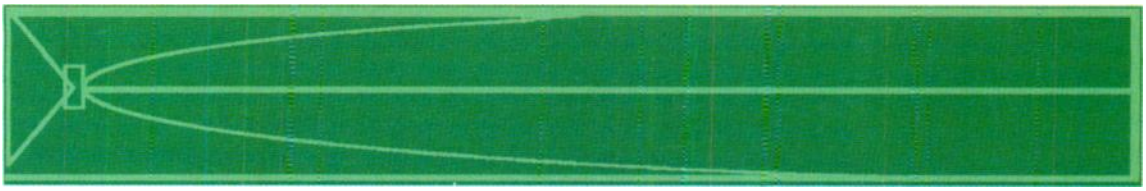
HOW TO MAKE THAT NEW BOX BEAUTIFUL

FOUR: 1996 US$7.00
CANADA $8.00

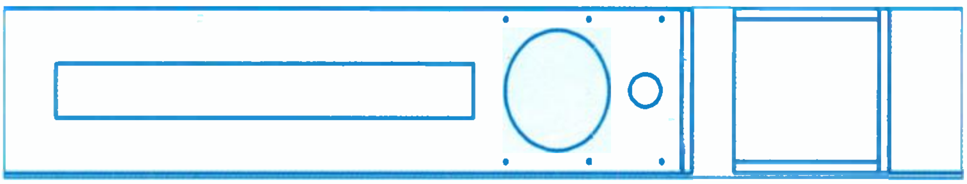
Speaker Builder

THE LOUDSPEAKER JOURNAL

A QUARTER-LENGTH TRANSMISSION LINE



BUILDING A BIG 40″ PLANAR



CHOOSING AND USING COILS

QUICK, EASY-TO-MAKE PIPE SPEAKE

SLICK PERFORMANCE ANALYSIS ON A MAC

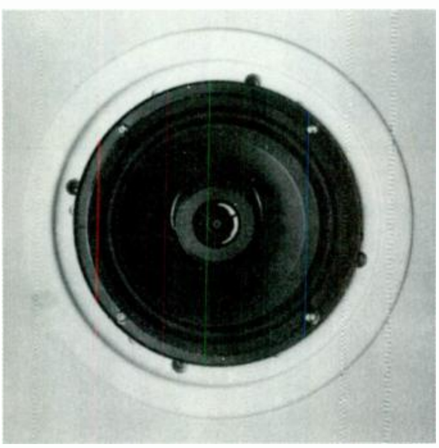
Good News

➲ HIT ROK BOTTOM
Designed to complement KRK Systems' near-field monitor line, the RoK Bottom 8Ω subwoofer boasts 110dB of maximum SPL and a sensitivity of 91dB. The sub, available either unpowered or powered with a 250W amplifier, features a 12″ polyglass long-stroke woofer and 2.1ft^3 enclosure. Distributed by Group One Ltd., 80 Sea Lane, Farmingdale, NY 11735, (516) 249-1399, FAX (516) 753-1020.

Reader Service #104

MADE IN THE USA
The newly-established American Speaker Manufacturing supplies OEMs with loudspeakers for use in autosound, hi-fi, public address, and other audio equipment. A.S.M. will construct transducers to almost any design requirements and specified parameters. For more information, contact American Speaker Manufacturing, Inc., 700 Jessie St., San Fernando, CA 91340, (818) 837-4516, FAX (818) 837-6611.

Reader Service #101



∩ SPACE-SAVING SPEAKER
B & W announces the super-compact CCM60 in-wall speaker, which requires a mounting cutout of 7 7/8″ in diameter by 3″ in depth. Uniting a 6½″ polypropylene mid/woofer with a coaxial 1″ dome tweeter, the CCM60 generates 80W of continuous power, a 60Hz–20kHz frequency response, and 90dB SPL sensitivity. B & W Loudspeakers of America, 54 Concord St., North Reading, MA 01864-2699, (508) 664-2870, FAX (508) 664-4109.

Reader Service #105

METER SOUND LEVELS
Rion's NL-05, NL-15, and NL-18 sound-level meters—used to determine building acoustics, noise control, diagnostics, and HVAC measurements—are available from Scantek, Inc. The NL-18, for Type 1 measurements, offers seven functions, 100K memory, a real-time clock, and two large LCD screens. Type 1 is plotted with the NL-15 and Type 2 with the NL-05; both meters promise AC and DC outputs, 60dB dynamic range, analog and digital display, and 20 hours of battery life. Scantek, Inc., 916 Gist Ave., Silver Spring, MD 20910, (310) 495-7738, FAX (310) 495-7739.

Reader Service #108

RIBBON TECHNOLOGY
The Image Acoustics RT-Series two-way loudspeakers combine a 12″ × 0.5″ single-ribbon tweeter and two rubber surround/polypropylene cone woofers. The Model RT-1 boasts 8″ woofers and a transmission-line bass enclosure, the RT-2 sports a pair of 6½″ woofers, and the RT-3 offers a duo of 5¼″ woofers and a Helmholtz resonator configuration. Each version is housed in a cabinet of black laminate and mahogany. Image Acoustics, Inc., 97 Elm St., Cohasset, MA 02025, (617) 383-2002, FAX (617) 383-2003.

Reader Service #102

TWO NEW CHOICES
MIDI Land offers two new speaker systems for multimedia PC users, the MLi-S20 Plus and MLi-818. The MLi-S20 Plus comprises a subwoofer with 40W of power output, a pair of 3″ satellite speakers, a double-hinged 5¼″ driver, and 35Hz–20kHz of frequency response. The MLi-818 four-channel surround-sound system features an AUX output jack, 3″ full-range drivers, 20W RMS power output, and a frequency response of 20Hz–20kHz. MIDI Land, Inc., 440 S. Lone Hill Ave., San Dimas, CA 91773, (909) 592-1168, FAX (909) 592-6159.

Reader Service #103

← ***Reader Service #36***

Good News

FLICK A B.I.C.

Three home-theater speaker packages—the HTS-1, HTS-2, and HTS-3—are newly released from B.I.C. The HTS-3 incorporates four C-5 speakers, one V52CLR center-channel speaker, and a V-1000 powered subwoofer; the HTS-2, however, utilizes three C-5s for the left/center/right channels, two Adatto A-1 speakers, and a V-1000 powered subwoofer; the HTS-1 encompasses two pairs of Adatto A-1s, an Adatto 4.2 center channel speaker, and a C-10 PAS passive subwoofer. B.I.C. America, 887-B Hampshire Rd., Stow, OH 44224, (216) 918-2011, FAX (216) 928-8392.

Reader Service #110

RESOURCE CONTROLLER

Adiabatic enclosures, controlling cabinet resonance without acoustical stuffing or internal damping, complement Total Media Systems' new Adiabat 8.5 full-range loudspeakers. In addition to a 91dB/W/m sensitivity rating and linear impedance, the Adiabat 8.5 employs a phase-locked crossover network and time-aligned® front baffle. Total Media Systems, 50 Schmitt Boulevard, Farmingdale, NY 11735, (516) 777-7058, FAX (516) 777-7059.

Reader Service #106

SPRING RETURNS

Electroswitch announces the C1 Spring Return selector switch for audio applications, testing, and measurement. It features a compact size (0.8 in^2), three selector positions, and up to 25,000 life cycle operations. Electroswitch, 2010 Yonkers Rd., Raleigh, NC 27604, (919) 833-8016.

Reader Service #111

ONE-FOR-ALL

Celestion's Home Theater in a Box® (HTiB) combines a subwoofer module, including a 10″ 60W subwoofer; one center channel speaker; and four shielded effects speakers with 3½″ drivers, 1″ dome tweeters, and mounting brackets. Dolby Pro Logic™ decoding, a hand-held remote control, Dolby Surround sound processing, and video gray components further enhance the HTiB system. Celestion Industries, Inc., 89 Doug Brown Way, Holliston, MA 01746, (508) 429-6706, FAX (508) 429-2426.

Reader Service #107

VINALLY, A COMEBACK

The Vinyl Valet offers new and reissued classical, jazz, blues, folk, and rock on vinyl records. Many limited-edition releases, out-of-print imports, and unreleased sessions are available on 150gm or 180gm vinyl LPs within original covers. A comprehensive catalog is updated on a monthly basis to include all in-stock titles and new releases. The Vinyl Valet, 509 West 15th St., Tempe, AZ 85281, (602) 829-8537, FAX (602) 968-8382.

Reader Service #109

Reader Service #35 →


Introducing
Dul'cet 5.1
Home Theater System
ACOUSTIC TECHNOLOGY INTERNATIONAL INC.
100 SPY COURT
MARKHAM
ONTARIO
CANADA L3R 5H6
TEL:905-475-3100,FAX:905-475-8226

Speaker Builder®

The Staff

Editor and Publisher
Edward T. Dell, Jr.

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

Assistant Publisher
Karen Hebert

Dennis Brisson Managing Editor
Swain Pratt Associate Editor
Courtney Howard Editorial Assistant
Linda Cardone Graphics Director
Diane Luopa Assistant Graphics Director
Joan Ahern Production Assistant
Suzanne Coté Production Assistant
Laurel Humphrey Marketing Director
Robyn Lasanen Circulation Manager
Doris Hamberg Administrative Assistant

Advertising Rates & Schedules

Peter B. Wostrel National Advertising Director
Linda M. Guyette Advertising Sales
Laura Brown Advertising Assistant
(603) 924-7292 **FAX (603) 924-6230**

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.

Subscription 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.

About This Issue

David Field has spent much time researching and studying transmission-line speakers. The results of his ruminations are presented in his T-REX design ("A Quarter-Wavelength Reflex Transmission Line," p. 8). His views, which are sometimes unorthodox, nudge the foundation of long-held beliefs, but his speaker, he claims, will stand the scrutiny of even the crustiest traditionalists.

With the publication of the reprint "Choosing the Best Filter Coils" (p. 22), we're doubly indebted: first, to Dutch language expert **John Fourdraine** for his translation work and, second, to the pros at Elektor Labs for sharing their extensive evaluation of coils.

How seriously should we consider tube speakers? This is a question that haunted **Dick Carlson**, who set out to find the answer in "Tubular Speakers" (p. 34). The author is the first to admit that they may not be pretty, but tube speakers are easy to construct and to place, and, most importantly, get the job done. He makes these "pipe dreams" a reality.

Daniel Patten's planar speaker design (Part 1, *SB* 8/95) generated much interest among readers. The second part (p. 38) puts this interesting design to the test, as the author provides performance results obtained in his local university's anechoic chamber.

Finally, in **Dick Moore**'s review of the Mac SLM software on p. 50, you'll discover how you can turn your Mac computer into a sound-level meter and spectrum analyzer.

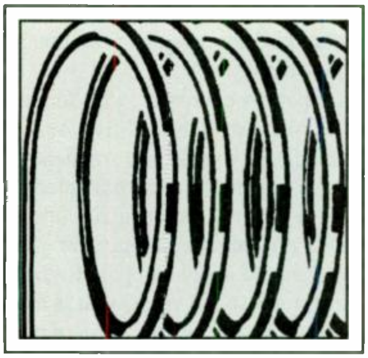
Speaker Builder (US USSN 0199-7929) is published every six weeks (eight times a year), at $32 per year, $58 for two years; Canada add $8 per year; overseas rates $50 one year, $90 two years; by Audio Amateur Corporation, Edward T. Dell, Jr., President, at 305 Union Street, PO Box 494, Peterborough, NH 03458-0494. Periodicals postage paid at Peterborough, NH and an additional mailing office.

POSTMASTER:
Send address change to:
Speaker Builder, PO Box 494
Peterborough, NH 03458-0494

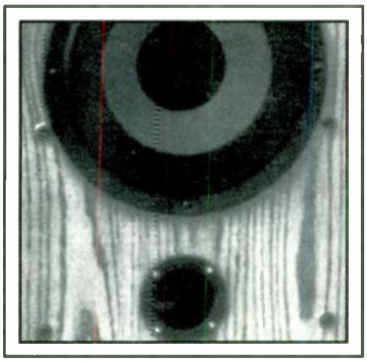
Speaker Builder

THE LOUDSPEAKER JOURNAL

VOLUME 17 NUMBER 4 JULY 1996



22



38

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 Publications, Inc., PO Box 494, Peterborough, NH 03458-0576, voice (603) 924-7292 or 1-800-524-9464, FAX (603) 924-6230.

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.

T-REX: A QUARTER-WAVELENGTH REFLEX TRANSMISSION LINE

By David I. Field

I have always been interested in transmission-line (TL) speakers because of their promise of deep bass, yet I have often been disappointed by demonstrations that failed to produce decent bass. I was invariably confused by explanations of the function of a TL and thought it was due to my technical ignorance. However, I've also noticed that experienced authors find themselves struggling with readers over facts they have not been able fully to explain to the satisfaction of the inquisitor.

Gary Galo's article, "Transmission Line Loudspeakers" (*SB* 1/82 and 2/82) left me with many unanswered questions, and readers' letters in subsequent issues threw doubt upon the validity of many of the assumptions concerning TLs. Myths appeared to abound, and disappointing results of an initial venture forced a reappraisal of the data. A basic understanding of what goes on inside a pipe is necessary though, to enable you to make rational design decisions. I fear that perhaps I am entering the lion's den, as much of what I say will not please the traditionalists!

STUFFING, BEGONE!

The basis of TL theory is, in my opinion, suspect. Trying to explain its function on the basis of a nonresonant pipe, while at the same time accepting a port output of significance, is logically inconsistent. It would be wiser to accept the fact that stuffing, as well as acting as a low-pass filter, also modifies, rather than eliminates, pipe resonances. The use of stuffing also modifies many parameters, making it difficult to predict outcomes. You will notice that I don't like stuffing, since I believe that speakers can be made to sound better without it.

The ensuing question as to whether a TL is a reflex speaker has sparked debate in the English hi-fi press, but not so much in *Speaker Builder*. The answer depends upon the design, as no two loudspeakers based on ¼ wavelength theory behave the same.

From data of published designs and my discussions with other amateur designers who have been able to measure impedance, it appears to me that a "pure" line with no chamber behaves like a pipe. In an unstuffed state, it exhibits regular impedance peaks that straddle the line resonances, diminishing in magnitude as frequency rises, but large enough to produce an uneven amplitude response. The addition of stuffing helps to damp out these peaks and troughs, smoothing the response. It behaves like a model predicted by Roberts in a computer program.

MODEL MODES

It is interesting to examine this model closely. At the ¼ wavelength frequency, there is a high-pressure mode behind the driver that controls resonance and reduces impedance to produce a dip in the impedance curve. Air velocity is at a minimum. At the open end of the pipe, there is low pressure but high velocity of air, explaining port output.

At ¾ wavelength (three times the ¼ wavelength frequency) a similar situation arises, with high pressure behind the driver, and another one occurs two-thirds of the way down the line. Also, there are high-velocity points at one-third the length of the line as well as at the output.

A similar pattern continues, with further, higher odd-order wavelengths (five, seven, nine... times the ¼ wavelength frequency), diminishing in magnitude at each fraction. If you wish to selectively damp such a line in an attempt to prevent overdamping of your speaker, you should apply damping to these areas of maximum sound velocity. It is usually necessary to damp only the third, or possibly the fifth, since—if the design is good—the higher fractions should be of sufficiently low amplitude to be ignored. The maximum impedances occur at the points of minimum pressure (*Fig. 1*), which is quite logical, for there is less loading on the driver.

The impedance peaks decrease with stuffing, and once adequate stuffing is in place, one large impedance peak is left below the system resonance (*Fig. 2*). However, don't forget that stuffing acts as a low-pass filter that both attenuates the amplitude and shifts the frequency of the resonant modes. Due to this frequency-dependent effect, the modes no longer occur at harmonically related frequencies, and this varies according to stuffing density. Roberts illustrates this well.[1]

It is obviously wise to design a line that filters out as many of the high-order modes as possible to reduce damping requirements. It would be fair to call the undamped line an acoustic labyrinth. The damped line behaves as Bailey described,[2] so you can call it a TL. Paradoxically, I do not consider his first published design a pure TL, since it has a significant chamber!

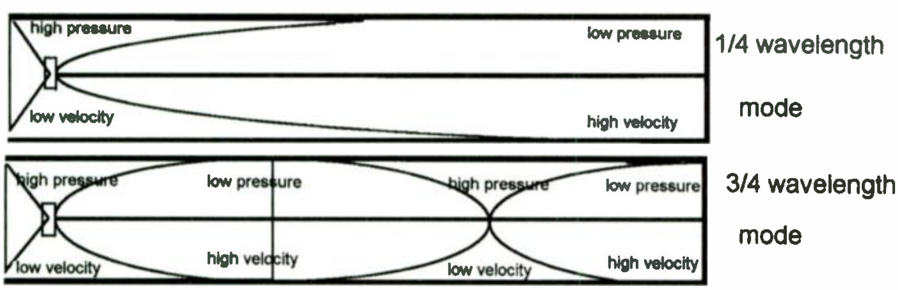


FIGURE 1: The ¼ and ¾ wavelengths.

THE REALITY

The model illustrated in *Fig. 1* does occur in practice. A line that's folded but built without a chamber exhibits impedance peaks as follows: 11, 50, 90, and 150Hz. If you assess the fundamental frequency as 25Hz (characterized by an impedance minimum I do not have), then the ¾ mode will be at 75Hz and the fifth mode at 125Hz.

Give or take a bit of jitter, these figures lie nicely in the impedance dips. Variations in predicted values can be explained by bends and other line irregularities. The fifth mode does not accurately fit in the last dip, but this could be explained by lossy effects in the line attenuating higher frequencies. The only way to abolish these resonances is to add damping material to the line. This line behaves like a traditional TL.

Adding a chamber at the drive-unit end of the line acts as an acoustic filter and reduces line modes, converting it into a reflex TL. This produces important measurable changes, and was a significant step forward achieved by Letts.[3] When I measured the impedance of my line, the results were very different. I found only two peaks, with a well-defined trough. This, I was told, was due to insufficient sensitivity in my method, so I repeated the measurements with great care and expert help, and the results were the same.

The initial impedance peak was at 12Hz, with the next peak of substantial size at 36.5Hz. The impedance dip centered at 19Hz. However hard I tried, at this stage I was unable to identify sufficient impedance variation to indicate another high-pressure line resonance, or set of resonances. I assume that the upper impedance peak relates to the chamber, and the lower one to the line.

The presence of a very small amount of stuffing made little difference in the findings; the initial impedance peaks of the two lines are similar: 11Hz and 12Hz. The traditional TL goes on to have spread-out peaks, whereas the line with a chamber has two peaks bunched together that cannot be related to any recurrent modal pattern, since the third peak should occur at 57Hz (using the initial impedance dip as the ¼ wavelength mode), at the tail-end of the main impedance peak.

This is evidence, I believe, that the reflex TL is altogether a different animal. The fact that the reflex line eliminates modal effects without the use of stuffing is, in my view, clear indication of its superiority. Some TL fans refuse to accept that a reflex TL is of the same family as the purer form. However, both have one similar characteristic.

RESONANCE QUESTIONS

Since Bailey's design appeared, it has often been stated that a line lowers the drive-unit resonance, although I have never seen any convincing evidence for this. Indeed, an article by Spear and Thornhill,[4] who were investigating the effects of fibrous stuffing, suggested the reverse. Increased stuffing appeared to raise the drive unit's resonance while lowering that of the pipe, thus producing the characteristic TL mid-bass fade. However, the combined resonance of the system would appear to be lowered below drive-unit resonance, a characteristic of TLs based on ¼ wavelength theory.

In my reflex TL, the two impedance peaks straddle that dip centered at 19Hz, below the drive-unit resonance at 25Hz. In reflex theory, this is the point of system resonance, which in my case has occurred below the drive-unit resonance. (In general, reflex speakers have a box resonance above that of the drive unit, but Lampton[5] and Pike[6] have shown that you can design a reflex speaker that places the box resonance below this. It would not be correct, therefore, to imply that a TL is the only way of achieving low system resonance.)

This was my initial conclusion from the data. However, after doing some more studies, I am left pondering. Port output did not appear to accurately match what the impedance trace should have predicted. I suspected that the drive-unit resonance was determining it, and that my enclosure may well be matched to a drive unit with a 19Hz resonant frequency. I eventually intend to explore this possibility by sourcing an alternative drive unit to see whether the impedance dip remains at 19Hz or is lowered further. However, my unit generally works well and has a low V_{AS} of 85 liters.

My proposed unit has a V_{AS} of 174 liters, which might upset the operation of the speaker. It could be argued that my line and chamber have some characteristics of a horn, for I understand it is important to have a low V_{AS} with a horn-loaded speaker. Would a V_{AS} of 174 be too high, or is my chamber large enough to supply sufficient loading to the drive unit? I'd be grateful for any advice.

AMPLITUDE RESPONSE

Amplitude response does not appear to be flat to the system resonance, as it falls gradually to frequencies below audibility. This means that a low woofer placement can be made without producing any boom or coloration, thus avoiding the high bass dip of a high-mounted woofer. I have often thought that the worst speaker response is one that is flat to resonance, since it appears to ignore the fact that the speaker will be used in a room, which will raise the low-frequency response. This "error" is invariably compounded by using high Q_{TS} drivers with small magnets because they are cheaper. The computer will produce a nice response curve without telling you anything about the quality of the bass in a room.

Judging by the plethora of cheap, high-Q_{TS} drivers with a low f_S, it is not difficult to manufacture such a speaker! It is harder and more expensive to produce a low-Q_{TS} driver with a big magnet and low f_S. However, such a unit gives a vastly improved transient response, which I consider more important. Now, with small speakers, it appears that the industry can get away with cheap units.

I suspect that the room interaction is less subjectively overbearing because the frequency of resonance is higher. (Low-frequency resonances can produce unpleasant pressure effects, as I know from earlier experience.) However, reviews of speakers with powerful low-Q_{TS} drivers (ATC SCM 50, 100, and 200) have noted that the bass quality is less affected by room boundaries. Blair[7] made similar comments in *Speaker Builder* when discussing a "reflex" style of TL (i.e., with minimal damping).

SPEAKER PLACEMENT

A traditional TL should have a high-Q_{TS} driver; otherwise, all the stuffing overdamps the speaker, making it prone to boom when placed near a boundary. The larger the speaker and the lower the f_S, the worse the problem. Similar difficulties arise with the majority of large reflex speakers. Little wonder that large speakers are often criticized for poor, heavy, and colored bass.

It is also possible that we should rewrite the rule book about speaker placement when using low-Q_{TS} drivers (produced by means of a large magnet and associated good electrical damping). I suspect that acoustic loading should also be considered, and that the interaction (or lack of it) is more than just the effect of the boundary raising the amplitude response. Dare I suggest that such a drive

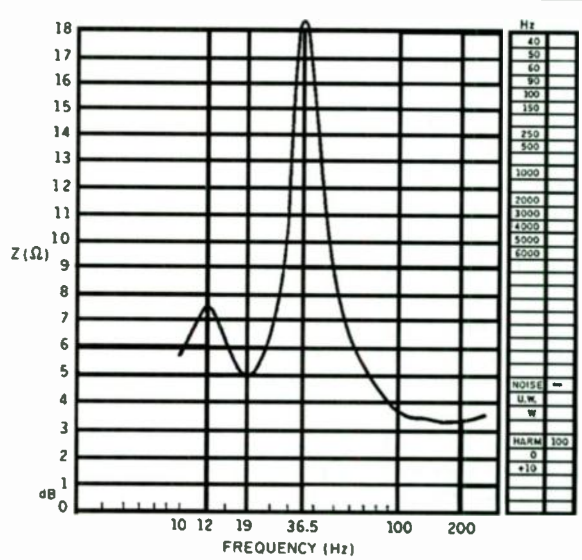


FIGURE 2: Impedance vs. frequency curve.

unit controls resonance better in both cabinet and room by reducing both amplitude and overhang?

I also find it strange that speakers are generally designed to achieve a low f_3, and consequently a sharp rolloff, again without considering how the room will affect the eventual result. Invariably the room averaged response has a big hump in the bass, a characteristic that I notice too many reviewers in some hi-fi journals praise as "good" bass. If only the speakers were designed with low-Q_{TS} drivers and a shallow rolloff, well damped! The f_3 would be much higher, but the room averaged response would be smoother, and the ultimate bass much deeper and more satisfying.

SPEAKER BEHAVIOR

This is the philosophy I have adopted with my speaker. I chose a low-Q_{TS} driver with a large magnet to ensure good electrical control of the diaphragm. Let the amplifier control the sound. This speaker behaves well in my room, being less fussy about placement and happy to sit up against a wall without booming—and mine are even sitting in a corner, a location banned from hi-fi circles since the days of Briggs!

Honestly, there is no booming, even at high power levels, and a corner placement enables the speaker to drive the room well at really low frequencies, providing a sense of substance. Although in theory the room eigentones should be stimulated, this does not occur in practice, partly because music waveforms do not last long enough to stimulate resonances. But I suspect that the electrical and acoustic control imposed on the diaphragm are also important.

At low frequencies, a room must be pressure driven, and placement near a boundary assists this. However, you could achieve further enhancement of the lower frequencies by adding a downward-firing woofer, rolling it off before the forward-firing woofer. I've been toying with the idea of incorporating this configuration into my speaker or a future design by adding an extra unit to the speaker base. In theory, I would have to enlarge the line's cross-sectional area, but perhaps in reflex TL theory that does not matter. I will continue to consider this option, since a combined full-range speaker and subwoofer has certain attractions. I think I might need some more measuring gear first, though.

ON A LARGE SCALE

So much for theory and philosophy; now to the details. When I started to build these speakers, I was determined to produce a product of the highest quality—as good as the best. They are large, designed for a largish room—26′ × 15′ × 8′—but I am sure

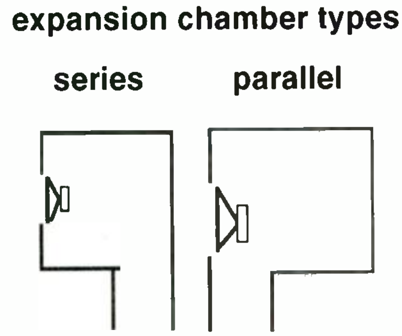


FIGURE 3: Expansion chamber types.

readers with good-sized rooms may also be interested.

I actually expanded my old TL with a line cross-sectional area designed for a KEF B139, a 10″ unit. It had no expansion chamber and a lumpy bass performance. A great deal of wool had been necessary, and there was plenty of boom at low frequencies, together with lots of coloration—all the characteristics I abhor! Initially it seemed spectacular, with the bass drum sounding amazingly powerful, but it was far from accurate, and some of the spectacular bass turned out to be high levels of distortion. It had the classic heavy-bass sound of a conventional TL and was hardly a successful design.

I literally cut out the top of the speaker and added an expansion chamber of the sort described by Letts. Its size was dictated by domestic considerations, but I suspect a larger chamber would be even better. With TLs, everything is delightfully rule of thumb, which is why they are such fun for amateur designers. If you make the chamber about 1/3 of the total volume of the speaker, you should get a good result.

The chamber certainly smoothed out the bass response and markedly reduced coloration, but this wasn't Letts's original intent. According to a discussion I had with him, his idea was to try to better match the drive-unit characteristics to the line.

TABLE 1

BASS SPEAKER SPECIFICATIONS

nominal size	250mm
sensitivity	90dB/1W/1m
impedance	8Ω
power	250W continuous
voice-coil diameter	75mm
voice-coil length	17.5mm
magnetic gap	7.5mm
flux density	1.3 tesla
total flux	251 maxwells
F_S	25Hz
Q_A	2.23
Q_E	0.32
Q_T	0.28
V_{AS}	85l
X_{MAX}	5.5mm
S_D	299cm^2
V_D	164cc

IDENTIFYING RESONANCE

It was not possible to completely eliminate the audible presence of what was presumably the ¾ resonance in my line that occurred at 75Hz. I identified this using nothing more sophisticated than an old Heathkit sine-wave generator (IG 18) and my ear. I was forced to add a small quantity of BAF wadding along the first part of the line to damp this resonance.

Interestingly, I was able to audibly identify this resonance, which I concluded came from the line alone, as it was physically decoupled from the drive unit by the chamber. I say this because it failed to make a significant impression on the impedance trace. It also had little subjective effect on the sound, and so was not of particularly high pressure, leading me to believe that it was only a line artifact, causing little interactive effect with the driver.

However, it happened to be exactly three times the f_S of the drive unit, so I was not sure whether this was relevant. Using the primary impedance dip at 19Hz as the fundamental resonance, this resonance should have occurred at 57Hz. Using the drive-unit resonance, it was smack on frequency. I then referred to the impedance curve, which was plotted on the correct graph paper for the job. Sure enough, there was an imperceptible "flattening" at the tail-end of the impedance peak, centered around 75Hz, and another impression of flattening around 125Hz. (I am afraid that the computer-generated plot is unable to illustrate this due to a lack of sensitivity. It is only apparent on a carefully plotted hand graph.) These, of course, could be the third and fifth modes, bearing no frequency relationship to the main impedance pattern.

So the line was behaving according to theory, and the chamber was decoupling it from the drive unit. It appeared that the drive-unit resonance was dictating the line resonances, while the impedance measurements suggested that the predominant behavior of the combination was more like a reflex system. Obviously, no simple computer program will predict the characteristics of such a speaker design.

My line-to-drive unit, with 8″ of end correction, measures 122.4″. By taking a line directly through the midline of duct and chamber (not quite the shortest length), port length to chamber is 90″. The port cross-sectional area is 12.5″ by 3.625″. By TL theory, my ¼-wavelength mode should be at 27Hz. A reasonable fit, I suppose, but as the impedance curve is reflex in character,

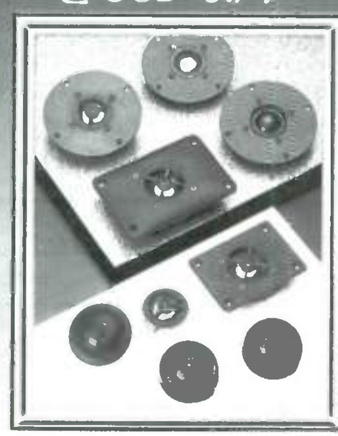
Reader Service #52 →

* SEPARATE CAR SPEAKER SYSTEM
* IN-WALL SPEAKER * TWEETERS

φ 13mm Neirbon
Super-Tweeter

Can Light Style/Square In-Wall

DOME TWEETER
@USD 0.79



Surface/Angle/Flush
Mounting Kits

COST DOWN !!

◎Best choice for cost saving effectively.
◎Most professional manufacturer for speakers.
◎Available for OEM design and free catalogues.

Forgings INDUSTRIAL CO., LTD.

SEND INQUIRIES TO: P.O. BOX 1823, TAIPEI, TAIWAN, R.O.C.
TEL: 886-2-585-3316/7 FAX: 886-2-594-2708 ATTN: MS.CHI YING

TABLE 2

PARTS LIST

Volt B2500.1 10" Studio Driver
ATC SM75-150 or SM75-150S
Morel MDT 33
Michell gold-plated loudspeaker binding posts—3 pairs
Grille-fixing studs—4
Felt
Loudspeaker grille cloth
1" quarter-round for grille frame

you should consider that ¼-wavelength theory acts only as a loose predictive rule in this context.

BACK TO BAILEY

Next, I went back to look at Bailey's original work. By 1972, he was unhappy about midrange coloration, blaming it on direct reflections within the first part of his line. His solution was to produce a line with a triangular cross-sectional area. In retrospect, I think he misinterpreted the cause of the coloration and therefore failed to supply the correct solution. Interestingly, this is a purer TL than his first design, since there is nothing that could be called a chamber at the beginning.

His amplitude response also had a couple of peaks that could nicely do for the third and fifth resonant modes. Arthur Radford manufactured an example of Bailey's first design, but not, to my knowledge, the second. His eventual conclusions were, I am sure, that the line was responsible for the coloration.

By the 1980s, Radford was marketing the Radford Studio 90, a large TL that had a generous chamber (taking up almost half the volume of the speaker) with a tapered line and a large throat. I had expressed an interest in building a TL, and when he demonstrated this to me, he stressed the importance of having this large throat at the start to reduce resonant effects.

I had shown him a copy of a design without much of a chamber that I was considering building, and he told me it would be colored. He was right! He had a keen ear for coloration, and had obviously concluded that damping alone was not going to resolve the problem. His speaker, damped in the traditional way with long fiber wool, was commendably low in coloration, but I thought that it was lacking in deep bass. Resolving the coloration of the TL had robbed it of its main rationale: good deep bass.

