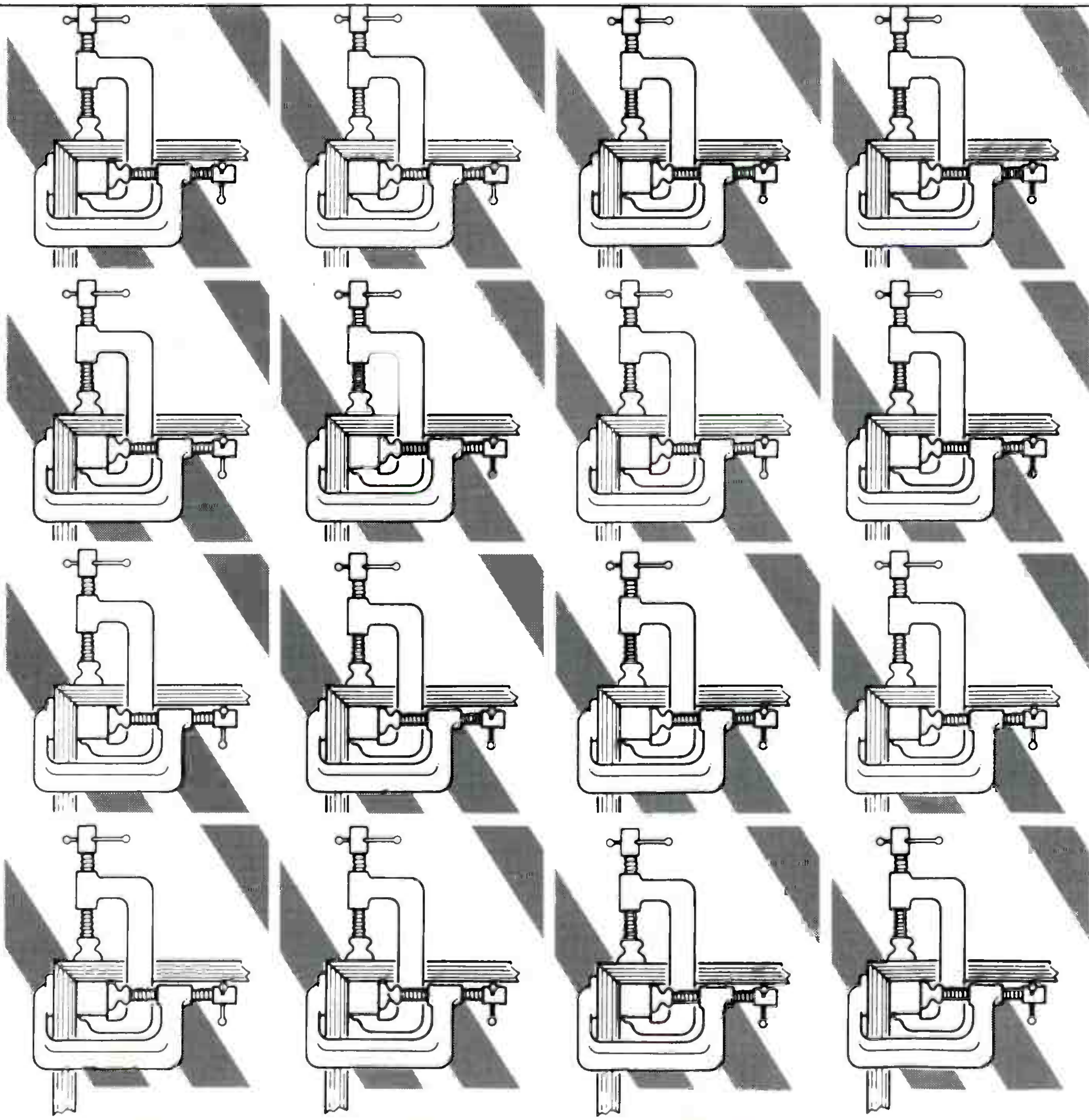
SPEAKER BUILDER

Corner 3-Way with Ribbon ◦ Zobels and Drivers ◦ Phase Alignment ◦ Thiele/Small Software



Good News

Many intriguing concepts are included in the new Point Source speakers by **DESIGN ACOUSTICS.** By removing the woofer from the front and pointing it downward they reduced the front baffle area considerably. The PS-8's front area is only 11 × 19" which approximates a point source about as closely as is practical with real drivers. Diffraction effects are minimal, improving the stereo imaging. An absorptive baffle surface, flush cabinet edges, and asymmetrically placed drivers also help. The woofer fires downward at a fixed distance from the base, pushing air through the narrow opening. This has the effect of mass-loading and slot-loading the long-throw woofer so that it produces a stronger and deeper bass than normally possible with such a small enclosure. In the three-way PS-10, the crossover points are at 200Hz and 2kHz to avoid frequency, time and phase nonlinearities in the midrange. Audition them at your favorite audio shop.

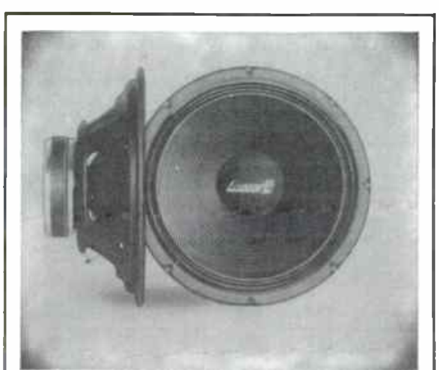
TELARC is now selling its records directly by mail and phone. For a nicely illustrated catalog listing all the latest and past releases, write to Dept. SB, Telarc Catalog, 23305 Commerce Park Rd., Cleveland, OH 44122.

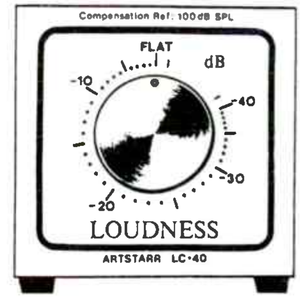
The new A100II from **BOSTON ACOUSTICS** uses redesigned drivers. The CFT tweeter, under development for over a year, has a self-damping copolymer dome, magnetic fluid convection cooling, high temperature voice coil insulation, and flexible lead wires. Precision and consistency in performance result from locater elements manufactured to tolerances more typical of the optical industry than speaker manufacturing. The woofer's cone is made from a mixture of wool and cotton fibers (no paper or wood pulp), to eliminate response irregularities at the upper end of its operating range. The enclosure retains the thin design of the earlier model, with special attention given to acoustic rigidity, driver location and room coupling. Write to them at Dept. SB, 130 Condor St., Boston, MA 02128 for details and the name of a dealer near you.

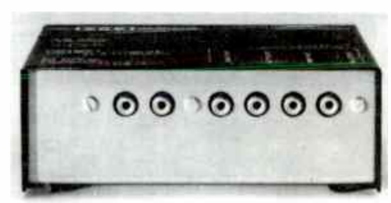
DYNAMIC ACOUSTICS, PO Box 646, San Ramon, CA 94583 has two new satellite and subwoofer systems, the 2200 and 2602. Both feature polypropylene woofers and soft domes for the midrange and upper frequencies. They will offer soon a complete series of polypropylene units for home speaker builders, and will include full and accurate parameters for each unit. Visit your nearest dealer for an audition.

A new moving coil cartridge with high output (2.5mV @ 1kHz, 5cm/sec) comes from **DYNAVECTOR.** The 10X3 features a short, stiff cantilever (6.5mm) made of tapered aluminum tube. The precision wound coils have over 400 winds per channel of 95% silver/5% copper alloy wire. Samarium cobalt magnets, precision alignments, and temperature independent suspension all contribute to its performance. Price is $150. Visit your dealer and listen to it.

If you build speakers for musical instrument sound reinforcement, **PYLE INDUSTRIES** has a new series for you: the Accent I. By concentrating more magnetic flux in the voice coil area, they have made a highly efficient driver suitable for hard rock/heavy metal applications. Their FRK voice coil forms withstand high temperatures and have a low expansion coefficient to retain their dimensions. All are 12″ and are offered in 30, 40, and 60 oz models in 8 or 16 ohm versions. For complete details, write to Dept. ZP, PO Box 620, Huntington, IN 46750.







About This Issue

Mike Lampton leads off this fourth issue (p. 7) with a delicious construction project whose details will enrich any future speaker project you undertake, sand panels and all. **Wilfred Harms** introduces us to the mysteries and advantages of the Zobel on page 14. **Kenneth Rauen's** excellent guidelines on how to build a horn mold and cast a horn as well as how to fabricate the pleated driver films for your Heil drivers begins on page 16. **Bob Ballard** also completes his project of a phase correcting crossover on page 26, with parts lists and a circuit card for easy construction.

Bob Carlberg continues his exploratory journey through all styles and modes of speaker building on page 31. Cork finishes for cabinets are reader Doug Cabaniss' unusual offering (p. 34) in *Designers Corner,* a surprising visual variable. We have tips from reader **Peter Jacquemin** on movable drivers and some Basic programs for Thiele/Small parameters from **Bob White** starting on page 33, as well as excellent book reviews from readers **Marovich** and **Kevil** on p. 36.

This issue also carries subscription expire news for some of you whose label code reads "XX82." We hope to welcome you back in our 83 series to another great year of fine articles on the crafting of loudspeakers.

SPEAKER BUILDER

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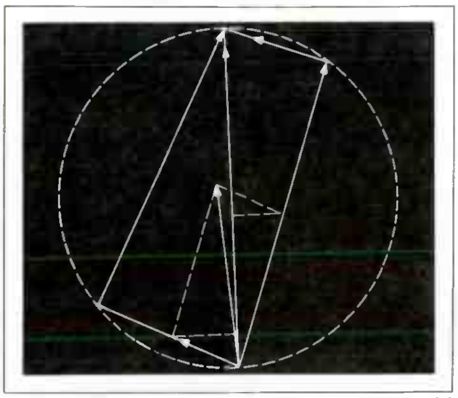

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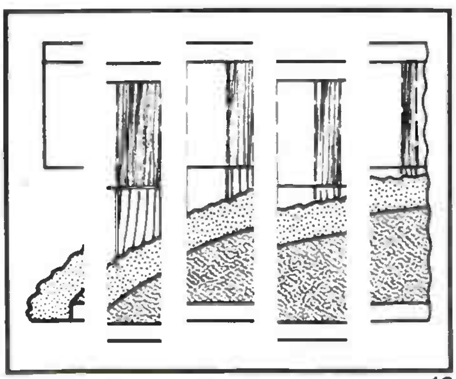

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FEATURES

DEPARTMENTS

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Editorial

The Catalog Connection

Good tools and good materials are absolutely essential for the pursuit of a flourishing and healthy hobby. I have become more deeply convinced of that primary fact each passing year of my love affair with audio. Early on I held to some widely believed prejudices about how dangerous commercial interests were to honest publishing. What I failed to notice—and most others seemed to ignore also—was a symbiotic relationship between a hobby's supply companies and the hobbyist.

As I look back on forty years of building all sorts of audio gear, I realize that I have learned a large part of what I know from catalogs. A good catalog lists and illustrates, describes and gives measurements of all sorts of things. Catalogs have a lot of ideas in them—ideas you and I never thought about. Sometimes the ideas behind the items in the catalog fit together with some thoughts I have had about other entirely different projects or enterprises. A snap sounds in my brain and suddenly I have an answer to something that has been in the back of my mind for some weeks or months.

I include in the general category of "catalog" those grubby newsprint things that many vendors resort to for "surplus" sales. These too are filled with items that stimulate the mind and the imagination. Catalogs are worth a lot of study and the active speaker builder will have an important place set aside to keep them in some sort of ready order, up to date, and handy for reference. Anybody who hasn't such a collection has not begun to be serious about this hobby.

Now some of you really aren't doing your proper homework about catalogs. We know because you call us up and ask where you can find this or that driver, or capacitor or tool. And the thing you are looking for is advertised in *Speaker Builder.* Plain as day. Sometimes the news you are looking for is in the classified section, maybe, but it is there.

This hobby of speaker building is suffering from a deeply serious case of invisibility, especially in these difficult days of economic crisis (read depression). The avocation is invisible because you don't bother to read the ads, collect your catalogs, and let the vendors know this is a very real, important hobby that you love a lot. If you speak up, they can know they are not invisible to you—first of all.

Second, they will realize that you are not invisible. We talk with the people whom we think ought to be sending their good news to you about the goodies they have to sell. But somehow we haven't been able to convince very many of them that you exist. In short, you are invisible too.

Now we could all sit around and gnash our teeth about this and bemoan it. But that wouldn't help. What will help is for you to be very vocal about your love for your hobby. Be very vocal when you buy anything from an advertiser: say that you are buying the stuff because you saw his ad in *Speaker Builder* magazine. If you buy something for this wonderful hobby from someone who does not advertise in *Speaker Builder,* then it will help enrich your hobby and enlarge the power of this magazine if you point out to the vendor that

Continued on page 32

A THREE-WAY CORNER LOUDSPEAKER SYSTEM

BY MICHAEL LAMPTON

Over the past ten years, many major improvements in speakers have taken place. Woofers now have much more accurate frequency response. Advances in phase response and time-domain design by serious manufacturers have reduced distortion and improved the imaging of midranges. The recent ribbon tweeters, some of them quite inexpensive, have overshadowed the older domes, cones, electrostatics, and piezoelectrics. Cabinet design now takes account of cabinet-edge diffraction, enclosure panel resonance, and time delay phase distortion. In short, so much has happened that a ten year old speaker is seriously out of date, and often could be improved by adopting some more recent design elements.

In this article, I want to outline some of the considerations which led to my present system, and provide construction information for those who wish to copy my design or embellish it for their own use.

The starting point for the design of any speaker system is to have a clear understanding of its end use. In a disco or a large auditorium, high acoustic outputs are required, while the subtleties of sound quality like "air" or imaging are secondary. Such systems often employ high efficiency horn loaded drivers having low diaphragm masses, huge thermal ratings, and large voice coil excursions. In the home, however, these high SPL's would be intolerable. For a serious listener, quality of sound becomes paramount and the speaker designer can trade off high efficiency for more massive but better damped drivers, with flatter response and gentler crossover slopes with better phase response.

Another benefit of low efficiency designs is extended low frequency response in a reasonably sized enclosure. The cutoff frequency is proportional to the cube root of the ratio of efficiency to enclosure volume, and you can rephrase this as, "To get a lot of deep bass efficiently, you need a big air reservoir." Subwoofers with modestly sized boxes have abysmally low efficiency because of this law. In my design, I have tried to strike a reasonable balance among these factors, using a 10.5ft³ (300 liter) enclosure, and a 0.6% efficiency to achieve a theoretical response down to 20Hz at −3dB. Few subwoofers can go any lower, and my system is two to five times more efficient than the popular bass commodes. Best of all, the setup described here avoids disjoining the bottom end from the rest of the spectrum, with no phase discontinuity in the lower midrange, giving a coherently integrated, solid sounding bass.

An important consideration is the size and shape of the listening room. Floor plans popular in California feature wide open activity and seating areas, and listeners are likely to be found at a wide range of angles off axis. Horizontal dispersion must be excellent if you want good imaging in much of the room. One option which minimizes the required horizontal coverage angle is placing the speakers in corners, so listeners can't be more than 45° off axis. The drivers I chose sound good up to 60° off axis, and you could put them in a rectangular box flat against a wall if you desire.

WOOFER SEARCH. Oddly the most challenging aspect of choosing an acceptable woofer was not in finding one with a powerful or accurate bottom end, but rather in finding one with a smooth and clean sounding midrange. In woofers, big peaks and valleys are common above a few hundred Hertz, mostly due to standing waves in the cone and its elastic surround.

To choose a woofer diameter is to make an agonizing compromise among several factors. Larger drivers have increased power handling capacity, but require a lower crossover point to minimize midrange cone resonances and dispersion problems. Smaller drivers handle less power, but move the resonances up out of range. Other things being equal, smaller drivers have better angular coverage.

For my design purposes, I chose the JBL 2213, a 12″ frame diameter driver having a particularly thick, massive, heavily damped cone. Free air resonance is 25Hz, and JBL uses it in modestly-sized enclosures with a 1200Hz crossover (response is remarkably smooth up to about 1kHz). This is available from dealers as No.2213H (not shown in the 1982 pro catalog, but it appears on the price list for $170). They use this same driver both in their home 3-way, the L-112 (where it is called the 128H), and in the professional version, the 4312.

Table 1 shows some of the physical parameters of this driver, averaged for four samples. Using these values, I explored a number of enclosure size and vent options using a small computer and WOOF, my woofer simulator program.[1] A very flat low end response occurs at 300 liters of adiabatic enclosure volume with a vent giving a Helmholtz frequen-

TABLE I

System input data	
Effective piston area	0.046 square meters
Woofer free air resonance	24.5Hz
Suspension stiffness	1350 Newton/meter
B L product	9.10 Weber/meter
Voice coil resistance	4.70Ω
Suspension Q factor	3.000
Adiabatic enclosure volume	0.300 cubic meters
Helmholtz frequency	21.0Hz
Constant parameters	
Effective woofer mass	0.057 kilogram
Enclosure air stiffness	1009 Newton/meter
Electrodynamic drag	17.62 Newton sec/meter
Asymptotic efficiency	0.634%

cy of 21Hz. There the theoretical response is nearly Butterworth and is down 3dB at 20Hz *(Fig. 1)*.

A sealed enclosure with the same volume has a gently sloping response dropoff in the low end, −3dB at 35Hz. In such a large cabinet, the woofer is overdamped. Although sealed enclosure designs have a more severe problem with cone excursions from in-band power, they offer a smaller bottom end phase shift as a result of their smaller asymptotic cutoff slope. They are also more tolerant of subsonic excitation.

For my system I wanted to experiment with a variety of ducts for simple listening comparisons of such options. The design features a duct holder into which a variety of ducts or a plug can be inserted without tools. For most purposes I recommend the 21Hz Helmholtz frequency.

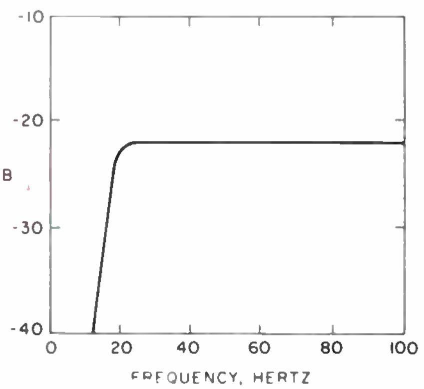

FIGURE 1: With the author's WOOF software, the computer plots a theoretical woofer frequency response. This curve is generated from the data listed in Table 1.

If you are familiar with the Thiele/Small alignments or the Lea/Lampton polynomial synthesis, you may be surprised to see an enclosure tuned lower than the woofer's free air resonance. This is an idea which I proposed a decade ago as a theoretical concept[2] which works only if the compliance of the air in the box is greater than the woofer's suspension compliance. To do this takes a big enclosure. The benefit is bass response that extends well below the woofer's free air resonance, without requiring a subwoofer-type slot loading scheme with its attendant loss of efficiency and its irregularities in midrange amplitude and phase response. This particular tuning lies close to a continuous family of alignments which I call "symmetrically bounded ripple." In this family, the response curve is allowed to go above or below its asymptotic value by a limited amount. (In the present design, based on a lossless enclosure model, the allowed ripple is about 0.03dB).

MIDRANGE CHOICE. Midrange loudspeakers are usually designed pretty much the same way woofers are, but scaled down in size and hence scaled up in frequency. The problem with most midrange cones is they don't sound as accurate as my reference unit, the electrostatic. However electrostatics have problems as well: to accommodate much power, they must be large, and so will exhibit directional beaming in the upper midrange.

The driver I've adopted for this project is the Jordan 50mm module. This British moving coil driver has a two inch metal cone. Although the manufacturer rates it for use across the whole 200Hz to 20kHz range, I do not recommend such use. At the low end, 500Hz would be a far safer crossover point, because of its rather limited thermal capacity and the desirability of minimizing cone excursion. At the top end it has what I regard as a rather serious problem. The four units I've tested all show a big (10dB) direction-sensitive depression in amplitude response between 8 and 10kHz. An even bigger peak at 13kHz brings the response curve briefly back up above its midrange asymptotic level. Through time-domain pulse testing I found ringing with an 80μS period. Also, in listening comparisons with a highly regarded electrostatic, I found a subtle coloration at the top end. This is lamentable, since the Jordan's midrange beats anything I've heard. It also measures very nicely: its response from 200Hz to 5kHz is ruler-flat.

The Jordan module needs a one liter enclosure. I have found that a sealed chamber of particle board fastened to the rear of the mounting baffle works fine, but it must be thoroughly damped to avoid introducing colorations into the midrange sound. I recommend lining this mini-enclosure with scraps of shag carpeting and then filling the remaining space with loosely layered glass fiber wool.

Some builders stack several Jordans together to improve midrange power handling capacity. I do not recommend this approach, because multiple drivers tend to blur transient detail. For example, with four drivers sharing the same frequency band, a single pulse of electrical signal will yield four acoustic pulses separated in time. If you need to increase power handling capacity, choose a beefier driver, or raise the crossover point so the woofer shoulders more of the load.

In England, Jordan modules are advertised at about $40 apiece; in the US the price is typically twice this, and you may have to wait a month or two for delivery. Even so I'd be hard pressed to name a comparable alternative.

BLUE RIBBON TWEETER. Those who have tried for years to get just the right focus, clarity, depth and "air" from an inexpensive tweeter should junk those domes and piezo horns and buy (or build) a pair of ribbon tweeters. They are extremely simple transducers. The voice coil is a thin metallic strip or spiral pattern evaporated onto a thin plastic film. This is suspended vertically in the gap of a strong permanent magnet, and your amplifier's output current flowing through the conductor causes the ribbon to vibrate directly. No separate diaphragm, dome, or horn is needed. As a result, you get phenomenal transient response, and a narrow slot radiating geometry for outstanding horizontal dispersion. Also you get a purely resistive 8Ω load (no transformers or any other adaptive circuits needed) for free.

Although the ribbon tweeter idea has existed for more than half a century, cheap, reliable ribbons of good quality have come onto the market only recently. I use JVC ribbons retailing for about $30 each. (I've heard Sony also has a comparable unit). Measurements on my JVC's show an amazingly smooth frequency response. At the low end, they are down 3dB at 3kHz. At the high end, they drop off gently (down 3dB at 16kHz) without the usual annoying peaks and dips most tweeters have, all the way out to 30kHz (the limit of my microphone). Best of all, the horizontal dispersion remains broad up to 14kHz, surely a result of the ribbon's narrowness.

ENCLOSURE. The chief concern in building any big enclosure is flimsiness. Whereas ¾" particle board ("underlayment" in the flooring industry) is entirely adequate for constructing bookshelf-size enclosures, bigger boxes demand more rigid panels to avoid mechanical resonances. Panels resist flexure in three ways: rigidity, mass, and resistance. At the lowest frequencies, high rigidity (or elastic spring coefficient) is the most important characteristic. Rigidity or stiffness is the ratio of static force to deflection. To stiffen a panel you can increase its thickness or brace it with cleats or studs. At the highest frequencies, high mass is the most important characteristic. Mass is the ratio of force to acceleration. You can increase it by making the panel thicker or by attaching heavy objects to it. Finally, at intermediate frequencies, where a variety of flexural resonances can occur, a large mechanical resistance, along with stiffness and mass, is needed. Resistance is the ratio of force to velocity, and this is what accounts for panel damping, causing vibration to die away rapidly.

The big panels in my corner enclosures take these requirements into account in

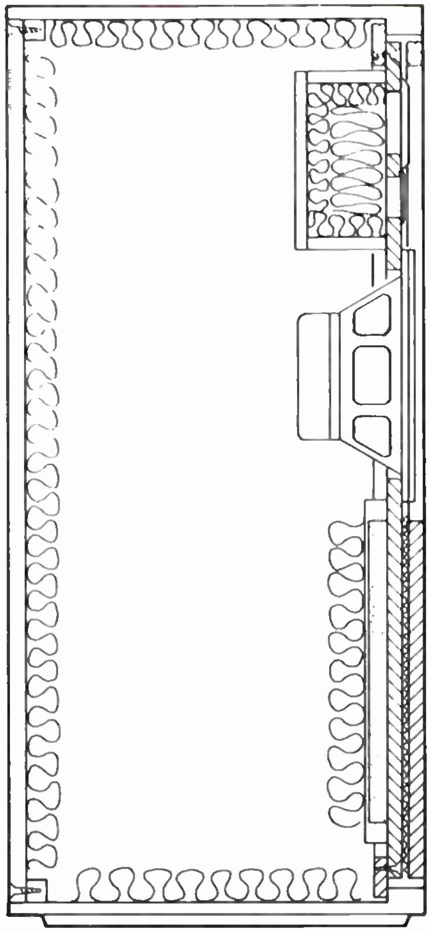

FIGURE 2: This cross section view shows the location of the drivers and the mini-enclosure. The interiors of both are lined with absorptive material.

three ways. First, a number of cleats glued to its inner surface stiffen each panel. Second, another panel (a layer of ¼" plywood) backs most of these for added stiffness. Third, fine dry sand fills the one inch air space between these surfaces.

