DIAGNOSING SPEAKER FAILURE—AND HOW TO PREVENT IT

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Speaker Builder®

THE LOUDSPEAKER JOURNAL

Taming The SUBWOOFER MONSTER
Bruce Carpman

Another Snail: A SIAMESE TWIN
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Editorial

WORDS, WORDS, WORDS

Our language in the English-speaking world is always in flux, at the mercy of any way at all that someone–or everyone–cares to use it. Lexicographers, like politicians, seem to follow public whim rather than holding to some kind of standard. Dictionaries must now be issued in new editions much more often just because usage determines meaning.

Speaker builders have a language as well and I thought it might be worthwhile to give a bit of space to discuss some of the words we use. From this I hope we can reach some kind of consensus on usage, or perhaps raise the issues for wider, and I trust fruitful, discussion.

The most obvious confusion is in the way we discuss this avocation's subject. I refer to the apparently interchangeable use of two words: speaker and driver. It seems to me there ought to be an easy way to avoid the kind of confusion which arises when we use the word "speaker" to refer to a box with drivers in it, and also to the motorized piston in a frame, to which we attach wires to push air into a room: the driver.

Our editors are constantly having to substitute the word "driver" for "speaker" when it is obvious that the writer means a woofer, a midrange or a tweeter, the hardware transducers which convert energy into motion into sound. I suppose speaker driver is an acceptable pairing, but when we mean a transducing device, it is just confusing to call it a speaker.

The second hazard is the pair of words grill/grille. The first of these is a device for overcooking hamburgers and hot dogs–sometimes referred to as frankfurters. The second is usually a cover for something unsightly (although most of us who like loudspeakers would not think our favorite drivers are objectionable visually.) However, the frame covered with sonically transparent material (approximately) which we use to cover the radiating face of a speaker is a grille, not a grill. The latter term is also sometimes used, English being what it is, to refer to an establishment that serves food, usually cooked by a grilling method. You can use the word as a verb, of course, if you are Kenneth Starr trying to cook the truth out of someone who has worked for or who is a friend of the President of the United States.

Recently I began to note that some of us are having trouble with another pair of words–generally confusing the two. The words are damping and dampening. Damping is an action of stopping something which is vibrating from doing so. The second of these terms means to make something wet. Stuffing a box with fiberglass or wadding or nylon fluff does not wet the box–it damps it. This damping effectively makes the box less reverberant and also sonically "larger" (which author Dick Pierce will tell you all about one of these days in an upcoming article).

This is as good a place as any to mention electronic quantity abbreviations. The pantheon of electronics pioneers include a group of people whose names have been attached to the phenomena they discovered.

Nicolo Volta gave his name to the pressure of an electrical charge (volts, abbreviated V). Georg Ohm is credited with discovering resistance; however, he had an unfortunate name since the capital O and the zero symbol would be hopelessly confusing so we substitute the Greek letter Omega (Ω) to designate the R quantity. Georg also formulated the law which bears his name $V = IR$. We attach André Marie Ampère's name to quantities of current since he formulated his part of the Ampere-Laplace law. There's also Michael Faraday and his clumsily large farad and Joseph Henry whose name is associated with units of inductance or permeance.

Now the rule is that we honor these guys and others whose names we associate with important quantities by capitalizing the letter representing the quantity (except for Mr. Ohm), but we spell out their names with a lowercase first letter when we are discussing those quantities (for example, ampere is abbreviated A, and henry is abbreviated H).

Indulge me a bit if you will here. The current wide, and depressing, use of a fine word is ruining it for its intended use. "That's incredible!" has become a cliché and is being used to mean a wide variety of adjectival alternatives such as beautiful, amazing, astonishing, surprising, unbelievable. I think usually that "awesome" is probably nearer to what people mean. Incredible is the inverse of credible–which simply means believable. Incredible in common use ought to mean that the person so described is lying, not to be believed, which is the problem the U.S. Senate was having with the President.

And while I have your ear, indulge me one further mini-diatribe: nearly everyone in our current age seems to me to have discarded a very large number of perfectly useful words in favor of what has seemingly become the omnicompetent one: FEEL. Feel is now being treated as a description of any number of mental states such as think, suppose, believe, judge, suspect, and many others. I suppose the state of the language has to do with society's present attempt to become as casual as possible about nearly everything. Manners are a joke, anything but first name attribution is a sign of anger or protest.

Ah well, the editor must be getting old. I'd better stop before all this gets out of hand.–Ed.

About This Issue

The pride and satisfaction that comes with a DIY approach to speakers is evident in **Bruce Carpman**'s project in this issue ("Frankenstein's Speakers," p. 8). His subwoofer design serves a dual purpose—as an elegant end table, and as a "monster" speaker that has made all the difference to his system.

Louis C. McClure shares with *SB* readers a little device he has found useful in his hobby. His "Handy-Dandy Impedance Measurement Device" (p. 22) is easy to build and works well, so we trust you, too, will find it useful in measuring speaker impedance.

The latest handiwork from **Bill Fitzmaurice**—"The Siamese Snail" (p. 26)—derives its name from the fact that this design shares one driver between two cabinets. The result is a unit that accommodates a popular 15″ driver, is the most efficient Snail to date, and delivers super performance.

Mark Williamsen provides a thorough look at some of the common causes of driver failure...during manufacture, in the field, or in use at home. He also shows you how you can detect many of these defects yourself, and, most importantly, how to fix them ("Loudspeaker Failure Modes," p. 34).

Mark Florian takes over the reviewer's chair in this issue as he critiques the latest speaker kit from Norwegian manufacturer SEAS. These Odin speakers serve double duty for both home audio and home-theater use, without the need to add a subwoofer ("Test Drive," p. 44).

Speaker building is as much an art as a science, and for years builders such as **L.J. Mertz** ("Bessel Box Subwoofer") have been wrestling with the duality of this hobby. Turn to p. 55 to find out how this author's subwoofer project incorporates an attractive and functional unit in his living-room setup.

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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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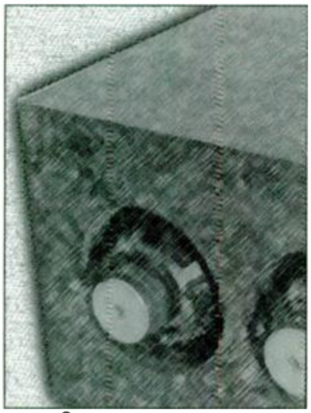

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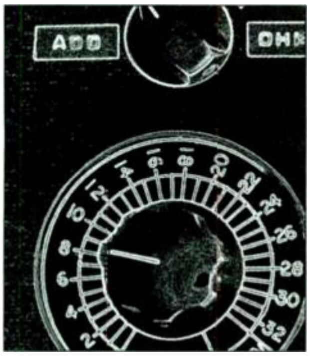

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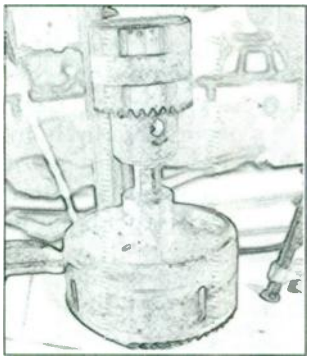

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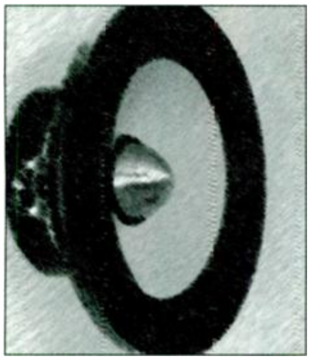

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Sometimes the simplest sub project can suddenly assume a life of its own and take over your living space. One audiophile relates his terrifying encounter with a 7-feet-tall giant.

Frankenstein's Speakers

By Bruce Carpman

Building a subwoofer to augment the bass from my KEF C85s seemed like a fairly modest project. I had been very happy with the overall sound quality of the KEFs since purchasing them six years before. I knew that someday I'd want to upgrade, but that would require an upgrade of almost my entire system, and I wasn't quite ready to open up my wallet for that project (I thought).

Although it had been quite some time since I had pursued DIY speaker building, I thought a few weeks' research would bring me back up to speed. I did not take the DIY approach to save money. I've learned from experience that by the time I'm done with a given project (if ever), I will have spent more money and time than I could justify. I did, however, wish to build a subwoofer that integrated perfectly into my living space. Also, after testing several commercial high-end subs, I believed I could do better myself.

UNINTENDED EVOLUTION

Two years later, this project has evolved into the entire system upgrade I had been trying to avoid. The end result is an active three-way system consisting of:

- One 350-lb subwoofer (*Photo 1*) from 10–70Hz containing four Audio Concepts, Inc. (ACI) DV12s in a dual Isobarik configuration and driven by a 3,000W Hill Audio professional amplifier;
- Two 3.5′-tall midbass drivers (*Photo 2*), each containing four Vifa long-throw 8″ drivers run from 70–250Hz, powered by a pair of Carver TFM 35 amps bridged to 700W each into 8Ω;
- Two 7′-tall Planer Magnetic speakers (*Photo 2*)—hereafter called ribbons for simplicity—from 250Hz up, driven by two Carver Silver Nine Ts for 900W each into 5Ω;
- Five amplifiers supplying a total of over 6kW of RMS power (not including center and surrounds);
- A home-built four-band parametric equalizer for the sub, a two-channel home-built six-band ⅓-octave equalizer for the midbass drivers, and a three-band parametric digital equalizer for the ribbons.

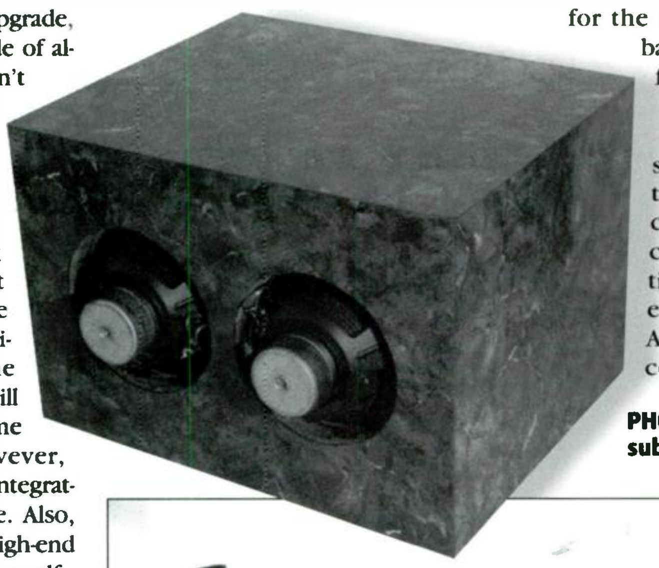

PHOTO 1: The author's dual Isobarik subwoofer "monster."

Although Audio Concepts supplied every driver in the system, this occurred entirely by coincidence. At each stage of construction, my initial investigations started elsewhere, but in every case wound up back at ACI. In fact, I had already done considerable research on the

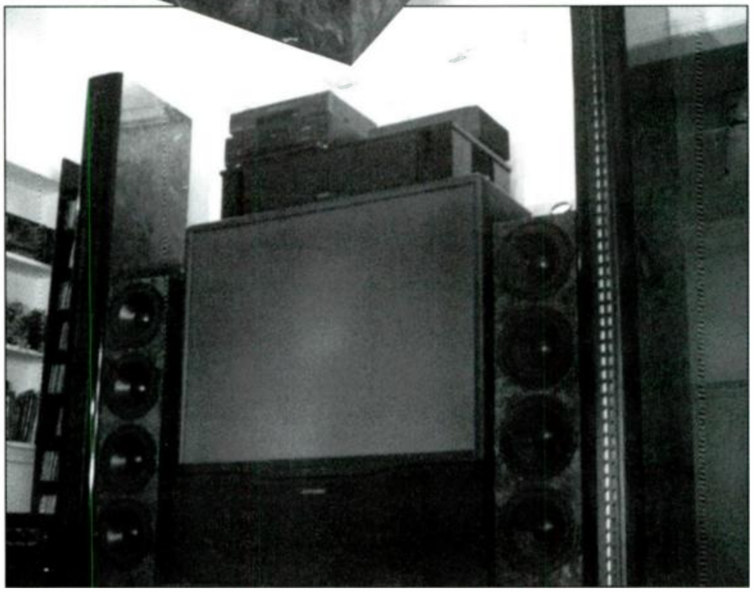

PHOTO 2: The author's completed system.

Bohlender Graebener RD75 ribbons before discovering ACI's performance-modified version called the VLS (vertical line source).

Not only did ACI supply the drivers for this system, but its customer support was exceptional–defective drivers replaced with no questions asked, and drivers exchanged for another brand when my initial calculations proved to be incorrect. My questions were always adequately answered (I dealt with Mike at ACI, almost entirely through E-mail).

Most of this article deals mainly with design philosophy and test results. I do not include detailed construction plans, since if you attempt a project of this magnitude, you'll probably wish to alter box shape to suit your personal living space. I'll also not deal with basic speaker-design theory to avoid repeating what others have covered elsewhere.[1]

THE DV12 SUBWOOFER

My initial intent was to integrate the sub into a coffee table in the middle of the room. I had it laid out very artistically, with the woofers firing upwards at an etched glass tabletop suspended several inches above them. It didn't take much research to figure out that this wasn't going to work for a number of reasons, primarily because a sub will lose most of its authority when placed away from room boundaries.

Driver selection for the subwoofers proved more difficult than I expected, although the final results were good. I started by calling most of the driver suppliers who advertise in *Speaker Builder*. My request to each was that I was looking for a subwoofer driver with which they had had good experience and which would extend deep into the low 20s, if not the high teens. I told them driver or box size was flexible, and that price was not an issue.

In every case, they recommended an 8″ or 10″ driver with resulting f_3s in the low 30s and peak-excursion limited output in the 110dB range. I could use several sets of these drivers to achieve acceptable maximum output, but they still wouldn't extend low enough, and box volume would be huge. I concluded that this was unacceptable, given that I was placing no real restrictions on the project.

The answer came once I placed a question on CompuServe's CEAUDIO Forum. One individual recommended ACI's DV12 as perhaps the ultimate sub driver. Once his reply was posted, it was quickly seconded by several others who had experience with this driver. In fact, one of the forum lurkers with whom I later talked by phone said he had tested just about every sub driver available.

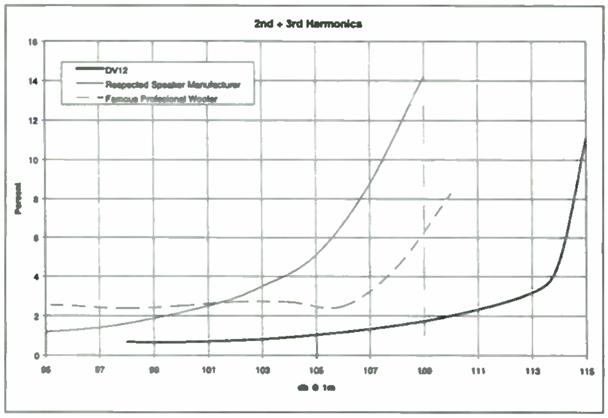

FIGURE 1: Comparison of the THD versus SPL characteristics of the author's final sub.

TABLE 1
DV12 SPECS

Impedance:	8Ω
f_s:	17Hz
Sensitivity:	89dB
Voice Coil:	50mm
S_d:	0.0545
X_{max}:	10.54mm
Q_{ts}:	0.44
V_{as}:	380ltr

He had found only one driver that exceeded the DV12 in performance, an 18″ giant with an aerospace-derived rare-earth magnet that required a cabinet the size of a walk-in closet and cost over $3,000 each. So I decided to settle for some DV12s. Several articles have been written for *Speaker Builder* about the DV12, but for those unfamiliar with it, the specifications are in *Table 1*.

LOOKS ARE DECEIVING

The DV12 is a dual-voice-coil driver with a fiber-reinforced paper cone and a stamped basket. The magnet seems small in diameter when compared to other high-quality drivers, and it appears quite long because of the dual voice coils and long throw.

Overall, the DV12 is not very impressive looking, but, as is sometimes the case, looks can be deceiving. It is a very clean (low THD), low-frequency driver that reproduces well into the inaudible 10–20Hz region. ACI is currently in the process of changing to an attractive cast-basket design for those who wish a more expensive-looking unit.

Figure 1 is a comparison of the THD versus SPL characteristics of my final sub. The two comparison drivers are normalized for driver size. In other words, you'd shift a driver with half the cone area 3dB to the right on the graph, since you'd expect 3dB less output. In this way, you can evaluate a driver's distortion characteristics independent of its size.

Although this is an unusual way to compare drivers, I believe it is more accurate than trying to compare them directly. An even more accurate method of comparison would be to normalize by box volume, but this quickly becomes complicated when you start to look at different possible volumes for each driver.

I do not mention the names of the comparison drivers for two reasons. First, I consider both to be quality drivers from reputable manufacturers, and I do not wish to disparage them, especially since both were probably designed with other characteristics in mind (extended high-frequency response, efficiency, long-term durability for professional use, and so on).

Second, these three sets of data were taken on different dates, in different locations, with slightly different testing equipment, and I do not wish to engage in battle with anyone if I'm not totally confident of my data. If not precise, this data is at least representative of these drivers. Conclusion: The DV12 plays very clean and also very loud.

CLOSED-BOX APPROACH

This DV12 is specifically designed for closed-box applications, and I believe there is nothing to be gained from porting it. It would not really improve low-frequency extension, and such a design would lose the natural low-frequency power handling that a closed box provides. (I have currently run more than 700W through each driver without damage or excessive heat.) Also, even the best ported design would have inferior transient performance.[2]

At this point I was undecided whether a single sub or a stereo pair would be preferable. I decided to build the initial test box with the goal of making a stereo pair that would integrate well with my

ABOUT THE AUTHOR

Bruce Carpman is an engineer for one of the big three auto companies, where he designs and implements testing systems in a powertrain laboratory. He has a degree in mechanical engineering from Georgia Institute of Technology, but finds his knowledge of computer and electrical engineering more useful. When he is not at work, he engages in many different activities, including customizing automobiles, building speakers and related electronics, mountain biking, and snowboarding.

KEFs. The subs would then serve double duty as a speaker stand. This "L" shaped box (*Photo 3*) was not easy to construct. I used steel internal bracing to maximize stiffness and minimize the internal volume occupied by the bracing. Since the driver would be in plain sight, I thought it was aesthetically necessary to mount the drivers back to back (if I decided the Isobarik configuration was indeed the way to go).

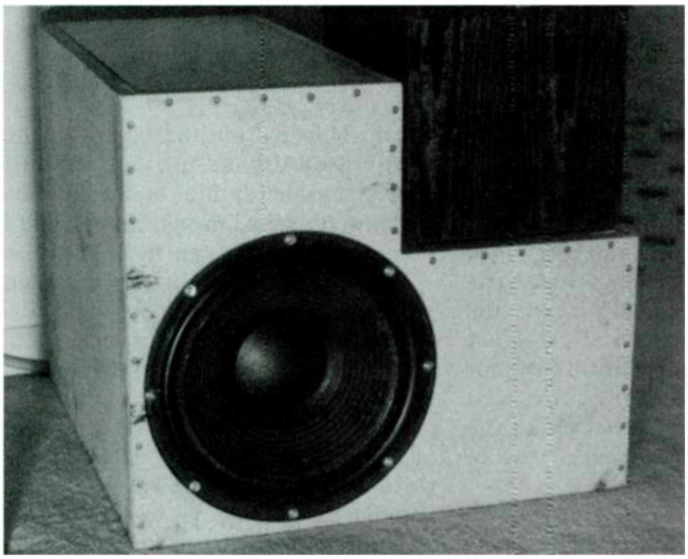

PHOTO 3: The initial "L-shaped" test box.

This necessitated constructing a tunnel to connect the two woofers. Using a cardboard form, I constructed a fiberglass/carbonfiber tube—again to maximize stiffness and minimize displaced volume. I coated the entire inside of the box with half an inch of roofing tar mixed with sand. This whole process was much too time-consuming for a test box, and, as you will see, I used different methods for the final subwoofer.

About midway through my construction of the first test box, Tom Nousaine's excellent article on subwoofer placement appeared.[3] His testing seemed to be well executed, so I decided to use my completed test box to confirm that his data applied to my system. Although I could not at this point test for the difference between mono and stereo operation, I thought that if I proved to myself that the single sub was unlocatable when operated under 80Hz, then a stereo pair would be unnecessary by definition.

I moved the single sub back and forth from under the right KEF to the left rear corner of the room and conducted blind and non-blind testing with several people. Although one individual thought he could "feel" the bass coming from beside him instead of in front (non-blind test), in over a year of use and dozens of demos with various individuals, no one has been able to locate the source of the bass until told that the end table is really a subwoofer in disguise.

CORNER REINFORCEMENT

The other determining factor I gleaned from Nousaine's article was the added bass reinforcement available when I placed the sub in a corner. My testing directly supported the article's conclusions. When placed in the corner, the sub extended at least 10Hz lower and was much more substantial at high-volume levels. The bass is still low and clean, but much of the visceral feel is gone.

I still think it would be better to derive all the bass directly from the driver instead of relying on room reinforcement (that is, to have a large enough subwoofer array in a very large room so that you are always sitting in the near field). But judging from my experiments, this would require four or eight of these Isobarik pairs, with somewhere on the order of 10kW of power. This is a little out of my league for now.

I decided to go with an Isobarik design for this subwoofer. The DV12 requires a rather large box for the low Q (<0.8) I desired. An Isobarik configuration is one in which you place two drivers acoustically in series (preferably front to front or back to back). When run in this fashion, equivalent box volume is doubled, allowing the cone area of two drivers in a box that would normally hold only one.

Of course, now the system would have four drivers (two Isobarik pairs), but this is a small price to pay for ultimate bass reproduction. I would have preferred an overdamped system, but obtaining a Q of less than 0.7 would have required a huge box, even in an Isobarik configuration (~9 ft^3).

ISOBARIK PROS AND CONS

Another claimed benefit of an Isobarik configuration is lower THD. This proved to be true to a modest extent at low volume levels. Where the Isobarik configuration seems to help most is at high SPLs, where it is able to play cleanly well past its theoretical X_{max}.

The disadvantage of the Isobarik configuration is the great amount of power necessary to drive this system. Some might find this to be a major impediment, but used high-power professional amps are generally available from dismembered bands and defunct night clubs. Note that the amp used here must extend only to somewhat less than 100Hz and doesn't need to be as fast or articulate as that used for the main speakers.

Some might ask why I need so much bass. First of all, I listen to all types of music, some of which simply sounds better when played loud and deep, and loud music becomes much less fatiguing when it is distortion-free. The second reason is more complex. It's my opinion that systems designed to play very loudly sound less strained and produce dynamics with a more effortless quality than do lesser systems. Whatever your opinion of horn drivers, this is usually one quality for which they are praised.

After taking measurements on several systems that do and do not meet the above criteria, I determined that 115dB was a good cut-off point. In other words, every part of the system should be capable of producing close to 115dB at 1m without distortion, compression, or any other negative effects. Of course, all speakers produce distortion (THD or intermodulation [IM]), and an increase in SPL always shows some compression. The object is to find the knee in the curves—the point at which the distortion increases dramatically.

My goal was to keep the second and third harmonic below 1% over the entire frequency range of each driver up to 115dB at 1m. Initial testing and research showed that IM distortion and compression would usually start to occur at approximately the same SPL as high levels of harmonic distortion. Hence, I concentrated on THD, which is easier to measure. (Since I tested over a dozen different drivers and many finished speakers while building this system, testing simplicity was helpful.)

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Unfortunately, nothing is ever free. In order to achieve my other goals, I had to sacrifice something, and I chose efficiency. This will be true throughout the entire project. The average efficiency of the entire system is approximately 87dB. A lot of power is required to reach 115dB.

SUBWOOFER LOCATION

As I've already indicated, I decided to locate the subwoofer in an out-of-the-way corner between two couches that were already in need of an end table (*Photo 4*). Although a 6ft^3 internal-volume subwoofer makes for a rather large end table, the depths of the couches allowed it to fit nicely without occupying more space in the room. In fact, even when it's in use, very few people will figure out it's not just a piece of furniture.

The end-table design allowed for a more constructable box than the L-shaped prototype. Also, using it as an end table next to the couch got it out of the way of the rest of the system (the front of the room is almost a wall of equipment at this point). I am still unsure whether having the sub next to the listener is a good thing. I'm crossing over at 70Hz with a high-quality, fourth-order filter, and if I could have placed it in a front corner, all arguments about being able to locate the sound would have been moot.

As it is, some very astute listeners will notice that they can sense the sound coming from beside them, even if they can't hear where it's coming from. This may seem like a bad thing for some listeners, but you also gain an advantage from this situation: you can *experience* the bass. With certain types of music and almost all movie sound tracks, this is a very big advantage. I don't think I could achieve this visceral sensation if I placed the sub in the front corner.

When I get a new house and am able to set up separate music and video systems, I'll probably experiment with shakers attached to the couch for the movie systems. These devices have gotten good reviews,[4] and they would allow me to place the sub in a front corner.

How stiff or well damped must a top-quality speaker enclosure be? Some of the "experts" on CompuServe CEAUDIO suggested that this is totally irrelevant. Except for very poorly constructed boxes, no added coloration of the music derives from the box itself. Although I have not verified this one way or the other, I believe you can find at least some degree of coloration in the box itself.

On my sub, for example, the woofers have a combined surface area of about 0.1m^2, and the box an area of over 4m^2. In my own as yet unproven logic, this means that to generate a 1% noise level, only 1/4000 of the motion of the speaker need be imparted into the box itself. Since my research failed to indicate any scientifically proven data on this topic as it correlates to audiophile-grade speakers, I decided to go with what I thought were some "directionally correct" assumptions.

ENCLOSURE QUALITY

What makes the best speaker enclosure? Should it be well damped, or very stiff, or some combination of the two? For instance, grade AB plywood is stiffer than medium-density fiber board (MDF), but it is not as well damped. A sand/tar mixture will do an excellent job of damping the box, but will add no stiffness.

A well-damped enclosure quickly absorbs any energy imparted into the box, causing quick decay of transients without lasting resonances, but it should also theoretically slow up the attack of a transient. In the limiting sense, imagine a woofer attached to a perfectly damped wall. Any force applied to it, along with the resulting motion, would be immediately absorbed, causing a total lack of sound. A perfectly stiff box, on the other hand, would neither absorb nor transmit anything, allowing the driver to do its job perfectly. Unfortunately, a perfectly stiff box is just as unobtainable as a perfectly damped box.

In the real world, as you increase the stiffness of a panel, its resonant frequency will increase. Theoretically, if you could stiffen the panel to a point where all the resonant frequencies are well above any input frequencies, it should be "stiff enough." It's commonly accepted that if an object's lowest resonance is at least five times the excitation frequency, the input will not excite the panel.

Since the first resonances of normal ¾" MDF panels are generally in the 50–300Hz region, an exceptionally stiff, well-braced panel should easily meet the above standard when used for a subwoofer with an 80Hz crossover. Extra damping is then unnecessary, assuming the motion of the woofers doesn't cause the entire box to move (solved simply by making the box very heavy).

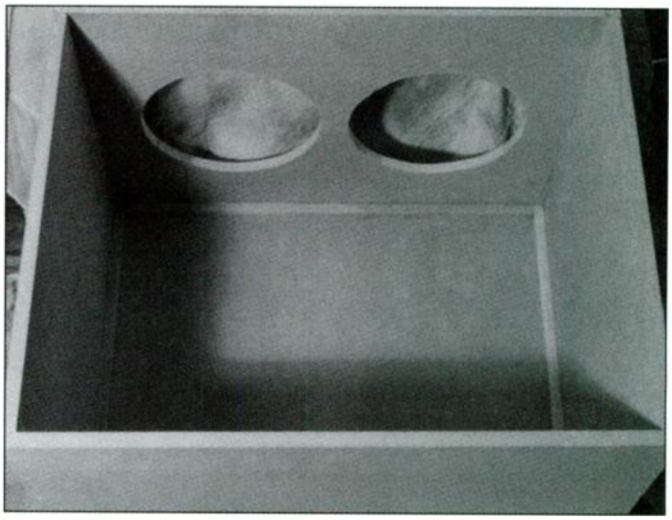
Instead of damping the box with sand and tar, I constructed this box using two layers of ¾" MDF sandwiched around ½" of sand/epoxy mixture. Plain sand would have made for better damping, but wouldn't have been nearly as stiff.

CONSTRUCTION DETAILS

For several reasons, I won't provide complete plans for this system. First of all, I designed it specifically for my room and

PHOTO 5: The bottom panel requires special construction to allow access to the inside of the box.

PHOTO 4: The sub in the corner between two couches.



World Radio History

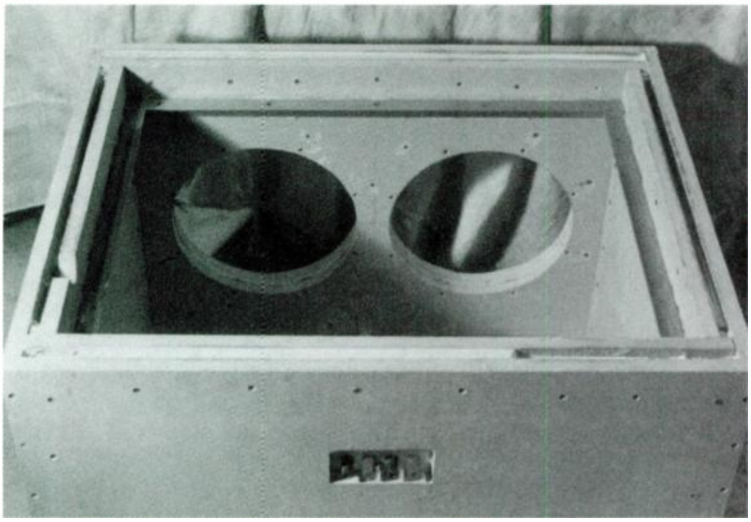


PHOTO 6: Double-box construction to accommodate the sand/epoxy mixture.

listening habits. I would highly recommend you do the same. Second, I continually modified my original plans as I went along, and I'd not be satisfied to provide a modified version of my initial plans, since I might accidentally leave something out. Third, I cannot imagine anyone actually trying to duplicate my efforts. We're talking about a lot of work here.