EXPANSION CHAMBER

By the 1980s, Letts and Radford had moved on to providing an expansion chamber, although Radford did not call it that. In 1992, Celestion provided an expansion chamber

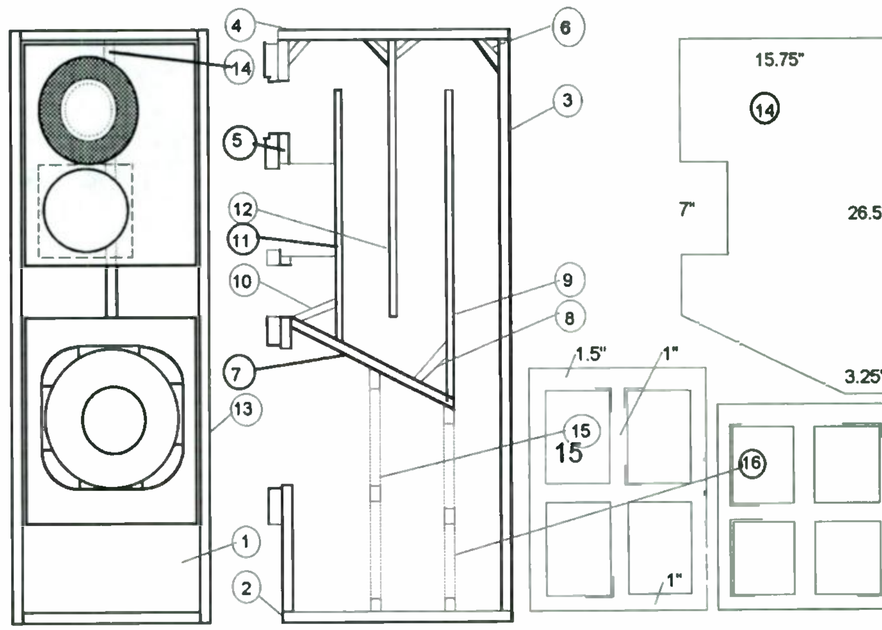


FIGURE 4: Construction specifications.

that was in parallel with the line, rather than in series, as is mine (*Fig. 3*). This was to ensure that the pressure at the line entrance was the same as the pressure at the drive unit. This is supposed to provide an advantage, but I am unsure whether this is the case. Celestion claims a reduction in midrange coloration, but this should also be achieved by a conventional expansion chamber. The direct coupling of the line to the drive unit does increase the amplitude response at resonance, but this is a mixed blessing.

I say this because when I examined Martin Colloms' review of this speaker,[8] the line's third and fifth modes are clearly identified in the port output with impedance glitches (at 90 and 150Hz, respectively). In comparison to my layout, this arrangement clearly couples the line more directly to the drive unit (since it produces significant impedance changes), partly defeating the object of the exercise. I would expect the bass to be more colored by this approach.

However, what it does show is that the ¼ wavelength resonance is at 30Hz, which happens to correspond with the main impedance dip. This fascinated me, because, as previously noted, this did not occur with my line and chamber arrangement. It was at this point that I began to wonder whether I had

TABLE 3

PARTS IDENTIFICATION

PART #	SIZE	QTY	REMARKS
1	13.25″ × 21.75″	1	Cut 253 mm hole
2	13.25″ × 17.25″	1	Bottom panel
3	13.25″ × 42.25″	1	Cut three holes for terminals
4	13.25″ × 17.25″	1	Top panel
5	13.25″ × 16.625″	1	Cut midrange square/tweeter circle in mirror image
6	6.25″ × 2.75″	8	45° chamfer along long sides
7	13.25″ × 13.625″	1	63° chamfer one end
8	6.25″ × 3.375″	2	60° chamfer along long sides
9	6.25″ × 23″	2	63° chamfer one end
10	6.25″ × 4″	2	54° & 63° chamfers along long sides
11	6.25″ × 18.875″	2	63° chamfer one end
12	6.25″ × 20.5″	2	Central line partition
13	17.25″ × 43.75″	2	Sides
14	15.75″ × 26.5″	1	Line brace requires cutouts
15	13.25″ × 18″	1	Expansion chamber brace requires cutouts
16	13.25″ × 15.25″	1	Expansion chamber brace 63° chamfer one end requires cutouts
17	15″ × 12.5″	1	Woofer baffle board; see text
18	16″ × 12.5″	1	Midrange/tweeter baffle board; see text

All pieces 19mm chipboard except 9, 11, & 12, which are 12mm.
Baffle boards are 21mm.

inadvertently designed my line for a drive unit with a lower f_S.

STUFFING EFFECTS

As I've said, I don't like damping because, to my ear, it adds a slowness to the sound, although it has the advantage of slightly raising the amplitude of deep bass from the line. As wadding acts as a low-pass filter, it must cause transient distortion, particularly if sound from the port boosts the lower bass.

This is a subtle effect: low-frequency square waves are converted into sine waves, producing a very clean sound, erroneously praised for purity of bass. In fact, I consider it a highly undesirable effect, stripping away all fine detail and nuances, leaving the same old boring, low-frequency sine waves. Maybe you will say you cannot hear such things, but can you be sure? Better no bass at all than this! No doubt this will produce an avalanche of criticism from TL fans, but for me, this is another reason why I feel that a reflex-based TL is superior to the "purer" model.

In an effort to stretch out still more deep bass from a traditional TL, builders add more stuffing, which has the effect of reducing drive-unit output more rapidly as frequency lowers. Because the stuffing also lowers the frequency of port output, a suck-out occurs in the bass between these two points that distorts the frequency balance of the sound, accentuating the lower tones to produce an unnatural heaviness on top of the slowness all that stuffing imparts.

Furthermore, the Q_{TS} of the drive unit then has to be raised to compensate for the over-damping the stuffing causes, which in turn decimates transient response and its associated detail. The only advantage is that the speaker would be smaller. In contrast, the reflex TL preserves the direct output of the drive unit to a lower frequency, due both to the action of the chamber and the lack of significant stuffing.

I feel quite confident in making this point, for when I was making the first reflex speaker, I was able to compare it directly with my old traditional TL. It was easy to identify greater output from the drive unit of the new design at lower frequencies, while the old speaker produced more port output. The new speaker sounded much lighter, but was much more accurate and detailed. The bass drum had impact and detail; it didn't just rumble and shake the furniture.

Furthermore, adding stuffing to the equation would make it difficult to predict the speaker's behavior, requiring you to calculate the reduction in line length for a given stuffing density, to achieve the desired line frequency. Then it would be important for you to calculate the rise in drive-unit frequency for the same stuffing density to "match" the drive unit to the stuffed line. It would be necessary to choose a unit with a lower f_s than the stuffed line, so that when it was inserted, the two frequencies would coincide.

You might think that you would then have a speaker that would perform to "theory." I suspect not, as another negative effect of stuffing—particularly if it is spread evenly along the line to include the high-pressure area behind the drive unit—is to reduce the effectiveness of the pipe in controlling the drive unit resonance. The result of this would be an undamped drive unit at resonance! This is another reason why I don't believe in a non-resonant loudspeaker and, perhaps, why transmission lines have not found favor with either manufacturers or the public.

SMOOTH BASS

My port output will now be both resonant and mildly filtered as it passes through some damping material, so is there an advantage? I suspect that the secret to achieving smooth, articulate bass lies in placing the resonance below most musical signals, and I believe I have achieved this at 25Hz.

Some resonance and "impressive" port output can be produced by movie soundtrack effects, synthesized rock tracks, and poorly designed CD players that have a propensity for generating heavy unnatural bass below the fundamental frequency of an instrument (an effect of jitter). "Reflex" coloration is generally absent, which initially deceives you into thinking that the speakers lack bass. However, you soon appreciate the smooth nature of the bass, which is "panel-like" in its presentation, but much tighter and able to handle more power. The lower organ stops are of course within the port resonance range, but as these are "resonant" sounds anyway, you don't notice the subjective effect.

It is worth remembering that resonance masks musical detail present at that frequency. Damping the resonance is only a panacea; it reduces the masking, but does not eliminate it. All reflex speakers, however good, suffer from this trait, even those you may be listening to as you read this article. And remember that their resonance, stimulated by many musical instruments, will mask the finer details.

As I have noted above, the impedance graph shows a well-controlled speaker with no significant aberrations caused by line effects. In fact, large, tall, reflex speakers are much more affected by this type of problem,

since their large chambers produce standing waves that are directly coupled to the drive units, producing impedance kinks. This results in the direct transmission to the drive unit of coloration that is more noticeable than the resonances of a decoupled line.

A well-designed TL is much superior in this respect, as the pockets of air between the line bends have resonant modes well outside the bass passband and so do not produce coloration. This structure also helps to diminish the effects of the line resonance, and I suspect that my use of a central line brace further enhances these advantages. It is clear that the well-braced major panels, an inherent feature of the design, reduce panel resonances to an insignificant level. The panel resonances that do exist are again moved out of the bass passband. The use of a dome midrange mounted on a substantial and well-braced baffle ensures that there is no smearing of midrange sounds by panel effects.

ATC'S MIDRANGE DOME

For me, one of the most significant designs in loudspeaker technology is ATC's midrange dome. I rank this unit as an advance on a par with the original QUAD electrostatic, since it offers low coloration, impressive dispersion, and awesome power-handling abilities. Although there are now a number of 3″ domes to choose from, none reaches the quality of the ATC unit. It projects the soundstage with excellent imaging over two-thirds of the room.

Its superior dispersion and low coloration result from its carefully damped soft dome. Grain, distortion, resonances—all masked by lesser units—are ruthlessly revealed by this speaker. It will not tolerate low-grade sources and amplifiers. (It is, however, very expensive, even in the UK, so you could consider a cheaper option, Dynaudio's D76, although its chamber is longer, so the baffle board might have to be deeper.)

Another advantage to this unit is its ability to cover a wide frequency range. In my design, it covers between 380Hz and 3.8kHz, the most sensitive area of hearing. It also exhibits a linear phase response that—coupled to its superior dispersion compared to a traditional cone—imparts the qualities of excellent imaging, depth and naturalness. Consequently, the crossover's phase coherence is less critical for the sound, since it is outside the most sensitive area of the midrange band. Of course, linear phase is the ideal if you have the necessary gear for setting up the speaker.

As a UK builder, I chose the Morel MDT 33, as it was readily available. It is a soft dome, with a mighty magnet providing vise-like control of the dome and a transient response second to none. It has attack when needed, but no metal dome tinsel.

Playing an impulse test signal through this tweeter gives you a cracking sound almost as realistic as an outdoor fireworks display. If you use music alone to assess the potential qualities of a tweeter, you may be fooled into believing that the bright presentation of a typical metal-dome tweeter is superior. However, this is not the case, as this effect is invariably due to a poorly controlled resonance. The Morel tweeter had the most heavily electrically damped dome of all those whose specs I studied.

If you cannot make the dome lighter, make the "motor" more powerful. It is also surprising how strong a so-called "soft" dome is. It actually takes quite a bit of abuse to damage it, while it is quite easy to deform a metal dome. Under heavy driving, an inadequately strong dome will break up, producing a "brittle"-sounding distortion. In contrast, a well-controlled and damped dome will produce a clear, open, and detailed treble.

I have also found from experience that improved transient performance results in a more detailed sound, not a brighter sound, which is what most people expect. In all these respects, I feel that the Morel tweeter provides an outstanding performance.

THE BASS UNIT

ATC bass units, well known in the UK, but less so elsewhere, have designs that are second to none, but the constraints of my line area resulted in my choosing a different unit. The Volt B2500 is a generous 10″ design with a big magnet, long-throw voice coil, and an adequately low Q_{TS} of 0.28. Its f_S is 25Hz, which matched my line length, and it handles bags of power without distress. With a stiff, paper-based cone, it is a very fine unit—superior to many highly praised alternatives whose specs reveal poorer magnetic control.

Other units may give you a lower f_S, but they achieve this with a much higher Q_{TS} and smaller magnets. The result is that they won't deliver as much bass power at the lowest frequencies, and the sound will be soggy, to boot. I have included the specs (*Table 1*) for those who want to try finding another unit.

ACTIVE CROSSOVER

Matching all these units in a passive crossover would be a nightmare, particularly since the midrange is nominally 15Ω, while the rest are 8Ω. I know there is a fashion for minimalist hi-fi at present, particularly in crossovers. Supposedly, less means more detail, but if you examine the amplitude responses of some minimalist crossover designs, you wonder why the speakers are appearing in a hi-fi journal.

Poor simplified crossover design can not only result in amplitude irregularities, but also poor off-axis response—and what about phase? Anyway, what about all the currents whizzing around through those coils and capacitors? Not exactly a recipe for linearity, and as I was not computer-literate at the time (I am beginning to learn), the prospect of designing a passive crossover seemed daunting, if not impossible.

An active crossover is the solution, and once you hear it, you'll never want to replace it. Individual power amps (MOSFET designs) provide linear drive to each unit: 60W to the tweeter, 100W to the midrange, and 200W to the woofer. With dB ratings ranging from 90 per watt for the woofer to 92 per watt for the tweeter, decibel output is no problem. At normal listening levels with classical music, the amplifiers are mainly cruising in Class A, but beware: these speakers can seriously damage your hearing if asked.

The crossovers are Linkwitz-Riley fourth-order, and are linear phase over the crossover region, with a 24dB per octave slope. Again, steep crossover slopes are frowned upon today by many of the hi-fi fraternity. But do not let prejudice cloud your judgment. The amplitude response is linear, as well, but there is a dip in the power response at the crossover point in the region of 1 to 2dB, the explanation of which is beyond my linguistic skills.

IMPOSSIBLE GOAL

I thought if I mounted the drive units with their acoustic centers on the same plane on

REFERENCES

1. "An Acoustical Model for TL Woofer Systems," M. Roberts, *Proceedings*, Institute of Acoustics, Volume 12, Part 8 (1990).
2. "A Non-Resonant Loudspeaker Enclosure Design," A.R. Bailey, *Wireless World*, October 1965 and May 1972.
3. "A Study of TL Loudspeaker Systems Honours Thesis," G. Letts, University of Sydney, 1975.
4. "Fibrous Tangle Effects on Acoustical TLs," R. Spear & A. Thornhill, *Speaker Builder* 5/91.
5. "A Three-way Corner Loudspeaker System," Michael Lampton, *Speaker Builder* 2/83.
6. "A 16Hz Subwoofer," Charles T. Pike, *Speaker Builder* 5/94.
7. "Works in Progress," Kevin Blair, *Speaker Builder* 2/94.
8. "Review of Celestion 300," Martin Colloms, *Hi-Fi News*, October 1992.
9. "Audio Design; A High Quality MOSFET Power Amp," Linsley Hood, *Electronics Today International*, July/August/September 1984, May 89.
10. "Electronic Crossovers Galore," Borbely & Gaertner, *Speaker Builder* 1/94.

the baffle board, and if their phase and amplitude responses over the frequencies in question were linear, I should end up with a linear phase and amplitude response. Regrettably, it proved impossible to achieve this. I now realize that the acoustic center of a drive unit is the voice coil. I have achieved positional alignment of the dome tips of the midrange and tweeter, so there will be some phase distortion.

The woofer is also not perfectly in phase, but this is less critical subjectively. You can achieve perfect linear phase only by adding phase shifters to the appropriate sections of the crossover, and adjusting them with the aid of appropriate gear attached to your computer. For me, this will have to wait a little, but at least the ideal is achievable with an active crossover.

If you examine *Fig. 4* and *Tables 2* and *3*, you will notice that the speakers are built as a solid box, with cut-outs to accommodate the backs of the drive units in the main cabinet. This allows very rigid mounting of the 21mm baffle board to which the units are bolted. In this design, the units are mounted asymmetrically. This is to ensure that the surface wave that passes along the baffle arrives at the two side edges at different times, thus reducing the amplitude disturbances, which can be quite significant in centrally mounted units.

I know that many hi-fi enthusiasts and reviewers listen to their speakers with their grilles off, since they sound brighter and better that way. Most speakers have square edges, and you'd be surprised how much that messes up the imagery. I mounted my grille on 1″ quarter-round, so that when I attached it, the imagery sharpened and the sound actually appeared to brighten. I then learned another little trick: if you glue felt onto the baffle, it will partially absorb the surface wave and improve the sound. It is also an expensive-looking way to finish off and cover over a few imperfections. A little felt ring on the tweeter also helps.

SPEAKER PLANS

I have included a plan of the speaker (*Fig. 4*) that you'll need to scrutinize carefully. I descended on my local do-it-yourself shop man with the details, and he was somewhat overcome. However, on a quiet morning, with an expert on his saw, we ended up with all the pieces accurately cut and chamfered to exact angles. The speakers then went together like a set of kitchen cupboards. As builders with construction skills far surpassing mine read this magazine, I am providing only a sketch plan of construction.

You place the top panel on the floor and attach the center-line brace to it. You then attach the line partitions like wings and affix the roof of the expansion chamber to the angled end of the brace. Be careful to make everything square.

Once you've got all these parts together, with the angled roof of the expansion chamber in place, you can glue on the sides. The bracing sections of the expansion chamber go on next. You'll need to drill all necessary holes for the wires, locate the wires, and make the holes airtight with lots of glue. Then put on the back and front panels, leaving just the floor, which you can screw on (but not glue) until testing, to allow fine-tuning and damping if required.

Having neither the equipment nor the skill to rout the front panel, I constructed each baffle of 3/8″ and ½″ sheets. The midrange requires just a hole with four bolt holes. The tweeter requires the small-diameter hole on the 12mm sheet and the larger hole on the thinner sheet, providing the cut-out. You must then smoothly bevel down the cut-out so that there is no lip along the tweeter edge. You should do this over the large circular area indicated on the plans. This arrangement results in the tweeter and midrange domes lying in the same plane. You can then firmly glue the two baffle boards together. I used clamping and screws, which achieved a very firm structure that I then bolted onto the cabinet.

WOOFER HOLES

For the woofer, you cut a circular hole in the main cabinet, and a similar hole in the 9mm baffle sheet. The thicker 12mm sheet has the larger cut-out so you can set the woofer in deeply enough to prevent the grille cloth from touching it on large excursions. All this can then be glued and screwed on. You will need woofer nuts that pin into the wood as you tighten, so all you have to do is offer up the drive unit to the baffle and bolt it on. You must attach a sticky gasket to the drive-unit frame so you can remove the top baffle to access the midrange unit. You can remove the tweeter and woofer by just unbolting them.

You can line the expansion chamber with heavy-duty felt, or if you're rich, you could stick on deflex sheets. I put four sheets of BAF 18″ by 12″ wadding in the first part of the line, two sheets folded on each side of the partition. The 1″ quarter-round for the grille frame needs to be carefully mitered at the corners. After placing the speakers on their backs, you then stick lots of cellotape near the corners of the speaker cabinet, place the grille frame in position, and glue its edges together. Then hold everything in place with more tape until the glue dries.

This rather primitive method ensures that if your speaker is not exactly square, the grille will fit. The cellotape prevents the frame from being glued to the cabinet. When the glue is set, you can peel off the grilles and remove the cellotape. Mine have remained perfectly strong. With the frame on the cabinet, drill small pilot holes through into the main cabinet to allow accurate placement of the grille-attachment studs on the frame and cabinet. Drill these holes to correct size, using the pilot holes, and then attach the two parts of the grille-location studs.

Paint the grille frame black, stretch on the cloth, and glue it with copydex. A hairdryer is useful for shrinking the fabric to a tight fit. Then glue the felt on the baffle for a Rolls Royce finish and sound. I veneered my speakers with iron-on veneer, a difficult task.

GREAT SOUND

I have indicated the qualities of the TL's sound. A large soundstage, particularly from CD, is its main strength. It produces glorious wood sounds from violins, cellos, and the classical guitar on vinyl, something a CD does not do as well. It has mind-boggling power output, with no hint of distortion, and pure treble that's clear of metallic effects but full of detail and able to reproduce metal instruments faithfully. The speaker is also able to project the feeling of "being there." This is because the images are projected into the soundstage with space around voices and instruments. This produces the uncanny feeling of almost being able to stretch out and touch the performers. These are characteristics largely provided by the excellent drive units.

If you are moved to build this speaker, do not anticipate spectacular bass. With good-quality source material, you should appreciate the subtlety of deep bass sound, which is much more satisfying than big effects. There is plenty of impact, when it's present in the source, together with detail in the bass line. This reflects the excellent transient performance of the bass section. I believe I've achieved transparency in the bass to match my chosen high-quality units, making the whole project well worthwhile.

ESSENTIAL SOURCES

I found that my source equipment was vital to take full advantage of these speakers, as they were so revealing. I had to rebuild my CD system completely, and only recently has it surpassed my turntable, strange though it may seem. I use a humble mark one Linn Sondek, bought in the '70s, an SME Series-4 arm with an Ortofon MC-30 super cartridge. Recent changes to my DAC, including the addition of an HDCD filter chip that reduces jitter and adds further refinement, have now moved the CD to the top spot.

My pickup stage, 20-bit DAC, and relay-switched line driver that uses an AD811 op amp as its active stage were all built from kits produced by a small Nottingham company called Audio Synthesis, with analog circuitry designed by Ben Duncan. High-grade components are used throughout, and the DAC has low-jitter circuitry with an Ultra Analogue converter.

My CD starts from a much modified Arcam Delta 170 transport with an improved low-jitter clock of my own construction, and a fast output stage. Power amplification is courtesy of a set of articles by Linsley Hood in *ETI* about a MOSFET power-amplifier design.[9] These are all high-quality designs, with the weakest link, I suspect, the active crossover, a Crimson design provided ready-built, fourth-order at 380Hz and 3.8kHz.

However, I have provided the crossover with an excellent power supply, which is probably the most vital ingredient. Of course, American builders have an excellent range of power amplifiers to choose from in the pages of *Audio Amateur*, together with the excellent active crossover designs in *Speaker Builder*.[10]

COMPUTER PROS AND CONS

After finishing this work, I had a chance to run the parameters of the design through a friend's computer on TL Boxmodel. This further convinced me that you should never base your decisions on a computer program alone, for if I had done so, I would never have built this excellent loudspeaker. The program was able to enter in a coupling volume, but this did not seem to take into account the acoustic filtering effect of an expansion chamber.

It did produce a fundamental double impedance hump, but it also showed a ¾-wave impedance hump that was not present in real life. The primary hump was of wrong proportion at the wrong frequency, but I could "juggle" it right by adding a small amount of stuffing to the program to mimic the filtering effect of the expansion chamber. The impedance glitch at ¾ resonance refused to disappear, however.

The amplitude plot seemed bizarre. It showed dramatic variations in the upper bass that I am quite sure do not exist. The most that I could subjectively identify was a small amplitude dip at about 50Hz, the ½-wavelength cancellation. This, I suspect, was again due to the fact that it is not illustrating the acoustic filter effect of the chamber.

However, I did think it may be more accurate in reflecting the amplitude response of the deep bass. This showed a low-frequency ripple to resonance at 25Hz, which some might view as excessive. However, the frequency is low enough not to produce problems in practice, and may again be less in real life when you include filter theory.

A frequency-response curve does not tell you everything, but the addition of stuffing to the first part of the line would reduce this. However, I suspect that the stuffing would remove the vibrancy of the deep bass. Anybody who enjoys the energy of the "thwack" of a bass drum will not want to filter this out. I would accept, however, that in a small resonant room, it might be necessary to increase damping. I would also not scale down this design for a smaller speaker, as this would place the fundamental resonance at a frequency too high for comfort.

SUPPLIERS

ATC
Gipsy Lane,
Stroud, Gloucester, England

AUDIO SYNTHESIS
PO Box 100
Ilkley, West Yorkshire, LS29 9XW, England

WILMSLOW AUDIO
Wellington Close, Parkgate Industrial Estate,
Knutsford, Cheshire, WA16 8XL, England
(Stocks all the loudspeaker drive units and electronic crossover boards)

Reader Service #24 →

World Radio History

CHOOSING THE BEST FILTER COILS

Translation by John Fourdraine

Coils play an important role in passive crossover filters, as do capacitors. It is quite wrong to think that a coil is nothing more than a roll of copper wire, for there are various kinds of coils, with different core materials, that all have their specific properties. To ease the choice for the speaker builder and at the same time provide more information on the phenomenon of self-induction, the Elektuur Lab has now done in-depth research on a number of coils.

You build a passive crossover filter with coils and capacitors, which are one another's opposites. A capacitor is simply a frequency-dependent resistor in which the resistance decreases with increasing frequency. A coil does exactly the reverse. It is also a frequency-dependent resistor, but its resistance *increases* with higher frequency. Of course, these are simplified notions, because the reality is much more complicated, but we'll get back to that later.

Before we get theoretical, let's refer to common practice. Not only do you have a large choice of capacitors, but coils also have various constructions, all with their pros and cons. This article presents information and measurement results on filter coils to help you know what to look for when applying coils in a crossover filter.

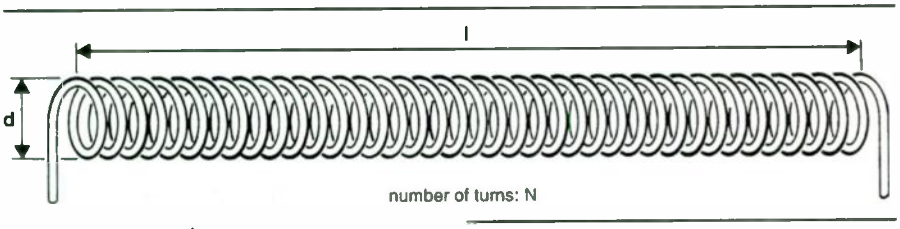
SELF-INDUCTANCE

Before getting into details, we must explain the operating principle of a coil. If you send a current through a coil having one or more turns, it generates a magnetic field that tries to cancel the cause of its own existence (the current) by producing a counter-voltage in the coil. The amount of that counter-voltage is: $u = L \times di/dt$.

The expression di/dt is the change in current per unit of time. L is a constant that depends only on the coil properties. We call this the coefficient of self-inductance. Its measurement unit is the henry (H). It follows from the above equation that a conductor has a self-inductance of 1H when a current change of 1A in one second causes a self-induced voltage of 1V. You can increase a coil's self-inductance by raising the number of turns, since this increases the number of magnetic lines the coil encloses.

The frequency-dependent behavior of a coil is shown in the equation for the impedance, with which most of you are probably familiar: $Z = 2\pi fL$. A coil in series with a loudspeaker will thus attenuate the higher frequencies, by the frequency-dependent voltage divider so created.

In electronic literature, there are many formulas for calculating the self-inductance of a coil, but generally these may not be accurate, because many factors must be considered. We illustrate with examples for a coil with one winding layer (*Fig. 1*).



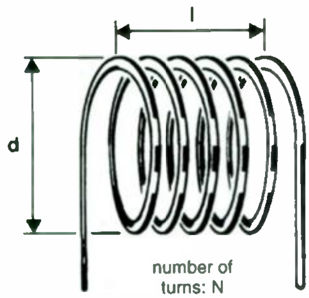


FIGURE 1: You can calculate the self-inductance of a simple single-layer coil with reasonable accuracy (number of turns: N).

Valid for a long coil: $L = (\mu N^2 A)/l$ (H)

Valid for a short coil: $L = (\mu N^2 A)/(l + 0.45d)$ (H).

Where $\mu = \mu_0 \times \mu_r$ = magnetic permeability of the core (12.57×10^{-7} for air); N = number of coil turns; $A = \frac{1}{4}\pi d^2$ (surface area of the coil in m^2); and l = total length of the coil in meters (not the length of the wire required).

We call it a long coil when the ratio of length to diameter is 10 or more. The formula for the short coil is reasonably reliable when the length is greater than the radius of the coil.

MORE COIL CONCEPTS

Try to imagine a coil's magnetic field as a large bundle of magnetic lines, and these lines as a magnetic current. We call this the magnetic flux (ϕ). Just as we have the concept of current density (current per unit area) for electrical current, we also have the magnetic-flux density (B), which is equal to the flux per unit area. In equation form: $B = \phi/A$.

In the formulas for the inductance-value calculation, you see that the core-material properties affect the inductance. So, by choosing another core material, you can raise or lower a coil's inductance without changing the number of turns. The magnetic properties of a material are noted as μ_r, the relative permeability. For paramagnetic materials, $\mu_r > 1$; for diamagnetic material, $\mu_r < 1$; and for ferromagnetic materials, $\mu_r >> 1$.

Since the magnetic field lines form a closed loop (*Fig. 2*), you can also increase the inductance by completing the core around the outside of the coil, so the magnetic path "conducts better." At higher current levels, however, the magnetic flux density may rise so high that the core becomes saturated. By not quite closing the core, leaving a narrow gap, the coil can handle a larger current. The disadvantage of this is a lower inductance than you get with a closed core of the same material.

OTHER COIL FACTORS

Just as with most other electrical parts, a real self-inductor consists not only of a coil; there are a few parasitic components attached. *Figure 2* contains the equivalent schematic of a practical inductor. We limit ourselves here to the behavior for audio frequencies

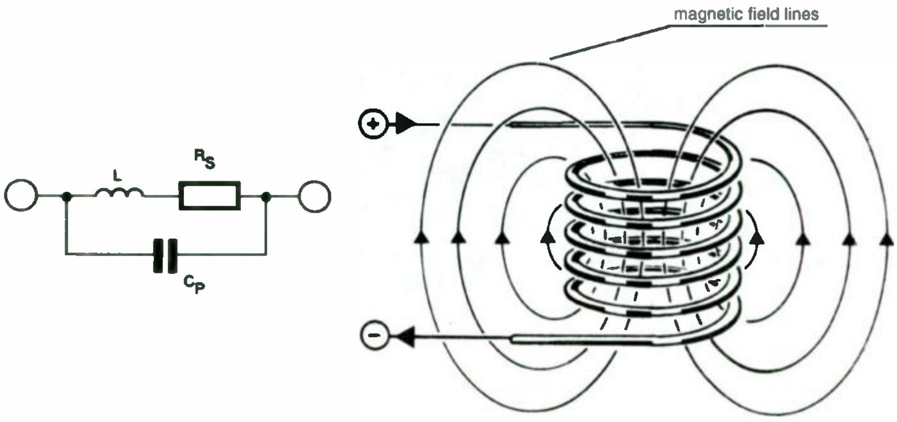


FIGURE 2: The equivalent schematic of a coil shows, aside from the inductor, a series resistor R_S, and a parallel capacitor C_P. The shape of the magnetic field is visualized to the right (magnetic field lines).

only; at high-frequency conditions it becomes more complicated. In series with the coil is, of course, a resistor representing the internal resistance of the wire used. In parallel with these two is a capacitor between the coil's wire turns. Since there are relatively few turns on an audio coil, its internal capacitance is usually very small (<50 pF). Thus, you can ignore it.

The internal resistance R_S (usually called R_i in a coil) is especially important in crossover coils. To get a good damping factor for the woofer, this resistance must be at least ten times smaller than the DC resistance of the loudspeaker. That makes it possible for the connected power amplifier to tightly control the voltage the cone movement generates in the voice-coil, and thus control the loudspeaker excursion.

Not all of a coil's characteristic properties are represented in this equivalent schematic. For an air-core coil it is fine, but for a cored coil the core's behavior should be added. A core not only raises the inductance, but it also has a couple of nuisance properties. Some finite energy is required to initially magnetize the core particles in a given direction. That's not serious with DC, but with a constantly reversing AC signal, energy must be spent continuously to "flip" the core particles. Also, the core will show saturation symptoms when the coil current rises to where all core particles are fully magnetized.

BH CURVE

Both problems are reflected in the so-called BH curve that you encounter occasionally in textbooks. In *Fig. 3*, you see two such curves, recorded from a pair of actual coils. The magnetizing force (H) is plotted horizontally, and the magnetic field strength (B) vertically. If you slowly raise the magnetizing force (increase the coil current) in an ideal coil, then the field strength will rise proportionally with the current. If you decrease the current, the field strength decreases proportionally. The BH curve is then a straight line (*Fig. 3a*).

In practice, it doesn't look as good. Initially nothing happens in a cored coil when you increase the magnetizing force. Only at a certain value of H will the field strength start to rise. If the coil current exceeds a certain strength, the field strength hardly rises because of saturation. With a decrease in coil current, the field strength decreases also, but lags behind the rising line. When the coil current reaches its zero value, the core still retains some field strength. With negative current values, exactly the same happens, but with reversed direction.

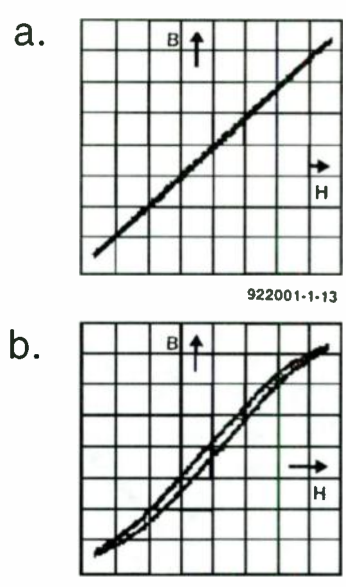


FIGURE 3: The BH-curve of the chosen core material tells a lot about the quality. a: an air coil, b: a coil core with substantial hysteresis and early saturation symptoms.

You understand that the rising and falling curves of a good cored coil must match as closely as possible, since this shows little or no hysteresis loss in the core. Hysteresis loss implies signal distortion, especially at the smaller signals through the coil. Crooked curve endpoints show core saturation, which also introduces distortion. As long as this limiting of B occurs at high power (for example at higher than 5A through the coil), you don't need to worry about it for hi-fi applications. If the limiting of B happens at 1A or 2A, watch out!

In *Fig. 3* you see two beautiful examples of this; *Fig. 3a* shows the BH curve of an air-core coil, while *Fig. 3b* shows the curve of an ordinary drum-core coil. Sadly, you will rarely see these illustrations in practice, since they relate more to the core material than to the complete coil. This does, however, give a good insight into the problems that arise with cored coils.

KINDS OF FILTER COILS

Before we start to discuss measurements, here is a rough outline of the kinds of coils applied in crossover filters (*Photo 1*). The coil with doubtless the best properties is the air coil. Its disadvantages are the high internal resistance at the higher inductance values (many turns are needed due to the low permeability of the air core) and the high price (a lot of copper is needed for a relatively low R_i). Saturation symptoms don't exist (at least, if no iron or ferrite is nearby), and distortion is also nil.