Sand-filled panels are not new to the speaker industry; they have been used by two British firms, and hobbyists occasionally adopt the method. [G. A. Briggs first suggested this technique in 1949.—Ed.] The layer of sand not only adds a substantial amount of distributed mass, but also greatly increases each wall's flexural frictional resistance. The benefit is a drastic reduction in bass coloration from enclosure vibration modes. If you hit one of these panels with your knuckles, you'll hear only a quiet brief rap rather than a resonant knock.

Sand is dirt cheap. That's a good thing too, because I needed about 500lbs for the pair. Fine washed river sand sells for about one cent per pound in my area. However, it contains moisture and must be thoroughly sun- or oven-dried before filling your cabinet walls with it, to avoid damaging the wood.

I've organized the woodworking part of the project into four tasks: the Exterior (top, bottom, narrow left and right sides), Rear (three panels joined together), Baffle, and Removable Grille.

EXTERIOR ASSEMBLY. This is the principal structural element holding everything together. Since most of the woodwork in this section is visible, neatness counts. I made the top and sides of prefinished ¾" walnut veneer plywood. The bottom and the slightly smaller pedestal plate can be made from lower grade plywood of similar thickness. The outside dimensions are 36×48×22". *Figures 2, 3,* and *4* show what the assembly looks like. The plywood is doubly thick around the front opening of the enclosure for a depth of two inches. This furnishes an inner vertical surface to fasten the baffle's rectangular mounting frame permanently and also helps to stiffen the top, sides and bottom. Many enthusiasts will, like me, not have access to a big table saw, which is essential for getting the long plywood cuts straight. I found the local lumberyard's price of $.50 per cut quite reasonable for a project of this scale.

None of the dimensions or angles is particularly critical, with the exception of the two mating surfaces at the miter joints. These demand some care; make the cuts accurately straight or you will end up with an obviously irregular joint. Again, you need a table saw for these 45° cuts.

To make the miter joint I used an internal corner block measuring about

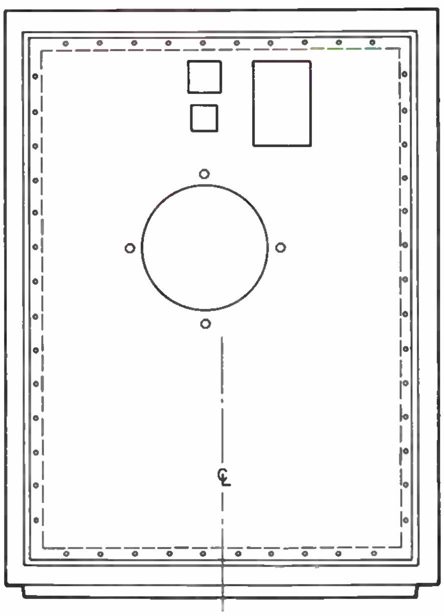

FIGURE 3: The front baffle has cutouts for the three drivers and the duct box.

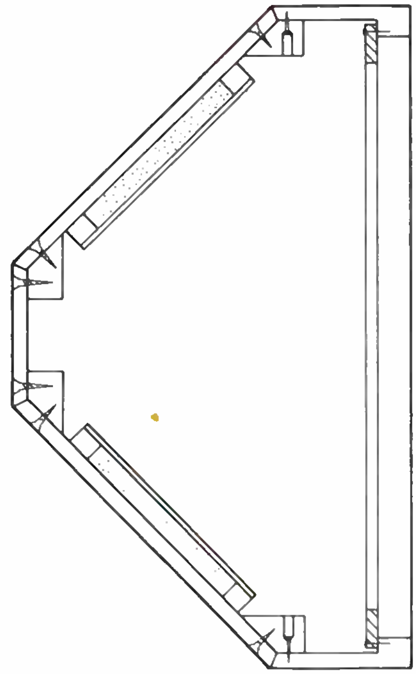

FIGURE 4: In this cross section view from the top you can see the location of the rear sand filled boxes.

1×1×4", and two big C-clamps (furniture clamps might be better). Set the joint face down on a hard flat floor and adjust things so the external seam is as flawless as possible, with both clamps tight *(Fig. 5)*. Verify that the joint makes a perfect right angle with a steel L-square. If it doesn't, your block needs cleaning or squaring up. Undo one clamp, remove one exterior piece, and apply yellow glue liberally to the exposed block face. Carefully replace the exterior part and realign the seam. Clamp it firmly. Now loosen the second clamp, apply glue to the block face and the bevelled miter surface, and reassemble. When you get the seam lined up, it will be full of glue. Tighten the second clamp, wipe away the excess glue, and recheck the right angles. Allow the joint to dry overnight. It will be amazingly strong.

The two joints at the bottom of the exterior assembly are also best done with the internal block method, but are a lot less demanding since no seam is visible. Make sure the enclosure's floor gets attached at right angles to the uprights, and its front is flush with them.

FINAL EXTERIOR STEPS. With these four joints complete, the remainder of the exterior is easy. Prepare the rectangular mounting frame that will become a permanent part of the assembly and will carry the front baffle. I used a sheet of ¾" utility grade plywood, cut to 34½×46½, so it will just fit into the exterior assembly. Cut a 30×42 hole in the middle (to hold the baffle and its equipment). Save the cutout for later use.

A sabre saw is essential for this operation. Beg, borrow or buy one.

Clamp this frame against a 32 × 44 sheet of particle board destined to become the baffle, and make sure you have a uniform one inch of overlap all around. Then match-drill ¼″ holes through both, roughly every 3″ along the frame's periphery. Unclamp the frame and drill these holes out to 5/16″. Install ¼-20 T-nuts in all the holes. T-nuts have three or four little teeth. Push each into the frame and hammer it down flat. Place the frame into position in the enclosure. Since the baffle's machine screws will be coming in from the front, the T-nuts must be on the interior side.

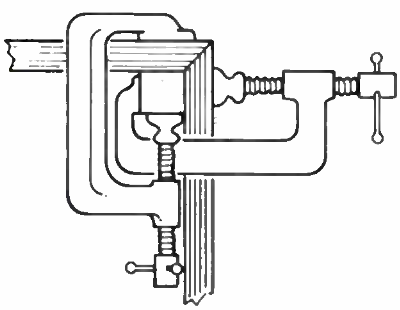

FIGURE 5: Use C-clamps or furniture clamps to make the miter joints.

Now glue and clamp into place two 46½ × 2 upright front doublers, a 33 × 2 top doubler, and a 33 × 2 bottom doubler. Adjust them carefully so the front edges are flush with the cabinet. With these doublers clamped firmly, allow to cure overnight. Then secure the now-captive rectangular mounting frame against the rear surfaces of the doublers, using plenty of glue and woodscrews. For this task, I found a #12 combination drill having a small bit, a large bit, and a countersink all in one to be handy.

The best way to finish the exterior's front edges is by gluing strips of walnut veneer onto them under pressure. To get this pressure, after gluing the strips on, place the whole assembly face down onto waxed paper over a carpeted floor. Weight it and wait until the glue hardens.

REAR PANEL ASSEMBLY. You can make this portion from a pair of 20 × 46½ panels and an 8 × 46½ panel, cut from ¾″ plywood or particle board. I joined these rather crudely by simply gluing and screwing them to a pair of 2 × 4 uprights, 42″ tall, from which I cut a corner at 45°. The woodscrews I used in this project are 1½″ long #12 Phillips flatheads. Their big size #3 Phillips head can take a terrific amount of torque safely, and provides good centering action for an electric screwdriver (which I highly recommend).

The left and right rear panels are sand-filled. Cut a 15 × 40 sandbox lid from ¼″ utility grade plywood, and cut two 40″ lengths and two 13″ lengths of 1 × 1 stock to form a 15 × 40″ frame. Also cut a few 1 × 1 × 4 cleats to help restrain the middle of the lid from bulging because of the considerable hydrostatic pressure of the sand. Apply a liberal dose of glue to both faces of the cleats and frame parts except for the top (one of the thirteen inchers). Assemble the whole thing onto the rear panel. Squeeze the joints together to eliminate leaks, then quickly nail the lid down tightly at the top. Pry out the top piece and let the whole assmbly dry overnight. Almost all the strength of the sandboxes comes from the glue in the joints; the nails just hold the joints under compression until the glue hardens. When the glue is completely cured, fill the sandboxes with sand. Before filling, be sure the sand is completely dry (sun dry it or bake it in the oven). Finally, install the top cleat with glue and nails to seal the sand inside.

To mate the exterior assembly to the rear panel, lay the rear on its back and lower the exterior onto it. Reach inside and mark the top and bottom with a pencil showing just where the interiors of the rear panels fall. Lift off the exterior and install 1 × 1 cleats along the pencil lines, using glue and a few screws. Cut and install the 2 × 4 uprights shown in the drawings; these join the extreme left and right edges of the rear panel to the exterior sides. I used no glue on the rear panel portions of these joints, so the rear could be removed in the future if necessary. Since an unglued joint can be leaky and flexible, I used a screw spacing of only about three inches around the entire rear.

The enclosure's interior can be finished now, by tacking scraps of heavy shag carpet to all the interior surfaces. To accommodate the speaker leads, I drilled a few ¼″ holes in the rear center panel. I intend to make a neater job of this by installing a pattern of heavy brass or copper bolts in the rear center panel, which would furnish electrical connections to the drivers without introducing any leaks. If you use the bolt idea, be careful to keep all connections clean and tight, and to solder wherever possible.

THE BAFFLE ASSEMBLY. This is a 32 × 44 rectangle of ¾″ particle board. I chose a vertical orientation of the three drivers to minimze the potential interference effects in the crossover regions, which could cause a complicated, undesirable horizontal radiation pattern. Since the higher frequency driver is above the lower in each crossover zone, the undesired vertical radiation pattern peak is directed downwards (towards my carpeted floor) rather than toward the reflective ceiling. Drivers are as close together as practical to minimize vertical dispersion problems. The ribbon, in particular, is high on the baffle to keep its axis at a good compromise height for seated and standing listeners. Finally, the vertical centerline of the drivers is two inches to the left or right of the baffle's centerline, to break the symmetry of the baffle's near field (the speakers are mirror-

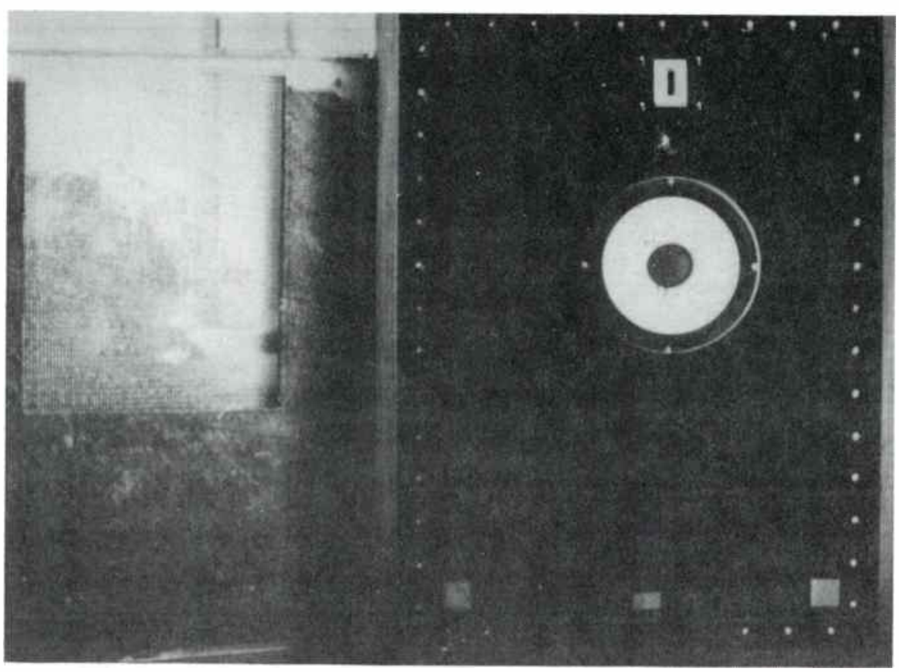

PHOTO 1: The completed system (with the grille removed) has impressively deep, clean bass, smooth midrange, transparent highs and excellent imaging at a wide range of listening locations.

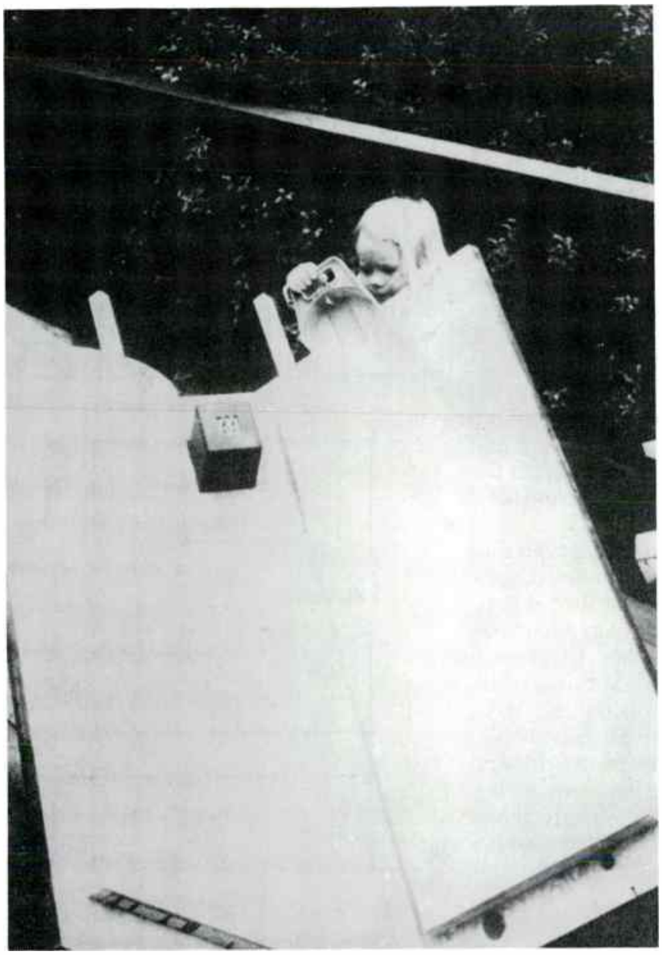

PHOTO 2: Building loudspeakers requires the skills of all family members. Sandbox authority Jennifer Lea Lampton filled the rear damper panels.

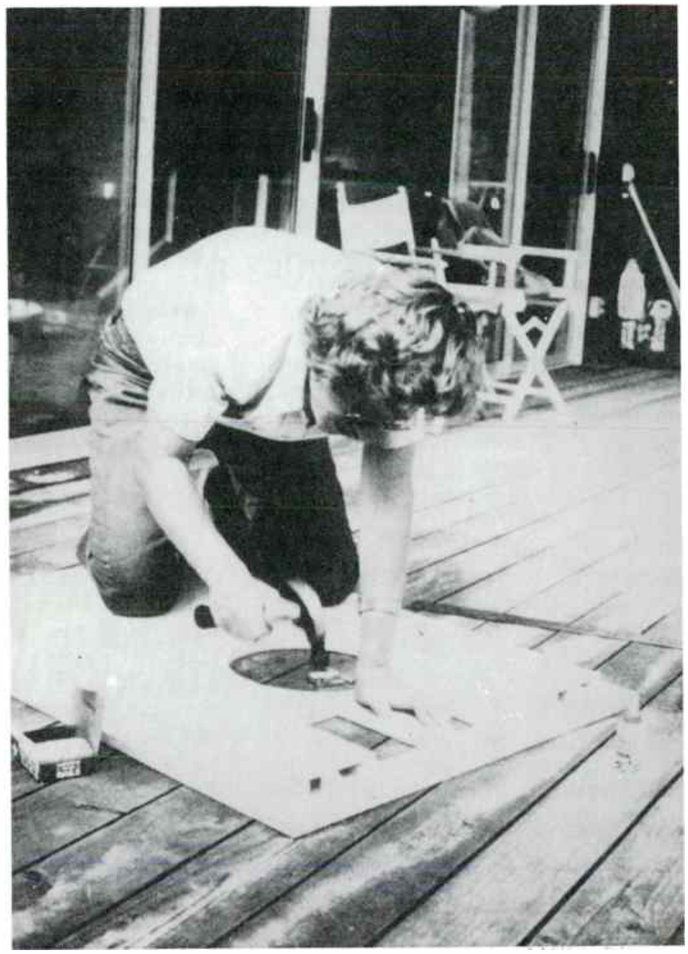

PHOTO 3: The author races against time to set the nails before the glue hardens.

imaged). A saber saw is best for cutting the holes for the drivers and duct. The cutout sizes are: Ribbon (3½" square), Jordan (2.8" square), JBL (11" circular), and duct (5×8, adjoining the tweeter and midrange).

Inside the enclosure, attached to the rear of the baffle is a partitioned box 4" deep made from ¾" particle board. (Note that the big particle board panels in this project are 44" high, and that sheets are sold in 48" widths. You'll get a lot of 4" strips. Don't throw them away.)

The duct portion of the partitioned box is open at the rear; the other part is the enclosure for the midrange and tweeter. Getting all the joints and seams of this mini-enclosure airtight is vitally important, so the drivers won't be forced into nonlinearity by the larger air pressures in the main enclosure. To make it airtight, apply a liberal dose of wood putty or silicone rubber sealant when assembling. The dimensions of the box are, like everything else in this project, noncritical. The inside dimensions of the duct holder in my design are 5×8, the same as the baffle cutout. For the mini-enclosure portion, the inside dimensions are 7×8.

Leave a zone about 1½" wide around the periphery of the baffle to fasten it to the main enclosure. I used the machine screw and T-nut arrangement described previously for this. The machine screws are 1½" long ¼-20 flat heads on three inch centers. Each goes about about ½" inward from the baffle's edge.

The remaining rear surface of the baffle defines a U-shaped zone 41" high by 29" wide where the sand will go. Cut 1×1 fir stock into eight pieces to fit this zone and cut a few short cleats to secure the sand panel's central portions. Make the rear of the sandbox from the 30×42 piece previously cut out of the mounting frame. Apply a liberal dose of glue to the 1×1's except for the top ones, and assemble the whole sandbox *(Photo 3)*. Press all the joints together firmly to eliminate sand leaks. Immediately nail the whole thing together as you did with the rear panels.

Wait at least 24 hours before shovelling your dried sand into the assembly through the two top openings *(Photo 2)*. Tilt it frequently to prevent voids while filling. When completely full, glue and nail the baffle's top cleats into place.

To complete the baffle, countersink the border holes to receive the mounting screws. Sandpaper all the rough edges. Sit the woofer into place face up, and mark and drill four 5/16" holes to accept the ¼" T-nuts. Clean the whole assembly with a household vacuum cleaner and brush nozzle. Spray the baffle with flat black enamel. When it dries, turn it face down and glue or staple a U-shaped piece of heavy carpet onto the completed sandbox. This will become part of the acoustic damping of the completed enclosure's interior.

The baffle is now ready to receive the drivers. Fasten the tweeter onto the front with four Phillips round head woodscrews. To mount the Jordan, apply a thin bead of silicone rubber around the mounting hole. Squash the Jordan's frame down onto the gooey rubber and let nature take its course. If you ever need to remove a Jordan, you can cut it out easily with a knife.

The woofer's frame comes pre-gasketed for rear mounting, but for both practical and acoustic reasons, I prefer front mounting. Apply a length of self-adhesive poly-foam weather stripping (½×1/8" cross-section) around the woofer's opening. Position the JBL on this and secure it with four 1½×¼" machine screws engaging the T-nuts on the back.

Before you close up the mini-enclosure, cut four small grooves for the midrange and tweeter leads, and line the inside of the little box with carpet scraps. Fill the remaining space with a loose wad of attic insulation. Bring the four leads out and secure the rear cover with four or more woodscrews. If your craftsmanship has been less than perfect, you'll need a bead of wood putty or rubber to obtain a decent seal against those huge air pressures soon to appear in the main enclosure.

At this point the finished baffle assembly is ready to install in the main enclosure. Feed the speaker leads through their access holes in the rear. Then, with a helper, hoist the baffle into position on the front of the erect enclosure. Install the 1½ x ¼-20 machine screws all around the front and be sure they are all started before you tighten any of them. Use an electric hand drill with screwdriver attachment to make the job easier.

THE GRILLE. Finishing touches like the grille can be left until the end. The grille is a heavy wood frame that literally hangs on the front of the baffle and wears a light grille cloth *(Photo 1)*. Use a 32 x 44 sheet of ¾" particle board for the frame. Cut an 18 x 24 hole in its upper middle to give the drivers and duct an unobstructed view of the outside world. Paint the outside flat black, and cover the inside surface with ¼" heavy felt (called "jute backing" by carpet shops).

Near each top corner of the baffle, install a stout woodscrew slanting at about a 30° angle. Leave at least a half inch exposed, since these will be the hooks to hang the grille. Drill inclined holes in the grille, large enough to clear the heads of the screws. To secure the bottom and keep the jute under compression, I made magnetic latches out of a handful of ½ x ½ x ⅛" ferrite block magnets. I glued a dozen or so to a 3 x 3 scrap of thin sheet steel and attached the assembly to each lower grille corner. Cut away some of the jute to provide room for the latches. A corresponding strike plate glued to the baffle with silicone rubber completes the latch. You can remove the grille from the speaker quickly and easily. Simply grip it at the bottom and yank it away from the magnets, pivot it up a foot or so, and lift it off the hooks.

Audiophiles are quick to point out that any grille cloth exacts a penalty in high-end clarity, since it is a distributed scatterer. However, if you have curious children in your home, your drivers will need some protection. Minimize the acoustic problems by using the most transparent, open weave cloth available, and keep the cloth close to the drivers. Avoid using bulk scattering foam grilles. With A/B testing, I can just barely detect the presence of my grille; otherwise it's unnoticeable.

THE CROSSOVER. Many audiophiles would prefer to triamp this speaker, and that would be ideal. You also could use a biamp setup for the woofer and upper drivers, with a high level network between the Jordan and the ribbon. A three way passive crossover is possible, and I'll describe a simple one below which, though not ideal, sounds good and will appeal to most builders.

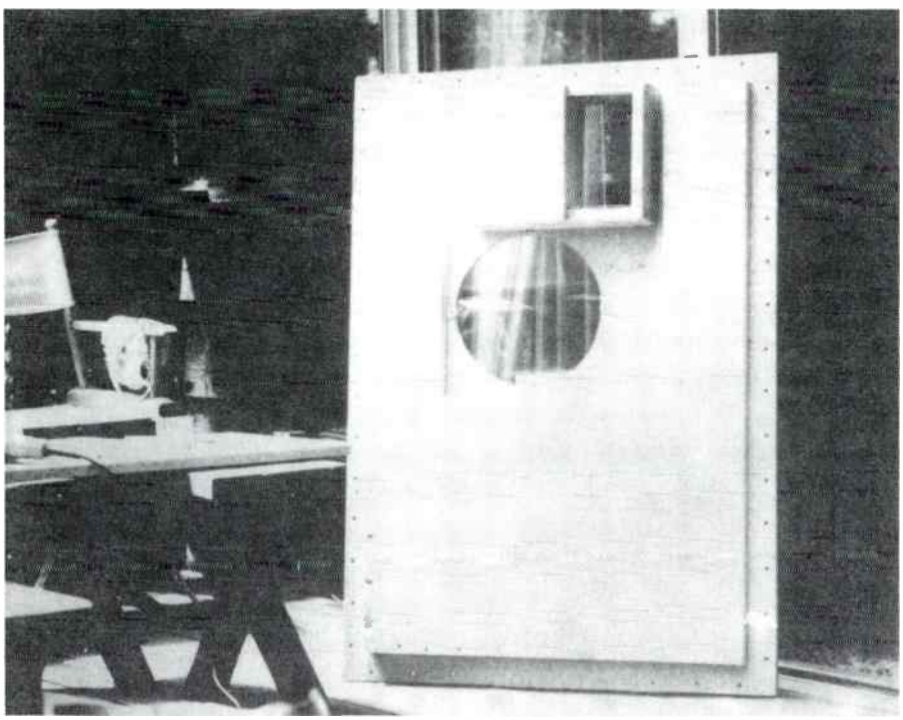

PHOTO 4: The mini-enclosure and duct holder attach to the rear of the baffle board, along with a U-shaped sand filled damping panel.

The limitations of the drivers govern the choice of crossover frequencies. For my system I chose 500Hz and 4kHz, which are compromises designed to trade off performance characteristics in the best possible way. For example if the 500Hz point were lower, the potential for colorations caused by the JBL's midrange directivity would decrease. However the Jordan would operate with increased excursion, resulting in greater distortion. A similar problem occurs at the 4kHz point.

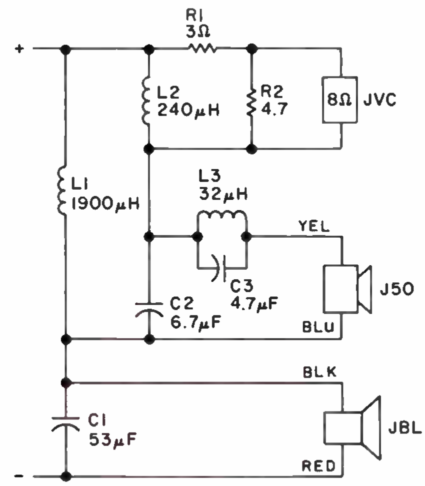

FIGURE 6: Although active crossovers are preferable, this simple single-pole three-way crossover works well. L1 & C1 set the 500Hz crossover point, and L2 and C2 set a 4kHz upper crossover. L3/C3 is a 13kHz trap for the J50. This is a six ohm system.

