

by David B. Weems

With this fourth edition, you'll be able to build a durable, low-cost system as good or better than most expensive units. The book includes basic speaker theory, types and functions of speaker enclosures, closed-box and ported-box construction, crossover networks and filters, computer programs for test and design, speaker equipment selection, testing speakers, speaker placement and acoustics, plus four simple projects. Four appendixes include formulas, wire data, computer programs and mail order listings. A useful glossary of terms is also included. 1997, 256pp., 7-1/2″ × 9-1/4″, softbound, ISBN 0-07-069429-X. Shipping wt: 1 lb.

BKT12 $19.95

High Performance Loudspeakers

by Martin Colloms

This best seller provides serious speaker builders with more information that ever before on perfecting their craft, including a new appendix for software. Topics covered include: theoretical aspects of diaphragm radiators, transducers, diaphragms, and technology, low frequency system analysis—room environments and theory, moving-coil direct radiator drivers; systems and crossovers; the enclosure; and loudspeaker assessment. This classic is considered one of the best audio books ever written, largely because the subjects are presented in an easy-to-understand manner with a minimum of mathematics, thus availing themselves to professional loudspeaker designers, technical writers, studio technicians, engineers, students, and do-it-yourselfers alike. United Kingdom Publication. 1991, 407pp., 5-5/8″ × 8-3/4″, hardbound, ISBN 0-7273-0807-6. Shipping wt: 2 lbs.

BKW1 $69.95

FROM OLD COLONY SOUND LABORATORY

To order call 603-924-6371 or fax to 603-924-9467

REQUEST YOUR COPY OF THE OLD COLONY SOUND LAB CATALOG TODAY!

The Loudspeaker Design Cookbook

by Vance Dickason

19 years after the publication of the first edition, the latest version of the loudspeaker "bible" is more popular than ever. The new fifth edition adds special chapters on the current trends toward home theater and more advanced, serious car audio accompanied by updated chapters from previous editions. 1995, 165pp., 8-1/2″ × 11″, softbound, ISBN 1-8825-8010-9. Shipping wt: 2 lbs. FOT #2102

BKAA2-V $34.95

Electrostatic Loudspeaker Design and Construction

by Ronald Wagner

This classic, once produced by TAB Books, is now published by Audio Amateur Press. Both a "how-to" book and an informative text on electrostatic speakers, this publication provides a step-by-step sequence for building full-range electrostatic speakers, and acquaints the reader with their basic operating principles. Appendix with construction information, index and bibliography included. 1987, 1993, 243pp., 7″ × 9-5/8″, softbound, ISBN 0-9624-1916-8. Shipping wt: 1 lb. FOT #2131

BKAA39 $19.95

Bullock on Boxes

by Robert M. Bullock III, with Robert White

Since 1980, readers of *Speaker Builder* magazine have delighted in the scope and clarity of Mr. Bullock's explanations of vented-box loudspeaker systems. Now these articles have been collected into a single volume—*Bullock on Boxes*. This book is an easy-to-read guide to designing and building vented-box systems based on Thiele/Small models. In addition to the background theory and descriptions of the models, *Bullock on Boxes* covers a variety of related information drawn from numerous resources. Also included with the book is a reprint of the *Speaker Builder* 1/82 article by Dr. Bullock on the subject of sixth-order alignments. Index, glossary, bibliography, and over 100 illustrations. 1991, 72pp., 8-1/2″ × 11″, softbound, ISBN 0-9624-1915-X. Shipping wt: 1 lb. FOT #2113

BKAA8 $10.95

Loudspeaker Recipes: Book One

by Vance Dickason

Taking advantage of the latest techniques for computer-aided design, Dickason lays a firm groundwork, both theoretical and practical, for successfully building a variety of two-way loudspeaker systems. Design is demonstrated by four two-way systems. Valuable insight even if you don't use CAD. 1994, 112pp., 8-1/2″ × 11″, softbound, ISBN-8825-8004-4. Shipping wt: 1 lb. FOT #2125

BKAA30 $24.95

Ultimate Auto Sound: Your Guide to Heaven on Wheels

by Daniel Ferguson

Improved, upgraded version of *Killer Car Stereo* contains double the material, including updated information on system architecture, cabinet construction, crossovers, and installation, plus a new chapter on vans. 1995, 100pp., 8-1/2″ × 11″, softbound, ISBN 1-8825-8009-5. Shipping wt: 1 lb. FOT #2129

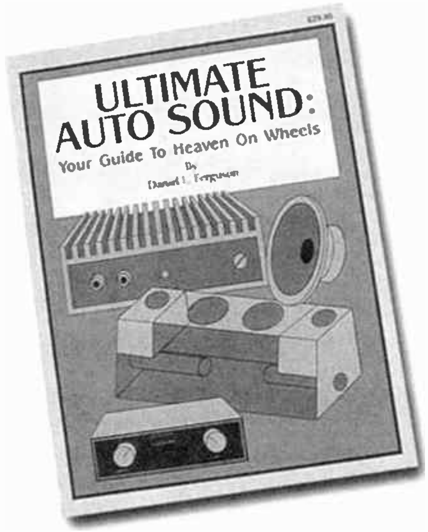
BKAA37 $29.95

SHIPPING & HANDLING ADDITIONAL

Book Report

ULTIMATE AUTO SOUND

Reviewed By Mark Florian



Ultimate Auto Sound: Your Guide to Heaven on Wheels, Daniel L. Ferguson, Audio Amateur Press. Available as BKAA37 through Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458, (603) 924-6526, FAX (603) 924-9467, for $29.95 plus $7 s/h in the USA.

Daniel Ferguson is a name familiar to many readers of *Speaker Builder*, both for his articles on improving auto sound and for his 1989 book, *Killer Car Stereo on a Budget: An Easy Cure for Ho-Hum Auto Sound.* When updating the audio system in my car, I searched all of the local bookstores and libraries, but all the information I found dealt with purchasing equipment from car-audio shops at exorbitant prices. I even visited several shops to listen to speakers. The good ones cost nearly $200.00 a pair!

Fortunately, I saw an ad in *Speaker Builder* for Dan's first book, which I purchased and used as a guide. It saved me a lot of money. The book was well illustrated with pictures and drawings, describing such topics as how to build the cabinets and how to assemble the electronic crossover for the subwoofer. In short, it was a do-it-yourselfer's dream!

In *Ultimate Auto Sound*, Dan imparts the knowledge and experience he has gained since the introduction of his first book. He remains a believer that auto sound's main limitation is not the electronics, but the poor-quality speakers found in most foreign and domestic cars.

CRASH COURSE

In Chapter One, the author surveys audio systems installed in most cars and their limitations. He then details, in a step-by-step fashion, how to improve the sound. Each of these steps is covered in detail in the chapters that follow. Chapter Two discusses possible architectures, offering clear diagrams and cost estimates. Dan clearly defines various audio specifications and explains how equalizers and amplifiers are used to upgrade present systems. Finally, a checklist helps you select an upgrade from all the choices presented.

Chapter Three is dedicated to six different front-speaker systems mounted either in the door, in the dash, or in a combination of the two. Each is thoroughly explained in detail. If you are more adventurous with the saber saw and desire an even bigger sound in the front, Dan meets your needs with a discussion of center-channel speakers, custom crossovers, and other options.

Chapter Four focuses on seven different rear-speaker systems. Designed exclusively for sedans, these projects range from simple to very complex. Using the adapter-based dimensions given, you can install multiple drivers in a single cut-out on the rear package shelf. Alternatively, you could build adapters that allow you to install an 8″ round driver in a 6″ × 9″ oval hole or an 8″ driver in a 5″ hole. With this chapter, Dan begins his description —completed in Chapter Nine—of how the electronic crossover tailors the response of a trunk-mounted subwoofer. He also provides diagrams showing the subwoofer response, filter response, and a combination of the two.