The bar-core coil is really an air coil, aided by a short core in the shape of a rod. Since the core plays a small role, the inductance and distortion increase relatively little. However, there are also long coils with an

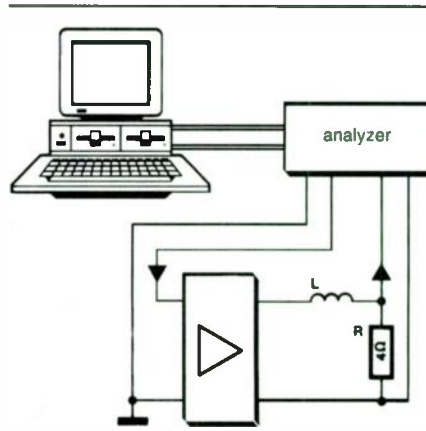


FIGURE 4: The setup used for the distortion measurements (showing analyzer and 100W amplifier).

equally long core that does appreciably influence the inductance.

Coils with a drum or "bobbin" core were often used in crossover filters until recent years. They offered reasonably large inductance and a low R_i for little money, but in the last few years their popularity decreased due to several reports that they produced significant distortion. In fact, this distortion depends on the core material used, as we shall soon see. Some excellent drum-core coils are available.

The pot-core coil has a better name in the loudspeaker world. It costs about as much as the drum-core type, but has more internal resistance for the same size. Here, too, the core material determines the qualities. The disadvantage of the pot-core coil is that its construction limits the space for the wire, so that you can use only smaller wire diameters.

A costly and bulky solution is the laminated-core coil. This type has a laminated-iron core, as in a transformer. Often it is simply the lamination stack of a transformer in which a very large air gap is created by omitting either the I-part or E-part of the stack. Especially for very large inductance values, you can obtain a low internal resistance with laminated-core coils. There is a lot of space on the bobbin to permit the winding of very thick copper wire. The distortion is generally reasonably low, and this type of coil can also handle very high power.

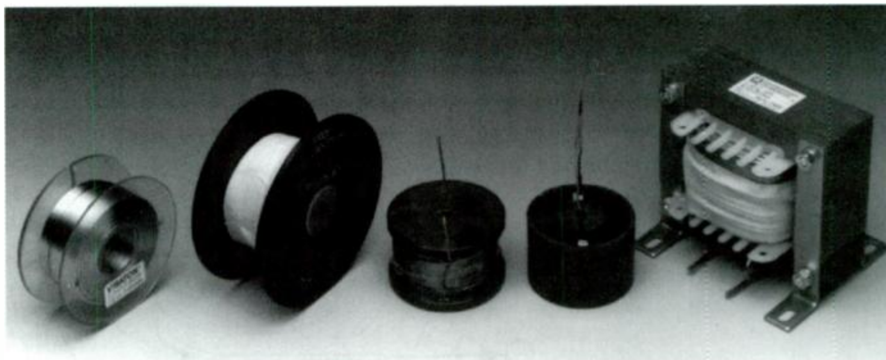


PHOTO 1: Commercial crossover coils (left to right): air-core coil, bar-core coil, drum-core (or "bobbin" core) coil, pot-core coil, and laminated-core coil.

COIL PERFORMANCE

Table 1 lists the coils gathered for testing. We had access to first-class measuring apparatus, including a Hewlett-Packard 4284A LCR-meter (*Photo 2*). We made good use of it to measure the exact inductance at various frequencies, as well as the internal resistance of all coils.

We used our own Audio Precision System 222 computer-controlled distortion meter/FFT analyzer for the distortion measurements, while a specimen of our Power Amp was ready as audio power driver. We plotted further measurements, such as the BH curves in *Fig. 3*, with a digital LeCroy oscilloscope, with the help of a custom-designed measurement setup.

INDUCTANCE & INTERNAL RESISTANCE

We started by measuring the most obvious things, inductance and internal resistance, with the HP 4284A. To research the frequency-dependent behavior of the various core materials, we measured the coils' inductance at different frequencies. In *Table 2* you see some characteristic results of these measurements for some of the coils. Since cored coils are mainly applied at lower frequencies, the inductance is given at 100Hz and 1kHz. The resistance is noted for DC.

The inductance of an air-core coil should in principle be nearly frequency independent. The reported deviation of 1.2% at 1kHz must be blamed on the measurement setup, where the cables and the connections slightly influence the measurement. If we factor this into the interpretation of the measured results, most cored coils appear very useful to at least 1kHz. Only some drum-core coils appear to decrease more at higher frequencies, but certainly not seriously.

From this table, we concluded that all coils are well suited for use in filters with corner frequencies to at least 500Hz. Above 1kHz, it would seem intelligent to apply air-core coils as much as possible, since their dimensions and internal resistance are reasonable for such frequencies.

The measurement of the coils' DC resistance shows that an air coil has unacceptably high R_i for larger inductance values. The rest of the coils don't vary much in internal resistance, but that depends mainly on the chosen inductance value; at higher inductances, all types of drum cores and laminated cores proved better than the rest. You can choose the resistance value to be larger or smaller, as you see fit, by taking a larger or smaller version of a particular type of coil (for example, use an F50 instead of an F40 drum core, or one with thicker wire).

PHOTO 2: LCR meter to measure coil performance.

DISTORTION AND LOADING

Further important properties of a coil are how much it distorts and the level of distortion-free power it can handle. *Figure 4* shows the measurement setup we made for this. All coils were connected as an L-R filter where the resistor was 4Ω (an application-oriented value). The corner frequency of this filter is about 300Hz with a coil of 2.2mH. The filter was connected to a power amp, which in turn was driven by the generator of the analyzer.

The harmonic distortion of the signal across the resistor was measured with the analyzer at different amplifier outputs (0.1, 1, 10, and 100W relative to a 4Ω load). Except for the load resistor and the connecting cables, there was no metal within 50cm to eliminate measurement errors from magnetically conductive objects.

Before we look at the measurement results, we must first explain about the choice of the measurement power used. For hi-fi applications, it is important that a coil distorts little at low power. The audiophile is playing with power that in 95% of all situations rarely exceeds a peak of 1W. Usually you listen at mW levels. One watt delivers appreciable sound in an ordinary livingroom with speakers of an average efficiency.

A coil must naturally be able to handle higher power, but

Audiophile Sweepstakes

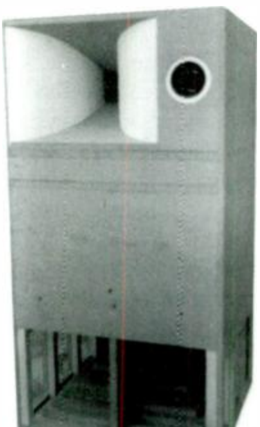
Enter and win one of these exciting prizes!

Simply complete and mail the reader service card in this issue or the coupon below and you will be automatically entered in our third and biggest yet, Audiophile Sweepstakes:

GRAND PRIZE

Our grand prize winner will receive a pair of **Electra-Print Audio 130EP Single-Ended Monoblocks** to drive his new **Edgarhorn System 80 horn system!**

Each monoblock uses a matched pair of Svetlana 911-3's and an exclusive dual tuned choke power supply to deliver 30 Watts of clean, reference-quality power. The design is reminiscent of the old McIntosh 75s.



A breakthrough in horn folding technology has allowed the utilization of a JBL 5″ monitor woofer on a 5′ long 80Hz bass horn. This high performance horn system is ideal for use with low power single ended triode amps. Unlike most other horn systems it can be used in small listening rooms.

FIRST PRIZE

The Audio Alchemy DDS Pro CD Transport

This new dual-chassis transport has the advanced new Pioneer "stable platter" CD transport system and offers both I²S & SPDIF digital output. This unit comes complete with full-function remote and detachable AC mains cord with integrated line filtering.

SECOND PRIZE

The Davidson-Whitehall Storadisc™ Library Series LS-360 CD storage unit

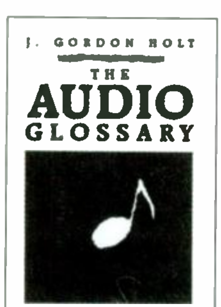
This unit, given an A+ rating in the December 1995 issue of *Audio* and chosen as *CD Review's* top choice in a 60 product comprehensive comparison, stores 360 CDs with a non-slip surface that holds even a single CD upright. This fine furniture-quality storage unit is a perfect balance of function and elegance. From Davidson-Whitehall of Atlanta.

3 THIRD PRIZES

Three of our readers will receive a $100 gift certificate from **International Audio Group** towards the purchase of the renowned **Sowter transformers**. Choose from a large selection of standard design push-pull or single-ended output, power, electrostatic loudspeaker, moving coil, or line transformers or custom design your own!

25 FOURTH PRIZES

The Audio Glossary by J. Gordon Holt



This sweepstakes is void where prohibited by law. All entries must be postmarked by December 31, 1996. Multiple entries are allowed and encouraged. Employees and relatives of employees of Audio Amateur Publications are ineligible for this sweepstakes.

Name: ____________________

Address: ____________________

City: ____________ State: ______ Zip: ______

[ ] Please enter my name in the Third Audiophile Sweepstakes
[ ] I'd like information from the advertisers in the following magazine(s):

O **Speaker Builder** Issue # O#4 O#5 O#6 O#7 O#8

O **Glass Audio** Issue # O#4 O#5 O#6

Reader: Please circle the reader service number as seen at the bottom of an advertisement in the magazine(s) about which you want information. For more, please see card in the magazine.

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
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

then the distortion can increase a bit. You must not forget in this case that the harmonic and intermodulation distortion—of woofers in particular—increases a lot at larger excursions. The upper limit of 100W in distortion measurement was set by the maximum power of the amp used. That seems to us enough for livingroom use; you seldom find more.

Distortion from a coil depends on the current through it and the voltage across it. The maximum power pushed into the coil is at the corner frequency of the L-R measurement combination, and the distortion will be highest there. The THD (total harmonic distortion plus noise) curves therefore reach their maximum around the corner frequency. The graphs (*Figs. 5–18*) show the THD from 20Hz to 2kHz.

We started by measuring the THD of the entire setup at the four power levels without a coil. The distortion from 20Hz to 2kHz at all power levels was between 0.006 and 0.009%, which is a good starting point for accurate measurement.

In all graphs, the 100W distortion is seen as a solid line. The 10W curve is a dashed line, and the 1W curve a dotted line. Finally, the 0.1W curve is dotted still finer.

MEASUREMENT RESULTS

The graphs show how much or how little distortion a particular type of coil produces. The air coil gives nearly ideal results (*Fig. 5*). At the lowest power, the curves rise a bit at the higher frequencies, but that is not due to the coil. It is caused by the reduced voltage across the resistor at frequencies above the crossover point, where more noise is included in the measurement result.

All cheap drum-core coils apparently produce more distortion, at low as well as high power (note the changed vertical scale). Saturation symptoms from the core cause several percent distortion in the 100W curve. In 40mm drum cores this saturation naturally starts somewhat earlier than in 50mm samples. Compare the ETM FR40 (*Fig. 6*) with the IT FR50 (*Fig. 9*).

Pot cores give much better results. The distortion varies between 0.01 and 0.04% at lower power. At 100W this climbs a bit, but remains quite acceptable. This type of coil clearly can handle more power than a drum core of the same size. The different makes of pot-core coils give nearly identical results, which points to the use of practically the same core material.

NEW CORE MATERIALS

So much for the "ordinary" core materials. Obviously, the coil manufacturers know the properties of their coils, too, and have therefore searched for other core materials that give less distortion and yet can also handle core power. The German firm InterTechnik (IT) entered the hobby market first with a heavy core material, Corobar. Corobar coils can handle enormous power, but until now we had no data on the distortion at low power, which is not so great (*Fig. 11*). An "ordinary" pot-core appears to produce tens of watts less THD at power levels. Corobar probably has hysteresis problems. For quality speakers, this material seems not to be the first choice, but it is very well suited for PA work.

A relatively new material is InterTechnik's Ferrobar, which is applied in the form of drum cores. This type of coil appears to possess superior properties, at

TABLE 1

COILS TESTED

TYPE	VALUE	OUTSIDE DIAMETER	WIRE DIAMETER
Air-core coil	2.2mH	70mm	1mm
ETM drum-core FR40	2.2mH	40mm	1mm
ETM drum-core FR40HQ	2.2mH	40mm	1mm
ETM drum-core FR56HQ	2.2mH	56mm	1.4mm
IT drum-core FR50	2.2mH	50mm	1.4mm
IT pot-core GK2	2.2mH	50mm	1mm
IT Corobar K7A	2.2mH	92mm	1.4mm
IT Ferrobar DR56	2.2mH	56mm	1.4mm
IT drum-core HQ40	2.2mH	40mm	1mm
IT laminated core E96	2.2mH	94mm	2mm
Remo pot-core GK1	3mH	35mm	0.7mm
Remo pot-core GK2	3mH	50mm	1mm
Visaton drum-core FC	4mH	40mm	0.9mm
Visaton drum-core LR	3mH	56mm	1.32mm

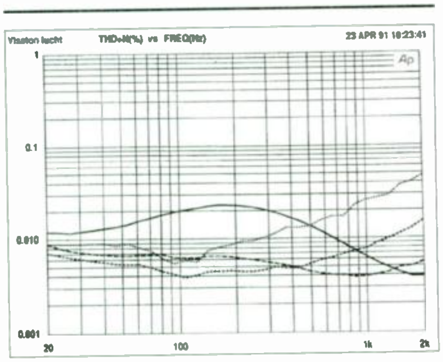


FIGURE 5: Air-core coil. The distortion curves of the coils in Table 1 are shown in *Figs. 5–18*, at respective levels of 0.1, 1, 10, and 100W.

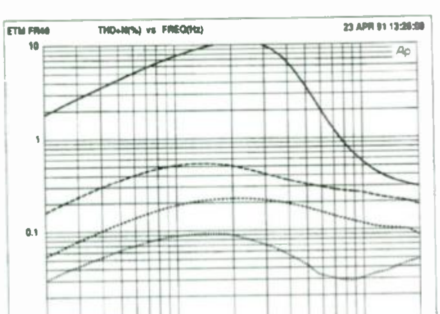


FIGURE 6: ETM drum-core FR40.

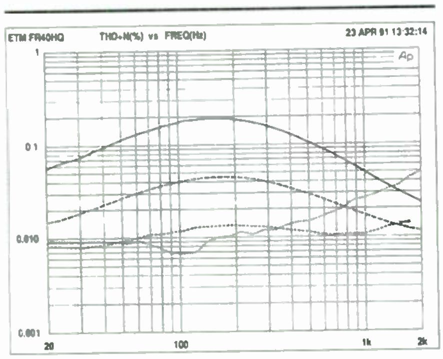


FIGURE 7: ETM drum-core FR40HQ.

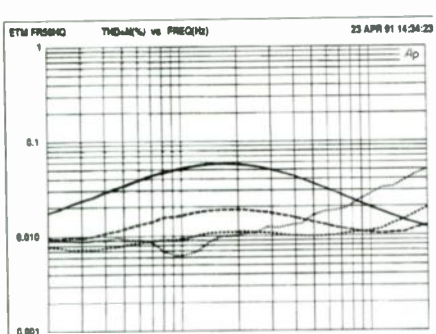


FIGURE 8: ETM drum-core FR56HQ.

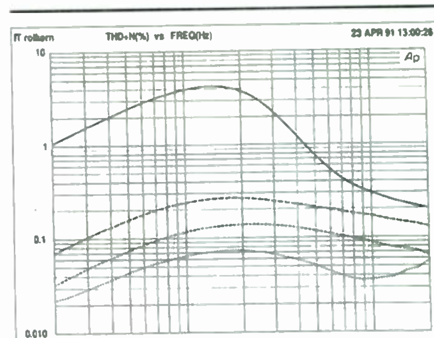


FIGURE 9: IT drum-core FR50.

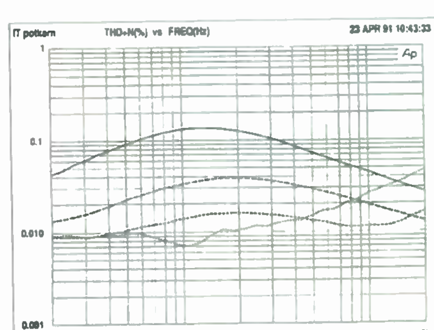
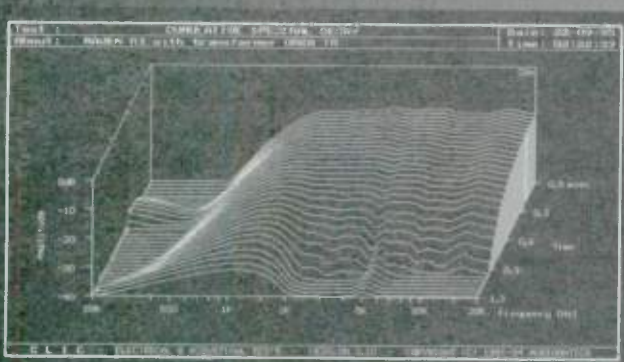


FIGURE 10: IT pot-core GK2.

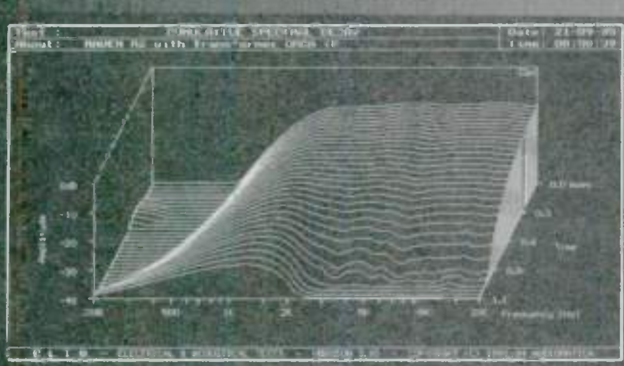
RAVEN

HIGH EFFICIENCY PURE RIBBON TWEETERS

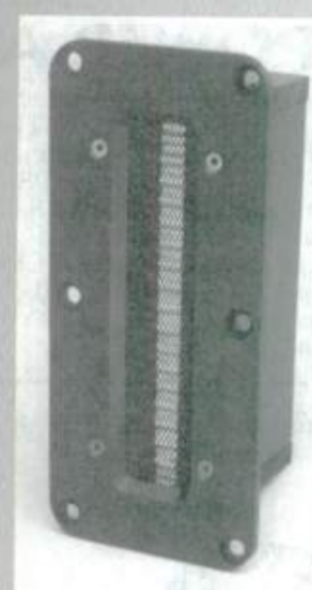
ORCA is sincerely proud of introducing these exceptional high frequency transducers from France. The RAVEN tweeter is a true ribbon tweeter, possibly the purest transducer available today. In a dome tweeter the signal is carried through the voice coil wire, and the sound is radiated by the dome attached to the voice coil. Here, the carrier of the electrical signal and the radiating diaphragm are one and the same part: the ribbon itself. Furthermore, the RAVEN ribbon is 100% pure conductive material, no metalized film. To have an idea of the high frequency performance of the RAVENs, imagine that the moving mass here is about 30 times less than a high quality dome tweeter. The music comes through effortless, almost immaterial. The special and massive NeFeB magnet of the RAVENs is five times more powerful than a conventional magnet. The result: the RAVEN R1 is capable of 118 dB peak with no measurable distortion (R2: 120 dB). At 10WRMS, that is continuous power now, R1 reaches 105 dB with less than 1% distortion, and R2, 107 dB. The RAVENs come with a specially designed matching transformer (very low distortion, low loss and wide bandwidth) for optimum coupling with your power amplifier. Now look carefully at the decay of these units !



RAVEN R1
KGS 1.14
LBS 2.5
92 x 80 mm
3.63 x 3.15 in.
Moving mass:
0.0061 g
0.0002 oz.
dB/W/m 95
2 KHz to 40 KHz



RAVEN R2
KGS 2.22
LBS 4.9
166 x 76 mm
6.54 x 2.99 in.
Moving mass:
0.013 g
0.0005 oz.
dB/W/m 98
2 KHz to 40 KHz



RAVEN TRANSDUCERS are distributed worldwide exclusively by ORCA Design & Manufacuring Corp.
1531 Lookout Drive, Agoura, CA 91301 - USA
TEL (818) 707 1629 FAX (818) 991 3072
E-Mail: orcades @ aol.com
OEMs, stocking distributors and importers inquiries welcome. Goods now in stock in America.

Reader Service #32

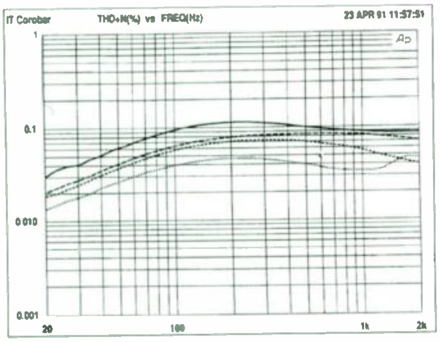


FIGURE 11: IT Corobar K7A.

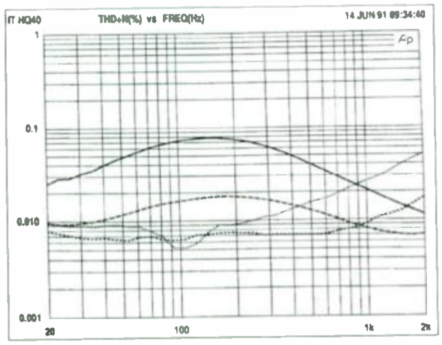


FIGURE 13: IT drum-core HQ40.

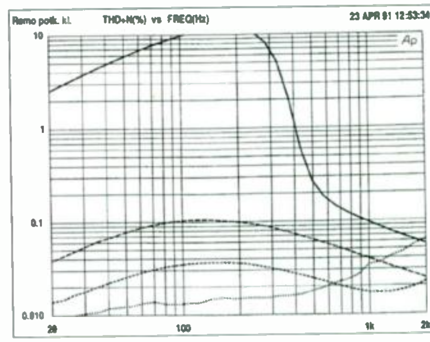


FIGURE 15: Remo pot-core GK1.

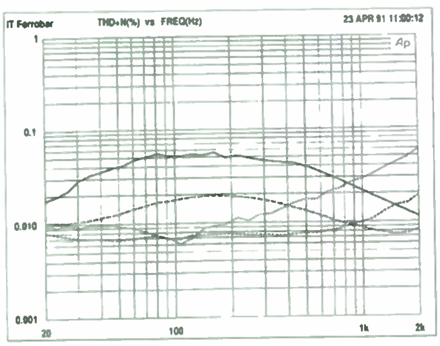


FIGURE 12: IT Ferrobar DR56.

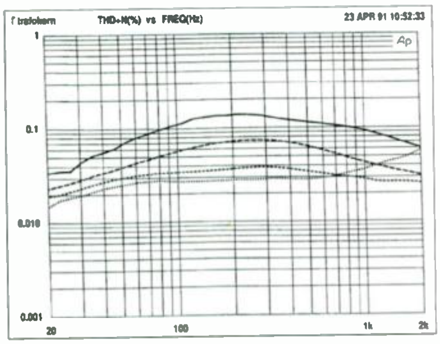


FIGURE 14: IT laminated core E96.

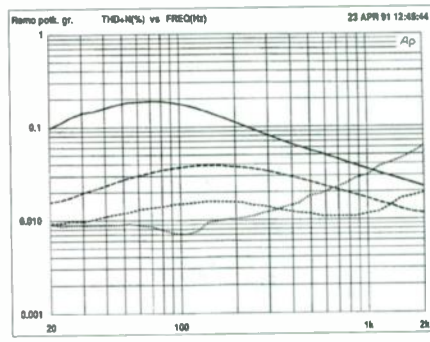


FIGURE 16: Remo pot-core GK2.

low as well as high power (*Fig. 12*). The curves run just above those of an air coil. Unfortunately, these coils cost three times as much as ordinary drum cores.

From ETM, also a German coilmaker, we received several samples of their new HQ coils (*Figs. 7* and *8*), which appear to possess practically the same properties as the Ferrobar coils from IT. The core materials

seas

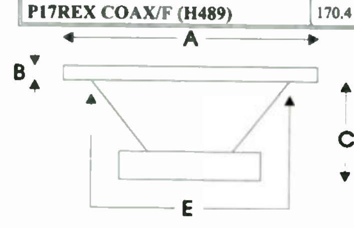
Audiophile Price List April 1996

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

Model	Size Description	Ω	Fs Hz	Qts	Vas Liters	X-max mm Peak	Power Watts	Sens. 1W/1M db	Cost Per Unit
Tweeters - *We have replacement voice coils for most Seas tweeters.*									
25TAFN/QG (H623)*	25mm alum. dome tweeter, neodymium magnet, grill	6	1800	*Audax wedge mounts fit this tweeter. Shielded.			100	89	$23.35
19TFF (H586)	19mm textile dome tweeter	8	1700				80	87	$16.95
25TFFC (H519)	25mm textile dome tweeter w/chamber	6	1200				80	90	$21.30
25TA/D (H533)	25mm Alum. dome tweeter w/Diffuser	6	1000				60	91	$19.50
25TAF/G (H398)	25mm aluminum dome tweeter with grill	6	1400				100	90	$19.95
25TAC/G (H400)	25mm alum. dome tweeter with chamber & grill	6	660				55	91	$23.50
T25 001 *Excel* (E006)	25mm Sonotex fabric dome tweeter with chamber	6	750				90	90	$62.50
Midranges									
MCA11RC (H143)	4.5" treated paper cone midrange	8	140	.72	1.3	.9	110	89	$34.90
MP12VC (H453)	5" poly cone, PVC surround, glass fibre plastic frame	8	90	.44	2.9	.9	90	89.5	$31.00
MP14RCY (H422)	5" poly cone midrange	8	42	.20	17.2	3	110	90	$37.65
MP14RCY/P (H522)	5" poly cone with phase plug	8	43	.18	16.6	3	120	90	$37.50
K2852 and K2851	Chamber for 11cm drivers: **$2.00**	Chamber for 14cm drivers: **$3.00**							
Woofers - *All woofers feature injection moulded magnesium frames and rubber surrounds.*									
CA11RCY (H149)	4.5" treated paper cone woofer	8	58	.24	5.4	3	60	86	$38.30
P11RC (H454)	4.5" poly cone woofer	8	55	.34	5.3	3	60	84.5	$31.95
P11 RCY (H455)	4.5" poly cone woofer, large magnet	8	55	.23	5.3	3	60	86	$36.30
P14RC (H395)	5" poly cone woofer	8	40	.28	18.9	3	60	89	$32.50
L14RC/P (H761)	5" Aluminum cone woofer, phase plug	8	39	.31	14	4	80	85.5	$45.90
W14CY 001 *Excel* (E008)	5" Magnesium cone woofer with copper phase plug	8	43	.36	10.6	4	70	87	$129.00
P17REX (H416)	6.5" poly cone woofer with large voice coil	8	34	.24	30.5	3	80	89	$45.15
P17RE (H419)	6.5" poly cone woofer	8	34	.33	30.5	3	80	87.5	$41.50
P17RC (H353)	6.5" poly cone woofer for sealed enclosures.	8	35	.32	40.8	3	60	89	$34.30
L17RCY/P (H763)	6.5" aluminum cone woofer with phase plug	8	32	.27	36	4	80	87.5	$56.50
W17E 002 *Excel* (E009)	6.5" magnesium cone woofer with copper phase plug	8	34	.32	29.5	4	100	87	$146.00
CA21REX (H333)	8" Paper cone woofer (used in Seas NJORD kit)	8	31	.34	81.3	3	80	93	$51.25
P21REX (H282)	8" poly cone woofer with 1.5" VC	8	33	.37	68.9	3	80	91	$52.30
P21RF/P (H511)	As above with phase plug and 2" diameter voice coil	8	34	.34	48.3	4	125	88	$56.15
P21RE4X/DC (H442)	Dual VC 8" woofer with poly cone	8/8	31	.30	66.4	3	90	90	$58.35
P25REX (H283)	10" poly cone woofer	8	27	.44	156.8	3	80	93	$57.75
25F-EW (H085)	10" paper cone **Repl. for Dynaco A25 Speaker**	8	26	.35	175	4	70	89	$47.70
CA25RE4X/DC (H372)	10" treated paper cone woofer	8/8	25	.31	187.9	4	90	91	$61.75
Coincidental Coaxial Driver - *The tweeter is mounted at the base of the woofer cone.*									
P17REX COAX/F (H489)	6.5" coaxial P17REX/25TFFN/G in a coincidental configuration.	T6 W8	T1.8K W35	W .25	W 26.9	W 3	T90 W100	T89 W89	$74.00

Unit	A mm	B mm	C mm	D mm	E mm
25TAFN/QG (H623)	60	2.1	18	45.9	45.9
19TFF (H586)	93.8	3.1	18.4	66.5	66.5
25TFFC (H519) / 25TAC/G (H400)	103.8	3.6	37.9	74.8	74.8
25TAF/G (H398) / 25TA/D (H533)	103.8	3.6	24.4	74.8	74.8
T25 001 *Excel*	110.4	6.3	52.7	75	75
MCA11RC (H143)	109.4	4.4	49.1	72	95.8
MP12VC (H453)	120.5	4.5	51.5	72	95.3
MP14RCY & /P (H422), (H522)	133.2	3.7	65.3	93	112.8
W14CY 001 *Excel*	133.2	3.7	65.3	93	112.8
CA11RCY (H149)/P11RCY (H454)	109.4	4.4	55.1	93	95.8
P11RC (H454)	109.4	4.4	49.1	72	95.8
P14RC (H395) / L14RC/P H761)	133.2	3.7	62.3	72	112.8
L17RCY/P (H763) / P17RE (H419)	170.4	3.8	67.7	93	145.3
P17REX (H416)	170.4	3.8	67.7	110	145.3
P17RC (H353)	170.4	3.8	64.7	72	145.3

Unit	A mm	B mm	C mm	D mm	E mm
W17E 002 *Excel*	170.4	3.8	67.7	110	145.3
P21REX (H282)/ CA21REX (H333)	215.4	4.7	75.3	110	186.8
P21RF/P (H511)	215.4	4.7	75.3	110	186.8
P21RE4X/DC (H442)	215.4	4.7	75.3	110	186.8
P25REX (H283)	261.2	4.2	82.8	110	229
CA25RE4X/DC (H372)	261.2	4.2	82.8	110	229
P17REX COAX/F (H489)	170.4	3.8	67.7	110	145.3



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

TABLE 2

INDUCTANCE AND INTERNAL RESISTANCE

TYPE OF COIL (2.2 mH, UNLESS NOTED)	SELF-INDUCTANCE IN mH AT 100Hz	AT 1kHz	CHANGE, 100Hz TO 1kHz IN %	DC RESISTANCE (Ω)
Air coil	2.273	2.246	−1.2	0.81
ETM drum-core FR40	2.229	2.18	−2.0	0.25
ETM drum-core FR40HQ	2.201	2.149	−2.4	0.29
IT drum-core F50	2.208	2.127	−3.7	0.16
IT pot-core GK2	2.204	2.170	−1.5	0.26
IT Corobar K7A	2.267	2.255	−0.5	0.30
IT Ferrobar DR56	2.261	2.165	−4.2	0.18
IT laminated core E96	2.325	2.279	−1.9	0.11
Remo pot-core GK1 (3mH)	3.041	3.038	−0.1	0.39
Remo pot-core GK2 (3mH)	2.951	2.946	−0.2	0.26
Visaton drum-core FC (4mH)	4.033	3.920	−2.8	0.45
Visaton drum-core LR (3mH)	2.957	2.840	−4.0	0.23

used appear very much like one another, although the curves show that they are not quite identical. The price is clearly lower than that of the Ferrobar coil.

One of the newest materials comes from the IT factory, namely HQ drum cores (*Fig. 13*). This is an entirely different material than Ferrobar, and lots cheaper. It appears from our distortion curves that these coils are at least as good as their Ferrobar colleagues. (The distortion is a bit higher at 100W, but note that the HQ coil is a 40mm type, and the Ferrobar coil is a 56mm type.)

CHEAPER SURPRISE

A surprise in the test was the LR coil from Visaton (*Fig. 18*). This appears to have properties strongly comparable to the Ferrobar coils. Visaton devotes only one line of text to it in the catalog, but this is really a very good coil! It appears to be a bit cheaper than the Ferrobar.

There is also the laminated iron-core coil from IT (*Fig. 14*), the distortion of which is a bit worse than a pot core. Thus, it does not score as high in the available range. This kind of coil is rather more interesting if you need large inductance values with a low internal resistance (for example: an E130 iron core with 10mH has an R_i of 0.17Ω, while a Ferrobar or drum-core coil is between 0.6 and 0.7Ω).

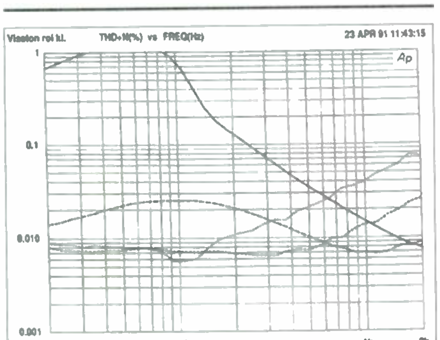


FIGURE 17: Visaton drum-core FC.

