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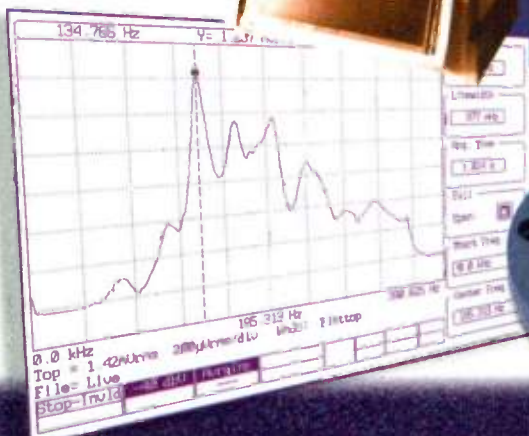
LISTENING TO  
**FOCUSED**  
ELECTROSTATS

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**DIPOLE COMES**  
**TOGETHER**

HOW GOOD/BAD  
ARE YOUR ROOM'S  
**ACOUSTICS?**

UNVEILING COMPLEX  
**IMPEDANCE**  
**SECRETS**

**THE FORCE:**  
A POWERED 4-WAY  
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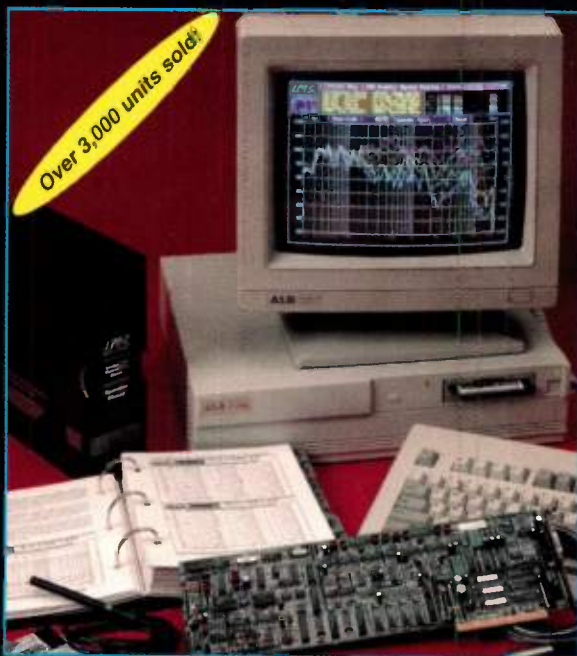
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#### ■ A COMBO KIT

Focal of France has introduced its line of raw-frame speaker components. From this, Speaker City, USA, has collaborated with Kimon Bellas (Focal USA) to produce a monitor system, the Focal 7KT. Designed using CLIO and SpeakEasy, this kit offers state-of-the-art parts and superior audio performance, according to the company. Speaker City, USA, 115 S. Victory Blvd., Burbank, CA 91502, (818) 846-9921, FAX (818) 846-1009, Website [www.speakercity.com](http://www.speakercity.com).  
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Crosstech Audio is manufacturing low-pass, and two- and three-way crossover networks @ 12dB that handle up to 1kW. All utilize polypropylene capacitors, air-core inductors, and the company's specially designed and manufactured printed circuit boards, using larger than normal foil runs. Each includes a composite polyurethane backing to absorb vibration, and the terminal connectors are soldered on for added strength and durability. Crosstech Audio, Inc., 30 Francine Ln., Staten Island, NY 10314, (718) 370-8399, FAX (718) 370-8297, Website [www.crosstechaudio.com](http://www.crosstechaudio.com).  
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#### ■ ARRAY OF READING

Two catalogs were released from Antique Electronic Supply (AES) and McFeely. The AES catalog includes a vast supply of tubes, parts, books, and supplies. Antique Electronic Supply, 6221 S. Maple Ave., Tempe, AZ 85283, (602) 820-5411, FAX (602) 820-4643, or (800) 706-6789. McFeely's catalog contains a variety of square-drive screws, machine screws, drill bits, storage solutions, and more. McFeely's Square Drive Screws, 1620 Wythe Rd., PO Box 11169, Lynchburg, VA 24506-1169, (800) 443-7937, FAX (800) 847-7136. Also released was *Basic Home Theater*, by Gordon McComb, a guide to create a movie-theater environment in your home. It discusses all aspects of the audio/visual revolution from TV sets, DVD players, and satellite dish antennas, to speakers, wires, connectors, and plugs you will need to plan, install, and maintain your home-theater system. PROMPT® Publications, (800) 428-7267.  
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*Stereoplay 1/96:*

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*Sound and Vision Magazine 1/97:*

"The theoretical deliberations in 1978 of Dr. Manfred Heckl, Professor for Acoustics at the Technical University of Berlin, were the first to establish the absolute certainty that the "Manger Concept" operated without any transient phenomenon whatsoever. But a great number of manufacturing obstacles had to be overcome before the concept reached series production. Nowadays the technical - and also the tonal - quality of the Manger transducer can be confirmed, and this development can certainly be regarded as revolutionary".

Operating from 170Hz to 33kHz as a true point source bending wave driver, the Manger is renowned for its utterly natural sound and transient perfection. It is extremely simple to use, requiring only a subwoofer to round out the bottom end.

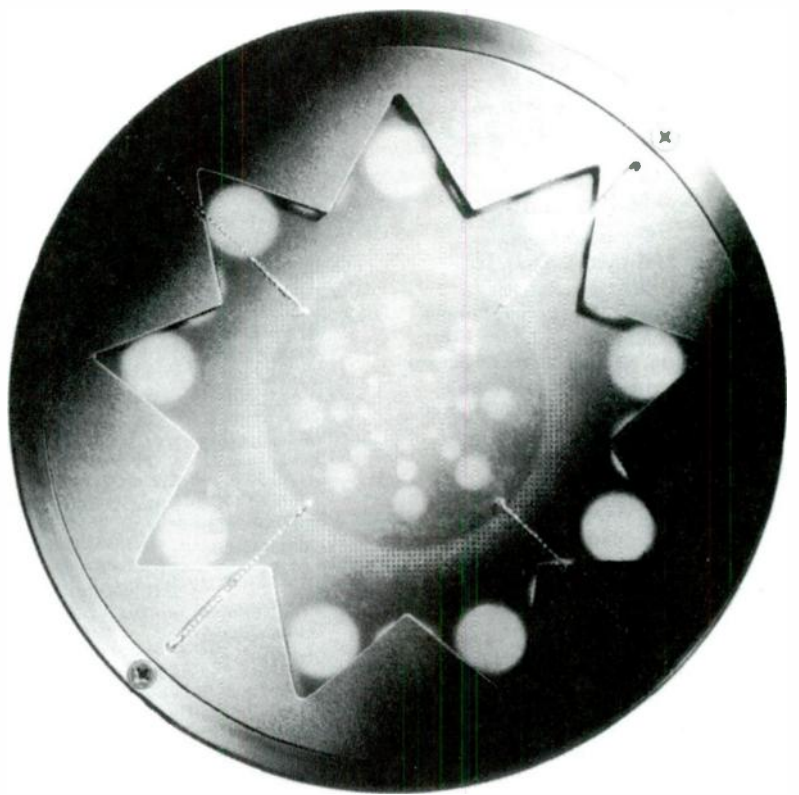
Perfect sound is "built into" these drivers. With no crossovers in the midrange, even beginning speaker builders can achieve better time, transient, and phase response than with any other multiway loudspeaker. Despite the relatively high cost of manufacturing the Manger, total system cost compares favorably with multi-component speakers using premium drivers and crossovers.

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With the new 15-magnet neodymium version, efficiency is 90db 1W/1m. Recommended Vb is a very small 8-10 liters for the 8 inch drivers. Driver depth is less than 2 inches, allowing for in-wall or in-ceiling mounting. Rise time is an incredible 0.014 milliseconds, about 2/3 of that required to play CD's. These are not frail drivers either - they are being used in discotheques as well as recording studios, and early Manger drivers used during research and development still meet specs after years of use.

Manger drivers, speaker kits, and finished speakers are now distributed in North America by B&R Acoustique. With strong roots in consulting engineering and audio/video recording and mastering, we can help amateurs and manufacturers alike develop extraordinarily great systems using Manger technology. Call, fax, e-mail, or visit our website for sales info. E-mail, fax, or regular mail are preferable to phone calls for technical requests. Stop by to listen at the 1999 International CES in Las Vegas, Alexis Park, suite AP1654, January 7-10.

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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

Many factors influence the design process of a speaker system. As you'll see in **B. Lamy's** line-source speaker project, perhaps the highest consideration is your own personal preference. This author from France addresses the design considerations, self-imposed guidelines, and driver and crossover parts selection in the first of his two-part article ("The Force," p. 8).

Want some enjoyable company the next time you take the family jalopy out for a spin? How about a backseat passenger that promises a well-behaved subwoofer sound? See **Dennis Colin's** "Real Backseat Bass," p. 22.

In "What's Really Happening in a Stuffed Line?" (p. 32), **Don Jenkins** experiments with different enclosure scenarios—using full- and partial-density loadings—to determine the effects on resonance.

Now that all the hard work is completed—constructing, positioning, and measuring—it's time for designer **Bill Waslo** to kick back and take a listen to his imposing-looking focused array system. Find out whether it sounds as awesome as it looks ("Focused Array Electrostatic," p. 36).

Even if constructing a "dipole monster" (p. 40) is not in your immediate speaker-building plans, you'll find many of **Timothy Sandrik's** design principles applicable to boxed speakers.

Also, be sure to check out **D.J. Meraner's** interesting analysis of speaker impedance in "Mining the Complex Impedance," p. 44.

In this issue's "Software Review" (p. 50), **Philip E. Bamberg** examines the latest version of ETF, a measurement program for evaluating room acoustics. This program receives high grades for an easy-to-follow manual, low price, graphic interface, and ease of use for the audio beginner, as well as the audio engineer.

Finally, driver expert **Vance Dickason** takes a look at two new Focal drivers—the Audiom TLR tweeter and 7K2 midrange ("Driver Report," p. 59).

*Speaker Builder* (US ISSN 0199-7920) is published every six weeks (eight times a year), at \$32 per year, \$58 for two years; Canada add \$8 per year; overseas rates \$52 one year, \$93 two years; by Audio Amateur Corporation, Edward T. Dell, Jr., President, at 305 Union Street, PO Box 876, Peterborough, NH 03458-0876. Periodicals postage paid at Peterborough, NH and an additional mailing office.

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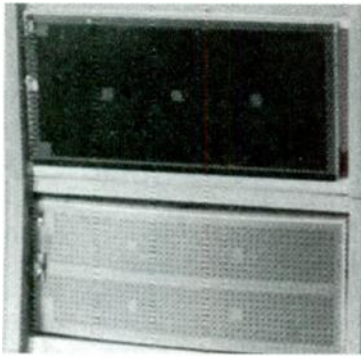
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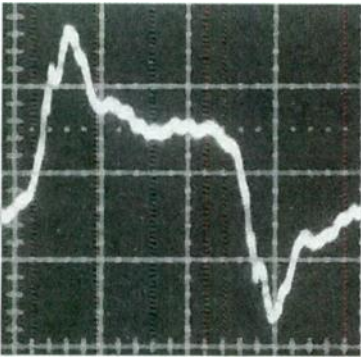
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# THE FORCE, PART 1

PLANNING FOR A 4-WAY, POWERED SYSTEM WITH SERVO-CONTROLLED SUBWOOFER

By B. Lamy

We all have reasons for what we do; for instance, I build a new speaker system because I enjoy not only its development and construction, but also finding the flaws that justify the construction of the next one. And so is born the Force. I also have reasons for this name: it's my fourth system, I love Star Wars, I really needed some force to break the spouse-approval-factor barrier for this new project, and for some technical reasons you will discover later.

The purpose of this article is to describe the whole process of designing the Force, starting from subjective desires and wills down to soldering and woodworking.

## DESIGN PHILOSOPHY AND SYSTEM CONCEPT

I am the kind of guy that reads *Stereophile* and spends many hours listening to speakers rather than to music. All these hours spent in comfortable chairs listening to the sound of carbon fiber and metallized polypropylene have proven to me at least one thing: all loudspeakers that provide a great deal of listening pleasure are based on a consistent design, with one or two (never more) basic guidelines, and are entirely engineered to satisfy these concepts. This is the case with Klipschorns (which measure terribly), Dunlavy SCVIs (which measure perfectly), and I hope also for the Force (which measures as you'll see).

I have built four systems up to now, in accord with my financial possibilities (I started at age 15), and they are all founded on the same basic "listening values"; the differences between them are due to budget considerations and to the major progress in loudspeaker technology. I think one significant advantage of designing your own speakers, apart from the creative pleasure, is the possibility of orienting the design to the qualities we like best.

Of course, this is true because the perfect loudspeaker still belongs to the remote future. Each design today, even the most expensive, is based on hundreds of compromises, and the best is the one that matches your compromises. Hence, my design strategy is as follows.

1. I try to write down which aspects of the sound are important to my ears, ranking them from highest to lowest priority. (See "Basic Listening Values" in sidebar.) This I do independently of technical ideas about what is or could be feasible. Doing this is not easy, especially when you are the designer, and I found the best way was to listen to a bunch of records (about 200 in fact) through my existing system and through a Sennheiser Orpheus headphone as a reference point, and to note what was pleasant and unpleasant in the sound of each record, trying to distinguish what was due to the record itself from what was due to the speakers. I ended up with both a list of "preferred items" or "listening values," as well as a list of strengths and weaknesses of my current speakers.

My existing system relied on Strathern ribbons (two per enclosure), with a closed-box Dynaudio 19W38 for lows and a Ceratech C211 above 7kHz. It was quite pleasant and electrostatic-like, but was weak in dynamics, and had a somewhat lean bass. The Stratherns also proved to have a difficult association with any tweeter, and suffered from severe reliability problems.

2. Step 1 outlines the final goal of the system: possessing characteristics adequate to reproduce optimally the sound properties I like the most. I then need to translate this goal into acoustic and electronic requirements. (See "Technical Solutions and Choices" in sidebar.) This is the trickiest and most exciting part of the process, because you can apply only a few rules with certainty, and there is so much room for experience, intuition, and mistakes. The outcome of this second step is a system concept, including the choice of speaker type (will it be a two-ways TL, a three-ways sub and satellite, and so on) and the "architecture" of the system, including what you do electronically and with wood and glue, and what is done through acoustic behaviour.

3. The next step is full of trade-offs: deciding on a budget; selecting drivers in accordance with the overall requirements; making preliminary driver measurements; and designing enclosure and basic filter topologies with the help of some simulations.

4. Finally come the electronic design (which is quite important in the Force system), speaker building, and tuning, including in-room measurements and subjective listening tests.

## QUESTIONS AND ANSWERS

### *What about tweeters?*

The main requirement is to provide a smooth transition with the midrange to avoid spoiling its quality (which means low resonance frequency and smooth transition band). They must also have high dynamics (compression in tweeters always means an awful noise). There is no other answer than high-quality tweeters.

### *What about filtering?*

This is a large issue. Before getting into details, I needed to specify whether I wished active or passive filtering. I chose active for the following reasons:

- Upgrading the system with new drivers is easier this way; also, with a given target response, active filters provide more freedom for individual driver accommodation than passive filters;
- This solution is more compliant for high dynamics for these reasons: no loss due to passive filters, power sharing between amplifiers (which reduces clipping risks, but also intermodulation distortions), better control of drivers because of direct coupling, and more low-level resolution and articulation);
- Matching driver efficiencies is straightforward, giving a broader choice.

### *Servo or ported box for bass section?*






*Servo.* Calculations showed that a ported-box solution was feasible with a high-quality JBL or Focal driver, but I opted for servo because I wished to try it and because it gave the same bandwidth in a smaller box. Another good reason is that I think "tight" and "fast" bass is linked to well-controlled transient behavior (but also because bass reflex often sounds tighter than closed and does not have perfect transient response) and to distortion levels. I completely disagree with the assumption that bass distortion is not important because the human ear cannot distinguish harmonic distortion in single low-frequency tones.



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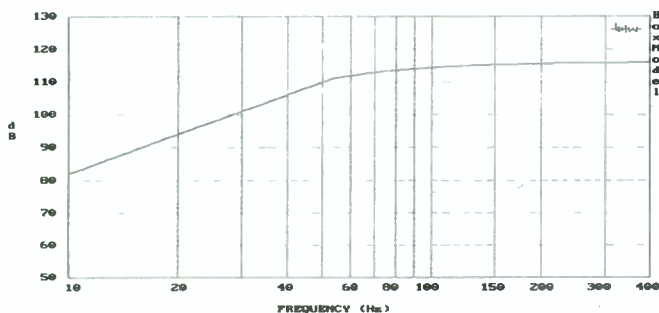


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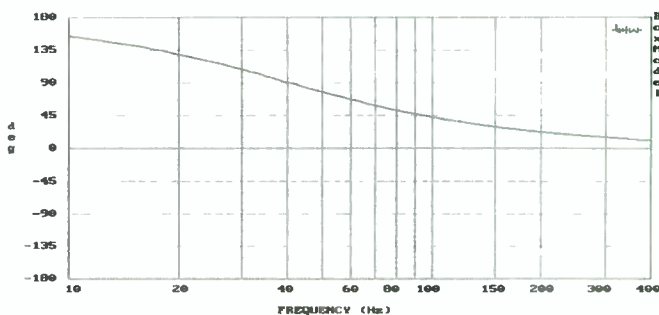
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**FIGURE 1:** Boxmodel simulation for the Madisound 10207DVC in a closed box (maximum SPL).



**FIGURE 2:** Phase response of the 10207DVC.

**Three ways or more?**

More. Choosing a servo limits the upper cross frequency to 100Hz (you can cross it higher, but you are outside the bandwidth of the feedback-control loop, and it is not satisfying from the engineer's point of view). Moreover, low crossover frequency means that you can use the sub box as a pedestal for the rest of the speaker (somewhat limiting the Allison effect).

Then, with a crossover frequency of about 100Hz, there is no available midrange that goes so low. A lot of bass-midrange exists, but a comparison using the Orpheus would eliminate them at once (I think they sound plastic and dark in the upper midrange), and if you can cross them to 100Hz, you are limited to 1.5–2.5kHz at the upper limit, which is not compliant with the above midrange requirements. I decided to go for a four-way system: sub, low midrange, midrange, and tweeter.

you can keep to the \$150 servo figure with a relatively slight performance decrease.

I did not include the price of testing instruments and simulation tools (calibrated mike, Liberty Audiosuite, Box-model, Calsod, Tektronix TDS220 scope, power supplies, signal generators, and so on). I constructed everything myself, including printed-circuit boards and woodworking. In the end, my initial budget was 25% too low, which must prove that I am a professional engineer.

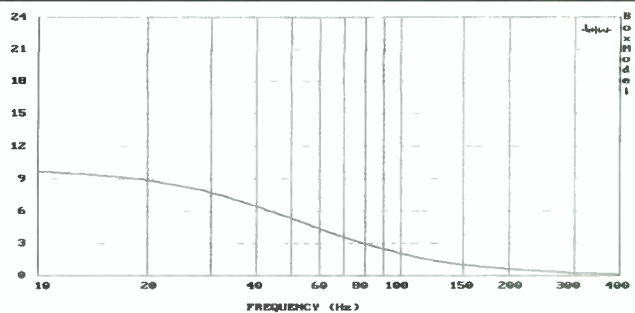
**SUBWOOFER**

For the subwoofer, many drivers would do, mainly because of the low cutoff frequency and the servo principle. Initially, I looked for those with high power handling and long cone excursion, which are necessary for servo-sub use. I first went to my local retailer and tentatively selected Audax, NHT, and Focal models. They met the requirements, but were quite expensive, and one day I saw a Madisound advertisement in *SB* that impressed me with its low prices and fairly smooth frequency responses.

From the available Madisound drivers, I selected the 10207DVC for the following reasons:

- It has a low  $f_s$  of 18.6Hz, which is appropriate for a servo configuration (high  $f_s$ /high  $Q_{ts}$  drivers designed for bass-reflex loading cause phase problems in the feedback loop);
- Despite this low  $f_s$ , the efficiency is quite good (92dB/1W @ 1m);
- It provides a 10mm peak-to-peak excursion, which is not awesome, but quite good.

I made some simulations using Boxmodel. To obtain more than 110dB SPL, I needed to have two 10207DVCs per box; the advantage of the low  $V_{as}$  is that a "small" box



**FIGURE 3:** Group delay of the 10207DVC.

of 2.5ft<sup>3</sup> provides a completely aperiodic response with limited phase shift, ideal for the closed-loop servo (*Figs. 1 and 2*).

The parallel compound is able to produce roughly 112dB SPL in the 50–100Hz band at the power limit of 200W (both coils driven), and since most records contain these low frequencies recorded equally loudly on both channels, I should have 2 or 3 more dB in the room—or about 115dB. Similarly, these drivers will deliver 98dB @ 20Hz. This is sufficient for realistic reproduction of most music, except perhaps the *1812 Overture* or other famous cone killers.

*Figure 3* shows that the excursion limit is reached at 50Hz (at full power); below this limit, you prevent cone bottoming either by electronic means or by turning down the volume.

Considering the \$50 price of the 10207, all these performances are more than good. Strengthening the bass is possible in this system by using very long-throw drivers such as the NHT 1259, or larger speakers (18"), but I was unable to find a better performance/price ratio.