A second decision is the choice of crossover slope. Horn loaded systems require a steep slope (18, 24, or 30dB/octave) because they tolerate very little drive below the horn cutoff frequency. Steep slopes benefit direct radiator systems too. They not only minimize excursion below the crossover point, but also improve vertical dispersion by narrowing the region where the two drivers radiate equal power and interfere with each other. A much milder slope of 6dB per octave offers the advantages of a much smoother total amplitude response across the crossover band, and a nearly perfect phase shift characteristic. It also saves parts, which is a significant cost reduction factor in a high level network. For the time being, I've adopted the 6dB slope, with the understanding that it trades off some power handling capacity in favor of transient accuracy.

In the schematic *(Fig. 6)*, L1 and C1 form the crossover between the woofer and midrange at 500Hz. L1 should be about 1900μH. To make this coil, I put 140 turns of 18 gauge magnet wire onto a 3" diameter ¾" long plastic coil form (the plastic spool gift wrap ribbon comes on). C1 should be about 53μF. To get such a value, I bought a big sack of tubular plastic film capacitors (mostly mylars, 2μF 200V) and wired them in parallel. This is ugly but effective. One nice feature of gentle slopes is the resulting networks are tolerant of component value errors. So, L1 and C1 need not be super-precise.

L2 and C2 form the upper crossover at 4000Hz. In this 6Ω system C2 needs to be 6.7μF, and L2 240μH. For C2 I paralleled a mylar and 4.7μF polypropylene. For L2 I used 49 turns on another gift wrap ribbon spool.

To clear up the 13kHz problem in my Jordans, I use a trap (L3 and C3 in the schematic). L3 is 32μH and C3 is 4.7μF. On the usual coil form, I needed 17 turns of #22 to get this value.

Resistors R1 and R2 compensate for the fact that the JVC ribbon is roughly 6dB hotter than the Jordan. Instead of fixed resistors, you could use an adjustable L-pad attenuator, but I haven't found it necessary.

DUCT SETUP. In any bass reflex enclosure, the duct's dimensions control the Helmholtz frequency of the enclosure. A good formula for a rectangular duct in an enclosure is:

$$f_H = \frac{54\sqrt{HW/V}}{L + \frac{1.5\,HW}{H+W}}$$

where H, W, and L are the duct's height, width, and length in meters, and V is the enclosure volume in cubic meters. The same formula nearly works if H, W, and L are in inches and V is in cubic feet.

If you don't install anything in the duct holder, the duct's dimensions are those of the holder alone, namely 8, 5, and 4.75". At V = 10.5 cubic feet, this comes out at 34Hz. With a variable frequency oscillator and voltmeter connected to the woofer terminals, you can verify this by measuring the frequency of the big electrical impedance dip due to the Helmholtz effect (mine measure about 33Hz). With this high a duct tuning you'll get some spectacular bass output in the 30 to 40Hz band, but not a particularly smooth, accurate, or extended bottom end.

The duct holder is designed for easy experimental installation of blocks of wood or chokes, to bring the Helmholtz frequency down as far as needed. For the recommended bounded ripple alignment you will want to get down to around 21Hz. You can do this by making H, W, and L 4, 4, and 6". Simply make a rectangular duct box from a pair of 6" long 2×4's and a pair of 8×6 slabs of ½" particle board *(Fig. 7)*. Wrap this box with a few turns of foam weather stripping and force it into the duct holder. With this duct, I measured the impedance dip at 21Hz.

You can also experiment with a sealed enclosure by nailing 5" lids over both ends of the rectangular duct box. With a removable plug, you can experiment at leisure. I recommend the 21Hz arrangement, but you can experiment and decide.

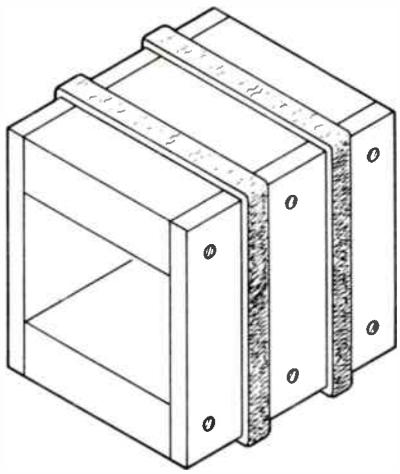

FIGURE 7: The duct holder will accept ducts of various sizes if you wish to experiment. Wrap with strips of weather stripping for a friction fit.

LISTENING EXPERIENCES. The first thing I did after getting these corner systems up and running was to rush out and buy a new phono cartridge. With the high definition of these speakers' upper spectrum, you can hear all kinds of things going on in your system, as well as on your records. Stereo images are about as good as any I've ever heard. Listen to Wayne Phillips' incredible percussion solo on side one of Charlie Byrd on Crystal Clear. Or listen to the exquisite *Verite du Clavecin* recording by Anne Chapelin on Sarastro. Why am I sitting here typing when I could be re-examining my whole record collection?

ACKNOWLEDGEMENT:

Many thanks to Jan and Joyce de Vries, who put up with countless evenings of comparative speaker testing in their home.

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1. M. Lampton, "Program WOOF: A Numerical Evaluator of Loudspeaker Systems," IEEE *Transactions on Audio* AU-20 #5, p. 364, 1972.

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EVALUATING THE ZOBEL

BY WILFRED HARMS

Although most home speaker builders use the popular Butterworth crossover designs of one order or another, recent studies show that the impedance variations of a driver can affect the results adversely. *Figure 1* shows the impedance variations of a typical woofer. Disregarding the complex changes at its fundamental resonance, the rising impedance above 300Hz presents a reactive load which must be nullified. An easy way to do this is to connect a resistor and capacitor in series *directly* across the driver, as in *Fig. 2*. This circuit is called a **zobel**.

The values of the components of the zobel vary from driver to driver and may be determined through trial and error. However, you need a signal generator, an audio frequency ammeter, and a box of parts. To calculate the values, read from the impedance curve the frequency (f_d) at which the impedance is twice the DC resistance (r) of the driver (this is *not* the advertised nominal impedance). Then the capacitance (C_z) = $.22/f_d r$ in μF, and the resistance (R_z) = 1.25r. Use the nearest standard parts value above these figures for practical circuits. When calculating crossover networks, consider the zobel's nominal resistance to be 1.15R.

In the example shown, r = 7Ω, and f_d = 2100Hz, so C_z = 15μF and R_z = 8.8Ω, say 10Ω, with nominal resistance 8.1Ω.

Readers interested in the technical considerations leading to this simple formula will note that the impedance variations of the driver correspond to those of a non-uniform inductor and resistor. The reactive components of the current through the driver and through the zobel are in opposition (A and B in *Fig.3*) and should be as close in value as practical. If you know the phase angle variations, you can optimize the values for C_z and R_z. With the impedance curve alone, you can get a good approximation.

Zobels usually are not useful with tweeters since their greatest problem is at the resonance point. They are not always appropriate with woofers, and simply adding a zobel to a well-designed crossover would degrade it. But when the woofer has significant impedance fluctuations to overcome, and when incorporated into the crossover's characteristics, the zobel can make your speaker sound its best. □

ZOBELS FOR POPULAR WOOFERS

	C_z	R_z
KEF B200	12µF	10Ω
KEF B110	10µF	10Ω
AUDAX HD20B25H4	25µF	8.2Ω
AUDAX HD17B25	10µF	8.20Ω

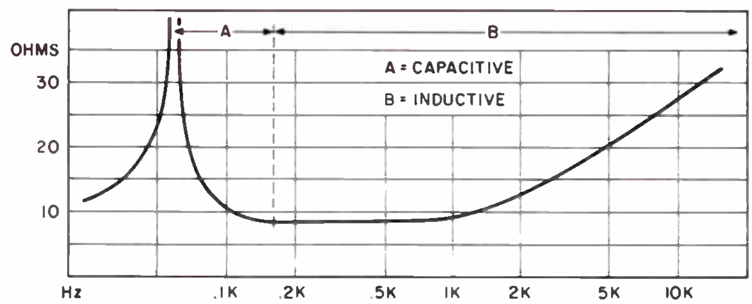

FIGURE 1: A typical woofer has this impedance curve. Unless you compensate for these impedance variations, the frequency response will vary also.

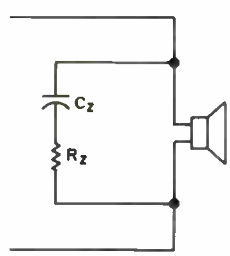

FIGURE 2: The Zobel is a resistor and capacitor in series, connected directly across the driver. It flattens out the frequency response by providing inverse characteristics.

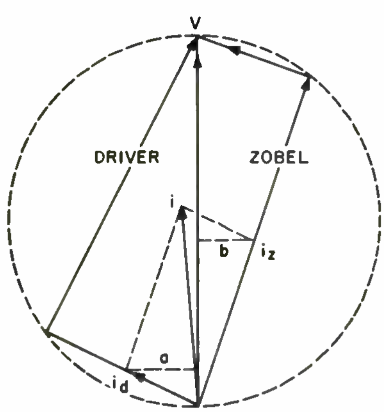

FIGURE 3: This phasor diagram shows the reactive component of currents and the relationship of the driver and zobel.

A HORN LOADED HEIL: Part II

BY KENNETH RAUEN
PHOTOS BY MARK SCHLORFF

The horn in the preceding article was a second generation model produced from a wooden original. I designed this from a set of equations (some are in the first article) so that the result would be a conical-exponential, 90° sectoral horn. Sectoral horns have straight sides forming an angle from the throat. Since I made the low frequency cutoff 250Hz, the mouth area was 240in², so I could make the dimensions 10 × 24″, very convenient for the AMT's shape. The flare constant works out to 2.78ft⁻¹ and you simply plug it into the exponential equation ($A_2 = A_1e^{kx}$) to determine the distance between any two areas of the horn.

The horn's flare is as follows: At 24″ of arc in a 90° sector, the radius is 15.3″. For a given arc length (ΔS) and a given angle in radians (ΔΘ), R = ΔS/ΔΘ. Since $A_2/A_1 = e^{kx} = 240/A = e^{(0.232\ in^{-1})\ x}$, k = 2.78/ft = 0.232 in^{-1}, A = $240/e^{0.232x}$, at x inches from the mouth.

With the last form of the equation, for any value of x, you can find the distance from the mouth and its corresponding cross sectional area (A). *Table I* shows the calculations used to derive the numbers in *Table 2* which describe the horn. These equations simulate a sound wave in a simplified way by using a semicylindrical wavefront approximation. The minimum value possible for h is the inward limit of the exponential flare. The approximation becomes absurd beyond this point because it becomes grossly inaccurate. The conical flare takes over just before this point, maintaining a slight angle to prevent standing waves. For our Heil horn, the transition begins at about 5.8″ of radius. The conical throat slopes to a height of 2.50″ at R = 0. The rectangular throat slot cuts off the end of the horn, as seen in the photos. If you plot the flare for the top and bottom surfaces as Y flare co-ordinate (h″) versus radius (R) on the x axis, this becomes the construction template.

Using these equations, you can design any variation of the sectoral, conical-exponential horn. If you want a 120° lower profile horn, start with different mouth area dimensions and set up your own tables.

WOODEN HORNS. I made the first pair of horns from plywood, styrofoam, sawdust, and yellow glue. Each horn has four component panels, two curved, and two flat. The second pair were of fiberglass, and I used the original wooden models as molds in this process.

For the curved panels cut a 90° pie slice shaped base (15.3″ radius) of ¾″ thick plywood. Using the template, cut

TABLE I

Variable	Symbol	Formula
Cross Sectional Area	A	$A = \frac{240}{e^{0.232x}}$
Radius	r	r = 15.3 in - x
Arc Length	ΔS	ΔS = 1.57r
Height	h	$h = \frac{A}{\Delta S}$
½ Height at Center Line	h′	$h' = \frac{h}{2}$
Y Flare	h″	h″ = 5 in -h′

TABLE 2

X	A	r	ΔS	h	h′	h″
0	240	15.3	24.0	10.0	5.00	0
1	190	14.3	22.4	8.48	4.25	0.75
2	151	13.3	20.9	7.22	3.61	1.39
3	120	12.3	19.3	6.22	3.11	1.89
4	94.9	11.3	17.7	5.36	2.68	2.32
5	75.2	10.3	16.2	4.64	2.32	2.68
6	60.0	9.3	14.6	4.11	2.06	2.94
7	47.3	8.3	13.0	3.64	1.82	3.18
8	37.5	7.3	11.5	3.26	1.63	3.37
9	29.7	6.3	9.89	3.00	1.50	3.50
10	23.6	5.3	8.32	2.84	1.42	3.58
10.5	21.0	4.8	7.54	2.79	1.40	3.60
11	18.7	4.3	6.75	2.77	1.38	3.62
11.5	16.6	3.8	5.97	2.78		
12	14.8	3.3	5.18	2.86		
13	11.8	2.3	3.61	3.27		
14	9.32	1.3	2.04	4.57		
15	7.39	0.3	0.47	15.7		

About the author

Kenneth M. Rauen received his BS in Chemistry from the University of Detroit in 1978. He worked as a laboratory test engineer at Ford Motor's Milan Plastics Plant. Currently he is the Injection Molding Specialist in the Video Disk Research Group for Producers Color Service in Detroit. He is a member of the AES and the Southeastern Michigan Woofer and Tweeter Marching Society.

17 ribs of 3/8" plywood, and glue them to the base. Adjust the length of each rib to fit. The result will be a wedge-shaped box, flat on the bottom, with 17 curved ribs forming compartments between them *(Fig. 1A)*. Fill the bottoms of these compartments with lightweight filler material such as spray foam insulation, up to about ½" from the tops of the ribs. Fill the remainder of the space, slightly over the tops, with a dry mixture of yellow glue and sawdust (as dry as possible without looking porous). Originally I used styrofoam to fill the bottoms of the compartments, but it settled after about two years and rattled. Lightweight fillers such as spray foam insulation are best but heavyweight fillers are undesirable because these horns will weigh about 30lbs as is.

After filling all the spaces and openings allow each panel a full month to cure. Sand and plane off the excess homemade "plastic wood" until the wooden ribs show through. This is now one of the two curved sections needed for one horn.

Glue and screw a pair of the curved surfaces which form the top and bottom of the horn to two plywood panels (11½ x 14½ x ¾") so the flat boards come all the way forward, creating an opening at the back of the horn. Plane off the back side of the horn to form a flat surface for mounting the driver. The opening should be 2½ x 1¼", measured from the inside edge of the flat side panels. Other methods of building wooden horns once a flare template is available include that shown in *Fig. 1B*. Concentric arcs of plywood or pressboard one above the other make a stepped contour which you can smooth out with the plastic wood filler material.

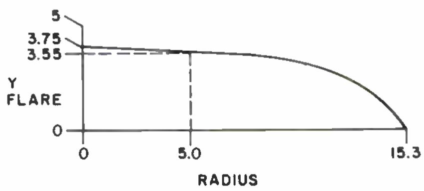

FIGURE 1: Draw the construction template for a conical-exponential horn according to the values calculated. Use this template to make 17 ribs.

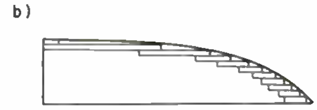

FIGURE 1B: An alternate construction method is to use concentric rings of decreasing radii to form a stepped approximation of the flare. Fill the steps with the "plastic wood" to smooth out the contour.

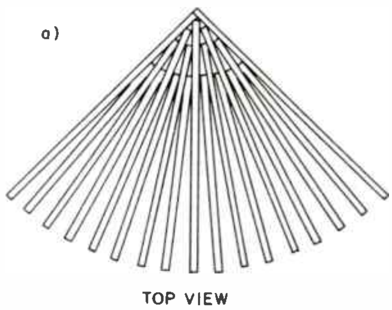

FIGURE 1A: Glue the ribs to a flat plywood base, adjusting their lengths as necessary. Fill the compartments with lightweight filler material, and top off with a layer of yellow glue and sawdust mixture. Plane and sand away the excess "plastic wood," leaving a smooth surface which follows the curvature of the ribs.

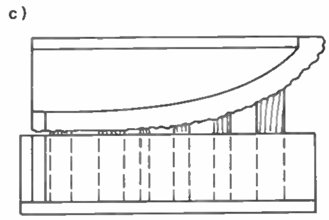

FIGURE 1C: To make fiberglass panels, first make a plaster cast of the contour. The wooden dowels support the wire mesh holding the plaster against the horn contour previously made.

FIBERGLASS HORNS. I later chose to replace my wooden horns with fiberglass reinforced polyester (FRP) models. Only the curved surfaces actually are FRP, the sides are still of wood. To make the FRP panels, you need a mold, and you can use the wooden horns as the forms for a plaster casting. I cut one of them squarely down the middle, horizontally, to yield a curved surface and vertical walls. Attach it to a plywood panel which overhangs the lip by several inches. You will need a frame, roughly an inverse of the curved surface, to support the plaster cast. Glue a 4 x 17 x ¾" piece of plywood to a piece 4 x 16¼ x ¾", forming a 4" high corner on a ¾" thick pie slice (17" radius, 90°) of plywood. Glue a 0.8 x 0.8 x 1¼ x 4" triangular prism in the corner of this structure, and about 10 to 15 lengths of 1½" diameter wooden dowel to the inside. Space out the dowels and adjust their lengths to follow the curve so that when this assembly is turned over onto the horn surface, they are ¼" to ½" from the curved surface. Bevel the ends to make them parallel to the curved surface. Now turn it dowel side up and staple a formed sheet of steel wire mesh to the dowels. Quarter inch mesh is ideal, and it should clear the horn surface when placed over it.

Smooth the horn surface and coat it with wax so the plaster can release from it. Blue Coral paste wax works well, but don't use liquid paste waxes. My mold lacked the drop-away sides at first, and I had such great difficulty getting the first shot out that the mold cracked. By retrofitting the wooden sides, I was able to nurse it through the three more shots I needed before it gave up the ghost. A wooden mold made from a negative of *Fig. 1B* will last considerably longer. However, thermoset polyesters have a strong affinity for wood, so you must apply the release wax carefully. Use too much rather than too little and be sure every square millimeter is covered.

Place the mold frame on the prototype. Mix enough plaster to use conveniently at one time, plop it onto the screen, working it in. Use as many batches as you need to cover the whole surface to about a ½" thickness above the screen. Work quickly, since wet plaster adheres poorly to dry plaster. Your mold will look like *Fig. 1C* viewed from one side. Allow several days for it to dry fully and separate the two pieces carefully. Assemble a 17x5¾x¾" and a 16¼x5¾x¾" plywood board with hinges to extend the lower sides up to the plaster so they can drop away to the side when needed later. Another triangular prism, hand placed, completes the mold.

Scrape any rough spots smooth with a spatula. Any undercuts, especially in the vertical edge, will create die-lock and may destroy the plaster cast. Wax the mold just as you did the prototype, and wax the two hinged boards and the corner insert as well. Tie a rope around the mold to hold the sides up.

Cut five pieces of fine woven fiberglass cloth with a scissors in a 90° quadrant with a 16¾" radius so that the 90° corner follows the weave. Place one piece into the mold corner and work the cloth to the contour (it conforms nicely).

Pour 2ml *(ca* 30 drops) of MEKPO (methylethyl-keto-peroxide) catalyst into 150ml of liquid polyester resin (about ⅔ cup). This is a 1% mixture by weight. Beware that **both components are highly flammable**, and *do not smoke* while working with this material. Also *be sure the working area is well-ventilated.* Mix thoroughly with a tongue depressor in a small plastic margarine tub for about two minutes. Spread the mixture onto the glass cloth, wetting it completely, and working all the bubbles out. Do not let a lake form at the bottom of the mold. Work fast, as this will gel in about 15 minutes at 70°F. (I found the 1% mixture too fast and used ¾%, which took about

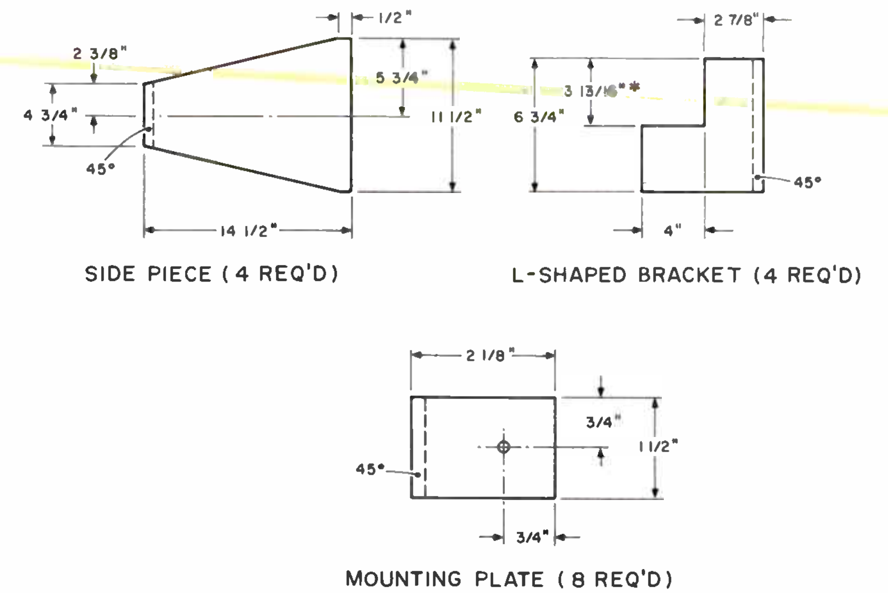

FIGURE 2: Cut 16 pieces of particle board with these dimensions to make two complete horns.

20 minutes to gel). At this point, pour or scoop out the remaining resin in the tub into a jar for disposal. The polymerization process is exothermic so expect the resin to get hot.

Wait at least 40 minutes from the start of the first coat to place the second sheet of glass. Proceed as above, with another margarine tub. These are reusable after the resin has hardened; just flex the tub to chip it out. Dispose of the tongue depressors (don't try to use brushes—you can't clean them fast enough). Allow at least five hours for the resin to cure fully after the last coat is applied, before removing the panel. Untie the rope and drop the sides. With a spatula or compressed air, gently ease the FRP panel off the mold using a lifting and pulling motion from the corner. Rewax the mold carefully and you are ready for the next shot.

Ten yards of fiberglass cloth at $30, one gallon of aircure polyester resin at $10, and 100ml of MEKPO catalyst at $1 went into the four panels. These supplies can be purchased at any boat shop.

PANEL ASSEMBLY. For two complete horns, you will need sixteen particle board pieces ¾" thick, cut according to the patterns in *Fig. 2*, eight 10-32 T-nuts, eight 1½" screws, and 17" of rubber gasket material. Begin by bevelling the four sides and four L-shaped pieces, 45°. The latter are not symmetrical, so bevel two on one side, two on the other. If you use a thicker Heil bottom plate, adjust the starred dimensions (for a ¼" plate, add ⅛") and move the T-nut locations accordingly. Bevel the eight mounting plates just as you did the sides, and hammer the T-nuts onto the bevelled sides.

Glue the top and bottom to the sides. Put one side piece bevelled side down on your workbench. Make two pencil marks along the 11½" edge ¾" from the ends and two pencil marks 1⅛" from the ends on the 4¾" edge. Apply five minute epoxy to the FRP edges, align them to the pencil marks and prop each side with a large cardboard box (or they will fall away). Make sure the ten inch gap is maintained at the panel ends (which are up in the air). After drying for one hour, attach the other side in similar fashion—no support needed this time—*(Photo 1)*.

PHOTO 1: The Heil driver mounts onto the horn with these brackets already glued into place. Note the rubber window gasket around the throat opening.

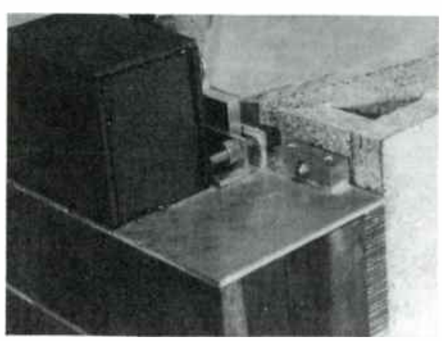

PHOTO 2: Attach the completed Heil driver to the horn as shown in this closeup.

The Heil driver must be almost completely assembled before the mounting platform can be finished. Turn the Heil's focus plate end up on the workbench. Cover the two plates with two pieces of paper just big enough to cover the front of the Heil, leaving the opening uncovered. Put the horn on top of this and align the throat opening with the plate opening (the horn will balance without support). Put the screws through the Heil's aluminum blocks, through the unbevelled side of the mounting blocks, and tighten. The long axes of the blocks should be parallel. Apply epoxy to the bevelled edges and one long side of the aluminum blocks and butt them up against the Heil and horn *(Photo 2)*.

