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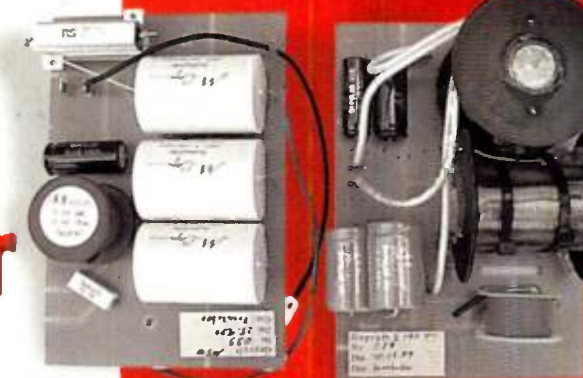

Build the Zerobox with Its Unique Bending Wave Driver

Dominic Lo Iacono

Stuffing Transmission Lines: Which Stuff & How Dense?

George Augspurger

Assembly for the Danish Tower

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Boxes, Crossovers & Measurements for a Hawaiian Compact

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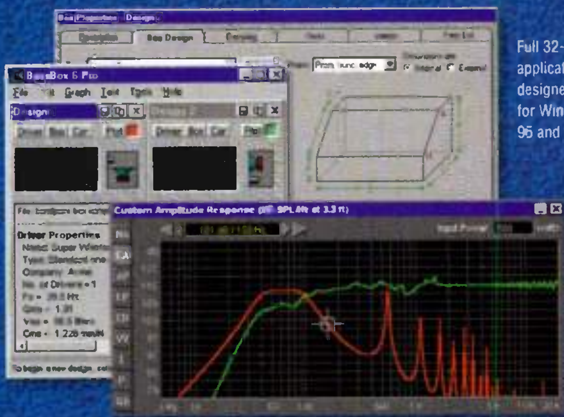

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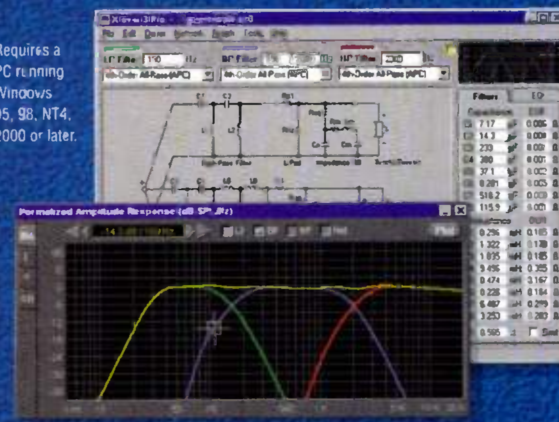

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Reader Service #3

Good News

■ NEWS BRIEFS

After 50 years in the Chicago area, Image Communications has relocated to a $200,000ft^3$ facility in Rockford, IL. The new address is 1801 Morgan St., Rockford, IL 61102-2690, 1-800-552-1639, 1-815-490-4390, FAX 1-815-490-4391.

The 109th AES convention will take place Sept. 22-25, 2000, at the Los Angeles Convention Center. For more information, contact AES, 60 E. 42nd St., Rm. 2520, New York, NY 10165, 212-661-8528, FAX 212-682-0477, E-mail HQ@aes.org, http://www.aes.org.

The Hi-Fi Show 2000 will be held September 21-24 at the Novotel, London West. For exhibit information, contact +44(0) 20 8774 0847 or FAX +44 (01) 20 8781 1158.

MCM Electronics catalog 43A is now available. It contains over 12,000 new items, including expanded selections in communications, computer, professional audio, test equipment, and tools. MCM Electronics, 650 Congress Park Drive, Centerville, OH 45459-4072, (800) 543-4330, FAX (800) 765-6960, Website www.mcmelectronics.com.

■ STRIKE UP THE BAND

The Belles Audio Nearfield Desktop System (BAND) is a CD-quality system for the PC, audio system, or home-theater system. The BAND includes a subwoofer and shielded satellites finished in natural cherry, medium oak, or natural maple. The amplifier supplies 65W to the subwoofer and 40W to the satellites. The remote-controlled preamplifier is compact enough to fit in nearly any available space. High-quality cables are included. For more information, contact www.powermodules.com.

Reader Service #136

■ SIGNATURE SERIES

RBH Sound's new loudspeaker line includes the 1266-SE, 661-SE, and the 1010 SEP, all of which feature aluminum metal cone drivers that use Kapton voice coil formers, an aerospace material capable of handling very high temperatures and completely resistant to electromagnetic interference. The 1″ ferrofluid fabric dome tweeter in both the 1266-SE and the 661-SE provides excellent dispersion at high frequencies, according to the company. RBH Sound, Inc., 976 N. Marshall, Bldg. 2, Unit 4, Layton, UT 84041, 801-543-2200, 800-543-2205, FAX 801-543-3300, website www.rbhsound.com.

Reader Service #135

■ X-CONNECT

Now you can control the input gain of your home audio or home-theater amplifier level with X-Connect. The latest version has no ground-loop isolator, which makes it suitable for most home audio applications, especially when you add a subwoofer or center channel amplifier and you wish to match the gain with the "other" system components. The unit operates from 0 to 50V RMS and has gold RCA inputs and outputs. It is also available with ground loop isolation. Harrison Labs, Inc., 303-841-5360, Harrison_Labs.INC@prodigy.net.

Reader Service #139

■ IN-WALL SPEAKERS

Atlantic Technology has introduced the System 20, a loudspeaker package that includes a front-channel satellite and a switchable dipole/bipole surround speaker. You can flush-mount the satellite in a standard two-by-four studded wall with 16″ centers. Atlantic Technology, 343 Vanderbilt Ave., Norwood, MA 02062, 781-762-6300, FAX 781-762-6868, www.atlantictechnology.com.

Reader Service #137

■ TRIPOLE SPEAKER

Miller & Kreisel Sound has introduced the Surround-55 Tripole™ surround channel speaker. The Surround-55 features a near-deal point source direct radiator on its front baffle, with an M&K phase-focused crossover feeding its 5¼ woofer and 1″ soft-dome tweeter. It also includes a dipole speaker using two unique 3″ paper cone mid-tweeters treated with a special damping compound. According to the company, these drivers achieve optimum phase and sonic coherency, as well as a very smooth and transparent sound from 300Hz through the critical midrange and above, due, in part, to their operating without any midrange crossover. M&K, 10391 Jefferson Blvd., Culver City, CA 90232, 310-204-2854, FAX 310-202-8782, www.mksound.com.

Reader Service #138

About This Issue

In this issue's lead article, veteran speaker builder **Dominic Lo Iacono** constructs a home for the Zerobox 109 kit contents. The results are smart-looking enclosures for some high-quality German drivers ("Zerobox 109," p. 8).

What really goes on in a stuffed pipe? Noted researcher **G.L. Augspurger** tackles this question in the second of his series, which he recently presented at the NY AES convention. We're pleased to present his findings based on computer simulations of loudspeaker design and stuffing material ("Transmission Lines Updated," p. 16).

Your construction skills will be put to the test in the second part of **Paul Kittinger**'s Danish Delight project (p. 22). Attention to detail and directions will result in a great-sounding and great-looking three-way tower design.

In the concluding part of his series ("The Menehune MX-1," p. 32), **Jim Moriyasu** provides extensive driver measurements and construction details of the crossover and boxes. His compact satellite/subwoofer system proves once again that good things can come in small packages.

The Jasper Audio Circle Jig addresses one of the more common, yet critical, tasks of speaker building, taking the tedium and uncertainty out of making circle cuts ("Product Review," p. 42).

Audio veteran **Jesse W. Knight**'s Lexan crossover breadboard offers a great way to lay out crossover designs ("Tools, Tips, and Techniques," p. 54).

Speaker Builder

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JOHN STUART MILL

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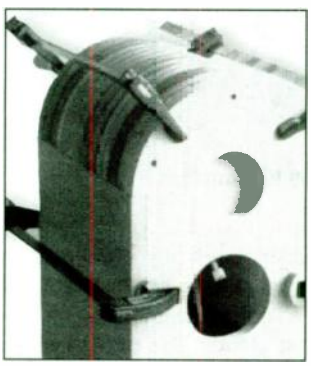

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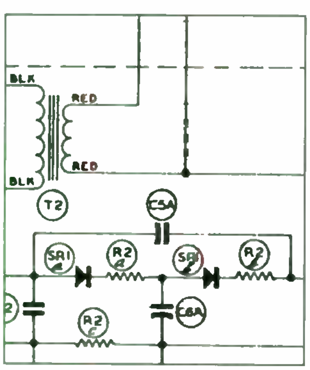

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DEPARTMENTS

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This author shows you how to build a box to house the Zerobox parts and reap listening enjoyment from this high-quality kit.

Zerobox 109

By Dominic Lo Iacono

The Zerobox 109 kit is based on a single Manger Schallwandler (MSW) transducer and a Scan-Speak 8″ paper carbon-fiber cone woofer. Manger speaker drivers are unique in being able to reproduce a true point-source bending wave with no crossover from 170Hz to beyond 30kHz. With a rise time of 13μs, 90dB sensitivity, nearly flat impedance, and an extremely smooth frequency response, they are among the best drivers on the market. More information on the Manger follows.

I chose to get the kit without the enclosures ($1,908), since I have been building speaker enclosures for some time and enjoy woodworking. *Photo 1* shows the kit contents, which are listed in *Table 1*. *Table 2* contains the system specifications.

THE MANGER SCHALLWANDLER TRANSDUCER

The Manger was developed over two decades of research by Josef Manger, winner of Germany's prestigious Diesel award for excellence in engineering. It is not a cone driver, but a flat circular panel driven by two voice coils. The best neodymium-iron-boron magnets are used to achieve a high gap field of 1.3 Tesla. Each voice coil is 16Ω and wired in parallel to achieve the 8Ω impedance. *Table 3* shows the full specs for the Manger transducer.

ABOUT THE AUTHOR

Dominic Lo Iacono has been a speaker builder for 25 years and an audio electronics builder and designer for 15 years. He has a Masters degree in materials science and works for a small high-tech company, Crystal Associates, where his duties include scientific research for medical and military lasers, as well as military missile warning systems. He holds four US patents.

I could go on about the impressive properties of this unique driver, but I will leave it to you to view the www.techmdb.com/products.htm site for yourself, where you will find abundant information about the Manger. And be sure to view the laser interferometry and the comparison of step responses to other speakers.

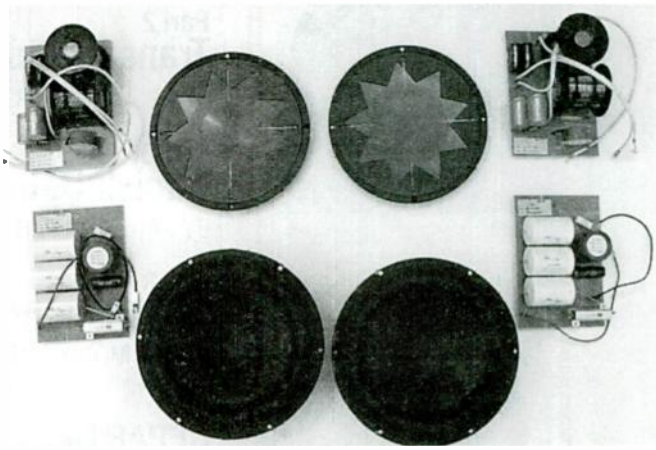


PHOTO 1: The Zerobox 109 kit contents.

CROSSOVERS

The well-built crossovers use high-quality parts. *Photo 2* shows one high pass and one low pass. Note the superior layout of the inductors, which are all rotated by 90°, minimizing crosstalk.[1] It is good to see crossover-design advancements published in *Speaker Builder* used by high-end companies.

Figure 1 shows the crossover schematics. The crossover cutoff frequency (f_C) is set low at 140Hz. I believe that keeping any crossover points far below critical midrange frequencies is a big benefit to sonic performance. Compounding this low f_C benefit is the lack of the need of any more crossovers up through 24kHz. *Figure 2* shows the component layouts and hook-up points for the crossovers.

ASSEMBLING THE ENCLOSURE

Figure 3 shows details of the enclosure. The construction material is 19mm (¾″) MDF or particleboard. I used the latter. Dimensions are given in millimeters (mm), and I left them that way, since I am a materials scientist and prefer using the metric system. You can convert to the English system if you wish, but if you have not built an enclosure using the metric system, give it a try.

At first glance, the enclosure appears to be rectangular, but further inspection shows it to be a trapezoid on edge. For further help in building these boxes, I made detailed drawings of the parts

TABLE 1
KIT CONTENTS

- Mangers, W05/1.2.216 (2)
- Scan-Speak paper carbon-fiber cone 8″ woofers (2)
- Assembled crossovers (2)
- Mounting hardware (not shown)
- Binding posts for the Manger (not shown)
- Also included were enclosure details, crossover schematics, hookup instructions and specifications

TABLE 2
SYSTEM SPECIFICATIONS

Frequency response	40Hz–24kHz
Crossover f_C	140Hz
Crossover slopes	LP: –18dB, HP: –6dB
Impedance	4Ω
Acoustical phase	Minimum of 360° over complete frequency range
Far-field behavior	Begins at 14cm
Dimensions	49 × 26 × 36cm
Weight	17kg

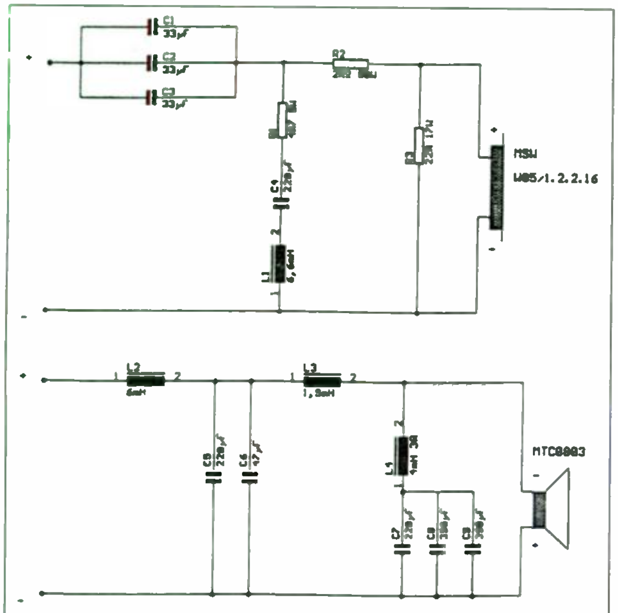


FIGURE 1: High-pass and low-pass crossover schematics for the Zerobox 109.

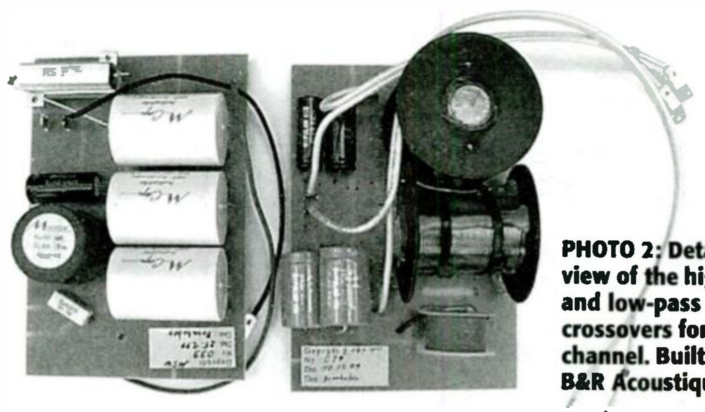


PHOTO 2: Detailed view of the high- and low-pass crossovers for one channel. Built by B&R Acoustique.

(*Fig. 4*), which you can use for cutting the panels.

In the construction, I used Liquid Nails glue and 38mm drywall screws. I made driver cutouts by using a router and a router compass. I don't recommend making these mounting holes any other way, for they are intricate, and require router precision. I won't go into all the cabinet-assembly procedures. Just use your favorite techniques. *Photo 3* shows the rough cabinet without the baffle to illustrate the way the inner partition panel is mounted.

After attaching the baffle and cutting the mounting holes, I finished the cabinet by rounding the edges with a belt sander and applying a few coats of faux stone-finish paint (*Photo 4*). I did not build grilles for this kit. Who would wish to hide those beautiful Mangers? You can decide for yourself, taking into consideration the drawbacks of grilles and the problem of keeping the drivers safe from damage.

FINAL ASSEMBLY

I stuffed the enclosure with medium-density damping material obtained through mail order. Be sure to fasten the damping securely to the inner walls, especially in the Manger section. The Manger chamber has some special guidelines for stuffing. It has circular openings in the back, and you should be sure to avoid getting any damping material in those holes. In fact, the damping material should be at least 75mm away from the back of the Manger. This is necessary so the damping material does not interfere with its bending-wave performance.

I used 12GA stranded wire for the electrical hookups. You can mount the crossovers inside or outside the enclosure as you please. I chose to mount them on the outside for accessibility. Loading the Scan-Speak driver into the lower chamber is easy and straightforward. Use a thin layer of silicone to form an airtight seal.

Loading the Manger requires using a terminal strip attached inside the enclosure. Connect the two voice coils in parallel to the terminal strip. Again, I used a very thin layer of clear silicone applied to the routed area of the enclosure to form a seal. *Photo 5* shows the finished pair of 109s.

TESTING THE ZEROBOX

My ability to measure the performance of the 109s is limited to an ADC SA-1 spectrum analyzer with only one octave-resolution from 32Hz to 16kHz. The vertical

TABLE 3
TRANSDUCER SPECIFICATIONS

Magnet material	Neodymium-iron-boron
Frequency range	80Hz–35kHz
Rise time	13µs
Sensitivity	90dB 1W/1m
Maximum SPL	110dB long term/ 116 short term
Recommended amp output	10–400W
Nominal impedance	8Ω
DC resistance	7.1Ω
f_S	75Hz
Induction B	1.3T
Voice-coil inductance	18µH
Air-gap energy	560mWs
Air-gap volume	350mm³
Air-gap height	5mm
Air-gap width	0.95mm
Voice-coil diameter	70mm
X_{MAX}	3.5mm

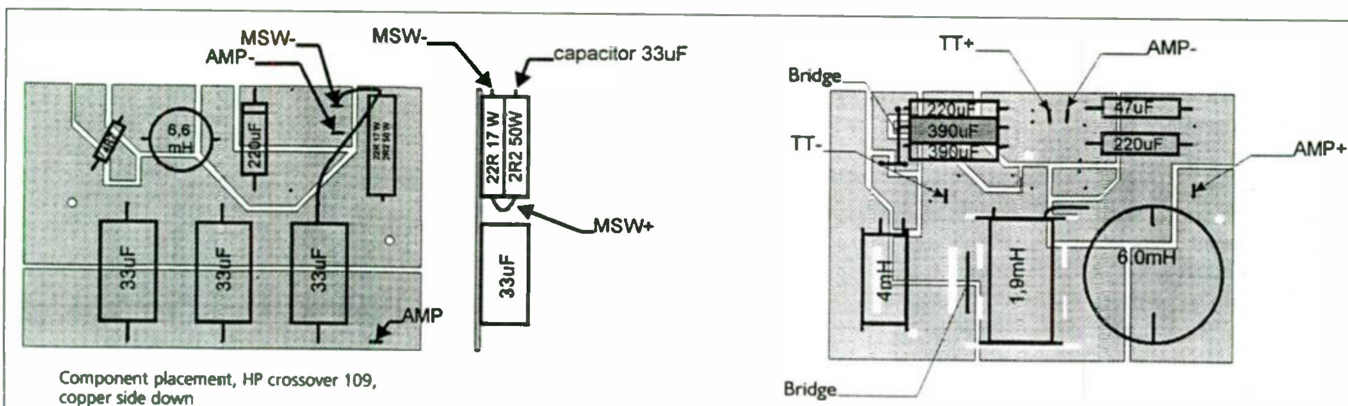
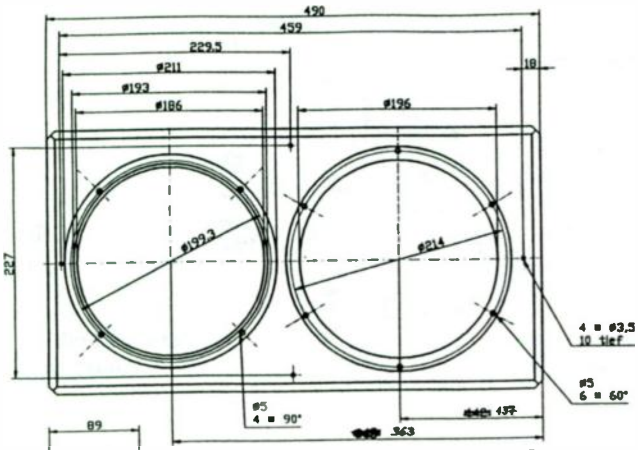
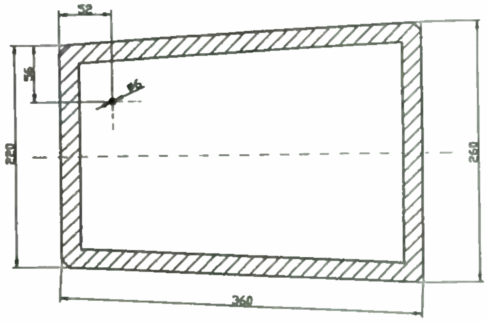
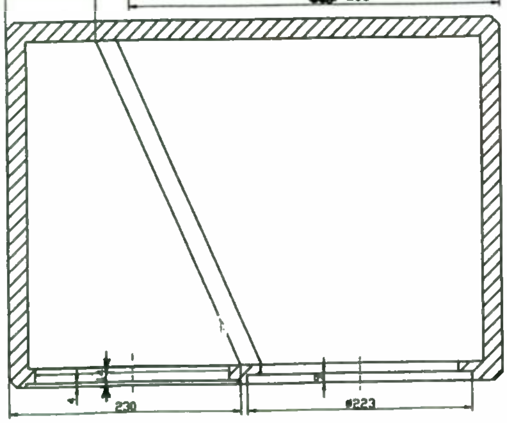


FIGURE 2: Component layout for the crossovers and electrical hook-up points.