**LOW-MIDRANGE**

Qualities for the low-mid are that it must go low enough to accommodate the 100Hz crossing with the sub, dictated by the servo possibilities, and provide a smooth transition at the upper frequencies as well as sufficient efficiency. The choices that I considered were the Audax HM170X2, the Dynaudio 17W75, the

**TABLE 1**

**SYSTEM BUDGET (US DOLLARS)**

Drivers	Projected	Actual
Sub	250	250
Low midrange	200	340
Midrange	300	350
Tweeter	300	600
Wood, etc	100	100
Amplifiers	450	430
Servo	150	400
SMPS	1000	1000
Filter	200	200
<b>Total</b>	<b>2950</b>	<b>3670</b>

**BUDGET**

The Force is expensive (*see Table 1*), but considering what is commercially available for \$3,500, I believe it is a bargain. Good tweeters are very expensive, and the servo also proved much more costly than expected because of sensors, not drivers. Nevertheless,

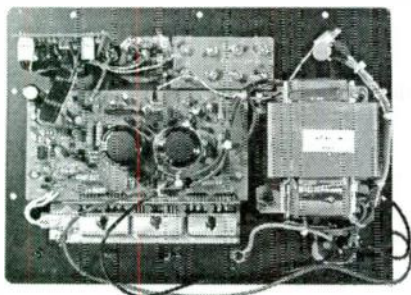


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Specifications for KG-5150 Subwoofer Amplifier	
Power output @ 8 ohms / 4 ohms	150W / 200W
THD	0.025%
S/N ratio @ rated power	95dB
Input sensitivity @ 100Hz - low level	150mV
Input sensitivity @ 100Hz - high level	2V
Input impedance	22k ohms
Auto on sensitivity	5.8 mV
Time for Auto Off	8 minutes
Weight	10.5 lbs
Dimensions W x H inches	11 <sup>7</sup> / <sub>16</sub> x 8 <sup>1</sup> / <sub>4</sub>
Cutout hole W x H inches	10 <sup>7</sup> / <sub>16</sub> x 7 <sup>1</sup> / <sub>4</sub>
Price Each	\$169.00

Woofer Suggestions					
Item	Size	Ft <sup>3</sup>	S/V	F <sub>3</sub>	W
Madisound 1252DVC	12"	3.5	S	30	75
Madisound Swan 305	12"	4.25	V	28	200
Eclipse W1238R	12"	3	V	28	200
Peerless 831727	10"	2.25	V	30	220
Peerless 850146	10"	3.1	V	27	220
Peerless 831857	12"	6	V	24	220
Scan-speak 21W/8555	8"	1.8	V	31	100
Scan-speak 25W/8565	10"	3	S	34	100
Scan-speak 25W/8565-01	10"	3.5	S	28	100
NHT1259	12"	3.5	S	29	300
Vifa M26WR09-08	10"	2.2	V	35	130
Dynaudio 30W100	12"	5.5	S	30	130
Dynaudio 30W100XL	12"	4.5	S	37	130



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## BASIC LISTENING VALUES

This section sums up what the system is supposed to reproduce best according to *my* taste; it is quite personal, of course, but I will try to indicate some rationale behind each characteristic in the following table:

### Design Behavior of the Final System

### Comments

#### Priority 1.

Provide transparent reproduction of the midrange, especially human voices, and, more generally, provide a convincing tonal balance on the whole audio band.

In my opinion, this is a basic requirement for any system, in the sense that if it is not satisfied, you will quickly become bored unless you restrict yourself to ambient music or pink noise (more or less the same, at least for measurements). I think this feature is the main reason for the commercial success of electrostatics, and I must admit that the use of the Orpheus certainly influenced the priority ranking for this criterion.

#### Priority 2.

Satisfy the dynamic range of the CD.

To my ear, dynamics are what make music alive (I listen to Boccherini, but also to the Foo Fighters) and provide a considerable masking effect on other flaws. The important fact is that dynamic ability must be consistent throughout the reproduced band. (The lack of this is one reason small monitors that don't distort much in the highs may become harsh and unbalanced on loud passages—compression on woofer and tweeter is not the same.)

#### Priority 3.

Possess high-quality bass below 100Hz.

This is a principal requirement for *any* kind of music, but—contrary to what is often said and written—more for chamber music and a cappella singing than for rock. Rock bass contains very high harmonics content, often greater than the fundamental, and low-level details are masked by the high average level, whereas in chamber music or jazz, ambience stems mostly from low-frequency information. Good-quality bass means punchy, and subjectively “fast.”

#### Priority 4.

Provide adequate stereo imaging.

Need be only adequate, not “pinpoint” or “3D.” In my opinion, imaging is intrinsically poor with stereo (apart from some binaural recordings), and “pinpoint” listening or mixing artifacts is not one of my main objectives. I will probably rank this factor higher when a true five-channel audio standard exists. It's so sad to see the commercial boom of home theater, with its ridiculous explosions, whams, and 3D whooshes.

## TECHNICAL SOLUTIONS AND CHOICES

According to the main guidelines for the design, I then translate the above requirements into the following technical possibilities.

Requirement	Possible solutions	Comments
Transparent midrange	Electrostatics	Top-quality midrange and low price for DIY, but does not satisfy the dynamic-ability requirement; difficult to match with a low-frequency driver; very sensitive to room placement. <b>Rejected.</b>
	Ribbons	They were the basis of my previous system; same flaws as electrostatics, when considering midrange (nevertheless, there are some very good ribbon tweeters). <b>Rejected.</b>
	Wideband cone midranges	Transparency in the midrange is difficult to achieve with crossovers in the phone band (500Hz–4kHz); wideband is a must, easily achieved by electrostatics and ribbons, not so easily by conventional drivers. Nevertheless, cone midranges are best suited for good dynamics. <b>Selected.</b>
	Wideband dome midranges	Generally more transparent than cone midranges, with smoother transition band and thus easier filtering; dynamics are usually not as high. <b>Selected.</b>
	Horns	Super dynamics, low distortion due to high efficiency, but very difficult to construct, exceeding my woodworking skills; difficult to match with other drivers. <b>Rejected.</b>

Morel MW 166, the Peerless 832732, and the SEAS P17REX.

I discarded some other very high-quality models from Scan-Speak and Eton because of their high price. Thanks to my friendly local retailer, I was able to borrow one of each of my selections for testing. I made two kind of tests: first, a frequency-response test at various angles with an IEC baffle, and second, a listening test that may be contrary to good engineering practices, but which I have used with success in the past.

For the listening test, I mount the driver in a 0.35ft<sup>3</sup> test box fitted with an Audax TW010F1 tweeter, and listen to music immediately after connecting the driver through a first-order low-pass filter and variable attenuator for the tweeter. Certainly, the load-

ing is not optimized, nor is the interaction with the tweeter, and the sound is awful, but its “awfulness” varies with the selected driver, and enables me more or less to predict the sound in a more elaborate configuration.

The frequency response measurements indicated that the Dynaudio, the Morel, and the SEAS (Figs. 4 and 5) had very smooth response, with a softer rolloff, especially at an angle, for the Morel and the SEAS. The listening

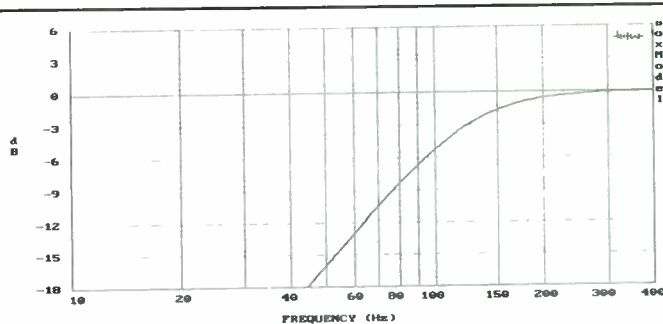


FIGURE 4: Response of P17REX.

tests slightly favored the Dynaudio and the SEAS.

Considering the price difference, I decided on the SEAS P17REX, which was also

Good wideband tonal balance	Single very wide-band driver (e.g., Lowther)	Efficient, simple and low cost, but incompatible with high dynamics and clean bass. <b>Rejected.</b>
	Multiway system, with careful matching of drivers by proper selection and advanced filtering	No other magical solution; decision to be made later on the number of ways and type of filtering. <b>Selected.</b>
Good dynamics, low-frequency section	Horns	Same as above for midrange; moreover, a horn is huge at these frequencies, and I don't desire a divorce. <b>Rejected.</b>
Good dynamics, mid-high frequency section	Proper choice of driver and the number thereof	Proper choice means dealing with the trade-off of efficiency versus linearity, which can be partially overcome by multiplicity of moderate-efficiency drivers. Price is also a concern. <b>Selected.</b>
Good dynamics, playing loudly	No clipping or severe distortion should occur for 110dB continuous playback level	Has consequences as to the choice of drivers (number, efficiency, power handling) and the associated electronics. <b>Selected.</b>
High quality bass below 100Hz	Closed box	Never sounds punchy enough to my ears, while I agree that they measure optimally on step response. <b>Rejected.</b>
	Ported box	Sound generally clean and fast when properly tuned. Possible, but they must be quite big to reach 20Hz (SAF), and may be sensitive to room placement. <b>Rejected.</b>
	Bandpass ported box	Possible, <sup>1</sup> but filtering is done acoustically and is not easily adjusted for matching the other drivers (high-frequency cutoff, slope). <b>Rejected.</b>
	TL	Best bass sound in my opinion, but they have to be big to reach 20Hz. <b>Selected</b> for further investigation.
	Servo closed box	May sound excellent, depending on the servo loop quality; easy to construct and requires only moderate-quality drivers for good results (except for large moving-coil peak excursion). <b>Selected</b> for further investigation.
Adequate stereo imaging	Single wideband driver or small two-ways	OK for imaging, but outsiders for bass reproduction. <b>Rejected.</b>
	Three-ways and more, one driver per way or D'Appolito configuration	More difficult to design, depending on phase response of the drivers and associated filter, but also on room influence. Moreover, not so original. <b>Rejected</b> for largely nontechnical reasons.
	Three-ways and more, line source drivers	They release some of the design constraints of traditional 3-ways (see Witham articles <sup>2</sup> concerning focusing arrays and 64-channel line sources). Compliant with the dynamics requirement (more drivers). Some limitation from room influence due to vertical beaming effect. <b>Selected</b> , despite their narrow "sweet spot." More on this at the end of the article.

So far, I have selected a 3- or 4-way system with a closed-servo or ported-box bass section, domes or cones in the midrange, and a line-source topology. But there are still some missing items and open questions.

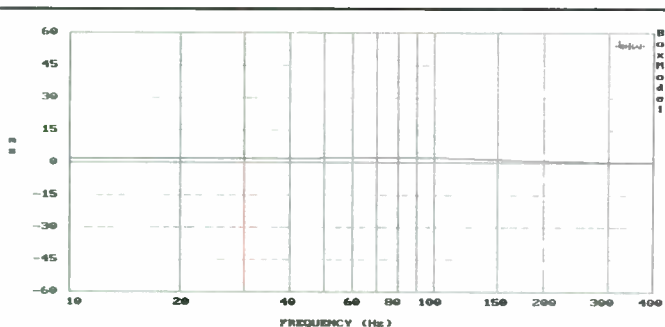


FIGURE 5: Group delay of P17REX.

more efficient (1.8dB). A single P17REX will achieve 108dB at a maximum electrical input of 70W. To obtain 115dB, I had to use four drivers per enclosure, which

heavy filtering in this critical area, for it has proven in my previous trials to cause veiled and unnatural sound rendition;

- Low distortion, which is critical in this

is also consistent with the line-source topology.

#### MIDRANGE

Very critical, indeed! My criteria for midrange choices were:

- Very smooth in-band frequency response and rolloff; I didn't wish to put

band, because harmonics fall in the maximum sensitivity region of the ear, and because 80% of the typical musical power is contained in this band;

- Low  $f_s$  to allow low cutoff, and highest possible cutoff at the other end.

I also made listening tests, with the previously selected P17REXs mounted in their optimal enclosure (0.14ft<sup>3</sup>), the same tweeter, and simple first-order crossovers. I made the following list of possible candidates: the Audax HM100X0 (cone); the Dynaudio D52 (dome); the Eton 4-203 (cone; not analyzed because I couldn't get one for the tests); the LPG50FA (dome); the Morel MDM75 (dome); and the SEAS 10 FM (cone).

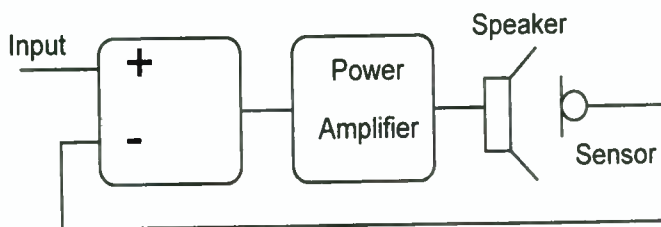


FIGURE 6: Basic acceleration loop.

I rejected the Scan-Speak 13Mxx and Ceratech C2-77 because of their price. None of the cone drivers were able to reach the level of transparency of any of the domes. This was so obvious, especially when comparing the sound with the Orpheus headphones, that I did not make any additional measurements. Of the domes, the Morel did not measure as smoothly on the IEC baffle as the manufacturer's specs indicated, and I finally chose the LPG50FA, since it was cheaper than the Dynaudio.

As to power output, the LPG was specified as 90dB SPL/1W/1m and measured 89, with a rated 100W maximum power. This leads to 119dB with a single driver, but keeping the low distortion figures (-45dB midband) given for 1W implied a practical power limitation of 15-20W. This led to five drivers per enclosure, which is OK for a line source.

TABLE 2

SYSTEM-A DATA OF BOXMODEL SIMULATION FOR P17REX

DRIVER	BOX
Mfr: SEAS	Kind: closed
Mdl: P17REX	$V_B = 5.00$ ltr
$f_s = 39.0$ Hz	$Q_{tc} = 0.711$
$V_{as} = 23.0$ ltr	$f_c = 124.56$ Hz
$Q_{es} = 0.350$	$Q_{as} = 10.0$
$Q_{ms} = 1.400$	$Q_{ts} = 50.0$
$R_e = 6.10$ Ω	$t_{mp} = 20.0^\circ$ C
$S_d = 130.0$ cm <sup>2</sup>	$b_{pr} = 751.0$ mm
$P_e = 60.0$	
$x_{mx} = 3.000$ mm	
$t_{mp} = 20.0^\circ$ C	
$b_{pr} = 751.0$ mm	

TWEETER

Tweeter distortion is less critical, especially when crossed above 5kHz, but compression is a concern (so many tweeters have ridiculous power-handling ability, sounding harsh and metallic). Smooth response and low  $f_s$  for easy blending with the midrange was a must.

On this simple basis, it became obvious that a good tweeter is a very expensive one; after a quick paper inquiry and also remembering some commercial speakers I'd heard,

I selected the following tweeters: the Ceratech C2 44; the Dynaudio D260; and the Scan-Speak D2905.

Then I proceeded to perform only listening tests, because I had been misled in the past with tweeters that measure OK but sound terrible.

I returned to my nonscientific test jig, replacing the cheap Audax with these units. The Ceratech was silky and perhaps the most transparent, but lacked the authority of the other two. The Scan-Speak had less impact than the Dynaudio, but sounded warmer. Nevertheless, I had the opportunity to get a second-hand Dynaudio at a lower price than a new one, so this was my final decision.

A single D260 can play at 120dB SPL peak without significant distortion, and a single unit can fit the needs of the Force system. Nevertheless, I decided to put three of them into each enclosure in order to satisfy the line-source principal.

It is clear that a "pure" line source with minimal interdriver distance (at least compared to the highest reproduced wavelength) would require maybe 15 LPG50s and 15 D260s, but this was clearly beyond my means.

DESIGN PROCESS

I began with the servo sub, which you can design independently of the rest, considering the low frequency cutoff and consequent

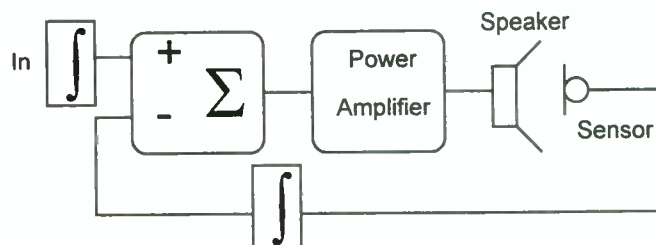


FIGURE 7: The speed loop.

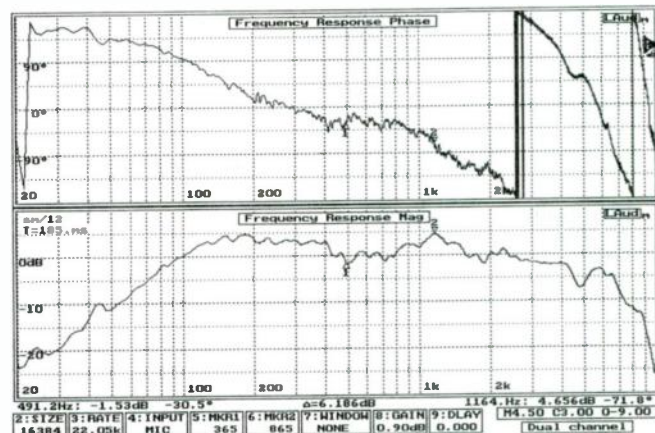


FIGURE 8: Response of P17REX in glass bowl, uncorrected.

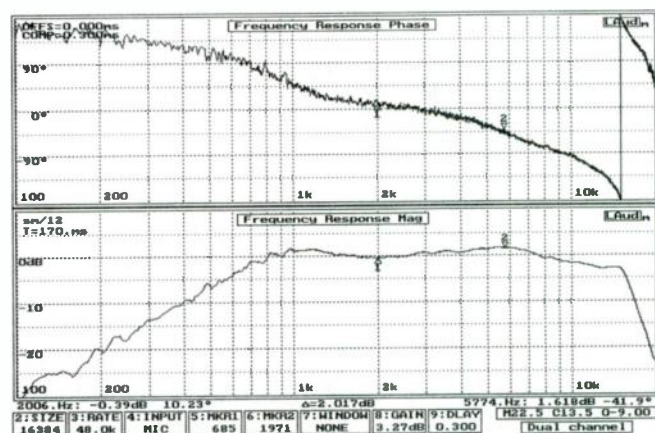


FIGURE 9: Response of LPG50 on test baffle, uncorrected.

flexibility for upper crossing. The principle of a feedback loop should be known to most of you, since it has been detailed by Mortensen<sup>3</sup>, but I will sum it up briefly. When a driver is operating in its so-called "piston" range, it delivers a sound power proportional to the cone acceleration. Hence, a feedback loop measuring this acceleration following an input signal is able to correct any anomaly in the driver behavior (i.e., distortion), and will also widen the usable band on the lower end (at the expense of considerable power injection and cone excursion, which limits the possibilities of such a device).

In practice, things are not so easy. Drivers are electromechanical devices, featuring

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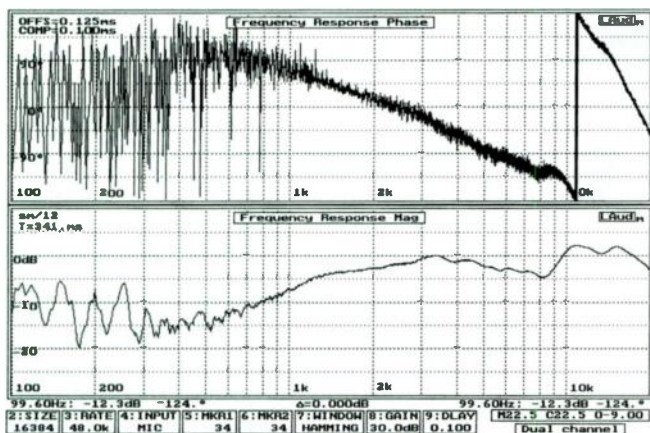


FIGURE 10: Response of D260 on test baffle, uncorrected.

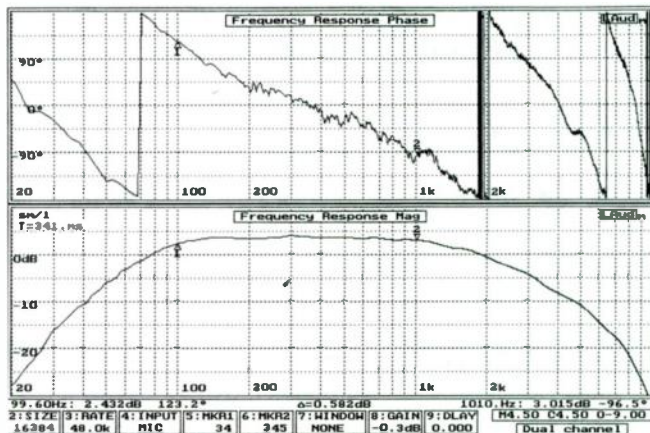


FIGURE 11: P17REX response with gyrator correction without filters.

nonminimum phase behavior. This leads to stability problems in the feedback loop, which you can avoid only by limiting the overall gain of the open loop and by careful phase compensation. (By the way, this means that any servo is designed for a given speaker, so its replacement by another woofer is very likely to cause destroyed cones and blown voice coils.)

In the Force, the low  $f_s$  of the 10207 gives desirable smooth-phase behavior; nevertheless, adjusting the loop parameters was not an easy task. For the basic theoretical accel-

eration loop (Fig. 6), I substituted a speed loop (Fig. 7), which gives the same theoretical result, since the same integration function is applied to input and sensor signals. Nevertheless, this enables you to improve loop behavior at high frequencies, and especially avoids instabilities due to high-frequency cone modes, and to the distance between the sensor and the cone, if any.

#### SENSOR CHOICE

First, I tried some piezo accelerometers, which work fine and provide zero delay to

the cone movement, but I was deceived by the resulting distortion measurements (more than 10% @ 40Hz/100dB SPL). Then I made some attempts with optics, but ensuring good linearity with high excursions is also difficult. I then chose a mike sensor, whose main limitations are SPL limit and time delay introduced in the loop. The SPL delay is not as bad as it might seem at first glance, since the  $1/r^2$  attenuation law applies only for far-field propagation. At one inch from the cone, the sound pressure is hopefully not 10,000 times greater than at one meter—just 20–30 times.

My first attempt was with an electret mike (the one used in the Mitey Mike), but even with the addition of a source resistor as specified in the Mitey Mike, distortion was still 5% @ 40Hz/100dB SPL. The (expensive) solution was the replacement of the electret by a Shure Beta 57, specially designed for high levels and low frequencies. I achieved 1.5% distortion and was happy with that.

#### INITIAL DRIVER MEASUREMENTS

Once the servo was done, I temporarily connected it to my old system to have the pleasure of rattling the windows, and also to allow long-term break-in and eventual retuning.

The next step was to measure the other drivers to see whether my samples were consistent with the manufacturer's specifications and to check deviation from sample to sample. To do this, I used an IEC baffle for the midrange and tweeter, which don't need any rear loading, so it's merely a matter of making a hole with a saber saw and plugging the device. The P17REX, however, needed some loading; at this point, I decided to use what would be their final enclosure.

I had read<sup>4</sup> that spherical enclosures are immune to midfrequency ripple due to internal standing waves, and I had a Pyrex semi-spherical cooking bowl, 9" in diameter, with

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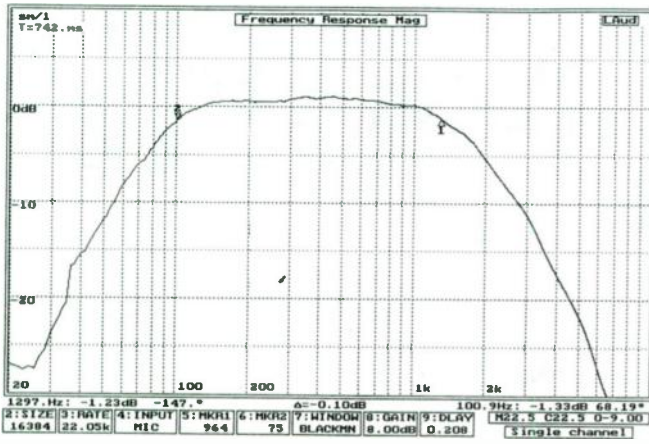


FIGURE 12: P17REX response with gyrator correction with filters.