Except for the bottom, I cut and constructed the outer panels of the sub in a conventional fashion (*Photo 5*). Then I cut strips of ½″ × 1″ molding and glued them into the top corners. At this point I poured the first batch of epoxy/sand mixture onto the top panel until I could level it to the edge of the half-inch molding (obviously done with the sub upside down).

Before the epoxy set, I placed a second top piece of MDF into the box on top of the epoxy and molding, gluing it to the molding and screwing it into place. I inserted several screws through the middle of the panel to render the epoxy as void-free as possible. In doing this, you must take care not to warp the outside panel.

Next, I cut more molding and glued it into the corners of one side, as well as down the middle of this side panel. I attached a second side piece of MDF to this molding. Sand/epoxy mixture was then poured into the slot at the top of this side (actually the bottom), and I forced a final piece of molding down into the slot horizontally to compress the epoxy as well as to seal it in (*Photo 6*).

I repeated the above procedure for the remaining three sides. The only thing different about the front panel was that I cut a piece of ½″ board to fit in the slot around the woofer cutouts, since without them the panels would obviously be impossible to fill. In retrospect, a front panel made of three layers of MDF would have been almost as stiff—and a lot easier to construct.

BRACING THE BOX

I then braced the inside of this box in the corners and from side to side with a combination of 1″ × 2″ and 2″ × 2″ lumber. The bottom of the box (the top of the upside-down assembly) was constructed the same way, but as an individual panel designed to fit snugly inside the box. I bolted strips of 1.5″ steel 90° corner stock to the inside of the box two inches down, and then bolted the lid flush to the steel rails using 16 ¼″ bolts.

I used silicone sealant to seal the rails to the box, and high-density-foam weather stripping to seal the lid to the rails. You can thus easily remove the bottom for modifications, yet the box is airtight and very sturdy. This entire assembly weighs over 350 lbs complete (*Photo 1*).

I stuffed the box heavily with Dacron, both to increase the effective internal volume and to damp internal reflections. The drivers, mounted face to face, are fastened rigidly to the box by T-nuts inserted into the outer face and bolted from inside the cabinet. You must be sure that the drivers are sufficiently separated so that the adjacent surrounds cannot touch. If I had fashioned a tunnel to mount the drivers back to back as I did in the prototype, it would have occupied a large amount of the box volume, causing a higher Q or necessitating a larger box.

The rather ugly baskets of two of the drivers do face outward. The original intent was to make cloth-faced grilles to cover them, but after trying out the sub between the couches, I decided the baskets weren't visible unless you specifically looked for them under the couch arms. If my furnishings change in the future, I would make an attractive frame to cover them.

The drivers are mounted rigidly for the same reason the box is built to be stiff. If the driver is isolated from the box, then the basket will shake as the cone moves. The front panel's main function is to hold the driver as still as possible. I do not believe, as some have proposed, that they should be isolated so that they are able to move on their own.

WIRING PERMUTATIONS

Each driver has two voice coils: Each Isobarik pair has two drivers, and the speaker has two Isobarik pairs. This makes for many wiring possibilities. Since my current amplifier has no problems driving a bridged 4Ω load, I currently have each two-coil pair wired in parallel, each Isobarik pair wired out of phase, but in parallel, and each Isobarik pair wired to its own set of binding posts. This configuration gives me two 2Ω loads, which are then wired in series—just the right load to extract 3kW from the Hill amp.

My living room has a modern-bachelor look to it—black, white, and splashes of bright color, with not a single traditional wood accent in sight. With this in mind, I decided to finish the cabinets with Formica instead of a wood-grain veneer. This isn't as bad as it sounds. I managed to find a reasonably realistic-looking black-marble Formica that matches the rest of my décor quite well.

Once the corners are properly finished with a router, it offers several advantages over other finishes. Since it's made for kitchen-counter tops, it's virtually immune to scratches, dents, and spills; it cleans up very easily; and the smooth, high-gloss finish looks totally professional. Many people believe that to finish a speaker in anything but wood-grain veneer is sacrilege, but I think the marble look is quite appropriate, especially given the weight of the speaker.

The sub sits directly on the carpet. The initial plan was to experiment with spikes, but this proved unnecessary. Even the loudest movie explosions can't even begin to move this speaker. A glass of water placed on the top won't even ripple.

CROSSOVER

I use a Marchand XM9-3AA fourth-order, constant-voltage crossover for the sub (*Fig. 2*). This crossover is sold as a kit as well as in completed form. What is especially nice about it is that the complete schematics are provided along with recommended changes for implementing

MADISOUND

Madisound Spring Cleaning Sale

QTY	Description	Price Each
7000	**ERO 2.2 mfd Mylar capacitor**, axial, 10%, 250V, 12mm x 30mm long, 43mm long leads, Green	$0.40
3600	**Panasonic 2.75 mfd Mylar capacitor**,10%, 250V, 24 mm x 8 mm x 16mm, Dipped, 32mm lead	$0.30
29000	**T.I. 3 mfd Mylar capacitor**, axial, 10%, 100V, 32mm x 14mm diameter, 90mm leads, Yellow	$0.40
16000	**Panasonic 3.3 mfd Polypropylene capacitor**, 200V, 33 x 11 x 22mm, dipped, 35mm leads	$0.60
4200	**Elpac 5 mfd Mylar capacitor**, axial, 10%, 50V, 10mm T x 7mm W x 31mm L, 55mm leads, Yellow	$0.40
8500	**Matsushita 10 mfd Mylar capacitor**, 10%, 100V, dipped, 14 x 24 x 30mm, 34mm leads	$0.90
480	**Audax DW50M 14mm poly dome tweeter**, 4Ω, 94dB, Fs 2050, 45 watt, direct drive poly dome with diffuser, fluid cooled, 50mm round flange (no mounting holes)	$5.00
26	**Vifa D27TG85 1" textile dome tweeter**, 6Ω, Same as D27TG45, but without silk in the dome, Fs 650 Hz, 100W, 91dB, 104mm flange with 74mm cut out hole size, ferrofluid cooled VC, linear response front plate	$18.00
265	**MB Quart MCD-25S 1" Titanium dome tweeter**, 8Ω, Fs 1000, 90dB, 100watt, 3.75" square flange, very smooth response to above 20KHz	$18.00
260	**Philips AD163 1" textile dome tweeter**, 8Ω, Fs 1300Hz, 50 watt, 92dB, 92mm x 80mm flange (3.6" x 3.2"), frequency response from 3,000Hz to 20kHz, a classic	$10.00
410	**Seas 25TFFC (H519-06A) 1" textile dome tweeter**, 6Ω, chambered back, Fs 1200 Hz, 90dB, ferrofluid cooled. Same as the standard H519, but with the leads on apposing sides. 2kHz to 20kHz	$15.00
24	**Peerless 850247 5" Autosound woofer**, 4Ω, CSC-X composite sandwich cone with rubber surround, short circuiting ring for lower distortion, round 5 1/8" round with 4 mounting tabs, 90.2dB, 100W, 2.36" depth with 4.6" mounting hole, Fs 63Hz, Vas 6. ltrs, Qms 2.65, Qes 0.48, Qts 0.41, Re 3.7Ω, x-max 2.5mm	$28.00
27	**Seas T17REX/P-H (H644) 6.5" woofer**, 8Ω, Clear poly cone with bullet shaped phase plug and high loss rubber surround, 88.5dB, Fs 33 Hz, Vas 27.5 ltrs, Qms 1.76, Qes 0.30, Qts 0.25, Re 6.1Ω, x-max 3mm, Le 0.8mH, VC Ø 39mm, F3 of 90Hz in 0.15cf sealed or F3 of 60Hz in .25cf vented 1.5"Ø x 6" long. Smooth	$28.00
22/ Yellow 26/ Black	**Eton 7-370/32 Hex 7" woofer**, 8Ω, Yellow or Black Kevlar Sandwich Hexacone, low resonance plastic chassis, rubber surround, 90dB, Fs 47 Hz, Vas 21.3 ltrs, Qms 2.35, Qes 0.35, Qts 0.30, Re 7Ω, Cms 0.86 mm/N, Mms 12.9 g, Sd 132.7 cm^2, BL 8.8 N/A. Flange is 184mm Ø with a 145mm Ø cut out. F3 of 109Hz in 5 ltrs sealed or 75Hz in 7.5 ltrs vented 1.5" Ø x 3.6" long. Very smooth to 4kHz (No X-over???).	$70.00
60	**Stanford Acoustics MSF165B30R, 6.5" woofer**, 8Ω, **shielded** magnet, paper cone, foam surround, 30 watt, 90dB, Fs 33.7Hz, Vas 49.3 liters, Qms 3.17, Qes .36, Qts .32, good response to 4kHz, F3 of 73Hz in 0.4ft^3 sealed box or F3 of 48Hz in .7ft^3 w/ 2" Ø vent x 5" long	$10.00
140	**Seas CA21FE-HD (H320) 8" woofer**, 8Ω, treated paper cone, foam surround, cast frame, 91dB, Fs 33 Hz, Vas 90.7 ltrs, Qms 2.32, Qes .48, Qts .4, Re 6Ω, Mms 17 g, BL 7, F3 of 59Hz in 1 cubic foot sealed or F3 of 39 Hz in 2.2 cubic feet vented, 3" Ø vent by 5.8" long or F3 of 45Hz in 1.5 cf with 2" Ø vent by 3.7" L	$29.00
100	**Seas P21REX/P (H626) 8" woofer**, 8Ω, polypropylene cone, rubber surround, cast frame, phase plug, 90dB, Fs 34 Hz, Vas 64.6 ltrs, Qms 2.23, Qes .41, Qts .35, Re 6.1Ω, Mms 21 g, BL 8.5, F3 of 69Hz in .7 cubic feet sealed or F3 of 45 Hz in 1.2 cubic feet with 2" Ø vent by 3.2" long	$32.00
150	**Peerless 850410, 10" woofer**, 4Ω, Sandwich poly cone with rubber surround, 95dB, 42 oz. magnet, Re 2.75Ω, Sd 0.0332 sq.M, BL 9.81 TM, Vas 93.6 ltrs, Cms 597.9 µM/N, Mms 42 g, Fs 31.75 Hz, Qms 1.72, Qes 0.24, Qts 0.21, 200W, X-max 2.5mm, Le .524mH@1kHz, VC Ø 39mm. You can put this woofer in a 1.25 cubic foot enclosure with a 3" Ø vent by 5" long for an Fs of 40Hz and 95dB efficiency.	$42.00
40	**Dynaudio 30W100, 12" woofer**, 8 ohm, foam surround, polypropylene cone, 4" diameter voice coil, 300mm diameter magnesium cast frame, 4mm linear excursion; 14mm maximum excursion, total distortion below 0.8%. Madisound measured specs: Re 5.5Ω, Krm 1.48, Kxm 14.35, Erm 0.852, Exm 0.679, Sd 0.04 sqM, BL 6.82 TM, Vas 352 ltrs, Cms 1549.5 µM/N, Mms 44.26 g, Mmd 39.66 g, Fs 19.219 Hz, Qms 2.693, Qes 0.632, Qts 0.512, Le 0.863 mH@1kHz, 130 watt. This woofer will work well in a sealed box of 5 cubic feet, fully stuffed, with an F3 of 28Hz. The regular price is $321.20.	$240.00

Orders can be placed using Visa, Mastercard, Discover card, C.O.D. cash or prepayment. Personal checks must clear before shipping.

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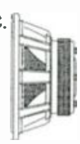

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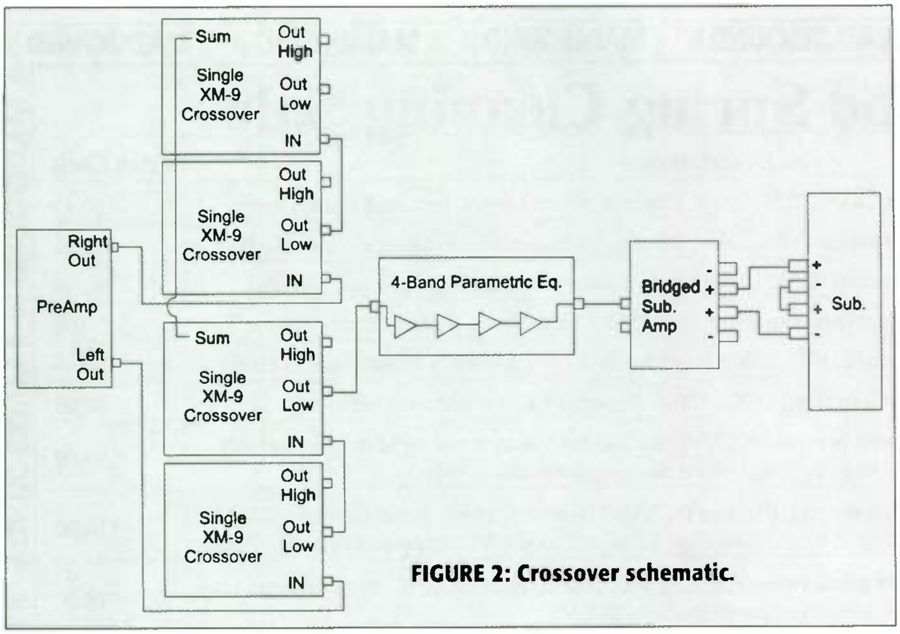

FIGURE 2: Crossover schematic.

other filter topologies. The case is designed to hold four single-channel modules, yet is large enough also to hold Marchand's eighth-order modules (which became convenient later on).

Although the high- and low-pass gains are adjustable via potentiometers, the crossover frequency isn't; you must set it with resistor blocks, which you can buy or easily make yourself. This may be considered a drawback by some, but I find it to be an advantage, since you can set the frequency very accurately, with no mismatch between channels. If you've never tested them, you might not believe how bad most crossovers with ganged potentiometers actually are. For this project, this unit allows you to combine both low-pass channels for input to a single subwoofer.

The low-pass output of this crossover runs into a home-built four-band parametric equalizer. I built this unit starting with an etched board from PAiA (Parametric Eq. 6760) that was designed to be a guitar equalizer, and hence had neither the low-frequency range nor the high Q (tight bandwidth) that I required. After some major redesign and assembly using high-quality op amps, 1% resistors, and polypropylene capacitors, I finally got this unit to do what I wished, but just barely.

I won't bother to provide any details on this part of the project, since I believe there are easier ways to equalize the bottom end—perhaps a parametric unit from a car-audio system. (Rane makes an equalizer that has a separate bass channel with a parametric equalizer for that channel only.)

I do not recommend ⅓-octave equalizers for the subwoofer, since they lack sufficient tunability, but if you *do* decide on a ⅓-octave unit, make sure it is "constant Q." If not, the bands in the bass region will overlap so much that room tuning will become all but impossible.

EQUALIZING TO FIT

Yes, equalizing the sub to fit the room is almost a necessity if you desire even, semismooth frequency response. If you enjoy your current system and have never measured its in-room frequency response, don't. What you discover may just ruin any future listening. The point is that we all believe our own stuff is the best until we have proof to the contrary.

Rooms wreak havoc with even the best speakers. This is especially true of the low frequencies. Even the most carefully designed audio rooms (a luxury most of us don't have) will reinforce some frequencies at the expense of others. If you wish to make yourself really miserable, get your hands on an FFT analyzer instead of the more commonly used ⅓-octave analyzer. The high-Q peaks and valleys will make you think you're listening to an 80-year-old phonograph.

Fortunately, studies have shown that our ears are not sensitive to anomalies much finer than ⅓-octave. My personal philosophy is that I like to measure a system with greater resolution than is marginally necessary; hence I use ⅙-octave. This is more sensitive than ⅓-octave, but won't drive you quite as crazy as will discrete FFTs. Since I program all my own instrumentation, I can use whatever methods I choose. Even though I used ⅙-octave to evaluate and tune this system, all the graphs in this article are done with ⅓-octave to provide better comparisons with more commonly available data.

Figure 3 shows the in-room frequency response of the sub measured at eight different listening positions (notice the great difference from position to position). The thick line is the average of these eight positions and is what I used for adjusting the equalizer. *Figure 4* shows the response before and after

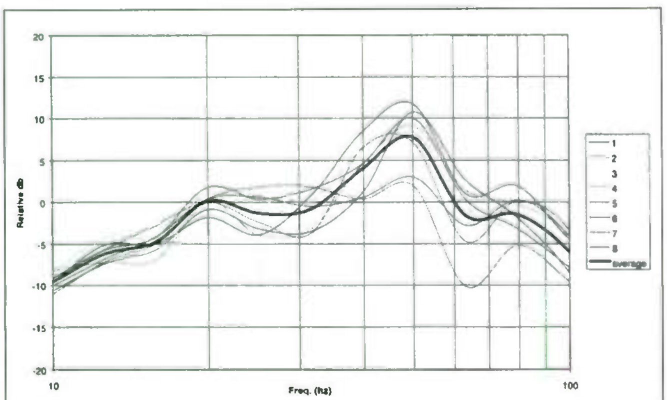

FIGURE 3: The subwoofer's in-room frequency response, measured at eight positions.

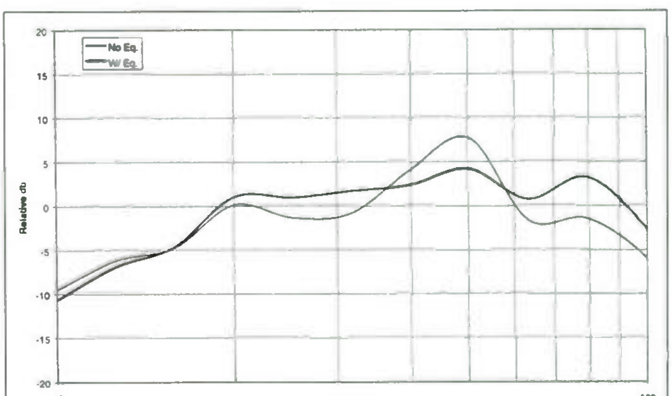

FIGURE 4: Average in-room frequency response, before and after equalization.

Swans M1 kit

The Swans M1 minimonitors open a new line of affordable high-end loudspeakers featuring several technological achievements and sound quality distinctions.

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

The drivers used in the M1 represent a new high performance design from Hi-Vi Research. The 5-inch paper/Kevlar cone woofer has a rubber surround, cast aluminum frame and a magnetically shielded motor system. This driver utilizes a central phase plug to avoid air compression, improving frequency response and dispersion. The extremely rigid cone is hand coated with a special dampening compound to further maximize its performance. The cone is then coupled to a selected grade rubber surround that provides break-up free operation and very low distortion even at high power levels. These key features greatly contribute to the M1's clear transparent sound and effortless dynamic performance.

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

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 M1 an exceptional ability to reveal the true dynamics of instruments with a complex high frequency spectrum.

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

M1 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 M1's vertical dispersion is well controlled in the 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 M1.

Swans M1 kit includes:

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

Cabinets are not included.

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.

Retail price: US$ 410.00 (delivered)

Delivery in US within 4-6 days.

Warranty 3 years, 30 days money back guarantee.

High sonic resolution Loudspeaker with room friendly performance

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

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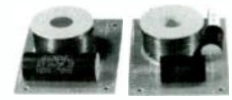
F5 Bass-midrange



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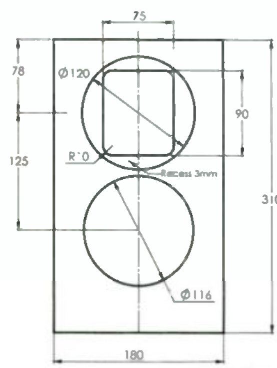
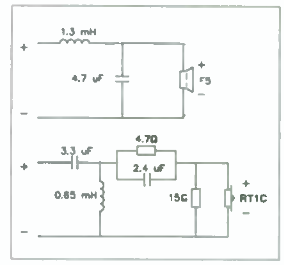
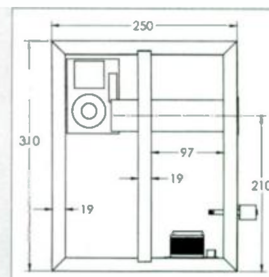
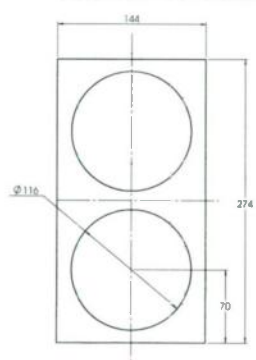


Front view

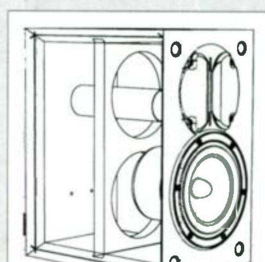




Right view of the cabinet with accessories(right side panel removed)



Internal panel



SPECIFICATIONS	
Frequency response (1m,half space)	53Hz-40kHz,±2dB
Sensitivity,1W/1m (100Hz-8kHz averaged)	85 dB
Nominal impedance (7.2 ohms minimum at 250 Hz)	8 ohms
Harmonic distortion At 90dB SPL, 100Hz-10kHz, 1m	THD less than 1%
Power handling	50W nominal, 90W music
Dimensions,HxWxD	310x180x250 mm

Amplifier requirements:
30W recommended minimum.

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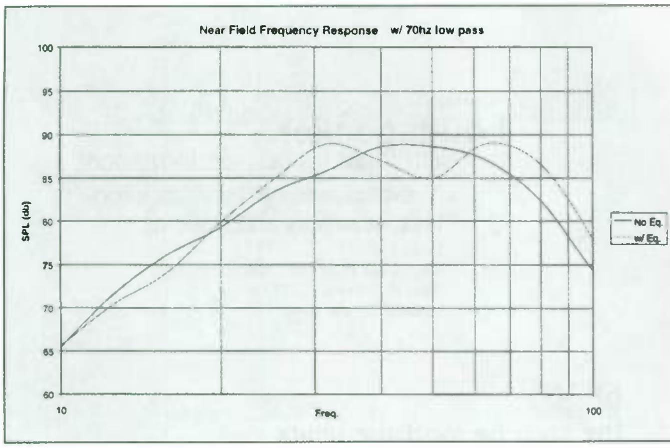

FIGURE 5: Near-field output of the speaker before and after equalizing, but both with low pass in place.

equalizing. Notice that the frequency response for the final equalizer settings is not "perfect."

When adjusting an equalizer, it is critical to constantly evaluate the system by ear. The equalizer will not only change the frequency response, but will also modify phase, distortion, and other characteristics of the music—a process inherent to running a signal through a piece of electronics.

My final settings are based on critical listening with all types of music, as well as through measurement. After I arrived at these final settings, I closed the black box containing these adjustments, and it hasn't been opened since. I treat an equalizer as a "set and forget" piece of equipment, not something you tweak at will. *Figure 5* is the near-field output of the speaker before and after equalizing, but both with the low pass in place.

AMP CHOICES

At first, I ran the output of the equalizer to a Carver 1.5t for amplification. This amp puts out 350W per channel RMS, with over 4dB of headroom. I ran each channel into one Isobarik pair of woofers. This worked very well, but I could still clip the amplifier before the sub would distort (to be honest, this occurred only during demos, not during realistic listening). I tried several other amplifiers, but never found that any of them did any better job than the Carver.

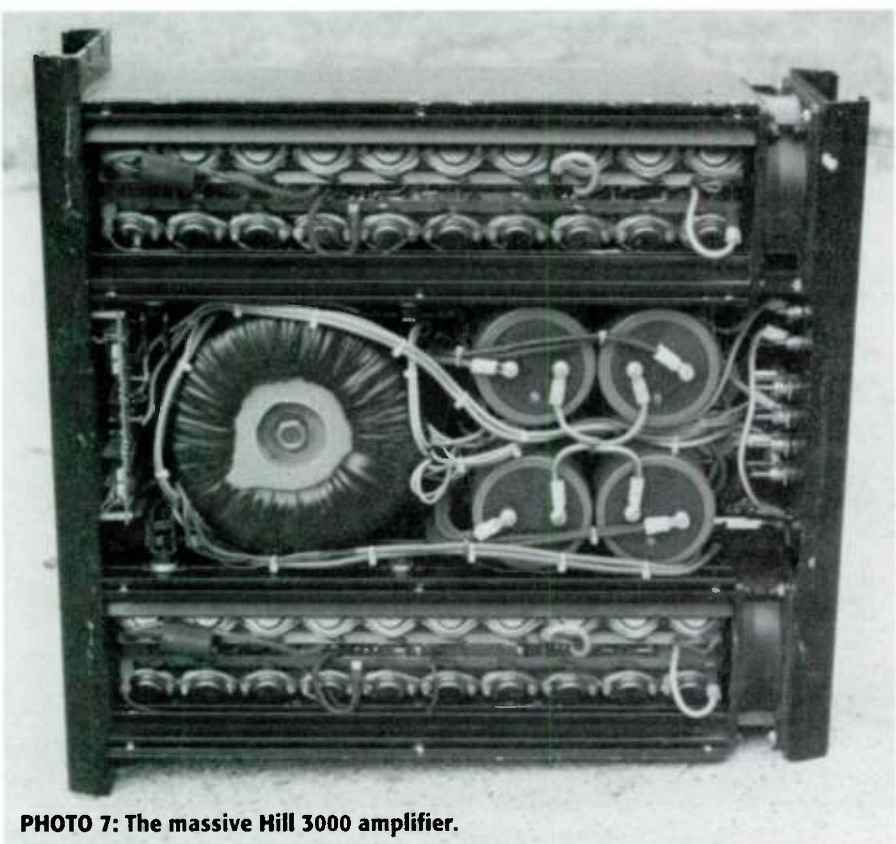

PHOTO 7: The massive Hill 3000 amplifier.

Then I came across the Hill. Hill Audio was a company in England that used to make amplifiers for professional use. This particular model (the 3,000) puts out 1.5kW per channel RMS into 2Ω, a combination that works perfectly. The drivers start to bottom out just as the amp starts to reach its peak.

This is an interesting amp. It's not beautiful, and has no massive heatsinks (the chassis itself, in combination with two thermostatically controlled fans provide the cooling), and I had to cycle air through it for two days to get the cigarette smell out of it. It's obviously meant for clubs, not living rooms. It weighs 90 lbs, has four oil-filter-sized capacitors, a huge 8″-diameter, a 5″-deep toroidal transformer, and 40 output devices (*Photo 7*).

I got it dirt cheap from a local band that had broken up. It may not look pretty, but no one can see it, since it's strapped to the ceiling in the basement underneath the sub. Not only does this amp enable the sub to play louder, but it seems to provide a "tighter" sound as well. I have no evidence (either measurements or blind tests) to prove this claim.

I had to make some modifications to adapt it for home use. When I bought it, it would occasionally add a slight pop to the sub (about every 10–20 minutes). After much experimentation, I found the pop was caused by the thermostatically controlled fans turning on and off. Just by luck, I had a set of fans of exactly the same size that could be variably controlled by a thermistor. No on-off, so no pops.

RESULTS

I am very happy with the results of my entire system, but I'm ecstatic with the performance of this sub. If I had it to do over, I wouldn't change a thing. Nothing I've heard or measured comes close to the clean, extended, limitless bass provided by this unit. Music with low-frequency content is smooth, clean and effortless, and movies have the kind of impact that even a top-of-the-line THX-approved theater can't match.

One aspect of this project that doesn't occur to most people became one of the most important factors in bringing out the full potential of the subwoofer: fixing the house. The addition of a deep, powerful subwoofer to a 50-year-old house produced many noises which were unrelated to the musical source. Pictures, windows, and knick-knacks rattled, doors shook in their frames, and floor

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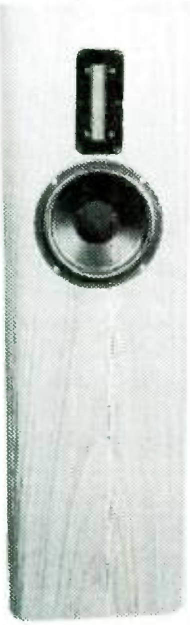

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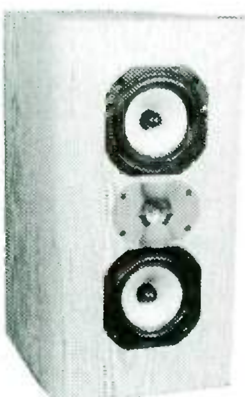

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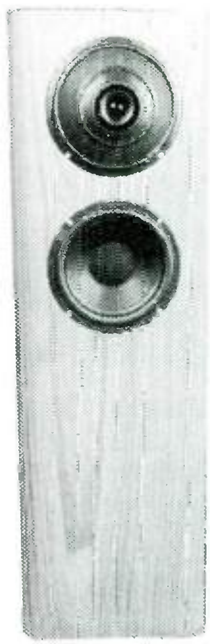

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boards vibrated against the joists. In fact, the noise level in the room is so high that the harmonic distortion was completely drowned out. I had to start taking my THD measurements with a near-field mike, with another placed at one meter to record the SPL.

Listening to music, it was hard to tell what was wrong—just that there was some unwanted coloration from somewhere. The best way I found to isolate the noises was with a function generator into the amplifier. By sweeping the frequency, I could isolate specific noises, chase them to their source, and eliminate them.

I made a number of fixes, including placing silicone sealant and braces on many of the basement joists, recaulking the windows in their frames, rearranging and isolating knick-knacks, and even covering the window above the sub with Styrofoam insulation siliconed directly to the glass.

As with any good subwoofer, after you become adjusted to it, you don't even remember it's there until it's gone. With most music at reasonable levels, the sub seems to disappear. I sometimes find myself reaching down under the armrest of the couch to see if it's actually playing. It has truly spoiled me.

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Now you have no excuse to be without the ability to measure your own speaker impedance values. Here are some easy-to-follow plans for an indispensable addition to your tool box.

A Handy-Dandy Impedance Measurement Device

By Louis C. McClure

Loudspeaker manufacturers usually specify the nominal impedance of their loudspeakers as either 4Ω or 8Ω. We usually take these figures for granted, assuming that the speaker has a true impedance of 4 or 8Ω for purposes of designing crossover networks or impedance-compensating devices, making system-impedance networks, determining resonant frequencies, checking the relative flatness of the impedance of transmission-line (TL) enclosures, testing the effectiveness of changes in the system, and so on.

