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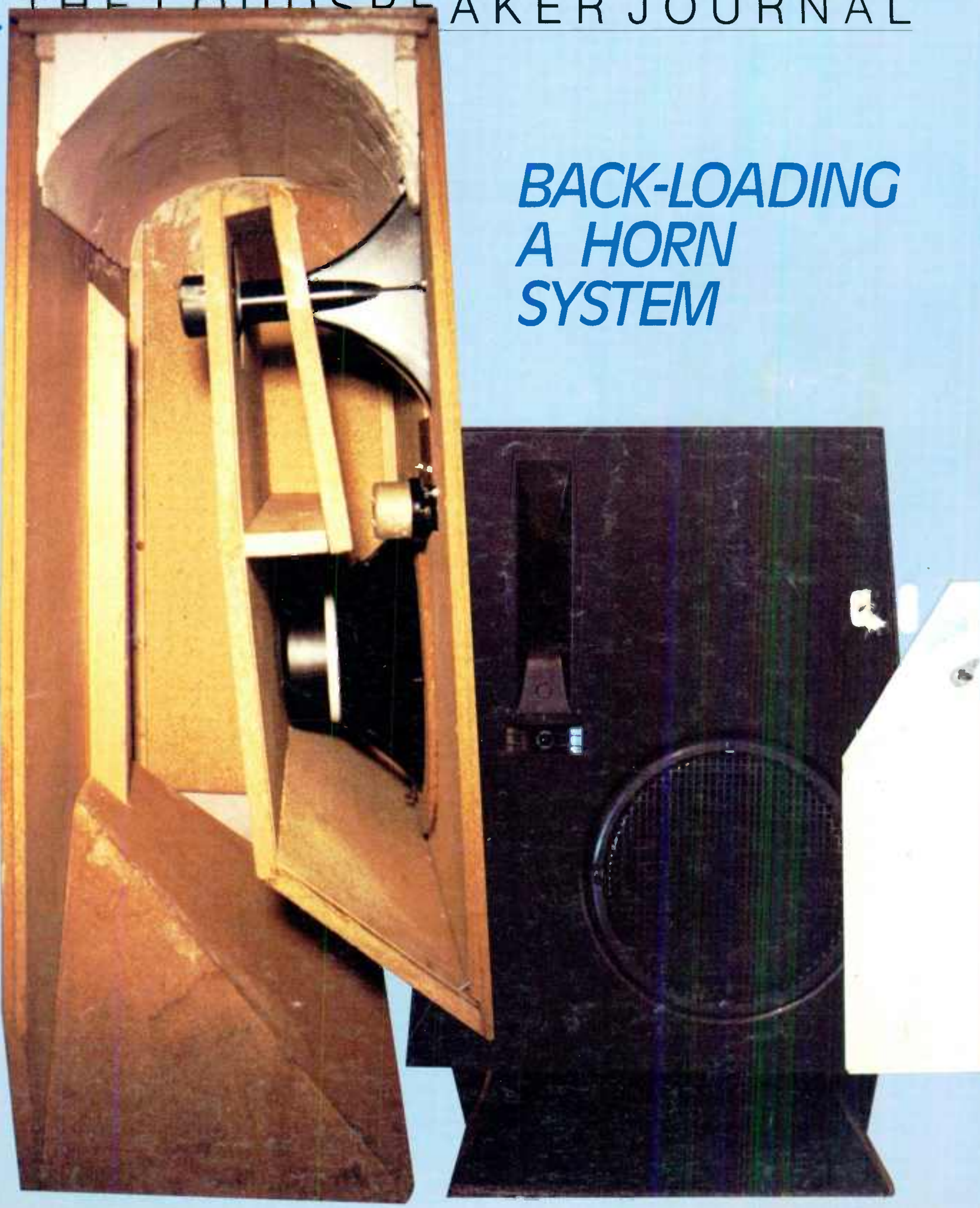
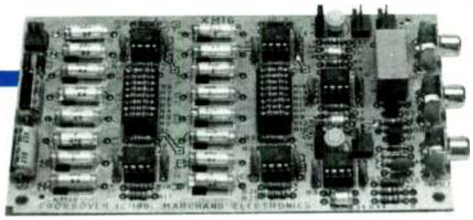
Speaker Builder

THE LOUDSPEAKER JOURNAL



BACK-LOADING A HORN SYSTEM

Good News



The XM-16 Electronic Crossover Network, which features a 48dB/octave filter slope made possible by its eighth-order constant-voltage design, has been released by **MARCHAND ELECTRONICS**. The crossover frequency can be set between 20Hz and 5kHz using plug-in frequency modules. Signal-to-noise ratio is better than 110dB and harmonic distortion at 1kHz is less than 0.001%.

The circuit incorporates a two-section, four-stage filter network with pre and post amplification and ambient-signal protection during startup and shutoff. Output level controls are included on the board but can be remotely located on your control panel using the optional XM-16 PT, a remote cable, connector, and potentiometer assembly. The unit uses 1% metal film resistors, 1% polystyrene capacitors, and gold-plated connectors throughout. All components are mounted on a 3.2″ by 5.8″ double-sided circuit board with plated-through holes. Each audio channel requires its own XM-16.

The XM-16 is available in kit form with detailed assembly instructions and circuit description (XM-16-K, $59.95) or assembled (XM-16-A, $79.95). For more information, contact Marchand Electronics, 1334 Robin Hood Lane, Webster, NY 14580.

Fast Reply #HF1068

DESIGN ACOUSTICS, a division of Audio-Technica US, has introduced the PS-55CV, a full-range, two-way loudspeaker system designed for video applications or for use as the center channel voice in a sophisticated surround-sound home theater system. The speaker is also suited for use in pairs as part of multi-channel audio/video and home theater systems.

The system is shielded to prevent interference with the video signal, which can be caused by the proximity of unshielded speaker magnets to the video screen. You can place the compact (7″ by 10¼″ by 6″) speaker directly on a television receiver/monitor without picture degradation.

The PS-55CV incorporates a 5¼″ long-throw woofer and a ¾″ ferrofluid-cooled dome tweeter, and it offers a frequency range of 65Hz–20kHz. When used with full-range center-channel systems, it delivers the entire signal and can handle the higher power levels typical of such systems. When used with a limited range system, the PS-55CV provides clean bass performance down to the cut-off point, particularly important in the 100–200Hz range.

The finish of the PS-55CV is black ash vinyl. Pre-drilled bracket holes in the rear of the cabinet make wall mounting the speaker near the video screen a simple procedure.

The PS-55CV sells for $119.95/ea. For more information, contact Dorie Johnson or Roxanne Ricks, Design Acoustics Division, Audio-Technica US, Inc., 1221 Commerce Dr., Stow, OH 44224, (216) 686-2600.

Fast Reply #HF22

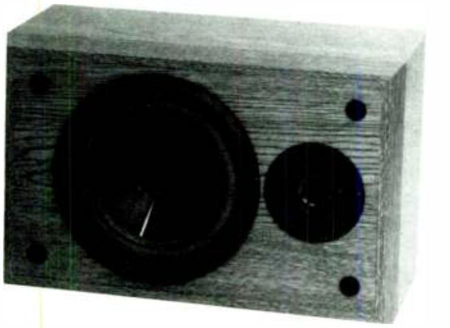
ROCKFORD has announced three assembly kits developed for industrial/vocational students and hobby kit builders. Kits include a 10W/channel amplifier, two 6.5″, 8Ω satellite speakers, and a 10″, 8Ω subwoofer. Each comes with a 72-page assembly workbook containing photos, illustrations, glossary, and suggested quizzes.

You can assemble these kits for use with a Walkman™ cassette tape player or Discman™ disc player, creating a complete stereo system. You can also decide on the finishing look, colors, and materials, or select finishing materials from Perfect Interface, Rockford's accessory division.

As individuals are involved with kit assembly, they will also be exposed to Rockford's national Practice Safe Sound Campaign.™ The introduction of safe sound principles will be accomplished in part through a series of safe sound "tips" created by cartoon characters Boomer,™ Woofer,™ and Tweeter.™ New merchandise items, including T-shirts and stickers, supporting the Boomer™ projects are also available.

For more information, contact Rockford Corp., Educational Services, 613 S. River, Tempe, AZ 85282, (602) 967-3565, ext. 3010.

Fast Reply #HF56



INFINITY has introduced the Reference E-L, a modest-sized (11⅝″ by 7½″ by 6⅝″) bookshelf loudspeaker. It uses Infinity's polypropylene cone. The unit features a 5¼″ woofer and a wide dispersion, ½″ polycarbonate tweeter.

Frequency response of the Reference E-L is 70Hz–20kHz, ±3dB, with the crossover frequency set at 5.5kHz. Nominal impedance is 6Ω. Recommended power is between 10 and 60W RMS, with efficiency rated at 89dB at 1W/1M. The speaker is available in Chatsworth oak or black ash vinyl.

The E-L sells for $169.95/pair. For more information, contact Richard Baccigaluppi or James Wunderlich, Infinity Systems, Inc., 9409 Owensmouth Ave., Chatsworth, CA 91311, (818) 407-0228, FAX (818) 709-9486.

Fast Reply #HF354

← ***Fast Reply #HF29***

OPTOELECTRONICS offers a 16-page brochure describing the firm's newest handheld and benchtop instruments. It includes descriptions, technical data, and useful tips on how to use frequency finding handi-counters, universal counter-timers for lab and field, PC-based counters with Windows 3.0 for control and display, active preselector bandpass filters, and antennas and accessories. It is free to all involved in subaudio to 3GHz.

For more information, contact Bill Owen, Optoelectronics Inc., 5821 NE 14th Ave., Fort Lauderdale, FL 33334, (800) 327-5912 or (305) 771-2050.

Fast Reply #HF1137

POLYDAX has announced the DTI01, a 1" pure titanium dome tweeter that creates an extended high-end performance. Using a proprietary radius compliance surround technology, the DTI01 is characterized by a smooth transient response and precise imaging. Other features include a two-layer voice coil, high-sensitivity level (95dB, 1W/1M), and a heavy duty 10 oz. magnet. The frequency range is 5-30kHz.

Polydax has also introduced a new line of Norsorex gaskets. A super-damped material, Norsorex was initially developed as surround material and is used on Polydax's high-end loudspeaker components.

Placed between the loudspeaker basket and cabinet, these gaskets help eliminate vibrations and resonances. Available in a variety of custom sizes, the gaskets have been designed to fit all Polydax standard drivers.

A test kit is available to show the difference between Norsorex gaskets and the most common gasket material. For more information, contact Polydax Speaker Corp., 10 Upton Dr., Wilmington, MA 01887, (508) 658-0700.

Fast Reply #HF1345

AUDIOACCESS has launched their six-zone receiver, the MRX. Among its most notable features are compatibility with the twisted-pair wiring format defined by the EIA CEBUS standard, a special stereo AM/FM tuner section, and the fact that the MRX is the first multi-zone, multi-source receiver to come equipped with six 40W/channel amplifiers and six separate zone controllers, providing six zones with independent control of source and volume level without affecting any other zone.

Audioaccess has also announced a lineup of custom installation accessory products that simplify the installation of entire home entertainment systems. The Source Equipment Interface ($500) module is an infrared interface module that lets Audioaccess control systems integrate with most other brands of source equipment without hard-wiring.

The SRM/2 ($200), an updated version of the company's Speaker Relay Module, provides independent on/off control of speakers in rooms within the same zone. Another module, the Special Interface Module ($300) helps integrate Audioaccess' control systems with any computer-controlled equipment.

For more information, contact Richard Frank, Frank Marketing Associates, 8 Mohave Rd., Medfield, MA 02052, (508) 359-5977, FAX (508) 359-5343.

Fast Reply #HF1354

Due to surveys at the AES in Paris and at the Musikmesse in Frankfurt showing that businesses most often use Speakon loudspeaker and amplifier connectors, **NEUTRIK** has intensified the automation of its production assembly and has doubled its capacity. Also, Neutrik is working on a draft for an IEC standard.

SPEAKEASY has introduced Filter Designer 1.0, an electronic circuit analysis program. Its primary emphasis is loudspeaker crossover networks and passive or active audio filters. It can import data from SpeakEasy's Low Frequency Designer program and other sources to facilitate computation of a total loudspeaker system response including effects of driver, enclosure, and crossover. It also functions as a basic circuit analysis program for other types of design work.

System requirements are an IBM PC or compatible with 640K minimum, EGA/VGA/Hercules or AT&T graphics, and Epson or HP compatible printer support.

Filter Designer 1.0 sells for $195. For more information, contact SpeakEasy, 46 Cook St., Newton, MA 02158, (617) 969-1460.

Fast Reply #HF68

TRUE IMAGE has announced version 2.0 of MacSpeakerz, a loudspeaker design application for the Macintosh. In addition to frequency response, this version calculates and displays cone excursion, impedance, phase, and group delay responses for loudspeaker drivers in a closed or vented enclosure. Version 2.0 also includes an array of interactive loudspeaker calculators, each dedicated to a particular aspect of loudspeaker design.

The program requires 512K of memory and one 800K disk drive. It is fully compatible with System 7.

MacSpeakerz 2.0 will be shown at the Acoustical Supply International booth during the 91st convention of the Audio Engineering Society to be held in New York City from October 4–7. It sells for $299. Registered users can get upgrades at a discount.

For more information, contact Sharon Alsup, True Image, 349 W. Felicita Ave., Suite 122, Escondido, CA 92025, (619) 480-8961.

Fast Reply #HF1355

CAIG's CRAMOLIN® ProGold 100 is a nonabrasive/noncorrosive formula that conditions gold connectors, thereby enhancing their conductivity characteristics to transmit electrical signals efficiently. The product coats the entire connector surface, providing protection from abrasion (insertion resistance), wear, and atmospheric contamination.

CRAMOLIN ProGold 100 is ideal for use on edge connectors, batteries, interconnecting cables, plugs, switches, sockets, relays, and so on. It is available in spray, liquid, precision dispenser, wipes, and pen applicators.

For more information, contact Mark K. Lohkemper, Caig Laboratories, Inc., 16744 W. Bernardo Dr., Rancho Bernardo, CA 92127, (619) 451-1799, FAX (619) 451-2799.

Fast Reply #HF167

SESCOM has available a catalog of new products. It includes new product areas as well as extensions of other product lines. Categories are isolator series, hand-held test equipment, field pro-series, new portables, and rack electronics. For a catalog, contact Sescom, Inc., 2100 Ward Dr., Henderson, NV 89015-4249, (702) 565-3400, FAX (702) 565-4828.

Fast Reply #HF664

Continued on page 8

Speaker Builder

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About This Issue

Horn enthusiasts who dislike the harshness of the Klipschorn may approve of **Rick Steiner**'s back-loaded wall horn project. Beginning on page 10, he provides a brief history of this type of horn, along with construction tips and procedures for building one.

Marc Bacon has named his speakers "Intégrité" because he believes they show integrity as truthful sound reproducers. To read about his design goals and procedures, turn to page 22.

Often articles about transmission lines fail to mention the relationship between stuffing density and line length. **Larry Sharp**'s helpful equations help fill this void. Turn to page 30.

Dan Ferguson, author of *Killer Car Stereo on a Budget*, is again improving the sound of car audio—this time in his friend's Ford Bronco. Details of the project begin on page 32.

The Minimus 7, a popular speaker for many years, has undergone seemingly random variations in different production runs. Beginning on page 38, **James Lin** proposes a general approach to modifying all versions.

Glen Travis, on page 40, offers suggestions for helping others resolve problems they may encounter in speaker and cabinet assembly.

Beginning on page 44, Contributing Editor **Gary Galo** reviews *Audio Anthologies Volumes 2* and *3*.

Finally, we welcome a new columnist to *Speaker Builder*. **David Moran** will be reviewing loudspeakers in the marketplace. He introduces himself on page 52.

On our cover: **Rick Steiner**'s back-loaded wall horn speaker. Photo by the author.

In *SB* 3/91, we omitted mentioning that the ribbon speaker gracing Scott Wolf's system is David Graebner's Auricle 5 from SpeakerLab (6307 Roosevelt Way NE, Seattle, WA 98115).

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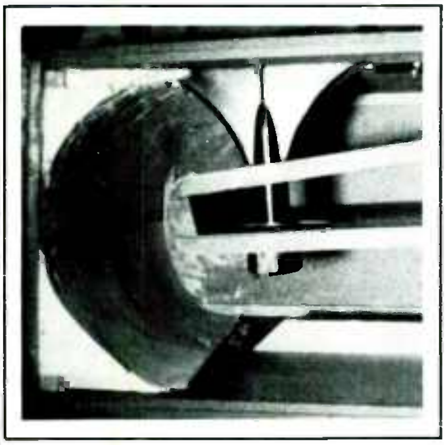

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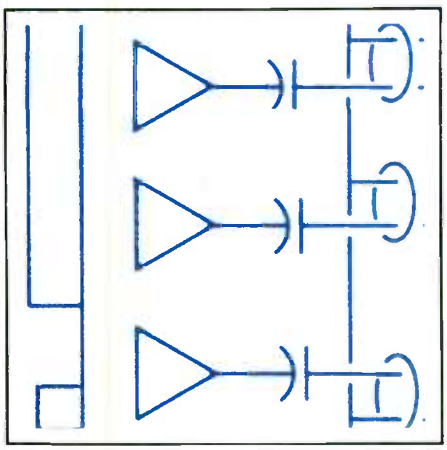

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FEATURES

DEPARTMENTS

Continued from page 3

STANFORD RESEARCH SYSTEMS has announced several products. The SR760 ($4,350) is an FFT spectrum analyzer with a 90dB dynamic range. Its frequency spans from 191MHz–100kHz and it has a 50kHz real-time bandwidth. Analysis functions include THD, PSD, octave, band, and side-band analysis. Averaging (vector, peak hold, and RMS) can be performed on up to 64K scans. RS-232 and GPIB interfaces are standard. Applications include vibrations, acoustics, noise analysis, and electronic design.

The DS345 ($1,895) synthesized function generator offers digitally synthesized waveforms to 30MHz with 1μHz resolution. Outputs can be simple sine, triangle, ramp, or square waves or complex arbitrary signals with up to 16,300 points and sampling times to 25nS. Internally synthesized modulation capabilities include phase continuous linear and logarithmic frequency sweeps, as well as amplitude, frequency, phase, and burst modulation. The GPIB (IEEE488) and RS-232 interfaces are optional ($495) and a high-stability ovenized timebase sells for $650.

The SR700 series LCR meters measure R+Q, L+Q, C+R, and C+D at frequencies ranging from 100Hz to 100kHz. The basic accuracies of the SR715 ($1,495) and SR720 ($2,295) are 0.2% and 0.05%, respectively. Features include five selectable source frequencies (four for the SR715), three drive voltages (0.1, 0.25, and 1V), and internal or external DC bias. The automatic binning and limit features, standard RS-232, and optional GPIB and parts handler interfaces make these instruments ideal for production testing. Optional SMD tweeters ($350) and Kelvin clips ($200) are also available.

For more information, contact Stanford Research Systems, 1290 D Reamwood Ave., Sunnyvale, CA 94089, (408) 744-9040, FAX (408) 744-9049, TELEX 706891 SRS UD.

Fast Reply #HF1353

ELECTRO-VOICE has introduced the S-40, a two-way personal-sized monitor designed to accommodate a variety of monitoring and playback applications. It features a 5¼″ direct-radiating polypropylene woofer coupled with a 1″ ferro-cooled soft-dome tweeter. Its long-term power handling is rated at 160W per EIA standard RS-426A.

The S-40 includes EV's exclusive PRO™ circuit protection, providing independent protection for the woofer and tweeter. In case of overdrive, the circuit limits the power delivered to the components and automatically resets when the system returns to a safe level.

Weighing 5 lbs., the S-40 has threaded inserts in combination with optional mounting hardware, providing a flexible mounting system. The vented enclosure is constructed of high-impact polystyrene structural foam and is available in black or white.

For more information, contact Keith Clark, Electro-Voice, 600 Cecil St., Buchanan, MI 49107, (616) 695-6831, FAX (616) 695-1304.

Fast Reply #HF453

TECHNICAL AUDIO DEVICES, a division of Pioneer Electronics (USA) Inc., has manufactured the TD-4002 high-frequency compression driver, its first product produced at TAD's new manufacturing and assembly facility in Long Beach, CA.

Continued on page 91

Editorial

IS AMERICA WAKING UP?

Last Monday morning, over my daily coffee and donut at the best donut shop in America—eat your heart out Dunkin Donuts—I came upon a most interesting news story on the front page of *USA Today*'s financial section (July 8, 1991). The shop is Nonie's, which has figured in a couple of episodes of St. Elsewhere's and makes donuts daily in the hundreds of dozens for the lucky residents in our area.

The news story concerns 35 computer superstores, some of which are tripling their business each year. They offer everything for computers from drives to boards to software to power supplies. I haven't visited one of these as yet but their existence, and the promise of 51 more by the end of this year, signals a sea change in attitude on a vital issue very close to my heart and mind. Indeed, the existence of the magazines it is my privilege and pleasure to publish is based on a faith in the ability of Americans to master technological detail and to manage it with their own hands.

According to *USA Today*'s report, Americans own 75 million personal computers. Kathy Rebello, the story's author, also reports that the prime reason behind these new stores is computer savvy. Most of the computer retailing in the US up until now has been based on the common idea about individual capability which is taught in every business school in the country; most people are dithering idiots technically and need someone to hold their hand in operating anything more daunting than a can opener.

In most areas of human endeavor, US magazine editors have swallowed the line completely. Nowhere more thoroughly than in the steadily shrinking number of magazines about audio and electronics. The only growth area in audio publishing today is in the subjective review media. And when it comes to our only mass circulation types, we are down to one French-owned operation, which controls both *Stereo Review* and *Audio*.

While the review practices and policies in the Hachette-owned audio periodicals have changed somewhat, the theme is mostly "Home, home on the range. . . . Where seldom is heard, a discouraging word." And much of the time the key word is not "seldom," it's "never."

If you are at all interested in seeing a contrast, pick up a copy of *PC-Magazine* or *PC-World*. The reviews are forthright, clear, and although sometimes less than thorough, they are not concerned that some company will lose sales because of negative comments. A new publication for corporate do-it-yourself buyers of computing equipment was launched here in Peterborough last month. From the beginning, these publications have been highly critical in reviews of equipment from even their largest advertising clients. And we are talking IBM-large for size.

Over in the audio field, you hear sobbing from the manufacturers whose product review earned only a "wonderful" rather than "stupendous." It seems not to occur to audio manufacturers that offering some new twist each year to help the marketing department does not make up for the mediocrity of the product.

Why are there going to be *Toys-R-Us*-type computer stores all across America within two years? Because the people who read the computer magazines in the US have learned a great deal about computers, far more than they can possibly have learned from our mass circulation audio publications. Computers today are the erector sets of technology. They are complicated and sometimes frustrating, but putting them together and getting them to run well is something any reasonably intelligent person can do. And if there is a problem, information is available in abundance from the magazines and books on the subject.

The history of audio and electronic do-it-yourself in this country is strewn with the carcasses of dead publications who thought Americans were incapable of doing things for themselves. Nothing of this kind has happened in Germany where no such assumption about the capabilities of the general population were ever entertained by magazine managements. The result? Today three competing publications within Germany are dedicated to all phases of electronic construction, each having a circulation of over 100,000. Any German city of 20,000 or more population will have an electronic parts store which will make your local Radio Shack look like a kindergarten.

Fortunately for the future of electronics—and the human endeavor—the Europeans and the Japanese are happily building all manner of electronic equipment. And they have the information infrastructure to support and nurture it.

Evidence is building that where publishers have resisted the business school/marketing syndrome which prefers that consumers behave as ignorant proles, considerable human accomplishment and satisfaction are possible. Look at woodworking. That endeavor is served by several superior magazines who balk at nothing, apparently, in publishing projects of all levels of difficulty. *Fine Woodworking* and *American Woodworker* are both wonderful examples encouraging an avocation which had all but died out in America by the mid seventies.

Have a look at the offerings on public television these days. Everything from Julia Child's cuisine to the astonishing achievements of the "This Old House" or "New Yankee Workshop" programs certainly do not betray any tendency to underestimate the abilities and intelligence of their audiences.

This magazine offers some small bit of evidence that many of you are rediscovering your neglected capabilities. The small string of retailers scattered across the US who are attempting to meet your needs for supplies and parts for your speaker building hobby, tell me they are significantly larger than they were 12 years ago when *Speaker Builder* was first published.

I believe we are finally beginning to wake up in the US. We are rediscovering the hands we have really are quite capable of doing things— fun things, interesting things. The day may even come when we grow up, technically. The computer superstores are a very good sign.—E.T.D.

A BACK-LOADED WALL-HORN SPEAKER

BY RICK STEINER

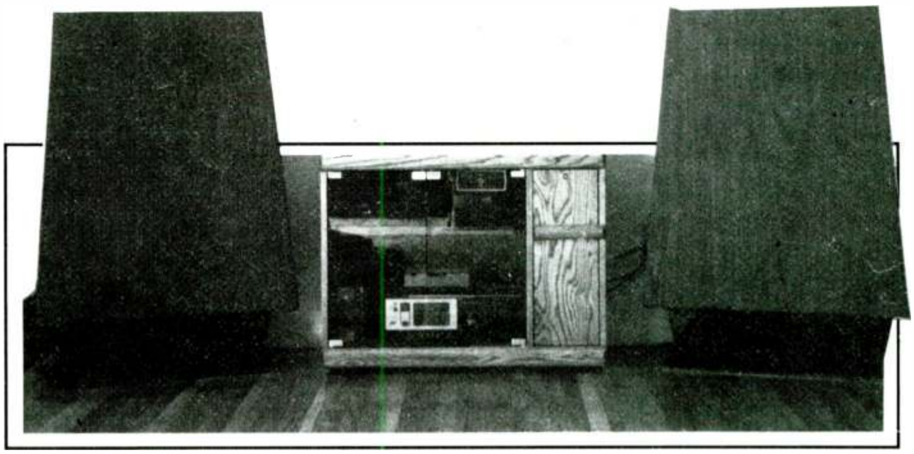

PHOTO 1: System set up in living room.

Most audio enthusiasts are familiar with the folded bass horn loudspeaker, usually designed for use in a corner or along a wall. This type of loudspeaker typically uses a 12 or 15″ dynamic woofer, the cone's front coupled to the horn's throat (sometimes via a "compression chamber" or air volume) and its back loaded by a "back chamber" of specified volume. This type of loudspeaker is eloquently described in Bruce Edgar's "The Show Horn" article (*SB* 2/90, p. 10).

Another class of bass horn loudspeakers allows the front of the woofer cone to radiate directly toward the listener, with its back loaded into the horn's throat, almost invariably using a "compression chamber." This class of design is usually referred to as the "back-loaded horn."

Back-loaded horn loudspeakers have been available for more than 50 years. Olson and Hackley[1] described a "combination horn and direct radiator loudspeaker" in 1936, which also appears in Olson's classic *Elements of Acoustical Engineering*. This design's popularity seemed greatest in the 1950s, when it typified the medium-priced corner loudspeaker market (*a la* Klipsch "Rebel"). A considerable percentage of this period's corner back-loaded horns were home-built using EV or University plans and components.

Why was this design popular with amateur speaker builders? From the hi-fi amateur's perspective in the 1950s, the back-loaded horn offered some of the the fully loaded horn's benefits at a fraction of its cost. Its principal advantages were:

- When used with an appropriate driver, it offered an overall efficiency in the low bass that seemed much greater than the reflex design, making it match better with a horn midrange and treble driver.
- The basic back-loaded horn design was much easier to construct than a fully loaded bass corner horn and seemed more tolerant of driver specifications than the reflex design.
- A back-loaded horn allowed the woofer to extend well into the midrange via direct radiation above the horn's mass cutoff, unlike a fully loaded bass horn. This minimized the need for a large, expensive, low-cutoff midrange horn.
- A back-loaded horn was potentially more compact than a fully loaded horn for a given size driver, since the need for a back wave loading chamber was obviated.

Did it sound good? As a design, it was a barely acceptable mid-fi loudspeaker. Unfortunately, the drivers of the day, when loaded with a high cutoff, short horn, often produced significant resonance peaks. Compared to the atrocious "bass-reflex" designs of the time, however, a back-loaded horn sounded relatively smooth.

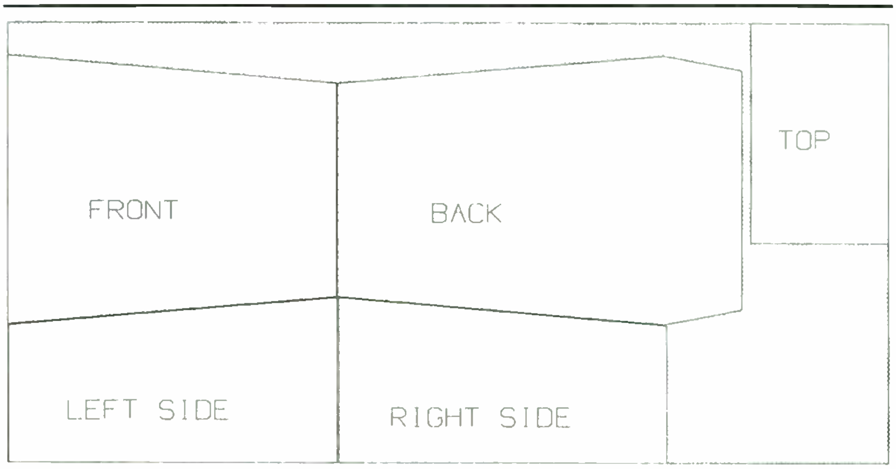

FIGURE 1: External parts layout.

What benefits does a back-loaded horn offer today's amateur speaker builder? All contemporary aspersions on the merits of horn loading aside, some 1950's advantages are still valid: high efficiency, potentially compact design, low price, and relative ease of construction compared to a fully loaded design. Intuitively, a modern, low f_S, low Q_{TS} driver in a back-loaded horn should provide smoother response than 1950's technology could afford.

15-YEAR PROJECT. I suppose this is a typical speaker builder's story. In 1975, I purchased a set of tweeter and midrange horns from Speakerlab, along with their XC3 crossover, intending to build a high-quality horn loudspeaker system (the tweeters are EV HT35 clones and the midranges seem to be EV 8HD diffraction horns and Atlas drivers). Three years later, I got serious about an enclosure design, having completed my college commitments.

After considering several alternatives, I discovered it was virtually impossible to design a fully horn-loaded woofer that could extend to the relatively high 1kHz midrange crossover. Rather than use a four-way system, I considered the back-loaded horn design as a compromise that could minimize my investment and still yield acceptable performance.

Not wishing to rely on optimally positioned, "clean" corners in my listening room, I chose a horn design that could be placed along any wall and still provide acceptable coupling into the room. As I wished to keep the horn relatively short and I needed a large mouth area to support the 40Hz horn cutoff, I opted for a relatively large diameter woofer (15"), with correspondingly large V_{AS}, which could support a large throat area.

I arbitrarily limited the maximum cabinet dimension so I could cut the outer portion of the enclosure from a single 4' by 8' sheet of particle board (*Fig. 1*; *Fig. 2* shows the inner parts laid out on two sheets). I tapered the sides of the cabinet to avoid standing waves in the horn and angled the front panel slightly to direct the axis of the midrange and tweeter toward a seated listener. The overall dimensions are 44½" tall by 18" deep by 30" wide, including the foot and horn mouth at the floor (*Fig. 3*). The enclosure has a distinctly unconventional appearance, vaguely reminiscent of an Egyptian monolith. My sister calls them "Darth Vader heads."

The mouth area is effectively fixed by the 18" by 30" dimension and is allowed to expand only slightly in the 90° bend

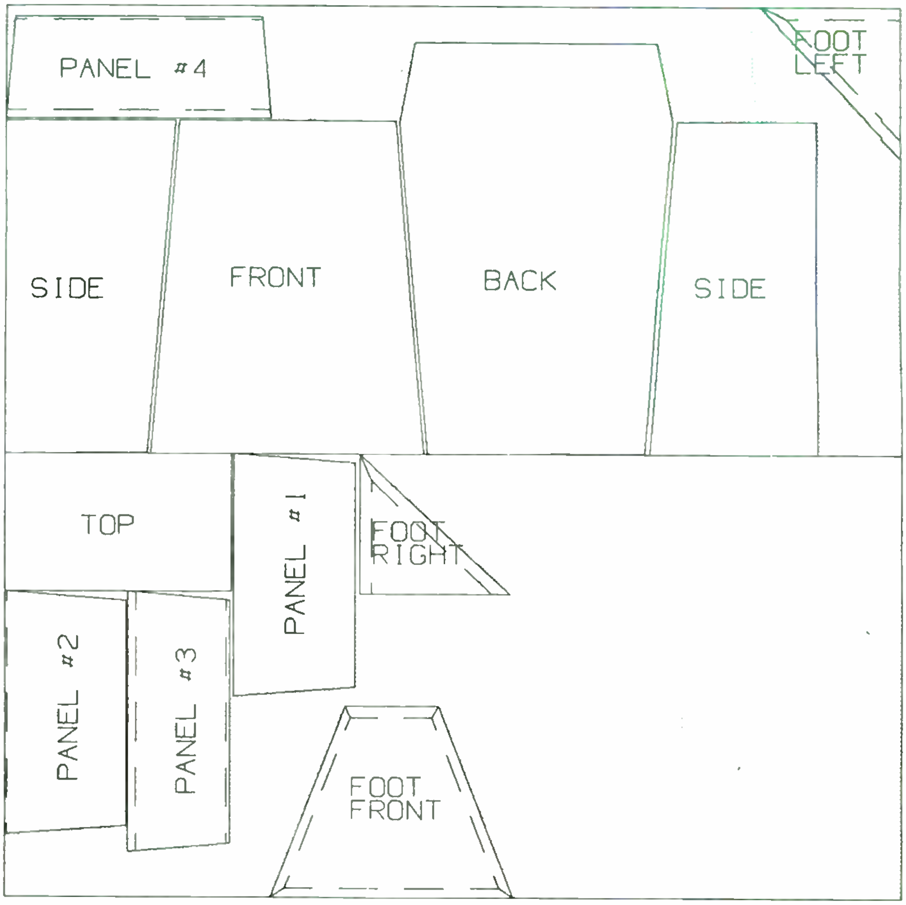

FIGURE 2: Internal parts layout.

at the floor to approximately 4 ft.² This area is obviously much smaller than the optimum mouth diameter of one wavelength at the desired f_C of 40Hz. This problem is partially mitigated because a wall horn radiates into a solid angle of π and not the 2π of a horn in a flat baffle, thus producing an effective mouth area of approximately 8 ft.² Peaks in the throat acoustical curve of more than 3dB should still occur; however, see Olson, paragraph 5.24.

Smaller than optimal mouth areas in low-frequency horns have been used before, however. The Klipsch La Scala, for example, is a highly regarded compact horn loudspeaker that uses a 4 ft.² mouth area and claims a frequency response of 45Hz–17kHz (±5dB). I admire the La Scala for its clean reproduction of percussive bass sounds, as well as its remarkable efficiency.

I decided to proceed with the design and take my chances. I settled on a throat area of approximately 85 in.² and a length of about 60 in., yielding an exponential flare rate of around 35Hz. This contour fit conveniently within my maximum dimension and still left enough room in the compression chamber for the woofer. A tractrix or hyperbolic profile might enhance bass loading and accommodate a deeper driver, but I opted for the well-understood throat-loading characteristics of the exponential contour.

Figure 4 shows the drivers' internal arrangement and the bass horn pieces. The tweeter magnet partially obstructs the bass horn's throat and the midrange horn partially obstructs the first section. I judged these obstructions to be of little significance on overall performance, as they restrict less than 5% of the total cross-sectional area. (When referring to the internal pieces of the bass horn, I will use the numbering scheme in *Fig. 5*.)

In 1979, I had cut out all the major pieces from the three sheets of ¾" high-density particle board. In 1980, however, I was assured that my landlord would never approve of these 4' behemoths, so I quickly slapped together an inexpensive 12" bass-reflex design that used the tweeter and midrange horns. These speakers served me well through four years of naval service and two years of condominium ownership, at which time my wife, apparently tired of the peeling contact paper finish, indulged me with a pair of Magnepan SMGas, for which I am continually grateful. This relegated the horns to the parts bins.

In 1989, however, I looked at the spacious living room of my new home and thought, "Now is the time." I rescued the slightly water-damaged, 10-year-old parts for my wall horns from my father's leaky garage. The woofers, unfortunately, were unrecoverable.

I now needed to select woofers that matched the peculiar characteristics of my enclosure. Having read Bruce Edgar's outstanding horn articles, I was somewhat prepared for the task. I matched my design's 85 in.^{2} throat to a pair of Oaktron T9337 15" drivers from Speaker City (10615 Vanowen St., Burbank, CA 91505, (818) 508-1908; $49.50 on special) with measured Q_{ES} = 0.36 and 0.33, Q_{TS} = 0.31 and 0.31, f_S = 22.5 and 20.5Hz, and V_{AS} = 13.7 and 17.7 ft.^{3}, yielding the following optimal throat size:

$$S_{TO} = 2\pi\, f_S\, Q_{ES}\, V_{AS}/c = 89.5 \text{ and } 107.7 \text{ in}^2$$

My enclosure's drivers yield a mass cutoff of around 125Hz:

$$f_{HM} = 2f_S / Q_{ES}$$

In a fully horn-loaded design, this low mass cutoff would have been unacceptable, but the back-loaded horn design allows the woofer to act as a direct radiator above the horn's mass cutoff. (I will later discuss the effect this low-mass cutoff has on the overall sound.) The lack of an optimally sized back-loading chamber to cancel out throat reactance near the cutoff frequency, as described by Bruce Edgar, undoubtedly limits the bass extension possible with this horn, but the overall compromise is reasonable.

THE PROJECT BEGINS. I assembled the speakers early in 1990, fully occupying five weekends. The speaker is divided into three major subassemblies: the front panel, the center "snail" section, and the back panel/foot. The center section required the most attention as I opted to fill the two upper 90° corners with plaster (*Photo 2*). This resulted in admirably smooth transitions, but forming the molds and pouring the plaster required considerable time and effort—quite frankly, a waste of time considering the horn's mass cutoff frequency.

The back panel and foot required a significant amount of bracing to support approximately 100 pounds of cantilevered weight. I deliberately avoided cutting any wire or mounting holes in the back panel or foot for fear of weakening them.

Dimensions for internal horn parts and external panels, as well as driver center-

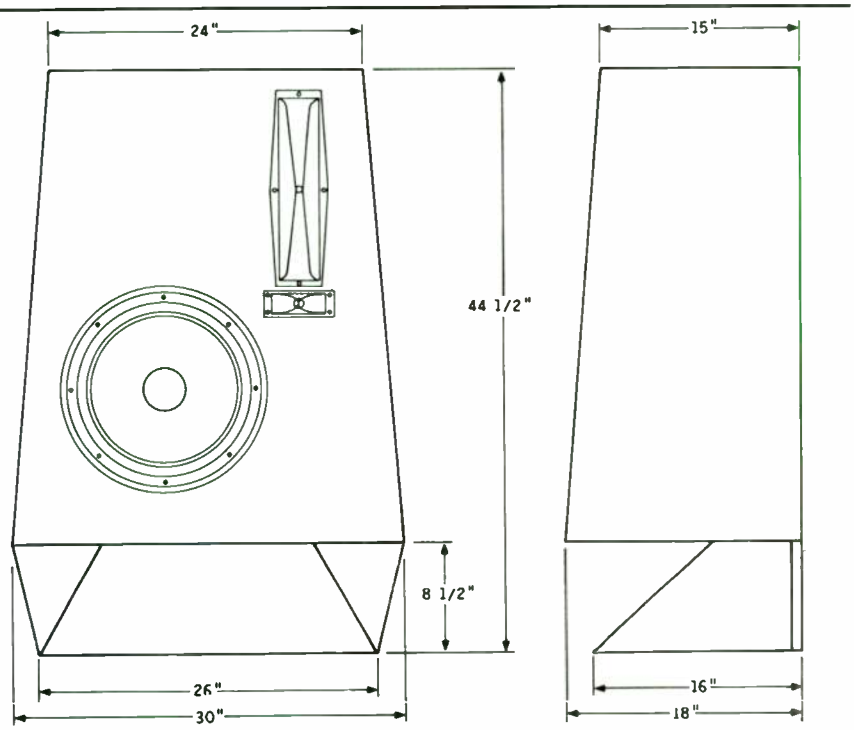

FIGURE 3: Overall back-loaded wall horn dimensions.

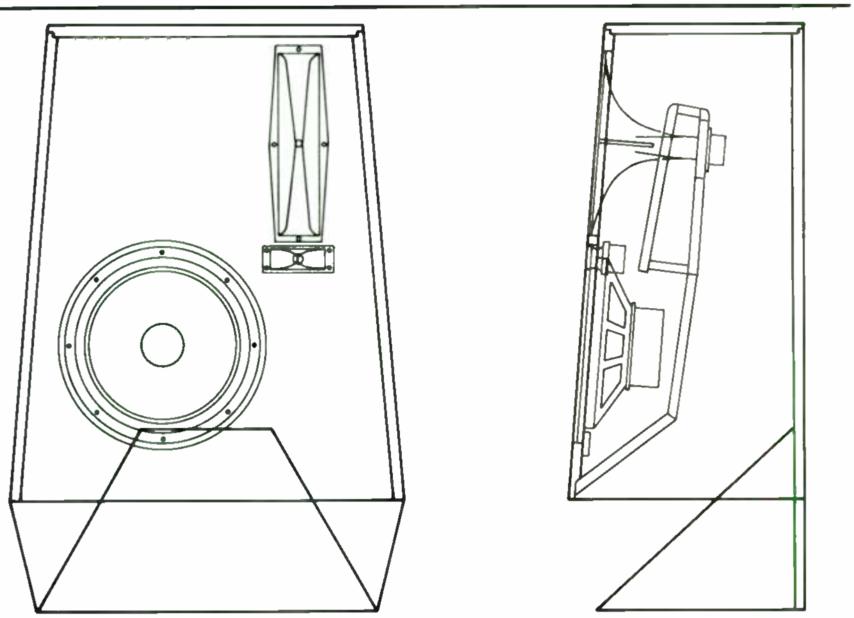

FIGURE 4: Internal arrangement of drivers and bass horn pieces, including the "foot."

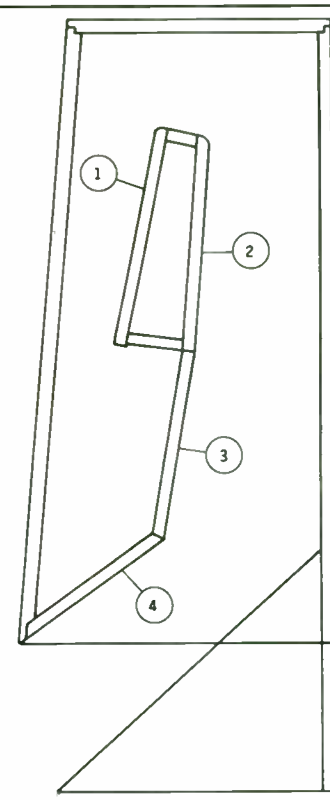

FIGURE 5: Internal horn reference numbers.

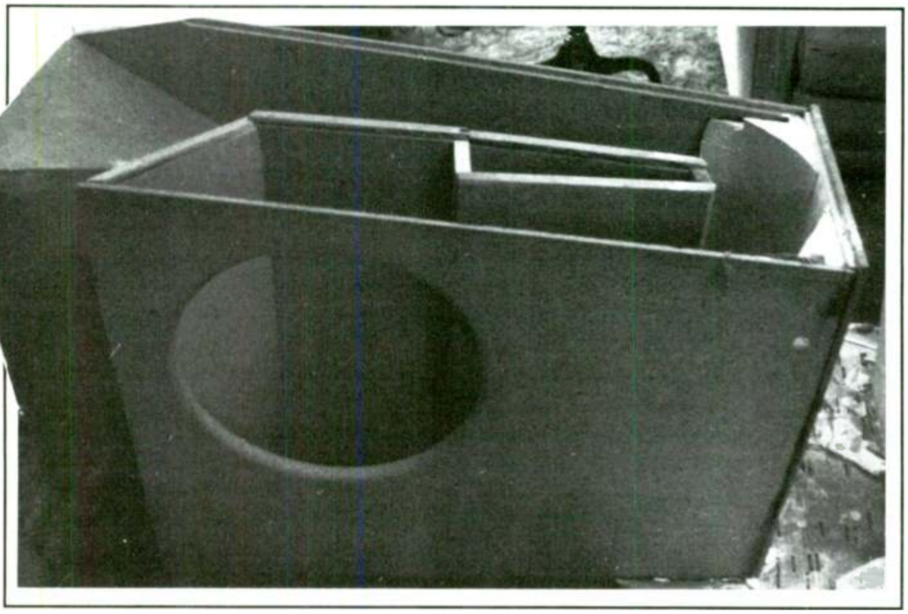

PHOTO 2: Pouring plaster in the upper corners.

line dimension, are given in *Figs. 6–9*. Centerline dimensions for dado cuts in the side panels are in *Figs. 10* and *11*.

BITS AND BLADES. If you lack a table saw or radial arm saw, you will be at a disadvantage in attempting this project. All cuts can be made with a circular saw, and in fact most of the preliminary cuts on the larger pieces were, but it is sometimes dangerous and is extremely difficult to make accurate cuts on smaller pieces with a hand-held saw. This project will also require a router, and a screw gun or a high torque VSR drill helps save time (and blisters) when you are driving screws into place.

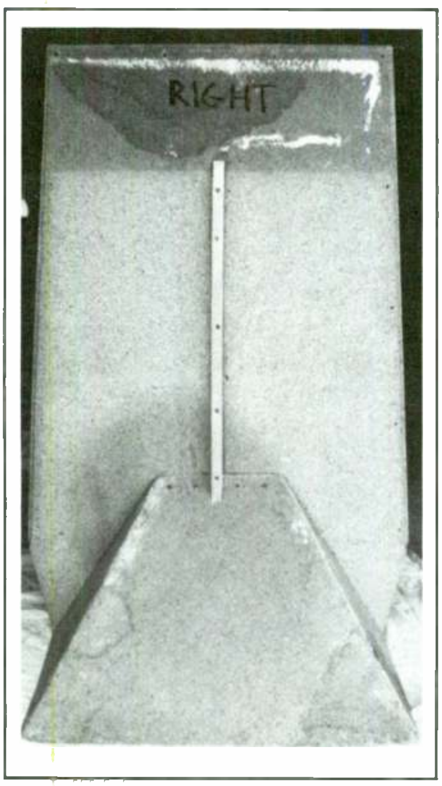

PHOTO 3: Back section, including foot. I recommend a more substantial brace than the 1 by 3 shown here. Note water damage on the top of the panel.

Carbide-tipped router bits are a "must" when you're cutting particle board: the high glue content overheats cheap steel bits and causes serious scorching along the cut. You will need a ¼" and a ¾" plunge, a ⅜" rabbet, and a ⅜" or ½" roundover; these may be expensive, but are handy for any work with ¾" particle board. Plywood blades in your table saw will provide a smooth cut in particle board, although a 40-tooth carbide blade may also work well.

FASTENERS. I recommend using standard No. 10 bugle head deck screws (cad-plated with high grip thread) as they tend not to spin out in particle board as easily as typical drywall screws or wood screws. Use 2½" long screws for 90° joints and 1" long ones for fastening battens to the particle board surface.

I highly recommend using a pilot hole to prevent drift and splitting, and countersinking the heads on outside surfaces. Even bugle heads won't pull flush in high-density particle board without countersinking. I always glue screwed joints and avoid using nails in particle board unless the screw might split the wood (such as in rabbeted joints).

OUTER CONSTRUCTION. I cut all flat pieces from ¾" high-density particle board. For added support, you may wish to use ¾" marine plywood instead for the back panel (*Photo 3*). All cuts on the back, front, sides, and top were made at 90°; the angle of the sides and front is only 5° from vertical, a difference you can easily make up for by sanding.

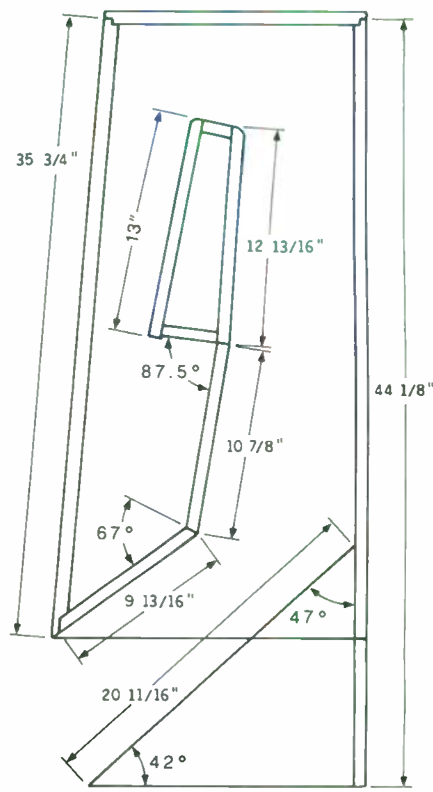

FIGURE 6: Side view of the parts dimensions.