Apply epoxy to the outward edges of the T-nut blocks and the bevelled edges of a mirror-image pair of Heil supports. Hold each bevelled side upward and inward, butting against the horn, T-nut blocks, and the bottom of the Heil. Do not move anything. Let this cure overnight. Turn the horn right side up, unscrew the Heil and remove the paper.

Coat all the wood surfaces with polyester resin, keeping the screw holes open. One pint of resin is adequate for one coat, which is all I used. Allow at least three hours before handling. You can apply it with a large paint brush which you should clean with acetone before the resin sets; this coat applies fast enough for cleaning.

Cut and fasten strips of rubber gasket to fit securely around the throat opening. I used fiberglass tape backed with EPDM rubber gasket (window gasket). The horn assembly is now complete.

HEIL MAKING. The chosen structure (front radiating only) seemed easier to build than any of the bipolar designs, including ESS's. My results indicate a problem because of the restriction of the rear wave, and you may wish to experiment with ways to solve this. I wanted the strongest magnetic field reasonable. At $50 per pound, Alnico was too expensive, so ceramic was my choice. Large magnets of this size are not available commercially, so I ordered custom magnets. You may use several smaller magnets joined together also.

Some of the AMT's parts were made for me in a machine shop. If you can do any of this yourself, or have a friend who works in a machine shop, you will save yourself much expense. The top and bottom plates can be made of any rigid, nonmagnetic material, since they are primarily to hold everything together. (I made 0.125" FRP panels, but you could use masonite. Aluminum is good because you can bolt the mounting blocks onto it). The patterns are shown in *Figs. 3* and *4*.

Start by gluing the focus plates together with epoxy. Each of four sets of front plates contains 14 "A" plates alternating with 13 "B" plates. Each of the two sets of rear focus plates contains 14 "C" plates and 13 "D" plates. Make sure you maintain right angles in the structure, and allow full curing time.

Epoxy the four banks of magnets (roughly 14 lbs) to the front focus plates, all with the same polarity. When cured, epoxy one side to a bottom plate. Cure again, and epoxy the other side, using strong nonmagnetic bracing, because the two banks repel each other strongly. Make sure it is weighted on top to keep the bottom from bowing. When these magnet assemblies are fully set, remove the bracing, and put the steel back plates in place. Forget the epoxy: you will not need it here. Protect the magnets by placing a piece of plywood over the ends so they don't crack. *Watch your fingers:* the steel is attracted with considerable force by the magnets. Slide the wood out when done. Apply epoxy to the areas on the back plate and bottom plate where the rear focus plates will go. Slide the plate assembly down the back plate and center it. The magnetic fields in the subassembly are stable at this point. Allow it to cure as is.

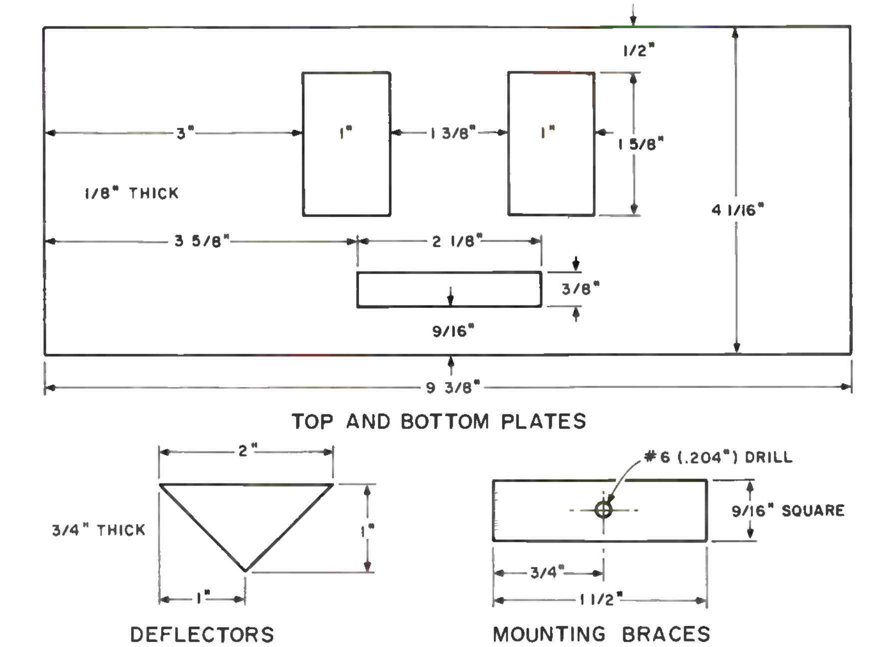

FIGURE 3: Make the Heil driver's top and bottom plates of FRP, masonite, or aluminum.

Glue the top in place. Glue the two deflectors onto the back plate between the rear focus plates and the magnets, and once again, let the glue set *(Photo 3)*.

Cut eight 4" aluminum angle braces. Four of them must have one edge trimmed to $^9/_{16}$". Cut square holes near the ends of the longer edge for the carriage bolts, and epoxy them to the to the top and bottom panels, centered in front of the diaphragm opening. Cut holes through the other four strips to accept

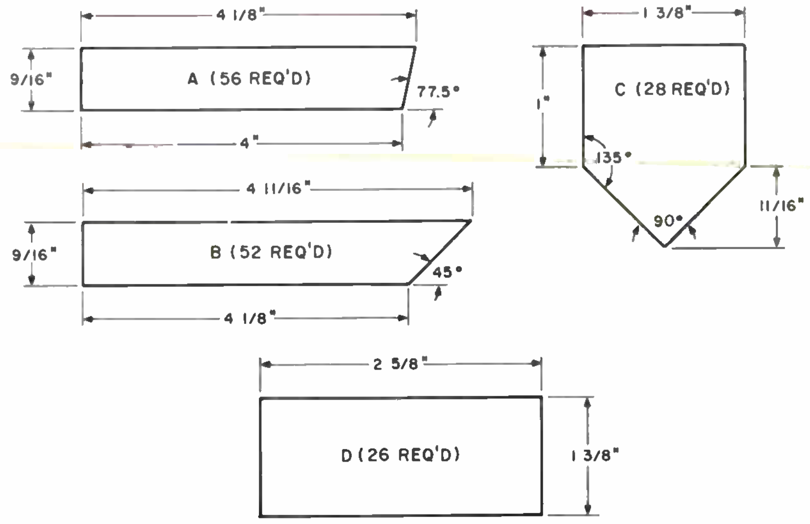

FIGURE 4: Have a machine shop cut the magnets' focus plates from 13 gauge steel. Stacks of alternating A and B plates form the two pairs of front focus plates for two Heils. The two sets of rear focus plates use alternating C and D sections.

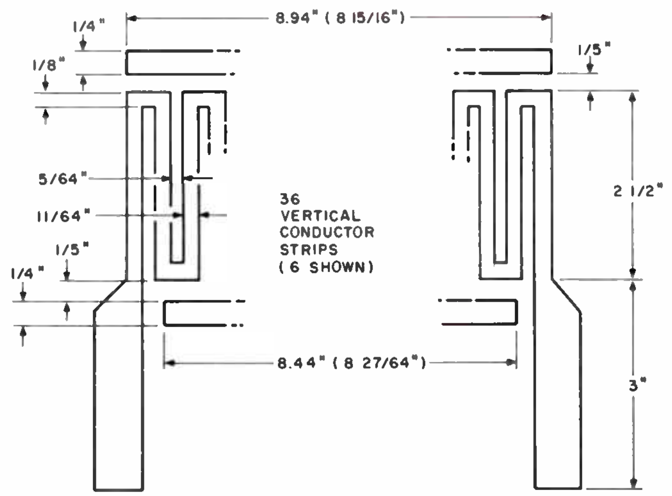

FIGURE 5: Select either a 4:1 or 2:1 conductor type. The 4:1 has these dimensions.

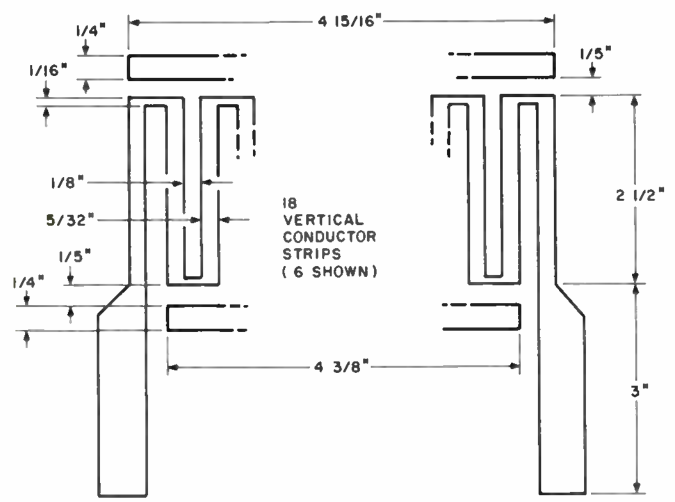

FIGURE 6: Use this pattern for the 2:1 conductor.

the bolt threads, but do not glue them down, since they will hold the diaphragm mounts in place.

Make two $^{1}/_{16}''$ leather gaskets with a $2^{1}/_{2}x1^{3}/_{8}''$ centered hole. After coating the backs lightly with epoxy, lower them into the magnet gaps and press onto the front focus plates and the aluminum angle braces with a knife or spatula. Assemble the pressboard parts with epoxy, as seen in the photographs. Stuff these densely with long hair wool before the final gluing. Now the Heils are ready for attaching to the half-done horns.

FABRICATE DIAPHRAGMS. Start by wrapping a sheet of aluminum foil over the wood cutting block, smoothing out all wrinkles. With a pin and straight edge, dot the foil at all corners of the pattern selected *(Figs. 5 and 6)*. Score the foil lightly with the pin and straight edge between the points. When all your lines are

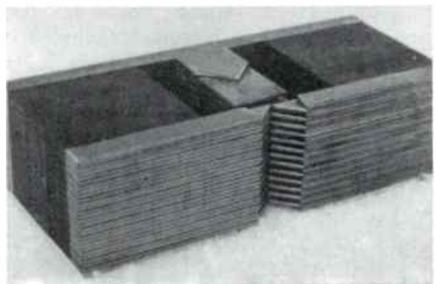

PHOTO 3: After gluing the magnets and focus plates together the completed assembly should look like this.

in the right places, cut the vertical strips between the intended conductor paths with a razor blade and remove. Use the honing stone whenever the blade feels dull; it helps immensely. Cut the conductor leads free (with the conductor still attached at the top and bottom edges). Apply the thinned rubber cement as uniformly as you can to the conductor, but keep it off the wide leads and the scrap foil. Now trim the rest of the foil away, saving the scraps for the stiffener strips you will need later. Position the foil in the middle of the board and tape a sheet of polyethylene, at least one inch wider on all sides than the cement coated foil area, to a large diameter PVC pipe section (the circumference must be greater than the height of the film used).

Make sure all wrinkles are out of the film, and, using the pipe like a rolling pin, slowly roll the film onto the foil. Run it back and forth to squeeze the air bubbles out. Carefully peel the film from the tube and place it foil side up on the board. From the scrap foil, cut eight stiffener strips, and rubber cement them together in sets of four for Neil Davis' technique, or sets of two for mine. Coat one side of each with cement.

For Davis' style, locate two sets of four with the rubber side down on the film (the 1/5" spacing must be uniform so even tension can be delivered later). Coat the entire surface of aluminum and polyethylene with rubber cement, except for the wide conductor leads. Roll another sheet of plastic on and squeeze out the bubbles.

For my construction style, press two sets of two stiffeners on the film with the roller. Turn it over and do the other side. Now turn the film foil side up and coat the entire conductor with vinyl repair compound (for electrical insulation). Trim the edges at the stiffeners and the end conductors to a rectangle with the bare leads sticking out *(Photo 4)*. This technique gives no performance advantage and eventually the foil lifts off the film. Use Neil's technique with 0.5 or 0.75 mil film with my stiffener method over the two film layers.

Now you can pleat the diaphragm. Slide the coat hanger wire under the film at one end and pick it up with both middle fingers. Using the thumbs and forefingers, roll the film over the wire. Turn the film over for each successive pleat. The film is now loosely folded.

The end conductors are too weak to use as is, so strip four inches of 18 gauge zip cord for each lead. Twist the strands together and tin the last inch. Roll the wide foil ends over each wire, slip heat-shrink tubing over each and shrink them with a match. Be careful not to heat the diaphragm film—it will shrink also. Use wire harness tie straps to snug the leads a little tighter. At this point, use

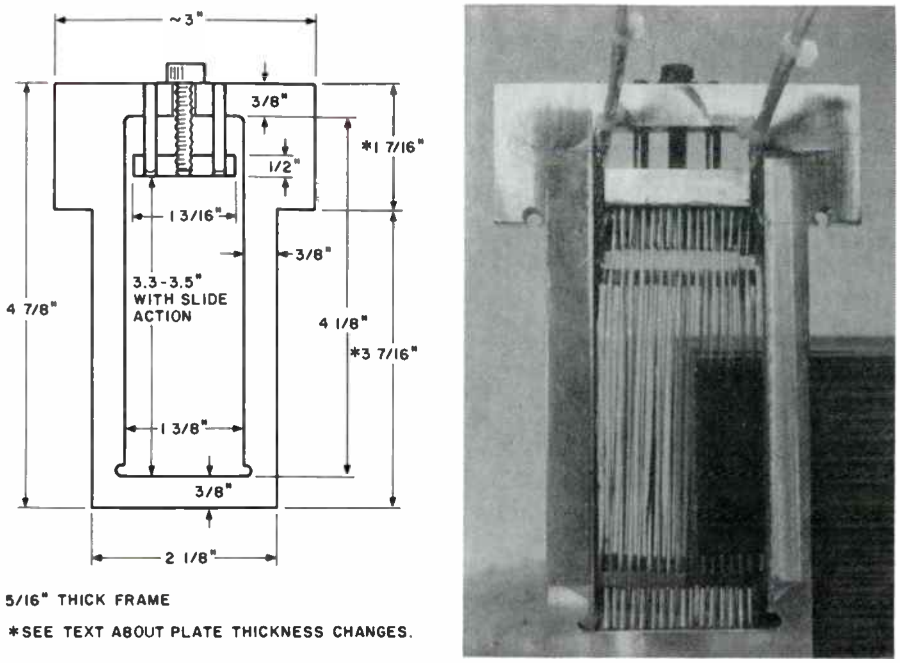

FIGURE 7: The diaphragm mounting frame holds the pleated driver. Tension can be adjusted with the nut at the top.

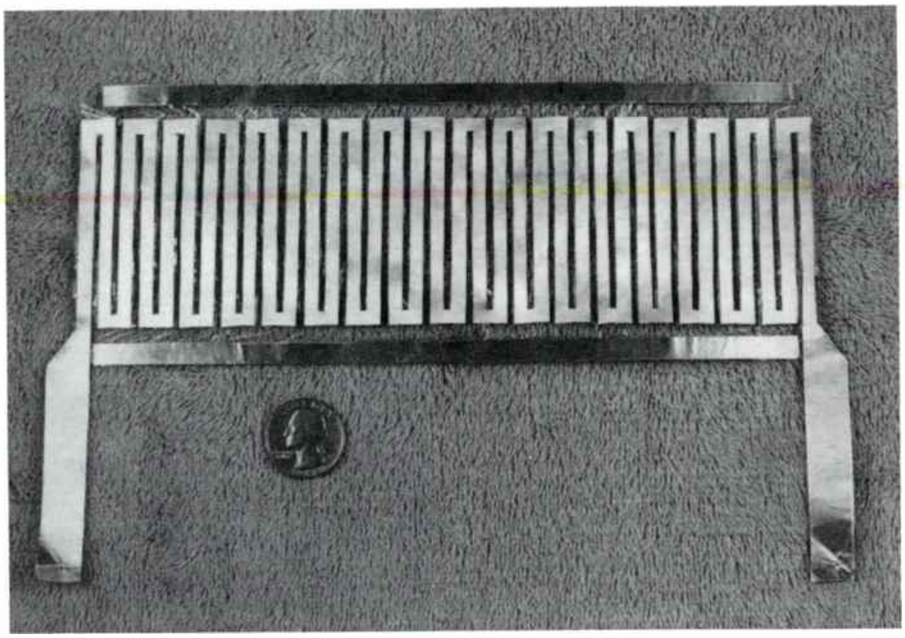

PHOTO 4: Glue the conductor to the plastic film, leaving the wide leads free. Note the position of the stiffener strips.

PARTS LIST

Machine Shop Made Parts
4 Aluminum diaphragm frames
4 Aluminum tension bars for the frames
2 Steel back plates, $9^3/_8 \times 2^1/_2 \times {}^1/_2''$
8 Aluminum mounting braces for the Heil-to-Horn assembly

Cost: about $150

Additional Machine Shop Parts
56 13 Gauge steel "A" focus plates
52 "B" focus plates
28 "C" focus plates
26 "D" focus plates

Cost: about $200

12 custom made ceramic magnets, $3 \times 2^1/_2 \times 1''$

Cost: about $200

Source: Storch Products Co., Inc., 11827 Globe Rd., Livonia, MI 48150

4 Top and bottom plates
Masonite baffle extensions
4 $3^5/_8 \times 2^1/_4 \times {}^1/_8''$ front and back
8 $2 \times 2^3/_4 \times {}^1/_8''$ side
8 $3^5/_8 \times 2^3/_4 \times {}^1/_8''$ top
Long fiber wool
Five minute epoxy
8 $1 \times {}^1/_8''$ diameter steel dowels
4 1" 10-24 Allen head screws
8 ¼" carriage bolts and hex nuts
32" of aluminum angle bracing
2 $4^1/_4 \times 2^1/_8 \times {}^1/_{16}''$ leather gaskets
1 roll of 1 mil aluminum foil
1 roll of polyethylene sheet (0.5-1.0mil)
Rubber cement, thinned 1:1 with acetone
Vinyl repair compound, thinned as above
Heat shrink tubing
15" zip cord, 18 gauge
Wire harness wraps
4 wooden deflectors $2^1/_2 \times {}^1/_4 \times {}^3/_4''$
Wood cutting board $12 \times 8''$
5" straightened coat hanger wire
PVC pipe, large diameter, at least 10" long
Fine tip paint brush
Large paint brush
Acetone
English rule/straight edge
Razor blades
Honing stone
Weight ($2 \times 2''$)
Tweezers/needle nose pliers
Tongue depressors

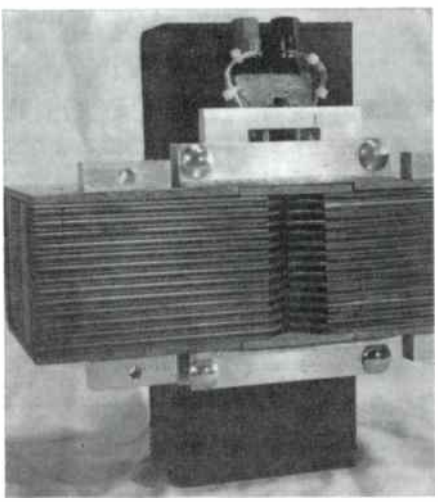

PHOTO 5: The finished Heil driver looks like this before attaching to the horn.

needlenose pliers to put more bend in the pleats. Do not crease any of them. The diaphragm will still not take its final shape, especially the double film type.

The aluminum mount *(Fig. 7)* which holds the diaphragm provides a controlled, rigid, easily removable frame. (I think Neil Davis' attachment method is one reason for the rattling problem). Assemble the mounts. The dowels in the mainframe are press fits, and slip fits in the tension block. This is the tricky part: try to squeeze the diaphragm and place it in the mount on the wood board with the leads just barely pushed between the tension block and the frame. Patience is a virtue here. Take the $2 \times 2''$ weight and slowly push the diaphragm into the mount, arranging the pleats as you go. Now relax: the rest is easy.

Push the diaphragm against the wood board. This design spaces the diaphragm exactly between the focus plates, so it will not be damaged when lowered into the magnet gap, nor will it buzz from touching a nearby surface. Lower the tension block so the stiffeners touch the frame at both ends. Straighten the leads so nothing is wrinkled and space the pleats equally. Apply just enough epoxy at the stiffeners to contact the frame. Remove the weight and use your fingers to hold any bulges down until the five minute epoxy gels. Don't glue the sides or the leads yet. Turn the structure over in 30 minutes and place it at the end of the wooden board so the leads hang over it. Glue the other side. Allow several hours to cure. Stretch the diaphragm with the screw just enough to straighten the pleats a little. If they feel noticeably taught, you have gone too far. Straighten the leads and push them further into the gap. Now glue the sides, then the leads in the gaps, and put a dot of glue on the screw head to secure it. When cured, trim any glue sticking out from the frame with a razor blade very carefully. The diaphragm is now complete.

Slide it into the magnetic gap with the leads pointing back and tighten in place. The leads are awkwardly placed, but then no design is perfect. Place a flashlight battery across the leads to verify polarity. (The positive lead squeezes the fronts of the pleats together when connected to the positive side of the battery). Attach the 5-way binding posts to the baffle extensions for extra strain relief.

Attach the horn and wire the AMT to your tweeter leads from your crossover network. Use a frequency over 300Hz (I recommend 500Hz). Of course, if you don't like horn loading, you can use these diaphragm construction techniques in one of Neil Davis' bipolar magnet structures.

Pad down the output, and enjoy.

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KC-4A: ELECTRONIC CROSSOVER, KIT A. [2:72] Single channel, two-way. Values of R_1, R_2, C_1, C_2 must be specified with order. All parts and C-4 circuit board. Includes new LF351 ICs. Each **$8.00**

KC-4B: ELECTRONIC CROSSOVER, KIT B. [2:72] Single channel, three-way. Values of R_1, R_2, C_1, C_2, must be specified with order. All parts and C-4 circuit board. Includes new LF351 ICs. Each **$11.00**

KK-6L: WALDRON TUBE CROSSOVER: Low pass. Single channel, 18dB/octave, Butterworth, [3:79] includes Bourns 3-gang plastic pot, level control, Mullard tubes, board, and three frequency range determining capacitors. **Specify ONE frequency range per kit please.** (Hz.): 19-210; 43-465; 88-960; 190-2100; 430-4650; 880-9600; 1900-21,000. Single channel. Each **$43.00**

KK-6-H: WALDRON TUBE CROSSOVER: High pass. Single channel, 18dB/octave, Butterworth, [3:79] includes Bourns 3-gang plastic pot, level control, Mullard tubes and 3 frequency determining capacitors. Please specify one of the frequencies above. No other can be supplied. Each **$45.00**

KK-6-S SWITCH OPTION. 6-pole, 5-pos. rotary switch, shorting, for up to five frequency choices per single channel. Each **$8.00**
When ordered with two kits above, Each **$7.00**

KK-7: WALDRON TUBE CROSSOVER POWER SUPPLY. [3:79] All parts, including board, transformer, fuse, semiconductors, line cord, capacitors. Will power four tube x-over boards (8 tubes), one stereo bi-amped circuit. Each **$88.00**

SBK-A1: LINKWITZ CROSSOVER/FILTER. Speaker Builder's [4:80] first kit, including all parts and board for one channel of the three-way crossover/filter/delay. 24dB/octave at 100Hz and 1.5kHz and 12dB/octave below 30Hz, with delayed woofer turn-on. Board is 5½×8½. Requires ±15V supply, not supplied. Use the Sulzer supply KL-4A with KL-4B or KL-4C.
Per channel **$64.00**
Two channels **$120.00**
SBK Board only Each **$14.00**

PASSIVE

KF-7: CROSSOVER FOR WEBB TLS. [1:75] Passive four-way crossover, in pairs, assembled. Components are included for both STC and Celestion tweeters. Made by Falcon of England. Pair **$87.50**

FILTERS & SPEAKER SAVER

KF-6: 30Hz RUMBLE FILTER. [4:75] Two channel universal filter card supplied with WJ-3 (F-6) circuit board and all basic parts, 1% metal film resistors and 5% MKM capacitors for operation as an 18dB/octave 30Hz rumble filter. 30Hz, 0dB gain only. Kit may be adapted as two- or three-way single channel crossover with added capacitors and resistors. Each **$19.75**

KH-2A: SPEAKER SAVER. [3:77] This basic two-channel kit includes board and all board-mounted components for control circuitry and power supply. It features turn-on and off protection and fast opto-coupler circuitry that prevents transients from damaging your system. 4PDT relay and socket included. Each **$35.00**

KH-2B: OUTPUT FAULT OPTION. Additional board mounted components for speaker protection in case of amplifier failure. Each **$6.75**

KH-2C: COMPLETE SPEAKER SAVER WITH OUTPUT FAULT OPTION. Each **$40.00**

KL-5 WILLIAMSON BANDPASS FILTER. [2:80] Two channel, plug-in board and all parts for a 24dB/octave 20Hz-15kHz with precision cap/resistor pairs. TL075 IC's. Each **$31.00**

SYSTEM ACCESSORIES

KH-8: MORREY SUPER BUFFER. [4:77] All parts & board for two channel output buffer to isolate tape outputs in your preamp from distortion originating in a turned-off tape recorder. Many uses for this versatile matchmaker. Each **$14.00**

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KF-1: BILATERAL CLIPPING INDICATOR. [3:75] Single channel, all parts and board for any power amp up to 250W per channel. (Does not work well with Leach Amp). Powered by amp's single or dual polarity power supply. Each **$5.50**
Two kits, as above **$8.25**

KJ-3: TV SOUND TAKEOFF. For extracting the TV set's sound to feed your audio system [2:78] Circuit board, vol. control, coils, IC, co-ax cable (1 ft.) and all parts including power transformer. Each **$21.50**

KJ-4: AUDIO ACTIVATED POWER SWITCH. Turn your power amps on and off with the sound feed from your preamp. [3/78] Includes all parts except box and input/output jacks. Each **$50.00**

KK-14A: MacARTHUR LED POWER METER. [4:79] Two channel, two sided board and all parts except switches, knobs, and Mtg, clips for LEDs. **LEDs are included.** No chassis or panel. Each **$110.00**

KK-14B: MacARTHUR LED POWER METER. [4:79] As above but complete with all parts except chassis or panel. Each **$137.50**

KL-2: WHITE DYNAMIC RANGE & CLIPPING INDICATOR. [1:80] One channel, including board, with 12 indicators for preamp or crossover output indicators. Requires ±15V power supply @ 63 mils.
Single channel. Each **$49.00**
Two channels. **$95.00**
Four channels. **$180.00**

BENCH AIDS & TEST EQUIPMENT

KH-7: GLOECKLER PRECISION 101dB ATTENUATOR. [4:77] As basic to measuring as a good meter, and more accurate than most. All parts except chassis and input/output jacks to build author's prototype including all switches and loads. Resistors are MF 1% and 2% types. Each **$50.00**

KL-3C: INVERSE RIAA NETWORK. [1:80] Two channels, 1% polystyrene capacitors and metal film resistors, gold jacks, cast aluminum box, solder lugs and alternate 600 ohm or 900 ohm r_2' /C_2' components. Each **$35.00**

KL-3R: INVERSE RIAA. [1:80] Resistor/capacitor package complete. Stereo R_2' /C_2' alternates. Each **25.00**

KL-3H: INVERSE RIAA. [1:80] Box, terminals, gold jacks, and all hardware, (No resistors or caps) in KL-3C. Each **$13.50**

KF-4: MORREY'S MOD KIT FOR HEATH IG-18 (IG 5818) SINE-SQUARE AUDIO GENERATOR. [4:75] Includes two boards and all added parts needed to modify the Heath unit to distortion levels of parts per million range. Replacement sine-wave attenuator resistors not included. Each **$35.00**

KG-2: WHITE NOISE/PINK FILTER [3:76] All parts, circuit board, IC sockets, 1% resistors, ±5% capacitors. No batteries, power supply or filter switch. Each **$22.00**

KJ-7: VTVM BATTERY REPLACEMENT KIT. [4:78] All parts to replace your VTVM's battery with a regulated supply. Each **$7.50**

KJ-6: CAPACITOR CHECKER. [4:78] All parts to build an accurate meter for measuring capacitance, leakage, and insulation. Check phono & speaker lead capacitance effects. Includes all parts with 4½" D'Arsonval meter. Each **$78.00**

KK-3: THE WARBLER OSCILLATOR. [1:79] For checking room response and speaker performance without anechoic chamber. All parts and board. Each **$56.00**

KL-6 MASTEL TIMERLESS TONE BURST GENERATOR. [2:80] All parts with circuit board. No power supply. Each **$19.00**

KM-1: CARLSTROM-MULLER SORCERER'S APPRENTICE [2:81] All parts except knobs, chassis. Includes four circuit boards. For construction of the first half of A Swept Function Generator, with power supply. Each **$145.00**

KM-2: CARLSTROM-MULLER PAUL BUNYAN. [3:81] All parts except knobs, chassis, output connectors and wire. Includes two circuit boards and power supply. Each **$85.00**

KM-3: CARLSTROM-MULLER SORCERER'S APPRENTICE/PAUL BUNYAN [2:81, 3:81] All parts in KM-1 and KM-2. Each **$225.00**

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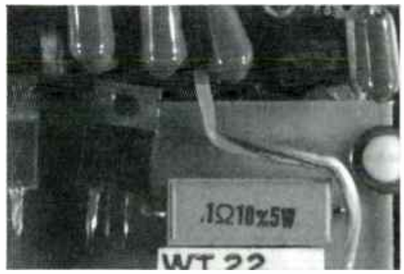

The headphone output on most amps usually is a large resistor in series with the output to knock the level down to what is suitable for driving headphones. The resistor reduces the amp's damping ability, leaving your headphone drivers less tightly controlled. You will also suffer the distortions produced by the resistor's particular nonlinearities. To solve these problems, Jim Boak has designed a high performance amp specifically for headphones. Built around the powerful 540 op amp, it features a circuit modification, derived from Walt Jung's work, which gives the op amp a highly linear transfer characteristic. The resulting distortion curve has that gentle rise associated with good tube amps, and a clean, wide open sound quality you will enjoy thoroughly every time you listen on headphones. To top it off, Boak gave it excellent power supply regulation. Each channel has independent power supplies using three-terminal regulators to deliver stable voltages across the entire audio range. The amp may be configured for driving either electrostatic or dynamic headphones, and parts for both are included.

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- Three-way active crossover
- Phase shifting circuits to fine tune your system
- Easy method to measure actual acoustic phase relationships among drivers
- Op amp filters simplify design
- Rumble filter built in

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An Active Crossover with Phase Correctors: Part II

BY ROBERT BALLARD

Part I gave an overall view of the principles behind the crossover. In this issue I will show how to measure phase angles among your drivers and how to use the crossover to align your system.

ALIGNING THE CROSSOVER. Since the midrange driver is "home base" for the system, align the bandpass filter circuit first, because the exact crossover frequencies to be used result from the adjustments and measurements of the bandpass filter.

You can determine nominal frequencies for the two crossover points from the driver manufacturers' published frequency response curves. From these, find the R and C values and insert the parts into the circuit. One of the purposes of this procedure is to determine the exact crossover frequencies since these will most likely differ slightly from the nominal. The exact frequencies will be designated F_{LX} for the low frequency and F_{HX} for the high frequency, and will be the same for both left and right channels.

PROCEDURE. The same sine wave generator must be used for all adjustments and measurements and should be turned on at least ½ hour prior to its use to stabilize for drift. Extreme accuracy is not so important as consistency and repeatability.

1. Omit straps S_1-S_4.
2. Set all trim pots except R_{17}, R_{36}, and R_{47} to midpoint.
3. Set trim pots R_{17}, R_{36} and R_{47} to full on.
4. Connect a ±15V (nominal) DC power supply.
5. Connect sine wave generator (SWG) to pin B at strap S_1.
6. Connect oscilloscope vertical to the output to the midrange amplifier (the wiper of R_{36}).
7. Increase SWG voltage to obtain suitable voltage output at about 1500Hz. Then move scope leads over to the SWG output and adjust to get on a convenient set line on the scope graticle. This SWG voltage must be maintained constant and monitored at all times unless you trust the regulation of your SWG.
8. Move scope leads back to the output of the bandpass. Connect horizontal sweep lead to SWG output.
9. Set SWG frequency to the frequency calculated for actual values of R and C for the 400Hz high pass. Switch scope to external horizontal sweep and adjust R_{21} until you get exactly 180 degrees. Make a written record of the frequency used for later reference.

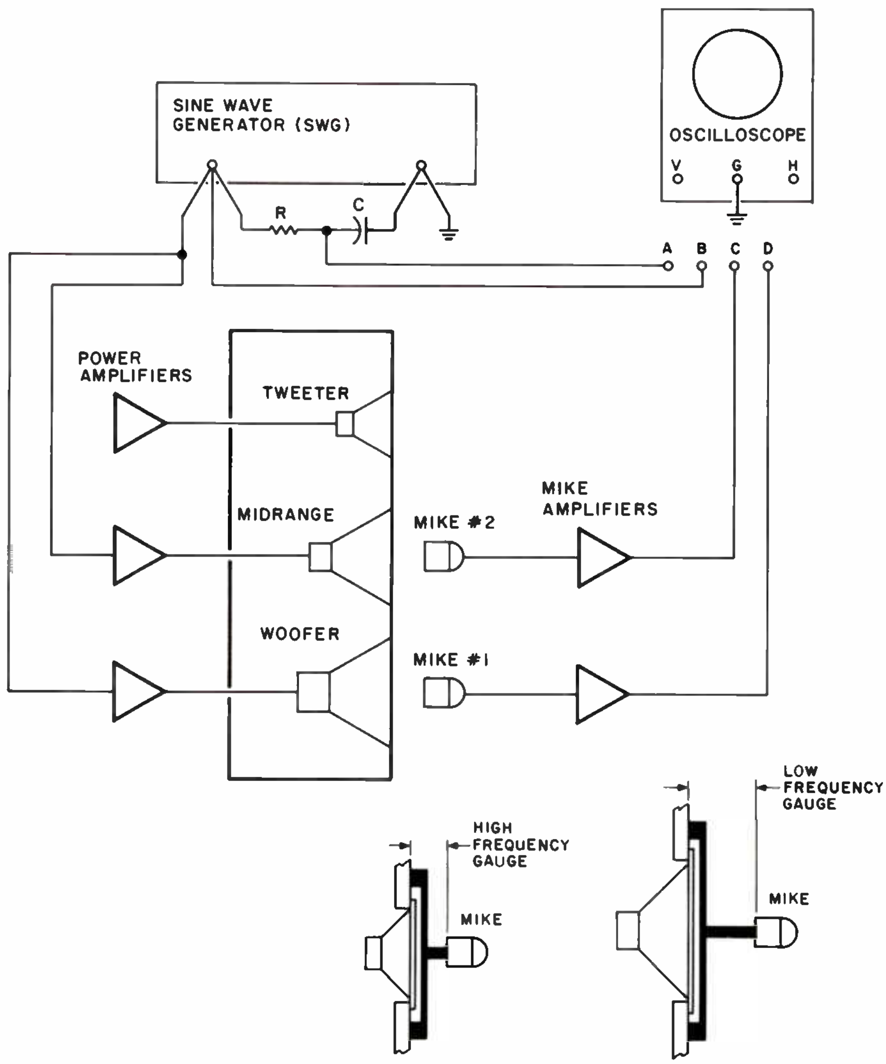

FIGURE 7. This test setup measures the phase difference between drivers. After determining which quadrant each is in, use a diagram such as Fig. 9 to help visualize the difference. This will determine actual values for R and C in the phase shifting circuits.

10. Return to the internal sweep and measure the voltage output and record it.

11. Make subsequent measurements of voltage at 1000, 1500, 2000, and 2500Hz. If a slight hump appears at 1500 or 2000Hz, disregard it, use the value on either side for reference, and record this value. The voltage measured in step 10 should be down 6dB (or ½ the value at this step). This 6dB point can be ± 0.5dB. If it is outside this range, then change frequency used in step 9 upwards or downwards by 5-10Hz as required and repeat steps 9, 10, and 11.

12. The final frequency which satisfies both the 180 degree angle and the 6dB attenuation is F_{LX}, the woofer crossover frequency.

13. Set SWG frequency to the calculated values of R and C for the low pass part of the bandpass. This is the nominal 3500Hz. Switch the scope to external sweep and adjust R_{29} until you get exactly 180 degrees.

14. Switch back to internal sweep and measure the voltage output. It should be down 6dB from the value observed in step 11. If not, then take corrective measures as outlined in step 11.

15. The final frequency which satisfies both the 180 degree angle and the −6dB point is F_{HX}, the tweeter crossover frequency.

Now adjust the 400Hz low pass to F_{LX} and the 3500 high pass to F_{HX} using the same techniques as described above. This time you are not *looking* for a frequency. You must *adjust* to obtain the *same* frequencies. After this is completed, you have finished adjusting the left channel. In aligning the right channel, adjust the bandpass for the midrange amplifier for F_{LX} and F_{HX} exactly to obtain the 180 degree angle. During this process, make sure that you don't accidentally adjust the trimpots on the completed channel.

Check the operation of the input buffer amplifiers and the phase shift circuits to make sure that they are functioning properly and that you have some control over phase angle using the trim pots in the phase shift circuits. The phase shift trim pots get their final adjustment during driver alignment. As the last step install straps S_1 through S_4 in both left and right channels.

DRIVER PHASE ALIGNMENT. With the circuit properly tested and adjusted on the bench, we are now ready to start driver alignment using the test setup shown in *Fig. 7* except that mikes 1 and 2 should be positioned in front of the left and right channel midrange drivers. Since they are used as the pivotal drivers, we start by adjusting their phase. Connect C to V and D to H. The high and low frequency gauges must be used to position the mikes in the following procedure. Check phase angle at F_{LX} and adjust R_{21} until it is zero. Then check it at F_{HX} and adjust R_{29} until it is zero. The settings of *R_{21} and R_{29} must remain fixed from this point on.* This is their permanent setting.

In the next step, position the mikes in front of the woofer in the right channel and midrange driver in the left channel as shown in *Fig. 7.* Check phase angle at F_{LX} and adjust R_3 to get zero degrees. Then move the mike from woofer to tweeter (right channel). Remember, if

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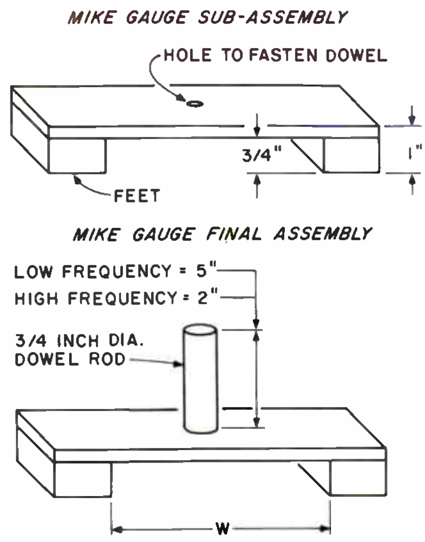


FIGURE 8. Make these gauges very precisely so that accurate measurements result. Keep all reflecting surfaces (including test gear and yourself) well away from the mikes.

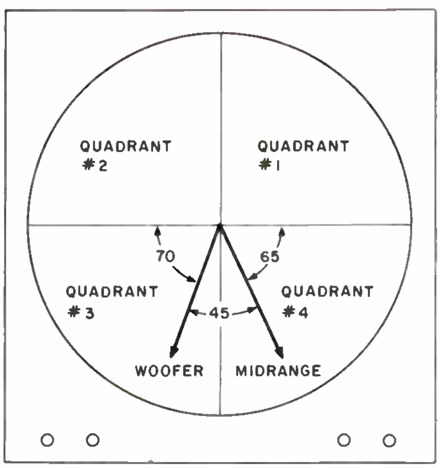


FIGURE 9. Woofer phase angle was measured as 70° in Quadrant 3, midrange was 65° in Quadrant 4. Subtracting the sum from 180° leaves 45°. Since leading vectors rotate counterclockwise, and the midrange is ahead of the woofer, the shifting circuit must advance the woofer 45°.

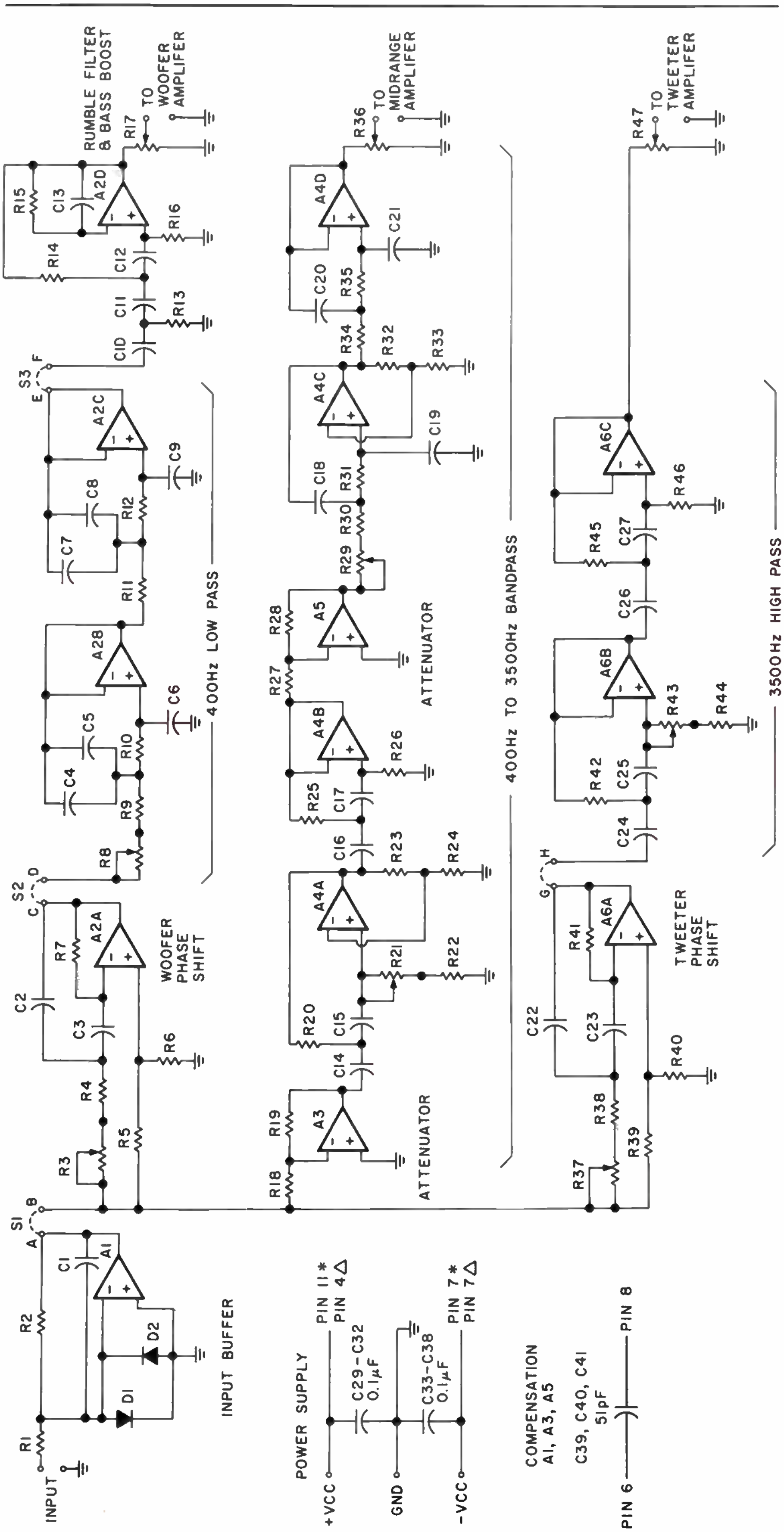


FIGURE 10. Schematic for three-way active crossover features variable phase shift for precise alignment of your system.

PARTS LIST

R_1 100k
R_2 200k

For Woofer Advance of	40°	50°	60°	
R_3	5k	5k	2k	Trimpot
R_4	10k	9.1k	8.2k	
R_5	100k	82k	75k	
R_6	100k	82k	75k	
R_7	51k	43k	36k	

R_8	2k trimpot		
R_9	5.1k	R_{23}	20k
R_{10}	6.2k	R_{24}	18k
R_{11}	6.2k	R_{25}	7.5k
R_{12}	6.2k	R_{26}	7.5k
R_{13}	220k	R_{27}	10k
R_{14}	15k	R_{28}	4.7k
R_{15}	270k	R_{29}	2k trimpot
R_{16}	2.2MΩ	R_{30}	6.8k
R_{17}	10k trimpot	R_{31}	7.5k
R_{18}	18k	R_{32}	20k
R_{19}	4.3k	R_{33}	18k
R_{20}	7.5k	R_{34}	7.5k
R_{21}	2k trimpot	R_{35}	7.5k
R_{22}	6.8k	R_{36}	10k trimpot

For Tweeter Advance of	40°	50°	60°
R_{37}	2k	2k	2k
R_{38}	9.1k	7.5k	6.8k
R_{39}	82k	68k	56k
R_{40}	82k	68k	56k
R_{41}	43k	33k	30k

R_{42} 4.7k
R_{43} 2k trimpot
R_{44} 3.6k
R_{45} 4.7k
R_{46} 4.7k
R_{47} 10k trimpot
$A_{1,3,5}$ Type 531 IC Op Amp
$A_{2,4,6}$ Type 4136 Quad Op Amp

Trimpots should be of best quality available.

D_1 and D_2 1N4848

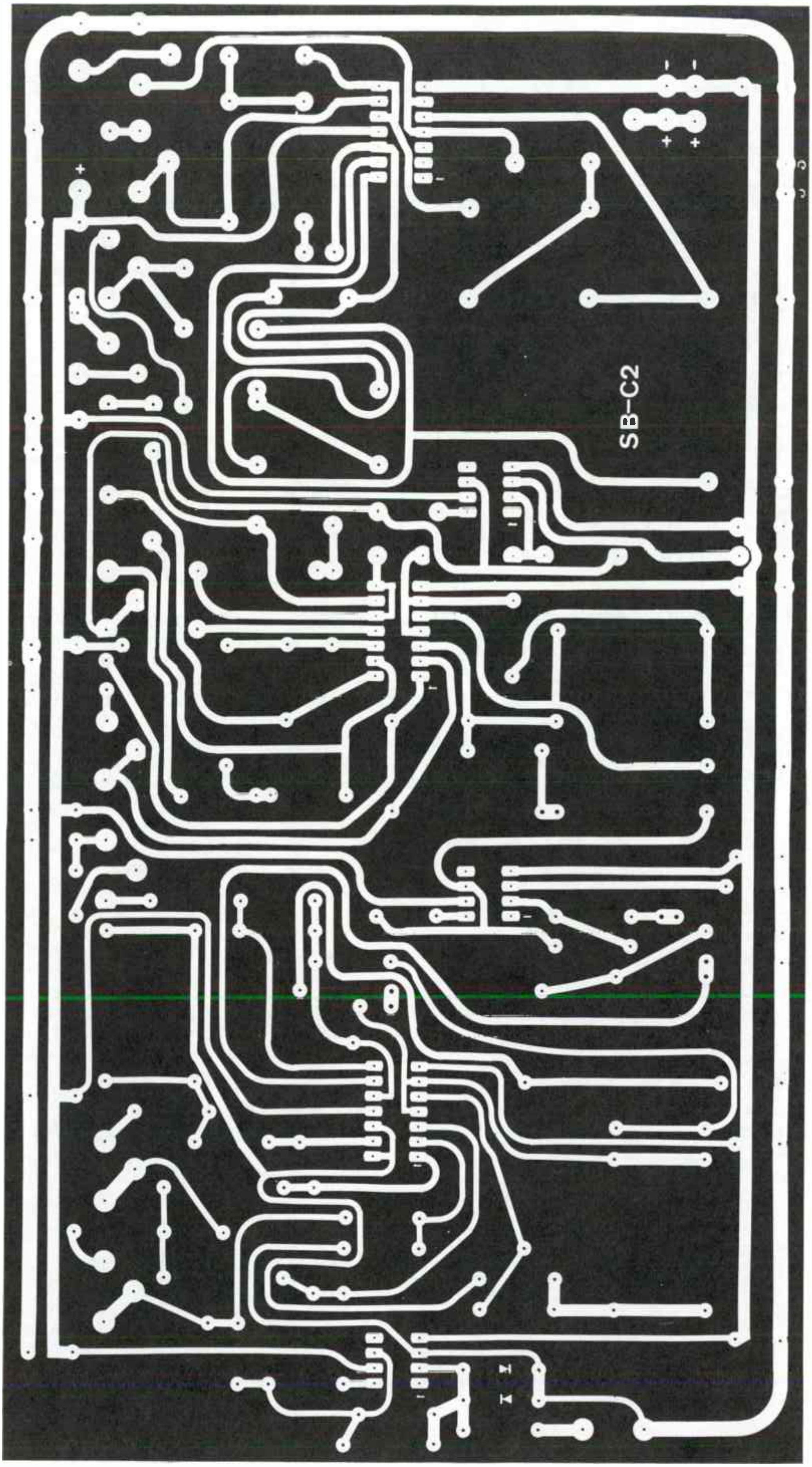
All resistors are ¼ watt 5%

All caps are polystyrene or polypropylene. Test and select matched sets ± 1% for each crossover frequency.

C_1 10pF
C_2-C_{12} .047 μF
C_{13} 100pF
C_{14}-C_{17} .047 μF
C_{18}-C_{27} 6800 pF

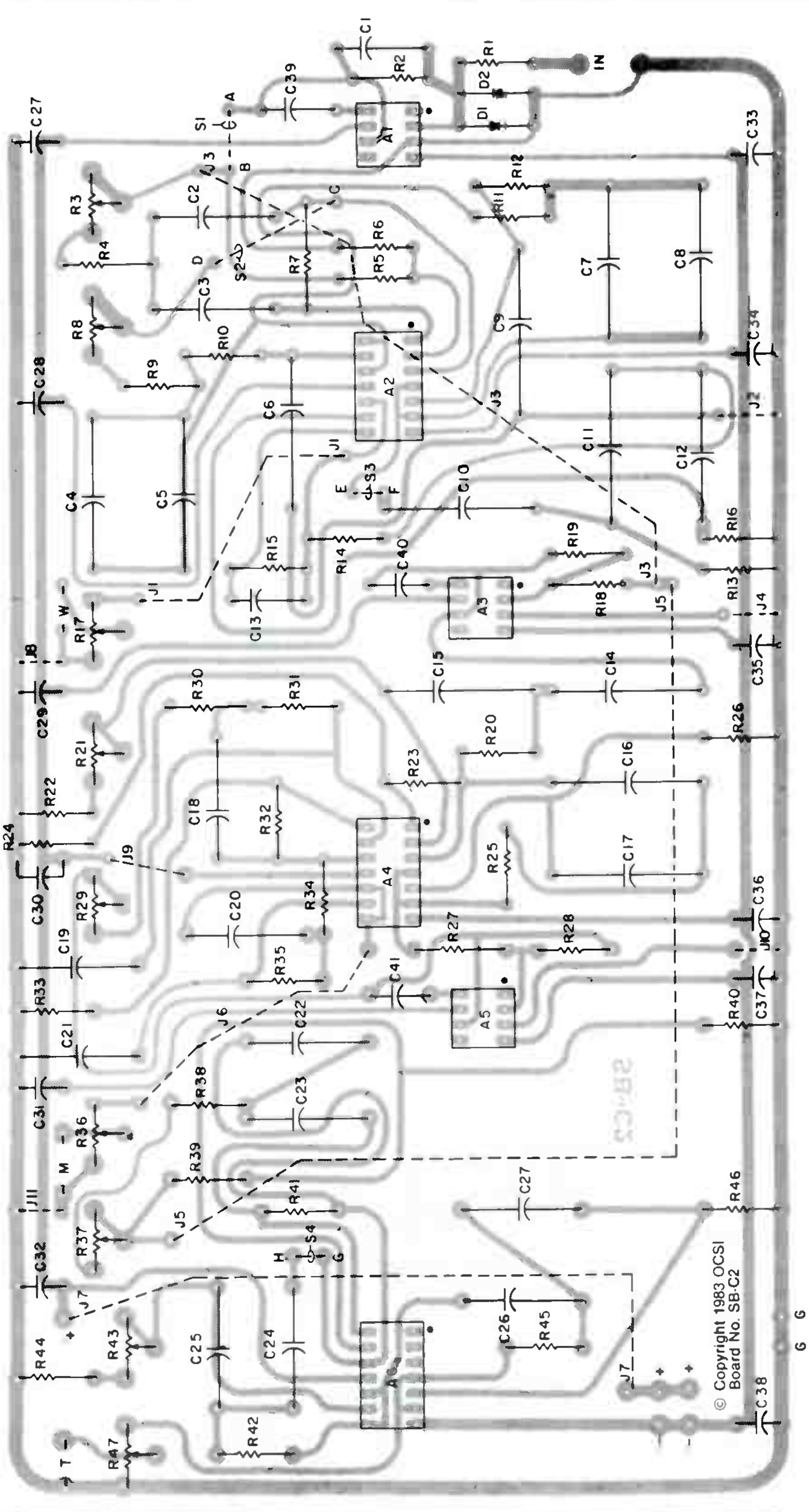
Power Supply
C_{29}-C_{32} .1μF
C_{33}-C_{38} .1μF
C_{39}-C_{41} 51μF

For F_{LX} = 400 Hz F_{HX} = 3500 Hz


SB-C2

you reversed the tweeter leads earlier, then leave them reversed. Check phase angle at F_{HX} and adjust R_{37} to get zero degrees. Repeat for the other channel using the same F_{LX} and F_{HX} and the midrange in the right channel.

At this time move the midrange driver from the left channel speaker to the right channel speaker and visa versa. All of the drivers are now in phase alignment among each other in the same channel and between channels. Before you tear this setup down, use the microphones to adjust the level settings to the input of the power amplifiers so that adjacent drivers have equal SPL's at the crossover frequency. Start by setting woofer trimpot R_{17} to full on. Then reduce the midrange setting to get the same sound output at F_{LX}. Then adjust R_{47} for the tweeter in the same way. Subjectively, these settings might be too accurate for some individuals. However, they can be readjusted later to suit individual preferences.



COMPONENT SIDE

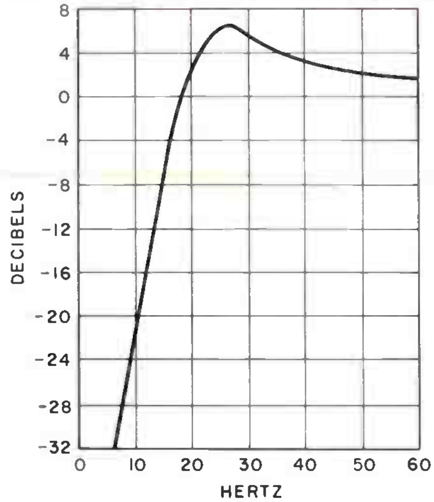


FIGURE 11. Rumble filter has steep rolloff, and the bass boost flattens the woofer's response.

At this time your stereo system is completely phase aligned from the preamp's output to the acoustical output of the speakers. If other parts of the system (phono cartridge, tape head, tuner, and preamplifier) exhibit any phase shift, the system will reveal it unmercifully. I know of no simple methods available to the amateur audiophile to determine and correct for phase shift between channels on phono cartridges or tape heads.

ULTIMATE JOY. With playback source, preamplifier, electronic crossover, power amplifiers, and drivers all properly connected, you can sit back in your easy chair (although that isn't the best kind of chair to use) and listen to glorious stereo music. Your system will pinpoint the location of every instrument and voice with such precision that you can tell whether a pianist is facing you or has his back to you by the location of the bass and treble strings. Images are no longer fuzzy or diffuse. They have a clarity and detail which will thrill you. With direct coupling between amplifiers and drivers instead of passive crossovers (which deteriorate damping factor and present insertion loss), transient response is next to the real thing. The throes of giving birth to this child are well worth it. Good luck and happy stereo sound. □

A strongly opinionated cautionary tale of one man's fifteen-year search for the ultimate home built speaker system

A SPEAKER BUILDER'S ODYSSEY: PART II

BY ROBERT CARLBERG

After my initial efforts with drivers and the effects of enclosures on them, I decided to design and build a speaker based on what I had learned up to that point. The result was what I called the "Walnut Pines."

SYSTEM 4: WALNUT PINES. My next pair was a commission job from my sister, who liked the sound of my Experimenters. We chose the 10″ woofers in the same Lafayette line, and again the same Calrad Tweeters.

The cabinets were identical to my Experimenters, except proportionally larger. My sister was also concerned about the furniture value of the cabinets, so we decided to use "real wood"—in this case (green) pine. Don't ever do this. The wood warped as it dried out, and it was hell pulling all the cabinet corners together with an assortment of internal L-brackets, external pipe clamps, and numerous screws. The speakers sounded terrific and looked great when they were finally squared up and finished with a walnut stain, but for the trouble involved I can't recommend green pine.

SYSTEM 5: BOOM BOXES. My next pair was also a commission job, this time from a trusting workmate. The ground rules were a little different on this pair: he liked *a lot* of bass, like more than normal. To accomodate this odd request (I tried but failed to dissuade him), I found it necessary to go to another make of woofer. In shopping around, I found what I was looking for at Speakerlab. Their 12″ woofers had very thick and heavy cones, yet their magnets were smaller than my Lafayette 8″. In a cabinet this had the effect of doubling all the bass notes, providing a very satisfactory rumble in the low-end.

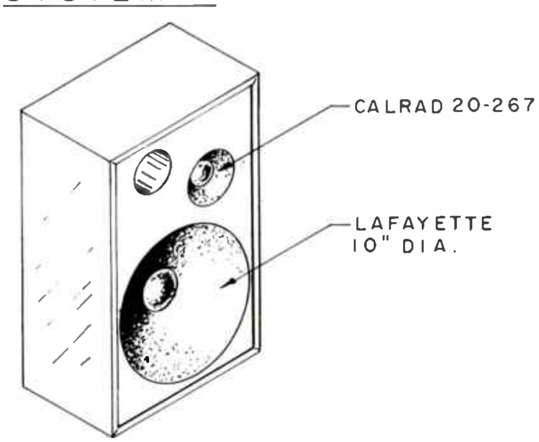
The cabinet damping had little effect on the woofers, since after all it was the voice coil/magnet assembly that was causing all of this distortion. But my commissioner was tickled pink with the undamped sound, and who was I to argue when he was paying?

For the midrange (the Speakerlabs understandably hadn't any midrange response), we chose Philips midranges with attached backcans. They are clean, open, fairly neutral, and easy to mount, although the excursions were such that high decibel levels caused them to bottom out audibly. For tweeters I again used the old Calrads, not having found another I liked better.

The ¾″ particle board cabinets were covered with a walnut-pattern plastic laminate (I was working for a laminate manufacturer at the time). The cabinet dimensions were sized to bass-reflex proportions (since hybridization had no improvement here).

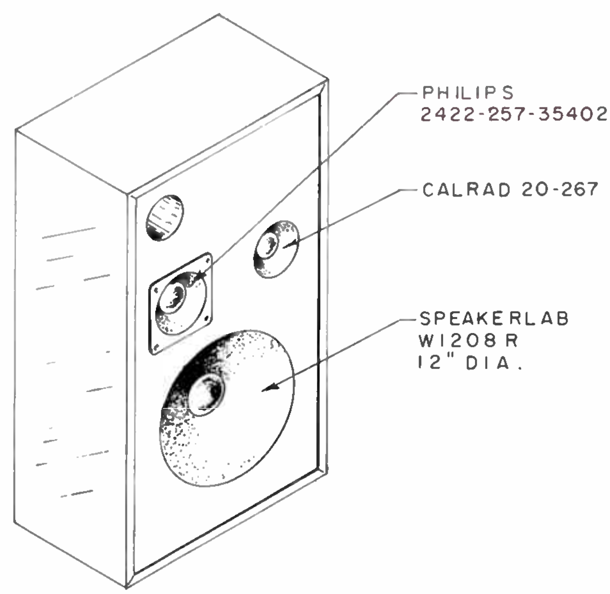
The crossovers, which for the first time required more than a simple $2.2\mu F$

SYSTEM 4



APPROX. SIZE: 12" WIDE × 21" HIGH × 8" DEEP
2000 IN^3

SYSTEM 5



APPROX. SIZE: 18" WIDE × 30" HIGH × 10" DEEP
5400 IN^3

capacitor on the tweeter, were quite effortlessly constructed using parts and instructions bought from Speakerlab. For crossover components, and for grillecloth, I heartily recommend Speakerlab.

SYSTEM 6: OMNI TOWERS. It had been a couple of years since I had built a pair for myself, and I began to feel the urge for something new. At this time, Ohm 'F's were all the rage, with their 360 degree radiation touted as THE ANSWER to stereo imaging. I was not impressed by the Ohms themselves (too boomy and muted), but the idea of omnidirectionality had captured my imagination.

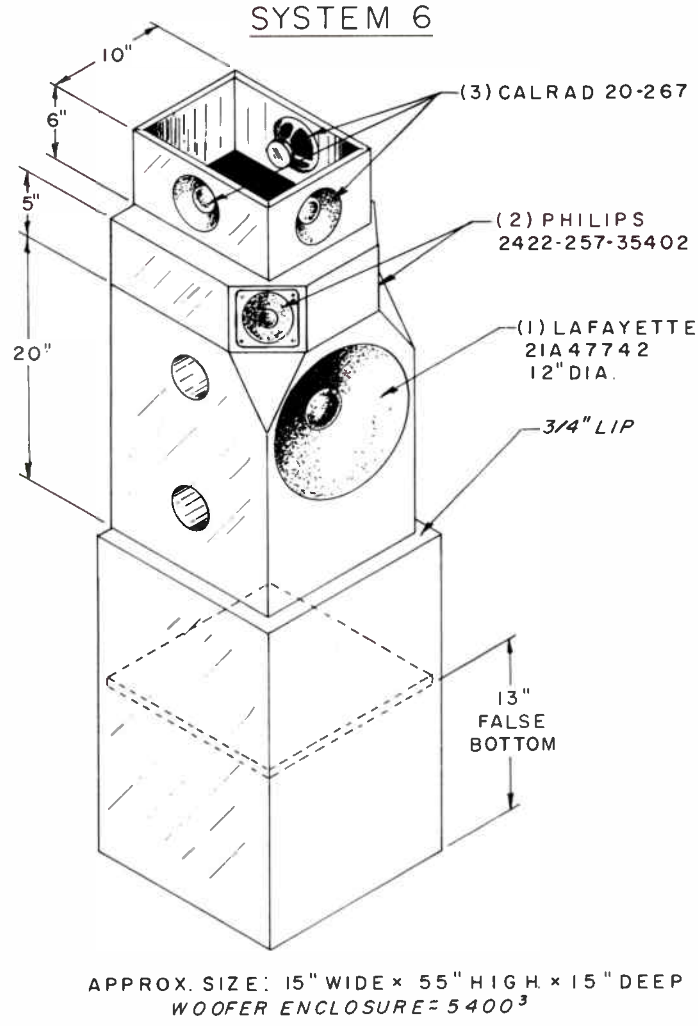
Keeping the Experimenters as a second set for the bedroom, I began construction on a floor-standing, three-way semi-omnidirectional main system for the living room. I started with the 12″ version of the Lafayette woofer—which proved to be every bit as good as the 10's and 8's—in an enclosure radically redesigned for omnidirectionality. At the same time, the internal volume was kept to previous proportions, with ducted ports on the sides (for wide dispersion) and full of pillow foam.

Above the woofer enclosure was a wedge-shaped removable midrange enclosure, housing two of the Philips midranges angled out at 45 degrees from the woofer. As an experiment, the backcans were removed, and the internal volume of the midrange cabinet was used to provide loading. Empty it sounded terrible, with a little foam it was somewhat better, tightly stuffed with foam still a little better—but still poor. I cut out the back and placed it midway in the cabinet, cutting the volume in half. It sounded a little better, but not much, so I cut it out once again and moved it all the way up until it was just touching the backs of the midranges. It still sounded worse than with the cans on, so I cut it out one last time and went back to the original layout. For once the manufacturer was right.

The high frequencies were handled by three of the Calrad tweeters on the three forward sides of a ½″ particle board box bolted on top. All three bolt-together sections were carefully fitted to avoid rattles, but a 1/16″ rubber sheeting was used between for extra insurance. The empty space behind the midranges was ideal for mounting the crossover components, which were again assembled with the service of Speakerlab.

When I was about half finished with these cabinets, Dahlquist DQ-10's came on market. Their open transparent sound was a revelation to me, but mostly I was taken by their 3-dimensional imaging. My woofer cabinet was already designed (by accident) for minimum reflection, and the midranges (at 45 degrees from the woofers) were just by accident quite close to voice-coil aligned with the woofers. I adjusted the dimensions of the tweeter box, then under construction, to attempt to align their voice coils with the others. Dahlquists are not omnidirectional, though, so obviously omnidirectionality was not the one true answer. My Omni Towers, while the best thing I had yet built, were still no match for the Dahlquists in the high-end, and were sold at the first audition for a friend of "Boom Boxes."

NEXT TIME: THE MONSTERS



Editorial

Continued from page 6

he's missing a golden opportunity because he doesn't use the medium to sell his wares to more of your fellow hobbyists.

We pay a further penalty for being a small, specialized publication for do-it-yourself people. Manufacturers of finished speaker systems don't advertise in our pages since they assume you are all going to build your own. We answer by saying that lots of you will buy and own speaker systems of several sorts—and often the kind that you cannot take the time to build for yourself. We are convinced that you are entranced and delighted by speaker technology in general and are turned on by any beautifully crafted system whether you built it yourself or not. That's another message that is vital to this hobby of ours.

Meantime, we can at least enhance our present lines of communications. Refuse to be invisible. Find and establish contact with the many fine vendors who do use this publication. They are enthusiasts, very often, just like yourself. They will be glad you did. We will. And you will too. □

Tools, Tips & Techniques

Apple Programs for Thiele/Small

I have been using some "quickie" programs written in BASIC on my Apple to work out Thiele/Small computations. They are far more convenient than punching keys on my HP-33, which soon gets old when playing "What if . . ." The first program, "Crossover Design," calculates the component values for two-way passive crossovers with 6, 12, and 18dB/octave slopes. The equations and circuit topologies are from Martin Colloms' *High Performance Loudspeakers*, pp. 135-137. You could extend this program to help design three-way crossovers and to account for driver characteristics.

The second program, "Response Function," is taken from David Weems' book *How to Design, Build, and Test Complete Speaker Systems*, p. 175, and is an Applesoft adaptation of D. B. Keele's calculator program for vented boxes. The calculations are based on the exact T/S model and you must know or determine by testing the values of fs, Qts, Vas, fb, and Vb. The output is a table of response values (in dB, relative to a reference value of one) at selected frequencies. If you want other frequencies, or more of them, simply change the DATA statements. You could also replace the READ . . . DATA instructions with INPUT F9 to get specific frequencies of interest.

These programs are easy to incorporate into larger, more sophisticated programs. Those of you who can read them probably have developed similar ones for your own use. But for those of you who were putting off buying a home computer, or who just got one for Christmas, these are examples of what you can do. I would like to share programs and ideas with other readers who have been exploring this field. I know you're out there. Some areas that need to be covered include: crossover design incorporating phase and impedance compensation, time smear calculations, and computer models for transmission line systems.

I am currently working on converting a very good program, given to me by D. B. Keele of JBL, from Cromemco BASIC to Applesoft. This does all the things my "quicky" programs do, but all in one, plus some.

Please send any microcomputer programs you may have to me, and I will act as a clearinghouse. They don't need to be in BASIC, or only for the Apple II.

Bob White
Houston, TX 77034

```
100  PRINT "ENTER FREQUENCY IN HZ
     ,IMPEDANCE OF DRIVER AT CROS
     SOVER"
200  INPUT F,R
300 P = 3.1416
350 S = 1.4142
400 C1 = 1 / (2 * P * F * R)
500 L1 = R / (2 * P * F)
600 C2 = 1 / (2 * S * P * F * R)
700 L2 = R / (S * P * F)
800 L3 = R / (S * P * F)
900 C3 = 1 / (2 * S * P * F * R)
1000 C4 = 1 / (3 * P * F * R)
1100 C5 = 1 / (P * F * R)
1200 L4 = (3 * R) / (8 * P * F)
1300 L5 = (3 * R) / (4 * P * F)
1400 L6 = R / (4 * P * F)
1500 C6 = 2 / (3 * P * F * R)
1600  PRINT "C1 IS 6DB HI PASS": PRINT
     C1
1700  PRINT "L1 IS 6DB LO PASS": PRINT
     L1
1800  PRINT "C2 IS 12 DB HI PASS"
     : PRINT C2
1900  PRINT "L2 IS 12 DB HI PASS"
     : PRINT L2
2000  PRINT "L3 IS 12 DB HI PASS"
     : PRINT L3
2100  PRINT "C3 IS 12 DB LO PASS"
     : PRINT C3
2200  PRINT "C4 IS 18 DB HI PASS"
     : PRINT C4
2300  PRINT "C5 IS 18 DB HI PASS"
     : PRINT C5
2400  PRINT "L4 IS 18 DB HI PASS"
     : PRINT L4
2500  PRINT "L5 IS 18 DB LO PASS"
     : PRINT L5
2600  PRINT "L6 IS 18 DB LO PASS"
     : PRINT L6
2700  PRINT "C6 IS 18 DB LO PASS"
     : PRINT C6
2800  END
```

FIGURE 1: This listing will calculate component values for passive two-way crossovers with 6, 12, and 18dB/octave slopes.

```
10  PRINT "ENTER DRIVER FS(HZ),QT
S,VAS(CUFT),FB(HZ),VB(CUFT)
20  INPUT F,Q,V,F1,V1
30 A = (F1 / F) ^ 2
40 B = (A / Q) + (F1 / (7 * F))
50 C = 1 + A + (F1 / (7 * (F * Q)
)) + (V / V1)
60 D = (1 / Q) + (F1 / (7 * F))
65 L1 =  LOG (10)
70  READ F9
80  IF F9 > 200 THEN 10
90 W = F9 / F
92 W1 = W * W
100 H9 = W1 * W1 /  SQR ((W1 * W1
 - C * W1 + A) ^ 2 + (B * W -
D * W1 * W) ^ 2)
110 Y = 20 *  LOG (H9) / L1
111  PRINT F9,Y
112  GOTO 70
120  RESTORE
125  GOTO 10
130  DATA  10,15,20,25,30,35,40,4
5,50,55,60,65,70,75,80
140  DATA  90, 95,100,110,125,160
,180,200,210
150  END
```

FIGURE 2: This listing will calculate the db output of a T/S alignment at selected frequencies. By changing h and α, you can find an acceptable alignment for a given driver.

Moveable Drivers

Since most pre-preamplifiers, preamplifiers, electronic crossovers, and power amplifiers have a 20kHz rolloff frequency, they exhibit a phase shift of 90 degrees. A 20kHz signal will be 90 degrees out of phase with a 20Hz signal and this can be compensated for in two ways. The first is to extend the rolloff frequency to approximately 3MHz so minimum phase shift occurs from 20Hz to 20kHz. This concept is excellent for planar speakers such as full range electrostatics and magneplanars. Very few audiophile electronics exhibit these characteristics while maintaining stable performance. The second method of compensation is to stagger drivers, positioning the midrange driver slightly behind the woofer and the tweeter slight-

Continued on page 44

Designer's Corner

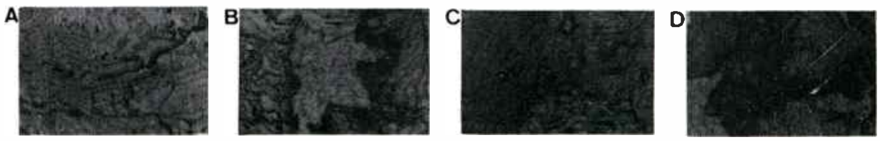
Cork Topped Speakers

I have been building speakers for about eight years, and have always had a special interest in their appearance. Recently I departed from the wood veneer look to one more pleasing—and cheaper. Cork veneer wallpaper has a beautifully complex grain pattern which you can highlight with various staining techniques. The cork finish helps to blend the speaker into the room and makes large cabinets seem less monstrous. Using small sheets of cork veneer wallpaper as part of the room's decorative motif not only aids visual blending but also helps to break up standing waves and provide more uniform dispersion. People seeing these cork speakers for the first time are amazed at the idea and comment positively and enthusiastically.

A coating of polyurethane sealer serves several functions. First, it protects the cork and prevents it from flaking. Second, it darkens and intensifies the grain pattern. Third, it prevents the cork from absorbing high frequencies. I like to use two to four coats of sealer, but the "special touch" I have discovered is to start with a coat of diluted black turpentine (the remainder after cleaning a brush is ideal). This darkens the cork slightly and sets off its pattern well. When thoroughly dried, I apply one or two coats of satin urethane.

To apply the cork wallpaper, you will need these materials:

1. Razor knife and blades.
2. Paper backed (not pre-pasted) cork veneered wall paper.
3. 20-30 ozs of ready mixed adhesive. Ask for details at the paint or wallpaper shop. If they recommend powder mix, add one part of white glue to five parts of the mixed paste.
4. Straight edge.
5. Brush, rolling pin, damp sponge.
6. Coarse sandpaper.



(A) This is the plain cork, wallpaper veneer untreated. (B) After two coats of urethane, the pattern has more character. (C) Staining the cork with flat black enamel, thinned, emphasizes the cork's grain. (D) Adding one coat of urethane finish protects the stained cork and intensifies the grain pattern still further.

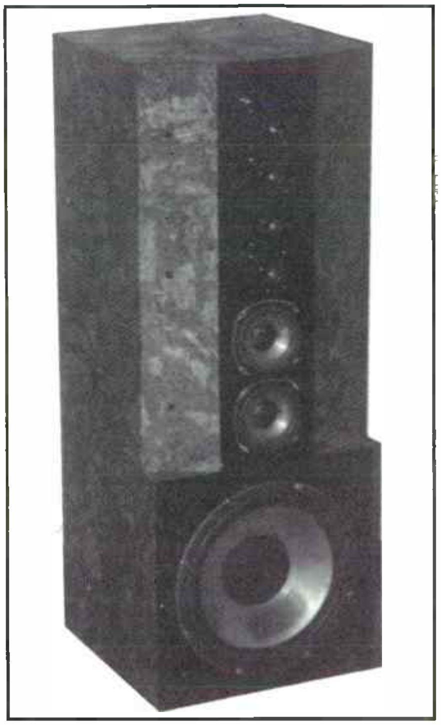
7. Satin urethane (½ pint), thinned black or brown flat enamel or black diluted in turpentine (optional).