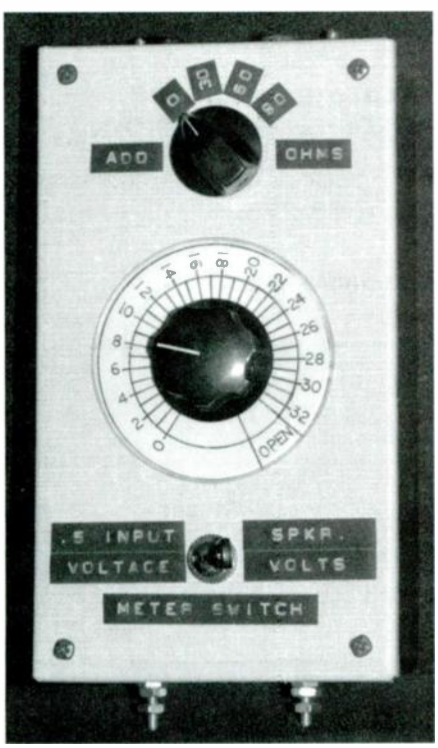

PHOTO 1: Handy-Dandy impedance measurer.

If you look at the impedance plot of a typical driver, you find anything but a flat, constant impedance, yet you need the plot to determine the impedance value you must plug into the formulas for designing a crossover network for the speaker.

USEFUL AND CHEAP

I have devised and constructed an instrument I call the "Handy-Dandy Impedance Measurement Device" (*Photo 1*). It is simple, economical to construct, and easy to use. Actually, most amateurs will have most of the necessary components lying around in their junk boxes, but in any case purchasing the parts new should cost no more than $20.

One advantage of the Handy-Dandy is that it is unnecessary to maintain a constant output voltage from the signal generator. Instead, you can apply an input voltage of approximately 1V from an amplifier connected between the signal generator and the device. A built-in voltage divider cuts the input voltage in half when switch S2 is in the 0.5 INPUT VOLTAGE position (*Fig. 1* and *Photo 1*). This voltage is fed to the volt-ohmmeter (VOM) for a reference voltage, and then you switch S2 to SPKR VOLTS and read the voltage across the speaker terminals. Adjust R1 until the two voltages are the same. Then the dial reading on S1 is the impedance at that frequency. Perform this procedure for each of the ⅓-octave frequencies, record, and plot the results on a ⅓-octave frequency chart.

I suggest beginning at a frequency much lower than the driver's resonant frequency. This will essentially read the DC resistance of the voice coil. As you approach the resonant frequency, you should take readings in smaller increments to show the rapid increase in impedance when approaching resonance.

I place a power amplifier between the signal generator and the device in order to isolate the generator from the load presented by the driver (*Fig. 2*).

I often encounter drivers that have impedances greater than the maximum resistance of the rheostat, which is 33Ω. A rotary switch (S1) at the top of the device (*Photo 1*) permits the addition of 30, 60, or 90Ω in series with the rheostat in order to increase its range. Thus, you can measure impedance up to a maximum of 122Ω.

The Handy-Dandy uses an 8Ω L-pad as

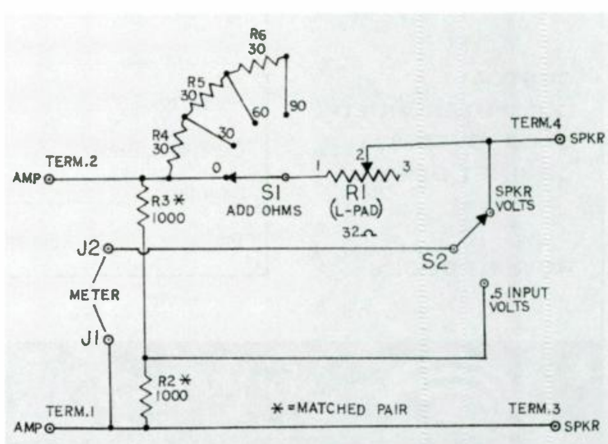

FIGURE 1: Handy-Dandy schematic.

a rheostat, calibrated just as any variable resistor. All you need for calibrating it is an accurate ohmmeter. A digital multimeter (DMM) is preferable, but you can use an accurate analog VOM if no DMM is available.

Before you embark on the following description of the construction, calibration, and use of the Handy-Dandy, you should examine *Table 1* to identify the various symbols used throughout the discussion.

CONSTRUCTION

The first step is to make sure you have the necessary parts on hand. Assembly is simple and straightforward:

1. Lay out the front panel (cover) and the ends of the plastic box, and drill holes as shown in *Fig. 3*.
2. Install the 2-pole, 6-position rotary switch, the L-pad, and the DPDT or SPDT switch.
3. Install the two meter jacks in the upper end of the plastic box.
4. Install two 8-32 × ¾″ screws and nuts in the two holes in each end of the plastic box.
5. Wire the device as shown in the schematic (*Fig. 1*). Twenty-gauge stranded wire works well for this purpose. Make the wires sufficiently long to permit folding the cover to one side for wiring, servicing, or adjustment. Check the wiring to make sure there are no errors. Bundle the wires together as needed (*Photo 2*).

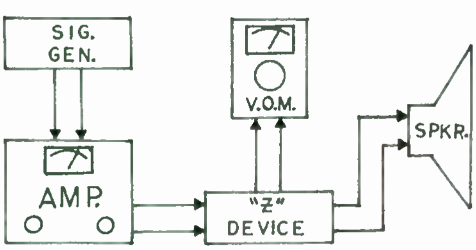

FIGURE 2: Block diagram of interconnection of device and test equipment.

CALIBRATING THE L-PAD (R1)

1. Draw three concentric circles of 1″, 2″, and 2¾″ diameter on a piece of posterboard to form the dial for R1.
2. Cut along the outside of the outer circle.
3. Cut a ¾″-diameter hole in the center of the dial.
4. Place the dial on the panel, over locking nut of R1. Tape in place temporarily. Make marks on the dial and the panel at the top, bottom, and each side of the card for indexing.
5. Turn R1 fully counterclockwise. Install the pointer knob on the shaft at this position, with the pointer at approximately the 7-o'clock position. Tighten the knob's set-screw. Set S1 to "0."
6. Connect one lead of a DMM or VOM to terminal 2, (the right-hand terminal on the top of the box). Connect the other lead to terminal 4, (the right-hand terminal on the bottom of the box). Set the meter you're using to measure ohms on the lowest scale.
7. With R1 in full counterclockwise position, measure 0Ω between terminal 2 and terminal 4. Make a light pencil mark on the dial in line with the pointer. Label this point "0Ω."
8. Rotate R1 clockwise until you obtain a reading of 1.0Ω. Again make a light pencil mark on the dial in line with the pointer, and label this point "1Ω."
9. Continue this procedure for each 1Ω increment from 0 to the maximum value of R1 (approximately 32Ω).
10. Remove the pointer knob and dial.
11. Place the dial over a piece of cardboard and tape it in position. Using a compass, reestablish the center point of the dial.
12. Using an inking pen, make a radial mark between the inner and the middle circle. Align a straightedge between the center and the mark representing the ohms setting on the dial. Make these radial marks for each 1Ω increment on the dial. Print the ohmic values between the middle and outer circles of the dial.
13. Reinstall the dial on the panel. Align the reference marks made in Step 4 above and tape in place temporarily.
14. Recheck the calibration at 0, 8, 16, 24, and full scale. If necessary, slightly readjust the position of the dial to achieve accuracy at all points.
15. When you've verified the accuracy,

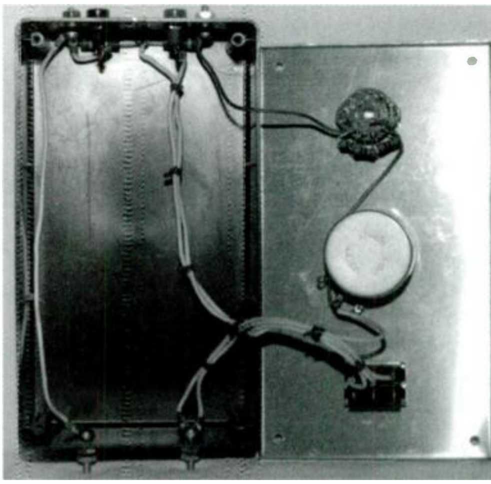

PHOTO 2: View of inside of device.

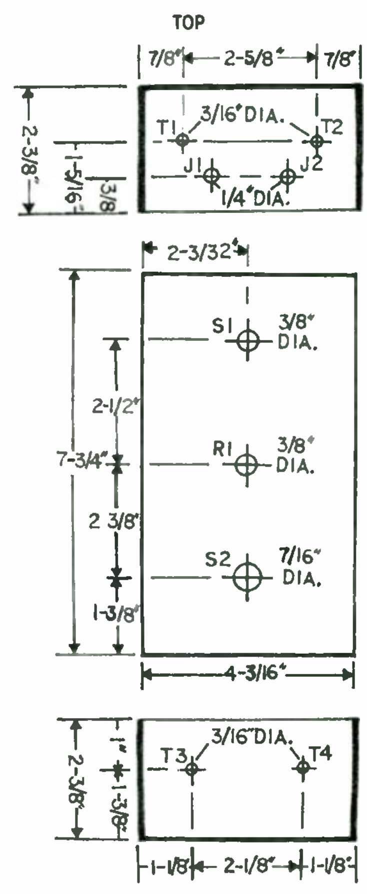

FIGURE 3: Physical layout of chassis and location of components.

TABLE 1
IDENTIFYING SYMBOLS

SYMBOL	FUNCTION
J1, J2	Output to voltmeter
R1	L-pad used as a variable rheostat; should have approximately 32Ω resistance between terminals 1 and 2
R2, R3	Matched pair of resistors across the input terminals, used to divide the input voltage by 2
R4–R6	30Ω, 1W, 1% resistors used to increase the ohmic range of R1
S1	Selector switch that adds 0, 30, 60, or 90Ω to extend the range of R1
S2	Switches the meter input between the 0.5 input voltage to the voltage across the voice coil
Terminals 1, 2	Input voltage from amplifier
Terminals 3, 4	Output voltage to voice coil

The front panel controls are, from top to bottom, S1, R1, and S2. Terminals 1 and 2 are on top of the enclosure, while terminals 3 and 4 are on the bottom.

PHOTO 3: Device being used to measure impedance of a driver mounted in a test box.

TABLE 2
PARTS LIST

J1, J2	Banana jack (Radio Shack #274-725)
R1	8Ω L-pad (as rheostat), 25–50W, 32Ω 1–2
R2, R3	1000Ω (preferred), 1W, closely matched
R4–6	30Ω, 1W, 2% or better (RCA #831030 or equivalent)
S1	Selector switch, rotary, 2-pole, 6-positions (Radio Shack #275-1386 or equivalent)
S2	Toggle switch, SPDT, 5A, 125V AC, (Radio Shack #275-603 or equivalent)
Molded enclosure	Radio Shack RSU-11907714 or equivalent
Wire	18 or 20 gauge, as required
Tie wraps	
Pointer knobs (2)	
4 each 8-32 screws and nuts (input-output terminals	
Solderless banana plugs (optional for test leads)	Radio Shack #274-721 or equivalent

glue the dial in place using ordinary household cement.

The calibration of the dial is very important, since it will determine the overall accuracy of the device. Be as careful as possible when performing this procedure.

OPERATION

The Handy-Dandy is quite accurate. Connect the test equipment as shown in *Fig. 2* and *Photo 3*. To perform a resonant frequency test:

1. Set the signal generator to a low frequency, perhaps 20Hz.
2. Set S1 to "0."
3. Set R1 to "0."
4. Set S2 to SPKR VOLTS.
5. Adjust amplifier for a 1.0V output as read on the VOM.
6. Slowly increase the signal-generator frequency until a peak is obtained on the VOM. This will be the resonant frequency of the driver or speaker system.

To perform an impedance test of the driver or speaker system:

1. Connect the test equipment as above.
2. Set S1 to "0."
3. Set R1 to "0."
4. Set S2 to 0.5 INPUT VOLTS.
5. Make a mental note of the voltage on the VOM.

6. Flip S2 to SPKR VOLTS.

7. Increase R1 until the VOM reads the same voltage as noted in Step 5. This will be the impedance at this frequency. After finding the proper setting of R1, I usually flip S2 to the opposite position and check that the reading on the VOM does not change. This is an easy double-check. Record this frequency and the R1 dial reading.

8. Set the signal generator to the next higher frequency in the ⅓-octave frequency group. Repeat Steps 4–7 above. Continue this procedure for each of the ⅓-octave frequencies. There will be some instances, in the vicinity of the resonant frequency, when you will need to switch S1 to the +30, +60, or +90Ω position, as well as adjust R1 to obtain the same voltage as when S2 was in the 0.5 INPUT VOLTS position. Be sure to add these values to the value of R1 for the total resistance. Also, be sure to return S1 to the "0" position when possible.

If you wish to plot the results on quadrille-ruled paper, list all the ⅓-octave frequencies on the x-axis (horizontal), and impedance on the y-axis (vertical). You will note that each vertical line on the graph coincides with the ⅓-octave frequency sequence. No interpolation is required (*Fig. 4*).

You can also use the Handy-Dandy to monitor changes when experimenting with impedance-compensating devices, tuning TL enclosures, determining the impedance of an unknown driver or speaker system, and so on. The uses are limited only by your ingenuity.

Have fun building this little device, and good luck. I believe it will be a valuable addition to your present equip-

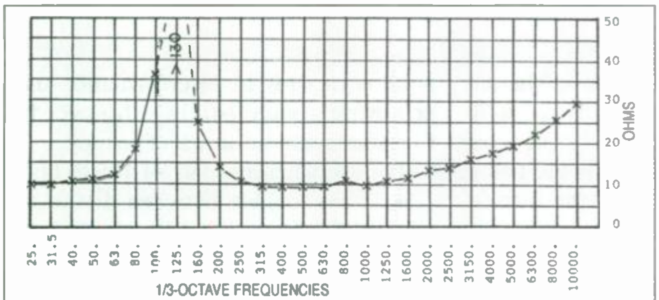

FIGURE 4: Impedance plot of a 6½″ driver in a test chamber.

Author Bill Fitzmaurice continues his revolutionary Snail series with this effort featuring a 15″ driver. This latest horn design consists of two identical cabinets sharing a common driver.

The Siamese Snail

By Bill Fitzmaurice

I decided to build a Snail, utilizing a 15″ driver, sized in between the original Snail and Snail II. The reason for this latest design is that I anticipate that most people who construct Snails will use drivers they already have in other cabinets. The 15″ size is the most popular for bass, keyboard, and PA cabinets, but Snail II is a bit too large for most applications. So I set about to design a Snail that would be the smallest size possible to accommodate a 15″ driver and still blow away the competition.

The biggest design problem was to gain enough mouth area, as well as a sufficiently large back chamber, to house a 15″ without ending up with a $10ft^3$ box; my design goal was $7.5ft^3$. I built a shrunk version of Snail II, but it did not meet my expectations, and so forced me to try something new. The Siamese Snail was the result (*Photo 1*).

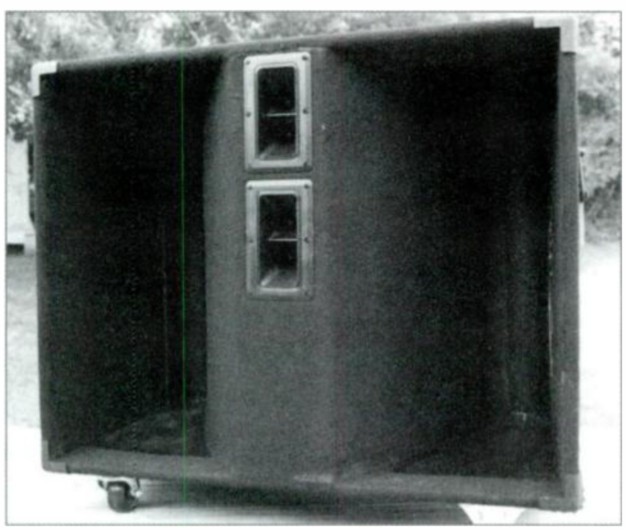

PHOTO 1: The finished Siamese Snail.

DUAL-THROAT SOLUTION

The physical limitations of the cabinet size required a horn length shorter than I would have preferred. To help compensate for this, I devised a dual-throat horn, in which the front wave of the driver feeds one horn throat while the rear wave is ducted to another, which has a longer path to travel before reaching a junction where the front wave and duct output merge. While this extends by only a few inches the length of the horn fed by the port, with a horn this short every little bit helps.

You may well question whether having two different path lengths might lead to phase cancellation problems. The answer is yes, if the path lengths are sufficiently different so that the frequencies passed through both pathways are half a wavelength apart. But since the ducted pathway passes frequencies only up to about 100Hz, a differential of less than 12″ will not affect the phase adversely.

This configuration has a second benefit. You can make the initial flare rate of the horn fed by the front wave fairly rapid to promote better high-frequency loading, while the bass-rich duct outputs are fed into a throat with slower flare rate for maximum bass extension.

The final design quirk was to split the cabinet into two identical halves, resulting in a box resembling a Klipsch cornerhorn in that its cross-section resembles a pair of conjoined twins: two cabinets sharing a common driver. On stage, it proves to be the most versatile of the Snail series for live-performance use, achieving a wide bandwidth never before seen with this much efficiency.

The average sensitivity of 105dB up to 1.5kHz lies roughly between that of the original Snail and Snail II, while above 1.5kHz, the horn's multiple throat configuration and its having only two 90° bends gives performance heretofore unheard of from a folded horn. The driver's sensitivity up to its nominal cutoff at 3.5kHz is at least as high as you would expect from an infinite baffle.

As a result, you can use this cabinet for electric bass with no mid-drivers and still have a strong midrange presence. For PA or keyboards, you can add tweeters crossed over at 3.5kHz—again, with no midrange drivers required. Even inexpensive piezo tweeters will give all the power you could want on the high end, and without expensive crossovers or biamping.

A TOLERANT SNAIL

I designed this cabinet around the EVM-15 B driver, but it will work well with most high-quality, cast-frame, extended-range 15″ MI drivers with F_s of less than 45Hz, Q_{TS} of less than .30, a V_{as} of less than $8ft^3$, and sensitivity of 95dB or more. My experiments have shown that, unlike Thiele/Small (T/S) boxes, the Snail design is very tolerant of spec differences.

The cabinet is constructed primarily of ½″ plywood, even the baffle, since the self-bracing Snail geometry makes heavier materials unnecessary, though you may use them if you wish. The main advantage of thicker materials is their workability. Today's ½″ plywood is advertised as being 15/32″ thick, though the sheet I purchased for this project measured 7/16″ which might cause some problems in joinery for unskilled woodworkers.

Nominal ¾″ plywood is both weighty and expensive, but ⅝″ is a good alternative if you are hesitant to use anything thinner. Because of the variations in actual material thickness, the parts-list dimensions (*Table 1*) are approximate only, and must be adjusted to take into consideration the actual materials used. The nominal finished cabinet size if built with ½″ material is 24″H × 30″W × 18½″D.

As usual, I used all butt joints, fastened with drywall screws and construction adhesive, with all screws piloted and deeply countersunk. Use 1″, 1¼″ and 1⅝″ lengths, depending on the joint, so as not to pierce exterior walls. Wherever possible, clamp parts together to ensure proper alignment, and then drill and screw.

Also note that I describe the cabinet in a lying-down configuration, which allows you to align the tweeters vertically for maximum horizontal dispersion. You can stand the cabinet "upright," with the longest dimension (30″) considered as the "side," instead of the top, as the text describes, but you do so at the cost of a loss of horizontal high-frequency dispersion.

CONSTRUCTION PROCEDURE

The first step is to create the horn-brace pattern (see *Fig. 1*), which you cut from a piece of plywood measuring 16″ × 9½″. Draw a horizontal line across this piece 1½″ from its lower edge. Mark a point on this line ½″ from the left edge of the board. Then mark a second point 3″ to the right of the first and 2½″ up from the line. Mark additional points at 3″ intervals, with distances to the line of 4¼″, 5⅝″, 6 11/16″ and 7½″, respectively. These points outline the actual contour of the outer wall of the horn plate.

Into each point, drive a small finishing nail, leaving most of it still exposed. Bend a thin sliver of ⅜″ plywood tightly against the line of nails, and secure it in place with more nails. Now trace the sliver's position onto the plywood (*Photo 2*). Remove the sliver and the nails, and cut along the lower trace. Discard the upper part of the pattern; the lower part is the horn-brace pattern. To take account of the baffle and cabinet front, trim the appropriate amount of material from the front and rear of the pattern, determined by the baffle's and cabinet front's actual thickness.

Use this pattern to trace a total of seven identical braces, each 1½″ wide. When you trace, the inner edge of one brace becomes the outer edge of the next, which greatly simplifies the cutting procedure (*Photo 3*). You can fashion the braces either from the same plywood

FIGURE 1: Top view of Siamese Snail; ducts, throat reflectors, tweeters not shown.

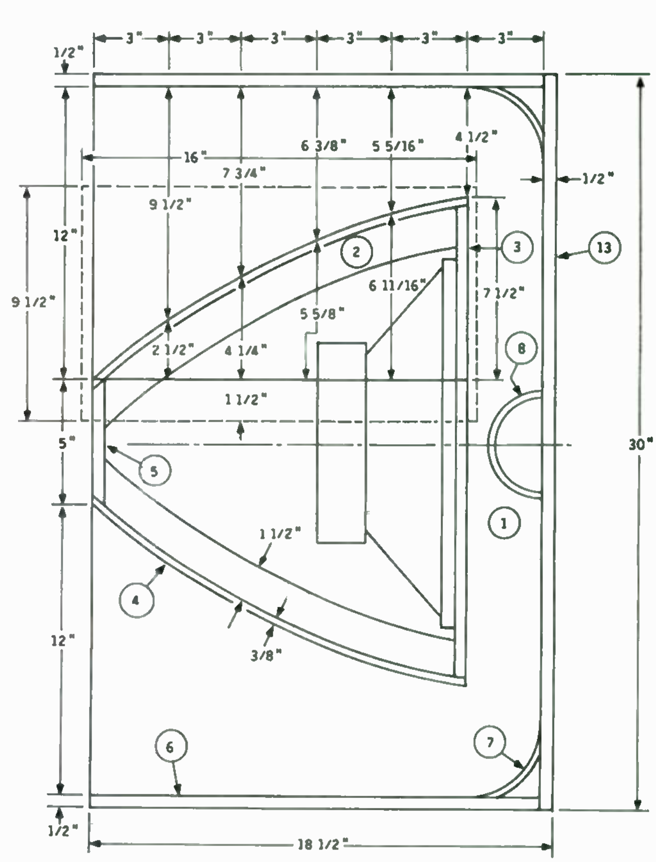

TABLE 1
PARTS LIST

(See text for materials; all dimensions are approximate, depending on materials used. The numbers preceding each item refer to the circled identifying numbers on *Figs 1* and *2*.)

1. Top, bottom	18″ × 29″
2. Horn braces (8)	see text
3. Baffle	19¼″ × 23″
4. Horn plates (2)	22 15/16″ × 16¾″
5. Front	23″ × 5″
6. Sides (2)	24″ × 18″
7. Corner reflectors	6″D ⅛″ wall plastic drainage pipe (see text)
8. Throat choke	4″D ¼″ wall PVC pipe (see text)
9. Throat reflector A (2)	9¾″ × 3″
10. Throat reflector B (2)	9¾″ × 3″
11. Throat reflector C (2)	19⅜″ × 3″
12. Throat cap (2)	4″ × 3″
13. Back	24″ × 30″

EVM-15B driver (or equivalent)
Motorola KSN-1177 drivers (2)
Drywall screws
Construction adhesive
Paint, carpet or other finish as desired
Hook-up wire (14 or 16 ga.)
Jack
Hot-melt glue
Casters
Handles
Protective corners or edging
3″ PVC pipe for ducts
Egg-crate acoustic foam

Total cost of prototype is about $325, built as described in text.

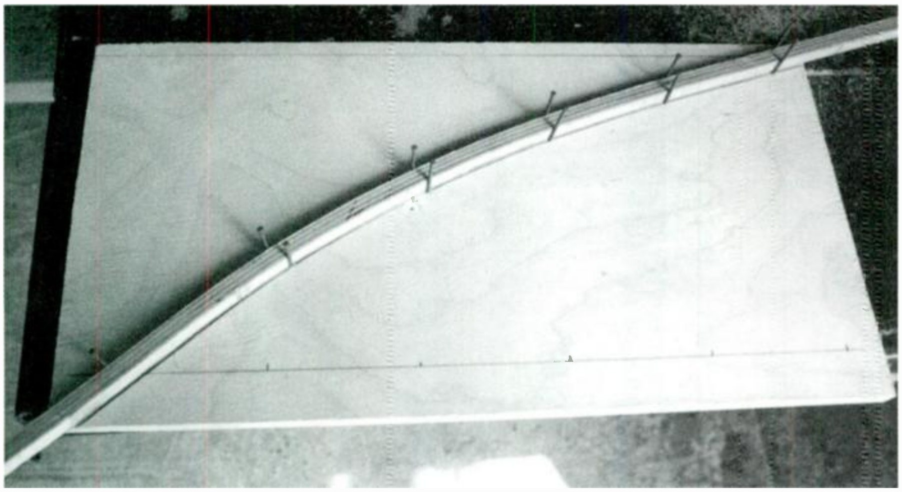

PHOTO 2: Tracing the curve of the horn-brace pattern.

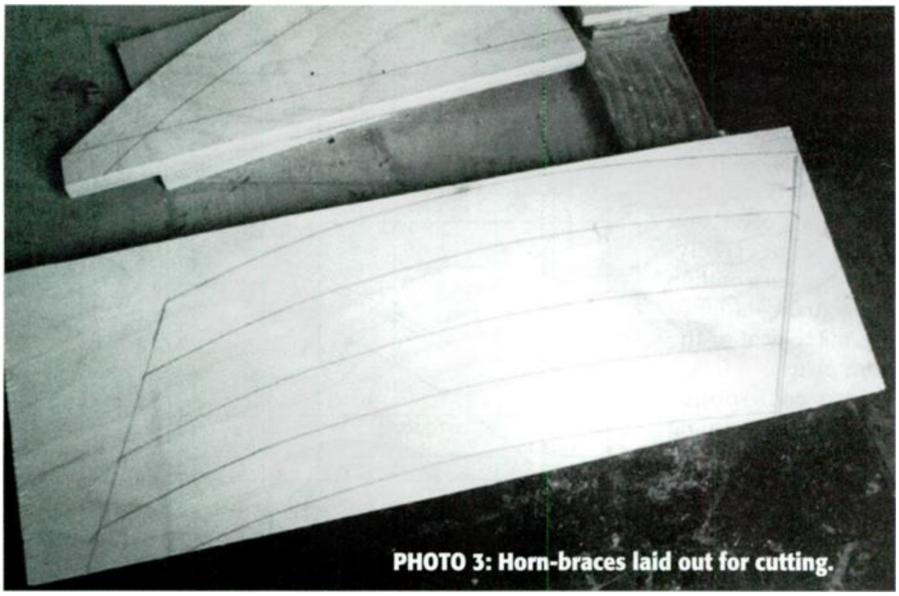

PHOTO 3: Horn-braces laid out for cutting.

PHOTO 5: Duct-hole drilling.

as the cabinet walls, or from thicker lumber if you like. When you've finished tracing, also cut the original pattern to 1½" wide, giving a total of eight braces.

Cut out the cabinet top and bottom, using a straightedge and the horn braces to mark all the parts' locations on both sides (*Fig. 1*). The bottom will have a "sidedoor" panel cut in it for driver access. Draw the cutting line for this door ½" in from and parallel to the inside of the baffle, then midway between the inner and outer edges of one horn brace to within about 3" of the cabinet front, then straight down to the other horn brace, and finally along *its* center back to the baffle again.

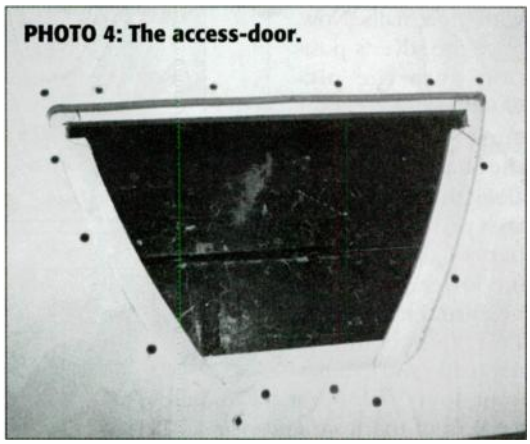

PHOTO 4: The access-door.

Cut out the door with a saber saw, starting with a plunge cut. Attach two horn braces to the bottom, along with additional scrap plywood cut to size to form a sealing flange around the perimeter of the hole. Trim the flange as required to make sure that the driver frame will fit through it (*Photo 4*).

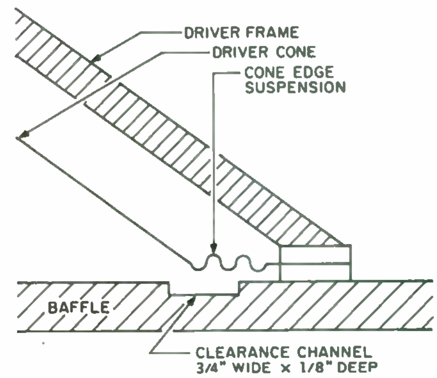

FIGURE 3: Clearance channel to prevent the cone edge from hitting the baffle.

CUTTING THE BAFFLE

The baffle is next (*Fig. 2*). Cut the upper and lower edges at a 10° angle, to match the taper of the horn. Draw the locations for all the parts, cut out the driver hole, and install tee-nuts for driver mounting.

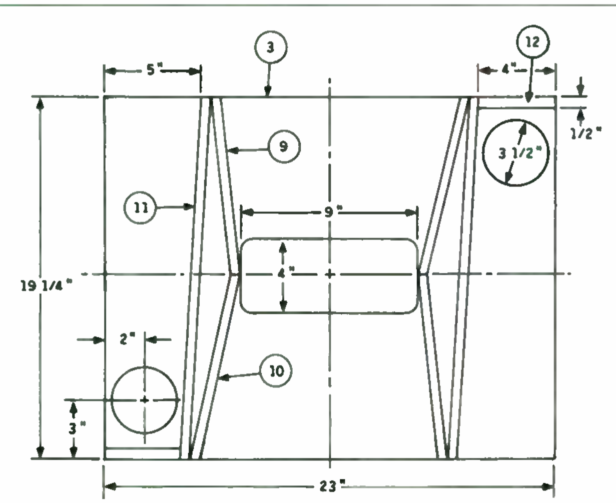

FIGURE 2: Baffle layout and dimension; throat choke not shown.