I rabbeted the side, back, top, and front joining edges to ⅜" with a router. (Once you've determined the dimensions, rabbeted joints aren't much more trouble to assemble than butt joints and result in a better seal and more accurate assembly.) Then I carefully laid out a ¾" dado, ⅜" deep and cut it in the side

Continued on page 15

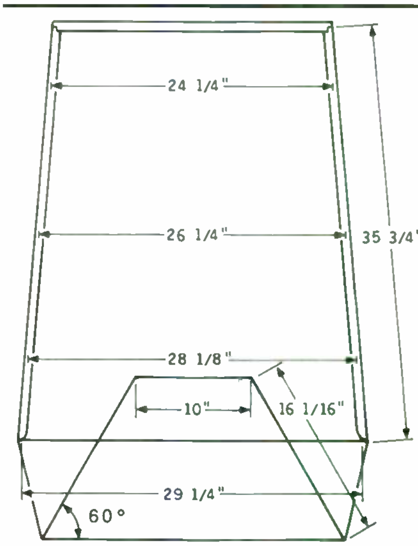

FIGURE 7: Front view of the parts dimensions.

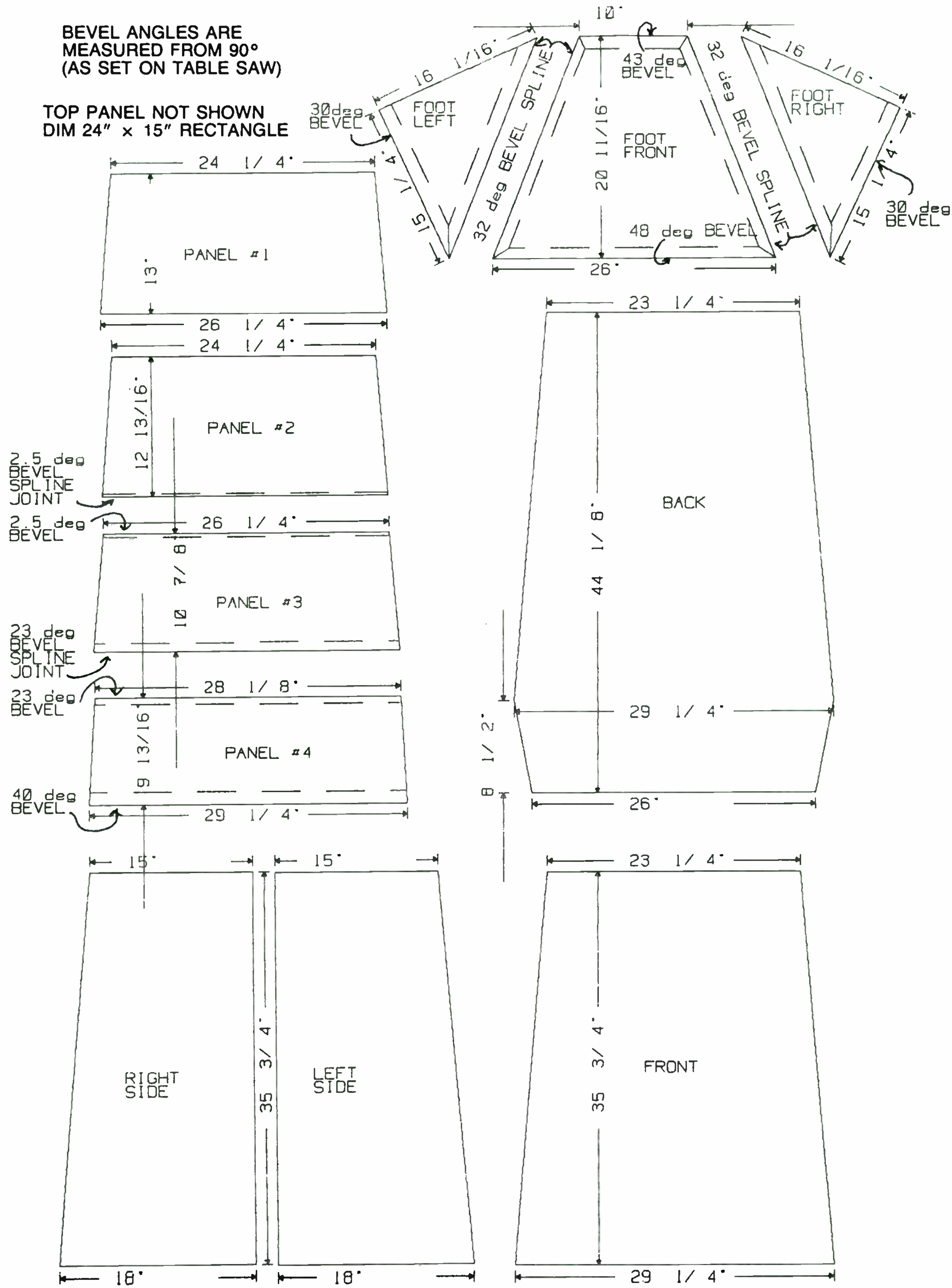

FIGURE 8: Dimension of the unassembled parts.

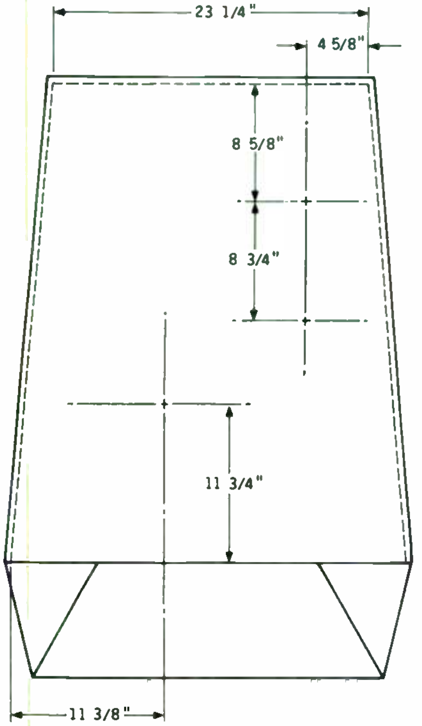

FIGURE 9: Centerline driver positions on the front panel—right side. Left side is mirror image.

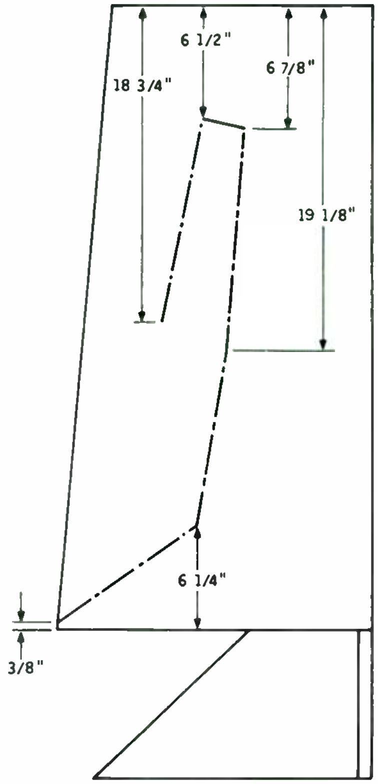

FIGURE 10: Dado centerline dimensions (vertical).

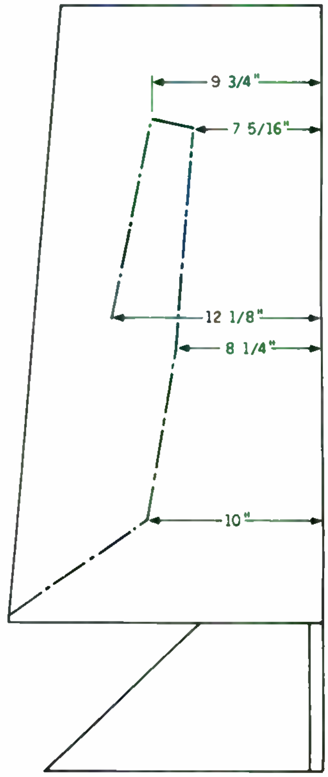

FIGURE 11: Dado centerline dimensions (horizontal).

Continued from page 13

pieces to accept the internal panels of the snail section. Finally, I dry fitted the top, front, back, and side pieces and marked each for installing battens and T-nuts.

Make any joint you may reopen (in this case joining the front and back panels to the center section) with 10/24 (or heavier) T-nuts and machine screws. Glue and nail/screw 1 by 1 (actually ¾ by ¾) white pine battens around the inside surfaces of the "stationary" side of each joint, roughly 1/16" from the inside edge of the removable panel when it is in position. If your lumberyard doesn't have the appropriate size battens, rip them down from inexpensive 1 by 2 stock.

Once the glue had dried, position the removable panel and carefully lay out and drill holes for the machine screws exactly ⅜" from the edge of the removable panel, going completely through the batten. (Extra care here will save much frustration later.) I prefer 10/24 flat-head screws, countersunk slightly below the panel outside surface. The T-nut should receive a squirt of RTV under the flange before being carefully hammered into the inside edge of the batten. The RTV will keep the T-nut from pushing out of the batten and falling inside the speaker (which would inevitably happen as you inserted the last screw during final assembly). You may need to enlarge the batten hole slightly to fit the shoulder of the T-nut. Do not force the T-nut into the batten as it may split the wood.

My suggested batten layout is pictured in *Fig. 12*. This may seem like a lot of time and effort when you could easily shoot a few wood screws through the panel. After having to open up particle board cabinets assembled with wood screws and spinning out more than half of them, I am convinced it is worth the extra few hours to make the speaker serviceable. A well-crafted loudspeaker will

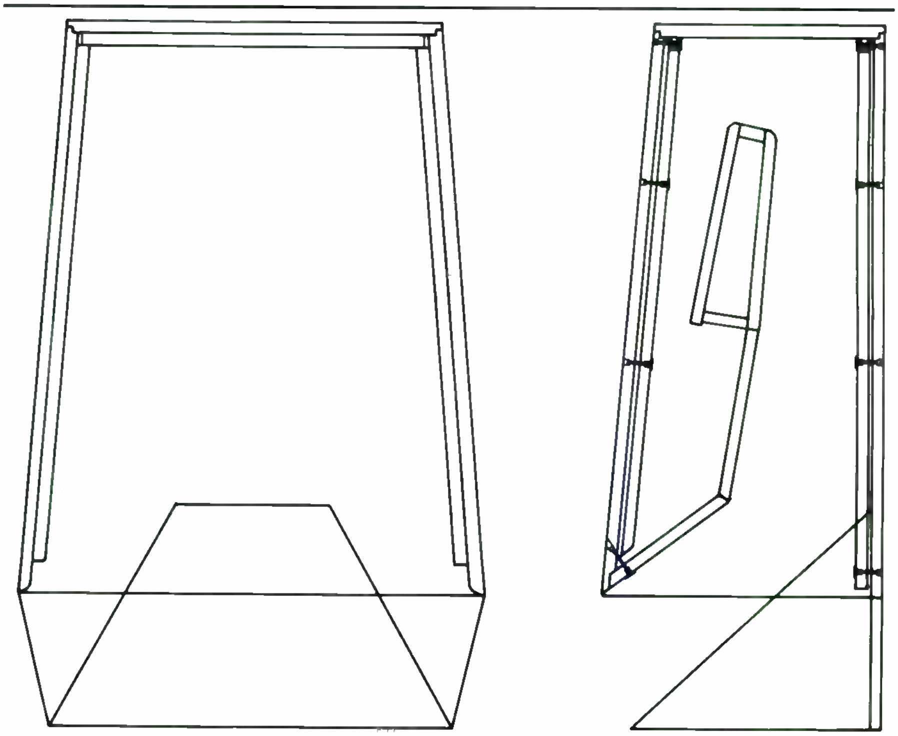

FIGURE 12: Suggested batten layout and T-nut positions.

easily last a lifetime, so you might as well make it something in which you can take pride.

Once you have installed the battens and T-nuts, you can assemble the outer pieces without glue. This is handy for assembling the internal pieces and mounting the midrange driver.

INTERNAL ASSEMBLY. I carefully cut the four internal panels slightly oversize and trimmed them to size on the table saw. The angles of pieces 2–4 (along the back side of the horn) must be accurate. Assemble these parts "dry" in a side panel to check their fit. I joined internal pieces 2 and 3 using a ⅜" tongue and groove, offset by the required 5° angle. This produced a solid joint, but is more complex than required. I recommend using a beveled miter joint, reinforced with a ⅛" Masonite spline; this size is convenient because it fits snugly in the kerf of most standard circular saw blades. I have supplied miter joint angles and I assume most readers who attempt this project understand how to make a splined miter joint.

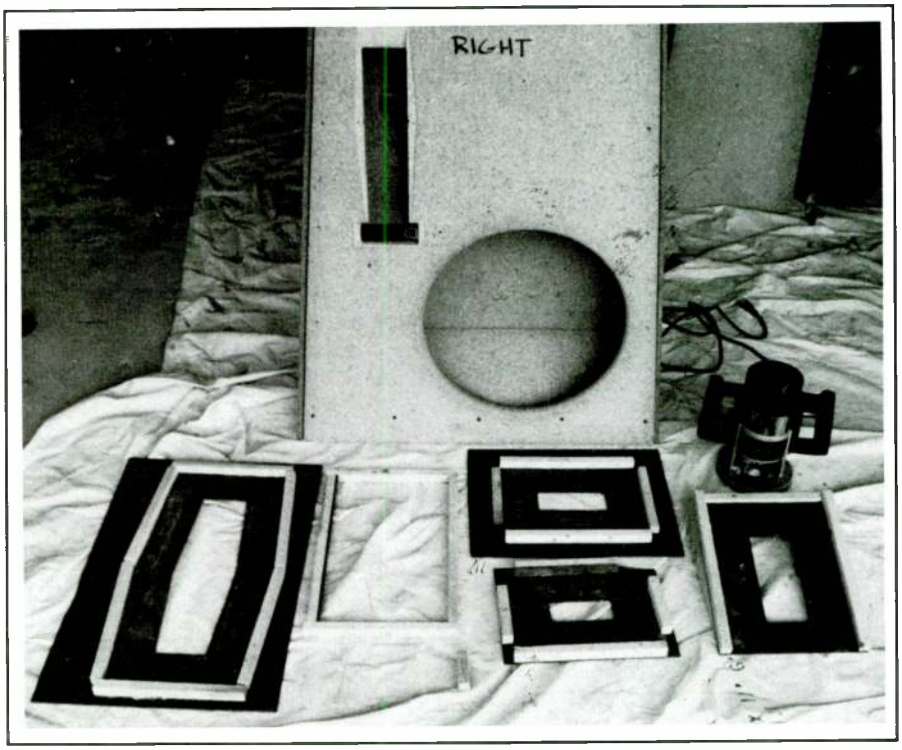

PHOTO 4: The array of router templates used to mount midrange and tweeters. Making templates is time consuming, but is the best way to get a professional finish.

I cut the boards connecting internal pieces 1 and 2 from 1 by 4s. I did not rout out dados in the side panels to accept them, but it is a good idea. Once all internal pieces were trimmed to fit nicely, I laid out and drilled pilot holes in the side pieces for the wood screws and countersunk the outside surface. Before using any glue, dry fit all pieces (top, side, back, front, internal pieces, and other side), using duct tape to hold joints together where required.

I recommend gluing the internal pieces together on *one side only*, namely the side away from the midrange. This will allow room for cutting the reliefs in the internal panels for the midrange horn and driver. Once all pieces are glued into the side panel, dry fit the other side in place (you may need a mallet) and turn the entire assembly upside down to shoot in the wood screws.

When the glue dried, I reassembled the outer pieces and placed the speaker face up on the floor. After laying out the driver positions on the front panel, I used a 12" long ¼" diameter drill to locate the center of the midrange. Be extremely careful and use a small tri-square to ensure the hole you drilled through the internal pieces 1 and 2 is orthogonal to the front panel surface. Any misalignment will make final assembly difficult and any substantial force applied in final assembly may warp the midrange horn's flange. I believe this long drill technique to be the easiest and most accurate approach.

I made special router templates (*Photo 4*) for mounting the midrange and tweeter flush with the front panel, adding a professional touch and allowing a wood grain grille cloth to be smoothly stretched completely around the upper

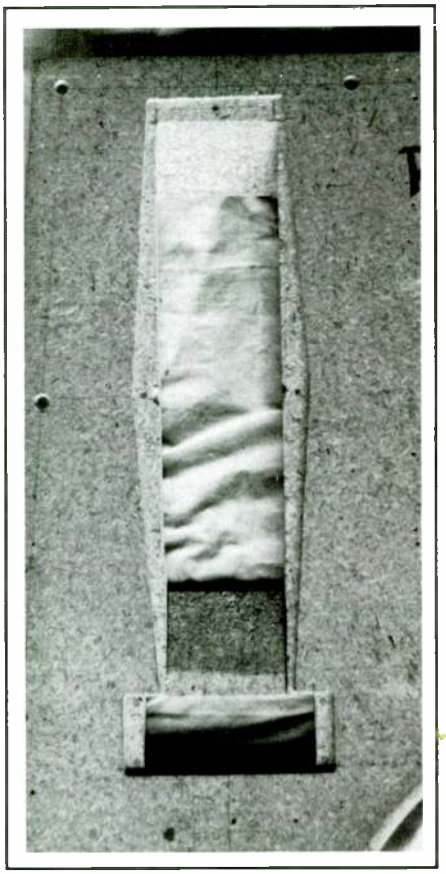

PHOTO 5a: Closeup of the cutouts for the midrange and tweeter. Center section is removable to clear magnet assembly for tweeter.

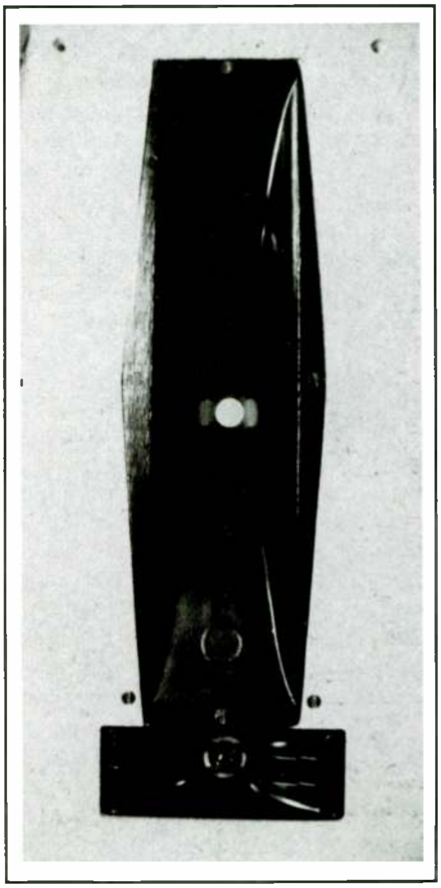

PHOTO 5b: Closeup of midrange horn and tweeter in front panel.

section of the speaker. Obviously, I made no attempt to align the acoustic centers of the drivers, aesthetics winning out over sonic merit. An aligned horn array on top of the existing cabinet would have resulted in a speaker nearly 6′ tall.

With the templates, I made a few practice runs on scrap lumber before actually cutting into the front panels. I made five templates: one for the inside hole of the midrange horn, one for countersinking the outside flange, one for the inside of the tweeter horn, one for the tweeter flange, and one for cutting the angle relief for the midrange horn at the top and bottom of its hole. I used a brute force approach to making the templates, tracing the outside (using a ¼″ diameter plunge bit). It might be wiser and faster to use Nicholas Clifton's technique ("Tools, Tips & Techniques," *SB* 3/86, p. 28) for making templates. Bolder woodworkers than I may cut the reliefs without templates, using straight cutting guides clamped in position. Bon chance!

My tweeter has a nonremovable driver with a diameter larger than the horn flange's width. This required a section of the front panel be removable (*Photo 5a*) to seal the panel adequately. I used a piece of Masonite, fastened to the inside of the front panel by 8/32 machine screws, to which I glued a scrap of particle board

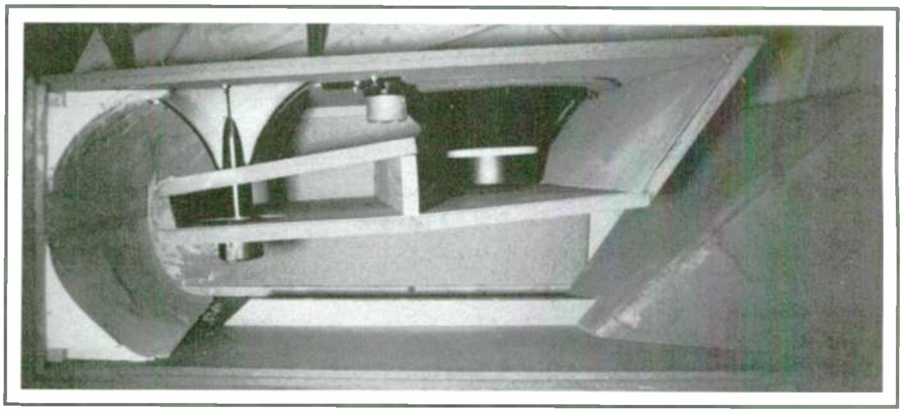

PHOTO 6: Side view of speaker during assembly, with drivers in position. Holes cut in the center section to accommodate midrange horn/driver are more clearly shown in *Photos 7* and *8*.

shaped to fit snugly in the lower portion of the midrange hole and accommodate the midrange and tweeter horn flanges (see *Photo 6* for more detail).

I used a hole saw to cut the hole for the midrange horn (*Photo 7*) in internal piece 1 and shaped it with a half-round rasp to fit the horn's contour. The 5″ diameter hole in piece 2 for the midrange compression driver (*Photo 8*) was cut with a circle cutter (fly cutter) and a slow speed, high-torque VSR drill. Circle cutters, which use a single cutting tool and arbor, are dangerous at high speeds and should be limited to about 400 rpm.

I mounted the woofer to a ring of ½″ particle board and glued and screwed it to the inside of the font panel. The mounting ring approach lets you set the woofer back from the surface of the front panel, which is handy for affixing the grille cloth and making the product look more professional. I cut the 16″ hole in the font panel with a saber saw and circle cutting guide, but you could cut it with a router. I used the ⅜″ round-off router bit to flare the outside edge of the woofer opening, which may minimize unnecessary diffraction. I also cut the woofer mounting ring with a saber saw. Here's a handy hint: cut the outside circle of the mounting ring first.

PHOTO 7: Front of center "snail" section, fully assembled. Note hole in panel for midrange horn.

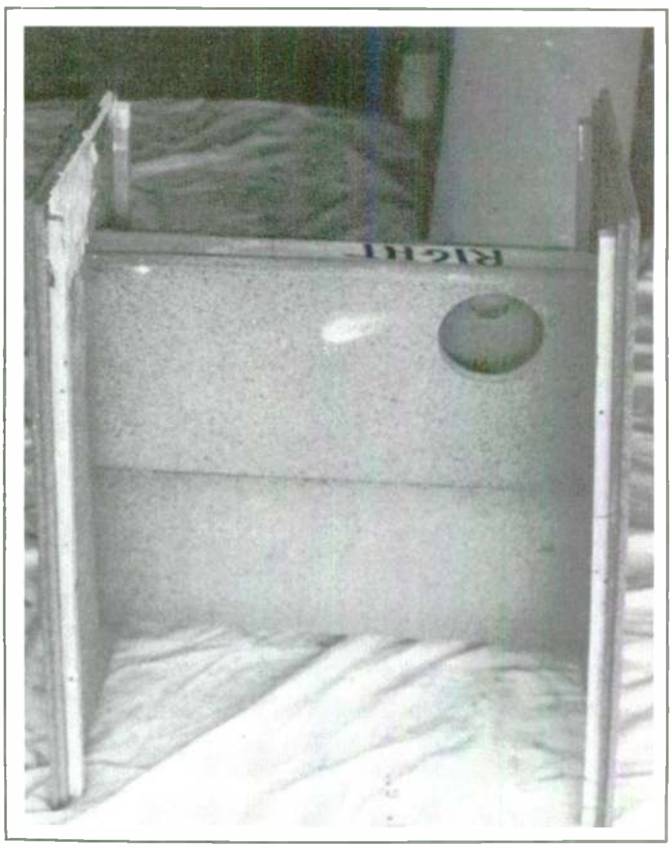

PHOTO 8: Back of center "snail" section. Note hole for midrange compression driver.

I trimmed the three pieces of the foot to form a 90° angle with the back and put them together dry to check for flatness and squareness. I assembled these parts using splined miter joints and glue. Use extra care in this step; one of my finished speakers exhibits a little wobble because I failed to ensure the foot was square and the bottom flat.

With the foot glued and dry, I notched the top section with the table saw and a chisel to allow room for the 1 by 2 brace on the inside of the back panel. I installed this brace first, with glue and screws (pilot drilled to avoid splitting), from the bottom of the back panel to about 12" from the top. (A heavier brace, perhaps up to 2 by 4, may be more appropriate.)

Next, I glued and screwed the foot permanently in position because I didn't think any batten or "remakable" joint would hold up to the considerable pressure placed on the foot. I used about ten 2½" screws per foot, shot in from the back (pilot drilled and countersunk, of course). I used a ¼" piece of Masonite to close the bottom of the foot and glued and screwed it into position. (You may prefer to use ½" or thicker plywood or particle board to enhance the strength and integrity of this assembly.)

Filling the upper corners in the horn with plaster as I did is unnecessary and far too difficult. Bruce Edgar had implied in casual conversation that no corner transition is necessary if the mass cutoff of the horn is less than 300Hz. "Radiused" or "reflective" flat corner transition pieces may be a good idea if you're lucky in your woofer selection and get a mass cutoff over 300Hz.

After I finished the corner transitions and completed the midrange horn and driver holes in the internal pieces, I glued and nailed the top section to the side piece attached to the internal assembly, then glued the other side piece to the top and internal pieces. Next, I nailed the top piece to this side piece and shot screws through the side piece into the internal pieces, as before. This completed assembly of the center snail section of the speaker. You may need to cut the corner transitions with a coping saw to clear the midrange horn.

I used 3" dimpled acoustic foam on the back surface of the compression chamber and mounted the crossover, L-pads, and terminals inside the compression chamber. The binding posts and level controls are located inside the front lower portion of the bass horn for two reasons: they are accessible when the grille cloth is in place and the speaker pushed flush against the wall, and they are not visible or tempting to young (or not so young) curious fingers. As an added precaution against my 3-year-old son's curiosity, I used metal mesh grilles over the woofers (common sense winning out over aesthetics and sonic merit).

I rounded all outside edges with a ⅜ round router bit to minimize diffraction and to facilitate installation and removal of the grille cloth sock, which fits snugly over the upper portion of the speaker and is held in place inside the horn mouth with strips of Velcro. I painted the entire speaker enclosure with primer/sealer (white shellac) inside and out and finished it in a durable black polyurethane enamel.

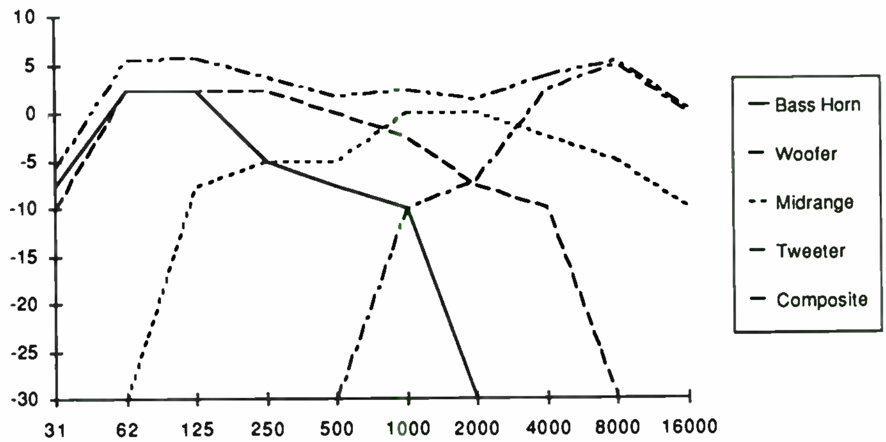

FIGURE 13: Individual driver and composite near-field responses.

SOUND/MEASUREMENTS. These speakers can play *very* loudly. In my rather large living room, two-thirds volume on my 60W/channel amplifier will produce uncomfortable levels. These speakers' high efficiency and dynamic range provide an impact and realism to percussive sounds I haven't heard in many nonhorn systems.

Bruce Edgar and I measured overall frequency response using his AudioControl RTA-1 octave band analyzer and a pink noise source. We took near-field (6") measurements from the bass horn mouth, woofer, midrange, and tweeter (*Fig. 13*); the "composite" near-field response derived by logarithmically adding individual driver octave band levels. The measured far-field (6') response curve is provided in *Fig. 14*.

Bass output is substantial down to 40Hz, below which the horn flare rate cutoff and throat reactance effects prevent virtually any output from the horn. Some direct radiation occurs below the horn cutoff frequency, but it seems to be at least 6dB down from the horn-loaded regime, confirmed by the far-field measurements in *Fig. 14*. Although not impressive bass on paper, it does provide strikingly clean, effortless reproduction of tympani and double bass. The 32Hz pedal point on *Also Sprach Zarathustra* is distinctly audible, but doesn't have the

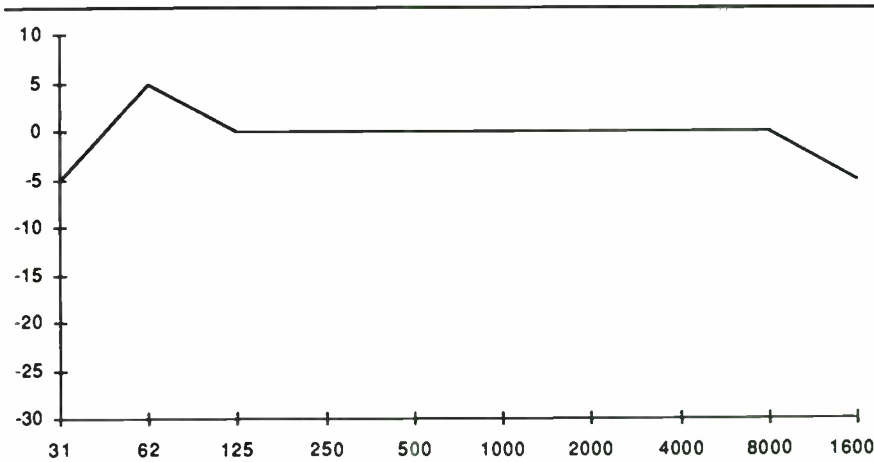

FIGURE 14: Far-field (6') response in listening room.

authority of some high-power vented systems. This lack of ultra-low bass is not noticeable on most musical passages, however.

Occasionally certain bass notes show a distinct overemphasis, noticeable only on certain types of music and most prevalent when the listener is seated near a wall. Certain jazz or rock ensemble pieces busy in the bass region can be slightly confusing and rather muddy. Symphonic music fares well, however. Telarc's *Firebird* is remarkable on these speakers. Small groups or combos come across well, particularly if the bass line is pronounced. This ripple in the bass response may be due to the small mouth area, but an uneven transition between horn loading and direct radiation is more likely the cause.

The frequency response "hump" in the 63-125Hz range, as shown in *Figs. 14* and *15*, graphically illustrates this "bassiness." By closely examining *Fig. 14*, you can see this bass hump is probably caused by reenforcement of the bass horn response with woofer direct radiation. *Figure 15* illustrates the low-frequency impedance characteristics, with a distinct resonance at 64Hz.

In hindsight, the key to a successful back-loaded horn design is a smooth transition from horn loading to direct radiation. I believe this should happen at as high a frequency as possible, but Bruce Edgar may think otherwise (refer to his Show Horn article). The horn's 125Hz mass cutoff falls in the middle of the register of most bass instruments, and bass lines that transverse this frequency region will understandably be muddied and confusing. This explains why these speakers reproduce some pieces so clearly, yet others have a touch of "one note bass."

Cabinet vibrations may also play a role, as I can feel front-panel vibrations even at moderate levels. (I will explore internal bracing and damping materials at a later date.) It is also unclear how much of the bass ripple is due to room resonance. Placed against a wall, these speakers are necessarily at a node for several modes of acoustic resonance in the room. My living room is rather large (approximately 17′ by 25′), with hardwood floors, a single throw rug, and not much furniture. The speakers are positioned along the short wall, immediately adjacent to a stone floor entry hall, which acts as its own large-scale Helmsholtz resonator. Moving the speakers away from the wall reduces, but doesn't eliminate, the muddiness.

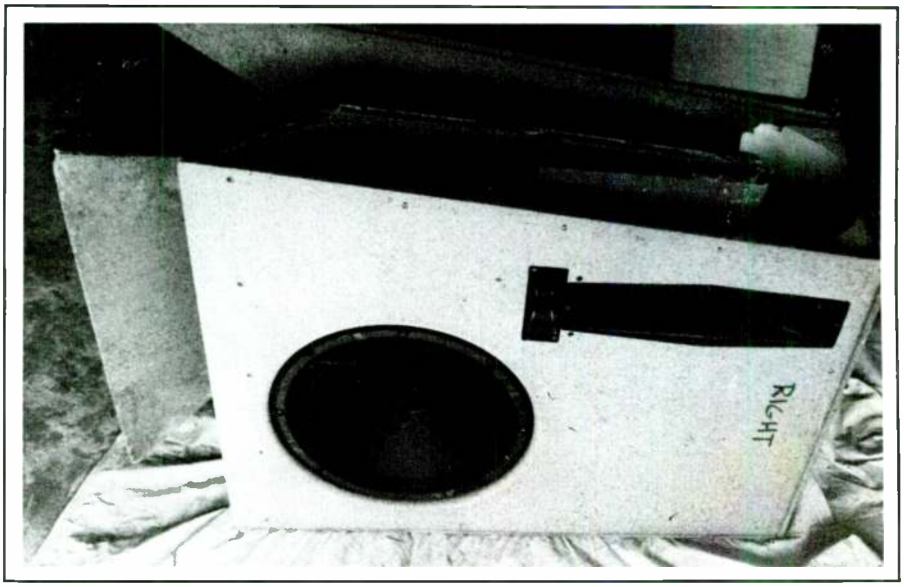

PHOTO 9: The speaker during assembly, showing driver in position.

Don't be misled by all this speculation and diatribe regarding the boominess of these speakers. As the measurements indicate, this bass anomaly is limited (approximately a 6dB hump) and overall the speakers sound very pleasant—definitely less boomy and a lot punchier than some BB4 "bass box" alignments I've heard.

A relatively minor flaw I've noticed is that the lower midrange direct radiation from the 15″ woofer (500Hz-1kHz) is very directional, much more so than the mid and treble horns. Off axis, this results in a slight hole where male voices ought to be and is particularly noticeable on the spoken word. Angling the speakers inward results in a good, but fairly small "sweet spot."

Using an audio oscillator, I've observed both beaming and lobing (peaks and nulls off axis), probably due to the woofer cone's breakup modes. This problem may not be easy to fix cheaply. I'm considering designing an acoustic lens of open cell foam and gluing it inside the metal grille in front of the woofer. (I remember JBL doing some things with circular metallic mesh acoustic lenses for their direct radiator midranges in the 1970s.)

I have always admired midrange and treble horns for their projection and immediacy, as well as their silky reproduction of brass and strings. These horns live up to my expectations, but are a trifle harsh on female vocals. They could probably benefit from the crossover mods suggested by Benjamin Poehland in *SB* 3/86 (p. 22). Imaging is adequate, if not particularly crisp. I have arranged the cabinets so the midrange and horns are at the outside edge to provide the widest possible artificial proscenium (or sound stage), the same technique used in my Magnepans.

I have noticed no problem with woofer flutter below the horn's flare rate cutoff, even when playing Telarc's *1812* (with cannon) at moderate levels. This surprises me, as I expected a problem at ultra-low frequencies where the woofer is unloaded. My amp has an 18Hz subsonic

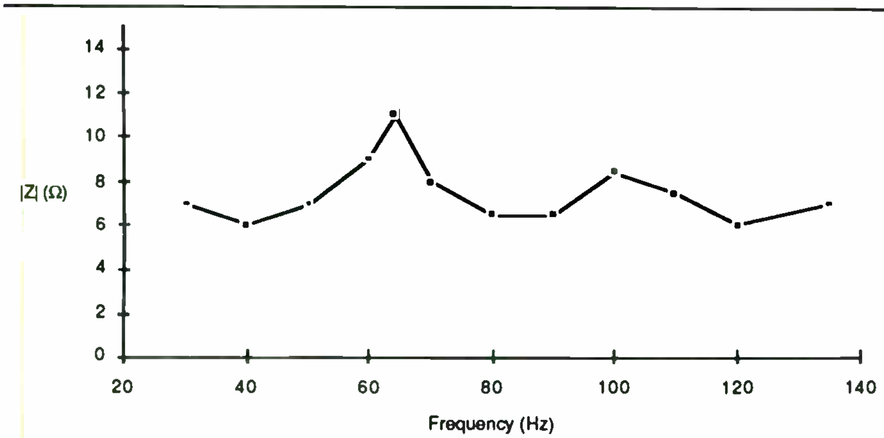

FIGURE 15: Low-frequency impedance characteristics.

PHOTO 10: Typical amateur speaker builder's workshop/garage.

filter, which I usually keep engaged to be safe.

ADVICE FOR SPEAKER BUILDERS. In selecting a driver to support this horn's relatively large throat area, you are confronted by the unavoidable problem of a relatively low horn mass cutoff frequency (illustrated in *Table 1* of Bruce Edgar's Show Horn article).

A better compromise than the driver I selected is possible: using a woofer with a slightly higher f_S (around 40Hz), lower V_{AS}, and lower Q_{ES} could result in an f_{HM} of around 300Hz with the same S_{TO}. This would change the horn-to-woofer transition, but exactly how I don't know. I had originally thought a high-quality, professional woofer would be more efficient and provide greater output and detail in the low midrange, typical of the presence peak of some musical instrument drivers, which might smooth the transition from horn loading to direct radiation.

Overall efficiency of the Oaktron T9337 is around 100dB/W at 1M, based on an impromptu comparison with a Cerwin Vega LE15 using Bruce Edgar's handy analyzer. Using a driver with a high mass cutoff could arguably hinder performance by extending the horn-to-direct radiator transition and result in a broader hump. Since the Oaktron T9337 is no longer available, it will be necessary to experiment with alternate drivers. *Table 1* lists the optimal throat size and mass cutoff of some candidate drivers based on their published specs.

The midranges and tweeters I used are currently available from parts supply houses (such as ITC in Los Angeles) for reasonable prices. Because of the lower midrange beaming and lobing problem mentioned earlier, however, I suggest you use an Edgar Tractix midrange (*SB* 1/86, p. 7) placed on top of the bass cabinet, crossed over over around 400Hz.

Use more substantial bracing than the single 1 by 3 I used inside the back panel to support the weight of this speaker. Within one month after I completed the assembly, the back panel developed a minor warp, resulting in less than ¼" shift at the top of the speaker. I encourage you to brace the front panel with a few 1 by 2s and coat all internal surfaces with a damping material. The front is the largest single unbraced panel, and it also supports the woofer. Tapping on the front panel of my finished speakers reveals a distinct resonance.

If you insist on using plaster in the upper corners, practice pour smaller pieces first. I lined the corner in plastic and used linoleum, duct taped and tacked at the edges, as a mold. I found out the hard way this doesn't have the rigidity to hold the corner in a single pour. Instead, use several small pours, with the plaster fairly soupy.

The plaster was anchored to the top piece using partially exposed drywall screws. Using a single, flat piece of wood to turn the corner is probably an acceptable alternative, considering the mass cutoff of 125Hz, and it is far less messy. The reflection corners employed by Bruce Edgar in "The Show Horn" might work nicely.

SUMMARY. Back-loaded horns should not be wantonly disregarded by home speaker builders simply because they are low tech. In fact, they are extremely complex. Horns in general have a bad reputation due to a handful of improperly designed and poorly executed speakers. Unfortunately, many commercially available all-horn systems aren't in production; if an audiophile decides he doesn't like the Klipsch sound, he assumes he doesn't like horns.

The innovative, limited production designs by JBL and Kevin Ingram are sadly not available for audition by most audiophiles, including me. One friend, who particularly dislikes the harshness of Klipschorns, was favorably impressed by my back-loaded wall horns. He did, however, find them a little bassy, confirmation of the tragic flaw I have already discussed.

I should note that a back-loaded horn doesn't necessarily provide a smaller enclosure or lower f_3 than a vented alignment. Using Bullock's tables (*SB* 3/81, p. 18) for the drivers I selected, a QB_4 alignment would require around 7.6 ft.³ (approximately a 2′ cube) and result in

Continued on page 90

TABLE 1

POSSIBLE CANDIDATE DRIVERS FOR THE BACK-LOADED WALL HORN

	Efficiency (dB/1W at 1M)	S_{TO} in.²	f_{HM} (Hz)
McCauley 62244	102	97	274
EV EVM 15L	99	60	344
JBL E130	105	64	400
Cerwin Vega LE15	101	65	200

ABOUT THE AUTHOR

Rick Steiner is a senior systems engineer for a southern California aerospace firm. This is his fourth loudspeaker project and his first bass horn. He considers himself a "budget audiophile," interested in getting maximum enjoyment for minimum investment.

World Radio History

INTÉGRITÉ: RATIONAL SPEAKER DESIGN

BY MARC BACON

Two years ago, I began a project to upgrade the quality of my living room speakers. Dozens of paper designs and three prototypes later, I completed the final (for 1990) pair of speakers. I named them Intégrité—French (since I live in Quebec) for integrity, reflecting my belief that they are accurate sound reproducers.

This article will attempt to describe in detail the systematic design choices involved in building the speakers, with somewhat less emphasis on actual construction details. My intent is not that you copy the design (although anyone is free to build a similar speaker for non-commercial use), but rather to introduce neophytes to a step-by-step decision process that will unfailingly produce good results and so remove the fear of failure.

More companies produce speakers than any other component of the sound reproduction chain, with each one touting the virtues of their products. More than any other component, speakers affect the subjective quality of the reproduced sound, with many proprietary variations designed to produce a special effect to the detriment of accurate reproduction. Worse, many fledgling speaker companies have very little engineering or quality assurance, but spend money better devoted to R&D on advertisement, trading substandard products for increased short-term profits.

The average home builder lacks the testing facilities to outclass reference speakers designed by reputable companies, but can approach their performance at a fraction of the cost by paying attention to basics, purchasing high-quality components, and building better cabinets. It is feasible to make domestic speakers subjectively better than commercial units selling for $2,000/pair, although you would be lucky if your home-built units bettered $5,000/pair speakers. Better still, the speakers you build will reflect your budget, abilities, and personal philosophy with regards to music reproduction. With that introduction, I will begin detailing the design process used to develop the Intégrité.

SUBJECTIVE DESIGN GOALS. It is more important to describe the sound you like, than to begin with the intent of "building a transmission line using 18" woofers capable of handling 1kW/channel." Once you know your sound preferences, you can choose the means to achieve it. Although subjective words don't mean the same things to everyone, listing your subjective criteria is as important to success as listing specific measurable objectives. For example, Klipsch and KEF are successful, yet they serve different markets.

My preference is "British" sound. I love the transparency, realism, and "disappearing box" effect of B&W 801 Matrix speakers, as well as the excellent imaging and bass sections of KEF 104/2s with their D'Appolito mid-tweeter sections and bandpass subwoofers. I also like certain high-end Ellipson models for their extremely rapid transient response, although my tastes in decorating are not as modern as Ellipson's. I therefore determined to make a system delivering that accurate sound, but better suited to my budget and available design and test equipment.

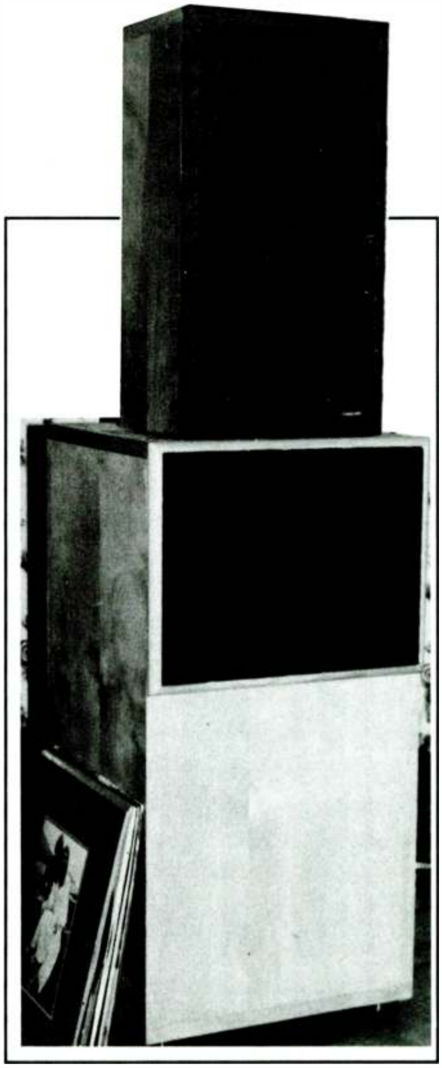

PHOTO 1: The Intégrité speaker system.

Specific descriptors I listed for my preferences follow:

- Lack of listener fatigue. Many initially pleasing speakers have a "forward" sound that does not wear well.
- Clarity and detail, with no instruments lost in massed groups.
- Realistic soundstage, even off-axis.
- Superlative transient response.
- Low distortion, even at high listening levels.
- Ability to accurately reproduce piano, the spoken male voice, classical guitar, snare drums, organ music, and trombones. Each of these makes very exact-

ABOUT THE AUTHOR

Marc Bacon, age 32, is an American father of two, making his home in Quebec. With degrees in welding and electrical engineering, he is presently director of manufacturing for a large custom metal fabricator. He builds speakers to combine learning with relaxation, while obtaining pleasure from the resulting music.

ing specific demands on tonal accuracy and lack of coloration. Very few speakers can do a credible job of reproducing all of them.

OBJECTIVE DESIGN GOALS. Cost and space are primary design considerations, unless your listening room resembles the grand ballroom of the Waldorf Astoria. In that case, I suggest you privately audition the Infinity IRS and hire a reputable acoustical engineering company to tweak the acoustic properties of your listening area. For most of us, setting cost and space criteria jointly with our spouses has a pronounced effect on the perceived success of the final result.

In my case, a 60-80 liter enclosure was practical. My wife enjoys good music as much as I enjoy tinkering with speakers, and has become accustomed to reasonably sized cabinets.

Cost is a problem for Canadian hobbyists. We have only one domestic distributor for most high-end drivers and crossover components, and their prices reflect that fact. Buying from the US means a 16% exchange, 7% value added tax, and 8% duty, plus international UPS rates. This easily adds 40% or more to published US catalog rates. In my case, it meant not buying the *ne plus* ultra in drivers, but trying to obtain the best sound for the buck. Specifically, it means buying Morel tweeters instead of Dynaudio, and SEAS woofers and midranges instead of Dynaudio, Focal, Eton, KEF, or Scanspeak.

My budget did permit me to do better than stamped-frame, small magnet units from lower-priced suppliers. This is in keeping with my Yamaha integrated amplifier, Hitachi compact disc player, JVC cassette player, and Realistic turntable. Lest audiophiles accustomed to Nakamichi, Krell and Oracle sneer, be aware that Canadian electronic equipment also suffers from a cost disadvantage similar to loudspeaker components, and that discretionary income is lower due to our more progressive personal income tax.

Your design, building, and measuring equipment will also affect your choices. In my case, I had a PC with personally developed spreadsheets for bass section design and Ralph Gonzalez's excellent LMP for crossover design (*Figs. 1* and *2*). For building, I had access to typical home woodworking tools. Testing equipment was the most rudimentary, consisting of a VOM, some excellent CDs, and the combined ears/brains of my wife, friends, and myself. Although this does not provide objective measurements, buying from a reputable speaker supplier who provides units with repeatable specifications in my experience can circumvent the need for most test equipment, as long as the designer chooses to go a tried and tested route with regard to crossover and cabinet design.