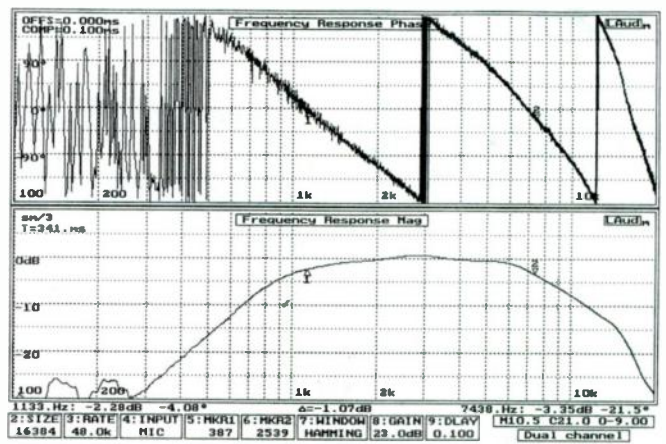


FIGURE 13: LPG50 response with gyrator correction and filters.

an internal volume of  $0.177\text{ft}^3$ . I used Box-model to define the response of the P17REX in such an enclosure (Fig. 8), and it gave an almost perfect result, a smooth response without overshoot and a very constant propagation delay. I decided to use the bowls.

The measurements of the LPG50 and D260 are shown in Figs. 9 and 10. For all measurements, I used Liberty Audiosuite v2 with a calibrated Mitey Mike.

The curves are the means of all samples for each type of driver. I measured each one

individually, exported the data to ASCII files and wrote a small Basic program to calculate the mean for each data point. I did this to make filter calculations on the "average" driver, providing some adjustment potentiometers where necessary for individual tuning.

### D260 PROBLEMS

I was deceived by the D260's measurements, but a quick verification made with a brand new sample with the same test setup confirmed the reason why mine were bargains:

they are affected by a 5dB dip at 8kHz and a roll-off after 15kHz. This was consistent within  $\pm 2\text{dB}$  in all the samples, which suggests a production problem rather than accidental damage (I'm not sure, however, because Dynaudio drivers are usually manufactured to a very high standard and individually checked).

Nevertheless, considering the \$600 price of six new units, and the fact that the 8kHz dip could be the beginning of the final filter, I decided to keep them. This means that the tweeter filter section discussed later should be modified in cases of "normal" D260s.

On the other hand, the LPG50s measured wonderfully! All ten samples were within a  $\pm 1.5\text{dB}$  margin from 1–10kHz. Such repeatability is very rare in drivers. The only anomalies were a broad 1dB dip centered on 2kHz and a broad 1.5dB bump centered on 5.5kHz. The most critical part of the system was safe.

The overall frequency response of the P17REX (Fig. 11) was quite in accordance with Boxmodel predictions, but my spherical enclosure proved to cause more standing-wave problems than expected (probably because the bottom of the bowl is flat and not spherical). The consequence is a 5dB dip centered at 500Hz.

### FILTER DESIGN

My initial idea was to use second-order Linkwitz-Riley filters (technical reasons for that are indicated in Dickason's work<sup>5</sup>, and I personally prefer the sound of even-order LRs to the third-order Butterworth or Bessel filters commonly used in D'Appolito configurations). The usable band of the various drivers was sufficient for this (but not for the first-order Butterworth loved by many audiophiles), but I wished to correct irregularities in the passband.

After some trials with modified LRs, they became so modified that they were no

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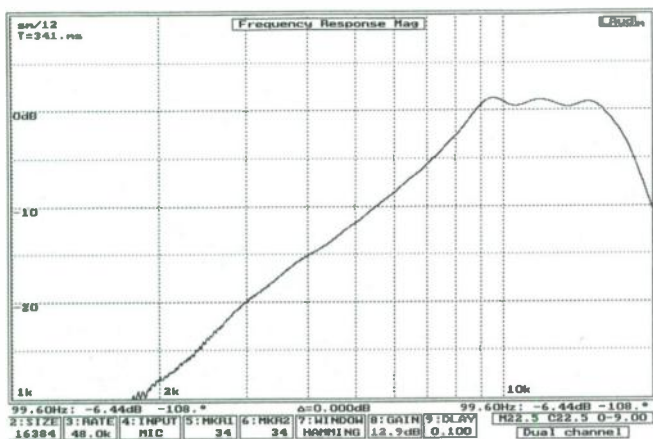


FIGURE 14: D260 response corrected with filters.

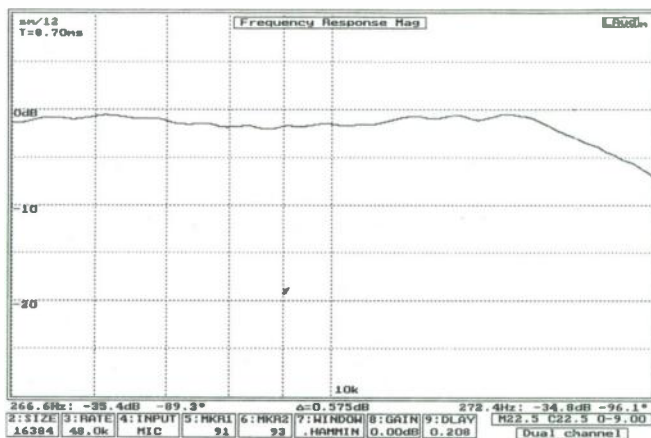


FIGURE 15: D260 response with 1m response combined with LPG50.

longer LRs or Butterworths or anything else, and I had phase problems with inadequate removal of bumps and dips.

I then remembered the use of LCR traps in passive crossovers to correct such irregularities, so I attempted a transposition of passive LCRs into electronic gyrators (simulated inductors). This proved to be much more efficient than my first approach, and I designed gyrator correctors for each driver, striving to achieve an almost perfect driver before adding LR filter sections.

You see the result of this correction for the P17REX in Fig. 12. You can achieve perfect regularity within 1dB, thereby demonstrating the efficiency of the process. The midrange and tweeter corrected responses are shown in Figs. 13, 14, and 15. (These plots also include the LR filters.)

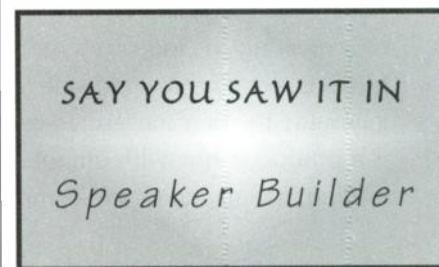
#### CROSSOVER FREQUENCIES

I wound up with virtually ideal drivers, but then needed to decide the values of the crossover frequencies. I based my choices

on rather straightforward considerations, first making an attempt, and adjusting if necessary. In fact, my first selection proved correct and remained unchanged:

- The 0.177ft<sup>3</sup> enclosure of the P17REX dictated the 125Hz crossover with the sub;
- You cannot cross the LPG50 lower than 1.5kHz; its  $f_s$  is 800Hz, and the distortion curves given by LPG begin to rise under 1.5kHz; I wished to cross it as low as possible, and there was no problem in this area with the P17REX, so I went for a 1.5kHz value;
- The Dynaudios had their rolloff problems, and so was born the 7.5kHz high crossover point.

Such a selection process may seem very frivolous to serious designers, but again, it proved satisfactory, despite Murphy's law. In Part 2, I'll continue with driver placement, the electronics involved, and construction details.



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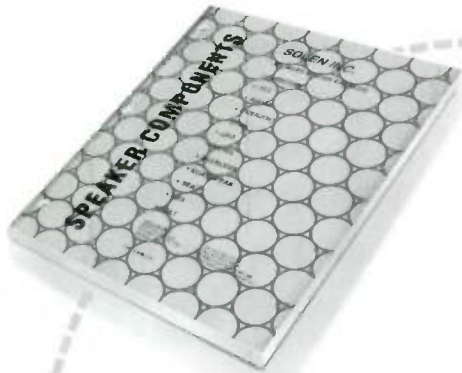
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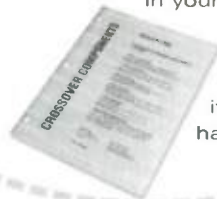
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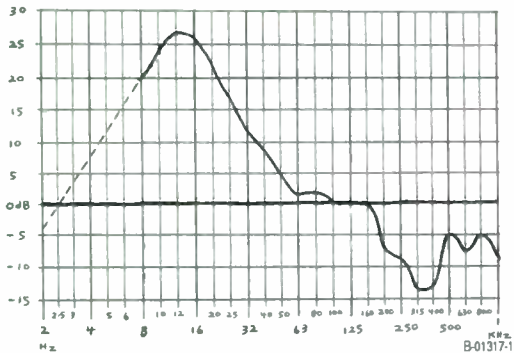
# REAL BACKSEAT BASS

By Dennis Colin

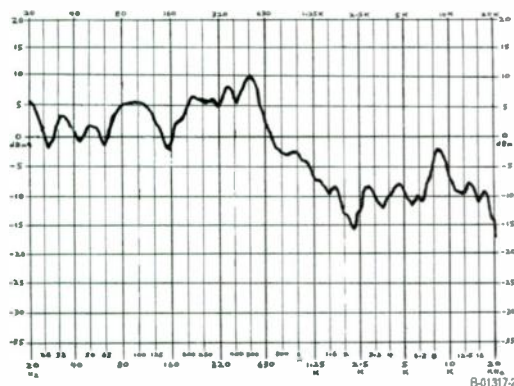
If your vehicle's backseat has a floor woofer boxes this article describes can add truly high-fidelity bass to your mobile sound, without the boomy resonance of trunk installations.

## CABIN FEVER

Anyone can get 12Hz response in a car. *Figure 1* shows the "cabin gain" (a car's low-frequency "room" gain) of my mid-size sedan. (This is the difference between a woofer's response in the car and close-miked in a large room.) Relative to free-air response, the small enclosed space makes frequencies below about 60Hz appear as an almost DC-coupled uniform pressure load



**FIGURE 1:** Car cabin gain; woofer on rear floor and mike at driver's ear position, versus same woofer closed-miked in room.



**FIGURE 2:** Trunk subs (Soundstream reference 10s in 1ft<sup>3</sup> sealed boxes) plus rear-deck 6 × 9s (Soundstream Pro-B69).

on a sealed-box woofer, since the longest interior dimension is shorter than a half-wavelength. Sound pressure below 60Hz is then proportional to cone excursion, rather than acceleration (as in free space).

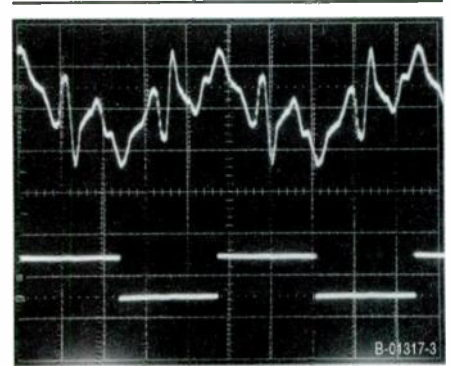
The result is a 12dB/octave rise below 60Hz, down to 12Hz in my car. (LF cutoff is determined by air leaks; if both car and woofer enclosure were air-tight, the response would extend to DC!) Connecting a battery to the woofer would cause sustained cone excursion, resulting in sustained cabin air-pressure change. So a small sealed box ( $f_3$  of 60Hz) is compensated down to 12Hz or so, making for ease in reproducing sub-sonic bass.

## NOT SO FAST

You say you would also like smooth bass response? Well, then, this leaves out most car "sub installs" (in English, woofer installations). I had installed such a system in my '94 Dodge Intrepid, along with rear-deck mid/hi units, but was very dissatisfied. The components were good—Soundstream Reference 10s in 1ft<sup>3</sup> sealed boxes, with first-order crossover (CO) to Soundstream PRO-B69 6 × 9 mid/high units in the rear deck. The drivers were probably  $\pm 3$ dB flat over their ranges; in a store-room audition, they sounded very good.

Now look at *Fig. 2*, the response at the driver's ear location (using the Mitey Mike capsule,  $\pm 2$ dB, 10Hz–20kHz, 1/6 octave smoothing, and true-RMS detector). The horrendous 25dB drop from 600Hz to 2kHz, and the 7dB peak at 9kHz, were probably due to the "horn" loading of the rear-deck 6 × 9 location. Naturally, the perceived sound balance was lousy (I can't think of a better word that's fit to print).

But my biggest complaint was poor bass clarity—sometimes an octave drop from E2 to E1 (82Hz to 41Hz) on an electric bass guitar would be inaudible! And all bass transients (strings, drums) were very



**FIGURE 3:** Trunk/deck, 41Hz squarewave.

blurry, more than you would think from the 6dB pk-pk variations in the curve from 20–320Hz.

*Figure 3* shows why. This was the response to a square wave at 41Hz (bass guitar open E-string frequency). Do you see any semblance of a coherent acoustic pulse here? I don't, nor did I hear any!

*Figure 4* shows the same thing over a longer time, with a 10Hz square wave. Note that the main resonant oscillations



**FIGURE 4:** Trunk/deck, 10Hz squarewave.

## ABOUT THE AUTHOR

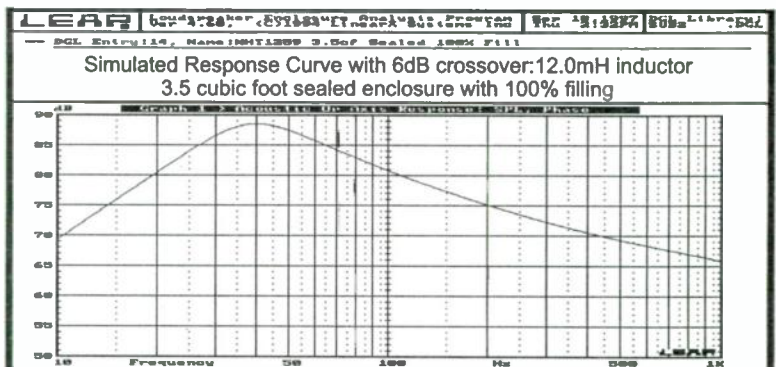
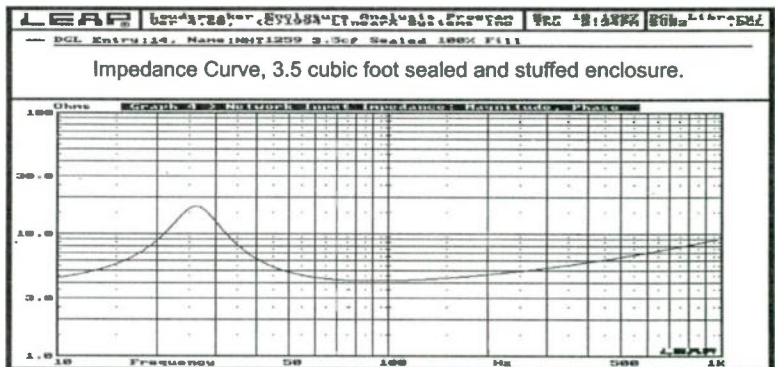
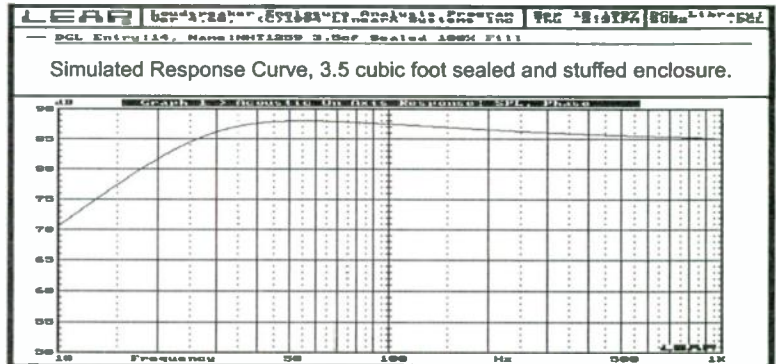
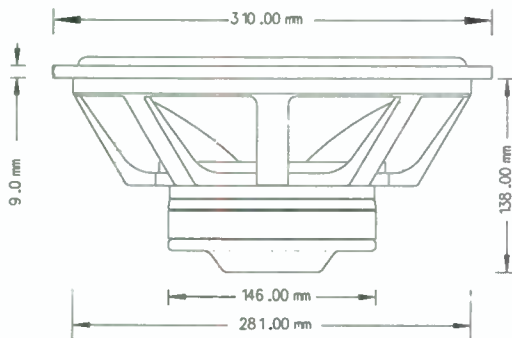
Dennis Colin, an RF engineer by trade, has pursued the perfect speaker dream since childhood, when he enjoyed live symphonies with his father playing the violin and flute. He has been a band keyboard musician, recording engineer, and designer of the (analog) ARP 2600 music synthesizer and a 1kW audio amp for a/d/s/. He published an article on a voltage-controlled filter (*JAES*, 1971), and made a presentation on the audibility of phase distortion (Boston Audio Society, circa 1973). He has also written some articles and a review (*Audax A651*) for *Speaker Builder*.



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Leap Erm	0.772
Leap Exm	0.743
vcL	1.06mH @ 1K
Bl	9.574 Tm
Qms	2.680
Qes	0.533
Qts	0.445
Voice Coil Height	34 mm
Air Gap Height	8 mm
Xmax	13.0 mm Peak
SD	0.0491 m <sup>3</sup>
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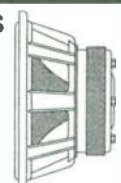
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**PHOTO 1:** Focal 8K5412 in 0.9ft<sup>3</sup> sealed box.

rear floor to be the most ideal spot in my car that could accommodate a 1ft<sup>3</sup> box. (I use a stereo pair of woofers, even though some claim not to hear stereo bass; pity them!)

Photos 1 and 2 show my 0.9ft<sup>3</sup> sealed boxes with Focal 8K5412 8" Kevlar woofers with first-order CO at  $\approx 300\text{Hz}$  to a 20-year-old, mostly functional pair of a/d/s/ 300C units in the rear seat corners.

Figure 5 shows the combined response, both channels driven. Interestingly, the 10dB drop from 300–400Hz is not that noticeable. Besides, the single-channel responses (Fig. 6) show different anomalies, as does Fig. 7, where the drive signals to the two channels are 90° out of phase (simulating typical stereo phase differences).

But the sound is very clear, without audible resonance, and transients—including bass—are very solid and realistic. Note that Fig. 8 shows only a 3dB pk-pk variation from 12–320Hz! By the way, some of the 300–400Hz dip may be due to the lower sensitivity of the a/d/s/ re the Focal. With biamping, the use of a more efficient mid/high unit, or a good front mid/high installation, you could probably get  $\pm 3\text{dB}$  response from 12Hz–20kHz, with good time adjustment facilitated by the close-to-driver woofer location. Bear in mind this is “room” response, at the listener’s ear. Try that in a living room!

About that a/d/s/ 300C: Fig. 9 shows its close-miked and 1M room responses. Note the high-frequency smoothness and its good pulse response (Fig. 10); the square-wave is close to a textbook third-order response (Fig. 11). I’ve used these speakers for 20 years since I purchased them while working at a/d/s/. I have yet to hear more real-sounding instruments from any other car speaker, or almost any home speaker. I don’t work



**PHOTO 2:** Focal and a/d/s/ in car.

for a/d/s/ now, so this is a testimonial, not an ad.

### SOUND OF THE FOCAL and A/D/S/ SYSTEM

Figure 12 shows the 41Hz (low E) square-wave response of the rear floor/seat Focal and a/d/s/ system. There is no comparison to Fig. 3! (Neither does Fig. 13 compare to Fig. 4)

With this system, the bass guitar and drums not only sound real, but you can feel the transients and string vibrations solidly, as you would at a live performance. Absolutely none of the “whumpiness” you hear when trunk-sub rappers go by.

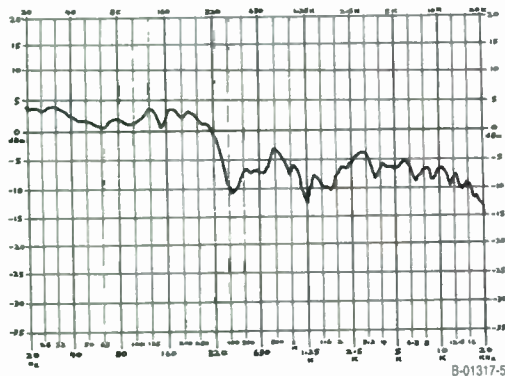
I should mention that my trunk/deck setup can sound nice with some vocals, since its resonance adds a warm “theater” effect. But because I must have my reproduced tonality sound natural, I now use only the floor/seat system (plus a/d/s/ front-door speakers). Believe me, if you like bass, once you hear it reproduced with  $\pm 1.5\text{dB}$  flatness and timing accuracy down to 12Hz, there’s no turning back.

Two cautions about this system: First, if you use the rear-seat location for mid/high

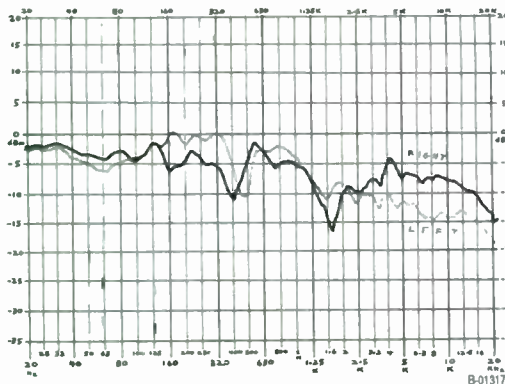
lasted about 15ms, corresponding to about 16 feet of equivalent acoustic smearing.

### THE SIMPLE FIX

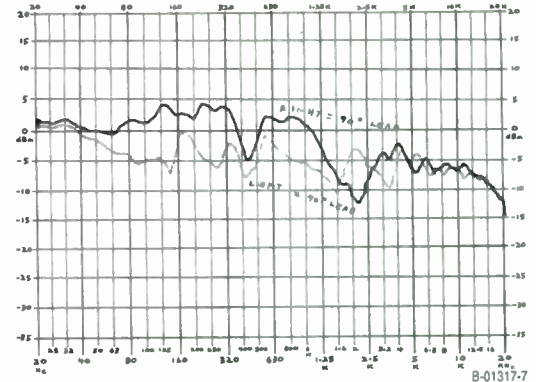
The three most important criteria for woofer success are the same as in real estate: location, location, location! Well, I found the



**FIGURE 5:** Focal 8K5412 (0.9ft<sup>3</sup> sealed box) on rear floor, plus a/d/s/ 300C on rear seat, both channels driven, mike at driver’s ear location.