FIGURE 3: Details of the Zerobox 109 enclosure construction.

resolution is 1dB. I know some may chuckle at this, but the SA-1 was calibrated a year ago by a friend who had access to an Audiocontrol SA3050. The SA-1 with mike was within +1dB over its 32Hz-16kHz range. A similar performance was recorded for the pink-noise generator on the SA-1.

I plan to upgrade in the near future. The normalized frequency response for both 109s measured at 1m is shown in *Fig. 5*. From the frequency response supplied with the kit (*Fig. 6*), you can see that its performance matches the expectations very well. The step response (*Fig. 7*) is very impressive, and I believe is the main reason for the imaging and detail performance of the 109s.

LISTENING-TEST SETUP

I auditioned the Zeroboxes using my home-theater system with three different configurations. Some may object to home theater, so I first used a stereo setup. The room is 28′ by 26′, with an 18′ vaulted ceiling. It is carpeted, and I consider the room to be moderately "live."

The first setup consisted of a Pioneer Elite DV-05 DVD/CD player using the digital coax output. The signal from the DV-05 was fed into a Lexicon DC-1 upgraded to the latest software version for digital-to-analog conversion. I set the effect selection on the DC-1 to bypass, and provide amplification with a stock Hafler DH 220. The connections from the amp to the 109s were #6GA pro twin leads. My listening position was 18′ away and centered.

The source material varied from female vocalists Anita Baker, Tony Braxton, KD Lang, and Sarah McLachlan, to pop artists like The Cranberries. I also used some Bach and Tchaikovsky for nonvocal evaluation. In my opinion, female vocals are good source material for evaluations.

In addition to stereo evaluation, I used the 109s for front left and right channels of my home theater with Dolby Digital (AC3 5.1) and DTS source material. For the AC3 5.1, I used the "Music for Montserrat" DVD, and for the DTS source I chose the Eagles' "Hell Freezes Over" and Bee Gee's "One Night Only." A DTS version of the CD "Holst the Planets" was also included to eliminate the video impact.

I placed the 109s at ear level (when seated) on top of two subwoofers, which are my own creation, designed using Bass Box Pro. Each sub contains one JBL 2245 18″ woofer loaded into a 250 ltr vented trapezoid-shaped enclosure tuned

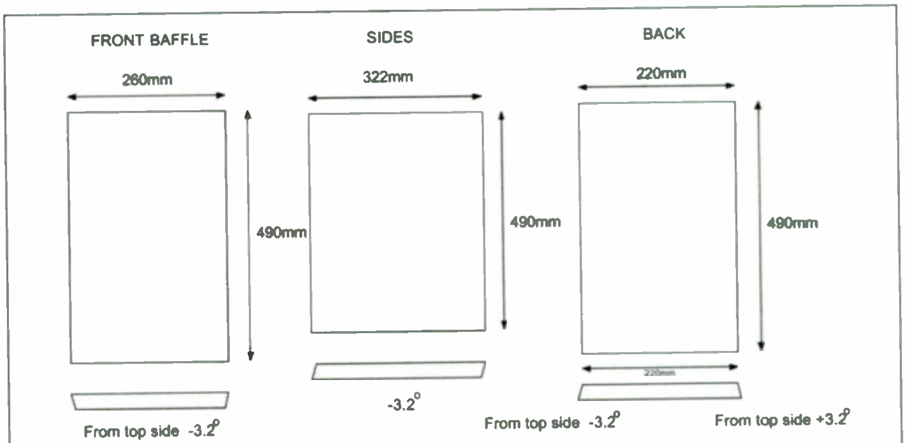
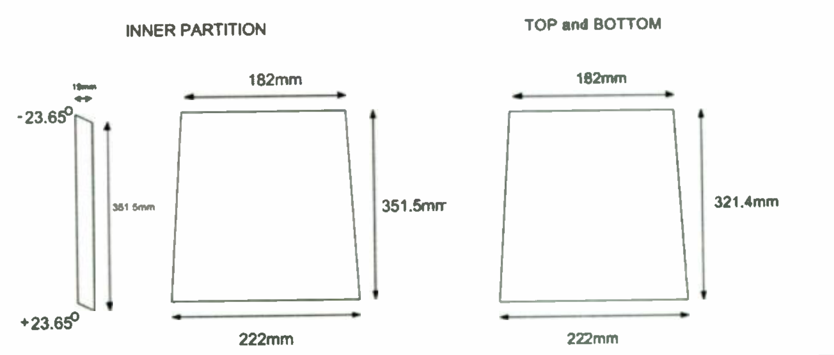


FIGURE 4: Details of the Zerobox 109 enclosure parts.



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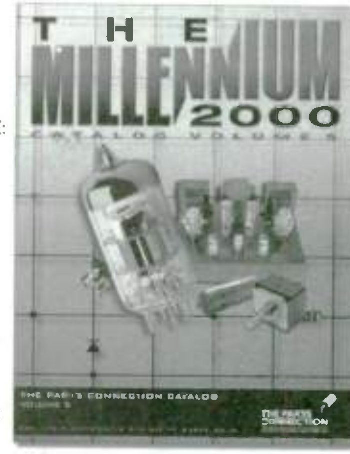

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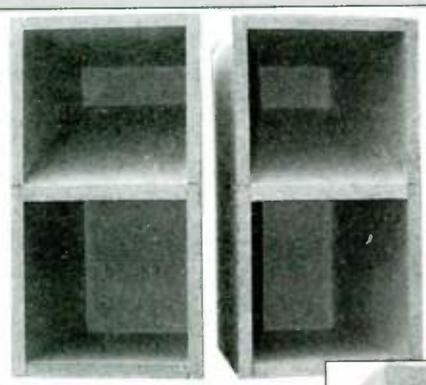

PHOTO 3: The rough cabinets without the baffles, showing the inner partition panels.

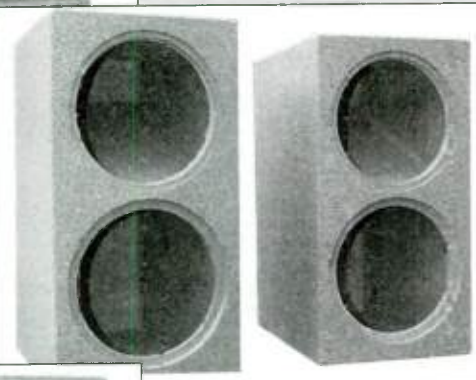

PHOTO 4: Finished pair of Zerobox 109 enclosures.

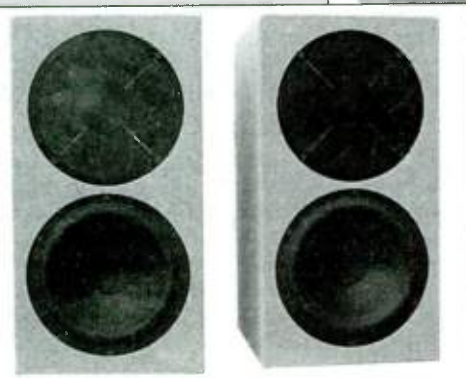

PHOTO 5: Completed Zerobox 109 kit ready for testing.

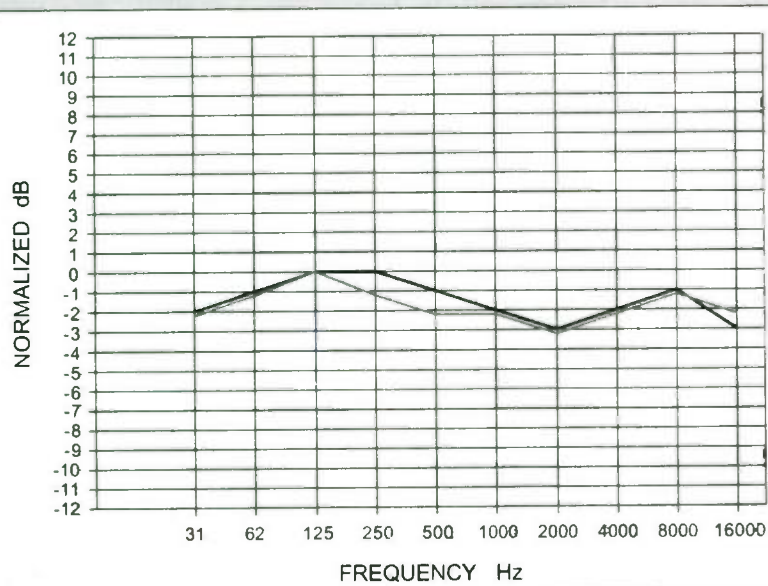

FIGURE 5: Zerobox 109 frequency response measured for left and right channels.

to 16Hz. I did not use the subs for the first set of listening evaluations.

The second setup was similar to the first, but with the subs added. I used an active crossover 24dB/octave set to 60Hz, which I built as a kit from Marchand Electronics, model XM9L. Again, the Hafler DH 220 supplied the amplification for the 109s, and the subwoofers were powered by a BGW 750B.

The third evaluation setup was a full home-theater 5.1 setup. I used the 109s as the left and right fronts, and configured them as in the second setup. The center channel was a home-built design using a Dynaudio D28 tweeter and two 6.5″ Vifas arranged in a D'Appolito configuration. The Vifas are time-adjusted by lining up the voice coil to the D28. I bi-amplified the center channel by using another Marchand XM9L and an additional DH 220. The left and right rear channels were the same as the center speaker, driven by another DH 220 and using Linkwitz-Riley 24dB/octave passive crossovers.

LISTENING-TEST RESULTS

The first and most amazing thing about the Zerobox 109s is the soundstage. I and three other evaluators with "experienced ears" were amazed by the fact that the sound did not seem to originate from the 109s. The soundstage was right there in front of you, and because of the low transient distortion of the Mangers, it was precise and three-dimensional. The only other speakers I know that can achieve the sensation of not listening to speakers at all are electrostatics. I would rate the imaging performance of the 109s as being equivalent to some electrostatics I have auditioned such as the Quads and Martin Logans.

Female vocals were natural and clear, revealing every detail. The performance of the 109s with classical music sources was also impressive, with depth and precision. Never were the 109s fatiguing, even listening to loud pop music such as The Cranberries' "Zombie." I should point out that the 109s are not very adept at producing any acceptable acoustic levels much below 80Hz. It is

REFERENCES

1. Sanfilipo, Mark, *SB* 7/94, pp. 14–16.

SOURCES

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obvious that the 8″ Scan-Speaks are not capable of pushing large volumes of air, but they do match very well to the Mangers. The impressive performance of the 109s is mostly due to the Manger transducer.

Not too surprising, the best performance overall was with the addition of the biamped subwoofers. Next was the evaluation of the 109s in a home-theater environment. How does a pair of speakers that sounds as good as the Zerobox 109s perform in a home theater? I would describe the experience as nothing short of phenomenal. The music-concert sources became as realistic as though we were sitting in the front row. The DTS sources produced a soundstage and imaging superior to anything I have heard before.

I was not alone in this evaluation; my other three friends also agreed it was the best thing they had heard. Maybe it was the surround effect, but I don't think so. I took out the 109s and put in the standard left and right front speakers (which were the same as the rear ones), and the soundstage degraded and seemed flat when compared to the 109s. Again I inserted the 109s, and the three-dimensional soundstage was restored.

CONCLUSIONS

At the risk of starting a debate on LP or CD, CD or DVD, AC3 or DTS, stereo or surround, I will say that the DTS-encoded DVD or music CD may be the best source out there for the consumer. Maybe this is true only for my particular system. I know that some of you still cling to those vinyl recordings, and I still listen to many of my LP records. What I am saying is that DTS is impressive, and my experience with the Zerobox 109s has raised the level of enjoyment for my complete musical and home-theater experience.

I am so impressed with the performance of the 109s, specifically the Manger transducer, that I am in the process of upgrading my entire system to include the Manger in all of the five-channel speaker designs.

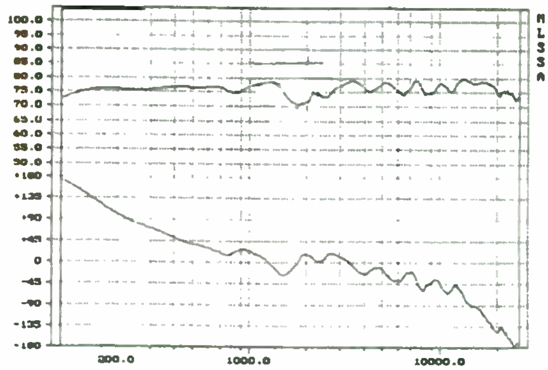

FIGURE 6: Frequency and acoustical phase responses for the Zerobox 109. Data measured by B&R Acoustique and supplied with the kit.

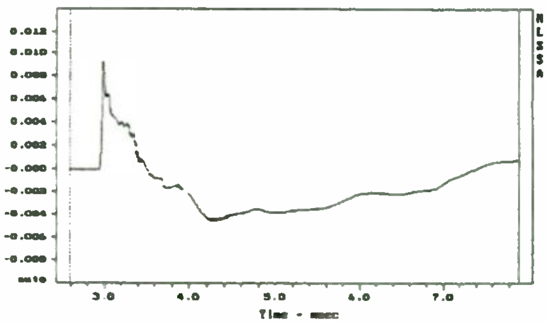

FIGURE 7: Step response of the Zerobox 109. Data measured by B&R Acoustique and supplied with the kit.

Material selection and density are critical considerations when stuffing a pipe.

Part 2

Transmission Lines Updated

Stuffing Characteristics

By G. L. Augspurger

A VERY BRIEF HISTORY OF STUFFED PIPES

In the early 1900s lightly stuffed pipes were used as nonresonant sound conduits or absorbers. For example, Olson's ribbon microphone terminated the rear surface of the ribbon in a tube damped with tufts of felt.

Benjamin Olney's Acoustical Labyrinth, patented in 1936, appears to be the first application of damped pipes to loudspeaker design. "A tube filled with absorbing material of gradually increasing density was first considered, but it soon became evident that such a device...would be difficult and expensive to construct."[8]

Olney decided it would be more practical to use absorptive lining instead of stuffing. His analysis suggested that both diaphragm motion and pipe radiation would be small at the quarter-wave frequency. He expected that at an octave higher, absorption in the tube would still be relatively low, so pipe radiation would reinforce cone radiation.

"If the absorbing material be properly chosen and a sufficient quantity employed," he wrote, "the higher-order resonances and antiresonances of the tube will be suppressed, and the driving point impedance at the higher frequencies will be determined largely by the absorption in the tube." Olney was also aware that in a pipe with losses, the speed of sound is less than in free air. He speculated that the wave front would gradually become curved as it traveled through his labyrinth.

He then built such a device and made exhaustive measurements that confirmed that pipe radiation substantially reinforced cone radiation around 70Hz, and then rolled off rapidly at higher frequencies.

LABYRINTH OR BOX

In fact, what Olney built, measured, and patented was not what he described as an acoustical labyrinth. It probably functioned more like a damped vented box. (No one seems to have noticed this.) However, later versions built by Stromberg-Carlson definitely were lightly damped pipes. By then the inventor recommended that the pipe's quarter-wave resonance should match the speaker's cone resonance for linear response down to f_p.

In 1965 A.R. Bailey described his experiments with "nonresonant" stuffed pipes.[9] He tested pipes stuffed with fiberglass and with long-fiber wool and decided that wool was clearly superior. He reported that wool at a density of 0.5lb/ft^3 closely matched the characteristic impedance of air above 100Hz, yet provided a high rate of sound attenuation. More surprisingly, near 30Hz the speed of sound through a wool-stuffed pipe was slowed by about 50%. For pipe radiation to reinforce cone radiation in the 30Hz region, he was able to reduce pipe length from 30′ to 15′.

A little more than ten years later, a paper appeared by L.J.S. Bradbury[10] that attempted to provide a scientific basis for Bailey's findings. Bradbury postulated that aerodynamic drag would set fibers in motion at low frequencies, effectively adding mass and slowing the speed of sound through a stuffed pipe. He developed an elaborate theoretical analysis that allowed acoustical behavior to be predicted from a knowledge of fiber diameter, mass, and packing density.

Using Bradbury's equations, Robert Bullock developed a computer program to design transmission-line loudspeaker systems, but the results were less than satisfactory. One reason may be that Bradbury's formula for computing the drag coefficient was admittedly tentative. Another is that some of his underlying assumptions may be incorrect.

MATS AND BLANKETS

In 1980 Hersh and Walker published a thorough analysis of the acoustic behavior of Kevlar® mats and blankets.[11] Their findings should be applicable to any similar fibrous material. Citing previous work, the authors emphasized the importance of fiber orientation in relation to the direction of the sound wave as well as interaction between fibers in determining the drag coefficient. Like Bradbury and others, Hersh and Walker measured a dramatic reduction in sound speed at low frequencies. However, their theoretical model assumes that the fibers are stationary.

An enormous amount of work has been published regarding the acoustic behavior of fiberglass and similar fibrous materials. Books have been written on the subject. However, like Hersh and Walker's paper, much of this material relates to duct silencers, engine mufflers, or aerospace design, and is not readily available to loudspeaker designers. As far as I can tell, there is sufficient evidence to support the following general statements:

- If the thickness of the material is greater than a fraction of a wavelength, then attenuation increases with increasing frequency.
- Wave propagation through fibrous packing slows at lower and lower frequencies. This effect is associated

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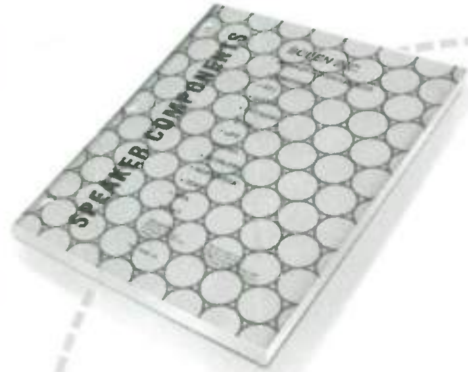

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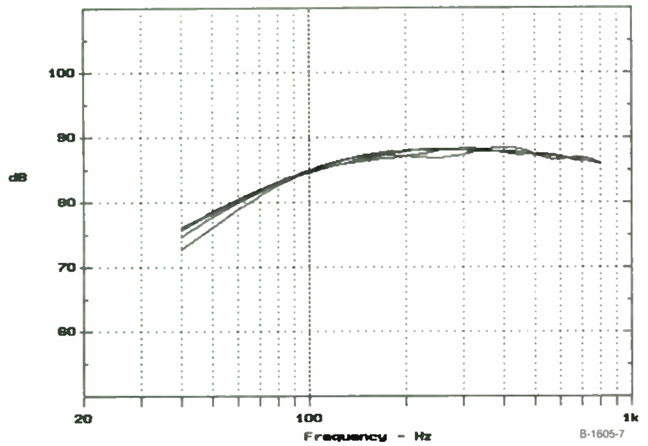


FIGURE 7: Response of 100Hz pipe with varying sound speed. Relative speed: 0.80, 0.63, 0.50, and 0.40.

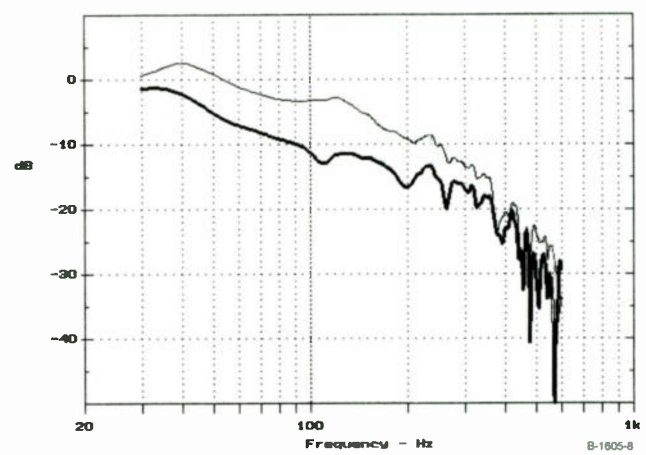


FIGURE 8: Comparative pipe transfer functions.

with a reactive (mass) component of acoustic impedance.

- Air expansion and contraction are at least partially isothermal, but this factor is small in relation to other effects.
- Any motion of fibers can be ignored when you are modeling basic acoustical behavior.
- Orientation of fibers is important. A random tangle may behave differently than a mat woven from the same material.

SLOW SOUND – SOME CAUTIONARY COMMENTS

Bailey's experiments suggest that you can cut the size of a transmission line in half by loosely stuffing it with wool. Bradbury seemed to accept the idea. It seems almost too good to be true, and it is.

Yes, the effective length of a short stuffed pipe is equivalent to a longer empty pipe at low frequencies, but a change in acoustic impedance is involved. More important, propagation speed and damping are tied together. A "slow" pipe is a damped pipe, and damping is the more important factor. Moreover, even if you speculate that wool does slow wave propagation to half the speed in fiberglass for the same damping (which it does not), the net result is not what Bailey reported.

My computer simulation allows damping and sound speed to be specified independently. *Figure* 7 shows what happens when damping is constant but relative sound speed is varied over the range from 0.8 to 0.4. There is some change in low-frequency response, but it becomes significant only about an octave below f_3, which remains stubbornly fixed at 100Hz. In terms of transmission-line response, trying to measure and specify sound speed is both uncertain and unnecessary. It seems that, for the past 30 years, we have all been chasing the wrong rabbit.

To get a clearer picture of what the stuffed pipe is doing, the loudspeaker's amplitude and phase response must be eliminated. Instead of summing loudspeaker and pipe outputs, you can use complex division to derive the pipe transfer function–pipe output in relation to cone output. Now you have a way to compare various kinds of stuffing on various pipes regardless of the loudspeakers used for individual tests.

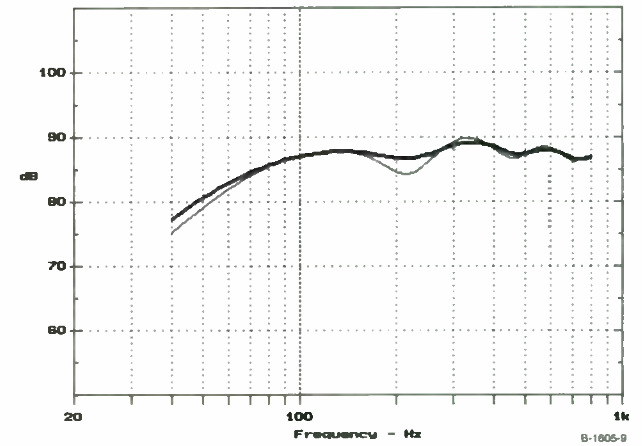


FIGURE 9: System response: flared versus tapered (bold).