Specific objectives for a proposed speaker specification are made by Colloms in *High-Performance Loudspeakers*, 3rd ed. Without measuring instruments, I cannot state whether I indeed met those criteria. I will, however, go through the

TABLE 1

BASS CONTOUR EFFECT TRUTH TABLE

SPST	SPDT	CURVE	f_3 (Hz)	f_6 (Hz)
ON	"bypass"	1	34	22
ON	"network"	2	36	22
OFF	"bypass"	3	55	42
OFF	"network"	4	70	39
ON	"off"	5	82	50
OFF	"off"	6	151	80

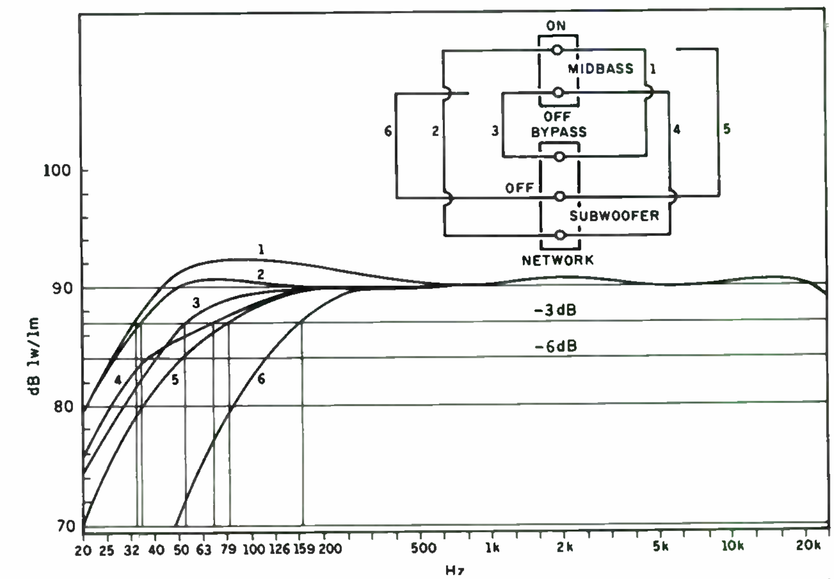

FIGURE 1: LMP predictions: bass contour affect. Legend—on-axis, no room response: 1. midbass "on," subwoofer "bypass," 2. (flat): midbass "on," subwoofer "network," 3. midbass "off," subwoofer "bypass," 4. midbass "off," subwoofer "network," 5. midbass "on," subwoofer "off," 6. midbass "off," subwoofer "off."

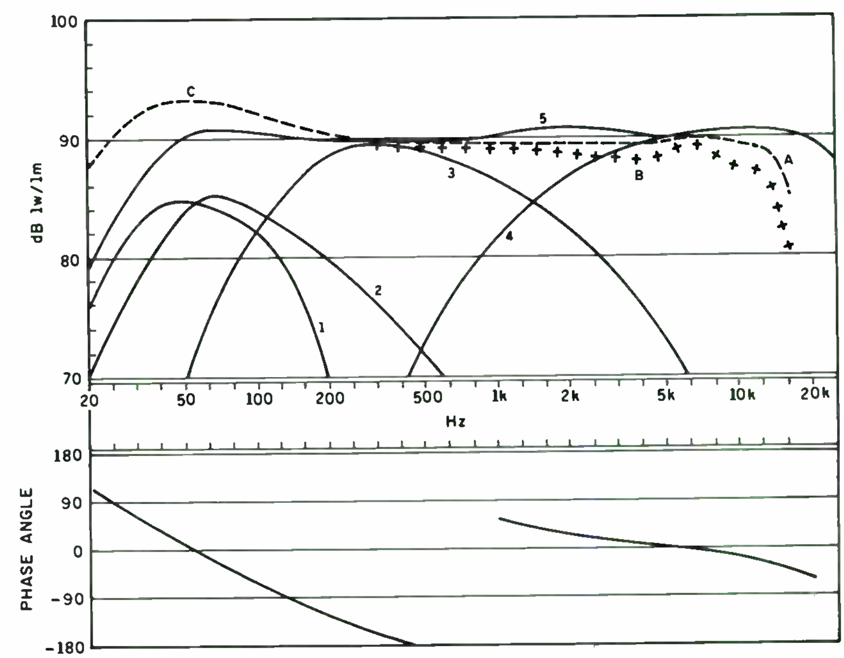

FIGURE 2: LMP predictions: bass contour "flat" position. Legend: 1–5 on axis, 1. bandpass subwoofer, 2. acoustic suspension woofer, 3. midrange, 4. tweeter, 5. composite response, A. 30° off-axis, B. 60° off-axis, C. typical room response (bass).

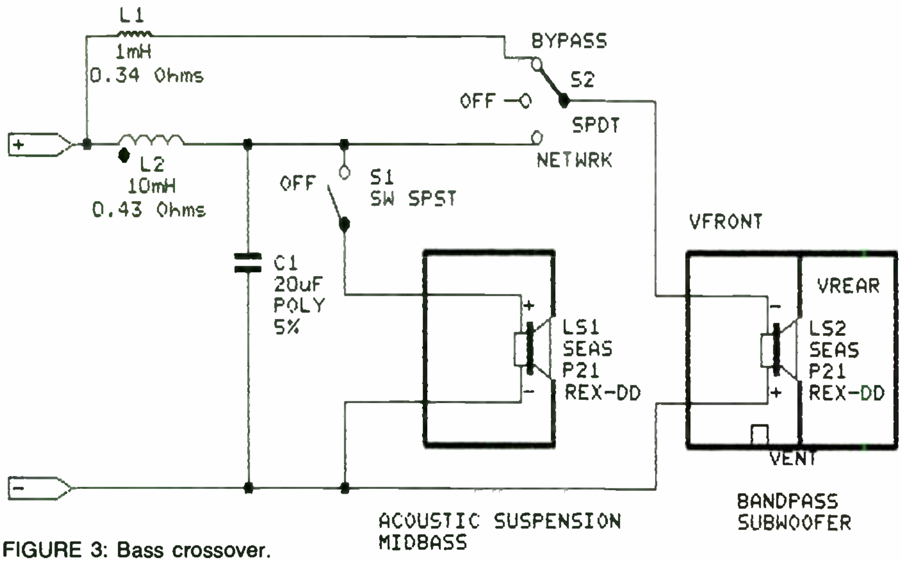

FIGURE 3: Bass crossover.

TABLE 2

ACOUSTIC SUSPENSION MIDBASS
SEAS P21 REX-DD

Q_{MS}	2.4
Q_{ES}	0.44
Q_{TS}	0.372
f_s	33Hz
V_{AS}	69l
Given SPL	91dB 1W/1M
Chosen V_B	30.49l
α	2.26
R_G	0.43Ω
With both drivers in parallel	
R_E	3.05
Q_{ES}'	0.502
Q_{TS}'	0.415
Calc. SPL	88.2dB 1W/1M
Q_{TC}	0.75
f_B	59.6Hz
f_3	56.4Hz
Damping ratio	0.667
With subwoofer bypassed	
R_E	6.1
Q_{ES}'	0.471
Q_{TS}'	0.394
Calc. SPL	88.8dB
Q_{TC}	0.71
f_B	59.5Hz
f_3	59.5Hz
Damping ratio	0.7

list, describing whether the design "on paper" and subjective results met Colloms' proposals.

1. **Axial pressure response**: 60Hz–15kHz ±2dB (sine), 100Hz–10kHz ±1dB (octave averaged), response below 60Hz tailored to boundary conditions.

My design on LMP provides 50Hz–20kHz ±1dB, with six different options for tailoring the bass response below 200Hz to boundary conditions. The staggered heights of the different drivers above the floor help to avoid problems in the 150–400Hz range due to cancellations from the floor. Bass is good, extending with little distortion to an f_3 of 34Hz with subsonic cone control.

2. **Off-axis response**: ±10° vertical within 2dB of axial, ±30° lateral within 4dB of axial.

The D'Appolito configuration and use of low crossover points with small drivers gives good control in the vertical plane and exceptional off-axis linearity.

3. **Harmonic distortion** (90dB): 100Hz–20kHz < 0.3%, below 100Hz < 2.0%.

Use of dual midranges, a high-power tweeter with ferrofluid damping, and large magnet drivers keeps cone motion well controlled in the midrange. Using dual woofers, with the subwoofer working in a bandpass enclosure, large magnets, and the SEAS "dynamic damping" graduated suspension stiffness feature, makes for clean bass. Distortion caused by subsonic excursion is inaudible, as the acoustic suspension and bandpass enclosures control subsonic movement.

4. **Harmonic distortion** (96dB): 100Hz–20kHz < 0.5%, below 100Hz < 6%.

Due to the factors mentioned in item three above, the chosen enclosure volumes, and the high power handling capabilities of the individual drivers, X_{MAX} is not exceeded at 96dB. I chose to use an acoustic suspension enclosure as the low-pass filter for the midrange units, however, with no capacitor in the signal path, meaning that near their box resonant frequency of 149Hz, heavily amplified synthesizer-based percussion causes the small cones to pant visibly, but the effect is inaudible.

5. **Sensitivity** (2.83V/1M): greater than 88dB.

TABLE 3

BANDPASS SUBWOOFER
SEAS P21 REX-DD

Q_{MS}	2.4
Q_{ES}	0.44
Q_{TS}	0.372
f_s	33Hz
V_{AS}	69l
Given SPL	91dB 1W/1M
Chosen V_{FRONT}	11.89l
Chosen V_{REAR}	20.6l
Chosen V_{TOTAL}	32.49l
B	1.1548
f_B	68.8Hz
With both drivers in parallel	
R_G	0.43Ω
R_E	3.05Ω
Q_{ES}'	0.502
Q_{TS}'	0.415
Calc. SPL	88.2dB 1W/1M
S	0.5
SPL in box	85.7dB 1W/1M
Q'T	0.866
f_s/Q_{TS}'	79.48
f_l	34.9Hz
f_h	135.9Hz
Damping ratio	0.5774
Vent length for 6.28 sq. in. vent	6.25″
With crossover bypassed	
R_G	0.0Ω
R_E	6.1Ω
Q_{ES}'	0.44
Q_{TS}'	0.372
Calc. SPL	89.3dB
S	0.558
SPL in box	86.8dB
Q'T	0.776
f_s/Q_{TS}'	88.71
f_l	42Hz
f_h	133Hz
Damping ratio	0.644
Vent length for 6.28 sq. in. vent	6.25″

The Intégrité speaker has a calculated sensitivity of 90dB 1W/1M. A speaker with 88dB sensitivity would require 1.58W of power to produce 90dB.

6. **Power rating**: at least 100W peak program power.

This speaker has nominal rated music power of 200W for all drivers, assuming 6dB/octave slope at 500Hz for midrange drivers. Using a 149Hz corner frequency for the midrange causes a downrating, but it is safe to assume the speakers can handle more than 100/1.58 = 63W of power. (I lack the money to do destructive testing.) Listeners will leave the room with no sign of strain from my 35W/channel amplifier with its 3dB dynamic headroom.

7. **Impedance**: 8Ω nominal, 6Ω < Z < 20Ω, phase angle of 30°, 100Hz–20kHz.

TABLE 4

ACOUSTIC SUSPENSION MIDRANGE SEAS 13F-GMBX

Q_{MS}	2.2
Q_{ES}	0.41
Q_{TS}	0.346
f_s	75Hz
V_{AS}	7l
Given SPL	92dB 1W/1M
Chosen V_B	2.39l
α	2.92
R_G	0.2Ω
With both drivers in series	
R_E	12.2Ω
Q_{ES}'	0.417
Q_{TS}'	0.35
Calc. SPL	90.3dB 1W/1M
Q_{TC}	0.694
f_B	148.6Hz
f_3	151.4Hz
Damping ratio	0.72

These speakers do poorly with regards to constant impedance. Avoiding active circuitry to achieve bass contouring means nominal impedance of 4–8Ω for bass section (actually considerably higher due to resonance peak), 16Ω for midrange, and 8Ω for tweeter. They should not be paralleled with other speakers for most amplifiers. I did use a Zobel in the midrange section to achieve predictable crossover response. Use of 6dB filters means a straight phase response with frequency rise predicted by LMP.

8. **Maximum SPL**: 105dB, 1M for domestic use.

This calculates to 31.6W input power, which is far below the calculated X_{MAX} limits. The speakers play so cleanly at high levels that you are tempted to turn them up, which is not good for the ears. Unlike many speakers, they don't become annoying at high SPLs.

9. **Size**: 25–50l for domestic use.

The Intégrité is larger than what Collom's suggested, as I chose additional bass extension, using a dual woofer format to reduce distortion, and using a D'Appolito midrange/tweeter/midrange configuration to achieve precise imaging. Also, the midrange/tweeter section is larger than the required box volume, due to the use of considerable foam filler to control box resonances. The overall size still meets with my wife's ideas of aesthetics.

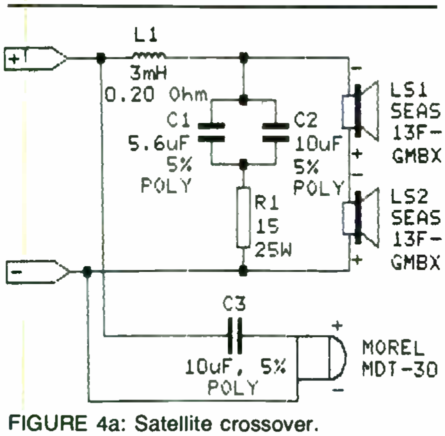

FIGURE 4a: Satellite crossover.

CABINET AND CROSSOVER. I chose a D'Appolito MTM configuration, having first been introduced to it listening to KEF 104/2s, and having built two D'Appolito speakers previously. In addition to the excellent imaging characteristics due to limiting vertical dispersion and good polar response, the use of two midranges effectively cuts cone excursion in half. This was important to me, as I chose not to have a low-pass electrical crossover to the midranges, and wished to lower possible IM distortion. Like Tannoy and KEF concentric drivers, the D'Appolito approximates a true point source. Not only is this good for theory, but it makes music believable and three-dimensional.

The downside of the MTM arrangement is that you must buy two midranges instead of one. Also, I've found that using larger 8″ bass-midrange drivers in an attempt to get a D'Appolito two-way configuration is subjectively disappointing, as the sound comes from too tall an area in the vertical plane to be believable, even if the crossover frequency is kept low.

I chose a first-order crossover throughout. It makes large demands on the drivers, especially the tweeter, but the transient response and subjective depth given to the music make it worthwhile. I believe the depth results from the phase relationships between the drivers. A word to the wise, however. Unless you have access to a computer and a crossover simulation program, use a third-order or higher filter to avoid response irregularities. For example, I had to spread crossover frequencies considerably to avoid a hump in response between 1 and 2kHz. Without LMP, this would not have been easy.

Bass section contouring to fit boundary conditions is important. It avoids room placement problems and boomy or thin bass. Ideally, you would incorporate negative feedback/electronic control of the woofer cone with a bass contouring circuit and biamplification. My budget did not permit this, so I designed passive bass contouring around a combination of electrical and acoustical high-pass filters for a total of six contour positions. The design has proven to be extremely satisfactory.

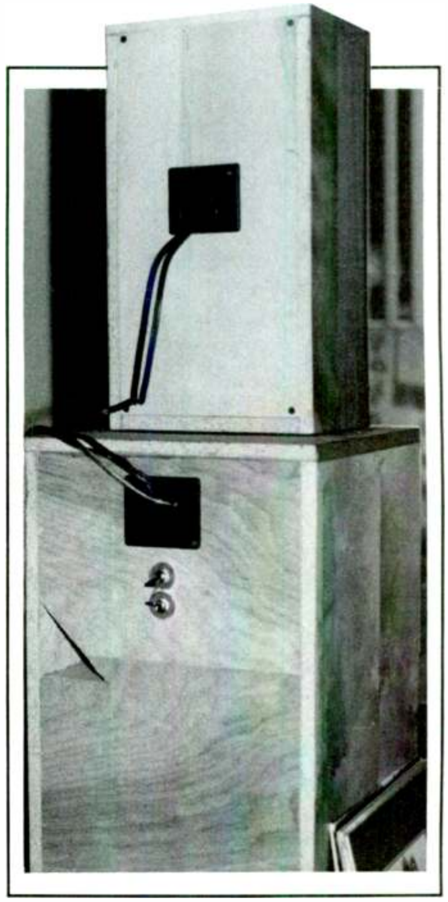
PHOTO 2: Wire connections on the back.

DRIVERS. I chose SEAS 13F-GMBX midranges for their wide, flat response and similarity of on-axis to off-axis curves, indicative of controlled cone breakup. These drivers have a large magnet system, excellent acceleration, and a low (75Hz) resonant frequency. Although they use a stamped steel frame instead of die-casting, it is of a very heavy gauge. The rated sensitivity is high, permitting use in series for a higher impedance and better damping factor, further improving transient response.

Subjectively, the speakers are superb. Their only drawbacks are the rather short excursion limits and the fact that a poorly damped rear enclosure will reflect through the light cones. I prefer these paper cones to many plastic ones, as they don't mask detail. SEAS has done an excellent job of cone doping and matching surrounds.

Morel MDT-30s were chosen for tweeters. Although nearly identical to their Dynaudio D-28 counterparts, they cost approximately 60% as much. Use of hexacoil, ferrofluid, and stranded tinsel wire leads results in high power handling and good resonance damping, while their double chamber lowers the resonant frequency and provides a smooth shallow rolloff from 2kHz. The units have an excellent off-axis response as well, without the large peaks indicative of major breakups at frequencies departing from piston behavior.

An excellent way to evaluate tweeters subjectively is to play them alone through a single polypropylene capacitor (6dB/octave filter) with values chosen to allow as low a crossover frequency as practical. When you do this with the Morel units, you can hear astounding depth, clarity, and realism. Many competitive drivers sound tinny and sibilant when unsupported by other drivers in lower ranges.

Finally, I used dual 8" woofers, since I didn't require 20Hz bass, didn't wish to have refrigerator-sized cabinets, yet wished to hear most bass fundamentals. I selected SEAS P21 REX-DD units as their stiff, yet well-ventilated die-cast magnesium frame, large magnets, graduated suspension stiffness, and low IM distortion make them a lot of speaker for the money. Also, they are very smooth up to 500Hz and quite good up to 3kHz, although my design didn't require that extension. This allows a predictable crossover response.

T/S AND CROSSOVER DESIGN. Thiele/Small design is quite simple, as detailed in *Tables 2–4* for the acoustic suspension woofer, midrange enclosures, and bandpass subwoofer. Note, however, that the value of series resistances in the crossover must be accounted for in the driver Q calculations and driver sensitivities. The process is iterative as follows:

1. Unless you have enough equipment to run response curves, use a photocopier to enlarge published response curves to fill an 8½" by 11" sheet of paper. It is much easier to work from large-scale curves.

2. Model each driver's response using LMP or a similar crossover/driver modeling program with no crossover. Be as accurate as possible.

TABLE 5

MIDRANGE/TWEETER MODULE MATERIAL LIST

(Two per stereo pair)
11/16" exotic plywood
(veneer-faced particle board)
top: 7 3/8" × 10 3/8"
bottom: 7 3/8" x 9"
sides (2): 7 3/8" × 18 11/16"
front/back (1 ea.): 9" × 18"

3/8" cork
front: 8 7/8" × 17 7/8"

3/4" square cleats: four 9" pieces

7/16" × 3/4" quarter round trim
two 10 3/8" pieces
two 19 3/8" pieces

Miscellaneous hardware
four ball connectors
two 2.39 liter plastic flower pots
one can spray-in urethane foam
silicone caulking
white glue
iron-on tape to match veneer
four rubber stick-on feet
Radio Shack fiberglass
hot melt glue
solder
wood screws
engraved nameplate

Crossover parts
one gold-plated binding post
one 3mH, 0.2Ω, iron-core inductor
two 10μF, 5% polypropylene capacitors
one 5.6μF, 5% polypropylene capacitor
one 15Ω, 25W, 5% power resistor
two SEAS 13F-GMBX midranges
one Morel MDT-30 tweeter
16-gauge stranded wire

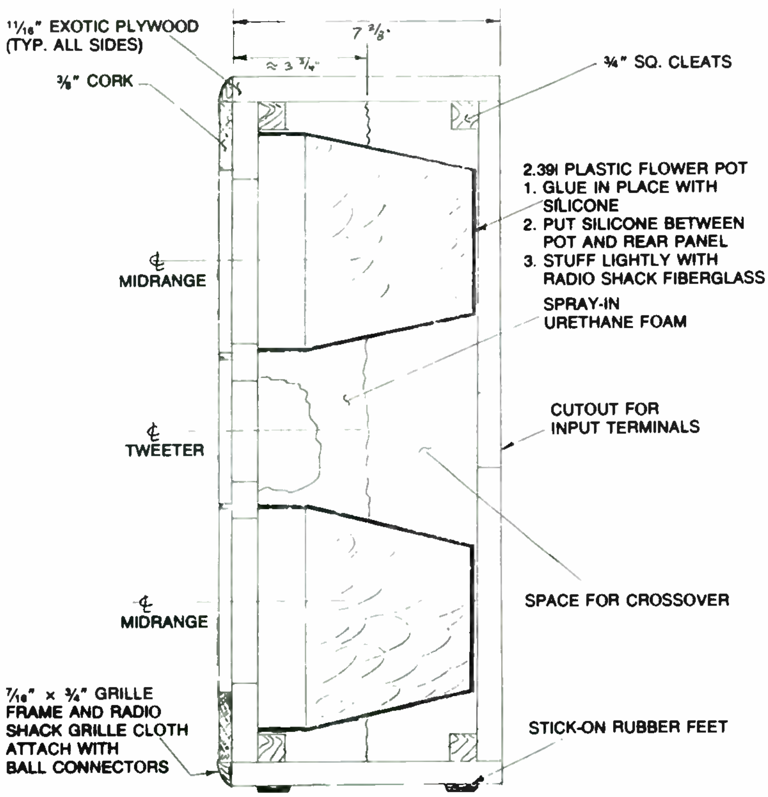

FIGURE 4b: Satellite section A-A.

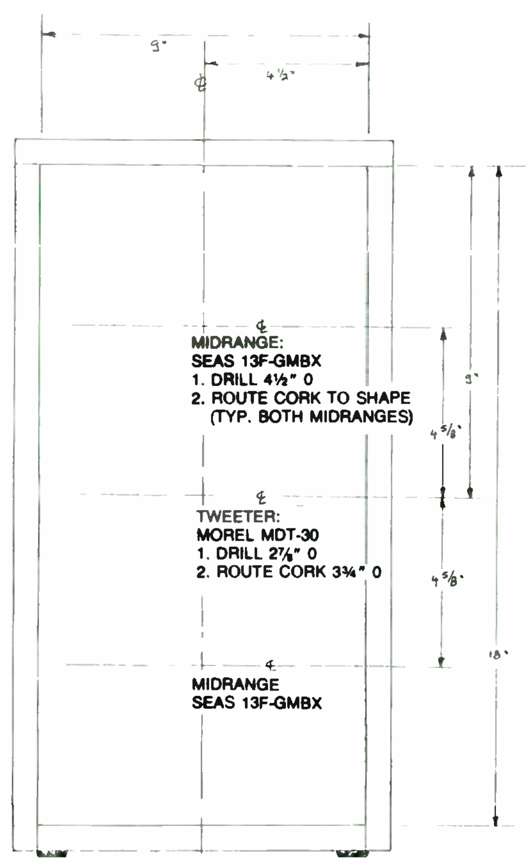

FIGURE 4c: Satellite elevation.

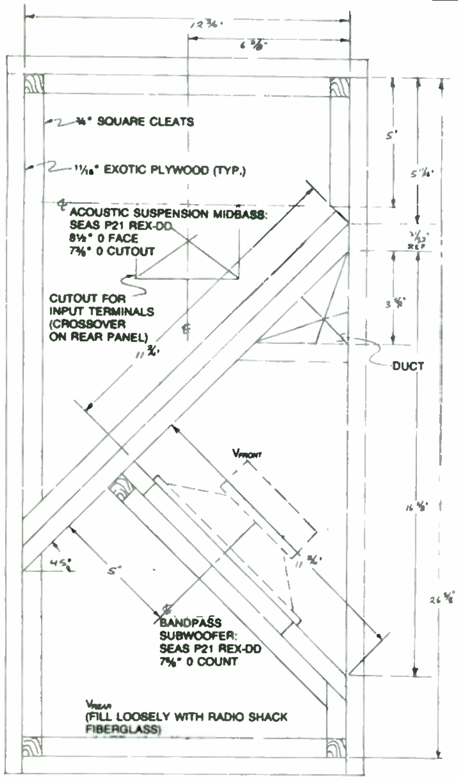

FIGURE 5a: Woofer: section A-A.

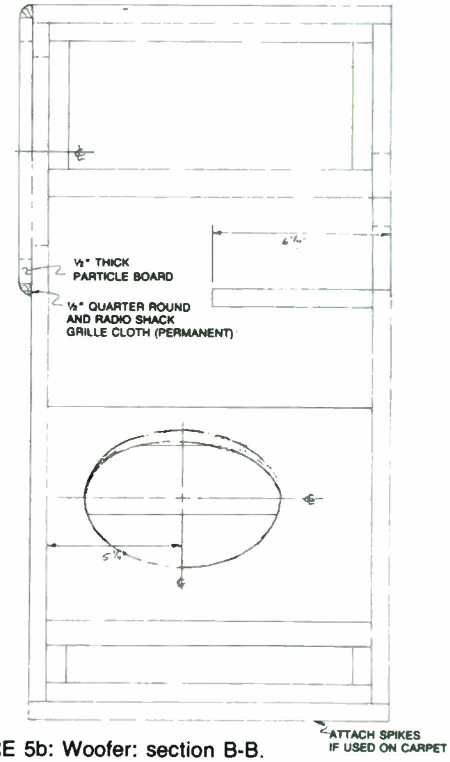

FIGURE 5b: Woofer: section B-B.

3. In accordance with your design objectives, choose crossover points and curves that will let you design a "textbook" crossover.

4. Look up typical inductor series losses for the values selected, include them in driver Q calculations, and check to ensure that the box doesn't get too large. Also, check the effect of series losses on driver sensitivities.

5. Model the complete crossover.

6. Change component values for desired frequency and phase response. With each change, repeat step 4.

7. If reverberant response is important, model it as well using the component values selected.

A spreadsheet or programmable calculator is essential to evaluate driver Q and sensitivity changes quickly with series resistances. Note that if you choose to use a passive bass contouring scheme as I did, you must calculate Thiele/Small parameters for each contour switch position. The configuration shown (*Fig. 3*) has the advantage of reducing individual Q when drivers are paralleled for bass emphasis. Thus, although overall bass level is increased paradoxically transient response is also improved.

Examination of the crossover shows the basic design's simplicity. The "subwoofer" is an acoustic 12dB/octave filter with a 69Hz center frequency. The bass boost switch allows it to be switched to one of three positions:

1. Working in series with a 10mH inductor for an 18dB/octave cutoff and a damping factor (S) of 0.5.

2. Working directly connected to the amplifier, with only an acoustical filter, for a 12dB/octave cutoff and an S of 0.558. You can use an optional 1mH coil to avoid excessively low impedance in the midrange for sensitive amplifiers.

3. Turned off.

The acoustic suspension woofer can either be switched on to work through the 10mH coil, or simply turned off. The 20μF capacitor is used to smooth a small ripple in the midrange predicted by LMP, which is not audible, as far as I can tell. It does not constitute a true 12dB/octave filter. No Zobels are used on the woofer sections, as they are cut off before any appreciable rise in impedance due to voice coil inductance.

The two midranges have no capacitor in the signal path, relying instead on their boxes to limit cone excursion. The high-pass cutoff is provided by a single 3mH inductor. A Zobel consisting of two polyproplyene capacitors in parallel (15.6μF) and a 15Ω, 25W resistor ensures the crossover works as predicted. Note also the absence of level-setting resistors due to the matched sensitivities of the drivers. Such resistors typically increase the driver Q and hurt transient response. A better solution is to choose drivers with smaller magnets and lower sensitivity.

The tweeter works through a single 10μF capacitor for a 6dB electrical crossover at 2kHz in addition to its natural rolloff. With the calculated midrange corner frequency near 1kHz, true acoustical crossover occurs at a very low 1.4kHz. The tweeter is robust, however, and performs well due to its 700Hz resonant frequency and ferrofluid damping. Accordingly, I chose not to include impedance compensation for resonance.

Strangely enough, to get good phase and frequency response, you must invert the midrange driver's leads. Without LMP, this would not have been intuitively evident.

ENCLOSURE DESIGN. The midrange/tweeter enclosure (*Figs. 4b* and *c*) is separate from the woofer enclosure to permit easy angular orientation toward the listener and to avoid colorations in the midrange caused by woofer-induced cabinet vibrations. Furthermore, this avoids the danger of a leak between woofer and midrange cavities, which can cause serious colorations, as well as damage to the midrange at high levels.

I used ⅜" cork for the front panels, bonded to 1¹⁄₁₆" exotic plywood. Cork is

Continued on page 29

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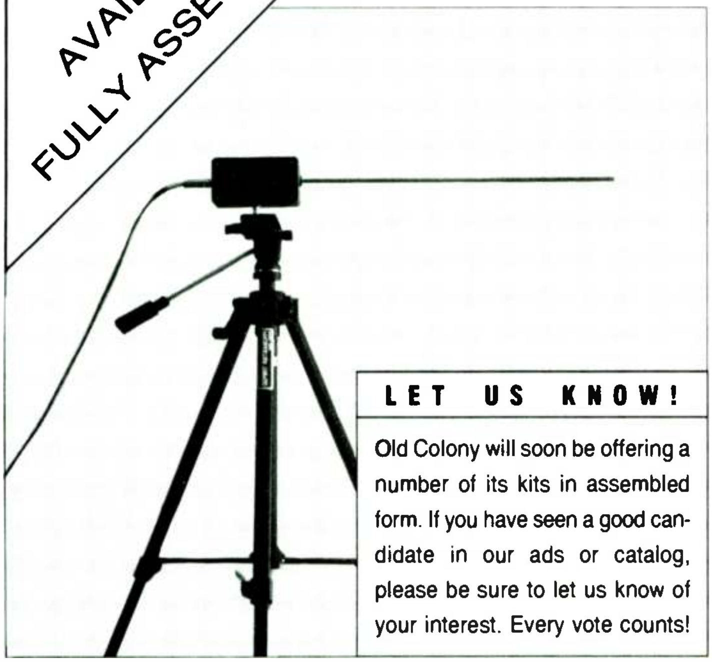

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Old Colony will soon be offering a number of its kits in assembled form. If you have seen a good candidate in our ads or catalog, please be sure to let us know of your interest. Every vote counts!

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Unassembled kit comes complete with PC board, mike cartridge, custom brass wand, all components, and (undrilled) blue case. For greater accuracy, a mike calibration service is available at a small additional charge (details come with kit), although most users do not find this step necessary. Tripod, 9V battery not included. From *SB* 6/90.

Other purchasing options available:

KD-2AM	Assembled Mitey Mike with calibrated cartridge	**$229**
KMW-1	Unassembled KD-2 (above) plus unassembled companion KK-3 Warbler Oscillator (case included; please see complete KK-3 specs elsewhere in this section), at a savings of $19!	**$229**
KMW-1AM	Assembled KD-2 with calibrated cartridge plus assembled KK-3, at a savings of $29!	**$349**
KMWP-1	Unassembled KD-2 (above) plus unassembled companion KK-3 Warbler Oscillator (case included) plus unassembled companion KSBK-E4 Super Switchable White/Pink Noise Generator (case included; please see complete KSBK-E4 specs elsewhere in this section), at a savings of $38!	**$289**
KMWP-1AM	Assembled KD-2 with calibrated cartridge plus assembled KK-3 plus assembled KSBK-E4, at a savings of $58!	**$449**

THE WARBLER OSCILLATOR — **KK-3**
Dick Crawford — **$99**

This unit will produce a swept signal covering any ⅓ octave between 16Hz and 20kHz. The total harmonic distortion at the output is less than 1.5%, and the output voltage is adjustable from 0 to 1V. When used with a microphone, the Warbler is more effective than a pink noise source in evaluating speaker system performance. It also reveals the listening environment's effect on sound through reflection and absorption. The sweep rate is set at about 5Hz. The kit includes 3 ¼" × 3 ⅜" PC board, transformer, all parts, and article reprint. Case included. This device is the most accurate tool available for determining a speaker system's actual performance in a room. From *TAA* 1/79.

Other purchasing options available:

KK-3A	Assembled Warbler	**$149**
KMW-1, KMWP-1	ALSO AVAILABLE IN COMBINATION WITH MITEY MIKE TEST MICROPHONE AND SUPER SWITCHABLE WHITE/PINK NOISE GENERATOR. PLEASE REFER TO KIT KD-2 ELSEWHERE IN THIS SECTION.	

SUPER SWITCHABLE WHITE/PINK NOISE GENERATOR — **KSBK-E4**
Bernhard Muller — **$79**

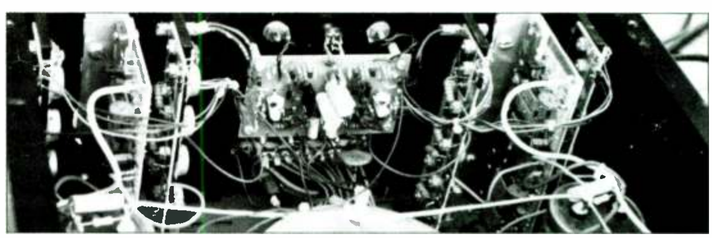
This unique kit features a stereo/mono/reverse-polarity switch that distinguishes it from other generators. CMOS digital circuits form a pseudo-random bit stream generator switchable between mono, stereo, and stereo reverse, and another switch selects pink or white noise output. Pink noise rolls off between 16Hz and 20kHz at 3dB/octave and at 6dB/octave above 20kHz, while white noise is constant through the 16Hz-20kHz range. The unit is powered by a 9V battery, not included. Included is an article reprint outlining the generator's use in audio system evaluation; the article is especially helpful with speaker evaluation methods and room placement problems. The kit comes complete with 4 ⅛" × 2 $^{3}/_{16}$" PC board, ICs, precision resistors and capacitors, and switches. Case included. From *SB* 4/84.

Other purchasing options available:

KSBK-E4A	Assembled White/Pink Noise Generator	**$129**
KMWP-1	ALSO AVAILABLE IN COMBINATION WITH MITEY MIKE TEST MICROPHONE AND WARBLER OSCILLATOR! PLEASE REFER TO KIT KD-2 ELSEWHERE IN THIS SECTION.	

ADCOM POWER SUPPLY REGULATOR — **KY-2**
Kit Ryan — **$99 per chan.**

This popular mod was designed for taming Adcom's GFA-555, but it adds sweetness and definition to just about any amp in the 80V-in, 60V-out, 10A-regulated family. Mounts in existing case; complete with PCB, custom heatsink, and Japanese transistors. Two usually needed. From *TAA* 4/89.



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a natural for front panels. It is easily routed to shape, provides a somewhat resilient mounting surface to decouple the drivers slightly from the cabinet, and provides a nonreflective front panel of a rich appearance. Exotic plywood is a name for extremely dense particle board with a thin veneer of real wood. Not being a professional woodworker, I found it easier to work with this material than to apply veneer to raw particle board.

I screwed all drivers in place and sealed them with silicone. I made the grille frame from 7/16″ by ¾″ quarter round molding, which barely projects (1/16″) above the cork, providing rounder edges to avoid reflections of high frequencies. The rear panel is ½″ particle board. The front panel size is similar to the one I used to test the midranges, to avoid response irregularities due to diffraction effects.

Simple plastic flower pots were used for rear acoustic suspension enclosures. They are inexpensive and come in many sizes. Besides providing nonparallel walls, they can simply be held in place with silicone glue, and require almost no labor. I used a small amount of Radio Shack acoustical fiberglass in each flower pot, melted a hole through the rear to pass leads, and sealed drainage holes with silicone. To avoid ringing of the thin flower pots, I filled the space around them with spray-in urethane foam to a depth of approximately 3″. This provided extremely rigid, nonresonant enclosures, with no need to caulk the wood joints or provide more corner cleats than necessary for assembly. The enclosures sit on four rubber stick-on feet to isolate them from the woofer modules.

The acoustic suspension woofer and bandpass subwoofer are housed in a common enclosure (*Figs. 5a* and *b*). Both acoustic suspension and bandpass enclosures provide a natural 12dB/octave rolloff below resonance and control of subsonic excursion, as well as subjectively good transient response. I chose the bandpass subwoofer to provide a selection of bass contours, as well as for the reduced distortion provided by damping the cone in both directions. Also, the acoustic low-pass filter eliminates distortion products, providing a more fundamentally pure sound. The vent is triangular to reduce self-resonance.

I oriented the internal bracing at 45° angles to avoid standing waves and to rigidly brace the enclosure. I cannot overemphasize the importance of proper cabinet bracing and damping. Over the years, I have built two sand-filled designs, one of which was with very cheap drivers. Many people prefer the dead cabinets with inexpensive components to conventional cabinets with better drivers. This is one area where home builders can far outclass commercial designs—companies simply can't afford the time needed to build a "dead" enclosure.

Sand filling, however, increases the time required to build the enclosures, the total weight, and the overall cabinet volume. Hence, for these units, I thought it wiser to use heavy internal bracing and cleats in every corner. Sealing was accomplished by caulking all joints with "Mono" brand sealant. All material was again 11/16″ exotic plywood, with an additional ½″ particle board on the front panel around the woofer.

Although the P21 REX-DD woofers provide excellent sound, they have bulging surrounds, which make flush-mounting a problem unless the grille cloths are mounted away from the front panel. Since cavity resonances are not a problem at the low frequencies involved in this design, I chose the ½″ particle board surround. A simple perimeter of ½″ quarter round holds the grille in place. Stainless steel wood screws serve as spikes to couple the speakers to the floor. Lining walls of the acoustic suspension enclosure and the rear volume of the bandpass enclosure with fiberglass as well as some volume filling helps further reduce standing waves.

RESULTS. In my obviously biased opinion and that of my close acquaintances, the sound is very good, even better than their prototypes. Even nonaudiophiles give unsolicited praise when listening to them. Of course, like most of this magazine's readers, I hope to build even better speakers with time. Meanwhile, these provide enjoyment for the entire family.

In summary, remember the steps to success for the homebuilder:

1. Define subjective design goals in terms of commercial speakers you like and specific sound qualities you find pleasing in live performances.
2. Define objective goals in terms of cost, size, available design, construction, and testing instruments, and commonly accepted engineering criteria.
3. Choose an enclosure configuration.

Continued on page 90

TABLE 6

BASS MODULE MATERIAL LIST

(Two per stereo pair)

11/16″ exotic plywood
(veneer-faced particle board)
- top: 14⅛″ × 14⅛″
- bottom: 12¾″ × 14⅛″
- sides (2): 14⅛″ × 27 5/16″
- duct: 4 5/16″ × 5 9/16″
- front/back (1 each): 12¾″ × 26⅝″
- large divider: 19″ × 12¾″
- small divider: 12¾″ × 12 7/16″

½″ particle board
- 10⅜″ × 13⅛″

¾″ square cleats
- cut to suit, sealing all joints

½″ quarter round trim
- two pieces

Miscellaneous hardware
- silicone caulking
- Radio Shack fiberglass
- white glue
- iron-on tape to match veneer
- spikes (optional for carpet)
- hot melt glue
- solder
- wood screws

Crossover parts
- one gold-plated binding post
- one 10mH, 0.43Ω, iron core inductor
- one 1mH, 0.34Ω, air core inductor (optional, see text)
- one SPDT, center off, 120V AC, 5A
- one SPST, 120V AC, 5A
- two SEAS P21 REX-DD woofers
- one 20μF, 5% polyproplyene capacitor
- 16-gauge stranded wire

OPTIMIZING TRANSMISSION LINE LENGTHS

BY LARRY D. SHARP

In recent years, many articles have appeared in *SB* concerning transmission line designs. While most have been informative, only a few have mentioned the obvious relationship between stuffing density and line length. A lack of mathematical equations defining TL characteristics has probably kept many from attempting this type of speaker design.

A certain amount of math is involved, but don't let the equations scare you. Work them through, and you'll see where I'm going. When you're finished, I think you will understand TLs better.

THE MATH. Many builders calculate transmission line length using the following formula:[1]

$$\frac{1}{4}\lambda = \frac{1{,}130 \text{ ft./sec.}}{f_s \text{ (Hz)}} / 4$$

The length this method determines is correct for an undamped line. When the line is filled with a damping fiber, like wool or Acousta-Stuf®, it ceases to be an acoustical labyrinth and becomes a low-pass filter. This requires an equation modification. We must find the speed of sound through fiber.

The speed of sound through air at 0°C is 1,087 feet per second. To find the speed of sound at any temperature, use the formula below:[2]

$$c = \frac{1{,}087 \times \sqrt{273 + t°C}}{16.52}$$

Since 72°F = 22.3°C, you can see that the speed of sound at 72°F is 1,130 feet per second.

Bradbury's equation for the speed of sound through a fibrous material like wool or Acousta-Stuf follows:[3]

$$c' = \frac{c}{\sqrt{1 + (P_a/P)}}$$

where c′ is the speed of sound through fiber, c is the speed of sound through air at 72°F (1,130 ft./sec.), P_a is the density of the stuffing material (0.5 lb./ft.³), and P is the density of air at 72°F (0.0745 lb./ft.³).

In the *Loudspeaker Design Cookbook*,[3] Vance Dickason lists the density of air as 1.18 kg./cubic meter (0.0736 lb./ft.³), which is correct for 76°F. However, I am attempting to standardize all values at 72°F for the convenience of using the 1,130 ft./sec. speed of sound.

Bradbury's equation using a stuffing density of 0.5 lb./ft.³ of fiber provides the following results:

$$c' = \frac{1{,}130}{\sqrt{1 + (0.5 / 0.0745)}}$$

$$= \frac{1{,}130}{\sqrt{7.71}} = \frac{1{,}130}{2.77} = 408 \text{ ft./sec.}$$

Now try 0.75 lb./ft.³:

$$c' = \frac{1{,}130}{\sqrt{1 + (0.75 / 0.0745)}}$$

$$= \frac{1{,}130}{\sqrt{11.1}} = \frac{1{,}130}{3.33} = 339 \text{ ft./sec.}$$

And 1 lb./ft.³ is:

$$c' = \frac{1.130}{\sqrt{1 + (1 / 0.0745)}}$$

$$= \frac{1{,}130}{\sqrt{14.4}} = \frac{1{,}130}{3.80} = 298 \text{ ft./sec.}$$

Now, instead of 1,130 ft./sec., replace *XXX* in the formula below with speeds of 408, 339, and 298 for quarter wavelength lines:

$$\frac{XXX \text{ ft./sec.}}{f_s \text{ (Hz)}} / 4 = L'$$

This lets you calculate line length at various cutoff frequencies. *Table 1* and *Fig. 1* indicate the length of transmission lines at frequencies from 20–50Hz and stuffing densities of 0.5, 0.75, and 1 pound per cubic foot of enclosure volume.

DESIGNING YOUR TL. Now that you've done the math and see the results, you may question those numbers. After all, can you really expect a 50″ long line to go down to 25Hz? Using a woofer with a low f_s, I don't see why this figure can't be met. If you don't trust the equations, add 25% to your TL; it won't hurt anything.

The other considerations you should look at are woofer Q_{TS} and cross-sectional area of line. After selecting a woofer, consult *Table 1* for an appropriate line length. Use a minimum cross-

ABOUT THE AUTHOR

Larry Sharp is the owner of Mahogany Sound in Mobile, AL. He has been involved in audio since 1966 when he built a Carlson enclosure for his hi-fi system. He served in the Navy as an electronics technician during the Vietnam War, then spent seven years as a broadcast engineer. Today, he also works as a process control technician in the pulp and paper industry. He is married and has two children.

TABLE 1

QUARTER WAVELENGTH TRANSMISSION LINE LENGTHS USING BRADBURY'S EQUATION

Freq. (Hz)	**0.5 lb./ft.³ 408 ft./sec.**		**0.75 lb./ft.³ 339 ft./sec.**		**1 lb./ft.³ 298 ft./sec.**	
20	5.10	61.2	4.24	50.9	3.72	44.6
25	4.08	48.9	3.39	40.7	2.98	35.8
30	3.40	40.8	2.82	33.8	2.48	29.8
35	2.91	34.9	2.42	29.1	2.12	25.4
40	2.55	30.6	2.12	25.4	1.86	22.3
45	2.26	27.1	1.88	22.6	1.65	19.8
50	2.04	24.5	1.69	20.3	1.49	17.9

sectional area (CS1) behind the woofer at least 25% greater than the effective cone radiation area (S_D). Most 8″ woofers have an S_D of about $33.3in^2$, so a minimum of $42in^2$ would be good.

John Cockroft[4] recommends increasing the cross-sectional area of a TL for stuffing densities above 0.5 $lb./ft^3$, so to use the 0.75 $lb./ft^3$ or the 1 $lb./ft^3$ density lengths from *Table 1*, you probably should increase the minimum cross-sectional area by 40–60% greater than S_D, respectively.

John also addresses the issue of driver Q_{TS}. He believes a shorter line should use a woofer with a higher Q_{TS}. Lines longer than 41″ can use a Q_{TS} of 0.4 or less, while lines 25–40″ long should use a woofer Q_{TS} of 0.4–0.6, and for lines shorter than 24″, a Q_{TS} of 0.6–0.75 should work well.

In several issues of *SB*, readers have commented on the equations that Mr. Cockroft developed for "The Unline." On page 83 of *SB* 3/90, he made a statement we all should read. He simply says, "Consider the article a road sign: it points out the direction, but it doesn't walk the road for you."

I agree with his statement. Don't let the fear that you may not know enough about transmission lines stop you from proceeding with what will probably turn out to be the most satisfying speaker project you ever attempt. Sit down with a pad of quadrille graph paper, and using the tables and equations that have appeared in these articles, make a scale drawing of the ideas that come into your head. Then, cut the wood and build your TL design. You will probably be amazed at how good your transmission line speaker system sounds.

WHETHER TO TAPER. Some articles have recommended maintaining a constant cross-sectional area along the entire length of a transmission line.[1,5] While this works well, I must point out that lines with parallel wall surfaces will invariably cause standing waves and resonances to occur somewhere along the length of the line at various frequencies.

Several articles have recommended tapering the line,[6-8] and I believe this is the ideal approach. Tapering a TL eliminates the possibility of major resonances and standing waves, which slightly improves the efficiency of your TL and reduces the enclosure's overall size. In fact, the TL design shown in A.R. Bailey's original article[9] was a tapered line.

Taper the line to no less than 50–60% of S_D at the terminus area. You can taper a TL continuously by using angled baffles so only the side walls of the box are parallel, or you can taper in progressively smaller steps as Craig Cushing did with his compact TL subwoofer.[8]

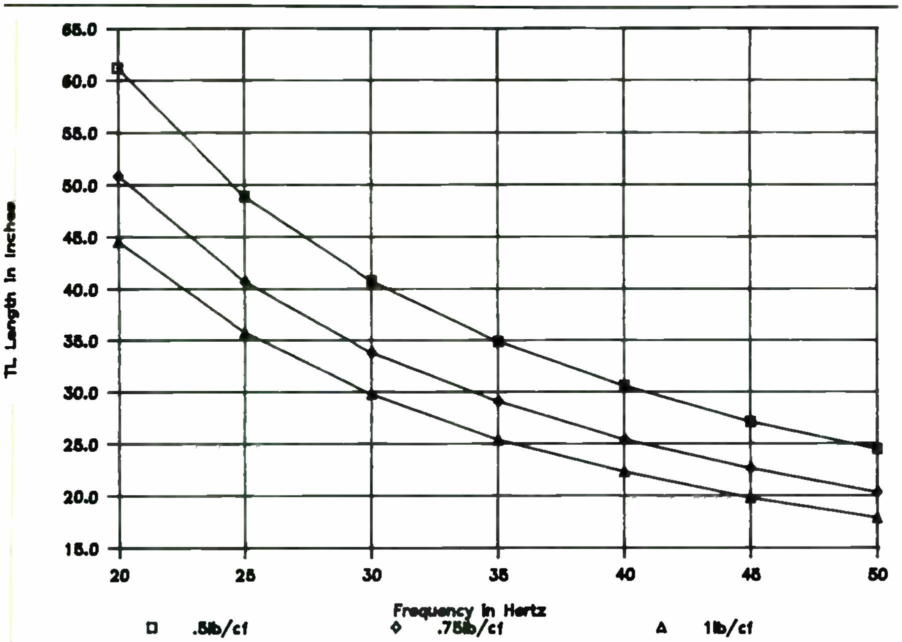

FIGURE 1: Transmission line length using 0.5, 0.75, and 1 $lb./ft^3$

FIBER'S ACOUSTIC PROPERTIES. A damping material inside a speaker enclosure absorbs midrange reflections that would otherwise bounce around inside the box and cause secondary emission from the driver cone. Without damping material, a speaker will be loud and colored in the midrange. In a transmission line, the damping fiber acts as a low-pass filter that eliminates all frequencies but the deepest bass. The woofer's output in the lower octaves is reinforced by the output at the terminus.

Most audiophiles agree that wool outperforms polyester as a damping material, and those who have tried Acousta-Stuf swear this is far superior to wool. But what makes one fiber sound better than another? The answer lies in basic physics.