**FIGURE 6:** Focal and a/d/s/, separate channels.



**FIGURE 7:** Focal and a/d/s/, both channels driven, 90° phase difference between drive signals.



# Swans M2 kit



The Swans M2 is a floorstanding model that features several technological achievements and sound quality distinctions.

The speaker system is a two-way bass-reflex design with MTM driver configuration. The front baffle is very narrow with rounded edges to reduce cabinet diffraction for better clarity and imaging. The internal panels and corner reinforcement bars substantially suppress unwanted cabinet vibrations. The bottom part of the cabinet is sealed and can be filled with sand or lead shot for better stability and further performance improvement. A port is mounted on the rear panel.

The drivers used in the Swans M2 represent a new high performance design from Hi-Vi Research. The 5-inch paper/Kevlar cone bass-midrange has a rubber surround, cast aluminum frame and a magnetically shielded motor system. This driver utilizes a central phase plug to avoid air compression, improving frequency response and dispersion. The extremely rigid cone is hand coated with a special dampening compound to further maximize its performance. The cone is coupled to a selected grade rubber surround, this provides break-up free operation and very low distortion even at high power levels. These key features

greatly contribute to the Swans M2's clear transparent sound and effortless dynamic performance. Swans M2 delivers amazing bass without running in "doubling" or Doppler distortion problems.

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

The vibrating element of the tweeter is almost weightless in comparison to a conventional dome driver. This unit provides an immediate and precise response to any transients in original signal, and gives the Swans M2 an exceptional ability to reveal the true dynamics of instruments with a complex high frequency spectrum.

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

Swans M2 provide very even acoustic power dispersion. The important horizontal early reflections that create spatial impression and add to the overall presentation have the same even spectral balance as the direct sound, these are crucial features of a good loudspeaker.

On the contrary, the vertical dispersion is well controlled in the midrange and high frequency domain in a 15° arc symmetrically to the reference axis. While 15° create adequate room for adjusting a listening position, the floor and ceiling reflections are well down in amplitude. This feature greatly contributes to the clarity of sound and imaging of the system.

Swans M2 kit includes:

- 4x F5 paper/Kevlar bass-midrange drivers,
- 2x RT1C isodynamic tweeters with sealing gaskets,
- 2x dedicated tweeter crossovers,
- 2x dedicated bass-midrange crossovers,
- two ports and two Swans logos,
- two pairs of heavy-duty gold plated terminals.

Cabinets are not included.

For those who are interested in a home theater set up, the instructions and parts for correspondent central channel speaker are available.

The drawings of the cabinet shown here represent general dimensions required for optimum bass performance. Rounded corners are advisable as they improve imaging and clarity. Actual finish and appearance is a matter of personal taste. The system should be installed on adjustable spikes and slightly tilted back to aim tweeter axis at listening position.

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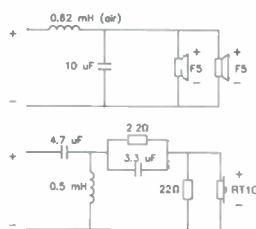
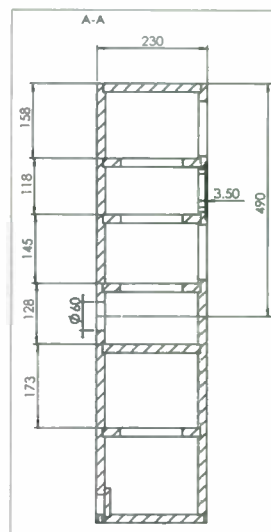
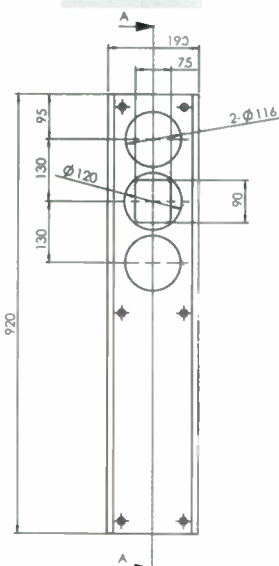
RT1C Tweeter



F5 Bass-midrange



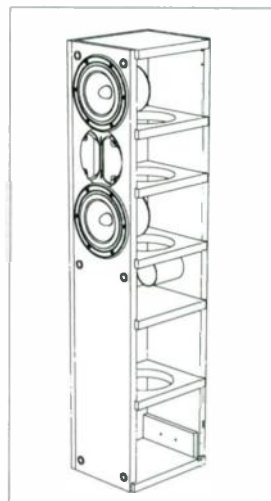
Filter



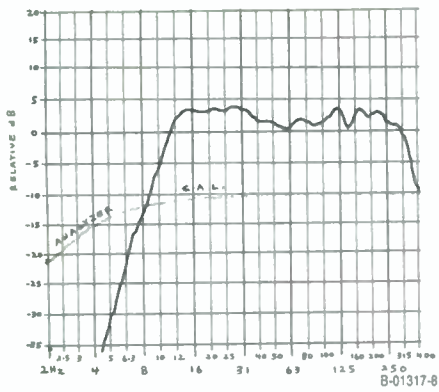
## SPECIFICATIONS

Frequency response	53Hz-20kHz, ±2.5dB (1m, half space)
Sensitivity, 1W/1m (100Hz-8kHz averaged)	87.5 dB
Nominal impedance	4 ohms
Harmonic distortion	THD less than 1%
At 90dB SPL, 100Hz-10kHz, 1m	
Power handling	80W nominal, 150W music
Dimensions, HxWxD (without spikes)	920x190x230 mm 36 1/4x7 1/2x9 inches

Amplifier requirements:  
30W recommended minimum.



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**FIGURE 8:** Low-frequency response: Focal 8K5412 (8") in 0.9ft<sup>3</sup> sealed box, pair on rear floor of 1994 Dodge Intrepid.

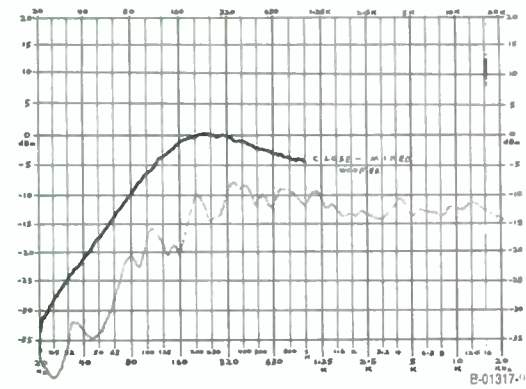
units, fasten them securely with seat belts to prevent them from flying in a panic stop. Second, if you have a conventional autosound system, don't measure its frequency response, and especially not the transient response—you'd probably want to rip it out (unless you like the sound and can ignore the measurements).

### BASS/MID CROSSOVER

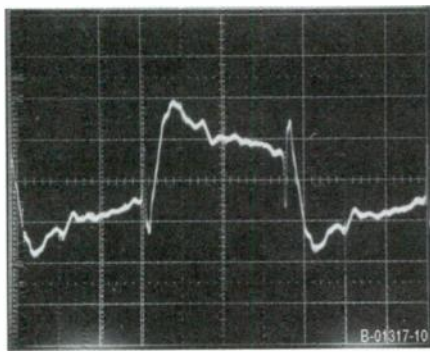
This information is for reference only, since my present system could benefit from further research in flattening the 300-400Hz shelf dip. (Fig. 5).

Figure 14 shows the CO I used; it's true first-order, noninverting. With the woofers closer to the listener than the mid/high units, the usual problem with woofer phase lag (deep CO notch) is eliminated. (The anomalies in Figs. 5-7 vary with position and distance and are not present in free-space, close-miked measurement, so are probably due to car acoustics.)

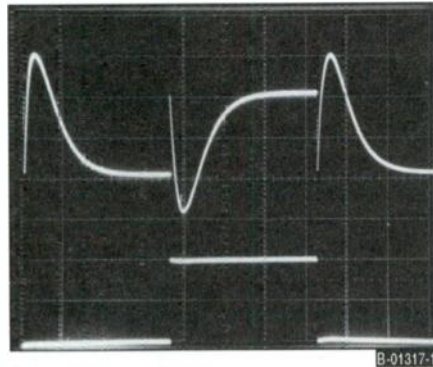
Photo 3 shows the felt I wrapped around the a/d/s/ 5"-cone rear basket to lower its



**FIGURE 9:** a/d/s/ 300C S/N 10867-2. 1m on axis, 2100ft<sup>3</sup> live room, 1/6 octave smoothing, felt damping on woofer rear; changed tweeter CO cap from 6.8μF to 17μF.



**FIGURE 10:** a/d/s/ 300Hz square-wave response.



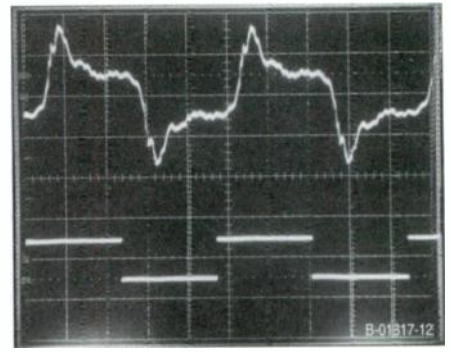
**FIGURE 11:** Ideal third-order CO square-wave response.

100Hz resonance impedance peak through mechanical damping (Fig. 15). Otherwise, the desired simple series (140μF) cap would not attenuate around 100Hz, causing a response peak and excessive excursion. I learned this the hard way; after 12 years of 50W-per-channel pounding without this damping, about 75% of the surround ripped (but the drivers still worked), so I glued them with Dynaudio's Constantly Elastic speaker glue. Now they're almost as good as new.

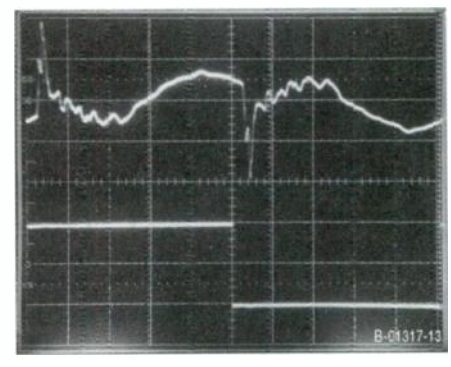
### ASSORTED COMMENTS

1. If you just desire a system that breaks bass-SPL contest records, simply install three 18" woofers in the trunk and power with 900W—some people do! But you probably won't get better-sounding bass than with a simple rear-floor, sealed-box subwoofer.

2. With such smooth, subterranean extended bass, you can add tremendous electronic boost—for loudness compensation or pleasure—without its sounding unpleasantly boomy or resonant. I must admit to using a 12dB/octave electronic rise from 60Hz down to a maximum of 18dB at 20Hz. Much music has a small but present energy



**FIGURE 12:** Focal and a/d/s/, 41Hz square-wave response.

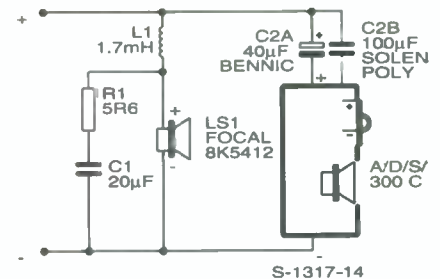


**FIGURE 13:** Focal and a/d/s/, 10Hz square-wave response.

content down to 20Hz. When you hear a response smoothly rising to +18dB at 20Hz, the effect seems to be like the raw, natural, sheer power that you hear and feel in a good live performance, where room gain often results in similar response. Even at moderate reproduced volume, you hear simply amazing bass depth, clarity, and power.

3. I chose the Focal unit because of my great satisfaction with Focal's 10" unit (10V 516J) in a home system (Photo 4), the 8K5412's smooth response (Fig. 16), and its low Q<sub>s</sub>. Note that a Focal 10" is used in the sub for the well-acclaimed Aria speaker.

With a nonphase-inverting first-order CO to the midrange, these drivers in a sealed box reproduce bass with such tonal accuracy and transient-impact solidness that the



**FIGURE 14:** Focal and a/d/s/ crossover.

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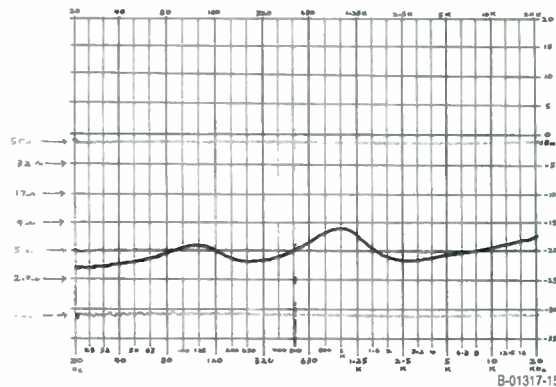


**PHOTO 3:** Felt damping on a/d/s 5" mid/woofer.

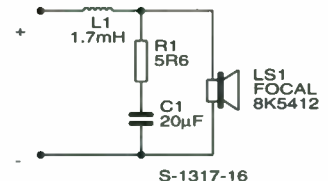
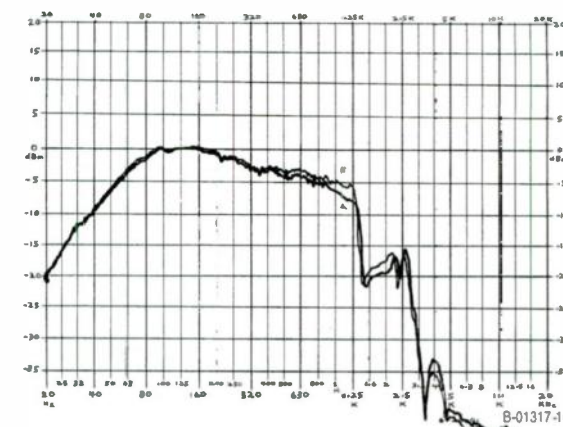
difference from live music is small enough that you don't notice it (unless you've recently heard the real thing).

4. In most vehicles, the best location for bass accuracy (not necessarily power) is near the center of the enclosed space. Due to the small interior dimensions (in comparison to a room), standing-wave augmentation from boundary placement (car trunk) is not only unnecessary for low bass, but rather adds severe mid-bass coloration.

5. Most car-stereo installers recommend that trunk subs face backwards, unlike my setup. I found that this did result in less mid-bass peakiness, but it lowered efficiency about 10dB and didn't reduce the sense of blurring, or time smear. Either way, the improvement with the floor woofers



**FIGURE 15:** Impedance, a/d/s/ 300C, felt damping on woofer rear; tweeter CO cap changed from 6.8µF to 17µF.



**FIGURE 16:** Focal 8K5412 in 0.9ft<sup>3</sup> sealed box, mike 1" on axis, 2100ft<sup>3</sup> live room.

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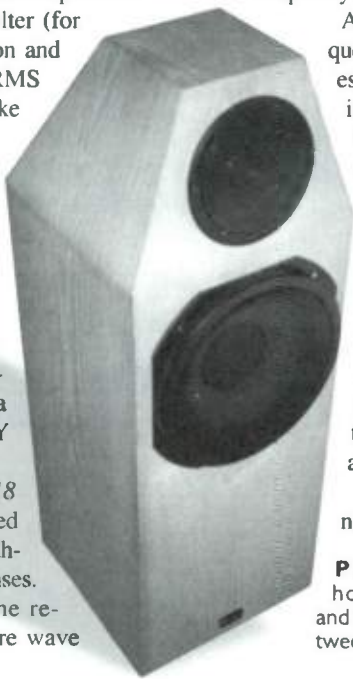
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is more than dramatic; it's like comparing live music to a big garbage can. Of course, I'm sure you've heard many such acoustic garbage trucks roll by, and the type of "music" often played belongs in one.

6. *Photo 5* shows my personally designed audio analyzing equipment, consisting of a low-distortion sine/cosine sweep oscillator, tracking bandpass filter (for ambient-noise suppression and spectral analysis), true-RMS log (dB) detector, and mike preamp using Panasonic WM-60AY capsules (used in Mitey Mike).

For transient responses, I used an HP8116A pulse/function generator, Tektronix 475 oscilloscope, and Tektronix C-4 camera, while for response plots I used a Mosely Model 135 X-Y chart recorder (*Photo 6*).

7. *Figs. 17, 11, and 18* are, respectively, idealized second-, third-, and fourth-order CO transient responses. The upper traces are the responses to a 70Hz square wave

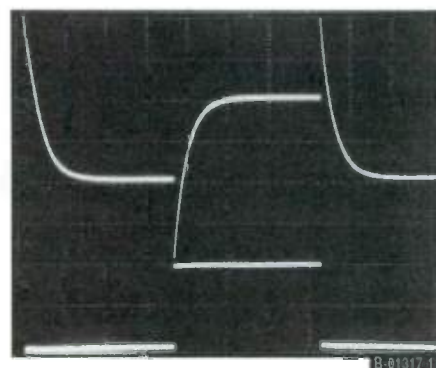


(lower traces) fed through a first-, second-, and third-order all-pass circuit with  $\pm 0.2$ dB amplitude flatness, DC  $-100$ kHz, but with a phase shift of  $0^\circ$  at DC and approaching  $-180^\circ$ ,  $-360^\circ$ , and  $-540^\circ$  at high frequencies. On a log-frequency scale, phase shift is centered at 200Hz, corresponding to the CO frequency being simulated.

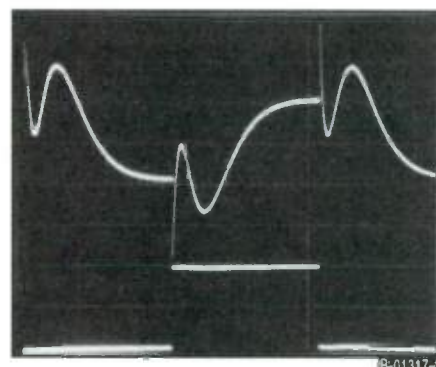
Although the amplitude/frequency spectra of these responses are identical to those of the input square waves  $\pm 0.2$ dB, the sound is not. Time smear (delay of low-frequency components versus high ones) is 1.6, 3.2, and 4.8ms, respectively, whereas in a letter by Dick Crawford regarding my article "Waveform Phase Distortion" (*SB 1/97*), he mentions  $100\mu$ s (0.1ms) as the lowest accepted threshold of phase-dispersion audibility.

This is why I used a true noninverting, first-order CO for

**PHOTO 4:** "Omni-Focus"; home speaker with Focal 10" and bipolar pair of coincident mid/tweeter units.



**FIGURE 17:** Ideal second-order CO square-wave response.



**FIGURE 18:** Ideal fourth-order CO square-wave response.

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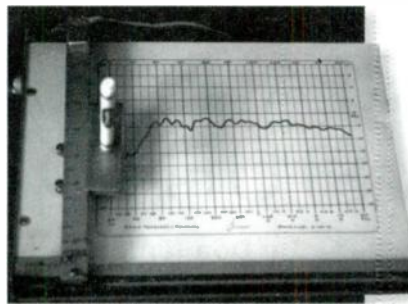
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**PHOTO 5:** Low-distortion sine/cosine sweep oscillator, true-RMS detector, audio filter, and mike preamp.

bass/mid; phase dispersion (time smear) for higher-order COs is inversely proportional to CO frequency. The a/d/s/ unit's mid/high CO is around 3kHz, and is effectively third-



**PHOTO 6:** Mosely X-Y chart recorder.

order (second-order electrical plus acoustic rolloffs). Time smear is therefore only about 200µs, which is inaudible to me when I'm listening to music.

8. *Photo 7* shows the Mitey Mike capsule (Panasonic WM-60AY) positioned near the driver's ear location, within the vehicle.



**PHOTO 7:** Panasonic WM-60AY capsule (used in Mitey Mike II) at driver's ear location.

## ACKNOWLEDGMENT

I would like to give credit to Kelly's Stereo of Laconia, NH, for its excellent construction of my woofer cabinets as well as perfect installation of the head unit (Eclipse) and Soundstream amp. It's only 50W per channel, but that's enough to hear and feel amazing bass clarity to below 20Hz.

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# WHAT'S REALLY HAPPENING IN A STUFFED LINE?

By Don Jenkins

I found it intriguing that John Cockroft's article about the Bailey T-Line in *SB* 1/98 referred to a report discussing the use of a specific filler material to reduce the sonic velocity in an enclosure. My first reaction was that this was an incorrect interpretation of the basic laws of physics, but a review of the referenced article by Bradbury in the *JAES* of April 1976 provided additional information.

In his article, Bradbury develops a theory as to how the fiber loading reduces the effective sonic velocity and provides some details about the way the characteristics of the fiber affect the velocity reduction. In several experiments trying to duplicate the limited test data in the Bradbury article, I came up with

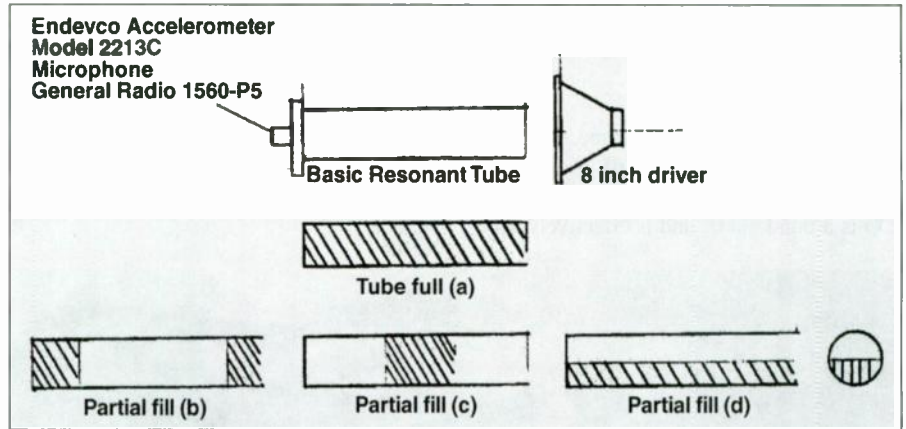


FIGURE 1: The experimental apparatus.

several questions on the actual efficacy of the concept.

## RESONANT TUBES

The experimental apparatus that I used is shown in *Fig. 1*. This was a resonant tube excited by an 8" free-air driver with either an accelerometer or microphone at the closed end to determine the resonant modes. I used two tubes, one 2.5" in diameter and 17" long, and the other 3" in diameter and 29" long. The shorter tube used the accelerometer while the 29" one used the microphone.

*Figure 2* shows the basic resonance characteristic for the 17" tube, while *Fig. 3* shows that for the longer one. The fiber filler used in these tests is a polyester type that you can load to a density between 0.4–0.66 lb/ft<sup>3</sup> and apparently still meet most of the criteria required by Bradbury's theory.