CAR REMODELING

Hatchback owners who don't have a rear shelf but still want great sound should consult Chapter Five. The author describes two dual-woofer systems, each using Madisound's popular 8″, 10″, and 12″ woofers in both vented and sealed enclosures. Since these designs require you to build a box, a table shows internal dimensions of the box, vent diameter and length, net internal volume, box frequency, –3dB point, resistance values in the electronic crossover, and frequency-response plots for each configuration! In other words, it contains everything.

Chapter Six is devoted to those of you who own pickup trucks. It outlines the installation of six "killer" sound systems in compact-, mid-, and full-size trucks, including extended-cab as well as conventional designs. These systems range from a single driver to four drivers in a custom box. Once again, a table provides all the needed enclosure information described in Chapter Five. Chapter Seven is a brief description of two systems, forward and downward firing, modified specifically for vans and sport-utility vehicles.

Chapter Eight is your complete guide to building, wiring, and finishing the cabinets described in the previous chapters. Dan also includes some additional designs using drivers from MTX, Kicker, and Pyramid. For adventurous souls, this chapter also presents two Isobarik designs.

Chapter Nine thoroughly covers the functions, construction, and testing of the electronic crossover. Dan lays out all of the details, so that even a beginner with no experience but dreams of clear, deep bass can assemble a working unit, and, in doing so, save him- or herself at least two hundred dollars.

DRIVING IT HOME

The work of the preceding chapters is brought together in Chapter Ten, which details the complete system installation. It starts off with a list of tools and materials to gather before you begin. Few events are as frustrating as getting into the middle of a project only to discover you're missing something or that you ran out of wire two feet ago. The time and frustration saved will be your own. This section also includes schematics for several problem-solving circuits: a remote turn-on circuit with adjustable delay; an adjustable subwoofer isolation relay, for when your head unit isn't compatible with a powered antenna; and current-sensing remote turn-on circuits, with and without an adjustable delay.

Chapter Ten also explores noise problems, such as ignition pops and alternator whine, as well as solutions. One thing I would add regarding alternator whine is to make sure the alternator ground is clean and tight. Many alternators are mounted to their brackets with rubber bushings to reduce vibration. Therefore, they are electrically insulated and rely upon a separate ground-strap bolted to the engine block. Since you don't want this connection to look like a dirty battery terminal, it would be a good place to spray some Cramolin.

The chapter further describes how to tune the electronic crossover to your vehicle, and it includes a summary of the DIY process, from beginning to end. If you've more money than time, then purchase an assembled electronic crossover and subwoofers with enclosures and pay a local installer to do the hard part.

The last chapter, "Dream Systems," is designed for adventurous souls who want to squeeze the last bit of performance out of their installation. Here, Dan discusses upgrading the all-important front speakers with home-quality premium drivers and custom third-order passive crossovers. He presents a schematic for driving a center channel from the stereo signal and for using digital signal processing (DSP). Numerous references and resources are included in the back as well as a specification sheet for Madisound's dual voice-coil woofers and coaxial drivers.

In summary, this comprehensive book covers it all from design to installation to tuning. I highly recommend it to anyone interested in high-quality auto sound at a reasonable cost. Following Dan's suggestions will achieve the highest-quality sound you're likely to find anywhere for a reasonable price.

Ask SB

GOLDEN CUBE

As a new subscriber interested in building my own speakers, I have discovered that acoustical engineers frequently cite a preferred ratio of 0.62:1:1.62 for speaker box dimensions. But a vast variety of currently popular commercial speakers, such as tower speakers and dipole and bipole speakers used for main and surround applications, seem to be ignoring this basic rule. What formulas determine the cabinet dimensions for tower speakers and the cabinet size for dipole and bipole speaker designs?

Melvin Tieszen
Commerce City, CO

Ralph Gonzalez responds:

If you apply the "golden" 0.62:1:1.62 ratio to tower speakers, I believe you can use multiples of any of the dimensions and achieve similar effects. For example, double the last value and use 0.62:1:3.24. If you are building a dipole using an open baffle rather than a box, then obviously you can't apply the ratio, though using any two terms for the baffle dimensions (e.g., 0.62:1) will help reduce diffraction-induced irregularities. But if you are using a box for your dipole or bipole, then the ratio should apply as well as to a conventional speaker.

However, my opinion is that you should not let this ratio govern your speaker design! If you deviate from it, you will see only a slight worsening of standing-wave activity in your enclosure. Just try not to make any of your dimensions a multiple of one of the others. For example, 1:1:1 or 1:2:4 are bad, while 1:1.5:2.5 is fine. Make sure your box contains acoustic foam and is constructed solidly with good damping.

A speaker design must be well-balanced, addressing the critical issues of frequency response, power handling, dispersion, enclosure resonances, and aesthetics. Concentrating on only one of these issues is a common mistake of hobbyists and professionals alike (especially when a splashy advertisement is desired).

CYLINDERS 'N' SPEAKERS

I've noted several designs in which tubes, approximately the same size as the driver, were used as sealed midrange enclosures. Bill Dudleston's Legacys, various Thiele designs, and the article "A Modular Three-Way Active Loudspeaker" (*SB* 4/90) utilize this approach. This seems a simple and structurally sound method, and I was under the impression that loading a driver into a cylinder resulted in minimal standing-wave problems. So I was somewhat taken aback when a distributor of loudspeaker components informed me that loading a driver this way produces severe standing waves, causing response irregularities as high as 10dB.

I can't imagine that the forementioned designers counteracted such extreme deviations with passive filtration, so I can only assume a construction technique exists to alleviate the problem. I've considered making the inner surface of the rear panel concave and using "Deflex," but I'm not convinced that these methods will solve the problem.

Leigh A. Wax
Gainesville, FL

Contributor G.R. Koonce responds:

You raise a very interesting point. Certainly closed cylindrical tubes have been used many times as chambers for open-back midrange drivers. For example, the "drum" midrange driver is simply an open-back driver that the manufacturer has sealed into a closed cylindrical chamber.

Thick-walled cardboard tubes—available in just about any diameter—make excellent midrange chambers; I have used this approach many times. If you make the tube "full depth" and glue it securely to both the front panel and back wall, it additionally stiffens these two panels and prevents the box from "ballooning" front to back under acoustic pressure. Thus, such a tube performs three functions at very low cost and with reasonable loss in box volume.

It is well known that loading a driver with a rigid tube of any cross-section geometry

TABLE 1

WAVELENGTHS FOR MIDRANGE EXAMPLE

	At 600Hz	At 4kHz
λ = wavelength	22.56″	3.38″
λ/6	3.76″	0.564″
λ/10	2.26″	0.338″
λ/20	1.13″	0.169″

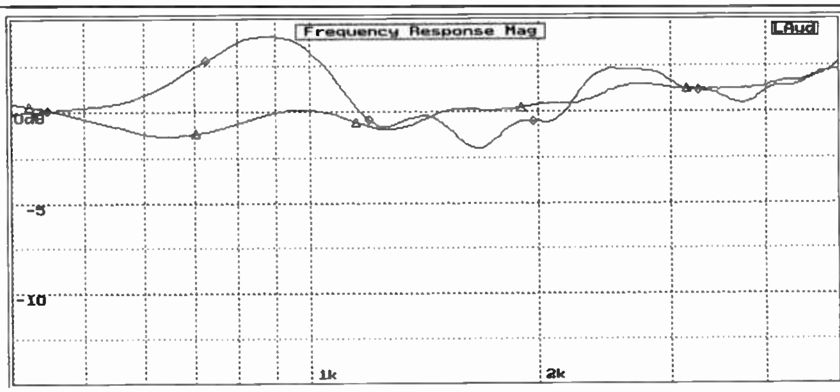


FIGURE 1: Measured on-axis response of open-back midrange on baffle and with cylindrical chamber.

can have a major effect on the driver response. I spent considerable time (SB 6/95) investigating this effect on low-frequency waveguides (also called resonant-tube systems). This technology allows small drivers to produce usable acoustical output down to the bottom end of the audio band, so tubes clearly can have a major effect on a driver's response. The question then becomes, do such problems occur when you use a cylindrical tube as a midrange chamber?