Sound consists of a complex series of waves composed of compression and rarefaction of air molecules caused by the vibration of the speaker cone. *[Among other things.—Ed.]* The surface area of a damping material greatly determines what the material's absorption coefficient will be. A fiber with more

Continued on page 90

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UPGRADING A BRONCO'S SOUND SYSTEM

BY DAN FERGUSON

When a co-worker, Steve, purchased a new Ford Bronco with a premium sound system, I was interested in hearing what Ford had been doing for Bronco sound. After a parking lot audition, I concluded the system could be described as "inoffensive." Not wishing to insult the proud new owner, I suggested he listen to the relatively inexpensive system in my humble 1980 Toyota pickup. After hearing the dramatic difference, he began to consider the possibilities and costs involved. Over a period of time, we developed a design for a system upgrade that met his needs at a total cost for materials of $400.

Eventually, the system was an unqualified success. I say eventually because it took two modification sessions to achieve the final result. In the end, however, the system sounded wonderful and Steve was pleased with the results.

For me, the fun was in designing an upgrade for yet another vehicle application I had not seen before. The experience was even more enjoyable because this type of system was not commercially available at any price, let alone the modest cost of the upgrade.

STARTING POINT. Original equipment in the Bronco consisted of a high-quality DIN-sized (flat face) dash unit and four speakers. The front drivers were round, 4½" diameter units with whizzer cones mounted in the upper forward quadrant of the doors—a preferred location. The rear 6" by 8" oval drivers were mounted in an equally good location in the walls approximately 2½' behind the front seat and approximately 18" above the rear floor—nearly the same elevation as the fronts. Because of these favorable speaker locations, stereo imaging and balance was very good, much better than dash and package shelf setups in most sedans.

The Ford deck has the following features: AM/FM stereo radio with seek and scan; 5W/channel × 4; Dolby-B tape noise reduction; auto-reverse tape transport with buttons for tape direction, fast-forward, and reverse; LCD displays; clock; and bass, treble, volume, balance, and front-rear fader. The sound of this equipment was, as I said earlier, inoffensive. The single most descriptive word would be "smooth." I heard no trace of harshness when boosting the treble to compensate for the lack of tweeters. The original oval speakers have very good (perhaps even prominent) midbass, giving the impression of real bass. After a thorough listening test, during which I played all my favorite test tapes, I was convinced the system had good potential for upgrading.

UPGRADE DESIGN. The first step in any upgrade is to understand the objectives. Here are the ones Steve and I developed for his Bronco:

- No interior vehicle modifications.
- System must be attractive and complement interior design.
- Cargo space utility must not be adversely affected.
- Budget limited to $500.

MAIN SPEAKERS. The first step in designing a quality autosound system is to determine which components you can save and reuse. I was certain we would retain the factory deck, but we had some work to do to check out the speakers.

Because the Bronco's front door-mounted speakers were difficult to remove and the rears easy, we chose to base most of our decisions on evaluations made on the rear speakers. Also, the front and rear speaker's basic sound is quite similar. Finally, the owner (understandably) chose to not remove the front door panels unless absolutely necessary. (We didn't find it necessary.) Four screws later, I was holding an impressive-looking 6" by 8" driver. It was fairly heavy, especially for original equipment, and had a paper cone with cloth roll sur-

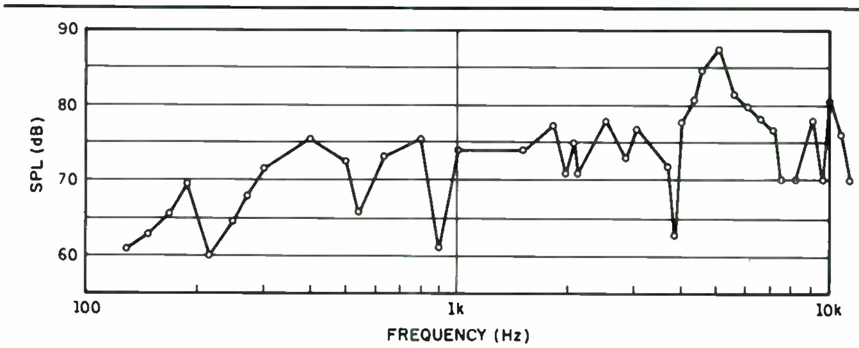


FIGURE 1: Frequency response of stock Ford 6" by 8" speakers in a 1989 Bronco.

ABOUT THE AUTHOR

Dan Ferguson has a Master's Degree in mechanical engineering from Clemson University. He is a serious amateur jazz guitar player and speaker builder and has built a number of autosound systems. He also authored the book, Killer Car Stereo on a Budget. *He is currently employed as a project manager with a large consumer products company.*

PHOTO 1: Finished front tweeter installation.

PHOTO 2: Finished rear tweeter installation.

round and a whizzer cone for improved high-frequency response.

We unplugged the leads, attached my signal generator, and set the driver back in its mounting hole. Using a Radio Shack sound level meter placed on the

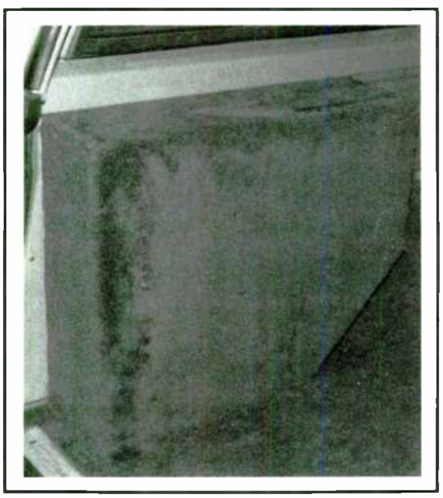


PHOTO 3: Finished left subwoofer cabinet.

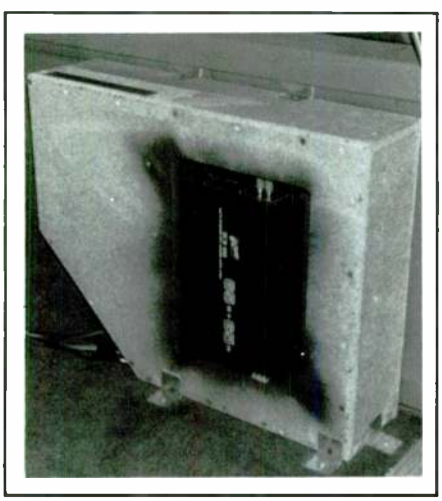


PHOTO 4: Nearly complete right subwoofer cabinet with power amplifier.

center console, we developed the in-vehicle frequency response shown in *Fig. 1*. The graph, however, bears little resemblance to what I thought I was hearing as it wasn't very smooth. In general, vehicle space resonances color speaker frequency responses, which perhaps was the case with the Bronco. As you will see later, it became a major factor in tuning the upper-bass response. In any case, the original factory speakers sounded considerably better than the frequency response graph indicated. One last "excuse" for the frequency response irregularities could be because my measurement equipment is crude at best.

Having made enough excuses for the data, I trusted my ears and opted to retain the original rear drivers. It followed, then, that we would add tweeters to the rear units. We needed to make a similar decision about the front speakers. We were running out of time at this first session, and the only way to get to the front speakers' leads for testing was to pull the deck. Again, relying on my ears, I elected to at least try to retain the original front speakers and add tweeters there also.

ADDING TWEETERS. For cost effectiveness, great sound, and ease of installation, I selected the venerable Polydax TW-60s, in wedge mounts, supplied with $5.5\mu F$ Mylar caps. We installed these on the front door panels and rear walls as shown in *Photos 1* and *2*. Up front, we attached the tweeters to the plastic door panels with a single sheet metal screw and a drop of silicone caulk. In the rear, we attached them with one of the existing speaker mounting screws. This limited interior modifications to two small holes drilled in the front door panels.

SUBWOOFER CONFIGURATION. Next, we determined where to place the subwoofers. I had a preconceived notion they would fit under the rear seat. However, after examining that area, I concluded that *nothing* would fit there, as the seat sits flat on an elevated floor plan. Also, the only convenient place to mount the power amplifier(s) was the large console, which would reduce the storage area. It also had the potential to generate excessive heat from the powertrain.

I retreated to the cargo area. We also had to overcome problems here as the volume was quite large compared to the driver's space. This created the possibility for poor acoustic coupling to the front of the vehicle. Then the system would have the typical problem of projecting cleanly past the large, rear seat, which would subdue bass attack. Finally, a traditional box system would occupy much of the cargo area, which was also objectionable.

Sitting in the driver's seat, I noticed a large gap between the rear seat back and the vehicle side walls. By building two shallow cabinets and mounting them vertically, a vertical slot-loaded design could project cleanly through the gap in this location. Since there seemed to be no other good prospect, we settled on this design. It turned out to be a good choice.

The Bronco cargo area has two trapezoidal recesses in both rear side walls. The available net volume there, however, was only 200 in^3. We decided to use that volume as part of a larger enclosure as it permitted reducing cabinet depth by 1″.

Since the wheel wells intruded into the compartment, we would make the cabinet the same depth. Doing rough math ahead of time, we set the tailgate, side window sill, and wheel well as natural boundaries for the cabinets. The shape of the cabinets, after a series of trial-and-error attempts, became a pair of trapezoids—a smaller trapezoid to fit inside the vehicle wall recess and a larger one for the main cabinet. Aesthetically, this suited the Bronco well. *Photo 3* shows the final results.

To be sure our measurements were correct and the cabinet design looked right, we installed full-size cardboard mock-ups. The right side cabinet included additional space to house the relatively large power amplifier since no other location was available (*Photo 4*).

Luckily, the cabinets had sufficient space to accommodate my favorite subwoofer design, a Thiele/Small sixth-order alignment. Through some tight maneuvering, we directed the ports and slot-

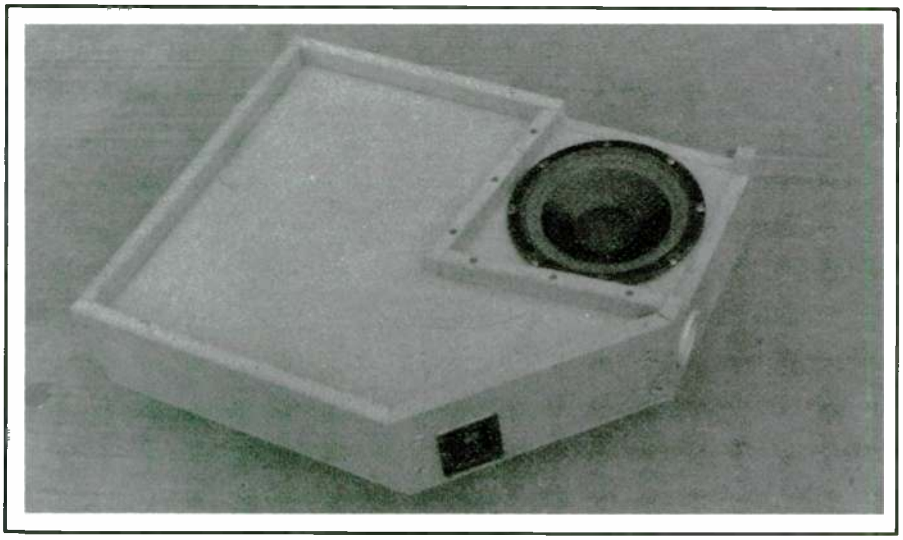


PHOTO 5: Left subwoofer cabinet with top removed.

loaded speakers to fire in the same direction through the gaps between the rear seat back and vehicle side walls. To facilitate pressure-coupling the woofers' front wave to the slots, I designed a baffle to seal off the woofer's rear and bottom, *Photos 5–7*. I chose the Madisound 81524 DVC woofers for this alignment. These speakers with porous dust caps have a loss factor (Q_L) of about 5 (relatively high); but in a T/S sixth-order alignment, they have an f_3 of 32Hz in a 0.7 ft³ box. At $25 each, they are an impressive bargain.

Figure 2 shows final box details. Since the net box volume is approximately 6% less than theoretical, I increased f_B to 34Hz and planned to do an in-vehicle tuning of the electronic filter for a −3dB point of about 34Hz as well, or less depending on the results.

THE ACTIVES. For electronics, we would use only two components (I thought)—one of my handbuilt subwoofer filter/crossovers and a single power amplifier. For the latter, I chose a 65W RMS per channel Hi-Comp model HCB0865 from Crutchfield. Although it is unfortunately not in their current catalog, it is an absolute best buy at $130, considering it is a full-featured unit with a 0.05% THD rating at full power.

The subwoofer filter construction details, shown in *Killer Car Stereo on a Budget*,[1] are beyond the scope of this article. The theoretical tuning for the filter's high-pass section from Bullock's alignment tables[2] is Q_F = 1.814, with a characteristic frequency of 31.8Hz. However, as you will see later, we altered this significantly due to the large vehicle resonance at about 43Hz.

The recommended subwoofer filter sums both right and left channels and provides a mono output to the power amplifier. It also has a low-pass filter with adjustable crossover frequency. This feature, along with adjustable gain, lets you obtain a seamless blend between the subwoofer and the vehicle's main speakers. Because of the input configuration, you can use the filter on either high- or low-level signals from the dash unit. The circuit topology is plain vanilla—straight out of Walt Jung's book.[3] All parts are stocked at Radio Shack. (A handbuilt prototype is available from the author for $75.)

BOOSTER AMPLIFIERS. During my initial listening tests, I determined that external power amplifiers (or boosters) were unnecessary for the main speakers as the original system played loudly and cleanly. It had far greater output than the owner would ever require. However, we later found that the capacitor-coupled outputs from the Ford deck limited low-bass response to 50Hz. Eventually we added an 18W/channel Hi-Comp, model HCB-8036 to the rear channels to provide a 100Ω dummy load for the deck's 1,000μF output capacitors. This extended the rear channel's bass response nicely and provided the proper signal content for the input to the subwoofer filter. This

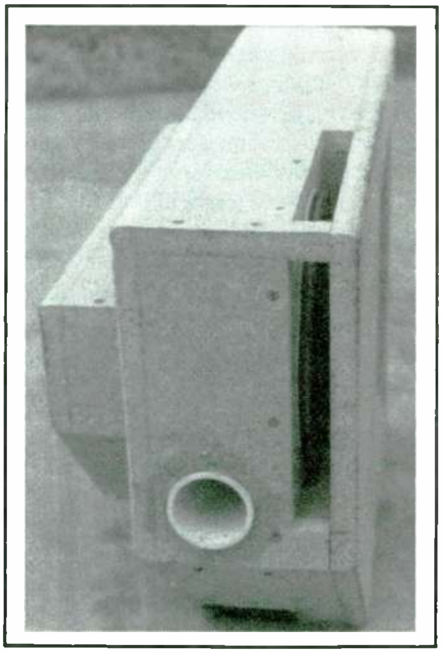


PHOTO 6: Front of right subwoofer cabinet.

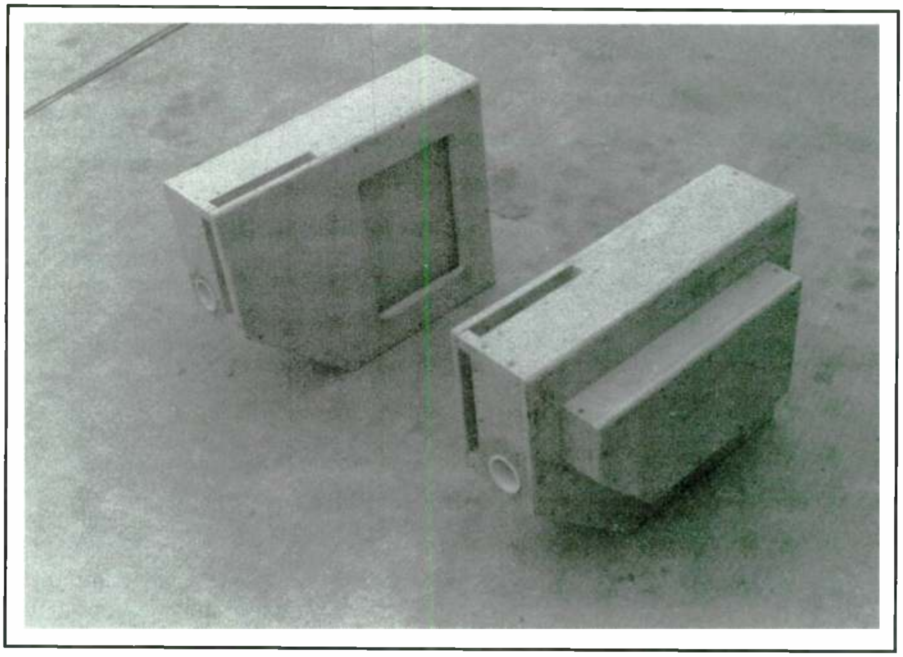


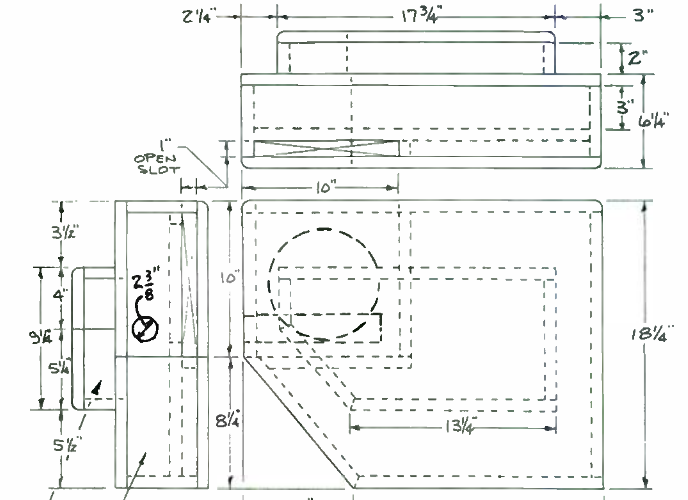
PHOTO 7: Completed subwoofer cabinets ready for mounting.

modification increased the system cost by only $50.

CONSTRUCTION. When all materials were on order, except the small power amplifier for the rear speakers, it was time to go to work. We spent one afternoon cutting out the pieces for the two subwoofer cabinets. Starting with a 4′ by 8′ sheet of ¾″ high-density particle board, we were eventually left with two piles of relatively small pieces and almost no waste. Since we didn't plan the cut sequence ahead of time, we have no record of what we actually did, so be prepared to run out of material if you're not careful.

The next day, Steve spent eight hours dry-fitting all the pieces and determining the relative location of the subenclosures on the main enclosures. It took another four hours to disassemble the enclosures, cut the openings with a saber saw, and reassemble them with copious amounts of Elmer's glue. (We attached the cabinet tops with only silicone caulk and screws to permit removal if we needed to access the speakers.) After the glue dried, we routed most of the cabinet edges, as shown in *Fig. 2* and the photos, to facilitate carpet installation.

Next, we lined the cabinets with fiberglass from Radio Shack and installed the speakers, wiring, ports, and terminal cups. We sealed the ports and cups with silicone caulk and installed the speakers with #8 × 1″ panhead sheet metal screws and Mortite rope caulk.



Volume (V_1)
= [(23.0 − 0.75 − 0.75)(18.25 − 0.75 − 0.75) − (0.5)(8.25 − 0.75)(8.0 − 0.75)](3)
= [(21.5)(16.75) − (0.5)(7.50)(7.25)](3) = (360.13 − 27.19)(3) = (332.94)(3) = 998.8 in³

Volume (V_2)
= [(17.75 − 0.75 − 0.75)(9.25 − 0.75 − 0.75) − (0.5)(5.25 − 0.75)(4.5 − 0.75)](2)
= [(16.25)(7.75) − (0.5)(4.5)(3.75)](2) = (125.9 − 8.4)(2) = (117.5)(2) = 235 in³

Total Volume = 998.8 + 235 = 1,233.8 in³ = V_B

FIGURE 2: Subwoofer cabinet details. Port dimensions equal 2″ diameter by 8″ long.

WIRING. Steve ran wiring in the Bronco as listed below:

- One #10 (red) from the fender-mounted starter relay "hot" terminal through the firewall and along the right door sill to the rear cargo area.

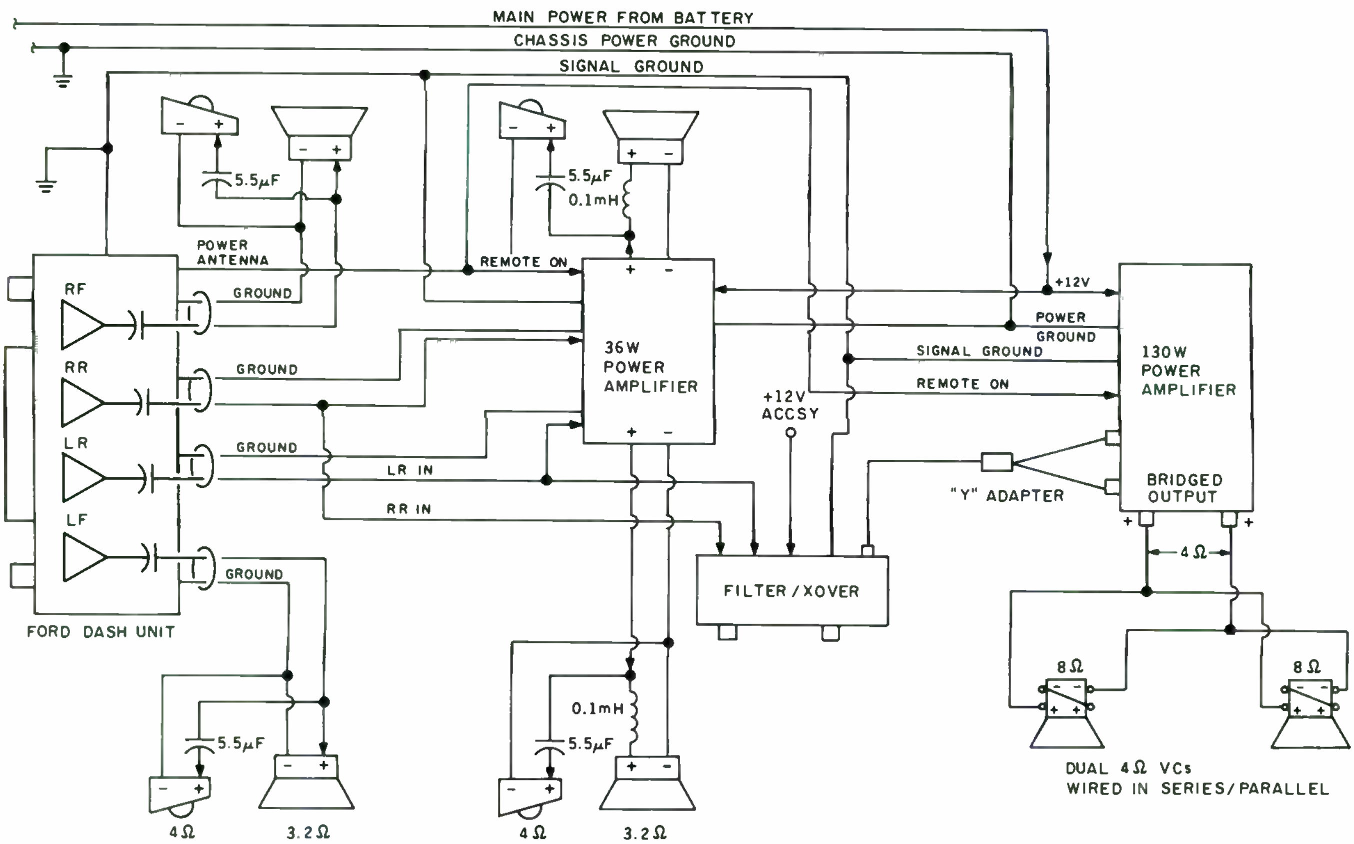


FIGURE 3: System schematic.

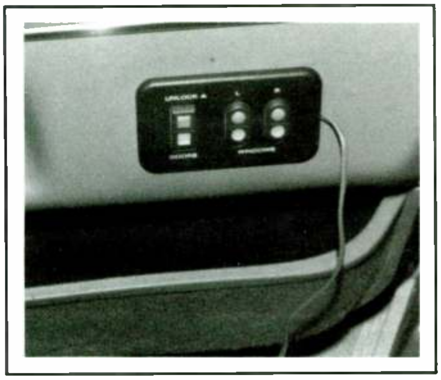


PHOTO 8: Tweeter wiring ready for hookup.

- One #10 (black) from an electrical chassis ground strap terminal under the hood—same routing as the red.
- Three #18 red and black pairs from the dash to the console.
- One #18 green pair from the dash to the console.
- Two #18 red and black pairs from the console to the rear cargo area.
- One shielded cable from the console to the rear cargo area.

After mounting the various components, we installed the interconnecting wiring (*Fig. 3*). Removing the radio (or deck unit) was quite easy. The entire trim plate for the radio and heater controls pops off under gentle prying and the radio is secured with four sheet metal screws.

Wiring the front tweeters was difficult since Steve elected not to remove the door panels and risk rattles. Instead, he carefully pried off the power door lock escutcheon plates and the rubber cable boots in the lower front door edges and fished a red/black #18 pair down through the door panels to the rubber cable boot. We made a parallel, soldered (as always) splice to the front speaker leads in very close quarters in the rubber boot area.

We filed a notch in the front edges of each power door lock plate large enough to accommodate the #18 zip cord. When we snapped the lock plate and rubber boot back in, the wiring installation was invisible except for the protruding leads (*Photo 8*). All internal wiring, including the tweeter's capacitor, was hidden inside the wedge. *Photo 1* shows the finished installation.

Wiring the rear tweeters was *much* easier. Removing four sheet metal screws puts the rear 6″ by 8″ ovals in your hand with plenty of slack in the wiring to make a hookup. We removed the drivers from their grilles and drilled two small holes in each one's plastic mounting ring so the tweeter leads could pass between the ring and the plastic grille. We then installed a pair of 20-gauge wires in each side and spliced into the factory speakers leads (*Photos 9* and *10*).

Looking at the response curve, you can see that the rear speakers have significant output above 7kHz, the tweeters' crossover point. A pair of 0.10mH chokes were readily available and since this was approximately the correct value, I installed them in series with the rear speakers. Subjectively, Steve and I agreed it made the rear speakers sound smoother, so we used them.

After soldering and taping all connections, we reassembled the rear drivers and tweeters. Note to all speaker builders: given no time constraints, I would have done a more rigorous crossover design including impedance plots, Zobels, and so on. If you attempt a similar mod, this design has plenty of room for refinement.

INITIAL TESTING. We powered up the system after each modification to ensure we'd made no errors, and if we had to correct them before proceeding to the next step. The hookup, however, was fine. With all circuits roughed in and the uncarpeted cabinets lying on the floor, we had again run out of time; Steve used the system for a week while he decided how to secure them vertically to the cargo walls. Eventually, he removed the plastic window trim molding and found suitable body anchor points. Then, using aluminum angle material, he attached the cabinets at the top, bottom, and front with sheet metal screws.

Prolonged listening tests revealed a substantial dip in the upper bass. Clean, low bass was over-abundant; however, upper bass was weak and lacked attack. This was especially evident on kick drums; the slap was not there.

Back in my shop, we ran a frequency response test on the filter/subwoofer system using a signal generator, frequency counter, and Radio Shack sound level meter. *Figure 4* shows the results. While the subwoofer had sounded smooth in the shop earlier, it now had an irregular response with a large peak at 43Hz followed by a dip at 65Hz. I had no explanation for this until I later read Tom Nousaine's article "The Battle of the Boxes."[4] Using a Ford Aerostar Van as a test vehicle for comparing four full-range box systems, Mr. Nousaine encountered similar response anomalies. While free-air tests of the boxes were relatively smooth, the in-vehicle's bass responses were all similar to the Bronco's. Also, the April 1990 issue of *Voice Coil* reports the same findings for sedans.[5]

By trial-and-error tuning, I improved the subwoofer's response to the solid curve in *Fig. 4*. This was audibly superior, but still less than perfect. The final filter setting was Q_F = 0.69 at 50Hz, but this was partly because I ran out of pot range and time. I believe a pot value

TABLE 1

ITEMIZED COSTS

Hi-Comp HCB-865 power amp	$130
Hi-Comp HCB-8036 power amp	40
Madisound 81524 DVC woofers	50
Polydax TW-60 W/wedge mounts	40
Audo Sound Lab subwoofer filter	75
Particle board	10
Wiring, glue, screw, and so on	50
Total	$395

PHOTO 9: Tweeter wiring installed in rear coax spacer.

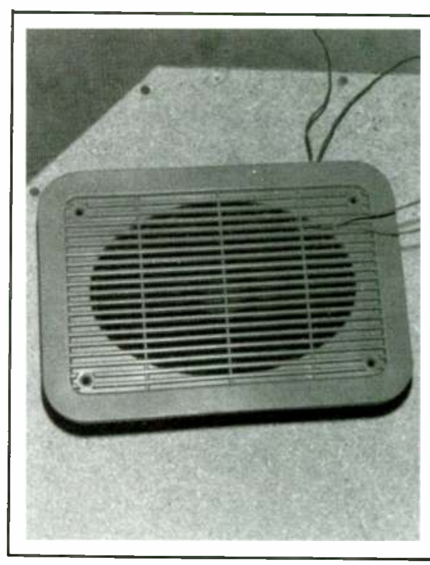


PHOTO 10: Rear speaker ready for tweeter installation.

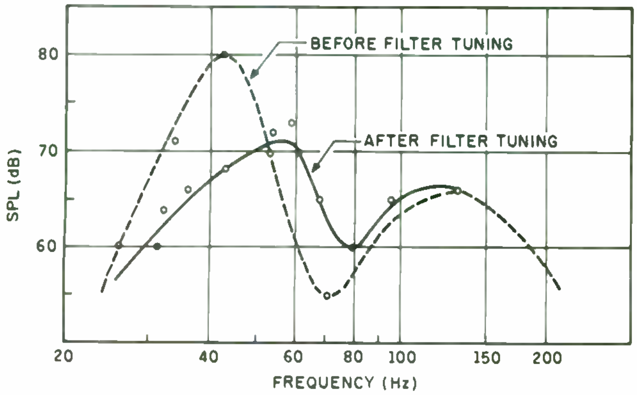


FIGURE 4: Bronco's subwoofer response.

change to lower the filter's Q to about 0.50 will yield further system improvement, a modification we are planing to do. Because the Ford factory speakers had prominent midbass, it also became necessary to cut the bass control about 20% to create natural-sounding male voices.

While all these changes produced positive results, the system still had insufficient midbass attack, which I concluded was due to the capacitor-coupled Ford deck. It took a trip to the local authorized repair center to look at the deck's schematic. Sure enough, it showed the standard pair of dual IC power amplifier chips. However, where many other designs use these chips in bridged, direct-couple pairs, Ford has opted for four independent output channels. Without the benefit of bridging, the biased outputs must have series-coupling capacitors to function. The math dictates that a 1,000μF capacitor connected to the 3.2Ω speaker yields an f_3 of 50Hz.

The final step of installing the Hi-Comp booster amp for the rear main speakers was successful. Bass attack was now quite natural, while everything else stayed the same. The bottom line is that this upgrade sounds very good. It has plenty of headroom, smooth highs, and extended lows. The Ford deck is a nice piece of equipment and sounds like it, now that it has been unleashed.

Two final notes: After extended use, Steve liked the 18W booster amp's improved punch so much he installed one on the front channels as well and reported improved clarity and front sound staging. Ford owners should plan to install a four-channel booster amp or two stereo amps as the best configuration for upgrading one of these systems. That will certainly be my approach on future Ford upgrades.

The Bronco's bass response dip is apparently a common problem and looks like a good candidate for a parametric equalizer. I suppose it's time to get back to Jung's op amp books and dust off the breadboard.

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2. Bullock, Robert M., "Thiele, Small, and Vented Loudspeaker Design, Part V: Sixth-Order Alignments," *SB*, 1/82, p. 20.
3. Jung, Walt G., *Audio IC Op-Amp Applications*, Howard W. Sams & Co., 1978.
4. Nousaine, Tom, "Battle of the Boxes II," *Car Stereo Review*, September/October 1990, p. 62.
5. Dickason, Vance, *Voice Coil*, April 1990, Audio Amateur Publications, p. 3.

A VERSATILE MOD FOR ALL MINIMUS 7s

BY JAMES LIN

Radio Shack's Minimus 7 has been a popular, inexpensive speaker system for the past ten years or more. Although quite good for the price, its design contains problems that are obvious candidates for improvement.

The basic speaker configuration has remained the same over the years and is shown in *Fig. 1*. As you can see, the tweeter has a 12dB/octave crossover at a nominal frequency of 2.5kHz, but the woofer is run full range. As William Hoffman noted (*SB* 1/88, p. 36), the lack of a woofer crossover means the woofer's ragged high-frequency response is not rolled off and therefore interferes with the tweeter response, adversely affecting the sound. Also, the tweeter is about 3dB more efficient than the woofer, exacerbating the light tonal balance expected in a speaker with a limited low-frequency response.

On the surface, the solution would seem obvious: add a woofer crossover and pad down the tweeter. However, although the model number has remained unchanged, the Minimus 7 has undergone several changes as various sources were used for the woofer, tweeter, and other parts. Such changes are common in any product with a long production life, as one source becomes unavailable or, in the best case, as component improvements are incorporated into production *[or cheaper vendors are used.—Ed.]*.

In many cases, substituted parts are simply chosen because they do not require much, if any, redesign—for example, substituting the same value capacitor from a different manufacturer. In the case of the Minimus 7, the low cost would indicate that Radio Shack probably has not redesigned the speaker, but has simply substituted "suitable" parts based on cost considerations.

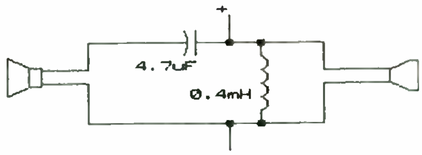

FIGURE 1: Stock Minimus 7 crossover.

Given this, you can assume that, regardless of tweeter variations, the tweeter impedance in the crossover region has remained relatively stable and close to the nominal 8Ω value so it will interface reasonably well with the crossover. Unfortunately, because of the lack of a low-frequency crossover, the woofer impedance has no such constraint on variations aside from the nominal 8Ω specification, and significant variations in woofer voice coil inductance can and do occur ("Mailbox," *SB* 6/89, p. 74).

These variations require you to change any proposed woofer crossover. Since the woofer changes have not been accompanied by a change in model number, it is impossible to take a cookbook approach and say "use this crossover with this Minimus 7 and that crossover with that one." When I first suggested an article on modifying the Minimus 7, Editor/Publisher Ed Dell pointed out the numerous reports in *SB* of seemingly random variations in Radio Shack products and concluded it was impossible to modify a Minimus 7 because "there is no such thing as a Minimus 7," or more precisely, several possible Minimus 7s hide under the same name.

A GENERAL APPROACH. Having argued it is impossible to design a modification for the Minimus 7, I will now propose a slightly more general approach to such a modification, which I believe you can apply to all versions of this speaker. Because of the woofer variations, however, the modification requires that you make measurements on your speakers' woofer, as I will discuss below.

Figure 2 contains my suggested modification, which consists of three changes. First, I added a Zobel (a series RC circuit) in parallel across the woofer. These components cancel the voice coil inductance, so the woofer/Zobel combination will have a flat, resistive impedance through the crossover that is approximately the DC resistance. The Minimus 7, specifically the woofer, has a nominal impedance of 8Ω, which means all versions of the woofer should have a DC resistance of 6Ω, with only small varia-

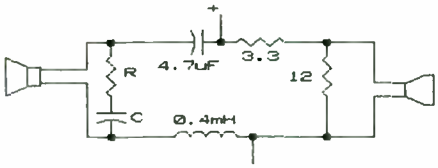

FIGURE 2: Suggested crossover modification. See text for details on how to calculate R and C for the Zobel across the woofer terminals.

TABLE 1

MINIMUS 7 PARTS LIST

3.3Ω, ½W carbon film
12Ω, ½W carbon film
5W wire-wound resistor (see text)
nonpolar electrolytic capacitor (see text)

ABOUT THE AUTHOR

James Lin was a graduate student in physics before switching to medicine. He was an Oncology Fellow at Memorial Sloan-Kettering Cancer Center before moving to Galveston, TX, where he teaches medicine. He has built several electronic kits and projects from Audio Amateur *and has written for* Speaker Builder.

FIGURE 3: Setup for measuring speaker impedance. Adjust the amplifier volume control for an output of 10V across the 1kΩ resistor when the speaker terminals are shorted out. Then hook up the speaker and measure the voltage across its terminals. A 10Ω impedance should give 100mV, a 20Ω impedance 200mV, and so on.

tions. Thus, adding a proper Zobel across any version of the woofer will remove the problem of large variations in woofer impedance due to varying voice coil inductance, leaving only the small variations due to differences in voice coil resistance.

This allows the second change, the shift of the coil in the existing crossover from the tweeter circuit to the woofer circuit, to give a 6dB/octave rolloff in the 2.5kHz range for all versions of the woofer. Since a low-order crossover is relatively forgiving of variations in components, the small variations in woofer voice coil resistance should not lead to any problems. The coil is shown in the negative leg of the crossover simply because it is easier to implement this way. This change also reduces the tweeter crossover to 6dB/octave.

For the third change, I added a 3.3 and 12Ω L-pad resistor combination to the tweeter circuit to reduce its efficiency so it would match the woofer efficiency more closely. This L-pad also reduces variations in the tweeter impedance, stabilizing the high-frequency crossover point; ½W carbon film resistors will work fine.

ZOBEL CHANGES. All these changes are cookbook except for the Zobel. As mentioned, the different woofers used in this speaker have varied in their coil inductances, and thus require different Zobels. To obtain the proper R and C for your speaker Zobel, measure the woofer's impedance curve alone up to 7–8kHz, along with its DC resistance.

To make this measurement, use the setup in *Fig. 3*. If you do not have a sine wave generator, use a CD player and a CD test disc with spot sinewave frequencies to measure the impedance at various frequencies, then draw a smooth curve between them. R should be a 5W resistor with the closest value at or above the DC resistance; if the DC resistance is 5.9Ω, pick R = 6.2Ω. To obtain C, find the frequency (f) at which the impedance is 1.414 times the DC resistance and calculate C = ½πRf. This is not a precision calculation, and taking the closest standard capacitance will probably be adequate.

If this lack of precision offends you, I will point out the above calculation assumes an overly simple resistor plus inductor model of speaker impedance. If you try to fit this model to the measured impedance curve at different frequencies, you will find that the calculated inductance easily varies by a factor of 50% or more. For my woofers, which have the same impedance curve as in Mr. Hoffman's article (*SB* 1/88, p. 36), I found R = 6.2Ω and C = 22μF. I recommend using a 5W wire-wound resistor for R.

A nonpolar electrolytic is inexpensive, adequate, and in keeping with the quality of the drivers. You should solder the Zobel directly across the woofer terminals, avoiding the tips where the push-on terminals fit. You may wish to confirm the result by measuring the woofer's impedance curve with the Zobel in place.

THE FINAL TOUCHES. Implement the remaining changes at the crossover, which is contained on the plastic input terminal plate. Screws hold this plate in place inside the cabinet and you can easily remove it once you have removed the drivers and fiberglass damping. The physical configuration of this piece has changed over the years, so a diagram of my crossover may not match yours. However, I suggest the following general procedure.

First, locate all the crossover parts and terminals. Desolder the coil wire from the terminal where it connects with the capacitor and the positive (blue) tweeter wire. Desolder the negative (black) woofer wire from the negative (black) input terminal and solder it to the free end of the coil. Insulate the junction with tape or heat-shrink tubing. Then, desolder the capacitor where it connects with the positive (blue) tweeter wire terminal, and solder a 3.3Ω, ½W resistor between the capacitor and the tweeter wire terminal and a 12Ω, ½W resistor between this tweeter terminal and the negative input terminal. You may also wish to experiment with damping the cabinet with a thin layer of Mortite or Duxseal lining the inside.

Now reassemble the speaker, taking care to ensure that the woofer and tweeter wires go to the correct drivers. (Recall that in the stock speaker, both black wires come from the negative input terminal, but in the revised cross-

Continued on page 90

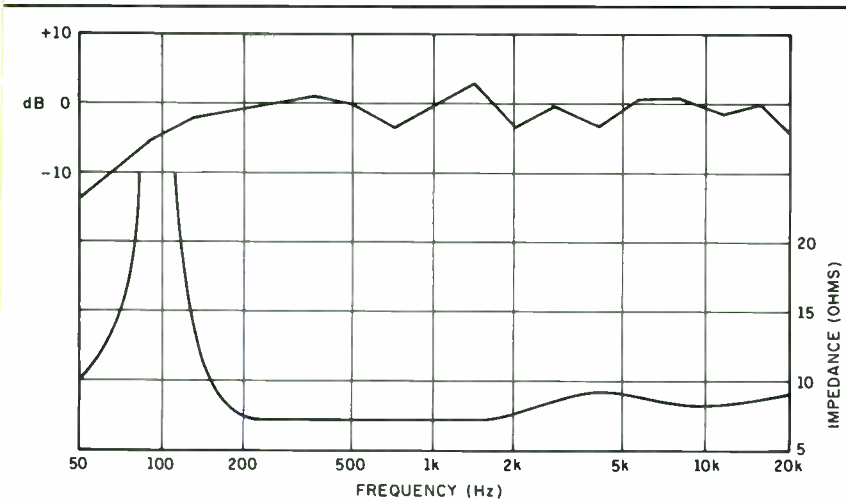

FIGURE 4: Frequency response (using pink noise and Heathkit ½-octave analyzer at about 10" with the speaker sitting on a tripod in the middle of the room) and impedance curve of the modified Minimus 7.

SUPPLIERS

Digi-Key
701 Brook Ave. South
PO Box 677
Thief River Falls, MN 56701-0677
(800) 344-4539

Mouser Electronics
2401 Hwy. 287 North
Mansfield, TX 76063
(800) 346-6873

SIMPLIFYING CABINET ASSEMBLY

BY GLEN R. TRAVIS

Learning is always easier when you can use the comments of others as guides for evaluating your own questions. Here are a few of mine you may find helpful.

MEASUREMENTS. Near-field measurements are suitable for mid and high frequencies, but will not give a true representation of low frequencies. If our ears were positioned where the near field microphone was, the measurements would almost be valid. It still wouldn't account for low frequencies coming from a cabinet's vent or port.

Small speakers can look good when you take measurements a few inches from the speaker, but in a large room, the bass response ceases to exist. To have bass frequencies reproduced effectively at listenable levels in a large room, air in quantity must be moved. This requires that the small speakers have the same cone area as large speakers. It can't be. It's a law of physics. I've never seen formulas that give the relationship of total air volume movement to room volume for a specific frequency. A room must have a minimum volume and proper dimensional measurements, and your ear or other listening device must be positioned at a point where the reflected and original frequencies will not cancel each other.

CABINET VOLUME. Trying to minimize cabinet volume is like attempting to make a 4′ organ pipe resonate the same as a 16′ one. No one has accomplished that feat yet. Even satellite speakers should be large enough to be used alone. Any cabinet should be large enough with generous internal damping—polyester stuffing—to have no resonances of its own within its usable operating range. (Polyester filling is inexpensive and effective. Using plenty helps damp resonant peaks and makes the cabinet think it's larger.)

More than an interesting octave of bass is lost by imagining that a 1 ft^3 cabinet can give the bass response of a 4 ft^3 cabinet. Too much attention is given to trying to reach 40kHz. Often the useless comment is made, "It sure puts out a lot of bass for its small size." Using tone controls is only a partial solution.

SPECIFICATIONS. The specifications we read are often the result of designer's or some advertising agent's imagination running wild. Words have always been cheap. Either make your own measurements of the components you plan to use or have someone with the proper equipment and know-how do it for you. Even name-brand drivers have been up to 50% off on the stated impedance and up to 30% off on their free-air resonance point.

A break-in period of several hours while operating a speaker at about 20Hz with 20W or more pumped in can sometimes lower the free-air resonant point a few hertz. On some speakers I've had to cut part of the spider away. Yes, power handling capability is lost, but full frequency response was the important factor in that particular instance.

Resistors, capacitors, and inductors have their tolerances—some up to 15% off. By the time you've determined the total error possible, your calculations have become a questionable guide. Measure all your components first. Select those closest to the required values. Then put them in the circuit and measure the results. If necessary, change the parts to reach your design goal.

One of the most amusing suggestions says, "After you've made your calculations to four significant figures, add 20–30% to the value to be on the safe side." That is not my idea of acceptable engineering.

CROSSOVERS. Expecting off-the-shelf speakers and crossovers to match is a dream bordering on impossibilities. First you must measure the speaker impedance at the crossover frequency. It will probably need a resistance/capacitance compensating network connected in parallel with the voice coil to keep the impedance constant if you cross over above 200Hz. This is usually referred to as a Zobel circuit. Use at least a 12dB/octave slope. Then the speakers can perform at their designed best. Try to cover the voice range with one speaker. Leave the bass for one designed for bass and the treble for one designed for treble. These comments apply whether you are using either passive or active crossovers.

With a pink noise source and a spectrum analyzer or a signal generator with a decibel meter, you have a good chance of verifying your crossover design and matching efficiencies. Otherwise, you are depending on your own or someone else's wishful thinking. You often wonder if some manufacturers check their products.

The use of a pink noise source and a spectrum analyzer can give you a good idea of where you can best place your speakers for what you would like to hear in your particular room.

ABOUT THE AUTHOR

Glen Travis has a basic degree in chemistry, but his interests and further education have expanded his knowledge to include electronics, physics, photography, Indian history, organ, and local museum participation. His work effort was designing and testing aerospace and uranium concentration equipment. Self-education never stops. He is retired and as busy as ever.

My Best System

This system consists of two 12″ TA-305s (available from Madisound) in an 8 ft³ cabinet for frequencies below 180Hz. For midrange and treble, an 8″ Vifa P21WO-20 is crossed over at 2.5kHz with a Vifa D26TG-35 in a 1½ ft³ cabinet. I filled both generously with polyester fiber to dampen any cabinet-dimension reflections. *Figure A* shows the crossover network. Different speakers may require different values. You must measure them for operating and crossover impedances.

A smaller and less expensive low-frequency system could use a single dual voice coil 15″ Madisound 15254 DVC speaker in a 4–5 ft³ cabinet. The same crossover (two) and two satellites would complete the full range requirements. Using a ten-band equalizer can help compensate for variations in speaker efficiencies should they exist.

To arrive at the above choice of speakers, I've bought and tested more than 50 brands and sizes. My test equipment consists of a dual trace oscilloscope, an audio frequency generator, a pink noise generator, a ½-octave spectrum analyzer, a calibrated microphone with decibel readout, an LCR meter, an AC millivolt meter, and a decade resistance.

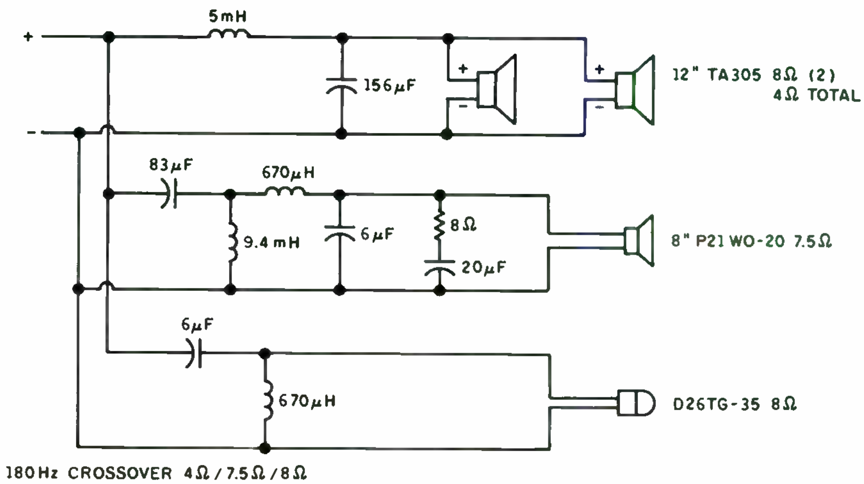

FIGURE A: Crossover network.

SPEAKER SELECTION. Deciding which driver to use is probably the hardest problem to resolve. Some of us have spent many dollars and much time trying to find the best speakers and how to improve on those we've collected. You hate to throw them away after you have checked their performance and found them to be not quite as perfect as their specification sheets indicated.

Besides peaks in response, efficiency matching, power handling capabilities, price, and size, another problem is distortion. If the cone moved as one piece, you would have acoustic magic. Different surrounds, different spider materials, different cone materials, and differential pressure loading between the voice coil and the cone edge add up to the sound you hear from a specific driver.

You can easily identify harmonic distortion by playing a single frequency from 100–500Hz into an unmounted driver while holding it close and perpendicular to your ear. In this position, the fundamental will cancel and the harmonics will predominate. A microphone positioned in the same place as your ear and a dual trace oscilloscope will show the harmonics in case a prejudiced listener says he can't hear a problem with his favorites. The best thing to do is use distortion-free drivers. They do exist. Keep searching until you find them.