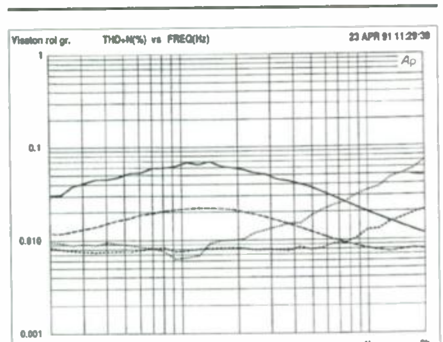


FIGURE 18: Visaton drum-core LR.

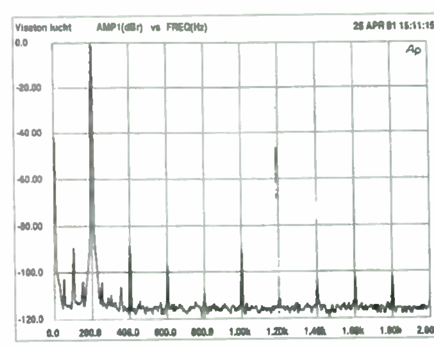


FIGURE 19: Spectral components of air-coil distortion. (Other coils' distortions are reproduced in *Figs. 20–24*.)

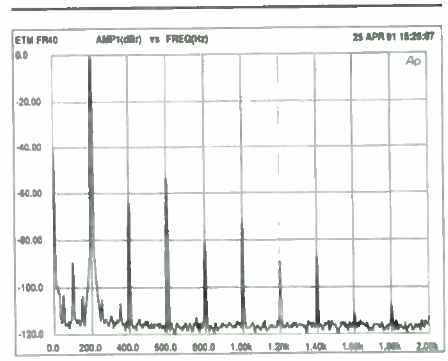


FIGURE 20: ETM drum-core FR40.

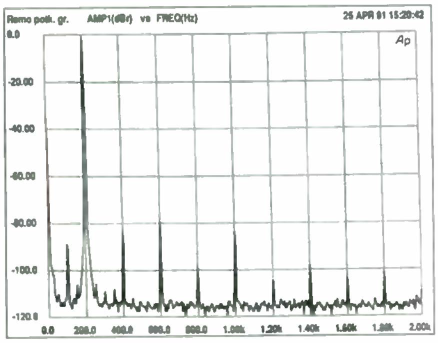


FIGURE 21: Remo pot-core GK2.

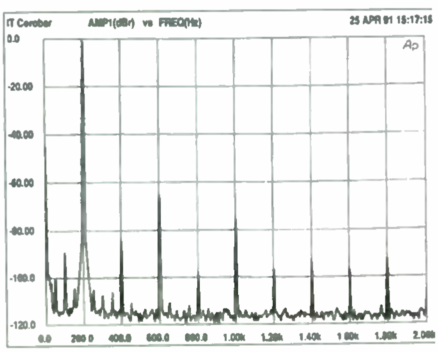


FIGURE 22: IT Corobar K7A.

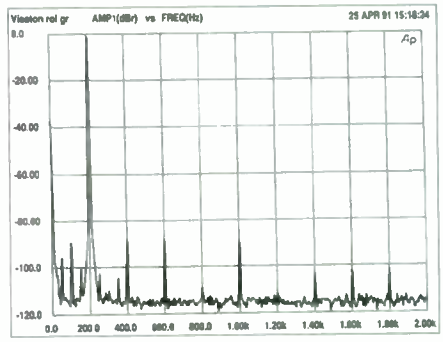


FIGURE 23: Visaton drum-core LR.

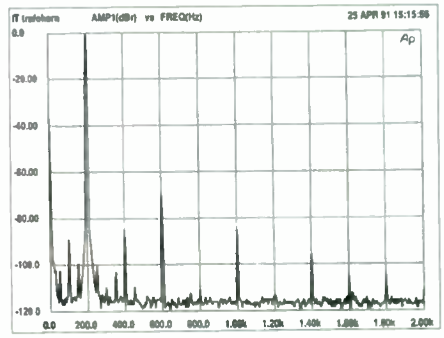


FIGURE 24: IT laminated core E96.

Finally, we have the spectral details of the distortion products, measured with the FFT analyzer, at 200Hz and 1W. *Figure 19* shows what the air coil produces. *Figures 20–24* give a few characteristic measurements for each kind of coil. Those with a conventional core material (drum core and pot core) appear to split their distortion similarly between even and odd harmonics, which is audibly advantageous (we tend to notice odd harmonics more readily than even). The Corobar coil (*Fig. 22*) gives mainly odd harmonics, which is not to its advantage. In all the exotic drum-core materials (*Fig. 23*), a smooth spectrum was measured, which also was very low. The laminated core (*Fig. 24*) also generates mainly odd harmonics, which must be blamed on the material used in the laminations.

CONCLUSIONS

After studying all these measurements, we drew the following conclusions:

As we noted earlier in this article, the best coil is one without a core: an air-cored coil. But that is not always possible, especially with larger inductance values. If you wish to apply a relatively cheap cored coil, a smart choice is the pot-core coils. The brand does not matter, because nearly all of them use the same kind of core material, judging by the measurement results. If you really want something better without spending too much, the best choice is the new HQ coil from IT, which has minimal distortion at low as well as high power.

As good in quality are the Ferrobar coils from IT, the HQ coils from ETM, and the LR coils from Visaton, but these all cost much more. The laminated-core coils are appropriate for very large inductances with low internal resistance. They have more distortion than the better cored coils, but their low R_i is unsurpassed. Besides that, they also can handle high power.

The Corobar coils are different. They don't have such a low R_i, due to their small core, and on top of that they produce comparatively more distortion at low power. They don't seem suitable for quality speakers, but they have one advantage in that they can handle enormous power with little distortion. So if you like to work with high power (or make very low-efficiency speakers), then Corobar coils may be for you.

Finally, there are the ordinary drum-core coils, which distort more than any other coils tested, although the distortion has a fairly benign character. Here too, there seems to be little difference in quality between the brands. You can use these for cheap speakers, but they are not suitable for superior filters. They have, however, one big advantage over pot-core coils for true enthusiasts: you can easily wind wire onto or off of them, if during experimentation you want to change the values a bit.

We hope that this article has given you a somewhat better insight into the qualities of the different kinds of coils.

TUBULAR SPEAKERS

By Richard G. Carlson

Many years ago, while visiting the office of one of my college professors, I noticed an unusual-looking loudspeaker that used a small cone driver loaded into a tube or cylinder. The bass response of this speaker was very impressive, and I resolved to build such a speaker some day. Some 30 years later, I finally took up the task.

ATTENTION-GETTERS

Why a tube speaker? They are not pretty, but they are great for the patio and the garage, and they attract attention. I have a pair hanging in the corners of my office, and rarely does a day go by without someone commenting on them.

TUBE ADVANTAGES

Although a cylinder is one of the worst shapes in which to model a loudspeaker[1], there are some definite advantages. For example, tube speakers are easy to locate (they "hang" just about anywhere); there is no grille to contend with or fabricate; finishing is not much of a factor (unless you demand color coordination); you do not have to be a "master craftsman" to build them; and, according to Martin Colloms[2], cylindrical cabinets have the particular advantage of a very high radial stiffness—that is, panel coloration is considerably lower than a rectangular enclosure of similar wall thickness.

The actual design and methods of construction came to me one day as an inspiration, so I decided to build them and document the details. Materials you need for this project are almost like things you would find rummaging through the trash. Actually, most of the lumber I used was scrap. You will need 4″ ABS or black drain pipe for the tubes (I recommend new material—do not use pipe culled from someone's old plumbing system), ¾″ particleboard or MDF scraps, ½″ plywood scraps (not mandatory), two L-brackets, two 4.5″ midbass drivers, two 10mm dome tweeters, two capacitors (for crossovers), and some speaker wire.

If you buy everything new, it will cost about $70. It took me about three hours to build both speakers, and a novice can easily build them in an afternoon. Each speaker has a (theoretical) frequency response of 55–20kHz and an impedance of 8Ω, and handles 50W of power.

Choosing a low-frequency driver was not a difficult task, as I already had two 4.5″ Madisound drivers on hand. I modeled them using BassBox. My goal was to obtain an f_3 of 55Hz. Actually, I ended up with two tubes of slightly different lengths (don't ask me why) and modeled an f_3 of 52Hz for one tube and 54Hz for the other. The operational objective was to have a reasonably flat response from 55–20kHz. *Figures 1* and *2* include the BassBox output reports for the driver and for each of the enclosures.

FACE-DOWN WOOFER

Since I planned to mount the woofer face downward on each tube, I thought the midrange output might be a little subdued for useful applications. Then, looking at the output graph (L.E.A.P.) that Madisound includes with all driver specifications, I saw that the woofer's output would easily repro-

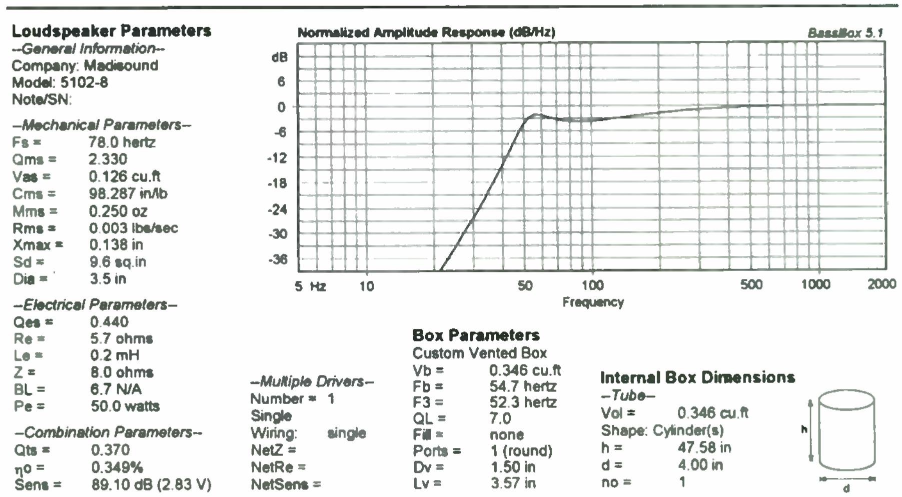


FIGURE 1: Tubular loudspeaker parameters (longer tube).

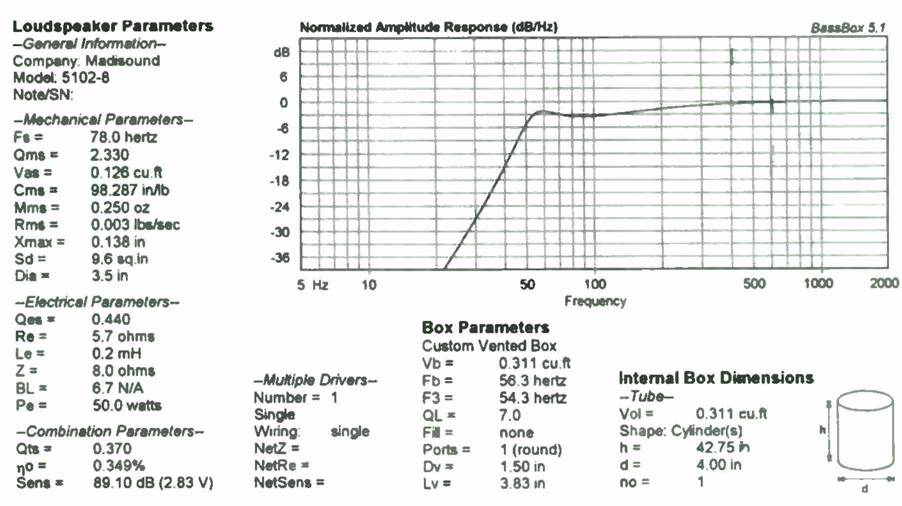


FIGURE 2: Parameters for the shorter tube.

duce frequencies up to 3kHz and, with some dips and peaks, audibly to 5.5kHz. This, then, was really a better midrange driver than a woofer!

Albeit, with the driver facing downward, it was bound to lose some of the midrange clarity. I proceeded in spite of this, because I needed to complete this project to satisfy a curiosity that had haunted me for more than 30 years. (Refer to *Figures 1* and *2* for the specifications and predicted response graphs for each of the loudspeakers.)

ENCLOSURE BUILDING

Next came the construction of the enclosures. My power miter saw has a 10″ blade that makes very clean cuts in the ABS tubing. If you're using a similar saw, mark the spot where you want to make the cut, hold the ABS stock firmly against the rear fence, and push the saw arm so the blade cuts through the ABS as far as possible. It will be about ½″ short of cutting through the entire piece. Let the blade come to a complete stop, and, leaving the blade in the groove, rotate the tube until the uncut portion is at the very top. This allows part of the blade to remain in the groove for proper alignment. Now cut through the remaining section. The end result should be a clean cut without any secondary cuts or unevenness.

The next step is to make the speaker-mounting and vent baffles. Although this enclosure is a tube, it requires baffles just as a rectangular-shaped box. The rear baffle on a conventional box is normally a solid piece, with the exception of a hole for an input cup. However, a tube needs a baffle at one end for the speaker and a baffle for the vent or port at the other (assuming a bass-reflex configuration). I chose to make square baffles to simplify wall mounting (*Photo 1*).

Use two 24″-long pieces of ¾″ MDF or particleboard, glued and nailed together. in which to cut the four holes for the speakers and vents. Here's the tricky part. When making the holes for the speakers, use a circle cutter on a drill press. Cut half-way through the stock with a 4¼″-diameter setting for the speaker openings. Turn the stock over, readjust the hole cutter for the outside dimension of the ABS tube, which is exactly 4½″, and complete the holes. (It's helpful to experiment on some scrap until you get it right.) You'll end up with two holes, 4½″ in diameter on one side to fit the tubes snugly, and 4¼″ on the other side to fit the speakers. After you've made the holes, trim to 6″-square pieces.

VENT BAFFLES

The vent baffle is a different scenario. The 1½″ vent requires a 2″ hole (if you use 1½″ ABS). (If you use PVC for the vent, the mount-in hole will be less than 2″.) Experiment with this cut to ensure that the vent piece fits snugly. Before making the vent cut, make the 4½″ cut into which the 4″ ABS tube will fit. Using the circle cutter, make a ¾″-deep cut, clean out the circular groove and verify that it fits snugly on the tube, then cut the hole for the vent. This hole must pass through the entire 1½″ piece, which means you must cut it from one side, then turn the stock over to complete the hole, for the cutter is limited in the depth to which it can penetrate. When completed, each piece will have a ¾″-deep circular groove on one side for the tube, and a hole 2″ in diameter for the vent.

Cut the 1½″ vents to their required lengths and insert them into the vent holes. Each vent should be mounted flush with the outside portion of the vent baffle. Apply glue

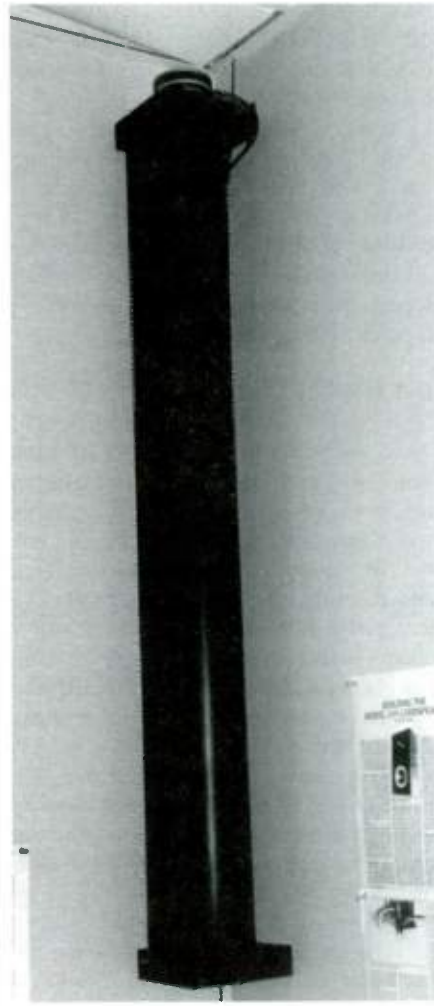


PHOTO 1: The tubular speaker, mounted to the wall.

generously around the base of the vent where it meets the baffle. Wait until the glue sets before proceeding. Then apply glue in the two circular "grooved" pieces and mount them on the tube by tapping them with a mallet. They should mount easily, snugly, and evenly. Don't worry about any excess glue inside; it helps to keep things tight and reduces the possibility of air leaks in the enclosure.

Apply a little glue to the inside portion of the 4″ hole and slip it over the other end of the tube until it is fully seated (or until it meets the 4½″ portion). When you've seated this piece on the tube, place the tube on a flat surface and rotate this piece until the flat surfaces on the sides of the baffles at each end are parallel. You must do this *before* the glue sets; otherwise, the tubes will not rest evenly against a wall when you install them.

Cut the ½″ plywood to fit very snugly between the top and bottom pieces. Cut a hole large enough for the tweeter to mount from the front (location not critical). Screw the tweeter in place. Then glue the plywood piece in place. If you do not wish to mount the tweeter this way, place a dab of silicon glue on the rear of the tweeter and press it onto the tube at the location you prefer.

To complete construction, mount the woofer (face down), install the wire to the speakers, wire the capacitor in series with the tweeter, and mount the tubes in place. I used L-brackets mounted on the rear of the tubes (opposite the tweeters) to suspend them from the ceiling. (You could hang them with eye bolts instead, which might actually work better.) I placed the speaker tubes in corners to boost the bass response.

FULL-RANGE SYSTEMS

The tubes are full-range loudspeaker systems that are simple to construct, kind to the budget, and very effective as a functional audio component, as well as a novelty conversational item. I am using low-end tuner/amplifier components to drive the tubes. The overall sound is pleasant and open—high and middle frequencies blend well without a trace of heaviness in either range. This is surprising, considering the configuration of the woofer and its expected midrange output. Bass response is full-bodied, although at first it was somewhat subdued. Boosting the bass control on the amp helped, although placing the tubes in the corners of the room improved low frequency even more.

I have satisfied my desire to build the tubes and, in view of the short time it took to make them, I must give them a high rating. Their LF output will not peel the paint from your walls, so you will probably not receive many complaints from your neighbors. However, you should be completely satisfied with their performance in your ship, garage, patio, office, or wherever you choose to locate them. You are certain to receive a considerable number of comments, and you may even lure another soul into the wonderful world of speaker building.

AUTHOR'S POSTSCRIPT

Since the initial writing of this article, a close associate of mine has acquired the tube speakers. He located them in the corners of his daughter's room, with the backs of the woofers nearest the walls (magnet side) parallel to the floor. The tubes are not very noticeable now when you're entering the room, especially since he painted them to match the wall color. (If not painted, the tubes look like barrels of large guns or cannons.) Bass output seemed tighter and deeper, and midrange output from the corner placement was reinforced, perhaps from the reflective (horn-like) properties of the corners. The tweeters were mounted on the wall two feet from each tube and two feet (down) from the ceiling facing the opposite end of the room. In this configuration, imaging is reinforced.

REFERENCES

[1] Olson, H.F., "Direct Radiator Loudspeaker Enclosures," JAES, 17, No. 1, pp. 22–29.

[2] Colloms, M., *High Performance Loudspeakers*—Third Edition, Pentech Press, pp. 222–223.

Part 2

A PUSH/PULL PLANAR SPEAKER QUEST

By Daniel Patten

I hope some of you have built the 40″ wire planar speaker (WPS40) or at least that it has aroused some interest (Part 1 of this article, *SB* 8/95). I am now building my fourth set and have made a few improvements as well as a few measurements. This project has gone well, or at least my ears think so. A few of my audio friends even agree, a result that is tough to come by.

This article was interesting for me to prepare, because I had the opportunity to compare several speakers in a controlled environment. I find it amazing how well a speaker can sound even though the measured characteristics seem to be quite poor. In general, however, speakers with better measured performance usually also sound better.

In Part 1 of this article, I detailed the construction of the WPS40. The main objective of Part 2 is to present measurements and technical data.

IMPROVEMENTS

I made all measurements on my second set of speakers without any frame (as shown in Part 1). The second set is identical in construction to the Part 1 set except for one minor addition. Although I was generally pleased with the sound after listening for about a month, certain frequencies tended at times to be a little harsh. This typically happened at very percussive moments in the music.

I experimented with damping the diaphragm around the edges with silicon, weather tape, and cotton. This generally helped control the problem, but it unfortunately diminished the overall brightness of the speaker. My solution was to install ¾″-wide, ¼″-thick open-cell insulation tape on each side of the magnets on the front and back plates. This seemed to make a big difference (*Fig. 1*).

I believe the foam increases the performance because it lets the diaphragm move in a more controlled fashion across its whole surface. Where the diaphragm is exposed to the slots in the plate, the pressure wave can exit easily; where it is exposed to the closed portion of the plate, the pressure wave is reflected back. The open-cell foam helps absorb the pressure wave and minimize its reflection. A better design for the metal work might be to cut out slots where I placed the foam. I don't believe this would be detrimental to the rigidity of the structure.

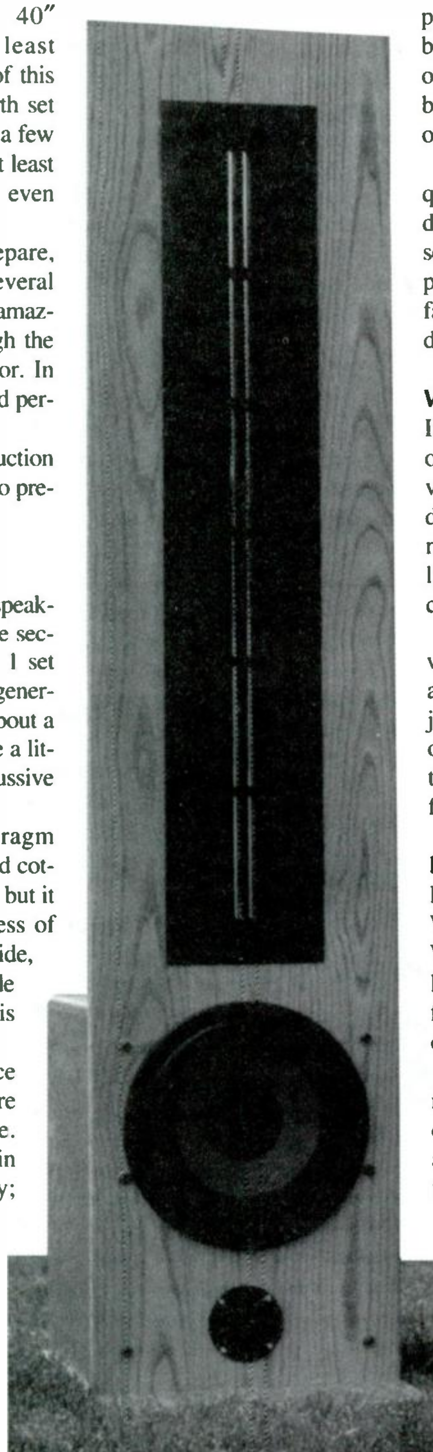


PHOTO 1: Completed WPS40 speaker.

Probably the greatest improvement in the sound quality came through having a helper hold the diaphragm tight while I bolted down the second set of spacers. Actually, I had help from two people for this process; the construction went much faster, and there were far fewer wrinkles in the diaphragm to eliminate with the heat gun.

WHAT NOT TO TRY

In Part 1, I promised to make the 7/16″ spacers out of aluminum. I did, but it does not work very well. I was unable to clamp the Mylar® diaphragm firmly, because the nonporous aluminum does not allow the cement to set properly, and the aluminum tended to bow when clamped.

The best solution, which is also cheaper, is wood. You must, however, use a hardwood, such as oak. Softwoods are inadequate, since the nuts just keep on sinking in, preventing a good clamp on the diaphragm. Oak spacers are rigid enough that the fully assembled WPS40 does not bend or flex at all.

HOW DO THEY SOUND?

I mentioned in Part 1 that I preferred the WPS40s to my old reference Acoustat 2200s. Well, I still do. The sound is excellent. All of my listening to the WPS40s has been in an open frame. They seem to work best at least a couple of feet from the rear wall.

Both passive and active crossovers yield good results. They perform well with a simple 60µF capacitor in series (6dB slope), producing approximately a 400Hz crossover point. I used the same frequency for my active crossover (24dB slope).

The WPS40 is a very easy load to drive. I have encountered no problems with Hafler DH500, SE120, Audio Research D100A, and a home-brew LM12. In fact, the LM12, configured for 45W, had no problem driving the speaker to very loud levels.

In my stereo system, I primarily listen to two types of speakers: electrostatic and dynamic. The Acoustat 2200 has been my mainstay for several years. It does a fine job

ABOUT THE AUTHOR

Dan Patten currently works at DAS Inc., an electrical-engineering firm that specializes in very high speed data acquisition and network-server fault-tolerance hardware. In his spare time, he likes to design high-end audio electronics and speakers. He can be reached via E-mail at dpatten@dasengr.com.

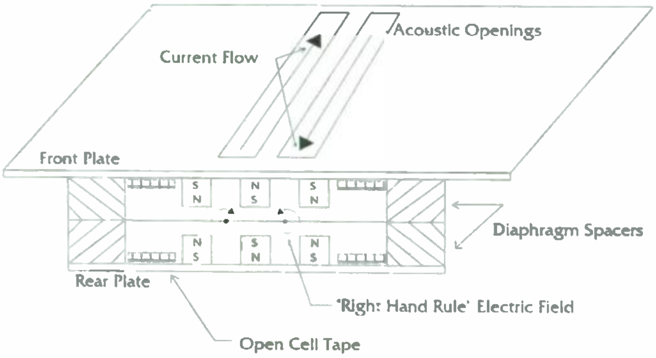


FIGURE 1: Foam placement.

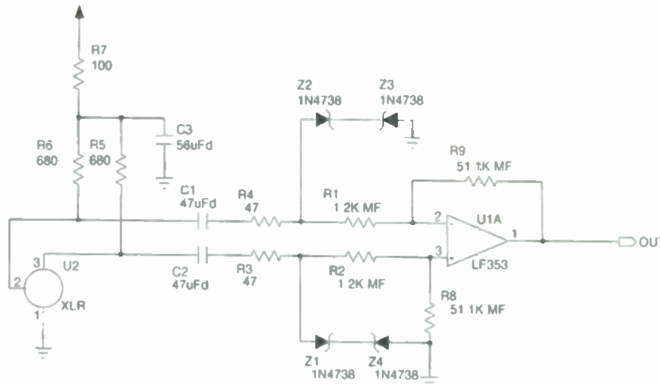


FIGURE 2: Microphone preamplifier.

for most types of music, but sometimes seems to me a little "mellow." The WPS40s are a good cross between the electrostatic and dynamic types. They have very good horizontal dispersion characteristics, image well, are room friendly, and quite dynamic.

MICROPHONES AND EQUIPMENT

I have access to a local university's anechoic chamber and the associated equipment. I was quite excited when I first got into the chamber. However, my excitement took a down turn when I found that all of the measurement equipment was specific for speech analysis. The available microphones were inexpensive vocal-recording types with unknown frequency-response and sensitivity measurements.

Needing to buy a microphone, I purchased a Neutrik 3382. I made all my measurements with the 3382 and a custom preamp. Other equipment consisted of a Stanford Research function generator and a Tektronix 520 oscilloscope.

As mentioned in "Three Affordable Measurement Microphones" (*SB* 4/93, p. 70), the 3382 needs phantom power and a preamp. *Figure 2* presents the preamp I

TABLE 1

Impedance: 6.7Ω pure DC
Capacitive component: <0.001nF
Inductive component: <0.001mH
Power handling: >200W sustained
Weight, magnet (per panel): 120 oz
Weight, total (per panel): 30 lbs
Diaphragm thickness: 0.5/1,000 inch
Conductor gauge: 36 AWG

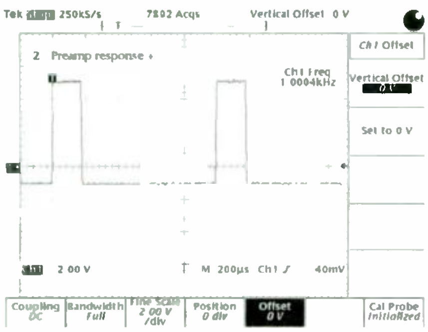


FIGURE 3: Preamp positive input.

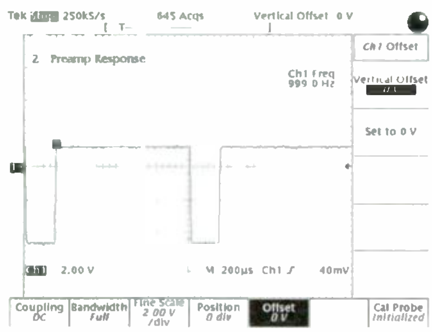


FIGURE 4: Preamp negative input.

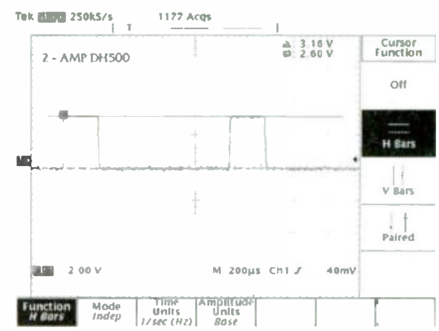


FIGURE 5: Amplifier impulse response.

TABLE 2

WPS40 PARTS LIST/SOURCES

AVAILABLE THROUGH AUTHOR
WPS40 Speaker
WPS40 Cabinet

MCM
(800) 543-4330
adjustable port
PN# 50-575

RADIO SHACK
10″ woofer grille
PN# 40-1346

ZALYTRON
(516) 747-3515
Focal 10K516J

designed to work with the 3382. This fairly simple design was breadboarded and has been working quite well.

PREAMP COMPONENTS

I will describe the major components of the design from left to right. Resistors R5, R6, and R7 provide a 12V phantom power source to the microphone. Capacitors C1 and C2 block the phantom DC power from reaching the inputs of the operational amplifier. Since the mike is capacitive coupled, when it is plugged or unplugged, large voltage transients can be generated.

Components Z1, Z2, Z3, and Z4 are 8V zener diodes to protect the operational amp. R1, R2, R9, and R8 form the amplifier's gain stage. These resistors should be precision types. The resistor ratio yields a gain of approximately 46.

I measured the frequency response of the preamplifier by shorting one input and injecting a signal into the other. The frequency response was 10Hz–20kHz (flat) and 4Hz–50kHz (−1dB). I plan to modify the design by adding an AC-to-DC conversion stage so I can use a standard DMM to measure the amplitude, rather than always having to use an oscilloscope.

Figures 3 and *4* show the impulse

response of the preamplifier, with waveforms for both the positive and negative inputs. The frequency of the test signal was 1kHz with a pulse width of 200μs. As you can see, the preamplifier's frequency response is quite good (i.e., the rising and falling edges are quite steep).

Figure 5 shows the impulse response measured at the output of the amplifier. I did all my testing with a Hafler DH500 amplifier. Here also, a pretty good response shows that the amplifier is not a limiting factor in the measurements. When I had determined how all the test equipment should perform, I moved those speakers into the anechoic chamber and made some measurements.

GENERAL SPECIFICATIONS

One of the measurements I am able to present (*Table 1*) is the WPS40's impedance, which is a pure DC resistance (read amplifier-friendly). With the equipment available to me, I was unable to measure any inductive or capacitive components. To verify this, I placed a resistor in series with the driver and measured the voltage drop across the driver as I swept a function generator through the audio band. The voltage did not vary.

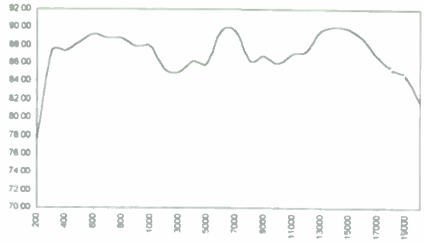


FIGURE 6: Frequency response.

How did I measure power handling? I would like to know how speaker manufacturers do it. My "scientific" method was to pick a weekend when no one was going to be around at work, hook up a 250W amplifier, turn up the preamp until the voltage across the speaker yielded approximately 200W average power, then leave the building! They were still working fine Monday morning.

FREQUENCY RESPONSE AND SENSITIVITY

I made the first measurement of the frequency response with the Neutrik 3382 microphone, DH500 amplifier, Stanford Research function generator, and one WPS40 speaker without a baffle. I plotted the points by hand

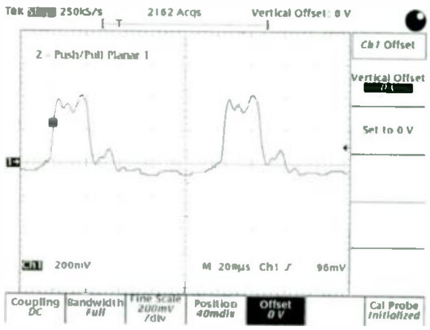


FIGURE 7: WPS40 planar speaker with no baffle or crossover.

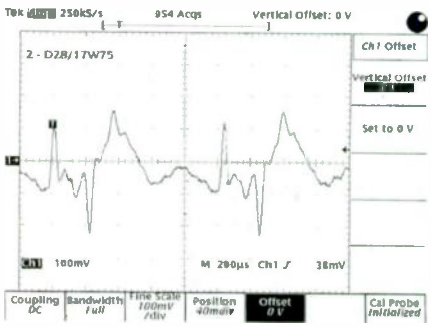


FIGURE 8: Dynaudio D28/17W75 in vented box.

