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Speaker Builder

THE LOUDSPEAKER JOURNAL

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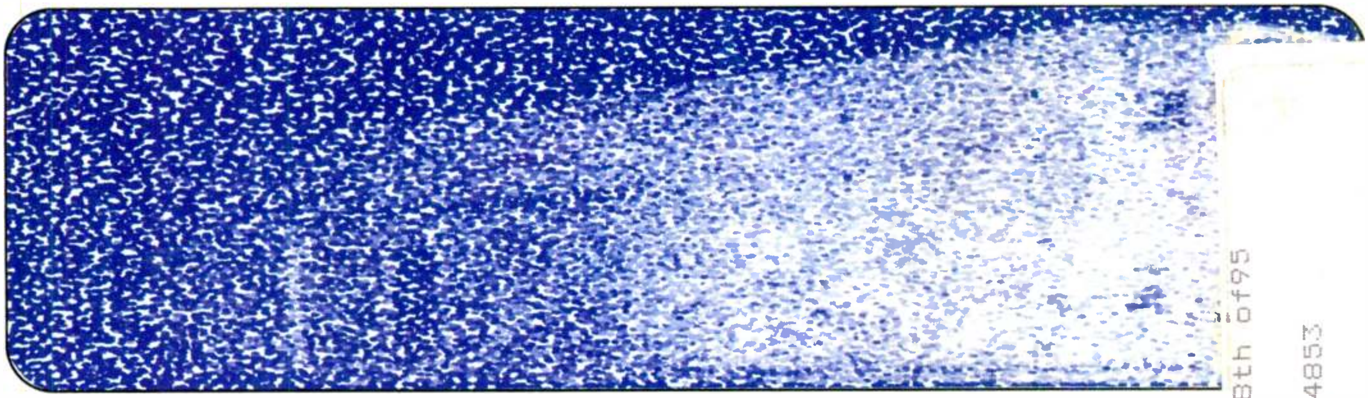

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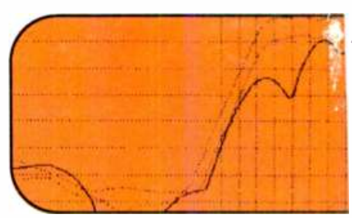

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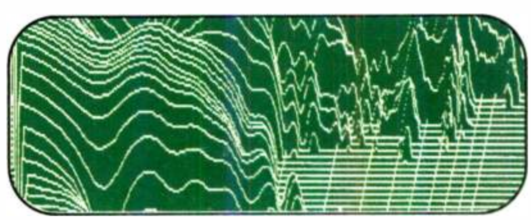

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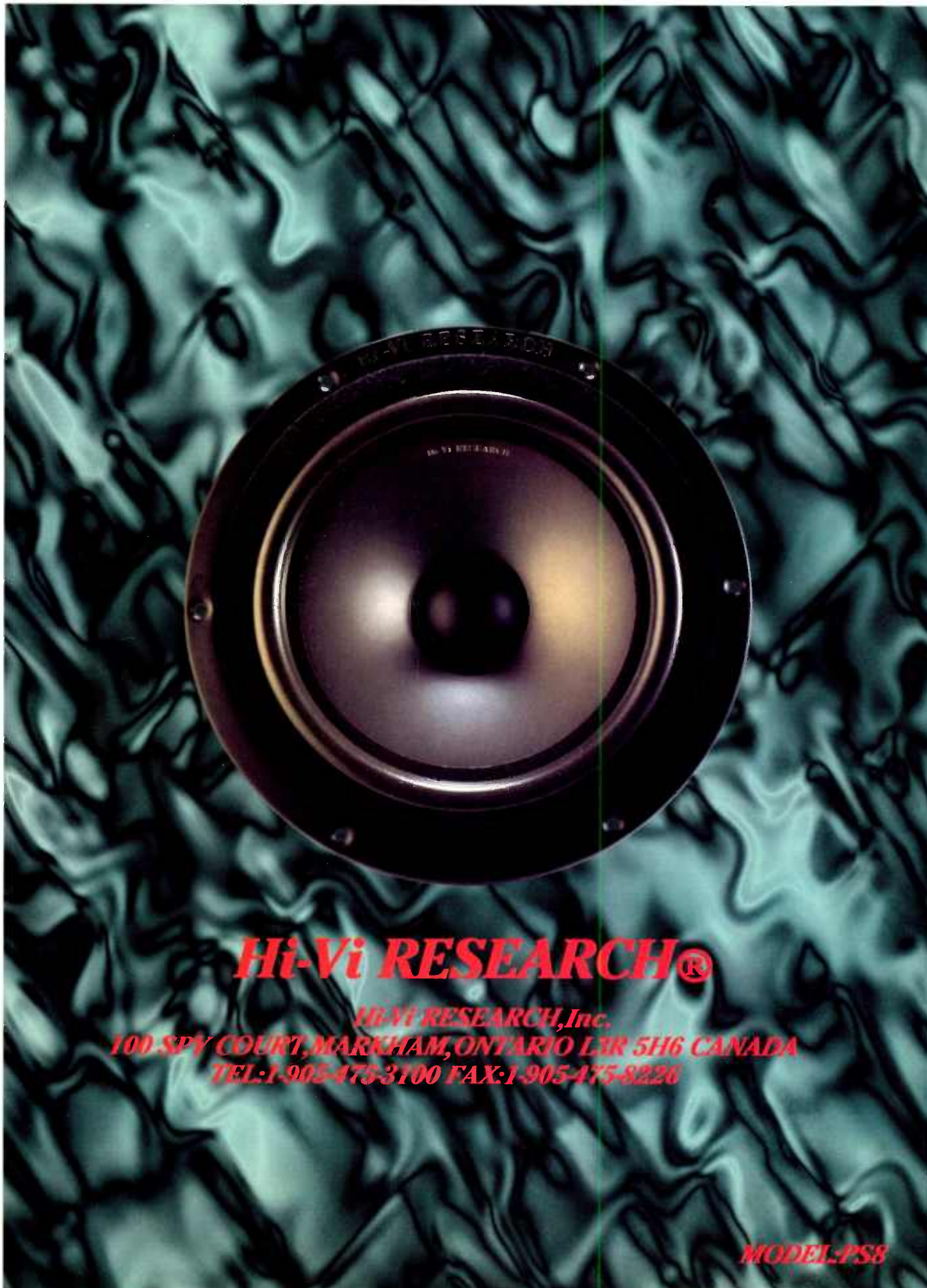
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Good News

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■ AUTO-TRANSFORMERS

A new line of toroidal auto-transformers offers an alternative to full-isolation transformers for step-up or step-down applications. The devices are up to 70% smaller than full-isolation designs of the same power rating, depending on the specified output voltage requirements in relation to input voltage. Standard power ratings are 250VA, 500VA, 750VA, and 1kVA, with custom ratings available as options. Toroid Corp. of Maryland, 2020 Northwood Dr., Salisbury, MD 21801-7805, (410) 860-0300, FAX (410) 860-0302.

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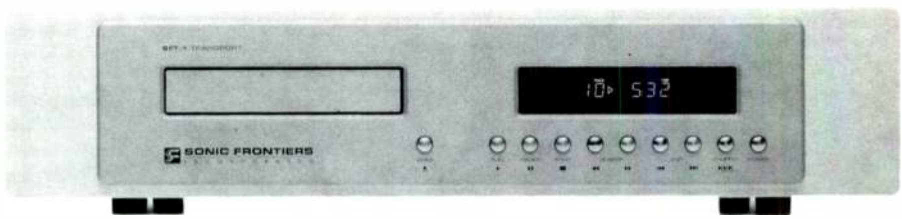
■ ANNUAL CONVENTION

The 99th Annual AES Convention will be held October 6–9 at the Jacob K. Javits Convention Center in New York. This year's theme, "Audio in the Interactive World," reflects the impact of interactive technology on the rapidly evolving pro audio industry. More than 100 technical papers, a dozen workshops, and numerous special events and seminars are being prepared for the expected record attendance. Audio Amateur will be attending the show—be sure to stop by our booth and say hello! For more information, contact AES headquarters: 60 E. 42nd St., New York, NY 10165-2520, (212) 661-8528, FAX (212) 682-0477.

■ INVENTORS' ON-LINE BB

An inventors' bulletin board is now on-line at the New Jersey Institute of Technology. The new resource is a collaboration of the Fontel Foundation and NJIT's Enterprise Development Center. The service assists entrepreneurs with technical, administrative, manufacturing, and marketing problems usually associated with the development of new inventions. The Fontel Inventors' Bulletin Board is on-line continuously at (201) 643-7219 or (908) 463-5434. It can be reached with software set at 8 data bits, 1 stop bit, and no parity, at modem speeds from 2,400 to 28,800 baud. Fontel Foundation, Inc., 11 Coventry Court, Englishtown, NJ 07726, (908) 536-4360, FAX (908) 972-4988.



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Reader Service #109

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Good News

■ **TEMP CONTROLLER**

The Dial-Temp Soldering Iron Controller was developed to moderate fixed-temperature soldering irons into variable-temperature tools for working with heat-sensitive electronic components, or for other applications requiring lower tip temperatures. The device is compatible with any 15–1.6kW iron, and adjusts tip temperatures from 150°F to full heat. Featuring a grounded wall plug and receptacle, the Dial-Temp provides 15A capacity. Hot Tools, Div. of M.M. Newman Corp., PO Box 615, Marblehead, MA 01945, (617) 639-1000, FAX (617) 631-8887.

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TRAPEZOIDAL LOUDSPEAKER

The KP-3002-C is a two-way, vented system in a trapezoidal enclosure. It features a 2″ titanium dome compression driver coupled to a Tractrix Wave™ 60° × 40° horn, and a 15″, 300W woofer housed in a ported cabinet. The 15° trapezoidal design allows the enclosure to be used individually or in multiple-system arrays. Locking Neutrik™ ¼″ connectors afford easy biamping. The proprietary KLiP™ circuit serves as a protection device for the HF driver, and fuse-protects both the LF and HF sections. Klipsch Professional, 149 N. Industrial Park Rd., Hope, AR 71801, (616) 695-5948, FAX (616) 695-7623.

Reader Service #111

■ **TEST DISC**

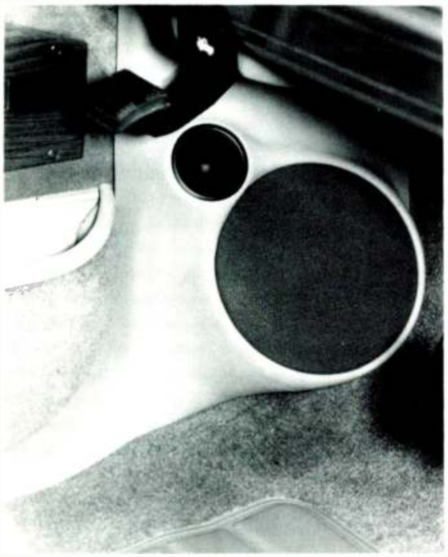
The Professional AudioVideo Retailers Assoc. (PARA) has commissioned Sheffield Lab to create a new test disc. Cuts include two each of pop, jazz, and classical music, two demonstration, and five technical. The disc was designed to help A/V consumers better understand and set up their audio/home theater systems. A group of independent audio dealers worked with Sheffield Lab to produce the disc. The 1995 PARA Test & Demonstration Disc is available at participating PARA dealers nationwide. PARA, 10 E. 22nd St., Suite 310, Lombara, IL 60148, (800) 4-PARA94, (708) 268-1500.

Reader Service #112

■ **SOFTWARE TOOL KIT**

The BenchCom™ Software Bundle is a complete set of tools and utilities for PC Instruments' PC-based products. The software includes: four different graphical user interfaces (DOS, Windows, OS/2, and Windows NT); DLLs; programming libraries (with support for C, C++, Basic, Pascal, Visual C++, and Visual Basic); third-party application drivers; and utilities for printing, plotting, and data file translation. Benchcom is provided with every instrument purchased from the company. PC Instruments Inc., 9261 Ravenna Rd., Building B11, Twinsburg, OH 44087, (216) 487-0220, FAX (216) 425-1590.

Reader Service #110



KICK PANELS

Q-Forms are replacement automotive kick panels featuring molded mounting locations for two-way speaker systems with woofers up to a 5¼″ and 1′ tweeters. The woofer location is covered by a molded grille covered in an acoustical cloth. The panels allow speaker systems to be installed without cutting of the vehicle. Sizes are available to fit more than 20 models, with colors which match the specific application. Q-Form kits are complete and include detailed mounting instructions. Ai Research, PO Box 159, Stillwater, OK 74076, (405) 624-6722, FAX (405) 372-5489.

Reader Service #102

Editorial

SOUND AT WHOLESALE

As Christmas approached in the second year of my marriage, I decided that the nicest possible gift for my bride would be a brand new, sparkling washer and dryer. While it is true that we needed these appliances, since we had a newborn and synthetic diapers hadn't yet been invented, nonetheless it turned out not to be the most romantic expression of my affection and regard for my spouse.

Both the practical and romantic approaches to marital relationships have their uses, of course. But it is vitally important to know the difference.

Your audio system is not a spouse (although a surprisingly large number of audiophile spouses consider the rivalry serious enough that the distinction is without a significant difference), but the ways in which this avocation takes its adherents often look quite similar.

For some searchers of good sound, the game is really one of "beating the system." A good system sounds even sweeter to the owner's ears if the pieces are bargains, ranging from significant savings to virtual theft.

In a society obsessed with consumption coupled with planned obsolescence, there is certainly a lot of hardware excellence floating around in yard sales these days. One of our editors gleefully showed me a vintage KLH Model 11 dating from the '60s which was making quite wonderful music in his daughter's room. The suitcase-style LP player with detachable speakers sounded just excellent. The changer had needed some work, one speaker cable had to be replaced and the entire system cleaned, but at a price of just $2 from a local yard sale, it was a dazzling discovery. After he attached a repaired CD player to the AUX inputs of the unit, it sang beautifully through its minispeakers.

Fair enough. A friend of this editor remarked later, however, that the latter had invested about $300 worth of time (10 hours in a lab equipped with $2,000 worth of equipment) in the update of a $2 bargain. What the editor brought to this project was a lifetime of experience and knowledge, and the origin of that resource was something quite different from bargain hunting.

This editor's interest in electronics as a schoolboy grew steadily as the years passed. His interest in music deepened as he grew older. His technical knowledge became the basis for a first job, but all the while the pursuit of musical excellence became much more than a casual matter.

His work in audio has become a major component in his own life experience. It has, as I can understand from my own experience, become a profound commitment into which he pours a lot of time, quantities of energy, and all the intelligence he can muster.

I can look back to my own journey over the years and see how my interest grew steadily from the time I first heard a piece of classical music from a 78 rpm disk played on a vintage RCA Victrola. Without quite realizing it, I began searching for more and more information, and collected recordings, and then equipment. But all of it goes back to the core of that first experience of music. The appetite for the music is at the bottom of it all.

I suspect that a great deal of the misunderstanding and controversy that continues to simmer between groups who have been dubbed "golden ears" and "meter readers" is a matter of basic motives. What infatuated audiophile can sit idly by and ignore what his ears tell him about the difference in sound of two power amplifiers which happen to measure identically? A passion for excellence and better answers to the questions of comparative quality won't let you give up the quest because scientific measurement says no differences exist.

If the issue is merely practical results, then a cheaper capacitor, op amp, transformer, or whatever component happens to be in question will be quite satisfactory. Certainly this is a reasonable answer to such questions if we are dealing with pragmatic issues.

Our quest for high-quality sound is admittedly arational, although viewed from the cooler sidelines, it may well appear to be irrational. Its root is difficult to define entirely. It is a thirst for the knowledge that overcomes the defects and deficiencies. Unlike the design engineer who works in a world of possibles, price points, manufacturing practicalities, and competitors, the amateur's quest is a love affair. It is a zeal for an impossible perfection which considers commitments of time and money as necessities for achieving small increments in improved sound. On the other hand, it is certainly evident that for many audiophiles a more modest view of this pursuit is satisfactory. The end result is only a washing machine and a dryer, nothing more.

I would argue that any advance in almost any human endeavor is, more often than not, the result of a passion in some human heart and mind. Those obsessed with a question, a mystery, or a disease often seem quite irrational to others. And the innovators are often criticized and even vilified by those who are still comfortable with conventional views.

Surely there must be room in this avocation for all levels of enthusiasm. At one level we have those who just want enough knowledge to successfully upgrade a sound system to a better level. At the other end are the passionate extremists who will go to any lengths to find a slight advance in resolution and clarity. We will do well to understand each other and realize where and how far this muse of music takes each of us.

Take stock of your own relationship. What do you expect from this audio avocation? What are you investing in it? Time, talent, treasure? How important is the relationship? What kind of rewards and satisfactions flow back to you from your commitment? How much is enough? For myself, I cannot think of many life investments which have paid better dividends.

When I sit in my favorite chair of an evening and switch the system over to CDs or sometimes to LPs, the magic of the music tells me, however indescribably, what this pursuit is all about. The surprise of a new performance of a well-known pop tune or a familiar symphony releases something in me and adds a dimension to life which really isn't possible in any other way, exactly.—**E.T.D.**

Speaker Builder

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

❧ John Stuart Mill

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About This Issue

With the approaching colder months, it's an appropriate time to consider heading back indoors to the comfort of a good DIY speaker building project. This issue examines several unique schemes to enhance the sound performance of your system.

First, **G.R. Koonce** introduces the acoustic waveguide approach, which he uses to tackle the problem of producing acceptable levels of bass with small drivers ("Waveguide Path to Deep Bass, Pt. 1," p. 8). In the first of this three-part series, he experiments with constructing a double-ended waveguide structure.

Bill Waslo offers a different method to in-room hi-fi reproduction. As a follow-up to his focused array system in *SB* 4/95, he continues to make a strong case for this configuration, in which distributed reflected signals combine with simultaneous direct signals. After jury-rigging a setup to test this concept, he presents his preliminary measurement and listening results in "Testing a Simple Focused Array" (p. 24).

Marie Shrewsbury provides a step-by-step procedure for building your own midrange horns. After experimenting with different materials, the author settles on a concrete version. You'll be pleased to witness the blossoming of this Morning Glory design for improved sound quality ("Morning Glory Midrange Horn," p. 18).

Unlike dice, shoes, and bookends, two subwoofers may not necessarily be better than one, as **Tom Nousaine** explores in "Stereo Bass: True or False?" (p. 16). This article will probably unearth more questions than it settles, as the author shatters several myths in his investigation of subwoofer placement.

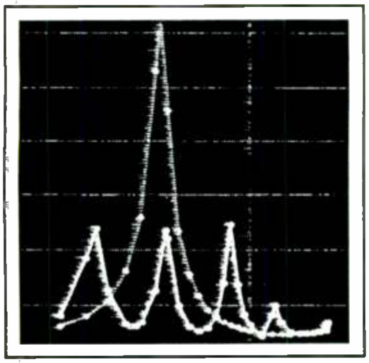
Good tools are not the only essential ingredients of a successful workshop; you also need a good reference source when a problem arises. **Bob Wayland** recommends several titles that should be included in every woodworker's library ("Wayland's Wood World," p. 38).

Contributing editor **Joe D'Appolito** offers a detailed review of LinearX's pcRTA, a real-time analyzer that you might consider for its many features and ease of use ("Product Review," p. 42).

Speaker Builder

THE LOUDSPEAKER JOURNAL

VOLUME 16 NUMBER 6 SEPTEMBER 1995



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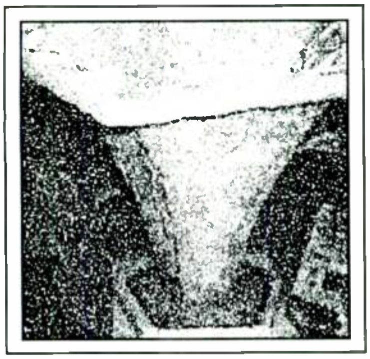

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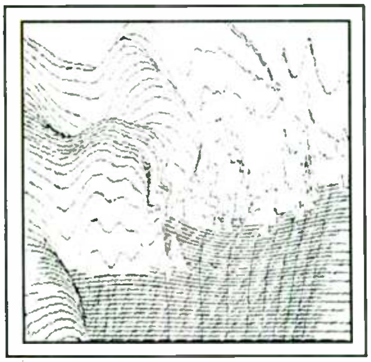

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DEPARTMENTS

Part 1

THE WAVEGUIDE PATH TO DEEP BASS

By G.R. Koonce

Many years ago, I did the bass portion of record playback via multiple 15" drivers, which certainly produced the needed quantity of bass. In recent times, I have come to prefer the bass articulation of smaller drivers, in the 6.5–8" range. This article covers my most recent quest to develop acceptable bass extension with these smaller drivers.

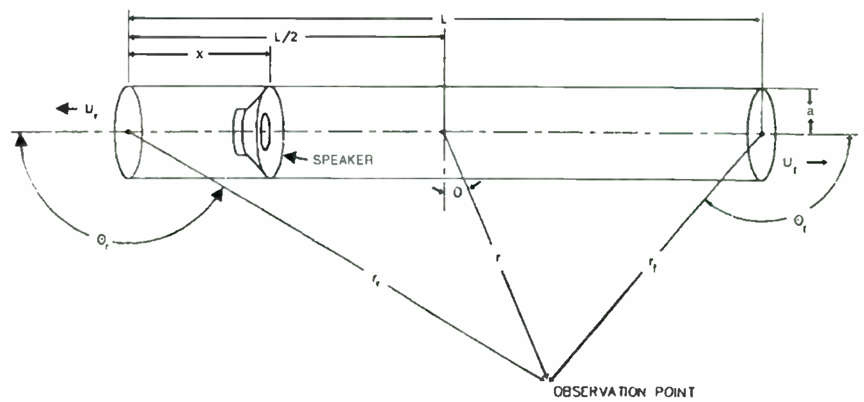

FIGURE 1: Resonant-tube loudspeaker notation (Fig. 9 from Ref. 1).

MAJOR PROBLEMS

There are some problems with trying to generate extended bass—say flat to within 3dB down to at least 35Hz—with small drivers in normal direct-radiating systems (i.e., vented and closed-box systems):

- Moving air: to produce acceptable levels of bass, you must move large quantities of air. The smaller the driver-effective cone area, the larger the displacement must be to accomplish this feat. Reasonably priced small drivers tend to have only moderate linear-displacement capability.
- Efficiency: a direct-radiating system has an efficiency in the passband equivalent to that of the driver reference efficiency. Thus the driver must be very efficient or able to handle lots of thermal power to produce the required bass. Reasonably priced small drivers tend not to be high powered.
- Low f_S: to design a flat response with a low –3dB cutoff frequency, the driver must have a low free-air resonance (f_S). Typical small drivers do not have a low enough f_S. You can add mass to the cone to lower f_S, but this lowers the driver efficiency, which is counter to what you are trying to accomplish.

It is clear that to produce acceptable bass performance with typical small drivers, the ideal approach is one that provides:

- An acoustic gain so the thermal power and displacement limits of the small driver produce acceptable low-frequency output levels.
- An approach that allows a low system f_3 without requiring a very low f_S for the driver.

The transmission line (TL) is a direct-radiator system that reportedly will produce an f_3 value below the driver f_S. Since a major portion of its passband is produced by the forward face of the driver, its efficiency is limited to the driver's reference efficiency, so it does not offer the desired acoustic gain. There are nondirect radiating approaches that do provide these advantages. The oldest is probably the horn, but the problem with this approach is the size—absolutely unacceptable for my needs in the 35Hz range.

Over the last several years the bandpass system, another nondirect radiating system, has evolved. I have run numerous small drivers through the software to design bandpass systems, but none has produced the desired low f_3. Because the bandpass-system response is based on the driver f_S, it does not meet the second provision listed above. Another device receiving much attention in recent years is the acoustic waveguide, certain forms of which offer the promise of acoustic gain and low f_3 for a driver of reasonable f_S.

WAVEGUIDES

In general, a waveguide is any structure of constant or expanding area that transports a wavefront. The horn certainly fits this definition. The more common use of the term pertains to devices designed to control the wavefront at the acoustic output point and thus direct the unit's radiation pattern (i.e., directivity). The "constant-directivity" horn, used at midfrequencies and above, produces an acoustic radiation pattern that is basically frequency independent and represents an example of this form of waveguide.

Another class of waveguide structure uses constant-area pipe sections to produce low-frequency output augmented by the resonant property of such pipes. This waveguide comes in two varieties, single-ended and double-ended. A single-ended waveguide has a pipe on one face of the driver, while the other face radiates directly—in effect, an unstuffed transmission-line system. In a double-ended waveguide both driver outputs (both sides of the cone) feed pipes; in effect, you have a driver set somewhere along the length of a pipe.

This article covers the development and testing of an experimental double-ended low-frequency waveguide structure. *Figure 1*

PATENT NOTICE

The experimental structure discussed in this article may be covered by the patents shown below. Proper arrangements should be made before you undertake anything other than experimental investigation using this technology.

Patent No. 447,749 to P.G.A.H. Voigt, 1936 (England)

Patent No. 1,969,704 to A. D'Alton, May 25, 1933 (US)

Patent No. 4,628,528 to A. Bose and W. Short, 1985 (US)

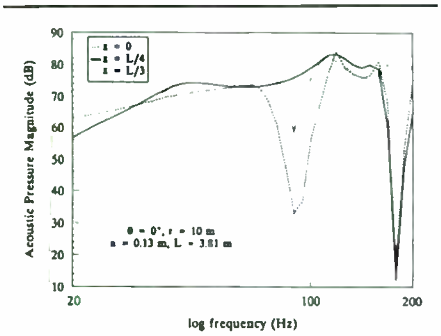

FIGURE 2: Relative output pressure magnitude of resonant-tube system (Fig. 10 from Ref. 1).