One of the largest radio stores sells a three-way system with a 5″ midrange driver that is a good example of a distortion generator. The cause is differential loading between the cone edge and the cone center at the voice coil. Poking holes in the center of the sealed dome relieves the pressure of trapped air and causes the distortion to disappear. This is a cost-free and effective fix.

Some manufacturers relieve the pressure behind a sealed dome by venting the voice coil through the rear of the pole piece. Some vent through the voice coil's top sides along with a porous spider. Others vent through an open dust cover.

LOW-FREQUENCY DRIVERS. Two tens instead of a 12—two 12s instead of 15. Why? The cost for two smaller units is usually less than an equivalent single larger one of the same efficiency. Two identical drivers automatically give a 3dB increase in volume. Plus, the bass reflex response time is shorter. To produce real bass, you must move air, which requires moving cone area a sufficient amount.

CABINETS IN GENERAL. Never skimp on bracing. It prevents rattles and panel resonances. Also, keep the cabinet airtight to avoid creating air hissing noises. If you use braided wire to connect speakers and crossovers, the wires will not break from nicks and handling. Also, use screw-type terminals to connect the cabinet to the amplifier. Then mount the speakers as high above the floor as practical to eliminate floor-cancelling reflections.

Finally, use solid thick cabinet panel materials and use all the speaker frame screw holes. Thin frames vibrate and leak air around their mounting edge. Having the midrange and tweeter in a cabinet or cabinets separate from the bass speakers will let you try different speakers, crossovers, and cabinets individually. Besides, some of us do change our hearing and ideas now and then.

OLD COLONY SOUND LABORATORY

LOUDSPEAKERS, VOLUME 1 — **BKAS1/1**
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From The Audio Engineering Society's Anthology Series, 61 papers, covering the years 1953 to 1977, written by the world's greatest transducer experts and inventors on the design, construction, and operation of loudspeakers. 1980, 448pp., 8 ¼ × 11 ¼, softbound.

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Designed as a reference on PSpice for the design and analysis of analog circuits, this book clearly explains how to use the features of PSpice to solve common electrical and electronic problems, as well as some in nonelectrical areas. Topics include DC operation, transfer functions, frequency response, and noise analysis. SPICE is an acronym for Simulation Program with Integrated Circuit Emphasis, and PSpice is a SPICE-derived simulator created by MicroSim Corporation. Companion software for the book is available (see below). 1988, 200pp., 7 × 9 ½, softbound.

SPICE BOOK/SOFTWARE SPECIAL! — **BKPH2/S**
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From The Audio Engineering Society's Anthology Series, 32 articles of the works of Richard C. Heyser on measurement, analysis, and perception, reprinted from the pages of the *Journal of the Audio Engineering Society* and other publications representative of the field, including *Audio* magazine and that of IREE Australia. The anthology serves as a memorial to the author's work and as fundamental material for future developments in audio, and will undoubtedly provide the stimulus for expanded discussion. 1988, 280pp., 8 ¼ × 11 ¼, softbound.

AUDIO IN DIGITAL TIMES: CONFERENCE PROCEEDINGS — **BKAS6**
$34.95

Forty-four papers presented by experts on digital audio at The Audio Engineering Society's Seventh International Conference held in Toronto on 14–17 May 1989. Digital audio, from the history, basics, hardware, and software, to the ins and outs, was the topic of the conference. Illustrated with many figures and tables. 1990, 384pp., 8 ¼ × 11 ¼, softbound.

THE SOUND OF AUDIO: CONFERENCE PROCEEDINGS — **BKAS7**
$34.95

Twenty-four papers presented by authors highly regarded in the engineering community at The Audio Engineering Society's Eighth International Conference held in Washington, D.C., on 3–6 May 1990. The topics were devoted to the progress of sound, including measurement, recording, and reproduction. Textbook style, fully illustrated. 1990, 384pp., 8 ¼ × 11 ¼, softbound.

DIGITAL AUDIO: COLLECTED PAPERS — **BKAS8**
Barry Blessner, et al., editors — **$34.95**

First publication of papers presented at The Audio Engineering Society's Premiere International Conference held in Rye, N.Y., on 3–6 June 1982, authored by the world's leading experts in the application of digital techniques in the field of audio engineering. Twenty-five of the 27 papers are transcribed, edited, and published for the first time. Subjects include basics, converters, measurements, rate conversion, recording formats, error correction, manufacturing, and applications. Includes a Soundsheet disk with audio demonstrations of digitally synthesized sounds. 1983, 268pp., 8 ¼ × 11 ¼, softbound.

MICROPHONES: TECHNOLOGY AND TECHNIQUE — **BKB3**
John Borwick — **$29.95**

Beginning with a brief history of the relevant technology, this book then goes on to explain the basic theory of acoustics, electricity, and magnetism. The working principles and design of all types of microphones are explained in considerable detail, with examples of popular current models and descriptions of microphone accessories. The second half of the book provides guidelines on the creative balance techniques to be used for musical instruments, voices, and ensembles of all kinds, in both classical and pop music. Production methods are outlined both for studios and for on location, with notes on public address operations for live shows. Borwick is considered THE authority. United Kingdom, 1990, 241pp., 7 ½ × 9 ½, softbound.

THE ART OF ELECTRONICS — **BKC1**
Paul Horowitz, Windfield Hill — **$54.95**

Completely up-to-date with the latest technology and standards, this second edition features completely rewritten chapters on microcomputers and microprocessors, digital electronics, and low-power and micro-power design (both analog and digital). Many new tables have been added, including ones for A/D and D/A converters, digital logic components, and low-power devices. The quintessential electronics text and reference. 1989, 1100pp., 7 ½ × 10 1¼, hardbound.

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Here is a completely revised edition of the famous text by the well-known authority, with more than half the pages and chapters revised or completely rewritten to cover new developments in acoustical instruments and measurement procedures, including sound and vibration meters, intensity meters, spectrum analyzers, recorders, computers, and noise measurement devices. 1948, 1989, 841pp., 5 ¾ × 8 ¾, hardbound.

ACOUSTICS—AN INTRODUCTION TO ITS PHYSICAL PRINCIPLES AND APPLICATIONS — BKAC2
Allan D. Pierce — $37.95

This volume introduces the physical principles and theoretical basis of acoustics, concentrating on those concepts and points of view that have proven useful in applications and phenomena such as noise control, underwater sound, architectural acoustics, audio engineering, nondestructive testing, remote sensing, and medical ultrasonics. The text is supplemented by problems and their answers. 1981, 1989, 678pp., 6 ¼ × 9 ½, hardbound.

EXPERIMENTS IN HEARING — BKAC3
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Considered obligatory reading for all those who want to claim literacy in the auditory sciences, this classic on hearing contains many of the vital roots of contemporary auditory knowledge. 1960, 1989, 760pp., 6 × 9, softbound.

ACOUSTICAL DESIGNING IN ARCHITECTURE — BKAC4
Vern O. Knudsen, Cyril M. Harris — $27.95

This book is a comprehensive, nonmathematical treatment of architectural acoustics, completely revised with new illustrations and updated to eliminate obsolete materials. In handbook format, it covers all the general principles of acoustical designing and includes specific applications. 1950, 1980, 408pp., 5 3/8 × 8 ½, softbound.

ACOUSTICS — BKAC5
Leo L. Beranek — $27.95

This volume is an indispensable source of practical acoustical concept and theory for acoustical and electrical engineers, scientists, and consultants, with new information on microphones, loudspeakers and speaker enclosures, room acoustics, and acoustical applications of electromechanical circuit theory. 1954, 1986, 491pp., 6 × 9, softbound.

MARQUETRY AND INLAY: TWENTY DECORATIVE PROJECTS — BKT21
Alan and Gill Bridgewater — $15.95

Complete with 200 illustrations, a glossary, and an introduction to tools and techniques, BKT21 provides step-by-step directions for easy-to-do projects. This book gives woodworkers an opportunity to add a valuable new skill to their repertoire—inserting fine woods and decorative veneers into finished surfaces. 1989, 192pp., 7 × 10, softbound.

TONMEISTER TECHNOLOGY: RECORDING ENVIRONMENTS, SOUND SOURCES AND MICROPHONE TECHNIQUES — BKTE1
Michael Dickreiter — $19.95

Recently translated from the German by Stephen F. Temmer, this rare book for the first time provides an English-language reference integrating music and musical engineering. Used by the German Broadcasting System Technical Training Center as a text to train people who graduate from a music conservatory and opt to go into broadcast, TV, recording, or sound reinforcement engineering, this book will appeal to neophytes as well as professionals in the music and audio engineering fields. Profusely illustrated, with every other page illustrations. 1984, 1989, 142pp., 6 × 9, softbound.

HEARING: ITS PSYCHOLOGY AND PHYSIOLOGY — BKAC6
Stanley Smith Stevens, Hallowell Davis — $27.95

This multidisciplinary book leads readers from the fundamentals of the psychophysiology of hearing to a complete understanding of the anatomy and physiology of the ear, including the relationship between stimulus and sensation. 1938, 1983, 512pp., 5 ½ × 8 ½, softbound.

ELECTROACOUSTICS: THE ANALYSIS OF TRANSDUCTION AND ITS HISTORICAL BACKGROUND — BKAC7
Frederick V. Hunt — $27.95

This volume provides a comprehensive analysis of the conceptual development of electroacoustics, including the origins of echo ranging, the crystal oscillator, the evolution of the dynamic loudspeaker, and electromechanical coupling. 1954, 1982, 260pp., 5 ½ × 8 ½, softbound.

VIBRATION AND SOUND — BKAC8
Philip M. Morse — $27.95

One of the most widely used texts and references on the science of acoustics, this volume provides students and professionals alike with a broad spectrum of acoustics theory, including wave motion, radiation problems, the propagation of sound waves, and transient phenomena. 1936, 1981, 468pp., 6 × 9, softbound.

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TOTAL HARMONIC DISTORTION —CARTOONS FROM STEREO REVIEW — BKPB1
Charles Rodrigues — $7.95

This hilarious collection of 118 of the author's classic cartoons on audio, video, and music is the perfect gift and/or a wonderful conversation piece. Also featured are a foreword by William Livingstone and an illustrated autobiographical sketch by Rodrigues himself. One of a kind. 1988, 132pp., 6 ½ × 7, softbound.

SHEET METAL HAND PROCESSES — BKDE2
Claude J. Zinngrabe, Fred W. Schumacher — $18.95

For help in building that special enclosure, this volume will prove indispensable, introducing the beginning sheet metal technician to basic instruction in the properties and selection of metal and the processes performed with measuring and marking, bench, cutting, piercing, joining, and soldering tools. BKDE2 includes an excellent selection of illustrations, and every process is described in an easy-to-understand, step-by-step fashion. 1974, 209pp., 7 ¾ × 10 ¼, softbound.

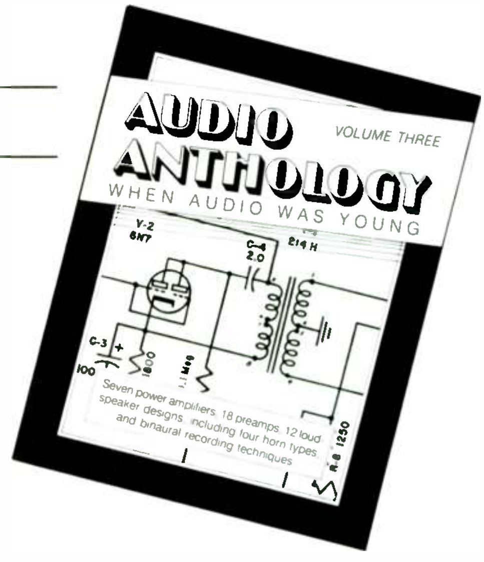
CABINETMAKING, PATTERNMAKING, AND MILLWORK — BKDE4
Gaspar J. Lewis — $34.95

If making your own speaker cabinets has led you into woodworking, this book will be a great addition to your library. Designed for advanced high school, vocational, technical, and apprenticeship programs, it provides the reader with the skills necessary for proficiency in each of the three areas of specialization. Also included are three sections common to all three fields: the nature of wood and its uses; how to use hand tools, portable power tools, and stationary woodworking machines; and methods of joinery. 1981, 438pp., 7 ½ × 9 ½, hardbound.

Book Report

Audio Anthologies

Reviewed by Gary A. Galo
Contributing Editor



Audio Anthology—Volume Two, compiled from *Audio Engineering*, January 1950 to July 1952 and *Audio Anthology—Volume Three*, compiled from *Audio Engineering*, August 1952 to June 1955. C.G. McProud, editor. Reprinted by Audio Amateur Press, Peterborough, NH. Each $16.95 from Old Colony.

TAA readers will recall my enthusiastic review of the reprinting of the first volume of the *Audio Anthology* (*TAA* 1/88, p. 45). It has sold well enough to warrant further volumes, which are fine successors, offering much fascinating reading. Volume Two includes 45 articles from past issues of *Audio Engineering*, many of these authors now recognized as audio legends.

David Hafler, who needs no introduction, and co-author Herbert I. Keroes lead off with two articles on ultra-linear power amplifiers, the second being a modification of the famous Williamson design. The lead article's first paragraph reminds us little has changed since 1951. The authors point out:

"It has been claimed that there is no more room for improvement of power output stages since other elements of the complete sound system . . . are far inferior. There is a prevalent belief that 'one good amplifier is only marginally different from another.' The proponents of this line of thought imply that significant improvement in power amplifiers is extremely difficult to achieve, and with this idea the authors agree, but the authors disagree as to the *need* for further improvement."

Hafler and Keroes offer a design that optimizes the performance of tetrode output tubes to yield performance rivaling triode designs. Their unique arrangement energizes the screen grids from a tap on the primary of the output transformer. To modify the Williamson amplifier, replacing the output transformer is necessary along with a minor change in the feedback loop. Interestingly, arguments still persist among users and designers of tube amplifiers regarding the merits of all-triode designs.

One of the most interesting articles is McProud's "Recording Characteristics." Anyone still confused about disc equalization, constant amplitude, and constant velocity cutting will find this article as clear and as technically correct as any in print today. Also, McProud's article on "Construction Practice" is especially informative, covering parts selection, layout, and wiring practice. It begins by stating that "regardless of the design and layout, the final performance of an electronic unit depends upon its components and the way they are put together." McProud seems to be telling us parts quality may have an effect on the performance (sound?) of our audio equipment. Today, with parts choices far more sophisticated than those in 1950, many designers still refuse to believe parts quality can make a difference in the sound.

Tenny Lode offers an article on "Stereophonic Reproduction," still a curiosity in 1950. The title is deceiving, however, as the article explains a method for creating electronically reprocessed stereo from monaural recordings. Those who still purchase reissues of mono recordings abhor such practices, since they usually degrade otherwise perfectly acceptable monaural sound.

By the late 1950s, all high-quality tube preamplifiers used DC filament supplies to reduce the hum level. L.B. Ledge, in his article "DC Heater Supply for Low-Level Amplifiers," describes an outboard DC supply for operating phono and microphone preamps. One possible application for these circuits is G.H. Floyd's "A Mixer and a Preamplifier for the Recording Enthusiast," which used an AC filament supply. Preamplifiers abound in this second volume of the *Audio Anthology*. The most extensive is Wade B. Denny's "For the Discriminating Listener: An Audio Input System." This flexible six-input preamp features DC filaments for the low-level amplification, tone controls, and a dynamic range expander, which can be modified to function as a noise suppressor.

Ulric Childs' article, "Dynamic Negative Feedback," describes a system for using current feedback to counteract the varying loudspeaker impedance. His concept was most important at the time it was written, since vacuum tube amplifiers were rather sensitive to the load impedance presented by the loudspeaker. This is a contrast to modern solid-stage designs. Another article on feedback, by Warner Clements, explores the virtues of *positive* feedback to counteract the effect of the voice coil's changing impedance.

David Sarser and Melvin C. Sprinkle offer a sequel to the article printed in *Audio Anthology—Volume One*. "The Musician's Amplifier Senior" is a higher-powered version of its predecessor offering an enormous 40W. The authors proudly state their previous amplifier "has gained an enviable reputation in Europe and Australia for its excellent fidelity." We are also told "those who did not cheat on the quality of the parts used have been hearty in their praise." It is unfortunate some designers and builders believe parts quality is now good enough that even Radio Shack carbon film resistors are more than sufficient for high-performance audio equipment.

Several articles related to loudspeaker design are included. The bass-reflex loudspeakers described appear rather crude compared to modern designs based on the work of Thiele and Small. Nor will the horn theory appear sophisticated when compared to the work of Bruce Edgar. Nonetheless, these articles provide excellent insights into the evolution leading to our present level of understanding. Volume Two is well worth reading.

Volume Three

This volume of *Audio Anthology* contains 43 articles. Although power amplifiers form a small part of this collection, they present several interesting designs. David Sarser and Melvin Sprinkle are household names to readers of the previous anthologies, and they return here with their latest version of their "musician's amplifier." Called "The Maestro," it incorporated the 6146 output tube, which had only recently been introduced by RCA. The authors note the usual 10–15W amplifiers lack the clarity and definition of live music in the concert hall. "The Maestro" boasts 90W of power from 25Hz–30kHz, an enormous amplifier for its time.

Stanley White describes an amplifier he calls the "Powertron." An abundance of preamplifier designs are featured. Wade B. Denney's 1954 article describes a dual-channel preamplifier that can be used for genuine stereophonic recordings or for creating pseudo-stereophony from monaural sources. His pseudo-stereo method employs multiple power amplifiers driving several loudspeakers, altering the tonal characteristics of the individual speakers to simulate a stereo effect. In Denney's opinion, the simulated stereo is preferable to a single monaural point source. Today, most collectors of historical recordings are horrified when mono recordings are doctored for "fake stereo."

Two other articles give further evidence of a new-found interest in stereo. R.J. Tinkham clarifies the differences between binaural and stereophonic recording and reproduction in a 1953 article. A photo in his article shows what he describes as a "complete portable stereophonic recorder, with amplifiers and power supply." Although he doesn't mention the brand name, the recorder is the famous Ampex 350-2, one I'm familiar with since the Crane School of Music had owned two. This three-piece "portable" recorder consisted of one case housing the transport (barely movable by one person), another containing two channels of electronics, and a third for the power supply. Putting handles on the cases made the 350-2 portable.

A 1952 article by James Moir titled "Stereophonic Reproduction" describes the reasons behind our ability to localize sound sources. Some startling information is presented in Mr. Moir's article. He cites tests by Bell Labs "indicating that a stereophonic system having an audio bandwidth of 3,750 cps as having the same aesthetic appeal as a monaural system 15,000 cps wide." Joseph Maxfield, co-inventor of electrical recording, is quoted as saying "I would rather hear two-channel reproduction flat to 6,000 cps than a single-channel system flat to 15,000 cps; it is more pleasing, more realistic, more dramatic."

These opinions would seem to run contrary to those expressed by many listeners in the late 1950s. Many audiophiles at the time were not willing to part with their wideband monaural systems, using very large loudspeakers, in favor of a two-channel system with more compact speakers. Quadraphonic sound, in the early 1970s, was short-lived for similar reasons. For a given amount of money, most critical listeners preferred a two-channel system that delivered true high-fidelity performance to a mediocre four-channel system. Of course, the lack of compatibility among the competing quad systems was another reason for its demise. I find it fascinating to discover how opinions have changed over the course of our audio history.

The lack of a standard for disc equalization is still evident in the preamplifier articles. Wayne Denny, in the article mentioned above, settled on the AES curve (later adopted by RIAA) since he believed it was the only one used to any great extent. Charles R. Miller, in describing a control preamp for the Williamson amplifier, offers five LP equalization settings.

The transistor makes its first appearance in Basil T. Barber's article, "A Transistor Phonograph Preamplifier for Magnetic Pickups." Barber offers a tutorial on basic transistorized amplifiers and compares the grounded base, grounded collector, and grounded emitter configurations to their triode tube counterparts. His circuit is a two-transistor, feedback-based circuit using CK-721 and CK-722 devices. Barber gives a lengthy discussion about the advantages of using transistors and even recommends using tantalum capacitors despite their high cost. According to the author, this preamp performs well in the listening tests, although he doesn't expect it to "render obsolete its vacuum tube counterpart." Would any of today's audio engineers find this preamplifier audibly indistinguishable from the best contemporary RIAA phono preamps, if the equalization and levels were matched within 0.1dB (double-blind, of course)?

Volume Three features many designs for preamp tone controls and equalizers. Stereo FM also makes its first appearance in the anthology. Editor McProud describes a two-channel converter for AM/FM receivers—not by adding a multiplex decoder to a mono FM radio, however. Instead, McProud offers a way to modify AM/FM radios so both receivers can operate simultaneously. At the time, some broadcasters were airing experimental stereo programs using an AM transmitter for one channel and an FM transmitter for the other.

No fewer than 12 articles on loudspeakers appear in this volume. The early 1950s were certainly an age of large loudspeakers. Perhaps the article that drives home this point best is James Ferguson's "The Concrete Monster." Ferguson describes a 16′ concrete horn built into the side of his house. As the editor notes: "It could only happen in California. We envy his originality—as well as his apparent disregard for domestic relations."

Loudspeaker designers are finally paying attention to cabinet resonances. Gladden B. Houck, of Hirsch-Houck Labs fame, provides a tutorial on internal bracing for bass-reflex loudspeakers, including mathematical justification for his methods.

Like the previous installments, Volume Three of the *Audio Anthology* provides a view of our audio history that is both entertaining and educational. I look forward to the remaining installments. *[Please see ad on the facing page for ordering information on Volumes 1–4.]*

Tools, Tips & Techniques

LAMINATE SANDWICH

I'm an avid *SB* reader hooked on the Swan IV system. I devised an alternative method of clamping the veneer/particle board laminate. By elevating my pickup truck on two jack stands, I can apply the required pressure to the laminate "sandwich" (*Fig. 1*). Jack stands distribute the pressure over three points, on about a 12″ triangle—perfect for the approximately 16″ speaker panel width.

You can modify the stacking arrangement and materials depending on available scrap material. For example, you can replace the load-bearing metal plates with two-by-fours (although this will increase the height you must lift your vehicle). Cutting the corrugated cardboard spacers out of scrap shipping boxes will help even out the stack.

You must raise both wheels of your vehicle. It is important to work on a flat, level surface. A smooth concrete driveway is best. Find a suitable cross member or other chassis location that allows you to center everything. When lowering your vehicle onto the jack stands, check that even pressure is applied to both stands. As you lower the vehicle, "thump" on the stands with your fist. If the pressure is uneven, one will feel less solid.

Make sure the other two wheels are properly blocked. Be careful when raising and lowering the vehicle, especially if you use two types of jacks, as I did (a hydraulic, chassis type on one side and a bumper jack on the other). Perform a dry run to check your technique. Allow plenty of room to move out of the way if the vehicle becomes unstable.

When I applied the epoxy/cotton fiber mix, the surfaces soaked up the epoxy, so I coated the veneer and the particle board for a more consistent joint. This required two shots of the mixture per laminate. Also, I used the 206 slow hardener. Since the cure cycle is about the same, I don't see the advantage in using the 205 fast hardener. Even with the slow hardener, I do not recommend laminating more than two panels at a time.

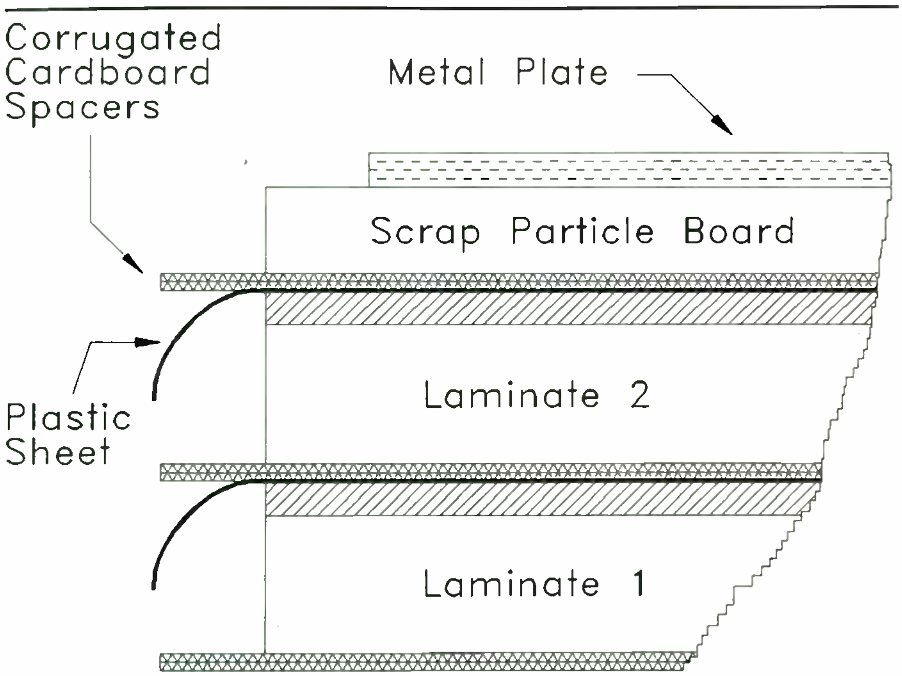
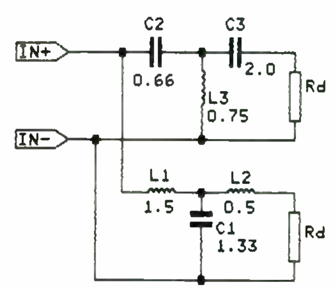


FIGURE 1: The stack arrangement.

My satellite speakers are terrific and the imaging is spectacular. I used 1″ MDF board with a ⅝″ radius on each corner. The front baffle is also routed for flush-mounting the drivers. For finishing, I chose not to laminate because of the complexity, but instead epoxy-coated the inside and outside of the box and used a black gloss polyurethane paint. I "gooped" the treble coupler onto the box's back rather than onto its inside.

Hubert Biagi
Tucson, AZ 85719

A DIVIDING NETWORK MOD



Capacitors multiply by $1 / W_o R_d$
Inductors multiply by R_d / W_o
W_o = crossover frequency
Dots show phasing

FIGURE 1: Butterworth third-order divider.

Component values for the Butterworth third-order, two-way divider network are shown in *Fig. 1*. The loads are shown as purely resistive. In practice, at a typical 3kHz crossover frequency, the low-pass (LP) driver has a large inductive reactance in series with the resistive component. The reactance and resistance are often nearly equal at the crossover frequency.

To terminate the LP network with a resistive load, it's accepted practice to shunt the LP driver current with an impedance equalizing network. *Figure 2* shows the component values. Equalization is not entirely satisfactory, because about half of the output current is diverted through the

Continued on page 50

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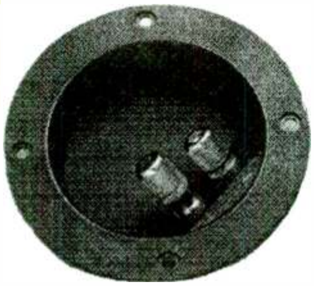

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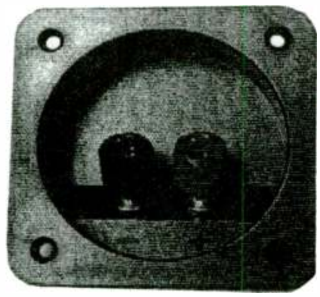

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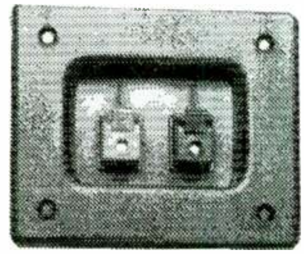

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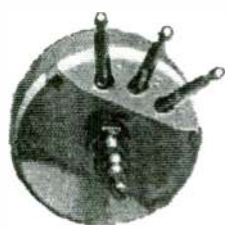

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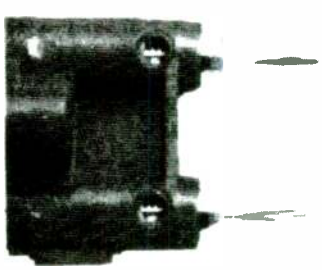

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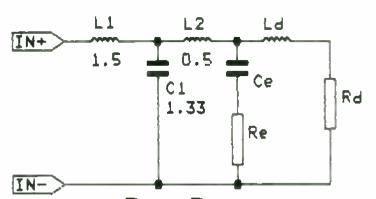


$R_e = R_d$
$C_e = L_d / R_d^2$

FIGURE 2: Inductive load with equalizer.

Continued from page 48

equalizer, at the crossover frequency, causing a dip in the frequency response, together with a phase lag in the LP driver current.

Odd-order networks seem to have the advantage that you can use the LP driver inductance as one pole of the network, in place of L2, thereby eliminating L2 and avoiding use of an equalizing network. Unfortunately, this circuit is not practical for use with the normal Butterworth network, because L2 is always smaller than the driver inductance (L_d).

However, you can use the driver as one pole of the network if you retain the equalizing network and the driver reactance and resistance are equal at the required crossover frequency. The frequency at which reactance and resistance are equal is conveniently about 3kHz for many types of drivers. You can add extra reactance in the form of a series inductor to drivers with too little reactance at the required crossover frequency; drivers with too large reactance are not suitable.

With the driver adjusted to the required inductance and equalized to the characteristic resistance, the values of L1 and C1 can be realized to form a Butterworth third-order network. This network has the response:

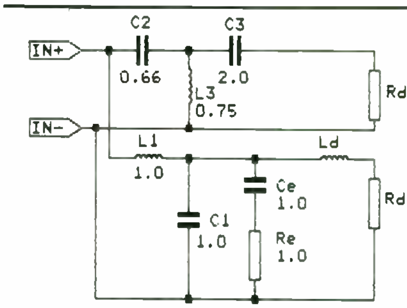
$$1/(pT^2 + pT + 1)\,(pT + 1)$$

which you can consider as two separate networks in cascade, provided each is terminated with the characteristic resistance. The two-pole network ($pT^2 + pT + 1$) is terminated with the driver, which has been equalized to the characteristic resistance. The driver, acting as the single-pole network, is terminated by its own resistance, which is the characteristic resistance. Hence, both sections are terminated separately with the characteristic resistance.

The driver has the response $pT + 1$; therefore, T has the value R_d/L_d. You then find the values for L1 and C1 by substituting R_d/L_d for T in the network $pT^2 + pT + 1$. The components L1 and C1 have the simple values L_d and L_d/R^2_d, respectively. *Figure 3* shows the modified Butterworth network.

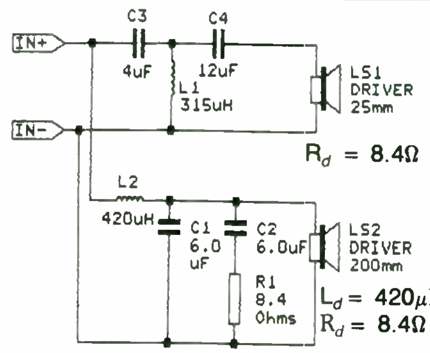
The series inductance in the LP network is reduced from $2L_d$ in the normal network to L_d in the present design. Current is still diverted through the equalizing network, but correct driver current is maintained; the diverted current is drawn from the driving source as an excess over the driver requirement.

The modified network has particular advantages for the home builder. When you build dividers for a stereo system, it has two similar L1 inductors. You can build one inductor into a divider and use the other with a resistor to simulate the LP driver. The HP network is terminated with the characteristic resistor and a dual-channel oscilloscope monitors the divided outputs. The oscilloscope is set to its summing mode, so the network outputs are recombined. When the networks have been built correctly, their summed output has the constant amplitude as the driving frequency is varied.



$W_o = R_d / L_d$ Rad/Sec
Capacitors multiply by L_d / R_d^2
Inductors multiply by L_d
Resistor multiplies by R_d

FIGURE 3: Modified Butterworth divider.



W_o = 20k Rad/sec = 3.18kHz

FIGURE 4: Practical Butterworth divider.

With the network driving the signal used to trigger the oscilloscope, you can see the phase change between the input and the summed outputs. You can invert one oscilloscope channel to simulate the preferred driver connection. While both connections have constant frequency response, the inverted connection has a much smaller phase change at crossover compared to the non-inverted connection. *Figure 4* shows practical values for a network built using the formula in *Fig. 3*.

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VOICE COIL DESIGN

Four people (Satoru Simizu, Faiz Pourarian, Edwin B. Boltich, and Suryanarayan G. Sankar of Advanced Materials Corporation) working under contract to the Marshall Space Flight Center in Huntsville, AL, have developed improved speaker voice coil actuators. This work was begun in an attempt to solve two problems:

1. Nd-Fe-B (neodymium-iron-boron) magnets have the highest flux density at room temperature, but their energy decreases below a temperature of 140 Kelvin (K) because of electron spin reorientation.
2. A different magnetic circuit design was needed for a high energy voice coil magnet.

A speaker voice coil output force is proportional to the driving current imposed on it and exhibits good linear motion control, but joule heating losses must be reduced in the moving coil windings to improve efficiency for low temperature operating conditions, such as in space. You can reduce a voice coil's heating loss, also known as copper loss, by increasing the flux density in which the coil operates. This flux density increase allows a reduction in the current required to generate a given amount of force, thus making the voice coil more efficient.

To develop a new magnetic circuit design, an analytical model, finite element analysis, and performance testing were used. This design uses a strong radial magnetic field produced by permanent Pr-Fe-B (praseodymium-iron-boron) magnets, which do not have the electron spin problem at low temperatures.

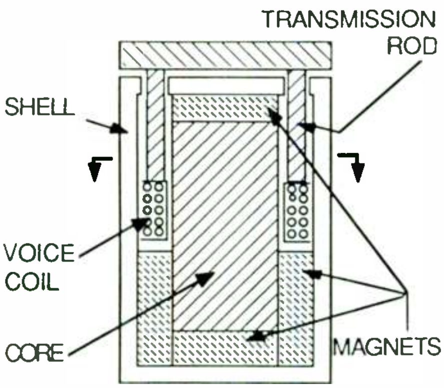

FIGURE 1: Closed-circuit design.

The design is a closed circuit that enhances the useful flux density and almost completely eliminates magnetic interference with other equipment. This design encloses the voice coil within magnet segments in a soft iron shell. The voice coil former surrounds a soft iron core. *Figure 1* shows this new design. The current leads that connect to the coil, and rods that transmit force from the coil, are fed

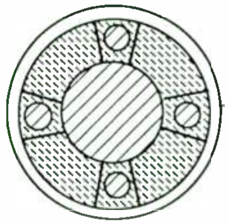
FIGURE 2: Section view.

through small gaps between the magnet segments as shown in *Fig. 2*, the section drawing (the wires are not shown).

Using the new circuit design, two Nd-Fe-B prototypes and one Pr-Fe-B prototype were built. One showed an improvement in excess of 40% in copper loss compared to a similar size commercial device. The Pr-Fe-B prototype exhibited a 12% increase in output force at 77K, compared to a 4% decrease in output force using Nd-Fe-B magnets at that same temperature.

The adoption of portions of this new design by commercial hi-fi speaker manufacturers may yield more efficient products. The Patent Counsel at Marshall Space Flight Center will answer questions regarding the commercial use of this invention.

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MORAN *in the* MARKET

AN INTRODUCTION

By David R. Moran

Loudspeaker systems are the last really interesting area in audio.

No, wait. Maybe stereo microphony—where to put the mikes, what their pickup patterns should be—ought to be included in this broad generalization.

Oops, so should psychoacoustics, maybe ...and DSP simulations of the patterns of a given performing space's reverberation.

But you must have loudspeakers to hear and appreciate any of those other areas, to evaluate them by ear in a room, to improve them. Speakers are the *sine qua non*, literally, the "without which, nothing." And most conventional loudspeakers I'm familiar with (a good number) do an uninspired and uninspiring job of it. So, for that matter, do most unconventional designs I have heard.

At one point a few years ago, Lexicon was demonstrating one of their interesting, versatile, potentially wonderful-sounding concert hall-simulation products for the home (in the CP series), which FYI is designed by an engineer who is a veteran choral singer. The company was using six or so airless, constricted-sounding (at some angles actually honky) Celestion two-ways, with one or two 6″ woofers and a single 1″ tweeter. This is of course the design configuration most of the world uses these days. And I thought, "Come on, first things first. Let's get the basics right: some really smooth and broad-dispersion—or at least more consistent-dispersion—systems in here."

But before I grip the lectern to begin my favorite sermons on loudspeaker horizontal directional response (radiation pattern), or "least-cubes" boundary augmentation, let me pause. Anyone who will measure loudspeakers, write about them, pontificate about the field, especially in these prestigious pages and to this canny readership, ought to introduce himself.

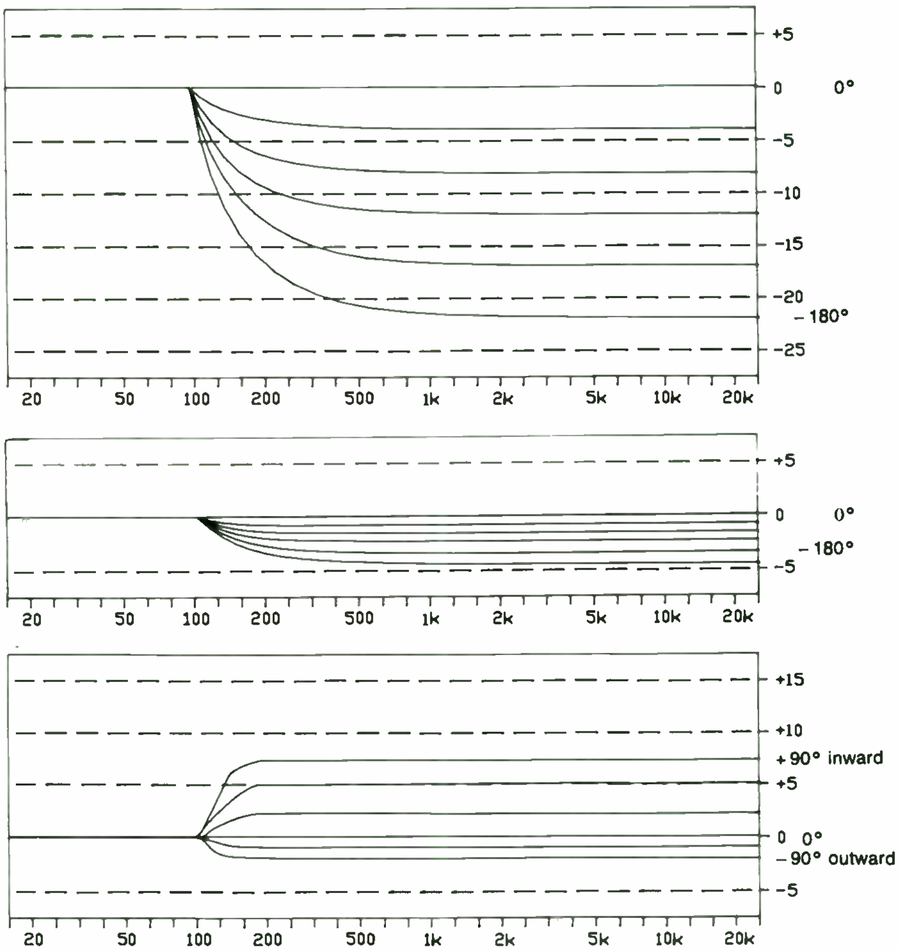

FIGURE 1: Imaging-consistent design goals. The top set would achieve very tight, focused uniform imaging, with directivity starting around 200Hz. The middle set is the same but with a very airy, spacious sound, almost omni-equal, yet still yielding consistent and stable imaging. The bottom set of curves represents a speaker design somewhere between the previous two, and re-aimed. Its loudest (+90° inward) axis is pointing toward its partner (its 0°, so-called on-axis response still is out toward the listener). This design produces true "Stereo Everywhere," and is a bear to achieve.

But Enough About You

By introducing myself I hardly mean my resume. I have no academic training in physics, electronics, or acoustics. I'm 44 and, as a recent audiogram dramatically showed to my great dismay, don't have very fine low-level high-treble hearing. (Sensitivity thresholds are what an audiogram measures, and before you turn the page with a harrumph I encourage you to get an audiogram yourself, preferably from one of the very few places that do reliable measuring above 8kHz.)

What else? I've been a serious if not very accomplished musician, serious meaning I've played in a rock band for pay and otherwise, and also for myself play late-Beethoven (Op. 111) and other piano works, including a recent performance of a Joplin rag in front of an audience of 150 (who didn't pay anything). The jolting anxiety of *that* gave me a whole new perspective on actual performances by musicians in public, on my harshness as a reviewer, and in consequence an altered perspective on audio, or at least my own goals for it.

I've also been a serious (paid and also federal-grant-winning back when government did that sort of thing, if you can believe it) classical-music critic. Finally and more to the point here, for decades I have been an audio editor and writer, mostly about loudspeakers, in *Stereo Review*, *CD Review* (where I was speaker tester for the last couple of years), the Boston *Phoenix*, the BAS (Boston Audio Society) *Speaker*, and in a paper at this fall's NY AES convention.

My Big Break in audio came when I had the great fortune to work, from 1982 to 1988, as technical editor and writer in the engineering department of dbx—surely, per staffer if not absolutely, the audio world's most interesting and accomplished engineering group. What a windfall! Delta-modulation and low-bit A/D and D/A conversion, showing the way for the rest of the world; US stereo TV, with Zenith; continuous-averaging real-time analysis, and automatic EQ; fancy, well-judged analog signal processing and noise reduction; and so on.

Horizontal Radpats

Best of all, and of greatest interest here, was the dbx Soundfield Imaging loudspeaker program. I now could pick up on something that interested me most keenly about loudspeakers over the years: the notion that it was their radiation pattern or directional responses, especially horizontally because of where our ears are, which determined their sound signature.

This idea had been expressed persuasively by an MIT student named Mark. Davis in an article in the late, lamented *High Fidelity* in 1978, complete with tests, and in other venues. You could equalize two speaker systems to be the same in smoothness (or whatever) at any distance or specific angles, but if their horizontal radiation patterns were different, they still would not sound the same.

The day I joined dbx, I discovered that Davis—now with an MIT Ph.D in EE/psychoacoustics—had also joined just a few months earlier, to pursue (among myriad projects in signal processing) ideas he had about a line of loudspeakers. This line was going to comprise configurations of genuine phased arrays whose goal was to produce flat response at all or most horizontal angles but *not at the same level.* A comprehensive test Davis had performed with many subjects (see *JAES*, November 1987; the mechanism in a room appears to be distance/intensity trading, not the catchier time/intensity trading) also showed what these overall levels should be for the listener to hear properly balanced—balanced left/right as well as bass/treble—stereo as he or she moves well off the centerline "sweet" spot.

I liked the "Stereo Everywhere" idea, and its execution as dbx uniquely did it sounded generally superb, impartial reviewers seemed to agree. It's not the same as simple cross-firing of drivers, as many seem to think; it entails the most elaborate crossover work and iterative value-crunching by computer.

I was even more taken with the general idea and execution problems of horizontal directional responses that are uniform, or consistent, with angle, whether they're uniformly beamy or uniformly wide-dispersion, and however they're aimed. Invariably loudspeakers, directionally, are wide across the midrange and get beamier up into the treble, usually irregularly so where the tweeter flares in broadly. This has unhappy results for imaging if not for sound. It is true even for so-called constant-directivity speakers I have measured, and virtually all others.

You will be reading a lot about this large issue: what loudspeakers should do in this regard, what they do do, how they fail and what that means, and what their playback might sound and image like if they were to succeed (or how many different ways it could sound and image, depending on where the loudest axis is pointed). I have many ideas and measurements about how poor a lot of woofer-tweeter or midrange-tweeter crossover designs are, and how very few designers pay any attention to the off-axis performance of their chosen driver on its given-width baffle. I have seen and heard and measured a lot of loudspeakers with (to mix metaphors) lumpy stitches, or seams, at the crossover at off-axis angles.

I wish to hear from those of you who do pay attention to these things. How do you make your decisions, and how do you know? And what's your goal? I once asked Paul Barton of PSB speakers, the Canadian company that helps underwrite some of the important NRC (National Research Council) loudspeaker research, what he did about the off-axis woofer gulley and then tweeter "flare-in" likely to be found in one of his 8"/1" two-ways. He looked at me as if he had no idea about what I was asking. "It's smooth off-axis," he explained. Oh, I said to myself.

If you agree that horizontal directional response is important to the imaging and sound of a loudspeaker, which of the ideal radpats in *Figs. 1* and *2* should we strive for?

With the proper design of lensed horns, it is not impossible to achieve uniform horizontal directional responses—I've seen it and heard it, and it isn't patented yet. Indeed, recently Canon announced yet another system in the Stereo Everywhere mode, using a curved dish of some sort to reflect the sound. Such speakers if truly successful have lucrative applications in video-conferencing, by the way; have your venture backer give me a call.

If such a widely dispersed kind of sound isn't to your taste, it's still possible to be "uniformly beamy" *a la Fig. 1* (top) although it will take a lot of hard, imaginative, novel work to make the lower midrange so. I believe it's important to get as much high treble into the reverberant field as possible, but many like it otherwise. In any case, today's purportedly narrow- or focused-dispersion designs don't achieve their own goals fully, and don't cut it to my ear (*Fig. 2*).

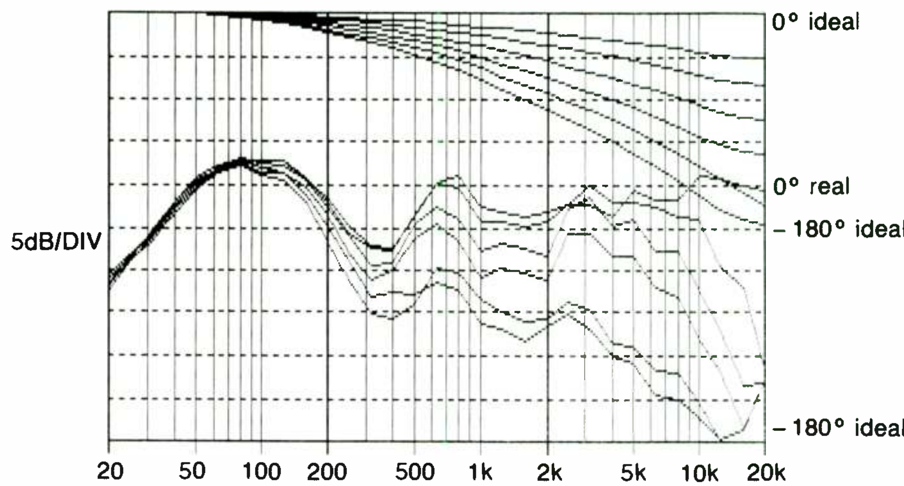

FIGURE 2: At top is the avowed conventional ideal for a speaker's horizontal radiation pattern, when it is thought of at all. The goal is said to be smoothly declining output with angle. As in *Fig. 1*, these graphs are 5dB per division, from 20Hz–20kHz, and show horizontal frequency response from 0°, the topmost curve of each set, to –180° or directly behind the cabinet, the bottommost curve. In-between curves would be –30, –60, –90, and –135, let's say. At the bottom is the actual performance of a 6″ (x 2) / 1″ two-way in the current popular style, floorstanding but with woofers up toward mid-cabinet, measured outdoors on the ground. See text for more details.

Ripple

I also have long been a student of Roy Allison's work (and "paying user," that is, owner, of his speakers) showing what happens when you place the driver that reproduces the 70–700Hz range at various distances and at various ratios of distance from the near corner. So you'll be getting sermons about that.

Allison has recently posted on CompuServe his free software program, to run on Lotus 1-2-3, which conclusively shows the best places to locate a loudspeaker in a room and what kind of ripple can result if you don't. (It shows you how to fill in the 350Hz hole—"floor bounce"—typical of speakers as shown in *Fig. 2*, bottom.) As far as I know, it is more thorough and accurate than the software from Sitting Duck and Snell.

The answer is to stagger the distances to front wall, side wall, and floor, preferably approaching a geometric-mean set of ratios. Worst results— absolutely—will be had by making the location cubical, for example, 3′ by 3′ by 3′. In any room, and with any loudspeaker, and at any listening position, you'll get a notch or valley you wouldn't believe, like *Fig. 2*, bottom, or worse. Remember this the next time you visit a friend with an English or American "high-end" loudspeaker (or read a review in a tweak magazine) whose manufacturer has recommended using the optional stands and being sure each speaker is well in from the side wall and well out from the front wall. Note that the same holds for "stand-equivalent" cabinet configurations, with the woofer(s) well up off the floor.

Protocol

I'll be doing my measurements in a "listening room without walls," anechoic-chamber-with-floor environment: my quiet backyard. I'll use a compensated AKG microphone feeding an ANSI III RTA/PC (from dbx pro, now marketed by Sound Technology) which features arithmetically manipulable memories and, crucially important, continuous averaging of pink noise. (Snapshop pink-noise analysis, such as you see in other publications, is highly misleading.)