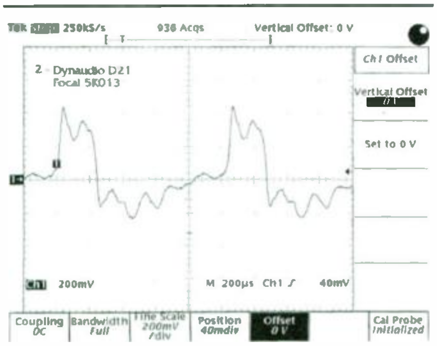


FIGURE 9: Dynaudio D21/Focal 5K013 in sealed box.

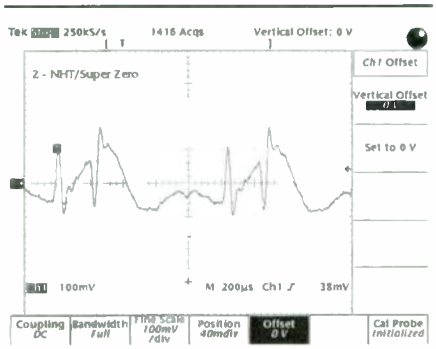


FIGURE 10: NHT Super Zero.

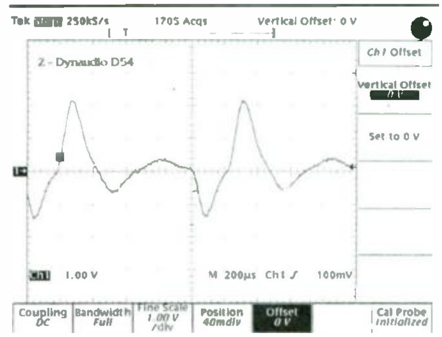


FIGURE 11: Dynaudio D54 with no baffle or crossover.

on graph paper and inserted the rough data into a spreadsheet. *Figure 6* is the result. The speaker has approximately a ±2.5dB variation from 300–18kHz. Efficiency is quite good—approximately 89dB 1W/m—as the graph shows.

IMPULSE RESPONSE

I obtained several plots in the anechoic chamber, using the Tektronix 520, BK function generator, Hafler DH500 amplifier, and the Neutrik microphone. I used the same input signal (level, frequency, and duty cycle) for each speaker/driver: 200µs in width with a 1kHz rate at 1W power. I chose this frequency because it was in the bandwidth capability of all the drivers on hand. The microphone was approximately 8′ from the speakers.

The plots in *Figs. 8, 9,* and *10* are for finished speakers in a cabinet, each using a simple first-order passive crossover. The plots in *Figs. 11, 12, 13,* and *14* are individual drivers without crossovers.

As you can see in the impulse plots, the WPS40 (*Fig. 7*) has the most accurate response, with the Dynaudio D21/Focal 5K013 the runner-up. The speaker in *Fig. 13* has been a favorite over the years, especially since it is a relatively inexpensive combination.

Keep several factors in mind when comparing the results in these plots:

1) Individual dynamic drivers cannot duplicate an impulse perfectly because they have limited bandwidth.

2) Multidriver speakers usually have crossover components (inductors and capacitors) that have a detrimental effect.

3) A typical driver is not a perfect DC load to the amplifier. Its inductance and capacitance interact with amplifier/cables and also have an adverse effect on the impulse response.

4) Driver speed/damping is the ability of the

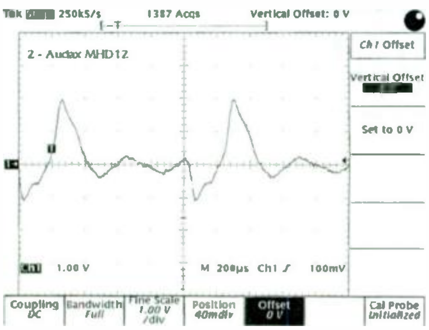


FIGURE 12: Audax MHD12 with no baffle or crossover.

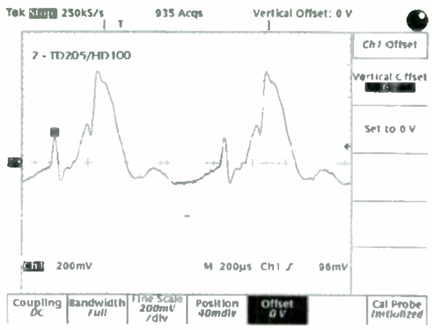


FIGURE 13: Peerless TD205/Audax HD100 in sealed box.

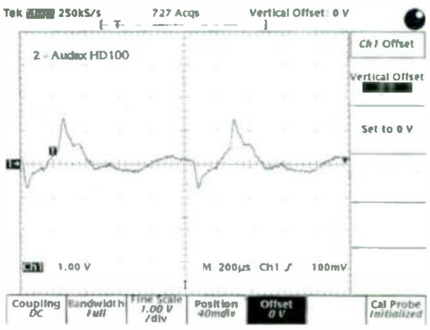


FIGURE 14: Audax HD100 with no baffle or crossover.

driver's diaphragm to start and stop quickly. In this respect, the planar speaker excels because of its low-mass diaphragm and dual-motor push/pull magnet.

THE SECOND SET

I used the first set of speakers with a set of subwoofers I had built. The enclosure was an open frame that positioned the vertical center of the WPS40 at ear level for a sitting listener. The cabinet is shown in Part 1.

On the second set of speakers, I mated the planars with a dynamic woofer. I designed a big box to mount to the frame supporting the WPS40 and drew some rough plans for a cabinet maker. I was surprised at their large size and poor proportions.

Since I was a little strapped for cash at the time, I used some old Dynaudio 21W54 woofers from a past project. The wood grain of the front panel looked so nice that I decided to mount the woofer facing the rear, which turned out to be a mistake. Back to the drawing board; I decided to make the next speakers better proportioned and not so big.

THE THIRD SET

On my third try, I integrated a different subwoofer with the WPS40. From previous experience with Stratherns and Gold Concepts samples, I knew finding a woofer to complement the capability of the WPS40 would be difficult. Having had good results with the Focal Kevlar cone woofers—they are very "fast" and mate well with planars—I chose the Focal 10K516J. It is efficient, works well in vented cabinets with <2ft^3, and can handle a lot of power. My cabinet is 1.8ft^3, with a vent tuned for 35Hz. Some properties of the Focal 10K516J woofer are:

- Kevlar® cone: light and stiff;
- "J" version: long voice coil;
- High power: 250W;
- Cast frame: rigid structure.

This combination does sound good. My best results have been with a constant-phase electronic crossover; however, a simple first-order passive crossover also works well. I used Axon 60μF polypropylene capacitors in series with the WPS40, and CFAC 3mH inductors in series with the woofers, which yields a 400Hz crossover point.

As for cabinet specifics, I considered for a long time how to protect the woofer from my three-year-old (woofer-poking) son. The standard woofer grilles do not fit the Focal woofers. My solution was to mount Radio Shack 12″ grilles over the Focals. This worked quite well, as you can see in *Photo 1*. For the vent, I utilized an MCM variable-length port with a 2.5″ internal diameter. (*Table 2* lists parts and sources.)

My cabinet maker is willing to make duplicates of the same design if any reader is interested. A pair of cabinets is UPS deliverable in three cartons. The price is yet to be determined, but will probably be in the $350–$450 range. If you want a pair, please let me know.

WHAT'S NEXT

I am now building my fourth set. I am using the same processes outlined here. I have found 0.33/1,000 Mylar® to use for the diaphragm for this set, and I also might experiment with smaller-gauge wire.

In addition, I'm searching for a process to bond the wire directly to the diaphragm—maybe even a metal deposition/etch process. If anyone has information on such processes, please let me know. E-mail me at dpatten@dasengr.com.

In conclusion, I am pleased with my last cabinet design and will probably stick with it. This has been a very exciting project, and I believe I have come up with a process for making a very high-performance speaker system at a fairly reasonable cost. Your questions or comments are welcome.

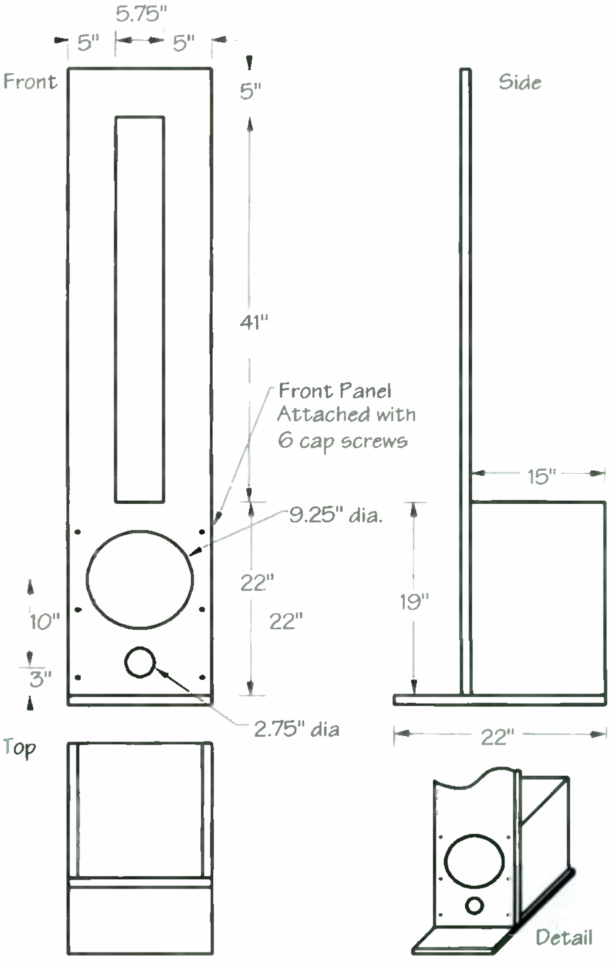


FIGURE 15: Cabinet-construction details.

Wayland's Wood World

SPEAKER AESTHETICS

By Bob Wayland

When I go into a high-end audio store, the first thing that strikes me is the excellent quality of the woodworking. It had better be very good indeed for a $2000 system, but you can't see the internal structure, the critical substructure. The quality of audio reproduction must be equaled by the aesthetics of the overall enclosures for you to be willing to spend that amount.

As home speaker builders, we often don't go that extra step that means the difference between a delighted response and, "Gee it sounds great, but couldn't you do something about the way it looks?" Yes, you can, and it is easy!

THE GOLDEN SECTION

There are two very visible attributes that catch your attention when you look at an enclosure: the overall dimensions and the edges. The shape of the enclosure is one of those wonderful areas where art and science work together nicely. As human beings, we have a built-in preference for the proportions of the so-called golden section or ratio, a geometric mean known at least as far back as the ancient Egyptians. Designs and forms based on the golden section are particularly pleasing to the eye. They occur in many paintings, buildings (the Pyramid of Cheops, for example), and in astonishing ways in nature's patterns, notably in the sunflower, some pine cones, and other spiral forms. In his book, *The Power of Limits*, Gyorgy Doezi shows just how universal this ratio really is.

Mathematically, the golden-ratio number is derived as follows: divide a line segment of unit length at a point such that the ratio of the shorter part (a) to the longer part (b) is equal to the ratio of the longer part (b) to the whole segment ($a + b = 1$). Since $a = 1 - b$, the resulting proportion is $(1 - b)/b = b/1$. Rearranging and simplifying this equation gives $b^2 + b - 1 = 0$. The positive solution of this quadratic is $b = .618...$, the "golden number," often symbolized by ϕ or G. Curiously, the equation shows directly that the square of b, the longer part, equals a, the shorter part: $.618^2 = .382$.

For our purposes, this ratio, .618, appears in the dimensions (a, b, and c) of a "golden-section" box (*Fig. 1*), in which a:b:c = 1.618:1:0.618; but also note that a:c = 2.618! The easy way to determine your dimensions is to set the volume of the enclosure = b^3 and find b; then a = 1.618b and c = 0.618b. By choosing the dimensions according to the golden ratio, you will also ensure that for a square enclosure, the minimum number of panels will have the same dimensions and the same vibrational frequency.

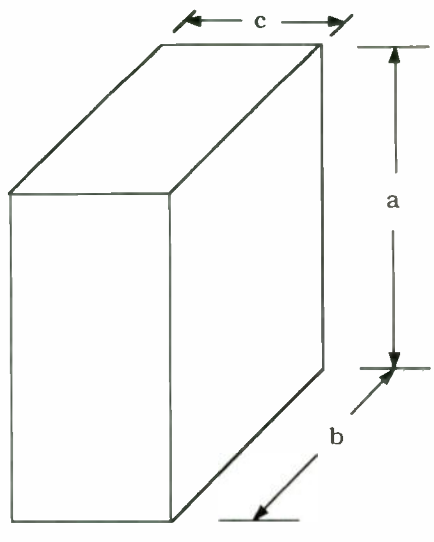


FIGURE 1: The golden-section box.

ROUNDING EDGES

The easiest treatment for edges is a simple round-over. The next series of edge treatments all make the assumption that you have been extremely careful while building your enclosure. This means that not only have you ensured that the enclosure itself is square, but also that your table saw is properly aligned ("Wayland's Wood World," *SB* 6/93, p. 50).

There are a number of things you can do to soup up the ordinary smoothly rounded edge. If you have rounded the edges and want to embellish them, try setting the saw blade at an angle between 5° and 15° and cutting both sides of all edges that are not parallel to the front of the enclosure. The result will be as shown in *Photo 1* (10° cut).

Notice the blending of both hard and soft edges. You can control the softness of the edge farthest from the hard corner edge by the angle you use. I would suggest that you make some practice corner joints and then make a set of cuts at 5°, 10°, and 15° to find one that best suits your design. If you go much beyond 15°, I suspect you will find the result a bit harsh.

There can be a problem with the integrity

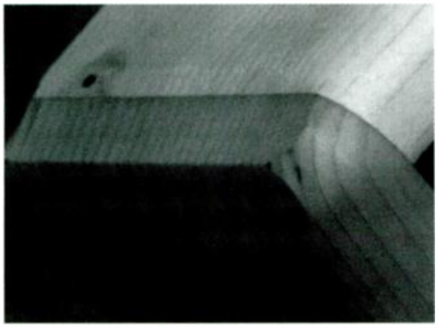


PHOTO 1: Hard-edged sides with a rounded front edge.

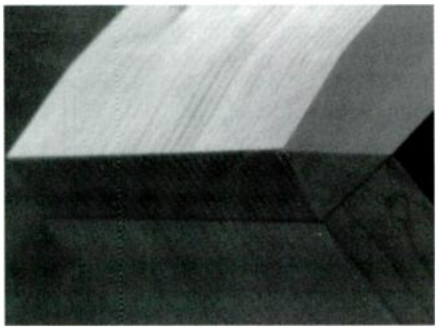


PHOTO 2: Hard-edged sides and front.

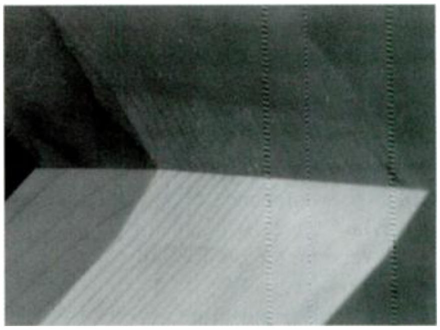


PHOTO 3: Hard edges, both sides and front, for a 45° biscuit joint.

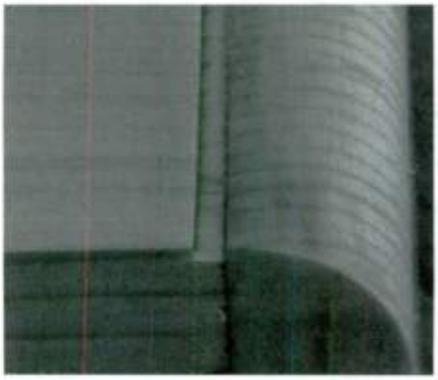


PHOTO 4: Edge scoring on a simple butt joint.

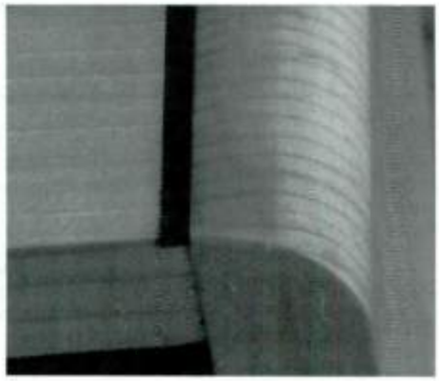


PHOTO 5: Inlay to create contrast in the transition between the grain patterns of a simple butt joint.

of the corner joint when you use this approach. One good correction is to make an internal brace like the one shown in *Fig. 2*. This has the additional advantage of getting rid of sharp internal corners, thus producing a smoother sound. You should add this type of brace to most of the joints I will describe in this column. But realize that adding them will change the volume of the enclosure.

ANGLED CUTS

The next step in this progression is to replace the rounded front-face corner with an angled cut. This produces a number of hard edges, as shown in *Photo 2*. The rich interplay of the hard edges is emphasized by the simple butt joint used to make this corner.

The front-edge angle of cut can be stronger than the side edges to produce an even more radical transition. One of the more interesting aspects of this treatment is that the appearance changes with alterations in the angle of the light illuminating the enclosure. The play of shadow against a highlighted surface makes an ever-changing shape.

The discontinuity caused by the butt joint

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 Cross-over • 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 Sys-tem • Build and Use a White/Pink Generator • Sound Pressure Level Nomographs •

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

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

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

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

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

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

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

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 •

There's More ☞

Please send me the following back issues of Speaker Builder

❑ 1995 $32 ❑ 1994 $32 ❑ 1993 $25 ❑ 1992 $25
❑ 1991 $25 ❑ 1990 $25 ❑ 1989 $18 ❑ 1988 $23
❑ 1987 $20 ❑ 1986 $20 ❑ 1984 $18 ❑ 1983 $18
❑ 1982 $18 ❑ 1981 $18

SHIPPING BACK ISSUES

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

❑ Check or Money Order ❑ Discover ❑ MC ❑ VISA

DISCOVER/MC/VISA NO. ________ EXP. DATE ________

NAME ________ ACCOUNT NO. ________

STREET & NO. ________

CITY ________ STATE ________ ZIP ________

Speaker Builder
Post Office Box 494, Dept. B96, 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.

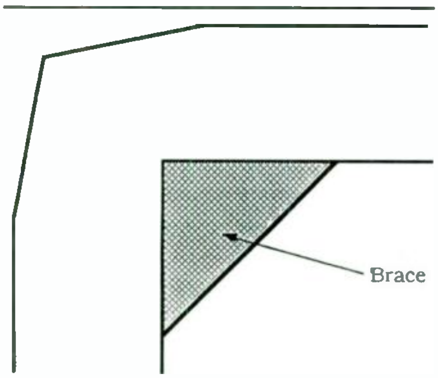


FIGURE 2: Corner brace.

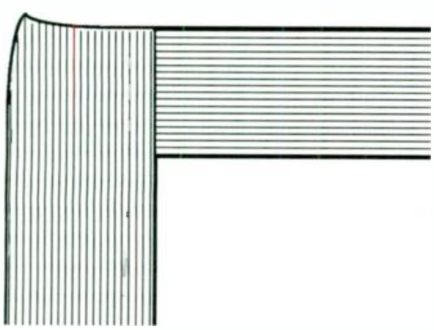


FIGURE 3: Impish edge treatment.

of *Photo 2* can be changed by making the corner joint a 45° biscuit joint (see *SB* 5/94). Note the contrast of the result shown in *Photo 3* with the butt joint in *Photo 2*. The main effect is that one facet of the joint shown in *Photo 2* has disappeared in *Photo 3*. This simple change produces a less cluttered effect—at the expense of an interesting interplay of visual impact.

One aspect often overlooked is the importance of the grain of the wood at the edge. The difference between the butt joint as compared to a 45° joint is that the grain structure of the two joined panels must be chosen carefully. Always examine closely the grain of the wood at an edge, and then decide what treatment will produce the best effect. Do you want the discontinuity of having the grain patterns perpendicular to each other, or a smoother transition with the grain in the same direction? Should you try to match grain-pattern spacing for figured woods? This is much like taking a photo—you should always ask yourself first what message you're trying to convey.

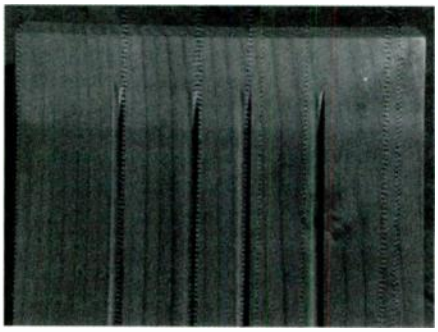


PHOTO 6: Side decoration produced by simple, unequally spaced cuts.

GENTLE DECOR

If you like rounded corners, there are other ways of enhancing the edge. A very gentle decoration results from a saw cut just at the joint, as shown in *Photo 4*. I have found that this works best when the cut is entirely on the plain face, not the end grain. This has the effect of breaking the simple butt joint, making it much more visually appealing.

PHOTO 7: Abstract patterns cut on a jigsaw in different woods.

The cutting pattern of many common saw blades produces a V-shaped bottom. You might want that effect in your design; if not, I suggest that you flatten the bottom. An easy way is to use a mill file edgewise to remove the V. Again, this comes down to what message you are conveying. The V leaves an

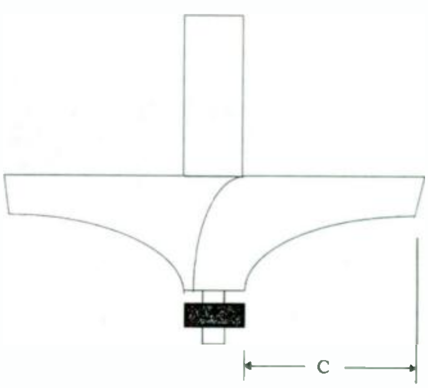


FIGURE 4: Thumbnail router bit; note that the profile is an ellipse, not a circle.

PHOTO 8: Abstract fish "swimming" against the grain.

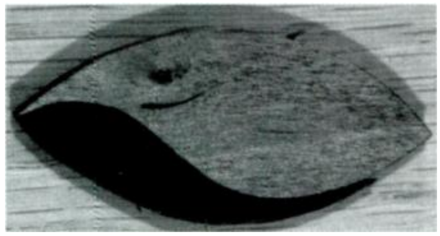


PHOTO 9: Abstract fish "swimming" with the grain—note the addition of a shadow of contrasting wood.

unsettled image; the flat bottom produces the image of a channel for the sound to escape.

If you want to make a stronger statement, there is a step beyond the slot, one that requires a bit more attention to detail. This is to add an inlay to the slot. Here, use a contrasting wood: dark for light-colored woods, or light for dark-colored. The dark on light is shown in *Photo 5*.

An exotic but subtle variation of this technique is to use the same wood for the inlay as for the cabinet, but with the grain of the inlay running in the direction of the long dimension of the strip. When you first see it, you think that something is not normal. Then your mind catches on, just as with a good joke. Try it; I think you'll like it.

FLAT AREAS

So much for the edges; what about the general never-never land of the broad flat areas of the sides, top, and bottom? Much like the blank canvas an artist sees, this just begs for something to break the monotony. Most of us are not artists, but there are simple ways to produce pleasing results. Either you can put a decoration *on* the surface, or a decoration *into* the surface.

An effective, uncomplicated technique is to make a series of saw cuts into the sides. One such application is shown in *Photo 6*. This keeps the effect of the V-bottom saw cut. There are also many, elaborate, ready-made designs you can inlay: most woodworker-supply houses have a display to choose from. The variety of themes allows for almost any motif you might fancy.

A step beyond this that you might consider if you have some spare change is a new technique, *The 3D Router Carver System*, distributed by CMT, that allows you to carve accents with a plunge router. The drawer and corner patterns of *The 3D Router Carver System* can easily spruce up an enclosure.

The addition of decorations to the surface is an enchanting approach that gives you almost endless possibilities. I happen to like abstract designs and will illustrate this part of the column with transcending patterns. You can change the approach to reflect your taste.

After a moment's reflection, I cut out the pieces shown in *Photo 7*. For some reason my mind was on fish that day. It would be easy to make a school of fish, even to the extent of having the patterns from one satel-

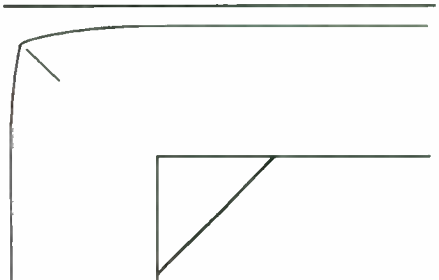


FIGURE 5: Gentle-edge profile.

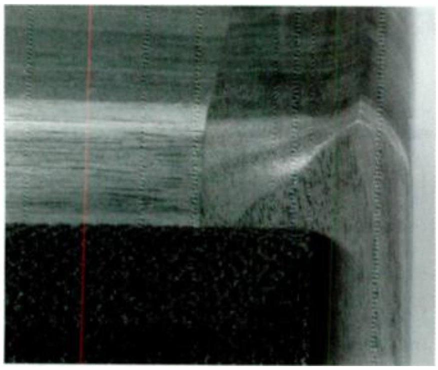


PHOTO 10: The impish edge treatment.

lite interact with those on another satellite or subwoofer. In *Photo 8*, the fish leitmotif is shown swimming across the grain, as if across waves of water. In *Photo 9*, the fish are swimming with the flow of the grain. Note the addition of a shadow that contrasts with the fish.

If I were working this into a design, I would use a small-diameter drum sander to carefully fit the pieces together. Also, I would round the edges to separate the pieces visually. Clearly, before starting, you must consider how this form will fit in with your overall design for the speaker cabinet.

I happen to be the sort that lets things happen and will change my design in midstream. Others must know exactly where things will end before starting. The art of speaker building requires being both sorts at once. Careful attention to the electromechanical details of high-end speaker building cannot be left to chance; the finishing touches that determine the visual impact leave room to experiment.

LAST STEPS

The last edge treatments require only a router, roundover, and bowl bits. The first is meant to give the impression of an impish nature. The side edges of a satellite have a slight horn, as seen in *Photo 10*. The cross section of this edge is shown in *Fig. 3*.

The concave cut is made before assembly with a bowl-and-tray bit from CMT Tools. You can do this with your router by clamping the side panel between two scrap pieces of 2 × 4 and using an edge guide to make multiple passes until you have a smooth, concave surface. You form the vertical convex surface after assembly with a large-radius roundover bit, at least ¾″.

Make a scrap piece twice the thickness of the horn and attach it to the horizontal surface with double-sided tape. Carefully set the depth of cut to obtain the contour you want and rout. Be careful not to follow the edge around the corner, which you must shape by hand with files, sharp knives, and sandpaper.

A variation on the rounded corner that I really like is made with a thumbnail router bit. Normally, you use this bit to make table edges, but you can adapt it to produce great detail on corners. The profile of the thumbnail bit is shown in *Fig. 4*.

The profile for the corner of the enclosure is shown in *Fig. 5*. You can make this with the thumbnail bit by placing a piece of scrap wood on the surface of the side you are not routing, offsetting the bit by ¼″ or so. (The amount of the offset determines where on the C cutting edge you make your cut.) The scrap is easily held in place with double-sided carpet tape. You may find that the sharpness of the edge needs to be different; if so, just change the amount of offset to produce the desired effect.

Of course, there are many other variations to these suggestions. A good source of ideas is your local high-end audio store. Pick up some of the literature and let your imagination go!

SOURCES

CMT Tools
310 Mears Blvd., Oldsmar, FL 34677
(800) 531-5559; FAX (800) 870-7702
cmttools@packet.net and http://cmttols.com.catalog/

Software Report

MAC SLM: A MAC SOUND-MEASURING TOOL

By Dick Moore

As I was leafing through a recent *Speaker Builder*, an Old Colony Sound Lab advertisement caught my attention. The headline proclaimed: "SLM: Sound-Measuring Tool for MAC." I read the ad copy, which described a sound-level meter and spectrum analyzer, and immediately ordered the Mac SLM software.

FOR WHICH MACS?

Mac SLM is designed to run under System 7.x on 68020 and later Macs, such as the II family, Centris, Quadra, LC, PowerBook, Performa, and Power Macs. Most of these have built-in audio I/O. For machines that lack audio inputs—those earlier than the IIsi—you need a sound card. Because the measurements Mac SLM makes require intensive computation, I strongly recommend a Floating Point Unit (FPU). Mac SLM currently comes in three versions: MacSLMnoFPU is for '020/'030/'040 machines without an FPU (such as the "LC" version of the '040 in later Performas, LCs, and PowerBooks) and for Power Macs; MacSLM030 and MacSLM040 are for machines with those CPU chips *and* FPUs.

Most Macs have a mono input with a built-in microphone preamp and an 8-bit A/D converter that runs at a maximum sampling rate of 22.254kHz. The AV Quadras, all Power Macs, and Macs with sound cards have CD-quality I/O, with stereo line-level inputs and 16-bit ADCs typically running at 44.1kHz. In all cases, you input audio signals by plugging the analog audio into a 3.5mm mini-jack on the computer's back panel and enabling the Sound Control Panel to select I/O parameters. Because Mac SLM accesses only the left channel in stereo machines, you can use a mono mini-plug—the left channel is the "tip" connection of the analog stereo-input jack.

The sampling rate of the Mac you're using imposes an upper limit on frequency range. The 8-bit, 22.254kHz Macs have a useful upper-response limit of slightly more than 10kHz, while the upper limit of the 16-bit, 44.1kHz machines is a bit more than 20kHz. All Macs with built-in sound input have sharp cut-off antialiasing filters to prevent spurious signals in spectra. The low-frequency limits of both types extend below 20Hz.

The 8-bit Macs have a potential linear amplitude range of about 48dB (6dB/bit), but in practice you can expect about a 40dB linear range using the Mac as a level meter. The 16-bit Macs have a potential range of 96dB, but, again, you should expect the linear range to be quite a bit less. You also need to be cautious about input levels. I found that for an 8-bit IIsi with mike-level input and AGC on, the maximum input level is about 6mV RMS (17mV P-P). With AGC off in the SLM mode, the maximum input is 1.4mV RMS (4mV P-P). My Power Mac 7100/80 has line inputs with maximum levels of about 0.3V RMS (0.85V P-P).

A note about impedances: my Power Mac has a measured input impedance of 13.4kΩ. This is not high, but it should be OK unless your mike preamp or other equipment has unusually high output impedance.

WHAT MAC SLM DOES

Mac SLM requires very little external gear to make sound-level, spectrum-analysis, and frequency-response measurements. It includes various sound-level-meter functions (hence the package's name). For SLM and noise-spectrum measurements (as opposed to frequency-response measurements using a noise test-signal source), all you need are a suitable microphone and some source of noise or sound that you want to measure. For frequency-response measurements of any kind, you need a source of wideband pink noise, such as a CD with a 20Hz–20kHz pink-noise track or a generator like the fine Muller unit. (See "A Stereo Noisemaker," *SB* 4/84; #KSBK-E4 kit, $69 plus shipping, from Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458, 603-924-6371, FAX 603-924-9467.)

For measuring amplifier/equalizer response, you also need an attenuator to reduce the unit's output signal to mike or low-line levels, depending on the Mac you're using, and some cables for connections. For speaker-response measurements, you need a flat, wideband microphone, such as a Mitey Mike (*SB* 6/90; #KD-2 kit, $159 plus shipping, from Old Colony), an attenuator (see next paragraph), and cables.

FIRST, SOME SLM

The owner's manual states that Mac SLM is designed primarily to analyze noise signals from microphone inputs. Its SLM modes display dB SPL readings of 0.1dB resolution with big, easy-to-read white numbers on a black background. The SLM modes are complete with flat, A, B, and C filter weightings. There is no provision, as on hardware SLMs, for selecting standard fast or slow averaging times. The response is either "slow" or "quite slow" by default, because the flat readings update at a rate of several per second, and it computes the A, B, and C filter weightings with DSP routines that take a second or more to complete and require a number of

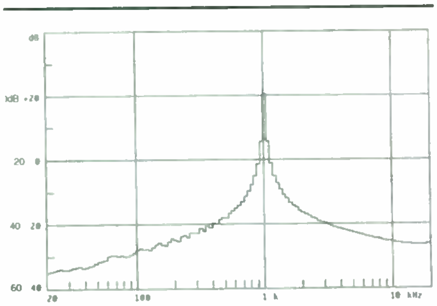


FIGURE 1: Oscillator 1kHz sine-wave measurement.

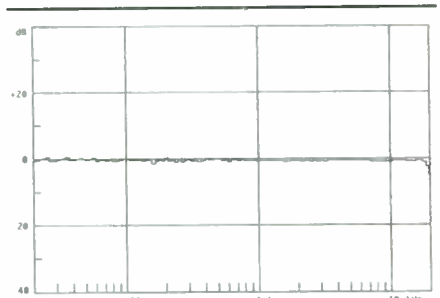


FIGURE 2: Spectrum of input from pink-noise generator.

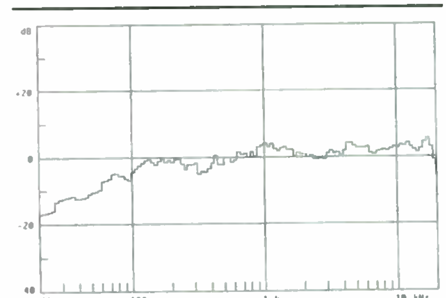


FIGURE 3: Spectrum obtained with first rebuilt speaker.