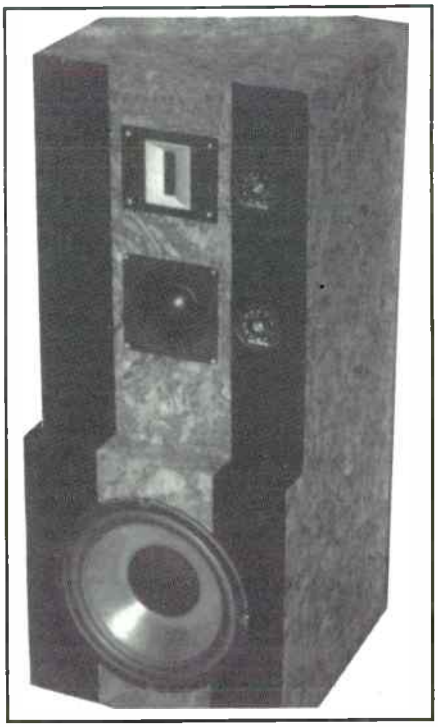
To apply the cork to the cabinets:

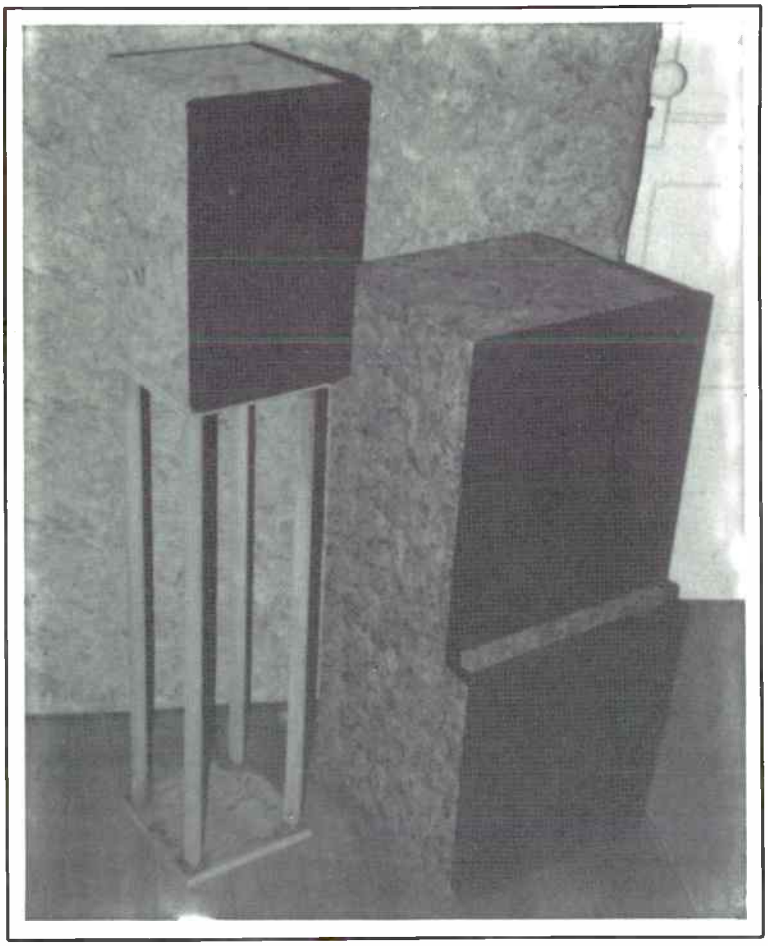
1. Prepare the surface by roughening it slightly with coarse sandpaper.
2. Unroll the cork (paper side up) on a large table. Position the speaker on top and mark the outline with a pencil. Remove the speaker, and cut the cork (leave 1/10″ for trimming).
3. Prepare the paste mix, possibly using a mixer or blender, which helps to avoid lumps. Using a 3″ or 4″ brush, coat one side of the cabinet evenly. Also coat the cork, being sure the edges are covered.
4. Take a rolling pin and press the material onto the cabinet using progressively increasing pressure until the paste is "squeeze free." Check the edges to be certain the cork is still fitted properly, since some shifting will occur. Wipe excess paste off immediately with a damp sponge.
5. After drying thoroughly, apply to the other sides, and trim the edges.
6. Apply the stain and sealer as described above.

Because of the urethane sealer and the cork's thinness, very little high frequency absorption occurs, and the appearance is most pleasing. I work primarily with Thiele/Small vented enclosures and use many of the components and designs offered by SRC in Dallas. I've built five sets for my own use, and several more for others.

Douglas Cabaniss
Sullivan, IN 47882







Books

Les Haut-parleurs. ("Loudspeakers")

Paris, 1981. 317 pp.
Preface by R. E. Cooke (KEF).
Available for 145F plus postage from the publisher, Editions frequences, 11 boulevard Ney, 75018 Paris, France.

Reviewed by Hunter Kevil

Jean Hiraga, the Franco-Japanese journalist, is surely one of the great personalities of modern high fidelity. A Renaissance man of sorts, he has touched base with all branches of audio knowledge and speculation, writing with panache, eclectic curiosity, an occasional flagrant disregard for received opinion, and above all the rare knack for communicating the technical points clearly, succinctly, and vividly. If, on the one hand, he has written constructional articles on electronics of his own design or on the significance of the shape of amplifier distortion spectra, on the other we should not be surprised to read him on audio and astrology or the different auditory structures of the brain in Asians and Westerners. His devotion to audio as an *art* is no less great than as a branch of engineering science. His extremism in the pursuit of high fidelity—always effervescent and engaging, if not wholly reliable—is clearly no vice.

The present book does not disappoint. Divided into three parts, it treats drivers and horns (209pp), enclosures (42pp), and crossover filters (24pp). A 36-page appendix gives graphs of data, many photos of speakers, and a bibliography. The page distribution reveals that the primary emphasis is on drivers and horns. The little section on crossovers is hardly more than an add-on (which is just as well, since it relies on old-fashioned constant-K theories.

The topic of speaker placement and room acoustics, which would require a separate volume, is deliberately omitted. The approach taken is comprehensive within historical sequence. All significant aspects of speaker design are treated in some detail while the narrative ranges from Bell's telephone of 1876 to Klein's new ionic plasma tweeter. The lion's share of attention is given over to the standard moving-coil, dynamic speaker perfected by Rice and Kellogg of GE in the early 20's. Interestingly, Paul Voigt was working independently in England at the same time, and the Frenchman Dufour-Huguenard succeeded in making a moving-coil headphone driver in 1915.

Actual priority, however, goes to Sir Oliver Lodge, who in 1898 constructed a low-impedance moving-coil transducer. At that time there were of course no amplifiers capable of driving such a load (are things much different now?), and Lodge's invention quickly became a museum piece. Hiraga devotes considerable space to the classic designs, such as the Quad ESL, the Orthophase of the early 60's, and the fabulous Blatthaller of 50 years ago, which had 25% efficiency, power-handling of 800 watts, and a diaphragm capable of moving a 20kg weight.

An astonishing plethora of engineering inventiveness has gone into the development of the loudspeaker, and indeed, according to the author, apart from refinements of existing principle, very little new material has appeared under the speaker sun since the publication of MacLachlan's classic *Loudspeakers* in 1934. MacLachlan, a physicist, is one of Hiraga's heroes, a man whose clairvoyance placed him far in advance of the engineering practice of his day. It was not until very recently that instrumentation good enough to verify some of his findings has been available. We are also given an excellent discussion of horn speakers, the great contribution of early Western Electric research being underscored. The legendary all-horn Japanese systems are also mentioned, along with the imposing Onken, Kato, and Iwata horns. The short section on enclosures is also well done.

For those who only want to know about the current state of speaker engineering, Martin Collom's excellent *High Performance Loudspeakers* (2nd ed) will suffice. But the rest of us, our curiosity piqued, will find this a hard book to put down. (The fact that it is written in French will prevent many from ever picking it up. But if you have a little French, I would encourage you to jump in. The level of linguistic difficulty is not high, and the 300 graphs and diagrams make it easy to follow the text.)

This is not a constructional book (though details for making the famous Onken woofer and Iwata midrange horns are given.) But Hiraga does have a pretty astute set of ideas on what the best design criteria and the wisest trade-offs should be, and the reader will be presented with a very large number of ideas and rules of thumb to help him order his thinking, select drivers, and adapt existing designs to his own needs. To give one example, the claim that use of absorbent material to reduce standing waves inside a box can lead to a subjectively depressed midrange was so stimulating that I intend to try for my next midrange cabinet an absorbentless French design of 1962 using interior baffling to diffuse standing waves. It is the presence of such thought-provoking ideas and suggestions that makes this such a fascinating and valuable book.

Theory of Electroacoustics

by Josef Merhaut
(translated from Czech Third Edition by Richard Gerber.)
McGraw-Hill Inc., 1981. 312 pp. bibliography, $45

Reviewed by Scott B. Marovich

For many years, a standard work on the mathematical physics of loudspeakers and microphones has been Frederick V. Hunt's comprehensive and witty *Electro-*

acoustics (Harvard University Press and John Wiley, 1954), long out of print. Now Josef Merhaut, Professor of Electrical Engineering at the Technical University of Prague, known for his papers during the late 1960's on electrostatic loudspeakers, has produced a book of great value to amateurs interested in designing their own loudspeakers or microphones. It aims to be comprehensive and covers most of the theory presented by Hunt, omitting the wry historical survey which made the older work such a delight, but offering more detailed analyses and examples, many first published by the author.

There are seven chapters and a knowledge of undergraduate physics, calculus, and linear differential equations is required to appreciate most of its content. But Chapter One, concerning moving mechanical and acoustic systems and important concepts such as mechanical and acoustic resistance, mass, compliance, and impedance, can be understood using only high school algebra and mechanics. You can learn much from the later chapters, even without the necessary background, if you focus on general principles and try not to get distracted by the unfamiliar math.

In Chapter Two he analyzes resonant frequencies and acoustic impedances of vibrating objects having geometries often encountered in loudspeakers and microphones—plates and membranes of various shapes, rods, and beams—for both "natural" and "forced" (by external source) oscillations. Chapter Three introduces the mathematics of sound propagation in gases, deriving its velocity, the medium's acoustic resistance, power transmitted, and introduces a little about calculating diffraction effects. Chapter Four analyzes the directional characteristics of simple radiators such as a "point source," sphere, plate, ring, and piston, while Chapter Five considers the theory of horns.

Chapter Six begins the real "meat" of the work (most of the new material) as it analyzes impedances and frequency responses of electromagnetic and electrostatic drivers using "equivalent electric circuit" models developed by Merhaut that predict how a driver's mechanical impedance and acoustic load are reflected to a driving amplifier as an electric load. Like the driver-plus-enclosure models of Thiele, these allow a thorough analysis of the driver's frequency response when driven by "real world" amplifiers. Chapter Seven similarly analyzes some common microphone designs.

Merhaut has produced an illuminating volume for those seeking to understand electroacoustic transducers deeply.

SB Mailbox

SUCCESS AND PLEASURE

I have built several speaker systems since 1969, when I discovered the McGee Radio Catalog (1901 McGee St., Kansas City, MO 64108). The first few attempts sounded terrible, but I learned gradually and now I am certain an amateur can build an acceptable system, even without test equipment.

Your articles on Thiele/Small parameters were the breakthrough for me. As I write, I am listening to an EMS 803 woofer in a $1.25ft^3$ box ported to 40Hz with an f_3 of 45Hz. I use a 2″×5″ Motorola piezo tweeter wired in parallel with the woofer. I bought this woofer because at the time it was one of the few with specs available. This is one of my most successful systems and the least complex.

In learning how to build speakers, I have found some techniques and "rules of thumb" which may be of help to others just beginning.

I have built enclosures from ¾″ high density particle board using butt joints sealed with Elmer's Professional Carpenters Glue and finishing nails. I use One Stroke wood finish by New York Bronze Co. PVC pipe works well for ports.

The 6dB/octave series network works best in most cases. For a "Quasi Second Order" network with slopes in the octave on either side of the crossover point, multiply the inductance and divide the capacitance by 0.707. The main exception is when crossing over to a horn midrange or tweeter. Here a 12dB/octave parallel network works best.

I like piezo tweeters with no network at all when using a woofer or midrange with a natural rolloff matching the horn cutoff frequency of the piezo.

Drivers disperse well up to the point defined by 13,440Hz divided by the effective cone diameter (or 0.8 of the nominal cone diameter). Try to crossover at or below this point. Some drivers work fine above this point, so don't hesitate to experiment.

For home use, I like 8″ woofers best, but prefer not to use anything over 10″. Small woofers have better bass when used in a reasonable size box, and offer better dispersion and transient response. A woofer 10″ or smaller will go high enough to crossover to a dome midrange using a Quasi Second Order network. If I have impedance curves for both drivers I try to crossover where the rising curves intersect—usually about 10 ohms at 1kHz.

I believe complicated crossovers hamper efficiency and dynamic range; the best sounding systems have no network or else a simple 6dB/octave series network.

If someone in the Des Moines area has the test equipment and the knowledge to measure speakers, I would appreciate hearing from him or her.

Phil Watson
Indianola, IA 50125

LETTER WRITERS AHOY . . .

We need your cooperation in the matter of your welcome letters to authors and other readers. Please enclose a stamped and addressed envelope if you expect a reply. If the author/reader lives outside the USA, please include two International Postal Reply coupons (available at your post office) instead of stamps on your envelope.

In questioning authors, please leave room in your letter for replies which should relate to the article, be framed clearly, and written legibly. Please do not ask for design advice or for equipment evaluations.

Letters to authors or other readers cannot be acknowledged, unfortunately. Any letter which does not comply with the requests above will not be answered.

HI FI BASS GUITAR

As an electric bass player, I have hoped *SB's* coverage would extend to the area of high quality speakers for musical instruments. Although the literature finally is beginning to turn to the subject of high fidelity sound rather than just loud sound, most of it ignores the problems of live performance.

Arthur F. Josselyn
Churchville, PA 18966

DRIVER TESTS

In John Kasowicz' letter *(SB* 3/82), he refers to problems of measuring Thiele/Small parameters for drivers at differing load levels. The best approach is to make the readings at the lowest possible drive level. The T/S model is derived under a small signal assumption. As the signal increases, the driver becomes significantly nonlinear and parameters measured will not be those assumed by the T/S model. Exact values for h, alpha, and f_B are not possible because the measurement techniques assume that the vented box has Q_L = infinity, which is clearly not the case.

The best advice I can give is to run several evaluations at a low drive level and take the average of the values. The calculated response using these parameters should be quite close to the measured output of the system at a low drive level.

Robert M. Bullock
Oxford, OH 45056

GALO UPDATE

After Part II of my transmission line project was published *(SB* 2/82), Madisound (8982 Table Bluff Rd., Madison, WI 53711) experienced a run on the Audax 10″ bextrene woofer, which is now back ordered. They have begun manufacturing a 10″ polypropylene woofer, which I tested recently. It is superior to the Audax in many respects. With a free air resonance of 24Hz right out of the box, before break in, its extreme low response (below 35Hz) is more solid. The transient response is faster than the Audax. Bass drum attacks are more life-like: the feeling of the beater hitting the head is more realistic on the Madisound. The TL-10's imaging is better, probably because the polypropylene is stiffer and more linear near the crossover frequency. Although it uses a foam surround, which I have not liked in the past, the foam seems to work well with the polypropylene. This is the first foam surround woofer I have found which has a low enough free air resonance and a low enough Q_{ts} (0.27), and is now my first choice among possible woofers for the TL-10.

Many readers are aware that Transcendental Audio has gone out of business. Madisound has been expanding their selection of crossover components, and builders should find most of what they need in their current price list.

Gary Galo
Potsdam, NY 13676

SANDERS ESL/TL UPDATES

The practical experience of many builders, and my own testing have revealed even easier construction techniques for ESL's than those originally published in *SB* 2/80, 3/80 and 4/80. Insulating the drivers is unnecessary, since the arcing is no worse without it, and they still work satisfactorily unless the arcing is prolonged. Personal safety remains an unanswered question. They can shock you whether insulated or not, but in neither case does the situation seem dangerous. To be safest, completely enclose the speakers in a plastic grille cloth such as the material recommended in the original article (available from Mellotone, 1044 Northern Blvd., Roslyn, NY 11576 (516) 484-5940).

A pair of my ESL transformers can be wired to a single ESL so that the effective turns ratio can be increased to 90:1 with no degradation of the frequency response or power handling. By wiring the secondary leads in series, using the connection between the leads as a center tap for the power supply, and by driving the primaries in series. See schematic diagram for details. The only danger is possible peak voltages above 5kV which might arc the transformer windings. However, it takes a pretty healthy amplifier to achieve those voltages. If you are running a smaller amp such as the Pass Class A, or Williamson Twin 20, this technique may be just what you need to raise the SPL without buying a new super amp. An additional pair of transformers for $70 is cheaper than a new amp.

Take care to wire the transformers with the windings in phase or you won't get any output. Arcing the transformers does not appear to cause any damage, and wiring them wrong will not cause damage either. Don't worry, you will be able to determine when they arc, because of the horrible noise you will hear on loud transients. You will get a clean 6dB SPL increase with double transformers.

Several readers have asked where to get Mellotone grille cloth and perforated aluminum. The grille cloth is usually available at electronics supply houses. If you just can't seem to locate any, then you might try my supplier (sorry, I don't stock this for resale) which is: Erlanger Sales Company, 4217 West Jefferson Blvd., Los Angeles, CA 90016. I do not know whether they will sell small quantities direct, but they surely can direct you to a suitable source in your area.

The Lincane perforated metal pattern is available from many hardware and home improvement stores in 0.020" thickness. It is a standard item in the *Ace Hardware Association Catalog* which is used for stocking a large number of the hardware stores in the USA. The material is listed under Reynolds Metal Company and the item number is 1202 (natural aluminum finish), or 1205 (gold finished). As of this writing (1-81) it is about $6/sheet.

The mylar diaphragm film I sell now is heat shrinkable. You can build the speakers without using a stretcher simply by pulling out the big wrinkles and taping down the edges in several places. Rub the graphite on and glue on a stator. When cured, lift up the assembly and shrink the film with a heat gun until smooth with uniform high tension. Then glue on the other stator. Hair dryers are not hot enough, but heat guns are available from hobby shops for $20-$30.

I constantly get requests for alternative methods of making the diaphragms conductive. Graphite is still the best method I know of—simple, easy, cheap and reliable. Exact resistance and coating uniformity are not important.

Devcon now makes "two-ton" epoxy in a 30 minute cure mixture in 9 oz squeeze bottles available from hobby shops. Obviously this is ideal for our use and more economical than tubes.

Transformers are still available, but the price has gone up to $42 each. Mylar film is available in 30×48" sheets for $10. Both are postpaid.

Decoursey Labs has a complete set of

SB *Mailbox*

electronics for $250, which includes crossovers, gain/EQ stage, and power supply, assembled on a nice chassis.

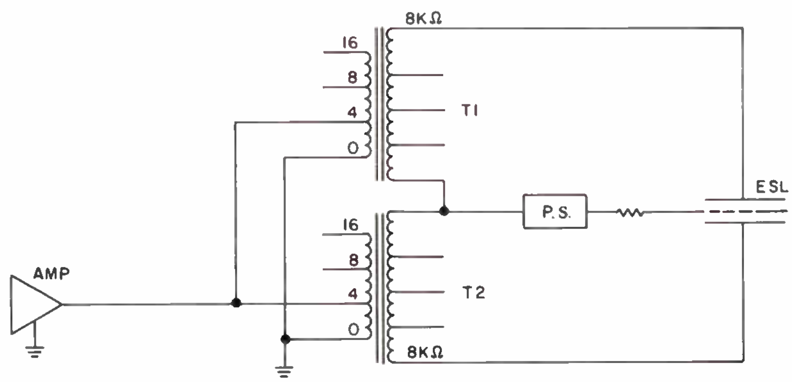
If your ESL doesn't work, it almost always will be a diaphragm problem. To test the transformer output, put a high impedance meter across the stator terminals and play some music (quietly, or you will arc your meter). Using a 100 to 300V scale, you should get a reading.

The diaphragm can have two problems. The most common is having no voltage, which almost certainly results from a poor diaphragm contact. First make sure your high voltage power supply is working by touching the supply wire to either of the stators. You should see an obvious arc. Then plug it into the diaphragm and alternately unplug and plug each stator wire while everything is on. You may leave the preamp's volume control down so no music plays. This simple test tells you a great deal. First, a properly operating system will make a small "pop" when you plug either stator in. If the diaphragm is not energized, you will not get the pop. If one stator pops and the one on the other side does not, then you have a short circuit between the diaphragm and one stator. To determine which side has the short, first discharge everything by shorting the stator terminals to the diaphragm, then put an ohmmeter between stator and diaphragm. You will get an infinitely high reading on the good side, and a few thousand ohms on the shorted side. Usually vacuuming the speaker or blowing it out with compressed air will fix the short. If you have a bad diaphragm contact, resulting in no pops, replace it.

The only other common problem among readers is that some perforated metal is flatter than others, and sometimes the metal flexes inward, touching the diaphragm at some points. This shows up as a shorted stator. The fix is easy, but cosmetically not nice. Place a small screwdriver or punch in each hole along the insulator of the offending section and pry gently until the metal does not touch the diaphragm.

On the transmission line drawing on p. 28, *SB* 4/80, you will notice a small discrepancy. The enclosure depth is indicated as 18" but if you add up the dimensions, it is 17.75". The best solution is to space the baffle at the rear of the enclosure 6" rather than 5.75". For those who didn't notice the problem, don't worry; it won't affect the performance.

I made additional tests on various stuffing materials. To make a long story short, "Polyester Fluff," generally available in one pound bags in sewing shops, is also satisfactory. However, it does not damp as well as wool, so you will have to stuff the enclosure somewhat tighter. Two and a half to three pounds per enclosure was about right. It needs no support since it will not settle, and needs no mothproofing.



I hope these tips have been helpful; fortunately, hundreds of readers have had zero problems and are happy with their systems. However, for those occasional problems and questions, I remain available by phone (202) 358-1427, after 6:00PM, or by letter. Parts are in stock, and I ship promptly after receiving your check or money order.

Roger R. Sanders
Sanders Systems
1578 Austin St.
Atwater, CA 95301

COUNT HUM

I have been using a test box similar to the Widget Box for years. Saffran's Widget article and Bullock's article in *SB* 1/81 both describe use of a counter along with the oscillator. This is fine except for the price, and as Mr. Bullock says, that accuracy is poor just where we need it, below 45-50Hz.

My hint is this...a free, highly accurate calibration source between about 10 to 240Hz. Simply check your oscillator dial against the 60Hz power line frequency via our friend the Lissajous patterns. Most scopes have a 60Hz signal source output available on the front panel. If not, a small, low voltage, transformer can be used as drawn in *Fig. 1* below.

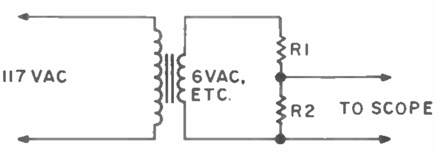


FIGURE 1. R_1, R_2 are an optional voltage-divider, if output voltage of xfmr is on the highside.

The nice Lissajous display ratios are best at 20, 30, 60, 120, etc., just where we need them. I mark little color coded lines right on the oscillator dial, for 20Hz, 30Hz, etc. Instant adjustment, and easy interpolation.

Roy C. Koeppe
Tulare, CA 93274

MORE DRIVER TESTS

This is in response to John Kasowicz's letter in *SB* 3/82. He raises two issues which are probably bothering many readers. They are: 1. accurate measurement of driver equivalent volume, V_{AS}, and 2. variation in f_S and thus Q_{ES}, Q_{MS} and *VAS* with drive level.

V_{AS} is the most difficult driver parameter to measure. This is true for at least three reasons:

1. V_{AS} is a function of local temperature and atmospheric density, and the mechanical stability of the driver suspension compliance. It varies with time and location.
2. The electroacoustic models relating V_{AS} to measured electrical parameters are only approximately correct.
3. The equations for these electroacoustic models are very sensitive to errors in the measurements.

How important is it to know V_{AS} accurately? Keele[1] shows that a 25% variation in V_B (or a comparable variation in V_{AS}) will produce less than a $\pm$1dB variation in the passband response of the popular B_4 and QB_3 alignments. A 25% variation in V_{AS} has even less effect on the passband response of popular closed box alignments ($\alpha > 3$, $Q_{TC} < 1.1$). So V_{AS} does not have to be known too well unless you wish $\pm$0.1dB response and your room cooperates.

Several procedures for measuring V_{AS} exist. I will discuss four:

1. free air/closed box
2. open box
3. open box/closed box
4. added mass in free air

The first three techniques are well covered in Bullock, *SB* 1/81. They determine V_{AS} indirectly using electrical measurements and an appropriate electroacoustic model. The last technique determines driver mechanical compliance, C_{MS}, indirectly using an electromechanical model and then converts this to V_{AS} using the equations of a mechano-acoustic model. The great advantages of method four are that it requires no test box and gives accuracy comparable to method one, perhaps the best of the electroacoustic approaches.

Method one measures f_S, Q_{ES}, f_c and Q_{EC} and uses Bullock's equation to compute V_{AS}. Method two measures F_L, F_H, and F_M in an open tuned box and uses Bullock's equation 12 to compute V_{AS}. This method is approximate since it assumes $F_M = f_B$, where F_B is the port/box resonant frequency. Method 3 drops the

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approximation of method two and determines f_B from f_L, f_H, and f_C using

$$f_B = \sqrt{(f_L^2 + f_H^2 - f_C^2)}$$

and then computes V_{AS} using

$$V_{AS} = V_B\,[(f_H^2 - f_B^2)(f_B^2 - f_L^2)(f_H^2 f_L^2)]$$

which is the correct form of Bullock's equation. For those technically inclined, Benson[2] has the most complete derivation of the formulae for the first three methods (see Pt. II, Appendix 2 and Pt. III, App. 2, 3, 4 and 5).

All of these methods assume box losses are negligible. This is not a bad assumption for the closed box method where you can attain unlined box Q's in excess of 10 easily. High box Q's are more difficult to get in a vented box. Small discusses this problem[3] Even carefully built test boxes can display Q's of three or less due to leaky surrounds and other phenomena. The approximation $f_M = f_B$ breaks down when the box Q is low and f_B is very different from f_S, *ie* $h \neq 1$. This problem is further aggravated by the fact that f_M is very difficult to measure. Benson[2] shows that if you use the zero phase angle method, the measured value of f_m always will be less than f_B due to voice coil inductance. The minimum impedance method is only slightly better. By choosing a high value for f_B (*eg*, $2f_S$) the effect of voice coil inductance is further amplified. Contrary to Bullock's recommendation, method two does not always work well with small boxes and high f_B, *ie*, $f_B \geq f_S$. The substitution of f_M for f_B can lead easily to a 10% error in the latter. This in turn can produce a 20% error in the calculated value of V_{AS} for typical open-box parameters. The objections to method two are eliminated by method three which determines f_B directly from open and closed box measurements using the three easily measured frequencies f_L, f_H, and f_C in equation one. Then you can find V_{AS} with equation two or a somewhat simple equivalent form given by Benson[2]

$$V_{AS} = V_B\left(\frac{f_c^2 f_B^2}{f_L^2 f_H^2}\right) - 1$$

Method four is especially attractive since it does not use a test box. Its lack of popularity in the literature is surprising. In this method, first measure the free air resonance of the driver, f_{SA}. Then add a known mass, M, to the cone and measure the new free air resonance f_{SAM}. These data are sufficient to calculate the driver suspension mechanical compliance, C_{MS}. Using the cone area, S_D, you can then compute V_{AS}. The appropriate equations are

$$C_{MS} = \frac{1}{(2\pi)^2 M}\left[\frac{(f_{SA}+f_{SAM})(f_{SA}-f_{SAM})}{f_{SA}^2\, f_{SAM}^2}\right]$$

and

$$V_{AS} = \varrho C^2 S_D{}^2 C_{MS} = 1.39\,(10^5) S_D^2 C_{MS}$$

where

ϱ = air density (1.18 kg/m³ at 22°C)
C = speed of sound (345 m/sec at 22°C)
S_D = cone area in meters²
C_{MS} = driver mechanical compliance (meter/Newton)
M = added mass in kg

For this method to work well, you should try to get a frequency shift of 25% or more. For large woofers this may mean adding 30-60 grams to the cone, symmetrically about the cone apex. The material must be nonmagnetic (coiled solder wire, non-hardening putty, etc). The driver must be vertical to prevent preloading the suspension and you must weigh the added mass accurately. Finally, if S_D is not given by the manufacturer, you can calculate it to a good approximation using the diameter of the middle of the surround, since a portion of the surround contributes to the effective piston area.

At this point an example will help. Say we have a 12″ acoustic suspension driver with the following parameters

f_{SA} = 20Hz
Q_T = 0.3
S_D = .048 meters²
f_{SAM} = 15.5Hz

with 40 gms added to the cone. Then

$$C_{MS} = \frac{1}{(6.28)^2(.040)}\left[\frac{(20+15.5)(20-15.5)}{20^2(15.5^2)}\right]$$

$$= 1.20(10^{-3}) \text{ meters/Newton}$$

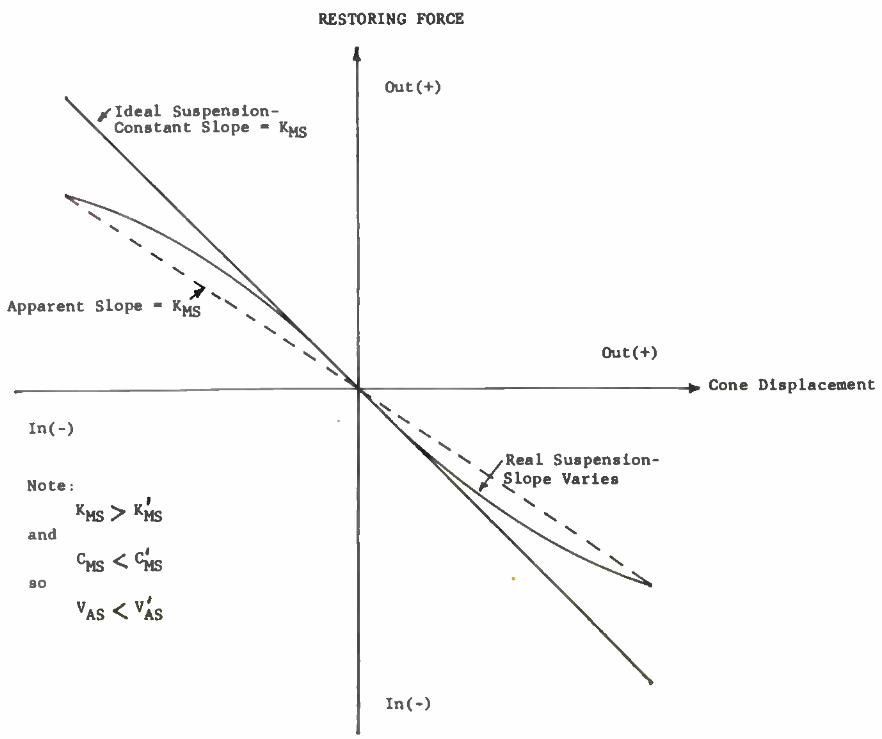
and

$$V_{AS} = (1.18)(345)^2(.048)^2(1.2)(10^{-3})$$

$$= 0.388 \text{ meters}^3 = 13.7\text{ft}^3$$

Notice that a frequency meter with 1Hz resolution would yield a measured f_{SAM} of 15Hz and a calculated value for V_{AS} of 16.1ft³ for 17% error. Thus the frequencies must be measured to 0.1Hz to get V_{AS} accurately (adding more mass if practical would reduce the effect of measurement errors).

On the other hand, using the incorrect V_{AS} = 16.1 ft³, you would choose V_B = 3.5 ft³ to get a second order Butterworth response with a computed f_C of 47.3Hz. The actual f_C and Q_{TC} would be 44.6Hz and 0.67 and the actual passband response would be within 1dB of the desired response.



RESTORING FORCE VS. CONE DISPLACEMENT FOR IDEAL AND REAL LOUDSPEAKERS

SB Mailbox

Using several different drivers and test boxes I have obtained excellent agreement between methods one and four *(ie* 10%). Method three also works well when box Q's are above five. I do not use method two because of the difficulty in measuring f_M and relating it to f_B.

Let's look briefly at the second issue raised by Kasowicz, variation in f_{SA} with drive level. This is a well known phenomenon which has little effect (ignoring distortion) on loudspeaker *system* (driver plus box) response. It is caused by nonlinearity in driver compliance. In an ideal driver the cone restoring force supplied by the driver suspension (spider and surround) is directly proportional to cone displacement from neutral (see figure). The proportionality constant (slope of ideal curve) is the suspension stiffness, K_{MS}, which is the reciprocal of C_{MS}. In a real driver the restoring force drops with increasing displacement producing an apparent stiffness which falls with increasing drive level. As the suspension becomes less stiff *(ie,* more compliant) V_{AS} increases and f_{SA} and Q_{TS} drop.

This phenomenon has almost no effect on system response. Take the closed box. As V_{AS} increases with drive level, f_{SA} and Q_{TS} drop by the square root of the percentage change in V_{AS}. The closed box system resonance and Q, f_C and Q_{TC}, are equal to f_{SA} and Q_{TS} multiplied by $\sqrt{1 + 2}$. For values of α greater than 3, the increase in V_{AS} causes α (V_{AS}/V_B) to increase enough to keep f_C and Q_{TC} almost constant.

A similar situation exists in the bass reflex design. Keele[1] shows that the bass reflex pass band response is insensitive to changes in V_{AS}. Again what happens physically is that changes in V_{AS} cause complementary changes in f_{SA}, Q_{TS}, and α to maintain proper system alignment.

In summary, you should measure driver parameters at the lowest drive level for which your equipment will provide reliable readings and remember that 20% errors in V_{AS} will have little effect on final system response.

Joseph A. D'Appolito
Andover, MA 01810

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2. J. E. Benson, "Theory and Design of Loudspeaker Enclosures," "Part I: Electro-Acoustical Relations and Generalized Analysis," *Amalgamated Wireless (Australasia) Ltd. Tech Rev.*, Vol. 14, pp 225-293 (May 1971): "Part III: Introduction to Synthesis of Vented Systems," *ibid.*, Vol. 14, pp 369-484 (Nov. 1972).

3. R. H. Small, "Vented-Box Loudspeaker Systems, Parts I-IV," *JAES*, Vol. 21, pp. 363-372, 438-444, 549-554, 635-639 (1973).

Tools, Tips & Techniques

Continued from page 33

ly behind the midrange so that the system is acoustically in phase. Variable driver positions permit optimization when electronics and speaker/interconnect cables are changed.

The Fulton Premieres, Dahlquist DQ10's and other speakers utilize this principle. This configuration offers two advantages. First, each driver operates in its most linear range, and second, all drivers can be staggered to achieve better phase coherence among them.

Since planar speakers generally cannot be staggered (although owners of Timpani I-D's often vary the placement of the panels), I recommend that high quality, high bandwidth audiophile electronics be used. A better compromise in my opinion is to select or build adjustable speakers and fine tune the driver positions until the speaker is in phase with the electronics, speaker cable, and interconnect cable.

Speaker cables and interconnect cables also can produce phase shift through the skin-effect phenomenon (high frequencies tend to travel on the circumference of the conductor and low frequencies travel through the center portion of the conductor.) Adjustable staggering of drivers offers a good method to compensate for system phase shifts introduced by the electronics and by connecting cables. It permits you to optimize a system for a specific combination of equipment, and make the necessary changes when you upgrade a part of your system.

Peter B. Jacquemin
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Selects between up to 4 phono inputs. Used with DBP-6 or 6MC, allows for selectable loading of cartridges.
DBP-6 PHONO EQUALIZATION KIT......................32.95
Allows adjusting the input capacitance of the phono input of every preamp and receiver with low loss Polystyrene Capacitors.
DBP-6MC RESISTIVE LOADING KIT....................32.95
Allows adjusting load resistance from 10 to 200 Ohms for moving coil cartridges. Gold plated phono plugs in both kits.
DBP-8 SPEAKER WIRE 12 ga., in 3, 6, 9 meter and bulk.
DBP-9AU BANANA PLUGS Eight gold plated, solderless..11.95
DBP-9H BANANA HANDLES Four red, four blk............5.50
DBP-9J GOLD PLATED DUAL BANANA JACKS 2 pk....14.95
DBP-10 PHONO ALIGNMENT PROTRACTOR...........21.95
Allows adjusting the lateral tracking error of a mounted cartridge to within ¼ of one degree. Non-technical instructions & case included.
DBP-12 AUDIO CABLE 10 meter (33 ft)..................65.95
Low capacitance (400pF) stereo interconnect cable, terminated with rugged gold plated phono connectors. Custom lengths available.
DBP-13J GOLD PLATED PHONO JACKS (¼") 8 pk.....11.95
DBP-13JR GOLD PLATED PHONO JACKS (⅜") 8 pk.....14.95
DBP-13P GOLD PLATED PHONO PLUGS 8 pk............9.95
DBP-14 GOLD PLATED SPADE LUGS 8 pk...............5.95
DBP-CK CRAMOLIN AUDIO KIT contact treatment........12.95
ELECTRONIC CROSSOVERS...6, 12, 18, 24dB..........Inquire
At your dealer or direct. Orders under $45, add $2.50 Handling.

DB SYSTEMS
Main St., Rindge, NH 03461 (603)899-5121

THE BOSTON AUDIO SOCIETY INVITES you to join and receive the monthly B.A.S. SPEAKER with reviews, debates, scientific analyses, summaries of lectures by major engineers. The BAS was the first to publish info on TIM, effects of capacitors, tonearm damping, tuner IM dist., Holman's and Carver's designs, etc. Sample issue $1. sub, $15/yr. P.O. Box 7, Boston, MA 02215.

Southeastern Michigan Woofer and Tweeter Marching Society

Detroit area audio construction club.

CONTACT: DAVE CARLSTROM 10155 Lincoln Huntington Woods, Michigan 48070 313-54-48453

SAN FRANCISCO BAY AREA AUDIOPHILES, Audio Constructors society for the active, serious music lover. We are dedicated, inventive and competent. Join us in sharing energy, interest, expertise, and resources. Send self-addressed stamped envelope to S. Marovich, 300 E. O'Keefe St., Palo Alto, CA 94303 for newsletter.

THE AUDIO SOCIETY OF HONOLULU cordially invites you to attend one of our monthly meetings and meet others like yourself who are interested in the how's and why's of audio. Each meeting consists of a lively discussion topic and equipment demonstrations. For information on meeting dates and location contact Bob Keaulani at 1902 South King Street, Honolulu, HI 96826. (808) 941-1060.

PACIFIC NORTHWEST AUDIO SOCIETY (PAS) consists of 50 audio enthusiasts meeting monthly, second Wednesdays, 7:30 to 9:30 PM at 4545 Island Crest Way, Mercer Island, WA. Be our guest, write Box 435 Mercer Island WA 98040 or call Bob McDonald (206) 232-8130.

SERIOUS AUDIOPHILES in Conn., or Putnam or Dutchess Co., NY, contact John J. McBride, 33 Perry Dr., New Milford, CT 06776 (203) 355-2032.

CONNECTICUT AUDIO SOCIETY WANTED. Serious audiophiles in Conn., or Putnam or Dutchess Co., NY, contact John J. McBride, 33 Perry Dr., New Milford, CT 06776, (203) 355-2032.

PRIVATE FOR SALE

DCM Time Windows (modified) Cabinet deadened with Duxseal internally. Outboard mounted crossover with TRW poly caps and Dale resistors. Purchasing electrostatics. $350. Four Eminence 12″ woofers taken from Sound Lab subwoofer system. $15 each. Harry Paller, 8203 Walsh, River Grove, IL 60171, (312) 456-1285 after 7 CST.

Great American Industries drivers at below cost: 10″ 28 oz. polyprop (10W828PF), $35/pr. 8″ 20 oz. polystyrene (8WM820LP), $30/pr. 6.5″ 20 oz. polystyrene (68W20LP), $28/pr. Audax HD13D34H 8Ω, $38/pr. All components brand new. 626 Robinhood Pl., San Antonio, TX 78209, (512) 824-8556.

KEF B139, $175/pr. PEERLESS: KJ20DMR 2″ dome mids, $38/pr, TX 255 10″ poly. woofers, 4 ohm, $49/pr, PHT 19 tweeters, $19/pr. AUDAX: MH017HR37TSM 6½″ mid., $62 pr, HD13D37 1½″ dome mids, $42/pr, HD17B25J2 6½″ Bextrenes, $36/pr. SEAS: H204 3″ dome mids, $55/pr. Possible trades. Steve, (805) 964-0245. 9AM-1PM weekdays, anytime weekends.

Revox B77 with dust cover and 9 tapes, $1000, $1800 new. AGI 511A stereo preamp and wooden case. 3 nanosecond risetime, $250. Mitsubishi DA-A10DC 100W amp, $250. 1 Sennheiser 421, $150. 2 M500 Beyer Ribbon Mikes, $250 pr. 2 M3500 Revox Mikes, $200 pr. All in excellent condition with boxes and all papers. Paul Stangeby, 3713 E. Virgin St., Tulsa, OK 74115, (918) 834-8926.

JVC UA7045 arm, new, never mounted, $165. GAS Grandson (metered) and Thalia, both mint, $400. GAS Thoebe, mint, $265. Jordan modules, new, raw, $70 ea. Jordan modules, 2 pr. mounted in clay and wool filled cylinders, $300. Bearcat 220 20 chan. scanner, $275. Panasonic 2900 AM/FM/3bd sw receiver, mint, $185. Commodore N60 flight computer and manual, $60. Russ, PO Drawer H, Foresthill, CA 95631, (415) 494-2700.

Hafler DH-220 Kit, DH-110 Kit, $550 both. DH-355 cylinder speakers, $325 pr. EUMIG C-1000 preamp with M/C input, M-1000 amp 125W per channel, power LEDS $580 both. Harman-Kardon CD-401 cassette w/Dolby HX, 3 heads $585, CD-301, $435. HK-580i $390 receiver, HK680i $500. Radio Shack Model 3 computer, 48k, four drives, 6.4 meg hard disc, mail list, printer, much software, sell all or parts, $3725 takes all or best offer on parts. Sony PCM-F1, $1450, TC-K555 3 head cassette, $350, Ace Audio Preamp, $55, PS Audio preamp, $40. Integral systems 700 amp, 350 watts/chan rack mount monster, superb for biamp or PA/Disco use, $400. Dyna Mark 6 mono tube amps, exc. cond., $300 pr. or b/o. Dual 506 turntable, grado G-1 + cart. $200 or b/o, (203) 777-1476.

Audiopulse Model 1 w/rackmount, very clean, $200. 3 pairs handcrafted, veneered speakers designed for use with the Audiopulse or similar system, $75/pr—cost of materials. Sansui AU117 amps at $100 available with each pair of ambience channel speakers. Russ Button, PO Box 27643, San Francisco, CA 94127, (415) 239-5337.

Dale Goldenfinned non-inductive 250W 4 ohm resistors new, matched to .01% w/m.o. or cert. check limited amount, w/hardware $16. Nick Palladino, 33 Village Rd. North, Brooklyn, NY 11223, (212) 996-2252.

Infinity E.M.I tweeters as used in I.R.S. system $16 ea., as used in the Q.R.S. system $25 ea. Michael Marks, 448 Westover Hills Blvd., Apt. 206, Richmond, VA 23225, (804) 233-7041.

15″ bass spkrs, w/7 cu. ft. enclosures, custom made, $200/pr. EV, mid-range horns, $125 pr. Motorola piezo tweeters, $10 pr. Jim Thornhill, 2112 S. Beacon St., Muncie, IN 47302, (317) 747-4017.

PRIVATE WANTED

Copies of the following books: *Passive Audio Network Design* by Howard M. Tremaine (Howard Sams & Co., 1964); *Loudspeaker Design Cookbook* by Speaker Research Associates. Paul A. Wishnafski, 2 Michaels Way, Wallingford, CT 06492, (203) 269-4294.

Discs: Brubeck plays Brubeck, Brubeck in Amsterdam. Heathkit electronics courses. Lew Offsink, 8800 Shore Front Pkwy, Rockaway Beach, NY 11693, (212) 945-0004.

I'm looking for 1 pair used Strathearn ribbons and Dalesford D100/200 in good condition. Send price quote to: Jay Hageman, 2044 Glenco Terr., Ft. Worth, TX 76110.

Old coax—triaxials: Jensen 15″ G-600, 12″ SG300, 223, 222; Stephens 15″ 152 AX; Racon 15″ 15HTX, 15X-B, 12″ 12HTX, coaxials; RCA 15″-12″; Calrad 12″ TX4; GE 12″ A1-401; Stentorian 15″; Stromberg 15″ RF484, 475; 12″ RF487, Norelco full range 8″ AD4800M, AD4877M; 10″ AD1050M. Singles ok. No cabinets. Grundig portable radio TR 3005, TR6000 (1), Satellit 3000, or C-9000 in good cond. Ask friends. B. Kalish, 565 Walnut Ave., Redlands, CA 92373.

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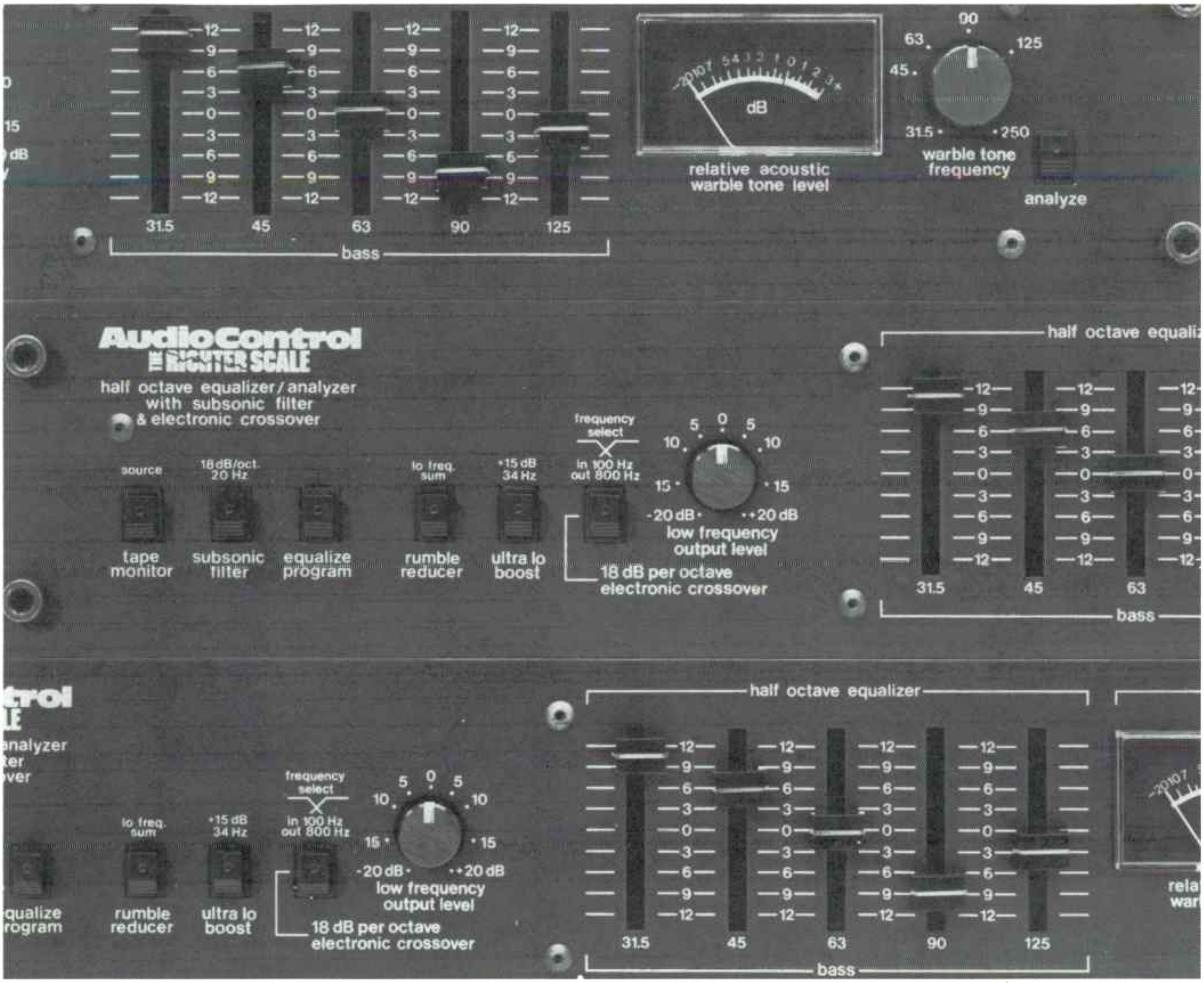

NEW HOPE FOR UNDERSIZED BOTTOM ENDS.

±1dB 20Hz-20,000Hz.

The Richter Scale™ is the world's first half-octave bass equalizer with built-in electronic crossover, Rumble Reduction Circuit, 18dB/octave Subsonic Filter, Ultra-Low Bass Boost circuit, sweepable Warble Tone Generator and Measurement Microphone. All in a unit just 14" x 2.5" x 6."

For precise equalization the Richter Scale employs a half-octave Warble Tone, the same type of test source used by B&K for calibration of its precision microphones under 150Hz. The stereo output tone is read with an Audio Control phantom-powered condenser Measurement microphone and a special damped ballistics dB meter.

The Richter Scale's Rumble Reduction circuit mono's bass under 200Hz to cancel vertical record components and tonearm resonances.

The 18dB Tchebechev subsonic filter is down 24dB at 10Hz.

An Ultra-Low Bass Boost circuit adds +15dB at 36Hz, seemingly an overabundance of EQ, but in reality barely compensation for the cumulative loss from microphones, analog tape, and mastering, not to mention wimpy woofers.

The electronic crossover is a special asymmetrical design with 18dB/octave roll-off of bass and 6dB/octave roll-off of treble. In addition to 100Hz subwoofer and 800Hz 3-way crossover points, the unit is dealer modifiable to any other custom crossover point. A recent Stereo Review evaluation observed less than ±.25dB deviation from flatness across the whole audio spectrum.

Overall distortion was found to be .003% compared to our modest .015% published spec.

How much?

$249.

For either a half-octave equalizer/analyzer or electronic crossover alone, a stunning price.

Write us for more information.

And then enlarge someone's bottom end soon.

shown: D-11 octave/analyzer, R/S, D-10 octave

AudioControl

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