I take a measurement at 0° (on axis), continuously averaging 7–10′ away, 30–40″ off the ground, and ±15° or so off the nominal center angle. Then I repeat the measurement at 30, 60, 90, 135, and 180° (unless the speaker is designed for against-the-wall placement). I'll also take a range of measurements in real, typical-enough listening rooms inside.

As appropriate, I will look at bass distortion and at impedance and reactance. I do not believe and have seen no data supporting the belief that a loudspeaker's "time-domain"/phase performance is important to its sound once it's above the minimal threshold all modern, serious speakers pass. So there will be no measurements of group delay and the like.

Rocketry

This is not rocket science, folks, in my opinion. A speaker's performance can be completely characterized by looking at its amplitude (magnitude) response, both at a given angular slice and as its coverage over a range of angles; its phase response;

Continued on page 90

Technology Watch

SUBWOOFERS and MOTIONAL FEEDBACK

By Peter Muxlow

With the recent articles on subwoofers in *SB*, it seemed appropriate to look at the highly regarded Velodyne subwoofer.[1] This operates over the frequency range of 20–85Hz ±3dB and uses motional-feedback to control the driver. It has an accelerometer to sense the cone acceleration. This gives a signal proportional to the low-frequency sound pressure.

The patent[2] details two problem areas—low- and high-frequency stability in the feedback loop. An occasional low-frequency oscillation at the 1Hz unity-gain crossover frequency was the result of the air pressure variation on the accelerometer. However, enclosing the accelerometer in a sealed enclosure—an airtight can—will easily fix this. The high-frequency instability is believed to be caused by standing waves on the cone interacting with the accelerometer, causing deviations in the open-loop transfer function.

For me, the interesting part of the patent was how the inventors observed and subsequently fixed this problem. They made Bode plots (graphs of the gain and phase against frequency) of the system using a spectrum analyzer. In effect, they measured the feedback stability margin of the complete loop and tried different "mechanical" ways of improving it.

The patent details the methods used:

- Using a trumpet-shaped cone.
- Inverting the dust cap cover.
- Altering the wave propagation in the cone material by putting clusters of holes through the cone in selected areas. Or, adding a dopant to sectors of the cone, which alters the elastic properties, in turn altering the wave propagation.

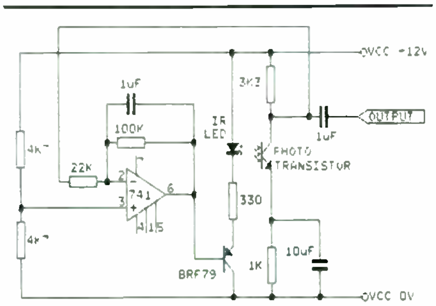

FIGURE 1: An optical circuit for detecting loudspeaker displacement. The LED is attached to the cone of the LS. The photo transistor is attached to the frame.

- Placing weights around the circumference of the coil former. This reduces the interaction between the waves in the cone and the accelerometer.

Another method to test the stability of the completed servo has occurred to me. Rest the lid of a jar on the loudspeaker's cone to distribute the impact force of the cone more evenly. Drop a weight of about 50 grams from a distance of 100mm onto the jar lid. Then observe the accelerometer's output on a scope. The impulse response displayed should exhibit minimum ringing and should be damped quickly. *[Readers who try this should proceed with caution to avoid an accidentally vented cone.—Ed.]*

The cost of an accelerometer is a problem mentioned in previous *SB* articles. Alternative transducers do exist. In *Wireless World*, Young published an optical circuit for detecting loudspeaker displacement.[3] It uses an LED and a photo transistor (*Fig. 1*).

A British patent by D. Birt[4] shows an ingenious transducer (*Fig. 2*). A long air-cored solenoid is mounted on the center pole of the driver magnet. A short conductive cylinder is attached to the voice coil former and coaxially surrounds the solenoid. An RF current feeds the center-tapped solenoid (*Fig. 3*) and the RF voltages at respective ends are rectified and then subtracted from one another.

When the conductive cylinder is positioned symmetrically about the center of the solenoid, its eddy current losses are distributed equally and the transducer output is zero. As the voice coil moves, the cylinder is no longer symmetrical, so the RF voltages at the two ends of the coil are no longer equal. This results in a DC output voltage proportional to the position of the cylinder, and a polarity dependent on the direction.

Finally, the transducer has a multiple feedback system—one feedback loop is proportional to the velocity of the cone (using an accelerometer) and the other is proportional to the current through the voice coil. This feedback combination gives an interesting advantage: "The System Q is decoupled from the enclosure and driver parameters giving a wider range of design of closed-box loudspeaker systems."[5] This feedback system also has

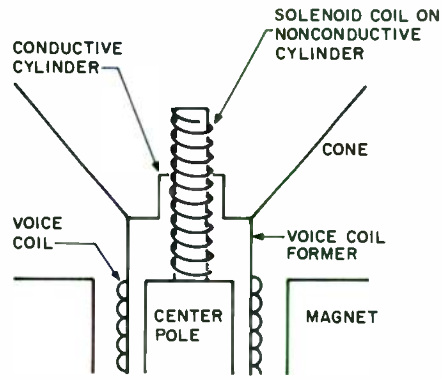

FIGURE 2: D. Birt's transducer.

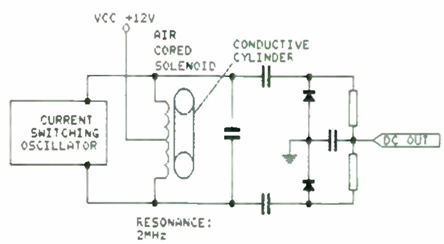

FIGURE 3: RF current feeds the center-tapped solenoid.

insensitivity to driver parameter variations, a great advantage with some driver parameter spreads being ±20%. Extra references to subwoofers and motional feedback are detailed below[6–9] for readers wishing to investigate other ideas.

The availability of a high-quality, low-cost $35 PVDF accelerometer was reported in *Voice Coil* Vol. 4 No. 4 (PVDF Transducer, PO Box 3178, Philadelphia, PA 19147-7718).

REFERENCES

1. "Design Considerations for an Accelerometer-Based Dynamic Loudspeaker Motional Feedback System," AES preprint no. 2863.
2. American patent no. 4727584.
3. *Wireless World*, July 1982, p. 49.
4. British patent no. 2207323A.
5. "Loudspeaker Distortion Reduction," *JAES*, December 1984.
6. "Motional Feedback in Loudspeakers," *Wireless World*, March 1974.
7. "Motional Feedback in Loudspeakers," *Audio*, August 1975.
8. "Motional Feedback," *Acoustica*, Vol. 10/7, 1961.
9. British patent no. 1568026.

SB *Mailbox*

Q SOUND DEFENDED

Shame on you, Ed Dell, for making such a biased and one-sided attack on Q Sound in your editorial entitled "Will Loudspeakers Become Irrelevant" (*SB* 2/91, p. 11). Then to back up your opinion, you used selective quotes from *Popular Science* and Mr. Barry Fox. Nothing suggested any serious listening tests to support your conclusion nor any attempt to solicit comments from Archer Communications. Even Mike Wallace gives the opposition a better chance than you did. Comparing this new technology to a hallucinatory drug and implying "trained listeners" find Q Sound "immediately annoying" is preposterous. Let's not confuse facts with opinion. Since only two Q Sound encoded disks were available at the time of printing, this hardly seems enough material to make any definite judgments.

Considering the open-minded approach *SB* has toward innovations, it's not in keeping to slam the lid on this new process based on philosophical grounds alone. If this issue is as important as your editorial implies, then critical listening tests, as well as interviews with company officials and sound engineers, are in order. Readers wishing to do their own A/B comparison may do so very easily. Just play a selection like *Vogue* from Madonna's "I'm Breathless" album with the "Q" encoded version on her latest hits compilation CD "Immaculate Collection." Other CDs containing Q Sound include the latest releases by Sting, Paula Abdul, and Luther Vandross.

The real downside to this technology is the misuse of its capabilities to create an "experience" rather than an improvement in realism. This is evidenced by floating voices and the like on the Paula Abdul release. In stark contrast, however, is the excellent sound produced on the Luther Vandross offering. Let's not fool ourselves into thinking that by using this process we are somehow tainting an original event. Most, if not all, recorded music is the pasting together of many original events that are mixed down to two tracks. The final product is the reality as conceived by the engineer which never took place as a complete performance. Giving the engineer Q Sound is therefore just one more tool with which to work.

We cannot undo any poorly made recording. On the positive side, we can enjoy the benefits of encoded processes like Q Sound without the necessity of buying extra hardware or speakers. That is certainly good news for everyone but the equipment manufacturers.

William B. Willes
New Orleans, LA 70124

See the editorial in SB *3/91. Mr. Willes ought to know we don't shame people for their ideas here.—Ed.*

NORMAN H. CROWHURST

1913-1991

I am profoundly saddened to report that Norman H. Crowhurst died on March 7, 1991 after a brief illness. He was 77. Born November 3, 1913 in Southend-on-Sea, England, he earned degrees at Streatham Hill College and at Goldsmith's College, S.E. London Technical College, where he was later a senior lecturer. Mr. Crowhurst's career began at Johnson & Phillips Ltd. In 1935 he became Chief Engineer at Tannoy, Ltd. where he remained for ten years.

He and his wife emigrated to the US in 1953. He was honored with a Fellowship by the Audio Engineering Society in 1959. He and Mrs. Crowhurst became naturalized citizens on Nov. 17, 1960.

Norman Crowhurst was certainly one of the most prolific of authors in the audio field, having contributed to 32 commercial publications and many professional journals. He once claimed to have written over 2,000 articles and papers and some 50 books. He held a number of patents.

He was an associate member of the British IEE, Senior member of British Sound Recording Association, a member and fellow (1959) of the AES, a member of SMPTE, IEEE, ASE, National Council of Teachers of Mathematics, and Professional Engineers of Oregon.

He worked as editor at several British and US publishing houses both on staff and as a consultant. He also spent two years working at Fairchild Recording Equipment Company.

Mr. Crowhurst was best known to electronics buffs, and especially audiophiles during the 1950s and '60s, as a well-known author on audio theory and construction. He developed many unique answers to problems, such as a stereo power amplifier which sported only one pair of output tubes but two transformers. He had an unusually clear writing style and an exceptional ability to explain difficult theoretical concepts in terms beginners could understand. He had a remarkable number of admirers among his readers who credited him with being the first author to stimulate their appreciation for audio and electronics.

In mid-October of 1990 the bicycle he was riding was struck by a passing car, in his adopted home town of Dallas, OR. Medical examination revealed little or no obvious damage but he failed to recover completely. He became ill in late February and was bedridden for much of each day. His death came suddenly from heart failure.

FATAL VISION

As audio components improve, the world of high-fidelity moves forward. When manufacturers redefine hi-fi's goal in their own interest, they embark on a perilous journey. The marketplace turns a deaf ear, whether it be Quad sound, "L" cassette, or Datman, if products do not fulfill hi-fi's mission.

Your editorial "Will Loudspeakers Become Irrelevant?" is relevant. The audio world is being transformed from stereo located on a line between loudspeakers to 3-D surround sound. Images appear throughout a broad central bilateral arena. How well surround fulfills the canons of hi-fi depends in large measure on the role loudspeakers will play. They must be engineered to a new reality if they are to close the gap from live versus recorded sound.

Scientists have been able to isolate sound waves the way a magnetic resonator scans parts of the human anatomy. Music is divided by chronological intervals in time lapse snapshots and displayed like slices of bread lifted from a loaf. These bilateral studies confirm the theories of Blumlein and the ambisonic format developed by Michael Gerzon and marketed in the UK (*Wireless World*, March 1974).

Time lapse snapshots of a simulated soundfield graphically display our sonic impression—what we hear. Each interval has its own footprint. It arrives on its own timetable with radical changes in frequency, intensity, and direction. How well do Q Sound, DSP, SRS, and Pro-Dolby Surround contribute to greater high-fidelity? They do not when used by consumers rather than in the recording studio. They are an assault on rational acoustical engineering. They alter the sonic impression by modifying phase, intensity, and directionality of the direct/reflected soundfields. Images may wander or spread across an entire wall.

Ambisonics, however, maintain the aural presentation of a performance the way the artist had intended. It is a natural phenomenon. It occurs in the concert hall when the live performance is given. It exists on all stereo CDs from *The Music Man* of the 1950s to state-of-the-art digital *Fats Waller Direct* to CD. Ambisonics enables CD owners to have the benefits of bilateral 3-D stereo without altering the artist's vision of his music. Speaker designers must learn the new rules for 3-D surround.

Speaker Builder serves its readers well by exposing faux hi-fi and informs them on emerging technologies that fulfill hi-fi's goals.

Herbert I. Gefvert, CEO
AV Tech

MADISOUND WOOFERS

In response to Gary Galo's "Woofer Mini-test" letter (*SB* 1/91, p. 82) on Madisound dual voice coil (DVC) woofers, I wish to share my experiences in using these. Madisound has been my main supplier of (home) speaker components since 1985. Their promptness, quality, and technical support deserve a lot of praise.

I recently made a subwoofer, front, and rear surround-sound loudspeaker system for a friend, using all Madisound woofers.

When I began the project, I had little difficulty in selecting woofers for the front and rear speakers: I used the Madisound 6102 and 5102 woofers, respectively. The subwoofer, however, presented the greatest challenge.

I have built many subwoofers, mostly for nightclubs and discos using large EVs and JBL single voice coil woofers, and I have built several home subwoofers using two LF driver configurations or dual voice coil drivers from other suppliers. My friend asked that the subwoofer be constructed so the driver was not visible from any side, so I considered a down-firing configuration using the Madisound model 15258 15″ DVC driver. (The model 12524 mentioned in Gary's letter was a misprint.)

I discussed this with the folks at Madisound and they advised against it, saying the speaker's performance specifications are based on vertical, not horizontal, placement. A horizontal LF driver configuration may also require extensive testing before optimum results can be determined. On that advice, I abandoned the idea of the down-firing subwoofer and talked my friend into a "conventional" (vertical) design. I also decided to use the Madisound 15″ DVC driver for the project. Madisound carries an 8Ω version (15258) and a 4Ω version (15254) of the 15″ DVC woofer.

I constructed the cabinet of ¾″ walnut-veneered MDF to an internal volume of 2.5 ft.³ Madisound claims an f_3 of 39Hz. A quick check on the speaker designing program I use revealed an f_3 of 37Hz. Madisound recommends a sealed box for their 15″ DVC woofer. I prefer vented boxes, but when I calculated the T/S parameters for this driver, my PC told me a B-4 alignment would be achieved using a 22 ft.³ box. So much for the vented enclosure.

Once I started on the subwoofer project, I discovered external dimensions were not as critical as for vented boxes. Since I needn't be concerned about a vent, slight changes in cabinet dimensions were of little consequence. The greatest concern, however, was obtaining a proper cabinet seal. Sealed enclosures *must be airtight* to function properly. Otherwise, a significant loss of bass output will result.

I made a woofer seal from foam packing material. It works great and is very forgiving. Silicone sealant is probably best for those who have little patience in constructing such a seal, but it makes cabinet access more difficult. You should also seal the inside of the enclosure with glue and a sealant.

I constructed two two-way second-order crossovers (one for each channel) and located them inside the subwoofer enclosure. One is used as a low-pass filter for bass, the other as a high-pass filter (above 125Hz) for the satellites. (I elaborate here because I wish to emphasize the conventional crossover method used in this system.)

As they say, "The truth of the pudding is in the eating." I was eager to try this "new" subwoofer as I had one with which to compare it. Three years earlier, I had built a 5 ft.³ subwoofer using a 15″ DVC (non-Madisound) driver in a vented configuration and was pleased with it—until I listened to the Madisound subwoofer.

The Madisound subwoofer's low-frequency output was smoother, crisper, and a little more efficient than the one in my system. It is approximately one-half the size of my subwoofer, which makes it less obvious. A close examination of the Madisound driver reveals mechanical and aesthetic qualities—a large vented magnet, large voice coil, attractive black polypropylene cone, inverted poly dust cover, high-quality foam surround, and attractive "masking" over the entire gasket. Indeed, almost unheard of quality in modern American drivers. In my opinion, the Madisound 15″ DVC LF driver would be a bargain at twice the price.

PHOTO 1: Subwoofer in a 2.5 ft.³ enclosure using the Madisound 15258 15″ DVC woofer. The rear (surround) speakers employ Madisound 5102 woofers and Polydax tweeters.

About four years ago, I used the Madisound model 1252DVC 12″ DVC woofer as a subwoofer for the family car. It yields very deep bass and is still used today. It is not the powerful driver the model 15258 has proven to be, but it has served well over the years. The other two models (10204 and 12204, 10″ and 12″ versions of the 15258) appear to be as serious as their bigger brother (although I have never used them). However, I have used Madisound's 1054 (10″) woofer in several custom systems with impressive results. I have no doubts about whether these smaller dual-voiced beauties could perform the job.

Richard G. Carlson
Garden Grove, CA 92641

Contributing Editor Gary Galo replies:

I thank Mr. Carlson for his thoughtful letter on the Madisound woofers and his experiences with them. He correctly points out that one of the model numbers was incorrectly listed in my letter. The 15″ driver I received was the 15254, which contains the dual 4Ω voice coils. I checked my computer file and discovered I had listed the model number correctly in my original letter. Unfortunately, a few numbers were changed in the typesetting. Thanks for catching the error.

SILICONE SOLVENT

This concerns Mr. Rivera's question about a suitable solvent for silicone (*SB* 3/91, p. 93). I have found that lacquer thinner works quite well, but the process is rather slow. Once thinned, however, it can be applied easily with a brush. I have used it successfully on dust caps, dust cap glue lines, cones, and corrugated cloth surrounds. I do not recommend applying it to rubber or foam surrounds because the thinner may attack such materials.

David J. Meraner
Scotia, NY 12302

ON VENTED BOXES

George Augspurger's article "New Guidelines for Vented-Box Construction" (*SB* 2/91, p. 12) is quite interesting. When using stagger-tuned multiple ducts with a length ratio of 1.73:1, the article says "several." Does this imply two ducts? Also, as many PA cabinets use a "shelf" to create a rectangular duct, will f_B predict for this case using the correction for a rectangular vent? Is it okay to use vents on the back of the box?

I'm curious about your double-chamber reflex and wish to know the pros and cons over a conventional reflex. Does it provide lower distortion and reduced excursion over a broader range? Do you always expect a dip from interaction of the outer vents and does this have any significance in light of room-induced aberrations? Is there a "point" where you expect the driver excursion to increase?

Bob Bullock did some modeling of the dual-chamber reflex and initially thought the upper bass was "depressed." I believe he will now investigate further and make a program to deal with the interactions of the driver, chambers, and vents. I hope

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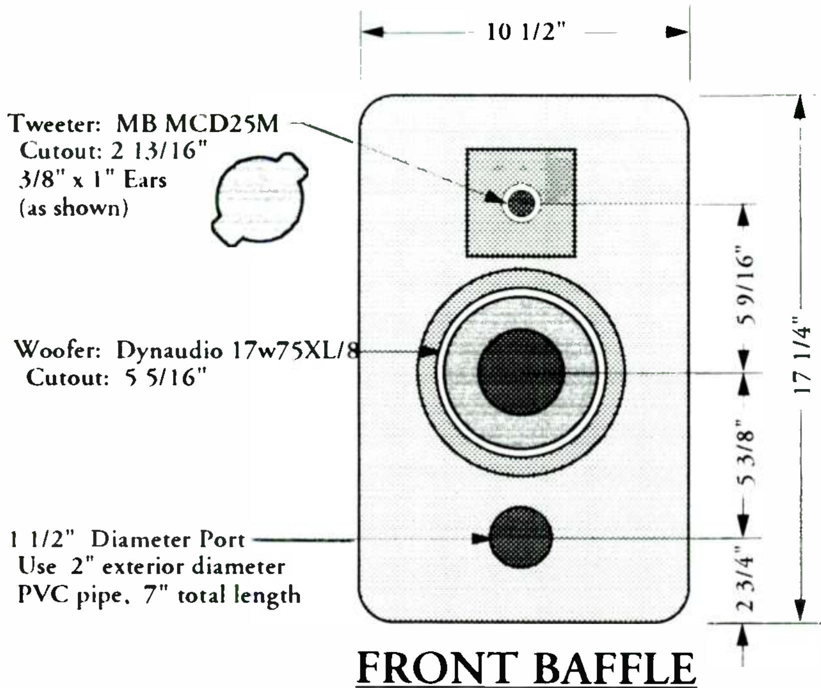
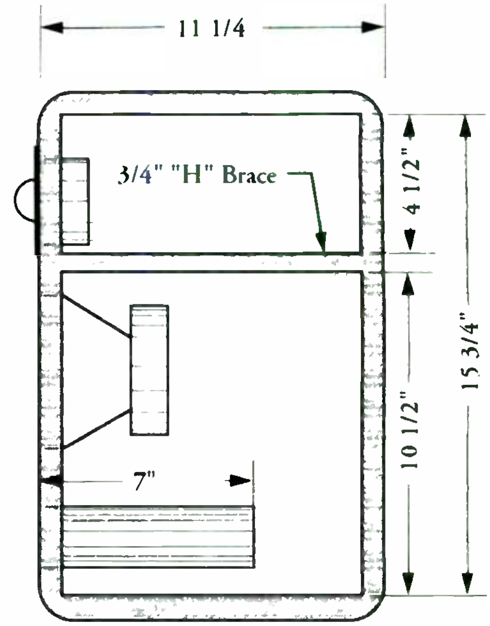


FRONT BAFFLE



SIDE SECTION

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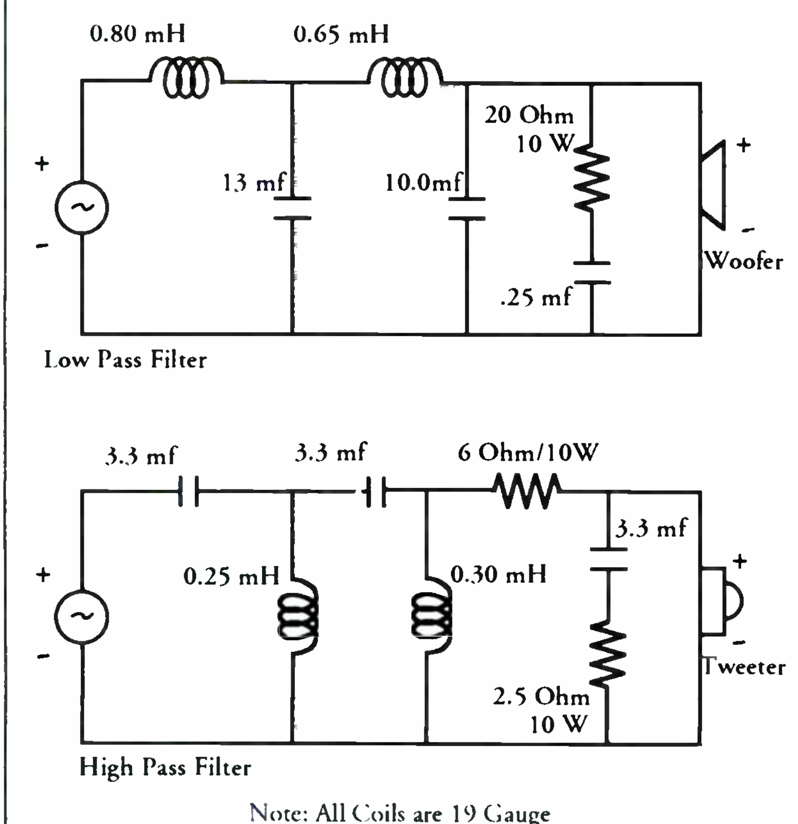
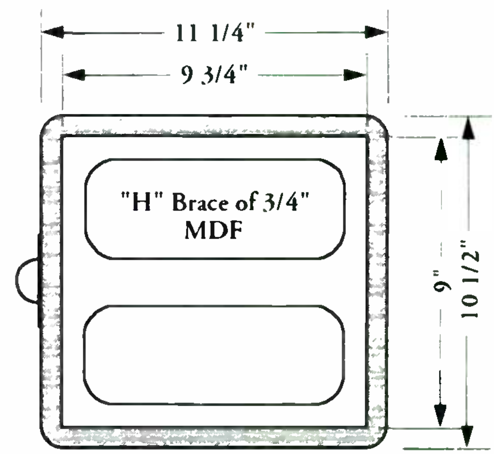


CROSSOVER NETWORK



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Continued from page 58

to try a dual-chamber for bass guitar with a VBL E-140, but I'm unsure where to start. I could go with 4 ft.³ and divide it into two chambers setting the low f_B for the 40Hz low E. Does that sound okay? What approach do you suggest for a dual-chamber reflex to make a bass guitar box and to make a hi-fi woofer in which T/S parameters are known?

Bruce Edgar is looking at "tapered pipes" for use as a bass guitar box and possibly a subwoofer. Do you think this may be a viable alternative loading method? I have a Karlson for my bass guitar, but I have only made Z measurements so I'm unsure what it does.

Fred Ireson
Huntington, WV 25701

G.L. Augspurger replies:

First, let me answer your questions about vents and vent tuning.

1. The idea of suppressing organ pipe resonances by varying the lengths of multiple ducts was suggested as an interesting idea. To be effective, you would probably need three or four vents. However, one of the points of my article is that organ pipe resonances are not apt to be a real problem anyway.

2. Using a box surface as one wall of the vent is common practice, but it is difficult to adjust and adds still another factor for which you must account. I haven't tested this, but the required end correction is probably around 1.5 times the narrow dimension, plus the factors for aspect ratio and number of vents.

3. If you move the vent to the back of the box, you can tune it over an octave or so by playing with the distance between the box and the wall behind it. Some commercial systems have used this arrangement. Other side effects of vent placement are discussed in "Ask *Speaker Builder*" (1/91, p. 45).

4. Tapered vents, or stubby "horn-loaded" vents, were once popular. The configuration may suggest some secondary nuisances like air turbulence and organ pipe resonances, but the system still behaves like a conventional vented box. On the other hand, a small box driving a relatively large horn is a different animal entirely, and its performance cannot be predicted from vented-box theory.

The truth about double-tuned boxes is the subject for another article. The configuration was used by some English loudspeaker designers in the 1950s and 1960s. My only contribution was to add a third vent, mainly out of curiosity.

In 1961 when the double-chamber design was described, it seemed logical to me that it would load the speaker over a wide frequency band, thereby reducing cone excursion and distortion. I also believed it would not require tuning to a particular driver. Later, when I was able to build a breadboard analog circuit, it became apparent that none of those assertions is entirely true. The behavior of a double-chamber vented box with its driver on an outside wall is notably different from the currently popular bandpass enclosure with the driver inside.

Figure 1 is a simplified "mobility" analog circuit of a speaker in a vented box. At first glance, it looks as if the speaker is driving the port, C2, which then drives the box, L2. However, these two elements are connected in series and their relative placement is immaterial. The backwards connection has some advantages if you build an experimental circuit rather than a computer simulation, but my intention is to make it easier for you to understand the double-chamber analog that follows.

Far-field acoustic power output is proportional to sound pressure inside the box. (See Beranek's *Acoustics* text.) You can add circuit elements to simulate the acoustic load or simply measure the voltage across L2 and then calculate a 6dB/octave correction factor at low frequencies.

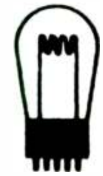
Figure 2 represents my three-vent, two-chamber reflex design. It may look odd, but if you mentally disable various elements, you will see the analog is valid. As a matter of fact, by setting various vent resonances to zero, you can use the circuit to model six nontrivial box designs.

What about the JBL LE8T in my original 3 ft.³ double-chamber box? This driver has a small cone and a low-mass moving system. It delivers usable response to 30Hz in an 85 liter (3 ft.³) box tuned to 35Hz. In the original double-chamber design, its response is essentially the same except for a notch around 65Hz. According to my analog simulation there *is* a useful reduction in cone excursion between 20 and 35Hz. If program material is rolled off below 20Hz, the double-chamber design gives an extra 3dB of headroom for a given maximum cone excursion.

More conventional loudspeakers like the JBL

Continued on page 62

VACUUM TUBE DEALER PRICE LIST (MAY 1991)



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12AT7	3.90	3.40	3.30	" " " " "
6146B	12.50	11.50	10.50	" " " " "
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GE

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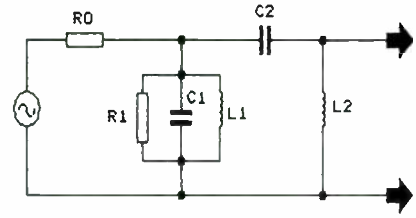

FIGURE 1: Conventional vented box.

TABLE 1

VENTED-BOX PARTS LIST

R0	voice coil resistance
R1, C1, L1	speaker mechanical system
C2	vent mass
L2	box air compliance

Output voltage across L2 is proportional to cone/vent velocity.

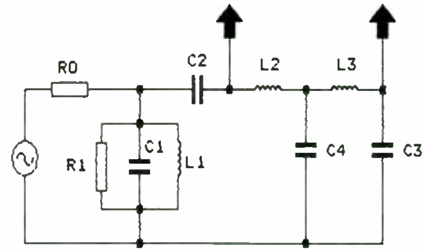

FIGURE 2: Two-chamber vented box.

Continued from page 60

E-140 or 2225H do not appear to benefit from double-chamber loading. The net effect is an undesired notch and that's all. Unfortunately, the notch is inherent in the double-chamber geometry. It can be suppressed by making a big, lossy system with lots of vent damping, but that was not the original design premise.

The questions you asked are logical ones and I don't wish for my answers to discourage your experiments. Analog circuit analysis is a wonderful way to understand, compare, and predict the performance of loudspeaker systems. However, a design that has theoretical problems may still be fun to build and its real-world performance may show up desirable properties not apparent in the computer analysis.

TABLE 2

TWO-CHAMBER VENTED BOX PARTS LIST

R0	voice coil resistance
R1, C1, L1	speaker mechanical system
C2	main vent mass
L2	main chamber compliance
L3	second chamber compliance
C3	second vent mass
C4	inner vent mass

Output voltage across L2-L3 is proportional to cone/vent velocity.

SPEAKERS AND HORNS

I have spent countless hours of fascinating reading of *Audio Amateur* and *Speaker Builder* since my dad subscribed during the 1970s and have started buying back issues through Falcon Acoustics. I have built several pairs of vented-box speakers, as well as a great sounding minihorn, plus three Lang Class A amps to use with my active filters, power supplies, and other devices.

I have several questions regarding speakers and horns. First, I have some general questions about drivers. What are the practical/physical reasons why manufacturers can't make drivers with resonances way below bass frequencies? Undoubtedly, some extreme drivers have succeeded.

Will a driver's response necessarily fall off below resonance frequency? What causes resonance and why does it have such an effect on useful response? Can resonance peaks/troughs be "poked" out electronically.

Driver resonant frequency is a chief design parameter for bass reflex and the above questions should allow me to get to the nitty gritty of why it is so important. For example, I can use a Class I box response for my KEF 139s, which pushes

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Continued from page 62

the response below the driver's resonant frequency. Is this a good idea? Will there be any decent output below resonance?

Now I have questions more specific to horns. Could you describe a driver designed from scratch specifically for horn loading? How would it differ from drivers already on the market? Would you consider the Bando drivers unsuitable?

I like my front- and rear-loaded horn similar to Dirsdale's minihorn (WW 1974). However, if I wish to use a horn system with a 20′ long bass horn and a 1′ midrange horn, how do I integrate the two with regard to a zero delay plane (*Fig. 1*)?

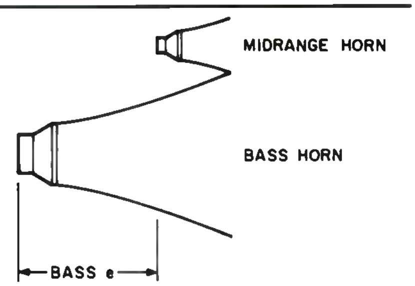

FIGURE 1: Midrange driver distance exceeding 20′.

With box type speakers, drivers are sometimes offset fractions of an inch or electronic delays are incorporated in the crossover, but in horn systems tens of millisecond delays seem necessary.

If I haven't misunderstood, are 20mS electronic delays feasible and of sufficient quality?

Please explain when and why phase plugs are necessary and how to design the shape and position.

I hope you can answer the above questions because my next project will be a multihorn system with each driver front- and rear-horn loaded. Unfortunately, I must fold the bass horns unless I virtually sit inside the mouths.

Mark Denehy
South Glamorgan, CF6 1DA
Great Britain

Contributing Editor Bruce Edgar replies:

Many 15″ drivers are made with resonances in the 20-25Hz region. To go to lower resonant frequencies with typical cone materials means larger woofer sizes (18″ or larger). Hartley has done it, as have Ramsdell and McCauley (advertised in *SB*), but these drivers are expensive. Also, the market is limited because they require large enclosures, which can take up a large fraction of a typical living room. The other reasons for not going below 20Hz are that the region is inaudible and you may have infrasonic problems with your turntable.

All direct radiators operate in a mass-loading mode whereby the mass of the cone loads the system. The air load or what goes into the radiation of sound is about 1% of the total. Mass loading always takes place for frequencies above the resonant frequency. Below the resonant frequency, the response will roll off at a rate dependent on the type of enclosure, usually at 12dB/octave. So the resonant frequency is an important landmark that determines the useful lower response range of a given woofer.

A woofer resonance is a result of a mass (woofer cone) and a spring (woofer surround and spider) interaction. A weight at the end of a spring will oscillate if you pull it down and let it go. A typical woofer would also oscillate if it were not so well damped by the surround, spider, and the magnet. The only way you can usually see the resonance is to make an AC impedance measurement, which will peak at or near the resonant frequency.

In an enclosure such as a sealed or vented box that matches the driver properly, the speaker resonance is modified by the box to give a flat low-end response and a controlled rolloff. In a sealed box, the resonance will be shifted up by the additional spring of the trapped air behind the woofer. In contrast, in a vented box, the additional acoustical resonant circuit of the vent and the box volume can extend the useful response below the speaker resonance. The many readily available computer programs such as Bullock's BoxResponse will guide you to the proper box size. Electronic equalization is used only when you go to some particular alignments or smaller box sizes.

For woofers in wide bandwidth (50-400Hz) bass horns, I look for a resonance (f_s) in the 40-50Hz range and a Q_{ES} below 0.25. These parameters will give mass rolloffs ($F_{HM} = 2 \times f_s/Q_{ES}$) in the 300-

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Continued from page 64

400Hz range. Ideally, the rolloff should be around 400Hz to mate with a midrange horn. For a subwoofer horn, you can use a driver with a resonance of 20-25Hz and a Q_{ES} of 0.5 to give a mass rolloff near 80-100Hz. The flare frequency determines the low end.

The Bando driver may work on a midhorn, although I have not tried it. Its cousin, the Jordan module, will work on a midhorn, but it has a nasty resonant peak at the low end. If you try a Bando driver, you may have to gap the throat by ¼″ to ½″ to smooth out the low end ("The Edgar Midrange Horn," *SB* 1/86, p. 7).

Keep your Dinsdale horns if you like them. Small 70-100Hz horns give better imaging and response in the midbass region than a big 50Hz horn. Then add a subwoofer to cover the bottom octaves. Time delays can be a problem in bass horns, but you can tolerate 4-5mS below 500Hz according to psychoacoustical experiments. Of course, at higher frequencies, alignment by time becomes more critical. At 100Hz, I don't know what the ear will tolerate, but 20mS might be excessive.

If you are worried about time delays, you have alternate solutions. One is to build a subwoofer with four 15″ woofers. The combined area of the four drivers will move air like a horn with low distortion and without the time delay problem.

The other solution is to build a horn matched to the room as described by Rex Baldock in "Acoustic Compensation" (*Hi-Fi News*, pp. 490-495, 1964). He built a 17′ long horn underneath his living room floor and placed the drivers for the midbass and higher frequencies in the room above the basshorn drivers (underneath the floor) along the wall opposite the listening position. Seating was over the basshorn mouth opening in the floor. The sound above 100Hz traveled across the room in the air, whereas the bass traveled through the bass horn underneath the floor to arrive at the listening position with very little time differential.

Phase plugs are used when the wavelength is comparable to the diaphragm or throat size. In most bass and midhorns, they are not required. Phase plugs prevent phase cancellation at high frequencies and are usually found in tweeter and some midhorns where the response extends beyond 10kHz.

MORE THAN TIPS

I was very surprised when I received my first *SB* journal. I thought it would be stapled photocopied pages on tips for building speakers. Instead, it is a professional journal with a range of articles. I am a beginner, having built about four systems so far, and prefer the intermediate level articles. The "Pox Humana" column by Brock (*SB* 2/91, p. 92) is a very honest and touching statement.

R. Burke
Philadelphia, PA 19128

E-V 30W KUDOS

I had no idea an aura surrounded the E-V 30W. I have had one since the early 1960s. Being a bass freak, I would not swap it for its weight in gold. Mind you, it did not reach its full potential until the advent of the transistor amplifier and the compact disc. I say this because tube amps never had that slam in the deep bass region and few really deep low frequencies were recorded on vinyl without an awful lot of rumble to go with it.

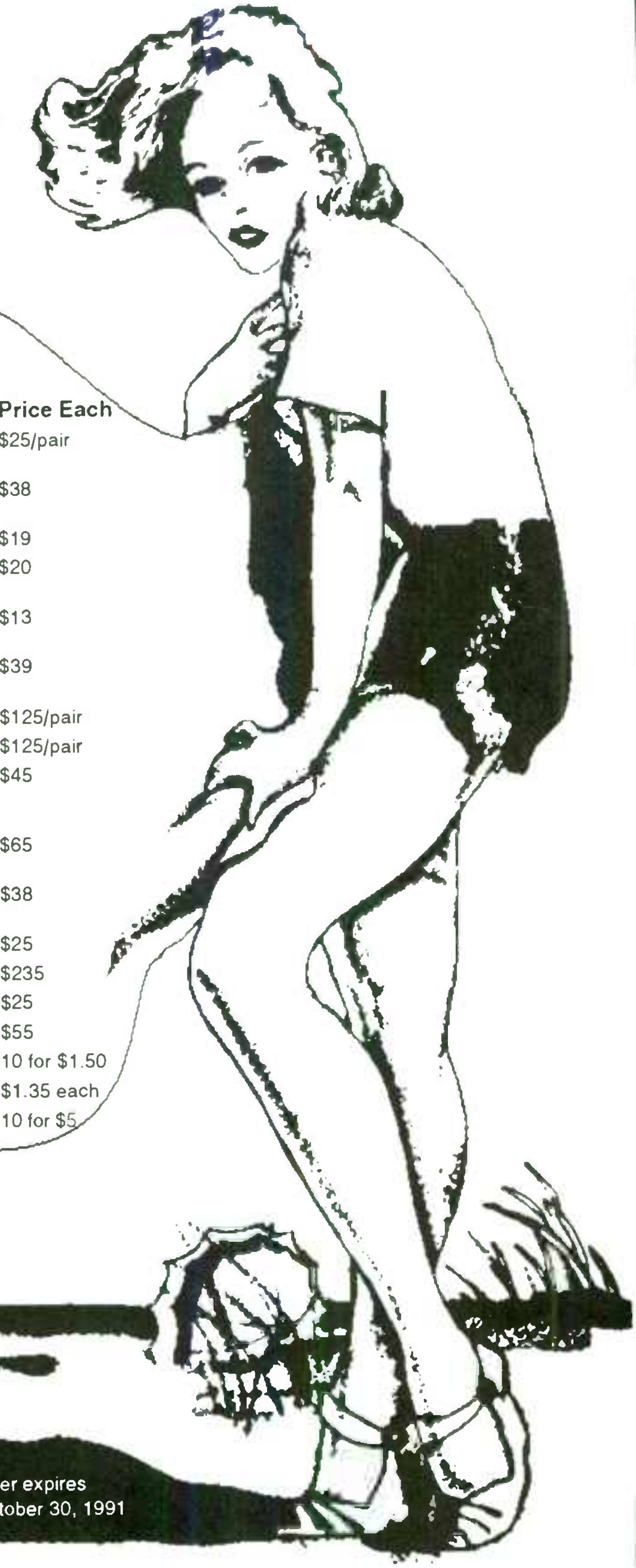
Talking of recordings, when I bought Telarc's version of *1812*, I noticed a warning to reduce the volume because of the digital cannons. I ignored the advice since I knew my system could take it, but I was not fully prepared for the tremendous explosion of those cannons. When I first heard them, I thought I was listening to a re-creation of the Big Bang. It was better than the earth-moving special effects of the movie "Earthquake."

The E-V 30W can really belt it out and in my opinion a large cone has no real substitute. Like Thomas Meacham, mine is crossed over at 80Hz and is driven by a 200W Tigersaurus.

P. Best
Dorset DT6 5BQ, UK

Continued on page 69

Beach Blanket Bargains from Madisound



Summer—Fall 1991

Qty	Description	Price Each
200	Vifa H25TG31 1" horn loaded dome tweeter, chambered back, 96db, 100 watt power handling	$25/pair
58	Morel MDT-32 1" fabric dome tweeter, replaceable voice coil.	$38
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90	Audax MHD10P25FSC 8Ω 4" woofer, paper cone, rubber surround fs 52.4 Hz, Qts.4, Vas 5.58 Ltr.	$20
225	Vifa C17WG69 fs 44, Qts.55, vas 35.8 lt 50 watt 89db, 6" treated paper foam surround	$13
8	Scan Speak 7" clear poly cone 18W/8542 fs 30, Qts.23, Vas 62 ltr, 88db x-max 6.5mm, 10 ltr box=f3 66hz	$39
5 pair	Morel MCW224 9" car woofer with grill	$125/pair
5 pair	Morel CW8 9" car woofer with grill	$125/pair
15	Focal 8N412 8" Neoflex woofer, Fs 36.4 Hz, Qts.295, Vas 60.8 Ltr, Xmax 5.45mm, 75 watt 91db, good for two way system	$45
10	Focal 8K515 Kevlar 8" woofer, Fs 31.7 Hz, Qts.244, Vas 84.8 Ltr, Xmax 7.73mm, 150 watts	$65
11	Focal 10C02 10" paper cone fs 27.2, Qts.45, Vas 163 ltr, 130watts, 90db 72 ltr box=sealed f3 43hz	$38
100	Eminence 10" poly fs 23.8, qts.33, Vas 269 lt 92.1 db	$25
20	Eton 11-580/50 Hex 11" Kevlar ,Fs 23hz,Qts.3,Vas 180 Ltr.	$235
200	Eminence 12" poly fs 24.8, Qts.32, Vas 299 lt 93db	$25
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12,000	1.0μfd Wima mylar, PC mount, 10% 100 volt	10 for $1.50
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Ordering Information: All speaker orders will be shipped promptly, if possible by UPS. COD requires a 25% prepayment, and personal checks must clear before shipment. Adding 10% for shipping charges facilitates shipping procedure (Residents of Alaska, Canada and Hawaii, and those who require Blue Label air service, please add 25%). There is no fee for packaging or handling, and we will refund to the exact shipping charge. We accept Mastercharge or Visa on mail and phone orders.

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OLD COLONY'S USER-FRIENDLY SOFTWARE

Speaker Designer™

Release 1.2 by Stuart E. Bonney

A loudspeaker system design aid and modeling tool for use with both closed and vented systems over the frequency range from 10 to 300Hz. Computes and displays system frequency response, power handling capabilities, and relative sound pressure level (SPL) outputs for each of 26 discrete frequencies over this range. Includes one year support by the author when the user registers this Shareware product. Each **$19.50**

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Loudspeaker Modeling Program

by Ralph Gonzalez (*SB* 1, 2, 3/87)

LMP produces a full-range frequency response prediction for multi-way loudspeakers, including the effect of the crossover, driver rolloffs, interdriver time delay, "diffraction loss," etc. (Includes author support.) Each **$17.50**

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"Souped-Up" LMP provides professional-quality graphics and a fast, friendly, user interface. Remains compatible with LMP data files and is available for IBM PC (CGA, EGA, VGA, or Hercules graphics) and Macintosh computers. The Macintosh version also provides square wave analysis with audible output.

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Driver Evaluation and Crossover Design

by G. R. Koonce (*SB* 5/88)

Disk 1 evaluates the suitability of drivers for closed, vented and passive radiator enclosures, and allows detailed designs of vented boxes.

Disk 2, in addition to driver evaluations, allows the design of first-, second-, and third-order crossovers. 5¼"IBM: 360K, DS/DD. Each **$12.50**

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Driver Evaluations DRI-1B5
Crossover Design CRS-1B5

Active Filter Design

by Fernando Garcia Viesca (*SB* 4/88)

Calculates component values for Butterworth filters in four configurations: High- and low-pass in second- and third-order. (Includes author support.) Each **$17.50**

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Two-Way Active Crossover Design

by Gary Galo (*SB* 5/88)

Performs the calculations for the eight two-way active crossover designs described by Bob Bullock using formulas exactly as given in the articles; plus a program to calculate V_{TH}. (Includes one year user support.) Each **$20**

Specify:
IBM 5¼" 360K DS/DD TWO-1B5
IBM 3½" 720K DS/DD TWO-1B3

Stepped Volume Controls

by Joseph O'Connell (*TAA* 4/88)

These ready-to-run Mac programs come on a 3½-inch SS/DD disk initialized as a 400K disk for compatibility with all machines. Also included are the Pascal source codes, should you wish to customize them for your own use. **Program A.** Precisely matches the resistor values to the measured or estimated source and load impedances, yielding great accuracy. Your volume control can have 3 to 99 positions. The program will ask you how many dB each step should be attenuated and has provisions for a standard audio taper or any other taper you devise. **Program B.** Calculates the taper that will result with your actual resistor values, because you are limited to standard values or with series and parallel combinations. It can also show the effects of different source and load impedances on the taper. Both programs (contained on the same disk) allow you to save their output to a text file and include author support via mail. Each **$25**

Apple Macintosh 3½" SS/DD SVC-1M3

BULLOCK & WHITE

BOXRESPONSE

Model-based performance data for either closed-box or vented-box loudspeakers with or without a first- or second-order electrical high pass filter as an active equalizer (*SB* 1/84). *The program disk also contains seven additional programs as follows:*

Air Core: This program was written as a quick way of evaluating the resistance effects of different gauge wire on a given value inductor. The basis for the program is an article in *Speaker Builder* (1/83, pp. 13-14) by Max Knittel. The program asks for the inductor value in millihenries (mH) and the gauge wire to be used. (NOTE: only gauges 16-38.)

Series Notch: Developed to study the effects of notch filters in the schematics of some manufacturers. Enter the components of the network in whole numbers (i.e., 10 for 10μF and 1.5 for 1.5mH) and indicate whether you want one or two octaves on either side of resonance. Output is frequency, phase angle and dB loss.

Stabilizer 1: Calculates the resistor-capacitor values needed to compensate for a known voice coil inductance and driver DC resistance.

Optimum Box: A quick program based on Thiele/Small to predict the proper vented box size, tuning and −3dB down point. It is based only on small signal parameters, therefore, it is only an estimate of the response at low power (i.e., limited excursion).

Response Function: Calculates the small signal response curve of a given box/driver combination after inputting the free-air resonance of the driver (f_S), the overall "Q" of the driver (Q_{TS}), the equivalent volume of air equal to the suspension (V_{AS}), the box tuning frequency (f_B), and the box volume (V_B). Output is the frequency and relative output at that frequency.

L-Pad Program by Glenn Phillips: Appeared in *Speaker Builder* (2/83, pp. 20-22). It is useful for padding down a tweeter or midrange while still retaining the same load as the driver itself.

Vent Computation by Glenn Phillips: Calculates the needed vent length for 1, 2 or 4 ports of the same diameter. Input box volume in cubic feet and required tuning frequency (f_B), output is vent length and vent area for each case.

Medium: 5¼" SS/DD Disk. Price, **$25**.

Specify:
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IBM Plus Graphics
BOXRESPONSE BOX-2B5G **$50**

PASSIVE CROSSOVER

This disk is a result of Mr. Bullock's extensive research concerning first-, second-, third-, and fourth-order passive crossovers in *Speaker Builder* 1, 2 & 3/85; **$25**

Specify:
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CALSOD

Computer-Aided Loudspeaker System Optimization and Design

by Witold Waldman

CALSOD is a new entry into the field of crossover network optimizing software available for the IBM PC desktop computer. It combines the transfer function of an LC network with the acoustic transfer function of the loudspeaker, by using some form of iterative analysis. CALSOD creates, through the process of trial-and-error curve fitting, a suitable transfer function model which it can then optimize. The program is the subject of CALSOD author Witold Waldman's research paper "Simulation and Optimization of Multiway Loudspeaker Systems Using a Personal Computer" which appeared in the Audio Engineering Society *Journal* for September 1988, pp. 651-663. CALSOD differs considerably from other software since it models the entire loudspeaker output of a multiway system, including the low-end response, and the summed responses of each system driver.