*Figure 4* is a frequency sweep of the small tube fully loaded (*a* in *Fig. 1*), i.e., equal-density loading for the whole volume at 0.66 lb/ft<sup>3</sup>. The resonant point does move to a lower frequency—from free-air resonance of 185Hz to 125Hz. This is not as much of a reduction as Bradbury would predict. His theory would

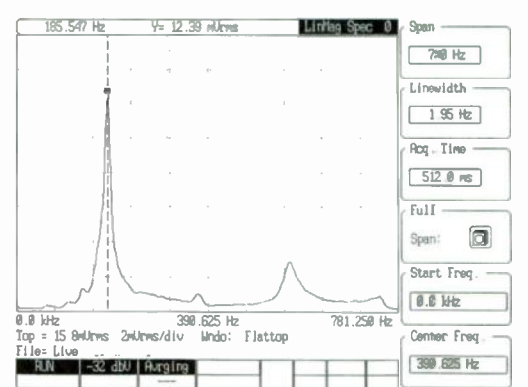


FIGURE 2: Basic resonance characteristic for the 17" tube.

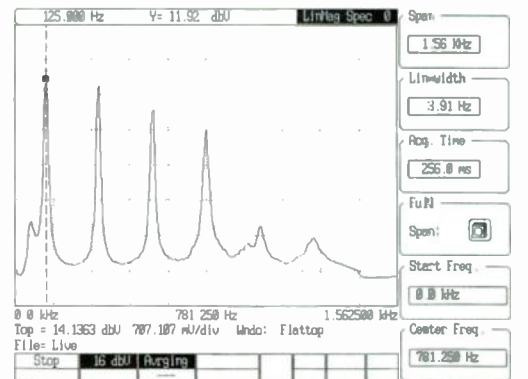


FIGURE 3: Basic resonance characteristic for the 29" tube.

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lower the resonance to about 90Hz.

Figures 5 and 6 show different loadings. Figure 5 (b in Fig. 1) and Fig. 6 (c in Fig. 1) show a split pack, where the plug is about half the volume of the tube at a density of 0.66 lb/ft<sup>3</sup>. Figure 7 is for the filler in one-half of the volume, but only on the bottom half (d in Fig. 1). Figure 8 is for the fully loaded 3" tube at a density of about 0.4 lb/ft<sup>3</sup>.

### TEST RESULTS

Several observations result from these tests. The resonance (sonic velocity) was not reduced nearly as much as the Bradbury theory would predict. One cause of the discrepancy may be the different fill I used—polyester instead of wool—and this is certainly a valid comment. That important difference aside, the more interesting result is that the reduction in apparent velocity is not linear with frequency. Bradbury discusses this, and his theory provides for this effect.

Figures 2 and 3 are for free-air resonance, i.e., no filler in either tube. Figures 4 and 7 are for fully filled tubes. If the filler actually modified the velocity of sound and was equally effective for the entire tube volume, you would expect the harmonic characteristics—both in relative amplitude and frequency—also to be equal.

The difference in harmonics between Figs. 2 and 4 indicates more modification of the tube's sonic characteristics than a simple reduction of the interior sonic velocity. It also seems to indicate a "nonlinear" nonlinearity. That is, the effect on the harmonics appears to be related to other variables than just frequency.

A second indication is that the energy distribution seems to be "smeared" by the action of the filler. Figure 4 seems to show a redistribution of energy around the resonant point. The resonant peaks are not sharp. Figure 7 also shows this, particularly the peak at 781Hz.

For speaker-enclosure builders, the second point seems more important. That is, as

### INSTRUMENTATION NOTES

A Stanford Research DS345 function generator drove the driver.

Spectra derivation was done by a Stanford Research Model SR760 FFT analyzer.

An accelerometer attached to the closed end of the small tube served as the input to the SR760.

A General Radio Type 1551-C SLM was the input to the SR760 from the large tube.

The small tube was a heavy cardboard mailing tube. The large tube was 3" PVC pipe.

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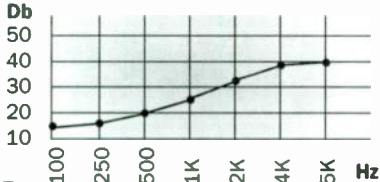
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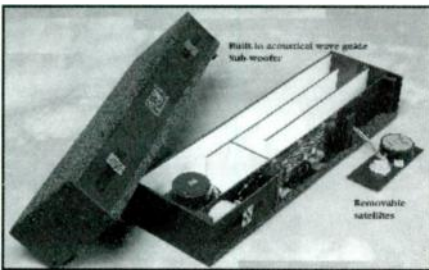


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the resonant frequency decreases, its "bandwidth" increases. This is not a very good technical description, but it may indicate that the energy in the excitation medium that is near the fundamental frequency of the enclosure is "smeared" together.

My first impression is that this is a phase problem. The filler does not impose on the volume the characteristics of a homogeneous fluid, as the Bradbury theory requires. Instead, the transmission medium is markedly nonhomogeneous. This provides many sonic paths, each effectively with a different sonic velocity. For frequency energy near resonance, these phase differences could result in smearing.

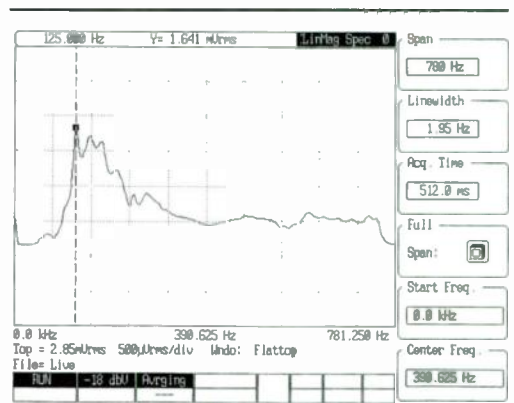
### ARITHMETIC LESSON

The velocity of sound in any elastic medium is equal to the square root of the ratio of the bulk modulus of the medium to the density. For gases, the modulus is equal to the pressure, so that the sonic velocity is equal to the square root of the pressure-to-density ratio. In his analysis, Bradbury assumes isothermal characteristics for the medium in the enclosure. This reduces the arithmetic somewhat in his derivations, which Bradbury duly notes, but there is still a difference of about 18%, because the transmission through air is adiabatic. For the adiabatic process, the ratio becomes ( $\gamma \times \text{pressure} / \text{density}$ ).

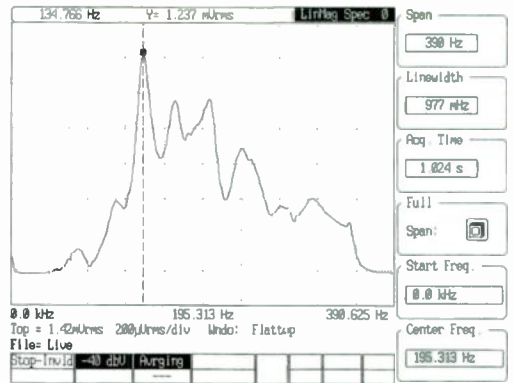
The theory is that if the fibers have a large surface area relative to their density (inertia), then at low-frequency transmissions through the medium, the fibers will "move" (in phase) with the gas molecules and provide an effective increase in the density of the fluid while holding the modulus constant, thereby decreasing the effective sonic velocity.

Experiment shows there is without doubt a decrease of the effective sonic velocity within a resonant enclosure with the use of certain fiber fillers in the transmission volume. My admittedly limited tests seem to show that the transmission velocity is not constant throughout the medium, but may have many effective velocities. Since the distribution of rigid fibers in a volume is almost by definition nonhomogeneous, there must be

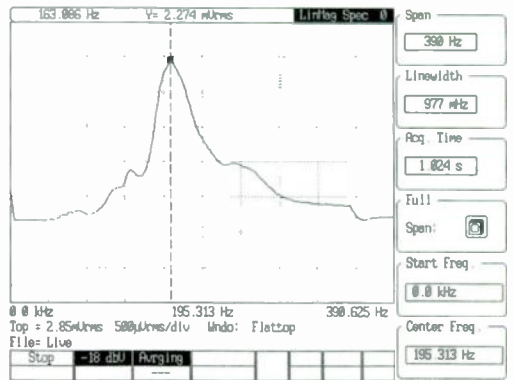
**FIGURE 7:** Results with the filler occupying the bottom half of the tube's volume.



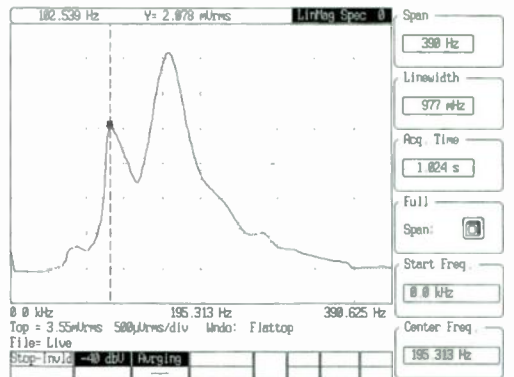
**FIGURE 4:** Frequency sweep of the 2.5" tube, fully loaded.



**FIGURE 5:** Results with a split pack, the total about one-half the volume of the tube.



**FIGURE 6:** Here the plug is also about half the volume of the tube.



many paths for the energy to travel, each potentially with a different velocity.

This possibility is shown in *Fig. 7* for the split pack, where you can clearly see the free-air peak and the attenuated lower-frequency peak due to the fiber pack. Using the Bradbury theory to examine any one sonic path seems to indicate that the greater the reduction in velocity, the greater the attenuation of that path will be. This is true because the effective reduction in velocity is due to the inertia of the interfering fiber structure. The energy in this path is then reduced by the acceleration of the fiber mass.

## CONCLUSIONS

If the action of the fiber/air mixture is as Bradbury theorizes, then at the end of the path the energy will arrive in many different phases, amplitudes, and—by implication—frequencies. This could possibly produce the smearing seen in the small tubes.

The advantage of a large structure, i.e., a full-size speaker enclosure, would be to approach a more homogeneous medium, since the fiber's physical size is constant, while the enclosed volume—actually the length—becomes greater in ratio with respect to the constant fiber diameter.

Maybe Bailey found the perfect syner-

gism between his enclosure sizes and his selection of filler.

Do any *SB* readers have additional results that can provide more data on the loading of enclosures with the objective of lowering the resonant frequency? Full-scale tests where the resonant point has actually been measured and shows at least a 50% reduction in resonance would be of great interest. Together with these measurements, the determination of changes in harmonic content, if any, of the enclosure could also be evaluated.

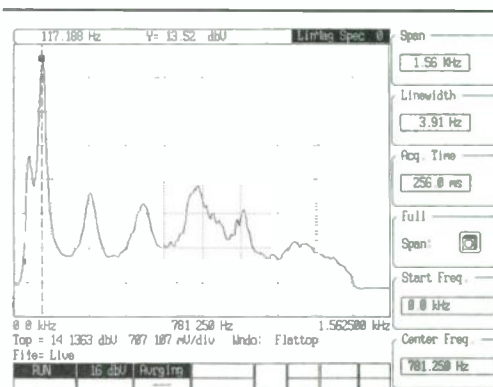


FIGURE 8: The fully loaded 3" tube.

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# FOCUSED ARRAY ELECTROSTATIC, PART 3

By Bill Waslo

In the first two parts of this series, I've discussed the concept of the focused array electrostatic system, its construction, placement, and measurements. In this final installment, I put the feasibility of this design to the test, as I reveal the results of how it sounds.

## LISTENING TESTS

Listening tests on the FAE system have convinced me of two main points. First, the sound from certain CDs on this system is indeed the most convincing that I have heard. The best recordings, though, are surprising. My current favorite "show off" CD is "Jacques Brel is Alive and Living in

Paris," Columbia CGK 40817. Perhaps this is because of the predominance of vocals (at which the FAEs excel) or maybe just because I really like the music and have been able only now to make this recording sound good.

This musical-theater cabaret-style production from the '70s—not exactly hi-fi recording's most revered period—was likely recorded in a studio rather than on a stage or in an original acoustical environment such as I was trying to recreate. But when I play this, it seems the performance is live.

I have a disk from Harmonia Mundi (picked up long ago with a catalog)—Vivaldi's Flute Concertos by Janet See and

the Philharmonia Baroque Orchestra—that really shines on this system, as do many of the Nimbus recordings. The feeling of openness and space ahead can be very absorbing, perhaps emphasized by the direct contrast from a virtual wall of loudspeakers positioned close in front during the audition.

The hi-fi standbys "Famous Blue Raincoat" by Jennifer Warnes (purely studio) and the eternal "Belafonte at Carnegie Hall" also make you sit up and take notice. The Carnegie Hall recording gives a distinct sense of a large, good-sounding room in front. Somewhat disconcerting, however, is the lack of any such sense of that same room



PHOTO 1: Nipper gets an earful of the focused array electrostatic section.



PHOTO 2: The author upon completion of the FAE section.

being above or behind (I can imagine the home-theater fans chuckling at this). It seems as if the closer you get to accurate sound in some ways, the more obvious the missing elements become.

I became aware of another factor when I first experimented with coherent arrays of drivers prior to the FAE system: external noises seem more bothersome to me when I'm listening to a focused-array-type system. It's not that the sounds of people, garage doors, telephones, or laundry noises seem any louder; it's just that they seem out of place in the sound field being created. At the focus of the array is a distinct acoustical place, but sounds from the "real" room environment are still able to travel to that place and disturb the illusion.

The sound of the FAEs can best be described as very "present." When Rikki Lee Jones sings, she is right there in front of you. When Linda Ronstadt sings, the recording technique used and the focused array effect sometimes combine to give the impression that she is singing about 12" from your face—you are where the microphone was, which is a strange effect. It is virtually impossible to read and difficult to even daydream when listening to some recordings. The sound commands your

attention, as does the imposing size and the nearness of the speaker arrangement, and I can't say which is the stronger factor.

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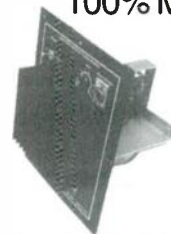
This brings me to my second main conclusion after listening to this system: The FAE setup in this configuration is too intimidating for general use. This is not so much a criticism of the sound, but an observation of the psychological effect of the perceived mass and closeness of the speakers. Five feet away seems much closer than I had imagined.

The curved electrostatic arcs are rather attractive in a way, and have a certain elegance and artistic appeal. But combined with the woofer towers (each 22" wide and 70" tall), which must be placed in my room between the FAE arcs, and with the necessarily fixed-position listening sofa, they totally dominate the modest listening room space. When a single bass cabinet (only two drivers) per side is used instead, the psychological effect is much better, but the bass quality suffers substantially due to loss of directivity and more limited total cone area. Perhaps narrow towers using four woofers would be a good compromise.

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listening position reinforces the feeling of imposition given by the bulk of the towers. When a listener first moves into that spot, he immediately feels the change in sound that occurs, and notices the loss of it when he moves out of the focus. In many ways it's like having exceptional, immovable, six-foot, floor-standing headphones!

I have become a believer in the necessity to arrange a room for a comfortable psychological, as well as acoustical, effect. It is not enough to deal only with the objective considerations of what makes for more accurate sound, but you must also consider the human factors, such as who is listening. And

the act of so obviously wrapping speakers around a human listener is likely to be detrimental to his listening experience.

#### ACCURACY VERSUS ENJOYMENT

Which brings me back to an original goal of this project: to determine whether accuracy in terms of echo minimization is achievable and a worthwhile goal. I would say that it has been achieved to a fair degree, and is by itself worthwhile. I would add, though, that it is not possible to separate entirely the experience of the sound that is recreated from the way it is recreated. In other words, maximum sound accuracy may not be

worthwhile if the hardware needed is difficult to become comfortable with over long periods.

I recently ran a poll on the internet newsgroup rec.audio.opinion, asking what effect hi-fi users were trying to achieve. The choices I suggested included (1) making the listener seem as if he's at the original recording site, (2) making it seem that the performers are in the listener's stereo room, or (3) making a generally pleasant sound from the system (as opposed to emphasizing accuracy). I did not get a large number of responses to my poll, but I was surprised that most respondents chose number 3: "making a generally pleasant sound."

And I can't really argue against that position. After all, complete accuracy is still unavailable (is it ever difficult to tell any

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#### ACKNOWLEDGMENTS

Many people have been generous with assistance, comments, encouragement, and discussion while I was making this system. Others have been unknowingly helpful as sources of technical information. Many thanks to the following and to any I may have inadvertently left out (in alphabetical order): Alan Cadiz, Ed Dell, Kim Girardin, G.R. Koonce, David Lucas Company, Roger Sanders, Tim Sandrik, Tony Seaford, Carol Stewart, Steve Temme, Robert Thompson, Ronald Wagner, and Barry Waldron.

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stereo system's sound from live performance?). Meanwhile, we prefer to listen to some music now even before all the bugs are worked out (if ever) and to make it work for us any way we can. If subjectively good (not just objectively accurate) sound is a goal, then in an individual system it is valid to utilize any effects that the user may prefer. These might include intentionally added low-order harmonic distortion, fill sound from back reflecting drivers, verb units, loudness buttons, or even wooden disks and tweaks that operate only in the listener's imagination.

The listener's mind is at least half of the equation. Perhaps because of my technical background, my psychological preference tends toward accuracy in the sound field. But I've found that even I am not willing to sacrifice all other factors involved in the listening experience for the sake of blind accuracy. The FAE system, even though it succeeds in many technical goals, remains under development. As always, audio design is an art of finding the best compromise. ➤

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Publisher: Edward T. Dell, Jr., PO Box 876, Peterborough, NH 03458-0876. Assistant Publisher: Dennis Brisson. Owner: Audio Amateur Inc., PO Box 876, Peterborough, NH 03458-0876.

Stockholders owning or holding 1 percent or more of the total amount of stock: Edward T. Dell, Jr., PO Box 876, Peterborough, NH 03458-0876. Known bondholders, mortgages or other securities: None.

	Average # copies each issue during preceding 12 months	Single issue nearest to filing date
Total # copies printed	13,125	13,000
Newsdealer sales	2,202	3,598
Mail subscriptions	7,383	6,807
Total paid circulation	9,585	10,405
Free distribution complimentary	314	300
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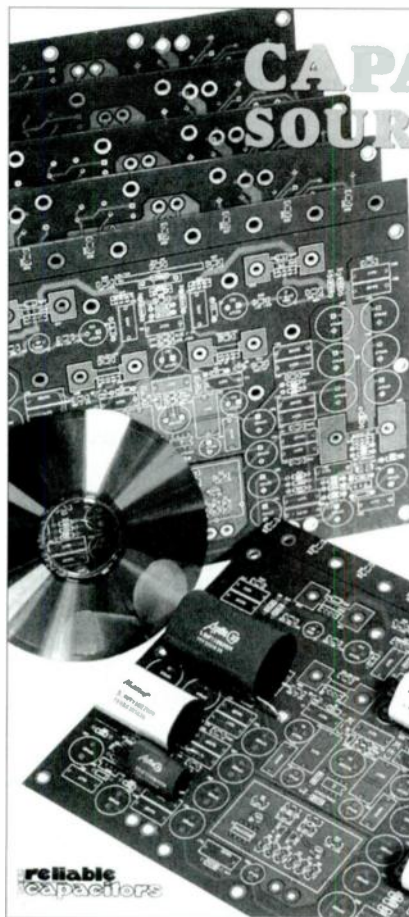
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Reader Service #69

# DESIGNING A DIPOLE MONSTER, PART 3

By Timothy E. Sandrik

Most loudspeakers are designed to have heavy, stiff cabinets. In most cases this is the most cost-effective way to ensure the absence of sound-coloring cabinet vibrations. Those following this report will realize that the Michigan Technological University (MTU) "Concept Speaker" did not follow this approach. Our speaker was optimized for low weight, and while it was costly, you could implement the ideas in a much less expensive speaker.

## CAUSES OF VIBRATION

When you begin to consider the cause of coloration by a vibrating panel, there is quite a lot you must take into account. Several important questions to ask are: How does vibration get to the panel? How do the wavelengths of sound relate to the dimensions of the panel? Is the panel large enough to radiate a significant amount of sound?

The answer to the first question depends on the speaker. Most have a physical connection between the driver and the various panels of the box, and such a link is one path of sound transmission. In a boxed speaker, the acoustic connection from driver to air to panel is another path—usually the more significant.

The second question relates to how things vibrate; in the case of a panel, there are two ways: as one piece, moving in the same phase, or in "breakup," with varying phase. The frequency range where the panel vibrates significantly as one piece depends on the mass and stiffness of the material, and how it is constrained or held.

At wavelengths smaller than baffle dimensions, the panel may also vibrate like a string, having different magnitude and phase at different points. The strength and frequencies of these "breakup" vibrations depend on the panel's mass, stiffness, and damping.

## ACOUSTIC OUTPUT

Those who have made panel-vibration measurements or who read *Stereophile* may be familiar with the appearance of an accelerometer's output expressed in a "waterfall" plot. This gives you a measure of the acceleration, velocity, and displace-

ment—versus frequency and time—of a point on the panel. What is really of interest, though, is the acoustic output of the panel relative to that of the driver(s).

The total acoustic output of a panel depends on the product of the displacement and surface area of each section of the baffle. In breakup, each section's displacement differs in magnitude and phase. The point is that, as with drivers, the more of them there are in phase, the greater the output, and those out of phase will cancel to some extent.

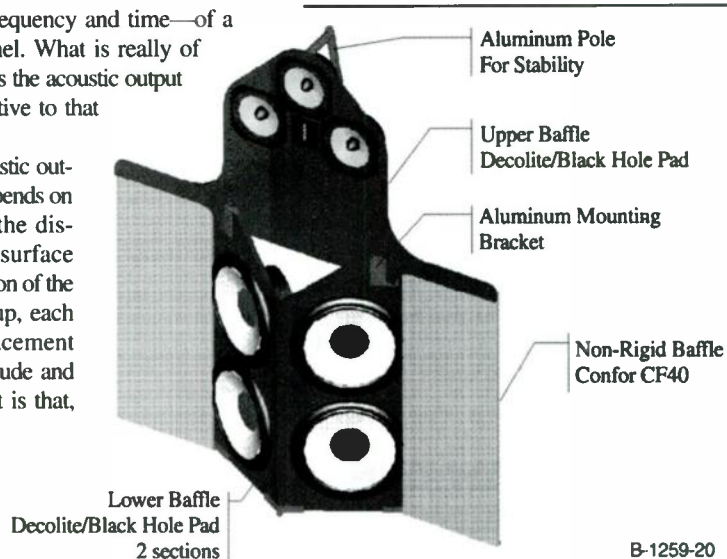
This certainly makes matters complicated, since to reduce transmission losses from inside a cabinet, stiffness is important at low frequencies. At high frequencies, the pressure on the inside of the cabinet walls is not in phase at all points, and the mass of the panel primarily limits transmission from inside the cabinet.