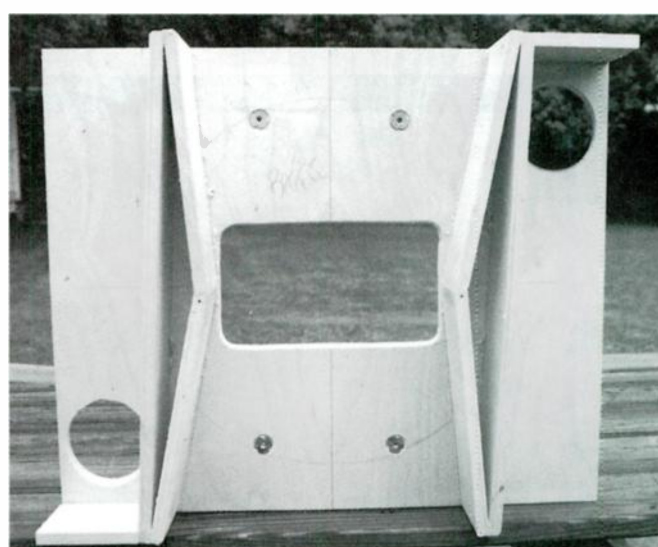

PHOTO 6: Throat reflectors attached to the baffle.

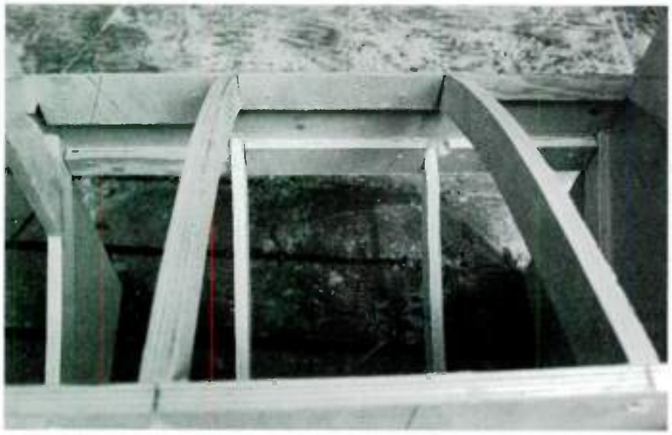

PHOTO 7: Blocking pieces inserted between the braces.

PHOTO 8: Cabinet ready for attaching the horn plates.

Use a router with a ¼″-radius rounding bit to chamfer the driver hole on both sides, and countersink the tee-nut heads to allow the throat plates to fit flush over them. Use a hole saw to drill the two duct holes, which must be drilled at a 15° angle, since the ducts are on an angle so as not to hit the inside of the horn.

You can do this easily by using a drill press with its table tilted to 15° and the baffle clamped to it, and a piece of scrap between the baffle and the table to accept the saw blade (*Photo 5*). On the driver side of the baffle, use a router to cut a channel to prevent the cone edge from hitting the baffle in long excursions (*Fig. 3*). As an alternative, you may create a spacer from ⅛″ or ¼″ plywood to gain the required clearance.

When the prep work on the baffle is complete, attach all of the throat reflectors and caps (*Photo 6*). These reflectors have angles at their ends too slight to bother taking into consideration, but be sure to glue all their intersections airtight. When the glue has set, use a sander to slightly round off all joints.

Attach the baffle to the cabinet top and bottom, followed by the cabinet front, whose edges must be cut at a 40° angle, again to match the horn taper. The remaining horn braces are next, two attached to the top, and the other four to the baffle and the front, spaced evenly across the cabinet. Some trimming of these interior braces where they meet the baffle may be required in order to clear the driver frame. Make sure you trim them before installation!

Then cut some scrap plywood pieces as blocking to fit behind the cabinet front in the spaces between the braces

PHOTO 9: Temporary scrapwood pieces to facilitate clamping the horn plates.

(*Photo 7*). Use a belt or disk sander to chamfer these blocks to the same level as the front and the braces. The cabinet is now ready for you to attach the horn plates (*Photo 8*).

HORN-PLATE ATTACHMENT

Using plenty of adhesive and screws, attach the horn plates to the baffle. Then pull the plates into place with long clamps as you drive additional rows of screws every 3″. You cut the horn plates from ⅜″ plywood, and here inexpensive three-ply works better than more costly grades because it bends more easily; flex the sheet before cutting to determine the more flexible axis of the wood.

Cut the plates about 1⁄16″ narrower than the width of the baffle and front, to make it easier to fit them in place. To facilitate the clamping, screw temporary scrapwood clamping cauls to the horn plates (*Photo 9*). After the adhesive has set, sand the horn plates flush with the baffle and front, slightly rounding over the joint. At this point, attach the cabinet sides (*Photo 10*).

The corner reflectors require a 3″-radius bend, which you can easily obtain by quartering some 6″ plastic drainage pipe, discarding the perforated sections. You can safely and accurately cut this on a table saw by first screwing the pipe to a piece of plywood to keep it from rolling (*Photo 11*). In similar fashion, halve a piece of 4″ PVC pipe to obtain the half-moon-shaped throat choke.

Trim both the corner reflectors and the throat choke to fit, and then glue them to the cabinet using a hot-melt glue gun. In the case of the throat choke, cutting the compound angles exactly for a tight fit with the throat reflectors would be a difficult chore; instead, cut it to approximate size, filling the space between it and the throat reflectors with foam weather stripping to act as a dam that will hold the hot-melt glue until it sets (*Photo 12* and *13*).

USING TWEETERS

If you wish to use tweeters for a full-range cabinet, I suggest Motorola Twin-Bullet piezos; two of these mounted on the front give a sensitivity that matches the woofer well, while the vertical array delivers maximum horizontal dispersion. Cut the holes for the tweeters (*Photo 14*), and then line the chamber with acoustic foam. Drill a ¼″ hole through the baffle for the speaker wire, and use hot-melt glue to seal around the wire once it's in place.

Install the driver and attach the wires to it; if you're using tweeters, they are parallel wired to each other and wired to the woofer with a 4Ω resistor in series (*Fig. 4*). Like all the Snails, driver clearance is very tight, and you must drive the mounting screws by feel. To ease the job,

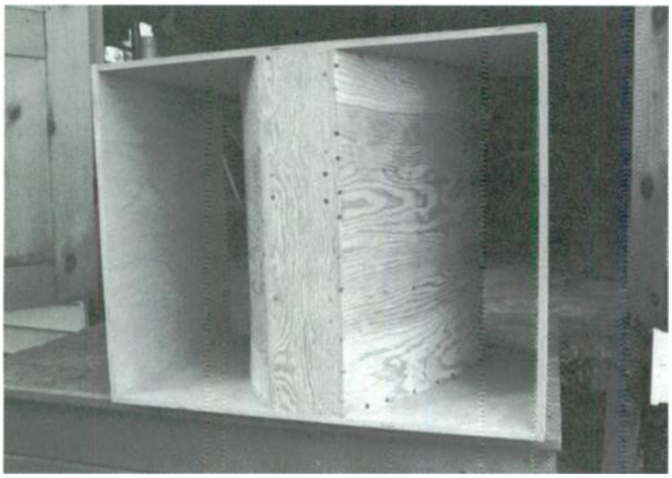

PHOTO 10: Horn plates in place and sides attached.

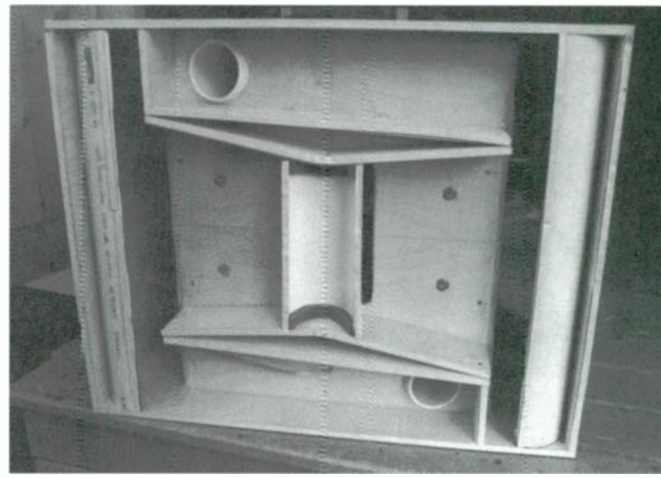

PHOTO 12: Corner reflector in place.

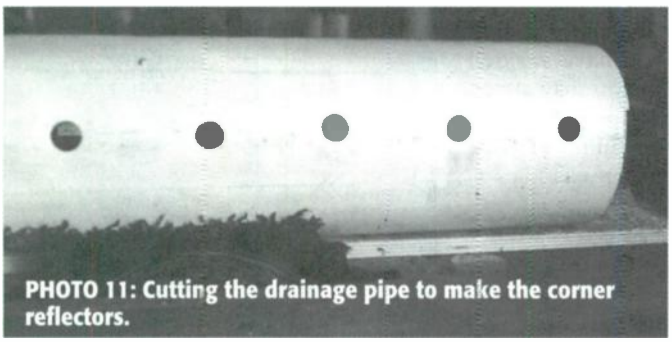

PHOTO 11: Cutting the drainage pipe to make the corner reflectors.

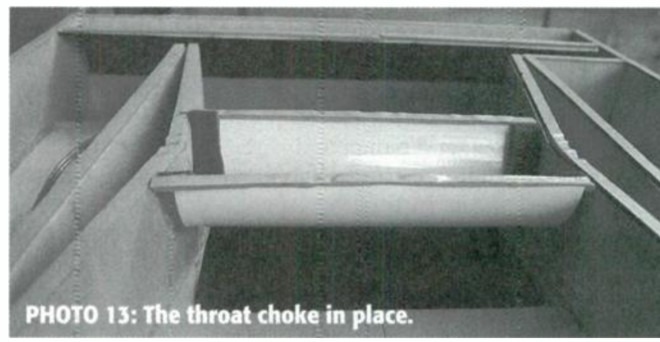

PHOTO 13: The throat choke in place.

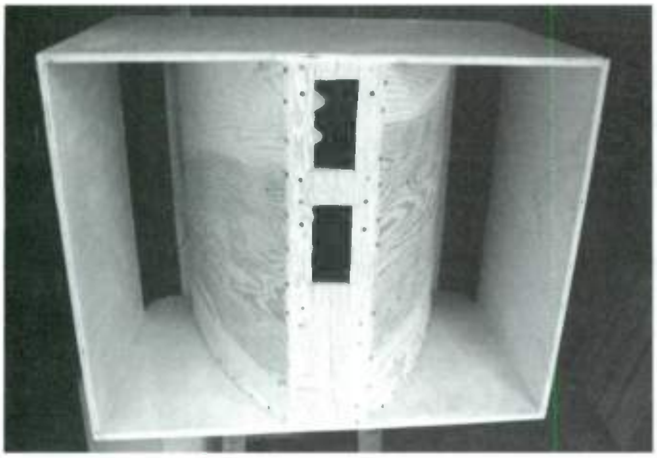

PHOTO 14: Holes cut for the tweeters.

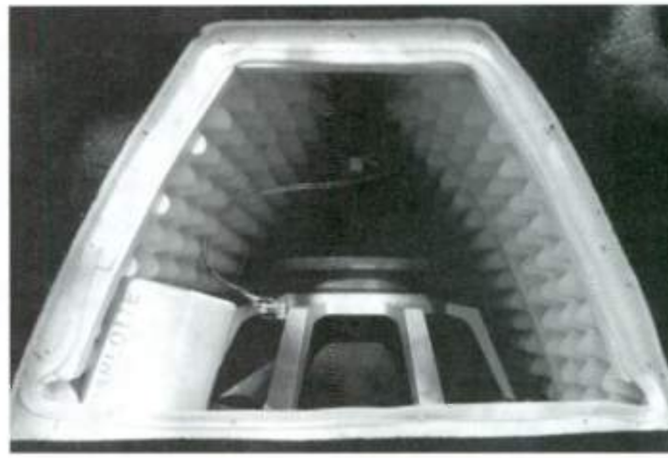

PHOTO 15: Weather stripping applied to side-door flange.

use allen-head bolts rather than slot head, with Phillips-head an alternate choice.

The ducts, 7″-long sections of 3″ PVC pipe, are mounted on an angle, but their ends are cut straight across. Glue them in place with hot-melt, and mount and wire up your jack of choice to the cabinet back, but don't attach the back yet. Apply weather stripping to the side-door flange (*Photo 15*) and screw the door in place.

Hook up the cabinet to an amp and feed it some high-level low-frequency tones, either from a tone generator or a test CD, listening and feeling for leaks in the chamber, and sealing any you find with hot-melt. Once you have verified that the cabinet is tight, you may attach the back, trim-flush or round over all exterior joints, apply the finish of your choice, and install casters and handles as desired (*Photo 16*).

For electric bass, the tweeters are not really necessary, so you can omit them, but their inclusion makes it easier to adjust your amp tone to match what will appear in the full-range speakers of a PA

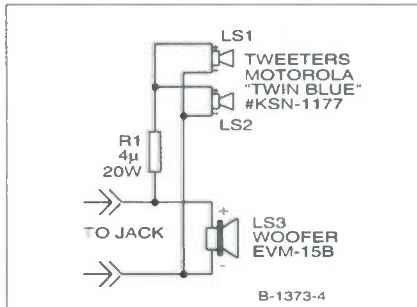

FIGURE 4: Driver wiring.

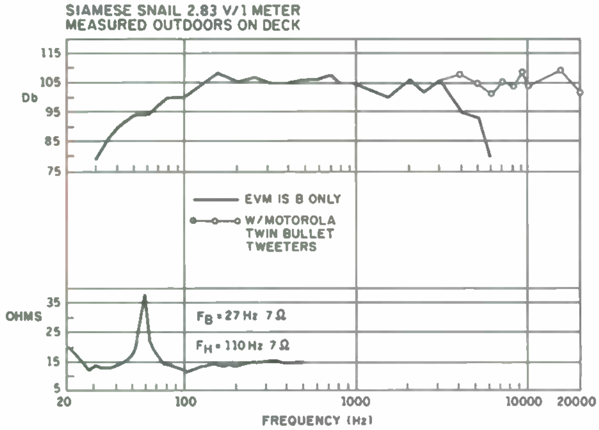

FIGURE 5: Measuring the Siamese Snail's performace.

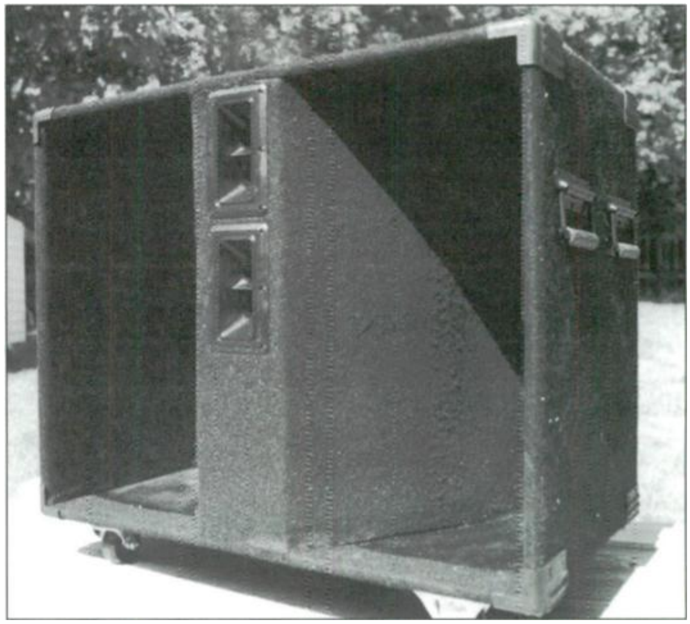

PHOTO 16: Exterior finish applied, and casters and handles installed.

when the bass is run through it. Many keyboard players accustomed to the restricted frequency range of guitar-amp cabinets may find themselves turning the treble down at first, but will soon come to appreciate the harmonics of a full-range cabinet. See performance measurements in *Fig. 5*.

This cabinet is excellent for PA in most respects, but you must elevate it above the heads of the audience for proper dispersion. Since it is too heavy for stand mounting, you'll need scaffolding if a high stage isn't available. On the other hand, for permanent "fly" mounting, the cabinet's low profile is ideal. Finally, for home-stereo use, you'll need both a very tolerant wife (or husband) and distant neighbors, but you won't need a large amplifier.

A patent application has been submitted by the author for Vented Throat Horn Loaded Speaker Cabinets. Designs using this concept are offered to readers for their personal use only. Any commercial use of said designs or of said concept without a licensing agreement with the author may constitute an infringement upon the author's patent protection rights.

What are the common causes of driver failure? How can you spot these? How do you fix them? This author provides the answers to these and other questions.

Loudspeaker Failure Modes

By Mark Williamsen

Moving voice-coil loudspeaker drivers are simple devices. The magnet structure is fixed to a rigid basket, with the moving system made up of cone and voice coil mounted to the basket with a flexible suspension. Not much to go wrong, is there? Well, I will list for you some of the things that can go wrong, as well as symptoms, possible corrective actions, and methods of detecting problems in the first place. I'll be covering four basic kinds of problems, including manufacturing defects, mechanical damage, electrical overstress, and thermal overstress.

MANUFACTURING DEFECTS

Manufacturers in general do a very good job of obtaining consistent, reproducible results when assembling loudspeaker drivers. But you should at least be aware of the kinds of things that can go wrong in manufacturing.

Most acoustical properties of a loudspeaker driver depend on the mass and stiffness of the component parts in the moving system. The mass of each item (cone, voice coil, dust cap, suspension, and so on) is easily measured by weighing on a scale. Most drivers have one component whose weight is not fixed before assembly, and that is the cement that secures the voice coil and dust cap to the cone. When used, mechanized applicators can make the amount of cement more repeatable.

Stiffness is trickier to measure. If a component vendor changes a raw material or process step that alters the stiffness, the driver manufacturer may not find out right away. If suspension stiffness changes, the resonance frequency of the speaker will shift, revealing the change. What you can do about this is measure the resonance frequency[1] of each woofer you will use, and be skeptical of any which varies too much from the manufacturer's spec. If you are using Thiele/Small methods to design your cabinets, also measure the Thiele/Small parameters of each driver.[2]

If there are voids or gaps in the cement holding the suspension, cone, voice coil, and dust cap together, these components may produce buzzing or flapping sounds (something like a kazoo) at certain frequencies. Use an audio oscillator and power amplifier to sweep across the nominal range of the driver to detect this kind of defect. Be careful not to exceed the driver's power-handling ability. Be especially careful of driving the unit outside of its nominal frequency range. I'll discuss this in more detail later on.

If you find a visible gap, you can try to fill it with a similar cement. This may best be left to the manufacturer, since there is no easy way to tell what kind of cement was originally used.

MISHAPS DURING ASSEMBLY

During the assembly of drivers, there are several things that can go wrong that interfere with free motion of the cone. Most drivers have two tinsel lead-outs that connect the voice coil to the terminal strip. These have an optimum length, and if too long or too short, can interfere with cone motion. If the lead-outs are too long, they can slap the back of the cone at certain frequencies. To detect this, sweep the loudspeaker. You may be able to correct this yourself by bending the leads, or resoldering them at a reasonable length.

If the lead-outs are too short, they can stretch tight, limiting maximum excursion of the cone at low frequencies. Use a sweep oscillator, or move the cone by hand to detect this. Drive the speaker at resonance to get maximum cone excursion, then observe lead tightness. If you move the cone by hand through the expected range of excursion, the lead-outs should have some slack remaining at both extremes.

To move the cone, carefully grip its front and back with the fingertips of both hands. Be sure to push symmetrically, so as not to rock the cone. Don't exceed the expected range of motion for the driver. You may be able to correct this defect by straightening the leads or resoldering them at a greater length. Let the manufacturer do this if under warranty.

Note that the soldered joints may suffer from cold solder, both at the terminal strip and where the tinsel leads meet the voice-coil wires at the neck of the cone. If you find an open circuit in a speaker that has not been electrically overstressed, it may be due to a cold solder joint, which you can fix with a soldering pencil.

MAGNET-GAP PROBLEMS

Since loudspeaker drivers have tight tolerances in the magnet-structure gap where the voice coil sits, it is entirely possible to get a chip or rub between the voice coil and magnet structure. Chips are usually magnetic, either steel shav-

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ings or slivers of magnet, since non-magnetic particles will easily fall out of the gap and won't interfere with the voice coil. Once a driver is assembled, magnetic chips (if any) tend to stay put inside the motor.

It is conceivable, however, that a chip could be present inside the motor, and then fall into the gap later. You can detect chips by moving the cone by hand, or by sweeping the speaker. The clue is a buzzing or rattling sound, depending on frequency.

If the chip is between the voice coil and the pole piece, you can remove the dust cap and pull out the chip with adhesive or masking tape. Replace the dust cap, and the driver is almost as good as new.

If the chip is between the voice coil and the front plate, you must remove the entire cone and voice coil as one assembly to get at the chip. Then, you can recone the speaker, after which it should be as good as new.

A variation on this occurs when rust and corrosion in outdoor applications cause magnetic particles to enter the gap. Plating of the metal parts in the magnet structure before assembly controls this in all but the harshest conditions.

Rubs are caused by the voice coil touching the pole piece or front plate at some point in its range of travel. Move the cone by hand and feel for interference with your fingertips, or sweep the driver and listen for a scraping sound, probably at resonance, where excursion is the greatest.

Fixing a rub usually requires reconing the driver. If the driver continues in use with a bad rub, the insulation will wear off the windings, resulting in an intermittent short circuit between the voice coil and magnet structure.

One more possible manufacturing defect is that the motor was magnetized in the wrong polarity or with insufficient strength. You can easily check polarity by connecting a 1½V battery across the woofer. When you connect the + pole of the battery to the + terminal of the driver, the cone should move towards you, away from the basket.

The easiest way to handle a reverse-magnetized driver is to clearly mark the actual polarity on the back of the driver. There should be no effect on other electrical and acoustical properties. You can observe magnetic-field strength by checking the impedance curve or measuring sensitivity.

Multiple woofers in a system should have similar impedance curves and sensitivity. Note that most magnetizers operate in a saturation mode, so field strength depends mainly on the properties of the magnet, rather than on the adjustment of the magnetizer.

MECHANICAL DAMAGE

If you drop a driver from a sufficient height, either by itself or in a cabinet, one of two things can happen. First, the chassis may bend, misaligning the motor and voice coil. This will appear as a rub that you can detect by moving the cone by hand or by sweeping the driver. Reconing may fix a slight misalignment, but you should consider replacing the whole driver.

Even worse, the magnet structure may fail, allowing the pole piece to slam against the front plate, effectively locking the voice coil between the pole piece and front plate. In this case, you will not be able to move the cone by hand, and sweeping the driver will produce little or no output. The forces within the motor are such that there is no way to center the pole piece again without first demagnetizing the structure. The speaker is then normally a total loss.

If you have a driver with a dented dust cap, it is fairly simple to pull it back out with a piece of adhesive tape. For felt or cloth-screen dust caps, you can also snare the middle with a pin or needle, and pull it out. Appearance may suffer, but performance in non-critical applications is normally not affected. Sweep the driver to be sure nothing came loose in the process.

You can glue small holes or tears in the cone in noncritical applications. Choose a cement that remains resilient when dry. Don't bother fixing a hole in the surround, since it's likely to fail again, like a patch in the sidewall of a tire. For critical applications, the driver must be reconed.

ELECTRICAL OVERSTRESS

Once a driver is checked out and installed in your project cabinet, what could go wrong? Well, if you have a super-power amplifier with loads of headroom, it is conceivable that you could burn through the insulation on the voice-coil windings. Magnet-wire insulation typically withstands hundreds of volts, but standard winding techniques result in the input and output leads crossing one another where they leave the coil.

If the insulation happens to be weak at this point, and input voltage momentarily exceeds the dielectric strength, an arc will result. If it continues for more than an instant, the wire will burn through, leaving an open circuit, or—even worse—welding the input and output leads together to cause a direct short across your amplifier. In either case, the speaker quits working and must be reconed.

With some drivers, it is possible to drive the cone inward far enough to damage the voice coil. Magnet thickness affects maximum negative cone excursion, since a thin magnet can allow the voice coil to bottom out against the back plate. A well-designed driver prevents this by letting the suspension bottom out before the voice coil hits the back plate. Bottoming sounds horrible, and if repeated more than a few times, will damage the end of the voice coil, resulting in a permanent rub.

Many drivers use a humped back plate to allow more negative cone excursion. You may also see drivers with two ring magnets stacked on top of each other to allow more cone excursion. Unfortunately, this has little effect on field strength.

Also, it is possible for a high-power amplifier to demagnetize some drivers. This can show up as a depressed impedance curve or reduced sensitivity. The manufacturer can remagnetize the driver, but you might want to select a different driver for your application if this happens.

THERMAL OVERSTRESS

Probably the most common cause of failure in the field is thermal overstress. Manufacturers and users alike are eager to think their speakers are powerful, so they frequently drive them beyond safe limits. But what is a safe limit for any given speaker?

Many manufacturers use a simple model that specifies two quantities, RMS nominal power, and peak maximum power. This model suffers from two inadequacies. First, you can verify the rating only by testing the speaker to destruction. Second, this model doesn't help you derate a driver when ambient temperature is elevated. Some manufacturers don't even tell you at what ambient temperature their power ratings apply!

A much more suitable model is the thermal circuit, used by many semiconductor manufacturers.[3] Given a known thermal resistance from voice coil to ambient and a known ambient temperature, the thermal circuit model lets you predict with a fair degree of accuracy the actual voice-coil temperature that will result from a specific power input. Then you can decide if the voice-coil temperature is reasonable for your application.

The voice coil will have some maximum operating temperature, depending on materials and construction, above which mechanical failure is likely. In addition, the DC resistance of the voice coil shifts upward as temperature increases, so there will probably be a temperature less than the ultimate maximum at which resistance shift will be unacceptable in your design.

I believe that 100°C is a reasonable limit. Voice-coil DC resistance increases by about 30% at 100°C. Some vendors install voice coils capable of withstanding 200°C or more. The DC resistance of such a voice coil will have increased by almost 70% by the time the temperature reaches 200°C.

OVERSTRESS CONSEQUENCES

Since the voice coil is under power when you exceed its thermal limit, the

Measured vs. Predicted Temperature in Copper Wire

measured temperature deg F	converted to centigrade deg C	measured resistance Ohms	predicted temperature deg C	error deg C
208	97.8	8.376	97.8	0.0
200	93.3	8.224	91.8	-1.6
190	87.8	8.098	86.8	-1.0
180	82.2	7.943	80.6	-1.6
170	76.7	7.813	75.5	-1.2
160	71.1	7.685	70.4	-0.7
150	65.6	7.541	64.7	-0.9
140	60.0	7.401	59.1	-0.9
130	54.4	7.249	53.1	-1.4
120	48.9	7.123	48.1	-0.8
110	43.3	6.993	42.9	-0.4
100	37.8	6.846	37.1	-0.7
90	32.2	6.699	31.3	-0.9
81	27.2	6.597	27.2	0.0

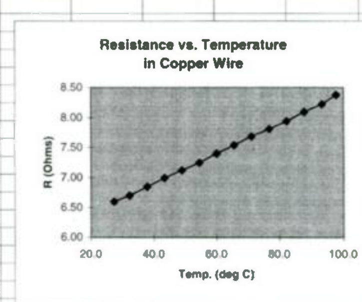

FIGURE 1: Measuring resistance to determine temperature in copper wire.

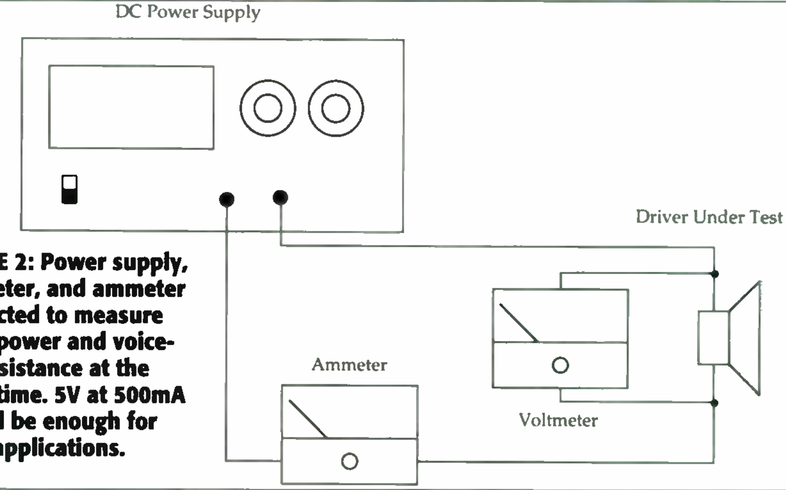

FIGURE 2: Power supply, voltmeter, and ammeter connected to measure input power and voice-coil resistance at the same time. 5V at 500mA should be enough for most applications.

cement holding the windings together softens, while at the same time the current causes the application of force. The result is that some of the windings come loose from the coil. This causes a rattle or buzz when the speaker is swept, even after returning to lower temperatures. It may also show up as a rub if you move the cone by hand. You must have the speaker reconed to correct this.

As you can see from this discussion, the power-handling ability of a loudspeaker depends mainly on the thermal resistance of the voice coil. Larger-diameter voice coils have more surface area available to radiate heat, and therefore have lower thermal resistance and more power-handling ability.

Magnet size is usually larger for drivers with larger voice coils, but magnet size alone doesn't predict power handling. Also, don't be fooled by dust-cap diameter. It is easy for a manufacturer to install an oversize dust cap to give the appearance of a large voice coil. For a more realistic view, look in the side of the basket at the neck of the cone, where it meets the rear suspension. This will probably be closer to the actual voice-coil diameter.