The program performs a lot of tricks. One of the more spectacular of these allows the designer to specify the location of the driver acoustic centers using an XYZ coordinate system. Thus, if the designer expects to mount a driver combination on a flat baffle, the summed response can be optimized to compensate for rearward displacement of a woofer's acoustic center with respect to a tweeter. CALSOD can model up to seven drivers at a time in a four-way system giving the summed response and acoustic phase response of the entire system.

The CALSOD program comes on a single 360K floppy, and requires one directory and two subdirectories in installation, plus access to the DOS GRAFTABL file, which it uses for a couple of special symbols. The 133-page User Manual, provided on a second disk, is well written, adequately describes the various program functions, and contains an excellent tutorial example, which demonstrates the use of the program.

Specify:
IBM 5¼" DEMO .... CAL-2B6D $ 5.00*
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IBM 2 x 5¼" 360K DS/DD .. CAL-2B6 $65.00
IBM 3½" 720K DS/DD CAL-2B4 $67.50

*** Usable as credit toward later purchase of full CALSOD.**

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CAR ENCLOSURES

I am interested in Isobarik tunnel enclosures for automotive use. They seem to have a decided advantage where space is at a premium. I wish to build one using either two 8″ or two 10″ woofers and having as small a net volume as possible (ideally less than 1 ft.³).

I would greatly appreciate your opinions on the following: which drivers you believe would work best for this type of alignment, whether to go with a vented or a sealed enclosure, and what formulas to use in the calculation.

Mike Manry
Apple Valley, CA 92308-7786

Contributing Editor John Cockroft replies:

This is the first letter I have written to a reader in some time. Due to personal problems, I have found it necessary to give up (at least for now) virtually all activity related to speakers. I apologize to those who sent me letters recently. I am unable to answer them at this time. I have always enjoyed receiving letters from readers and answering them and I hope to do so again in the future. This letter came when I could answer it and its answer seemed to be of interest to many besides Mr. Manry.

I really have no experience with car speaker systems (that's one place I enjoy not hearing a radio because it's one of the few places I get a chance to think), but I have had some experience with Isobarik, or compound, systems. One would think, on the face of it, these systems might be helpful in such a system as you contemplate.

Since receiving your letter, I spent quite some time going through various catalogs I have on hand. I was surprised how little was available to aid me in the solution to your problem. I finally found a speaker unit that shows promise (at least based on its published specs), the VMPS BC 820/8 8″ woofer. (It was in a year-old Just Speakers catalog [contact A&S Speakers, 3170 23rd St., San Francisco, CA 94110, (415) 641-4573, FAX (415) 648-5306]; I don't have a current copy for some reason). Its specs are f_s = 40Hz, Q_{TS} = 0.36, and V_{AS} = 1.8 ft.³ Last year the device sold for $27.95 a copy, which sounds reasonable.

For the compound configuration, V_{AS} would be one-half of the above figure, or 0.9 ft.³ Since you wish to keep the box small (below 1 ft.³, you said), I started off with 0.5 ft.³ (net internal volume). This turned out to be too small because with the Isobarik tunnel, the rear speaker, and the duct (the specs of this speaker make it necessary to have a ducted design, although in other cases I'm sure a sealed system would function well), it seemed impossible to get a box of the right volume and still fit in all the elements. If you make the box deep enough to accommodate the rear speaker and the tunnel, it is either too narrow to fit the tunnel or too short to allow the duct to be placed in a reasonable position.

I next tried 0.75 ft.³, which seems to work okay as I was able to fit in all the parts. It came out to a gross internal volume of 0.945 ft.³ (just inside your ideal requirements).

Since we know the desired net internal volume and the value of V_{AS}, we can calculate the value of V_{AS}/V_B (also known as alpha because the Greek letter is often used to symbolize it). This is the ratio between the compliance of the speaker and the enclosure, both expressed as enclosed volumes of air, to make the relationship easier to comprehend. We need to know this ratio to find out just how well the speaker will fit into the box (not physically, but acoustically). It will help tell us how the system will sound with this setup. We divide 0.9 by 0.75 and get V_{AS}/V_B = 1.2.

From this ratio (and some other speaker specs), we can determine f_3, the final −3dB down point of the frequency response curve as it leaves the passband and enters the stopband. This is where the sound will continue to roll off until it reaches silence (or at least the system's noise level), f_B, the frequency the box must be tuned to (via the duct) to allow it to compensate for the speaker's deficiencies caused by its placement in this size box. We can also determine just how much the lower end of the response curve will peak or dip (or if it will remain flat) just before it enters the stopband. In other words, we will know whether the speaker/box combination will suit our purpose.

Incidentally, what I'm using for f_S is really f_{SA}, the woofer's resonant frequency in free air. The more accurate figure would be f_{SB}, the speaker's resonant frequency in this box. You can't determine this without building the box and mounting the speaker in it and measuring and calculating f_{SB}, which is beyond the scope of this letter. If you

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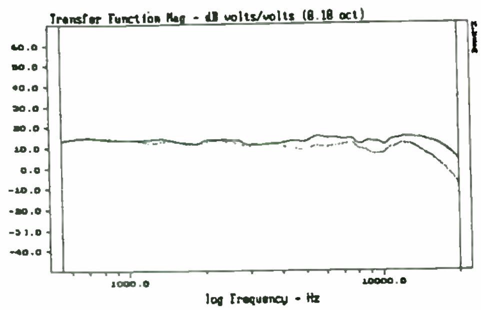
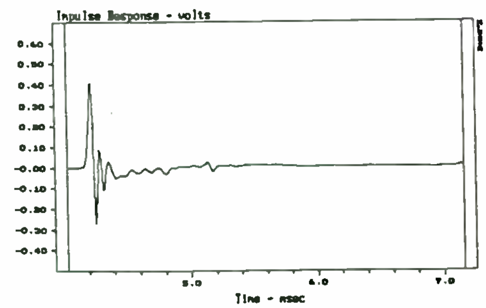
Do you deserve the best?





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If you want the excitement and power of live music and quality videos you will relish the *Alpha's* dynamic range. Even at very high output levels the *Alpha's* music is clean and lifelike.

Unlike most high-output designs, the *Alpha* does justice to the finese and beauty of acoustical music and sounds just as full at low volume as it does at lease breaking levels. Appreciate well-recorded vocals like never before!

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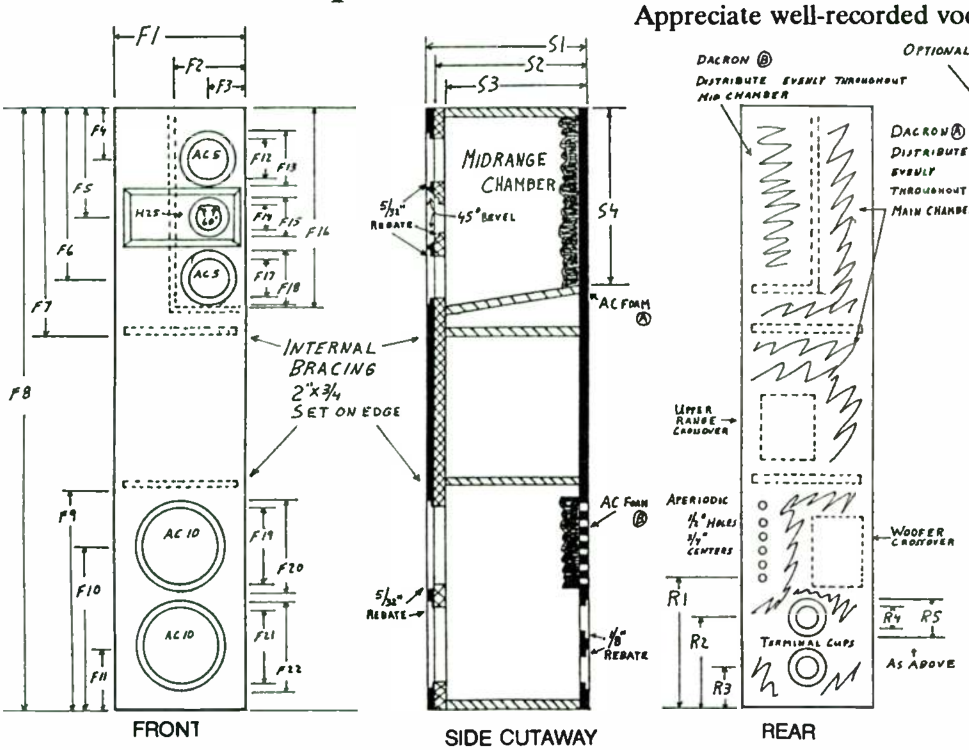

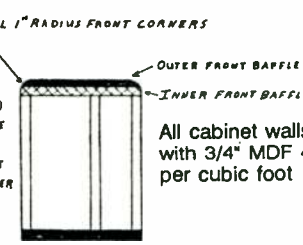

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F3	4"	F10	16"	F17	4 3/8"
F4	5"	F11	6"	F18	5 13/16"
F5	11"	F12	4 3/8"	F19	9 1/8"
F6	17"	F13	5 13/16"	F20	10 1/8"
F7	23"	F14	3 1/8"	F21	9 1/8"
				F22	10 1/8"
S1	16"	S2	15 3/8"	S3	14 7/8"
				S4	18"
R1	13"	R3	4"	R5	4 3/16"
R2	9"	R4	3"		

Alpha

Drawn by: MQD 5/91

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AC Components div. Audio Concepts, Inc.

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Continued from page 69
wish to do this, I have discussed this and other measurements and calculations for vented boxes in "The Demonstrator" (*SB* 2/87, p. 29).

I should again call attention to the fact that in that article, equations 4-6 have an error (the same error): V_{AS}/V_B should have the parentheses enclosing the entire expression, rather than just V_{AS} as printed. In many cases, f_{SB} is fairly close to f_{SA}. It is usually a few hertz lower. I do remember one case in which it was actually a bit higher. (Perhaps I goofed, but I couldn't figure out where.)

My guess is that for a woofer in a car environment, with its high noise level, high sound reflectivity, and so on, that the use of f_{SA} would result in an acceptable woofer. If not, proceed to work out f_{SB}. Make sure when you build the system you allow for duct removal and replacement with one of a different length. Using ducts made of PVC plumbing pipe (available at building supply stores) helps simplify things.

First, to determine f_3, make sure the frequency goes low enough to be considered. For this, take the square root of V_{AS}/V_B and multiply it by f_{SA} (or f_{SB} if and when you get it). This would be:

$$f_3 = \sqrt{1.2} \times 40 = 43.8\text{Hz}$$

I certainly think this would be low enough for a car woofer. The interior car dimensions will probably limit the lower frequencies (at least as far as full volume sound is concerned). To obtain a frequency of 43.8Hz (which has a wavelength of 25.8 ft.) at full volume would require that the listening space have a dimension at least one-half as long as the wavelength, or 12.9 ft. Perhaps in a van or station wagon you could realize most of this speaker's potential.

Now we come to f_B. Incidentally, I should have mentioned that the equations I'm presenting here, in designing this box, were worked up by D.B. Keele and have been published in several sources (and deservedly so). So again we come to f_B:

$$f_B = (V_{AS}/V_B)^{0.32} \times f_{SA} \text{ (or } f_{SB})$$

You can easily solve this on a scientific calculator. In this case, punch in V_{AS}/V_B (which is still 1.2). Then punch the Y^x key, then 0.32, and finally the equals key. It will take a second or two for the calculator to perform the calculation (which will be 1.0600784). Multiply this by 40 to get 42.4HZ for f_B.

To find the peak, or dip at the low end of the frequency range, use the following equation, where R is ripple:

$$R = 20 \text{ Log}_{10} (V_{AS}/V_B)^{0.35}\ 2.6Q_{TS}$$

Start, as you did with the last equation, by punching in V_{AS}/V_B, then do the stuff with the Y^x key (only 0.35 this time) and equals (1.0658926). This must be multiplied by 2.6 times Q_{TS} (which is 0.36), so just go × 2.6 × 0.36 = and you get 0.9976755. To convert this to decibels, press the log key, which will give you the logarithm to the base 10. Wait a couple of seconds for the answer, which you multiply by 20. In this case, it's −0.0202141dB. The minus sign indicates it's a dip, not a peak. Actually, it's flat; anything that's only ²⁄₁₀₀ths of a decibel isn't anything at all.

Now that you've had all that fun figuring out this stuff, you discover you might have a good system (assuming the published specs are relatively correct for the two units you may end up with). If you have the equipment, measure what you get when it arrives. (You should break in the speakers for a few hours to loosen up the suspensions before you measure.) Lacking that, you could build the system and see what you get. Chances are the system will be usable. (However, just in case, at this point I slip quietly around the corner and make a break for it.)

We still must determine the duct dimensions that will give us the f_B of 42.4Hz:

$$S_V/L_{VB} = (6.28\ f_B/345)^2\ V_B$$

S_V is the cross-sectional area of the duct. The value 345 is the approximate speed, in meters, of the speed of sound at sea level (I suppose at 70°F) and V_B is the net internal volume of the enclosure in ft.³ (in this case 0.75). You can perform it on the calculator as it is written:

$$6.28 \times 42.4$$

then punch the divide key:

$$345 = (0.7740156)\ X^2\ (0.5991001) \times 0.75$$
$$= (0.4493251)$$

(The figures in parentheses are the answers on the calculator and are not to be punched in.) The final one was S_V/L_{VB}. Once again, I think these equations are the work of D.B. Keele. (If I'm wrong, I apologize to the real author.)

S_V/L_{VB} gives the ratio of the cross-section area to the effective length of the duct. Because one end of the duct is flanged (the speaker baffle acts as
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a flange) and the other end isn't (it just sticks out, inside the box), this represents a special case and we must make a correction for the actual length of the duct. (All other situations also represent special cases and must be corrected, but we don't really care at this point—at least I don't.) You must cut off some of the duct.

I will skip ahead here for a minute (mostly because it's 4 a.m. and I'm trying to remember the equation). I will arbitrarily pick a 2″ inside diameter for the duct tube. First, because I think it will prove to be a practical size (experience, man) and second, because the cross-section area (S_V) equals π. (That means every time I want S_V, all I must do is punch the π key. I'm a bit lazy at this time of night.)

Ok. I remembered the equation for the correction:

$$L_{VC} = 0.825\sqrt{S_V}$$

L_{VC} is the length in inches to be cut from the duct that the previous equation calculated to make it "correct." Note the quotation marks. We're not out of the woods yet. This correction is only to set us up for the final correction (sounds like "the final problem"). The big problem is that I have never been able to make the final correction correctly. Now I don't even remember the equation to attempt it (and I don't care to). The equation was supposed to make everything come together, to hit the nail on the head, so to speak. The trouble was I heard a lot of air swishing around the nail head every time I swung the hammer. What happens is that when I get this close, I get out the old frequency generator and cut up a bunch of ducts with lengths both longer and shorter (as well as the predicted one) and have a go at it. I try the short ones first because that is the way it is supposed to be. A lot of times I find that a duct 0.7 times the calculated duct is quite close. That might be the one to try first.

Now, let's calculate the duct. Using the 2″ I.D. duct:

$$3.14\ /\ (S_V/L_{VB})\ (0.4493251) = 6.9918033 - L_{VC}$$

(I just realized we didn't calculate L_{VC} either.) The square root of 3.14 is 1.772, etc., times 0.825 = 1.46 (say 1½″). This gives us a duct of 5½″. If we should invoke the magic 0.7, we come up with 3.85″. (Isn't that an impressive sounding number?) I hope your luck is running.

Figure 1 is a sketch of a way this project might work out. The speaker, tunnel, and duct are all mounted on the speaker baffle. I suggest mounting this baffle to the rest of the enclosure with a ¼″ bead of silicone rubber (bathtub caulk). Hook up the wires, then press the baffle into the rubber and line up the cover to the box.

Let the silicone rubber squish out and look like hell. Later (like tomorrow), when it is dry, take a wet single edge razor blade and trim it off. Make sure when you are putting things together, you don't let the speaker leads get caught between the baffle and the top of the box. While the rubber is drying, weigh down the baffle with something heavy, like bricks. When you finally decide on the right duct, glue it in with the silicone rubber, putting the duct almost all the way in the hole. Put a bead of the

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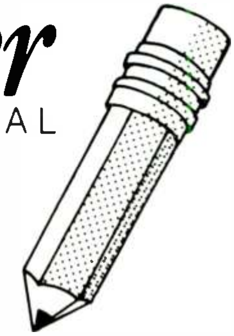

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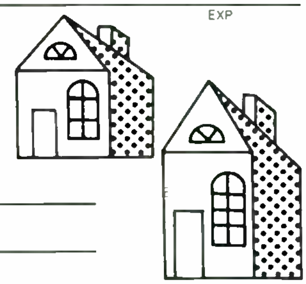

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rubber around the duct about ½" from the end. Then, push the tube in place with a twisting motion. You can trim off any mess later as described above. This messy stuff should be done over newspapers.

Keep the Isobarik tunnel as short as reasonably possible for two reasons. First, the longer it is, the more volume it takes up. This makes the enclosure larger. Second, if the rear speaker is too far behind the front one, it will broadcast information out of phase with the front speaker, through the front speaker cone, smearing the sound. I have never heard this phenomenon with the short tunnels I used, even at higher frequencies, but other designers have reported on this. I understand that the speakers were separated a considerable distance from each other.

If you plan to use this only as a woofer (as I suppose you do), you should have no problem, as the wavelengths of the frequencies involved would be several feet long. I think the tunnel is long enough (on the sketch), but it would be better if you had the actual speakers in hand, so you could measure everything and determine the length. If you must lengthen the tunnel by any serious degree, add similar volume to the gross volume of the box. If it's only ¼" or so, forget it.

Make the connecting wires in the tunnel long enough so you can mount the speaker, but not long enough so they flop against the rear speaker cone. Maybe after attaching the wires to the speaker, you could turn the speaker 90° so the wires would tend to wrap around the front speaker basket and not

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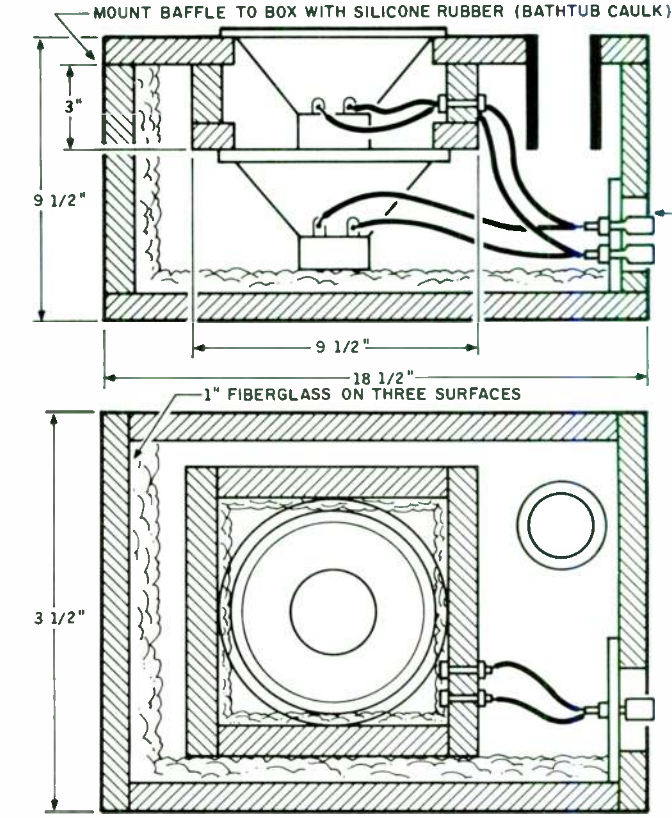

FIGURE 1: Compound woofer system based on the published specs of the VMPS 8", 8Ω woofer (f_S = 40Hz, Q_{TS} = 0.36, V_{AS} = 1.8 ft.³). Divide V_{AS} in half for this system. Wire the woofers in parallel to get 4Ω; wire both woofers with the same polarity. The material is ¾" particle board. Woofers are available from Just Speakers.

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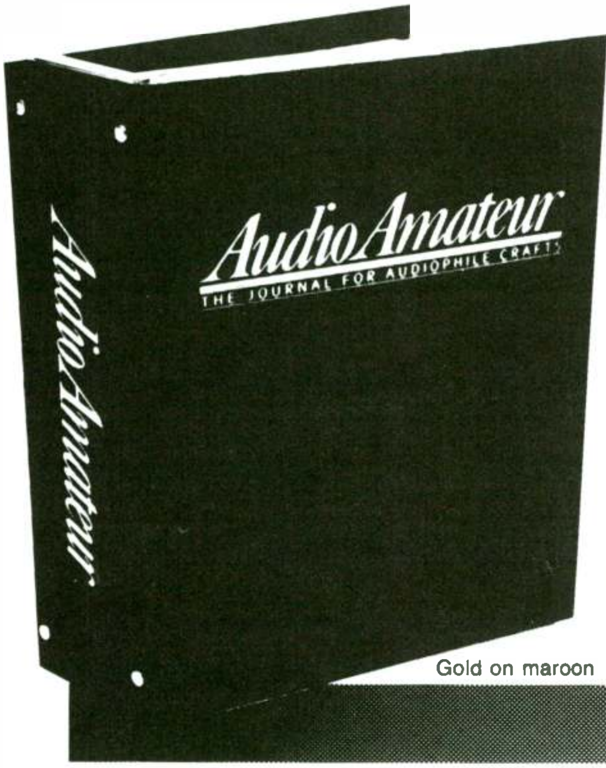

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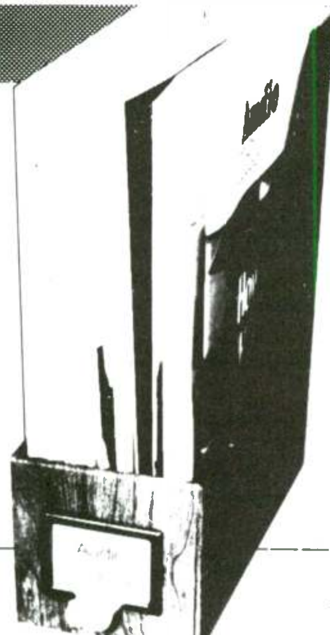

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dangle; #10 brass pan head machine screws, with nuts and solder lugs, make good feedthroughs through the tunnel walls.

Wire both speakers in the same phase (so they both move in the same direction at the same time). Wiring them in parallel would probably give you the best impedance for a car amplifier. Use 1″ thick fiberglass batts (Radio Shack) on the panel opposite the speaker baffle and the end and side panel farthest away from the duct. Spot glue these in place so car vibrations won't dislodge them.

When measuring the tunnel length, make sure you have room to allow for the forward throw of the rear speaker. The cone shouldn't be allowed to hit the front speaker's magnet.

I hope this has been helpful.

WOOFER PREFERENCES

I wish to build a speaker system like the one in "Octaline Meets D'Appolito" (*SB* 2/91, p. 38) by William Wagaman. However, I wish to use the 6½″ Eclipse W6518R woofer instead of the Vifa P17WJ. According to the article, the Eclipse woofer was recommended as the first choice for this design.

Do you still maintain the Eclipse is the better choice? If so, could the author give me a filter arrangement and component values to match the W6518R woofer to the Dynaudio D28af tweeter?

If my woofer changes, must I change the enclosure dimensions? By how much?

Is the speaker 4Ω, and can this be changed to 6 or 8 without any adverse side effects?

Do you think the damping effects of the modeling clay and the sand-filled baffles are worth the effort over using just wool or foam and Acoustical Magic?

I would greatly appreciate your technical recommendations.

Tom Combs
Peru, NE 68421

William Wagaman replies:

I think either woofer brand will work in my design. I'm happy with the Vifa drivers. To use different ones, proceed as follows:

First, install the drivers in the stuffed speaker boxes and get a full impedance curve. Do not hook up the tweeter at this time. You will use this information when you calculate the coil size you need for the crossover. Run two curves, one with, and one without, impedance compensation. Meniscus should supply the resistor and capacitor values needed when running the drivers in parallel.

Second, use a spectrum analyzer and a pink noise generator to get an idea of the system frequency response. You can buy analyzers for a relatively small amount. Mine cost $50 from BSR. You can use either the built-in pink noise generator, the Old Colony generator, or a CD test disc. If something is wrong, your ears will inform you and the analyzer will show you exactly where it is wrong.

If the frequency response is flat up to 3kHz, great. Try putting a coil in series with the woofers and check the resulting frequency response. If it looks and sounds good, add the tweeter to the system. Don't be afraid to use asymmetrical crossover points. Theory is one thing, reality another.

The driver cross-sections determine the enclosure cross-section. The drivers from both manufacturers are nominally 6.5″ in diameter so the cabinet dimensions are the same.

The loudspeaker I designed is 4Ω for a very small part of the impedance curve. I consider it a mild load in comparison to some impedance curves I have seen. Any decent amplifier should have no problem driving the loudspeaker. I do not know of any way to bring up the impedance curve. After living with the speaker for more than a year, I do not believe it is the problem I previously mentioned.

It is tweak time. As we all know, loudspeakers are designed and sold at certain price points. The cabinets, drivers, and crossovers make up part of a loudspeaker's cost. A few things the home builder can add to his speakers would not be cost-effective for the speaker manufacturer. The materials are not the problem, the labor is. True, it is a pain to smear clay on the cabinet walls (interior walls only, please) as it takes time and effort. True, it is a pain to pour and seal sand in the cavities. However, it works and works well. I cannot speak of the effective-

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ness of the Acoustical Magic paint. It may work as advertised.

I hope you build my speaker design. Put the time and effort in the cabinets and fine-tuning the crossover parts. You will be rewarded many times over.

WHAT'S BEST?

I am planning to build a dipole subwoofer somewhat along the line of James Lin's (*SB* 6/89, p. 10), Robert Camp's "Big Dipole" (p. 52), Celestion's System 6000, and also the long-forgotten Enigma Subwoofer of a few years back.

In selecting driver units, what is the most important parameter to consider? Throw, diameter, surround construction and material, power handling, speaker Q, or something else?

Assuming equal throw, four 10" units have about the same area as two 15" units. Which is the better choice?

I need to use an equalizer, no doubt. The Richter Scale III is the obvious choice. What about the Basis? I think this interesting EQ should be reviewed. The Richter Scale was, so why not this one?

Ngai Lee
Brooklyn, NY 11214

James Lin replies:

I wish I could answer Mr. Lee's questions in the form he has asked them. Unfortunately, they contain what I believe to be a common error, that one or two qualities define the "goodness" of a driver. I'm sure Mr. Lee would not ask, "What is the most important factor in choosing a husband or wife?" But something about technical matters such as speakers seems to invite this sort of question. If only life were that simple. In fact, in engineering, the most successful designs are those in which many qualities are balanced.

Having said that, I will at least attempt an answer to the first question, which I will rephrase as "What are some of the important qualities (note plural) to look for in a driver for a dipole subwoofer?" Briefly, as I discussed in my article, some of these qualities are large, linear volume displacement (the product of cone area and throw) and an appropriate Q value. Because the ear's inherent insensitivity to low frequencies, a subwoofer must be capable of quite high output at low distortion.

Since the amount of linear volume displacement available governs output, the volume displacement is important, particularly in dipole subwoofers because they are inherently wasteful, losing large amounts of output due to front-to-back cancellation. In my design, for example, only about 6% of the output at 25Hz is actually heard as sound, the remainder being cancelled. Thus, a large cone area and a linear, long cone throw are equally important.

A Q value in the 0.7-1.0 region makes for simple equalization via a 6dB/octave slope to give flat far-field response. Other Q values can be accommodated as in my design; however, they may require more complicated equalization. Some manufacturers, such as Carver, use very high Q values of 2.5-3.0 to eliminate the need for equalization; however, such drivers are specially designed for that purpose and are unavailable to the amateur, as they are essentially worthless for anything else. Indeed, even quality drivers with a Q of 0.7-1.0 are uncommon, since most drivers available to amateurs are designed for sealed- or vented-box designs, which generally require a much lower Q.

Quality of construction is always important, but using specific details of design or construction such as cone material, surround construction, and so on to differentiate between drivers is a flawed approach. A good driver using an "inferior" design will beat a poor driver with "superior" design every time. I regard power handling as the least important factor in choosing a driver. It describes what input a driver can handle, whereas what matters is whether the output is sufficient for your purposes. As a Boston Audio Society member once described, "Praising a speaker for its power handling is like praising a car for its gas consumption."

Mr. Lee's second question is simply unanswerable. While it is at least reasonable to ask for a comparison of specific drivers for a particular purpose (although designers may differ in their choice of driver, depending on the qualities they value most), asking such a general question is akin to asking, "Who are superior, blondes or brunettes?" Of course, one might say, all other things being equal, but in real life, all other things are never equal, and practical differences will outweigh theoretical ones (and if all other things were indeed equal, you would have nothing to choose).

Finally, as to the third question, Mr. Lee does not indicate the size of the subwoofer baffle he plans to build, nor the main speakers he intends to use. As I stated in my article, the size of the baffle will determine the equalization required, and the choice of main speakers will affect the crossover point. I have no experience with the Basis, and therefore cannot comment on it. I have not used the Richter Scale either, but have read reviews of it. Based on that, I would not recommend that the Richter Scale, or any similar design, be used as a substitute for the type of crossover outlined in my article. The reasons for my opinion are as follows: first, the amount of equalization required for a dipole subwoofer of reasonable size is on the order of 12–15dB. This is at or even beyond the capabilities of many graphic equalizers.

Second, using such large amounts of equalization will inevitably result in a lumpy equalization curve, when what is needed is a smooth 6dB/octave rise to compensate for the falling output due to front-to-back. Using feedback equalization around a single op amp as in my article will easily and inexpensively accomplish this for less cost and with better results than using a graphic equalizer.

Third, the choice of crossover point should be individualized for the main speakers. As I stated in my article, using a subwoofer indicates the crossover point will inevitably be located around the region where the main speakers are rolling off themselves. When you design the crossover, you must take into account the variation in both phase and frequency response that this entails, and a proper crossover is as important as a good driver. A custom, dedicated crossover is by far the best solution. A universal crossover does not necessarily produce bad results, but it rarely if ever gives optimum results, just as an off-the-shelf crossover is rarely as good as an integrated design.

Finally, if Mr. Lee is interested in more detail, I suggest he read the technical discussion in my article, as well as the references listed therein.

TL MODELING

Peter Hillman's superb articles (*SB* 5/89, p. 10 and 6/89, p. 32) awakened my interest in TL loudspeakers. Of special interest was the detailed documentation of performance. My curiosity was piqued by a point implied in Mr. Hillman's measurements (but not presented explicitly in the text): α (the ratio of the speed of sound in free air to the speed in the fiber tangle), which has entered the lore of TL designers, appeared to be frequency dependent. This led me to read Mr. Bradbury's article, which verified this point. It was clear, moreover, that Mr. Bradbury's approach yielded reasonably accurate predictions of α and β and the fit with Mr. Hillman's data further indicates this was a productive approach. I was pleased to find ex-

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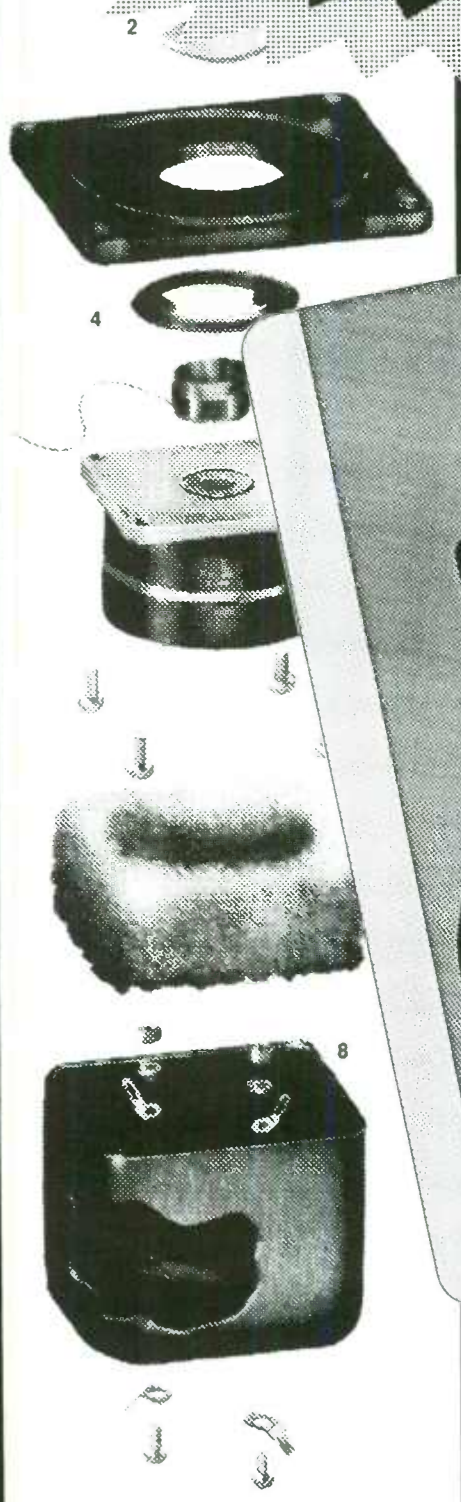

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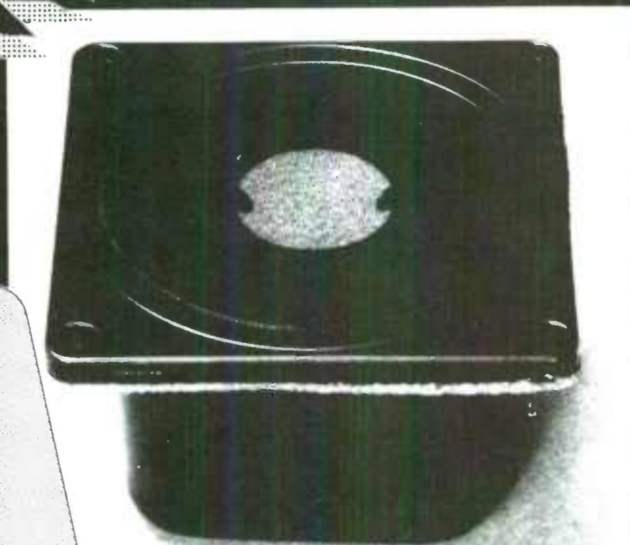

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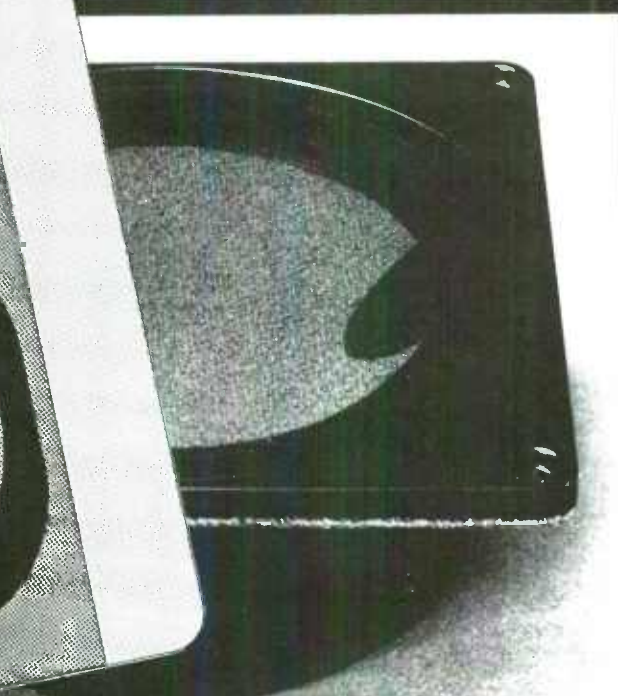

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pressions in Mr. Bradbury's paper for driving impedance and port velocity and, while I'm not an engineer and know little of acoustics, I began to use these equations for a computer simulation of TL behavior.

It was relatively simple to use equation 9 to relate "stuffing" parameters to the frequencies at which a given line was ¼λ, ½λ, and so on. Vector addition of the port to a constant real 1 for the driver gave an idea whether the output of the port was helpful. I also simulated the mechanical load on the driver using equation 8. From the curves in *Fig. 10*, I deduced that the positive values of the imaginary Z were probably due to "stiffness" and should add to the Z due to C_{MS}, while negative values should add to Z from M_{MS}.

To couple the driver to the line, I multiplied the line impedance by sd²/area of line (more on this later). I scanned the output for minima in the mechanical impedance, which I assumed would correspond to maxima in the electrical Z. Things became interesting: the model predicted (in a qualitative way) some of the cryptic behavior noted for TLs—double peaks for short lines, higher f_S on increased stuffing density, the position of the resonance peak in Mr. Hillman's empty line, and the appearance and disappearance of peaks in Mr. Cockroft's Microline (*SB* 5/89, p. 28). This is quite reasonable: in the region of frequency of interest, the main reactive mechanical impedances acting on a driver are nearly equal and opposite; the line presents small reactive impedances—capacitive which increases as one approaches λ/4 (the high-frequency extension of this is increased by increasing stuffing density) and inductive below λ/4; depending on circumstances, these may augment or null the mechanical impedances.

The model had a major glitch, though; it predicted values of port radiation around ¼λ, which were much too high (*Figs. 7* and *8* in Mr. Bradbury's article). The same seemed true for Z. The line needed damping or loss. In equation 13, Bradbury assumes elastic transfer of momentum from air to fiber. This is almost certainly incorrect, so I decided to introduce a "loss" through this coupling. Since the leap from equations 10–13 to 8 and 9 is beyond me, I fudged this by replacing the extensive loss parameter:

$$\beta \times \omega \times L/a_o$$

in equations 8 and 9 with:

$$\beta \times \omega \times L/a_o + \text{damp} \times \alpha \times L/a_o$$

where damp is a variable from 0–1. By using a value of damp of around 0.1–0.2, results became more realistic. (More about losses later.)

The results encouraged me to ask how

an actual simulation would look so I attempted to simulate a complete system's acoustic and electric behavior. Since I didn't know how this should be done, I looked up information on loudspeaker behavior in Mr. Colloms' book. I assumed the cone's velocity, U, would be directly proportional to:

$$BL / (R_E + R_G)$$

and that it would be inversely proportional to the mechanical:

$$Z_R \text{ (line)} + R_{MS} + \omega \times M_{MS} - 1 / (\omega \times C_{MC}) - Z_i \text{ (line)}$$

and electrical impedances. From the models I've seen, I took this to be:

$$B^2L^2 / (R_E + R_G)$$

on the driver. These inputs seemed to work in trial simulations of closed boxes. To convert U into acoustic output, I multiplied U^2 by an f^2 function, which incorporates the resistance of air and the ratio of wave length to circumference of the diaphragm. I applied the same to the port, assuming a massless piston of the same area as the driver. I also used Mr. Colloms' *Fig. 3.28* to compute electrical Z and its phase.

Using the model, I ran simulations of Mr. Hillman's speaker. While with a little fudging I achieved reasonable agreement between model and report, I noted the following defects:

1. The model exaggerated the driver's rolloff.
2. The model overestimated the driver's loading (resistive and capacitive) by the line. (To achieve a reasonable simulation, it was necessary to use a line area about 2.3 times the actual *average* area of Mr. Hillman's line.)
3. The model failed to predict enhanced output of the port between 20 and 40Hz, and between 50Hz and 1.5kHz. (Enhancement in the former region and suck out in the latter were underestimated.)
4. Mass loading suggested in those regions and below 20Hz was not predicted.

First, let me note that as a chemist I'm aware of the utility of heuristic models in which complex behavior is simulated by relatively simple functions chosen because they work, rather than because of any reflection of actual physical behavior. Simulation suggests this might be the case here. The results are more sensitive to parameters (length, density, driver parameters) than to the fudge factors. Acoustic output is relatively insensitive and impedance more so, a simple reflection of measurement. TLs are intrinsically well-behaved, with slow rolloff and little ripple (provided adequate stuffing is present).

Problem 1: This seems largely a consequence of 2 and 4.

Problem 2: While I have somewhat compensated for losses due to energy transfer, other important losses are present. The line is shunted capacitively along its length and more importantly, at each reduction in area and at each fold, some energy is reflected back to the driver. Resolution of this seems prohibitively complex (an infinite series of transcendental terms?). My results suggest that these effects can be modeled as a shunt and moreover, since simple exaggeration of the line area produced reasonable values for phase, magnitude, and location of the impedance peak, it appears that a scaled phantom of the line itself could serve as a reasonable facsimile of this shunt (perhaps paralleled with an RC term derived from the volume of the line and density of stuffing). The scaling term could be determined empirically and related to the taper and number of bends, and of course port out must be reduced by shunt. Such a term should be a well-behaved predictor as the range of value is small, the effect on output fairly small, and the "validity" easily tracked by impedance behavior.

Problems 3 and 4: I have no idea what is happening here. I suspect mutual loading and differences between the impedance of the port and the air may account for some but not all of 3. The fact of 4 makes it seem probable that the line is simply a more efficient half- and full-wave resonator than predicted by Mr. Bradbury's equations. A simple solution, however, is to add a damped cos:

$$\cos\,(\alpha \times \omega \times L/a_o)$$

to the real velocity of the port (Mr. Hillman's data suggest the reciprocal of a cos(h) or cos(h^x) function with a max at about 1λ in the line). Since efficient resonance at $2n\lambda/4$ implies mass loading, a similar j × absolute cos or j × $\cos^2$ function could correct the impedance. While these functions may depend on the line's shape and stuffing density, the beauty is that, once again, the range of values and the influence on output are both small.

Reflection and my simulations suggest that TLs have valuable intrinsic characteristics: an ability to present a fairly level and largely resistive load over a couple of octaves resulting in a 6–8dB rolloff, which may be compensated to some degree by port output along with quite unproblematic "tuning." This suggests a relative insensitivity to R_E (ability to pad without introducing nasty peaks). It also suggests that short lines packed to higher than typical density, using high Q drivers or shunting the line with a resistive vent

("Vario-vent") could provide greater bass extension and much gentler rolloff than a closed box of the same volume, a nice result if you accept that the speaker response should meld with the approximately 5dB/octave enhancement offered by boundary loading in a normal room. (I plan to build a folded 5 ft., 2.5 ft.³ box with a 10″ driver to test this.) Finally, the model suggests that for a given driver and a given volume, loose optima are among the inevitable tradeoffs. A good model should help to explore these as well as unconventional loadings based on the introduction of deliberate resistive or capacitive shunting (easily added to the model).

Clearly, you have done work on this using tools far superior to mine. Is what I have done to date reasonable? Does my model contain gross errors? Are the proposed refinements reasonable? Has your own work led to more refined solutions or to intractable conflicts with real behavior? Do you have more data on the performance of real lines, particularly lines without folds or taper, which you could share with me as I try to work out the fudge factors? (Unfortunately, I have limited facilities for acoustic measurement.) Have you any data on the performance of Mr. Cockroft's "free lunch" lines?

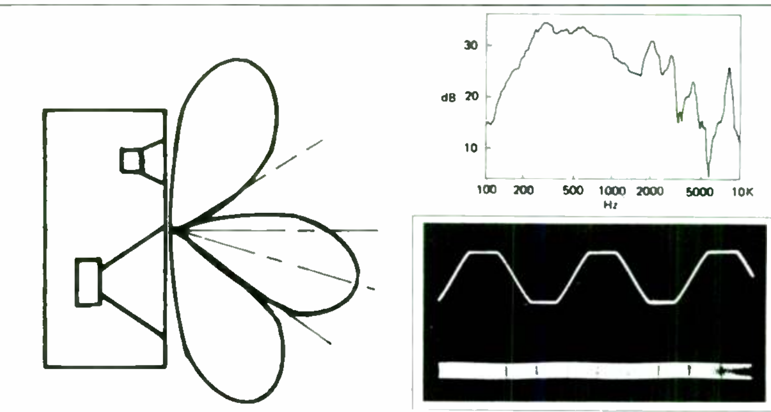
My model suggests impedance peaks at approximately the right frequency and magnitude with a broad flat impedance and a gentle 6dB rolloff for the driver commencing at a fairly high frequency; loading by boundaries at about 2, 5, and 8 feet could produce the effect of considerable bass extension. On the downside, the lines seem to have too little packing in one respect: they are too short acoustically and cancellation by the port appears to add an extra 4-6dB rolloff at fairly high frequency.

Robert H. Hesse
Cambridge, MA 02142

Contributing Editor Robert Bullock replies:

My work on transmission lines consisted in taking Mr. Bradbury's acoustic model and adding the driver to the system. I then programmed this model and ran comparisons with its predictions and data supplied by Peter Hillman. The results were not satisfactory, but I still submitted the work to the AES. The referee recommended against publishing the paper because the acoustic part of the model was based solely on Mr. Bradbury's work.

Other work has been done that I was unaware of at the time. Much of it is compiled in a 1975 University of Sydney honors thesis titled "A Study of Transmission Line Loudspeaker Systems" by G.S. Letts. I have a copy of this thesis and intend to study it with the idea of improving Mr. Bradbury's acoustic model, but I have yet to return to the project. I would send you a copy of the thesis, but it is nearly 200 pages and I don't care to spend the time reproducing it. If you are interested, you could get it on interlibrary loan as I did, or I could



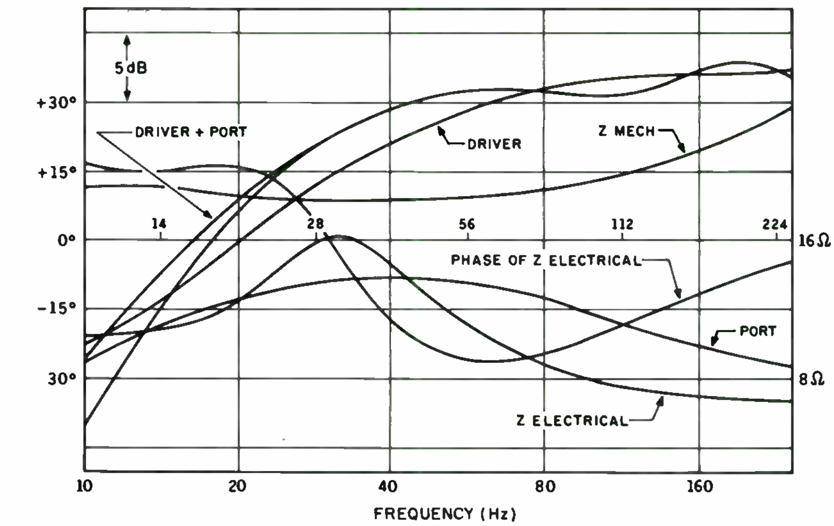


FIGURE 1: Simulation. 0.4mH for L coil. Object: Dynaudio 30W54 in 8′ line of area 1.75 × 5. Stuffing: 0.5 lb./ft.³ Density: 0.954. Diameter: 22.5m. I used 0.2 for damp and 4.0 for area of line/S_D.

send the chapters on modeling if that would suffice.

All the TL data I have I got from Peter. I prefer you request it from him. I believe he would be willing to share it. Also, he has refined his measurement techniques since we worked on the project, and his new data would be preferable.

By the way, he measured both folded and unfolded lines and the fold seems to make little difference. Also, the model I designed allowed a flare in the line, that is, a "reversal horn," which didn't help the data fit much, as well as selection of sound in the line, which did help somewhat.

It is fairly easy to build a complete transmission line model using the transmission matrix approach. Lampton has a complete T-matrix description of a driver in his paper "Transmission Matrices in Electroacoustics." All that you need do is multiply this driver matrix on the right by the acoustic model matrix. I would be glad to send you the information if you are interested.

I believe the only way to improve the model is to incorporate additional mechanisms as you have been doing. However, I am not enough of a physicist to comment on the merits of your particular enhancements except to say they sound plausible. I do prefer mechanisms that are reflected by model parameters whose value is set by a system measurement, rather than a parameter used solely to move the model into agreement with data.

Let me know if you are interested in the transmission matrix approach to modeling.

[Author Hillman has declined to reply to the Hesse letter.—Ed.]

K-HORNS REVISITED

I read Bruce Edgar's "The Klipschorn Throat Riddle" (*SB* 4/90, p. 28) with great interest. I built a pair of K-Horns (Speaker Lab) many years ago, used them for about a year, finally changed to a pair of EV 30″ (EV W30) system because somehow the K-horn resonate at about 120Hz.

After reading your article, I plan to build them again; this time I will build the woofer part only as a subwoofer to my B&W CM2 speakers (the most musical speaker I ever heard), using a Marchand Electronics (1334 Robin Hood Lane, Webster, NY 14580, (716) 265-4930) electronic crossover at 60-75Hz with 24dB/octave. I also plan to use ¾″ thick plywood instead of the original design's ½″. The Eminence 15″ (part #290-185) from Parts Express seems to be an excellent candidate for the driver (f_s = 40Hz; Q_{ES} = 0.41; Q_{MS} = 3.7; Q_{TS} = 0.37; V_{AS} = 10 ft.³; SPL = 96dB, 1W, 1M; mag = 56 oz.; power = 100W RMS continuous). Besides, the price is very attractive.