The problem then is that the frequency range of the significant breakup resonances overlaps the frequency range where the stiffness or mass of the baffle is not adequate to oppose the internal pressure. So, the ideal box must either be infinitely stiff, infinitely heavy, or both.

## DIPOLE PANEL

Well, our project has no box. That solves some problems, but creates others. On a flat baffle in free space, there is no pressure from the driver(s) forcing it to move. Since the panel is a dipole, any panel vibrations also have dipole radiation, as well as lower total power. There are also fewer panels to move—only one in the case of our speaker.

A dipole is usually not held as well at its edges, so it is less stiff and thus more susceptible to vibrations from the physical connection to the driver(s). The moving



B-1259-20

FIGURE 20: Diagram of speaker.

mass of the drivers is what excites the baffle to move. In the case of a dipole, large amounts of driver surface area (usually corresponding to moving mass) or baffle area are necessary for adequate efficiency. Either way, this means the potential for trouble.

You can minimize the baffle's potential to vibrate in the following ways:

1. Make the basic structure of the baffle very light, strong, and stiff.
2. Use only enough of the light, strong, and stiff material to support the drivers.
3. Use very low-stiffness, highly damped material for most of the baffle area not occupied by drivers.
4. Treat the remaining area with a layer of heavy damping material.

Figure 20 is Robert Lawson's solid model of the speaker, with callouts added by the author. This illustration will help clarify the remaining discussion.

## BAFFLE PROBLEMS

The light and strong materials composing the baffle are aluminum and Decolite, the latter a composite material made by the Balte Corporation from two thin sheets



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of fiberglass attached to a balsawood core. Since the Decolite is so light and stiff, it is very prone to vibrate.

We experienced this with some early prototypes, as we tried to find a baffle that would give us enough surface area to reproduce 30Hz at 93dB with 2.83V. No matter how we rearranged things, we always ended up with a huge amount of open area. The open area wasn't the problem, for we could treat each section to bring its output down significantly. The problem was that the treatment always involved a weight penalty.

Ryan Mihelich and I ended up at a carpet store asking for scraps of carpet pad—"the kind you can't blow through," we said. Obtaining some samples, we went back to the lab, put a driver in a small baffle, and then clamped onto it a piece of wood to double the baffle area. We measured the bass output a couple of meters from the baffle, and then replaced the piece of wood with carpet pad.

With the pad, the bass output suffered only about 0.5dB at 30Hz. We did some quick math and realized that if we used just enough Decolite to hold the drivers and used something like carpet pad for the rest of the baffle, we could double the number of Focal 12V726S woofers.

Confor is something like carpet pad, but a lot cooler. Made by E-A-R Specialty com-

posites, it's a highly damped foam that's similar to disposable ear plugs. If you squash it into a ball, it takes about 30 seconds to return to its original shape. A golf ball dropped onto ½" of Confor CF40 won't bounce. Like the carpet pad, it works as a barrier, extending the size of the baffle without radiating a significant amount of sound.

In the case of a dipole, where the baffle is driven to vibrate through physical connections and not pressure, you can use a very low-stiffness material. The low stiffness means that the curtain of Confor vibrates with such varying phase that many of the vibrations will cancel one another. The very high damping means that the vibrations do not ring long, and it can potentially damp the vibrations in the panel to which it is attached, as a surround can do on a driver.

#### TRIAL DESIGNS

Planning to use Confor for some of the baffle, we then sketched and built different designs, trying to find one that would stand best on its own and use the least amount of stiff material without sacrificing performance. The "kink" in the lower panel allows the baffle to stand very nearly by itself.

To give it some help, and to lend some stiffness to prevent it from swinging, we built an aluminum triangle from c-channel and

thin-walled tubes. The two-sided triangle attaches to the "trailing edges" of the lower panels and meets at a point behind the speaker. A pole extends from the point of the triangle to the top of the top panel.

Originally, the speaker was intended to have four midrange drivers in the top panel. Improving the radiation pattern made it necessary to remove a midrange from below the tweeter. This opened up our largest vibrating area. We suspected, but could not confirm, that its worst resonance was between 250–500Hz, and since the four woofers operate up this high, there was a potential problem.

This section, and the rest of the rigid baffle, was treated with Black Hole Pad damping material, which is very dense and very well damped in bending. Treating the baffle with this changed the characteristic sound of the open section from a "ping" to a "puh," and added only 5 lb to the speaker. Photo 4 in Part 1 shows Ryan Mihelich, Robert Lawson, and Brian Zarembo with a completed baffle.

#### BOXED-SPEAKER HINTS

I'm sure few of you will run out and start building dipoles, but there are some key points for boxed speakers in this discussion. If you can make your box stiff and heavy, do so, but realize that both the mass and stiffness

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are a long way from infinity, and you may just push your panels' frequency range in a direction to make a vibration more audible.

In most cases, you will be constrained by aesthetics, weight, or getting a bang for your buck. Eating up all of your internal volume so you can have thick cabinet walls may not be best for overall performance. Phase shifts in the voice range and limited low-frequency extension may not justify 3"-thick walls on a speaker that needs to fit into an entertainment center.

Brace your cabinet to make unequal panel sections, and realize that much of your problem will be where the panel is bending, or breaking up. An 1/8" or 1/4" of Black Hole Pad may do more good than doubling or quadrupling the cabinet thickness and panel mass. You might try four layers of 1/4" plywood, held together with a home-made glue of construction adhesive and sand. ▶

#### ACKNOWLEDGMENTS

We gratefully acknowledge the help and advice we received from the following:

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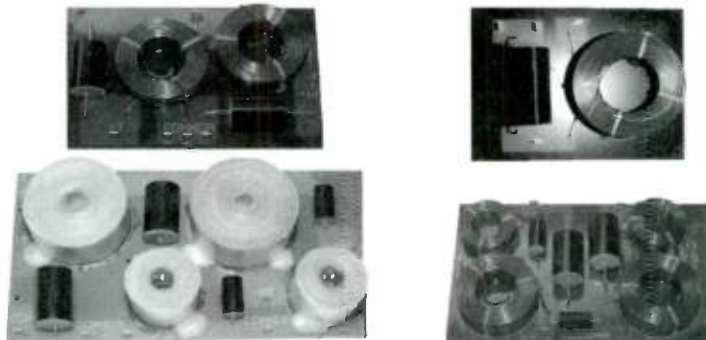
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Speaker Builder 7/98 43

# MINING THE COMPLEX IMPEDANCE

By D.J. Meraner

In the *SB 2/88* issue, Vance Dickason presented a tutorial on the nature of a speaker's impedance, with particular emphasis on the special demands that "bad" impedance loads present to the amplifier serving it. Upon rereading this article recently, it occurred to me that you can extract additional information from a speaker system whose complex impedance is known.

For example, the tutorial's Figs. 8 and 9 (Figs. 1 and 2 here) give the impedance and phase of a bass-aligned second-order system. When a speaker is powered by an amplifier with negligible internal impedance, its output voltage will remain constant regardless of the speaker's impedance variations. Therefore, the speaker's complex impedance will determine the power delivered to it.

In this case, I wished to discover how the power delivered varied with frequency. I assumed that the output voltage held steady at 2.83V. I calculated the current to the speaker as the applied voltage divided by the impedance, or  $I = 2.83/Z$ . The resistive component of impedance is the product of the impedance and the cosine of the impedance angle, or  $R = Z \times \text{Cos}(A)$ . Then the power input is the current squared times the resistive component, or

$$P = \left(\frac{2.83}{Z}\right)^2 Z \text{Cos}A = \frac{8 \text{Cos}A}{Z}$$

## INVERSE CURVES

The result of these calculations is shown in Fig. 3, where the power curve is overlaid on the impedance curve. Note that the power curve is very nearly the inverse of the impedance curve. More interesting is

## ABOUT THE AUTHOR

A graduate of Rutgers University College of Engineering, David Meraner has worked for 35 years as a designer of hydroelectric generators and nuclear-reactor coolant-pump motors for General Electric Co. A life member of the Institute of Electrical and Electronics Engineers, he has long been an audio enthusiast, with his interest rekindled by the work of Thiele and Small. The Scotia, NY, resident also designs and builds speaker systems for family and friends.

the power dip at the system's low-frequency resonance, because, were it not so, cone excursions would become excessive.

Perhaps this is a good time to point out another characteristic of second-order alignments. The SPL generated at low frequencies by a vibrating piston in a small sealed box in a normally resonant room was given by J. D'Appolito (*SB 4/84*) as:

$$\text{SPL} = -86 + 40\text{Log}(f) + 40\text{Log}(D) + 20\text{Log}(\text{App})$$

When you plot this function on semilog paper for a given driver, the line has a slope of 12dB/octave. Expressed another way, any driver that is executing a rolloff at this rate does so at constant cone excursion. Furthermore, if the system's  $Q_{TC}$  is 0.707 or less, cone excursion in the roll-on region will become smaller and smaller. Obviously, then, if the allowable cone excursion is not exceeded in the roll-off region, it will not be exceeded in any other frequency region.

This supports the design of a three-way system in which the bandpass filter does not have a high-pass section. The midrange driver, in a closed box, is allowed to roll off acoustically at 12dB/octave, and is mated with the woofer that is rolled off electrically at the same rate.

To avoid interaction with the woofer's resonant range, the midrange system's  $f_3$  should not be less than about 150Hz. In addition, it should have a generous  $X_{MAX}$  capability and a system  $Q_{TC}$  of at least 0.707, which implies an  $F_S/Q_T$  ratio of at least 212. (See G.R. Koonce's *SB 7/84* article, "Trade-Offs in Closed Box Alignments.") My first encounter with the application of this concept was in Marc Bacon's *SB 4/92* article, "The Danielle."

## IMPEDANCE COMPENSATION

Another use of the complex impedance revolves around impedance compensation. *Speaker Builder* has published many articles on this subject.<sup>1-5</sup> I have used impedance compensation in many of my designs, but whenever I did, I wondered what the penalty might be for converting the imped-

ance presented at the speaker terminals from a complex impedance to one that is resistive, or largely so.

This finally led me to make an analysis. My model was an 8" woofer in a closed box. My compensating network consisted of a 7.5Ω resistor and a 65μF capacitor. This resulted in a compensated impedance that ranged from 5.6–6.5Ω. For simplicity, I selected a first-order low-pass filter set at 1.91kHz. With a compensated speaker load of 6Ω, the required value of inductance calculated to 0.5mH.

Figure 4a shows the circuit I was analyzing and Fig. 4b the per-unit output voltage of the filter versus frequency. The filter output voltage appears across both the compensating circuit and the speaker. Following the same procedures used elsewhere in this article, power delivered to the compensating network and to the speaker will have the form:

$$P_c = \left(\frac{E_{pu}}{Z_c}\right)^2 Z_c \text{Cos}\theta_c \quad P_s = \left(\frac{E_{pu}}{Z_s}\right)^2 Z_s \text{Cos}\theta_s$$

Subscript c denotes the compensation network, and subscript s the speaker.

I calculated the impedance and phase of the compensation circuit from the given values as follows:

$$Z = \sqrt{R^2 + x^2},$$

where  $R = 7.5$  and

$$x = \frac{10^6}{2\pi f 65} = \frac{2448.5}{f};$$

$$\text{phase angle } \theta = \text{arc tan}\left(\frac{x}{R}\right).$$

The plot of this data, thus calculated, is shown in Fig. 5.

The speaker's impedance and phase are shown in Fig. 6. The solid curves represent test data using procedures outlined in J.M. Markwalter's *SB 2/94* article entitled, "Measuring Speaker Impedance Without a Bridge." In his article, he warns against

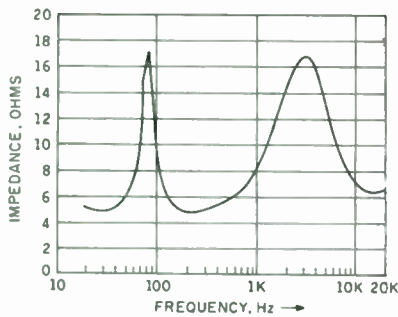


FIGURE 1: Impedance-magnitude plot.

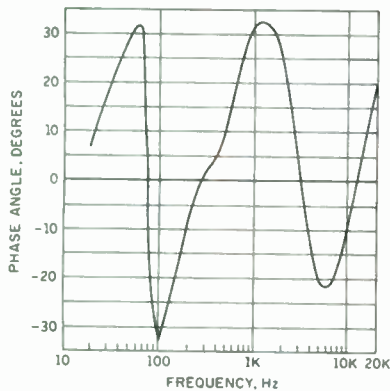


FIGURE 2: Phase-angle plot.

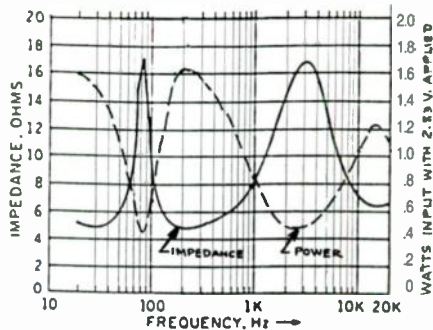


FIGURE 3: Calculated power and impedance curves.

using a speaker's published values of DC resistance and voice-coil inductance to calculate impedance and phase. The dotted curves in Fig. 6 show the results of not heeding his warning.

I performed the indicated calculations at

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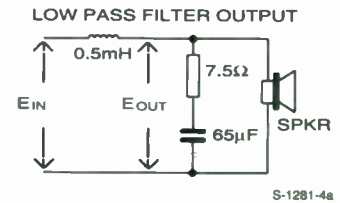


FIGURE 4a: Low-pass filter output.

three frequencies; the results are shown in Table 1.

Perhaps this somewhat alarming data will inspire readers to devise ways either of eliminating the need for impedance compensators, or of lessening their power demands.

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3. R.M. Bullock, "Passive Crossover Networks," SB 1/85.
4. D.J. Meraner, "Is Impedance Compensation Worthwhile?" SB 3/87.
5. V. Staggs, "Exploring Loudspeaker Impedance," SB 5/94.

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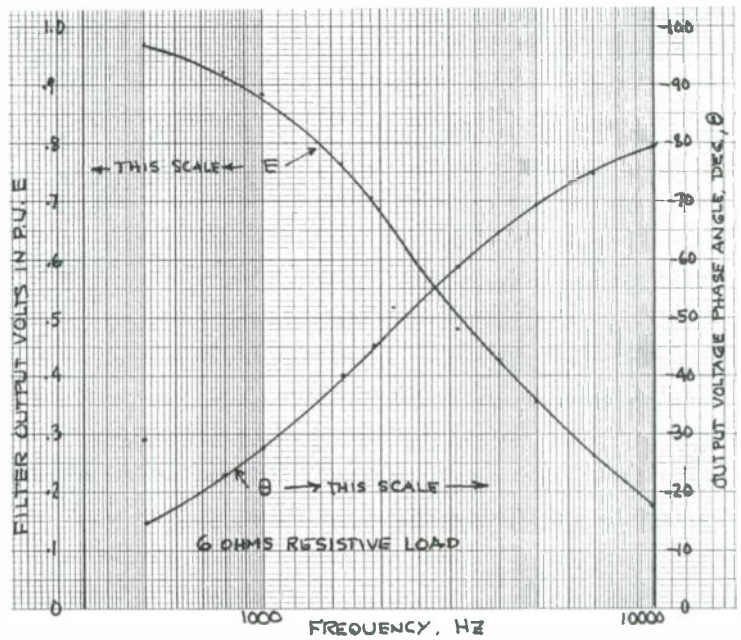


FIGURE 4b: Output voltage versus frequency.

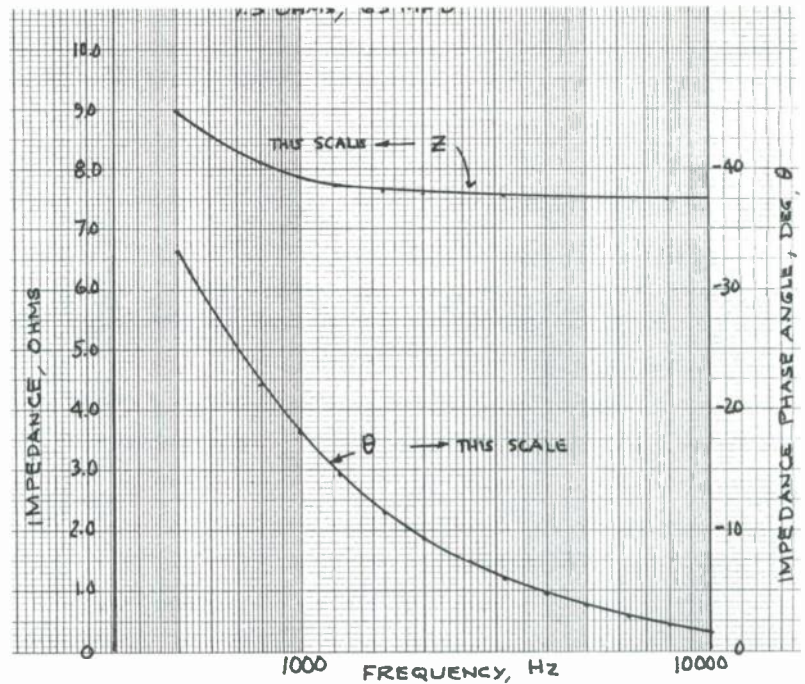


FIGURE 5: Impedance and phase-compensation network. 7.5Ω, 65μF.

TABLE 1

**SPEAKER CALCULATIONS**

FREQUENCY	$E_{PU}$	POWER TO COMP CKT	POWER TO SPEAKER	TOTAL POWER	% TO COMP CKT	% TO SPEAKER
1000	0.875	0.0928 $E^2$	0.0477 $E^2$	0.1405 $E^2$	66%	34%
1910	0.707	0.0644 $E^2$	0.0189 $E^2$	0.0833 $E^2$	77.3%	22.7%
4000	0.650	0.0555 $E^2$	0.0095 $E^2$	0.0650 $E^2$	85.4%	14.6%

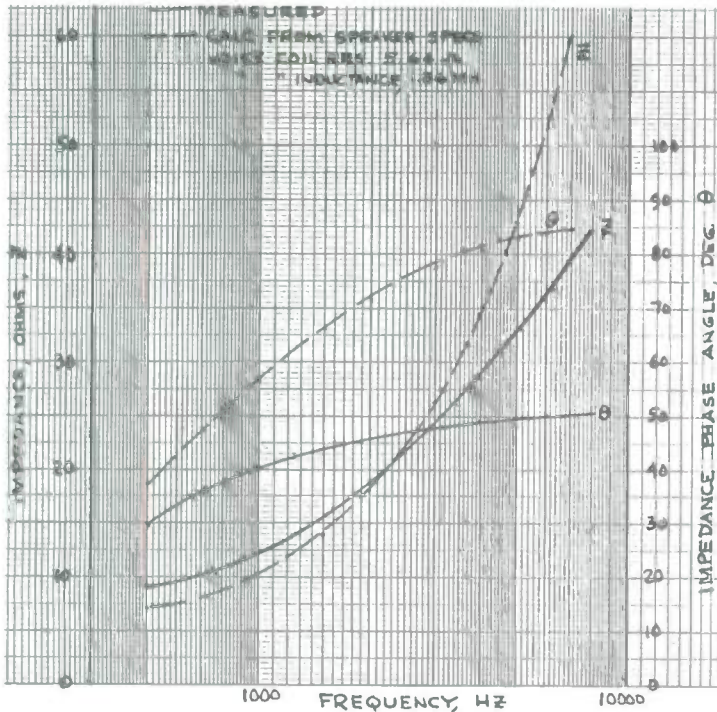


FIGURE 6: Impedance and phase measurements.

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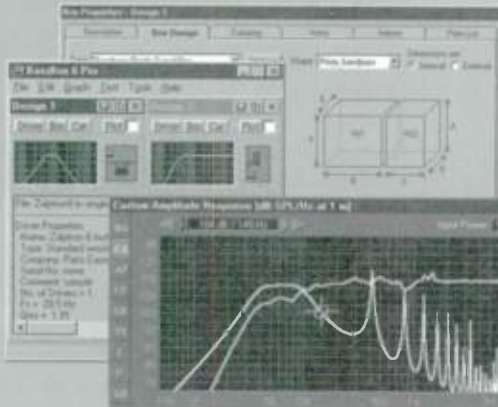
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Reader Service #17

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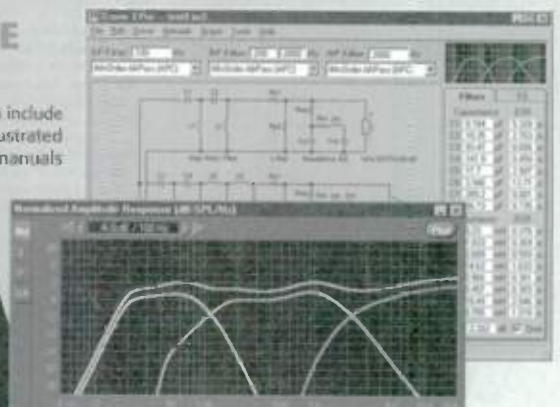
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Reader Service #3

# SB Mailbox

## ESL UPDATE

I would like to commend Mr. Waslo on his excellent electrostatic project series ("Focused Array Electrostatic," *SB* 5/98-7/98). It is a very well thought out treatise and clearly demonstrates that he is adept in the many facets of acoustical theory and design.

I believe, however, that it is only fair to readers that we update some details he mentioned, as Mr. Waslo purchased the kit materials from us over two years ago (July 1996). Furthermore, our technical objectives have always been to constantly improve our products based on customer requirements and the advancement of sound reproduction. Our reasonable pricing has always been an encouragement to the audio enthusiast, as Mr. Waslo's endeavor attests.

Let's cover the details that need to be updated:

1. We have hired a full-time professional that both designs and manufactures our complete line of matching transformers. All of these have been designed specifically for

electrostatic loading and superior audio reproduction. We have many customers that praise the most important issue—sound quality.

2. Over the years our Battery Bias Supply has undergone many refinements. The latest version uses double the voltage (6V), has a new special inductor (wound by us), and many other circuit changes that contribute to its very low noise level and increased voltage output.

I exalt and praise both Mr. Waslo and Audio Amateur Corporation for all of their efforts in seeking "The Audio Truth."

Tim Kelly  
Sales Manager, David Lucas, Inc.