I refer you to Leo L. Beranek's work (Acoustics, pp. 28–35, available from Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458, 603-924-9464, FAX 603-924-9467) involving the case of a piston (the driver cone) driving a rigidly closed cylindrical tube (the tubular midrange chamber). Two points from this work are of importance here:

1. To have plane wave propagation, which is required to maximize the resonant tube effect, the tube diameter must be small compared to the sound wavelength. The limiting value to be considered is generally taken in the range 6–10, or, tube diameter < wavelength/(6–10), required for major resonant tube effect.

2. If the tube length is small compared to the wavelength, then the tube looks like a simple compliance, i.e., just an air volume. The limit given is normally about 20, or, tube length < wavelength/20 is no problem.

Taking these two requirements together indicates you must have a tube much longer than its diameter to have major resonant tube effects. Ever notice that those drum midranges generally have a length about the same as their diameter?

Let's take the example of a 4″ open-back midrange driver in a 5″ (inside diameter) cylindrical tube that is 8″ long. The midrange driver is used over the range 600Hz–4kHz. Table 1 summarizes the wavelengths involved over this frequency range. It is clear that over the full frequency range the tube length exceeds (wavelength)/20, so it is a "long tube." Note, however, that the tube diameter always exceeds (wavelength)/6, so the frequency range used for a midrange is too high for a typical cylindrical chamber to behave as a resonant-tube system.

This does not mean that standing waves are not a problem in a cylindrical midrange chamber, just that it is an acceptable choice of shapes. You must worry about reflections from the back wall no matter what chamber shape is involved. The resonant frequencies supported depend upon many factors, and calculations can become rather involved; this area is also covered by Beranek in Acoustics, pp. 285–297. The belief that a cylindrical chamber is a great choice because it will support only a resonance along its length is not valid here. That condition is only true when the tube is long and thin, just what we have shown is undesirable.

Figure 1 shows the measured response (without smoothing) of a 4″ open-back midrange driver over the frequency range 400Hz–5kHz when baffle-mounted and chambered by a flat-backed 9″ long by 6″ inside-diameter cylindrical tube. Over the desired frequency range of 600Hz–4kHz, the driver deviates from flat by −1.3 to +1.5dB for a total window of 2.8dB, which is quite good. When the chamber is added, the response deviates by −2.0 to + 4.1dB for a total window of 6.1dB. Clearly, the tubular chamber has bad effects, adding peaks at 880Hz and 2,530Hz and dips at 1,665Hz and 3,725Hz, but nothing of the 10dB magnitude that you were led to expect and is possible in a resonant-pipe system.

Remember that the purpose of the midrange chamber is to prevent the radiation from the rear of the midrange cone from contributing to the system output without harming the desired front radiation. The size of the midrange chamber is normally set by compliance (V_B) requirements to shape the bottom end of the midrange *response or to maintain a low system resonance (f_C) to minimize impedance effects of the midrange crossover. To absorb the rear cone radiation, you usually fill or heavily line the midrange chamber with damping material. Making the rear wall of the chamber a nonflat surface as you suggest is also helpful in minimizing front-to-back resonance problems.*

In summary, I consider the cylindrical midrange chamber an excellent choice. I normally line the tube with damping material, with a thick wad at the back wall. Only if the driver is handling frequencies much longer in wavelength than the tube diameter do you encounter resonant tube problems. If the tube diameter and length are nearly the same, you should be safe at any frequency. Damping material is normally required in any midrange chamber independent of its geometry.

ISOBARIK PROJECT

I recently bought two Realistic single-voice-coil 18″ woofers (40-1309) at my local Radio Shack. I want to use these in a single cabinet. I hope to build an Isobarik push-pull-style cabinet, with speaker cones set face to face, and out of phase with each other. I am considering a down-firing cabinet vented with two 5″ or 6″ ports.

Can I wire the left channel into one of the speakers, and the right channel into the other, with one speaker being wired out of phase compared to the other? (The two speakers will *not* be wired together in any way, either series or parallel.) Or should I just build separate boxes and forget about the single Isobarik box design because these speakers have only single voice coils? If I decide to wire these two speakers for a two-channel Isobarik, what would the internal volume be? Should it be ported, what would be the port dimensions, and can I calculate it as an ordinary vented box?

Here are the specifications:

Nominal impedance	8Ω
DC resistance	6.83Ω
Free air response (f_s)	16.5Hz
V_{AS}	41ft^3
Moving mass (M_{MS})	192.6g
Mechanical Q (Q_{MS})	1.986
Electrical Q (Q_{ES})	0.225
Total Q (Q_{TS})	0.20
Peak power capacity	200W
Peak to peak (X_D)	6.1mm (¼″)
Gap flux density (B_G)	7850gauss (±200gauss)

TABLE 1

ENCLOSURE DESIGN—OPTIMUM VENTED BOX

V_B =	4.535ft^3
f_B =	29.8Hz
f_3 =	43.7Hz
Fill =	normal
Ports =	1 (round)
Dv =	4.00″
Lv =	4.39″

TABLE 2

ENCLOSURE DESIGN—OPTIMUM CLOSED BOX

Vc =	3.044ft^3
Fc =	6.25Hz
f_3 =	62.8Hz
Q_{TC} =	0.0707
Fill =	none

TABLE 3

ISOBARIK DESIGN—OPTIMUM VENTED BOX

V_B =	2.267ft^3
f_B =	29.8Hz
f_3 =	43.7Hz
Fill =	normal
Ports =	1 (round)
D_v =	3.00″
L_v =	6.44″

What would be the best way to seal these speakers together face to face about the enclosure wall (bottom)? Do you have any bandpass ideas for these 18″ subwoofers? The spec sheet includes drawings of an "ideal" vented enclosure with an internal volume of 8ft^3. However, using the vented box formulas from a Radio Shack book, I have come up with an ideal box volume of 6.1ft^3. Which is correct?

In Isobarik design, should I cut my V_{AS} in half or by one-third? How do I calculate sealed-box volumes? If a woofer gives me only Q, V_{AS}, f_S, Q_{ES}, and Q_{MS}, can I calculate sealed volumes?

Also, how should I mount and seal the woofers? My problem is in sealing the front of the frame to the boards. The front "gasket" has considerable gaps in it for bolt-head clearance. I believe I will be trimming this down flush with the metal frame edge. Should I router a recess in the board—the width of the overlapping frame—so I can caulk more efficiently?

I am planning to purchase at least one Radio Shack 12″ dual-voice-coil subwoofer (40-1350). Using the specs from the RS catalog, I figure that this speaker is not meant to be ported (vented). What is the ideal sealed internal box volume of this subwoofer, and could I "safely" port this speaker? If I calculate a vented box for this driver, I come up with a box with a whopping internal volume of 12.4ft^3!

This sounds like a very promising driver, having a low F_O of 21Hz, and a high sound pressure level of 95dB, making it very efficient using both voice coils. I hope you can come up with some ideas for my situations, so I can hurry out and buy one (or maybe a couple).