My calculation (by using your formula) shows that the slot is not required. The S_{TO} and S'_{TO} are about 133 in.²; the F'_{HM} is 155Hz. I wish to cross over at 65-75Hz for the subwoofer.

These values show this is an excellent driver for those interested in building the horn as a subwoofer. For F'_{HM} in the 300Hz region, this driver can have a slot opening much larger than 39 in², thus enhancing its efficiency. Please comment.

In your previous articles, you mentioned problems of mating the bass horn with conventional speakers. Is this still true? Why? If it is a phasing problem, could it be solved by placement? Please shed some light on these matters.

James Y. Pann
Richmond, CA 94806

Contributing Editor Bruce Edgar replies:

Your letter was written about my original K-Horn throat article in *SB* 4/90, which was corrected in the 6/90 issue. The Eminence 15″ will have a mass rolloff of 195Hz according to the information you supplied. If you rebuild your Speaker Lab K-Horn, use the 6" by 13" throat instead of the constricted 3" by 13" throat. The Eminence 15" speaker's optimum throat size is 131 in.², but the smaller 6" by 13" throat will extend the upper response only slightly.

You can use the horn as a subwoofer with a direct radiator if you use an electronic crossover. The Marchand XM6 has an adjustable crossover frequency. I suggest you experiment with the frequency to achieve the most seamless transition between the subhorn and the B&Ws. It may not be 60-70Hz and could be higher depending on room interactions and relative speaker placement. You also may need to use an equalizer to tame any irregularities in the K-Horn. If after the experimentation, you find an arrangement that works best, live with it until your ear gets used to the setup. If you discover you don't listen to your system much after the change, return to your original B&W setup and recalibrate your ears. Good luck in your project.

AN AUDIO ADVENTURE

Desiring a speaker that could do it all, I quickly became infatuated with Joe D'Appolito's Swan system. The advantages of Kevlar cones appealed to me as well, so the Focal 5K013L was a natural choice. Picking the "perfect" tweeter was not so simple. A local audiophile once told me of the sonic virtues of matching tweeters, but this seemed elusive until I spotted an ad for the MDT 33 in *SB*. Since the woofer crossovers would be 18dB active with bass boost, I chose to build the satellite third-order crossovers active as well.

I first built the satellites as sturdy, sealed enclosures, but I could not get the upperbass to sound right. Singers didn't have a body to go along with their voice, even with a diffraction equalization circuit centered at 150Hz. Then the Aria 5 appeared in *SB*. This could be the answer, I thought. My Aria 5 cabinet plans soon arrived and I was building again. Hats off to Joe on the compromises he balanced in this design. Using the rectangular vent as a brace and for high-frequency separation of the mids was very efficient.

Did it work? Yes and no. The sound now had more upperbass bloom and even a smoother upper midrange, but the dip at about 150Hz still remained. Time to add the woofer module.

I chose woofers on the basis of low f_s, moderate Q_{TS}, and long X_{MAX}. The Audio Concepts JC-12 seemed a good choice. Being a novice at vented designs, I stuck with a sealed box. The JC-12s need about 2½ to 3½ ft.³; with two on each side, a 6 ft.³ cabinet was a good bet.

These weren't going to be just any cabinets—they would be *solid*. I used 1¼" particle board glued and screwed, extensive bracing throughout, and Acoustical

Magic inside and out. I screwed the drivers in place with lag screws.

With my masterpieces built, it was time to move them into the listening room. I never considered the cabinets would weigh more than I do. Oh well, at least they'll sound great, right? After painstakingly moving them around the listening room trying to integrate them with the satellites, I wasn't satisfied.

What could be wrong? I used symmetrical third-order high-pass and low-pass slopes at 100Hz. I time-aligned® the bass to the mids by moving the cabinets 33" behind the satellites. (I did a lot of listening and found that moving the bass cabinets even a ¼" could be heard.) The system design was good, but what about the listening room and speaker interactions?

Having renewed my subscription to *Stereophile*, I received their Test CD as a bonus. It includes warble tone test signals to check speaker bass performance. A quick trip to Radio Shack for a sound level meter and I was ready to begin. Placing this meter at the listening position displayed shocking results. The output was level at 1kHz and 200Hz, which was good. But from there on down to 20Hz was a horrible roller coaster ride. For example, 5dB down at 160Hz, 3dB down at 125Hz, 4dB up at 50Hz, 7dB up at 40Hz, 2dB down at 25Hz—well, you get the picture. I began moving the woofers around again, but after a month or so found I was only robbing Peter to pay Paul. I could explain the dips or peaks by analyzing room dimensions and speaker placement, but I couldn't cure them. *[Gary Galo reports that the* Stereophile *warble is incorrect. It is 200Hz and should be 5Hz.—Ed.]*

Back to *SB* for help. I recalled an ad for the Audio Control Richter Scale Series III, so maybe help was available. A ½-octave equalizer with a fourth-order crossover could fit into my system. A 24dB Linkwitz-Riley crossover is in phase at the crossover point, however, which means the woofer and satellite placement must be really close to be time-aligned®.

My bass cabinets were far too tall to place the satellites on top and placing large bass cabinets beside them would definitely destroy the excellent sound stage I was used to hearing. I could build small bass cabinets the exact height of the satellite stands (24"), but this would result in a woofer system Q of 1.3. Could the Richter control this problem, as well as the room boundary problems?

After I placed the Series III into the system, I experimented with crossover points and equalization. I ended up with the woofer-to-satellite crossover point of 200Hz, which solved the dip in response due to satellite height and equalized the woofers flat to 25Hz. This was a dramatic change for my system. Vocals now had body and the image of an acoustic bass remained absolutely stable. After listening, I found the bass-mid integration best with the satellite front panel 1" behind the bass module front panel.

Is the Richter Scale perfect? No way. First, it is impossible to get your system perfectly flat at the listening position. Adjusting the ½-octave equalization bands is frustrating because changing levels on one band affects the output on adjacent bands above and below. So compromising is inevitable. Although this is good, it is not a high-end audio product. Construction is mid-fi and parts quality is only fair. This unit cries out for 1% metal film resistors and polypropylene capacitors throughout. Also, a low-impedance dual-mono power supply would increase depth and widen the soundstage.

Perhaps the folks at Audio Control would consider marketing an audiophile version of this useful product.

It takes many other considerations and fine details to make a system sound like music. *SB* readers all know the value of resonance control in speakers, but don't forget the rest of your system. Damping

CAVEAT CORRESPONDENTS

Things that go bump in our round file:

1. "I'm thinking of building a 16-in, 8-out console in my basement. What tape recorder should I buy?"
2. "Is my Fisher Z-705 receiver worth updating? Where should I begin?"
3. "Although I forgot to enclose a stamped, self-addressed envelope, please answer the following nine questions based on my experiences building your inverted RIAA kit."
4. "Please forward this (unstamped) letter to Ralph J. whose letter appeared in one of the 1970 issues—don't remember which."
5. "I have a Milhous 10W integrated stereo amplifier and a Gesundheit turntable. Which of the following six cartridges would you recommend?"
6. Queries with no stamped, self-addressed envelope or postal coupons enclosed.
7. Letters without return addresses on them whose envelopes have strayed away somewhere.
8. Illegible hand-written letters scrawled on odd scraps of paper. If you have no access to a typewriter, please try to be sure our typesetter doesn't lose his eyesight and his mind in deciphering your writing. (This is especially important if you want us to publish your classified ad.)

the cabinet panels on all your electronics is helpful. Also, you should treat your CD player like a turntable. Finding a low-frequency null spot in your sound room and using various vibration control devices make for better CD sound. Here's a tip for anyone who still owns a Monster Cable Discus. I painted the top of mine with Acoustical Magic and the sound of the CDs is much improved.

Christopher J. Hoff
St. Louis, MO 63146

SERVO REPLY

Since the Editor inquired about servo-controlled systems I have auditioned (*SB* 3/91, p. 74), I will try to remember a few.

- Infinity Servostatic 1: 18″ dual VC drivers, with dedicated servo amps.
- Infinity Servostatic 1a: 18″ dual VC drivers, with dedicated servo amps.
- Velodyne, ULD 12, 15, 18.
- Philips Little David: a small two-way with built-in servo amps.
- Visonik: similar to the Little David.
- Entec: I think the smaller one.

I'm sure I have used others as well, but they escape me at the moment. Does the Infinity IRS use servo control?

No, I haven't tried to build any myself, since I believe better solutions to the general problem of high-quality, low-frequency reproduction exist.

For deep, fast bass, I prefer a critically aligned passive-radiator system. Such a beast is uncommon because it is easy to get passive-radiator designs wrong. Consequently, you may never have experienced the real thing. I don't know of any commercial systems that have gotten it right, but some may have.

My second choice is a good transmission line. Properly set up transmission lines sound surprisingly good. They're a bit tricky too. I liked the look of Scott Wolf's "Pipe" (*SB* 3/91, p. 28). Since I have a set of MW-162s sitting here, I might play around with the idea. It looks like fun.

My first look at Mr. Mortensen's comments came with the 3/91 issue. I hope I didn't offend him or Mr. Brown, both of whom wrote excellent articles on the subject. My main concern is that the average *SB* reader might think servo control is a panacea of sorts. Both authors are obviously well aware of these issues and limitations, as the subsequent discussions have brought out.

I think it is wonderful *SB* encourages such interplay between readers and authors. The result is always better understanding and knowledge for everyone.

Randall Bradley
Hannacroix, NY 12087

Wall-Horn Speaker

continued from page 20

an f_3 of about 30Hz. My back-loaded enclosures have an effective internal volume of approximately 9 ft.³, higher f_3, and more theoretical ripple in the low-frequency response. With this in view, I'm not sure I could recommend construction of this enclosure to anyone not already committed to building a bass horn. To be honest, I don't think the efficiency advantage and impact of bass horns necessarily justify the increased complexity of construction over a vented alignment.

For someone determined to build a horn-loaded speaker system, however, this back-loaded design has the potential to be a strong performer and is more compact and certainly easier to construct than any fully loaded 40Hz bass horn I have seen.

REFERENCES

1. Olson & Hackley, *Procedures of the Institute of Radio Engineers*, Vol. 24, No. 12, 1936, p. 1557.

2. Since the initial draft of this article, I have diagnosed this beaming effect to be a problem resulting from the rather large spacing between the midrange and the woofer, combined with the shallow (6dB/octave) slope of the crossover. I am currently preparing a followup article describing alternative crossover designs for the back-loaded wall horn.

ACKNOWLEDGMENT

I compliment Bruce Edgar for his design and common sense approach to home-built horn loudspeakers. His work has been an inspiration for me in completing this loudspeaker project. I particularly appreciate his Show Horn article, even though it was published after I had completed my speakers. I thank him for his help measuring my speakers and his constructive criticism of this article. Perhaps he could provide a few hints or suggestions for future back-loaded horn designs.

Intégrité

continued from page 29

4. Select your drivers.
5. Optimize Thiele/Small, crossover design, and engineering calculations.
6. Design and build enclosures, taking into consideration geometrical and physical characteristics that promote good sound.
7. Test with available instruments and build prototypes until you are satisfied.
8. Enjoy the results.

Optimizing TLs

continued from page 31

surface area will break up and disperse a speaker's rear wave better than a fiber with less surface area.

Although you would need a microscope to see the shape of a fiber cross-sectionally, sound is easily affected by that shape. What you can see is the length of a strand of fiber. Polyester is a round, straight fiber—useful, but not great. Wool has cross-sectional ridges and a natural wave along its length. This gives wool more overall surface area than polyester, explaining why it sounds better. Acousta-Stuf is tri-lobal in shape and multi-directionally crimped. It has several times the surface area of wool.

CONCLUSIONS. Almost anyone can design a great sounding transmission line speaker system using the information presented in *SB*, *TAA*, *The Loudspeaker Design Cookbook*, and many other books available through Old Colony Sound Lab. Good luck with your TL design.

Minimus 7 Mod

continued from page 39

over, only the tweeter terminal comes from the negative input terminal.)

The resulting modification is completely internal, thus retaining the stock appearance, has a better frequency response than the stock unit, and has a flat impedance curve (*Fig. 4*). Listening tests confirm the improved tonal balance of the modified speaker over the original. This mod's disadvantage is that the tweeter now has less protection than in the stock unit due to the more gradual crossover slope. This has not been a problem so far in my samples. The other problem, as in any mod, is that the original warranty is no longer in effect.

Moran

continued from page 54

and its distortion as a function of input. How we hear these things, and how much less significant the last two are compared with the first, is also well-known.

So bring on the samples!

Oh, did I forget to say—loudly—what a "dream" audience of colleagues this is to write for? I am, to put it mildly, very much looking forward.

Good News

continued from page 8

"Building a Future in Sound" is the theme of the upcoming Audio Overview—II, a one-day educational seminar at the Ryerson Theatre in Toronto on September 21. Its purpose is to attract newcomers to the profession and to provide attendees with an update on recent developments, new concepts, and future trends in the audio industry. Topics to be presented include advanced loudspeakers, analog systems, digital audio technology, digital workstations, psychoacoustics, recording and monitoring techniques, room acoustics, and more.

Attendance fees for newcomers include the first year's membership in the **AUDIO ENGINEERING SOCIETY**. A year's subscription to the *JAES* and monthly mailings are also included.

For more information, contact Ron Lynch at (416) 266-2377 or Neil A. Muncy at (416) 298-3835.

ELECTRO-VOICE has introduced the DH2A, a high-performance compression driver capable of high acoustic power output over a wide frequency range. It provides 6dB more output above 10kHz than its predecessor, the DH2. This model incorporates a new diaphragm and surround and a new convex-drive phase plug.

The screw-type input terminals provide a positive electrical connection. Each will easily accept a pair of 12-gauge or smaller wires. The DH2A's front housing provides a direct 2" horn attachment.

For more information, contact Keith Clark, Electro-Voice, 600 Cecil St., Buchanan, MI 49107, (616) 695-6831, FAX (616) 695-1304.

Fast Reply #HF453

SPARKOMATIC has introduced the Bass Cannon (STW-800), an amplified tube subwoofer. The unit provides 100W of maximum bass power and can be added to the sound system of automobiles and trucks by mounting it behind a seat or in the trunk or hatchback.

Dual voice coil 8" long-throw woofers provide distortion-free bass and the built-in amplifier will enhance low frequencies at all power levels. The nondirectional bass music sounds are delivered through both ends of the rear ported tube. The STW-800 has a sensitivity of 92dB and a frequency response from 30–250Hz.

The Bass Cannon sells for around $100. For more information, contact Andrew Bergstein, Sparkomatic Corp., Milford, PA 18337-0277, (800) 233-8831 or (800) 592-8891 in PA.

Fast Reply #HF781

Fast Reply #HF318

Fast Reply #HF45

CAMBRIDGE SOUNDWORKS has introduced Ensemble II, a high-performance three-piece speaker system. It consists of two compact satellite speakers and a subwoofer and uses an acoustic bandpass filter design. The satellites have a long-throw 4" midrange driver and a 1¾" direct radiator tweeter with a 5/8" integral dome. The speakers are constructed of rigid ½" fine-grain MDF composite board with a gunmetal gray Nextel finish and a metal grille. Each satellite measures 8" by 5" by 4" and weighs 5 lbs. The system will work with any home stereo with 25W/channel or more.

Ensemble II will be sold only factory-direct for $399 through the company's sales and service facility at (800) 252-4434. A color catalog of all Cambridge Soundworks products is available free on request.

NEUTRIK's A1 Audio Test and Service System contains a sweepable generator, analyzer, and oscilloscope. It measures wow and flutter, noise, crosstalk, frequency, and THD + N. A large backlit LCD shows single measurements numerically or as sweeps in graphical form. Hard copies of screens are available when connected to most standard dot-matrix printers. This instrument is autoranging, autotuning, autonulling, autoscaling, autocalibrating, replacing up to eight conventional instruments.

For more information, call (908) 901-9488.

In an effort to strengthen its distribution network, **POLYDAX** has announced a distributor agreement with McBride Loudspeaker Source Inc. of Waterloo, Ontario. McBride has more than 20 years of experience in the audio industry and has recently started their own mail-order program.

For more information, contact McBride Loudspeaker Source Inc., 638 Colby Dr., Waterloo, ONT, Canada N2V 1A2, (519) 884-3500.

ALTEC LANSING has announced the AHT-2100, the first in a series of home theater loudspeakers being developed under its license agreement with the Lucasfilm THX division. It can be mounted on or in the wall and it uses a crossover and configuration of eight speaker drivers to accomplish surround-sound envelopment. The bass drivers are front-firing and two arrays of matching mid- and high-frequency drivers are positioned at a 125° angle.

The two-unit system will be available this fall for $800/pair. The final six-unit system, when available, will cost around $3,000. For more information, contact Andrew Bergstein, Altec Lansing Consumer Products, (800) 258-3288.

CARVER CORPORATION has introduced two audio/video Sonic Holography® receivers, the HR-742 and HR-732, designed as control centers for home entertainment systems. With the remote control, you can access three video and six audio sources.

Both receivers employ Carver's asymmetrical charge-coupled FM detection technology, which can transform multipath-distorted FM radio signals into clean, clear FM stereo. The HR-742 has an 80W/channel power amplifier, while the HR-732 has a 60W/channel amp. Each receiver has a large alphanumeric digital display that indicates the audio and video signal routing and a 30-preset AM/FM tuner. All current programming and control settings are stored in nonvolatile memory.

The HR-742 has a 75Ω coax input switch that lets you select between the TV antenna input and the output of a cable TV box. Other HR-742 features include separate preamp outputs and main amp inputs and a "sleep" switch that lets you program the receiver to shut off automatically within 10 minutes to 2 hours.

Both receivers will be available in August. The HR-742 sells for $629.95 and the HR-732 for $499.95. For more information, contact Gordon Sell at (201) 509-0097 or Lori Kaufman at (206) 775-1202.

PSB SPEAKERS introduced a compact (16¼" by 9" by 12½") two-way system at the summer Consumer Electronics Show in Chicago. The Stratus Mini is for free-standing use or can be augmented by a subwoofer. An optional matching stand is also available.

The system is composed of a ¾" aluminum-dome tweeter and a long-throw 6½" midbass driver, integrated by a 24dB/octave L-R crossover network. Performance parameters are a frequency response of 55Hz-20kHz ±1.5dB (−3dB and −10dB at 45 and 34Hz, respectively), with a crossover point of 2.2kHz, and a listening room sensitivity of 86dB at 1M with 2.83V input. As throughout the Stratus line, the Stratus Mini's tweeter is below the midbass unit.

Made of furniture-grade cabinetry, the unit has finishes in light or dark oak or black oak, and all internal surfaces are lined with felted damping material. The cabinet includes an internal shelf brace and has dual five-way, gold-plated binding posts. The baffle and grille frame are beveled.

The Stratus Mini sells for $800/pair, stands for $200/pair. For more information, contact Bryan Stanton, PSB International Inc., 633 Granite Court, Pickering, ONT, Canada L1W 3K1, (212) 752-1600.

Fast Reply #HF1350

THE MONSTER DESIGN GROUP, a division of Monster Cable® Products Inc., has introduced the Persona One™ personal sound system, designed to give a small speaker system the electronic capability to re-create a large speaker experience. Its Ambience Recovery System (ARS™) recovers the ambience and nuances present during the recording process but lost in traditional stereo playback technology. No phase shift, time delay, or signal processing is added.

The system is designed for use with portable cassette players, CD and DAT portables, portable video players, televisions, and computer workstations. It is amplified by 20W: 10W/channel at 0.5% THD, 4Ω with power bandwidth of 30Hz–30kHz ±1dB at 0.5% THD. The three-way speaker system frequency response is 70Hz–18kHz ±3dB and the speakers are powered by a standard 18V DC, 1A desktop power supply with AC adapter.

This lightweight and compact (8″ by 3½″ by 5″) unit also includes a Dual Lock™ mounting system for attachment to various surfaces including television monitors. An optional compact desktop stand, carrying case ($25), and servo-controlled micro subwoofer system, the MS Sub™ ($159.95) are also available.

The Persona One sells for $229.95. For more information, contact Gary Reber at (714) 677-4668.

A two-way mini loudspeaker system that offers full-range performance, the SL250, has been introduced by **SIGNET**. The compact front profile (10½″ by 7″) makes the speaker easy to position in any environment. A QB_3 filter alignment optimizes bass-to-volume ratio and improves the speaker's low-frequency transient response and power-handling ability.

The 5½″ woofer's paper cone is lightweight and is treated to damp resonances and reduce distortion. A rolled rubber surround on the woofer provides high dynamic range, longer performance life, and reduced distortion. The system's ¾″ metallized polycarbonate dome tweeter, cooled with ferrofluid, allows maximum power handling. Specs: frequency response, 55Hz–25kHz; recommended amplifier power, 15W–1kW; impedance, 8Ω.

The Signet SL250 is finished in black woodgrain vinyl and sells for $150 each. For more information, contact Gary Post, Signet, 4701 Hudson Dr., Stow, OH 44224, (216) 688-9400.

Fast Reply #HF23

ALPINE ELECTRONICS OF AMERICA has introduced their 5951 compact disc remote changer CD Shuttle with keypad controller and FM modulator package. Designed to simplify its addition to OEM or aftermarket systems by using an FM modulator, the 5951 installation is further streamlined by its two-piece controller/modulator. Instead of having separate RCA-type connectors for audio, the device will transmit audio through its DIN cable, simplifying installation and reducing noise problems.

The 5951 uses 8x oversampling, 18-bit hybrid digital-to-analog converters, and digital de-emphasis/noise shaping. It also employs Alpine's improved DR-mechanism for better trackability and 20% faster disc changing times. The unit can be mounted ±30° from the horizontal or vertical position and the keypad controller is easy to install.

The 5951 sells for $620. For more information, contact Richard Frank at Frank Marketing Associates, 8 Mohave Rd., Medfield, MA 02052, (508) 359-5977, FAX (508) 359-5343.

Fast Reply #HF146

Fast Reply #HF617 →

Now in North America

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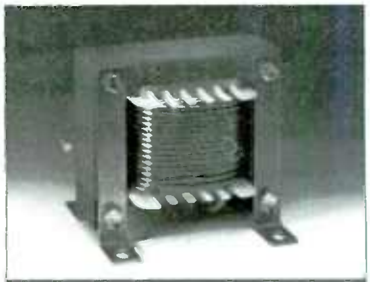
This style former can be used for Air Core Coils as well as with a Ferrite bar.

Bell Core Coils reduce strayfield and saturation.

Corobar Coils for High End Crossovers with High Power Capability and Low Distortion.

Ferrobar Coils for super low distortion.



Transformer Core Coils have super low resistance and with our unique core configuration, less distortion.

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Classified Advertising

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CUSTOM PASSIVE CROSSOVERS built to your specifications. No minimum quantity. Only the finest components used. Quick response, satisfaction guaranteed. ***AMS ENTERPRISES***, 1007 Capello Way, Ojai, CA 93023. T2/92

MIT AUDIO CABLES, Van den Hul, Cardas, MAS Masterlink, OCOS, Magnan, including Teflon insulated hookup wire for rewiring components; MIT capacitors; Solen polypropylenes to 200μF!, WonderCaps-solder-wire; HOLCO, Vishay & Resista resistors; Music posts & all types of audio connectors; RAM tubes; Tone Cones; NAVCOM products; Shallcross attenuators, many parts & accessories. $1 catalog ($3 overseas). ***MICHAEL PERCY***, Box 526, Inverness, CA 94937, (415) 669-7181. T6/91

ROTTEN FOAM? Re-surround any speaker! (412) 375-9203. T6/91

WHALE COVE AUDIO for SWAN IV drivers and crossovers, Pedal Coupler I or II active crossovers, and the Right Whale Kevlar mid-range, ceramic tweeter and crossover set for either the SWAN IV or the ARIA 5. Box 98, Swan's Island, ME 04685, (207) 526-4343. T2/92

FOR SALE

Rare and unusual KEF model K-2 Celeste MK-II two-way speakers, made 1966 in England, real wood construction, oval type, first class condition, still sound great, never abused, these are quality units and collector value well worth the $200 price and I pay shipping, Ed, (305) 891-2267.

Audio Control C-101 equalizer $200; Magnavox CD552 carousel CD changer, $160; Carver 400T amp, $200; Phase Linear 4000 II, $200; Souther SLA-3 linear arm, $125; SAE 2800 parametric equalizer $325. Andy Sommerberger, 2506 South 20th, Sheboygan, WI 53081, (414) 458-2057.

Hafler D200A power amp, $225; Magnavox CDB473 CD player, $115; DBX 3BX range expander, $200; KEF 103.2 speakers, $425 pair; ADS CM-5 speakers, $350 pair; all with boxes. Dale Shore, 9426 SW 140th Ct., Miami, FL 33186, home (305) 382-9291, work (305) 238-5598.

Heath AD-1702 electronic crossover, two-way, 6/18dB/oct six stepped 40-150Hz crossover points, independent hi/lo sections, precision caps, switchable subsonic filter, heavy rack-mount chassis, mint condition, $225. Fred Janosky (215) 693-6167.

Boulder 50D power amplifier, 150W, 8Ω; 250W, 4Ω, highly recommended by Dick Olsher of *Stereophile*, $1,500 firm. Art,(415) 528-3552.

Focal 401 single voice coil per driver, D'Appolito monitors, 4/$100; Panasonic Leac tweeters 10TH200D 2/$35. Les Winter, 201 East 17th St., New York, NY 10003, (212) 673-8248.

Pioneer SX-9000 stereo receiver, vintage 1970, like new, $100; TEAC X-1000R reel-to-reel tape deck, $600. Jeffrey C. Hudlow, 7038 Hemlock Course, Ocala, FL 32672, (904) 687-8513.

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Phoenix, Az. 85016
(602) 956-6344

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Thorens TD-124 turntable, $150; Grace 707 tonearm $50; Tandberg TCD-330 cassette deck for 220V, $40; B&K 5MHz oscilloscope, $40. Pedro Rodriquez, 11 Jeffrey Amherst, Amherst, MA 01002.

Hi-Fi News & Record Review 1965 to 1987 complete, $100, you pay shipping, will donate to institution. Charles T. Pike, 186 Grove St., Lexington, MA 02173 (617) 862-4712.

Carver CT-7 preamp/tuner with Sonic holography and remote and SAE dual high resolution power amp Model A202 100W Rms/8;Q or 150W/Channel/4;Q, $650 plus shipping for both, mint condition. Mr. Willes, (800) 227-6121 M-F, 9-5, central time.

Crown D-150A Series II amplifier, retail $795, asking $330; Soundcraftsmen TG- 3-44R ⅓-octave professional equalizer, retail $700, asking $400. Both mint. Darren, (313) 851-1296.

Bozak speakers, (2) B199A 12" woofer 16; (2) B209B 6" mid range 8; (4) B200V 2" tweeter, pair 2 N104 crossover 400Hz and 2500Hz $20, each item. Frank Hnat, 7312 Johnnycake Rd., Baltimore, MD 21228, (301) 455-0148.

Two Gauss 4883B 18" extended bass woofers, never used, perfect $200 each. One new Dynaudio 30W54 in sealed box, $90. Andy, (516) 269-9776.

Horn drivers, pairs: Altec 288, 291, 802, 808; JBL 2425; EV 1823; University T-40; Altec Mantaray horns, pair Bor 288s; pair Bor 802s; Horn Turntops EV St-350; JBL 2402H; Altec 803, 904-K, 421, 511; Transylvania tube horns; crossovers, JBL 3115; Altec 809, 1209, N 3000A; evenings, David, (914) 688-5024, ext. 36.

Fisher FM200 tube-type FM tuner, mono with multiplex out jack, mint performance, cosmetics OK but not great, $65; many vintage tubes, new/old stock, $5; used $2. Al Wirtenberg, 15 Wilson Rd., Weston, CT 06883, (203) 544- 9270.

Brubeck Direct, slight damage, $50; MFSL Poco $30; Little Feat double, $60; Magical Mystery Tour, $30; Sticky Fingers slight damage, $22; imports Sgt. Pepper, Yellow Submarine, Rubber Soul, Genesis, Sticky Fingers, $20 each. Stones 3D good, $30; Pink Floyd, Animals Pink Vinyl, jacket and sleeve $30. R. Kinneson, (815) 657-8488.

Lafayette SK-180 10" Trihelix speakers (triaxials) superb sound, pristine condition, $60 pair; one Altec 409T coaxial 8" speaker, mint, $25; 25 x 17 ½ x 11 ½ professionally built walnut speaker enclosures, undrilled baffles, $60 pair; Scott 340 FM receiver, near mint, original tubes, papers, $175. Horace, (703) 578-4929.

YOUR 50 WORDS
In our private classifieds ARE FREE
OVER 50: Send money (20 cents/word)

Swan IV bass enclosures, beautiful oak finish with all rounded corners, $600/pair; Pedal Coupler, active crossover, rack mount, built to spec with volume control, CD input, preamp loop and premium quality components, $200 or both for $750. Geoffrey Dillon, (213) 965-9173.

SOTA sapphire turntable with Linn Ittok LV-II arm and Karma cartridge, $550; Oracle Alexandria turntable with Prelude arm, $400; Thorens TD-125 turntable with Shure SME arm, $300; McIntosh XR5 speakers, $600; Carver C-2 preamp, $300; Carver M-500t amp, $350; Dayton-Wright SPA preamp, $300; Terk Pi antenna, $40; Koetsu Black cartridge, $150. Ted Kircher, 2431 Deerfield Dr., Ashtabula, OH 44004, (216) 964-9632.

Nakamichi N580 cassette, $250; JBL studio monitors, $500/pair; JBL D130F, damaged, $250/pair; woofers, large Advent, $70/pair; Audio Concepts AC10, $110/pair; Dynaudio 22W75, Pioneer PT6 horns, Philips AD5061, B/O; 100' 12 gauge version of original monster, $60; 10 gauge $80, will cvt, assorted test equipment. Tom (215) 551-7060, machine after fourth ring.

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☐ Private For Sale ☐ Private Wanted ☐ If Trade, please indicate # of insertions ______

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

Definition of a word: A series of letters with a space before and after. Count words, not letters. Any words over 50, 20¢ per word. Trade ads are 70¢ per word and indicate number of insertions. Deduct 10% for a 4× contract in *Audio Amateur* and a 6× contract in *Speaker Builder*, deduct 5% for a 2× contract in *Glass Audio*.

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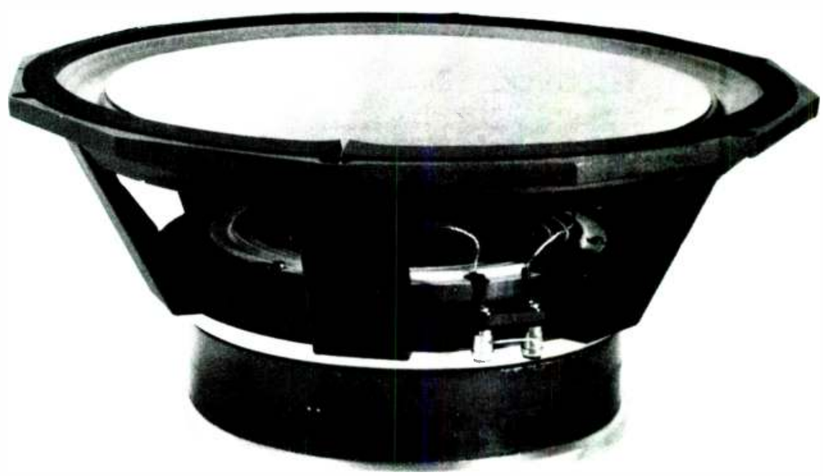
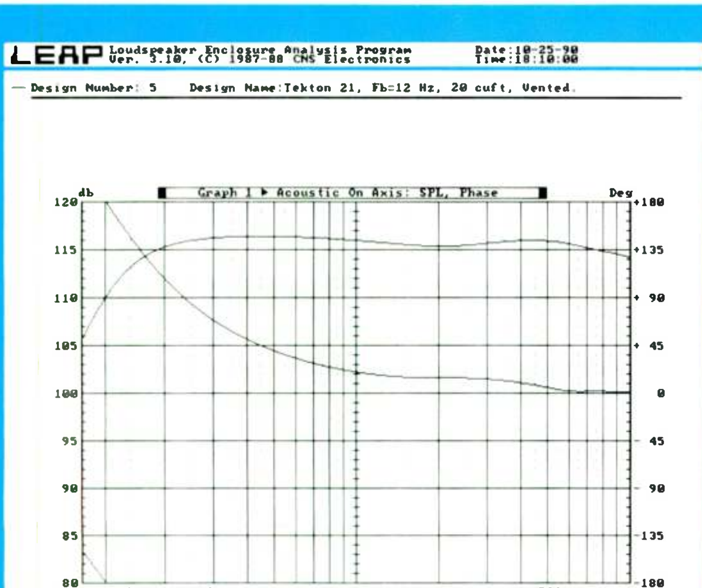
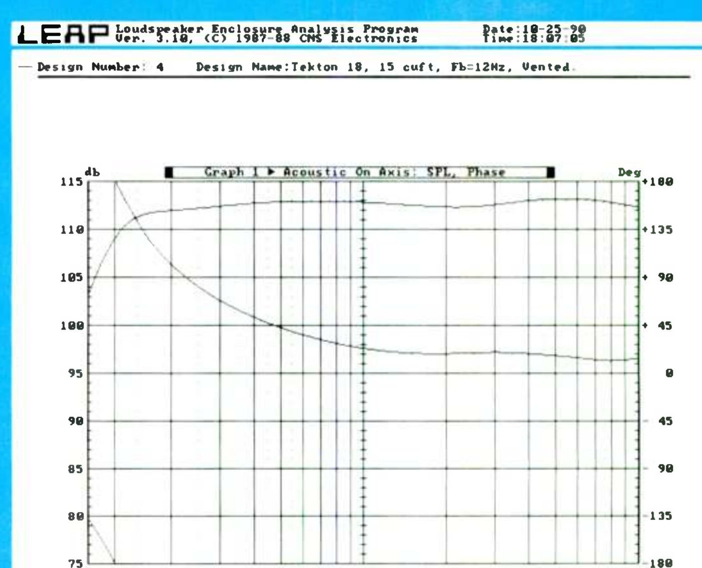


TEKTON 18
5 in. diam VC





Hafler DH-500 factory assembled amplifier, 1 ½ years old, $425. Randy, (717) 898-3085.

Hafler DH-110 preamp, excellent condition. Carl Sonksen, 5002 Capital Ave., #4, Omaha, NE 68132 (402) 554-0370.

Thorens TD-147 turntable Shure 9the. All accessories, used 250 hours to tape records, mint condition, $250 original owner, E. Marshall, 34-13 80th St., Jackson Hts., NY 11372, (718) 478-9011.

DeCoursey three-way crossover 18dB/oct. 125, 2.5KHz, extra modules 250, 1000Hz $200; Nikko amp 200W, $200; Jensen Flexair 15" woofer, $40; rigid cylinders for 5 ¼" speakers $50; surprise box of odd drivers, no pairs, $50; Jordan 5" aluminum Gne speakers $150; subwoofer, $75. Jerry, (212) 364-3485.

Pair Dyna MK IVs mint, $275, AR-1 woofers, PAS $65; Curcio circuit boards and power supply, boards stuffed by professional engineer, $250; dbx 228 with box and manual, $90; Pioneer TV9500, TV tuner, $45. Joe Jenning, 4903 A South Orchard, Tacoma, WA 98467 (206) 473-3572. PST message after fourth ring.

12 gauge silver coated, Teflon insulated, stranded copper wire, twisted pair (red and black), $1.35/ft. Geoffrey Dillon, 575 Levering Ave., Los Angeles, CA 90024, (213) 965-9173.

JBL bullit, slot and "baby-cheeks" tweeters, $100-$125 each; Altec 811 horns, $75 each; $420 for six; MTX-EV screw-on titanium HF drivers, 2.5-17kHz response, $70 each, 4 for $250; miscellaneous custom-made LF horns and LMF horns. Tom, (914) 271-5228 EST until 11.

Soundcraftsmen DC 2215 unity gain graphic equalizer, excellent conditon, original box and papers, $125 (list $449). Bill Tidwell, 520 South Fourth St., #300, Las Vegas, NV 89101, (702) 385-7170.

WANTED

Surplus/used capacitors 1-15;mF, 100-300V and air-core coils (.1 to 15 MHz 16awg or larger) for prototyping. Loftech test sets, old issues of *Audio Engineering, Wireless World,* etc. Tom (914) 271-5228 till 11 pm EST.

Manuals, schematics for Webster Electric model TP45 and Pilot Radio model SA260. Bob Jensen, 8 Heather Lane, Reading, PA 19601.

Jordan 50mm modules in good working condition, looking for total of 4 modules. Carl Sonksen, 5002 Capitol Ave., #4, Omaha, NE 68132 (402) 554-0370.

Old Klipsch catalogs, JBL literature; books, display systems, Engineering, Luxenbery, Kuehn; old books showing point contact transistors; old Hewlett-Packard and Tektronix catalogs; Throne of Merlin, (R.C. Schaller). D.R. Schaller, 6704 Schroeder Rd., Suite 6, Madison, WI 53711.

Plans for building the Speaker Lab SK speakers, the plans are no longer available from Speaker Lab. John Fitzpatrick, 178 West Orange St., Brentwood, NY 11717.

Cover for Elco HF-35 or Elco HF-50, Arc or similar quality, stripped case for project CSP-3, SP-5, etc. Joe Jennings, 4903A So. Orchard, Tacoma, WA 98467 (206) 473-3572 message after fourth ring.

Technical data on Jensen H223F 12" coaxial driver; tube-type hi-fi equipment by Marantz, Scott, Hadley, Rel, Brook, McIntosh (reasonable); Al Wirtenberg, 15 Wilson Rd., Weston, CT 06883 (203) 544-9270.

CLUBS

THE ATLANTA AUDIO SOCIETY is dedicated to furnish pleasure and education for people with a common interest in fine music and audio equipment. Monthly meetings often feature guest speakers from the audio manufacturing and recording industry. Members receive a monthly newsletter. Call: Chuck Bruce, (404) 876-5659, or Denny Meeker, (404) 872-0428, or write: PO Box 361, Marietta, GA 30061.

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

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

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

CHICAGO AREA ENTHUSIASTS WANTED for audio construction club. Call Tom, (312) 558-3377 or (708) 516-0170 evenings for details.

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

THE COLORADO AUDIO SOCIETY is a group of audio enthusiasts dedicated to the pursuit of music and audiophile arts in the Rocky Mountain region. We offer a comprehensive annual journal, five bi-monthly newsletters, plus participation in meetings and lectures. For more information, send SASE to: CAS, 4506 Osceola St., Denver, CO 80212, or call Art Tedeschi, (303) 477-5223.

LONDON LIVE D.I.Y. HI-FI CIRCLE meets quarterly in London, England. Our overall agenda is a broad one, having anything to do with any aspect of audio design and construction. We welcome everyone, from novice to expert. For information contact Dick Bowman, 081 520 6334.

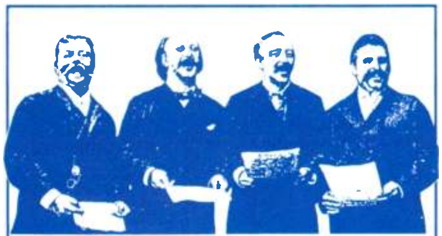
MEMPHIS AREA AUDIO SOCIETY being formed. Serious audiophiles contact J.J. McBride, 8182 Wind Valley Cove, Memphis, TN 38125, (901) 756-6831.

NEW JERSEY AUDIO SOCIETY meets monthly. Emphasis is on construction and modification of electronics and speakers. Dues includes monthly newsletter with high-end news, construction articles, analysis of commercial circuits, etc. Meetings are devoted to listening to records and CDs, comparing and A-B-ing equipment. New members welcome. Contact Bill Donnally, (201) 334-9412, RD2, Box 69D, Miller Dr., Boonton, NJ 07005; or contact Bob Young, (201) 381-6269.

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

SOUTHEASTERN MICHIGAN WOOFER AND TWEETER MARCHING SOCIETY (SMWTMS). Detroit area audio construction club. Meetings every two months featuring serious lectures, design analyses, digital audio, A B listening tests, equipment clinics, recording studio visits, and audio fun. The club journal is *LC, The* SMWTMS Network. Corresponding member's subscription available. Call (313) 477-6502 (days) or write David Carlstrom, SMWTMS, PO Box 721464, Berkley, MI 48072-0464.

Fast Reply #HF1151



WANTED

AUDIO CLUB MEMBERS

(Good singing voice not required)

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

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

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

AUDIO SOCIETY OF MINNESOTA. Audiophiles, music lovers, scratch builders, record collectors, tube freaks, digital freaks—we've got 'em all! Monthly meeting, tours, audiophile concerts, special guests, etc. Now in our 13th consecutive year! Write ASM, PO Box 32293, Fridley, MN 55432.

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

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

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

THE WESTERN NEW YORK Audio Society (WNY Audio Society) is an active and growing audio club located in the Buffalo area. We issue a quarterly newsletter and hold meetings the first Tuesday of every month. Our meetings have attracted many local and distant manufacturers of audio related equipment. We are involved in all facets of audio—from building to purchasing at discount prices. For a copy of our current newsletter and information regarding our society, please write to M.A. Monaco, WNY Audio Society, PO Box 312, N. Tonawanda, NY 14120.

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

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

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

Advertising Index

Fast Reply #HF81 →

Parts Express International Inc.

Parts Express now introduces...

n response to our customers' request, we at Parts Express, in cooperation vith a major speaker manufacturer, set out to design a loudspeaker that can vithstand the harsh environment of today's automobiles. The Thruster Car udio Woofer Series is the result of those efforts. By combining the best eatures from a variety of manufacturers into a single speaker, we have eveloped a woofer that is virtually indestructible when installed properly. You sked for a speaker with a surround that would not rot and turn to dust. So we ad our surrounds treated with a special fungicide. You asked for a cone with he low mass of paper but with the rigidity of polypropylene. So we coated our ones with a polymer resin. You wanted a speaker that could produce the igh SPL's that win auto sound competitions. So we designed our Thruster eries with large magnet assemblies to provide high flux densities. You anted a frame with the rigidity of diecast aluminum without the high cost. So e had our steel frames stamped from thicker steel with rolled edges and einforcing ribs to be superior to standard steel frames. You wanted the best f all worlds and we did our best to deliver. We are so confident that our hruster Car Audio Woofer Series will live up to your expectations that if you uy one of our woofers and are not completely satisfied, we will refund the urchase price within 15 days from date of purchase.

hruster Car Audio Woofers are available in 8", 10", 12", and 15" sizes for stallation flexibility.

Features:

- Heavy gauge stamped steel frames prevent the magnet from vibrating loose and causing the voice coil to become misaligned in the gap.
- Red foam surrounds are treated with a special fungicide to withstand the high humidity in todays automobiles.
- Oversized magnet assemblies provide high flux densities for increased efficiency and improved damping on the voice coil, increasing power handling capability at low frequencies.
- Large diameter voice coils for increased power handling and less heat build-up.
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- Polymer resin coated cones provide resistance to moisture and sun as well as increase rigidity without adding excess mass.
- Two color printed dust caps, red foam surrounds and "Wet Look" cones create a stunning appearance that will give you an extra edge on the competition in auto sound contests.
- Manufactured using the latest in robotic controls; high quality is assured.

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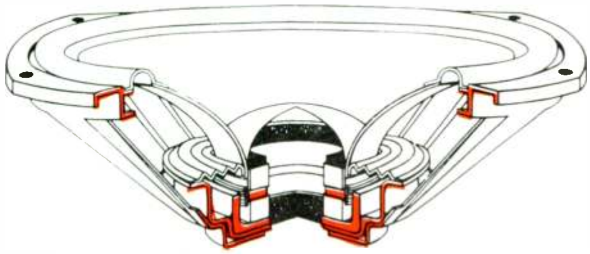
15 day money back guarantee · $15.00 minimum order · We accept Mastercard, Visa, Discover, and C.O.D. orders. · 24 hour shipping · Shipping charge = UPS chart rate + $1.00 ($3.00 minimum charge) · Hours 8:30 am - 7:00 pm EST, Monday - Friday 9:00 am - 2:00 pm Saturday. Mail order customers, please call for shipping estimate on orders exceeding 5 lbs. Foreign customers please send $5.00 U.S. funds for catalog

MW 1275

DPC Cone Double Magnet 12" Woofer



A high quality 12" woofer — unique vented double magnet system housed in a magnesium pressure cast chassis. An extremely shallow DPC (Damped Polymer Composite) cone with foam surround — low resonance frequency — smooth frequency response and with high power handling capability — 3" voice coil with aluminium wire — suitable for three-way systems.

Excellent bass response and low distortion resulting from the longer voice coil, allowing a more linear excursion.

Specification

Overall Dimensions	Ø 306mm(12") × 94mm(3.7")
Nominal Power Handling (Din)	250 W
Transient Power — 10ms	1000 W
Voice Coil Diameter	75mm(3")
Voice Coil Type / Former	Hexatech Aluminium
Frequency Response	20-12000 Hz
FS — Resonant Frequency	22 Hz
Sensitivity 1W/1M	90 dB
Z — Nominal Impedance	8 ohms
RE — DC Resistance	6.4 ohms
LBM — Voice Coil Inductance @ 1 Khz	0.62 mh
Magnetic Gap Width	1.35mm(0.053")
HE — Magnetic Gap Height	6mm(0.25")
Voice Coil Height	14.5mm(0.57")
X – Max. Linear Excursion	4.25mm(0.167")
B — Flux Density / BL Product (BXL)	0.65 T / 5.4 NA
Qms — Mechanical Q Factor	3.80
Qes — Electrical Q Factor	1.0
Q/T — Total Q Factor	0.8
Vas — Equivalent Cas Air Load	270 litres (9.6 ft³)
MMS — Moving Mass / Rmec	55gm / 2.25ns/m
SD — Effective Cone/Dome Area	503 cm²
Cone/Dome Material	DPC (Damped Polymer Composite)
Nett Weight	1.50 kg

Specifications given are as afte[r] 24 hours of running

morel high fidelity range

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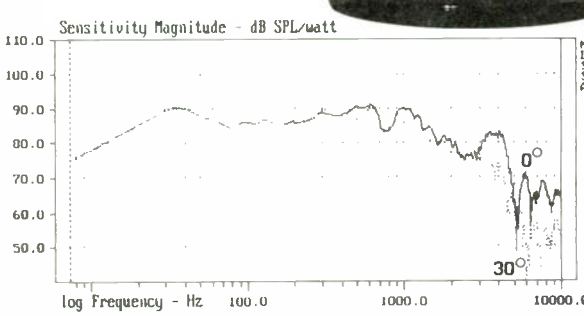

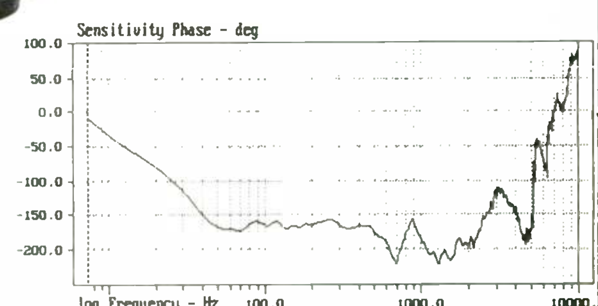

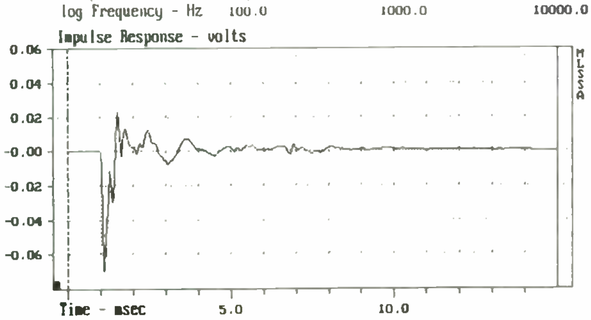

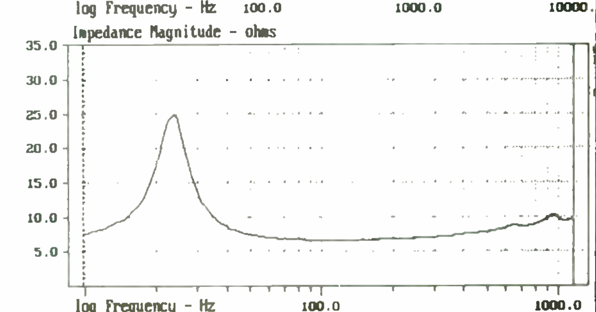

Morel operate a policy of continuous product design improvement, consequently specifications are subject to alteration without prior notice.

Fast Reply #HF14