## HELP WANTED

About five years ago I drove to Dallas (from Michigan) to pick up two Tekton Infra Bass Subwoofers (18" and 21"), hoping to build cabinets as soon as I returned home. But it is five years later

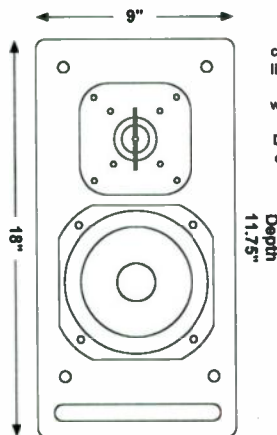
and still no cabinets. I have since lost the little bit of information I had on them and would like to start the cabinets as soon as possible.

Does anyone know who I might contact to get the general specs (I lack the resources to test them), or some proven designs on these monsters?

The only information I remember about these units is that they can handle gobs of power—1.2kW, I believe (I have a Crown Macro Reference)—and require quite large enclosure designs— $X_{max}$  was ( $\frac{3}{4}$ ") and (1"), and could reach extraordinary lows "in the low teens." They need to be mounted upright (the cones are too heavy for the surround to support) and weigh 70+ lbs. and 90+ lbs. They were made in England and were partly/wholly designed by a gentleman from ORCA (an Indonesian, I believe, whose name I can't recall).

Herman Renes  
HR1965@aol.com

## New Product From Speaker City, U.S.A. The Focal 7KT



Focal of France, one of the worlds leading manufactures of high quality speaker components today, has introduced their new line of raw frame speaker components. From this, Speaker City, U.S.A. has collaborated with Kimon Bellas at Focal U.S.A. to produce a great sounding monitor system. Designed using Clio and SpeakEasy, this kit offers state of the art components, dynamic output performance, and superior sonic characteristics.

### Specifications

Impedance: 4 ohms nominal  
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Sensitivity: 91dB 1w/1m  
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I am living in England and several years ago (1970s or early 1980s) we purchased KLH Model 101 Marlboro speakers for a family hi-fi system. My children managed to push in the speaker cones on them.

I am now looking for someone who would have replacement speakers to fit this range. Can any readers help?

Doug Whitehead  
Doug@rom.net

Does anyone know what happened to Babb speakers? Are they still building for the marine industry?

Scott Guthrie  
sd.guthrie@sympatico.ca

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

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# Software Review

## ETF 4.0

Reviewed by Philip E. Bamberg

**ETF 4.0**, by Douglas H. Plumb; a Windows 95-based software program for evaluating room acoustics; ETF, 53 Stevenson Rd. North, Oshawa, ON L1J-5M4, Canada, (800) 301-1423, FAX (905) 721-7540, E-mail sales@etfacoustic.com, Website www.etfacoustic.com, \$199.95 plus shipping.

ETF 4.0 is an effective and easy-to-use room-acoustics measurement and evaluation program. It comes on a single CD that contains both the program files and analog test-signal source. Put the CD in your computer to install the program and support files. Then put it into your CD player to generate the test signal through the stereo and into the room. Record and analyze the test signal directly from within the ETF program.

The resulting energy-versus-time curves are broken down into five frequency bands. From there, you can quickly view energy-time-frequency information in multiple formats: energy versus time ("decay time" for five frequency bands), energy versus frequency ("frequency response"), and energy-time-frequency ("waterfall" plot for four frequency bands).

Although no microphone is included, it is claimed that the program evaluates only relative acoustic changes, and therefore any mike

that will work with the computer is OK. There are some advantages to using a higher grade of microphone or a dedicated mike preamp. ETF sells this equipment as well.

A slide-show-style tutorial covers small-room acoustics basics—resonance, reflection, diffusion, and decay time. Taking almost no time, the demo is very helpful in giving you a quick overview of the purpose and concepts of the program.

Two extensive online manuals are also included. The *ETF4 Manual* is a user's guide to measuring and perfecting room acoustics. It includes sections on basic small-room acoustics, ETF measurement and evaluation techniques, and reverberation tools. There is even a section on design aids for acoustical reflection and resonance control devices. You not only can ascertain acoustic problems, but have a good chance of correcting them as well.

Numerous references to other published sources are included. Since I had read several of these already, I gained a sense of confidence in Mr. Plumb's product before I ever tried it. ETF4.0 is the online help manual. Written with hypertext links throughout, this document navigates quickly to more information and answers.

I found these online documents to be very

helpful and complete. It is obvious that many hours of work (and research) have gone into them. Those of you who offer DIY acoustic software for sale, take note: thorough and well-written documentation lends credence to your product's maturity.

### APPLICATION

I purchased ETF primarily so I could "go mobile." My lab already has LinearX LMS and Liberty Audiosuite systems for loud-speaker development, but I had been looking for a room-evaluation program that would run on my notebook computer. Now I have a way to visit my customers' systems and rooms—even their cars—and provide them with measurements, evaluation, and advice.

One word of caution for laptop owners: be sure your computer is not only compatible, but *capable*. Mainly, you want to be sure you have a large enough disk drive. The program requires Windows 95, and ETF makes other recommendations as to minimum system requirements. But realize that each raw data-acquisition file can occupy 2MB of disk space.

For one home-theater evaluation, my raw files occupied about ¼ gigabyte! Of course, you could always erase the raw files as you go. My 2GB drive is typically about 1/3 full,

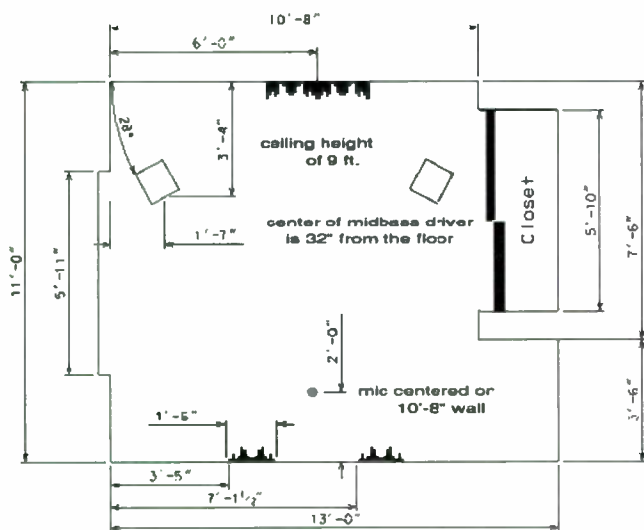


FIGURE 1: Test room layout.

B-1288-1

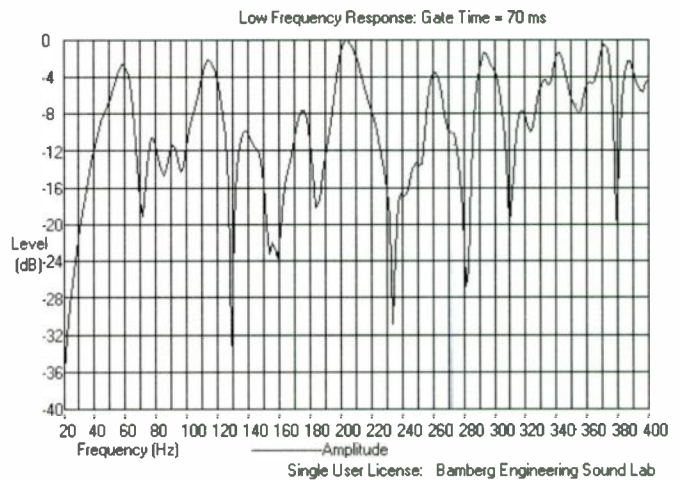


FIGURE 2: Low-frequency response after optimizing speaker placement.

Single User License: Bamberg Engineering Sound Lab

B-1288-2

so I have the luxury of keeping the raw files for a while should I ever wish to reevaluate them. A fast CPU is useful here: my Pentium 133MHz required less than two minutes to calculate the curves for each raw file.

For home use, you will need either to take your computer into your listening room, or to construct a long extension cable to go from the mike preamp to the computer.

While the documentation continually emphasizes that ETF's purpose is to measure room acoustics and *not* loudspeakers, you must still produce and receive a sound source. The signal received at the microphone will be the sum total response of a particular combination of room, loudspeaker, location, microphone, and audio system. Therefore, any deviation from flat of any of these components will ultimately show up in like manner in the final "room" response.

What I am emphasizing here is that all system components are subject to scrutiny for possible deficiencies and appropriate methods of "treatment." In one case, for example, I used ETF as a temporary loudspeaker-measurement tool to set speaker midrange and tweeter controls prior to testing the room (Fig. 1). For this task, I moved the stand-mounted speaker out to the middle of the room, then positioned the mike one meter

in front of it. Once satisfied with improved speaker response, I moved it back and continued with the rest of the "room" session.

You should always be aware that no measurement system can measure the room response alone, i.e., separate from the rest of the audio system. Yet any improvement in the audio gear and the control over environment variables will get you closer to the stand-alone room response. In other words, a calibrated microphone couldn't hurt. Even borrowing a pair of speakers with a known relatively flat power response will yield better results.

On the other hand, you shouldn't fall into the trap of always focusing on frequency response alone. ETF is primarily a time-based measurement tool, and you will shortly see an example where an acoustic change made to the room is barely observed in the frequency-response curves, but is more readily noticed with the energy-time curves.

One room-acoustic quality you can see irrespective of system response is the sound-decay behavior of the room—reverberation. And this is where ETF excels. With the TEFT™-like special-source signal, the calculated curves display as a sharp rise in sound level, followed by a gradual decay back to silence. Encoded within the characteristics of

these "backside" slopes is the true behavior of the room.

## PROGRAM TEST

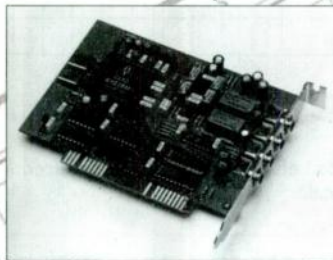
I used ETF versions 3.0 and 4.0<sup>1</sup> in a friend's 11' x 11' x 9' room, an apartment bedroom finished in standard drywall. There was nothing in this room but the stereo system, which consisted of a pair of 7" two-way monitors, known to measure flat. These were positioned three feet from the front wall, and three feet from the side walls. In the left side wall was a large window with mini-blinds. In the right side wall was a double sliding closet door.

The room treatment consisted of dual female Styrofoam diffusers at the front wall between the speakers (12 elements, 16ft<sup>2</sup> total), and two male diffusers (15ft<sup>2</sup>) at the back wall located at the first reflection points. The listening position where I placed my Liberty Instruments microphone (with preamp) was just in front of the rear wall. The mike was taped to a camera tripod and oriented verti-

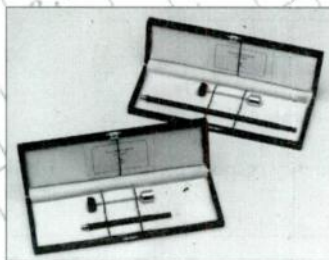
## ABOUT THE AUTHOR

Philip Bamberg is an electrical/mechanical engineer and president of Bamberg Engineering Sound Lab, a custom loudspeaker development and consulting company.

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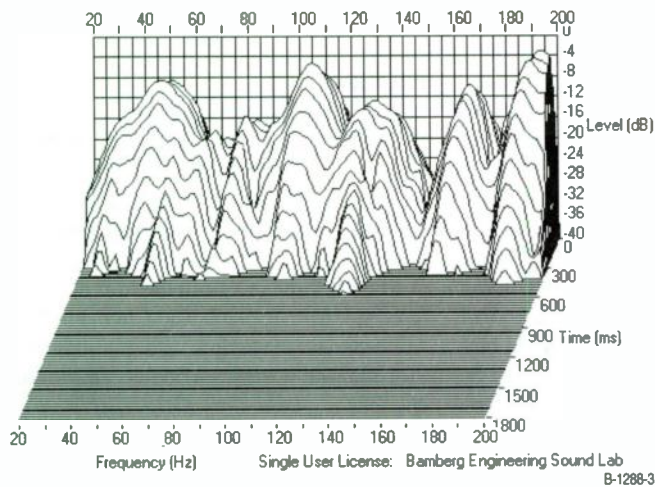
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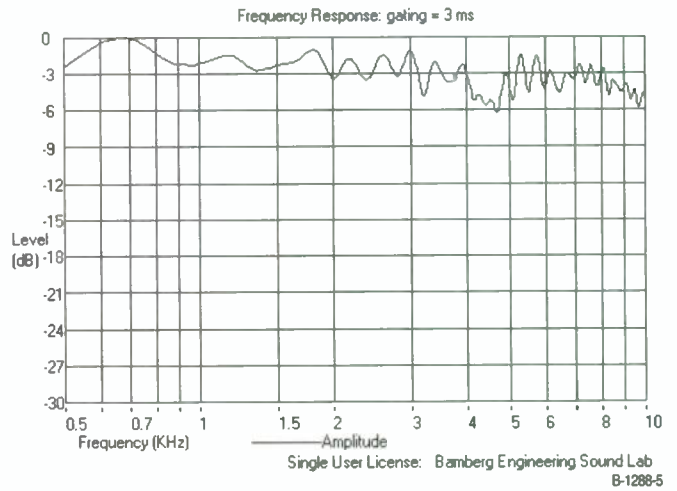
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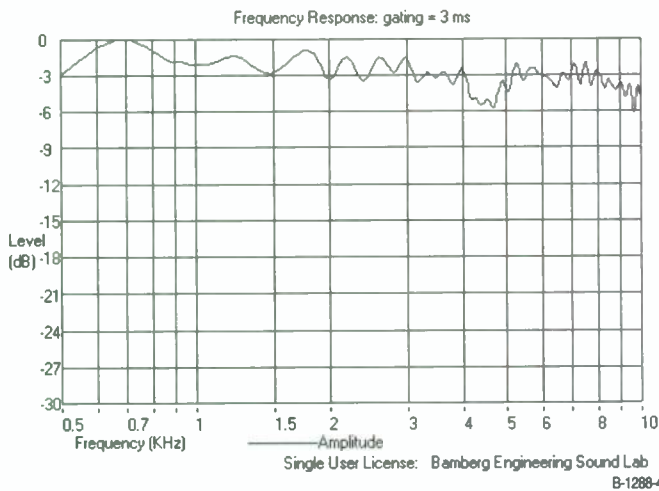




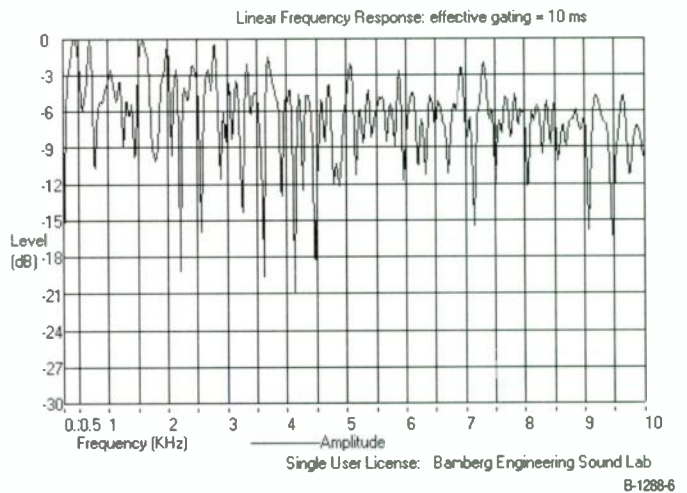
**FIGURE 3:** Low-frequency response after optimizing speaker placement, 3D ETF display.



**FIGURE 5:** Right-channel mid- and high-frequency response, 3ms gating, log scale.



**FIGURE 4:** Left-channel mid- and high-frequency response, 3ms gating, log scale.



**FIGURE 6:** Left-channel mid- and high-frequency response, 10ms gating, linear scale.

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Agent: Doug Plumb

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**Speak\_32** introductory beta version \$299.<sup>95</sup> USD.

**Fit\_32** available Jan. 1, 1999, \$399.<sup>95</sup> USD.

cally. Only one channel at a time was driven for all measurements.

Whenever I work on room acoustics, I like to improve the lower three octaves first. After finding the speaker positions that show the smoothest low-frequency response, I then check the upper six octaves. To do this, I listen for imaging qualities, which are generally better when the speakers are away from

the walls, and poorer when they are close. Rather than improve the imaging at the expense of smooth bass, I prefer to leave the new speaker locations alone and treat the room instead.

Because of this methodology, I elected to go straight to low-frequency evaluation. You display the time-frequency curve with just two mouse clicks, first for frequency-

range selection, then for the "top down" view. I chose the "20-200Hz Low Frequency Range" button, then the "Top View"<sup>2</sup> button. The frequencies 80, 120, and 170Hz were "missing," with very narrow-band dips in the time curve. But more importantly, long resonances of +300ms increase were seen at 55 and 130Hz. From 200Hz on up, the time-frequency curve was very con-

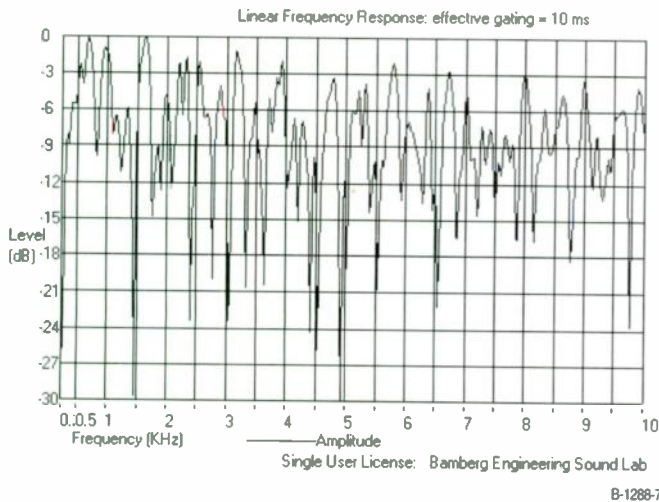


FIGURE 7: Right-channel mid- and high-frequency response, 10ms gating.

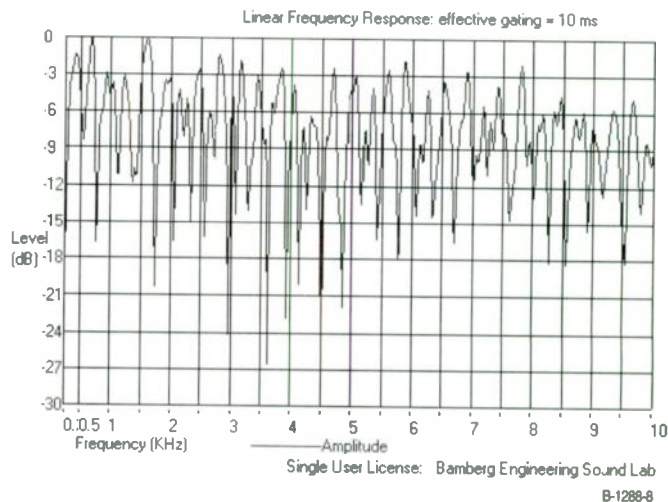


FIGURE 8: Left-channel mid- and high-frequency response with no diffusers.

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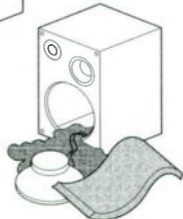
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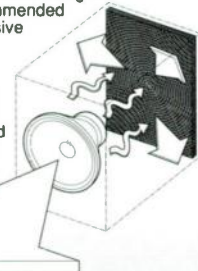
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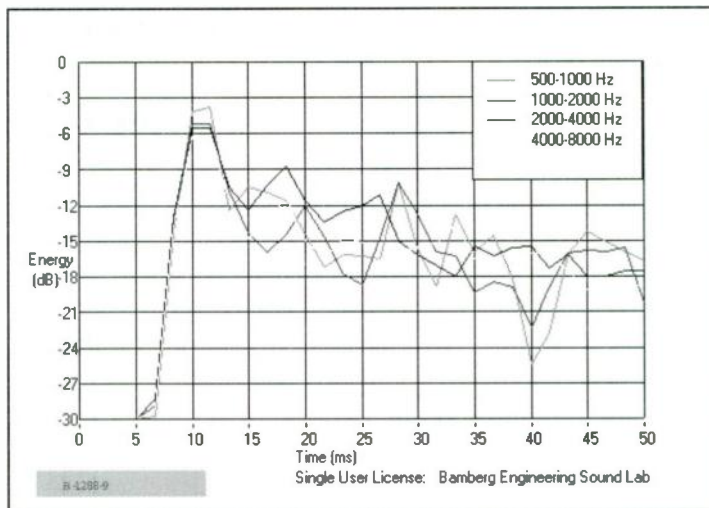


FIGURE 9: Left-channel with diffusers, ETC short-time display.

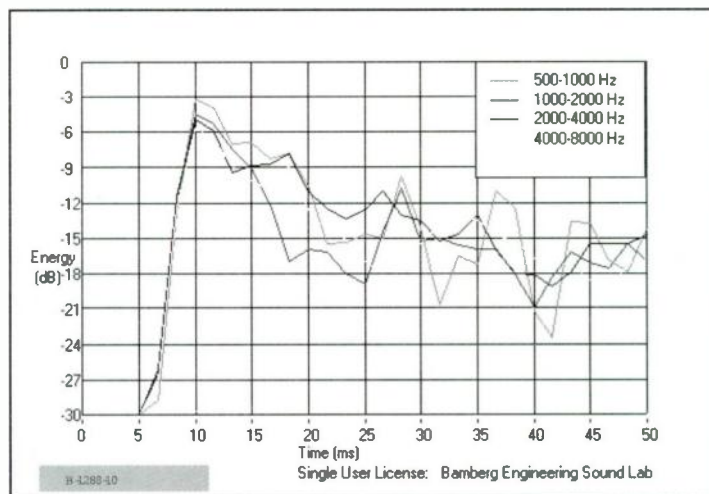


FIGURE 10: Left-channel with no diffusers, ETC short-time display.

sistent, averaging 250ms decay time.

Correlating the 60Hz resonance as a 9' half wavelength (the height of the room), we placed the speakers at one-quarter of this distance from the side walls, or 30" from the wall to the center of the woofer. To visualize how this "one-quarter-wavelength rule" is effective, imagine the wave leaving the speaker, traveling one-quarter wave to the nearest reflection, then traveling back to the speaker again. Now it has traveled one-half wave longer than the direct sound, and therefore is 180° out of phase, thus reducing the listener's perceived sound level. We also moved them to points 40" from the front wall. Now the woofers were located at x-y-z distances of 20", 40", and 32" from the nearest room boundaries.

## SMOOTH RESPONSE

Figure 2 shows the 20-400Hz low-frequency response at the new speaker locations. Although many resonances and nulls exist, they all reach approximately the same height and depth. In other words, this is actually a fairly smooth response. Notice also how the peaks don't exceed the average level as much as the valleys drop below it, and that the peaks have a rounded look, while the valleys have a sharp bottom. This is because in the speaker/room interaction, the loudspeaker is the driving force.