Jace A. Bigelow
Electromechanical Engineering-
Technology Student
Vermont Technical College
Randolph Center, VT

Richard Carlson responds:

Thank you for referring your questions to me. You humbled me by respecting my opinion and guidance as a professional. First of all, may I say that you have restored my faith in today's youth just by the pursuit of such a project. It brings back fond memories of when I was a teenager struggling with audio terms and engineering concepts.

The specifications you provide are complete enough to model the woofer singly and as a pair in a compound (Isobarik) configu-

ration. Using BassBox 5.1, I plotted and determined the box parameters for this woofer. Table 1 *shows the optimum vented box specifications. In a vented (fourth order) enclosure, the recommended (internal) box volume is 4.5ft³. At this volume, the box resonance is 30Hz, while the* f_3 *is 44Hz.*

This is acceptable for professional applications, but not for home use. Considering that this driver has a calculated sensitivity of 95dB @ 1W, 30Hz should be audible at 86dB, which is acceptable for home use.

I prepared box parameters for this woofer in a sealed box (Table 2*). The* f_3 *is 63Hz in a 3ft³ box. If you decrease the size of the box,* f_3 *will increase, but* Q_{TC} *will also increase, theoretically yielding a stronger bass output.*

With the woofers installed in the same box in a compound (Isobarik) configuration (Table 3*), the box size is reduced by one-half for the same output. However, although the computations show that the net sensitivity will be 97dB, loudspeaker output will drop by 3dB, to 94dB. I do not know why, but the computations for the predicted* f_3 *for the Isobarik configuration should have decreased some, but did not show in the box parameters.*

Some other observations based on my models:

- *Using the woofers in a single cabinet (for a total of two subwoofers) increases your construction efforts, but provides a 6dB boost (101dB) in low-frequency output when used in the system.*
- *Using the woofers in one cabinet in an Isobarik configuration requires only one cabinet, but requires some tricky construction techniques. Low-frequency output will drop, but should more closely match your current system's output sensitivity.*
- *It appears that you were correct in assuming that the woofers should be used in a vented enclosure.*

Using nuts and bolts for securing the woofers is probably your best bet, although you should exercise caution with the bolts. Do not overtighten them, as this will certainly cause frame damage and ultimately a change (adverse) in loudspeaker performance.

The baffle should be one you can remove from the box exterior. If the speaker baffle is fixed, then your bolt-tightening process becomes more complicated. I support your thoughts on recessing the woofers face down. This will ensure proper woofer alignment and seating. A simple remedy to the "leaky gasket" problem is to apply some foam window gasket material (sticky on both sides) over the gasket of each driver. This is very inexpensive and works every time!

Finally, ports used for your vented subwoofer(s) should use a 4" (inside diameter) tube (I use ABS—the black tubing used for sewers) for the subwoofer using one driver cut to a 4.4" length. For the Isobarik configuration, a 3" tube is required at a length of 6.4" (a 4" tube may be used, but must be 12.5" in length).

I sincerely hope I have answered your questions in a way that will encourage you to complete this project. Specifications aside, when a builder completes a project, tests the speaker, and listens to it over a period of time, he/she "knows" if this design was good or not. Consider the feeling of accomplishment you will have when the project is complete and when you (and your friends) are doing some serious auditioning. The great thing about particleboard is that it is relatively inexpensive, so if you don't like what you hear, return to the drawing board, redesign the speaker, and build another one based on your redesigning effort. This will enhance your construction techniques and make you a more critical listener.

On a final note, I would like to urge you to acquire The Loudspeaker Design Cookbook *by Vance Dickason (available from Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458, 603-924-9464, FAX 603-924-9467). I strongly feel that the majority of your curiosities will be greatly satisfied in this (must read) reference.*

SB *Mailbox*

SPECTRA PLUS UPGRADED

Pioneer Hill Software announced that Spectra Plus version 4.0, a full 32-bit Windows application, is now available directly from the developer. The full software, in a 30-day trial copy, can be downloaded from the company's website. To receive additional information, contact Pioneer Hill Software, 24460 Mason Rd., Poulsbo, WA 98370, (360) 697-3472, FAX (360) 697-7717, E-mail pioneer@ telebyte.com, website http://www.telebyte.com/pioneer.

CABLE CHARACTERISTICS

In *SB* 1/97, Stephen Lampen wrote a letter "taking exception" with my 6/96 article, "A Cheap, Hi-Tech Cable." This article—edited from my original letter—explains the effects of wire resistance and defined the term "characteristic impedance." It seems that Mr. Lampen skimmed the article because he felt that his statements about wire resistance were at odds with mine. They weren't. What makes his letter difficult to follow is that he fails to distinguish between "impedance" and "characteristic impedance." They are two different things. This basic misunderstanding would make my article quite confusing, which is why I defined the terms. I'm sure that one of the engineers at Belden could do a better job of explaining the difference for him than I.

One company, Alpha Core, markets an expensive and well-reviewed line of cables and interconnects which touts characteristic impedance of the same magnitude as that which my article describes. However, Mr. Lampen's opinion that characteristic impedance is only important at high frequencies, or with long runs of wire, is a common one.

Feedback is always welcome, both positive and negative, as long as it is appropriate and accurate. My value for the characteristic impedance of a twisted pair of this wire was off by 25%. That is useful information. If some Belden cable can be configured for improved audio performance, I'm eager to hear about it.

Working for Belden, Mr. Lampen is in a unique position to experiment with some of the foam-insulated wire he describes. And he can compare its sound quality and measurements with what I have described, or with his current standard. Knowing the impulse response into an actual speaker carried over three to five meters would be helpful. He could also examine the time smearing of the signal, and examine transient performance. Actual resistance, inductance, and capacitance could be measured. Dividing inductance by capacitance and taking the square root gives characteristic impedance. An article describing these factors would be superior to mine, based only on the information available to me and my listening experience. I hope Mr. Lampen will consider such an endeavor.

John Day, MD
Austin, TX

Stephen Lampen responds:

Many people, even in the professional world, treat wire and cable as non-issues, so I am always willing to debate just what wire and cable can do, how they perform, and what the limitations are.

I went back and re-read Mr. Day's original article to be sure I hadn't "skimmed" anything. Mr. Day is indeed correct, "impedance" and "characteristic impedance" are not necessarily the same thing. As he suggested, I discussed the terms "impedance" and "characteristic impedance" with a number of staff engineers.

"Characteristic Impedance of Cables at High and Low Frequencies," written by the Belden engineering staff, summarizes impedance as the relationship between inductance and capacitance. This means that the impedance of a cable starts at a very high number at low frequencies and follows a down-sloping curve until high frequencies are reached.

Somewhere between 1MHz and 10MHz, the impedance typically settles down to a nominal amount—provided a frequency-stable dielectric material is used. Engineers refer to this as the "asymptotic impedance," the characteristic *impedance of the cable. For high-frequency applications such as analog video, digital audio, digital video, and radio frequency, the characteristic impedance value is used to determine suitability for a particular application.*

All cables do not exhibit the same characteristic below 1MHz (many designs vary up to 10MHz). At audio frequencies, there is a rapidly changing impedance and, therefore, no characteristic impedance. *Luckily, the* *wavelength at audio frequencies is so long (five miles at 20kHz), that the impedance of a particular cable is of little consequence in terms of signal transfer. I would, therefore, question Mr. Day's assertion that any analog audio cable has a* characteristic *impedance at audio frequencies, such as the "8Ω impedance speaker cable" mentioned in his article.*

Mr. Day's suggestion of taking the square root of the inductance divided by the capacitance will yield an impedance value at one specific frequency below 10MHz. This will have little correlation with musical signals containing hundreds, even thousands, of different frequencies traveling simultaneously and producing complex patterns of harmonics.