MEASURING THERMAL RESISTANCE

Since many manufacturers don't publish this number, I hope you're wondering, as I did, if there is a way to measure it. It turns out that copper magnet wire has a characteristic resistivity that increases with temperature. In other words, you can apply power to copper windings in any device (motor, transformer, loudspeaker, and so on) and determine the temperature of the windings at the same time by measuring the increase in resistance. The number of degrees by which the windings heat up for each watt of input power is the thermal resistance. Here's how to proceed:

For this to work, you need a reliable formula that can determine the temperature of a length of copper wire. According to several references,[4,5] the temperature coefficient of resistance for annealed copper is 0.00393 per degree C, at 20°C. If the resistance R1 of a length of copper wire at 20°C is known, you can use the temperature coefficient in the following equation to determine the resistance R2 at temperature T2:

$$R2 = R1 \times (1 + 0.00393 \times (T2 - 20)) \quad [1]$$

With a little algebra, this equation can be solved for T2:

$$T2 = (((R2/R1) - 1)/0.00393) + 20 \quad [2]$$

If the resistance is known at some other temperature, you can write the equation twice, once for temperature T2 and once for temperature T3:

$$R2 = R1 \times (1 + 0.00393 \times (T2 - 20)) \quad [3]$$

$$R3 = R1 \times (1 + 0.00393 \times (T3 - 20)) \quad [4]$$

Dividing the two equations so that R1 falls out yields the following:

$$R3 = R2 \times (234.5 + T3)/(234.5 + T2) \quad [5]$$

And, finally solving for T3:

$$T3 = (R3/R2 \times (234.5 + T2)) - 234.5 \quad [6]$$

FORMULA TESTING

To see how well this actually works, I hand-wound a loose coil of 62.5' of 30-gauge copper magnet wire (available as part of Radio Shack #278-1345). Standard copper-wire tables show that #30 wire has a resistance of 0.1052Ω per foot, so this coil should have a resistance of about 6.57Ω at 20°C. The coil actually measured 6.60Ω at room temperature, which in my case was 80°F, or 26.6°C.

Calculation of Thermal Resistance in 20 Watt 5-1/4" Driver

measured current Amps	measured voltage Volts	calculated resistance Ohms	power dissipation Watts	calculated temperature deg C	temperature rise deg C	thermal resistance deg C/Watt
0.1494	1.066	7.139	0.159	29.51	2.85	17.89
0.2825	2.012	7.122	0.568	28.88	2.22	3.91
0.4050	2.957	7.301	1.198	35.51	8.85	7.39
0.5150	3.934	7.639	2.026	47.99	21.33	10.53
0.6350	4.990	7.858	3.169	56.11	29.45	9.29
0.7350	6.043	8.222	4.442	69.55	42.89	9.66
ambient temperature:		26.66				
resistance at ambient:		7.062				

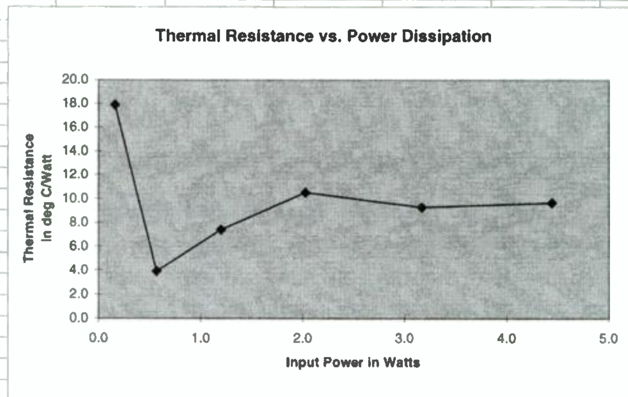

FIGURE 3: Calculating thermal resistance in loudspeaker driver by measuring temperature rise in voice coil.

Calculation of Thermal Resistance in 4 Watt 5-1/4" Driver

measured current Amps	measured voltage Volts	calculated resistance Ohms	power dissipation Watts	calculated temperature deg C	temperature rise deg C	thermal resistance deg C/Watt
0.1495	1.030	6.891	0.154	31.759	5.099	33.108
0.2888	2.021	6.999	0.584	35.939	9.279	15.900
0.4150	3.068	7.393	1.273	51.148	24.488	19.233
0.5175	4.070	7.865	2.106	69.384	42.724	20.285
0.5975	5.003	8.373	2.989	89.032	62.372	20.865
ambient temperature:		26.66				
resistance at ambient:		6.759				

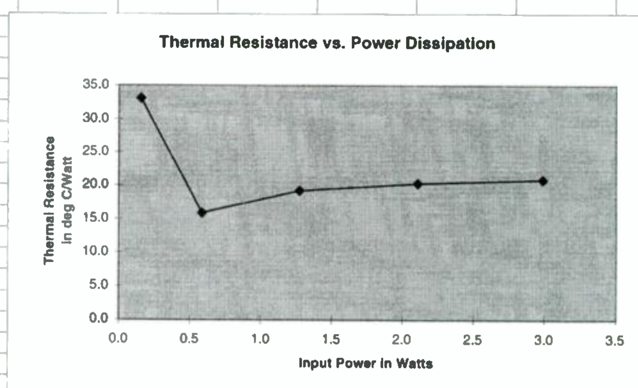

FIGURE 4: Measurement of *Fig. 3* performed on a lower-rated driver.

Next, I put the coil, a kitchen thermometer, and boiling water into a coffee cup, and measured the coil's resistance as the water cooled back down to an ambient level. I took care to keep the bare ends of the coil high and dry, away from the water. *Figure 1* shows the measured temperature, measured resistance (less my DVM's lead resistance), and predicted temperature using equation [6]. The difference between calculated and measured temperature was less than 2°C over the range from ambient to boiling.

Having satisfied myself that I had a good formula for determining voice-coil temperature, I bought a couple of inexpensive loudspeakers to use in measuring voice-coil temperature rise. I connected a voltmeter, ammeter, regulated power supply, and the loudspeaker as shown in *Fig. 2*. I set the power supply for constant-current operation—a big mistake as it turned out—and started taking measurements.

The problem with constant-current drive is that as the voice coil's temperature rises, its resistance increases, causing more power to dissipate, which in turn causes the resistance to increase still more, and so on. I couldn't get good readings because I was shooting at a moving target. I realized the experiment was out of control when the voice coil failed due to excessive heating. I knew it had failed when the voltage across it dropped suddenly and I smelled the burned windings.

LEARNING LESSONS

I learned the important lesson that constant voltage is a much safer way to drive a voice coil than constant current. Under constant voltage, as temperature rises and voice-coil resistance increases, the power dissipated in the voice coil drops, soon reaching a stable condition that you can accurately measure.

To avoid testing any more drivers to destruction, I took some time to think through how much power should be applied in testing. The driver I destroyed was rated at 20W RMS. I thought I could safely dissipate 20W continuously in the voice coil by applying a DC current from a power supply. I was thinking of the driver as if it were a 20W resistor or a light bulb.

The manufacturer probably had something quite different in mind, such as applying an AC signal at a voltage that would produce 20W RMS in an 8Ω resistor, with the power divided across a band of frequencies covering the nominal range of the driver. Testing at a single frequency is more stressful than broadband testing, and a DC input is a worst-case example of a single frequency.

I now believe that one-fourth of the rated continuous power is a reasonable limit for thermal-resistance measurements. You can calculate the voltage that produces a given amount of power as:

$$V=\sqrt{P\times R} \qquad [7]$$

ANOTHER TRY

For the 20W speaker with 8Ω impedance, the voltage that produces 5W is,

$$\sqrt{5\times 8} \qquad [8]$$

or 6.32V. With this in mind, I bought another sample of the 20W driver (Radio Shack #40-1354A) and took a series of readings, from 1–6V DC in 1V steps. First I adjusted the power supply to get close to the desired voltage. Then I waited for about 30 seconds for the voice-coil temperature to stabilize. Finally, I recorded the current through the voice coil and voltage across it.

I used mini-clips to grab the tinsel lead-outs as close as possible to the voice coil for the voltage measurement. You could also connect the DVM to the driver's terminal strip, but be sure you don't include any voltage drop across test leads or alligator clips in your voltage measurement.

After gathering the data, I typed it into the first two columns of the spreadsheet in *Fig. 3*. In the third column, I calculated the voice-coil resistance in ohms as:

$$R = E/I \qquad [9]$$

In the fourth column, I calculated power dissipated in the voice coil in watts as:

$$PD = E \times I \qquad [10]$$

In the fifth column, I calculated the temperature in the voice coil in degrees C based on the measured resistance under power and the resistance at ambient temperature, using equation [6]. In the sixth column, I calculated the temperature rise TR above ambient temperature TA in Centigrade as:

$$TR = T3 - TA \qquad [11]$$

Finally, in the seventh column, I calculated the thermal resistance RT in degrees C/watt as:

$$RT = TR/PD \qquad [12]$$

CHECKING THE DATA

To check the consistency of the data, I plotted the thermal resistance values. The first three seem inconsistent with the last three. After repeating measurements on this and other speaker drivers several times, I believe that errors in readings with small values of temperature rise are due mainly to resistance measurement errors swamping the desired temperature-rise effect. There may also be time-constant issues that settle out after several readings.

Temperature Rise vs. Time in 20 Watt 5-1/4" Driver							
elapsed time minutes	measured current Amps	measured voltage Volts	calculated resistance Ohms	power dissipation Watts	calculated temperature deg C	temperature rise deg C	thermal resistance deg C/Watt
0.0	0.8325	7.057	8.477	5.875	78.98	52.32	8.91
1.0	0.8100	7.062	8.719	5.720	87.92	61.26	10.71
2.0	0.8075	7.062	8.746	5.703	88.92	62.26	10.92
3.0	0.8050	7.063	8.774	5.686	89.97	63.31	11.13
4.0	0.8025	7.063	8.801	5.668	90.98	64.32	11.35
10.0	0.7950	7.064	8.886	5.616	94.10	67.44	12.01
20.0	0.7850	7.066	9.001	5.547	98.38	71.72	12.93
30.0	0.7800	7.065	9.058	5.511	100.46	73.80	13.39
40.0	0.7725	7.064	9.144	5.457	103.67	77.01	14.11
50.0	0.7700	7.064	9.174	5.439	104.76	78.10	14.36
60.0	0.7675	7.064	9.204	5.422	105.87	79.21	14.61
ambient temperature:		26.66					
resistance at ambient:		7.062					

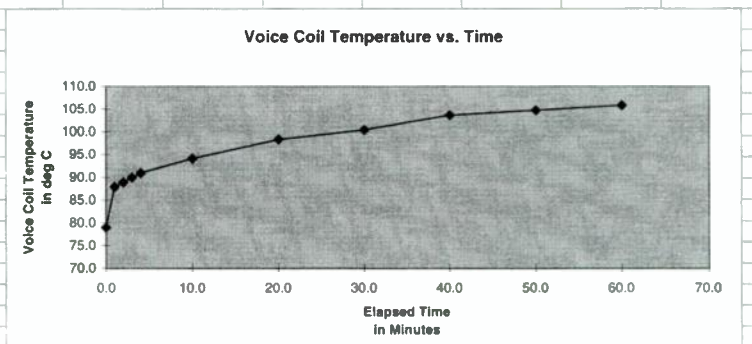

FIGURE 5: Temperature rise over time with continuous power input.

What all of this indicates is that for this driver, each watt of power dissipated in the voice coil will cause its temperature to increase 10°C. According to the thermal-circuit model, voice-coil temperature T3 is related to ambient temperature TA, power dissipation PD, and thermal resistance RT by the following equation:

$$T3 = TA + (PD \times RT) \qquad [13]$$

If the rated power of 20W was actually dissipated in the voice coil, its temperature would rise by 200°C. At an ambient temperature of 25°C, the voice coil would reach 225°C, almost certainly destroying the unit. If voice-coil temperature were limited to 100°C, then the temperature rise above ambient would be 75°C, and input power could not exceed 7.5W.

For comparison, I made the same measurements on a lower-rated driver from the same manufacturer (Radio Shack #40-1241E), as plotted in *Fig. 4*. With a thermal resistance of 20°C per watt, the nominal continuous rated power of 4W would produce a temperature rise of 80°C. At 25°C ambient, the voice coil would reach a temperature of 105°C.

This is a lot more conservative than the previous driver. Knowing the thermal resistance allows you to better match a driver to the application, especially where high power is involved, or when replacing a driver that has failed due to thermal stress.

There are two time constants associated with thermal-resistance measurements. Over relatively short periods of time—on the order of 15 seconds—the voice coil will quickly reach a steady temperature, given a fixed power input.[6] The pole piece and magnet structure have a large thermal mass compared to the voice coil, and hence will stay close to ambient over this 15-second interval.

If input power is maintained, the magnet structure will gradually heat up after minutes or hours have passed. This then becomes the ambient temperature surrounding the voice coil, effectively increasing thermal resistance over this longer period of time. *Figure 5* shows the voice-coil temperature rise over a period of one hour in a 20W-rated driver receiving a continuous DC power input of about 5W. As the magnet structure heats up, maximum power handling is decreased by a corresponding amount.

SWEEPING A SPEAKER DRIVER

Single-frequency testing, sometimes called continuous wave or CW, is a high-stress test for any loudspeaker driver. By manually sweeping across the audio band, you can isolate all kinds of quirks and problems, even with drivers of very good quality. With a little practice, you can also use this test to reveal many of the defects described above, including chips, rubs, loose windings, and slapping lead-outs, as well as cone breakup and rocking modes. Since you can make almost any driver misbehave at some specific frequency, this is a relative test, and you must judge what is expected behavior and what is really a defect.

As with thermal-resistance testing, you should, when sweep testing, limit input power to one-fourth or less of rated continuous power. If you're testing a multiway system, this means one fourth of the rated power of the lowest-rated driver in the system, usually the tweeter.

When sweeping a loudspeaker driver, don't look directly at the cone on axis. With a single input frequency, the sound level on axis can be uncomfortably, even dangerously, loud. Rather, position the driver so you are looking edge on at the rim. This will allow front and rear radiation of the desired signal to cancel at your ears so you can better listen to undesired sounds caused by defects.

If you find a problem that occurs at one steady frequency and can't decide whether it is really a defect, try sweeping slowly through the problem frequency. If the problem only appears when you stop at a particular frequency, it probably won't be audible with normal program material.

In the past, we used beat-frequency oscillators (BFOs) to sweep loudspeakers. The advantage of a BFO compared to other technologies is that it allows you to sweep across the three decades from 20Hz to 20kHz using a single dial with no range switching. These instruments were made by General Radio (today called GenRad, www.genrad.com), Bruel & Kjaer (now part of Spectris Tech, www.spectris .com), and other manufacturers. The modern equivalent is the so-called function generator.

Some of these newer instruments also allow you to sweep logarithmically from 20Hz to 20kHz without range switching. Internally, they start with a triangle wave, and adjust it by pushing and pulling until it looks like a sine wave. This technique is capable of harmonic distortion under 1%, but, unfortunately, the distortion that remains sounds distressingly like many loudspeaker-driver defects.

PHASE-SHIFT OSCILLATOR

For my own use, I have developed an

op-amp-based phase-shift oscillator, shown in the schematic of *Fig. 6*. A1 and A3 each produce a phase shift of 90° at the operating frequency. A2 produces an additional 180° of shift to produce a closed-loop shift of 360°. Gain around the loop is maintained at unity

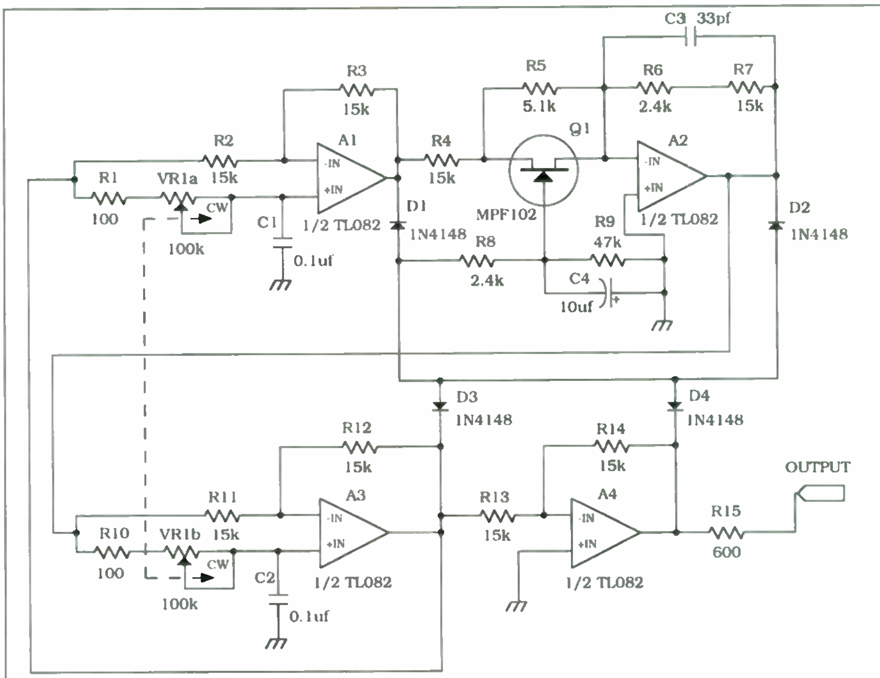

FIGURE 6: Three-decade audio oscillator for manually sweeping loudspeaker drivers. Power supply (not shown) should be ±12V DC, filtered, regulated, and bypassed.

by the automatic-gain-control (AGC) element Q1. The operating frequency F is described by the following equation where C1, C2, VR1a, and VR1b are as shown in *Fig. 6*:

TABLE 1
PARTS LIST

VR1	100kΩ stereo volume control	RS #271-1732
A1–A4	TL082 op amp (only 2 needed)	RS #276-1715
Q1	MPF102 N-ch. FET	RS #276-2062
D1–D4	1N4148 si diode	RS #276-1122
C1, C2	0.1µF film capacitor	RS #272-1053
C3	33pF ceramic disc capacitor (part of assortment)	RS #272-806

$$F = 1/(2 \times \pi \times C1 \times (VR1a + R1)) = 1/(2 \times \pi \times C2 \times (VR1b + R10)) \quad [14]$$

The frequency control is wired in reverse (clockwise for decreasing frequency) to give a pseudo logarithmic effect. The parts values shown, while easily available, will produce a range from about 16Hz to 16kHz. C1 and C2 actually need to be 0.08µF instead of 0.1µF to produce a true 20–20kHz range. You can substitute better op amps for the ones shown, as long as they are unity-gain compensated and have a power bandwidth including the highest frequency of operation. Note that the TL082 is barely adequate for this circuit. I also tried the similar LF353, but it couldn't hold up the high-frequency end.

Quadrature outputs are available from A1 and A3. In fact, the availability of quadrature signals makes the AGC very stable at low frequencies, especially compared to light-bulb based oscillators. You should make C3 adjustable, or at least changeable without too much trouble, since it eliminates ultrasonic oscillation and controls flatness at the high end.

As with any audio circuit, use an oscilloscope to check for oscillations other than the desired one before putting the circuit to use. Output with the circuit as shown should be around 2.5V RMS. R15 is provided to isolate and protect the output. You can directly drive headphones or small loudspeakers at this level. For larger loads, connect the output to a power amplifier through a variable attenuator. Use a modest-sized amplifier unless you are willing to have damaged drivers reconed.

SUMMARY

Most of the defects listed here can be detected with an ohmmeter, an audio-sweep oscillator, and by simple inspection of the driver and its moving system. Although many defects require reconing, you may be pleasantly surprised at finding things you can fix otherwise. However, the best cure is often prevention. For loudspeakers, that means knowing the limits, thermal or otherwise, and not exceeding them.

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Kit Review

THE SEAS ODIN

By Mark Florian

Madisound Speaker Components, 8608 University Green, PO Box 44283, Madison, WI 53744-4283, (608) 831-3771, FAX (608) 831-3771. The full kit with clear or black-oak veneered ¾" MDF cabinets costs $945 plus s/h, and $725 without cabinets.

SEAS (say-ahs), an acronym for Scandinavian Electro Acoustic Systems, was founded in 1950 as a spin-off from the two Norwegian radio manufacturers, Radionette and Tandberg. Headquartered in Moss, Norway, SEAS offers a wide selection of drivers in all price ranges. Loudspeaker manufacturers such as Triad and Jamo have used their drivers. The drivers used in the Odin (*Photo 1*) are from the Excel line.

PHOTO 1: The SEAS Odin loudspeaker.

The W17E002 6½" woofer (*Photo 2*) features an injection-molded magnesium cone, natural-rubber surround, magnesium frame, copper-plated top and bottom plates, copper shorting rings above and below a T-shaped pole piece, a 1½" 100W voice coil, and a solid-copper phase plug attached directly to the magnet system. F_S is listed as 34Hz, V_{as} is 29.5 ltr, linear excursion (X_{MAX}) is 8mm pk-pk, while maximum excursion is 19mm. The cone diameter from the center of the surround measured 5³⁄₁₆" (131.76 mm). Finally, Q_{TS} is listed at 0.32.

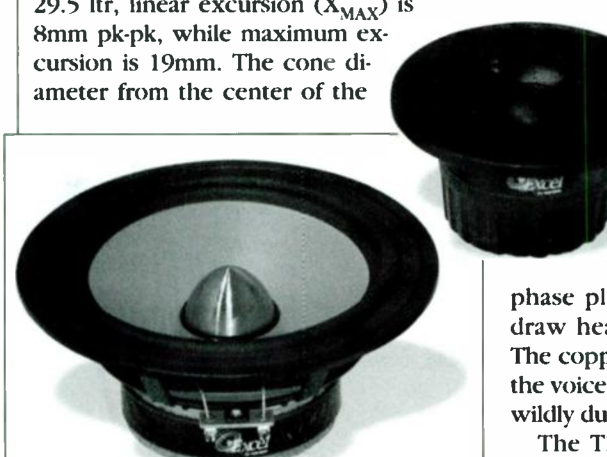


PHOTO 2: Close-up of woofer and tweeter.

The addition of the phase plug not only provides a smoother, more linear response towards the upper end of the woofer's response, but also eliminates the glue joint between the dust cap and cone. At higher frequencies, a dust cap can flop around, so to speak, causing response abnormalities. The phase plug also acts as a heatsink to draw heat away from the voice coil. The copper shorting rings help prevent the voice coil's inductance from varying wildly during large excursions.

The T25-001 1" tweeter (*Photo 2*) features a soft dome made of Sonotex fabric, a silver-wire voice coil, tinsel leads, ferrofluid in the voice-coil gap, a double magnet system, and a rigid rear chamber designed to minimize internal reflections. F_S is listed at 750Hz, voice-coil maximum power is 90W, and sensitivity is 90dB (1W/1m).

John Stone of SEAS and Tom Roberts of Madisound have used LEAP to redesign the Odin crossover. The original crossover appears on the Odin information sheet, available from Madisound, and also the Speaker Building Web page, and was redesigned to remove some ripples in the 1-3kHz region. The new crossover is shown in *Fig. 1*. I've been told that from a measurement perspective the response looks considerably better, but sonically you could argue either way. It will be interesting to see how well these goals were accomplished in the light of Joe D'Appolito's accompanying report.

WOOFER CIRCUIT

The woofer circuit is a first-order network (6dB/octave low pass), with the 5Ω resistor and 12µF capacitor providing impedance compensation. Because all metal-cone drivers exhibit a resonance peak at cone breakup, the 0.8µF cap in parallel with the inductor forms a notch filter to reduce the magnitude of the peak. The 3.0Ω resistor lessens the Q of the notch network to tailor the filter response to that of the drivers. The overall effect is for a smooth rolloff of the high-frequency response.

The tweeter crossover is essentially a first-order network with a twist. The 12µF capacitor provides the initial first-order rolloff, but the 0.25mH inductor and 200µF capacitor combination causes the tweeter to roll off faster on the low end. This network was used because of the ferrofluid in the voice coil. Finally, the combination of the 5Ω and 82Ω resis-

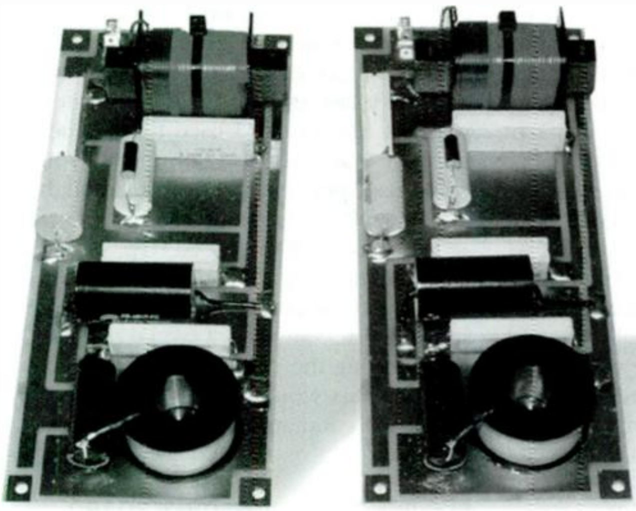


PHOTO 3: Preassembled crossover boards.

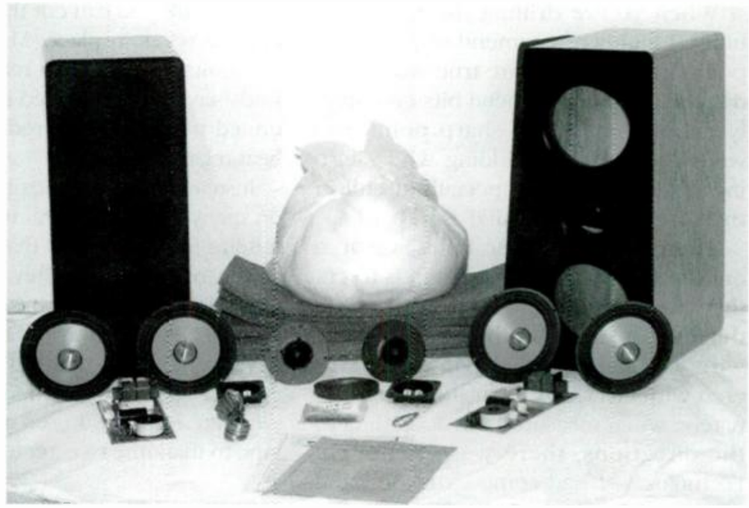


PHOTO 5: SEAS Odin kit contents.

tors helps to match the tweeter level to that of the woofers.

Photo 3 shows the assembled crossover boards. All resistors are sand-cast units. The 1.3mH inductor in the woofer circuit is an iron-core type, while the smaller 0.25mH unit is an air-core. The 0.8 and 12μF capacitors are Bennic polyesters, the 12μF unit is a Solen polypropylene, and the large 200μF cap is a Bennic electrolytic. Personally, I'd like to see a higher quality of resistor used in series with the tweeter. The crossover boards are made of epoxy, using a "minimum etch" design that maximizes the amount of copper left on the board to carry the signal. Just enough is removed to separate the various sections from each other.

The supplied cabinets (*Photo 1*) are very nice, well-built units featuring oak-veneered 1″ MDF on the top, bottom and both sides, with front and back faces made of plain 1″ MDF painted a glossy black. Each of the corners between the top or bottom and sides is made of solid oak with a ½″ round over. Countersinks are provided so that the drivers and the mounting cup sit flush with the baffle. In addition, the woofer holes are beveled on the inside of the cabinet, which is a nice touch.

Instead of a tube on the back to tune the enclosure, the Odin uses a 1⁵⁄₁₆″ × 7¾″ rectangular slot (*Photo 4*). Two internal braces made of ¾″ particleboard tie the back and two sides together and determine the height of the slot. According to Madisound, using a slot allows each of the woofers to be symmetrically loaded. The joint where the slot exits the rear wall is beveled, as are the surfaces inside the cabinet. Also included are well-made grilles of ½″ particleboard covered with a black cloth.

PUTTING IT BACK TOGETHER

The kit contents (*Photo 5*) include most items you'll need, even solder and screws. The tools required are an electric drill, a ³⁄₃₂″ drill bit, a #2 Phillips screwdriver, a 40–60W soldering iron, and wire strippers. The kit instructions are clear and easy to follow. The first step involves marking the pilot holes for the drivers and rear-mounting cup. I used a combination square to line up the driver mounting holes so they are horizontal and not tilted. To mark the hole positions, I used a sharpened pick, similar to an ice pick, only shorter. This makes a noticeable mark on the black baffle and provides a small indentation for the drill bit to prevent it from skidding across the surface.

TABLE 1
SPECIFICATIONS

Tweeter	SEAS Excel T25001
Woofers	Two SEAS Excel W17E002s
Cabinet Dimensions	21¹⁵⁄₁₆″H × 9 ³⁄₁₆″W × 13¹¹⁄₁₆″D
Weight	34 lbs.

PHOTO 4: Rear view of cabinet, showing slot detail.

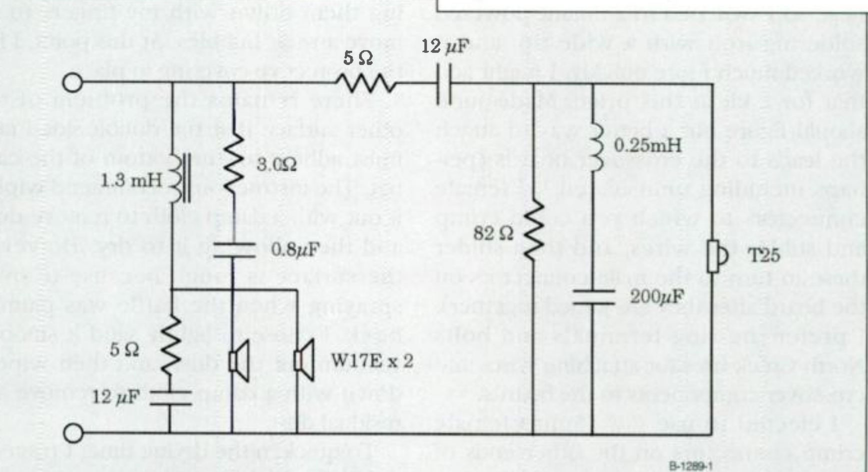


FIGURE 1: Odin crossover schematic.

When you're drilling the mounting holes, I highly recommend using a brad-point drill bit. These are true wood bits, not the blunt-nosed metal bits commonly encountered. The sharp point prevents the bit from skidding while starting the hole and is especially useful in this case because the MDF is so hard.

After you drill all the holes, vacuum out the shavings. The next step is to cut the wire to length and then strip and tin the ends. Included in the kit is 16-gauge wire, commonly called "zip-wire," covered with clear vinyl insulation. Unfortunately, when measured out according to the directions, there wasn't enough! Fortunately, I had some extra on hand to complete the wiring. Tinning the ends makes it easier to solder the wires to the speakers and the lugs on the crossover board.

The instructions include a note cautioning you not to try to force the wire into the small holes on the lugs, but instead to lay the wire flat on the lug and then solder. Since the lugs point straight up when the board is flat on a horizontal surface, I set the board up on its edge and leaned it against something so it would stay put. In this position, however, the woofer inductor blocks your view of the crossover connectors.