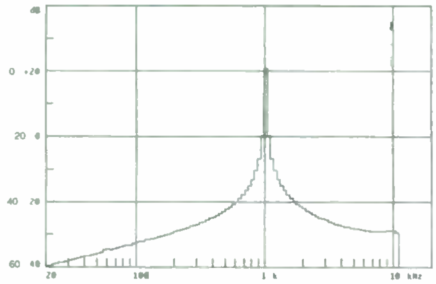


FIGURE 4: The 1kHz spectrum on a IIsi computer.

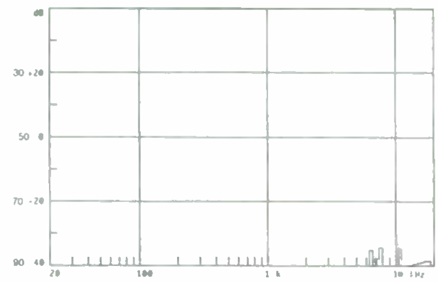


FIGURE 5: Dynamic-range measurements on the Power Mac.

samples to converge to a final value.

Hardware SLMs have variable-gain amplifiers or attenuators that give them a wide SPL range—from as little as 40dB to as much as 140dB. Mac SLM does not have variable gain or attenuators because the Macintosh does not. Adding an external preamp and/or a calibrated attenuator can make the range as wide as needed or as the mike itself allows.

Calibrated SLM operation is possible through a well-thought-out set of sensitivity controls that allow you to input the mike sensitivity (if known) in decibels relative to 1V at 0dB SPL, and also to input a separate "preamp-gain" decibel factor to achieve correct scaling (see the sidebar, "SPL Equivalencies for Mike Sensitivity Specs"). Because the Radio Shack and Tenma SLMs, to name just two, are relatively inexpensive, fairly accurate, and easy to use, I think most of you will be interested only in Mac SLM's various SLM modes for relative readings.

NOW, THE REAL FUN

The more interesting and valuable capabilities of Mac SLM involve frequency-response or spectrum analysis, and I believe these functions are where Mac SLM will be of most use to both professionals and hobbyists. Its analysis covers the frequency range from 20Hz to 20kHz, although, as mentioned above, it limits 8-bit Macs to an actual upper-band limit of just over 10kHz.

You can set the amplitude range of the

graphic display to either 80dB or 40dB and the bandwidth of the spectrum filtering to 1/3, 1/6, or 1/12 octave (Mac SLM's actual band centers are on the ISO-preferred frequencies). A menu offers a choice of spectral weightings for pink-noise or other-noise inputs, i.e., white noise, which allows you to measure power spectral density. Software DSP filters under the Filters menu remove either 60Hz or 120Hz noise components (not both), which may creep in from poor shielding or inappropriate equipment grounding.

You can time-average the spectrum measurements so they converge to stable levels, but you can also disable time averaging to show the spectrum of each captured sample. This simplifies looking for rapid changes of level or frequency, making initial adjustments of graphic equalizers, and so on. Mac SLM computes the displayed spectra, and updates occur about once per second.

Mac SLM provides nice features for storing a reference spectrum for comparisons and a background spectrum you can subtract from or add to later measurements. This background subtraction/addition feature lets you compensate for the response of the measuring system (rolloffs/peaks or a constant source of environmental noise). You can save all plots to disk and recall them for later review or printout. Amplitude resolution is limited by the screen or printer resolution and by the time you can bear to wait for time averaging.

USING MAC SLM

I didn't waste any time getting the MacSLMnoFPU version up and running on my Power Mac. It booted and ran smoothly on the 7100, which is notable, since we run System 7.5.1 on my machine and my wife's Mac IIsi. So far, Mac SLM has not crashed or frozen on either machine, although you must quit Mac SLM *before* you use System 7.5's power-key shut-down feature.

I suggest that after booting Mac SLM, you first select the spectrum bandwidth under the Spectrum menu's Graph Ranges selection before proceeding. The program defaults to the 1/3-octave bandwidth at start-up, which I find interesting, since that bandwidth is useless for measuring speakers, one of the primary uses for this software. Sound-reinforcement pros are more likely to use this bandwidth to evaluate environmental noise and to set graphic equalizers, so maybe this default makes sense. It would be handy, however, to be able to specify an alternative.

A SMALL MATTER OF CALIBRATION

It is important to know your computer's maximum input level (or its mike-preamp saturation) before ADC clipping. First check the specs for your computer or sound card, but be prepared for a bogus spec—the one for my Power Mac turned out to be 8dB higher than the real-world number. You'll need an oscillator and an AC millivoltmeter (or calibrated scope) to check it yourself. I'll send my calibration procedure to readers who write me with an SASE or leave me an E-mail message with an E-mail return address.

You need to know or measure your mike's output for a given input SPL to make sure you do not overdrive the input to the computer when testing speakers. To maximize measurement dynamic range, the input signal should be as close to maximum as possible, so it's handy to have an attenuator and a calibrated scope to monitor the peak-to-peak input to the computer.

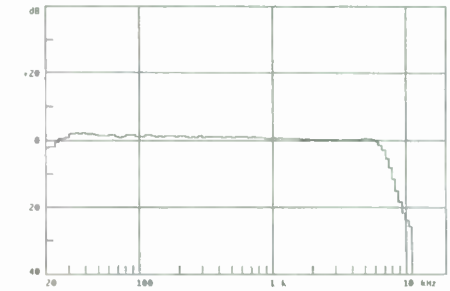


FIGURE 6a: Response limitations of the 8-bit Macs.

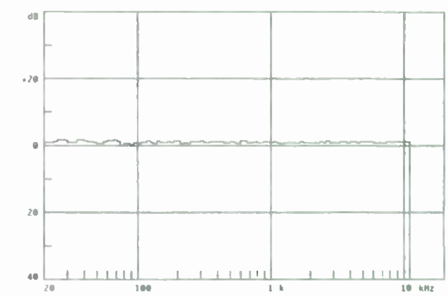


FIGURE 6b: Spectrum results.

If you prefer to calibrate to absolute SPL, calculate your mike-system sensitivity in dBV/μBar, subtract 74dB (because the mike-sensitivity cal field in Mac SLM is based on dBV at 0dB SPL), and enter the result into the mike-sensitivity field of the software. Now you can fiddle the preamp-gain fields (one for AGC on and one for it off) to get the right SLM reading from the software for a known mike-voltage output. If you know the mike's absolute sensitivity, this reading will give you the input SPL, which is what you want on the screen.

If you're confused, don't feel alone—it

took me about an hour to work it all out, and I'm supposed to know what I'm doing. Mac SLM's manual seems a little vague about this, since it doesn't discuss mike-sensitivity ratings, but it is accurate about the procedure. It's just frustrating that the manual doesn't discuss how to avoid the input-overload problems that I found with our two Macs.

REAL-WORLD TEST

I was building small, shielded satellite speakers from some old Advent 402 cabinets and crossovers using shielded drivers from MCM Electronics when the SLM software arrived, and nothing could have been more welcome. I calibrated the entire setup with oscillator and mike. *Figure 1* shows the resulting spectrum at maximum input for a 1kHz sine wave from the oscillator. This is with the 16-bit system of the Power Mac, and it is textbook performance.

FIRST GLITCH (SOFTWARE)

I was less than happy with low-frequency, sine-wave spectra below a few hundred Hertz. The fundamental peaks were low, and the bandwidth seemed too wide, yet the spectrum of a pink-noise input from my modified Muller Pink Noise Generator (*Fig. 2)* was spectacularly clean and flat when averaged over about three minutes (about 200 samples). I also got good usable pink-noise spectra in under one minute of averaging (about 50 samples).

Figure 3 shows the spectrum I got with my first rebuilt speaker. There is no sign of difficulty with the spectrum at any point, and the results followed a warbled swept sine-wave measurement extremely well.

I tried Mac SLM on my wife's IIsi, first establishing input levels and calibrating the level in the flat SLM mode, then running spectra at various frequencies. *Figure 4* shows the 1kHz spectrum, which has outstanding dynamic range and spectral shape despite the restricted linear range of the ADC. This shows what digital signal processing can do. I noticed that the low-frequency spectra were also very good. I was running the MacSLM030 version on the IIsi because it has an FPU. Was the difference due to the FPU processing of the IIsi or the emulated processing of the Power Mac?

A WORD FROM MAC SLM'S AUTHOR

I wrote the program's author, Dr. Victor Staggs, who pointed out that the difference was due to the sampling-rate difference versus his fixed sample size. To keep the computational overhead manageable at all sampling rates, he traded away some low-frequency resolution at the 44.1kHz rate to keep everything running smoothly. A forthcoming Power Mac native version of Mac SLM will not have this artifact.

The bottom line is that the minimum frequency resolution at the higher sampling rate is about 10Hz, whereas the effective bandwidth at the 22kHz sampling rate is about half as wide, giving narrowband results even at 50Hz. This doesn't significantly affect noise measurements, which are not hugely discontinuous, but does show up with sinewave sources. This is why the pink-noise spectra from the generator and speaker are very good.

SECOND GLITCH (USER)

Following the interesting results with spectral shapes, I wished to check dynamic range, so, going back to the Power Mac, I used an attenuator to reduce the input by 100dB. The resulting spectrum was full of crazy-looking noise peaks, beginning at 75Hz and going right up from there. I suddenly realized that the computer, monitor, oscillator, and voltmeter all shared ground loops through the power connections. I isolated all of the power grounds, and the crazy noise disappeared off the bottom of the screen, below –90dB (*Fig. 5*). I got nearly as good a result with the IIsi, so as far as spectrum measurements are concerned, you needn't worry about dynamic-range limitations with Mac SLM and any Mac computer.

Figure 6a shows the response limitation of the 8-bit Macs. Notice that the ADC's antialiasing filter rolls off the top end above 5kHz, then brick-walls the signal at about 11kHz. Storing this as a calibration spectrum and then subtracting it from another identical run produces the spectrum of *Fig. 6b*. Although nothing can fix the brick wall, note the correction of the rolloffs at the top and bottom ends. This feature is terrific.

LAST TWO GLITCHES (SOFTWARE)

First: In spectrum measurements on 8-bit machines, the AGC needs to be on, whereas on the 16-bit machines, it needs to be off (in either machine, AGC needs to be off in SLM mode). With the Power Mac and System 7.5, at least, if you turn the AGC off manually before running a spectrum, you'll get very peculiar results. The bottom line is that when you're running a spectrum on a 16-bit machine, let Mac SLM turn AGC off for you. Just click OK when the alert box appears. From then on, everything will be fine.

Second: The program doesn't support the background-printing feature of System 7.5. For measurements, just save the spectra to disk, which is very fast; then, after measuring, go back and call up and print out the spectra you saved. Dr. Staggs says that the program is just working way too hard to share any time with background operations.

CONCLUSION

Mac SLM is wonderful, reasonably priced software (#50F-SLM1M3G from Old Colony, $74.95 plus shipping) that has made a lot of my bulky old analog test equipment obsolete in one digital swoop. Once calibrated, the software runs flawlessly. Despite the 10kHz upper-frequency limit on 8-bit Macs, it is very useful for speaker evaluation. If the speaker is working well at 10kHz, it won't stray too far in the next octave.

For evaluating crossovers, woofer, and general performance, Mac SLM is a godsend. Perhaps the ideal computer for Mac SLM will be a Power Mac PowerBook running a native version. For sound contractors, any PowerBook with a full FPU '040 would be just the ticket.

I would love to see a little subroutine that flashes an icon in the display when the ADC peak output approaches within 2dB of maximum, and perhaps another to show levels below –30dB. This would eliminate an awful lot of screwing around with level calibration, and would be processor independent.

The bottom line: Don't try to take this program away from me; I mean it!

SB Mailbox

STANDARD SYMBOLS

Why doesn't *Speaker Builder* use the industry standard "Graphic Symbols for Electrical and Electronics" ANSI Y32.2-1975 in its diagrams? The symbols used seem to vary with the author. This makes it very difficult to read these diagrams.

John J. Huff
Stockton, CA

Speaker Builder *responds:*

All Audio Amateur's periodicals are relatively small, requiring compromises in production costs. With the advent of the computer, many authors can and do produce their own drawings and schematics. Many of the schematics are redrawn—sometimes by our longtime draftsman Bill Morello and sometimes by staff using OrCAD, a schematic capture program that includes the capability of producing circuit cards.

It is the editor's prejudice that the international symbology for schematics is superior to that followed in the United States. Those symbols are part of the ANSI standard, but seldom followed in the USA. The differences are slight, but the designator system is more obviously different. To the editor's mind, Americans are the rustic colonials who cannot bear to join the rest of the world in the use of a clearer, less ambiguous system. This also applies to measurement systems.

Audio Amateur prefers little boxes for resistors. We prefer the two small boxes for electrolytics, the filled one indicating the negative end. We much prefer the use of nanofarad along with the normal micro- and pico- prefixes to indicate capacitor values. Why US magazines and companies do not make use of the nano-prefix is a mystery to us. The decimal point in resistor values is riskier than using the abbreviated sign (the K, Ω, or R) in place of that tiny dot. Admittedly, it takes a bit of getting used to, but is liable to fewer mistakes.

In our view the ANSI standard, now 20 years old, could use a thoughtful update.

YOUR HELP IS NEEDED

Last November Dick Pierce, an independent speaker consultant living in Pepperell, MA, and a frequent author on loudspeaker issues as well as a programmer of unusual capabilities, was suddenly stricken with acute necritizing hemmoragic pancreatitis and underwent emergency surgery. He was transferred to the intensive care unit at New England Medical Center, Boston, where he remained in a coma for 48 days. He was hospitalized for an additional two months and cared for much of the time by his wife Linda, who is a graduate nurse.

Pancreatitis is an almost always fatal disease with a survival rate for those under 40 of 1%. Many of his friends thought several times we were going to lose him. As you may imagine, the medical bills, even with insurance, have become astronomical in size and since neither Dick nor Linda have been able to work at their regular pace, finances for the Pierce family have deteriorated in a major way. Dick is still unable to work and is slated for more physical therapy and possibly additional operations later this year.

I have taken the liberty of setting up a fund at our local financial institution, Granite Bank, Peterborough, in the name of Dick and Linda Pierce. I invite Dick's many friends and associates to join me in contributing, as generously as you can (and every dollar counts), to help in some small way to alleviate their financial woes. Please make checks payable to Richard and Linda Pierce, c/o The Pierce Fund, Audio Amateur, Inc., PO Box 576, Peterborough, NH 03458-0576. Thank you in advance for any help you may be able to give.

Ed Dell, Publisher

ALL IN THE FAMILY

For several years I have been using John Cockroft's "Shortlines" as a primary pair for my living room system, and have been most satisfied with the way the sound seems to emanate from the wall. I could not be more pleased.

Also, I constructed a pair of "Simplines" a few months ago and have just completed the upgrade with the Dayton tweeters ("The Super Simpline," *SB* 1/96, p. 18). As I write this I'm listening to a CD through the quad speed player on my computer, through an old AR amp, and to the Simplines that flank the hutch. Again, the sound drives out from the wall and is superb.

I must agree that the Simplines are the most pleasing to listen to. A major contributor is the fact that $35 can sound so good.

I, too, have a long history of using the FE-103 speakers ("The Simpline," *SB* 2/93, p. 14) and first bought mine from Olson. Thanks to your article noting their availability from Radio Shack, I was able to repair an old set of "minis" I made many years ago.

Thank you again for the many articles in *Speaker Builder* and the enjoyment from the speakers you designed.

Foster L. Spain
Atlanta, GA

Contributing Editor John Cockroft responds:

I bought my first pair of Olson FE-103s to put into the Sub-Miniature Speaker Enclosures and was quite pleased with them. I made a single prototype of the Simple Flat Sub-Mini. As with the Simpline, I used a 5/8″ × 11½″ × 4′ particleboard shelf.

The job is even easier than the Simpline. All pieces make use of the 11½″ width. Cut two pieces 12 7/8″ long for the front and back. Cut four pieces 2½″ wide for all the rest; then, cut a 3 5/8″ hole for the speaker centered 4 5/8″ from the top. You can achieve one pound per cubic foot stuffing density with about 2¾ oz of polyester fiberfill. I used the long dimension vertically.

The design uses one of my Simpline speakers, which is modified by two coats of PVA white glue (Elmer's) on the cone and dust cap. Don't get it on the surround. Add five grams of lead (nine split shot BB-size lead fish sinkers weigh this amount) to the juncture of the dust cap and cone (glued with white glue). I used some 1/8″ lead wire I had. See the Simpline article for method of attachment and "SB Mailbox," SB 2/96.

I used the Simpline contour filter in series with the positive (+) terminal of the speaker. This consists of a 10W, 10Ω resistor paralleled with a 50V or better 2μF Mylar® capacitor. The current Radio Shack listing of this speaker is 40-1197. It costs $10.95 and is in the auto section of the RS catalog.

*This speaker isn't in the same class as the Simpline and the Super Simpline, but it could have many uses. Used without a filter it could probably serve as a surround speaker in a home-theater setup. I once bi-amped it with a 12″ subwoofer, using the passive line-level crossover I presented in my Simpline Sidewinder Woofer article (*SB *4/95), which crosses over at about 160Hz. I also used a similar crossover with a crossover of about 340Hz. With either crossover it is a pleasant speaker.*

You could also place it in a child's room, where wall mounting could save space and reduce damage by tiny hands, or perhaps in your vehicle. You could use it as a school

DEVELOPER'S RESPONSE

I thank Dick Moore for his comprehensive review of Mac SLM. He has given the software quite a rigorous examination, which I hope will show readers just how useful it can be.

Mac SLM is a virtual instrument program sent into the world to sit inside the Mac of anyone who wants to measure sound and electrical signals. It has to adapt itself to whatever hardware it is in, and to whatever microphones and electronics are added to the measurement chain. In some circumstances, the user will have to provide some data to make Mac SLM accurate, and I am grateful that Dick has added a technical sidebar to illuminate how this is done.

My manual was written only to explain how to make Mac SLM work, and it was not intended to be a text on sound-measuring theory and practice. There are other good books and articles on that.

A new version of Mac SLM is imminent that will give all Macs access to their lower built-in sampling rates, so the user can sacrifice high-frequency extension for increased resolution. In addition, PowerMacs only will measure a longer sample interval at 44.1kHz. This will double the resolution for all Macs and quadruple it for PowerMacs. This version will also switch off AGC automatically in 16-bit mode without displaying a warning box.

An overload indicator and startup preferences would be great, but I could not include those things at the low sales price. If the user inputs a sine wave, it is easy to see any distortion harmonics on the display. You can sort out your gear this way before making a serious measurement.

Victor Staggs, Ph.D.
Orange, CA

SPL EQUIVALENCIES FOR MIKE-SENSITIVITY SPECS

Microphone sensitivities are rated in several different ways, with output voltage versus pressure units in: decibels sound-pressure level (dB SPL), microBar (μBar), Pascal (Pa), dynes/square centimeter (dyne/ cm^2), and Newtons/square meter (N/m^2). Here is how these quantities are *approximately* related:

94dB SPL = $1N/m^2$ = 1Pa = 10μBar = $10dyne/cm^2$ = $1.454 \times 10^{-4} lb/in^2$

74dB SPL = 1μBar = $1dyne/cm^2$ = $0.1N/m^2$ = 0.1Pa

0dB SPL = $20\mu N/m^2$ = 20μPa
= $200\mu dyne/cm^2$
= 2×10^{-10} atmosphere (bar)= 0.2nBar
= $2.9015 \times 10^{-9} lb/in^2$

More accurately,

1 atmosphere = 1 Bar = 194.09dB SPL = 101,330Pa (N/m^2)
= $1.0133 \times 10^6 dyne/cm^2$
= $14.693 lb/in^2$

For example, the sensitivity rating of Mitey Mike with its preamp is 39mV/Pa. This means that 94dB SPL at the mike will produce an output of 39mV RMS; a change of 20dB SPL will alter the output voltage by a factor of 10. The Panasonic WM-60AY electret condenser mike cartridge (from Digi-Key) has a rated sensitivity of −62dBV/μBar, which means that it puts out about 0.8mV RMS into its rated load impedance at 74dB SPL, or 8mV RMS at 94dB SPL.

Clearly, the Panasonic cartridge will work well up to 90dB SPL with an 8-bit Mac, whereas you need to attenuate Mitey Mike's output.

The situation is just the reverse with a Power Mac—Mitey Mike will work fine to 110dB SPL, while the Panasonic cartridge will need 34dB of amplification to work well at 94dB SPL.

REVIEWER'S UPDATE

I have used the new version (1.1) of Mac SLM, which offers significantly higher processing speed in its native power Macintosh version, as well as providing much better low-frequency resolution through selectable control of the sampling rate. As an example of the speed improvement, a pink-noise spectrum settles to within ±1dB of its final value in less than 20 seconds—this represents at least a ten times speed increase over the original version!

I have not tried the new versions that are supplied for the earlier Macs, but I can't see why they should not also work better than previously, thanks to the low-frequency resolution control alone. Dr. Staggs has also made the 1/12-octave resolution the default mode, which is very handy, and has fixed other user interface problems as well.

I highly recommend version 1.1 of the Mac SLM software for anyone using a Macintosh, especially Power Macs.

North Creek

Music Systems

High performance electroacoustic components
and accessories for the demanding audiophile

The Rhythm Project

and summer supplement
June, 1996

Simply Better Technology

North Creek
M U S I C S Y S T E M S

Background

History: The **MTM** (midrange-tweeter-midrange) loudspeaker style was first developed by Teledyne Acoustic Research (AR) in the late 70's as a high sensitivity loudspeaker system of controlled directivity. The style soon spread to other manufacturers, of which the KEF 104 was probably the most commercially successful. At the 74th AES convention in 1983, Dr. Joseph D'Appolito presented the landmark paper "A Geometric Approach to Eliminating Lobing Error in Multiway Loudspeakers". The paper clarified the acoustic qualities of the MTM configuration, and over the next few years it rapidly grew in popularity.

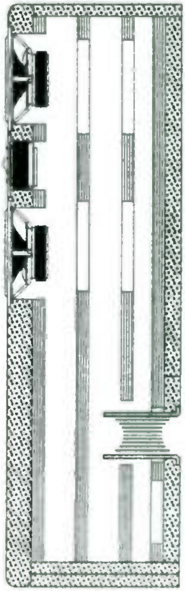
Characteristics: The MTM has several desirable performance characteristics that are difficult to achieve using conventional two-way loudspeaker designs:

Sensitivity and Impedance: First and foremost, the parallel-wired MTM configuration displays a 6dB increase in sensitivity when compared with the standard two-way. The sensitivity increase occurs because the driver effective cone area is doubled while the net impedance is halved (doubling current draw). Most high quality amplifiers have little difficulty driving the lower impedance, therefore the sensitivity increase is almost without negative consequence.

Radiation Pattern: When the MTM was first used in the Acoustic Research *Magic Speaker*, it was done so because destructive interference interactions in its radiation pattern created nulls in the same frequency region where the "floor bounce" usually occurs. It was later shown by Dr. D'Appolito that a positive interference lobe within a 15° window centered on the tweeter axis creates a large vertical listening position with nearly identical frequency response. Both of the above conditions are virtually impossible to achieve with conventional driver configurations.

The **Rhythm** Concept

The **Rhythm** was conceived as a cost-no-object high performance two way MTM loudspeaker system featuring high sensitivity, a detailed but romantic top end, smooth, natural, articulate midrange, exceptional imaging, and an aggressive, dynamic low end.



These sound like the design goals for virtually every midsized loudspeaker system; however, this level of performance is very rarely achieved. First of all, transparency throughout the midrange - the single most important element in high end reproduction - is difficult to achieve with a woofer larger than six or seven inches; however, bass response into the second octave at realistic listening levels requires significant air to be moved, virtually ruling out small woofers of conventional design.

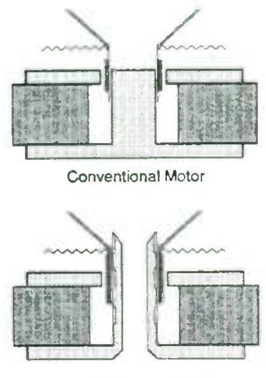
Secondly, a transparent, floating sound stage with image precision is almost impossible to achieve with monopole loudspeaker systems of large dimensions, again ruling out larger drivers.

Thirdly, to avoid upper midrange deterioration due to cone break-up and crossover parasitics while insuring midrange naturalness and image stability, a low crossover frequency - below 2 kHz - and uncomplicated crossover topology is required. This rules out virtually all conventional tweeters due to both power handling and excursion limits.

The system we present here achieves our design goals by fully exploiting the remarkable capabilities of two of the latest drivers from SCAN-SPEAK of Denmark, the 18W/8545 7" Carbon Fiber woofer and D2905/9300 1" soft dome tweeter, combined via a simple crossover network of the highest quality.

The Woofer

The SCAN-SPEAK 18W/8545 is a woofer of remarkable design. First and foremost, the driver is designed for enormous linear excursion. This is achieved through SCAN-SPEAK's development of the patent-protected SD-1 motor structure, diagramed below. Close inspection of the SD-1 system compared with conventional motors reveals the following:



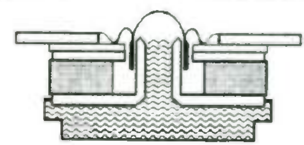
- The conventional motor structure voice coil length of 12mm or less is simply too short for reasonable output at low frequencies. Conventional top plate thicknesses of 6mm yields a peak-to-peak linear excursion of only 6mm (voice coil height minus air gap height = peak-to-peak linear excursion).
  The SCAN-SPEAK voice coil length is 19mm, yielding a p-p linear excursion of a full 13mm, *more than twice that of conventional woofers.*
- The conventional motor structure suffers from high second harmonic at low frequencies due to an asymmetric magnetic field about the top plate (air gap); that is, there is more stray flux below the top plate than above.
  The SCAN-SPEAK pole is extended well beyond the top plate, creating a symmetric magnetic field which greatly reduces low frequency second harmonic distortion.
- In a conventional woofer, high amplitude excursion modulates the voice coil inductance: outward travel decreases the amount of pole surrounded by the voice coil, reducing its inductance, where as inward travel increases the amount of pole surrounded by the voice coil, increasing its inductance. This is one reason why most woofer impedance curves do not look like a simple "resistor plus inductor" at high frequencies. This displacement-dependent voice coil inductance causes intermodulation distortion between high excursion low frequencies and higher frequency information, as well as creating frequency response aberrations by perpetually misterminating the crossover network. In addition, the inductance variations create a solenoid-type force between the voice coil and pole which introduces an offset to the coil rest position, increasing second harmonic distortion.
  The SCAN-SPEAK voice coil always surrounds an equal amount of pole, eliminating this source of distortion. The SCAN-SPEAK impedance curve is retraceable independent of drive level.
- In a conventional motor structure, current within the voice coil creates dynamic magnetic flux which modulates the motor field by partially demagnetizing and remagnetizing the section of the pole surrounded by the voice coil. This phenomenon creates both third and intermodulation distortion throughout the midrange, and is the other reason why conventional woofer impedance curves are nonlinear.
  The SCAN-SPEAK motor structure is constructed with copper rings, called "Faraday rings," bonded to the pole. The Faraday rings create a sympathetic flux which exactly matches the voice coil flux, eliminating this source of distortion.
- The concave cone-shaped, vented pole top eliminates reflections between the dust cap and pole while cooling the magnetic structure.
- The SCAN-SPEAK 18W/8545 cone is constructed of carbon fiber loaded paper and coated with damping compound. Damped carbon fiber is an exceptional cone material because it combines low mass with incredible strength, therefore it is extremely rigid at low frequencies yet can be easily controlled by the damping compound at mid and high frequencies. The 18W/8545 exhibits *nearly theoretically perfect performance for a 7" driver* - including the rising response and gentle turnover before roll off.

One can find far more detailed information about the causes and solutions of motor-induced distortions the AES publications Loudspeakers, Vol. 1 and Vol. 2 (60 E 42nd St, NY, NY 10165). Suffice to say that the engineers at SCAN-SPEAK have used every resource to develop and manufacture a motor structure which minimizes or eliminates the common second, third, and intermodulation distortions found in virtually all conventional loudspeaker drivers, resulting in a 7" woofer with exceptional low end performance even at very high volume levels while providing midrange purity rivaling the finest smaller drivers. The SCAN-SPEAK motor structure is unique and patent protected.

The Tweeter

The SCAN-SPEAK D2905/9300 represents the latest evolution of the tweeter which has long set the standard for musicality in soft dome tweeter design.

Comparing the D2905 to conventional tweeters, one finds the two marked differences:

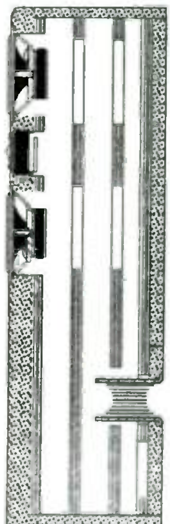


SCAN-SPEAK D2905/9300

- Conventional tweeters are constructed with a short-coil, long-gap geometry. This provides high linearity with limited excursion (typically 0.4mm), but dictates very poor performance under high excursion. Conventional tweeters, therefore, must either be crossed over at a high frequency or be used only in low power applications.
  The SCAN-SPEAK D2905 is constructed with a long-coil, short gap geometry; that is, it is constructed like a woofer. *The excursion of the D2905 is a full 1.0mm p-p, more than twice that of conventional tweeters.*
- Conventional tweeters have a limited air volume behind the dome and a flat top plate, which encourages reflection beneath the dome.
  The D2905 features a cone-shaped pole piece which is vented into a rear chamber, eliminating reflections while lowering the driver resonance.

The D2905 has long been used in many European and American high end designs, including several that are considered by audiophiles and reviewers alike as among the best in the world.

The Cabinet



The 18W/8545 is constructed with an enormous magnet structure and a very compliant suspension, yielding the Theile-Small parameters $Q_{ts}=0.31$, $F_s=28Hz$, $V_{as}=54$ liters. Small's EBP is 90.3, indicating a vented box. Over the years, we have found the QB3 alignment to offer the best compromise between bass extension and subjective bass quality. Therefore, our required cabinet volume is 43 liters, yielding a tuning frequency of 39.5Hz and an F_3 of 47.2Hz.

The cabinet is constructed based on the principles of the *North Creek Cabinet Handbook*; the rear is a 1½" MDF/Baltic Birch composite, the front is a 2½" MDF/Baltic birch composite, and Baltic birch internal bracing located aperiodically. The shell is ¾" MDF, and the internal surfaces are coated in North Creek Glop. This method of cabinet construction yields the most rigid, solid cabinet we have found constructed of wood materials.

Driver position is the standard MTM configuration, with the drivers centered on the fascia. The drivers are flush mounted and the fascia edges are radiused to minimize diffraction.

Access into the cabinet is provided via a removable panel in the cabinet rear. Cabinet ballast, the woofer crossover network, North Creek Glop and acoustic stuffing are installed through this panel, and additionally the low frequency tuning can be adjusted and optimized by accessing the port tube through this panel.

External cabinet dimensions are 9½ x 12 x 43, and all told the cabinets weigh in at a hefty 67lbs each, *sans* crossover.

The Crossover

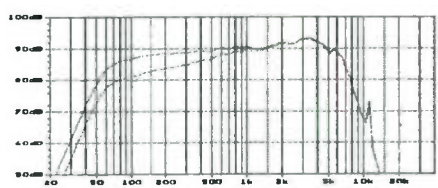
Crossover design is the single most important aspect of loudspeaker system design, and also by far the most difficult. For most high performance systems, engineering time from concept to sign-off is 1% driver selection, 4% cabinet design, and 95% crossover.

All North Creek crossovers are developed based on the following principles:

- Smooth, relatively flat frequency response on axis.
- Power response and out-of-phase curves should be symmetric about the crossover frequency.
- Filter transfer functions should be monotomic.
- Constructive interference is good; destructive interference is bad.
- Dips are better than peaks.
- The higher the overall impedance, the better.
- The fewer components involved, the better.
- The simpler, the better.

The 6dB Response Step:

The "6dB Response Step", also called the "Baffle Diffraction Step," is the most significant *acoustic* phenomenon one must deal with in crossover design, and also the phenomenon most often overlooked by amateur designers. Simply put, at the wavelength of sound roughly equal to twice the baffle width, the loudspeaker's radiation pattern changes from full-space (equal energy in front of and behind the loudspeaker) to half-space (all the energy in front of the loudspeaker). What this means to the designer is that the driver which measured reasonably flat in an infinite baffle anechoic chamber (the way most drivers are designed and measured) will actually have 6dB *less* bass and mid-bass when located out into the room. Hence, a loudspeaker design based on flat half-space anechoic frequency response and not corrected for the 6 dB response step may sound fine when flush against the front wall, but will be thin when placed out into the room where the sound stage is best. For our 9½" wide baffle, the step gradually manifests throughout the octaves bordering 712.8 Hz.



Effect of Baffle Diffraction Step (4π anechoic)

Note that with the MTM configuration, the 6 dB bass and midrange loss created by the 4π acoustic environment is compensated for by the increased system sensitivity. The resulting system exhibits a 4π in-room sensitivity throughout the lower midrange equal to the original 2π anechoic sensitivity of a woofer alone.

Other Frequency Response Considerations

Because we require a monotomically decreasing voltage plot across the woofer terminals and a simple crossover topology, *a driver with flat half-space frequency response is not suitable* (otherwise, the crossover would have to attenuate throughout the 6 dB response step region, go flat through the region above the step, and then begin attenuating again to mate the woofer with the tweeter - see Dickason Loudspeaker Recipes, Figure 4.44 for example.) The engineers at SCAN-SPEAK are well aware of this, and design their woofers with rising frequency response above 1kHz and a smooth high frequency roll off. The combination of the 6dB response step and rising driver frequency response above the step creates a *monotomically rising* in-room woofer response, which can be easily corrected to flat response by a *simple, monotomically falling* low pass electrical crossover slope.