On the other hand, I am very interested in Mr. Day's proposal that I experiment with physical characteristics to produce an ideal speaker cable. I would be even more interested to experiment in our lab with impulse response. I would be glad to work with him to produce a "fast" speaker cable, a design which is easily achievable. Nothing would make me happier than to produce a design that is repeatable in the lab, in terms of physical and electrical attributes, and which the high-end "listening" audience will find superior to standard designs.

IMPEDANCE COMPLEXITY

"Dynamic Characteristics of Driver Impedance," by Don Jenkins (*SB* 1/97) considers the electrical impedance of a loudspeaker driver. It is my understanding that the electrical impedance is the ratio of voltage to current in the circuit of interest. I know of two ways of looking at this.

One can measure the current into a driver (indirectly, by measuring the voltage across a reference resistor in series with the driver) and the voltage across a driver simultaneously. The time-dependent value of the voltage-to-current ratio will be the time-dependent value of impedance. Note that since oscilloscopes and other waveform-measuring gear do not know about complex numbers (voltage and current as a function of time are real, physical quantities), the time-dependent impedance is a real number. How does it get to be complex, that is, to have an imaginary part?

The English speaker manufacturer KEF was a pioneer of the digital measurement of loudspeaker acoustical and electrical quantities. KEF measured the impedance of its drivers with an impulse test and stored the sample values digitally. They then used the Fourier transform of the impulse response of the impedance (time-dependent) to yield the frequency response of the impedance (frequency-dependent).

The Fourier transform of sampled data offers the impedance that you would measure at a large number of discrete frequencies, where the sine wave is gated on for a time equal to the measurement period. It approximates what you would measure at the same frequencies with a steady-state measurement, which, I assume, takes an infinite amount of time.

The Fourier transform yields complex values, which are commonly represented by an amplitude and a phase; or, equivalently, by a real and an imaginary part.

In this scheme of things, a complex impedance makes sense only when you are making a steady-state measurement using a sine or cosine wave. The phase is then how you express the lead or lag of the current wave with respect to the voltage wave.

Assigning a complex number to a time average of the instantaneous impedance over some measurement period does not fit into the above scheme of things, and what it tells you is unclear. Since the instantaneous impedance is a real number, its time average should also be a real number. Just because it turns out to be larger than a driver's DC resistance, it doesn't mean the excess must be imaginary; it is still real.

Of course, you are free to cook up interesting test waveforms for finding time averages of the driver input impedance. These could well turn out larger than the DC resistance, depending upon the voltage waveform.

Input pulses are shown in Figs. 1a and 1b. They look like a square wave with a damped oscillatory tail. Does this mean that your signal generator produces a tail after its test pulse?

The current waveforms, also demonstrated in these figures, show a damped oscillatory wave followed by zero current at the end of the test pulse. This trend implies that the ratio of voltage to current must be infinite, because you will divide by zero after the test pulse.

One possible interpretation of the curves in Figs. 1a and 1b is that, during the test pulse, the amplifier acts as a perfect voltage source, after which it is as a perfect current source. This would be an unusual test setup.

"DC Pulse Test" in the article refers to impedance ratios in Figs. 4a and 4b, although I believe it should have read Figs. 3a and 3b. Since impedance ratio is not defined in an equation or the text, I presume it refers to the ratio of time-averaged impedance to DC resistance.

Victor Staggs
Orange, CA

Don Jenkins responds:

Dr. Staggs' letter contains a number of questions relating to impedance measurements and values and the pulse-test data shown in my article. The answers given here will separate the two. First, about the impedance questions.

Dr. Staggs writes that his understanding of impedance is that it is the ratio of voltage to current in a circuit. This is the impedance magnitude, *not the impedance. Impedance is always a complex quantity, otherwise it would be a nonreactive load, i.e., resistance.*

Several notation methods can be used to describe the impedance characteristic. The complex notation used in the article is one such method. With this notation method, for the value indicated by A + jB, the value of the resistive component of the load is A, while the jB term is the reactive component of the load. Mr. Staggs has described the term as being "imaginary," seemingly confused by the notation, and questions how you derive an "imaginary" value from "real" measurements.

The answer is that you don't. Both parts are "real;" they simply represent the impedance characteristics of the circuit. While impedance is always a complex quantity, it is, in the pure mathematical sense, not a vector. However, the use of the so-called impedance operator j permits you to use vector math when dealing with impedance in circuit analysis. The j notation indicates that the current in each element has a 90° rotation. By convention, a positive j indicates inductance, while a negative j indicates capacitance. This notation allows you to calculate the resistance to current (impedance magnitude) and the power in the circuit element (resistance); it also simplifies the vector arithmetic when you are required to combine impedance elements in a circuit.

The conventionally given values for impedance are RMS values based on a minimum of one complete power cycle. Since RMS values are determined by the integration of the time-varying voltage and current amplitudes relative to power, it follows that the impedance when using these values must also be an RMS value, again, relative to power. In systems where the power-cycle delivery is more or less "steady state," the circuit impedance may also be considered steady state without analytical compromise.

For systems that deliver power in some random transient mode, such as music, the impedance of the circuit changes with each change in the input current. To analyze this type of system, consider impedance as a point function—i.e., a value dependent upon the instantaneous value of the current's rate of change, the current amplitude, and the state of the system.

While impedance should always be considered a complex quantity, the rigorous interpretation of impedance when applied to a dynamic mechanical system in motion (such as a loudspeaker driver) is that it is a constantly changing complex quantity.

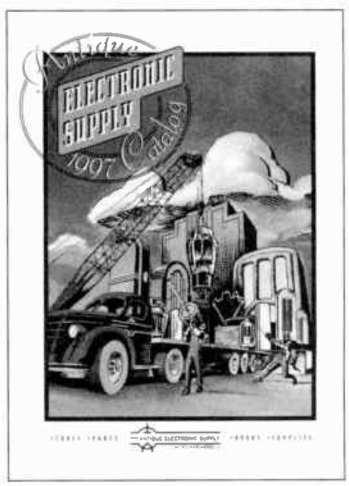
Figure 2 is a computer simulated 30ms 2V DC pulse into a specific driver. This model uses a $1\mu s$ time increment for the integration, which means that the impedance magnitude is calculated each micro-second. This value is the quotient of voltage applied across the voice coil and the resultant current. The simulation shows that the impedance magnitude does, in fact, vary with time.

Since the simulation is for one pulse, the impedance shown is for one power cycle. The integrated value of this impedance pulse was 7.9Ω when averaged over the 30ms time increment. Since the voice-coil resistance is 7.1Ω and the average resistance to current was 7.9Ω (RMS impedance magnitude), the pulse impedance can correctly be given as the complex value $7.1 + j3.5$.

The 3.5 variable is the equivalent RMS reactance value, in ohms, for this specific pulse and driver. This value will be different for other pulse widths, voltage amplitudes, and wave forms. As noted in the article, the apparent reactance for drivers is not the result of inductance, as in passive circuits, but is the energy transferred to the mass of the cone (acceleration) and used in the deflection of the cone structure (compliance).

In real applications, most of this mechanical energy is returned to the source. Even in large drivers, only a small fraction of this energy is actually converted to sound, absorbed in compression of the ambient air, or dissipated in bending work on the cone structure. Since neither the mechanical system nor the passive reactance of either inductance or capacitance retain appreciable circuit energy, their characteristics can be interchanged for circuit analysis.

to page 59



ATTENTION
CLASSIFIED ADVERTISERS

Dear Reader:

We are, regretfully, announcing changes in our classified advertising policy.

As you are most likely aware, it has long been our practice to offer free word classified ads to subscribers. This service is designed to help readers sell personal equipment or supplies and/or find specific equipment or services. These ads are located in the For Sale and Wanted sections. Classified ads from business or private parties selling equipment, supplies or services for profit are available on a cost per word basis only and are located in the Vendor (previously labeled Trade) section. Due to the cost and time involved in processing the hundreds of free For Sale and Wanted ads received for each cycle of issues, we are implementing the following new guidelines.