A good example is illustrated in *Fig. 8*. The two curves are unsmoothed pipe transfer functions derived from actual measurements. The upper curve appears to be a lightly damped pipe. Pipe output exceeds cone output around 40Hz, then levels out at 60Hz, and finally rolls off fairly rapidly above 150Hz.

The lower curve obviously shows more damping at low frequencies. With a little smoothing, it might represent a 40Hz, 6dB per octave low-pass filter. In the 100Hz octave band, it provides about 6dB greater attenuation than the upper curve.

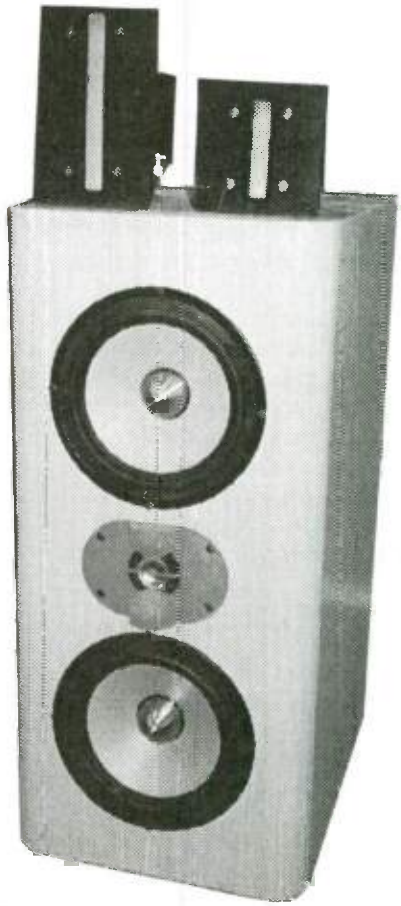
The two transfer functions also differ in their group-delay characteristics. The actual plots are ragged, but their general shapes can be described. The lower curve has a group-delay maximum of about 10.5ms at 40Hz, followed by a broad S-curve reaching 6.0ms at 125Hz and then gradually averaging out to 4.0ms above 250Hz. The upper curve generally has a similar shape, but peaks at about 8.0ms, with a secondary bump of about 5.0ms before joining the lower curve at 250Hz. At 40Hz and 125Hz the "speed of sound" is about 20% different between the upper and lower curves.

Now, the interesting thing is that the two sets of measurements were made on the same 4′ pipe with the same speaker and the same stuffing! However, this pipe has slanted sides. Its area is $21in^2$ at one end and $49in^2$ at the other. The upper curve was run with the speaker on the small end (flared pipe) and the lower curve with the speaker on the large end (tapered pipe).

The difference in system response is shown in *Fig. 9*. It is obvious that pipe geometry is just as important as length and damping in establishing transmission-line performance.

PRACTICAL DAMPING MATERIALS

The preceding example makes it clear that theoretical analysis of damping materials may not be the best approach to



understanding transmission line loudspeaker systems. One purpose of this project was to develop empirical guidelines based on actual measurements. After all, it really doesn't matter what the damping material is if you can predict what it will do.

So I proceeded to run response curves on pipes stuffed with a variety of materials ranging from steel wool to plastic packing pellets. The selection was rapidly narrowed to four well behaved, easily obtained materials:

1. Ordinary fiberglass thermal blanket. This is usually sold with paper backing, which you can remove.
2. Polyester fiber stuffing. I used Poly Fluff, a product of Western Synthetic Fiber Inc., Carson, CA.
3. Microfiber stuffing – Celanese "Microfill."
4. "Acousta-Stuf" – nylon polyamide fiber available from Mahogany Sound, Box 9044, Mobile, AL 36691-0044.

For practical reasons, you should avoid organic materials. However, Bailey preferred long-fiber wool, and present-day experimenters continue to follow his advice. Bulk wool is not easy to find in the US, so I tested fluffy wool yarn instead. It displayed no unusual properties, behaving roughly the same as Acousta-Stuf. Similarly, cotton puffs are roughly equivalent to microfiber.

Microfiber is light and fluffy. Acousta-Stuf is ropy and fairly heavy. For equivalent damping over a given range of frequencies, the packing density of Acousta-Stuf must be at least twice that of microfiber. Once this is taken into account, all four materials behave very much the same.

The reason for this happy state of affairs is that, for any given system alignment, precise damping characteristics are important only over a bandwidth of about two octaves. In a practical transmission-line system, useful summation of pipe output and cone output extends from perhaps an octave below f_3 to an octave above. At higher frequencies, pipe output continues to decrease, but the exact rate of rolloff is not critical. Similarly, at frequencies well below cutoff, you can disregard any minor differences in response.

DENSITY DIFFERENCES

For comparable results, a short pipe requires greater packing density than a long one. This seems to contradict common sense, but test results demonstrate it is true. It follows that system alignments must include absolute pipe length as a design factor.

If stuffing makes a short pipe behave somewhat like a longer pipe, can its effective length be further increased by increasing stuffing density? Yes and no. *Figure 10* compares transfer functions of 1.0 lb density Acousta-Stuf in a 6′ pipe with 3.0 lb density of the same material in a 2′ pipe. These are computer curves, but they accurately model test results below 300Hz or so. Over a wide frequency range, the two curves differ by no more than 1dB.

However, although effective sound speed is slower in the shorter pipe, it is not slow enough to make up for the difference in path length. In a practical transmission-line design, the cutoff frequency probably will lie between 0.7 and 1.4 times f_P. Within that range, adjustment of system response can be accomplished by changing loudspeaker parameters, not stuffing.

In practice, the optimum packing density for a given material is determined by acceptable passband ripple. Once this is done, overall system response is almost the same for all four materials. Even with best-fit matching, however, there are some differences in performance. At higher packing densities, fiberglass has greater high-frequency versus low-frequency attenuation than the other materials. On the other hand, at low densities it seems to be more prone to unexpected glitches in response.

Figure 11 shows measured pipe transfer curves of ½ lb fiberglass and 1 lb Acousta-Stuf. Up to 400Hz or so, the response of Acousta-Stuf rolls off fairly smoothly. In contrast, the fiberglass curve has a sag around 75Hz and a broad bump centered near 200Hz.

This is a typical example. In contrast to the computer model, pipe output is always lumpy, and different materials have their own characteristic acoustic signatures. In the range where pipe output contributes to system output, these differences may be audible.

STUFFING SPECIFICATIONS

For pipes of various lengths, it is possible to draw up a set of charts showing equivalent packing densities for the four materials tested. It turns out that a single table is adequate for general-purpose alignments, because short pipes always require high damping and long pipes require relatively light damping. Such a table is included in Part 3 of this report.

A few general rules of thumb may be useful. For most purposes, you can consider Acousta-Stuf and Poly-Fluff as pound-for-pound equivalents. In contrast, the packing density of fiberglass blanket must be half that of Poly-Fluff. The density of microfiber should be about a third that of Poly-Fluff, but the actual ratio is not constant.

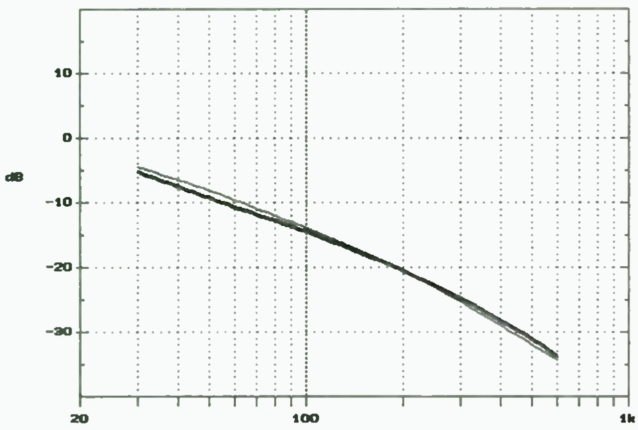


FIGURE 10: Acousta-Stuf transfer functions: 1.0 lb-density in 6′ pipe versus 3.0 lb-density in 2′ pipe.

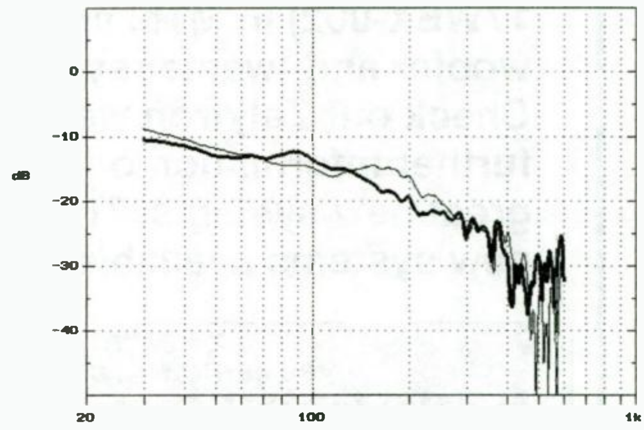


FIGURE 11: 6′ pipe transfer functions: 1.0 lb-density Acousta-Stuf versus 0.5 lb-density fiberglass blanket.

Swans M1 kit

Great news from Swans!

New beautifully cabinets for Swans M1 kits are available in three finishes: piano black, solid walnut and rosewood veneer. Totally irresistible!

The Swans M1 speaker system is a two-way bass-reflex design. The front baffle is very narrow with rounded edges to reduce cabinet diffraction for better clarity and imaging. The internal panel and corner reinforcement substantially reduce unwanted cabinet vibrations. A flared port is mounted on the rear baffle for smooth transition from the port to cabinet boundaries. This provides linear bass performance and absence of port noise. The heavy-duty gold plated binding posts are mounted directly on the rear panel to enable easy cable connection.

The 5-inch paper/Kevlar cone woofer has a rubber surround, cast aluminum frame and a magnetically shielded motor system. This driver utilizes a central phase plug to avoid air compression, improving frequency response and dispersion. These key features greatly contribute to the M1 s clear transparent sound and effortless dynamic performance.

The tweeter is a high-tech planar isodynamic design that employs Neodymium magnets and extremely light Kapton film, with flat aluminum conductors.

This unit provides an immediate and precise response to any transients in original signal, and gives the M1 an exceptional ability to reveal the true dynamics of instruments with a complex high frequency spectrum.

The crossover is a second order Linkwitz-Riley type resulting in an in-phase connection of the drive units. The crossover frequency between the two drivers is 3.3 kHz and only high quality polypropylene capacitors are used. Each filter has it s own dedicated board mounted on a special rubber interface to reduce vibrations and microphonic phenomenon. The filter boards are spaced inside the loudspeaker with the inductors positioned at right angles to minimize the interaction.

Swans M1 kit includes:
- 2x F5 paper/Kevlar bass-midrange drivers,
- 2x RT1C isodynamic tweeters with sealing gaskets,
- 2x dedicated tweeter crossovers,
- 2x dedicated base-midrange crossovers,
- two flared ports,
- two pairs of heavy duty gold plated terminals.

The drawings of the cabinet shown here represent general dimensions required for optimum bass performance. Rounded corners are advisable as they improve imaging and clarity. Actual finish and appearance is a matter of personal taste.

Price: $410 delivered without cabinets;
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Warranty 3 years. We accept VISA.

High sonic resolution Loudspeaker
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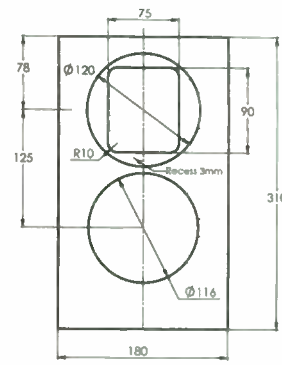
...explicit, easy to listen to, effortless, seamless and stunning.
Ernie Fisher
Swans M1 Speaker Systems Review
INNER EAR REPORT
Volume10, #3 1998

The step beyond the limits

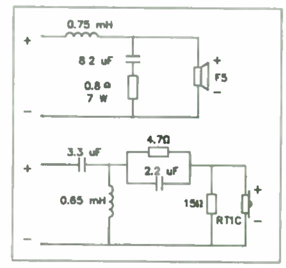
RT1C Tweeter

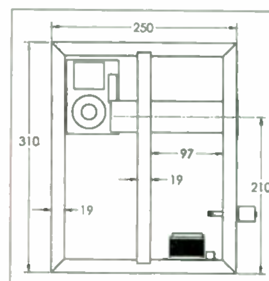
F5 Bass-midrange

Filter

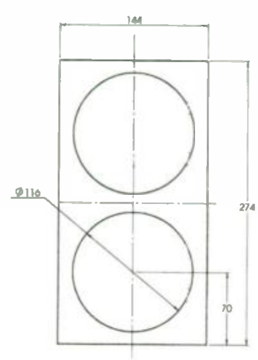


Front view

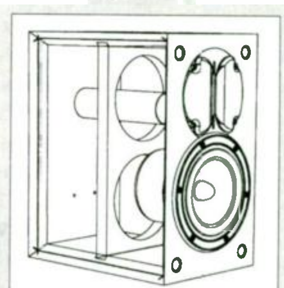




Right view of the cabinet with accessories(right side panel removed)



Internal panel



SPECIFICATIONS

Frequency response (1m,half space)	60Hz-35kHz.±2dB 55Hz-40kHz.-3dB
Sensitivity,1W/1m (100Hz-8kHz averaged)	86 dB
Nominal impedance (7.2 ohms minimum at 250 Hz)	8 ohms
Power handling	50W nominal, 90W music
Dimensions,HxWxD	310x180x250 mm

Amplifier requirements:
30W recommended minimum.

for more info please

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Which material is best? Each one shows deviations from ideal damping characteristics, and even with close-matching, these deviations may be audible. However, there are other factors to consider, such as consistency, availability, and ease of handling.

Ordinary fiberglass thermal blanket from three different sources seems to deliver consistent performance at packing densities of 1.0 lb or greater. Its unpacked density is about 0.6 lb/ft^3. However, it is nasty stuff to work with and seems more likely to shed fibers than Acousta-Stuf or polyester.

Polyester pillow stuffing seems to be fairly generic, but I don't know whether a batch from another manufacturer would match the performance that I measured using Poly Fluff. Over a useful range of packing densities, this is the easiest material to work with.

Acousta-Stuf is more expensive than the other materials, but its characteristics are closely specified. As delivered, it is ropy and must be thoroughly teased, especially at low packing densities. Otherwise, it is easy to use and does not shed.

Microfiber is like thistledown. Once compressed to the desired density it seems to stay in place. However, loose wisps drift around for days. If you use the brand name Celanese "Microfill," then its acoustical qualities should match my test results.

Any of these materials may be tricky to use in a large pipe requiring low packing density. Partitioning a fat pipe into two or more thin ones will help keep the stuffing in place and at the same time make the structure more rigid.

STUFFING VARIATIONS

Is there any practical way to increase pipe output in the frequency range of constructive summation while maintaining a steep rolloff at higher frequencies? You might follow Olney's example and use absorptive lining instead of stuffing. Consider a duct silencer. It contains very thick lining with a constricted air space in the middle. This arrangement provides minimal steady-state loss with high absorption above 100Hz or so.

I made a few test runs using thick lining, but it became obvious that in pipes of moderate size there simply isn't enough room to get the desired midrange attenuation. Moreover, in contrast to stuffing, it is almost impossible to develop general design guidelines. For these reasons, I decided to restrict this study to stuffed pipes. Some experimenters have combined lining and stuffing, but I don't see why the combination should be any more effective than the proper density of stuffing alone.

Graduated stuffing density is another favorite of experimenters. Some recommend higher packing density toward the pipe exit. Others insist that density should decrease from loudspeaker to exit.

It has long been known that a damped pipe can provide constant resistive loading over a wide frequency range if damping is light at the throat and steadily increases toward the exit. You can do this

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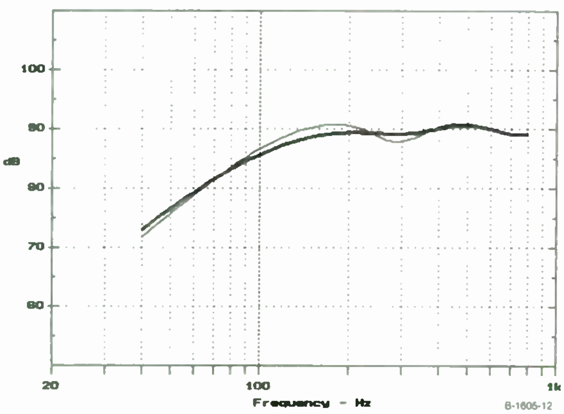

FIGURE 12: Overdamped pipe response: fully stuffed (bold) versus 0.8 length stuffed.

than homogeneous stuffing. It deserves further experimentation.

Another interesting variant is to stuff only the first 80% of pipe length and leave the exit region empty. Once everything is readjusted for acceptable passband ripple, there is no net improvement. However, the comparative performance graphed in *Fig. 12* suggests that this can be a useful technique for final tweaking after an experimental design has been built. Once you have assembled a folded transmission line, it is almost impossible to adjust overall packing density. However, it is easy to add or remove stuffing near the pipe exit.

Experimenting with damping location and density can yield usable variations in response, but I have found no magic low-pass filters. The most practical way to improve transmission-line performance is to change the shape of the pipe, and that is what I'll discuss in Part 3.

by varying stuffing density or by using a wedge of high-density fiberglass in place of stuffing. The latter configuration is often called a "terminated tube." It simulates the acoustic load of an infinite exponential horn and is used to test high-frequency drivers.

Constant attenuation at all frequencies is exactly what you don't want in a transmission-line loudspeaker system. However, when I measured a pipe with a fiberglass wedge, its behavior was not what I expected – not really worse or better

The author completes his project in this article, including final assembly and adding the finishing touches to his 3-way tower speakers.

Part 2

Danish Delight

By Paul L. Kittinger

With all the parts cut out, it's now time to begin assembling these speakers. You'll need temporary assembly jigs to assemble the towers. You've already cut the jigs from the ¾″ MDF—one piece 8″ × 12″, and four pieces each 3″ × 8″. Place the larger jig (but don't glue it in) into the top of the tower between the side panels where the arched top will eventually go, and the four smaller jigs across the front and back of the tower for clamping surfaces, substituting for the front and rear panels.

Photo 14 shows how the two side-panel assemblies, shelf/braces, and assembly jigs are clamped together while the glue sets. I used carpenter's wood glue for this and clamps of various types and sizes. I installed #8, 1¼″ wood screws through countersunk holes on the side panels into the centers of the shelf/braces.

To start this assembly process, lay one side panel with its outside down on your work surface, apply glue in the slots for the three shelf/braces, then insert the shelf/braces. Apply glue to the other edges of the shelf/braces and then set the slots of the second side panel onto them. Set in the larger assembly jig at the top, and the four smaller jigs into the front and back of the tower, and cinch up the clamps. Make sure the tower is aligned squarely and the shelf/braces are located properly in their slots before completely tightening the clamps and installing screws.

With care, this can all be done by one person, but don't be ashamed to ask for another pair of hands to help. It would not hurt to do a dry run first to work out the sequence of steps. After the glue has set for an hour or so, you can remove the clamps and the five assembly jigs.

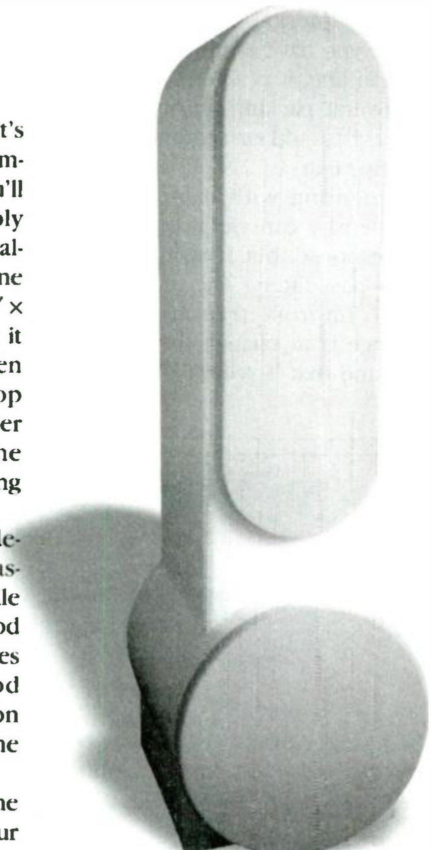

PHOTO 1 from Part 1: System front view with grilles.

PHOTO 2 from Part 1: System front view without grilles.

ATTACHING THE TOP ASSEMBLY

When the glue in the tower sides and shelf/braces has dried for 24 hours, you can glue on the top arch assemblies as shown in *Photo 15*. Before you do, however, attach Deflex® on the inside of the arch, using Weldbond adhesive. Of the three circles of Deflex listed in *Table 1*, you already will have used a large portion of two of them to line the inside of part C. From the remaining one, cut out enough pieces to line most of the underside of each arch assembly (you don't need to cover every last inch for this to be effective).

To hold the Deflex in place on the curved surface while the glue dries, you can weight it down with a coffee can full of sand or a bunch of nuts and bolts. Make sure to center the arch assembly exactly front-to-back on top of the tower's side panels. I used carpenter's

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Unit	Description	Ω	fs Hz	dB	Wat t	Price Each
ER-4	Air Motion Ribbon Tweeter - 1.5 to 30kHz!	6	450	92	100	**$285.00**
19 SD 1	3/4" Textile Dome Tweeter, dbl. magnet	8	1100	89	80	**$53.00**
25 SD 1	1" Textile Dome Tweeter, dbl. magnet	8	1000	90	100	**$56.00**
All Eton midranges and woofers feature Kevlar/Nomex Hexacone cones.						
4-300	4" Kevlar Midrange / Woofer	8	57	88	50	**$86.00**
4-300S	Shielded 4" Kevlar Mid/Woofer w/phase plug	8	56	85	40	**$98.00**
5-880	5" Kevlar Woofer	8	48	87	70	**$100.00**
7-350	7" Kevlar Woofer, low fs, linear response	8	33	89	60	**$118.00**
7-360	7" Kevlar Woofer	8	40	89	120	**$122.00**
7-372	7" Long Throw Kevlar Woofer with heat pipe	8	32	90	80	**$151.00**
8-472	8" Long Throw Kevlar Woofer with heat pipe	8	24	89	90	**$187.00**
8-800	8" Kevlar Woofer	8	31	89	120	**$144.00**
11-581	11" Kevlar Woofer	8	23	91	150	**$289.00**
12-680	12" Kevlar Woofer	8	26	91	200	**$384.00**

Eton Kits engineered by Eton in Germany

All kits include speakers, crossovers (coils as specified, poly caps in series with midrange and tweeter, eagle MO resistors), all brass gold plated input cups, black screws, port tubes and port tube trim rings, foam dampening pads and Acusta-Stuf (if called for) and el cheapo internal speaker wire. Cabinet drawings are included. **Cabinets are not available at this time**, we will have some made if there is enough interest. Kits are priced per pair and reflect a 10% discount from piece prices.