If you have a vise on your bench, you can flip the board around and clamp it in place so you can easily see the connectors. But you still have the problem of needing three hands: one each for the solder, the soldering iron, and to hold the wire in place! Lacking a vise, I decided to break the rules, enlarging the holes in some of the ¼″ male connectors and inserting the wires. I also made use of the holes that anchor the male connectors to the board.

Initially, I used an electric soldering gun, but found it didn't provide enough heat, so I switched to a butane-powered soldering iron with a wide tip, and it worked much more quickly. I might add that for a kit at this price, Madisound should figure out a better way to attach the leads to the crossover boards (perhaps including uninsulated ¼″ female connectors to which you could crimp and solder the wires, and then solder these in turn to the male connectors on the board after they are joined together). I prefer the ring terminals and bolts North Creek uses for attaching wires and crossover components to the boards.

I elected to use 3⁄16″ (5mm) female crimp connectors on the other ends of the wires to make removal easier if a driver should be defective. When everything checks out, you can cut these off and solder the wires in place. Many companies are hesitant to accept a returned driver if leads have been soldered in place. Again, tinned wires and lugs reduce the risk of heat-related damage.

Instead of the tiny, flexible lugs you see on many tweeters, SEAS uses gold-plated full-size 3⁄16″ metal tabs that widen to 7⁄16″ at the base, where they are firmly anchored to the flange, thus making it easy to get a good connection. Finally, in order to make identification of the woofer and tweeter leads easier when the foam and wool are in place, I used a small piece of tape to mark the tweeter lead.

MOUNTING THE CROSSOVER

With the wires soldered to the board, the next step is to mount the crossover inside the enclosure. The instructions say to "remove the backing on the double-stick tape adhered to the bottom of the crossover." Unfortunately, there was no double-stick tape on the bottom of the crossovers or anywhere else in the kit. Fortunately, I keep a supply of double-sided carpet tape on hand to use with router jigs. Before applying the tape, however, I decided to remove the plastic wire tie that protruded through the bottom of the board and held the iron-core inductor in place while the adhesive dried when the crossover was assembled. Otherwise, the board will not lie flat, and the tape won't work.

When you use screws to mount the crossover, wire ties aren't a problem. In this situation, however, screws are not an option because there isn't enough room to drill the holes. (Besides, trying to drive screws by hand into 1″ MDF is not recommended.) After cleaning the backs of the crossover boards with alcohol to remove any fingerprints, I laid down two strips of carpet tape, smoothing them down with my fingers to remove any air bubbles. At this point, I left the protective covering in place.

There remains the problem of the other surface that the double-sided tape must adhere to—the bottom of the cabinet. The instructions recommend wiping it out with a damp cloth to remove dust, and then allowing it to dry. However, the surface is rough because of overspraying when the baffle was painted black. I chose to lightly sand it smooth, vacuum out the dust, and then wipe it down with a damp cloth to remove any residual dust.

To quicken the drying time, I placed a small shop light into the cavity for a few minutes. Then I sprayed a couple of thin coats of clear lacquer on the bottom to seal the wood and give the tape a smooth surface to adhere to. The lacquer dries very fast, even faster when heated with the shop light. I used the lacquer because I already had some, but you could use spray enamel instead, though it would take longer to dry.

The reason for my added steps is that tape just doesn't adhere very well to a bare wood surface. Since the fronts are sprayed black anyway, I would suggest just spraying the cabinet bottoms black as well. This would seal the wood and provide a good surface for the tape to stick to.

SECURING THE CROSSOVER BOARD

The final step is to remove the protective paper from the carpet tape, slide the crossover board into the lower woofer hole and press down firmly to anchor it to the bottom. Another option is to glue in the crossover board with construction adhesive. If you ever decided to make changes to the crossover, however, you'd never get the board out in one piece.

The next job is to cut the foam to the correct size and then line the inside of the cabinet in the order given. Unfortunately, instead of the two sheets of foam measuring 27″ × 42″ according to the parts list, I received six pieces that measured 9″ × 21″, which is not enough. Fortunately, again, I had some extra foam of the same type used in the kit.

I weighed the wool on a postal scale and then divided it into four bunches, loosely filling the foam-lined cavities in the top and bottom of the cabinet while keeping it away from the slot and the backs of the woofers. After soldering the leads onto the rear-cup connectors, I installed the cup with four screws.

To install weather stripping, I find it convenient to lay an enclosure on its back and turn the driver over onto its face on the countersink. In this way you can rotate the driver while installing the weather stripping without damaging the rubber surround or tweeter dome, since the drivers are supported only on their rims. I then use an ice pick to poke a hole through the weather stripping from the backside at each screw location. I then connect the wiring, turning the driver over and installing it in place with the screws.

Before any serious listening, I broke in the drivers for 48 hours by continuously playing track 20 on *Stereophile*'s *Test CD 3*, which contains burn-in noise.

LISTENING TESTS

My stereo system consists of the Swan IV speakers, with the updated Linkwitz-Riley Pedal Coupler biamped with an unmodified Hafler 220 driving the bass units and a Borbely Servo 100 driving the satellites. The CD player is a CAL (California Audio Labs) Icon Mark II, and the preamp is an unmodified Hafler 110.

I set the Odins on top of the Swan IV bass cabinets, putting the tweeters at a height of 42″ from the floor. The distance between the speakers was 6′. I set my listening bench 10′ back, and toed in the Odins so that I could not see the sides of the cabinets. The dimensions of the room are 18½′ long and 15½′ wide, with an opening to the kitchen 8½′ wide by 8′ tall on the left side, when you're facing the speakers.

The floor is carpeted, and the furniture consists of a large entertainment center behind the speakers, a piano, a large table, and two couches. The ceiling is vaulted, with the center ridge at 11′ high. I listened with the grille cloths off.

When evaluating speakers, I like to use good recordings of female vocals and acoustic instruments, such as guitar and piano. I listened to many CDs during the tests, including Acoustic Alchemy's *Reference Point*, Andreas Vollenweider's *White Winds*, Barbara Streisand's *The Broadway Album*, Bob James' *Grand Piano Canyon*, Chesky's *Ultimate Demonstration Disk*, *Stereophile*'s *Test CD3* and The Rippington's *Moonlighting*.

Finally, a note about my own hearing: although I haven't had it professionally tested in quite a while, I can't hear the 20kHz warble tones on *Stereophile*'s *Test CD3*, and the 16kHz tone is very, very quiet. So my top end tops out right at 16kHz.

DETAILED SOUND

My first impression with the Odins is how extremely detailed and articulate the sound is. They put the crystal back in crystal clear. Small recording nuances, such as whispers and breathing, are clearly reproduced. Female vocals and classical guitar sounded warm and rounded without any of the harshness I've read about concerning metal-cone drivers.

Overall, the sound is slightly laid back, and seems to come from behind the speakers instead of reaching out and slapping you in the face. It's as though you could remove the Odins from the room and the sound would still be there. Personally, I don't like speakers with a very forward, aggressive sound. I find them fatiguing to listen to, even for short periods. Finally, the Odins are capable of producing deep bass (–3dB at 45Hz), making the addition of a subwoofer unnecessary.

In order to further explore the sound of the woofers, I listened with the tweeters disconnected. First I chose several piano selections from *Stereophile*'s *Test CD3*. I easily heard ambient information, and the piano sounded very natural.

Then I listened to the microphone test tracks recorded in a Sante Fe church and could easily locate the cowbell moving around the soundstage and hear the echoes from inside the church. I haven't listened to many speakers this way, but I was curious to hear the woofer's contribution to the overall sound. I noticed how clear the music sounded towards the end of a track as the level faded; it didn't turn fuzzy, but remained distinct up to the point where I could no longer hear it.

As an interesting twist, I watched several Laserdisc movies over two weeks, using the Odins as the main speakers in my surround sound system with no additional subwoofers. The result was very impressive. I can highly recommend the Odins for both audio and home-theater duty. They played loudly without any noticeable distortion, sounded very musical, and avoided the harsh treble character I've heard on many THX® speakers designed specifically for theater use.

As for Joe D'Appolito's measurements and results, I'll let the numbers speak for themselves. It is interesting to note, however, the differences between *Figs. 14* and *15*, which show IM distortion for woofer and tweeter, respectively. Also interesting is the performance of the woofer crossover circuit. At higher frequencies, it acts like an L-pad, changing the –6dB/octave slope to flat. Perhaps these two observations are related.

To sum up, I liked the sound of the Odins very much, but assembling the kit was frustrating because of the shortages. Madisound should recheck the materials list to be sure that enough supplies are included, and find a better way of attaching leads to the crossover boards. Not everyone keeps extras on hand to make up for such shortages. It's also frustrating when you spend $945 and find the kit incomplete. On the positive side, Madisound promptly ships extras or replacements when requested to do so. Once these problems are addressed, I would highly recommend this kit.

TESTING THE SEAS ODIN MTM LOUDSPEAKER KIT

By Joseph D'Appolito

I ran a series of impedance, frequency-response and distortion tests on the SEAS Odin kit constructed by Mark Florian. *Figure 1* is a plot of system impedance magnitude and phase. The plot displays the double-peaked curve of a vented system. The impedance minimum of 4.65Ω at 40Hz indicates the vented-box resonant frequency. At 170Hz there is an overall minimum impedance of 3.65Ω, which qualifies the Odin system for a 4Ω system rating. Impedance phase lies between ±40° over the full audio range—a relatively easy load for most amplifiers.

Figure 2 shows the Odin's ground-plane frequency response with the microphone placed on the tweeter axis at a distance of 2m. This response is equivalent to the 1m free-standing response.[1] This is a quasi-anechoic response with a 10ms window, valid above 100Hz.

NEAR-FIELD RESPONSES

Near-field woofer and port responses are shown in *Fig. 3*. These are summed by the MLSSA system—with proper weight given to the difference in areas of the combined woofers and the port—to obtain the complete near-field system response. The dip in woofer response at 40Hz is another indication of the vented-box tuning. Port acoustic output is also a maximum just above this frequency. A peak in the near-field response just above 500Hz is due to some high-frequency port leakage. Because the port exits to the rear, however, this peak does not appear on the 2m curve of *Fig. 2*.

Figure 4 shows the system near-field response of *Fig. 3* spliced to the quasi-anechoic response of *Fig. 2* at 125Hz to get the full-range response without the use of an anechoic chamber. Overall system response is flat within ±2.7dB from 50Hz-20kHz, with the low-frequency −3dB point at 45Hz. Response shelves down 1dB between 500-800Hz. Average sensitivity in the 50-500Hz range is 89.4dB/2.83V/1m. The corresponding figure for the 1-20kHz range is 88.4dB. The average sensitivity across the full response range is some 2dB less than SEAS's spec for the system.

ABOUT THE AUTHOR

Joseph D'Appolito, frequent *SB* contributor and author of many papers on loudspeaker-system design, holds four degrees in electrical and systems engineering, including a Ph.D. Previously, he developed acoustic propagation processing techniques for an analytical services company. He now runs his own consulting firm, specializing in audio, acoustics, and loudspeaker system design.

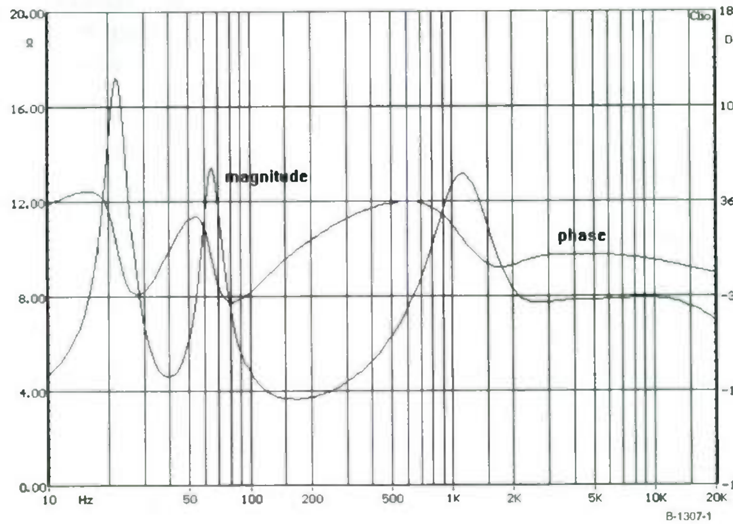


FIGURE 1: SEAS Odin system impedance.

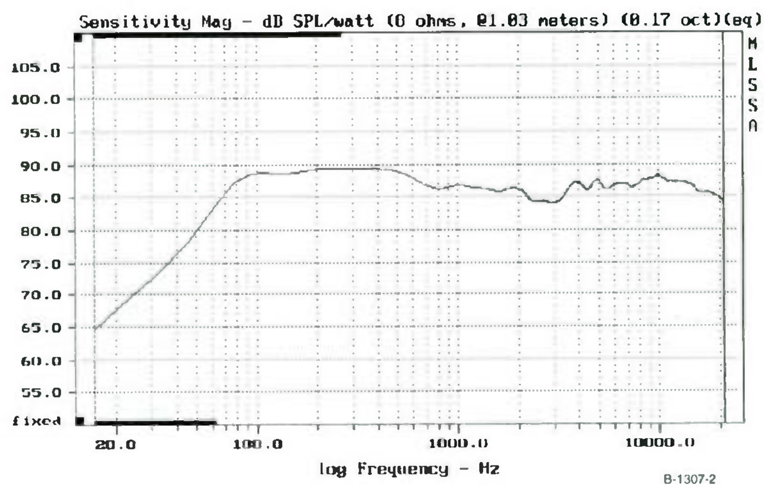


FIGURE 2: System 2m ground-plane response.

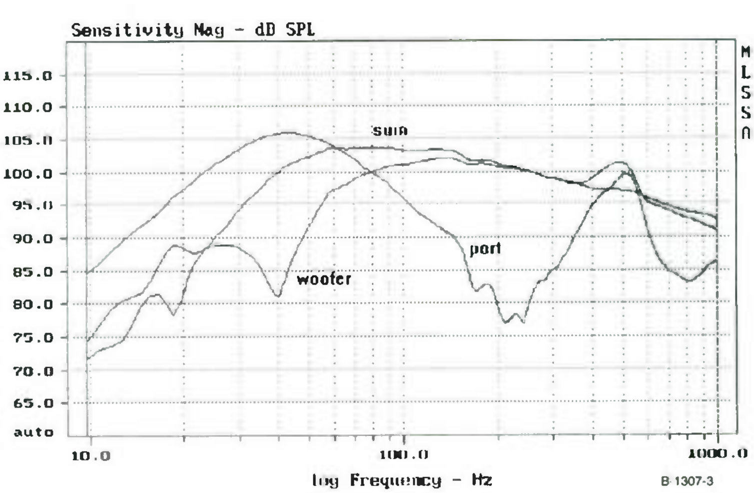


FIGURE 3: Near-field woofer and port responses and their sum.

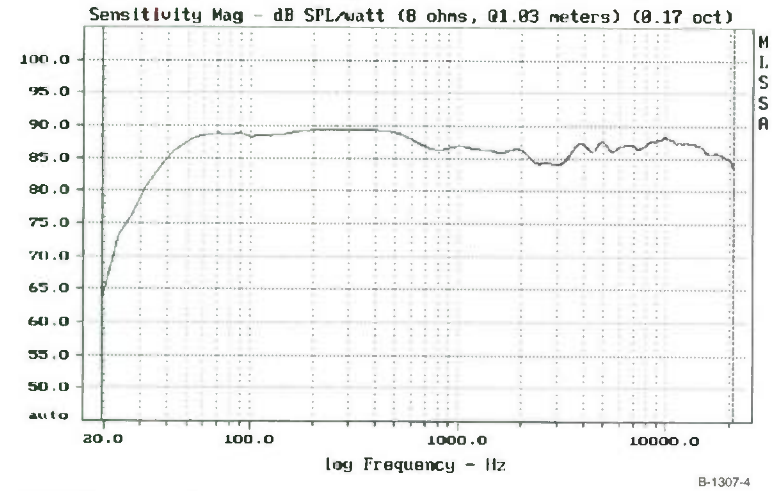


FIGURE 4: On-axis system response at 48", normalized to 1m.

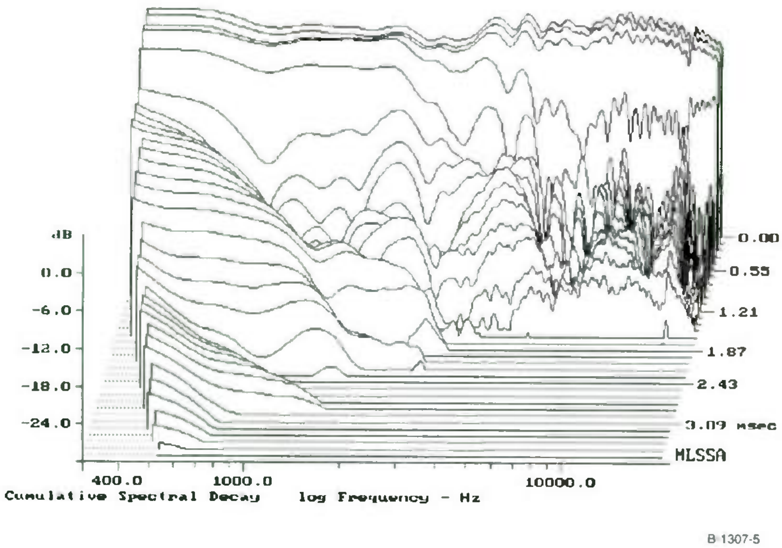


FIGURE 5: Cumulative spectral decay.

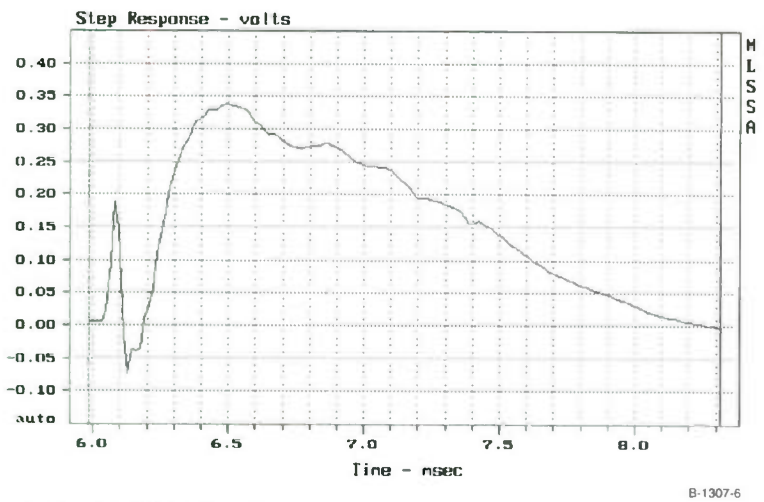


FIGURE 6: Step response.

The slightly elevated bass and lower mid-range response probably accounts for the excellent bass response reported by Mr. Florian. The shelved response will make this system sound slightly less forward than a comparable system with flat on-axis response. The response ripples between 4 and 6kHz, more clearly apparent in *Fig. 5*, are due to edge diffraction.

Figure 5 shows the cumulative spectral-decay (CSD) response. This waterfall plot shows the frequency content of the system response following a sharp impulsive input at time zero. On the CSD plot, frequency increases from left to right and time moves forward from the rear. Each slice represents a 0.11ms time increment. The total vertical scale covers a dynamic range of 32dB. Ideally, the response should decay to zero instantaneously. Real loudspeakers, however, are characterized by inertia and stored energy that takes a finite amount of time to die away. Prominent ridges parallel to the time axis indicate the presence of strong system resonances.

The first time slice in *Fig. 5* (0.00ms) represents the system frequency response. No strong ridges exist in the CSD, but there are response ripples above 4kHz caused by diffraction off the cabinet edges. The ripples are more noticeable here because, unlike *Fig. 4*, the plot is not smoothed. These ripples persist in the decay response out to about 1.5ms. Although not shown, the ripples decrease and response is smoother as you move off-axis horizontally. Decay response below 3kHz is controlled by the woofer and its crossover network. The overall decay performance is good.

TABLE 1

INTERMODULATION DISTORTION PRODUCTS

1900Hz = 900 + 1000	(second-order)
800Hz = 2 × 900 − 1000	(third-order)
1100Hz = 2 × 1000 − 900	(third-order)
2800Hz = 2 × 900 + 1000	(third-order)
2900Hz = 2 × 1000 + 900	(third-order)
4700Hz = 2 × 1000 + 3 × 900	(fifth-order)
4800Hz = 3 × 1000 + 2 × 900	(fifth-order)

A NOTE ON TESTING

The SEAS Odin kit was tested in the laboratories of Audio and Acoustics, Ltd., using the MLSSA and CLIO PC-based acoustic-data acquisition and analysis systems, with an ACO 7012 ½″ laboratory-grade condenser microphone and a custom-designed wideband, low-noise preamp. Polar response tests were conducted with the aid of a computer-controlled Outline turntable on loan from the Old Colony Division of the Audio Amateur Corporation.

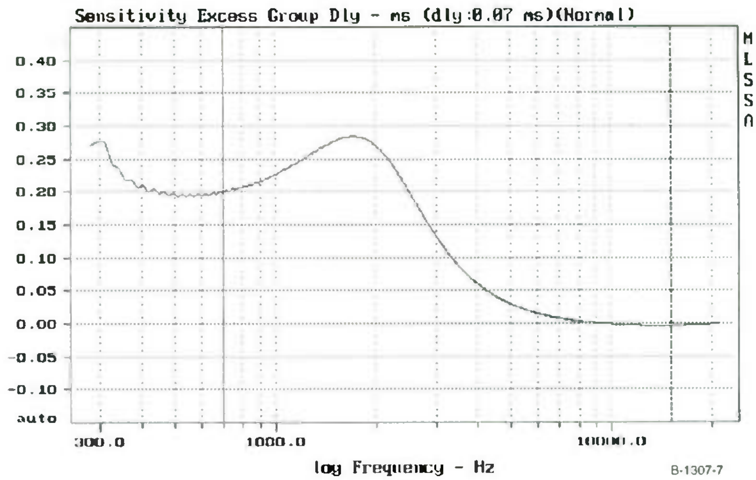


FIGURE 7: Excess group delay; Y(cursor) − Y(marker) = 0.202159.

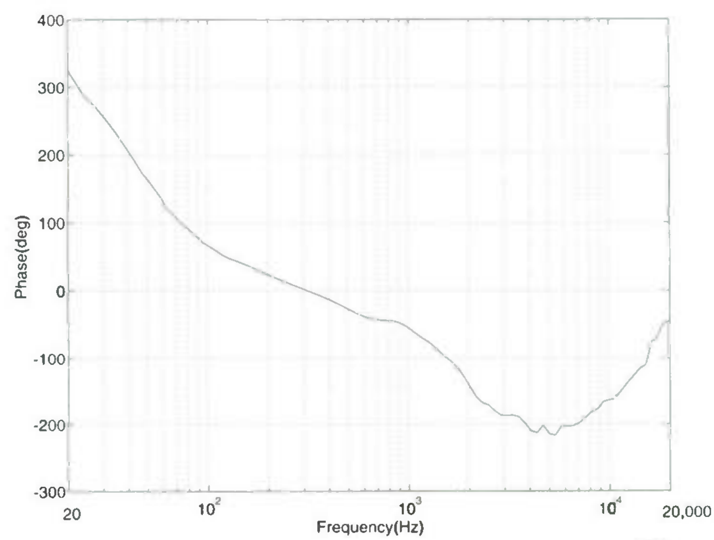


FIGURE 8: Phase response.

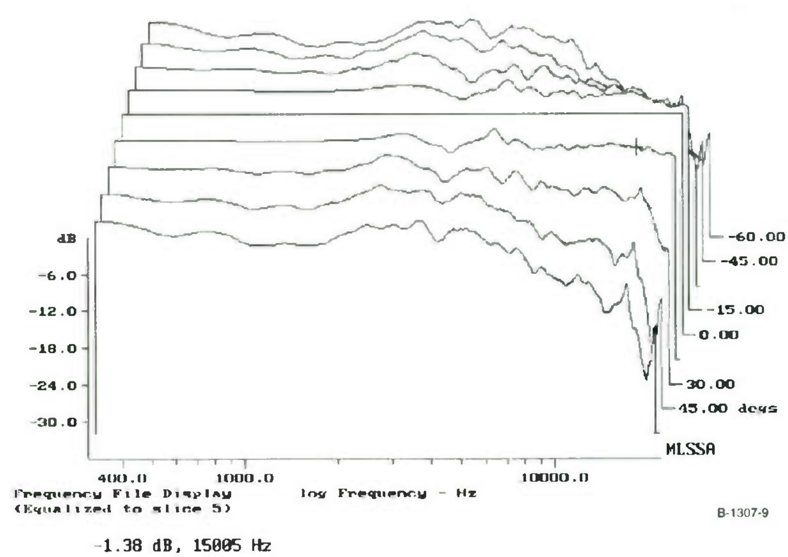
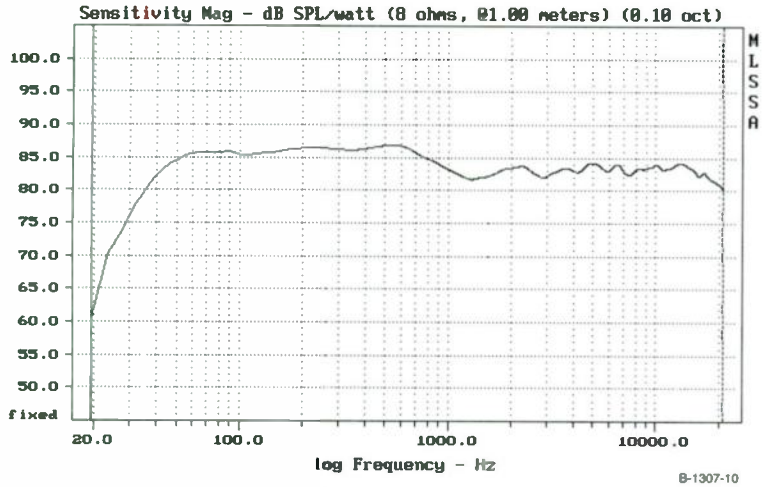


FIGURE 9: Horizontal polar response (60° left to 60° right).



B-1307-10

FIGURE 10: Response averaged over ±30°.

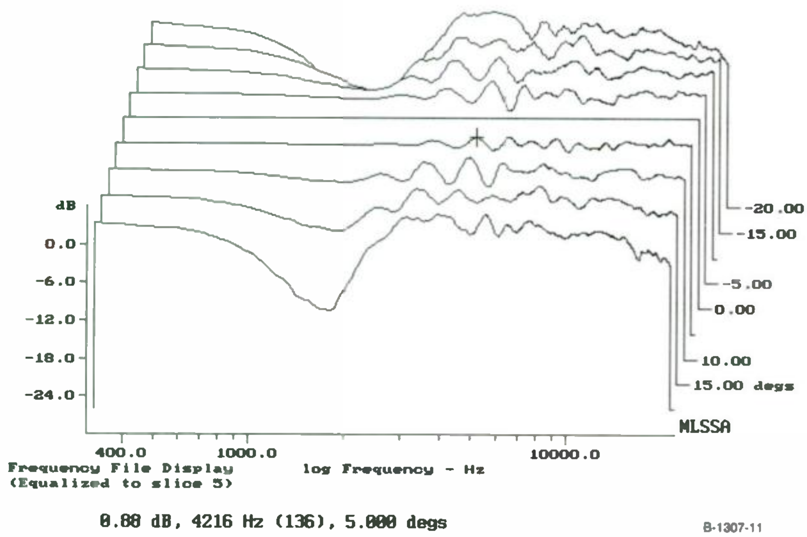


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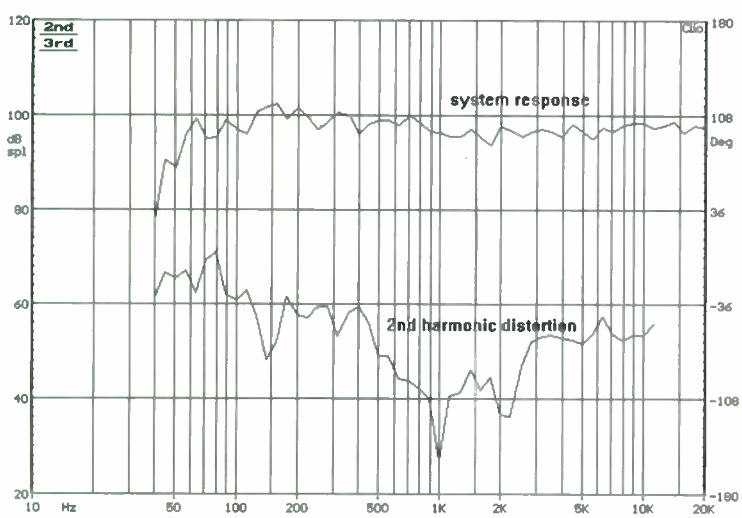
FIGURE 11: Vertical polar response (–20° to +20°).



B-1307-12

FIGURE 12: Second-harmonic distortion.

STEP RESPONSE

Figure 6 is a plot of system step response, obtained by a numerical integration of the system impulse response. The ideal step response should be a single rapid rise followed by a smooth decay through the 0.00 level. *Figure 6* shows two separate arrivals of acoustic energy, the initial sharper positive spike being that of the tweeter. This is followed by the woofer arrival, peaking about 0.4ms later. The drivers are both connected with positive polarity, but the system is not time-coherent.

A better view of this behavior is seen in *Fig. 7*, which is a plot of excess group delay[1] versus frequency referenced to the tweeter's acoustic phase center. This is a plot of delay in milliseconds versus frequency, which in a time-coherent system would be a flat line.

Above 10kHz, excess group delay is essentially zero, as it should be since it is referenced to the tweeter in this frequency range. The curve rises below 10kHz, peaking at a value of 0.28ms (280µs) at 1.8kHz before settling back to roughly 0.2ms below 700Hz. This plot shows that over its operating frequency range the woofer pair is some 200 to 280µs behind the tweeter. According to SEAS, the crossovers are first-order (6dB/octave), but the system is still not time-coherent. Excess group delay is a very accurate indicator of driver-time offset. System phase response referenced to the tweeter's acoustic phase center is plotted in *Fig. 8*.