If you wish to run a classified ad, you will now be charged a $10.00 processing fee for each For Sale and Wanted submission. This fee is due per ad and per magazine. As before, subscribers may run an ad of up to a 50 word maximum, however, each additional word will now be charged at the regular per word rate of $1.00 each for *Audio Electronics* and *Glass Audio* and $1.50 each for *Speaker Builder*. A check, money order or credit card number must be submitted with your ad to cover the applicable charges.

To help us process your ads with efficiency and accuracy, all word classified advertisers must now use our convenient new Classified Order Form when submitting hand written copy. Our new form is available in the classified section in each of our magazines. If you are not able to use the form, your submission will be accepted in type written form only. Please feel free to either mail, E-mail, or fax your ads (faxed and E-mailed ads must include your credit card information).

Please note that ad submissions that do not meet the above criteria will not run.

Thank you in advance for your understanding and cooperation. On behalf of the entire staff here at Audio Amateur Corporation, we look forward to providing you with the very best products and subscriber services possible.

Respectfully yours,

Edward T Dell Jr.

Edward T. Dell
Publisher

AUDIO Amateur CORPORATION

Classifieds

VENDORS

STATE-OF-THE-ART PASSIVE CROSS-OVERS featuring Hovland MusiCaps. Software available, free design guide. ***ALLPASS TECH-NOLOGIES, INC.***, 2844 Charmont Dr., Apopka, FL 32703-5972, (407) 786-0623.

ELECTROSTATIC electronics, transformers, Mylar®, information. From author ***ROGER SANDERS***, (505) 759-3822.

WE RE-CONE all home, auto, pro and vintage speakers. Re-foam kits, $10. ***TRI-STATE LOUDSPEAKER***, www.nauticom.net/www/speakers, (412) 375-9203.

FOR SALE

E-V Georgian and Cardinal, one each, 1957 kits, 15″ three-way, mahogany, near mint. Second owner, have original plans and ads. Craig, (812) 683-2211 days, (812) 683-5444 nights, E-mail berndtc@psci.net (Southern IN).

Two unused ADS midranges, for an ADS professional monitor. Have heavy Samarium cobalt magnets; one dome damaged by poor factory packaging and needs doped textile dome replaced. Dr. L.H. Steinberg, (215) 592-9765.

Two Bozak B200Y tweeters, original crossovers, new mylar caps, two Scanspeak 10″ 16W woofers. Exact replacement of Dynaco A-5; four Dynapleat 4W drivers, one tested, three unused; one original Advent speaker tweeter. All good shape, best offer plus shipping. Rafael, (305) 285-3432.

Pairs: AR3 woofers, $75; Motorola 1151A horns and 1188A drivers, $45; KSN 12165, $18; KSN 1177, $25; large Advent tweeters, $40; SEAS H-535 tweeters, $20; JVC 1101-01A tweeters, $35; AR2AX mids, $10; VIFA D27TG, $35; Jensen 4″ car JFX 1242, $20. Single University Cobraflex horn and SA-HF driver, $40; AR2AX tweeter, $20. David, (518) 399-3798.

Pair Advent I tweeters, $20; E-V RE85 Dynamic Lavalier mike, $35; E-V 649B Dynamic Lavalier mike, $25; Audio Technica AT816 unidirectional Dynamic mike, $20; one University N2B crossover, $10; Advent I woofers (needing surrounds) and Advent I crossovers. Jim, (708) 425-6719.

Dynaudio MDY-4 two-way speaker system from Madisound with D260 tweeters, 17W75ext bass/ midrange, Leap crossover and Deflex panels, kit fully assembled with oak veneer woodstyle cabinets. Superb sound, one year old, $500. Jerry, (414) 796-1827, ext. 3710, days (WI).

FREE PRODUCT INFORMATION! *SpeakerBuilder* THE LOUDSPEAKER JOURNAL

Use this card to receive free information and brochures about advertisers and editorial items in this issue of *Speaker Builder*. Reader service numbers can be found listed under advertisements throughout this issue. Simply circle the corresponding reader service number on this card and mail today!

To receive free material follow these steps:

① circle the issue number ☞ Issue: 1/97 2/97 3/97

② print your name and address below

③ answer all of the questions listed below

NAME

ADDRESS

CITY/STATE/ZIP

COUNTRY PHONE

Are you a subscriber to *Speaker Builder* ☐ yes ☐ no

ADVERTISEMENTS

01	02	03	04	05	05	07	08	09	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	51	52	53	54
55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100								

EDITORIAL

101	102	103	104	105	106	107	108	109	110	111	112	113	114
115	116	117	118	119	120	121	122	123	124	125	126	127	128
129	130	131	132	133	134	135	136	137	138	139	140	141	142

(Please note that this card expires as of 8/30/97)

1. Check one to describe the amount that you spent on new loudspeaker or horn systems over the last five years

01. ☐ Under $500 **02.** ☐ $500 - $1000 **03.** ☐ $1000 - $5000 **04.** ☐ Over $5000

2. Check one to describe what you have spent on parts and supplies to build/modify equipment over the last 12 months

05. ☐ Under $250 **06.** ☐ $250 - $500 **07** ☐ $500 - 750 **08.** ☐ $750 - $1000 **09.** ☐ Over $1000 00

3. Check which products you have purchased in the last 12 months

10. ☐ Hi-fi drivers **11.** ☐ Crossover network **12.** ☐ Crossover components **13.** ☐ Speaker design software **14.** ☐ Cables/connectors

15. ☐ Car speakers/systems **16.** ☐ Home theater speakers **17.** ☐ Speaker enclosures **18.** ☐ Acoustic panels/blankets

4. Check which category best describes where you purchase the majority of your parts and supplies for construction/modification (DIY) projects

19. ☐ Mail order suppliers **20.** ☐ Audio specialty stores **21.** ☐ Electronic discount stores **22.** ☐ Manufacturer direct

FREE PRODUCT INFORMATION! *SpeakerBuilder* THE LOUDSPEAKER JOURNAL

Use this card to receive free information and brochures about advertisers and editorial items in this issue of *Speaker Builder*. Reader service numbers can be found listed under advertisements throughout this issue. Simply circle the corresponding reader service number on this card and mail today!

To receive free material follow these steps.

① circle the issue number ☞ Issue: 1/97 2/97 3/97

② print your name and address below

③ answer all of the questions listed below

NAME

ADDRESS

CITY/STATE/ZIP

COUNTRY PHONE

Are you a subscriber to *Speaker Builder* ☐ yes ☐ no

ADVERTISEMENTS

01	02	03	04	05	05	07	08	09	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	51	52	53	54
55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100								

EDITORIAL

101	102	103	104	105	106	107	108	109	110	111	112	113	114
115	116	117	118	119	120	121	122	123	124	125	126	127	128
129	130	131	132	133	134	135	136	137	138	139	140	141	142

(Please note that this card expires as of 8/30/97)

1. Check one to describe the amount that you spent on new loudspeaker or horn systems over the last five years

01. ☐ Under $500 **02.** ☐ $500 - $1000 **03.** ☐ $1000 - $5000 **04.** ☐ Over $5000

2. Check one to describe what you have spent on parts and supplies to build/modify equipment over the last 12 months

05. ☐ Under $250 **06.** ☐ $250 - $500 **07.** ☐ $500 - 750 **08.** ☐ $750 - $1000 **09.** ☐ Over $1000 00

3. Check which products you have purchased in the last 12 months

10. ☐ Hi-fi drivers **11.** ☐ Crossover network **12.** ☐ Crossover components **13.** ☐ Speaker design software **14.** ☐ Cables/connectors

15. ☐ Car speakers/systems **16.** ☐ Home theater speakers **17.** ☐ Speaker enclosures **18.** ☐ Acoustic panels/blankets

4. Check which category best describes where you purchase the majority of your parts and supplies for construction/modification (DIY) projects

19. ☐ Mail order suppliers **20.** ☐ Audio specialty stores **21.** ☐ Electronic discount stores **22.** ☐ Manufacturer direct

Postage
Required
Post Office will
not deliver
without proper
postage.