Crossover Topology

Long familiarity with the SCAN-SPEAK D2905 tweeter has shown that its natural low end roll off, in conjunction with a simple second-order topology high pass filter and RLC resonance trap, yields an overall acoustic high pass characteristic of precisely third order. The simplicity of the lower order topologies - with only one reactive component in the signal path - will always outperform higher order topologies throughout the pass band, and the second-order topology with the trap provides both significant low frequency attenuation (imperative at high listening levels) and the ability to adjust the turnover Q.

To match the woofer to the tweeter, a third order acoustic slope is required. Electrically, the slope must begin at 200 Hz or so at about be 2dB per octave (to correct for the 6 dB response step), gradually maturing to a higher order. Initially, we begin with an impedance-compensated forth order topology, including damping resistors in series with all shunt capacitors and the first inductor being about twice that expected from formulae. While this is extremely complex, it is a suitable starting point. With five optimizable reactive components plus what amounts to three optimizable damping resistors in the woofer circuit, and six optimizable components in the tweeter circuit, a filter with the correct electrical characteristics may be quickly obtained.

Crossover Frequency Optimization

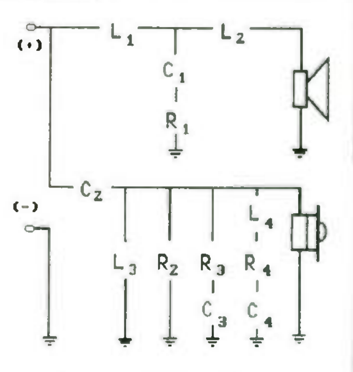
Analysis of the sum, power, and anti-phase curves of early combinations revealed that even with reasonably flat frequency response, both the power and antiphase curves were asymmetric about the nominal acoustic crossover frequency of 2kHz. We then began to vary the crossover point while adjusting for relative driver offset, and eventually developed several physically realizable possibilities of varying complexity that were worth popping together in the listening lab.

Subjective Evaluation and Final Crossover Design

It is at this point of the design process that one appreciates having a dedicated listening lab, measurement equipment, a fast computer, and a few thousand crossover parts - plus a coil winder - at their disposal. Prototypes were constructed and listening sessions began in June of 1995, entailing several hours per week over the next few months. High end crossover design is 95% listening, 5% measurements; most professional designers can come up with half a dozen combinations that all measure fine in an afternoon. A completed system must not only *measure* reasonably good, but also *sound* harmonically correct and intrinsically musical over an enormous range of material.

Furthermore, small component changes (on the order of 5%) and different capacitor combinations can have significant impact on system sound stage and imaging qualities.

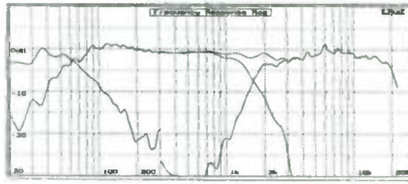
Crossover design was completed in March of 1996, and the final topology is shown below. This represents the best sounding combination, and the measurements verify that our objective goals were achieved. The tweeter section is a simple attenuated second order network, while the woofer section is very low Q third order network with a damping resistor in the T leg but without impedance compensation. In both cases, the drivers' acoustic roll off is third order.



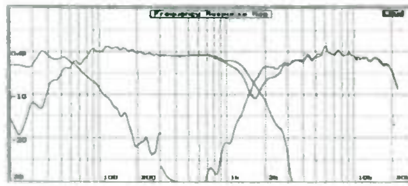
Rhythm Crossover Topology

The combined response is shown below, including the woofer and port close mic curves, and almost precisely matches a theoretical third order combination centered at 1.7 kHz, with the low- and high-pass frequencies staggered by a factor of 1.20, drivers in phase.

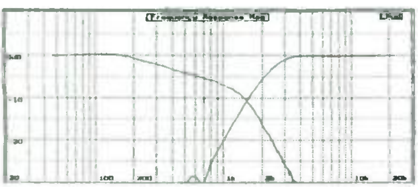
Note that the antiphase curve (below) is symmetric about the 1.7kHz crossover frequency, the antiphase null is quite deep, and there is absolutely *no* region of destructive interference. The tweeter -3dB point is 2100Hz acoustically and 2400Hz electrically, well within acceptable limits. At its 650 Hz resonance, the tweeter level is down 36dB acoustically and a full 32 dB electrically. Also note that the tweeter filter transfer function is monotomic. Lastly, note that the tweeter response is realized with only a single crossover component in the signal path. Naturally, this implies the tweeter series capacitor is the single most significant circuit element and must be of the highest quality.



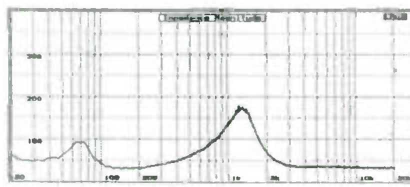
Combined Frequency Response



Antiphase Response



Filter Transfer Functions



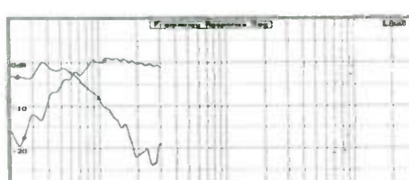
System Input Impedance

The woofer network topology is greatly simplified because the SCAN-SPEAK woofer has almost a perfect L+R impedance at high frequencies. Unlike conventional woofers, this impedance characteristic allowed us to consider the voice coil inductance as a series circuit element instead of forcing additional conjugate circuits to compensate for it. The topology then became simple damped third order that is correctly terminated, therefore we have precisely third order acoustic output. Also note that the woofer voltage transfer function is monotomically decreasing above 150 Hz. The other advantage to such a low crossover frequency is that the woofer is crossed out while still in piston, so any high frequency non-minimum-phase behavior and driver variation is inconsequential.

The end result is a very simple filter with *only three components in the signal path.* System sensitivity is conservatively rated at 89db ±3dB from 47Hz to 20kHz. The actual low frequency performance is dependent on room placement and vent tuning, and extends to below 40 Hz.

Low Frequency Performance

Inspection of the close mic frequency response curve reveals that the port output is centered 38 Hz, very close to the vent tuning of 36 Hz. This actually represents the best *sounding* combination (the theoretical QB3 specification called for a 39.5 Hz tuning). The port is adjustable via the rear access panel, so one may taylor the tuning by as much as ±.5 octave to best suite the associated electronics and room acoustics. The low frequency roll off is forth order below the tuning frequency, therefore the system is capable of considerable output into the mid thirties.



Woofer and Port Output (close mic)

Subjective Evaluation

This is of course the only important measure of a loudspeaker design's success. The criteria we evaluate are the system's overall harmonic integrity, its ability to create a convincing illusion of a live performance in the listening environment, and its *listenability* (a combination of the "goose bump", "foot-tapping", and "stay up late" tests). We don't consider a design completed until it excels in these three categories.

Harmonic Integrity: One would think that with modern test equipment this condition would be a given, but in reality it requires a very delicate balance between the low end tuning and midrange and top end voicing. Very small changes - on the order of 0.5 dB - over broad regions will completely upset this balance, and to further complicate the issue is the influence of the electronics and room. Our favorite test discs are Ry Cooder & V. M. Bhatt *A Meeting by the River* (Water Lily Acoustics 60997-0029-2) and Harry Connick, Jr. *When Harry Met Sally...* Soundtrack (CBS Records 7464-45319-2). The system presented - with a robust low end, a very gentle rise of 1dB between 300Hz and 15 kHz on axis and a gently falling third-octave averaged room response - sounds dead on.

The Illusion: In a few words: Sound stage, Focus, Presence. One must to use natural recordings of voice and acoustic music. The variations between venues is enormous, yet the system must recreate the dimensionality of each venue with equal ease. Focus and Presence are defined in lateral, horizontal, and vertical position. To this end, tight driver tolerances and 1% crossover component matching is essential. Our favorite test is track 6 of the Fairfield Four *Standing in the Safety Zone* (Warner Bros. 7599-26945-2), "Roll Jordan Roll". The Rhythm can focus so realistically down the middle and through the extremes that it is almost frightening. No kidding.

Image height requires an element of magic, and this loudspeaker has it spades. Our favorite studio test is the title track of P.J. Harvey's *Rid of Me* (Island 314-514696-2). Polly Jean's voice emanates from a precise point about four feet above and six feet behind the loudspeaker plane, literally *top dead center*, and the Rhythm can put it up there.

Listenability: This quality has no correlational measurement. Once a system is *listenable*, it becomes almost impossible to subjectively evaluate because one enjoys listening to the music too much, and realizes only after the goose bumps have subsided that the goose bump test was passed. The rhythm can do justice to everything from Bach to Zandig.

Adding a Subwoofer

Those who are familiar with Danish drivers have seen the venerable Peerless CC 12" subwoofer driver become more and more refined over the years. The CC12 has a very low resonance, a heavy cone, very long throw, an enormous magnet assembly, is now constructed with a Faraday Ring at the base of the pole. A 70 liter acoustic suspension enclosure produces a Q_{tc} of 0.88, an F_3 of 37Hz, and an F_{15} of 18Hz. In a normal listening room, with 15dB of gain below 40Hz, this translates into flat response all the way to 18Hz. Subjectively, the above combination reproduces the cleanest, tightest, most dynamic bass we have ever heard from a subwoofer this simple. We call it *Tahawas*, that is, the *Cloud Splitter*.

Merging the Tahawas subwoofer with the Rhythm (and other loudspeaker systems) is relatively uncomplicated, although we strongly suggest a separate amplifier be employed for each system. Sealing the Rhythm's vent (by removing the access panel and replacing the port tube with a cover) is absolutely necessary, as is true of *all* vented satellites. A small series capacitor between the pre-amp and satellite power amp serves as a perfect high pass filter for the Rhythm. The subwoofer may be driven either via a second or third order active low pass filter set at 80Hz and power amp, or from the amplifier with a passive low pass filter we provide. In either case, the subwoofer should be placed as close as possible to the room corners and must be connected in antiphase with the Rhythm satellites. The Rhythm/Tahawas combination is a true full range, four piece system of remarkable drive, pacing, clarity and dynamics.

Availability

We are releasing the **Rhythm** as a project; that is, packaged in component form but unassembled. The package includes drivers, all crossover components hand matched to ±1%, crossover boards, internal wiring, solder, connectors, binding posts, grille fasteners, screws, nuts, bolts, port tubes, NCMS Soft Glue, other adhesives, and the *Rhythm information packet*; in short, everything except the wood. The ability to read schematics, soldering skills, and electrical assembly skills are required to complete the project, and it is definitely not recommended for the first time builder.

- **Information Packet:** Consists of a complete packing list, cabinet diagrams and assembly manual, detailed crossover schematic, crossover layout and wiring diagrams, crossover assembly manual, the *North Creek Cabinet Handbook*, the *North Creek Wiring Guide*, other pertinent information, and a *single system construction license*. The price of the *Information Packet* is refundable with purchase of the project. **Rhythm Information Packet ...$20.00**
- **Rhythm Value Project** Consists of drivers, all 14 AWG air core inductors, Zen high frequency film capacitors bypassed with Harmony capacitors throughout, all Ohmite power resistors, all crossover components hand matched to ±1%, TefFlex AG™ wiring bypassed with Vampire OFHC copper, Big Posts™ binding posts, Big Toe™ spikes, etc; everything required to build the loudspeaker system except the wood. Component list price $1,029.00. **Rhythm Value Project ...$989.00 per pair.**
- **Rhythm Unlimited Project** Consists of drivers, all 10 AWG air core inductors, Zen high frequency film capacitors bypassed with Harmony and Crescendo capacitors for the woofer section, all Crescendo high frequency film-and-foil capacitors in the tweeter series section, Zen and Harmony capacitors in the tweeter parallel sections, all Ohmite power resistors, all crossover components hand matched to ±1%, TefFlex AG™ wiring bypassed with Vampire OFHC copper, Big Posts™ binding posts, Big Toe™ spikes, etc as above; everything required to build the loudspeaker system except the wood. Component list price $1,249.00. **Rhythm Unlimited Project ...$1,199.00 per pair.**
- **Rhythm/*Revelator* Project:** Identical to the Unlimited project above but supplied with the new SCAN-SPEAK D2905/9900 ***Revelator*** tweeter and using Crescendo film-and-foil capacitors throughout. Slightly faster than the Unlimited and offers even greater resolution. Component list price $1,687.00. **Rhythm/*Revelator* Project ...$1,575.00 per pair.**
- **Cabinet Flats**: fully pre-cut, pre-routed and pre-drilled cabinet boards, made exactly to our cabinet specifications and as outlined in the Cabinet Handbook. Require assembly, veneering, and finishing. Includes grille frame. ...$489.00 per pair.
- The Woodstyle REV 123 is also suitable for this project.

Please note that partially assembled crossovers and cabinet flats are not returnable.

- **Tahawas EX Project** (for electronic crossovers): Consists of one pair of Peerless CC12's, Big Posts, internal wiring, connectors, gaskets and screws. Cabinets much be constructed separately or purchased from an alternative supplier. **...$235.00 per pair.**
- **Tahawas Network:** Passive second order low pass network at 100Hz, optimized to mate the Tahawas to the Rhythm system. Consists of 12 AWG Music Coil inductors, Zen polypropylene film capacitors, Ohmite resistors, solder, wiring, connectors, crossover boards, etc. Network components only (does not include drivers) **Network ...$425.00 per pair.**
- Suggested Tahawas cabinets are MCM/AMS 80-430 or Woodstyle WS120 or equivalent.

Technical support concerning the **Rhythm** and other North Creek products is available over the phone on **Wednesdays only**. Please be certain your question is concise and that you have all relevant information at hand; other people may be waiting. Our technical support is limited to those products which we carry *only*. We will do our best to answer your questions; however, we simply do not have the resources or personnel to provide on-line technical support throughout our business hours. We can not answer technical questions in writing.

North Creek
MUSIC SYSTEMS

Main Street, Box 1120
Old Forge, NY 13420
Voice/Fax (315) 369-2500

MAILING ADDRESS	"SHIP TO" ADDRESS
Name ____________________	____________________
Address ____________________	____________________
City, State ____________________	____________________
Zip ____________________	____________________
Daytime Phone ____ - ____ - ____	____________________
☐ Please check box if your address has changed	Zip ____________________

Item Description	Quantity	Total Price

Shipping charges: Credit card orders are charged the exact UPS rate plus a $2.00 handling fee. International orders are shipped US Postal Service air mail and charged exact postage and insurance rates and any additional government or brokerage fees plus a $2.00 handling fee.

Subtotal:	
Shipping: 8% of subtotal, add $2.00 handling minimum charge $3.00	
New York residents add 8% sales tax	
Total	

METHOD OF PAYMENT

☐ **Check/Money Order**
(please allow two weeks for processing of personal checks)

☐ **VISA** ☐ **MasterCard** ☐ **American Express/Optima**

Card Account Number (please list all numbers on card)

Month Year Customer Signature

Expiration Date Required

Thank you for your order!

Design Without Compromise

PUBLICATIONS

North Creek Catalog: Our 1996/97 catalog plus updates, new items, updated pricing and our current sale flier, sent first class. The cost of the catalog is $2.00, refundable with purchase. We apologize that high printing and postage costs prevent us from offering these publications at no charge, however *we can not honor requests for complementary copies*. We will include the catalog at no charge with any purchase of $5.00 or more.

The Loudspeaker Design Cookbook The new **Fifth Edition** of the legendary cookbook has been greatly expanded, and includes in depth information on crossovers, low frequency alignments, driver testing, cabinet construction, and just about every other aspect of loudspeaker design. Author Vance Dickason has made this publication the most complete reference on the subject. This is **THE BOOK** for the serious hobbyist. 160 pages, soft cover.
The Cookbook ...$34.95

The North Creek Cabinet Handbook Our own publication documenting our approach to cabinet design. The *Handbook* features to-the-point discussions on almost every aspect of cabinet construction, including material requirements, brace positioning, and proper choices of adhesives. The *Handbook* is strongly recommended for those who wish to build a *great* loudspeaker cabinet from scratch. The $5.00 price may be deducted from any purchase over $100 within one year. **Cabinet Handbook ...$5.00.**

Loudspeaker Recipes, Volume One Also by Vance Dickason, Recipes specializes in computer aided design of two-way loudspeaker systems, and covers the mechanics of loudspeaker system design in detail. Soft cover. **Recipes #1 ...$24.95**

The North Creek Wiring Guide Our own publication documenting our method of crossover assembly. The *Guide* includes a discussion of signal path integrity, the correct way to treat connections between capacitors, resistors, inductors, and wire, as well as suggested materials. Also included is our standard wiring convention and suggested layouts for first, second, and third order crossover networks. The $5.00 price may be deducted from any purchase over $100 within one year. 12 pages. **Wiring Guide ...$5.00.**

Office Hours

North Creek Music Systems is open from 10:00 a.m. to 6:00 p.m. Tuesday through Thursday, 10:00 a.m. to 4:00 p.m. on Friday. Technical support is available during normal business hours on Wednesdays only.

How to Order

Call during our business hours above, (315) 369-2500.

Fax using a copy of the order form. (315) 369-2500, 24 hours.

Write using a copy of the order form: Main Street, Box 1120, Old Forge, NY 13420.

We accept **Visa**, **MasterCard**, **American Express** and **Optima** cards for phone and fax orders as well as personal and certified checks and money orders. All payments must be in U.S funds. COD orders require a 15%, non-refundable down payment.

Our guarantee, warranty, and return information is available upon request and is included with all shipments. We ship most orders with 24 hours.

(1) "Piéce de Résistance," *High Fi News and Record Review* Magazine, Link House Magazines, Ltd., UK March - June, 1987

North Creek
MUSIC SYSTEMS

Zen

METALLIZED POLYPROPYLENE FILM CAPACITORS

Zen high frequency metallized polypropylene film capacitors were developed in 1996 based on the original Sprague MIL C5514/CFR14 high performance metallized film caps.

Conventional metallized film capacitors use a European-made polypropylene film designed for low frequency filtering, rated from DC to 1 kHz. This film displays a loss factor significantly greater than our proprietary high frequency film, resulting in a capacitor with compromised high frequency performance, poor transient response, and significant intertransient noise. The *Zen* capacitors are unique in that they are the *only* reasonably priced caps we know of that use a true high frequency film, in this case a high current metallized polypropylene film that has been developed for applications between 20 Hz and 100 kHz.

The *Zen* capacitors have been optimized for high end audio applications. We specified low tension winding, a high conductivity alloy end cap to better match and seal the metallization layer, and actually have the 16 AWG silver-plated-copper lead hand soldered all the way along the entire cap end radius to maximize signal transfer while eliminating high frequency phase lag. Lastly, the capacitor directivity is determined by the printing on the label.

The sound of our *Zen* capacitors is truly exceptional. Midrange and high frequency information sounds far more natural than through other caps; smoother, softer, more delicate. Furthermore, these capacitors are remarkable in their ability to resolve fine detail without the slightest hint of grain or hardness. These are the finest metallized capacitors we have found for audio applications, easily outperforming most *exotic* capacitors at a fraction of their price. Made in USA.

FEATURES

- HIGH FREQUENCY METALLIZED POLYPROPYLENE
- 225 VDC: 150 VAC
- ESR RATED TO 100 kHz
- EXTREMELY LOW DIELECTRIC ABSORPTION
- EXCEPTIONAL HIGH FREQUENCY PERFORMANCE
- SELF-HEALING
- SILVER-PLATED-COPPER LEADS, TEFLON® JACKET
- PROVIDED IN MATCHED SETS

PRICES

PRICES		(L x D")
1.0 μF *Harmony*	5.50	1.75 x 0.70
2.0 μF	4.05	1.25 x 0.70
3.0 μF	4.35	1.75 x 0.70
3.9 μF	4.75	1.75 x 0.79
4.7 μF	5.20	1.75 x 0.87
6.0 μF	5.65	1.75 x 0.97
10.0 μF	9.35	1.25 x 1.10
30.0 μF	21.50	2.25 x 1.25
50.0 μF	34.25	2.25 x 1.75
100 μF	49.80	3.50 x 1.90

QUANTITY DISCOUNTS (non-mixed values):
5 - 9: 10%; 10 - 24: 15%; 25 up: 20%

The *Harmony* 1.0μF Bypass Cap

The ***Harmony*** bypass cap is made from a proprietary, 625 VDC version of our *Zen* high frequency metallized polypropylene film, and features a dielectric absorption 90% lower than conventional capacitors and an ESR fully one third lower. This is the most transparent metallized film cap we have ever heard, and strongly suggest it as a universal by-pass with *every* electrolytic or metallized capacitor stack. It also sounds great as an output coupling cap. Constructed with 20 AWG, 1000 V multistrand silver-plated-copper leads, Teflon® jacket, full radius soldered to high conductivity end caps. This is the latest technology in high frequency film from the largest supplier of quality film to the U.S. military. Available in 1.0μF only.

North Creek
MUSIC SYSTEMS

CRESCENDO
FILM AND FOIL CAPACITORS

CRESCENDO film-and-foil capacitors were designed in 1995 through 1996 as the ultimate expression of the capacitor designer's art. Initially developed for series applications with the SCAN-SPEAK D2905/9300 tweeter, the *CRESCENDO* capacitors have found their way into most of our loudspeaker and electronic circuits. In fact, we have found the *CRESCENDO's* to be the capacitor of choice for passive line level crossovers, and many of our tube-oriented friends feel it is the best coupling cap available.

For crossover applications, the *CRESCENDO* capacitors are without peer. The enormous conductor volume allows for flawless transient attack and superb definition even at the highest listening levels. We have also found the *CRESCENDO*'s midrange to be smoother and more liquid than any other capacitor we know of. In fact, we feel it is the first capacitor *ever* that is harmonically correct throughout the midrange.

The top end frequency performance of *CRESCENDO* capacitor stacks may be taylored to suite the specific tweeter needs. The 200V designs have a light, detailed upper extreme that is well suited to most soft dome tweeters and represents the most common voicing of high performance loudspeaker systems. Bypassing with 0.22µF, 0.47µF, or 1.0µF will soften the top end, providing a more romantic presentation without sacrificing detail. This combination is perfectly suited for metal and ceramic dome tweeters.

CRESCENDO capacitors are manufactured with a very high current, high voltage, high frequency film that is faster than any other film we have found. In fact, the pulse capability of a 1.0µF *CRESCENDO* cap is an astonishing *500V/µsec*. This translates into a top end with remarkable transient speed and a sound stage background that is dead silent.

While not inexpensive, judicious use of the *CRESCENDO* capacitors provide a performance increase worth many times their price. We strongly recommend them for critical applications in crossover, coupling and electronic applications. Made in USA.

FEATURES

- HIGH FREQUENCY POLYPROPYLENE FILM AND FOIL CONSTRUCTION
- EXCEPTIONAL MIDRANGE AND HIGH FREQUENCY PERFORMANCE
- ESR RATED TO 100 kHz
- EXTREMELY LOW DIELECTRIC ABSORPTION
- TESTED AND CLEARED AT THE FACTORY
- DISSIPATION FACTOR: < 0.08%
- RISE TIME:
  800V, 600V: >500V/µsec
  200V: >300V/µsec
- 10% TOLERANCE
- LEADS: 14 AWG SILVER-PLATED-COPPER, 600 VAC TEFLON® JACKET
- PROVIDED IN ±1% MATCHED SETS

PRICES		(L x D")
0.047µF 800V	$ 6.60 each	1.67 x 0.50
0.10µF 800V	7.45	1.69 x 0.70
0.22µF 600V	9.60	2.06 x 0.91
0.47µF 600V	12.25	2.06 x 1.03
1.00µF 600V	14.25	2.44 x 1.32
2.20µF 200V	14.75	2.44 x 1.00
3.00µF 200V	16.00	2.44 x 1.10
4.00µF 200V	17.50	2.44 x 1.20
5.00µF 200V	19.00	2.44 x 1.32
6.00µF 200V	20.50	2.44 x 1.40
10.00µF 200V	32.00	3.50 x 1.50

QUANTITY DISCOUNTS (non-mixed values)
5 - 9: 10%; 10-24: 15%; 25 up: 20%

Main Street, PO Box 1120, Old Forge, NY 13420 (315) 369-2500

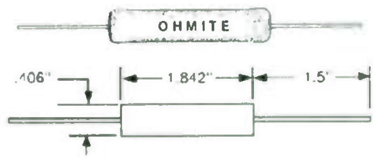
OHMITE 1% RESISTORS

There has been a long standing myth that *all resistors sound the same*. It is absolutely untrue. Subjective evaluation published by Duncan and Colloms (1) outlined the enormous differences in resistor sound quality, even between different lines of the same type. For most high power applications, the best sounding resistors on the market are the mil-spec wirewounds from OHMITE Manufacturing.

Our **OHMITE** power resistors are manufactured using a non-inductive winding pattern over a high temperature ceramic core, silicone-ceramic conformally coated, and rated with the military R-26 specification. One aspect of the mil testing is that the resistors withstand repeated, *1000 Watt*, 5 second overloads without sustaining any damage whatsoever. The leads are welded to the body and solder coated. These resistors also have an extremely low temperature coefficient (less than 50ppm/°C), and are pre-stabilized to offer decades of flawless service. 1% tolerance. Made in USA.

In terms of sonic quality, the OHMITE's surpass every other resistor we know of. They offer unlimited dynamics, exceptional detail, and stunning clarity. Even at *very* high volume levels they retain their intrinsic neutrality. These are the ultimate reference resistors.

OHMITE
Manufacturing Company

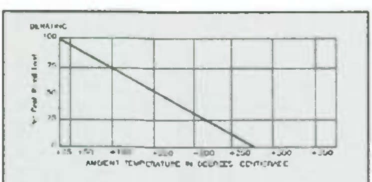


SPECIFICATIONS

- 10 WATT WIREWOUND
- 1% TOLERANCE
- OVERLOAD: 10 TIMES RATED WATTAGE FOR 5 SECONDS
- TEMPERATURE COEFFICIENT:
  1.00Ω - 8.06Ω: < ± 50 ppm/°C
  10.00Ω - 100.0Ω: < ± 20 ppm/°C
- DIELECTRIC WITHSTANDING VOLTAGE: 1000 VAC

PRICES

0.249Ω	...$5.50 each.
1.00Ω, 1.21Ω, 1.50Ω, 1.82Ω, 2.00Ω, 2.21Ω, 2.49Ω, 2.74Ω, 3.01Ω, 3.32Ω, 4.02Ω, 4.53Ω, 4.99Ω, 6.19Ω, 6.81Ω, 8.06Ω	...$3.25 each.
10.0Ω, 12.1Ω, 15.0Ω, 20.0Ω, 49.9Ω	...$3.10 each.
100.0Ω 5W	..$3.10 each.



QUANTITY DISCOUNTS

5 - 9	10%
10 - 24	15%
25 up	20%

Larger quantities upon request.
Discounts apply only to sets of the same resistance value.

How critical is pair matching:

Most resistors are ±10% tolerance; that is, a randomly selected pair can vary by as much as 20% and still be considered in spec. In series with a tweeter, that 20% variation translates directly into a 2dB output difference between the left and right channel - ***even if the tweeters are perfectly matched!*** This level of difference creates density variations within the sound stage, tends to skew specific images to one side or the other, and broadens image outlines. Tighter tolerance solves these problems. Always insist on ±1% matched pairs.

North Creek
MUSIC SYSTEMS

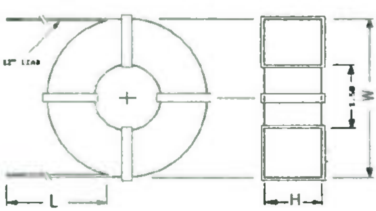
NORTH CREEK MUSIC COILS

North Creek Music Coil Inductors have been developed and optimized through an extensive program of subjective evaluation. We have tested many wired gauges of varying purity, core dimensions and materials, manufacturers, and even different insulations. Our military grade, high purity copper wire, combined with our proprietary manufacturing techniques and unique, low tension winding method yields an inductor superior to those offered by other manufacturers. North Creek is the *only* domestic manufacturer to use a low tension winding method, consistently producing an inductor with superior low end dynamics and a smoother midrange than coils available elsewhere.

Music Coils are manufactured in air core only. 18 AWG is suitable for applications where cost is the main consideration, or where a high DC resistance is required. 14 gauge is used by 95% of the high end community and should be considered an absolute minimum gauge for high performance applications. 12 and 10 AWG offer the ultimate in low end and midrange purity, and should be used in all applications where high performance drivers are employed. The sound of a 10 gauge coil is simply unmatched.

Music coils are custom wound to any requested value, 100% tested, and provided in ±1% hand matched sets. Tolerance is ±10% below 0.5 mH, ±5% for 0.5 mH and above. Manufacturing lead time is generally four days from order to ship date. Made in USA.

North Creek Music Coils



SPECIFICATIONS

- HIGH PURITY COPPER
- CONDUCTIVITY: >101.5% NEMA STANDARD
- MILITARY GRADE INSULATION
- VARNISH STABILIZED AND SEALED
- NYLON TIE WRAPS (4)
- DIELECTRIC WITHSTANDING VOLTAGE: > 2000 VPM
- AIR CORE

	18 GAUGE		14 GAUGE		12 GAUGE		10 GAUGE	
Value	DCR	Price	DCR	Price	DCR	Price	DCR	Price
0.15 mH	-	-	0.07	$ 3.40 each	0.05	$ 6.20 each	0.02	$ 11.00 each
0.20	-	-	0.08	4.00	0.06	7.40	0.03	13.30
0.30	0.24	$ 2.85 each	0.09	5.00	0.07	10.00	0.03	18.00
0.40	0.28	3.15	0.12	5.90	0.08	12.10	0.04	21.75
0.50	0.33	3.30	0.13	6.40	0.09	13.30	0.05	24.00
0.60	0.35	3.55	0.16	7.40	0.10	14.80	0.05	26.75
0.70	0.38	3.80	0.17	7.70	0.11	15.50	0.06	27.90
0.80	0.42	3.90	0.19	8.55	0.12	16.25	0.08	29.25
0.90	0.44	3.95	0.20	8.90	0.13	17.60	0.09	31.75
1.00	0.47	4.00	0.21	9.40	0.14	18.60	0.09	33.50
1.50	0.60	5.45	0.28	12.10	0.17	24.10	0.12	43.50
2.0	0.70	6.55	0.31	14.30	0.20	28.40	0.14	51.15
3.00	0.93	7.65	0.42	17.60	0.26	35.05	0.18	63.00
5.00	1.26	9.90	0.59	24.20	0.35	46.00	0.29	79.80
7.50	1.58	12.55	0.72	33.10	0.43	62.90	0.36	93.40
10.0	1.84	15.25	0.84	38.20	0.50	72.80		
15.0	2.42	18.05	1.15	42.85	0.74	84.30		
20.0	2.86	20.65	1.33	47.65	*Custom values are wound to order.*			

Quantity discounts of individual values: 5-9 pieces: 10%; 10-24 pieces: 15%; 25 up: 20%


North Creek
Main Street, PO Box 1120
Old Forge, NY 13420
(315) 369-2500
The Rhythm High Performance Loudspeaker Project features dual ulta-long throw SCAN-SPEAK18w/8545 7" Carbon Fiber woofers and the D2905 1" fabric dome tweeter in a vented cabinet of the highest quality. The precisely tuned crossover is constructed of the finest passive components and provided in 1% hand matched pairs. This full range speaker system offers superb musicality and unprecedented dynamics at a fraction of the cost of competitive systems available elsewhere.
Design Without Compromise
World Radio History

project or as a first speaker. However, for very little more effort, though of course less respectable looks, the Simpline and the Super Simpline will give at least an order of magnitude better performance.

Also, see SB 3/96 for my article on the Squatline. I recently modified this unit by raising the stuffing density to 1.375 lbs/ft³ and including bi-amping, using a passive line-level crossover similar to the one in the Simpline Sidewinder Woofer, but with a crossover of about 2040Hz. Both of these modifications significantly improved this device.

There's no reason why the Shortline couldn't benefit from this as well. It would probably do better with a stuffing density of about 1.25 lbs/ft³, using 24 oz of fiberfill. Since 16 oz is already in the Shortline, you must add eight ounces. Just put your hand up into the port and gently press upward, then add the new stuffing. This worked well in the Squatline, so it should be OK for the Shortline, since they're family members.

VALUE ADDED

With regard to Richard Campbell's review of Ray Alden's *Advanced Speaker Systems* (*SB* 2/96), I would like to emphasize two invaluable points that help make this book worth the price of admission:

1. The short synopsis of the theory of the infamous D'Appolito 3/2 configuration, and especially that we finally find in public print the statement that *all* filter orders are equally viable with the design.
2. Thiele/Small parameter variations for dual voice-coil woofers, i.e., how you must modify them for the intended application of series/parallel connnection and stereo/mono drive. I recall spending at least half a day in LEAP guessing, then modeling for verification, the changes to the various T/S parameters for a stereo-driven DVC subwoofer before I felt confident of the enclosure specifications. Now here it is in print for all to see.

Philip E. Bamberg
Bamberg Engineering Sound Lab
Tucson, AZ

BALLOONS, ANYONE?