POLAR RESPONSE

Figures 9, 10, and *11* show polar response. *Figure 9* is a waterfall plot of horizontal polar response in 15° increments from 60° left to 60° right when facing the speaker. The microphone is placed at tweeter height for this series of curves. All off-axis plots are referenced to the on-axis response, which appears as a straight line at 0°. For good stereo imaging, the off-axis curves should be smooth replicas of the on-axis response, with the allowable exception of the tweeter roll-off at higher frequencies and larger off-axis angles.

You can see the expected rolloff of tweeter response at higher frequencies and larger off-axis angles, but overall horizontal polar response is excellent. Tweeter response is down 10.9dB at 15kHz and ±45°. The corresponding figures at ±30° and ±15° are 5.5 and 1.4dB, respectively. This performance is fairly typical of 25mm dome tweeters.

Figure 10 shows the average response over a 60° horizontal angle (±30°) in the

REFERENCE

1. J. D'Appolito, *Testing Loudspeakers*, Audio Amateur Corporation, Peterborough, NH, 1998.

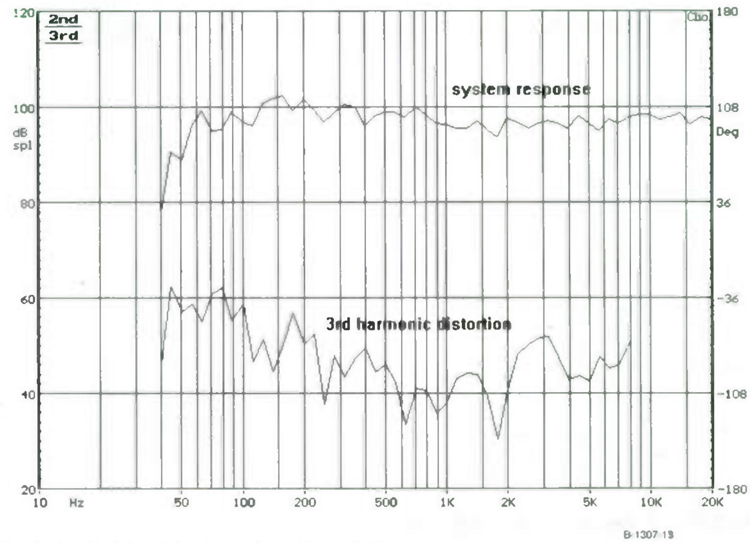


FIGURE 13: Third-harmonic distortion.

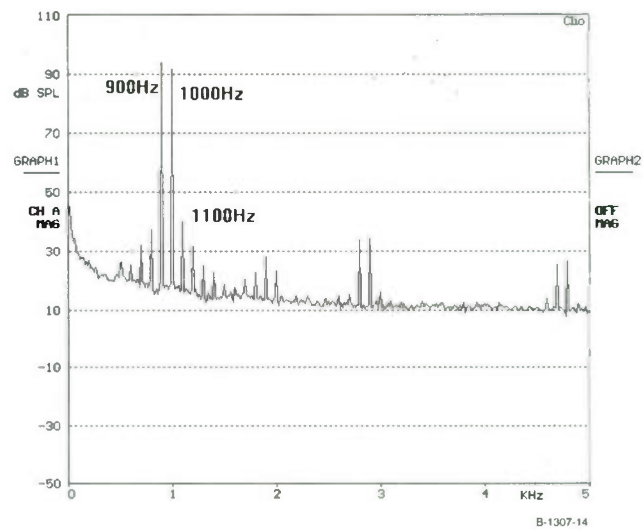


FIGURE 14: Intermodulation distortion of woofer pair.

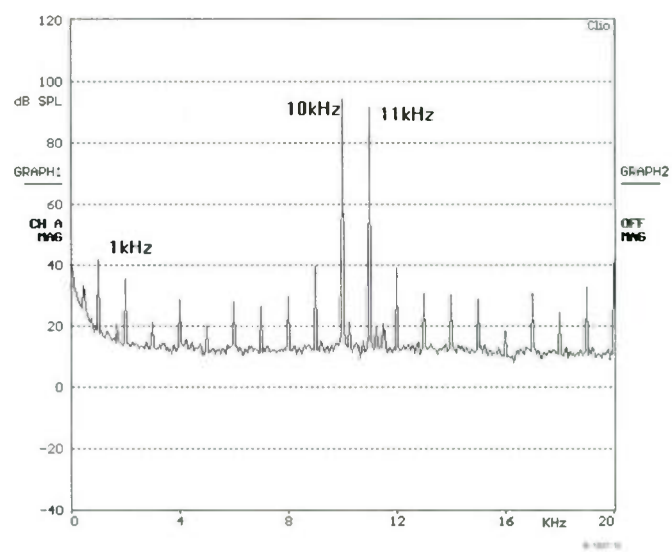


FIGURE 15: Tweeter intermodulation distortion.

forward direction. It reveals the 1dB shelving seen in the on-axis response, but otherwise is very smooth. This is excellent horizontal power response that suggests good direct-field coverage in the primary listening area, with little if any change in timbre with position. Image stability should be very good.

Figure 11 is the waterfall plot of vertical polar response, shown in 5° increments from 20° below the tweeter axis (–20°) to 20° above it. Response at ±5° is within 1.8dB of the on-axis response over the entire frequency range. The worst-case response dips at ±10° and ±15° are 2.2 and 5.9dB, respectively. Both of these dips are in the crossover region. The vertical polar response is fairly typical of MTM systems with drivers of this size.

DISTORTION MEASUREMENTS

I ran harmonic-distortion tests at an average SPL of 90dB at 1m. Ideally, you should make these tests in an anechoic environment. In practice, it is important to minimize reflections at the microphone during the tests. Out-of-phase reflections can produce false readings by reducing the level of the fundamental while boosting the amplitude of the harmonic. In order to reduce the impact of reflections, I placed the microphone 0.5m from the loudspeaker.

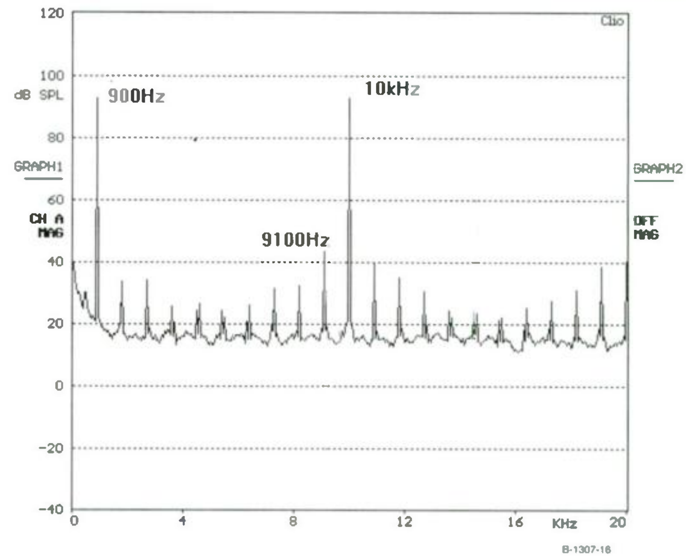


FIGURE 16: 900Hz/10kHz intermodulation distortion.

Figures 12 and *13* show second- and third-harmonic distortion levels in dB SPL versus frequency plotted in ⅙ octave steps. System frequency response is also plotted on these figures. The second- and third-harmonic distortion levels at 50Hz are 6% and 3.7%, respectively. The corresponding numbers at 100Hz are 1.6% and 1.3%. All system harmonic distortion is well below 1% above 120Hz.

I next measured intermodulation distortion (IM). In this test, two nearby frequencies are input to the speaker. IM creates output frequencies that are not harmonically related to the input. These frequencies are much more audible and annoying than harmonic distortion. If the symbols f_1 and f_2 represent the two frequencies used, then a second-order nonlinearity will produce intermods at frequencies of $f_1 \pm f_2$. A third-order nonlinearity generates intermods at $2f_1 \pm f_2$ and $f_1 \pm 2f_2$.

I examined woofer intermods by inputting 900Hz and 1kHz signals at equal levels. These frequencies are far enough below crossover that they should appear predominantly in the woofer output. I adjusted total SPL with the two signals to 90dB at 1m. The Odin system output spectrum for this test is shown in *Fig. 14*. The two largest spectral lines represent the input signals. The primary IM products are listed in *Table 1*.

Other lines on the plot are due to harmonic distortion, which I have already discussed. Most of the intermods are third-order. The largest distortion product at 1.1kHz is 56dB below the main output, which is equal to 0.16%. This is better than many solid-state amps and most tube amps.

TWEETER INTERMODS

I measured the tweeter intermods with a 10 and 11kHz input pair, also adjusted to produce 90dB SPL at 1m. The results are shown in *Fig. 15*. A number of IM products appear at 1kHz intervals on the plot, with the largest at 1, 9, and 11kHz. Total IM distortion is only about 0.3%, but the number of distortion products is disturbing.

The Odin crossovers are first-order, but the woofer crossover is shelved by the action of a notch network so that the ultimate high-frequency attenuation is only 7–8dB. Significant levels of the 10 and 11kHz signals are therefore getting into the woofers well above their preferred operating range. I suspect many of the lower-frequency distortion products are actually coming from the woofer pair and not the tweeter.

The last intermod test examines cross-intermodulation between the woofers and tweeter using frequencies of 900Hz and 10kHz. (A 1kHz signal would produce intermods that fall on harmonic-distortion lines, confusing the results.) This spectrum is shown in *Fig. 16*. The largest IM products fall at 9.1, 10.8, and 19.1kHz. Total distortion is only 0.3%, but again the number of distortion products is large. This may cause a harsh edge in complex orchestral and choral music at higher volume levels.

I conducted all of the above tests with the grille off. *Figure 17* shows the response of the system with the grille on, but referenced to the response without the grille. That is, it plots the difference in response under the two conditions. Below 2kHz, the grille causes the on-axis output level to rise about 1dB, but the response is still relatively smooth. Above 2kHz, however, the grille causes ragged response deviations of 5dB pk-pk. I recommend listening to this system with the grille off.

I arbitrarily labeled "A" and "B" the two samples of the Odin system that were available for testing. All the tests described so far were conducted with the B sample. One question of interest is how well the two samples match. *Figure 18* is a plot of the frequency-response difference between the A and B samples. The average sensitivity of the A sample is 0.7dB below that of the B sample. The deviation about this level is also 0.7dB. Hence a very slight shift in a balance control will match the two samples to within ±0.7dB.

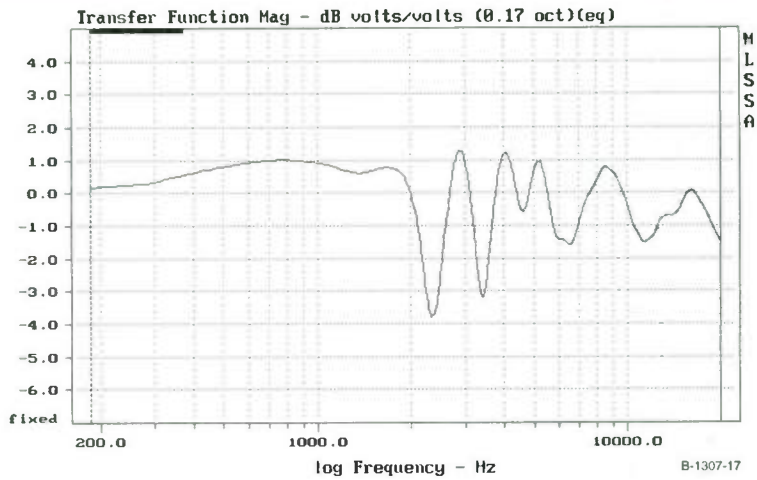


FIGURE 17: Effect of the grille on system response.

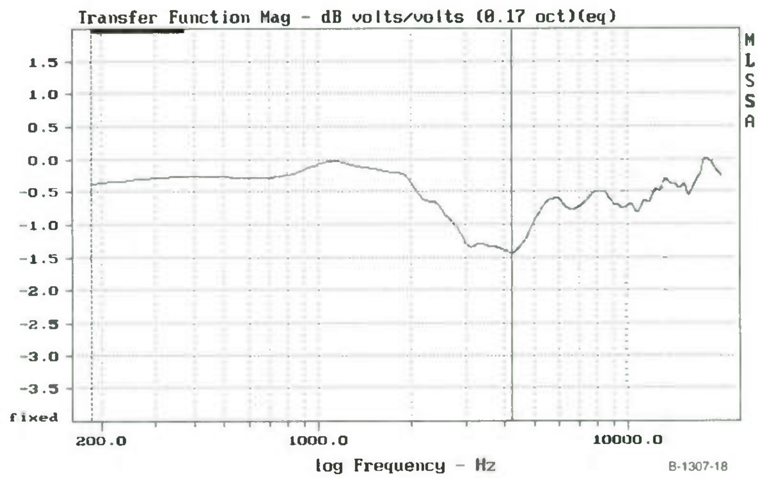


FIGURE 18: Response of sample A relative to sample B.

This author strives for household, as well as musical, harmony in this subwoofer construction project.

Bessel Box Subwoofer

By L. J. Mertz

PHOTO 1: The completed enclosure. The oak frame was ebony-stained after this photo.

My original design goal was to build a low-cost, high-quality subwoofer speaker to fill in the lower octaves in my existing stereo music system. As with any project, however, things are never as simple as you wish them to be, as I'll explain.

The project began with researching the supplier catalogs for a driver that would go as low as possible, of course, yet would fit inside a reasonably sized infinite-baffle box. Prior to determining the actual enclosure design or box size, I had made some flat rectangular masonite panels of various sizes to represent boxes of three, six, and eight cubic feet.

I believed that my wife should have a say in decisions on this project, and mockups would allow her to visualize the box in our living room. My stereo speakers are 2ft^3 each, on 16″ stands, and sit about 5′ out into the room. This placement draws the comment from every female visitor, "Must they be there?" So, it wasn't a surprise that a 3ft^3 box was considered the only appropriate size!

AGAINST THE TREND

There is strong evidence that the ported box is today the enclosure design of choice, but I selected the Bessel infinite-baffle design *(Photo 1)*. Using formulas in Vance Dickason's *Loudspeaker Design Cookbook* (available from Old Colony Sound Lab, PO Box 876, Peterborough, NH 03458, 603-924-6371, FAX 603-924-9467, E-mail custserv@audioXpress.com), charts for the Bessel-function, maximum flat-delay-response enclosure, and my Lotus program, I plugged in the various speaker manufacturers' data *(Table 1)*. I chose the SEAS CA25RE4X/DC, and Madisound faxed confirmation of the final design volume—2.6ft^3. (I like to bounce my ideas off an acknowledged expert before the investment, if possible.)

My musical taste includes both LPs and CDs, which have very different bass reproduction. A CD's bass seems dry and thin, and probably accounts for the popularity of the ported, or boom-box, trend, which fills in the missing bloom and adds impact to the bass. By contrast, the LPs fairly blow you over with bass. So a design that would not accentuate the LPs' bloom, yet would get deep enough to give the bass I desired for the CDs, dictated the large infinite-baffle design.

The reference in Dickason's *Cookbook* suggests that Bessel-function enclosures, with a Q_{TC} of 0.577, are close to transient perfect. The lower Q designs are considered optimum by many speaker experts, but have not found a strong following in the marketplace, where higher Qs, with ample bass bloom, predominate.

The advantage of this closed-box design is its shallow roll-off rate of 12dB/octave, which is more gentle than the ported type's steeper 24dB/octave slope. This slower rolloff allows you to boost the bass if you wish, without driving you out of the house on certain types of bass-accentuated material. The lower Q and the slow-roll-off-rate designs

ABOUT THE AUTHOR

Lester Mertz has recently moved from New Jersey to Apache Junction, AZ, where, as a project manager for Professional Services Group, he is responsible for an environmental site. He has built dozens of speaker enclosures over the years, including some from *SB* articles. He generally favors the larger designs, especially transmission lines, but he gave them up for love and household harmony. This latest design is similar to his first one, a Lafayette 12″ coax, built almost 30 years ago.

TABLE 1
SEAS CA25REX/DC SPECIFICATIONS

Impedance	8/8Ω
Frequency range	30Hz–1.5kHz
Maximum power (long term)	90W
Linear coil travel	8.0mm
Free air resonance	30Hz
V_{AS}	187.9 ltr
Q_{TS}	0.31

are also reputed to be more room-placement-friendly. I agree completely.

In building, take your time, work carefully, and think out each step beforehand (see parts list in *Table 2*). Measure three times, and cut once. I worked on this project for about two weeks, waiting for the glue to dry overnight. If you have only a few long clamps, you must plan carefully before moving to the next stage. Perhaps you can build two subwoofers with a partner and split the cost of the clamps. Good luck.

THE 2.6FT³ BOX

I made the enclosure from one piece of 1″ MDF board *(Fig. 1)*. This material is available as "counter top" from lumber-supply houses. I cut all panels with a 7.25″-blade standard portable saw, using a clamped metal straightedge. The layout takes advantage of the actual 30.25″ width of the factory-sized panel, using that as the height of the box. Label all the panels.

I glued and clamped the panels carefully, and then nailed them with 8d finishing nails. I had to buy several extra clamps, paying more than a surprising $100 for four 36″ bar clamps and four assorted smaller ones. I guess I have been away from the wood business too long—prices are up. It is possible that you could build a good enclosure without the clamps, but if you desire airtight construction, they are necessary.

After aligning the panels, nail and clamp while the glue is setting up. The nails are just reinforcing steel, not true clamping devices. In my experience, screws and particleboard do not integrate well; avoid using screws, since they bulge and break open the particleboard.

I used scrap wood for reinforcing blocks at several strategic places, and calculated all the extra pieces into the design, since they reduce the internal volume. Carefully wiping all the inside seams with a damp sponge to remove any excess glue will allow you to fit glue blocks later without needless scraping.

Note that while I cut the bottom panel to fit inside the enclosure, I cut the top slightly oversize and then routed it flush after the glue had set *(Photo 2)*. I used Elmer's Weather Tite glue, which, as claimed, did not run. This choice may seem unusual to woodworkers, since most use only yellow wood glue. But try it; it works fine.

If you so wish, adjust the placement of the inside bottom panel up or down to provide for different internal bracing or slightly different construction techniques (*Photo 3*). The underside of the internal bottom panel is handy for external location of the crossover wiring, or you can fill the space with sand, as I chose to do (adding a plywood bottom). The sand adds weight and stability to the finished structure.

After all that clamping, routing, and waiting, I still caulked all the inside seams with silicone. What the heck; if you have gone this far, you might as well take every path to ensure success. I've read that the better speaker manufacturers seal all the inside surfaces of their enclosures, since the MDF material releases formaldehyde gas that may damage the driver's performance over time. After the caulking has dried, coat all the interior surfaces with a quick-drying water-base paint.

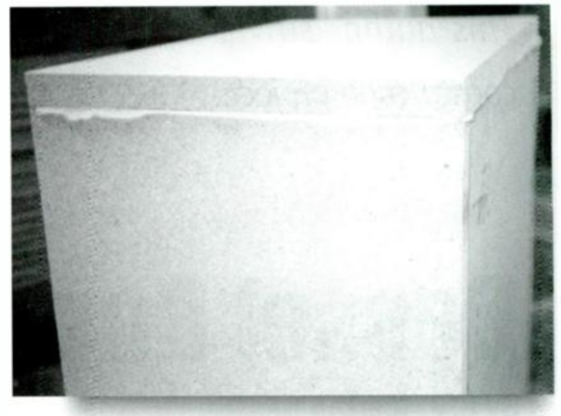


PHOTO 2: Back of cabinet, butt jointed, with top panel in place. The top panel is cut slightly oversized, then routed flush, before adding the formica.

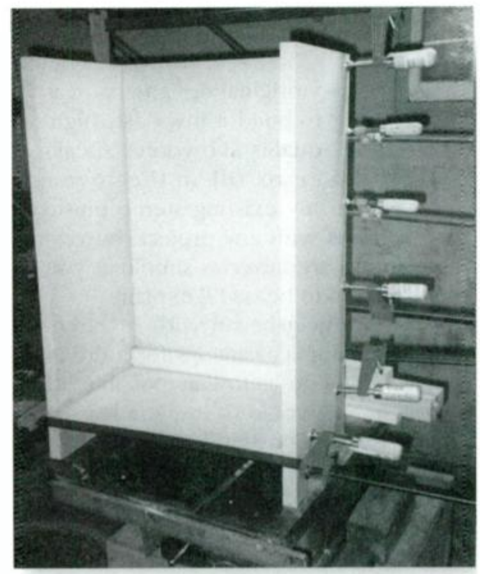


PHOTO 3: Side panels clamped to back and inside bottom panel.

FRONT PANEL

I chose to screw in the front panel, which meant clamping and gluing 1¾″ × ¾″ oak blocks, recessed one inch, around the inside of the front panel *(Photo 4)*. I also sealed this surface with silicone before mounting the panel. However, you may choose just to glue the panel in place and save some time.

In the front panel, I cut the hole for the driver, and routed space for its

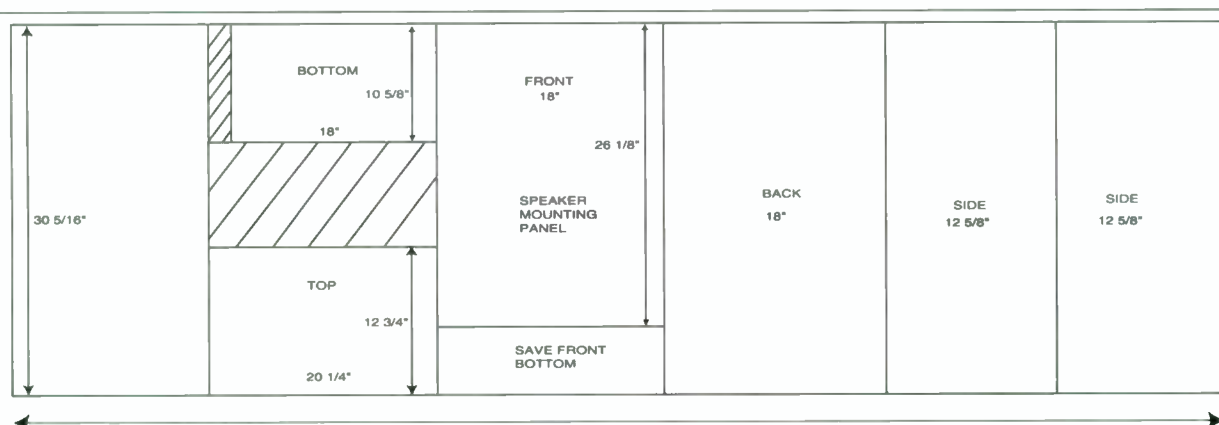


FIGURE 1: MDF cutting plan.

PHOTO 4: Completed cabinet without front panel. The inside bracing is red oak, which gives good holding power for the screws.

flange so the speaker would fit flush *(Photo 5)*. I secured the driver with machine bolts, nylon locking nuts, and silicone sealant. Only the machine screws and neoprene washers inserted between the frame and the bolt heads protrude, so I added no protective screen. The design places the woofer center approximately two feet above the floor. I believe front-firing placement gives the bass more direct impact and clarity.

The front-panel signal-input lugs—steel bolts through the 1″ panel, with copper lugs on the outside—mounted just below the speaker permit the use of very short internal leads. This front-panel arrangement allows the copper lug to contact the spade lug, copper-to-copper, which sounds best. The internal wiring is 10AWG copper twisted pair to lugs clamped on with a champ tool and soldered at the speaker terminals. The external wire is Kimber Kable 8 TC, with copper Post Master spades.

I owe this copper-to-copper tip to Richard Vandersteen, who passed it on to me more than 15 years ago. The popular audiophile magazines are now proclaiming this copper connection as a new innovation. New? Things just go in cycles. Look at the single-ended triode amplifiers and large horn speakers now back on the scene. Maybe beam power tubes and infinite-baffle speakers are next?

I filled the enclosure with R-19 fiberglass insulation (one pound per cubic foot). I placed two 16″-wide sections behind the speaker, curved away from it for clearance. I rolled up a third piece and wedged it into the very bottom of the enclosure. It seems like a lot of stuffing when you are trying to put it in there, but the unit sounds good, not tubby or overdamped in any way.

TABLE 2
PARTS LIST

MDF 1″	96″ × 30.25″ (see *Fig. 1*)
Oak braces	1.75″ × 0.75″ (various lengths cut to fit)
Oak molding	1.5″ × ⅜″ (miter to fit)
Exterior plywood	20″ × 13″ × 0.625″ (for base with sand fill)
R-19 fiberglass	6″ fill, approximately 7′ × 16″ (weigh out 2.6 lb)
Drywall screws, coarse thread, 1 lb	Number 6 × 1.625″
Finishing nails, 1 lb	8d × 2.5″
Elmer's Weather Tite glue	one quart
GE 100% silicone rubber sealant	clear
Quick-disconnect female lugs for 10-gauge (4)	(auto-parts store)
Copper lugs (4)	8–10 gauge (auto-parts store)
Steel bolts (4)	¼″ × 20″, 1.75″–2″ long
Nuts and washers (4)	¼″ × 20
10 AWG wire, red and black (4)	1′ each
8/32 machine screws (8)	1.5″ minimum
8/32 nylon locking nuts and washers (8)	
8/32 neoprene plumbing repair kit washers (8)	
Tee nuts (4)	⅜″ (to mount feet)
Bolts (4)	⅜″ × ½″ (adjustable feet)
Formica sheets (3)	2′ × 4′
Formica water-base adhesive (1)	One quart
Black spray paint (1 can)	
Crossover (122Hz)	
Ferrite core inductors (2)	18mH, low DC resistance (Madisound-Sledgehammer)
Nonpolarized stock (2)	80µF
Polypropylene (2)	12µF (Madisound-Chateauroux)

FINISHING

Once I'd nearly completed the unit, it was difficult not to slap it together and listen. But I resisted the temptation and finished the outside with black matte Formica® with mitered oak front trim *(Photo 6)*. This treatment was faster than spray painting, taking only half a day. The Formica adds some hardness to the panels, and also adds to the cost by almost $40.

I used Formica's own brand of water-based low-odor adhesive, which was very easy to work with. Allow it to dry before assembly. Place three or four wooden dowels across the tacky enclosure panel, and then carefully position the oversized Formica over it. Once it's in position, slowly ease the dowels out of the way. Once the two adhesive-treated pieces come in contact, they bond, and that's it.

Roll out the surface with a 3″ pressure roller (another $15) and trim off the overhang with a flush-trim carbide router bit—another $20. No clamps or waiting for paint to dry. Use a file or a sanding block to round off the sharp router edges. Spray the bottom with one quick coat of glossy black paint.

I also spray-painted the front panel earlier, and secured it to the finished box with coarse-thread drywall screws through pre-drilled holes spaced approximately every 5″. The four feet are made from ⅜″ tee nuts and hex bolts, which permit easy adjustment; just turn the bolt to set it level.

CROSSOVER

I would have preferred an electronic

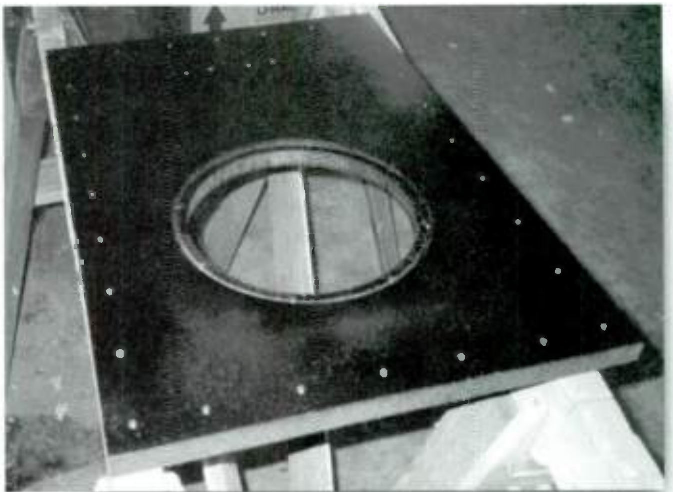


PHOTO 5: Front panel double routed to just over actual driver diameter. The deeper ¼″ outside groove was filled with silicone sealant, and the driver lowered in place to rest on the inside raised portion.

crossover, feeding a dedicated amplifier. Perhaps a kit is in my future, but for now, I used a simple passive 12dB network for each voice coil. Initially I tried a low-pass at 70Hz. Try two 18mH inductors in series (36mH total), and 142μF (made up of three paralleled units) of the best capacitors that are available for each voice coil or channel. The inductors are in series, and the capacitors across the inputs. This was another hundred bucks or so to Madisound.

PHOTO 6: Formica panels cut oversized, with the adhesive allowed to dry before joining the cabinet and material together.

When I began listening, the subwoofer seemed to be disjointed from the music and main stereo image, so after about six weeks of experimenting, I arrived at the 122Hz crossover, made from a single 18mH coil, with 92μF across each channel. This resulted in a very smooth bass presentation in my system, and the woofer disappeared as a separate unit.

Do not hesitate to try various crossover components until you are satisfied. The 91dB efficiency of the woofer is right in line with the main stereo speakers' 90dB, so I used no signal-dropping resistance, which also avoided interference with my amplifier's damping factor.

This speaker weighs nearly 100 lb, especially with the 20 lb of sand in the bottom, so you will need a friend to help you move it to the listening space.

LISTENING

I positioned the woofer slightly behind the main speakers, and sat back. The speed of the attack–drums, cello, piano, and other instruments was very impressive. I had been using a smaller, 8″ compound push-pull type in the system prior to this unit, and the improvement was immediately evident. I was amazed at the deep detail I now heard from the better CDs. I especially noticed this with orchestral music.

In the final analysis, I spent over $250, including the minor hardware and Formica finishing, but it is well worth every penny. That is low cost in today's marketplace!

In continued listening, now more than six months after the sub's completion, the bass has opened up even more, and the resulting sound is very detailed and convincing. I must admit that some of my projects seem very good initially, especially in the excitement of completion, but after a time they wear thin and become fatiguing. This project, however, has not disappointed me, but has grown better with more playing time. I recommend it unreservedly.

Sound System Engineering

by Don and Carolyn Davis

Second Edition. Like the first edition, *Sound System Engineering* is a comprehensive text–useful in the day-to-day work of designing sound systems. It is a practical manual that carefully examines a step-by-step method of accurately predicting such variables as acoustic gain, speech intelligibility, and required electrical input power while plans are still on the drawing board, saving time and money. Topics include the history of audio; audio mathematics; using the decibel and matching impedance; interfacing electrical and acoustic systems; determining loudspeaker directivity and coverage; the acoustic environment including large- and small-room acoustics; designing for speech intelligibility and acoustic gain; equipment such as microphones, loudspeakers and loudspeaker arrays, and delay devices; audio and acoustic instrumentation and specifications. Heavily illustrated with 11 appendixes. 1997, 1975, 665pp., 7⅞″ × 10″, hardbound, ISBN 0-240-80305-1.