SpeakerBuilder
THE LOUDSPEAKER JOURNAL

PO Box 5009
Pittsfield, MA 01203-5009

Postage
Required
Post Office will
not deliver
without proper
postage.

SpeakerBuilder
THE LOUDSPEAKER JOURNAL

PO Box 5009
Pittsfield, MA 01203-5009

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

COMPANY	PRODUCT	FAX
Acoustic Technology Int'l	*Hi-End Drivers*	1-905-475-8226
Antique Electronic Supply	*Tubes, Transformers, Books, and More!*	1-602-820-4643
DeCoursey Engineering Lab	*Made-To-Order/Custom-Built Active Components*	1-310-397-8498
Gasoline Alley L.L.C.	*Acoustasheet*	1-913-827-9337
Goertz	*Goertz Inductors*	1-203-384-0586
Harris Technologies	*BassBox and X*over*	1-616-641-5738
Hovland Company	*MusiCap Film and Foil Capacitors*	1-209-966-4632
Kimber Kable	*Speaker Cables, Interconnects, Etc.*	1-801-627-6980
Klein Tech Systems	*Acoustic Interface Pads*	1-561-845-9844
LinearX Systems, Inc.	*FilterCad*	1-503-598-9258
Mahogany Sound	*Acousta-Stuf*	1-334-633-2054
Markertek Video Supply	*Unique & Hard-To-Find Accessories*	1-914-246-1757
Morel Acoustics USA	*Loudspeaker Drivers and Car Speakers*	1-617-277-2415
Sound Clearing House	*Speaker Drivers*	1-541-343-3112
The Parts Connection	*Crossover Parts*	1-905-829-5388
True Audio	*WinSpeakerz & MacSpeakerz*	1-760-480-8961

Don't Delay, Fax Today!

AD INDEX

Pair JBL 1" horn drivers, Alnico with aluminum diaphragms; pair Altec 291A large Alnico horn drivers; pair 511, 811, 421 woofers; Pioneer Spec I, II, IV preamp and amps; two Nakamichi 6702X rackmount cassette decks; Community horns. David, (914) 688-5024.

WANTED

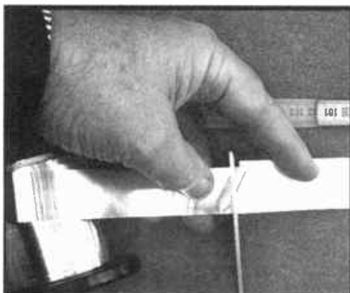
Dual 1015 cartridge holder. Rafael (305) 285-3432.

AR-3a speakers for major rebuild project. Need not work, but must be reasonably complete. Tom, (540) 886-2634.

I just acquired an old EICO 666 tube tester that has been butchered quite a bit. Does anyone have a manual/schematic diagram they could sell or copy? Jean Landry, 3597 St. Urbain, Montreal, PQ H2X 2N6, CANADA, (514) 845-1319.

Old hi-fi/theatre speakers/corners; Altec 604/605 coax, Altec 288 drivers, Altec 805, 1005, 1505/B horns (also 311-90, 329-A), Altec cossovers, Altec/WE 755A, WE 728B, 55/594 drivers. Sonny, (405) 737-3312, FAX (405) 737-3355.

Wanlass Paraformer line voltage regulators needed. Will pay top dollar. Any rating from 50VA to 2,500VA (2.5kVA) with 115V and/or 230V input and output, 60Hz. R.A. Young, 116 Cleveland Ave., Colonia, NJ 07067, (908) 381-6190, FAX (908) 381-3254.



SPEAKER BUILDER
CLASSIFIED INFORMATION

Three Classified Advertising Categories are available in *Speaker Builder*

VENDORS: For any business or professional private party selling equipment, supplies or services for profit.

FOR SALE: For readers to sell personal equipment or supplies.

WANTED: Help readers find equipment or services.

HOW TO ORDER AN AD

REGULAR CLASSIFIED (ads without borders):
$1.50 per word. $10.00 minimum.
Deduct 5% for a 6X contract.

CLASSIFIED DISPLAY (all ads with borders):
1" $65.00, 2" $115.00, 3" $150.00
Deduct 5% for an 8x contract

PAYMENT MUST BE ENCLOSED with your ad and mailed to *Speaker Builder* c/o, AAC Classified Dept., PO Box 576, 305 Union Street, Peterborough, NH 03458-0576. Ads can also be submitted by FAX (603) 924-9467 or by E-mail, audiodiy@top.monad.net. (*faxed and E-mailed ads must include MC, Visa, Discover or AmEx payment*).

SUBMITTING COPY: A word is any collection of letters or numbers with a space (*a slash (/) is counted as a space*) on either side. All hand written ads must be block printed on the form below. Please circle or underline all words to appear in bold. Illegible ads will be discarded. Submit copy by mail, fax, E-mail or on disc (QuarkXPress, Wordperfect, Microsoft Word 2.0 or 6.0, Word for DOS, Windows Write, or Word Star). If submitting by disc, include a list of fonts and graphics used and a printout of your ad.

SUBSCRIBERS! Subscribers are invited to run a word classified ad of up to a maximum of 50 words in the FOR SALE or WANTED sections for only a $10.00 flat processing fee (*per ad, per magazine*). Ads that exceed 50 words will be charged the regular rate of $1.00 for each additional word. All ads are run only once, and then discarded. Simply complete the Classified Order Form and include your subscriber number in the space provided.

CLASSIFIED ORDER FORM

Please check what type of ad you will be running.

☐ **VENDORS** ☐ **FOR SALE** ☐ **WANTED**

Advertisers are required to use this convenient form when hand printing your ad. Use block letters. 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 ❑ AMEX

CARD NUMBER EXP. DATE

❑ Check/Money Order Enclosed

Subscription Account Number: **A** ☐☐☐☐☐☐☐

NAME

COMPANY

STREET & NO.

CITY STATE ZIP

PHONE

AAC Classified Dept., PO Box 576, 305 Union Street, Peterborough, NH 03458-0576
FAX 603-924-9467

ALL ADS SUBJECT TO RUN AT DISCRETION OF PUBLISHER / AD DIRECTOR

Letters

from page 54

Also note that the driver circuit may show an impedance magnitude of less value than the voice-coil resistance (pseudo-"negative" reactance) during some parts of the input transient. This occurs when the voice-coil back EMF is in phase with the driving signal and is returning energy to the circuit. This is one reason why the impedance value must be determined over a complete power cycle. (Refer to my article, "The Damping Factor: One More Time," SB 6/94, to see how the amplifier impedance affects the energy transfer between a driver and an amplifier.)

Where energy transfer and storage is associated with accelerated mass and structural deflections, the classical electrical impedance definitions for an electromechanical system are rigorously correct, as the computer simulations show.

A salient point of this article is that impedance-matching networks for drivers, especially for low-frequency drivers with large cone displacements, may have different requirements based on the type of program material. High-amplitude, high-slope transients will see different driver impedance values than low-amplitude, low-slope transients.