The readers of *Speaker Builder* might be interested in my recent playing around with omnidirectional speakers. Some years ago, I wrote about ribbon speakers (*SB* 1/88) and was inspired to construct a pulsating cylindrical ribbon speaker (*SB* Mailbox, 4/88). This monstrous design was fun to build, but had a very low Wife-Acceptance-Factor (WAF). Furthermore, it didn't have much to say for itself and had some theoretical flaws, which readers kindly pointed out. It had to go, and became part of my neighbors' hen house.

However, from time to time I have thought further about a pulsating cylinder, or, even better, a pulsating sphere. Some designs have appeared over the years: the MBL speakers seemed to me a very good design—but at a murderous price. Then there were omnidirectional speakers, e.g., the Kugellautsprecher from Germany just after WWII—ball-shaped, with 32 drivers pointing in all directions—impractical and overlooked. There was also the Ohm speaker, with Lincoln Walsh's omnidirectional speaker. I had heard of it, but didn't pay much attention until I saw a refined and developed model at the '96 hi-fi exhibition in Copenhagen.

As you see (*Photo 1*) I did build a pulsating sphere of sorts. I butchered an inexpensive 6″ Monacor full-range speaker by removing the original membrane, and with the assistance of my nine-year-old daughter came up with a balloon as the new membrane. And it didn't sound so bad, but was definitely not high end. It did have some very good spatial potentials and played acceptably with the woofer section of my La Folia speakers.

For obvious reasons, I had to change the balloon every week, experimenting with sizes and shapes. I did use a preservative and had a spectacular membrane three feet high! It looked like a soap bubble, but played rather poorly, as the material damped the high frequencies too much.

A very small balloon blown up to the bursting point did much better. I glued it to the voice coil with contact glue, and it didn't rattle much except when it played piano and guitar music.

I had other problems with this new pet, such as keeping the air inside the balloon. I think a balloon made of aluminum foil might be much better for holding the air. Maybe one could construct a valve of sorts?

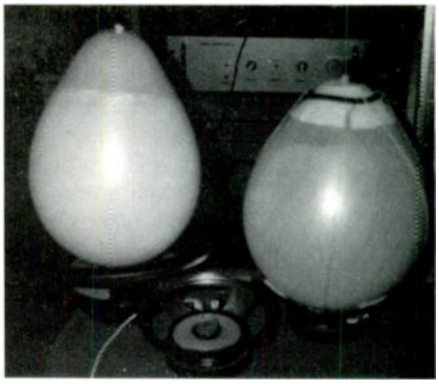


PHOTO 1: Reader Thofte's pulsating sphere design.

However, I abandoned the idea of a pulsating sphere and tried something like the DDD speaker—the same butchered speaker, but this time I got some anodized aluminum foil left over from Christmas. This material has a thickness of about 30µ and is quite well damped. I cut a cone and fitted it to the voice coil, again with contact glue (see *Photo 1*). And after some experiments, I made a lid of a smaller cone glued on top of the larger one. It had a good WAF and looked like a golden statuette, standing half a foot up in the air on a two-foot high speaker stand.

This speaker plays very well and has that magic spatial quality of an omnidirectional driver. Room information seems more like "the real thing" than with the ribbon speakers. On top of this, the driver was quite effective, and I had to damp it to match the ribbon woofer, which admittedly is not the most effective.

It did have a flaw: an undeniably nasal character, especially with women's voices. So I tried to damp the area around 900Hz with a 0.96mH coil and a 20µF condenser in series with the speaker. It seems to work! I call it "cone à la Walsh" in homage to the original idea.

I'm quite satisfied with my present sound, but it's a strain on my family life to have both a big ribbon speaker and this cone speaker filling the room. So I would like to build a conventional bass-section with a crossover around 250–300Hz. That shouldn't be too hard. Then I'd retire the ribbon speaker for a while.

Also, a better way to solve the nasal character of the sound could be to let the cone play into a small box filled with damping material. Or, maybe use the speaker in some horn construction? Perhaps other readers would like to join in on some of the projects. I welcome comments and ideas.

Ole Thofte
Copenhagen, Denmark

SUBJECTIVE OPINIONS

Good luck to Messrs. Colin and Bain ("Mailbox," *SB* 2/96) who would apply valid science to audio and warn us about side-show barkers and their wares. But when the snake-oil salesmen buy the advertising space and foot the bill for the magazine, what do you expect? Worse, the editor himself peddles such nostrums as CD rings.

Regarding the wondrous "new" TRT capacitors: non-inductive or extended-foil capacitors have been around for more than 60 years. I have two taken from a 1932 Atwater Kent radio, where they served as RF bypasses (*Photo 1*). I'm sure that Mr. Kent was not the first to discover their infinite properties, but since his 1934 service manual described them particularly clearly, I am enclosing a copy of the relevant page (*Table 1*).

To return to Mr. Colin's point: if the audio range extended to 10MHz, this "1000:1 smearing" business might have some validity. It does not. The editor could, if he chose, exercise some oversight of advertising and article content for the benefit of readers seeking technical guidance. There were no patent-medicine ads in the early issues of *Audio Amateur*, nor remarks such as "I put a TIM capacitor in my preamp and was blown away by the 20dB increase of the soundstage." Evidently, everyone is entitled to his opinion, but the editor should not appear to authenticate such speculations by repeating them uncritically. This is not (quite yet) the *National Enquirer*.

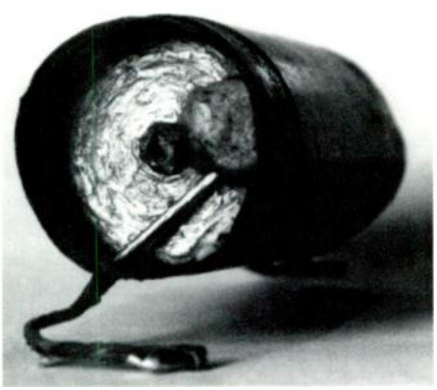


PHOTO 1: Atwater Kent .1μF 400V capacitor, showing the soldered connection to the tin foil.

If I hear a difference between the editor's credo ("*Speaker Builder* is published...in the interest of high-quality audio reproduction.") and his feeble reply to Mr. Bain that anything any listener says he hears is real, does that prove there is a difference?

Alan S. Douglas
Pocasset, MA

Editor's response:

Apparently the rise of scientific outrage in some can affect their ability to read. I did not, as Mr. Douglas states, say that what a listener says he believes he hears is real; I said only that he hears a difference. It is a real belief, but whether that corresponds to any verifiable reality is another question.

Apparently I did not make clear enough my position about subjective opinions. I abhor them in those who speculate about the motives of readers who say they hear a difference by making some specific change in their systems. The statements that such a reader is deluded are not based on fact. Any such statement would require a great deal more data than the critic has in his possession. To say that a listener is motivated by how much money he has spent on equipment is just the same sort of opinion held by the listener being criticized.

Such speculations about motive are not welcome, because they denigrate an individual. Readers are welcome to disagree with a subjective report on the effect of an upgrade, but they are not welcome to speculate about the motives of such listeners. It is totally unscientific, just for starters. Second, it is outside the acceptable limits of human discourse. In other words, it is rude. It is a justly famous category in formal logic, argumentum ad hominem, not acceptable in any debate.

I suppose Stereo Review *and* Audio *should, in all conscience, have rejected the first Philips ads for the compact-disc system when they first appeared. The claim was, "At last, perfect sound forever." And possibly the next year they might have balked at accepting the oxymoronic claim "...More Perfect*

TUBULAR FIXED CONDENSERS

(By Part Numbers)

Part No.	Value	Type†	Voltage	Super-seded by	Code No. printed on late type condensers
24509	.01 & .01	IND.	200	31190	
26550	.5	NI	200	.....	219
26660	.1	NI	200	.....	213
26820	.05	NI	200	.....	208
27234	.5	NI	200	26550	
27630	.01	IND.	200	.....	203
28040	.005	IND.	200	.....	201
28130	.0005	IND.	450	.....	402
:					
38160	.03, .015, .008	IND.	450	..	415
38260	.001, .004, .008	IND.	450	....	416

† Condensers designated as inductive (IND.) are constructed in such a way that the current must travel through one or more turns of the tin-foil plates in order to reach the ends of the plates. Such condensers have a slight inductive effect and are primarily used as low-frequency bypasses where the effect of this slight inductance is negligible.

Condensers designated as non-inductive (NI) are constructed in such a way that the current reaches the entire area of the plates without having to pass through any turns of the plates. Non-inductive condensers are used as high-frequency bypasses.

TABLE 1: Portion of capacitor listing from Atwater Kent Radio service manual.

Sound Forever." The marketplace takes care of such things. The response of the market was to point out the considerable shortcomings of the CD system. In publishing criticisms of advertisers in these pages, I think we fulfill our obligation to fairness.

If Mr. Douglas has some proof that CD rings have no beneficial effect, I would be glad to publish it. His opinion that they are in the class of "snake oil" is opinion, but his thinking so does not raise it to the level of scientific certainty.

BLINDFOLD TEST

I wish I had thought of using computer ribbon cable for speaker wire, as it appears to solve all the important problems at low cost. Eric Gilbert's article ("Make a Better Speaker Cable," *SB* 2/96) keeps the priorities in proper perspective: resistance, neat installation, inductance, and cost are presented first, and everything else last. Next time I need to run speaker wire under a rug, guess how I will do it.

Warren Bain's "Snake-Oil Warning" and Dennis P. Colin's "Ad Clarification" are also right on target ("Mailbox," *SB* 2/96). Until someone who has no vested interest runs a double-blind listening study of capacitors and cables, I plan to keep using surplus Mylar®, oil, and polypropylene caps.

I suggest that someone build four three-way stereo crossover networks: units 1 and 2 would have all InfiniCaps, soldered with Wonder Solder; units 3 and 4 would have new polypropylene caps in the tweeter circuit, multiple surplus Mylar caps in the midrange circuit, and motor-oil capacitors salvaged from dead hysteresis motors in the woofer circuit—all soldered with Radio Shack solder. Capacitors and inductors would be thoroughly tested for leakage and capacitance and trimmed to match (with the same type of caps). Only one set of speakers would be used with these external crossovers.

Next, the stereo crossovers would be mounted, with identical connectors, in four identical locking boxes by a technician unknown to the experimenters. The technician would first mount units 1 and 2 in the first and second boxes and label them A and B, or B and A, noting which is which in a sealed envelope. Then he would mount units 3 and 4 in the third and fourth boxes and label them X and Y (or Y and X); he would record this in another sealed envelope. Finally, the keys would be sealed in a third envelope.

Various cables could be hidden in old fire hose and tested the same way. Would this end the hype? I doubt it, but it just might slow it down.

According to my ears, test equipment, and spec sheets, distortion from nonelectrolytic capacitors and inexpensive cables is trivial compared to that caused by the very best speaker drivers. Listening without being influenced by product cost, hype, and design is very difficult for most of us. We hear what we want to hear. My test would eliminate wishful thinking. More light than heat would emerge from such a test. In the meantime, I will save my money for speaker drivers.

Speaker Builder is to be commended for printing letters critical of advertised products; please continue to be controversial. Many excellent products are advertised in *SB* that can back up their claims by wide acceptance or specs.

Jesse W. Knight
Woburn, MA

Classifieds

TRADE

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

THE BEST MUSIC YOU MAY NEVER HEAR. Free catalog. **CREATIVE MUSICIANS COALITION**, Dept. GBM, 1024 W. Wilcox Ave., Peoria, IL 61604, (800) 882-4262.

D.H. LABS has moved!! For information and review reprints on our high-performance **SILVER SONIC** audio cables, hookup wires, and connectors, contact us at PO Box 31598, Palm Beach Gardens, FL 33420-1598, phone/FAX (407) 625-8998.

NEW! BREAKTHROUGH SPEAKER PADS expand tonal range, add clarity, optimize full range reproduction, protect surfaces from spike holes, dampen distortion-causing vibration, maximize coupling, $7.95–$69.95. **KLEIN TECH SYSTEMS**, 4262 Northlake Blvd., Palm Beach Gardens, FL 33410, (407) 863-2198, FAX (407) 845-9844. Dealers welcome!

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

FOR SALE

Four Scan-Speak 18W-8546 Kevlar woofers, $175/pair or $320/all; four Vifa D25AG-35, $20/pair; eight audio-grade steel bobbins (like Madisound's), $5 each or will wind to suit. Phil, (800) 944-9056, ext. 271.

20MHz oscilloscope, dual trace with probe, reviewed in *Audio Amateur* 1/95, excellent condition, $275; Dynaco ST-70 with Van Alstine 70i mod, very good condition, $500. All prices include shipping costs. Greg Nawrocki, 21 Indiana St., Kitchener, ON N2H 2A4 Canada, (519) 745-1579.

Fluke 97 scopemeter with hard case and RS-232-C optical interface for computer and printer communication. Includes AC adapter, Nicad battery pack, probes, test leads, etc. Costs over $3,500 new, asking $1,900 Canadian funds. Budd, (604) 464-7732.

Altec: 291-A 8Ω horn drivers; 421 15″ woofers; N-1209-8A crossovers; JBL E-140 16Ω 15″ woofers; JBL "175" Alnico horn drivers, Dukane labels; EAW horns, similar to JBL 2345 but for Altec 1″ drivers; Sherwood S-2300 rackmount analog tuner. David, (914) 688-5024.

Onkyo T-9090 FM tuner with owner's manual, good condition, $125; pair a/d/s/ 7″ woofers, mint condition, $30. Will accept best offer. Dr. Steinberg, (215) 592-9765.

Master tapes, 28 year collection, over 100 hours of music. Mostly on-location, live symphony orchestra recordings, but also some jazz, vocal, choral, blue grass, and opera. Guaranteed finest technical quality, 10½″ reels, half-track, dbx. $1,000 plus shipping (will include Crown studio recorder and dbx for free). Roger Sanders, (505) 759-3822.

Fisher X202B, 45W/channel, $225; Rotel EQ, $40; pair Heathkit WM7s, 50W/channel, $250; Alphason Xenon tonearm, great sound, $250; QSC 1500a power amp, 350W/channel, 1,500 mono 4Ω, NIB, $500; Ampeg 100W tube guitar amp with stack, $750; Dynaco PAS-2X, $75; misc. tubes. James, (309) 837-2408, FAX (309) 837-6463.

WAMM crossover, first order Butterworth, 600Hz, 35 lbs each, $195/pair. Stephen, (707) 964-5857.

Pair JBL 2410 (pro version of LE-175), $200; pair JBL HL91 horn/lens, $125; pair Altec 288B, $375; pair MRII 564 horns for 288 drivers, $175; Crown D-150A IOC amp, $225; DC 300A series II, $400; 6–16 channel E-V and Yamaha mike mixers from $125; Dynaco SCA-80, $50. Kent Elliott, phone/FAX (913) 677-1824 (KS).

Audio Concepts speakers, model unknown, Dynaudio 17W7S and D28AF drivers, 10″ × 16″ × 8½″ light oak cabinets with black grilles, easily shipped, almost mint condition, $200 or best offer. Steve, FAX (614) 262-5958 (OH).

Cleaning house: woofers: four Madisound 1052DVC, $80; four 15258DVC, $150; four Audio Concept AC10, $140; four AC7, $40; four AC5, $40; four Focal 4VIII midwoofers, $100; tweeters: pair Focal T90TI, $50; four Seas H535, $40; four Vifa H25TG, $40. All terminals are solder-free. All prices include shipping. Hal, (540) 459-5571, FAX (540) 459-3809.

Classic coax studio reference monitors with 12″ E-V or University coaxial/triaxial drivers, 39″ × 15″ × 13″ cabinets with Grade A oak veneers and solid oak corners, 1″ baffles, $600–$750 per pair; pair complete cabinets without the drivers, $550; pair Altec 19s, mint, $1,750; pair Klipsch Heresys, mint, $550; pair AR1W, excellent, $300. Heerlein, (314) 579-0088.

Four pairs Altec 515E woofers, $400/pair; four pairs 291K drivers, $350/pair; five pairs MR64 horns, $250/pair; Heath AR15 receiver, $110; Dyna ST-70, $275; FM5, $40; McIntosh MC240, $1,400. Mike Frye, (612) 475-2993.

Cary SLA 70B Signature tube amp, 60W/channel, oil caps, $1,350; B&W 2000-3 shielded two-way monitors, $275; two ProAc Studio 100 monitors with target stands, $1,250. All in mint condition and less than one year old. Will split shipping costs. Mr. Willes, (800) 227-6121, 9–5 weekdays.

Pioneer PD-65 CD player, mint, $475; pair Madisound 10208 woofers, $50; single Scan-Speak D2905-9000, $35. Jerry, (601) 264-6971.

Pairs of small speakers in like-new condition: ARM1, NHT Super Zero, Radio Shack PRO-XL-5, Paradigm Titan, $150/pair; used classic Celestion SL-6S, $200. All plus shipping from Ohio. George Li, (216) 586-6707.

ESL sales, original performance from all pieces: pair KLH 9, $1,100; pair Janszen model 65, $125; pair Janszen model 130, $250. Buyer pays shipping costs. Jack, Box 368, Senecaville, OH 43780, (614) 685-2612.

Sony PCM-2500 DAT machine with all accessories and lots of spare parts including two upper drums and jigs for alignment, mint condition, originally cost $2,500, selling for $1,000. John, (201) 579-7849, eves.

Wife says no more speaker projects until these Infinity Quantum 3s are sold. Have new Pioneer 12″ subwoofers (used as woofer replacements), new MCM midrange soft domes, handmade grilles, ribbon tweeters and second mids to specs; needs pots. Asking $500. Dave, (818) 244-4753, eves. (PST).

Celestion 100s way modified (x3 loudspeakers), $575 or best offer; Lead cylinder sat/dual sub soundfield speaker system, modular, upgradable, $550 or best offer; Celestion DL4 II speakers, stock, included with 100s at $575 price; PS Audio IV preamp with HCPS with MCA & HCPS, $250. All reasonable offers considered. Robert Irwin, 936 Pearson Rd., Paradise, CA 95969, (916) 877-7734.

Theta digital cable, 1 meter, sealed, new '96, $90; pair Eminent Technology LFT-8 current tweeters, new '95, $795; ACI Titan subwoofers, $600 each or $1,100/pair; Luxman T-02 tuner with owner's manual, excellent, $225; AudioQuest Z digital cable, 1 meter, $45. Steve, (203) 397-3888, 7–10 p.m. (CT).

AR 2ax speakers, new foam, $75; KLH model 20 AM/FM changer plus speakers, $100; Sansui 2000A tube amp, wood, $75; Harman-Kardon TA3000X tube amp, excellent, $100; EMI (British) bookshelf speakers, three-way elliptical woofers, 4Ω, $125; AR 2 speakers, cabinets rough, will sell drivers only, $45. All plus shipping. Call for complete list. Roger, (941) 463-8887 (FL).

Four Dynapleat 6″ square speakers as described in *Speaker Builder* 2/94. Clark, (503) 288-2008, ext. 316, 7–3 (PST).

Single JBL 2242 HLP 18″ subwoofer, little usage, new model, $280 (was $619 new); four Audax HD134XO tweeters, high power, low crossover, $25 each or $85 for all; two Kicker C15 car subwoofers, $200 or best offer. Colin Dullaghan, 212 Daffon Dr., Indianapolis, IN 46227, (317) 888-9159.

WANTED

Experienced speaker cabinet builder or referral to one in Tucson/Phoenix area. Phil, (800) 944-9056, ext. 271.

Pair Dynaudio 21-W54 drivers, dead or alive, for reasonable price. Bob, (206) 824-2298, FAX (206) 824-2122 (Seattle, WA).

Hafler TransNova 9500 amp; used good drivers for experiments: pair Dynaudio M-560D, Esotar 54mm dome midranges, pair of current versions of Dynaudio D-54 or D-54AF midranges, pair Scan-Speak 13M/8636 midranges; pairs of Dynaudio 15-W75. Bill Donnally, 44 Miller Dr., Boonton Twp., NJ 07005, (201) 334-9412, eves. and weekends.

Old mikes, tape machines, audio gear, radio equipment, etc. Jim Diamond, PO Box 273, Trenton, MI 48183, (313) 783-9223.

Altec 291-16A drivers; Altec 291-16A diaphragms (stamped #21531); JBL 2402 "bullet" tweeters & diaphragms; Crown Macro-Tech 2400 amps, dead or alive. Bob, (804) 523-0711.

For 4240 Marantz receiver: bottom side plugged-in circuit board for sound determination. Koester, Postfach 1401, D-63204 Langen/Frankfurt, Germany.

Pair Acoustic Research AR3a speakers, plans, or sufficient info to build same. Fred Boatwright, 1217 W. Ellis St., Mesa, AZ 85201, (602) 969-7631, eves.

Nikko Audio ND-1000 stereo cassette deck, preferably in full working order, but will consider others. Willing to pay up to $100 for a mint unit. Rick, E-mail: arkgrafix@aol.com, (507) 625-9372 after 5 p.m. (CST).

Ad Index

50% OFF OVERSTOCK BOOK SALE!

Building construction this summer means we don't want to move these books anywhere else but OUTTA HERE!

ALL ITEMS MUST GO! CREDIT CARD ORDERS ONLY! All Sales Final! While Supplies Last! No Rain Checks!

QTY	ITEM #	NAME	REG.	NOW
3	BKAA2/G	Loudspeaker Design Cookbook IN GERMAN	$49.95	$24.97
7	BKAA2/P	Loudspeaker Design Cookbook IN PORTUGUESE	$49.95	$24.97
6	BKAC3	Experiments in Hearing	$34.95	$17.47
9	BKAC9	Acoustical Design of Music Education Facilities	$34.95	$17.47
3	BKAC12	Theatres for Drama Performance	$34.95	$17.47
2	BKAC13	Origins in Acoustics	$34.95	$17.47
3	BKAC14	Acoustics of Auditoriums in Public Buildings	$61.95	$30.97
2	BKAC15	Collected Papers on Acoustics	$44.95	$22.47
1	BKAH1	Measured Tones	$34.95	$17.47
6	BKAL1	Music Basics	$16.95	$8.47
5	BKAM1	Electronic Projects for Musicians	$19.95	$9.97
3	BKAM8	Electric Guitar Setups	$16.95	$8.47
2	BKAM9	The Musician's Guide to Home Recording	$24.95	$12.47
1	BKAR1	Digital Audio Engineering: An Anthology	$29.95	$14.97
5	BKAR2	The Compact Disc Handbook	$34.95	$17.47
5	BKAR3	Synthesizer Performance and Real-Time Techniques	$49.95	$24.97
8	BKAU1	Stereo Design for the Home	$7.95	$3.97
2	BKB2	The Art of Digital Audio	$89.95	$44.97
4	BKB4	Power Electronics Handbook	$84.95	$42.47
1	BKB5	Use of Microphones	$24.95	$12.47
3	BKB6	Audio Control Handbook	$32.95	$16.47
6	BKB7	Concert Sound and Lighting Systems	$21.95	$10.97
11	BKB9	Broadcast Sound Technology	$47.95	$23.97
1	BKB10	Coding for Digital Recording	$24.95	$12.47
2	BKB13	Sound Techniques for Video & TV	$24.95	$12.47
2	BKB14	The Sound Studio	$39.95	$19.97
2	BKB17	Operational Amplifiers/Clayton,Newby	$61.95	$30.97
4	BKB18	Operational Amplifiers/Dostal	$54.95	$27.47
6	BKB19	Troubleshooting Analog Circuits	$24.95	$12.47
2	BKB20	Sound Recording and Reproduction	$19.95	$9.97
1	BKB21	The Art of the Sound Effects Editor	$21.95	$10.97
3	BKB22	Effective Audio-Visual: A User's Handbook	$37.95	$18.97
1	BKB23	Sound Effects: Radio, TV, and Film	$37.95	$18.97
6	BKB25	Newnes Audio & Hi-Fi Handbook	$79.95	$39.97
2	BKB27	Advanced Audio Production Techniques	$32.95	$16.47
1	BKB28	Audio Engineer's Reference Book	$159.95	$79.97
1	BKB29	Microphone Manual: Design and Application	$36.95	$18.47
10	BKB41	The Art of Linear Electronics	$35.95	$17.97
1	BKC4	Analog Electronics with Op Amps	$37.95	$18.97
16	BKCM1	Introducing Digital Audio	$12.95	$6.47
5	BKCW1	There Are No Electrons	$12.95	$6.47
1	BKBL1	Audio Electronics Reference Book	$164.95	$82.47
18	BKBO1	Mobile Electronics Certification Program Study Guide	$34.95	$17.47
1	BKD3	Music, Physics and Engineering	$10.95	$5.47
9	BKD5	Fundamentals of Musical Acoustics	$16.95	$8.47
2	BKD6	On the Sensations of Tone	$14.95	$7.47
1	BKD10	Horns, Strings, and Harmony	$7.95	$3.97
4	BKD11	Science & Music	$7.95	$3.97
1	BKDE1	Op Amps and LInear ICs	$54.95	$27.47
1	BKDG1	Understanding/Installing Home Automation Systems	$29.95	$14.97
8	BKEV1	Solid State Audio Hi-Fi Construction Projects	$6.95	$3.47
3	BKEV2	Choosing and Using Your Hi-Fi	$6.95	$3.47
3	BKEV3	How to Use Op Amps	$9.95	$4.97
13	BKEV6	Modern Op Amp Projects	$6.95	$3.47
10	BKEV8	Audio	$11.95	$5.97
8	BKEV14	Digital Audio Projects	$9.95	$4.97
6	BKEV17	International Transistor Equivalents Guide	$11.95	$5.97
9	BKEV21	Preamplifier and Filter Circuits	$10.95	$5.47
6	BKEV22	Practical Electronic Filters	$12.95	$6.47
8	BKEV23	Public Address Loudspeaker Systems	$10.95	$5.47
5	BKHF1	Das Lautsprecherbuch #7 IN GERMAN	$29.95	$14.97
4	BKHL3	Guide to Sound Systems for Worship	$24.95	$12.47
4	BKHL4	Making Music With Your Computer	$17.95	$8.97
2	BKHL5	What's a Sequencer?	$5.95	$2.97
3	BKHL6	What's a Sampler?	$5.95	$2.97
3	BKHL7	What's a Synthesizer?	$5.95	$2.97
7	BKHL8	Acoustic Guitars And Other Fretted Instruments	$49.95	$24.97
4	BKHL9	Amps! The Other Half of Rock 'n' Roll	$24.95	$12.47
2	BKHN2	Radio and Electronics Engineer's Pocket Book	$27.95	$13.97
2	BKIE1	Wireless: The Crucial Decade 1924-34	$69.95	$34.97
2	BKIS1	Physics of Stereo/Quad Sound	$14.95	$7.47
38	BKKA1	A Desktop Reference of Hip Vintage Guitar Amps	$26.95	$13.47
45	BKMA1	The Wood Effect	$12.95	$6.47
7	BKMF1	High Fidelity Audio/Video Systems	$31.95	$15.97
7	BKMG1	Full Frequency Stereophonic Sound	$24.95	$12.47
4	BKMH1	Handbook for Electronics Engineering Technicians	$54.95	$27.47
6	BKMH5	Acoustics Source Book	$49.95	$24.97
2	BKMH7	Handbook of Transformer Design	$59.95	$29.97
2	BKMH8	Solders and Soldering	$59.95	$29.97
3	BKMH9	McGraw-Hill Electronics Dictionary	$49.95	$24.97
1	BKMH10	How to Test Almost Everything Electronic	$15.95	$7.97
4	BKMP1	The Musician's Guide to Multimedia	$19.95	$9.97
1	BKNEP1	New Ears: The Audio Career & Education Handbook	$24.95	$12.47
1	BKNO1	The Enjoyment of Music Standard Version	$47.95	$23.97
1	BKNO1/C	The Enjoyment of Music Shorter Version with Cassettes	$47.95	$23.97
2	BKP1A	The Penguin Guide to Compact Discs and Cassettes	$23.95	$11.97
1	BKP2	The Penguin Dictionary of Electronics	$12.95	$6.47
4	BKP3	The Penguin Dictionary of Music	$12.95	$6.47
8	BKP9	The Penguin Guide to Jazz on CD, LP & Cassette	$22.95	$11.47
4	BKPC1	Practical Digital Electronics Handbook	$14.95	$7.47
1	BKPC2	The PC Music Handbook	$14.95	$7.47
9	BKPC5	Practical MIDI Handbook	$14.95	$7.47
7	BKPC6	Electronic Music and MIDI Projects	$14.95	$7.47
9	BKPC7	Multimedia on the PC: An Introduction	$14.95	$7.47
7	BKPC8	Recording Techniques for Small Studios	$14.95	$7.47
9	BKPC9	Electronic Test Equipment Handbook	$14.95	$7.47
9	BKPC10	How To Set Up A Home Recording Studio	$14.95	$7.47
4	BKPH1	Handbook of Simplified Solid-State Circuit Design	$46.95	$13.47
3	BKPH2	SPICE: Guide to Circuit Simulation & Analysis Using PSpice	$27.95	$13.97
2	BKPH4	Introductory Operational Amplifiers and Linear ICs	$49.95	$24.97
1	BKPH7	Digital Signal Processing Experiments Using DSPlay w/ Disk	$34.95	$17.47
1	BKRI1	Recording Industry Sourcebook 1993	$64.95	$32.47
5	BKRS1	Getting Started In Electronics	$4.95	$2.47
5	BKS10	IC Op-Amp Cookbook	$24.95	$12.47
6	BKS18	TTL Cookbook	$24.95	$12.47
2	BKS22	Modern Dictionary of Electronics	$39.95	$19.97
2	BKS26	CMOS Cookbook	$24.95	$12.47
3	BKS28	Handbook for Sound Engineers	$99.95	$49.97
9	BKS32	How to Read Schematics	$19.95	$9.97
1	BKS35	Musician's Guide to Acoustics	$39.95	$19.97
6	BKS39	Making Sense of Sound	$10.95	$5.47
3	BKS40	Power Supplies: Projects	$10.95	$5.47
4	BKS41	Multitester Guide	$14.95	$7.47
4	BKS43	Random Access Audio	$26.95	$$13.47
4	BKS44	Understanding Telephone Electronics	$24.95	$12.47
8	BKS46	Ultimate Soundblaster Book	$34.95	$17.47
19	BKS47	Build Your Own Home Theater	$16.95	$8.47
3	BKS48	Sound Systems for Your Auto	$16.95	$8.47
6	BKS49	Harmonics	$24.95	$12.47
2	BKS52	Magic of Interactive Entertainment	$39.95	$19.97
1	BKSD1	70 Unique DIY Speaker Enclosure Ideas	$16.95	$8.47
2	BKSD2	70 MORE Unique DIY Enclosure Ideas	$16.95	$8.47
9	BKSM1	Record Shelf Guide to Classical Repertoire	$16.95	$8.47
4	BKSP1	Music Speech Audio	$34.95	$17.47
2	BKSR1	Using Time Code in the Reel World II	$19.95	$9.97
2	BKSV7	Modern Methods Acoustical Analysis	$69.95	$34.97
3	BKSY1	The Tapeless Directory	$24.95	$12.47
3	BKT9	Illustrated Dictionary of Electronics	$28.95	$14.47
1	BKT11	Understanding Electronics	$13.95	$6.97
7	BKT19	Troubleshooting/Repairing Audio Equipment	$19.95	$9.97
6	BKT20	Troubleshooting/Repairing CD Players	$24.95	$$12.47
1	BKT21	Marquetry and Inlay	$15.95	$7.97
4	BKT23	The New Stereo Soundbook	$19.95	$9.97
3	BKT29	Power Supply/Battery Charger Circuit Encyclopedia	$11.95	$5.97
10	BKT31	Lenk's Audio Handbook	$22.95	$11.47
5	BKT33	Woodworking for Beginners	$15.95	$7.97
11	BKT34	All Thumb's Guide to CD Players	$9.95	$4.97
2	BKT35	Troubleshooting/Repairing A/V Cass Plyrs/Recrdrs	$19.95	$9.97
3	BKTE1	Tonmeister Technology	$19.95	$9.97
3	BKTF1	Homebuilt Dynamo	$64.95	$32.47
2	BKTN2	Marquetry and Veneer	$9.95	$4.97
36	BKTP1	Heath Nostalgia	$9.95	$4.97
2	BKU1	The Audio Dictionary	$19.95	$9.97
4	BKVN3	Music, Sound, and Technology	$54.95	$27.47
1	BKVN5	DAT Technical Service Handbook	$49.95	$24.97
6	BKW5	Physics and the Sound of Music	$64.95	$32.47
4	BKW6	Operational Amplifiers/Barna, Porat	$59.95	$29.97
4	BKW7	Operational Amplifiers/Rutkowski	$69.95	$34.97
15	BKX1	Perception of Reproduced Sound	$9.95	$4.97

OLD COLONY SOUND LAB

PO Box 243, Dept. B964, Peterborough NH 03458
Tel. 603-924-6371, 603-924-6526 Fax 603-924-9467

SHIPPING: Add 7% USA 14% Other Surface 25% Other Air HANDLING: Add $2 per order

• MC • Visa • Discover • Check/money order US$ US bank•

Reader Service #19


MDM 85
MDT 33
MONSTER XP


Parts Express
1996
CATALOG
800-338-0531

High-Tech Audiophile Loudspeakers

Typical Double Magnet Woofer Cross Section

For Further Information Please Contact: **morel acoustics** USA
414 Harvard Street
Brookline, MA 02146
Tel: (617) 277-6663
FAX (617) 277-2415

Reader Service