Shipping wt: 4 lbs. BKB53 $59.95

The Art and Science of Analog Circuit Design

edited by Jim Williams

Each of the contributors to this collection brings his own voice to the realm of analog circuits. Along with practical advice on circuit design, humorous anecdotes from the authors' experiences and guidance for a future in the design field, you'll also find information about other aspects of engineering including marketing your product and career development. A must read for anyone pursuing a career as an analog engineer or anyone wishing a more complete understanding of this field. 1998, 397pp., 7″ × 10″, softbound, ISBN 0-7506-7062-2.

Shipping wt: 2 lbs. BKB52 $29.95

There are No Electrons

Electronics for Earthlings

by Kenn Amdahl

A book which demystifies the electricity and explains it in understandable and humorous fashion. Amdahl's approach to the subject will entertain as well as teach the basics of the physics of electricity. 1991, 322pp., 5½″ × 8½″, softbound, ISBN 0-9627815-9-2.

Shipping wt: 2 lbs. BKCW1 $12.95

Back-to-Basics Audio

by Julian Nathan

A thorough yet approachable handbook on audio theory, practice, and allied electrical systems. Electrical principles are discussed in elementary terms as a basis for understanding audio components and equipment. Written in a hands-on style, *Back-to-Basics Audio* provides a bridge between engineers, salespeople and technicians. In addition, home theater audio and projection are addressed in practical terms. 1998, 344pp., 6″ × 9¼″, softbound, ISBN 0-7506-9967-1.

Shipping wt: 2 lbs. BKB55 $39.95

An Introduction to the Psychology of Hearing

by Brian C. J. Moore

Fourth edition of this leading textbook in the field of auditory perception. New sections on the effects of peripheral compression, the processing of modulation, duration discrimination, binaural interference and perceptual coders. Key concepts are clearly explained. Over 160 references to articles and books published since 1990–a valuable resource for further study. Essential reading for audio engineers. Illustrated. 1997, 373pp., 6″ × 9″, softbound, ISBN 0-125056-27-3.

Shipping wt: 2 lbs. BKAD2 $45.00

Consumer Electronics for Engineers

by Philip Hoff

Written for a senior-level elective course in the electrical engineering department at California State University at Chico, this textbook gives the reader much practical insight into how consumer electronic equipment works. It analyzes commercial units using discrete circuitry, explaining the underlying principles and working from older designs through to the modern integrated circuit design. Heavy on math, exercise problems help check understanding of concepts. A comprehensive index and a glossary of all abbreviations are included. 1998, softbound, 7″ × 10″, ISBN 0-521-58817-0.

Shipping wt: 3 lbs. BKCA1 $44.95

The Car Stereo Cookbook

How to Design, Choose and Install Car Stereo Systems

by Mark Rumreich

Unlike books that cover only specific systems, the *Cookbook* shows you how to customize your system to fit your tastes, your budget, and your car or truck. Clearly organized by project type so you can easily find the information you need. Covers speakers, subwoofers, amps, equalizers, biamping and accessories. Learn to:

Get more amp power for your money
Achieve good imaging
Interface a CD changer to any system
Avoid common automotive noise problems
And other handy helps

Shipping wt: 2 lbs. BKMH27 $24.95

Cumulative Indices of the Journal of the Audio Engineering Society

Vols. 1-44 (1953-1996), AES Convention Preprints 9th to 103rd Conventions (October 1957 to September 1997)

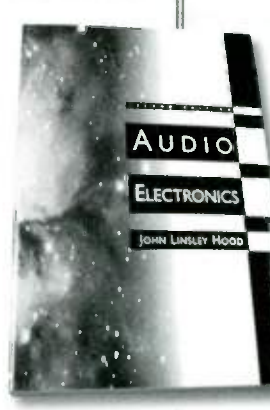
CD-ROM version of cumulative indices of the *Journal of the Audio Engineering Society* is an essential reference of titles, authors and abstracts in an easily searchable database. 1998, CD-ROM.

Shipping wt: 1 lb. CDAS1 $59.95

Audio Electronics

by John Linsley Hood

Now available in a second edition, this popular book has been expanded to include the latest developments in digital radio and television, Nicam 728 and the latest in Dolby noise reduction systems. For anyone involved in designing, adapting, and using digital and analog audio equipment, here is help in better understanding the underlying audio techniques and electronic equipment. One of the leading authorities, Hood presents a wide-ranging survey of the field. Digital and analog approaches are dissected and analyzed, using the no-nonsense style so well respected by the audio world. Index. 1999, 1995, 1993, 375pp., 6⅛″ x 9⅛″, softbound, ISBN 0-7506-4332-3.



Shipping wt: 2 lbs. BKB42 $47.95

SB Mailbox

CURVED ARRAYS

Thank you for your interesting Focused Array Electrostatic articles (*SB* 5–7/98). You achieved, with greater elegance, what I tried to in the mid-80s with my Curvilinear Vertical Arrays (CVAS) (*SB* 2/85). I also appreciate your honest and realistic approach to the results. I (and, I'm sure, others) would like to see some measurements as well.

I still have the CVAs, which, as the result of an overhaul, have the arrays fixed in a curve based on a listening distance of eight feet. I seem to be doomed to small living rooms in all my various dwellings; my current listening room is about 12 × 14 feet. One CVA is in a corner and the other is near a doorway–hardly ideal, but my options are limited. The room is rather lively from the thin paneling.

The CVAs face each other and the optimum listening area is at the peak of a triangle whose base runs between the centerlines of the speakers. At this spot (my only regular listening companion is my cat), the image displays excellent depth and fair lateral localization.

I've been convinced for years that much of what we perceive as "stereo localization" is actually just midranges getting beamy at their top end. With well-recorded orchestral pieces (like the Delos discs), sounds come from areas, not points. With popular music, the localization varies, getting much sharper with synthesizers. In some cases, I hear a soundstage larger than the room. Added echo effects particularly bring this out.

I've tried traditional placement, with the CVAs toed out from 45° (dual corners) to 15°. These speakers have very wide dispersion, so corners cause a horrendous amount of early reflections. Even away from walls, traditional placement yields a murky image, so I revert to the face-on setup mentioned above.

Once again, thanks for such an insightful article, and I'd be eager to see any further results of your research.

Scott S. Ellis
Panama City, FL

Bill Waslo responds:

Thanks for your letter and kind comments. I had not seen your Curvilinear Array, which was published before I became a *Speaker Builder* subscriber. I'll need to track down that issue of *SB* and have a look. I wish I could have made a reference to your previous work and thank you for bringing it to my attention.

I think even your current 8′ spacing would be a considerable improvement in reducing "intimidation factor" over the much too close 5′ spacing that I used. But I suspect that domination of the room environment will always be a disadvantage of this type of speaker system.

What kind of other measurements were you interested in seeing? There were a number of plots given in the second part of the series, but I am open to requests for others. The system is not set up at the moment, but other measurements can be collected later when we get it assembled again.

CO MODELING

"Modeling for Designing Passive Crossovers" (*SB* 8/98, p. 20) is one of the best articles in your magazine. I would like to confirm that the problems with CO networks are fully as serious as Mr. Koonce has indicated. The remarks on second-order networks which I have come to dislike for the same reasons were very affirming. I work with a purely empirical approach devoting years to one set of drivers. Live unamplified music is the primary reference. AKG K 240 phones are a secondary reference I have learned to use to restore normal perception after listening to incorrect sound during CO trials.

Perhaps the most valuable contribution that a good modeling program will make is the possible sorting out of physical and psychological factors in the listening experience.

Please keep us all informed on the progress of your work. Next time I need a CO I will try a modeling program.

Jesse W. Knight
Woburn, MA

G.R. Koonce responds:

I thank Mr. Knight for his kind comments on my article. At the time that article was written, I had developed about seven crossovers via modeling and constructed three of the systems. Today I have constructed seven systems developed via modeling and modeled crossovers for over 40 years, some of which should not be built. I am even more enthusiastic about the advantages of this approach now than when I wrote the article.

One thing I have learned is that there are some systems you don't want to build! In this regard modeling can save you a lot of time. Modeling can show that a certain pair of drivers just will not produce a system that has a reasonably wide, flat main listening lobe or a main lobe that radiates at a useful angle on a flat front baffle. You can quickly try all sorts of crossover combinations on a computer and find none of them will really produce a good flat baffle system.

Thus, not only can crossover modeling help you develop good systems, it can also identify systems you probably should avoid. Modeling will, of course, also allow you to investigate any potential improvement offered by introducing depth offset on one or more drivers.

As Mr. Knight affirms, developing crossovers the classical way can lead you to fear the second-order network. With modeling, you find that the second-order networks can indeed work very well with many systems, and I now tend to start with second-order networks and only change to a higher order if I can't get the results I prefer with all second-order sections. First-order sections normally require you to retain the Zobel and thus

FIGURE 1: 3″ dia., 57.5″ long tube full of wool at 0.48 lb/ft³.

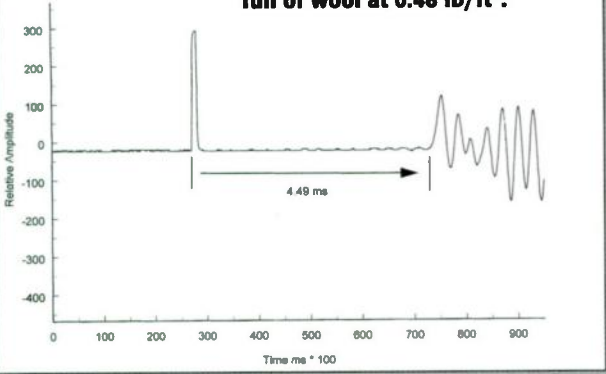


FIGURE 2: 3″ dia., 57.5″ long tube full of wool at 0.48 1b/ft³. Single sine pulse 50Hz.

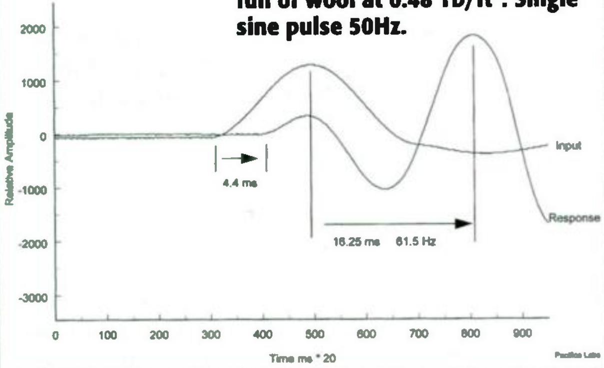
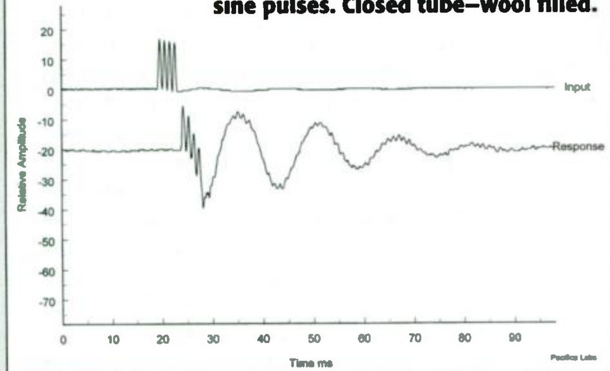


FIGURE 3: Response characteristic 4 sine pulses. Closed tube—wool filled.



actually require more components than a second-order section, so I tend not to use them.

Most speaker builders are aware that in theory the first-order crossover network allows building a linear phase system if the driver acoustic centers are properly aligned. Most are also aware that the first-order crossover is very difficult to apply with real-world drivers.

The article, "Minimum Phase, High-Order Filtering," by Timothy E. Sandrik (*SB* 4/98, p. 16), shows a method of developing high-order crossovers that can approach the phase performance of using a first-order network. I plan to look into applying this approach, which is almost ideal for working with crossover modeling, in future designs.

While professional modeling and optimizer software exists, there is still a need for a full-featured, low-cost modeling program for the homebuilder that supports data export files generated by a variety of computer-based quasi-anechoic testers. I still have hopes that the future can yield a library of accurate driver-modeling files to make the crossover modeling approach available to those without testing capability.

MORE TL RESPONSE

Don Jenkins has raised some interesting questions concerning the TL and specifically the difficult question of fiber effects on the TL's response ("What's Really Happening in a Stuffed Line?" *SB* 7/98, p. 32). While the question is too complex to deal with in this format, I would like to raise some cautionary notes concerning the data presented in the article.

1. The basic resonance of the 17″ long tube is markedly different from the response of the 29″ long tube (Figs. 2 and 3). This should have raised doubts about the effectiveness of the accelerometer used to measure the response for the shorter tube. The physics of the ¼ lambda resonance versus line length is the same in both cases, only the fundamental resonance frequency should have been shifted, from 200/185Hz for the 17″ line to 116/125Hz. The first figure is the theoretical resonance, the second is the measured frequency in Don's tests. The most glaring error is that the harmonic structure in Fig. 2 is so different from Fig. 3.

A more subtle point is the effect of the air density shifting the fundamental frequency, similar to the effect of the stuffed fiber mass. Air has a density same as fiber mass and will shift the harmonic frequencies according to the fiber-to-air ratio curve defined by Bradbury (eq. 5, *JAES*, April 1976). However, this equation must be convolved with the fiber-change-of-velocity equation to get the actual shift. The measured data (Laud MLS type data) for an unstuffed line shows that the fundamental will be shifted about +30%, the first peak about 6%, and the second peak about 1%, and so on. This is consistent with the impedance data for a unstuffed versus a stuffed line.

For Don's data (Figs. 2 and 3), the phase shift due to air density does hold approximately for the 29″ line but is reversed for the 17″ line. Now the complication in this is that for a stuffed line the fundamental will be shifted to a lower frequency, as shown in Fig. 8, for a "fully loaded 3″ tube."

2. The inconsistency in the data demonstrates that a basic understanding of the TL's air density resonance characteristics is not present and that for the shorter line the driver signal's spectral signature is mixed with that of the line resonance signature and that for the shorter line the fiber attenuation is not sufficient to separate the two. My suggestion is to try to define the fiber effects for a much longer line length, such as Bradbury used, i.e., two meters.

E. Jakulis
Avon, MA

Don Jenkins responds:

My thanks to Mr. Jakulis for his interest in the stuffed line article. The original intent of these tests was to determine whether the wool stuffing reduced the sonic velocity in the transmission line. As expressed in the article, I had doubts about how the theory of Bradbury was being interpreted. The initial evaluation method, and the one described in the article, attempted to use tube resonance as the evaluation parameter. This turned out not to be a satisfactory method for various reasons.

The data presented in the article is correct in that it shows true test results. Mr. Jakulis' comment that the difference in harmonic structure shown as Figs. 2 and 3 is "a glaring error" is somewhat of an overstatement. There is no "error"; the data is as measured. The fact that the harmonic content is different is another story.

My initial interpretation of the ambiguous results as a "phase problem" was marginally correct. Later tests show that the differences can be explained in part by phase relationships, but that self-generated frequency components also

contribute to the actions in a filled line, and to some extent to any closed resonant tube driven by a resonant, moderately damped, device.

Figure 1 is the result of a direct measurement of the sonic velocity in a wool-filled, open transmission line. There is no reduction of sonic velocity due to the wool. *Figure 2* shows a 50Hz sine pulse input to a closed wool-filled line. The response not only does not have any full cycle 50Hz component, but the self-generated resonant frequency response, which is a combination of line and driver, is of greater magnitude than the input pulse. This effect is what leads to questionable results of FFT analysis from impulse inputs to resonant transmission lines.

Mr. Jakulis observes that the driver spectral signature—I assume that this is the forcing function—is mixed with resonance signature—I assume that this is the response—and that a longer line will allow separation of the two. *Figure 3* shows how this is correct for a specifically selected length and input frequency such that the forcing function is complete, and has high damping, before the response is initiated.

As an aside, the test results from *Figs. 2* and *3* also confirm that there is no reduction in sonic velocity due to the wool stuffing.

PEAK PERFORMANCE

I have been using The Woofer Tester, by Peak Instruments Co., to measure a large number of "identical" drivers. I have found it to be rather "clunky" and would appreciate some advice on its use. I have noticed two problems:

1. After measuring a driver, it is necessary to exit the program and start again for the next driver to clear the memory of data stored from the previous measurements. If this is not done, then simply re-running the tests gives different values than if the test is started from scratch.

2. The "shift-print screen" function to print the results is next to useless on Windows-based machines (they are running an emulation of MS-DOS, not MS-DOS itself), and some MS-DOS functions don't work well. You may get any number of copies—you never know. I have found that the best way to overcome this is to run MS Word in the background. Then, using the "Mark" button (the dashed outline button in the MS-DOS window), highlight the text to be printed. Hit the "copy" button, open Word, and hit the "paste" button. If you are using the full screen for The Woofer Tester, hitting the "Print Screen" button on your keyboard is the same as the "Mark" and highlight function. Then you can print from Word. This is awkward, but it works every time.

It would be nice if Peak developed a Windows-based version—who uses MS DOS anymore?

Douglas Hurlburt
Potomac, MD

Brain Smith responds:

Testing a driver with The Woofer Tester is a two-part process. First, you measure fs, Qts. Second, you measure Vas. Then the entire T/S parameter list gets filled in. This process takes about 2½ minutes on most Pentium-class computers.

When testing many drivers in one session, you must remember to do both tests to each driver. If you perform only the fs, Qts test after a previous driver was measured you will notice T/S parameters from the previous driver.

To avoid confusion, it is advisable to exit the program and restart the system for each new driver, which takes only a few seconds. To exit the program you press the Q key; to restart you type W1 and press enter. It takes the same amount of time to do this as it would for a menu item to clear all memory.

It is not true that you need to quit each time. You simply need to remember to run both tests for each new driver.

You do have a good point about using Shift/PrintScreen. This is not an optimal solution, but it does work on every computer I have used. If you shut down Windows95 to a command prompt, you should have no trouble printing.

The Woofer Tester is a very cost-effective tool because the software is simple and easy to use. A fancy Windows95 interface would probably add at least $50 to the cost of such a program and would not make it any easier to use or any more accurate. It would simply be prettier to look at and make it easier to print results. It also might make it more useful by allowing results to be exported to a CAD tool such as BassBox.

I hope this clears up any misunderstanding. If you have any more questions, please feel free to post them to the technical discussion board on Part Express' website at www.parts-express.com.

Brain D. Smith, President
C&S Audio Labs, Inc.
Makers of the Woofer Tester
Distributed by Parts Express

HELP WANTED

I'm looking to do whatever it takes to build a sound system similar to the Wilson Maxx or Von Schweikert VR-10. I can build just about anything from wood or MDF, but know nothing about electronics. Is there a daring expert out there who would guide me through procuring a design and the source components?

Ted White
tjamesw@tm.net

I am surprised that there have been no letters in *SB* concerning the shunt network, considering I have never seen it used or discussed before, despite its potential. Have there been any further developments with its use? Not having any test equipment or appropriate network software (yet), I'm wondering whether Zobels can be used with them. Also, though I am a great believer in first-order networks, can higher orders be achieved successfully with shunt components?

R.D. Lewis
47, Heol Cennen,
Ffairfach,
Llandeilo,
Carms.,
SA 19 6UL
UK

I am searching for cabinet specs for a dual 12" ported woofer cabinet. I am using an EVM-12L from Electro-voice for a "punchy" bass, but wish to use a ported cabinet to improve low-end response. What info exists on adapting equations to work for dual woofer applications?

Lee Chiro
DRLEECHIRO@aol.com

I am looking for info on the Heil tweeters. So far I have drawn a blank here in the UK, so I am trying the USA. I have seen one demo here, but the guy selling the speakers (which were Swedish) could not help on the supply of the tweeters alone.

Paul Bailey
100336.2614@compuserve.com

I am a subscriber to *Speaker Builder*. I am about to start building a speaker project, but I live in an apartment and do not have woodworking facilities. I am searching for a reputable cabinetmaker (preferably with loudspeaker experience) in the San Francisco Bay area. Any help would be much appreciated.

Christopher J. Struck
Cjstruck@ix.netcom.com

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

Good News

■ WOOFER SERIES

Morel Acoustics USA, Inc., released a series of woofers from Shabani Industries, which includes a 12″ subwoofer, 6.5″, 5″, and 4″ drivers, all with cast aluminum frames, vented poles, and large-diameter voice coils. Also available is a 2.1″ soft-dome midrange, the MSD-56. Morel Acoustics USA, Inc., 414 Harvard, Brookline, MA 02446-2902, (617) 277-6663, FAX (617) 277-2415, E-mail sales@morelusa.com, Website www.morelusa.com.

Reader Service #135

■ GERMAN PROJECTS

Jack Burnett Associates LLC is offering a collection of loudspeaker designs from RCM Akustik of Paderborn, Germany, makers of Alcone® aluminum drivers. The nine projects include standing two-ways, satellites, a center speaker for home theater, and two subwoofers. Although the 30-page, 8½″ × 11″ booklet is in German, it contains easy-to-understand specifications, crossover schematics and parts lists, bills of material, analysis curves, and construction diagrams. Burnett Associates, PO Box 26, W. Peterborough, NH 03468, (877) 924-2383, E-mail FDTF77B@prodigy.com.

Reader Service #136

■ CANADIAN CATALOG

Solen Inc.'s 1999 catalog and OEM price list contains pricing on its Hepta-Litz inductors, Perfect Lay inductors, Fast Capacitors (metalized propylene), and power resistors. It also includes drivers from Airborne, ATC, Audax, Dynaudio, Eton, LPG, Morel, Peerless (Denmark), Scan-Speak, Vifa, Volt, as well as a wide variety of crossover and speaker parts (terminals, port tubes, grille cloth, screws, damping pads, foam, and so on). Solen Inc., 4470 Thibault, St-Hubert, QC J3Y 7T9, Canada, (450) 656-2759, FAX (450) 443-4949, E-mail solen@solen.ca, Website http://www.solen.ca.

■ THIN SPEAKERS

Researchers at VTT Technical Research Center (Finland) developed a sound amplification technology called Electro-Mechanical Film (EMFi), which allows loudspeakers to be built out of flexible plastic sheets 1cm-thick or less. The sheets are inexpensive and may be adapted to a wide variety of applications, including allowing you to speak voice commands into the screen on your desktops. The technology uses layers of biaxially-oriented polypropylene 0.05mm thick, so that when electrically charged, can convert electrical energy to vibration and sound, and vice versa. Invest Finland Bureau, (212) 614-4466.

■ BAS ANNIVERSARY

As part of its anniversary celebration and membership drive, the Boston Audio Society (BAS) is offering a free sample package of articles from its newsletter, the *BAS Speaker*, via E-mail (92kB) at dbsystems@ibm.net/Research Triangle/Node/5480/. You may also receive a sample issue for $2 by writing to BAS, PO Box 211, Boston, MA 02126. The club is also offering an introductory membership rate of $32.

Classifieds

VENDORS

RCM Akustik sub amps with crossover, speaker cones, more. Dealer, OEM inquiries invited. Free info. ***Burnett Associates***, toll free 877-924-2383, or E-mail FDTF77B@prodigy.com. Visit us at http://pages.prodigy.net/dear2/audio.

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Reader Service #7

AD INDEX

SPEAKER PROJECTS! Nine RCM Akustik designs include standing two-ways, satellites, center speaker, two subwoofers. In German, but easy-to-understand specs, crossover schematics, parts lists, analysis curves, construction diagrams. Thirty-page 8½″ × 11″ booklet, $9.95 ppd. ***Burnett Associates***, toll free 1-877-924-2383, or E-mail FDTF77B@prodigy.com.

FOR SALE

JBL: DLH-175 "salt shaker" horns and drivers; LE 85 drivers; 2420 drivers; H-91 conical horns; tweeter mounting brackets. Altec: 811 horns; 1285B crossovers; 418B 15″ woofers. Electro-Voice 1823M drivers. JBL 375 "show" driver, no magnet or diaphragm. Perraux 1150B rackmount. Pioneer Spec 1 rackmount preamp. David (914) 688-5024.

Denon amp 200W/ch, $400. Harmon Kardon PT2500 tuner preamp, $200. Both for $550, both in mint condition. Nick (559) 583-6511.

Dynaudio Esotec Aries system, components consist of two of each: 20W75 Esotec 8″ woofers; (list = $146); D260 Esotec tweeters (list = $126); Aires crossovers using highest quality parts, construction plans like new condition. F3 of 37Hz sounds fantastic! $400, 110 lb cabinets, free in WI. Jerry (414) 784-4726 eves., (414) 796-1827 x3710 days.

Hobbyist cleans house woofers: Audio Concepts AC-12 midranges; Eaton 7/380 tweeters; Morel MDT-33s and original large Advent crossover; Audio Concepts 24dB with Solen aircore ribbons; Legacy Pioneer 10201 semi pro 10½″ reel-to-reel tape deck (excellent condition), no reasonable offer refused. Bill (606) 341-3841.

Peerless drivers–"CSC" sandwich polyprop, cones, rubber surrounds, 5.25″. Model S96118, 12 pcs; and model S97036, ten pcs, $40 each. Model 833599 6.5″, two pcs, $50 each. Also some Morel drivers. Details: Dynamic Acoustics, PO Box 646, San Ramon, CA 94583-0646. V (925) 866-9500, F (925) 743-8167, E-mail dynamboat@juno.com.

Bozak drivers, indestructible, smooth sounding: two 8″, two 6″, and 12 2″ coaxial tweeters, all 8Ω, good, like new condition. Reasonably priced. Call Bob @ 310-676-4829.

Four Focal Audiom 12VX: two new, $225; two like new, $200. Marc McCalmont (603) 860-3085.

WANTED

Altec horn speakers, woofers, horns, crossovers, 515, 515B, 515C. Horns: 805, 1005, 1505A/B, 311-90, 329, 604, 605; 288B/C, 288-16 G/H. Larger corner speakers and console speakers, Laguna, Paragon; Western Electric horns, woofers, drivers, parts; Tannoy dual concentric, Goodman, E-V Patrician. Sonny, (405) 737-3312, FAX (405) 737-3355.

Aria-3 project and also pair Scan-Speak Polly-Pro 18W flash 8543 drivers. Call Regis at (724) 368-8019 evenings (EST).

Speaker Builder

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TITANIC 1200

Dayton Loudspeaker Co.®

The Dayton Loudspeaker Company is proud to introduce the **Titanic 1200 Subwoofer**. We feel Webster's definition of Titanic as "of great size, strength, or power", "of or like the Titans", perfectly describes this driver! With specifications like 16Hz Fs, 14mm XMAX (linear), 90dB SPL (2.83V) and 350W power handling, we're sure you will agree that this subwoofer is truly, **Titanic!**

We assembled a team of the best speaker designers in the industry with one thought in mind ... to build the finest home theater subwoofer on the market! These engineers were chosen because of their expertise and pioneering designs of long excursion, high output subwoofers. A dozen prototypes were built and rigorously tested before we were satisfied with the final design parameters.

The latest state-of-the-art manufacturing equipment and the finest materials available are used to ensure that each driver is built to the highest standards of quality. CAD design and CNC machining allow for precision fit and close tolerance alignment to increase flux density and enhance heat transfer. Only the finest components are utilized: a heavy cast aluminum basket to control unwanted resonance, a talc-filled polypropylene cone to ensure stable, non resonant operation, Santoprene® rubber surround for extended life and long excursion, an ultra high power voice coil assembly with a high temperature resistant Apical® former (which is far superior to standard Kapton®), and quality, high tech adhesives to hold it all together. Steel parts are coated with a black high emissivity coating (originally developed for NASA) which improves heat dissipation and lowers distortion. All of these components cost more, but are worth it!

Lets talk Performance!

Although the 12" Titanic was designed primarily as a sealed box woofer, we found it is also well suited for 4th order bandpass enclosures. One possible design is a 4.5 cubic foot bandpass that yields a frequency bandwidth of 17.5Hz - 70Hz (-3dB). This design produces an output of 112dB and remains linear down to 28Hz at full power!

You will be overwhelmed by the incredibly realistic low frequency that this driver will produce. We feel there is no other home theater subwoofer on the market today (at any price) that can outperform the Titanic! Go ahead, put the T/S parameters into your favorite box design software program and see for yourself what the Titanic 1200 can do!

SPEAKER CABINET NOT INCLUDED

Try it for 30 days ... If you don't feel this is the best home theater subwoofer you've ever heard, we'll refund your money! The Titanic 1200 is covered by our unconditional 5 year replacement warranty.

Thiel-Small Parameters

◆Power handling: 350 watts RMS/ 450 watts max. ◆Voice coil diameter: 2" ◆Voice coil inductance: 1.96 mH ◆Nominal impedance: 4 ohms ◆DC resistance: 3.66 ohms ◆Frequency response: 16-400 Hz ◆Magnet weight: 84 oz. ◆Fs: 16 Hz ◆SPL:90dB 2.83V/1m ◆VAS: 9.894 cubic ft. ◆QMS: 8.22 ◆QES: .42 ◆QTS: .407 ◆XMAX: 14.2 mm ◆Net weight: 14.6 lbs. ◆Dimensions: A: 12-1/8", B: 11-1/8", C: 6-9/16", D: 6", E: 2-3/4"

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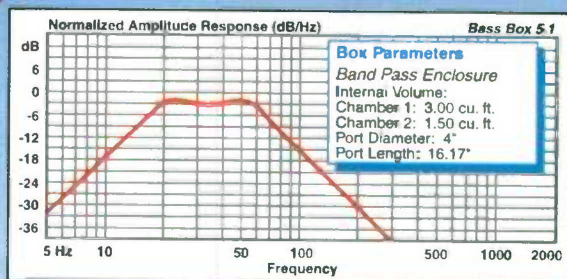

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The 1978 C.E.S. in Chicago was the very first time that Morel Acoustics USA, Inc. presented their product to the public. It became clear, early on, that the loudspeaker industry was in need of high quality speaker drivers. Shortly thereafter we introduced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

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

Integra

Push-Pull

Double Magnet

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

Typical double magnet ducted woofer.

For further information please contact:

Double magnet tweeter

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