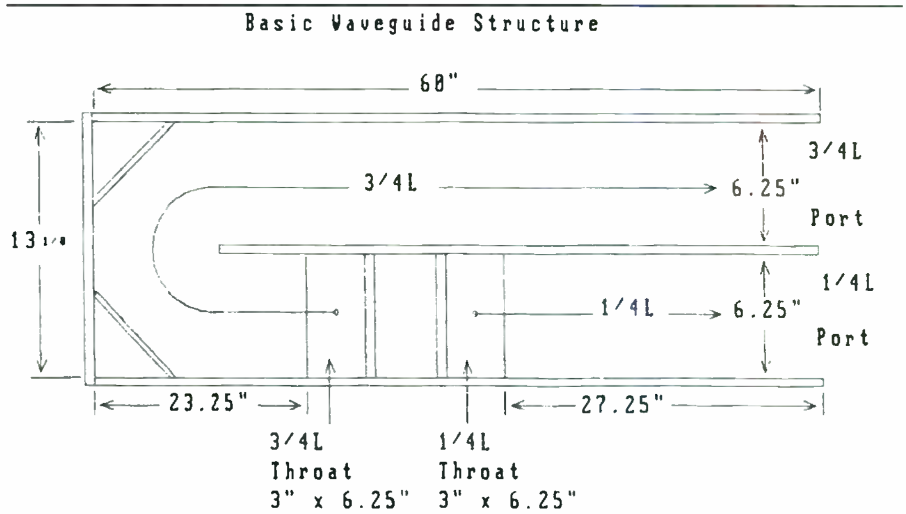

FIGURE 3: Drawing of basic waveguide structure tested.

(from reference 1) shows this waveguide configuration, and *Fig. 2* (also from reference 1) shows that if the driver is placed at the one-quarter point of the pipe, you obtain a reasonably flat and extended bass response. Note that reference 1 refers to this structure as a resonant-tube loudspeaker, which certainly describes how it works, but I will continue to use the term waveguide. This was the structure that I set out to investigate.

The driver feeds two pipes, the shorter being ¼L and the longer being ¾L, where L is the total pipe length. Reference 2 also addresses this structure and indicates that reasonable (6dB or more) sensitivity improvement is available, but that passband ripple is to be expected. I will refer to the input ends of the waveguide structure as throats, but since the pipes are of constant diameter, I will refer to the outputs as ports, rather than the term "mouth," as is used with horns.

ORIGINAL CONSTRUCTION

The problem was how to build a double-ended waveguide structure for experimental investigation with so many unknowns. While the references recommended round waveguide pipes, they would be difficult to build and practically impossible to "fold" into a reasonably sized structure for easy testing. I thus built with a rectangular cross section. The test waveguide was sized for 6.5" drivers to keep it as small as possible, so I used a 6.25" × 3" pipe area, which is just below the effective cone area of a typical 6.5" driver (waveguide area = 18.75 in^2; area of 80% of a 6.5" driver = 21.24 in^2).

It was difficult to determine the total length (L) required for a waveguide to meet my goal of usable down to 35Hz. Reference 2 indicated a usable passband from $\lambda/4$ to $5\lambda/4$, where λ is the wavelength of the ¾L portion of the waveguide. For a sound velocity of 1,128ft/s, at 35Hz the wavelength is 32.2′ or 387.7″. The ¾L portion of the waveguide must be one-fourth this length, or 96.7″; the total length L must then be 128.9″. I had on hand some sheets of particleboard that were 60″ long, which allowed me to build with a total length L of 126.8″. Thus, I might fall short of my 35Hz goal, but this is the type of information my testing program attempted to establish.

TABLE 1

INTERNAL GROSS VOLUMES OF DRIVER MOUNTING STRUCTURES (in^3)

W/O DRIVERS MOUNTED	VOLUME
Single 6.5″ driver mounting box	317.3
Single 8″ driver mounting box	423.6
Dual 6.5″ driver mounting box	378.0
Dual 8″ driver mounting box	670.6
Close coupling single–driver box	337.5
Rubber throat (volume between driver and each side of waveguide)	192.4

The concept was to build a waveguide structure that comes apart at the one-quarter point to insert a driver. Also, I required the two waveguide outputs (ports) located side-by-side so I could use near-field measurement techniques. I therefore decided to build the basic waveguide structure as shown in *Fig. 3*, with the ¾L portion folded so both ports were at the same end and with inputs (throats) located on the top.

Since this made it difficult to insert a single driver with both faces tightly coupled to the waveguide throats, I contemplated the use of two drivers driven out of phase. If the drivers behaved in an Isobarik fashion (testing shows they do not), then the volume of the box holding the drivers would be removed from system considerations. I built four box structures to attach to the basic waveguide structure: one for a single 6.5″ driver, one for a single 8″ driver, and two covering dual 6.5″ and 8″ drivers. All boxes were as small as possible to keep things coupled relatively tightly to the waveguide, but it was clear that the single-driver boxes would place a compliant volume between the back of the driver and the waveguide throat.

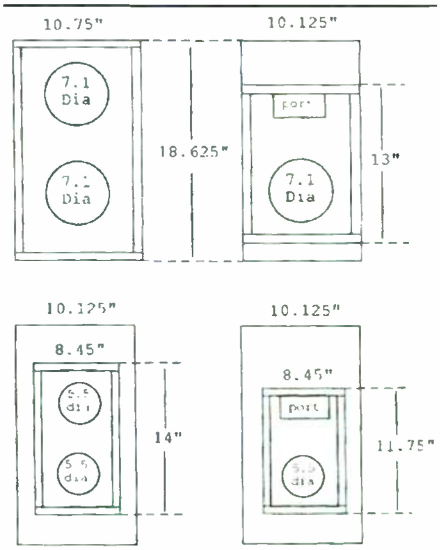

FIGURE 4: Drawing of four driver attachment boxes for basic waveguide structure.

Gross (drivers not contained) internal volumes for these boxes are listed in *Table 1*. All construction was with 5/8″ particleboard. Electrical connection to drivers was via brass sheet-metal screws threaded through the particleboard with dual sets of terminals for boxes that housed two drivers. Where the various pieces attached to the waveguide or a top fitted a box, the surface was gasketed with 1/16-inch-thick foam tape to try to maintain an air-tight union.

THE STRUCTURES

Figure 4 shows the four attachment boxes, and *Photo 1* shows the basic waveguide structure and four attachment boxes. The basic waveguide structure is at the right of the picture, the dual-driver boxes are rear left, and the single-driver boxes are rear center.

TABLE 2

CHARACTERISTICS OF DRIVERS USED IN TESTING

DRIVER	SIZE	f_S (Hz)	Q_{TS}	V_{AS} (ft^3)	TYP SPL dB/W/m	SURROUND MATERIAL	CONE MATERIAL & THICKNESS	NOM. Ω
A	6.5″	47–48	0.36–0.37	0.47–0.50	87.5	Foam	Paper (med thick)	4
B[1]	6.5″	75–76	0.64–0.75	0.39–0.40	89.2	Foam	Paper (thin)	4
C	6.5″	56–60	0.82–1.0	0.57–0.62	86.4	Foam	Poly (thin)	8
D[2]	6.5″	54–56	0.64–0.65	0.31–0.39	85.2	Foam	Poly (med thick)	4–16
E[3]	6.5″	49–52	0.46–0.51	0.18–0.20	83.1	Foam	Paper (thick)	4
T[4]	8″	62–63	0.67–0.83	0.97–0.98	89.5	Cloth	Paper (med thick)	8
U	8″	31–33	0.49–0.58	1.8–2.4	87.1	Foam	Paper (thick)	8
V[5]	8″	37	0.72	1.5	85.5	Foam	Paper (thin)	6
W[6]	8″	45–47	0.38–0.39	0.96–1.0	90.0	Foam	Poly (thin)	6
X[7]	8″	45–46	0.30–0.32	1.7–1.8	93.2	Foam	Paper (thin)	8
Y[8]	8″	37–40	0.45–0.47	2.4–2.5	90.1	Foam	Paper (thin)	8
Z	8″	29–30	0.48–0.49	3.5–3.6	88.1	Rubber	Paper (thick)	8

Notes: All drivers have forward half-roll surround except T.
1. This driver (B) has a large, flat, paper dust cap.
2. Dual voice-coil driver, data for voice coils in parallel.
3. Driver has a 2.4″-diameter thick cardboard disk covered in foam glued to cone, leaving only about ¾″ ring of cone exposed.
4. This driver has reverse half-roll surround and curvilinear cone.
5. Only have T/S parameters on one sample. Driver has vented dust cap and no front gasket, so does not seal well to test boxes.
6. Driver has vented magnet structure.
7. Driver cone has decoupling rings.
8. Driver cone has decoupling rings and large wizzer cone.

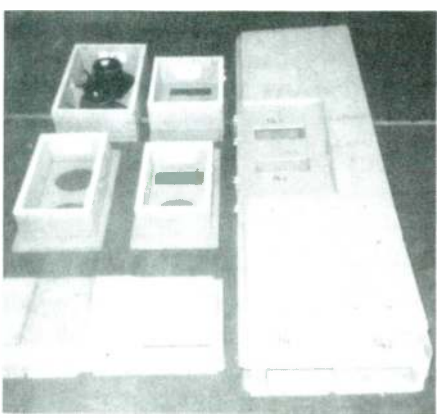

PHOTO 1: Basic waveguide structure: four original driver boxes and ¾L extension.

Also shown in the picture (left front) is an extension built for the ¾L portion of the waveguide (discussed below).

When you fold a rectangular structure, you change the area at the corners. To help correct for this, I inserted simple 45° baffles in the pipe, designed according to the simplest rule for the bending of high-frequency runs on printed circuit boards (*Fig. 5*). I used this technique wherever the waveguide structure was bent 90° in either plane. I recommend you review more recent work by Bruce Edgar ("The Monolith Horn," *SB* 6/93, p. 13), which indicates that this is not the best baffle configuration.

I planned to use the waveguide to investigate a group of 6.5″ and 8″ drivers representing a variety of T/S parameter groups. *Table 2* shows the basic information on each of these drivers, none of which I purchased for this investigation. Some were good drivers I simply had not used yet, but most had been around for a long time because I had not figured out how to do anything really worthwhile with them!

IMP TO THE RESCUE

With 12 different driver types to evaluate in single and dual combination, recording data was a major undertaking, since I wished to observe impedance and near-field (NF) response for all combinations. Fortunately, Liberty Instruments introduced IMP, which I purchased and constructed for this work. Being a bit leery of testing an unknown system type with an unknown test technique, I proceeded slowly. I still lack the necessary experience to properly judge the results that IMP produces (I tend to think in the frequency domain, not the time domain), but without IMP the data collection would have been too time-consuming to obtain all the results presented here. I highly recommended IMP (or the new Liberty Audiosuite) for anyone who needs one test set for impedance, T/S parameters, and acoustic measurements.

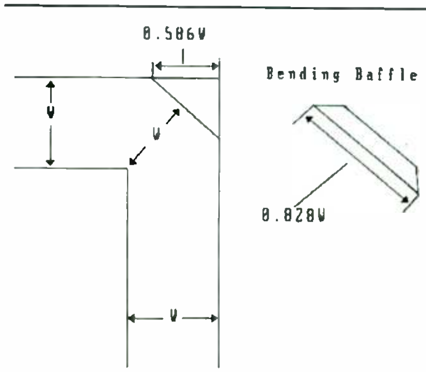

FIGURE 5: Drawing of how waveguide bending baffles were designed.

The test results cover a long time period, and I used various versions of the IMP software, some of which were Beta versions. Thus, the figures may not appear exactly as displayed by your IMP software. My original testing used the Pulse test waveform, while all later work used the MLS test waveform. Results agreed quite well, but the MLS waveform is vastly superior in its noise rejection, and I definitely recommend it.

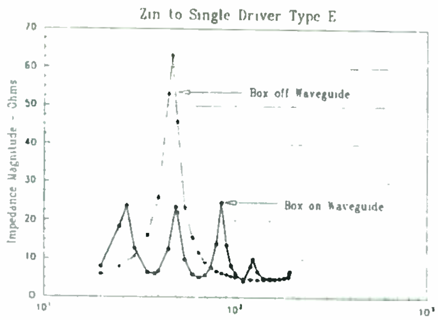

FIGURE 6: Z_{IN} to 6.5" driver type E via impedance meter.

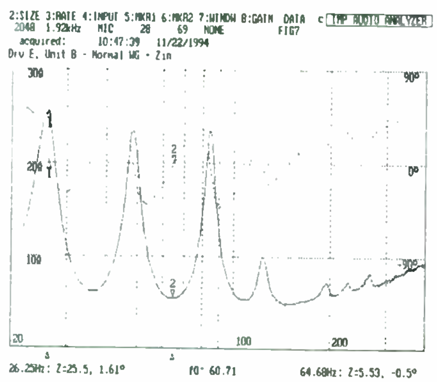

FIGURE 7: Z_{IN} to 6.5" driver type E mounted on waveguide via IMP.

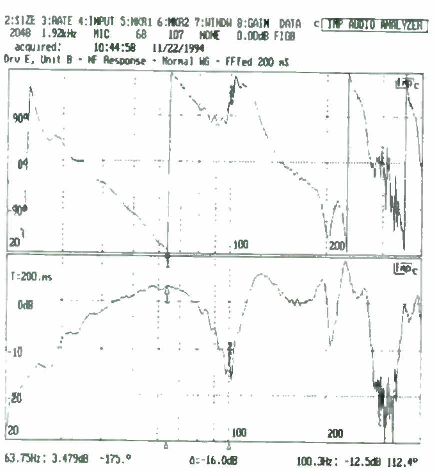

FIGURE 8: IMP near-field response for single 6.5" driver E on waveguide.

I was learning IMP during this investigation, so determining the exact time period to FFT was a mystery to me. Fortunately for NF testing, the room reflections are overwhelmed by the direct signal and you have more leeway in selecting the FFT period. Most data shown was generated using a rectangular 200ms FFT window, which should give accurate frequency resolution to below 10Hz. Some of the early data was reproduced with newer IMP software for reproduction purposes.

My first test was with the single 6.5" drivers. I mounted one unit of driver type E (*Table 2*) on the single 6.5" driver box and measured input impedance (Z_{IN}) with an impedance meter, both in the box alone (almost identical to the baffle Z_{IN}) and with the box attached to the waveguide structure (*Fig. 6*). The waveguide surely controls the driver input impedance, which still appears to show a peak at the driver f_S, but this is a coincidence; later curves show that the driver f_S does not even appear in the curves of Z_{IN} mounted to the waveguide.

Figure 7 shows IMP's rendition of Z_{IN} mounted on the waveguide, and agreement is excellent. I measured the acoustic performance of this driver/waveguide by placing the mike right at the partition between the ¼L and ¾L waveguide ports (see *Fig. 8* for these NF test results). The basic shape is what *Fig. 2* had led me to expect, but there is a major dip at 100Hz. The reason for this dip is that the single driver boxes change the length of one portion of the waveguide so the correct 3:1 length ratio is not maintained.

Fearing that the box between the back of the driver and the waveguide throat would have such an effect, I had planned to mount the single driver over the shorter ¼L portions, but in construction somehow positioned the driver over the ¾L portions, which made things three times as bad. In an attempt to cure this, I built an extension for the ¾L portion of the structure (*Photo 1*), to correct the length ratio as much as possible. This extension made a 90° rotation of the output to keep the two output ports relatively close together for NF testing, but the two ports were no longer side-by-side, so mike placement affected NF results.

Figure 9 shows the NF response for the single 6.5" driver waveguide system with the ¾L extension in place. The small dip in the response (near 89Hz) appeared in all 6.5" single-driver tests with all driver types, and I believe it to be a function of the driver diameter or some dimension of the driver mounting box. With single 8" drivers, a similar dip always occurs, but at about 83Hz. In general, performance with single drivers mounted this way was unsatisfactory, so I present no additional data.

FURTHER TEST RESULTS

The use of dual drivers driven out of phase offered more potential, and I tested them without the ¾L side extension. *Figure 10* shows Z_{IN} for the dual drivers Z; note that the driver resonances (29.3Hz and 29.8Hz) do not show as peaks on this plot. *Figure 11* displays Z_{IN} using dual drivers X, with main peaks similar to those in *Fig. 10*. *Figure 12* shows a typical NF response for dual drivers X, agreeing well with what *Fig. 2* predicts.

Since my waveguide output ports were located side-by-side, I believe the NF response shape should match the response shape of *Fig. 2*, but have seen no mathematical proof that this is true. There were slight differences in the NF response with different pairs of driver types, but generally *Fig. 12* shows the basic shape for all dual 6.5" and 8" drivers.

If the drivers were Isobarik in behavior, then the response shape would be the same as if either driver were driven alone. Under such conditions, you could use IMP to observe the output from the undriven driver for some

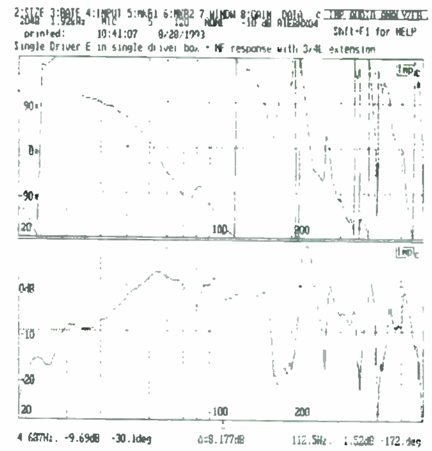

FIGURE 9: IMP near-field response for single driver E with ¾L pipe extension.

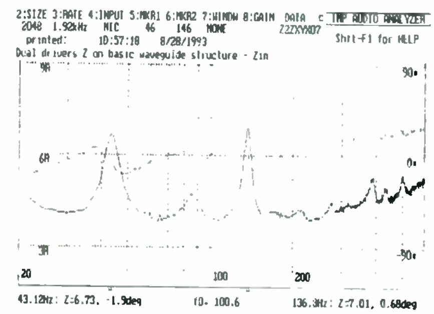

FIGURE 10: Z_{IN} for dual drivers Z on basic waveguide.

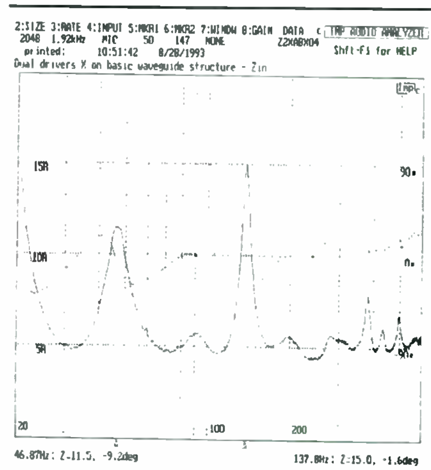

FIGURE 11: Z_{IN} for dual drivers X on basic waveguide.

TABLE 3

IDENTIFICATION OF UNITS DRIVEN AND MEASURED IN *FIGS. 13–16*

FIGURE	WHAT WAS DRIVEN	PULSE POLARITY	WHAT WAS MEASURED
13	Driver on ¾L	Normal	Voltage on ¼L driver
14	Driver on ¾L	Normal	Waveguide NF response
15	Driver on ¼L	Inverted	Voltage on ¾L driver
16	Driver on ¼L	Inverted	Waveguide NF response

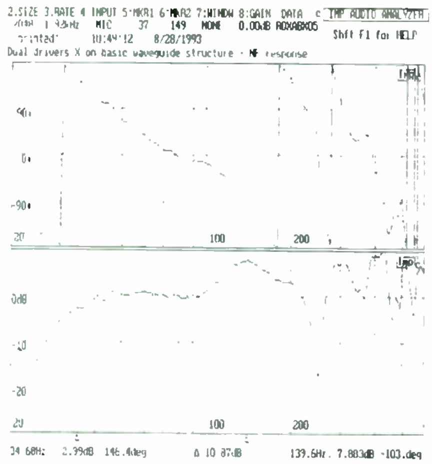

FIGURE 12: IMP near-field response for dual drivers X on basic waveguide.

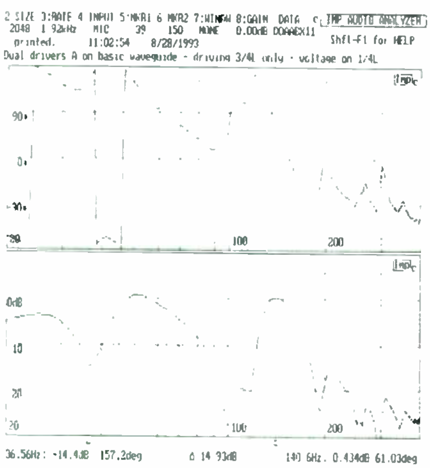

FIGURE 13: Voltage at ¼L driver A while driving ¾L driver A only.

idea of the displacement function for the drivers. In this area, I tested dual 6.5″ drivers type A. *Figures 13–16* provide the results for NF response with one driver driven and the electrical output of the other driver under these conditions. *Table 3* identifies details for each figure.

The two NF responses are similar but not identical. The same is true for the open driver voltage outputs, which means my assumption of Isobarik operation is invalid. Clearly, the waveguide has far more control over the drivers than does the small chamber in which they are enclosed, something that was apparent when I saw the first impedance curve for the dual drivers on the waveguide.

There is some information to be gained from the basic shape of the curves for open driver output voltage in *Figs. 13* and *15*. They do represent the driver displacement for the test conditions, even if they are not accurate for the case when both drivers are driven. There are no sharp peaks, which would have indicated large driver displacement at a specific frequency.

If you ignore the various dips in *Figs. 13* and *15* and determine the basic voltage from the undriven driver can be approximated by a straight horizontal line over the passband, then you can form a conclusion about the driver displacement. A dynamic driver's output voltage is due to the voice coil moving in a magnetic field and is thus a function of voice-coil velocity. A voice coil moving with sinusoidal motion of peak displacement X will have a displacement versus time function (x) given by:

$$x = X\sin(2\pi ft)$$

where X = peak displacement, f = frequency, and t = time.

The instantaneous voice–coil voltage (v) would be some constant (k) times the derivative of the displacement function:

$$V = \frac{d(x)}{dt} = 2\pi fkX\cos(2\pi ft)$$

The RMS voltage (V) would be:

$$V = 0.7072\pi fkX \quad \text{or} \quad V = k_1 fX$$

where constant $k_1 = 0.707\ 2\pi k$

The approximation of V as constant over the passband means peak displacement X halves as frequency f doubles. There is no indication of the magnitude of the peak displacement—just that the peak increases linearly as frequency is reduced. Note that this result is in contrast with the normal result for a direct radiator system, where in its passband the displacement will decrease 4:1 as frequency is doubled. The reason may well lie in the sloped response of the waveguide. The dual-driver waveguide seemed to be working about as theoretically predicted insofar as its NF response was concerned, so it was time to give it a listen.

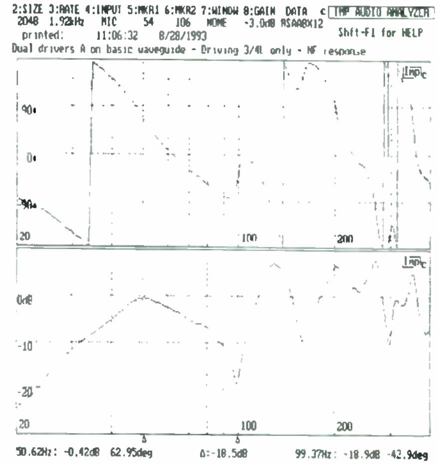

FIGURE 14: Near-field response for driving ¾L driver A only.

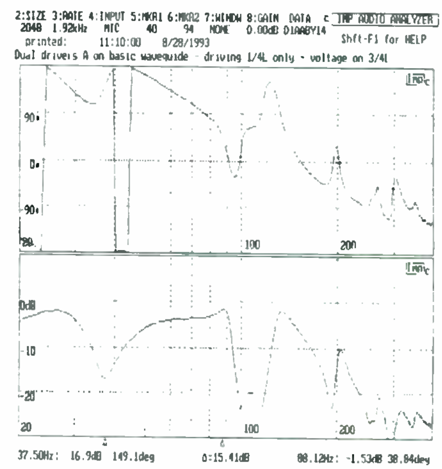

FIGURE 15: Voltage at ¾L driver A while driving ¼L driver A only.

LISTENING TO THE WAVEGUIDE

I moved the waveguide into the garage and placed it next to a three-way 8″ closed-box system that was to serve as the upper end for listening tests. I placed the waveguide on the floor so the ports were in line with the front of the upper-end system. I used a tunable second-order active crossover to drive the waveguide and upper-end system in a biamp configuration.

Since I had only one waveguide structure, all listening was done in monaural, which tends to produce less bass than a pair of speakers with the same response in stereo. I set the crossover frequency at about 100Hz to suppress the peak that appears in the waveguide response. It was immediately evident that you could not obtain a good setting of the waveguide level in comparison to the level of the upper-end system, something that experience has shown always means trouble. I tried the waveguide driven in both normal and

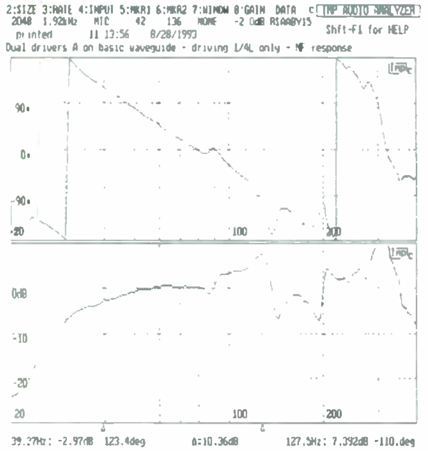

FIGURE 16: Near-field response for driving ¼L driver A only.

inverted polarity. Normal polarity for the waveguide is arbitrarily defined as positive voltage input causing positive pressure in (cone moves toward) the ¼L throat.

The only conclusion to be drawn was the combination was terrible! The waveguide was very strong on steady-state signals in its frequency range, but transient instruments sounded very weak. If you set the level on stringed instruments, it was way too low on drum, and vice versa. Set to a level where drum was still weak, pink noise tests with a 1/3-octave real-time analyzer (RTA) indicated the waveguide bass level was too high. The only time I had witnessed similar results was when testing a vented-box system in which the box was too weak and radiated nearly as much as the driver. The waveguide is a large structure with much surface area and very small output ports. Could it be the waveguide structure was not stiff enough?

I set the waveguide on sawhorses and fed it a couple of watts of pink noise bandlimited to 200Hz. Using the RTA, I then probed the output level at the output ports and around the various portions of the structure. The SPL from the top of the cover over the dual drivers and from almost all of the structure was less than 20dB below the port outputs, and did not have the same frequency spectrum.

Since the structure has a very large surface area, it radiated considerable audio energy. The structure was clearly not stiff enough. You are, in effect, building a horn that is all throat, so it must be very stiff. Rule #1: The waveguide structure must be very stiff. It was clear I needed to return to the building mode.

We have covered what I was trying to accomplish and the initial waveguide construction. Initial test results were very encouraging, but results of the listening session were disappointing. The waveguide structure is not sufficiently stiff as constructed. Part 2 will examine the waveguide revisions and additional fixtures, along with test results of these changes.

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1. D. Mapes-Riordan, "Horn Modeling with Conical and Cylindrical Transmission-Line Elements," JAES, Vol. 41, No. 6 (June 1993): 471–484.

2. W.R. Short, "Acoustic Wave Cannon: Sound for Cinema," *Audio* (Nov. 1991): 30–39.

STEREO BASS: TRUE OR FALSE?

By Tom Nousaine

In investigations of optimal subwoofer positioning (*Stereo Review*, January '95) the questions of multiple sources and stereo program content needed to be addressed before conclusions about woofer placement in high-quality systems could be drawn. More specifically, before drawing a set of rules about optimizing subwoofer performance, we need to know: (1) whether full separation to DC (now possible with CD) has made full bandwidth stereo a mandate; and (2) whether multiple sources are useful even without stereo programs.

First, stereo (out-of-phase left and right information) *does* seem to be available on modern CDs. My friends Eric Busch (DLC Design) and David Ranada (*Stereo Review*) confirmed this and supplied reference program material for experiments. So, no matter what you might think of it, there is full bandwidth stereo program content.

DOES IT MATTER?

Do we really hear in "stereo" at low frequencies? I was not convinced, but so much has been discussed about the enhanced sense of realism and spaciousness with stereo subwoofers, I was willing to investigate these promises of better system sound. Thus, I experimentally tested the perceptibility of stereo at low frequencies and the use of multiple subwoofers.

First, I set up a variable crossover (40, 60, 80, 125, and 150Hz at either 6dB or 18dB/octave high- and low-pass) and a pair of matching Klipsch SS12 subwoofers (set to maximum bandwidth at 160Hz low-pass). I placed the subs directly underneath a pair of Snell KII two-way main speakers (in their normal in-room locations) and ran through a sequence of test signals (sine-wave sweeps from 160–20Hz, pink noise) and music (bass drum and organ) while switching between mono and stereo.

I adjusted the mono feed with a Dynaco PAT-5 preamplifier to accommodate the summing gain and I matched levels to within 0.5dB from 30–80Hz with an MLSSA analyzer and microphone placed at center couch. The "stereophony" of the test setup is verifiable using the MLSSA system. Additional stereo comb filtering was clearly evident in the response graphs (*Fig. 1*) with uncorrelated pink noise.

However, I could hear no perceptual difference between mono and stereo using 80Hz crossover slopes, and neither could two other listeners in single blind presentations—even with the main L&R speakers switched off. At crossover frequencies above 100Hz the differences between mono and stereo tended to be locational in nature, as both listeners rated stereo and mono identical in spaciousness. Their opinion was divided between the two as "most natural" overall, indicating equivalent performance.

In sum, music listeners were unable to identify differences in monophonic and stereophonic reproduction at frequencies below 80Hz, even using programs that highlight stereo content and with speakers located at maximally efficient, stereophonic locations. I concluded that listeners do not perceive stereo information at subwoofer frequencies. Stereo is a higher-frequency phenomenon associated with locating sound.

STUCK IN A CORNER

However, this alone doesn't mean the use of stereo subwoofers is without ramifications. The desirability of multiple sources at low frequencies is intertwined with stereo. Conventional wisdom says that multiple sources differentially excite room modes, thereby smoothing in-room response. A similar case is often made for stereo sources: out-of-phase signals will differentially excite room modes leading to smoother in-room response.

Actually, maximally exciting all modes (width, length, height, oblique, and tangential) produces the smoother in-room response in a modal sense. This leads to best response at low frequencies with your subwoofer in a corner. Yep, it's true, the lowest, loudest, and flattest response comes from

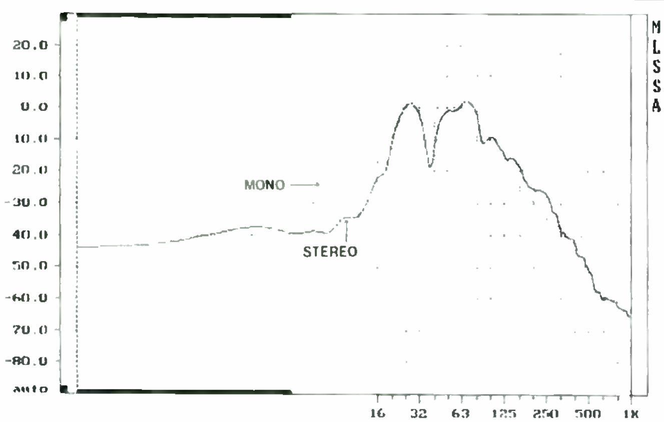

FIGURE 1: Two subwoofers at stereo locations. Stereo (solid) shows added comb filtering versus monaural reproduction at low frequencies.

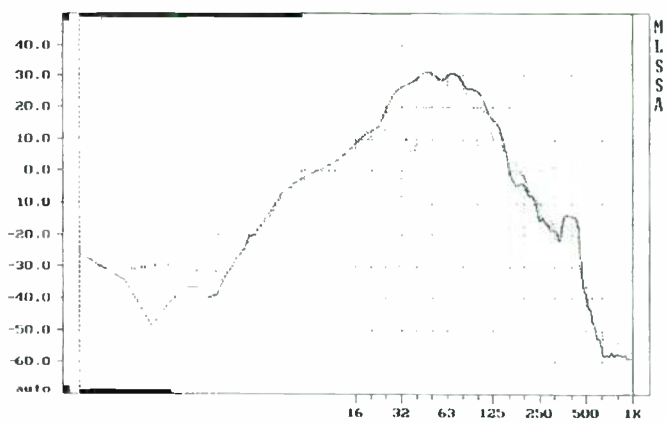

FIGURE 2: Low-frequency response with woofers in a corner (solid), midwall near door, and midroom. Corner location is much better.

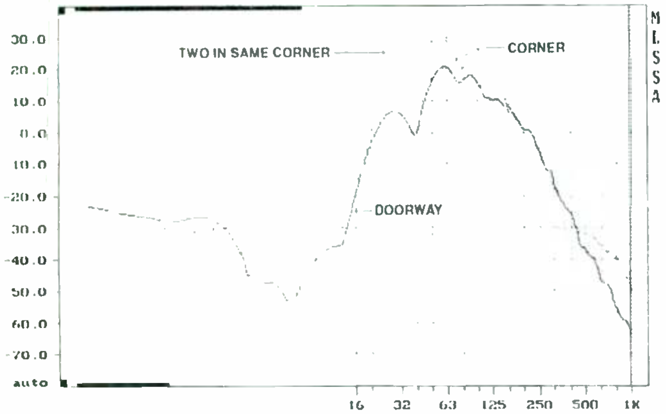

FIGURE 3: Moving a subwoofer into the corner produces flatter, smoother, and deeper bass. Adding a second subwoofer in the same corner increases output by 6dB.

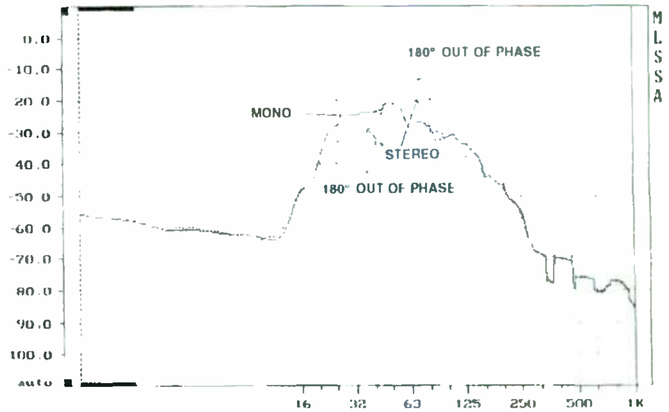

FIGURE 4: Driving a second subwoofer in stereo degrades response. Driving the second sub 180° out of phase (super stereo) makes things worse.

subwoofers located in the corner. Placing the sub midwall or out in the room does differentially excite modes, but this just produces modal notching irregularities. Response improves at low frequencies as we move the sub toward the walls and into corners (*Fig. 2*).

Furthermore, optimization occurs when multiple woofers are placed close together, so putting the second woofer in the same corner delivers identical frequency response and 3dB more reinforcement than placement in opposite corners (*Fig. 3*). Using a second woofer anywhere but another corner can reintroduce modal notching, which at higher frequencies may be perceived as "stereo" comb filtering, but at subwoofer frequencies just limits extension and output. Strategic placement (staggered midwall) of the second woofer can result in flat, low response while wasting about 6dB of boundary reinforcement. This may be useful in some limited cases, but the subwoofer must be driven in summed mono.

WHY MONO?

Using uncorrelated (stereo) pink noise with two corner-placed woofers yielded no measured change in response compared to mono L&R performance except for the summing gain. So mono and stereo are tied here. However, switching to stereo noise with the staggered midwall strategy slightly worsened response, and simulating "ultra stereo" by driving the second woofer 180° out of phase simply reintroduces the modal notching syndrome (*Fig. 4*).

My conclusion is that you should run multiple subwoofers L&R mono when possible because stereo may degrade performance of nonoptimal, noncorner-placed subwoofers. Also, a single larger subwoofer will deliver more output than two small ones because the output sums coherently and larger drivers generally have more linear travel.

In closing, I mention a few things your Mom forgot to reinforce. Do not mistake three-piece systems with crossovers above 100Hz for satellite/subwoofer combinations. They are mostly satellite/woofer combinations. The hottest, best-performing modern music and home theater systems employ full-range main speakers, with good response to 80Hz augmented with separate true summed mono subwoofers crossed over at 80Hz or lower and optimally placed in a corner.

A MORNING GLORY MIDRANGE HORN

By Marie Shrewsbury

Many first attempts consist of "junk" separates. Mine were forever breaking down. I would replace them with modern components whenever finances allowed.

Some months ago, I fortuitously acquired a pair of QuadII monoblock power amplifiers (a classic British vintage valve design) and preamp. I was captivated by the valve amplifiers' warm, fluid sound. They seemed to give a far more natural presentation than my solid-state amp. The catch was, they produced only 12W. While this would be sufficient for normal use, I was convinced they would perform better with a very high sensitivity speaker (94dB+), which would be capable of resolving the fine detail at which analog amplification excels.

I decided the most feasible solution was to use horns. As I did not have the money to spend on a Lowther or a Klipsch, DIY was the key. Thus began my initiation into the twilight world of the amateur speaker builder!

PLANTING THE SEED

A search through the Leeds [England] libraries turned up only a couple of articles, but I found enough references to justify a trip or two to the British Library. There I photocopied articles by Klipsch, Olson and Massa, Crabbe, Newcombe, and others, as well as a number from *Speaker Builder*.

Armed with this information, I promptly set out to build a midrange horn. My first attempt was with wood, but the pieces didn't fit together. A second try, using a wood/polyfill template cast into concrete, looked like a Henry Moore cinder block, and had a bungled flare rate. The third version, made from card and papier mâché, was too resonant.[1]

PHOTO 1: The author's crude prototype.

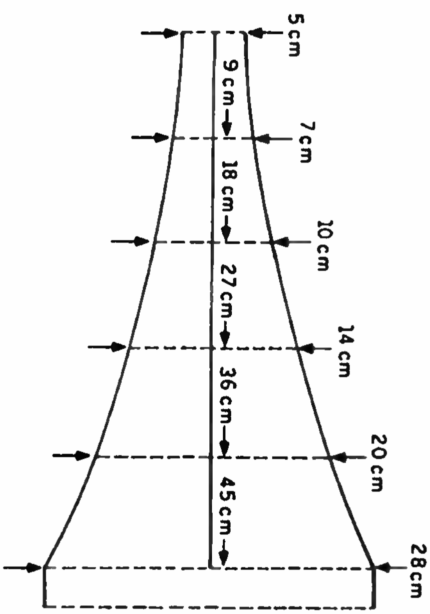

FIGURE 1: Template for cutting the five speaker sides.

Finally, I tried a different technique for casting into concrete. This produced a crude prototype with distorted sound. Nonetheless, it was a start.

WATCH IT GROW

I designed my horn to have a low-frequency cutoff of 208Hz, with a flare rate of one doubling every 9cm (*Fig. 1*). In a *Wireless World* article, Dinsdale proposes using a flare rate with a lower frequency cutoff than the mouth area.[2] Another source suggests this is not necessary for a midrange horn.[3] As a compromise, I used an actual mouth area optimal for 250Hz, with a flange (as described by Klipsch[4]) to provide the extra area required to reach 208Hz. This flange also braces the mouth against resonances. My mouth area is equivalent to a horn's circular section, with a diameter of $\lambda/3$.

A pentagonal section prevents parallel surfaces within the horn from generating standing waves, and is not much more difficult to manufacture than a square one. If you wish to make a smaller design using the construction principles outlined here, simply substitute your own dimensions for the side cutout.

The crude prototype in *Photo 1* served principally to test my manufacturing methods. It is positioned on top of a Goodmans Magister, which I needed for the lower frequencies (and includes grids to prevent my cats from scratching the drive units.)

LET IT BLOOM

I cut five sides from cardboard; each is cleaned and bent to increase flexibility (*Photo 2*). This also provides a better contour, so the sides more easily fit together. I tacked down the rim of each side to a board traced with the mouth's shape, and cut off the overlapping pieces with a Stanley knife. Then I attached the 48cm-long central rod, which I later used to brace the throat end.

The sides are joined with insulation tape. Be sure the edges meet evenly, with no overlap. Begin with the bottom and work progressively toward the top, as shown in *Photo 3*.

As a result of a miscalculation in determining the radial length of each side, the central rod was 1.5cm too short. I plotted the horn profile on a graph and measured the radial length from this, not realizing it assumed a square section. It seemed unlikely, however, that an increase in doubling distance of 3mm would cause any problems.

ABOUT THE AUTHOR

Marie Shrewsbury is self-employed, with technical qualifications in computer science and a certificate in counseling. Hobbies include watching films and playing rock music loudly.

PHOTO 2: Speaker "petals" tacked to a board prior to assembly.

PHOTO 4: Papier mâché application.

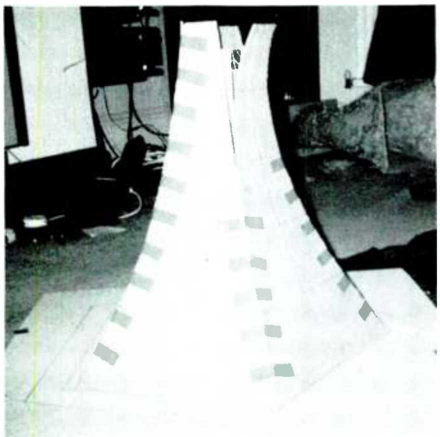

PHOTO 3: Attaching the sides.

I applied strips of papier mâché to the template, both as reinforcement and to smooth out small irregularities on the surface. This method also fixes the joint between the sides. The tape tends to peel away if left long enough, so I completed the process in one sitting, applying two coats of papier mâché and allowing the first to dry in between. Any "ripples" can be slit with a Stanley knife and smoothed with glue. Dab the glue onto the template, then place the strips of paper onto this, smoothing as you go (*Photo 4*).

You should also cover the joint between the template and the baseboard. (It must be sealed.)

CONCRETE CAST

The template should be watertight, or contact with the concrete will cause it to soak, which is moderately disastrous. It must also peel away smoothly from the wet concrete, so I used two coats of vinyl silk paint to seal it. After substituting a central rod of the correct length, I attached several card pentagons, which I taped to the sides to hold them in alignment at the throat. The top piece (*Photo 5*) is screwed through these into the central rod to provide a level surface for the concrete.

To cast the sides, prop the template up sideways, preferably against a wall. Spoon on and smooth down the concrete, using a "chopping" action with the side of the spoon to compact the concrete and expel trapped air. I maintained as closely as possible a depth of 2cm.

The concrete should meet both the top piece and the baseboard (*Photos 6* and *7*). I embedded 2.5cm nails in the concrete near the baseboard to reinforce the joint with the flange. Although this is probably unnecessary, after the collapse of a previous attempt I was taking no chances.

I used a proprietary brand of "quick drying path mix" concrete, which appears to contain fiberglass. It was sufficiently dry after 12 hours to allow rotating the template and casting the next side. Nails embedded in the exposed edges form a better joint with the adjacent side.

FLANGE WAYS

Once the sides have set, return the template to an upright position to cast the flange. Arrange five pieces of 34.5cm-long, 18mm-deep stripwood around the base, parallel with the sides. Mark their locations on the baseboard for a more precise flange width (4.5cm in this case). Apply the concrete in a similar manner to the sides, smoothing it with the stripwood. *Photo 8* shows the bricks I used to prevent the wood pieces from slipping (the top piece has been removed).

PHOTO 5: Sealing the speaker (with top piece attached).

When the flange set, separating the template from the concrete proved to be a two-person job. A friend held it upside down by the baseboard, while I worked a gap between the flange and the board. It came away cleanly to reveal a splendid internal contour. *Photo 9* shows it fresh from the mold.

The next step involves casting a similar

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1. A. Toneburst, "Low Cost Horn Loudspeaker System," *Wireless World* (May 1970): 202.
2. Dinsdale, "Horn Loudspeaker Design," *Wireless World* (from *High Fidelity Designs*, Darrington et al., p. 133).
3. B.C. Edgar, "The Edgar Midrange Horn," *SB* (1/86): 7.
4. P. Klipsch, "A New High Frequency Horn," *IEEE Trans Audio* (Nov./Dec. 1963): 202.

PHOTO 6: Applying concrete to speaker side. (Speaker is positioned sideways.)

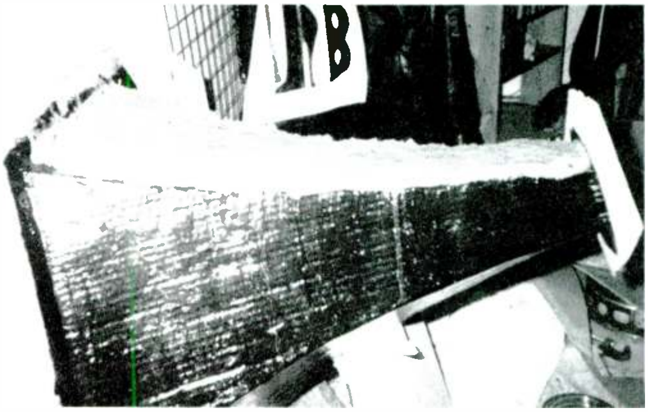

PHOTO 7: Letting the concrete set (note nails driven into baseboard).

flange onto the throat end, to which the drive unit mounting can later be attached. Not surprisingly, this is done in much the same way as the mouth flange, except the stripwood sides are 14cm long × 2.4cm high. I attached

PHOTO 8: Casting the flange.

five plus plugs, wrapped with insulation tape to prevent concrete seepage, 2cm in from each corner of the base.

The concreting procedure is as previously described. When it has set and the template is removed, the phase plugs will be solidly embedded, providing a base for the screws.

Photo 10 illustrates this process. The white blotches show where I used polyfill to eliminate small pockmarks in the surface. Apply it fairly liberally; the excess is easy to file off when dry.

MORNING GLORY BLOSSOMS

Initially, I sealed the inside of the horn with several coats of white Hammerite. While it improved the appearance, the Hammerite was too thick to penetrate some of the tiny pockmarks. A liberal application of vinyl silk would have worked better. Two coats of blue Hammerite gave the horn its "Morning Glory" appearance (*Photo 11*).

The outside finish is the final step. Because the surface was not in contact with the template, it was somewhat lumpy. My attempt to smooth one side with polyfill proved insufficient. I then found some "finishing plaster" which spreads very smoothly, as seen in *Photo 12*.

Unfortunately, I don't have access to high-tech equipment for plotting response curves. The best I could do was take a sensitivity reading, which I managed with an old JVC tuner/amp feeding equal amounts of white noise to two midrange units—one mounted in the horn, the other on a baffle of similar area. I miked them both at an equivalent distance from the diaphragm, and used the record level indicator on my cassette deck to measure the output. Bearing in mind that this method is not very accurate, it showed that I was getting 10dB more from the unit in the horn than the one on the baffle.

The drive units, a pair of old Philips midranges, were rescued from a three-way speaker with a blown bass. I conducted listening tests on the horn alone, with a Goodmans Magister supplying the bass, and with an experimental prototype bass horn (the latter integrated best). Live instruments and vocals are incredibly lifelike, resolution of low-level detail is exceptional, and there is no hint of coloration.

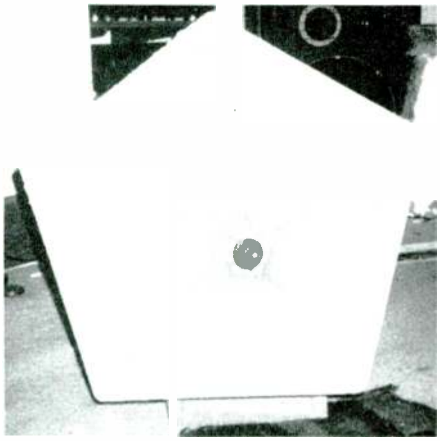

PHOTO 9: Concrete mold separated from the template.

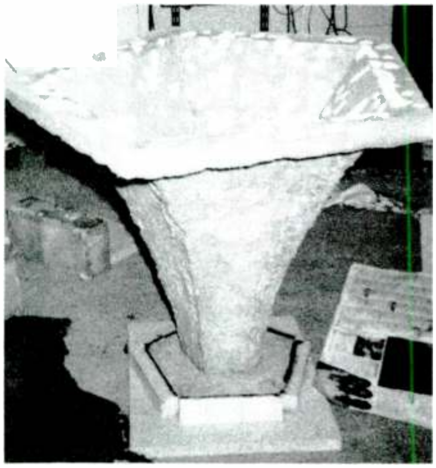

PHOTO 10: Casting the throat end.

PHOTO 11: The horn's inside finished with Hammerite.

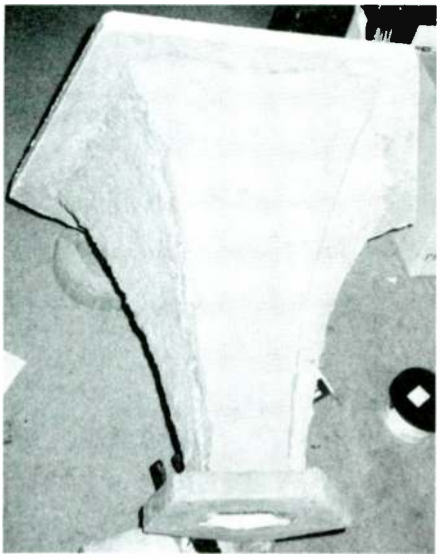

PHOTO 12: Smoothing the outside.

Unlike the square-section prototype, which even at a distance of 8–10′ sounded right only dead-on axis, the Morning Glory has excellent distribution. There is no change in sound even at 90° to the axis. I can only speculate that this may be due to cumulative reflections between the nonparallel walls.

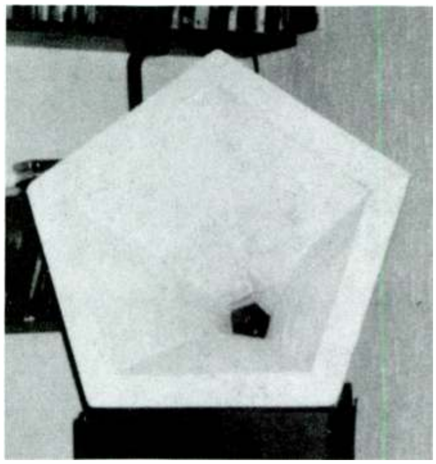

PHOTO 13: The completed horn.

NO REST

In the future, I would make several small changes in the construction of this design:

1. When papier mâchéing over the joint between the template and the baseboard (*Photo 4*), it would be better to fill in the gap before covering, either with filler or compacted papier mâché. The small kink here resulted in a slight rim (1–2mm) around the inside of the mouth.

2. I used only two layers of papier mâché, which left an imprint of the cardboard pattern on the horn. Using more layers should reduce this, although too many layers introduce kinks and bumps.

3. Replace the cardboard pentagons with a jigsawed wooden pentagon, and tack the sides to it at the throat. This will help prevent the sides from sliding out of alignment.

ACKNOWLEDGMENT

Thanks to the British Library for the volumes of information it made available, Mike Pepper for pointing me in the right direction, Kath Walters for moral support—and not laughing at the bizarre concrete shapes in the front room—and my cats Amelia and Dream for behaving in the presence of wet concrete.

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Reader Service #38 →

TESTING A SIMPLE FOCUSED ARRAY

By Bill Waslo

My previous article (*SB* 4/95, p. 10) described a concept for a "focused array" loudspeaker system. In case you missed it, the article outlined a method to configure an array of identical drivers spread out in a listening room so the path lengths of reflected signals, from each driver to the listener, all differ and the reflected signals are therefore spread out in time. The driver positions are, however, restricted to those at a fixed radial distance, so, unlike the reflected signals, the direct signals all arrive at the listener simultaneously.

The simultaneous direct signals add up as 20 log# (number of drivers), while the distributed reflected signals ideally total 10 log#. The intended effect is an enhancement of the direct signal intensity relative to the reflected signal strength, with the primary aim of reducing the effects of room acoustics on the perceived sound, while increasing efficiency and reducing distortion. On the down side, this is very much a "sweet spot" system for use by only one or two listeners.

When I wrote that article, I knew it would be a while before I would be able to manage all the woodwork to build the numerous speaker boxes to test out the scheme. I presented the idea to lure some of you speaker builders, who might be a little less pressed for time, into testing it.

Since then, I have found a way to perform some first-order tests of the concept. I already had four 4" midbass drivers, which I had acquired about a year ago with the aim of someday making a pair of D'Appolito-configuration satellite speakers. I remembered some of Cockroft's simple transmission lines (described in this magazine) which used pipe for the housing. My local hardware store sells thick-walled PVC pipe up to 4" in diameter and cuts it for free, so this provided a cheap, labor-free solution for some quick enclosures. Admittedly, use of only four drivers (theoretical enhancement of 6dB) is less than I would have preferred, but I believed I could at least get a feel for what to expect from a focused array.

CONFIGURING THE DRIVERS

I had four 42" lengths of pipe cut (that's what would easily fit in my car), stuffed each with polyester fiberfill, and mounted the drivers on one end of each pipe with shipping tape. Needless to say, this was not a detailed design. The measured response of each line using IMP showed a 6dB shelf drop below 500Hz. To compensate, I made a simple passive RC filter to precede the power amplifier. I originally set the filter to level off again roughly above 1kHz, but measurements and listening tests proved the drivers had a very ragged- and unpleasant-sounding high-frequency response.

I had little hope of using the focused array concept in the traditional tweeter frequencies anyway, because the very short wavelengths involved required the listener to be at a pinpoint location. I assumed that a separate single narrow dispersion tweeter would better serve the high frequencies and limit reflections via normal but not absurd beaming. Therefore, I used only a simple rolloff in the filter to handle the midrange shelf and additionally provide the low-pass characteristic for a crude crossover network.

The final woofer eq/electronic crossover network consisted of only a 2.2kΩ series

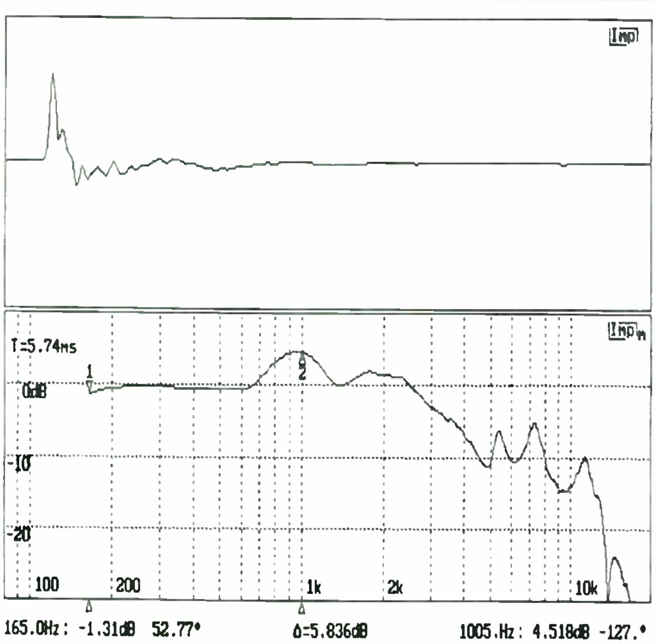

FIGURE 1: Anechoic response of midwoofer in pipe, with filter. Above: time domain. Below: frequency domain.

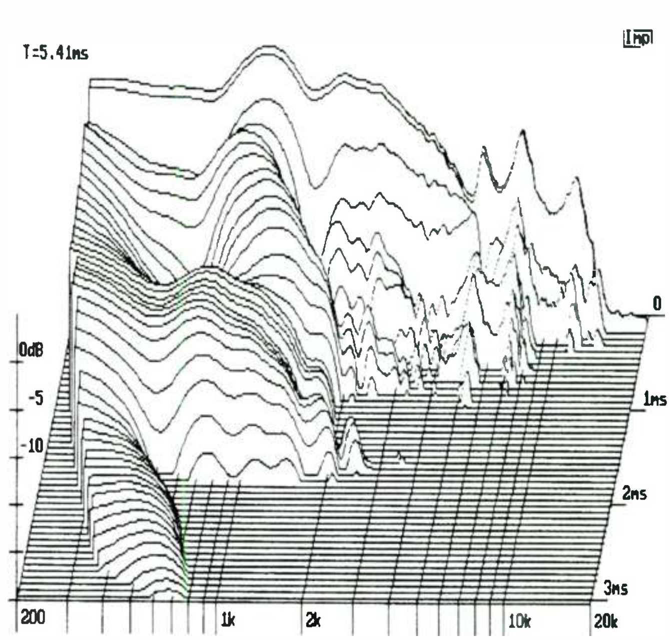

FIGURE 2: Midrange waterfall plot.

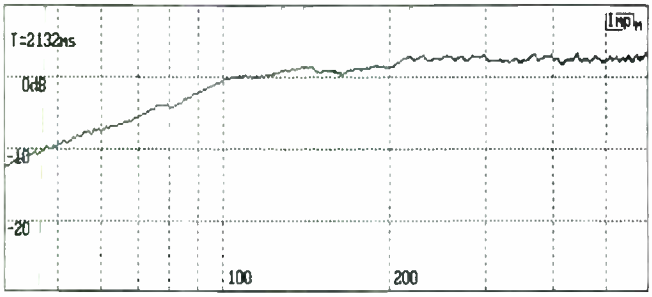

FIGURE 3: Near-field measurement of bass response.

PHOTO 1: Focused array setup in author's living room (photos by Darek Ball).

PHOTO 2: Arrangement of the pipe speakers.

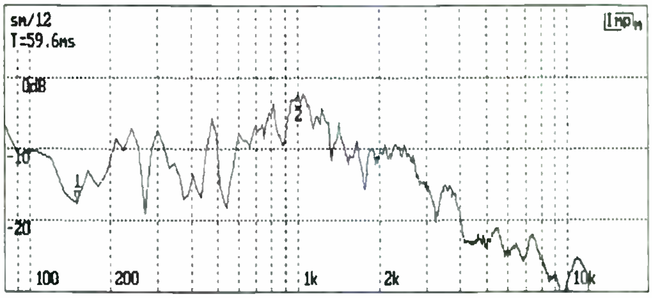

FIGURE 4: In-room midrange frequency response of single pipe driver without tweeter, measured at the listening position.

resistor from the preamp output to the amp input, and a 0.15μF capacitor across the amp input. For the high frequencies, I crossed-over a "Dynapleat" planar driver with a series 6μF capacitor, driven by a separate amplifier channel. I chose this driver because of its rather narrow pattern, due, no doubt, to a large radiating area.

A plot of a sample quasi-anechoic midrange response (no tweeter), measured 18″ from the cone, is shown in *Fig. 1*. The waterfall plot in *Fig. 2* shows a resonance at 1kHz and others still remaining above the 3kHz crossover point. A low-frequency near-field measurement provided the curve in *Fig. 3*. While not especially impressive, these curves looked reasonable. One of these mid-woofer drivers, configured with the "tweeter," sounded somewhat nasal and didn't play very loudly before breaking up. But using this as a reference point, I proceeded to the rest of the test.

Relying on only anechoic and near-field measurements, we tend to ignore some ugly facts. *Figures 4* and *5* represent the cold, hard, slap-in-the-face of reality. These are in-room response measurements of the same midwoofer speakers, including the effects of reflections. A living room is not a safe place for poor, defenseless speakers. The midrange curve has been slightly smoothed at 1/12 octave to average through the "grassy" appearance, which would otherwise result from all the interfering reflections.

ARRANGING THE ARRAY

Photo 1 shows the bizarre arrangement used in this test. A wooden stepladder supported two of the pipe speakers at different heights and at somewhat offset lateral positions (*Photo 2*). I mounted the Dynapleat (serving as tweeter) on a step of the ladder with shipping tape, with a handful of fiberfill stuffed behind it to help absorb the planar driver's back wave. A chair held another pipe, several feet off the floor and to the right, and two large throw pillows supported the fourth pipe about 13″ above the carpet.

I labeled the midwoofer drivers as A, B, C, or D, for reference to the data plots. I chose the positions strictly based on what could be managed from the available furniture and shop supplies, and other than being visually situated at random placements, they were not optimized according to any measurements. A couch approximately 8′ away was the target listening position. Since only four midwoofers were available, the setup was strictly monophonic.

I used IMP/M to aid in the alignment of the driver positions. I put the microphone at the target listening position and used the "cycling" feature to measure a repeating series of MLS acoustic responses, but watched only the upper time-domain plot of the calculated impulse response. Two drivers were first driven in parallel, and the resulting pattern on the computer screen showed the time offset due to their relative positions. When there was an error in the positions, two main pulses were seen rather than one; as the positions came close, they merged into a two-horned pulse (*Fig. 6*).

When the positions matched, the total pulse height peaked (*Fig. 7*). Using a laptop

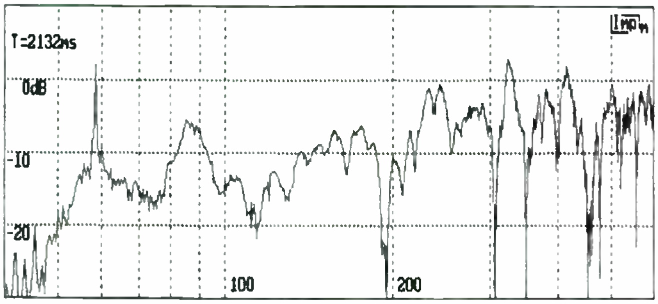

FIGURE 5: In-room bass response, measured from listening position, of single pipe driver.

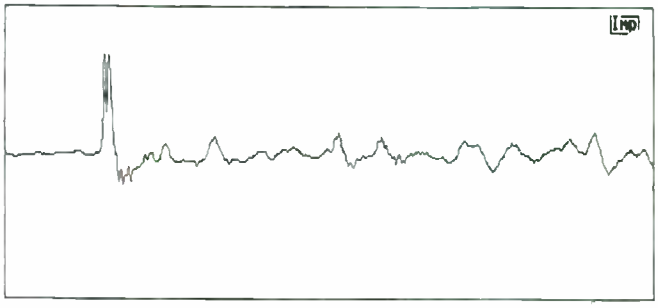

FIGURE 6: Time-domain pulse response for two midwoofer drivers, slightly misaligned.

computer on the floor near the arrangement, I watched the pulses while I moved the drivers closer to or away from the listening position. I repeated the process as I connected each successive midwoofer and tweeter to the amplifier. I adjusted the tweeter level by varying its amplifier channel's gain for optimal flatness as seen on the frequency response display.

MEASURED RESULTS

Figure 8 shows the time-domain plot via low sample rate of a single driven midwoofer driver, as sensed at the listening position. *Figure 9* shows the same plot, gain-adjusted to match peak amplitudes, for the case where all four simultaneous drivers are driven. *Figures 10* and *11* show similar measurements at the higher sampling rate.

Clearly, the basic idea works. The difference as shown on the plots is not dramatic, but, nonetheless, substantial. You can expect a stronger effect when 8 or 16 drivers per channel are used.

Figure 12 shows the low sample rate (4,096 points at 1.92kHz) frequency response for each of the four individual drivers, measured at the target listening position, and looking pretty grim. *Figure 13* shows the results for the entire focused array, which appears more uniform in both peak and average level (and more closely resembles the near-field measurement result of *Fig. 3*), but with a pronounced repetitive notch approximately every 35Hz. These notches are apparently due to reflections off the wall approximately 8′ behind the listener and to an unfortunate choice of array position in which all four drivers are nearly equidistant (relative to a low-frequency wavelength) from that wall.

This occurred to me only after the setup had been disassembled. A wiser choice would be to install the array so it fired in a diagonal, rather than perpendicular, direction to the back wall. Such a configuration is probably the obvious choice for a stereo configuration, but as I was thinking "mono" when setting this up, I thoughtlessly put it in front of the existing couch position and fired the array right toward a wall. Live and learn.

Figure 14 shows the high sample rate (4,096 points at 61.2kHz) response for each driver, and *Fig. 15* is the focused array version. The focused array is somewhat smoother and passably resembles the anechoic measurement shown in *Fig. 1*, but clearly there's still much room for improvement. The 35Hz repeating notches appear to persist, as well.

Figure 16 shows the system response made after the "tweeter" was connected, and includes the time-domain trace so you can see the definite narrow pulse reflections which the tweeter has allowed onto the response. The tweeter could stand to be a little more beamy for this application. I chose it because it was the only strongly directional tweeter driver available. The strange drop-off at about 7.5kHz is a characteristic which also appears when the tweeter is measured alone.

Figure 17 shows how the response varies when the listening position is shifted laterally 6″, 1′, and 2′ to the right of the focus point. The overall stability is reasonable to a little over a foot, in agreement with listening tests (described later), but falls apart at about 2′ off focus.

I have read that the ear fuses all sounds arriving within about 50ms. In *Fig. 18* we see the energy-versus-time curve of a single midwoofer driver over this duration, generated with a developmental version of the Liberty Audiosuite program, and in *Fig. 19* the same curve for the focused array. Both plots are normalized to the initial arrival peak, demonstrating the expected direct-versus-scattered enhancement of about 6dB for the four-driver system.

IN AND OUT OF FOCUS

With the caveat that my expectations could easily affect my listening opinions, I present the following subjective "review" of the focused array sound, as compared to the single woofer and tweeter sound and to the "unfocused array" sound outside of the listening position focus. You may justifiably question whether reflections should be reduced, making subjective reactions to this scheme very relevant. Of course, it would be helpful to have more than just my family's reactions, but I could not practically keep the setup (*Photo 1*) dominating my busy living room for more than a day.

First the verdict: I like it, but it is unusual,

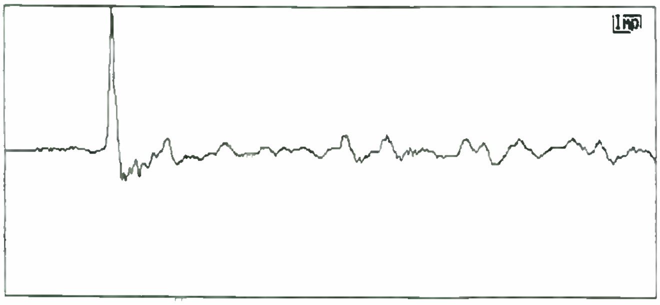

FIGURE 7: Pulse response of two midwoofers in alignment.

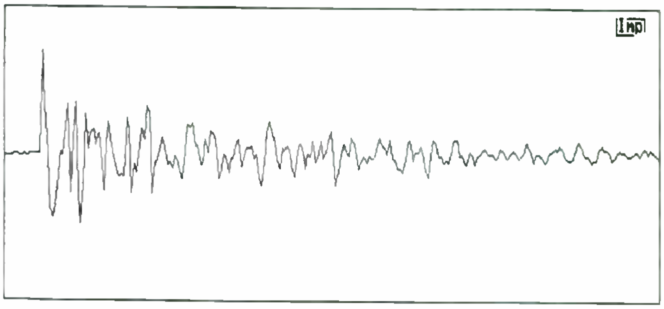

FIGURE 8: First 256 samples of the impulse response of one pipe driver, measured in-room at the listening position, low sample rate.

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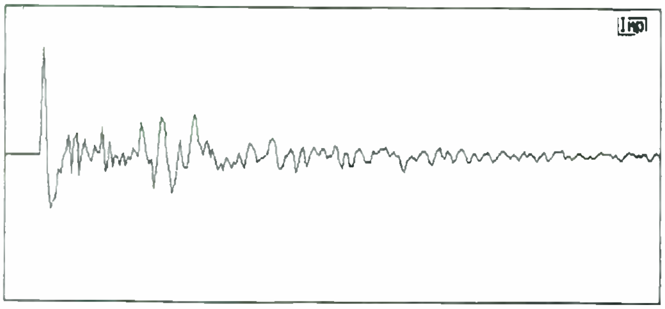


FIGURE 9: First 256 samples of focused array impulse response, measured at the listening position.

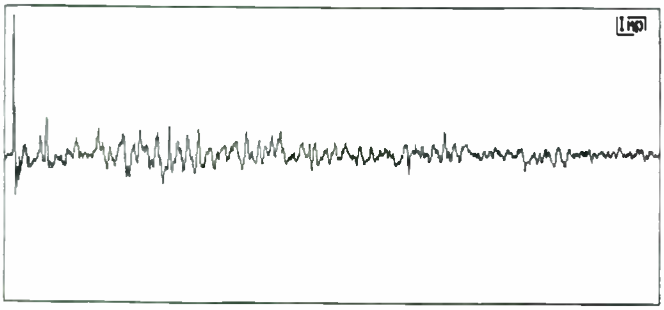


FIGURE 10: 4,095 points of single driver impulse response, in-room, high sample rate.

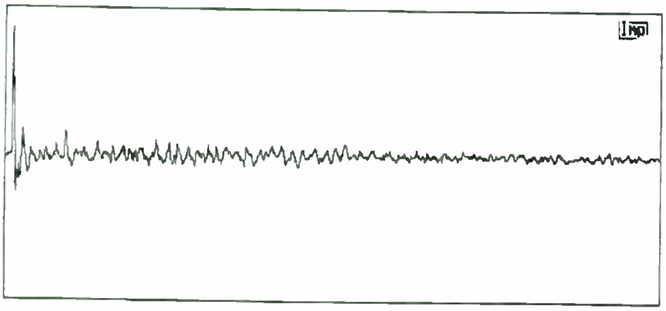


FIGURE 11: Focused array version of previous measurement, level reduced for same peak amplitude.

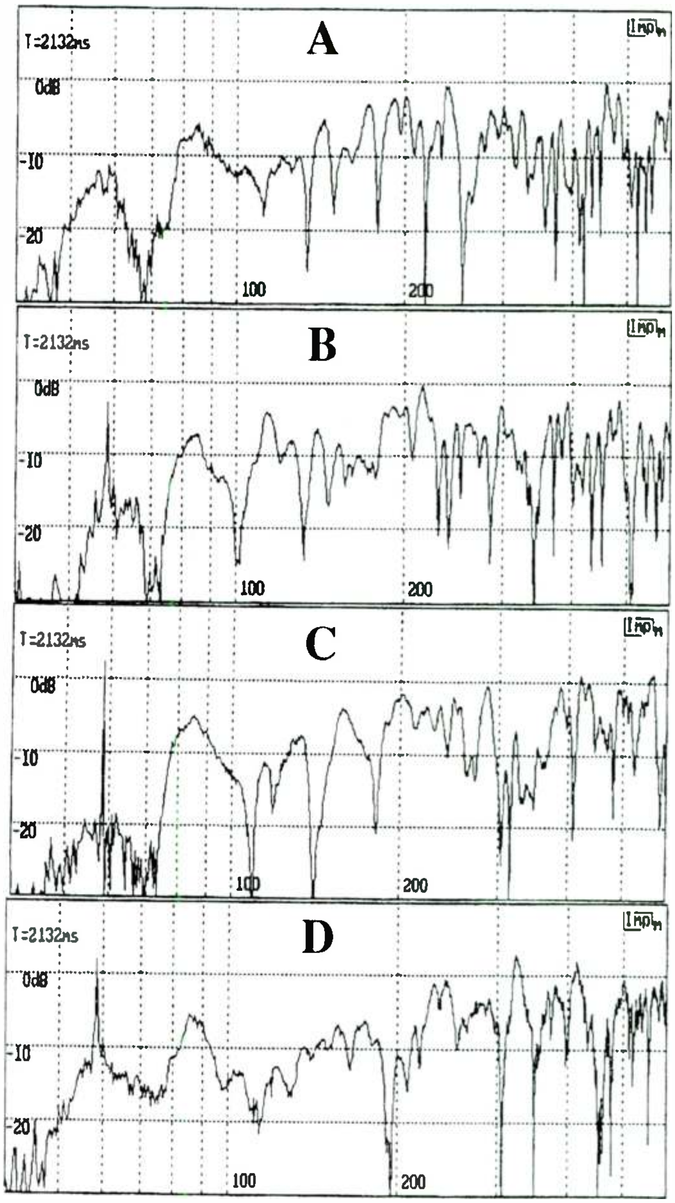


FIGURE 12: In-room bass frequency response of each pipe mid-woofer.

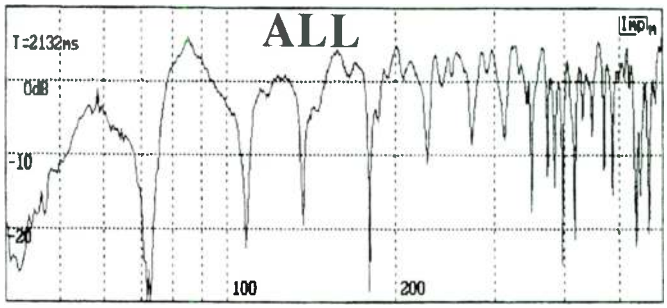


FIGURE 13: In-room bass response of the focused array, measured at the focus.

and not at all subtle. With some recordings (most notably vocals, acoustic guitar, and piano), it can grab you and make your eyes widen when you move into the focus. With others (one baroque string recording, in particular), it's just different and maybe not even an improvement. The effect can sometimes be a bit more engaging than you may desire. This system is more appropriate for music demanding close attention than for background sound.

One of the most noticeable effects is how vague (maybe even lousy) the sound is outside of the focus. The multiple drivers cause multitudes of interference patterns, as if the sound were entirely reflected. An indefinite effect—spacious, yet seemingly coming from no place in particular—brings to mind shopping-mall music playing at one end and you at the other. As my son described it, the sound you hear outside of the focus is somewhat as if it were down the hall from a room in which musicians are playing. Moving toward the focus is like moving into the room and sometimes right up to the musicians.

At the focus it sounds as if the room, or at least that part of the room directly in front of you, has changed. Some recordings (such as the Nimbus CD samplers) make the room ahead seem very large. Others (Rikki Lee Jones' "Pop Pop," for instance) give the effect of sitting at the entrance to a small recording booth, but not at all in an unpleasant sense. There is a sense of unusual clarity, but this may be due to the stark contrast to the extreme lack of clarity many feet outside of the focus. This system includes its own counterexample to cue your listening responses.

OTHER SUBJECTIVE RESULTS

Another notable feature of this implementation is the intense "mono-ness." There is a

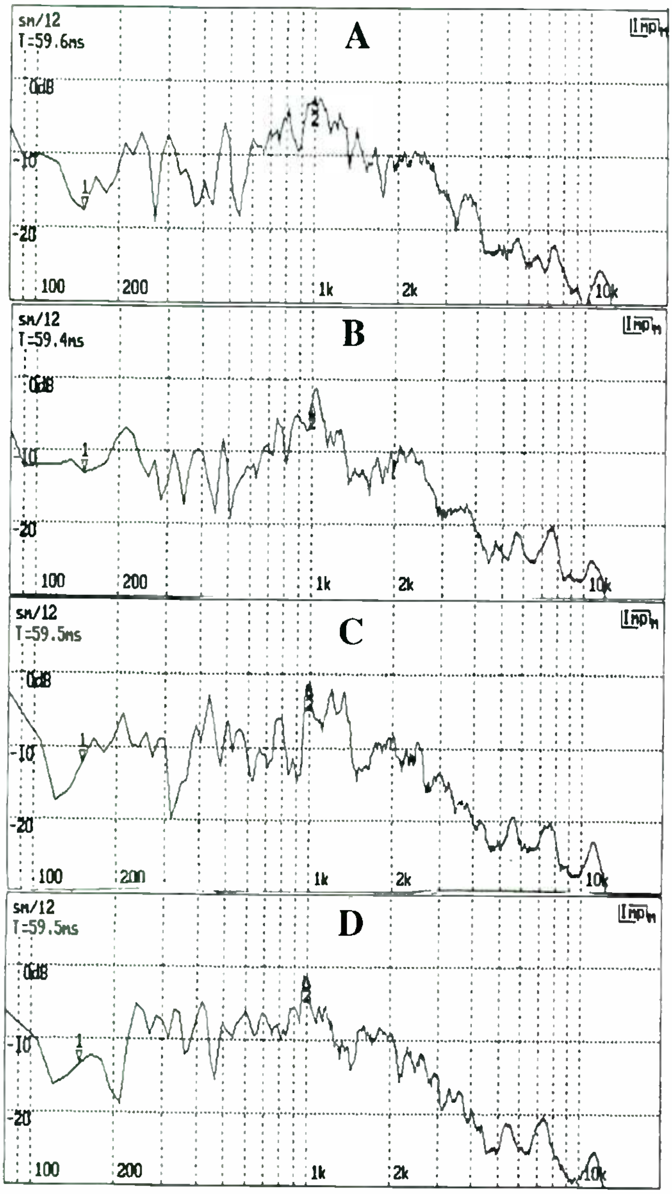


FIGURE 14: In-room midrange frequency response of each mid-woofer pipe.

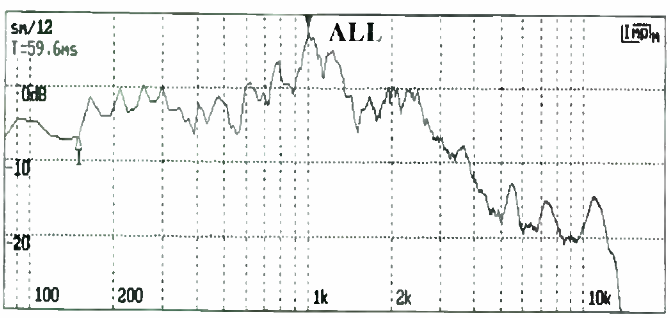


FIGURE 15: In-room midrange response of focused array.

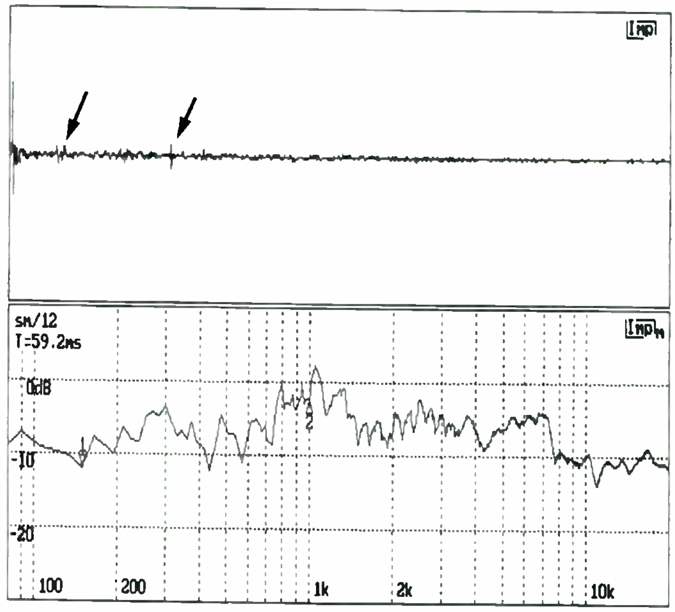


FIGURE 16: In-room response, with tweeter, at the focus. Prominent tweeter reflections are indicated on time-domain plot.

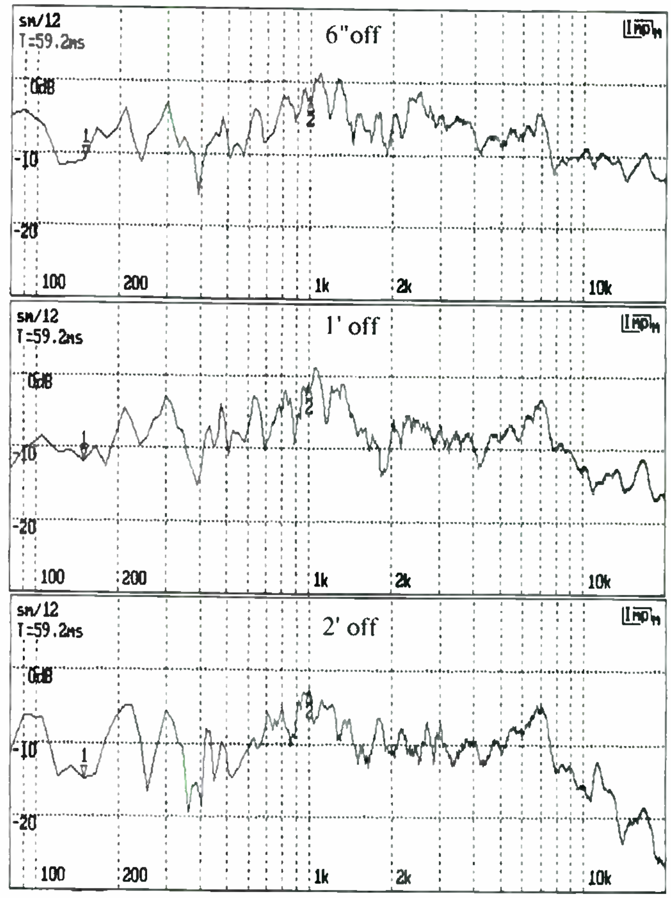


FIGURE 17: Midrange response variation off focus.

clear image with a sense of depth (I'm not sure how) that's definitely mono and will make you crave some left-right separation. This mono presentation showed a basic difference between focused array sound and headphone sound. Headphone sound, particularly mono headphone sound, tends to localize in the center of the listener's head. The focused array, while having a smoothness such as headphones can give, puts its sound out in front where it belongs. Also, the focused array image stays put when the listener moves his head while a headphone image sweeps across the room.

The critical effect of the "sweet spot" is not as pronounced when moving toward or away from the array as when moving up or down or sideways. Standing behind some-

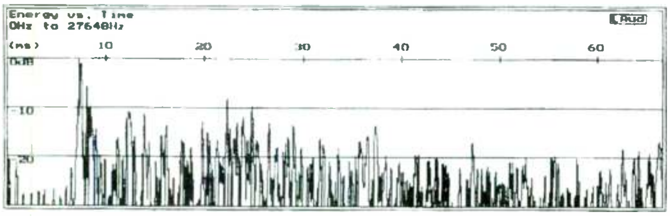


FIGURE 18: Energy-versus-time curve of single midwoofer, normalized to first arrival.

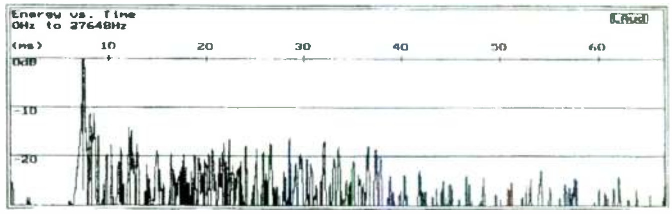


FIGURE 19: Energy time curve of focused array showing reduced reflection energy.

one who is at the focus, you still hear a good image, although it is still more specific than planar speaker sound. Side-by-side listening with a friend probably would be disappointing, although a reduction of the crossover frequency may help. In general, the apparent position of the sound source seems to be at the tweeter location, but then the tweeter was prominently visible and that's where the apparent source was expected to be. A fairer test is to set up an array of tweeters with only one playing with the midwoofers and then determine if listeners can sense the sound's origin.

There is also a sense of increased volume at the target listening position, as anticipated. This is not terribly dramatic, however, except perhaps in the bass. That may be more related to moving in and out of room modes rather than from going through the focus. I sense at the focus that these pipes are producing more bass than common sense or measurement would lead me to expect. Listening to a single pipe system with the tweeter does not give that sense, but then a single 4″ driver is probably going nonlinear trying to generate sufficient SPLs.

After collecting the measured data presented above and sampling a number of recordings, I readjusted the array drivers to focus on a point about 3′ closer to the array. A quick response measurement showed little obvious improvement, yet the listening test provided even more pleasing results. Perhaps the further reduced relative reflection intensity caused by moving nearer to the speakers could explain this result. Or perhaps it was just a better position in terms of room acoustics. This was the position at which about half of the listening test occurred. I don't think I ever spent so much time listening to mono.

I've used much space in this magazine for such a minimal setup, but I think it shows my enthusiasm for this scheme's results. I'm not sure it would be everyone's cup of tea; there are evidently listeners who even like the sound of speakers which intentionally increase the level of reflections. And many others would dislike the restricted listener position which the focused array requires.

WHAT'S NEXT?

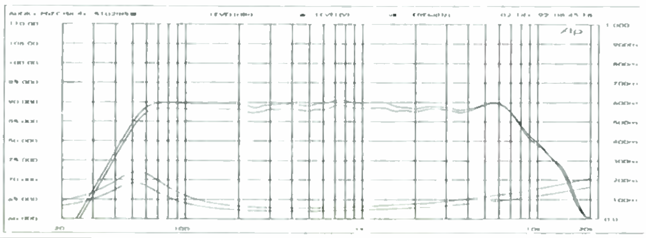
My future efforts will involve stereo, and more drivers per channel, for improved enhancement. And I'd like to determine how the array plays with drivers, enclosures, and a crossover design that sounds really good in a conventional setup (not really the case in my simple test). But for that I'll probably need to wait for someone else to do some building. If you give it a try, let me know how it works.

Madisound 5102R 4.5" Polypropylene Bass-Mid 4 or 8 Ω

	5102-4	5102-8
Fs (Hz)	50	52
Rscc (Ω)	3.28	4.73
VcL (mH@1K)	0.09	.12
Qms	1.50	1.41
Qes	.32	.33
Qts	.26	.27
Mmd (g)	6.13	6.5
Cms (μm/N)	1508.44	1353.76
Vas (Ltrs)	8.77	7.87
Efficiency (2.83V / 1m)	90	87
Xmax	1.5mm pk	
Power	50 w	
Magnet	12 oz	
Voice Coil	1" 2-Layer Kapton	
Cone	Black Poly	
Surround	Rubber	
Cutout/Depth	4.25"/2"	
Price	**$22.00**	

Rubber Surround

	Vented		Sealed	
	4 Ω	8 Ω	4 W	8 Ω
VB ltrs	2.1	1.9	1.4	1.3
FB Hz	75	78	-	-
F3 Hz	90	95	134	137
Port Diameter	1"	1"	-	-
Port Length	4.3"	4.5"	-	-



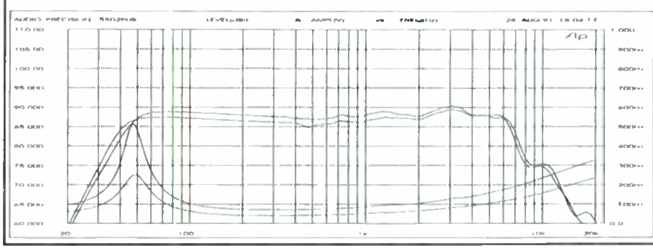
Madisound 5502R 5.25" Polypropylene Woofer 4 or 8 Ω

	5502R-4	5502R-8
Fs (Hz)	48	48
Rscc (Ω)	3.64	6.53
VcL(mH@1K)	.391	0.576
Qms	2.89	3.98
Qes	.47	.52
Qts	.40	.46
Mmd (g)	7.68	7.01
Cms (μm/N)	1349.5	1473.1
Vas (Ltrs)	13.8	15.1
Efficiency (2.83V / 1m)	89	87
Xmax	2.5mm pk	
Power	50 w	
Magnet	12 oz.	
Cone	Black Poly	
Surround	Rubber	
Voice Coil	1" 2-Layer Kapton	
Cutout/Depth	4.87"/2.25"	
Price	**$25.50**	

Rubber Surround

vented pole piece

	Vented		Sealed	
	4 Ω	8 Ω	4 W	8 Ω
VB ltrs	12	14	7	11
FB Hz	49	48	-	-
F3 Hz	50	49	80	71
Port Diameter	1.5"	1.5"	-	-
Length	3.5"	3.1"	-	-



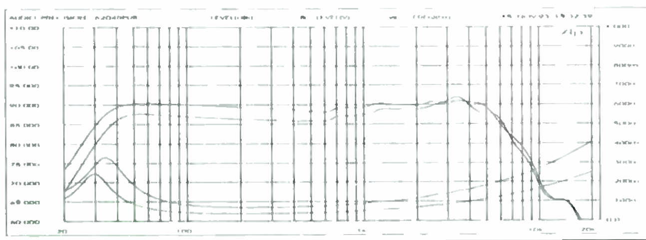
Madisound 6204R—6" Polypropylene Woofer 4 or 8 Ω

	6204R-4	6204R-8
Fs (Hz)	26.8	34.2
Rscc Ω	3.41	6.36
VcL mH@1K	.45	.70
Qms	2.68	1.80
Qes	.369	.457
Qts	.324	.364
Mmd (g)	11.3	13.3
Cms (μm/N)	2877.7	1524.5
Vas (ltrs)	71.9	38.3
Efficiency (2.83V / 1m)	90	87
Xmax	3.5mm pk	
Power	50 w	
Magnet	12 oz.	
Cone	Black Poly	
Surround	Rubber	
Voice Coil	1" 2-Layer Kapton	
Cutout/Depth	5.62"/2.87"	
Price	**$27.00**	

Rubber Surround

vented pole piece

	Vented		Sealed	
	4Ω	8Ω	4Ω	8Ω
Vb Ltrs	30	23	19	14
F_3 Hz	40	42	58	66
Fb Hz	33	38	-	-
Port Dia	2"	2"	-	-
Length	5.7"	5.6"	-	-



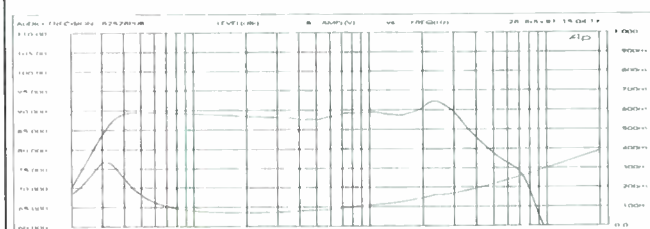
Madisound 8252R—8" Polypropylene Woofer 8Ω

Fs	31.6Hz
Rscc	6.35Ω
VcL @1K	.885mh
Qms	2.06
Qes	.45
Qts	.37
Mmd	23.6g
Cms (μm/N)	989.6
Vas	68 Liters
Efficiency (2.83V / 1m)	89db 1w/1m
Xmax	4.5mm pk
Power	75 w
Magnet	20 oz.
Cone	Black Poly
Surround	Rubber
Voice Coil	1.5" 2-Layer Kapton
Cutout/Depth	7.12"/3.37"
Price	**$39.00**

Rubber Surround

vented pole piece

	Sealed	Vented	Vented
Vb Liters	26	34	42
F_3 Hz	60	43	39
Fb Hz	-	33	35
Port Dia	-	2"	2"
Length	-	5"	3.2"



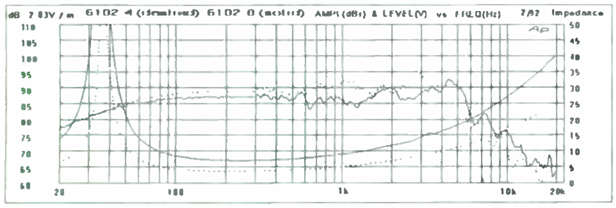
Madisound 6102
6.5" Polypropylene
Woofer 4 or 8 Ω

	6102-4	6102-8
Fs (Hz)	30	30
Rscc (Ω)	3.35	6.6
VcL(mH@1K)	.087	0.18
Qms	6.6	7.5
Qes	.35	.45
Qts	.33	.42
Mmd (g)	14.5	11.2
Cms (μm/N)	1812.8	2312.9
Vas (Ltrs)	39	49.7
Efficiency (db 1w/1m)	90	87
Xmax	3.5mm pk	
Power	50 w	
Magnet	12 oz.	
Cone	Black Poly	
Surround	Foam	
Voice Coil	1" 2-Layer Kapton	
Cutout/Depth	5.62"/2.87"	
Price	**$25.00**	

vented pole piece

	Vented		Sealed	
	4 Ω	8 Ω	4 W	8 Ω
VB ltrs	18	40	11.4	28
FB Hz	36	30	~	~
F3 Hz	41	33	58	47
Port Diameter	1.5"	2"	Qtc= .7	Qtc= .7
Length	4.6"	5.2"	Rg=.4	Rg=.4

**6102-4 / Dashed; 6102-8 / Solid



Madisound Driver Measurements

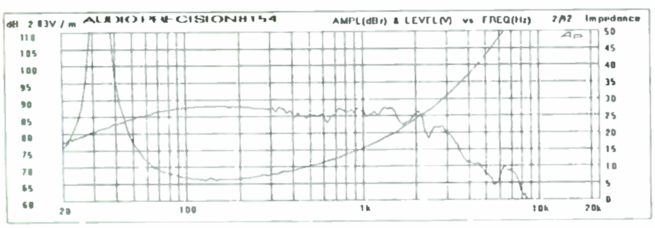
- All measurements made in a 37 m^3 anechoic chamber equalized to give response for an infinite baffle.
- All frequency responses measured corresponding to 2.83Vrms @ 1 meter, same voltage for 4Ω and 8Ω drivers.
- Dual voice coils are measured at 2.83Vrms per coil.
- Dual voice coil Theil-Small parameters are measured with voice coils in series using Delta Mass method with Audio Precision and Leap.
- Suggested box alignments are sometimes given with an (Rg) value, which is added resistance from inductors in series with the woofer. If you need specific box alignments, please call.
- Aperiodic dampening devices such as the Dynaudio Variovent and Scan-Speak Flow Resistor are very useful in sealed box applications. These vents reduce the impedance maximum at the resonance point, allowing for a more clear and defined bass, as well as the use of a driver in a box that is smaller than optimum volume.
- Some volume and linear equivalents:
  1^3 foot = 28.3 liters = 1728^3 inches; 25.4mm = 1"

Madisound 8154—8"
Polypropylene Woofer 8 Ω

Fs	30.6Hz
Rscc	4.55Ω
VcL @1K	.25mh
Qms	9.7
Qes	.28
Qts	.27
Mmd	34g
Cms (μm/N)	798.5
Vas	49.5 Liters
Efficiency	89db 1w/1m
Xmax	3.5mm pk
Power	75 w
Magnet	20 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	1.5" 4-Layer Kapton
Cutout/Depth	7.12"/3.37"
Price	**$36.00**

vented pole piece

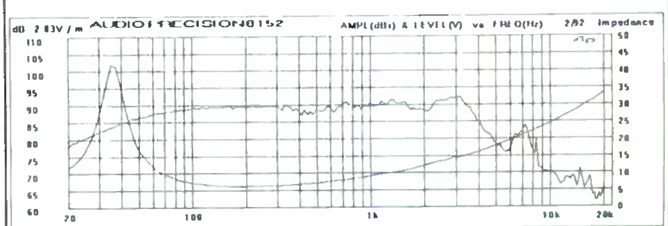
8154 B4 Alignments			
	Rg = 0	Rg = .4	Rg = .7
Vb Liters	15	19	23
F3 Hz	51	45	42
Fb Hz	46	43	40
Port Dia	2"	2"	2"
Length	6.1"	5.3"	5.1"



Madisound 8152—8"
Polypropylene Woofer 8 Ω

Fs	33Hz
Rscc	5.1Ω
VcL @1K	.13mh
Qms	3.5
Qes	.45
Qts	.4
Mmd	23g
Cms (μm/N)	889
Vas	55 Liters
Efficiency	89db 1w/1m
Xmax	3.5mm pk
Power	75 w
Magnet	20 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	1.5" 2-Layer Kapton
Cutout/Depth	7.12"/3.37"
Price	**$35.00**

8152 B4 Alignments			
	Rg = 0	Rg = 0	Rg = .4
Vb Liters	30	50	63
F3 Hz	43	35	33
Fb Hz	34.8	34.8	32.5
Port Dia	2"	2"	2"
Length	5.1"	2.5"	2.2"

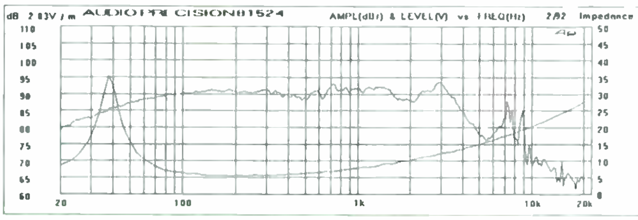


Madisound 81524—8" Polypropylene Woofer 4Ω

Fs	36Hz
Rscc	3.7Ω
VcL @ 1K	.1mh
Qms	3.9
Qes	.44
Qts	.4
Mmd	22g
Cms (μm/N)	819.59
Vas	51 Liters
Efficiency	89db 1w/1m
Xmax	2mm pk
Power	75 w
Magnet	20 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	1.5" 2-Layer Kapton
Cutout/Depth	7.12"/3.37"
Price	**$35.00**

Vented pole piece

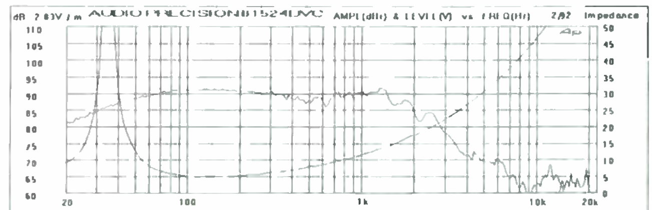
81524 B4 Alignments			
	Rg = 0	Rg = 0	Rg = .3
Vb liters	28	45	56
F3 hz	45	38	33
Fb hz	37	37	34.8
Port Dia	2"	2"	2"
Length	4.7"	2.3"	2"



Madisound 81524DVC—8" Dual Voice Coil Polypropylene Woofer 4Ω/4 Ω

Fs	31.7Hz
Rscc	3.5Ω
VcL @ 1K	.34mh
Qms	9.2
Qes	.32
Qts	.31
Mmd	38g
Cms (μm/N)	631.44
Vas	39.2 Liters
Efficiency	87.5db 1w/1m
Xmax	5mm pk
Power	80 w 40/40
Magnet	20 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	1" 2-Layer Kapton
Cutout/Depth	7.12"/3.37"
Price	**$37.00**

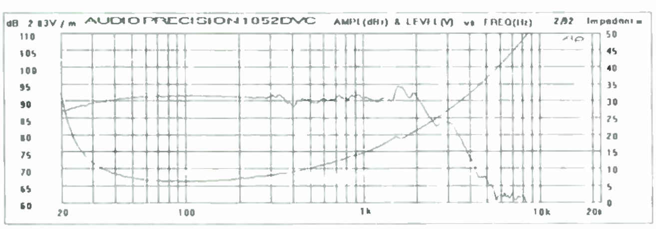
81524DVC B4 Alignments			
	Rg = 0	Rg = .5	Rg = 1
Vb liters	22	33	46
F3 hz	39	34	30
Fb hz	34	33.5	30
Port Dia	2"	2"	2"
Length	6"	5"	4.3"



Madisound 1052DVC—10" Dual Voice Coil Polypropylene Woofer 8Ω/8Ω

Fs	20.4Hz
Rscc	6.1Ω
VcL @1K	.46mh
Qms	3.68
Qes	.28
Qts	.26
Mmd	46g
Cms (μm/N)	1220.1
Vas	197 Liters
Xmax	6mm pk
Efficiency	90db 1w/1m
Power	50/50 w
Magnet	30 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	1.5" 2/2-Layer Kapton
Cutout/Depth	9.12"/4.45"
Price	**$45.00**

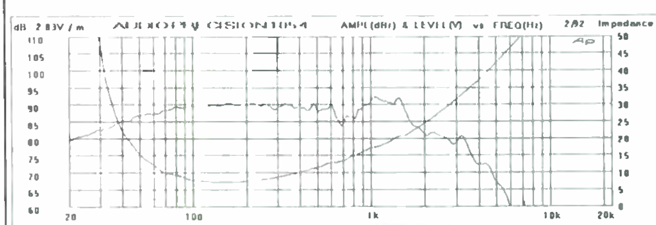
1052DVC QB3 Alignments			
	Rg = 0	Rg = .5	Rg = 1
Vb Liters	47	57	69
F3 Hz	38	35	33
Fb Hz	31	28.6	26.8
Port Dia	3"	3"	3"
Length	9.9"	9.3"	8.6"



Madisound 1054—10" Polypropylene Woofer 8 Ω

Fs	24.6Hz
Rscc	6Ω
VcL @1K	.24mh
Qms	4.07
Qes	.25
Qts	.237
Mmd	42g
Cms (μm/N)	997.57
Vas	160 Liters
Xmax	3.5mm Pk
Efficiency	92db 1w/1m
Power	125 w
Magnet	30 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	1.5" 4-Layer Kapton
Cutout/Depth	9.12"/4.45"
Price	**$43.00**

1054 QB3 Alignments			
	Rg = 0	Rg = .5	Rg = .9
Vb Liters	29	35	42
F3 Hz	52	46	43
Fb Hz	41.7	38	35.7
Port Dia	3"	3"	3"
Length	8.7"	8.3"	7.8"



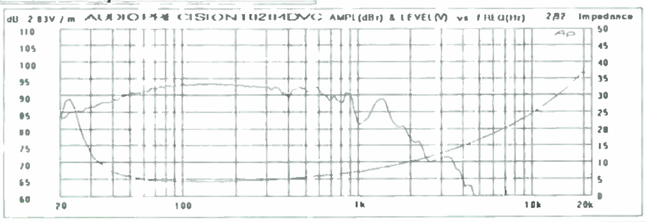
Madisound 10204DVC—10" Dual Voice Coil Woofer 4Ω/4Ω

Fs	21.2Hz
Rscc	3.6Ω
VcL @1K	.35mh
Qms	3.5
Qes	.21
Qts	.2
Mmd	50.4g
Cms (μm/N)	1045.4
Vas	168 Liters
Xmax	5 mm Pk
Efficiency	90.7db 1w/1m
Power	100/100 w
Magnet	40 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	2" 2/2-Layer Alum.
Cutout/Depth	9.12"/4.45"
Price	**$56.00**

Can be used with both voice coils in series for 8Ω or in parallel for 2Ω

vented pole piece

10204DVC B4 Alignments	Rg = 0	Rg = .5	Rg = 1
Vb liters	21	30	42
F3 hz	52	45	39
Fb hz	41.5	36.8	33
Port Dia	2.5"	2.5"	2.5"
Length	8.7"	7.4"	6.3"



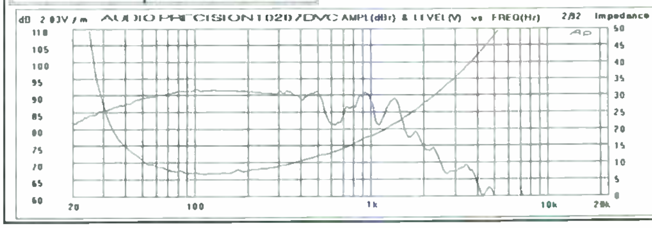
Madisound 10207—10" Dual Voice Coil Woofer 8Ω/8 Ω

Fs	19.2Hz
Rscc	5.7Ω
VcL @1K	.51mh
Qms	3.43
Qes	.23
Qts	.22
Mmd	57g
Cms (μm/N)	1138.6
Vas	184 Liters
Xmax	5 mm Pk
Efficiency	89.4db 1w/1m
Power	200 w 100/100
Magnet	40 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	2" 2/2-Layer Kapton
Cutout/Depth	9.12"/4.45"
Price	**$56.00**

Can be used with both voice coils in series for 16Ω or in parallel for 4Ω

vented pole piece

10207DVC QB3 Alignments	Rg = 0	Rg = .5	Rg = 1
Vb liters	26	33	40
F3 hz	45	41	37
Fb hz	35.5	32.5	30
Port Dia	2.5"	2.5"	2.5"
Length	9.5"	9"	8.6"

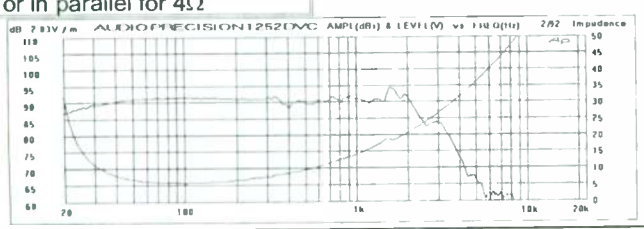


Madisound 1252DVC—12" Dual Voice Coil Woofer 8Ω/8Ω

Fs	15Hz
Rscc	5.6Ω
VcL @1K	.3mh
Qms	4.1
Qes	.39
Qts	.36
Mmd	78g
Cms (μm/N)	1331.4
Vas	533 Liters
Xmax	6mm pk
Efficiency	88.5db 1w/1m
Power	100 50/50w
Magnet	30 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	1.5" 2/2-Layer Kapton
Cutout/Depth	11.12"/5.0"
Price	**$48.00**

Can be used with both voice coils in series for 16Ω or in parallel for 4Ω

1252DVC B4 Alignments	Rg=0	Rg=0	Rg=0	Rg=0
Vb Ltrs	85	100	130	142
F_3 Hz	32.2	31	30	26
Fb Hz	QTC	QTC	QTC	17
Port Dia	.96	.9	.8	3"
Length	Sealed			11"



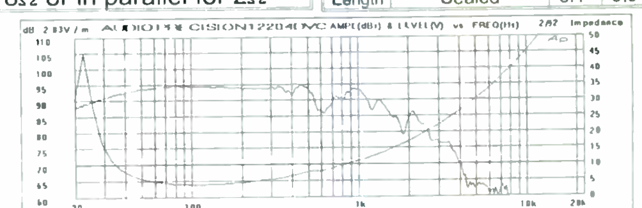
Madisound 12204DVC 12" Dual Voice Coil Woofer 4Ω/4Ω

Fs	22.8Hz
Rscc	3.6Ω
VcL @ 1K	.26mh
Qms	4.58
Qes	.42
Qts	.38
Mmd	68.8g
Cms (μm/N)	550.6
Vas	220 Liters
Xmax	5 mm Pk
Efficiency	90.3db 1w/1m
Power	200 100/100 w
Magnet	40 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	2" 2/2-Layer Kapton
Cutout/Depth	11.12"/5.0"
Price	**$60.00**

Can be used with both voice coils in series for 8Ω or in parallel for 2Ω

vented pole piece

12204DVC B4 Alignments	Rg=0	Rg=.5	Rg=5	Rg=0	Rg=.5
Vb Ltr	85	85	100	113	142
F_3 Hz	42	38	37.5	31	28
Fb Hz		QTC		24	21.6
Port D.	.75	.85	.8	3"	3"
Length		Sealed		6.1"	5.9"



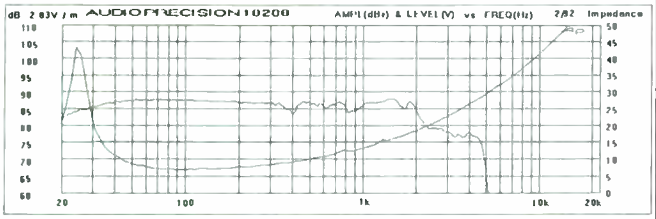
Madisound 10208—10" Sealed Box Woofer 8Ω

Fs	24Hz
Rscc	5.7Ω
VcL @1K	.13mh
Qms	4.62
Qes	.62
Qts	.54
Mmd	45g
Cms (μm/N)	900.5
Vas	145 Liters
Efficiency	87.5db 1w/1m
Xmax	6.5 mm pk
Power	100 w
Magnet	30 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	2" Kapton
Cutout/Depth	9.12"/4.45"
Price	**$53.00**

The use of fill will reduce the Qtc. This driver may be okay for free air applications to 45 Hz.

vented pole piece

10208 Sealed Box Alignments				
	Rg=0	Rg=.5	Rg=0	Rg=.5
Vb Ltr	99	99	142	142
F3 hz	32	31	31.3	29.4
Qtc	.86	.93	.78	.84

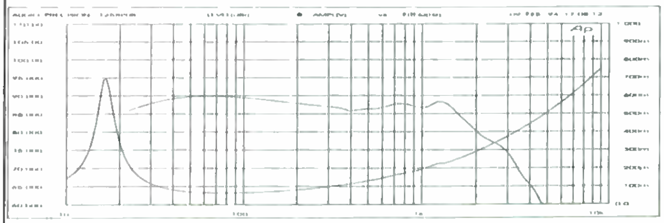


Madisound 1258 12" Polypropylene Woofer 8Ω

Fs	16.6Hz
Rscc	5.6Ω
VcL @ 1K	2.39 mh
Qms	5.32
Qes	.41
Qts	.38
Mmd	57.2g
Cms (μm/N)	1418.99
Vas	568 Liters
Efficiency	90db 1w/1m
Xmax (mm) pk	4
Power	75W
Magnet	30 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	1.5" Kapton
Cutout/Depth	11.12" / 5"
Price	**$44.00**

1258 Alignments			
Vb liters	70	85	100
F3 hz	37.5	35	34
Align.	Sealed	Sealed	Sealed
Qtc	1.15	1	.98

The use of filling will reduce the Qtc



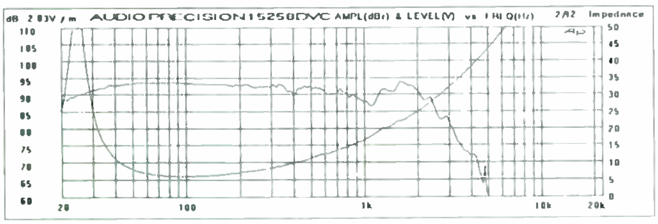
Madisound 15258DVC—15" Dual Voice Coil Woofer 8Ω/8Ω

Fs	22.5Hz
Rscc	5.5Ω
VcL @1K	.36mh
Qms	5.35
Qes	.52
Qts	.47
Mmd	121.5g
Cms (μm/N)	367.38
Vas	368 Liters
Xmax	5.5 mm pk
Efficiency	91db 1w/1m
Power	200 100/100 w
Magnet	60 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	2 (2") Kapton
Cutout/Depth	13.87"/6.0"
Price	**$80.50**

vented pole piece

15258DVC Sealed Box Alignments				
	Rg=0	Rg=.5	Rg=0	Rg=.5
Vb Liters	100	100	142	142
F_3 Hz	37.8	36.6	35.4	33.8
Qtc	1.03	1.12	.9	.98

It is recommended to use fill and flow resistive vents with this driver.



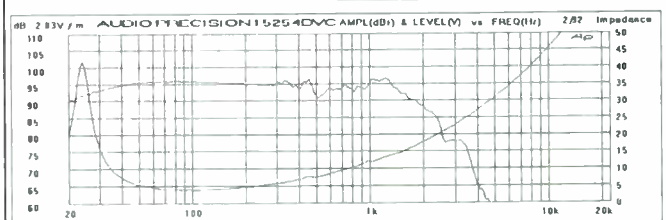
Madisound 15254DVC—15" Dual Voice Coil Woofer 4Ω/4Ω

Fs	23Hz
Rscc	3.7Ω
VcL @1K	.25mh
Qms	5.71
Qes	.47
Qts	.44
Mmd	122g
Cms (μm/N)	346.1
Vas	347 Liters
Xmax	5.5 mm pk
Efficiency	91.5db 1w/1m
Power	200 100/100 w
Magnet	60 oz.
Cone	Black Poly
Surround	Foam
Voice Coil	2 (2") Kapton
Cutout/Depth	13.87"/6.0"
Price	**$80.50**

vented pole piece

15254DVC Sealed Box Alignments				
	Rg=0	Rg=.5	Rg=0	Rg=.5
Vb Liters	100	100	142	142
F_3 Hz	40	37.7	38	35
Qtc	.92	1.04	.8	.91

It is recommended to use filling and flow resistive vents with this driver



Wayland's Wood World

REFERENCES

By Bob Wayland

We all have our favorite references, those books which somehow seem to have just the right information to solve frequently encountered problems. When I need to design an active filter, for example, I grab Stefan Niewiadomski's *Filter Handbook* (CRC Press, 1989, $30.95). Good reference materials such as this are an invaluable part of my workshop. This review covers some of my favorite woodworking references. I hope they will be as much help to you as they have been for me.

Because normally we are troubled by problems in specific areas, the general topics include:

- techniques
- tools
- materials
- inspiration

Before providing details, though, two good general references are worthy of mention. Ernest Joyce's *Encyclopedia of Furniture Making* (Sterling Publishing, 1989, $21.95) was originally printed in 1970, and revised and expanded in 1987 by Alan Peters. This book is primarily aimed at woodworkers with small shops. The careful coverage and detailed descriptions of common techniques are especially useful for woodworkers who are just getting started, but significant coverage of more advanced techniques is also included. The sections on veneering, marquetry, and inlay offer ideas for adding a personal touch to your enclosure. The last 40% of the book deals with the business end of woodworking, something which would appeal to that small fraction of professional speaker builders.

John L. Feirer's *Cabinetmaking and Millwork* (Bennett IL Publishing, 1982, $31.36) is an older book that is continuously revised. When I need to know of a new or different approach to a woodworking problem, this is where I turn. It is not detail-oriented, but instead covers considerable ground and emphasizes comprehensive coverage from the manufacturing point of view.

Both of these books, and the ones which follow, are quickly dated. Such recent advances as random orbital sanders and sandpaper attaching techniques are not covered. You can keep up with advances easily and cheaply by looking through woodworking supplier catalogs, such as the Garrett Wade catalog. While this works well for tools and materials, it is only marginal for techniques. Our primary aim is to build

speakers which function well and have an enchanting appearance. Most of the techniques we need are ones which have been successfully employed in the centuries of woodworking that have preceded us.

TECHNIQUES

The one area which causes the most confusion and has the most visible effect is finishing. Sadly, this is also where people keep their "secret recipes," often passed from generation to generation. When you examine the field, however, the underlying principles are really quite simple. Bob Flexner's *Understanding Wood Finishing: How to Select and Apply the Right Finish* (Rodale Press, 1993, $27.95) is a common sense, no nonsense instruction which removes the mystique associated with finishing.

Flexner carefully and precisely describes the preparation for finishing, which, if followed, will help prevent the mistakes that result in the need to strip a finish. Have you ever wondered whether you can apply a finish over wax? You'll find the answer in this book (only straight oil, oil/varnish blend, or shellac finish should be used). What is the difference between a pigment and a dye, and which is best for your enclosure? Flexner is good about identifying problems and offering solutions, and his book is easy to read, with practical inside information.

For the sheer joy of finishing wood as a vocation, read George Frank's *Adventures in Wood Finishing* (Taunton Press, 1981, $10.95). His practical advice on getting the most from your wood's color is not only a treasury, but contains information which is virtually impossible to find elsewhere. Did you know that potassium dichromate creates the illusion of great depth in mahogany, or that ferrous sulfate enhances the form inherent in bird's-eye maple?

You may often need to make your enclosure colorless. Frank includes an entire chapter on this subject. If you are the tenacious sort, and wish a truly remarkable finish, Frank explains how to produce a Chinese lacquer (there are over 30 steps). This book is slightly over 100 pages long; however, it holds your attention far longer than the time it takes to read.

Every new project seems to require a unique joint or method. So many good books on woodworking joints are available that I usually run the other way whenever a new one comes along, perhaps because my first one has been a long-time companion: *Tage Frid Teaches Woodworking: Joinery, Book I* (Taunton Press, 1979, $21.95). It has since been combined with *Book 2* (*Shaping, Veneering, Finishing*) and is sold as a single volume. [#BKTN3 for $29.95 plus $3 S/H in US from Old Colony Sound Lab.]

Frid's warm, gentle nature is evident throughout, and the step-by-detailed-step instructions make you feel he is right there looking over your shoulder, making sure you don't make a mistake. Although he uses the table saw extensively, he is fond of describing how to use hand tools. For example, there is a section on edge-joining boards using a hand joiner plane. If you don't have a joiner, this is essential given the narrow stock available today. His humor is evident in his advice on spreading glue when gluing up the boards to be edge-joined: "I then use the cheapest brush I can find—my finger. Spread the glue thinly but evenly."

Many other aspects of woodworking techniques are covered in the two previously mentioned general references. They will usually get you pointed in the right direction—the rest is up to your ingenuity!

TOOLS

When using tools, speaker builders have a specific set of requirements. The general operations, of course, are the same as for any other woodworker. While the specific operations have been the grist for this column in the past, a real need exists for the techniques to maintain and ensure the safe, accurate operation of your equipment. The books by Joyce and Feirer are a good starting place for the day-to-day problems.

Over the years I have bought book after book on jigs for power hand tools. After gathering dust, they all ended up in the Goodwill collection. The problem is that the jigs are for solving problems I don't have. (From the number of these books I see in used bookstores, I suspect others have had the same experience.) On the other hand, there are a few good books with general coverage.

The one piece of equipment at the heart of a workshop is the table saw. It doesn't matter whether the saw is a simple, portable bench model or an industrial cabinet device, the basic needs are the same. A remarkably straightforward and precisely written book on table saw use is Kelly Mehler's *The Table Saw Book* (Taunton Press, 1993, $25.95). Full chapters are devoted to saw blades, work spaces, adjustment and maintenance, safety, ripping, crosscutting, and joinery.

The suggestions made for ripping thick stock illustrate the care which is characteristic of the coverage. One of the first suggestions is to listen to the motor, and cut as fast as possible without bogging it down. Don't rip in a series of shallow passes, because the thick material is likely to distort and produce a piece which is no longer flat to the fence. When ripping bevels, always cut with the saw blade tilted away from the rip fence. The section on adjustment and maintenance can increase your accuracy and the pleasure of using your saw a thousandfold. Have you checked the flatness of your saw table top? What if it isn't flat? (One solution is to have it reground, but this is expensive!)

Other books are available on different tools. I suspect you will find that the instruction book which came with the equipment is better than what you can buy in the local bookstore. If you don't have a copy, you can usually get one by writing to the manufacturer. (You can find addresses at the reference desk of your local library or in the *Thomas Register.*)

MATERIALS

All too often, books on wood are scientific treatises which don't give the speaker builder any useful information. A notable exception is *Understanding Wood* by R. Bruce Hoadley (Taunton Press, 1981). [Available as #BKTN5 for $31.95 plus $3 S/H in US from Old Colony Sound Lab.] Working with wood makes you aware that hundreds of variables are interacting to create an environment of extreme complexity. You can begin to work in this environment only when you understand how wood and wood products react to being cut, seasoned, machined, joined, bent, and finished.

Hoadley's book gives you this knowledge. If you build an enclosure in Albuquerque in July and send it to San Francisco in January, how will this affect the integrity of the joints? The information in this book prepares you to arrive at a good idea for a specific configuration, but to do so you must read and understand the entire book.

We must work with the mechanical properties of wood, and perhaps the best engineering reference is the US Forest Products Laboratory's *Wood Engineering Handbook* (Prentice-Hall, 1990). [Available as #BKPH5 for $59.95 plus $3 S/H in US from Old Colony Sound Lab.] Chapter 4 provides a most helpful source when you need to find the right wood for the best response (or lack of response) to a vibrational pattern, including the speed of sound and the damping capacity or internal friction. Did you know that at room temperature the internal friction is at a minimum at about 6–8% moisture content? What moisture content is best to glue up solid wood, and what effect does this have on how your enclosure responds to a specific frequency?

to page 59

SOURCES

Bennett IL Publishing Co. Div. of Macmillan Pub.
3008 W. Willow Knolls, Peoria, IL 61614
(309) 689-3290, (800) 447-0680

CRC Press, Inc.
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Prentice-Hall, Inc.
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Rodale Press Inc.
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Sterling Publishing Co.
387 Park Ave. S., New York, NY 10016-8810
(212) 532-7160, (800) 367-9692

Taunton Press
63 S. Main St., Newtown, CT 06470
(203) 426-8171, (800) 243-7252

Product Review

LINEARX'S pcRTA

By Joseph D'Appolito
Contributing Editor

pcRTA, LinearX Systems, Inc., 7556 SW Bridgeport Rd., Portland, OR 97224, (503) 620-3044, FAX (503) 598-9258.

The pcRTA 1/3-octave real-time analyzer is built on a full-length, 8-bit PC card for use in IBM PCs and compatibles. All connections are made through a box which features four microphone inputs and a line-level input and output. The microphone supplied—the M51—has a claimed calibration accuracy of ±0.75dB, and a clipping level of 154dB SPL with very low distortion.

Features include built-in white- and pink-noise generators, 32 analysis bands (31 ISO 1/3-octave bands and one full band) realized with four-pole multiple-feedback analog filters, true-RMS detection with selectable averaging times, and SPL measurements with a resolution of ±0.025dB and a claimed accuracy of ±0.5dB. Spatial averaging is greatly facilitated by the program's ability to process up to four microphones simultaneously.

In addition to basic SPL measurements, pcRTA measures reverberation times and impedance (with 1/3-octave resolution), and performs IASCA and USAC scoring (auto sound) and home theater testing. Data displays include the usual bar graphs, line graphs of multiple measurements, and numerical text displays of single measurements to 0.1dB resolution.

Control software runs under the Windows 3.1 graphical operating system, with VGA or higher graphics. The software stores up to 20 curves, and supports scaling, math functions (addition, subtraction, multiplication, and division), as well as averaging of multiple curves. Simultaneous viewing of multiple curves or bar graphs is possible, with full selection of color and style for each curve. ASCII data import and export, clipboard export, and graphics export (both raster and vector images) are available, as are macros for repetitive Q/C operations. Although the system can be installed on a 286, LinearX recommends a 386 or better CPU with coprocessor and a minimum of 4MB RAM. I obtained the results cited in this review on an 8MB 486DX33.

FIRST IMPRESSIONS

The pcRTA came shipped in a sturdy cardboard box, which opened to reveal two Styrofoam trays stacked snugly within. One held the full-slot PC card in a protective antistatic bag. The other contained the user manual, four M51 microphones (each individually packaged in ziplock plastic bags, with connecting cables and 3.5″ calibration diskette), a connector box, and a 6′ interface cable with DB15 connectors on each end.

The multilayer PC card is a very sophisticated, beautifully executed combination of analog and digital circuitry. Two-thirds of the card is filled with four rows of surface-mount quad op amps, eight to a row. The op amps are flanked by numerous 2% polypropylene caps, chip resistors, and THAT ICs, which are very accurate true-RMS converters.

The remaining third contains a 12-bit A/D chip, additional quad op amps, and two LSI chips, "Pebbles" and "Bambam." These PLCC chips contain firmware which controls the interface between card and computer.

HARDWARE INSTALLATION

Be sure to ascertain whether you have sufficient power supply capacity. The power requirements are ±12V at 200mA and +5V at 230mA, with the biggest problem usually presented by the −12V supply. Hardware installation is otherwise relatively straightforward. The board uses neither interrupts nor DMA, so there are no IRQ or DMA jumpers to set; however, prior to installation you must select an I/O port address. Four address selections are available: Hex 21E (the default setting), 25E, 31E, and 35E. Jumpers for selecting the I/O port address are located just above the gold fingers of the bus slot connections. The card can be installed in any ISA 8- or 16-bit EISA or VESA slot.

The most difficult part of the installation process is finding enough clearance for the full-length card. These cards are becoming a rarity in modern PC add-ins. In fact, many newer systems have large obstructions which can interfere with full-length cards, such as CPUs with integral coolers in the forward half of the motherboard. I had to move two cards to other slots and rearrange the wires running to the reset and turbo switches in order to seat the pcRTA card on my system.

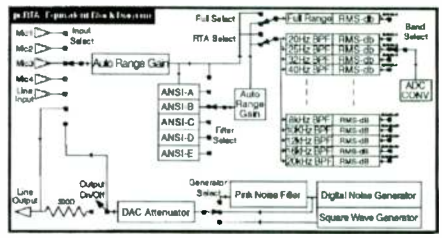

FIGURE 1: Functional block diagram.

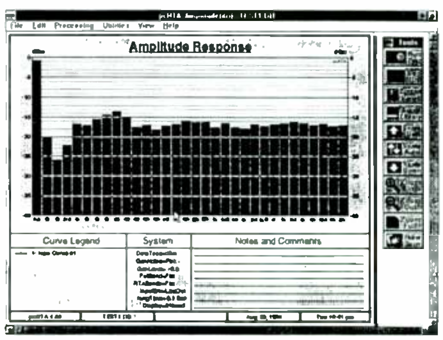

FIGURE 2: Opening screen.

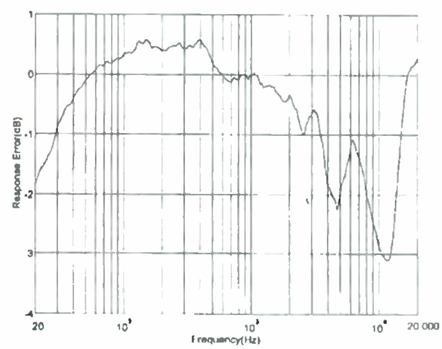

FIGURE 3: Calibration curve for a typical M51 microphone.

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☐ Audio Engineering Society Bibliographical Database/Schwamkrug (Germany). 6700+ spreadsheet entries include *JAES* 1953+. SOF-AES1B3. $49.95.

☐ Liberty Aids/Koonce. Enhancements for IMP and Liberty Audiosuite. SOF-AID1B3G. $19.95.

☐ AIRR Anechoic and In-Room Response Measurement/Bunn (France). For Soundblaster card. SOF-AIR1B3G. $49.95.*

☐ ALPAS-X Allpass Crossovers Deluxe/Tissi (Brazil). SOF-ALP1B3G. $99.00.

☐ AUDIOCAD Pro/Uibel (Germany). SOF-AUD1B3G. $119.00.*

☐ BASSBOX for Windows/Harris Technologies. SOF-BAS2W3G. $99.00.

☐ Benson Modeling/Koonce. SOF-BEN1B3G. $9.95.

☐ BOXRESPONSE with Graphics/Bullock & White. SOF-BOX2B3G. $50.00.

☐ Bandpass BOXMODEL/Bullock & White. SOF-BPB1B3G. $50.00.*

☐ CALSOD Standard/Audiosoft (Australia). Computer-Aided Loudspeaker System Optimization and Design. SOF-CAL2B3G. $69.95.*

☐ CALSOD Professional/Audiosoft (Australia). SOF-CAL3B3G. $269.00.

☐ FTIDUCT/Silva (Brazil). Duct-length calculator. SOF-DCT1B3. $25.00.

☐ *Elektor* Item Tracer/Hogenboom (Netherlands). In Dutch but easily used, sources 2700+ rare European electronic parts. SOF-EIT2B3. $7.95.

☐ Bass Horn Design/Senson. SOF-HOR1B3. $19.95.

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☐ Koonce Private Files #5—Driver Evaluation/Overshoot Function (Wright's Transient Response). SOF-KPF5B3G. $14.95.

☐ LADP Loudspeaker Analysis and Design Program/G & J Technologies. Windows. SOF-LAD1W3G. $134.50.

☐ LAUD Liberty Audiosuite/Liberty Instruments. Comprehensive audio testing using Personal Sound Architecture sound card in PC (not included). SOF-LAU1B3G. $269.00.

☐ LECD Loudspeaker Enclosure and Crossover Design/Gendale Technology (South Africa). SOF-LEC1B3G. $79.95.*

☐ Audio Literature Database/Schwamkrug(Germany). 2000+ non-AES entries, some European. SOF-LIT1B3. $29.95.

☐ LMP "Souped Up" Professional Loudspeaker Modeling Program (DOS)/Sitting Duck. SOF-LMP3B3G. $49.95.

☐ LMP Professional (Windows)/Sitting Duck. SOF-LMP3W3G. $69.95.

☐ LMP Professional (Macintosh)/Gonzalez. SOF-LMP3M3G. $39.95.

☐ BOXMODEL (DOS)/Bullock & White. SOF-MOD4B3G. $59.95.*

☐ WINBOXMODEL (Windows)/Bullock & White. SOF-MOD5W3G. $74.95.

☐ MACSPEAKERBOX/Micro Sound Associates. For Mac. SOF-MSB1M3G. $39.95.*

☐ LDP Professional Loudspeaker Design Powersheet/Bacon. SOF-PSI2B3. $69.95.**

☐ LDP Professional for Macintosh/Bacon. SOF-PSI2M3. $69.95.**

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☐ MAC SLM Sound Measuring Tool for Mac/Staggs. Revolutionary. SOF-SLM1M3G. $74.95.

☐ Speaker System Designer Plus/Bodzio Software (Australia). Known as SoundEasy in Europe, succeeds SSD 4.25. Windows. SOF-SSD5W3G.** $269.00.

☐ Transmission Line BOXMODEL/Bullock & White. SOF-TLB1B3G. $50.00.*

☐ The Listening Room (DOS)/Sitting Duck. SOF-TLR1B3G. $47.95.

☐ The Listening Room (Windows)/Sitting Duck. SOF-TLR2W3G. $89.95.

☐ The Listening Room (Macintosh)/Gonzalez. SOF-TLR3M3G. $67.95.

☐ Thiele-Small Measurement/Thompson. SOF-TSM1B3. $29.95.

☐ VENTWRK PLUS Vented Box Construction/Augspurger. SOF-VNT2B3. $19.95.

☐ Woofer-Satellite Offset/Sitting Duck. SOF-WSO1B3G. $34.95.

☐ X•OVER (Windows)/Harris Technologies. SOF-XOV2W3G. $29.00.

*$5.00 demo disk available for this program, usable as credit toward later full purchase.

**Requires spreadsheet software not supplied.

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All external connections are made via an interface cable, with DB15 connectors on each end that mate with a connector box. This box contains four 3-pin, female XLR microphone connectors and two ¼" jacks for line-level input and output. Attaching one end of the interface cable to the card and the other end to the connector box completes hardware installation.

SOFTWARE INSTALLATION

The program is itself a Windows application, and software installation can be accomplished from either Windows or DOS. (I installed from within Windows.) You need about 5MB of free hard disk space.

The procedure is quite straightforward. First create a pcRTA directory in the path of your choice. It should have three subdirectories for storing measurement data and a fourth—"export"—containing software for generating export products (graphs, screens, and the like) in a wide range of formats. All installed files are placed in the pcRTA directory path. You do not modify AUTOEXEC.BAT, CONFIG.SYS, or WIN.INI files, and no files are placed in your Windows or Windows/System directories. This is a nice feature in case you ever need to uninstall the program.

The entire installation procedure takes about five minutes. At the end of the main process, the software asks whether you have any Microphone Data Files (MDF), which contain the calibration data for microphones supplied by LinearX. Once these files have been read in, installation is complete. As a check, I installed pcRTA on two different machines and did not encounter a problem with either.

FUNCTIONAL DESCRIPTION

Figure 1 is a functional block diagram of pcRTA. It has two internal signal generators, one of which is a 19-bit Maximum Length Sequence (MLS) white-noise generator with a 2s cycle time. The other, a square-wave

TABLE 1

ABBREVIATED SPECIFICATIONS

NOISE GENERATORS	
Noise spectra	White, pink
Digital sequencer	19-bit MLS
Cycle time	2.0s
Pink noise filter	6-stage, ±0.5dB 10Hz–40kHz
Maximum output	+2.6dBm (RMS)
Output impedance	500Ω
SQUARE WAVE GENERATOR	
Output frequencies	31, ISO centers, 20Hz–20kHz
Frequency accuracy	±0.5%
Maximum output	9.6dBm (RMS)
Output impedance	500Ω
INPUT SOURCES	
Types	Mic1, Mic2, Mic3, Mic4, line in
Maximum input level	+20dBm
Input impedance	100kΩ
Full-band response	–3dB @ 0.6Hz and 150kHz
Full-band noise floor	–91dBm (input shorted)
20Hz 1/3-octave band noise floor	–130dBm (input shorted)
20kHz 1/3-octave noise floor	–110dBm (input shorted)
1/3-OCTAVE BAND FILTERS	
Dynamic range	>120dB
Detection method	True RMS
Averaging time	Selectable: 50ms–50s
Filter topology	Multiple feedback loop
Filter order/class	4-pole, second-order bandpass Class II
Design criteria	ANSI S1.11-1986, ASA 65-1986, Type 1-C
ANSI WEIGHTING FILTERS	
Filter types	A, B, C, D, E
Design standard criteria	ANSI S1.42-1986, IEC 537-1976 and ASA 51,575-601 1972
M51 MICROPHONE	
Frequency response (uncorrected)	±4dB, 10Hz–40kHz
MDF (corrected)	±0.75dB, 10Hz–40kHz
PRICE INFORMATION (as of 7/7/95)	
pcRTA 8-Bit card with connector box and cable	$1,495
M51 microphones	$ 250 ea
pcRTA 8-Bit card, connector box and cable with four M51 mikes	$2,245

generator with 31 output frequencies placed at the standard ISO 1/3-octave center frequencies, is used in the calibration process. The white-noise signal is passed through a six-stage shaping filter to produce a pink-noise spectrum with a claimed accuracy of ±0.5dB from 10Hz to 40kHz. The three signal sources are first fed to a 12-bit DAC attenuator for setting output levels and then routed to the line output through a 500Ω resistor.

All external input and output connections are made through a box which interfaces with pcRTA via a 6′ cable having DB15 connectors at both ends. The unit has five external inputs, four XLR unbalanced mike inputs, and a ¼″ female-jack line input. Each input has an impedance of 100kΩ and accepts a maximum level of +20dBm. Pin 3 carries +10V DC to power the mike's FET buffer. In addition to the external inputs, an internal input for analyzer calibration is directly off the DAC attenuator. There is also an external line-level output on a ¼″ female jack with a 500Ω source impedance.

All active inputs are fed to one of four autoranging gain blocks. They are then optionally passed through ANSI weighting filters and a second autoranging gain block before reaching the actual analyzer section. Each autorange gain block has a nominal gain of 20dB. The ANSI filters include A, B, C, D, and E weightings, which determine the effectiveness of the measured process according to various criteria. For example, the A-weighting curve approximates the inverse of the human audibility threshold at each frequency. By applying the A weighting to a measurement of low-level background noise, the measured spectrum is modified so as to indicate the relative audibility of the noise in each 1/3-octave band.

The analyzer function comprises 31 1/3-octave band filters, plus a full-range band. The former are analog filters, and use a multiple-feedback-loop topology to produce a four-pole, second-order bandpass response. Filter center frequencies follow the standard ISO 1/3-octave spacing (20, 25, 32...12,500, 16,000, 20,000Hz). The full-band frequency response is down 3dB at 0.6Hz and 150kHz.

Each 1/3-octave band filter is followed by a true-RMS log detector, which converts the measured signals into an equivalent decibel voltage level relative to either a reference voltage level of 0.775V (dBm) or a reference sound pressure level of 1P (dB SPL). Conversion to dB SPL requires an appropriately calibrated microphone. Averaging time

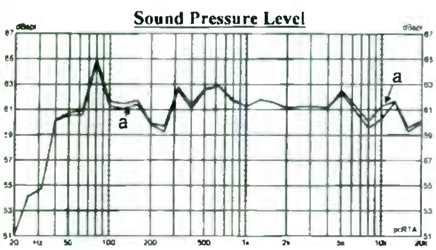

FIGURE 4: ARIA 5 1/3-octave frequency response measured with M51 #1 (a) and ACO mikes.

0.1	0.2	0.4	0.5	1.0	0.1	0.3	0.2
-0.0	-0.1	0.0	0.0	0.0	-0.1	0.0	-0.0
-0.4	-0.4	-0.3	-0.1	-0.4	-0.2	-0.4	-0.1
-0.1	0.2	-0.1	-0.0	-0.1	-0.2	-0.3	-0.3

FIGURE 5: Ratio of M51 #1 to ACO frequency response.

0.5	0.5	0.9	0.7	-0.1	-0.5	0.1	-0.4
0.6	0.6	0.6	0.6	0.5	0.4	0.8	0.2
0.1	0.0	0.0	0.3	0.1	0.4	0.4	0.8
0.6	1.3	0.7	0.6	0.4	0.1	0.1	0.1

FIGURE 6: Ratio of M51 #2 to ACO frequency response.

of the RMS detector outputs is selectable over a range of 50ms–50s. Pertinent specs are listed in *Table 1*.

ANALYZER CALIBRATION

Before you can perform any measurements with pcRTA, a calibration procedure must be run to align the analyzer with the computer in which it is installed. The program uses the computer bus clock for many purposes. Since each computer has a different bus speed, the calibration routine first measures this speed and then performs a range of tests on the analyzer itself. Other parameters requiring calibration include square-wave and white- and pink-noise-generator output levels, the exact gain of each autoranging gain block, ANSI filter gain levels, RMS detector scale factors, and the DAC attenuator. Be sure to allow the computer and analyzer board to reach a stable operating temperature by turning on the equipment at least 15 minutes prior to running the calibration routine.

Once software installation is complete, a new program group called "LinearX Systems" will appear in the Windows Program Manager screen. Double-clicking on the pcRTA icon starts the program. After initialization, the main graph screen comes up, as shown in *Fig. 2* (more on this later). To bring up the Analyzer Calibration screen, click first on the Utilities menu and then on "Analyzer Calibration." Clicking on "Run Calibration" initiates the process, which is automatic and takes about four minutes to complete.

MICROPHONE SETUP

One final step is required before you can begin to use pcRTA for acoustic measurements or microphone setup. Microphone data files (MDFs), containing microphone sensitivity and response data, are used to convert measured microphone output voltages into dB SPL. These files must be present or pcRTA will not process acoustic measurements.

If you purchased a LinearX microphone (extra-cost item) with pcRTA, the applicable MDF is supplied on a 3.5" disk. For any other mike you might use, you must construct your own calibration file. Instructions are included in the user manual.

Data can be processed from as many as four microphones in any one sequence of measurements. Each mike and its MDF must

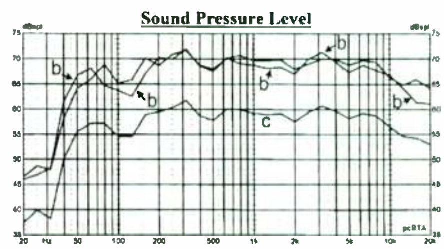

FIGURE 7: ARIA 5 1/3-octave frequency responses: (a) on-axis, (b) 30° off-axis, and (c) average of the two curves offset 10dB for clarity.

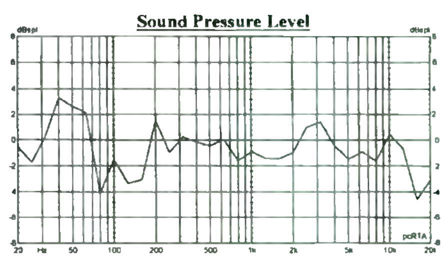

FIGURE 8: Ratio of on-axis to off-axis 1/3-octave frequency responses of ARIA 5.

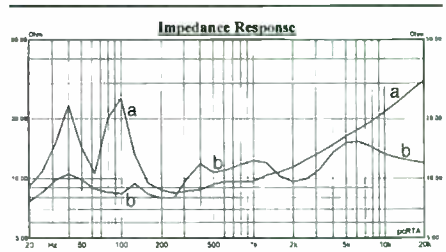

FIGURE 9: Woofer (a) and system input (b) impedance of three-way loudspeaker system.

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be specifically assigned to any one of the four mike inputs or the line-level input. (The latter is useful for line-level outputs from a microphone preamp.)

For mike assignment, click on the Edit menu (*Fig. 2*) to bring up the submenus. Select "Microphone Setup," and another submenu appears listing the inputs. Choose one and follow the instructions to install the MDF for your mike.

pcRTA IN DETAIL

The opening screen (*Fig. 2*) contains a graph area, a tool bar, and pull-down menus. The tool bar has icons for initiating a test sequence, signal generator on/off, vertical scale up/down and autoscale, graphic zoom and redraw, as well as buttons for calling up the curve library and control panel windows. Pull-down menus comprise File, Edit, Processing, Utilities, View, and Help.

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The Edit menu has seven selections: curve library, control panel, text, bar and line graph displays, mike setup, and notes/comments. A curve library holds up to 20 data curves, any or all of which can be displayed simultaneously. Each curve has its own title which is shown, together with its assigned color, in the legend below the plot area (*Fig. 2*). Up to eight lines of notes appear in the Notes and Comments window below the graph area.

Display modes for the graphing function

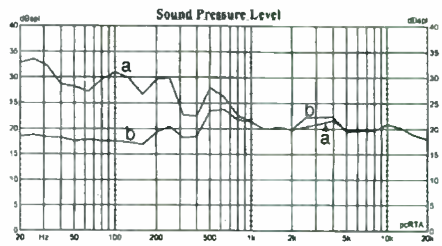

FIGURE 10: Unweighted (a) and A-weighted (b) background noise of basement lab.

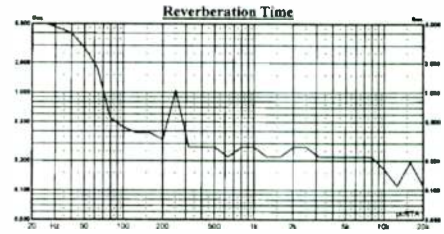

FIGURE 11: Reverberation times (RT40) of basement lab.

include the conventional bar graphs, as well as line graphs and single-curve text displays. Multiple curves in bar-graph form are extremely difficult to read, especially when more than two are displayed simultaneously. Here is one of many areas where pcRTA shines over conventional RTAs. Through the Edit/Line Graph Display menu option, you can set the color and style (solid, dash, dot) of each curve for easy visual differentiation.

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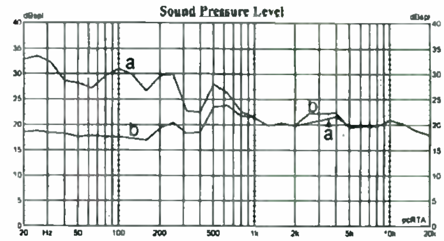

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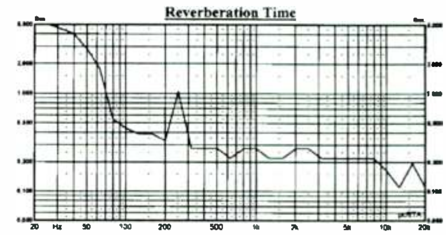

FIGURE 11: Reverberation times (RT40) of basement lab.

double-clicking on the System window under the graph area.

In the largest control panel of the three—amplitude—you can select the signal generator type (white or pink noise, or square wave), signal level, response weighting (flat and ANSI A, B, C, D, and E), averaging time (50ms–50s), input source and mode, graphics display type, and testing mode. Data may be either dBm or dB SPL.

Input sources include mikes 1–4, which may be selected in either the average or multiplex mode. In the average mode, the data from multiple mikes is averaged and placed in one curve, whereas separate curves for the data from each mike are set up in the multiplex mode. Graphics display choices are 1/3-octave, one octave, and single-band in text, bar, or line-graph format. Testing modes include continuous, peak hold, and cycle limit. The latter conducts the test a user-specified number of times, and holds and displays the results of the last test.

MATH OPERATIONS

A number of math operations in the Processing menu can be applied to stored data curves. (This very powerful feature is not commonly found in conventional RTAs.) These operations include scale, invert, multiply, divide, average, and sum. Selecting one brings up a screen, which allows you to pick the curve(s) from the current library on which the operation is to be performed, and specify the name and location of the result.

The divide function is especially useful. By selecting one curve as the reference and dividing all other curves by it, departures in decibels can be displayed. (Subtracting two curves in decibels is equivalent to dividing one by the other in numerical value.) This function is very useful for QC purposes, where you may have limits on allowable response deviations of, say, production loudspeakers from a reference standard response.

The Utilities menu provides support for ASCII data import and export, full graphics export of raster or vector images, and clipboard export, along with auto sound scoring and the previously discussed self-calibration routine. ASCII import in pcRTA is rather interesting. The frequency range and number of data points are controlled by the program, which interpolates or extrapolates the data as required to match the 31 ISO 1/3-octave data points ultimately retained.

Raster-image formats for export include, among others, BMP, GIF, JPG, PCX, and TIF. Raster-image files can be extremely large, while vector-image representations are very efficient and provide high-quality resolution. Vector graphics images can be exported in Windows Metafile, Adobe Illustrator v3.0, and Encapsulated Postscript format.

pcRTA IN ACTION

The following examples will give you some idea of the breadth of pcRTA's capabilities:

Microphone Calibration: *Figure 3* is a calibration curve for a typical M51 microphone. The response is within +0.7, −3.1dB relative to 1kHz from 20Hz to 20kHz. As stated earlier, LinearX claims this calibration curve is accurate within ±0.75dB. I thought it would be interesting to compare two of the four M51s supplied with my pcRTA review sample (selected at random and labeled #1 and #2) against my laboratory mike, an ACO 7012, which is flat within ±0.5dB from 20Hz to 20kHz.

I measured the 1/3-octave frequency response of an ARIA 5 loudspeaker with the three mikes, taking great care to place them in exactly the same location relative to the loudspeaker. According to LinearX, the M51 is calibrated against a B&K 4133 in the same manner as my comparison. Although all mikes are nominally omnidirectional, because the comparison is made in a reverberant environment, differences in off-axis response can exaggerate response errors. With systems such as MLSSA, IMP, CLIO, SysID, or LMS, it is possible to separate the direct and reverberant arrivals, and thus measure on-axis response without reverberant contamination. A difference also arises because LinearX calibrates the M51 at 552 discrete frequency points, whereas my comparison involves averaging over 1/3-octave intervals.

For the following measurements, I set pcRTA in the amplitude mode, with an averaging time of 10s. ARIA 5 frequency responses, as measured by M51 #1 and the ACO, are plotted in *Fig. 4*. The curves seem to agree very closely on the 5dB/div scale. Going to the Processing menu and selecting "divide," the M51 response was divided by the ACO response to obtain the ratio of the two in each 1/3-octave band. In the Edit menu, I switched the display from line graph mode to text mode to achieve the comparison shown in *Fig. 5*.

Microphone absolute sensitivity is usually calibrated at 1kHz. The difference between the two mikes at 1kHz is 0dB, meaning that their absolute calibration is the same. (Just prior to these measurements I verified the ACO sensitivity with a B&K 4230 sound level calibrator.) The worst-case deviation of M51 #1 from the ACO is 0.6dB. The M51 #2/ACO comparison (*Fig. 6*) shows M51 #2 off from the ACO by 0.6dB at 1kHz. If we remove this 0.6dB offset, worst-case deviation from the ACO response is +0.7dB and −1.1dB. Given the caveats of the preceding paragraph, and in particular the fact that these mikes could differ by as much as 1.25dB at any frequency and still be in spec, this comparison gives me confidence in LinearX's mike calibration accuracy claims.

Multiple Mike Amplitude Responses: With pcRTA again in the amplitude mode, I brought up the control panel, set input to "multimic," and selected microphones 1 and 2 in the multiplex mode. I placed mike #1 1.5m from the ARIA 5 on-axis, and mike #2 at the same distance 30° off-axis. After the program accumulated the 1/3-octave response data from both microphones, I reopened the control panel and set the mike mode to "average." Running the test now produced the average response from the two microphone locations. (This result could also be obtained by averaging the two curves through the Processing menu.)

The three response curves, shown in *Fig. 7*, are rather hard to interpret visually. Using the math processing function to generate the ratio of on-axis to off-axis response (*Fig. 8*) reveals a perhaps unexpected result. Normally, with a quasi-anechoic measurement, we would expect the low-frequency responses to agree, with departures occurring in the crossover region and at higher frequencies where the tweeter is more directional. The 1/3-octave RTA measurements, however, include room effects which are very sensitive to microphone placement. This accounts for the otherwise surprising +3, −4dB variation in responses below 300Hz seen in *Fig. 8*.

Impedance Measurements: The impedance mode is activated by clicking on the File menu and selecting in sequence the submenus "open" and "impedance." This brings up an Impedance Curve Library in which to store subsequent impedance measurements. Test leads from both the line input and line output are connected across the element whose impedance is to be measured.

Figure 9 is an example of pcRTA's impedance measurement capability. The first curve shows the impedance magnitude of a vented woofer in a three-way loudspeaker system. It displays the vented system's characteristic double resonance peaks. The second curve is the complete system impedance, as seen from the input to the crossover terminals. LinearX readily admits that these curves are not useful for design purposes; however, they give a coarse indication of impedance anomalies which might reveal problems with the speaker or other device under measurement.

Noise Analysis: This mode was not implemented in the version of pcRTA I reviewed, but you can fool the program into doing a background noise analysis simply by setting the generator output to zero and running an amplitude measurement. The selected microphone will then measure background noise.

Figure 10 depicts the background noise SPL in my basement lab averaged over 10s, with both unweighted and A-weighted curves shown. The unweighted level starts at 34dB SPL at 20Hz and falls to a constant 20dB SPL above 1kHz. In my experience, good home hi-fi listening environments are typically 12–15dB higher than this, especially at low frequencies. Applying A-weighting gives an average audible noise level of 20dB SPL across the entire audio band.

Reverberation Time: pcRTA measures the time it takes sound to decay by 20, 40, or 60dB in each octave band. These reverberation times are referred to as RT20, RT40, and RT60, respectively. For home listening, RT60 in the range of 2–3s for low frequencies, and much less than a second at the higher frequencies, is ideal.

To determine reverberation time, excite the listening volume with pink noise via a loudspeaker long enough to establish steady-state acoustic conditions, and measure the noise level in each 1/3-octave band. Then shut off the noise source and measure the time it takes the level to fall by 20, 40, or 60dB. In order to measure RT60, the noise level in each 1/3-octave band must be at least 60dB above background. For my basement lab this meant an SPL of 95dB at 20Hz—not easily done! I was able to measure RT40 using a three-way loudspeaker system with a 10″ woofer.

Place pcRTA in the reverberation time mode by clicking on the File menu and selecting in sequence the submenus "open" and "reverberation time." This brings up a Reverberation Time Curve Library for storing subsequent measurements. I set the reverberation control panel for a stimulus time of 1s and a 5s maximum integration time. The resulting reverb times (RT40) are shown in *Fig. 11*. The lowest two bands (20 and 25Hz) max out at 5s, the upper limit of integration, but actual reverb times are probably somewhat in excess of this value. The measured RT40s are in line with my lab's 15,000ft³ volume and acoustic treatment.

SUMMING UP

I have only two minor complaints. The manual is preliminary, and, as such, not up to LinearX's usual high standards. Installation and operations are well-covered, and there is a pretty good tutorial section. What has set previous LinearX manuals apart, however, are the rich number of application examples, which add greatly to an understanding of the system and how best to use it. Such examples are missing from the preliminary manual, but LinearX assures me that later revisions will include them. Also, several features—most notably the noise analysis mode—are still under development and not yet fully implemented.

The program is very easy to use. Anyone familiar with Windows-based software will have no problem getting up to speed quickly with pcRTA. If you are looking for an RTA, this is the most flexible, feature-packed offering in its price range on the market today. The additional functions, multiple-curve display and post-processing capabilities, and extensive data export facilities appear to set pcRTA apart from conventional RTAs. Over a period of several weeks during my evaluation the hardware and software performed flawlessly.

For those of you involved in the measurement and equalization of hi-fi or home theater systems, car audio installations, THX theater systems, or room equalization in general, pcRTA is all you need—and then some. Its full capabilities have yet to be explored, and the impressive graphics are sure to please.

By the time you read this review, LinearX's PAC3 portable analyzer chassis should be available. This unit has three full ISA slots, a battery-based power supply, and a 14W wideband amplifier. The battery is said to provide very low noise operation; a built-in charger runs off either AC mains or a 12V battery. PAC3 interfaces with your computer through the serial COM port. A notebook computer and PAC3 turn pcRTA into a fully portable analyzer, with two slots left over for additional add-ins.

One caveat: pcRTA is not the ideal tool for loudspeaker- and crossover-system measurement and design. CLIO, MLSSA, IMP, or LinearX's own LMS are better choices for this purpose. In particular, CLIO (recently reviewed in *SB* 4/95, p. 44) provides a basic 1/3-octave RTA and reverberation time measurement capability in addition to all the electrical and acoustical measurements required for designing loudspeaker and crossover systems.

MANUFACTURER'S RESPONSE

We would like to thank Joe for his excellent and thorough review of the pcRTA analyzer. We will be finishing the Noise Analysis mode very shortly, and will then be releasing a final completed manual including application data for car stereo, surround sound movie theater/home, and environmental acoustical analysis testing.

We will soon be releasing another new 1/3-octave RTA analyzer (pcRTAjr) with similar powerful computer-based features, but at much lower cost, for car stereo and other general-purpose applications that do not require all the advanced ANSI filtering and mike multiplexing features of the pcRTA.

We are also now shipping the new PAC3 portable analyzer chassis which enables notebook computer users to operate any of our computer-based analyzers, via a serial COM port, without the need of ISA bus slots. The PAC3 also includes a built-in 10W audio power amplifier, with ±0.25dB response from 10Hz–100kHz and THD <0.005%, and features AC, DC, or battery operation.

Chris N. Strahm
Engineering
LinearX Systems, Inc.

DRIVER ATTENUATION FOR MATCHING

When building speakers a frequent problem is matching individual driver sensitivities. Typically, a tweeter or midrange is substantially more sensitive than a bass driver; differences of 3–5dB are not uncommon for various quality drivers and even the individual drivers.

Vance Dickason's *Loudspeaker Design Cookbook* (fourth edition, p. 118) gives some design formulas for calculating the values of two resistors that can be connected to a driver to divide its output while still maintaining the same impedance as seen by the crossover network *(Fig. 1).* Although you can figure the formulas on a good pocket calculator, the following chart is very handy to determine those resistor values at a glance, without further work. I used the equations in Dickason's book for R1 and R2.

For convenience, *Table 1* gives resistor values for driver impedances of 2.5–12Ω in half-ohm increments, and attenuation from 0.5–6dB in half-decibel increments. In most cases the incremental values are more than adequate to cover all the common combinations you're likely to encounter. Trying to calculate and build networks with smaller increments of impedance and attenuation is probably not beneficial due to resistor tolerances and driver variations. Because of this, 5–10% tolerance resistors (which you can produce with series-parallel combinations for some of the more nonstandard values shown here) are more than adequate.

The exact *absolute* values indicated here are not necessary. But it is important that the *relative* values used in a speaker pair are very closely matched so image shifts will not occur, and that perceived sound character is the same for both systems. In addition, for best results you should use some sort of impedance compensation (a zobel network) on the driver itself so the attenuator network has a linear effect on the drivers' response.

You should never try to resistively pad down the level of a bass driver. The resulting drop in amplifier damping factor as seen by the driver can negatively affect the system's bass response. Specifically, the driver's damping at bass resonance can be substantially affected, resulting in a system with very boomy sound. If you have a woofer more sensitive than the midrange or tweeter, then it is best to start over with a set of drivers without a woofer sensitivity problem.

William R. Hoffman
Auburn, CA 95603

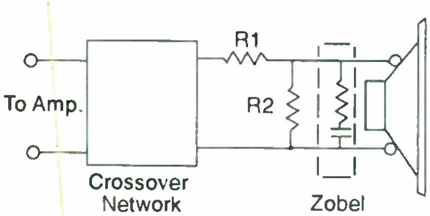

FIGURE 1: Attenuator circuit.

TABLE 1

ATTENUATION REQUIRED (dB)

Ω	-0.5	-1.0	-1.5	-2.0	-2.5	-3.0	-3.5	-4.0	-4.5	-5.0	
2.5	.14	.27	.39	.51	.63	.73	.83	.92	1.0	1.1	R1
	42	21	13	9.7	7.5	6.1	5.0	4.3	3.7	3.2	R2
3.0	.17	.33	.47	.62	.75	.88	1.0	1.1	1.2	1.3	R1
	51	24	16	12	9.0	7.3	6.0	5.1	4.4	3.9	R2
3.5	.20	.38	.56	.72	.88	1.0	1.2	1.3	1.4	1.5	R1
	59	29	19	14	10	8.5	7.1	6.0	5.2	4.5	R2
4.0	.22	.43	.63	.82	1.0	1.2	1.3	1.5	1.6	1.8	R1
	68	33	21	15	12	9.7	8.1	6.8	5.9	5.1	R2
4.5	.25	.49	.71	.92	1.1	1.3	1.5	1.7	1.9	2.0	R1
	76	37	24	17	14	11	9.1	7.7	6.6	5.9	R2
5.0	.28	.54	.80	1.0	1.3	1.5	1.7	1.8	2.0	2.2	R1
	84	41	27	19	15	12	10	8.6	7.4	6.4	R2
5.5	.31	.60	.87	1.1	1.4	1.6	1.8	2.0	2.2	2.4	R1
	93	45	29	21	16	13	11	9.4	8.1	7.1	R2
6.0	.34	.65	.95	1.2	1.5	1.8	2.0	2.2	2.4	2.6	R1
	100	49	32	23	18	15	12	10	8.8	7.7	R2
6.5	.36	.71	1.0	1.3	1.6	1.9	2.2	2.4	2.6	2.8	R1
	110	53	34	25	19	16	13	11	9.6	8.4	R2
7.0	.39	.76	1.1	1.4	1.8	2.0	2.3	2.5	2.8	3.1	R1
	118	57	37	27	21	17	14	12	10	9.0	R2
7.5	.42	.82	1.2	1.5	1.9	2.2	2.5	2.8	3.0	3.3	R1
	127	62	40	29	23	18	15	13	11	9.6	R2
8.0	.45	.87	1.3	1.4	1.8	2.3	2.7	3.0	3.2	3.5	R1
	135	66	42	27	21	19	16	14	12	10	R2
8.5	.48	.92	1.3	1.7	2.0	2.5	2.8	3.1	3.4	3.7	R1
	143	70	45	33	25	21	17	15	13	11	R2
9.0	.50	.98	1.4	1.9	2.3	2.6	3.0	3.3	3.6	3.9	R1
	152	74	48	35	27	22	18	15	13	12	R2
9.5	.53	1.0	1.5	2.0	2.4	2.8	3.2	3.5	3.8	4.2	R1
	160	78	50	37	28	23	19	16	14	12	R2
10.0	.56	1.1	1.6	2.1	2.5	2.9	3.3	3.7	4.0	4.4	R1
	169	82	53	39	30	24	20	17	15	13	R2
10.5	.59	1.1	1.7	2.2	2.6	3.1	3.5	3.9	4.2	4.6	R1
	177	86	56	41	31	25	21	18	15	13	R2
11.0	.62	1.2	1.7	2.3	2.8	3.2	3.6	4.1	4.4	4.8	R1
	186	90	58	42	33	27	22	19	16	14	R2
11.5	.64	1.3	1.8	2.4	2.9	3.4	3.8	4.2	4.6	5.0	R1
	194	94	61	44	34	28	23	20	17	15	R2
12.0	.67	1.3	1.9	2.5	3.0	3.5	4.0	4.4	4.9	5.3	R1
	203	98	64	46	36	29	24	21	18	15	R2

SB *Mailbox*

BAEKGAARD IS BACK

G.R. Koonce's *SB* 2/95 article ("The Baekgaard Crossover Technique," p. 20) prompted this letter, which, while it offers no comment on the article itself, provides some information that may be of interest. Mr. Baekgaard's filler driver paper evoked some "Letters to the Editor" in the AES *Journal* (Vol. 26, No. 9, pp. 650–654) from Messrs. Leach and Hoge.

I was fascinated by Baekgaard's paper ("A Novel Approach to Linear Phase Loudspeakers Using Passive Crossover Networks"). However, it appeared that the filler driver must have an extraordinarily wide bandwidth, and, if such drivers were available, why not just use first-order filters, without the filler driver? Also, if the effect of the filler driver can be produced by a discrete driver, couldn't the same effect be produced electrically?

After considerable diddling with my filter performance program, I discovered that an overlapped, second-order crossover produced an output that is in phase with its input. I built such a network and, with resistor loads, tested it with square waves and determined the predicted performance. However, I found that my "original" thought was not so original...after I ran across Vanderkooy and Lipshitz's paper, "Use of Frequency Overlap and Equalization to Produce High-Slope Linear-Phase Loudspeaker Crossover Networks," (AES preprint 1926, C-6).

Why not try to do this electroacoustically? That is, have a speaker manufacturer build a woofer and a tweeter with two voice coils; feed one pair of coils with the normal second-order filter signals, and the other pair the "filler" driver signals. This may have some merit, but it requires development capabilities beyond my means.

It seems that these Canadians are either anticipating my thoughts or shooting them down! For instance, when D'Appolito published his MTM configuration paper, I thought, "Now we can have a stable, horizontal acoustic axis and (with third-order acoustic slopes) also constant power." Not long after, I discovered Vanderkooy and Lipshitz's paper ("Power Response of Noncoincident Drivers," AES preprint 2049, F-4), which demonstrated: not so!

David Meraner
Scotia, NY 12302

Contributing Editor G.R. Koonce responds:

I thank Mr. Meraner for the additional information (which I had not seen before) on the Baekgaard "filler driver" crossover technique. W.M. Leach's comments pointed out that the Baekgaard technique may be constant-voltage, but it is not constant-power, which he considered important. W.J.J. Hoge commented that the technique produced a crossover that was not constant-resistance and that the driver and crossover components might better be used in a three-way system. E. Baekgaard replied with additional discussion on his technique and presented plots showing constant input impedance in the crossover region and a flat system acoustic response in a reverberant field.

I do not intend to reopen the general discussion of what is the "best" passive crossover. Articles discussing this have filled many pages, including those of Speaker Builder. *My "Crossovers for the Novice" article (*SB *5/90, p. 26) contained a* Speaker Builder *article mini-index, as well as simple definitions of the terms used above in summarizing the comments on the technique.*

Basically, a passive crossover takes in a single signal from the amplifier and divides the signal into frequency portions proper for each driver in a multiway speaker system. We care about what type load the crossover reflects back to the amplifier, what type source impedance each crossover section presents to its driver, how fast the various crossover sections attenuate the signal as you move out of its band, and how the various crossover sections "add" back together in terms of total power output and on-axis response. All of this is especially of interest with the real drivers applied, mounted in their proper locations, and examining their total acoustic response—a far more difficult task than just working with the crossover outputs into resistive loads.

All passive crossovers are a compromise; it is very difficult to build a three-way or more complex crossover that is constant-voltage and constant-resistance. It can be approximated via many drivers and crossover components. Each builder using passive crossovers must decide what compromises produce the desired sound quality.

DRILL BIT SOURCE

In his contribution to Tools, Tips & Techniques (*SB* 3/95, p. 57), Phil Bamberg noted the difficulty of finding 9/16 Forstner drill bits for use in installing grille snaps.

My current catalog from MLCS Ltd. (PO Box 4053, Rydal, PA 19046) includes 9/16 Forstner bits as a new item. Its price is $5.95, or $4.95 each if you buy three. Shipping (UPS) is free in the contiguous US. The stock number is #9026, and you should refer to catalog C-17C to order. Their toll-free number is (800) 533-9298.

R. Valentine
Old Greenwich, CT 06870

SAAB STORY CONTINUES

Several months ago I received a trial issue of *Speaker Builder* and was absolutely delighted to read Mark Florian's initial article on installing an upgraded sound system in his

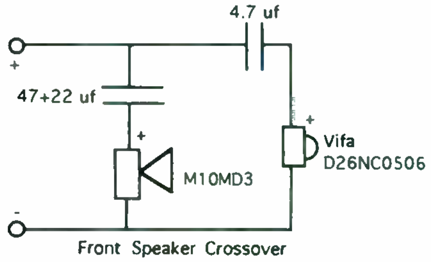

FIGURE 1: Front speaker crossover.

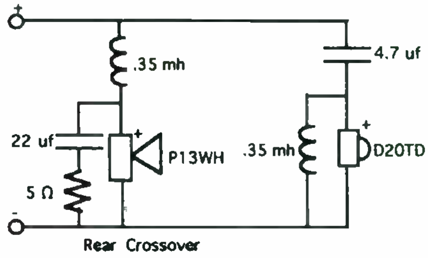

FIGURE 2: Rear crossover.

SAAB. As an owner of a 1988 SAAB 900 turbo, I have long considered replacing the factory speakers, so I regarded receiving that issue as close to divine providence. Needless to say, I subscribed to the magazine for the second and final installment of the article!

I have several installation questions, most of which are related to my lack of familiarity with the subject.

1. What type of crossovers did you use between the woofers and tweeters for the front and rear speakers?

2. What type of crossover did you use to control the subwoofer? (I have ordered a copy of Ferguson's book that you referenced in the article.)

3. Do you have plans or dimensions for the rear speaker enclosures? At the very least, what was the vent diameter in the speaker enclosure?

Thank you for a very timely article. Although the principles can be applied to any car, I believe it was most fortunate that you did all the work on a SAAB.

Bill Kennedy
Muncie, IN 47304

Mark Florian responds:

Thank you for your kind comments regarding my sound article for the SAAB. The tweeters on the front dash use a 4.7µF cap in series, and the midrange units use a parallel combination of 47µF and 22µF nonpolarized electrolytics (Fig. 1). *The schematic for the rear speakers is in* Fig. 2. *Madisound figured out these values when I ordered the drivers.*

*The subwoofer crossover circuit is straight from Ferguson's book, except for the modifications covered in the article. I have also included the outside cabinet dimensions (*Fig. 3*) of the enclosure, which uses 5/8" particleboard.*

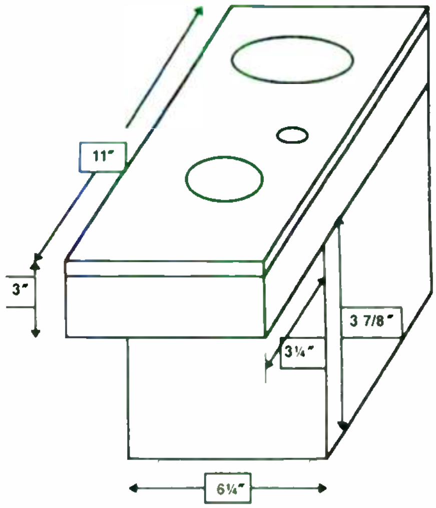

FIGURE 3: Cabinet dimensions (vent is 1" ID × 2¾" long, sch-40 PVC).

CLEANING UP THE SEWERLINE

While browsing through *Speaker Builder* 1/94, I came across the Craftsman's Corner presentation (p. 62) of your version of my Simpline (*SB* 2/93). I was rather surprised to see it, since I didn't recall noticing it when the magazine first arrived. Your ingenuity is intriguing, and your use of ready-made products is very clever. The entire project looks clean and sleek (in spite of the reported muddy bass).

Unfortunately, while you've succeeded in approximating the Simpline, your design differs from it in several areas, which might help to explain the differences in performance between your version and mine. A major problem lies in the diameter of the pipe you selected. A 4″ (inside diameter) pipe has a cross section of about 12½ in², which is approximately half of the cross section area I employed in the Simpline.

The Simpline has an internal volume of about 0.356′. The 4 oz of stuffing I specified resulted in a stuffing density of about 0.7 lb/ft³. Assuming your tube is 24″ long and allowing about 15 in³ for the volume of the speaker, your version would appear to have an internal volume of about 0.166ft³.

You didn't mention the weight of your pillow stuffing, so I'll assume that you used the specified 4 oz, which is 0.25 lb. That, divided by 0.166ft³, produces a stuffing density of about 1.5 lb/ft³. This high density, coupled with a cross section of only about half of what I used, suggests that your Simpline will probably remain in the bathroom a long time.

Schedule 40 tubing is rather thin, and is a poor choice to use in an environment subject to sonic vibration. The "voice" of the tube speaks out in unison with the speaker and things are not going well. (If only Judge Ito were here to ensure that both parties were not speaking at the same time!)

Getting to the bottom of things, we come to the feet. The feet should be long enough (or longer) to allow an exit area at the base that is at least equal to the cross section of the tube, which in this case is about 12½ in². To find the correct height, divide the cross section area by the circumference of the tube (circ = $d\pi$). In the case of your 4″ tube, the height is about 1″. You could make the area greater, but it wouldn't help much.

I'm assuming you used the contour filter. Omitting that would affect the spectral balance of the Simpline. If you were to use a 6″ dia. tube, the cross section would be a bit over 28 in². A 24″ long tube (minus 15 in³ for the space occupied by the woofer) would be 0.384ft³ in internal volume. For a stuffing density of 0.7 lb/ft^3, you would need 0.269 lb (4.3 oz) of pillow stuffing.

Using the calculation method of a couple paragraphs above, the length of the legs (they're becoming too long to be called feet) is close to 1-3/8. I used 25 in^2 as the figure, since I know that the Simpline is happy with that. I don't know if closet flanges come in a 6″ size, but from what I've seen of your brainstorming capabilities, I feel comfortable leaving that situation up to you.

I am very pleased that I discovered your presentation, even at such a late date. One final thought: I would think if a person had muddy bass, the bathroom would be an excellent place to clean it up. You might simply try 1.9 oz of stuffing (about 0.7 lb/ft^3) for the 4″ pipe, and spread the stuffing as evenly as possible.

John Cockroft
Sunnyvale, CA 94087

W. Werner responds:

I think we should all write a nasty note to the plumber's supply consortium indicating our extreme displeasure at their not having the decency to supply cheap plastic pipe and fittings in a wide variety of sizes to serve the needs of speaker builders everywhere. That said, I would heartily recommend Mr. Cockroft's comments to anyone attempting the sewer pipe version of the Simpline [sewerline?—the name does not deserve to be capitalized!]

I was intrigued by the original Simpline's ability to achieve good bass from such a small driver by mass loading and the use of a transmission line. To quickly satisfy my curiosity, I used materials available at my local hardware store. If better materials, as Mr. Cockroft suggests, are available, they are not at my store.

I wish rapid prototype materials were more readily available, since I am long on ideas and short on time. If anyone has ideas along this line, I would certainly like to hear them. The paper forms used for concrete posts might be good—I recall an SB article using them. However, what do I do for end pieces?

I haven't done much with my "sewerline" since building it and amazing myself with the transmission line and effects of mass loading (I haul it out now and then to impress visitors with what such a small driver will do), and have not tried Mr. Cockroft's suggestions. I will when time permits.

SAFETY CONCERNS

I understand the need to print more construction articles, which I find very interesting, but does *SB* really need 11-page construction/review articles from a novice? Anyway, I, for one, found much humor in Ms. MacArthur's quaint report ("Kit Report: Audax of America A652," *SB* 2/95, p. 42).

Her 21-step safety list is a must for anyone preparing to enter the Chernobyl of speaker building and soldering. Don't get me wrong—safety is very important, but Ms. MacArthur forgot to tell us to tape our shoelaces to our shoes so we don't trip and fall face first into our table saw that we forgot to turn off.

Ms. MacArthur, even with an ill child, you sound like you have too much time on your hands! Who else would rather strip individual strands of litz wire instead of dipping it into those awful, terrible, horrible, possibly, maybe, carcinogenic chemicals you don't want in your house? What about the brain cell(s) you destroyed by inhaling tin/lead solder fumes? Heaven knows what is in the plastic fumes emanating from all the terminal lugs you overheated. You didn't mention if you were wearing a face mask. When Duncan burps, do you banish everyone to the bomb shelter until your house airs out?

Ms. MacArthur, I would love to read about your escapades as you undertake the challenge of stuffing a circuit board with polarized capacitors, one of which is oil-filled, that you inadvertently wire up incorrectly.

William H. Wallace
Stockton, NJ 08559

Nancy MacArthur responds:

I was perplexed by your letter on safety issues raised in the A652 review but will try to respond to your concerns.

I couldn't find the "21-step safety list" to which you refer. I did write a section with 21 tips for novices, but only one of these (maybe two if you stretch) was about safety. The other tips covered soldering and construction techniques.

Why all the fuss about my decision to strip litz wires by hand? Individual circumstances vary. For example, a single adult or a family with teenagers generally will worry less about storing toxic chemicals than a family with toddlers. If using a chemical stripper on litz wires makes sense in your particular situation, by all means use it. It's up to you.

Including a few safety tips in an article aimed at beginners doesn't strike me as excessive. Believe it or not, occasional SB *articles for more advanced speaker builders also contain safety information. Dig out your back issues and take a look at Wayland's Wood World.*

LESS TECH TALK, PLEASE

I have been a subscriber off and on for several years. One of the reasons for the sporadic subscribing is because of the magazine's content. I have been a professional speaker rebuilder, cabinet builder, and stereo enthusiast for some time. I read *Speaker Builder* as someone who simply enjoys speakers. From this standpoint I become very discontented with the articles, so many of which are either by electronics engineers or master cabinet makers. They are weighed down with heavy math equations and formulas that very few readers could possibly begin to understand.

In addition, authors always just seem to have test equipment or a computer, and a program that they can plug information into and easily obtain an answer to the character and performance of a speaker or different box configurations. The only common or ordinary feature about these engineered projects is that they always include an old Radio Shack, Peerless, or Philips speaker. It almost seems as though the articles are written by engineers trying to reach out to the common guy the best he can, but he just can't seem to get there. I am sure both you and I know many talented engineers who just can't relate to the rest of the world.

Once in a while, a project hits the mark, using some conventional means with logical speaker choices and shows that with just a little common sense and some good advice from someone such as Madisound, an ordinary guy can build a decent-sounding device. Readers need to know more about the many brands and models of speakers that you advertise in your magazine: Dynaudio, Morel, Eton, SEAS, LPG, Vifa, or Peerless woofer, mid, or tweeter units. They need to know what they're buying.

How good is a particular brand? Can I achieve good performance from a Peerless or Vifa woofer or do I really need to spend all that extra money on a Dynaudio? What do these speaker combinations sound like with different kinds of music? What types of cone materials produce a smoother or punchier sound? What types of tweeter dome materials give a brighter, more realistic sound than indicated on a graph?

A good example of an article that could have been great is "A Flexible Four-Way System" (*SB* 4/95, p. 14). As with many articles, this one focused on how the author built this potentially great slamming system, failing to mention what it could do or how it sounded. The article was almost not even worth the space. Explore the system's potential, not just how to build the box.

I suggest that you include performance reviews on several speakers, from the many long-time models of various brands offered. Give your readers an idea of what they are like and what the market contains. Otherwise, the only recourse for readers is to spend their money and possibly be disappointed. In addition, advertisers would sell more product.

I also suggest more articles on using JBL, EV, Altec, Gauss, and Cerwin-Vega speakers for high-performance low-end and mid/high-end. Most of these speakers work great in a simple reflex box with the right volume, port, and with simple butt joints and proper bracing. While I realize some of your readers are technically minded engineers, the vast majority are not. *Speaker Builder* has so much potential, but is like a runner in a race who stubs his toe coming out of the starting blocks.

Steve Pleasant
Dayton, OH 45405

References
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INSPIRATION

An often-heard—and unfortunately true—remark is that our speakers are wonderful to listen to but godawful to look at. The shame is that it is our own fault. Somehow we make the mistake of thinking visible beauty is not important.

When I stopped making wooden objects for a strictly utilitarian purpose and started being concerned about the beauty of my enclosures, something changed. This attitude was brought to a head when I read *The Impractical Cabinetmaker* by James Krenov (Sterling Publishing, 1993, $14.95). Some topics covered are considerations on matching wood grains or the aesthetics of cabinet design. I hope your reaction is the same as mine when you read this wonderful book.

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Two Wharfedale 12″ cast frame woofers, W60D system, $120; two Lafayette 99-0092 free standing three-way crossovers, $30; transformer set from Eico ST-40, 20W with 7591 tubes, $65. Stanley, (216) 288-9480.

Crown IC-150A preamp, $125; pair JBL 2470 midrange compression drivers, $225. Kent Elliott, voice/FAX (913) 677-1824 (KS).

Dyna ST-70 power transformer, used; *Stereophile* issues Vol. 5: #10, Vol. 6: #1-6, Vol. 7: #1-8, Vol. 8: #1-8, Vol. 9: #1, Vol. 11: #5 & 6, Vol. 12: #3 & 4, Vol. 15: #2 & 3, Vol. 17: #1-12. George Krlich, 56 Oakdale Ave., Hubbard, OH 44425-2147, (216) 534-4225.

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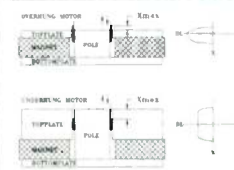

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Dipole wing enclosures for magnetic planar drivers, back 21″ wide, 8″ deep, opening: 4 1/8″ x 63″, cannot ship, $50. Joe, (609) 397-8315 (NJ, EDT).

Rare Pentron portable combination wire recorder, 78 rpm record player, AM radio and PA, $300; dbx 222 type II noise reduction unit, $80; dbx 224, $100; Ampex VR5100 1″ B&W video recorder with cable and tape, $50. Recorder too heavy to ship. Robert, (805) 522-2579.

Pair Altec 808 horn drivers, $225; pair 32C monitor horns for 808, $100; pair empty 9849 monitor cabinets for 12″ plus 32C horn, worn but sturdy, $100; Pioneer CTF1000 cassette deck, $275; pair ROR speakers, 2x6″ plus tweeter in each, black, $150; two mono tube integrated amps. David, (914) 688-5024.

Speaker project "estate sale:" pair Accuton C2-11, two pair Accuton C2-77, two pair Focal 8K516, custom DB Systems active crossovers, precision machined white birch MDF cabinets with biscuit joints. In boxes, uncompleted, can ship, $1,750. Also two pair Focal 8V416J, $125/pair; Audio Control C-101 EQ/analyzer, $145. Chris Hornbeck, (501) 664-8705.

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Carver M1.5T amp, 350W/channel, $400; SAE model 2900 preamp with built-in parametric EQ, $150. Both in mint condition. Nick, (209) 583-6511, after 5 p.m. PST.

Six Dynaudio 24W-100 woofers, four of them unused, $105 each; four Dynaudio D-52AF, $60 each; two Dynaudio 17W-75, $50 each. Will take best offer. Brad, (513) 433-6229.

1982 Boston Acoustics A150s, $50; 1988 Legacy Signatures, $1,000; pair Threshold Stasis One monoblocks, $2,000; Yamaha receiver, $50; Technics turntable, $50; Curcio Audio Engineering vacuum tube digital processor, $100. Mark Runnels, 1812 Wilson Lane, #101, McLean, VA 22102, (703) 448-3375.

LinearX LMS system with mike, $800 or best offer; ACO Pacific 1/2" 40kHz mike with power supply, $800 or best offer. Paul, (714) 841-6884, days, (714) 251-1006, evenings PST.

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Pair JBL 2404H tweeters, $150; pair 2420B drivers with 2305 horns, $300; 2231H woofer, $120; 5234 electronic crossover, $100. Paul, (410) 727-6930, days, (410) 661-9857, evenings.

ST-70 in perfect working order, clean chassis, very little pitting, completely stock although I will include recommended changes that will make this amp sing like Billy Holiday! $350 (includes shipping). Lloyd, (617) 232-2887.

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Crossover network wiring diagram for early large Advent speakers, serial numbers U183502 and U179073, will pay costs. Alex Weibel, 219 Lakeside Dr., McKees Rocks, PA 15136, (412) 787-8117.

Altec 436, 438 compressor amp; 1566, 1567 mike mixer; EQ, compressor, or mike preamp by RCA, Urei, White, Pultec, Langevin, or Fairchild. Kent Elliott, voice/FAX (913) 677-1824 (KS).

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