The room can *sustain* the energy, even reinforce it (up to several dB) at a modal frequency, but it cannot add any energy of its own. Conversely, the nulls are just that—they represent canceled energy. Increasing

the speaker drive level at a null frequency is largely ineffective. The room interaction continues to absorb that frequency just as well at the higher level.

This demonstrates that you should concentrate more on reducing problem frequencies, rather than trying to fill in cancellation frequencies. Figure 3 is the same data displayed in the 3D energy-time-frequency format. A true resonance appears as a long ridge that runs from the back to the front of the display. In this case, no resonance is seen to exceed 500ms.

Figures 4 and 5 show the 3ms-gated 500Hz–10kHz range for the left and right channels, respectively. (The shorter gate-window times are equivalent to more smoothing filters on the raw curves. The curve then looks closer to the familiar pink-noise-source frequency response.) Here you see more ripple in the right-channel response than in the left. For a closer examination, Figs. 6 and 7 show the same data calculated with the 10ms-gated analysis and displayed on a linear frequency scale. (This data is now valid for one extra octave lower.)

Now you more readily see the true nature of reflections. The classic comb-filtering effect of early reflections is displayed as a series of equally spaced spikes and dips. In this case, the 300Hz spacing corresponds to a 3ms delayed reflection. Apparently, the mini-blinds in the window on the left side of the room disperse reflected sound more than the hard closet doors on the right.

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Enough, now, of the familiar frequency-response curves that we have come to rely on so heavily. Take a look at that example I mentioned before, where the time-based curves show what's going on, while the frequency-based curves cannot. I said I like to position the speakers for the best bass response first, then improve the imaging with room treatments. How should the room be treated? With acoustic diffusers (and/or absorbers) strategically placed at the first reflection points.

To demonstrate their effectiveness, I mea-

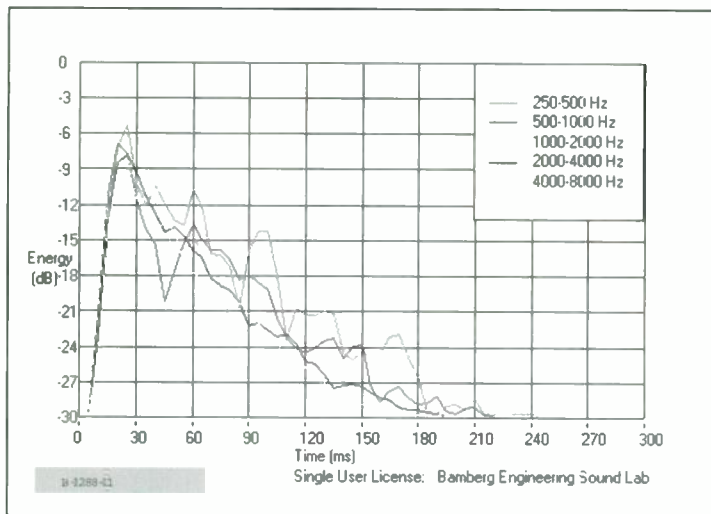


FIGURE 11: Left-channel with diffusers, ETC long-time display.

sured the room both with and without the diffusers in place. Figures 6 and 8 are the 10ms-gated frequency curves, with and without diffusers, respectively. Obviously, the plot with diffusers is cleaner than without. The characteristic difference is less distinct in the 3D waterfall plots (not shown).


Returning to the basic energy-time data display, Figs. 9 and 10 are the same data as in Figs. 6 and 8, respectively, but displayed as energy versus time (0–50ms). Now the effect of the diffusers is evident when you examine the time range from 10–20ms. This is typically the range for first reflections. On average, there is a 5dB drop in energy in this region when the diffusers are in place.

But wait, there's more. Figures 11 and 12 are the same curves, but displayed over the full 300ms range. Notice that with diffusers, the low-range curve is lower everywhere on the scale. With the diffusers in place, the delayed-energy curves show an increase in slope, dropping an additional

–3dB out at 150ms.

This also means that the room reverberation is shorter with diffusion. I clicked on "RT" and set the analysis-time window to 0–400ms to calculate the RT60 time for both cases. Without diffusion, RT60 ranged from

to page 58



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0.5–0.7ms. With diffusion, the RT60 curve (not shown) decreased to 0.5 and was perfectly constant at all frequencies.

### AUDIBLE RESULTS

From the sonic point of view, we noticed an improvement in overall frequency response as a “fuller” sound. This result is primarily from the improved speaker placement. Even more noticeable was the improved delineation of image placement and focus from left to right. For a single, centrally located listener in such a small room, you can get away with such a wide separation of the speakers. Otherwise, the image seems to “pile up” in the middle.

### SUGGESTED IMPROVEMENTS

The improvements made from version 3 to version 4 are fundamental and important:

- Source signal is available from either the CD player or the computer;
- Acquisition time is down to 20s, and can be made directly from the ETF program;

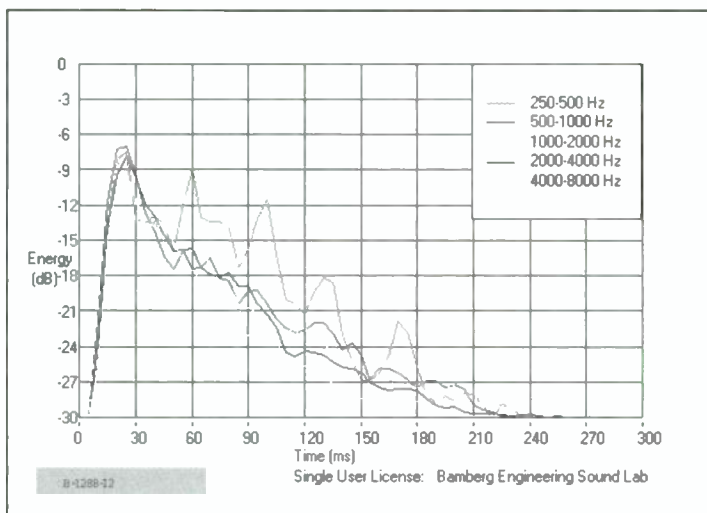


FIGURE 12: Left-channel with no diffusers, ETC long-time display.

- Raw-data amplitude and character are displayed to verify a good data set prior to analysis;
- Selectable gating times and linear/log scales display the data in the best way for interpretation and validity;
- Added harmonic-distortion capability;
- Improved RT60;
- Printing in color;
- Graph-export capability for subsequent publishing.

I would like to see further features added for the next version:

- If there's room on the CD, add some 1/3-octave test tones just for setting levels;
- ETF needs some kind of vertical-axis control, e.g., an absolute level for comparisons; also, set the 0dB level at one division down from the top. It needs selectable auto-scale/fixed-scale for vertical amplitude. The only way to conveniently compare changes is when you know the scale is not changing. With this feature implemented, I would next expect to see curve-overlay capability, which is better than the current “compare” feature.
- On the ETC displays, set time zero where 10ms is now. The left axis would plot at -10ms. Then all events plot with respect to the initial impulse being at time zero.
- Be able to annotate a minimum of the text file onto displayed curves.
- Notes files should follow the graph when swapping between compared files.

### CONCLUSION

At its eminently affordable price, I believe ETF is the most useful measurement program available for evaluating room acoustics. The graphical interface is excellent, with a large uncluttered display of the

curves, and just the right type and number of controls. Support documentation is quite thorough and is a must read for the first-time user.

### Manufacturer's response:

*Thank you for your review of my software. ETF software is built around tuning room acoustics. The design goals were to build an accurate and very robust tool that anyone could use (minimal hardware requirements) and supply great supporting documentation. You can run ETF on any laptop (Win95/NT) that has a half-duplex soundcard. More expensive analyzers can do what ETF*

*does and offer enhanced flexibility as well, but this enhanced flexibility requires much greater understanding of signal processing.*

*Tuning room acoustics is not an easy thing to do. ETF verifies results and is a measurement tool. This, along with our documentation and hard work, should allow nearly anyone to make an acoustical improvement.*

*One disagreement I have with the review is that it doesn't take three minutes to run a test. Test data acquisition time is 30 seconds, and to get frequency response and ETC diagrams takes less than 30 seconds after signal acquisition on a 486DX75 PC with 16 megs of RAM. If you decide to run a full test, it can take three minutes, but half of this time is spent calculating harmonic distortion, which is not required for room acoustics.*

Doug Plumb, ETF

### NOTES

1. Version 4.0 became available during the course of this review. I evaluated low-frequency room behavior with version 3, while I used version 4.0 for the mid/high-frequency behavior.
2. Note that the “Top View” feature of version 3 is replaced with “Examine Slice.” This is essentially the same function, but with the added ability to view the frequency-response curve at equal time intervals during the decay of the room sound. By “scrolling” through the series of frequency-response curves, it is easy to see how the reverberant nature of the sound progresses in time.

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# Driver Report

## AUDIOM TLR AND 7K2

By Vance Dickason

This driver report focuses on two new drivers from French OEM driver manufacturer, Focal. The Audiom TLR is a high-efficiency neo tweeter (*Photo #1*), while the Audiom 7K2 is a 7" high-efficiency midrange (*Photo #2*).

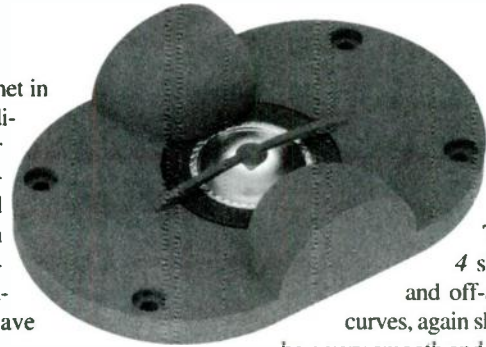
**Features:** The Focal Audiom TLR is a very elegantly crafted tweeter and comes packaged in its own decorative wood box. The device uses a 1" inverted titanium dome with a coated foam surround. The motor system

uses a neodymium ring magnet in conjunction with a 20mm-diameter aluminum-former voice coil damped with ferrofluid. The oval-shaped faceplate is made from 5mm-thick machined aluminum with a two-part machined solid-aluminum wave guide and phase plug.

The Audiom 7K2 is a high-efficiency midrange driver built with a semi-exponential Kevlar® cone, bullet phase plug for response correction, coated and pleated fabric surround, zamak alloy cast frame, and 40mm edgewound voice coil on a Kapton® former.

**Measurements:** I began by measuring the TLR's impedance using the LinearX LMS analyzer (*Fig. 1*). Resonance occurs at about 1175Hz, slightly higher than the factory spec of 1058Hz. The  $Q_{TS}$  specified by the factory was 0.51 with a 6.0Ω DCR, which was also close to the LMS-calculated 0.58  $Q_{TS}$  value with a 5.78Ω DCR. While Focal uses ferrofluid in the gap for cooling on the TLR, I adjusted the viscosity in this case so as not to damp the resonance.

Next, I mounted the TLR in an enclosure with a 15" × 8" baffle. Since I was not able to inset the oval-shaped faceplate, I built up a foam surface on the baffle level to the top edge of the faceplate for a reasonable chance at seeing the response of the tweeter without mounting-caused diffraction artifacts. *Figure 2* shows the frequency response to be very smooth and flat out to 20kHz with a ±2.2dB window. The factory measurement shown in *Fig. 3* gives a response that is ±1dB, undoubtedly obtainable with a better baffle arrangement than was available when I mea-



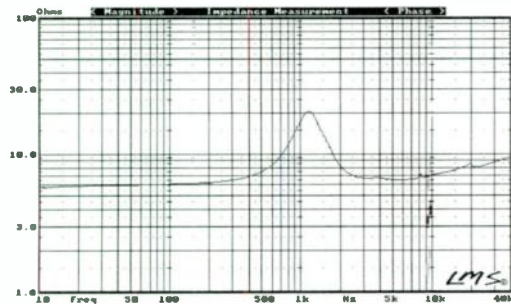
**PHOTO 1:** The unique Audiom TLR neo tweeter.

sured the TLR. *Figure 4* shows the on- and off-axis response curves, again showing this to be a very smooth and well-behaved

tweeter.

When measuring the 7K2, I imported the LMS-measured free-air impedance curve data (illustrated in *Fig. 5*) into the LEAP software. I then calculated T/S parameters using the LEAP curve-fitting routine. These parameters are compared to the factory data in *Table 1* (only single samples were submitted by Focal for this test).

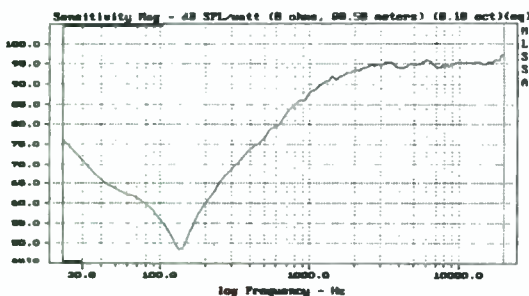
Although this driver is intended for use as a midrange driver and accompanied by some type of high-pass filter, I went ahead and performed a box simulation to see how large an enclosure would be required and how "loud" and "low" this driver would play. I made a



**FIGURE 1:** Focal Audiom TLR tweeter impedance.



**FIGURE 2:** TLR on-axis frequency response.



**FIGURE 3:** TLR factory on-axis frequency response.

**TABLE 1**

**T/S PARAMETER SET FOR AUDIOM 7K2**

	SAMPLE A	FACTORY
$f_s$	99.1Hz	99.9Hz
$R_{EVC}$	5.89	6.2
$Q_{ME}$	7.36	7.70
$Q_{ES}$	0.32	0.36
$Q_{TS}$	0.31	0.34
$V_{AS}$	8.0 ltr	9.1 ltr
Sens.	96.3dB	95.2dB
$X_{MAX}$	3.5mm	3.5mm



**FIGURE 4:** TLR on- and off-axis frequency response (solid = 0°, dot = 15°, dash = 30°, dash/dot = 45°).

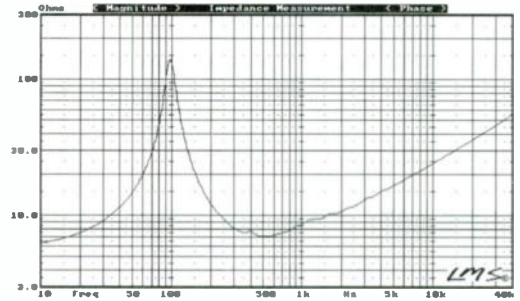
sealed-box computer simulation for the 7K2 with a 0.06ft<sup>3</sup> volume (not much bigger than is required to fit over the large magnet assembly) modeled with 50% fiberglass fill material. The results at 2.83V and 25V are depicted in Fig. 6. The midrange had a low-frequency limit of about 212Hz with a 90°

phase angle equivalent to a box Q<sub>TC</sub> of about 0.7. Figure 7 offers the group-delay curve at this voltage level.

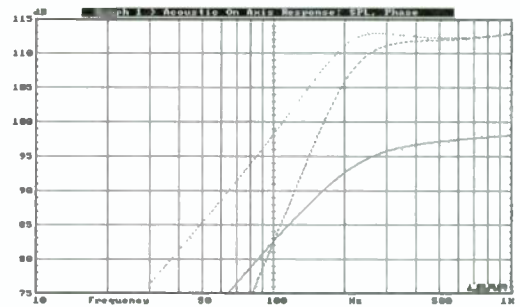
The 25V curve displayed in Fig. 6 also has an additional plot, showing the response with a 250Hz second-order Butterworth high-pass filter. Figure 8 has the excursion curve for the 25V level with and without the 250Hz high-pass filter. The maximum excursion at this voltage level with the SPL at a substantial 113dB is only about 2.25mm without the filter, and only 1.2mm with the filter. Since X<sub>MAX</sub> is 3.5mm for this driver, the limitation will likely be thermal before the voice-coil excursion maximum is reached. This is indeed a high power-handling product.

I measured frequency response semi-anechoically using a gated sine wave with the driver mounted in an enclosure with a 15" × 8" baffle. The on-axis curve is shown in Fig. 9. The response is very smooth and exhibits no major breakup problems at higher frequencies. The on- and off-axis response in Fig. 10 shows a -3dB frequency at 30° from the on-axis response to be about 2.7kHz. This would likely be a good maximum crossover frequency if the goal is to maintain a good system power response. Looking at the overall response profile, a crossover at this frequency would probably yield a very tight response of per-

**PHOTO2:**  
Focal's 7" Audiom 7K2 midrange.



**FIGURE 5:** Focal Audiom 7K2 midrange impedance plot.



**FIGURE 6:** 7K2 enclosure simulation (solid = 2.83V, dot = 25V, dash = 25V with 250Hz high-pass filter).

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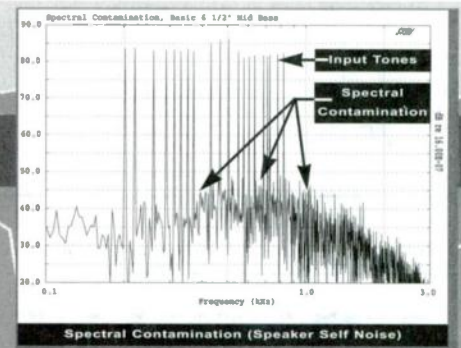
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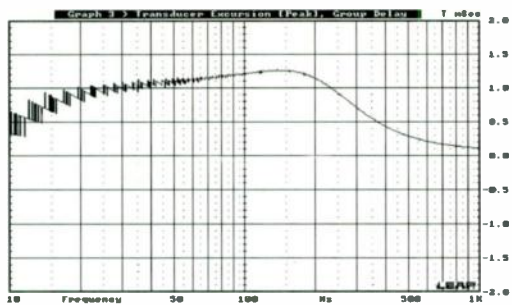


FIGURE 7: Group-delay curve for 2.83V plot in Fig. 6.



FIGURE 9: 7K2 on-axis frequency response.

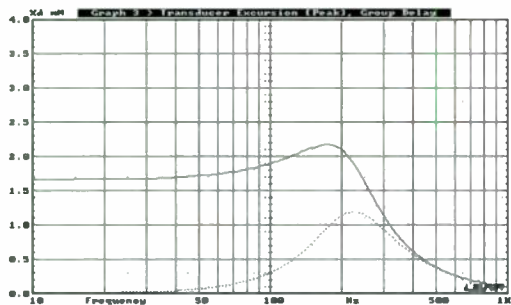


FIGURE 8: Cone-excursion curves for Fig. 6 (solid = 25V, dot = 25V with 250Hz high-pass filter).

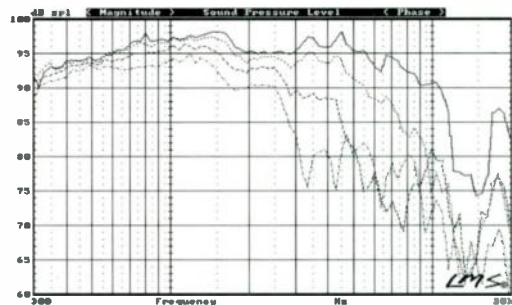


FIGURE 10: 7K2 on- and off-axis frequency response (solid = 0°, dot = 15°, dash = 30°, dash/dot = 45°).

haps  $\pm 1$ -2dB quite easily, depending upon the baffle arrangement.

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◆Power handling: 50 watts RMS/75 watts max ◆Voice coil diameter: 1" ◆Voice coil inductance: .70 mH ◆Nominal impedance: 8 ohms ◆DC resistance: 5.6 ohms ◆Frequency range: 54-5,000 Hz ◆Magnet weight: 12 oz. ◆Fs: 54 Hz ◆SPL: 88 dB 1W/1m ◆Vas: .42 cu. ft. ◆Qms: 1.50 ◆Qes: .46 ◆Qts: .35 ◆Xmax: 2.0 mm ◆Net weight: 2.6 lbs. ◆Dimensions: A: 5-1/2", B: 4-1/2", C: 2-3/8", D: 3-3/8", E: 1-3/8". **Ask for part #297-304.**

## M17SG-09-08, 6-1/2" Shielded Cast Frame Woofer

This affordable 6-1/2" shielded woofer is well suited for any A/V application. It features a cast magnesium basket, treated paper cone, rubber surround and a very smooth frequency response. Designed for vented enclosures with .35 to 1.00 cu. ft. of internal volume.

◆Power handling: 50 watts RMS/70 watts max ◆Voice coil diameter: 1" ◆Voice coil inductance: .7 mH ◆Nominal impedance: 8 ohms ◆DC resistance: 5.6 ohms ◆Frequency range: 34-5,000 Hz ◆Magnet weight: 12 oz. ◆Fs: 63 Hz ◆SPL: 89 dB 1W/1m ◆Vas: 1.87 cu. ft. ◆Qms: 1.36 ◆Qes: .47 ◆Qts: .34 ◆Xmax: 3 mm ◆Net weight: 2.6 lbs. ◆Dimensions: A: 6-5/8", B: 5-3/4", C: 3-3/8", D: 3-1/2", E: 1-1/2". **Ask for part #297-307.**

## P17SJ-00-08, 6-1/2" Shielded Cast Frame Woofer

The shielded version of the famous P17WJ-00-08, this woofer is perfect for A/V applications. It utilizes a cast magnesium basket, rubber surround, mineral filled polypropylene cone and a very smooth frequency response. Intended for use with vented enclosures with .35 to 1.00 cu. ft. of internal volume.

◆Power handling: 70 watts RMS/100 watts max ◆Voice coil diameter: 1-1/4" ◆Voice coil inductance: .84 mH ◆Nominal impedance: 8 ohms ◆DC resistance: 5.6 ohms ◆Frequency range: 35-5,000 Hz ◆Magnet weight: 25.4 oz. ◆Fs: 41 Hz ◆SPL: 87 dB 1W/1m ◆Vas: 1.16 cu. ft. ◆Qms: 1.28 ◆Qes: .48 ◆Qts: .35 ◆Xmax: 4.0 mm ◆Net weight: 3.8 lbs. ◆Dimensions: A: 6-5/8", B: 5-3/4", C: 3-1/2", D: 4", E: 1-3/4". **Ask for part #297-308.**



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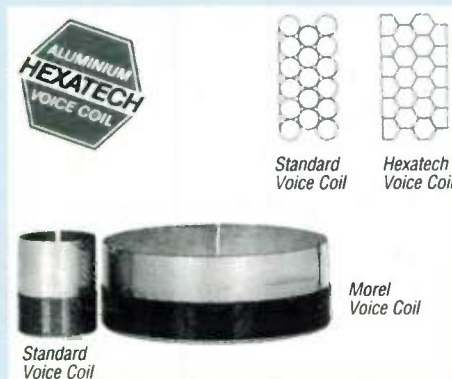


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