Eton 7.2 Kit - Bookshelf type 2-way design using the 7" 7-350 woofer and 1" textile dome 25SD1 tweeter in a vented enclosure. Crossovers are 6dB on the woofer and 12dB on the tweeter.
The price per pair is $395.00. Adding Nordost internal wiring is an additional $16.65.

Eton 8.1 Kit - Floor standing 2-way tower design using the 8" 8-800 woofer and 1" textile dome 25SD1 tweeter in a vented enclosure. Crossovers are 6dB on the woofer and 12dB on the tweeter. System phase compensation used at the crossover point. The cabinet is 39.3" T x 9.6" W x 11.8" D.
The price per pair is $450.00. Adding Nordost internal wiring is an additional $19.98.

Eton 11.2 Kit - Floor standing 3-way design using the 11" 11-581 woofer, 5" 5-880 midbass and ¾" textile dome 19SD1 tweeter in a vented enclosure. Crossovers are 12dB on the woofer, 12dB/18dB on the midbass and 12dB on the tweeter.
The price per pair is $990.00. Adding Nordost internal wiring is an additional $33.30.

Madisound is pleased to offer the Eton line of High-End loudspeakers. Eton's patented HEXACONE diaphragm, sandwiches a honeycomb shaped layer of Nomex between two layers of Kevlar. The resulting cone is extremely stiff and rigid, eliminating distortions caused by breakup resonances. The Eton woofers are very detailed and fast, yet smooth and natural sounding without coloration.

PHOTO 3: System rear view.

wood glue and installed two countersunk #8, 1¼″ particleboard screws through each side panel into the notch on the arch's bottom.

Now you're ready to attach the rear tower panel, tunnel, and front tower panel. As you did for the sides, attach BVD Pad rectangles to the insides of the front and rear panels as shown in Photo 10 (see Part 1), followed by ⅝″-thick foam rectangles on top of these Pads below the location of the upper shelf/brace. Apply carpenter's glue to the edges of the shelf/braces, edges of the vertical runners, and to the back of the top arch; then clamp the rear panel to the tower assembly (*Photo 16*).

Again, I installed one countersunk #8, 1¼″ wood screw into the center of each shelf/brace. I also ran three countersunk, #8, 1¼″ particleboard screws through the top of the rear panel into the arch. Once the glue on the rear panel has dried, seal all its inside seams with silicone sealant. Next, attach the midrange tunnel to the inside of the rear panel, using carpenter's glue and clamps (*Photo 17*). If you wish, you can also install some finishing nails or wood screws through the rear panel into the edges of the tunnel's four sides.

Note that the tunnel is not symmetrically located around the exit hole in the rear panel; it's offset so that the bottom edge of the tunnel top is aligned with the top of the exit hole. The tunnel should fit fairly tightly between the short pieces of 1″ MDF attached to the insides of the side panels.

SEALING THE ENCLOSURE

Before attaching the front panel to the tower, you should install the midrange wiring. Seal around this wire within and on both sides of the pass-through hole with silicone sealant. To attach the front panel I recommend using polyurethane glue, because you won't be able to reach in and seal all the inside front-panel seams with sealant after you attach the front panel.

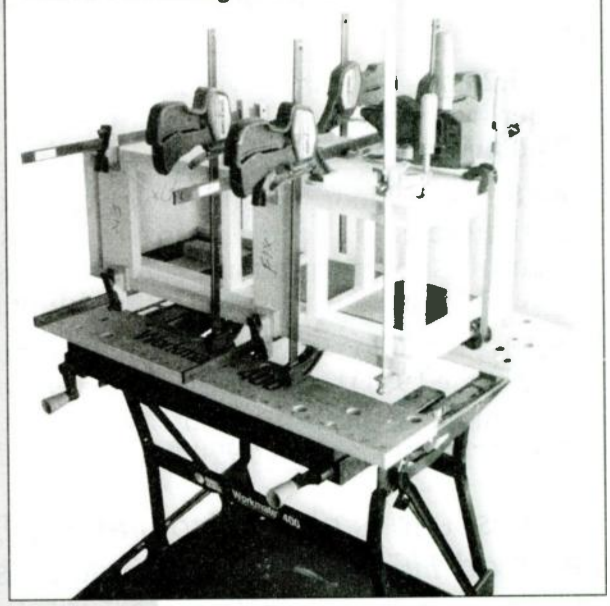
Polyurethane glue expands and oozes into all nooks, crannies, and seams as it cures, thus making a good seal. This glue is also moisture-cured, so slightly dampen the surfaces to be glued with a moist cloth or sponge and allow the moisture to soak in for about a minute. Apply the glue as directed on its container, then clamp and screw the front panel to the tower assembly (*Photo 18*) just as you did the back panel. Also, from each side of the tower and through the short piece of 1″ MDF, install one countersunk #8 or #9, 2½″ wood screw all the way into the tunnel sides.

When the glue in the towers has dried thoroughly, turn them upside down and locate the centers of the six

TABLE 1 (FROM PART 1)
CROSSOVER AND MISCELLANEOUS COMPONENTS

DESIGNATOR/NAME	VALUE, DESCRIPTION, (SUPPLIER)
L1	3.3mH, 0.22Ω, 16g, ferrite-core
L2	2.7mH, 0.29Ω, 16g, ferrite-core
L3	2.0mH, 18g, air-core
L4	0.75mH, 0.37Ω, 16g, air-core
L5	1.4mH, 0.55Ω, 16g, air-core
L6	0.25mH, 20g, air-core
C1	100μF, nonpolarized electrolytic
C2	50μF, nonpolarized electrolytic
C3	60μF, metallized polypropylene
C4	80μF, metallized polypropylene
C5	8.2μF, metallized polypropylene
C6	6μF, metallized polypropylene
C7	7μF, metallized polypropylene
C8	12μF, metallized polypropylene
C9	0.68μF, Mylar
R1, R6, R7	1Ω, 15W, ceramic
R2, R3	3Ω, 5W, ceramic
R4	2.2Ω, 10W, metal-oxide film
R5	1.8Ω, 10W, metal-oxide film
R8	18Ω, 10W, metal-oxide film
R9, R11	15Ω, 10W, metal-oxide film
R10	2.7Ω, 10W, metal-oxide film
R12	10Ω, 10W, ceramic
Woofer	25W/8565-01, Scan-Speak (Vifa)
Midrange	13M/8640, Scan-Speak (Vifa)
Tweeter	D2905/9300, Scan-Speak (Vifa)
Terminal cup	TD-CUP
Grille fasteners	Miniature male and female (ball & socket) sets (MAG)
Damping material	BVD Pad, 3 sheets at 18″ × 31″ (MAG)
Acoustical fill	Acousta-Stuf, 3 pounds (PE)
Acoustical foam	5/8″ thick, 1 sheet 27″ × 42″ (MSC)
Acoustical absorber	Deflex, "Subwoofer," 3 at 340mmDiameter (MSC)

PHOTO 14: Building the tower.



mounting holes on the bottom shelf/brace, matching them exactly to the same hole patterns in the flat tops of the cylinders. Drill out these holes and prethread them for #8 wood screws. It's also a good idea to slightly bevel the bottom front edge of the tower assembly, allowing the tower to fit the top of the cylinder a little better.

Locate the eventual position of the oak sub-panels on the towers' front panels, being careful to align the drivers' cutouts in both panels with each other, as well as centering them left to right. With the sub-panels temporarily clamped or taped in place, mark the locations of the 12 perimeter fastening holes and, with a pencil, draw the outline of the sub-panels onto the front panels. Remove the sub-panels and drill and prethread the 12 mounting holes for #8 particleboard screws. Temporarily install the oak sub-panels with a couple of screws.

Now place the upper grille boards around the sub-panels and clamp or tape them to the cabinet. As you did for the lower grille board, mark the front panel with the locations of the four grille-fastener holes. Remove the grille board and sub-panel, then drill out the front panel and the back of the upper grille board for the ball-and-socket grille fasteners.

PRELIMINARY SANDING

Before assembling the towers to the cylinders, you need to sand the tower arches and cylinder walls. If you were very careful during cutting and assembling, individual sections of these assemblies will be well lined up, without any significant peaks or valleys. But there are likely to be some variations from one section to the next, so it's best to sand and fill them now.

Do not repeat the mistake I made when building prototypes of the Danish Delights. If you use an electric sander having a compressible backing pad, the sander will ride on top of the hard glue joints and gouge the relatively soft MDF edges. This is the time to use the old-fashioned method of sanding by hand with a hard backing block. [Maybe a small block plane could work, also. – Ed.]

You need to sand with the curvature of these parts, not across the sections.

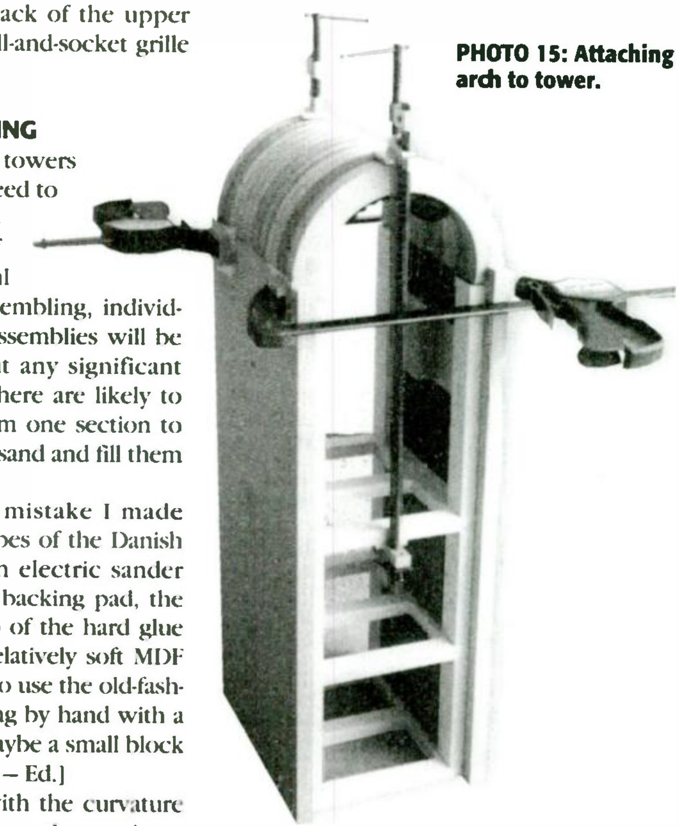


PHOTO 15: Attaching arch to tower.

TABLE 2 (FROM PART 1)
SIZES AND QUANTITIES OF WOOD PARTS
(Quantities are for two systems; all dimensions in inches)

SIZE	QUANTITY	FOR/DESCRIPTION
1″ MDF		
11¾ × 12½	24	Parts A and B
6 × 9½	12	Part F
1½ × 3	4	Side panel tunnel brace
¾″ MDF		
13½ × 13½	6	Parts C, D, and E
8 × 12	1	Tower assembly jig
3 × 8	4	Tower assembly jig
12 × 26*	4	Tower side*
9½ × 31	4	Tower front and back
6 × 9½	12	Part G
¾ BBP		
13½ × 13½	2	Lower grille board
6 × 10½*	4	Tunnel top and bottom*
8 × 10½*	6	Shelf/brace*
4-⅝ × 10½*	4	Tunnel side*
8½ × 26	2	Upper grille board
1½ × 11	8	Runner
1½ × 6	16	Runner
¼ MDF		
8¼ × 9¼	2	Crossover base
5¼ × 5¼	2	Tunnel grille board
½ SOLID OAK		
6-⅞ × 24	2	Sub-panel

*See text for correct width or length of these parts.

PHOTO 16: Attaching back panel to tower.

PHOTO 17: Installing the tunnel.

Yes, this takes time and is boring, but to get a good surface, it's the only way. Start by sanding down any high spots, and progress from fairly coarse, to medium, then to fine sandpaper. Add wood filler where necessary to fill seams or low spots.

Once you're happy with the surfaces of the cylinder and arches, fill all seams and countersunk holes in the tower with wood filler (you don't need to do this on the front panel of the tower where the oak sub-panel will be located—just don't leave any bumps there). Sand down smoothly all external surfaces of the tower, adding more wood filler and sanding further as necessary.

With a router and a round-over bit of ½″ radius, round off completely the outside edges of the tower, both front and back, then sand them smooth.

This is a good time to drill holes in the bottom of the cylinder base for inserts if you intend to use spikes. I used three Fowler Tiptoes®, two across the back of the base and one in the center of the front of the base. It might also be a good idea at this time to install tweeter wiring and Acousta-Stuf® in the tower. I used 3oz of Acousta-Stuf in each of the two bottom sections of the tower between the three shelf/braces. Now you're ready to attach the towers to the cylinders.

MORE POLYURETHANE GLUE

For the same reason I used polyurethane glue on the front panel of the tower, I used it to join the tower to the cylinder. Again, dampen the mating parts with water, allow the moisture to soak in for about a minute, then add the glue to one surface. Make sure also to dampen and use glue where the backside of the front assembly (part D) mates with the bottom front of the tower.

Set and center the tower left to right on the cylinder top and flush against the back of part D. From the inside of the cylinder, insert six #8, 1¾″ wood screws through the cylinder top into the tower bottom, using flat washers under the screw heads. Make sure the tower is centered squarely on the cylinder top and against the back of part D. Clamp as shown in *Photo 19* (both vertically and horizontally) and tighten the six screws firmly. Put one countersunk #8, 1¾″ particleboard screw through the top center of the parts D and E into the bottom of the tower front.

After this assembly has dried thoroughly, you can attach the back of the cylinder (part C). Use polyurethane glue again, plus clamps as shown in *Photo 20*. I also countersank several #8, 1¼″ particleboard screws around the perimeter of part C into the cylinder walls and the back of the tower. When using polyurethane glue, resist the urge to wipe off

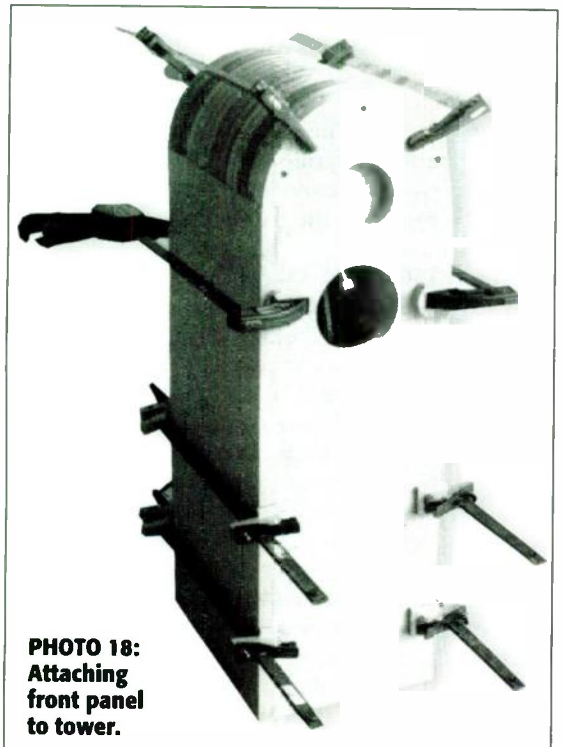


PHOTO 18: Attaching front panel to tower.

excess glue that seeps out of joints—simply let it dry. It's fairly easy to remove later by scraping and peeling.

FINAL SANDING AND PREPARATION

Make sure all countersunk holes are filled. You'll probably need to add some wood filler along the side seams between the bottom of the tower and the flat top of the cylinder, as well as where the four rounded tower corners meet the top of the cylinder. Take your time and be patient with this part of the process, because then you'll be much happier with the final result. In preparation for painting, vacuum the cabinet surface thoroughly, then wipe it down with a tack cloth. Since you don't wish or need to apply paint there, mask off the part of the front panels that will be covered by the oak sub-panels.

PAINTING

In the three spike-receptacle holes in the bottom of the base, I installed some long particleboard screws to act as feet. These allowed me to paint

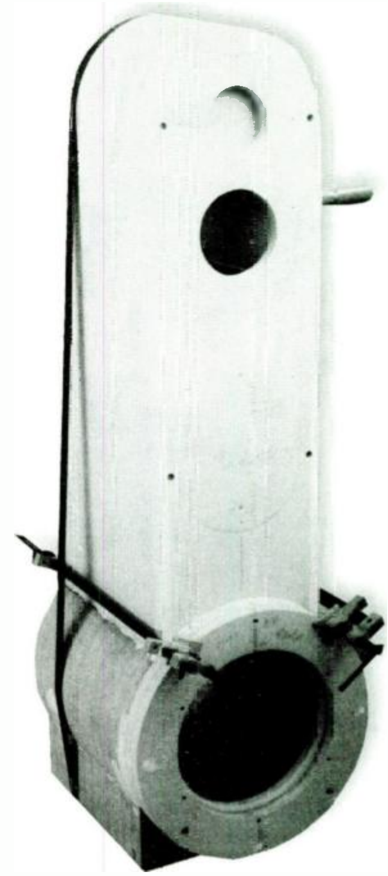


PHOTO 19: Mating tower to cylinder.

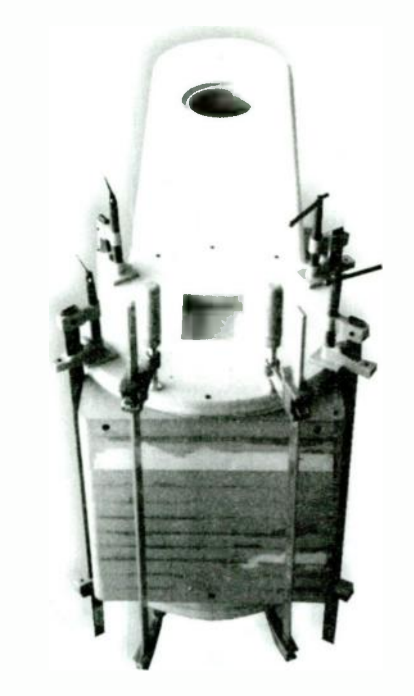


PHOTO 20: Attaching cylinder back.

the bottom and set the cabinet on the floor without messing up the newly painted area. I started with the cabinet lying on its front or back on top of my Workmate and temporarily removed these three screws. I painted the bottom, sides, and fronts and backs of the base, as well as under the cylinder at its front and back, turning the cabinet over on its other face as necessary. Then I reinstalled the screws in the base holes and set the cabinet on the floor on the screw heads for the rest of the painting.

I brushed on two coats of white primer and sanded with fine sandpaper after the second coat had dried thoroughly. With a stippling roller, I applied three coats of white, 100% acrylic paint over the primer, sanding very lightly between the second and third coats where needed. Using the stippling roller gives a textured finish that hides minor surface imperfections. Professional painters call these types of rollers "carpet" rollers because the material looks much like that used for carpets.

To enhance the textured effect, I lightly rolled over the paint just as it was becoming tacky without adding more paint. It takes practice to get the desired effect, but after finishing six pairs of speakers this way, I've become quite good at it. In areas where it's difficult to use the roller, I used the edge of a dampened paint-dipped sponge as a stippling dauber (first making sure the sponge was really clean). I allowed 72 hours drying time after each coat of finish paint before applying the next coat or proceeding with final assembly.

To finish the sanded surfaces of the oak sub-panels, I applied two coats of oil-based stain as directed on its can, and, after the stain had dried for 72 hours, I sprayed on three coats of clear satin polyurethane. After the clear coat had dried, I covered the entire back surfaces of the sub-panels with a layer of the BVD Pad, and trimmed away the BVD from the driver cutouts and around the holes for the perimeter mounting screws.

After sanding, the three grille boards for each cabinet need slightly different finishing. The lower boards need one coat of primer, followed by spraying with black paint on all surfaces. The upper boards need the same (but not on their backsides, which you leave completely unfinished). Finally, if you make the small grille boards for covering the tunnel exits, they need only priming with white paint on the front surfaces and edges (again, leave their backsides unfinished).

FINAL ASSEMBLY

Using grille cloth of your choice, cover the three grille boards. I used tan cloth for the upper and lower grille boards and white cloth, to blend with the paint, for the tunnel-exit grille. I prefer to attach the cloth to the backs of the grille boards with contact cement.

To do this, I use masking tape to temporarily attach the cloth to the back of the grille board on one side. On the opposite side, I brush contact cement onto the back of the board and allow it to set for a few minutes. Then, I stretch the cloth and stick it onto the contact cement. With one side attached, I remove the masking tape and attach the first side of the cloth to the board similarly.

Don't stretch the cloth too tightly across the width of the upper grille boards; if you do so, you may make its opening too narrow to fit properly around the oak sub-panels. Cut the cloth for all of the grille boards to allow at least a ½" overlap on the back. On the upper board, I overlapped the entire width of the frame on its back (and the same on the frame of the tunnel grille). After the contact cement dries, you can trim away any excess cloth with a razor blade or hobby knife.

Insert the male (ball) parts of the grille fasteners in the backs of the upper and lower grille boards. On the upper board, I cut holes in the overlapped cloth and inserted the balls' fasteners through the cloth. I attached the tunnel grille-board assembly by spot-tacking it in four places with silicone sealant. This bond is strong enough to hold the grille securely, yet will allow you to remove it, if necessary, without damaging the wood of the cabinet.

TERMINAL-CUP INSTALLATION

Place the cabinet with its back down on a sturdy work surface, being sure to protect its finish. In the front panels install all eight female (socket) parts of the fasteners for both grilles. Then turn the cabinet on its face and install the terminal cup with screws through its mounting holes. You should already have soldered wires to its two pairs of binding posts and terminated the opposite ends of the wires properly for crossover connections. The terminal cups I used came with a sealing gasket attached to their mounting flanges. If you use cups without such gaskets, use some adhesive-backed foam tape for this purpose.

Turn the cabinet on its back again and attach the oak sub-panel with 12 particleboard screws through the holes in its perimeter. Set the midrange and tweeter drivers into their cutouts, mark the locations of their mounting holes through their flanges, and then remove them. Drill these mounting holes completely through the oak sub-panel and the baffle, making them large enough to accommodate T-nuts—four at 8-32 for the tweeter, and three at 6-32 for the midrange.

Install the T-nuts by inserting them from the rear of the holes, pulling each one up tight with a bolt, flat washer, and screwdriver from the front of the sub-panel. You may need to snip off about one-third of the circumference of the T-nut flanges in order to have enough clearance. Vacuum out any wood shavings or dust that may have fallen into the cabinet. If you drilled the base for spike sockets or wish some kind of feet on the bottom, install these now.

ATTACHING THE DRIVERS

Setting the cabinet on its base, install the crossover with #8, 1¼" particleboard screws, and connect the wiring for all three drivers to the crossover outputs. Lay the cabinet on its back again. The woofer and tweeter must be sealed tightly to the cabinet when they're installed. You can use adhesive-backed foam tape for this, which is what I used for the woofers, attaching this tape to the cabinet or the back of the drivers' mounting flanges.

For the midrange and tweeter, I cut ½″-wide sealing gaskets from 0.040″-thick, adhesive-backed Neoprene rubber. I attached the adhesive side of the gaskets to the flange recesses in the oak sub-panel and poked holes through the gaskets for the mounting bolts. Even though the tunnel is completely sealed off from the rest of the cabinet, eliminating the need for a seal under the midrange flange, this gasket provides another small measure of isolation from cabinet vibrations.

I installed more Acousta-Stuf in the cabinet—8oz in the midrange tunnel (densely packed), 3oz behind the tweeter, and 6oz behind the woofer (use the wiring to the crossover to keep the Acousta-Stuf from actually touching the back of the woofer). The last steps are to attach wiring to all three drivers and mount them to the cabinet. For future accessibility I used crimped, solderless, slip-on connectors over the woofer terminals.

I wished to do likewise on the tweeter and midrange, but couldn't because their terminals were too small and flimsy. Instead, I soldered short lengths of wire to their terminals and terminated the other ends with inline, crimped, solder-less terminals. Of course, the wires coming from the crossover for these two drivers must have mating inline terminals on their ends.

If you don't think you'll have any need or desire to easily disconnect your drivers later, you can solder all connections (the sound is supposedly better with soldered connections). Be very careful when soldering to driver terminals; too much heat can damage driver coils, especially those for tweeters. Now snap on the front grille boards, and you're ready to listen.

PLACEMENT AND SOUND

In my listening room I separated my two cabinets about 6′ as measured from their centers. My "sweet spot" chair is 8′ away from the cabinets' fronts when I locate them about 2′ away from the wall behind them. With this arrangement, toeing in the cabinets until I can still see some of the inner sides gives very good results. Sitting farther away would require a smaller toe-in angle, while spreading the cabinets further apart would require a larger toe-in angle.

The speakers produce a soundstage width slightly beyond their outer sides, have good imaging and depth, and create a surprisingly realistic illusion of the height of the original venue. If you have a larger room or fewer restrictions, you may find that other arrangements produce better sound. When I play background music at fairly low volume levels, I place the speakers against the wall. The closeness of the wall reinforces the bass, thus compensating for my hearing's natural loss in the low frequencies.

I didn't do anything special to break in the drivers, but just played music through them, and I didn't keep track of break-in hours. The tweeter's sound did not change much over time. Both midrange and woofer seemed to take a fairly long time to loosen up, but both sounded pretty good from the start. Actually, I had already thoroughly broken in the drivers in prototypes of the Danish Delights I'd built previously. When I completed the version described here, the drivers were ready to go.

PROTOTYPE PROBLEM

While the point of this article is to tell

you about these and not the prototypes, the prototypes did have one problem that I eliminated in this newer design: a big dip existed in the woofer's response at about 125Hz, apparently resulting from the cabinet's internal height dimension causing a standing-wave cancellation. I was able largely to eliminate the problem by judicious use and location of various fill materials, but the low-frequency performance always seemed a little sluggish and stifled. In this newer version, however, the use of Deflex has cured the problem. The close-miked woofer measurements proved Deflex does indeed work as advertised.

Three other changes from the prototype to this version offered additional improvements: an increase of about 17% in the enclosed volume lowered both Q_{TC} and f_3; making the mounting baffle for midrange and tweeter a composite improved clarity; and switching from an all-second-order crossover to the more complex one used here decreased distortion.

I really enjoy listening to music played through the Danish Delights (I really like their looks, too, but my viewpoint is hardly objective). Their basic characteristic is one of ease, without, however, sounding rolled-off, or "slow," or lacking in their reproduction of percussive sounds or other transients. I'm often surprised by their ability to define the original venue; you can "hear the walls," so to speak. Recordings sound the way the recording engineers wished them to sound. All voices and instruments sound good and adequately realistic, but especially percussion, piano, and massed brass.

The downside is that defects in recordings are more apparent; inferior recordings aren't glossed-over by speaker limitations. On the bright side, though, superior recordings are that much more enjoyable. Are the sounds produced by the Danish Delights worth the difficulty in building them? I must answer with a firm yes, and I don't regret a single drop of sweat or any moment of frustration.

Reader inquiries can be sent directly to the author at bpkit@worldnet.att.net.

SUPPLIERS

Meniscus Audio Group (MAG)
4669 S. Division
Wyoming, MI 49548
(616) 534-9121

Madisound Speaker Components (MSC)
8606 University Green
Madison, WI 53744
(608) 831-3433

Parts Express (PE)
725 Pleasant Valley Dr.
Springboro, OH 45066
(513) 743-3000

Vifa/Scan-Speak USA (Vifa)
1860 Renaissance Blvd.
Sturtevant, WI 53177
(414) 884-4580

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After some more response testing of the satellite and subwoofer, it's time to box the drivers, construct the crossover, and take a listen.

Part 3

The Menehune MX-1

A Compact Satellite/Subwoofer System

By Jim Moriyasu

MEASUREMENTS

A full-range system measurement is shown in *Fig. 64*. I accomplished this by splicing a gated measurement to a ground-plane sweep at 250Hz. Relative to 100Hz, it looks as though the f_3 is 35Hz. The overall system response is ±1dB from 35Hz to 20kHz. Compared to the simulation, there is 0.5 to 1dB deviation in several areas. Usually, this is because the "parasitic" resistances of the capacitors used in the crossover are a little higher than assumed in the simulation.

Figure 65 shows the satellite system impedance, which drops as low as about 5Ω at 250Hz and reaches a high of around 16Ω at 70Hz and 1.6kHz. This also shows the difference between the constant-voltage and constant-current methods, the former showing an impedance peak at 80Hz while the latter shows a peak at 90Hz. The woofer impedance curve is seen in *Fig. 66*. While the low is at 5Ω at 200Hz at the f_C, at 32.28Hz it is 5.4Ω.

Reversing the tweeter phase results in a 13dB dip at 1.8kHz. This is shown in *Fig. 67*, where I have truncated the frequency scale to show only the gated measurement. This is reasonably close to the simulation and may be more a function of the microphone placement.

The midbass and tweeter responses with the crossover are shown in *Fig. 68*. Compare this with the simulation in Fig. 43 (in Part 2). And although the measurement is becoming ragged, it looks as though the tweeter's SPL response is at 55dB at 800Hz, which compares closely with the simulation in Fig. 31 (Part 2).

SATELLITE RESPONSES

The satellite on-axis and 15° horizontal off-axis response is shown in *Fig. 69*. Less than 1dB of deviation from on-axis occurs until 13kHz. The 30° and 45° off-axis responses are shown against the on-

PHOTO 1: Scan-Speak D2905/9300, Morel MW142, and Vifa M22WR ready for SPL testing.

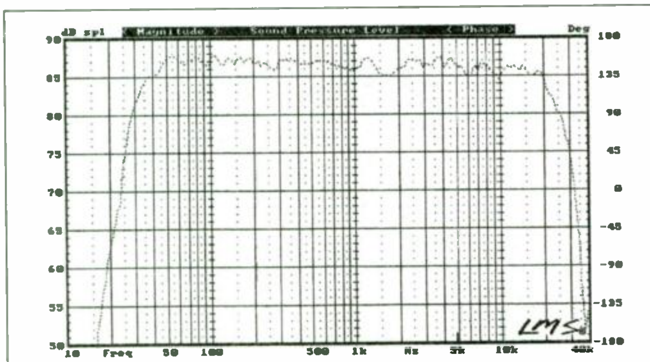

FIGURE 64: Actual full-range system SPL of ground-plane measurement splice to gated sweep at 250Hz.

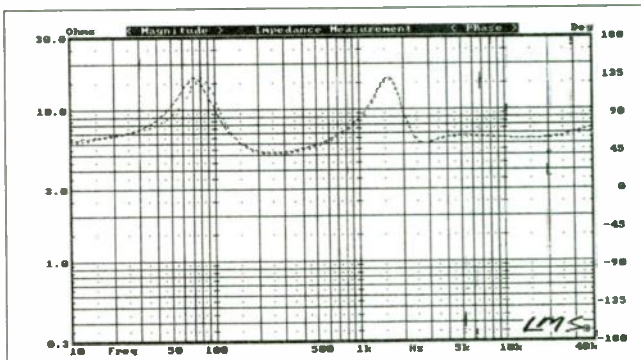

FIGURE 65: Satellite impedance measured with constant-voltage and constant-current method.

axis response in *Fig. 70*. The 30° off-axis response is down by 1dB starting at 1kHz, but turns up at 2.5kHz as the tweeter response takes over. It gradually drops by about 2dB until 12.5kHz, where it begins a steeper decline.

The 45° off-axis response is down 2dB starting at 1kHz; then it turns up at 2.5kHz and is down 5dB at 10kHz. These off-axis measurements indicate a fairly broad power response that is not very smooth because of the abrupt increase at 2.5kHz.

At 15° above the tweeter, a narrow 6dB dip develops at 4kHz (*Fig. 71*). Otherwise, the response is relatively smooth, indicating that a standing listener should experience little change. At 30° above the tweeter, the dip shifts lower in frequency to 1.8kHz, but is still relatively shallow and narrow (*Fig. 72*).

The response deviates more below the tweeter axis, since the midbass cone forms a cavity that helps to disrupt the response. As you see in *Fig. 73*, a 6dB dip at 2.6kHz is followed by a 2dB peak at 4.7kHz, and at 30° below the tweeter axis, a relatively wide 12dB dip develops (*Fig. 74*).

The woofer's response is seen more clearly in *Fig. 75*, where the frequency scale is truncated to 1kHz. The in-phase connection, the top trace, shows that the low- and high-pass responses have summed smoothly. Remember, though, that this is with the woofer polarity reversed.

The out-of-phase connection shows a 17dB dip null or cancellation, which is 5dB better than predicted in the simulation in Fig. 60 (Part 2). The separate responses of the woofer and midbass (*Fig. 76*) indicate that the two cross over close to 175Hz. Also, note that the midbass response is at 67dB at 80Hz, which should be low enough to avoid problems with its f_C at higher levels.

TIME-DOMAIN MEASUREMENTS

In the time domain, I made measurements with Liberty Audiosuite at 1m on the 7′ lift. Since the satellite sits on the subwoofer, it is closer to 9′ off the ground, providing for a 14ms time window free from reflections. There are no resonances showing in the satellite response in the cumulative spectral-decay plot of *Fig. 77*. The midbass response dominates the plot below 2kHz. Be-

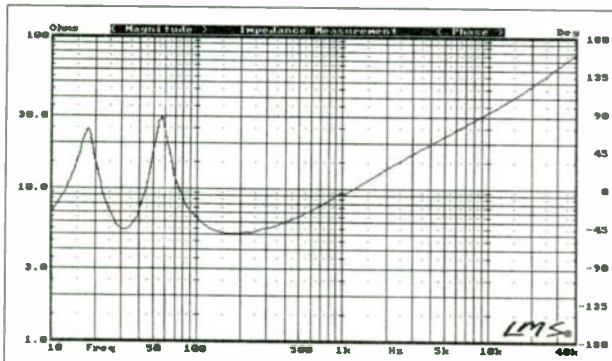

FIGURE 66: Woofer impedance measured with constant current.

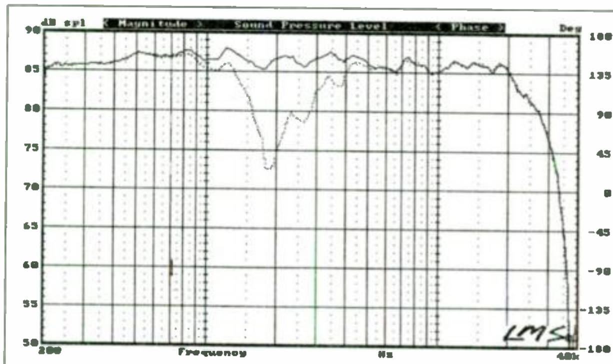

FIGURE 67: Comparison of system SPL with midbass and tweeter "hooked up" in-phase and reverse-phase.

FIGURE 68: Comparison of midbass and tweeter SPL responses and system SPL response.

cause of the fourth-order crossover, there is no sign of the mid-woofer's resonance ridge at 4kHz that was visible in Fig. 21 (Part 2).

To evaluate the cabinet panels for resonances, I attached an AMP accelerometer with double-stick carpet tape to the front panel of the woofer cabinet, just below the woofer. I fed the output from this device directly into LAUD's mike input, and the resulting impulse was converted into a waterfall plot. With a 60ms window, resonances showed up as long ridges that slowly decayed.

Figure 78 shows that the WS803 cabinet without bracing or panel damping has resonances at 200Hz and 800Hz. Even though I'll use the woofer with the XVR-1 active crossover, *Fig. 79* shows that the 200Hz resonance still could be a problem. *Figure 80* reveals that with the addition of a U-shaped brace made of ¾″ × 1½″ MDF, the 200Hz resonance has moved up to 300Hz and is down by about 7dB. The 800Hz resonance is lowered by 7dB, but another resonance has appeared at 1.3kHz.

However, with the XVR-1 active low-pass crossover in place (*Fig. 81*), the 300Hz resonance is down by 11dB and should not be much of a problem. Initially I tested the woofer cabinet with two ½″ hardwood dowels installed between the front and back panels (*Fig. 82*). While the 200Hz resonance decreased by 5dB, it split into two resonances that later reformed into one!

The satellite front panel had a significant resonance at 400Hz (*Fig. 83*). However, a 4¾″ × ½″ hardwood dowel braced between the front and the back panel and just above the woofer damps the resonance by 10dB (*Fig. 84*).

HARMONIC DISTORTION

I used Liberty Audiosuite to measure harmonic distortion. To test the woofer, I placed it out in the driveway more than

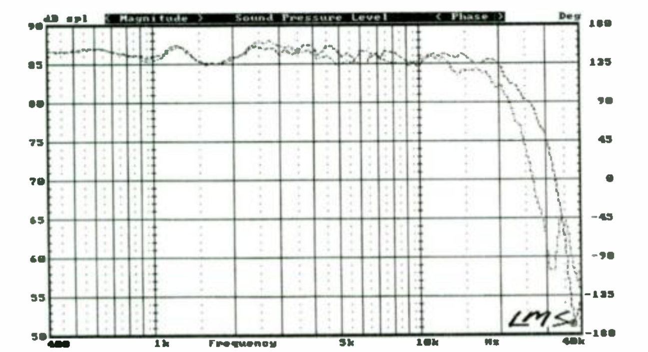

FIGURE 69: The satellite's measured on-axis SPL response compared to 15° horizontally off-axis.

FIGURE 72: The satellite's measured on-axis SPL response compared to 30° above tweeter.

FIGURE 70: The satellite's measured on-axis SPL response compared to 30° and 45° horizontally off-axis.

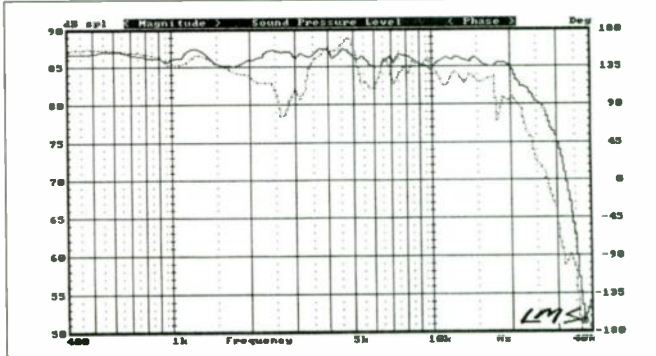

FIGURE 73: The satellite's measured on-axis SPL response compared to 15° below tweeter.

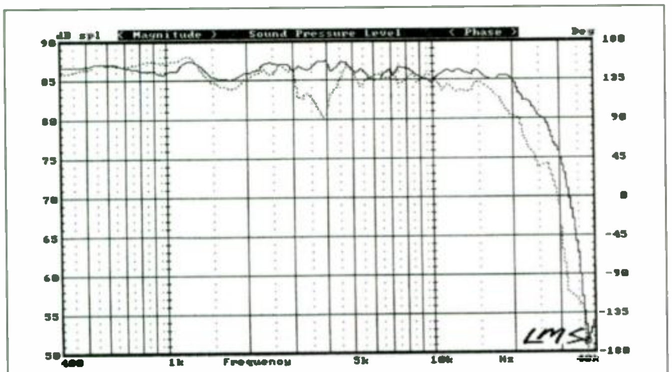

FIGURE 71: The satellite's measured on-axis SPL response compared to 15° above tweeter.

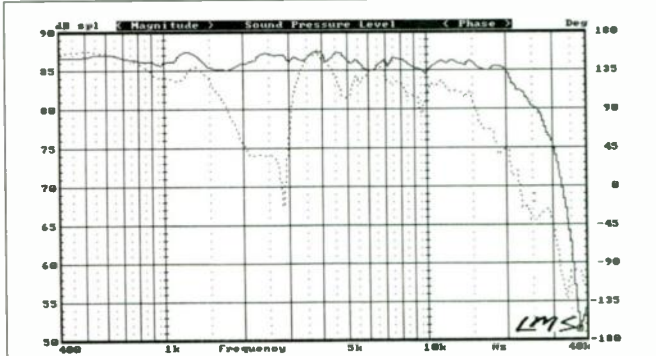

FIGURE 74: The satellite's measured on-axis SPL response compared to 30° below tweeter.

20′ from the workshop, and positioned the microphone at a distance of 1m on-axis with the woofer, which was tested between 20Hz and 250Hz with 38W of input.

Figure 85 shows the total harmonic distortion (THD) of the woofer with 38W. The THD remains below 10% until 30Hz, where it begins to climb rapidly until it reaches 100% by 20Hz. However, with the XVR-1 in place (*Fig. 86*), the THD is considerably curtailed, since it reaches only 25% at 20Hz. Since output below 35Hz is dominated by the vent, a larger vent would probably result in a lower figure.

I then measured THD for the subwoofer and satellite at 16W out to 20kHz at a 99dB level. Above 100Hz, distortion remains below 2% for the most part (*Fig. 87*). *Figure 88* shows second- and third-harmonic distortion. The tweeter and woofer have more second-harmonic products, while the midbass has more third harmonics.

I then switched to a gated measurement by placing the subwoofer and satellite on a 7′ stand and positioning the microphone at a distance of 2m on-axis with the tweeter. Because of the gating, I made the measurement from 300Hz. With 16W of input, the satellite's THD was mostly below 1%, with occasional peaks above 2% (*Fig. 89*). Second- and third-harmonic distortion is shown in *Fig. 90*.

The woofer's and satellite's step response (*Fig. 91*) shows

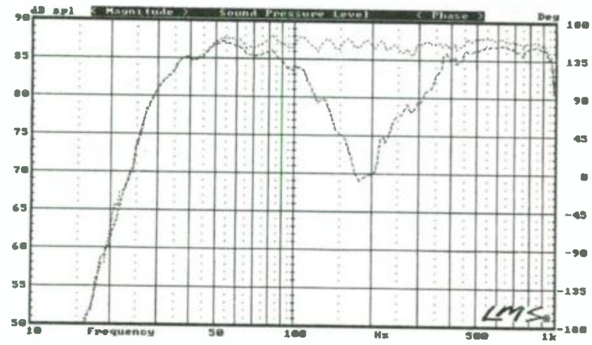

FIGURE 75: Comparison of system SPL with woofer "hooked up" in-phase and reverse-phase.

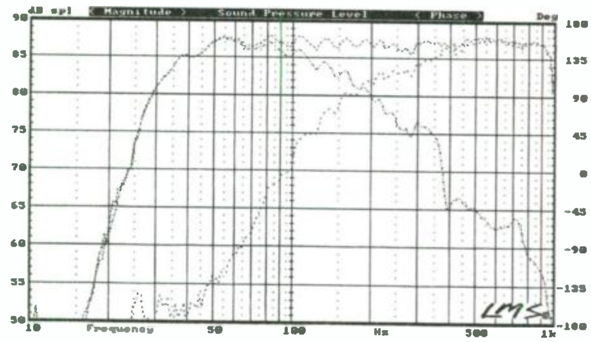

FIGURE 76: Comparison of midbass and woofer SPL responses and system SPL response.

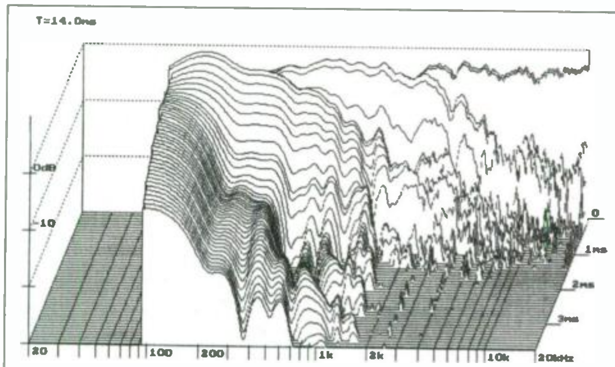

FIGURE 77: Cumulative spectral-decay plot of system measured at 1m.

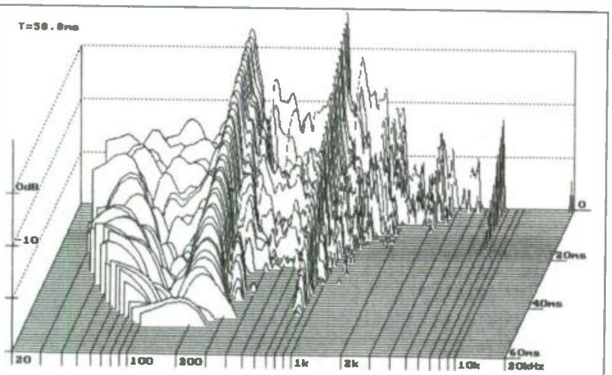

FIGURE 78: Cumulative spectral-decay plot of woofer cabinet without bracing and without active crossover.

the time delay caused by the physical differences in the drivers as well as the delay caused by the higher-order crossover. The midbass lags the tweeter by about 275µs. Since the measured physical time delay was 63µs, this suggests the crossover adds more than 200µs of delay.

The broad dip of the woofer, which is between 2 and 4ms, shows that it is connected reverse-phase. Measured group delay (*Fig. 92*) shows that the midbass lags the tweeter by 200–250µs.

Finally, I measured the satellites' response with their grilles in place and compared that to their response without grilles (*Fig. 93*). As you would expect, the 0.75″-thick grille causes the response to vary by plus or minus 2dB except at 3kHz, where it causes a 7dB cancellation.

THE SATELLITE ENCLOSURE

Using a fly cutter on a 16″ drill press, cut a 3⅛″ hole for the Scan-Speak 2905/9300 3½″ down from the top and centered 4″ from each side of the Woodstyle WS602 cabinet. The hole for the Morel MW142 is 4 11/16″ in diameter, up 3 9/16″ from the bottom of the cabinet, and centered 4″ from each side of the cabinet. See *Fig. 94* for details.

With a rabbeting bit, cut a ½″-wide by ⅛″-deep rabbet along the face of the tweeter and midbass holes. The tweeter will sit flush; the midbass will be up just slightly, but since its edge is slightly radiused, it will look okay. The Woodstyle cabinets are already painted a glossy black, but the rabbeting will leave an unfinished edge. I like a clean look, so I masked off the rest of the cabinet and sprayed the front with flat black latex enamel.

Drill 7/64″ holes for the input cups. Madisound supplies a GB-Cup input panel with gold-plated binding posts. The Woodstyle cabinets come with holes for the input cups. Solder the con-

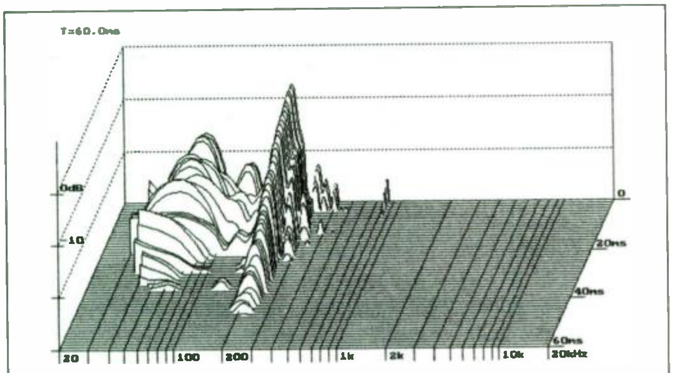

FIGURE 79: Cumulative spectral-decay plot of woofer cabinet without bracing but with active crossover.

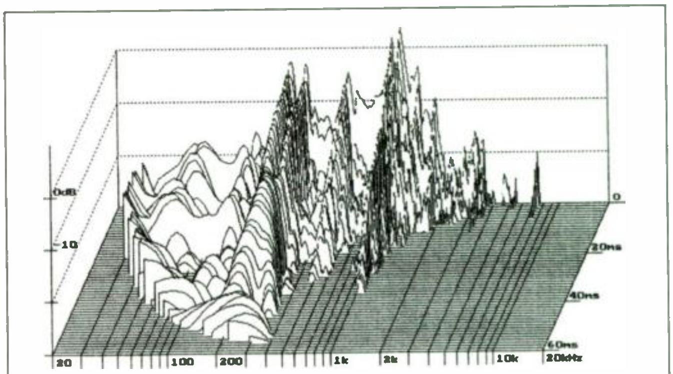

FIGURE 82: Cumulative spectral-decay plot of woofer cabinet with two ½″ hardwood dowels and without active crossover.

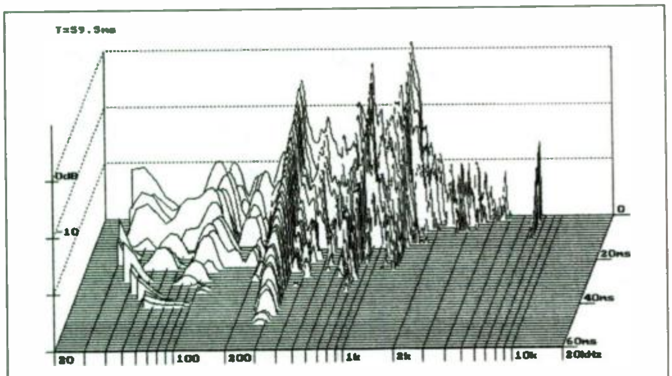

FIGURE 80: Cumulative spectral-decay plot of woofer cabinet with U-shaped brace and without active crossover.

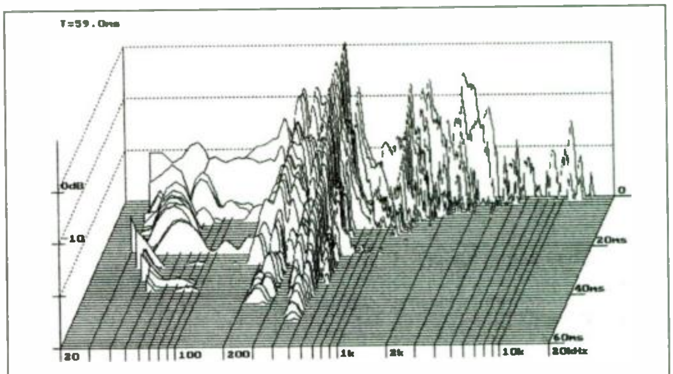

FIGURE 83: Cumulative spectral-decay plot of satellite cabinet without bracing and without active crossover.

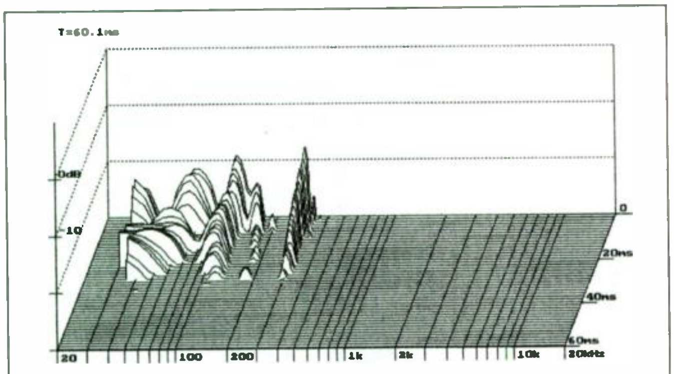

FIGURE 81: Cumulative spectral-decay plot of woofer cabinet with U-shaped brace and with active crossover.

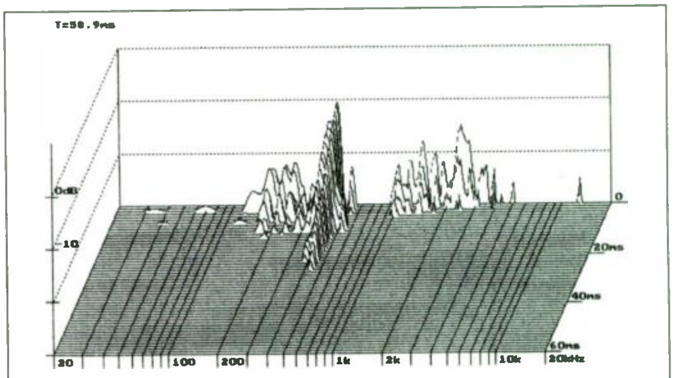

FIGURE 84: Cumulative spectral-decay plot of satellite cabinet with front-to-back ½″ dowel and without active crossover.

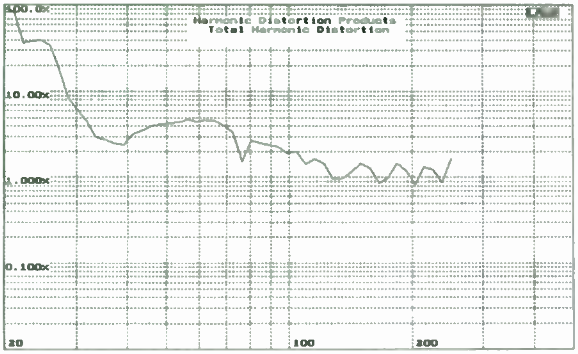

FIGURE 85: Ground-plane measurement of unfiltered woofer's total harmonic distortion at 1m with 38W.

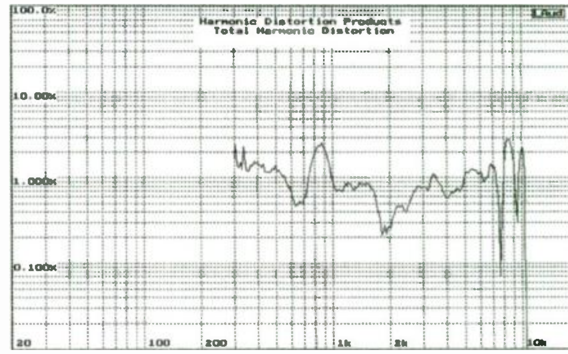

FIGURE 89: Gated measurement of system's total harmonic distortion at 1m with 16W with active "rumble" filter.

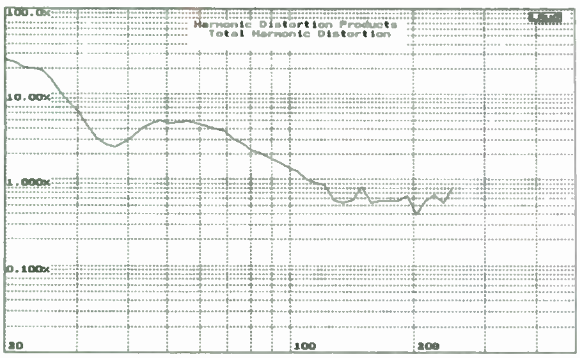

FIGURE 86: Ground-plane measurement of woofer's total harmonic distortion at 1m with 38W with active "rumble" filter.

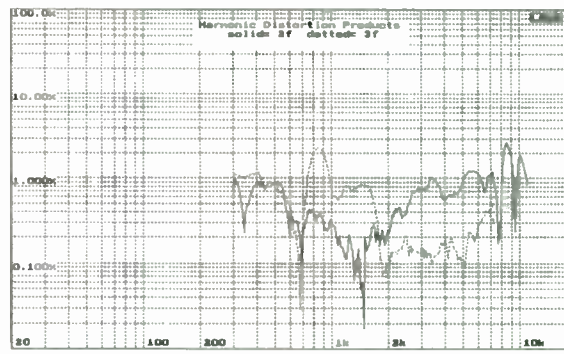

FIGURE 90: Gated measurement of system's second- and third-harmonic distortion at 1m with 16W with active "rumble" filter.

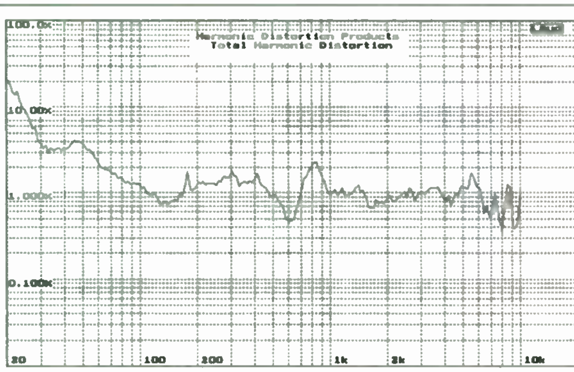

FIGURE 87: Ground-plane measurement of system's total harmonic distortion at 1m with 16W with active "rumble" filter.

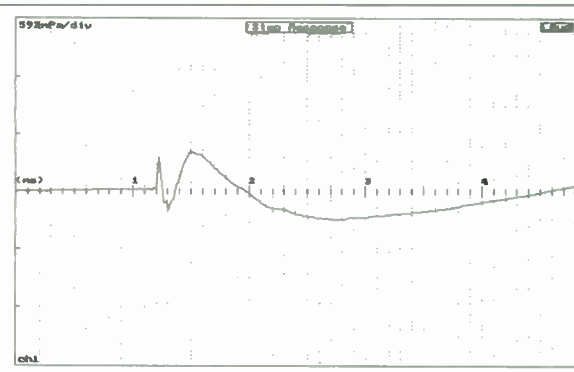

FIGURE 91: System step response measured at 2m on 7′ stand.

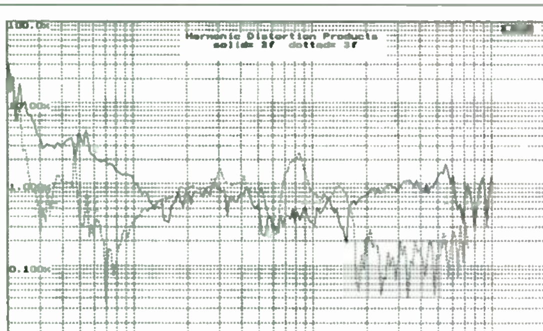

FIGURE 88: Ground-plane measurement of system's second- and third-harmonic distortion at 1m with 16W with active "rumble" filter.

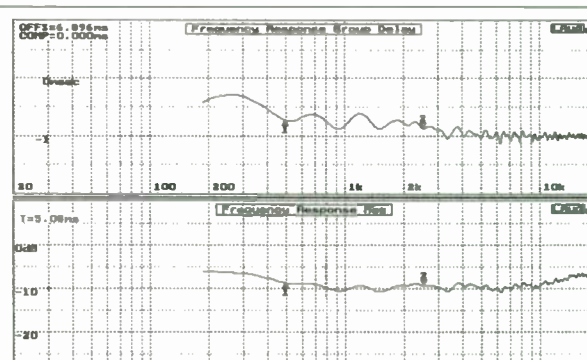

FIGURE 92: System group delay measured at 2m on 7′ stand.

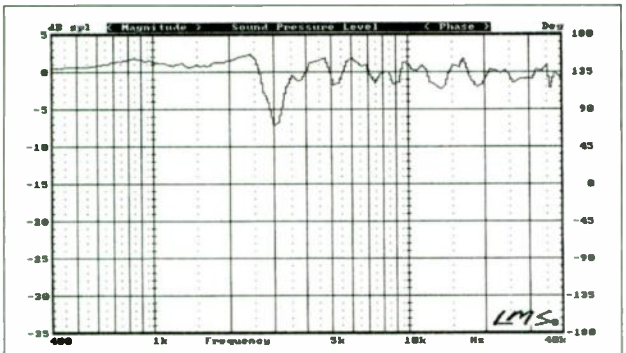

FIGURE 93: Net changes to SPL caused by grille frame.

necting wires to the binding posts, making sure you get the correct polarity with the wire color or marking, and attach the cups with four #6, ¾″ screws. (I would get them from Madisound or Meniscus when you order drivers and crossover parts.)

To help damp front-panel resonances, install a 4¾″ × ½″ hardwood dowel between the front and back panel just above the woofer. I damped the cabinets by placing 90 grams of Acousta-Stuf evenly into the enclosure.

THE SUBWOOFER ENCLOSURE

Center the 7⅜″-diameter hole for the Vifa M22WR 6″ from either side and 6″ down from the top of the cabinet. I again used my fly cutter on the 16″ drill press.

The hole for the port is centered 6″ from each side and 3¼″ up from the bottom on the front of the cabinet. It is 3 31/64″, just 1/64″ less than 3½. I suggest you drill some test holes in scrap wood to make sure the 3″ ABS pipe fits snugly in the hole (*Fig. 95*).

The ports for the M22WR are made out of black 3″ ABS pipe and are supposed to be 16¼″ long; however, since the cabinet is shallow, only 8¼″ deep, I used a 90° long-sweep elbow. Don't confuse it with the shorter elbow, which, because of its abruptness, will produce more disturbances to the air flow through the port.

For the front piece that sits flush with the face of the cabinet, cut a 2⅜″ piece of 3″ ABS, using a 6″ band saw if available. Then lay a sheet of 100-grit sandpaper on a flat surface and run the 2⅜″ piece over it to smooth the cut surface; follow that procedure with 230-grit. Since this edge of the port will be flush with the front baffle, it would be nice to have it smooth. Bevel the other end of the piece lightly with a medium file to make it easier to push into a hole.

Installing the port is fairly straightforward, but I recommend you try inserting the 2⅜″ piece only ¾″ into the front baffle, then bringing the elbow up from inside the cabinet. Tap the 2⅜″ piece down just ¾″ so the bottom is flush with the inside of the front panel. Then, holding the elbow up to the 2⅜″ piece, tap the top of it until it goes into the elbow and is flush with the cabinet front; I used a little three-in-one oil to keep the pieces from binding.

FITTING THE PORT

The pipes fit tightly, but I recommend a little wood glue or instant glue to fill the seams. For a nice cosmetic touch, I used a ¼″ rounding-over bit in a hand-held router along the inside edge of the port. The tiny flare probably has minimal impact on the airflow. I actually ordered a pair of flared ports but found they were an odd dimension (2½″), and I couldn't find a suitable elbow at the hardware store. Anyway, an elbow probably defeats the purpose of a flared port, which is to optimize airflow.

Calculating the correct length for the port is a problem because of the elbow. I averaged the length of the long side of the port with the short end to come up with 6¼″. Since the front piece is 2⅜″ and you need 16¼″ to tune the cabinet to 32.5Hz, cut the second piece to 7⅝″. I

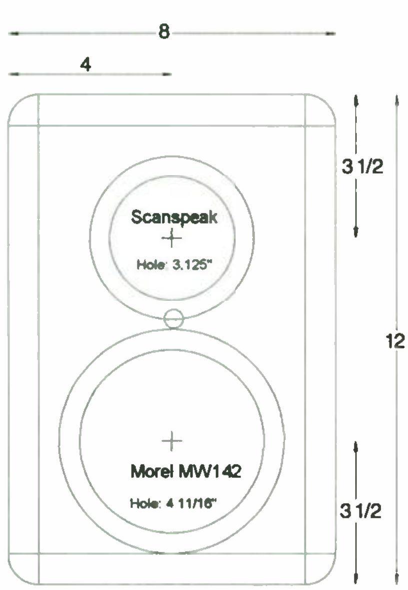

FIGURE 94: Satellite construction details.

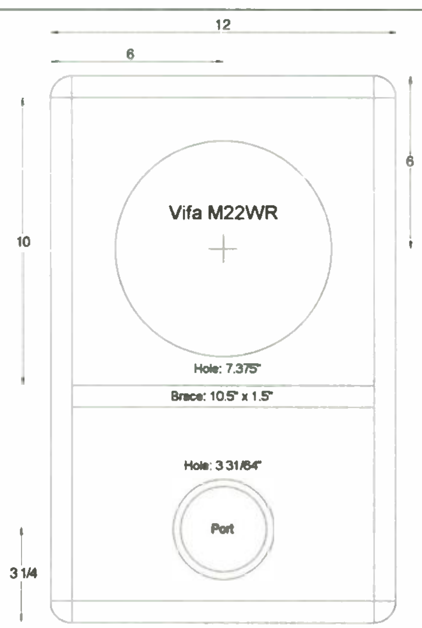

FIGURE 95: Woofer construction details.

TABLE 1
PARTS LIST

2	Scan-Speak D2905/9300, 1″ tweeter, from Meniscus
2	Morel MW142, 5″ midbass, from Meniscus
2	Vifa M22WR, 8″ woofer, from Meniscus
2	Woodstyle WS803, .88ft^3 cabinet, clear finish, from Madisound
2	Woodstyle WS602, .189ft^3 cabinet, clear finish, from Madisound
4	GB cup, input panel, from Madisound
1	Sheet of 1″ open cell foam for damping, hardware store
1	Acousta-Stuf, 1 lb, Mahogany Sound
1	3″ black ABS plumbing pipe (usually 8′ length), hardware store
2	90°, long-sweep, elbow, 3″ ABS plumbing pipe, hardware store
24	#6 × ¾″ black screws, from Meniscus
12	#8 × 1″ black screws, from Meniscus
1	Roll of foam weather-stripping tape, from Meniscus
1	8′ of 16-gauge wire, red/black jacket, from Parts Express
CROSSOVER PARTS (FROM MENISCUS)	
2	L1, 1.0mH, 16 ga, .11Ω, 500W, Quantum super ferrite
2	C1, 9.0µF, 250V, 5%, Solen
2	R1, 7Ω, 15W, 5%, wirewound sand filled
2	C2, 22µF, 100V, 10%, nonpolar electrolytic
2	C3, 6.2µF, 250V, 5%, Solen
2	C3, 1.0µF, 250V, 5%, Solen
2	C3, 0.22µF, 250V, 5%, Solen
2	L2, .3mH, 16 ga, .23Ω, 500W, air-core
2	C4, 12.0µF, 250V, 5%, Solen
2	C4, 2.0µF, 250V, 5%, Solen
2	C5, 3.0µF, 250V, 5%, Solen
4	R2, 5.6Ω, 10W, 2%, Lynx
2	R3, 10Ω, 10W, 2%, Lynx
2	R3, 1Ω, 10W, 2%, Lynx
Note: C3, C4, and R2 are paralleled to produce the specified value	
ELECTRONIC CROSSOVER	
XVR-1, from Audio Arts	

took several impedance measurements to verify the correct length.

Install a 10½″ × 1½″ × ¾″ brace on the inside of the front panel. It should have the ¾″ face connected to the front panel for stiffness. A healthy amount of yellow glue and two C-clamps do the trick. Then glue into place two 6¾″ × 1½″ × ¾″ braces onto each side panel, forming a U-shaped brace that stiffens each side and the front panel.

Line the cabinet with 1″ open-cell foam; I purchased a 30″ × 72″ sheet from Eagle Hardware for $12. If you size the pieces properly, they should hold themselves in place; for example, the piece that covers the top panel should be held up by the pieces that cover the sides.

Photo 2 shows the speaker system on my Load Jockey 350, a manual forklift commonly used by the air-conditioning installation industry to install ducts. Hence, they are commonly called "duct"

PHOTO 2: Subwoofer/satellite system on Load Jockey 350.

lifts. It has a 350 lb capacity and a lift range of 3′ to 7′.

Photo 3 shows the LMS M-31 microphone mounted at the end of a ½″ × 30″ aluminum tube attached to the top of a stand I made from a telescoping extension pole that is commonly used for domestic cleaning and often found in hardware stores. The mike stand can extend from 6′ to 12′ in height.

PHOTO 3: LMS M-31 mike on homemade mike stand.

CROSSOVER CONSTRUCTION TIPS

Since the satellite enclosures are relatively small, I installed the crossover parts for the tweeter and the mid-bass on separate ¼″ plywood boards, the midbass section measuring 3.5″ × 4″ and the tweeter section 3.5″ × 6″ (*Figs. 96* and *97*). I soldered the parts to terminal strips attached to the plywood with ¼″ screws, and tied the inductors into place with some copper magnet wire, since I've found that plastic ties fail after a few years. I also glued the capacitors and resistors with hot-melt glue to minimize vibration effects. Place the crossover boards on the sides of the speaker and hold them in place with two ⅝″ wood screws.

To minimize inductor coupling, position the coils as shown in the diagrams and orient the boards as indicated.

Since the speakers are too small to accommodate an electric drill, I fashioned a hand drill out of some scrap wood and a couple of drill-stop collars (*Fig. 98*). I drilled a 7/64″ hole in the wood block to hold the bit while I twirled it with the stop collars.

I built the XVR-1 as a kit. Since I've had some experience over the years with electronic kits, it took about four hours to complete. It was relatively easy to build, and except for the oscillation caused by R8 and R9, has worked flawlessly for over a year.

LISTENING TESTS

Hooking up a biamped system requires a little more work and concentration than normal. First of all, you must remember to reverse the phase to the woofer, which I did at the speaker-input panel. Then you need to make sure you properly connect the XVR-1 to the preamp and then connect it to each power amp. Finally, each power amp must be connected to the satellite or subwoofer.

My system is composed of a Van Alstine Transcendence Series Two preamp, a pair of Van Alstine MOSFET 120D power amps, and a Van Alstine FET 3 CD player. While not the most expensive or highly touted, Van Alstine equipment is wisely engineered, ruggedly built, and reasonably priced, producing very musical and enjoyable sound.

I must admit being pleasantly surprised by the sound of the Menehune MX-1. Since I had experience with the prototype, I expected this system to be similar, but while the bass is the same, it's clear that the new satellite drivers are superior. Highs are smoother, and there is much more detail. They re-create the musical experience more realistically.

This project has proved to me that designing loudspeakers requires both engineering and art. With solid engineering techniques, you can optimize power handling, low-frequency extension, dispersion, system impedance, and crossover phasing. Driver and cabinet resonances can be measured and treated, or avoided. Power response and on-axis frequency response can be smoothed and flattened. Engineering, at

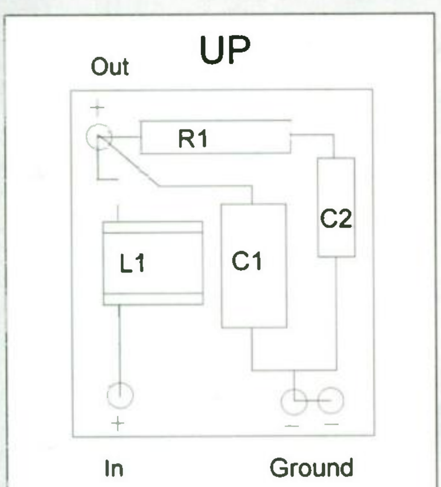

FIGURE 96: Midbass crossover-board layout.

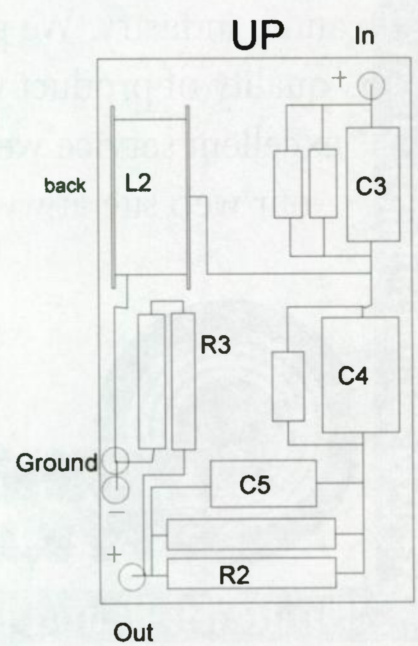

FIGURE 97: Tweeter crossover-board layout.

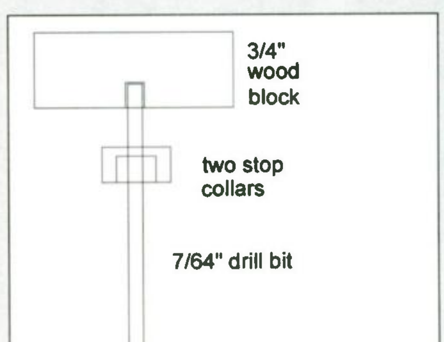

FIGURE 98: Hand drill.

TABLE 2
MEASUREMENT EQUIPMENT AND CAD SOFTWARE USED

Liberty Audiosuite (LAUD) from Liberty Instruments
Loudspeaker Measurement System (LMS) from LinearX
Loudspeaker Enclosure Analysis Program (LEAP) from LinearX

least, can strive to eliminate the measurable problems.

When all the engineering is completed, it becomes a matter of art as to whether or not the loudspeaker produces music. After all, no measurement made using LMS or LAUD or LEAP simulation could have told me that the Scan-Speak D2905/Morel MW142 combination would sound better than the Morel MDT30/Vifa P13 pair. Overall it is the best system I've put together and is certainly befitting of its Hawaiian namesake.

ACKNOWLEDGMENTS

Many thanks to Vance Dickason, whose books and advice have been much appreciated. Also, I wish to acknowledge Glenn Phillips of The Speaker Clinic, as well as Chris Strahm and Mike Frost at LinearX, for their patience and assistance. And last but not least, many thanks to Fred Janosky, of Audio Arts, for providing the XVR-1 active crossover.

SOURCES

Audio Arts
610-693-6740
audioarts@enter.net

Liberty Instruments
513-755-0252
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www.libinst.com

LinearX
503-612-9565
sales@linearx.com
support@linearx.com
www.linearx.com

Madisound
608-831-3433
info@madisound.com
www.madisound.com

Mahogany Sound
334-633-2054

Meniscus
616-534-9121
sales@meniscusaudio.com
www.meniscusaudio.com

Parts Express
725 Pleasant Valley Drive
Springboro, OH 45066
800-338-0531

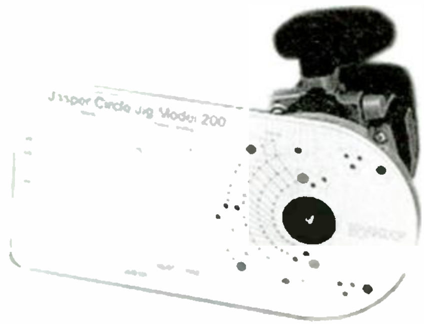
Vermet Machine Company
Hammond, IN
219-931-5406
(actually, contact your local air-conditioning equipment wholesaler)

Product Review

JASPER CIRCLE CUTTER

Reviewed by Philip E. Bamberg

Jasper Circle Jig Model 200 for cutting circles, mortises, and arcs with a plunge router. $49.95 plus shipping. Jasper Audio, 3612 Mangum Rd. #101, Houston, TX 77092, 713-681-9912, FAX 713-681-0576, E-mail jaspera@flash.net, Web site www.jasperaudio.com.



CUTTING CIRCLES THE OLD WAY

Speaker building requires a router, which is indispensable for flush trimming, contouring, and circle cutting. For years I have used a Porter Cable #690 router for these operations. For cutting circles I used the Porter Cable Magic Circle and Edge guide, which was quick to set up and easy to adjust. But it had its drawbacks.

To set the radius, I first measured the distance from the guide pin to the bit. For cutting an inside circle, I measured from the outside of the bit to the center of the guide pin. For an outside circle, I measured to the inside of the bit. Next I set the cutting depth to only about 1/16″ for the first test cut. (This was because I wasn't sure that the diameter would be correct. In fact, I usually drew the circle in place to make it obvious when I made a big mistake.)

After measuring the actual diameter cut by the router, I fine-tuned the radius again. I also checked the depth of cut, then set the depth gauge to match. Only when I was confident of the diameter and depth would I continue with the actual routing of the circle. Even then, things could change without notice; for example, the thumbscrews could loosen and change the radius.

Since the router was suspended above the circle guide a little, the cutting depth might not be consistent. I developed the technique of swinging the guide around the hole, and not the router itself. Otherwise, the depth might be too deep. Needless to say, I also always cut holes starting from the backside of the piece.

ABOUT THE AUTHOR
Philip Bamberg is an electrical/mechanical engineer and president of Bamberg Engineering Sound Lab, a high-end loudspeaker development and consulting company.

ENTER THE JASPER JIG

Always on the lookout for a better mousetrap, I decided to give the Jasper Jig a try. Here is why it is so much better than my previous circle guide:

1. The large jig plate bolts onto the bottom of the router base. No more "springy" depth uncertainty.
2. All the circle diameters are marked on the bottom of the plate. What you see is what you get. No more measuring the radius to the bit, and no more test cuts required. You may not be able to obtain a diameter to 1/32″ accuracy, but you'll find that every 1/16″ diameter is more than sufficient.

I decided to try the jig with a Black & Decker 1/4″ collet router that was not getting much use. Because the plate holes are calibrated for a 1/4″ diameter router bit. I bought a new 1/4″ spiral bit for $18. Now this old 1/4″ collet B&D router was not looking so useless after all!

The Jasper Jig fits many different routers, but the B&D, unfortunately, is not one of them. Undaunted, I decided to adapt the plate to the bottom of its base anyway. By studying the pattern of the mounting holes while rotating the plate around the router base, I discovered a combination of two holes that match the threaded holes in the base, yet still keep the plate centered. I screwed the plate in place at these two holes, then verified that the collet was perfectly centered to the plate by measuring. Once I was satisfied that this would work, I marked, punched, drilled, and tapped the third mounting hole into the router base.

Note that Jasper only recommends using its jig on routers for which they have an existing mounting-hole pattern, and only for plunge routers. Having experience with the Porter Cable guide, I was willing to try the Jasper jig on my non-plunge router and adapt it to its base. And the results were good.

TEST DRIVE

Although I usually have someone else cut all my cabinets for me, I still need to cut circles for woofer test boxes and for other custom speaker cabinets. The first cuts I made were for a few test boxes for measuring T/S parameters with the delta-compliance method.

Did you know that Black & Decker also makes two other indispensable tools for speaker building? These are their cordless screwdriver and Workmate. First I secured the medium-density fiberboard (MDF) panel in the Workmate and drilled the 1/8″ center hole. (It is best to drill this hole with a drill press, because the guide pin fits the accurate and perpendicular holes in the jig plate perfectly. If the centering hole through the material is not exactly perpendicular, the guide pin will bind in the plate or may wobble out the plate hole. A hand drill with built-in bubble is a viable alternative.)

I set the cutting depth to one-third the thickness of the material. Next I pushed the guide pin into the appropriate hole marked for the circle diameter. I made sure the pin stuck out from the plate more than the bit did.

Finally, I turned on the router and eased the guide pin into the hole in the panel. From there it was just a matter of swinging the router around to cut the circle. Near the end of the cut, I maintained a slight twisting backpressure against the router back to ensure that the bit cut into the scrap disc piece instead of the work piece. Once the disc was free, I ground off the little nub that remained where the bit began and ended around the circle.

Lately, I set the final cutting depth to leave a wafer-thin amount of material, thus holding the scrap disc in place. (If I'm careful, I dial-down the final cutting depth while the router is running, because the depth is set by a rack and pinion.) Then I just break out the disc and touch up the hole with sandpaper.

THE JASPER MANUAL

This is the same method I use for the Porter Cable guide, but is not recommended by Jasper when using a plunge router. Jasper's 10-page instruction manual explicitly describes how to secure the work piece with double-sided carpet tape against a large scrap piece of MDF that is ready to accept the guide pin. Next, the manual explains how to calculate the proper pivot-hole selection, including if mortising (flush mounting) will be required. Finally, it describes the procedure to switch on the router and plunge it into the work to route the circle.

Obviously, the Jasper-recommended method features much more control and safety. But for test-box holes or other less critical jobs, my quick-and-dirty method works fine.

For those who wonder whether 1/16″ increments in circle diameter are sufficient for accuracy, let me assure you they are. The excellent Jasper manual provides a terrific example of routing in the cuts for flush-mounting a 104.5mm diameter Scan-Speak tweeter.

First, convert the flange diameter to English units. Next choose a mortising bit of 1.25″ diameter. The manual determined that the 3⅛″ pivot-hole circle provides clearance for the tweeter flange, but by only 0.005″ all around the flange. The 3 3/16″ pivot hole yields 0.037″ clearance all around, which is realistically better for tolerances, paint buildup, and so on. For typical woofer holes, tolerance is even less of an issue.

You are reminded to consider the compressed gasket thickness when setting the mortise depth. The manual even describes in detail how to make clearance cut for the asymmetrical piece that protects the tweeter's terminals. Finally, the Appendix describes how to calculate the pivot hole for router bits other than ¼″.

There is no reason for you not to leave the Jasper jig on the router most of the time, even for non-circle routing operations. I found that the large flat base can even help with some special jobs such as when you need to route on a minimum-size baffle that already has driver holes and rounded edges. There is not much flat surface left from which to guide the router without tipping. The large overhanging Jasper base just gives you another means of control during these precarious operations.

Since the pivot holes are all silk-screened onto the upper side and protected with a durable coat of paint, there is no risk of them ever wearing off. Some users may complain that they cannot see the pivot holes from the topside. This is a minor inconvenience compared to the prospect of the silk-screening wearing off over time.

I found it helpful to put a small piece of masking tape on the jig's upper side, next to the selected pivot hole. With a pen mark pointing to the correct hole, I can leave the guide pin in the work, but not make a fundamental mistake when starting to cut the circle.

All in all, the Jasper jig simplifies one of the most common operations required for building speakers, while other guides make this procedure tricky. With the time you save and the accuracy you gain, you'll regard Jasper's jig a required tool for your collection.

Manufacturer's response:

The Jasper Circle Jig Model 200 was designed specifically to make speaker cutouts. The jig mounts to 20 different models of plunge routers, including Porter Cable 7539, 693, 7529, DeWalt 621, 625, Skil 1823, 1835, Bosch 1613, 1615, Hitachi M8V, TR12, M12V, all Sears, Ryobi, Makita, and Freud plunge routers.

The jig was designed for use with plunge routers. We do not recommend using a non-plunged router with this product. The Model 200 is manufactured on a CNC machine to insure that the router mounting holes and the array of pivot hole are located precisely with respect to each other. The accuracy of the jig relies on precise location of the router mounting holes and the pivot holes.

Jasper Audio would like to thank Mr. Bamberg for taking time to write this article.

Bill Jasper
Jasper Audio

SB Mailbox

SHAPING UP

I was very pleased with the presentation of my article "Determining Optimum Box Dimensions" (*SB* 2/00, p. 42). I wish to thank you for adding the excellent sidebar concerning the Golden Ratio in mathematics. I am very glad you included it with the article.

In the past, I have hesitated to include any information that may discourage amateurs from attempting to use information in my articles. I feared (perhaps unfounded) that they would quickly determine the material was too technical for them to follow. Apparently I was mistaken.

I also enjoyed G.L. Augspurger's Part 1 article Transmission Lines Updated (p. 24) and look forward to the second part of this excellent series. He has made a full-blown research operation on transmission lines.

The Danish Delight article by Paul L. Kittinger was also very interesting. I have been in contact with Peter van Vegchel in the Netherlands, who has a pair of unique folded horns, which he built for himself and for a dealer who wished to use them to demonstrate his vacuum tube amplifiers. He was gracious enough to send me a couple of photographs of his horns, which are indeed beautiful. (They may be seen at "Amateur/DIY horns and systems".) Construction involved considerable bandsawing and sanding.

I was reminded of my early days building 18-foot Chris-Craft utility boats in Caruthersville, MO. I worked in the woodmill and usually ran a dual-head shaper. I also built jigs and fixtures for the shapers.

Shaping would be the ideal way to accomplish many operations in speaker building, especially such units as Mr. Fitzmaurice's Snail horns. Even the Danish Delight would be considerably easier to construct by making more use of a spindle shaper. Please keep up the good work at Speaker Builder!

Louis C. McClure, Sr.
Van Buren, AR

DEBATING SPEAKER DESIGN

I'd like to make a few comments with respect to Mark Wheeler's series ("Navigating Speaker Design," *SB* 6–8/99), as I have investigated many of these same issues myself. I'll take them in turn.

First, I agree with Mr. Wheeler that there's little sense in purchasing a driver without a substantial amount of published specifications, including Thiele/Small parameters, frequency response, and impedance curves. It's too easy and inexpensive to make such measurements for any legitimate manufacturer not to provide this type of information! My experience is that manufacturer's published data is at least reasonably accurate and serves as a good starting point for a design.

I believe that the reason companies such as Madisound continue to play a large role in our market, as opposed to companies such as McGee Radio (now defunct for ten years, but at one time the biggest speaker wholesaler in the country), is largely because of the quantity and quality of information they supplied to customers. Madisound has always provided as much information as it could. McGee starved its customers of information and went out of business. Personally, I'm glad that the marketplace rewarded Madisound for its way of thinking.

Anyway, the focus of Mr. Wheeler's discussion is resolution, dynamics, and their relationship to the parameter Gamma "acceleration factor." I have studied this myself and would like to relate it also to his comments about cone materials.

Initially I thought the same about acceleration factor. However, further study has shown me that "resolution and dynamics" better correlate to other factors. Let me explain.

I spent about three years designing drivers at Jensen, and had plenty of time to experiment with a myriad of driver design variables. I have some different interpretations of Wheeler's experiments. Gamma = BL/Mmd, or motor strength per applied current divided by moving mass. And it is correctly described as "the rate at which the drive unit's moving parts can accelerate when a given signal is applied to the voice coil." However, I disagree in interpreting its correlation to a driver's accuracy in following a signal.

"Resolution" is a very subjective term, but I relate it to three measurable characteristics:

1. Extended high-frequency response
2. Accurate impulse response with absence of "ringing"
3. Absence of distortion

For a driver operating in its passband (above resonance and below its upper high-frequency limit), acceleration is essentially constant with frequency. In an ideal piston driver, it is exactly constant with frequency. So Gamma is related to sensitivity, not resolution. Empirically, you can measure acceleration with an accelerometer or calculate it based on SPL and surface area. Simply put, Gamma is not directly related to any of these three characteristics.

Mr. Wheeler compares two speakers with the same cone, chassis and magnet parts, but different Gamma parameters (due to different voice coils). He reports one driver sounded more detailed, more transparent, more dynamic, and hypothesizes that the higher Gamma results in the differences.

However, I believe this is because the lower-Gamma driver had a longer voice coil with more inductance, and attenuated high-frequency response compared to the other. A difference of only 1–2dB in the upper octave or two of this driver would certainly explain what was heard in the comparison. I firmly believe that most verifiable differences between audio components are differences in frequency response.

The motor system contributes to a speaker's performance in three ways:

1. It determines the sensitivity of the driver, as well as the intertwined Thiele/Small parameters.
2. It determines the excursion limits (X_{MAX}) and nonlinearity (distortion during long excursions).
3. It affects midrange distortion due to magnetic saturation of the pole piece as voice-coil current fluctuates. ("Copper Caps" and "Magnetic Shorting Rings," often found on more expensive drivers, are designed to combat this. When used, they also extend high-frequency response by as much as an octave by reducing voice-coil inductance.) Gamma affects only item #1.

My own experience indicates that by far the greatest determinant of a speaker's "signature" is its cone and moving parts, and their collective resonances.

At high frequencies, a speaker cone does not move as a piston, but rather sound waves propagate from the center to the edge. A speaker's response and impulse response are mostly affected by how effectively the wave is absorbed by the surround when it gets to the edge of the cone. The more the wave is reflected back into the cone, the more frequency/impulse response problems (and, subjectively, "resolution" problems) there will be.

I should add that the cone material per se has little to do with this. I've done considerable experimentation with many paper, plastic, and metal cones. You can't categorically say that Kevlar is better than paper, for example, or that paper is better than metal. Let me explain why:

1. All of these materials are dramatically different from each other.
2. How well they serve as speaker cones depends entirely on how well matched they are to the surround, as well as the cone and surround geometry. The whole system is an interdependent, complex equation.
3. Saying that "Polypropylene cones are best" is like saying that "Italian women make the best wives." I think we'd all agree that the perfect wife depends very, very heavily on the husband she's married to!

There is no "perfect husband" or "perfect wife." There are only good matches. (To be specific, good husbands and wives adapt to each other and become good matches.)

And likewise, there are no "perfect" or "ideal" cone materials. There are only characteristics that designers specifically choose to start with, then they tweak and refine their designs until the various parts are "married" together successfully.

Cone and surround material differences really boil down to a few basic physical parameters:

- Density
- Young's modulus (an inverse measure of elasticity)
- Linearity of elasticity (which is elusive to measure)
- Internal losses and damping

In a good driver, the impedance of the surround and cone are sufficiently well matched to provide very smooth response from resonance all the way to 2–3 octaves above the "piston" range of the driver. And such a driver will have excellent "resolution" regardless of the moving mass or BL of the motor.

Finally, as for matching drivers to one another, I believe this is purely a matter of using good crossover design to blend both frequency and polar response of two different drivers.

My experience is that a multi-driver system that sounds somehow "incoherent" simply suffers from inadequate crossover design. Of course, some drivers won't match each other no matter how clever the crossover design, but I believe that polar- and frequency-response measurements will almost always uncover the source of the problem.

Final comments from a former driver designer: When you purchase an expensive driver, study it, and ultimately design it into a high-performance system, it all seems rather mystical. Especially when exotic materials and hyperbole are involved.

However, consider the experience of gluing together all the raw materials one at a time: voice-coil wire, a former, a cone, a surround, a spider, a housing and motor parts, and then measuring, listening, and trying again. When you do this, the "mystery" and "magic" of speakers is gradually wrung out one drop at a time, and you realize that there's nothing mystical about this at all. Complex, yes—especially cone breakup modes—but mystical, no. It's all measurable, verifiable, and very, very physical.

All the mystery and magic is really in the marvelous apparatus God put on the two sides of our heads, and the emotions and response we experience when we listen to music.

Perry Sink
Berwyn, IL

Mark Wheeler responds:

I thank Perry Sink for his detailed response to my articles. It is very rewarding to know that my efforts have been read, and I'm sure Mr. Sink and I would enjoy debating speaker design long into the night. I will try to respond to some of his points in order.

We are in complete agreement about manufacturers' specifications. It would be beneficial if manufacturers also included the tolerances that apply to those specifications.

Cone materials: I agree about cones and surrounds and their interface, but the focus of the article was divining information from T/S parameters. But I can think of many examples of excellently researched and designed cone-surround assemblies that exhibited very low coloration but still managed to sound lifeless.

I did make the point that Gamma is related to sensitivity, but noted that my experience has been that measured sensitivity does not always tell the same story.

I suspect that part of the problem is the language ambiguity posed when trying to express subjective experience. I, too, would use the term "resolution" to describe such phenomena as "absence of ringing" and "low distortion," but I would prefer to refer to extended upper frequency response as "extended upper frequency response." I'm unable to think of a better word to describe the aural phenomena I described in my articles.

The experiments I conducted were of drive units operating well within their stated passband using a third-order active crossover to limit their upper and lower frequencies. Effectively the drivers were working as mid-range units despite being sold as bass-mid units. Due to the lower excursion requirements of their mid-range application, X_{MAX} and power handling were more than adequate. The two units in the main experiment used the same cone-surround assemblies, only the voice-coil former and spider assemblies differed. So cone-surround interface was experimentally controlled.

I am wholly in agreement that the sonic signature of a driver is predominantly that of cone-surround material. It does make sense to match the sonic signatures of drivers in multi-driver systems. I also agree that system coherence is very dependent on driver polar response and appropriate crossover design, but these were outside the scope of my articles.

Jensen speakers never seemed to make much commercial impact on the UK market, but I do recall from the '70s that a friend stocked them in his shop alongside the popular British models. It is ironic that my recollection of Jensen models is that they were very lively and dynamic, but compared to some of their British competition were not what we described as neutral low-coloration monitors. The Jensens I heard then were exactly the kind of high-resolution lively speakers that I found more musically engaging than some of the "neutrality at all costs" competing domestic products. They are among the designs that inspired me as an adolescent to pursue my own efforts at designing and building loudspeaker systems.

TL DESIGN

If I understand A. Monk (Transmission Lines series, *SB* 6/99, 7/99, and 1/00), the time when a transmission-line enclosure can be designed by someone without the appropriate engineering degree and a lot of non-Radio-Shack test equipment is still well into the future. To tide us over until that time, I suggest you reprint Roger Sander's response to Thomas Gillin's letter in *SB* 3/92, starting on p. 81.

That is what I will be using when it comes time to stuff the 18″ Jastak design (*SB* 4/73) I'm building for an Electro-Voice woofer purchased long before Thiele/Small was invented.

By the way, what is Miraflex and who sells it?

Art Day
7156 N.E. 288th St.
Kingston, WA 98346-9526

THREE-WAY REVISITED

I have several questions regarding the modest-cost three-way system described in the three articles appearing in *SB* 6/96–8/96.

First, let me say that I am a true amateur speaker builder. I'm not a retired electrical or NASA engineer, as so many of your readers seem to be. I simply enjoy good sound. I've built only one set of speakers, which was a modest two-way kit I purchased from Meniscus some years ago. With this in mind, here are my questions.

1. Having had three years or so to listen and play with the system, how does it stand the test of time? Would you do anything different?

2. Another alternative for me would be a good MTM design. Is it possible to roughly characterize the difference in sound quality you might expect between your three-way and an MTM?

3. The Eminence woofer you specified is not available now from Madisound, although I haven't looked too hard elsewhere. Is there a suitable alternative if the Eminence can't be found? I have found some current 8″ Eminence woofers, but not the exact one you specified.

4. I have almost zero experience assembling crossovers. I understand Madisound will assemble these for a reasonable fee. Is this an acceptable alternative for those of us with minimal electrical skills?

5. Also, have any *Speaker Builder* readers built your system? I follow the *SB* Mailbox fairly closely, but I can't recall any queries. It would be interesting to know whether other amateurs such as myself built your speaker and what their experiences were.

David Rykken
Portland, OR

G. R. Koonce responds:

Let me first thank Mr. Rykken for his interest in the "A Modest-Cost Three-Way System" series that appeared in *Speaker Builder* in 1996. I will address his questions in order.

1. I believe the system stands the test of time well. I use them as my "garage monitors" each summer while working on speaker projects and enjoy them very much. If I were doing it again, there are two things I would do differently. First, the crossover network would be developed via crossover modeling rather than by testing a large number of networks. This would have saved days of testing, as only the final design would need to be tested to verify the modeling work.

The other change is that I would have tried the low-resonance Vifa silk dome tweeters (D27TG-35-06 or D27TG-45-06) as candidates for the tweeter. They match the 6Ω requirement, and I very much like the sound of them. I have seen assertions in print that these Vifa silk dome tweeters were being discontinued, but Vifa says this is not true.

2. I'm a big fan of the MTM configuration or the WTW configuration with small mid-woofers. The intent of our project was a modest-cost system, which means using a minimum number of drivers. There is no way a WTW configuration with small woofers would make the bass requirement of f_3 at about 40Hz set for the project. The use of an MTM design with one or more additional woofers certainly could do the job, but increases the driver count and would be a more expensive system. I believe the straightforward three-way design is still the best approach for the lowest-cost full-range system.

3. If the Eminence woofer is no longer available, I cannot recommend any direct replacement. The woofer requirements are not critical due to the rather low crossover frequency used with the woofer, but I have not tested any woofers looking for a replacement.

4. The crossover is a critical component in the "sound" of a system. I believe it acceptable that you have someone build the crossover for you as long as they build the design shown in the article and not their idea on an "equivalent" three-way crossover. The first-order crossover used with those systems is rather simple, and construction should not be a problem. The third-order is rather complex, and getting it to fit in the area behind the tweeter could definitely be a problem now that "good" ferrite bobbin core coils are not available.

The cure might be to build the crossover external to the speaker boxes so all the room needed can be made available. Place just the L-pad in the area behind the tweeter.

Bob Wright still prefers the first-order crossover, while I still prefer the third-order. I am now using coils with a laminated steel bar core for the woofer and air core for the other drivers with good success. I have tested the steel bar coils, which are linear to high current and work well for the woofer crossover, but are big and a bit difficult to mount. I cannot recommend any of the ferrite bobbin core coils I have bought on the current market for woofer work, as they have very limited current capability.

5. We have heard from some people who have successfully built the systems. I believe most considered the box was too complicated; however, the box design is a major portion of the speaker design, and a simple rectangular box with a vertical front panel does not always produce the best-sounding system. My feeling is that one advantage of the speaker-building hobby is that you can trade your time against the lower cost of a system. Someone desiring "quick" results is much better off purchasing one of the many excellent kits available as documented by the tests in *Speaker Builder*.

R. O. Wright responds:

1. The system as constructed in the article has run trouble-free and has had no modifications made to it.

2. The design of sound systems is far from an exact science where the human ear is concerned. There is no exact way to predict how one sound system will compare with another. It is a kind of "build and listen" type of science, and each person hears something different from each individual design.

3. My only advice in this area is to contact Eminence and see whether they are still making the driver for anyone.

4. If Mr. Rykken has had no experience building crossovers, I would suggest that he buy his crossovers, if possible.

5. To my knowledge, there was only one other letter that was referred to me, and it was concerned with only construction.

MEASURING HORNS

I have a couple of questions regarding Bill Fitzmaurice's Snail Horn (*SB* 6/97, p. 6).

The article mentions that the horn is 33″ long. I don't see how. Do you not count the length of the 90° curves? How do you go about applying the expansion around turns (90° or less).

Glidden Martin
Citrus Heights, CA

Bill Fitzmaurice responds:

Folded horns have traditionally measured the horn length at the middle of the horn cross-section, a practice which I have followed. By measuring either the "inside" or "outside" of the horn, you could come up with a length either longer or shorter; the middle of the horn is a reasonable compromise.

My horns do go through expansion at their bends. I calculate the amount of expansion the same as I do horn length, using the center of the cross-section as the averaged horn length. This is admittedly an approximation—and not a very good one—of a straight horn, but is one compromise that must be accepted to gain the space efficiency the folded horn offers.

HELP WANTED

Can anyone advise me on the specs/availability of the transformers necessary to use individual late 1970s, Irish, Strathern ribbon speakers? The late Pat Doherty ran them direct (tri-amped), three in series, with a very robust amp. However, I wish to run four with a Denon AVR-1600 home-theater amp in a passively crossed-over three-way configuration. (I have the one-page article from a *Speaker Builder* back issue on a reader's system using them, and have found some original transformers on the internet for $150 each in Italy.)

I hope someone has some of the transformers for sale or can suggest a reasonably priced substitution.

Arthur C. McKay
6262 Almon St.
Halifax, Nova Scotia B3L 1V2

Readers with information on these topics are encouraged to respond directly to the letter writers at the addresses provided—Eds.

Classic Circuitry

IONOVAC MODEL 14A435

Courtesy of Dennis Frakee, Livingston, MT

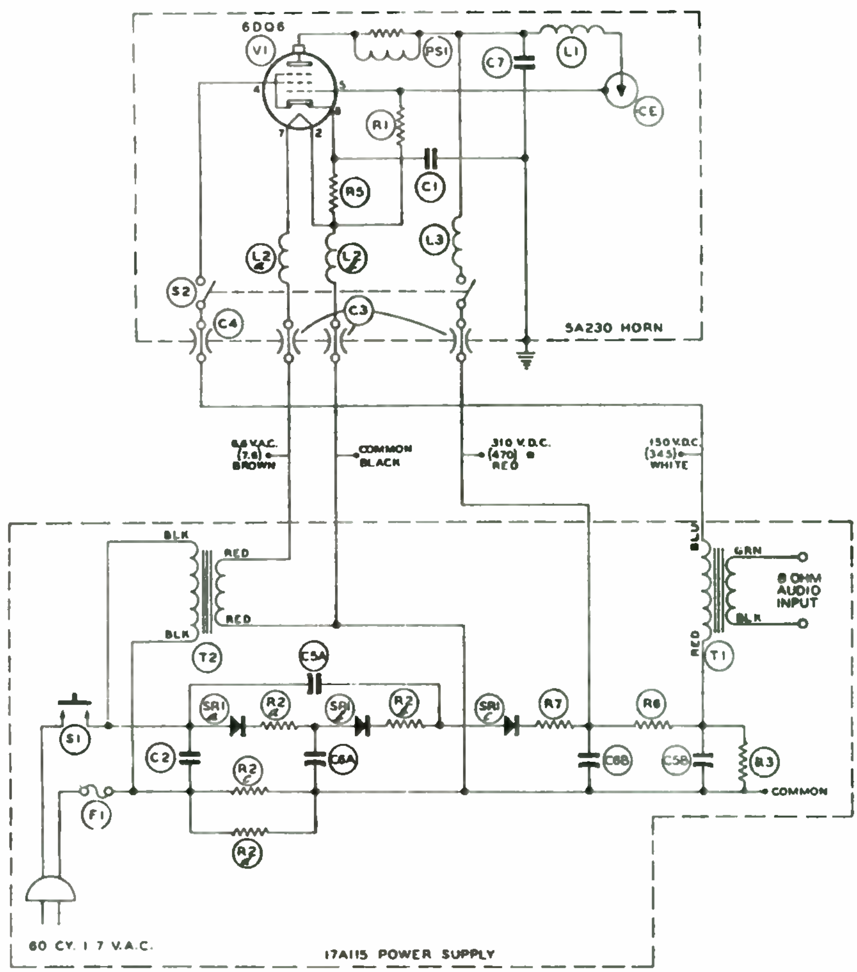


FIGURE 1: Ionovac schematic. Note: All voltages are measured between the designation point and common with a 20,000Ω/V (DC) meter. Do not measure plate voltage above L3. RF voltage is present and can damage meter.

TABLE 1
PARTS LIST

COMPONENT	DESCRIPTION	QUANTITY	PART NO.
CAPACITORS			
C1	.0022μF	1	199-1002 222
C2	.047μF, 60Hz V	1	199-4038 473
C3	1000pF, F.T 1000	3	199-9035
C4	10pF, F.T 10	1	199-9036
C5	20-20μF, 450V	1	199-9082
C6	40-40μF, 450V	1	199-9083
C7	12pF, 2500V	1	199-9084
RESISTORS			
R1	33kΩ, ½W	1	600-0080-333
R2	10Ω, 1W	4	600-0116-100
R3	220kΩ, 1W	1	600-0116-224
R4	47Ω, 1W	1	600-0116-470
R5	120Ω, 2W	1	600-0153-121
R6	33kΩ, 2W	1	600-0153-333
R7	100Ω, 5W	1	600-9047
SWITCHES			
S1	SPST	1	680-165
S2	DP, norm open	1	680-351
TRANSFORMERS			
T1	Modulation	1	710-40
T2	Filament	1	710-4143
MISCELLANEOUS			
PS1	Parasitic suppressor	1	115-1821
CE	Cell assembly (cell	1	204-7
	electrode)	1	207-8
V1	Electron tube 6DQ6	1	262-6DQ6
F1	Fuse 1A, type 3AG	1	320-010
L1	RF coil assembly	1	115-1819
L2	Inductor RF choke (fil)	2	393-4
L3	Inductor RF choke (plate)	1	393-7
SR1	Rectifier, silicon 1N2483	3	595-37

Classifieds

VENDOR

AD INDEX

FOR SALE

AudioClassics.com buys, sells, trades, repairs high-end audio. (607) 766-3501, 3501 Old Vestal Rd, Vestal, NY 13850.

WANTED

Copy of operation and service manual for HP4260A Universal Bridge. William McDermott, (312) 782-2345, E-mail mcdermot@alumni.iit.edu.

Vintage/newer speakers: Altec, JBL, EV, Tannoy, Rogers, Quad, Jensen, Western, B&W, etc. (405) 737-3312, FAX (405) 737-3355.

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Yard Sale

FOR SALE

Set of *Speaker Builder*, 1/80 to 1/00, less one issue, 7/98. Includes 116 issues in good condition. Price, $200 plus shipping charges. Approximately 42 lbs. Al, 210-344-8225.

New drivers from Audax, Dynaudio, Morel, SEAS, Vifa, and more. Used only for testing. Priced well below retail. Also, some finished speaker systems. Send for list. Contact Joe D'Appolito at audioltd@worldpath.net, or 34 Rust Pond Road, Wolfeboro, NH 03894.

JBL-2344 Bi-radial horns NOS $500; JBL-Century L-100, Mint, $500; JBL-L-26, $250; 2 dual 1219 turntables, $100 each; Sansui-9090 receiver, $150. Automobile: ADS-PH15 amp 3 to 6 chan-bridgeable 300W, new in box, $450; Alpine 7380 AM-FM cassette deck with remote, mint, $450; tweeters Alpine 6022, 2 pair, new in box, $100/pair; 6-320 I tweeters Samarium cobalt, $60/pair; 6-320 IS tweeters Samarium cobalt, $100/pair; 4-6062 Alpine midbass 6½" drivers, 2 pair, $150. Alan, (301) 596-5637.

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12. Noncompliance with any of these guidelines will result in your free personal-ad submission being refused for publication.

Tools, Tips, & Techniques

A LEXAN® CROSSOVER BREADBOARD

By Jesse W. Knight

My experience suggests that any connection that is not soldered is in time a bad connection. I have found clip leads to be useless when experimenting with crossover networks. Toggle and rotary switches also can introduce unpredictable resistance. Plugs and sockets are not reliable either.

While I was working for a remote island power company, I made a terminal board for a 100kW generator with a sheet of ¼″ Lexan, ⅜″ brass nuts, bolts, and washers that stood up perfectly, withstanding 140°F temperature swings and severe vibration. Next I used Lexan to make rotating rectifiers to convert two old generators to solid-state brushless operation. These spun at 1,200 rpm around the clock for years without failure, eliminating the need for hand-made brushes.

Lexan does not shatter, allowing bolts to be very tight. It compares to something between hardwoods and aluminum when drilling and cutting it, which is very easy. Lexan is only troublesome in a lathe, where it grabs, much as brass does. This inspired my design for a crossover breadboard that is transparent, allowing double-sided experimental circuits to be easily visualized.

BOARD DESIGN

I grew up with model trains rather than CAD-CAM, so I often make a test model to get a feel for how things will work. *Photo 1* shows a model that was designed to be photographed as well as provide design experience. Circuitwise it is nonfunctional, but I have included an assortment of components to aid visualization.

Note that I have used a nylon bolt, nylon washer, and nylon wing nut to mount the inductor. After you no longer need this test model, you can recycle everything into future crossovers. I believe all crossovers are provisional, inviting constant tweaking.

In the upper-right-hand corner of the photo is a ¼″ bolt holding two Radio Shack gold-plated ring terminals (278-334), to which wires have been soldered, not crimped. A star washer between the head of the bolt and the Lexan prevents the bolt from turning, as does a nut on the top side. Flat washers above and below the gold terminals prevent wear of the gold plating.

There are three drawbacks to this connection: expense, bulk, and ring rotation while tightening, which can break components. On the plus side, there is no oxidation problem and the connection is very rugged, as long as wires are not pulled in a counterclockwise direction.

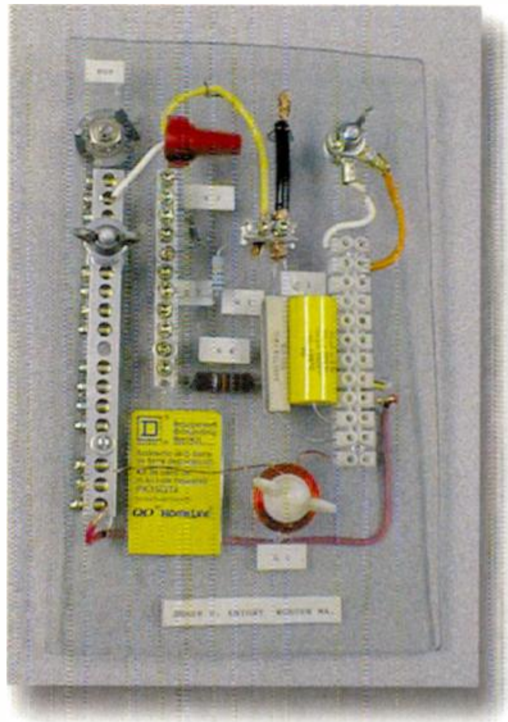


PHOTO 1: Lexan® Crossover Breadboard.

Starting at the left of the photo is an unaltered Square D grounding bar (PK15GTA), which has four clamping screws for wire, followed by a mounting hole for either vertical or horizontal mounting (shown horizontal). This pattern repeats 3⅗× for a total of 15 clamping screws and three mounting holes. This works well with unterminated components, and there is no rotation of the lead. Each time a screw is turned, oxidation is ground away. Note use of the bolt to connect back-side components (available at Home Depot).

Next is a section that I cut with a hacksaw through a screw hole after removing the screw. Making sections with several screws allows you to remove a wire or component without disturbing other connections. This great time saver is shown mounted vertically.

A two-screw section is used as a mechanically floating connection. This is ideal for joining two #8 megacables or combinations of caps, resistors, and differing cables.

For small wires I use a Radio Shack 274-680 European-style 12-position barrier strip, which is excellent for mid and tweeter circuit connections (far right).

Finally, there are wire nuts, which are a distant fourth in my opinion, but are quick, cheap, and easy. The twisting motion is certain death for resistors and caps, so I generally use these only for wires. It is not always easy to get a firm connection with differing wires either (top left).

GETTING A GOOD LAYOUT

You can do this by choosing the most complex design you plan to build. Then lay out the components to be used on a large sheet of paper in the positions they will occupy. Now you can cut terminal bars to suit each connection. Finally, you can transfer and mount these to a sheet of Lexan. You can mount terminals at the perimeter of the Lexan breadboard horizontally if desired, as screwdriver access will not be blocked. Place notes face up under the Lexan to indicate part locations and other data.

Twenty Years and More. . .

The 1978 C.E.S. in Chicago was the very first time that Morel Acoustics USA, Inc. presented their product to the public. It became clear, early on, that the loudspeaker industry was in need of high quality speaker drivers. Shortly thereafter we introduced several drivers and established the MDT-28/30 as one of the most popular and highly demanded tweeters on the market.

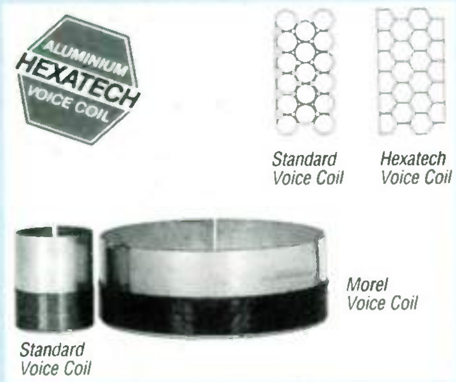
Through the course of the years Morel brought many unique and innovative products to the speaker industry. The introduction of the 3″ voice coil in a 5″ basket, using hexagonal shaped aluminum wire, utilizing a double magnet system and ducted design woofers and mid-basses are a few examples of the company's breakthroughs. Also introduced were the Integra concept (single motor system for both the tweeter and woofer) and the Push-Pull 8″ and 10″ subwoofers (dual motor system, dual voice coils with a single cone).

Integra

Push-Pull

Double Magnet

Morel Acoustics USA, Inc. has come a long way since 1978. Currently, the company has a diverse line of exciting products which includes over 40 models of tweeters, midranges, mid-basses, woofers and subwoofers. Being a leader in the field of speaker design, for our 20th year anniversary we are scheduled to launch several new products that are sure to attract attention.



Typical double magnet ducted woofer.

For further information please contact:

Double magnet tweeter

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