Dr. Staggs also questions Figs. 1a and 1b as to the damped voltage tail in the experimental data shown. These tests were made using a high-speed relay to apply the pulse. The DC bus has a parallel 90,000µF capacitor across it to ensure a rock-solid supply. The voltage is measured across the voice coil, and the current is measured in the line with a Tek 6042 Hall-effect current probe (DC to 50MHz). When the relay opens, the voice coil is effectively "open circuit," since the scope input resistance is >1MΩ. The trace shows the "free air, no load" damping of the cone, and there is effectively zero current in the voice coil.

Dr. Staggs has correctly noted the error in figure references in the text. Figures 3 *and* 4 *have been transposed with their references in the text. As to the impedance ratios referenced in the "DC Pulse Test" box, these curves show the nonlinearity of the cone structure and placement in the magnetic field. If the compliance were linear with displacement and the magnetic field were constant over the travel distance of the voice coil, the impedance ratio would be constant with input-voltage amplitude. This type of test is useful in showing how well designed, and assembled, any specific driver may be.*

MADE IN HEAVEN

A few years ago, the critics were raving over the NHT Super Zero as having nearly ideal upper bass/midrange response, correct timbre, imaging, and so on. Its only flaw was the slightly laid-back tweeter. Nonetheless, it was rated as a good buy for the money, if you don't require bass below 100Hz.

At about the same time, most of the same critics raved about the Radio Shack LX 5 PRO. The only problem with this speaker was the 4½″ upper bass/midrange driver, for which several fixes were proposed. However, they all raved about the dipole tweeter (Linaeum). This tweeter was rated as being equal to systems costing thousands of dollars, and better than several. One critic said "this tweeter loses itself when the speaker is placed away from the walls." These speakers were also considered a good buy, especially when on sale.

Well, you can guess what is coming. I bought four NHT 458 4½″ drivers, as used in the Super Zero, and four Linaeum tweeters, used in the LX 5 PRO. I built four three-liter cabinets using ½″ MDF covered by ¼″ oak plywood (except the front baffle, which is double thickness). I then installed a 0.30mH, 14 ga. coil on the woofer (nominal 6dB octave @ 4.42kHz) and a 6.0µF cap on the tweeter (nominal 6dB octave @ 4.42kHz).

This just might be a marriage made in heaven. They sound very nice (within their range), have all the strengths of each manufacturer and minimized weaknesses, and "image" like crazy. The quality sound this little box produces is almost unbelievable. I am using these with a spare basic amp as computer speakers.

Paying the list price for all parts, the project cost approximately $80 per speaker for everything, except the wood and finishing. I highly recommend this "marriage" to anyone looking for a nice DIY project for computer, rear-surround, or even main speakers when used with a subwoofer.

Bill Eckle
wmeckle@primenet.com,
wmeckle@juno.com

VOX POPULI

I just picked up the latest *Speaker Builder* magazine (2/97) and was shocked to find an article on how to build a toy soldering iron ("Building a Toy Soldering Iron"). What's next, toy loudspeakers? Why not spin off another magazine called *Toy Audio* or *Fake Speaker Builder*? There's more than enough topics about real speakers, crossovers, and box construction that should be covered before printing dribble such as that. It's a shame that the one magazine dedicated to amateur speaker building has stooped to this.

Gary Markowitz
MarkowitzG@nabisco.com

I have subscribed to *SB* magazine for many, many years and will continue to do so. I enjoy the subject matter! Or, at least, I enjoy what I thought was the subject matter. I'm sure you have already received comments on the now infamous "soldering iron" article; I will not add to them. Instead, I will simply state, from my own biased perspective, that I would like to see more articles about actual, home-built, do-it-yourself speaker systems designed and built by "Joe Woofer."

I really enjoy seeing pictures, construction diagrams, and design objectives of the various home-brew speaker systems. I enjoy the cabinet design/construction as much as, or even more than, the driver/ crossover selection/construction.

Lastly, I'm fascinated by horn design and construction, although that subject seems to fly in the face of the current rage for tiny satellites and anemic woofers. I would love to see at least one horn design/construction article in every issue!

Thank you for a wonderful magazine and for listening to my requests.

Kevin Jaggars
KEVIN.JAGGARS@co.hennepin.mn.us

I read the article "Building a Toy Soldering Iron" with mixed feelings. I am a retired designer who has worked for many major toy companies for a number of years. I firmly believe that you should never give a child any hand-held part, especially a toy made of hard material and pointed at one end.

I saw the "not for children under three years old" disclaimer, but I can assure you that any child's eye will become a magnet for these sharp points. That is the reason "better" toy companies design their product lines with large-diameter rounded "ends."

George Gilder
Forest Hills, NY

Nancy and Duncan MacArthur respond:

Mr. Gilder has brought up a very important issue. Most audio construction projects involve an element of risk. As adults, we gauge that risk and decide which projects are appropriate for us. With a project intended for use by children, the adult constructor bears an added responsibility for assessing the safety of the child. With the toy soldering iron, as with any other toy, the responsible adult must decide if the toy is appropriate for the child or children.

We agree with Mr. Gilder as to the importance of not constructing a toy with a sharp point. The toy soldering iron we built does not have a sharp point, as is shown in Photo 1 and explained in the text (SB 2/97, p. 20, step 6). The figures accompanying the article misrepresent the sharpness of the toy's point. Readers building this project should certainly make the tip of the soldering iron very blunt.

As parents we thought carefully about whether our particular child was old enough to play safely with this toy before we built it for him. At the age of four, Colin used pencils regularly, so we decided that he was old enough to play with the toy soldering iron, which is larger and has a much blunter point than a pencil.

Colin is seven now and still plays frequently with the toy soldering iron. Over the past three years we've had no mishaps with it. Colin does have to follow a few common-sense rules with the soldering iron. For example, we don't let him run with it or use it for sword fighting, just as we wouldn't allow him to run or fight with a pencil, a Tinkertoy® stick, a toy screwdriver, or a stick from the back yard.

Before giving a child any homemade toy, whether it's a beanbag or a toy soldering iron, the parent or other responsible adult should assess whether the toy is appropriate for that particular child.

SHARE THE WEALTH

Speaker Builder offers readers the opportunity to share their knowledge and show off their handiwork through this column. Send us your speaker-building tips or interesting circuit designs. If you have built an especially attractive or distinct piece of equipment, why not take some b/w photos of it and write a description of your efforts? Send your submissions to:

Tools, Tips & Techniques
Speaker Builder
PO Box 494
Peterborough, NH 03458
FAX (603) 924-9467, E-mail
audiodiy@top.monad.net

Remember, it's your magazine, and your contribution can help make it even better. And, we're willing to pay you a modest stipend for your efforts. So, put a few bucks in your pocket, but, most of all, become an active part of the audiophile community.

BOOKSHELF SPEAKER PLACEMENT

My four identical "bookshelf" speakers are connected (in stacks) to a stereo amplifier (*Fig. 1*). The resulting "warmer" midbass, along with wider and deeper sound stage, is due to lateral wave energy produced by the out-of-phase extra speakers. The effect works best with RCA, London, Mercury, and Telarc classical CDs.

Rick Oakley
Sudbury, MA

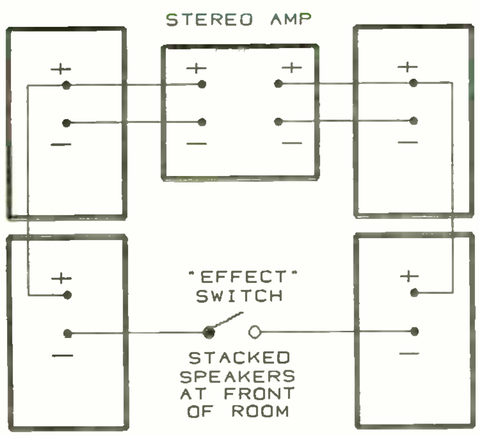


FIGURE 1: