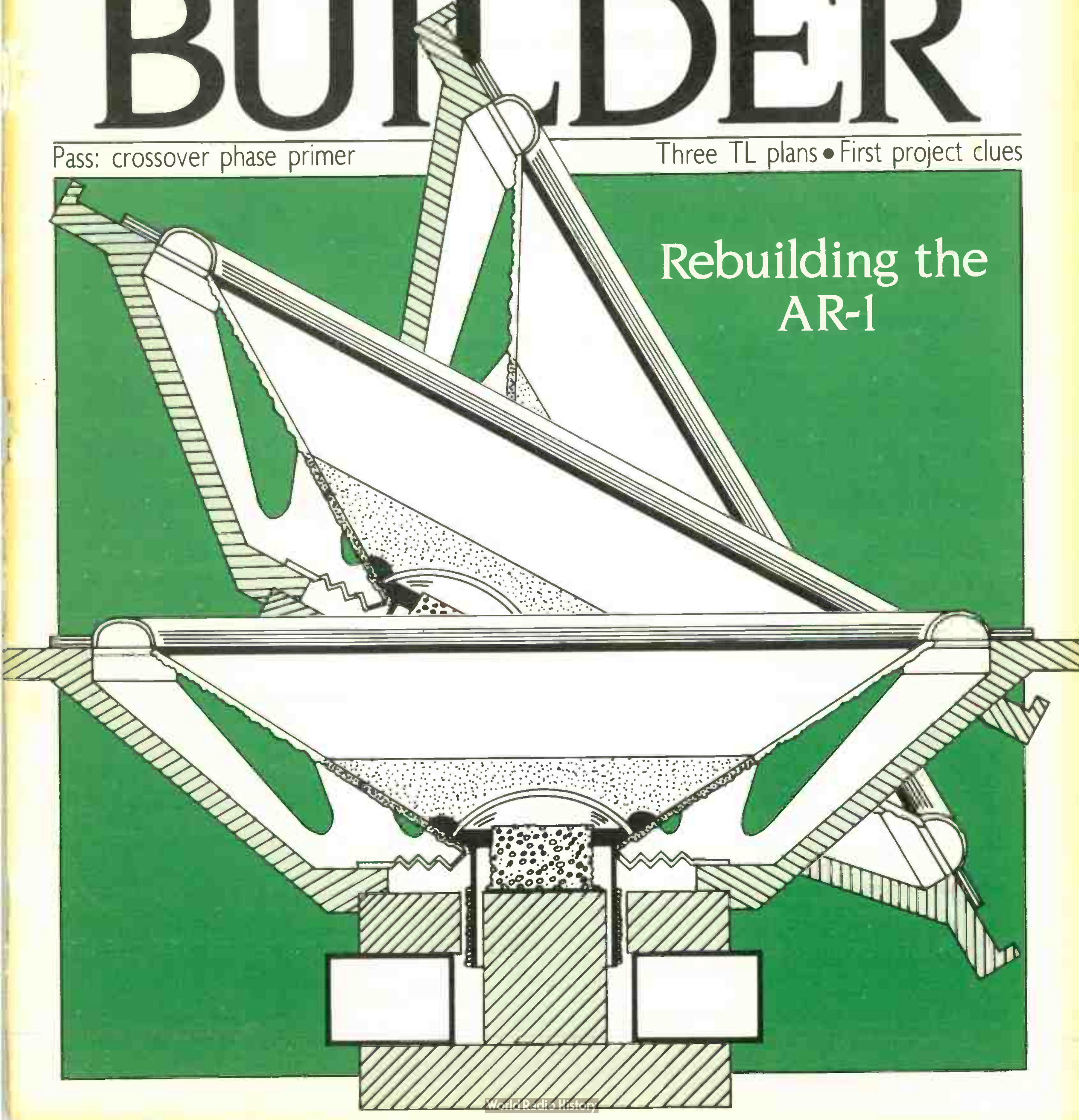
2/82

US $3.00

SPEAKER BUILDER

Pass: crossover phase primer

Three TL plans • First project clues



Rebuilding the AR-1

Good News

CELESTION has a new speaker featuring a passive radiator woofer and their laser-optimized tweeter. The passive radiator design, which was introduced by Celestion in 1966, improves low bass response and is relatively efficient. In this application, the woofer is 6" to facilitate low distortion midrange response, and the passive radiator is 8", extending bass down to 45Hz. The tweeter handles power well without distortion. Visit your dealer for an audition or write to them at Box 521, Holliston, MA 01746.

From **AUDIO CONCEPTS**, 1919 So. 19th St., LaCrosse, WI 54601 comes a nice price list written from the point of view of people who have built many speakers themselves. Descriptions, comments, and suggestions for use make the price list useful and friendly. They carry Audax, Dalesford, Jordan, Decca, and SEAS, along with recommended crossovers and parts. Cabinets are also available.

The Loft active crossover is available from **PHOENIX AUDIO LABORATORY**, 91 Elm St., Manchester, CT 06040. This unit's special attraction is its flat response in the crossover region, achieved using summed amplifiers. Though intended for professional use with 600 ohms balanced lines, it will accept high Z unbalanced inputs as well. Three configurations are available: a stereo 2 way, a mono 2 way, and a mono 3 way. Controls are nicely thought out so that accidental mis-settings are difficult.

JUST SPEAKER CO., 233 Whitney St., San Francisco, CA 94131 sells a variety of raw frame drivers including Audax, Becker, Foster, JVC, Philips, Jordan and SEAS. They also have crossovers as kits, assembled, or parts. Items of special interest include the ribbon tweeters from JVC and Foster, the SEAS treated-paper cone midrange, and the Audax aluminum cone supertweeter.

Woodworking tools for connoisseurs are featured in the new catalog from the **PRINCETON COMPANY**. Specialized and unusual tools for all kinds of tasks abound, including dovetailers, mitre boxes, routers, and elegant sets of carving tools. The planes on p. 26, made of beechwood and pearwood, with chrome-vanadium steel blades, are beautiful just to look at, and surely must be a joy to use. Exotic Japanese samurai saws which permit fine control are included, along with a Japanese sawstrap. Excellent English, German, and Scandinavian tools appear also. If you get tired of woodworking, try their gardening tools, or even their cheese knife. The address is PO Box 276, Princeton, MA 01541.

IMF Drivers

An English company, **BADGER SOUND SERVICES, LTD.** has recently become retail distributor for IMF drivers. Recognizing the needs of home builders, they will provide the necessary Thiele/Small parameters for these and other drivers. They have developed a series of recommended designs, including a transmission line system based on the Webb design which appeared in *TAA* 1/75. Several systems can include the amplifiers inside the speaker cabinets if desired. Write to them at First Floor, 46 Wood St., Lytham St. Annes, Lancs. FY8 1QG England.

Dispersion has been a problem for electrostatic speaker designers. Few of them have not dreamed of a spherical electrostatic device, no doubt. One who has dreamed and then acted is John Civitello. His new firm **GEOSTATIC, INC.**, is announcing the Geostatic Mark I system which features a spherical shaped electrostatic transducer which is fed by an amp crossed over at 450Hz. The bass is handled by two 12" drivers in a transmission line on casters. Power requirements for the electrostatic: 100W minimum into 2 and for the woofers 100W into 4. The system does not include power amps or crossover. Almost five feet high, the system weighs 150 lbs. The electrostatics are available separately and priced under $2500 pr.

The complete system with added woofers is just under $5000 pr. A crossover is available from Geostatic as well. Civitello is a long time reader of *TAA* and a dedicated audiophile. Those of you who enjoy electrostatics will want to keep up with what is developing here and get a chance to hear one of these new transducers if at all possible. Information is available from **GEOSTATIC, INC.**, 226 Vreeland Ave., Dept. TAA, Paterson, NJ 07504.

King Snake II Ultra speaker cable has been announced by **ESOTERIC AUDIO, USA**. Using "new improved fine gauge stranding and pure copper," the snake is said to improve transient response and bass. A variety of gold plated connectors is available to terminate the wire, or it may be purchased in ready-made lengths. See your dealer or write to 408 South Main St., Woodstock, GA 30188.

About This Issue

Back in the fifties *High Fidelity* published the first article ever on the brand new acoustic suspension speaker format. Edgar Villchur's bookshelf sized speaker used a new driver with a super compliant cone. **Walter D'Ascenzo** leads off this issue with a rebuild of what has become a classic, Acoustic Research's AR-1. D'Ascenzo takes his inspiration for the changes from Walt Jung, Chuck Hollander and Dick Marsh's "Pooge" articles in *Audio Amateur's* 1981 series.

Nelson Pass explores the many factors involved in the whole question of how crossover networks affect phase starting on page 12. In issues 3 and 4 we will follow up with some practical applications.

Wilfred Harms offers suggestions on improving passive crossovers on page 18. For those readers who have yet to build their first speaker, **David Baldwin** offers guidance, encouragement and practical tips on page 25.

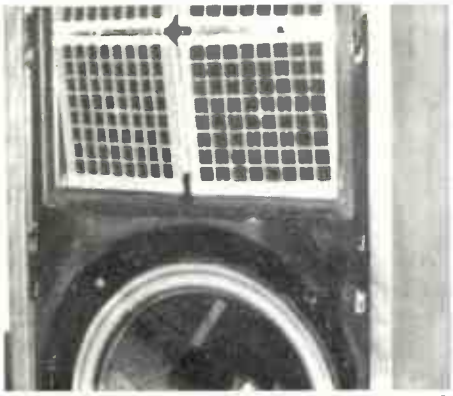
Gary Galo concludes his two-part series on transmission lines on page 24, with three sizes of construction projects.

We welcome two new people to the staff this time. **Steve Birchall** brings an array of talents and experience in music, recording and audio merchandising to his duties as assistant editor. **Nancy Estle** is responsible for the beautiful redesign of our pages and the cover art which is adapted from Walt D'Ascenzo's original drawings.

SPEAKER BUILDER

VOLUME 3 NUMBER 2 MAY 1982

FEATURES



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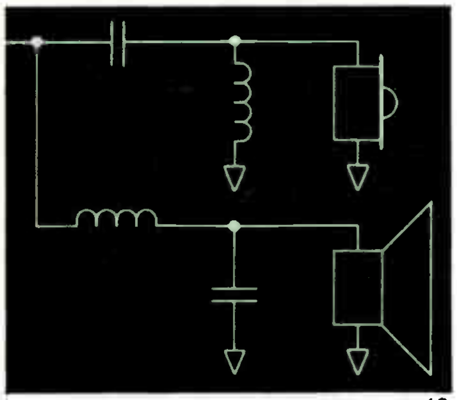

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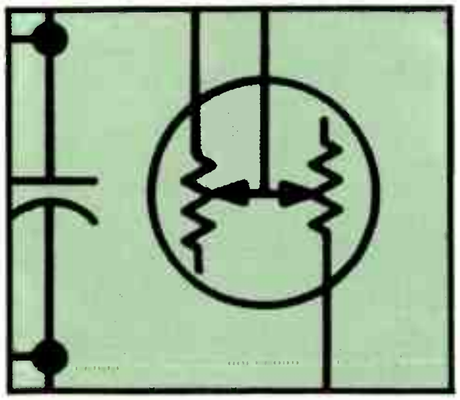

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Editorial

Is *enough enough*?

The saw's biting cut into a sheet of fresh plywood produces a smell I always associate with spring and loudspeakers. With the project well defined, the cutting drawings doped out thoroughly, a few gross of screws readily at hand, sharp blades on the jigsaw, the table saw, and the router, I am off on what is, for me, one of the world's most satisfying pursuits.

A new set of untried drivers, a revised crossover design, and some fresh ideas about damping resonances, avoiding diffraction, connecting the wiring through the panels, subsequent access to the unit's interior, and new finishes makes the prospect all the more inviting.

To the outsider all this doubtless looks like a trivial quest. For us it is sonic high adventure. The new speaker system always has a character of its own—a unique re-shuffling of the details in the familiar recorded favorites we know so intimately. How do we relate these variations to what is different in the new device we have just constructed?

In such a manner we assemble listening and speaker performance data in our heads. The sense of discovery is intense and one of the primary pleasures of our human capacity as makers. It is for us far more than a smug pride of accomplishing something most other people do not. It is adventure into an unknown region and doing it yields both the pleasures of the making and of new knowledge and understanding.

But this love of the quest is also a point of ridicule. Those of us who love good sound are used to the charge that we get more pleasure out of playing with the equipment or the tools than we do from the music. For such critics, music is apparently a self-justifying value. Craft or the exploration of mechanical/aesthetic interfaces apparently does not command an equal respect, or valuing.

The condescension in the critic's view that we hi fi nuts are a little crazy to spend the time and effort we do on what is apparently an endless search for "perfection" is, I believe, based on the pragmatic American belief that in all things there is some point where enough is enough. Objective support for or proof of the value of this viewpoint is not plentiful. In my view the spread of this "virtue" within American culture today is a cancerous, devastating phenomenon that blights a majority of the things we make. A standard of mere "good enough" degrades everything from prefabs, coffee cups, plastic shoes, and disposable lighters to TV sitcoms and soaps. A "good enough" auto industry is up against competition from cultures which view work and achievement as noble and will apparently go to any lengths to make a product that is better than anyone has made before—and for less money. "Oh, that's good enough for anybody" is a disease among us Americans that is the root of our troubles in many areas.

A large percentage of U.S. engineering talent is engaged in the very American enterprise of taking good, quality products and finding ways to make them cheaper—but, of course, "just as good." Those of us who pay for the "just as good" know what it is: cheap, shoddy, and disgusting. More profitable for the maker and not much else.

Part of my joy in my workshop turning out yet another speaker system with quality components is the chasm separating me from the unreliable, flimsy, fast world of throw-away "just as good." For me, enough will never be enough. And something tells me my humanity is a little stronger, a little more secure, for it

THE AR—1 REJUVENATED

BY WALTER D'ASCENZO

Many speaker systems leave much to be desired and at least to this observer, woofer systems generate the most complaints. You have only to read through equipment reviews in the various magazines to taste the full flavor of the problem. Comments such as: "...lacks deep bass range...", "...Speaker has a tendency toward boominess...", "...woofer does not blend well with upper range drivers..." abound. A review of even one speaker system that managed to escape criticism of its woofer would be hard to find. Acceptable performance in the deep bass range, bass detail, transition to the midrange and compatibility with low mass, "fast" drivers (eg electrostatic panels) are difficult to obtain at reasonable cost.

Acceptable performance can be defined as the following:

1. **Deep bass range** (25 to 40Hz). Output equal in level to the midrange output of the system.

a. The woofer should be able to reproduce *with impact and authority* such instruments as the concert bass drum and the pipe organ (which has pedal fundamentals reaching down to 32Hz).

b. A secondary effect at this level of performance is a sense of weight, but without constriction, low frequency ambience, if you will.

2. **Bass detail.** Fast transient response brings clarity and definition to the sound. Simple frequency response in the deep bass region is not sufficient. You want to be able to hear all the notes as they are being played. You will know it is good when you can hear crisp, well-defined attacks on plucked string sounds or a solid "whack" at the beginning of a bass drum stroke.

3. **Midrange characteristics.** Output should be flat to at least 2,000Hz, with minimal midrange "ringing." The woofer does not always behave as a piston in the middle frequencies but often breaks up into smaller vibrational modes which create coloration.[1] Several ways of controlling this problem exist, and will be used later.

4. **Compatibility with low mass drivers.** Often a speaker with mixed driver types lacks cohesiveness. Large cone woofers do not have the same sound as high performance tweeters (such as electrostatics), so the designer must minimize those differences. The system should *sound* like *one* full-range driver.

A PRACTICAL SOLUTION. Experience is the best teacher (or so the POOGE says). After working on seven generations of acoustic suspension woofers in my system and a couple more for others, I have evolved a way to select and modify drivers and tune the enclosure to these modified drivers which is easily repeatable for any hobbyist who knows some basic construction skills (see acknowledgements). More importantly, you will enjoy the "acceptable performance" that is so hard to obtain from commercially available speakers.

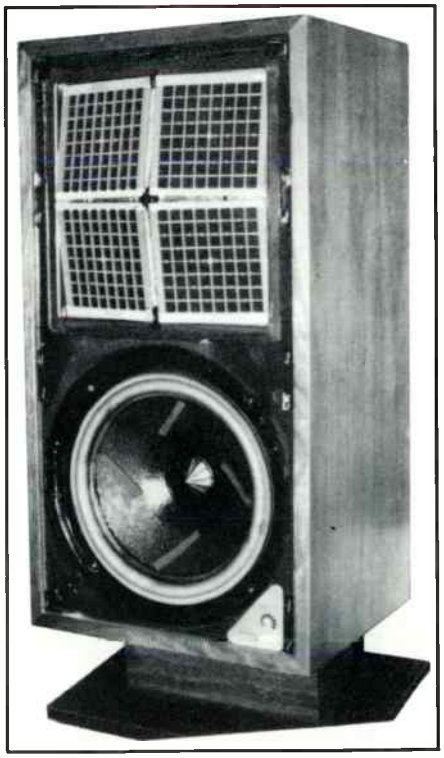

PHOTO 1: Modified Janszen Z412hp now has deep bass response matching the detail and low coloration of the electrostatic elements.

The instructions to follow will deal only with Edgar Villchur's brainchild,[1] the acoustic suspension woofer, its modification, and retuning of the enclosure. If, after reading through the material, you should ask, "Why don't the speaker manufacturers do this?" the answer is simple economics. The work is labor intensive and can increase the cost of a system beyond reason. Moreover, many speaker manufacturers believe that consumers prefer boomy, poorly defined bass, and have the sales figures to prove it.

STEP-BY-STEP 1. Select the drivers.

a. A 12-inch woofer provides the best trade-off between the size and mass. (The industry measures the diameter at the frame rather than the cone, so a 12-inch woofer has an eight-inch diameter cone.) You diehards out there can play around with larger diameter drivers. You will, I believe, sacrifice midrange performance and transient response if you do.

b. Free air resonance should be no higher than 20Hz and no lower than common sense dictates. Actually I have not seen any production drivers with a free air resonance below 15Hz, although Edgar Villchur has designed a system around a driver with a free air resonance of 10Hz.[1]

c. Cone material should be either the thick vacuum formed paper type[3] or the new polypropylene type. A more rigid cone has better transient response and resists break-up into smaller vibrational modes. Polypropylene has high rigidity and lower mass than paper.

d. The surround should be the half-round type of either rubber, closed cell foam or treated canvas. Usually drivers with a pleated surround are not compliant enough, resulting in a high free air resonance.

e. Magnet weight should be no lower than 30 oz. and no higher than 54 oz.[1] Keep in mind that magnet *assembly* weight does not count for anything other than marketing hype. You are looking for magnet weight only.

f. Impedance is not critical, however eight ohms will make life easier should you continue your project beyond the scope of this article and build a full range system.

g. Basket construction should be rigid and sturdy. You will get one "Atta-boy" if you locate a driver with a cast aluminum basket.

The 12-inch driver manufactured by Teledyne Acoustic Research, part no. W 12″ 200003 would be preferred. This unit worked well in my own electrostatic system and the POOGE sW-1 subwoofer. (See photos)

2. Select or build the enclosures.[2]

a. The optimum internal volume is between 1.7 and 2.0 cubic feet. Increasing the volume will not improve performance, but will degrade it. Naturally, the use of larger drivers would dictate a larger enclosure. Guidance toward that end can be obtained from Victor Brociner's article in the March, 1971 issue of *Audio* Magazine.[4]

b. Above all, a square box is out. Square boxes, because the distances between interior surfaces are equal, behave like Helmholtz resonators.[6] A rectangular box with proportions such as 25 inches long by 15 inches wide by 11 inches deep is acceptable.

c. The material used should be either reinforced particle board or plywood. The reinforcement should be by means of interior bracing to make the back and sides of the box as rigid as possible. Cabinet flexing causes mushy bass.

d. Construction should follow generally acceptable woodworking practice. Remember, the enclosure must be airtight.

e. Seal all joints and cabinet penetrations from air leaks.

3. Modify the driver. (*steps b, c and h not required for polypropylene drivers)

The cone has to be treated to damp spurious resonances and aid the midrange performance. Also, the empty chamber that is formed between the dust cap and the magnet pole piece has to be taken care of to eliminate resonances.

a. Very carefully cut away the dust cap with a razor knife, being ever on the alert not to puncture the cone.

*b. Temporarily stuff some tissue paper into the empty chamber around the driver's voice coil form to keep foreign matter away from the gap while performing the next steps.

*c. Using a commercially available liquid plastic such as Valspar®[d], soak the speaker cone through to a radius of two inches by carefully applying the plastic with a brush (see *Fig. 1*). Continue brushing until the cone material stops absorbing the plastic. You will know when because the plastic has soaked all the way through to the back side of the cone and the top surface is glazed and remains so. Allow to dry overnight or about 12 hours.

The rigid plastic portion of the driver cone now functions as a pseudo-midrange, making it easier for the woofer to propagate frequencies above 200Hz. The late Lincoln Walsh developed a full range driver in 1969 using this very principle.

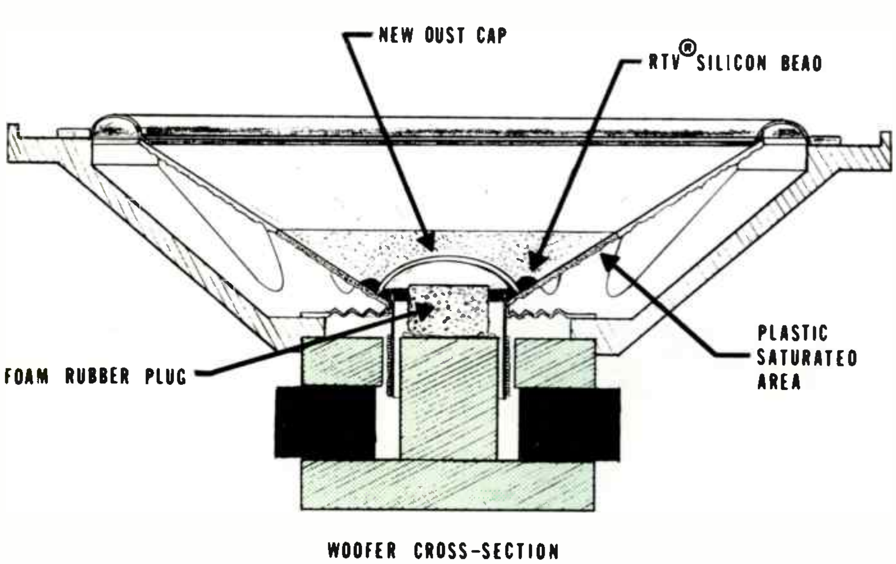

FIGURE 2: Resonances are controlled with new dust cap and foam plug in voice coil chamber.

d. Select a replacement for the dust cap. (When using a polypropylene driver, try to salvage the dust cap if it is made of the same material.) The replacement dust cap should be acoustically inert, light in weight, roughly convex in shape and made of a firm vinyl material. A trimmed vinyl drain stopper has served the purpose and so has a trimmed vinyl umbrella from a Christmas ornament. A little imagination while shopping in a hardware or gift store can go a long way. The diameter of the new dust cap should be only ½″ greater than the driver's voice coil form. Painting the new dust cap for better cosmetics is all right.

e. Remove the tissue from the empty chamber and bond to the magnet pole piece (using automotive weatherstrip adhesive[a]), a soft foam rubber plug cut to a diameter of ¼″ less than the inside diameter of the voice coil form and as long as possible, allowing clearance between it and the new dust cap with the cone bottomed out. (See *Fig. 2*) Foam that is used for making pillows and cushions found in fabric shops is suitable. The foam plug "stuffs" the chamber like a miniature enclosure eliminating a major source of ringing.

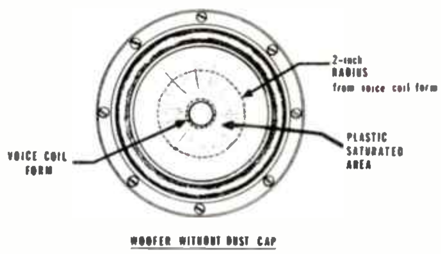

FIGURE 1: Modification begins with removal of dust cap and coating portion of the cone with plastic to gain rigidity.

f. Set the new dust cap in a bead (¼″ in cross-section) of GE RTV[4] silicon rubber.[b] Let cure overnight or 12 hours. The silicone rubber dampens resonances at the apex of the speaker cone (see *Fig. 2*).

g. Bond four sponge rubber strips such as Frost King® ⅜″ by 5/16″ weatherstrip tape© to each quarter of the cone, outside the area impregnated with plastic, using the weatherstrip adhesive.[a] These strips will extend from the edge of the first two inches of radius (or the part impregnated with plastic) to the edge of the surround at a 45° angle to the radius. (See *Fig. 3*)

The angle is important because it enables the rubber strips to dampen the outer portion of the cone in two directions, helping to eliminate undesirable coloration.[3]

*h. With common household rubber

PHOTO 2: Two of these POOGE-sWI subwoofers upgrade the single muddy 18" subwoofer of the Infinity Servo-Static I to reproduce deep bass with the clarity and purity of timbre needed to complement the electrostatic panels.

PHOTO 3: Close-up of the author's finished woofer. Note the plastic saturated area and the way the new dust cap is seated in the bead of silicon.

cement,[f] coat the remaining cone area not impregnated with plastic.

Besides getting high on the fumes, you are sealing the remainder of the cone. Most paper cones are porous and thus behave the same as an air leak.

4. **Stuffing the enclosure.**
Stuffing the enclosure has a direct effect on the in-cabinet-resonance of a driver and on coloration. Too little will yield an output peak in the bass, too much overdamps the system and attenuates bass response.[2] Not the right kind will have a direct impact on the coloration of a system. You have all heard stories of the benefits of using English wool in an enclosure.[6]

The key to this procedure is to tune for the lowest cabinet resonance.[4] In this case, 36Hz (approximately D) is a reasonable goal. In my experience a combination of two-inch foam (remember the type used in furniture?), Polydacron® fiberfill[g] (also used in furniture) and fiberglass[h] is the best way to remove coloration (damping and resonances) in the upper bass range and midrange frequencies. (See *Fig. 4*)

a. Place the speaker on its back, and starting with the bottom of the enclosure, lay in a 2-inch-thick layer of the foam, being sure to cut clearance in the foam for the reinforcing struts in the enclosure.

b. Follow with the Polydacron© fiberfill just about up to the bottom of the woofer. Take fluffy balls of the Polydacron© and fill the box with these until you have it packed in such a way that you can slip your hand through the filling. The filling should resist your hand but at the same time let it pass. Would fluffy-firm help? A safe bet would be approximately 20 oz. by weight.

c. Finish off with a three-inch layer of fiberglass batting just below the driver. To keep stuffing material out of the moving parts of the woofer, place a piece of cheesecloth or similar material around the basket.

d. Mount the driver, sealing it with either a rubber gasket if the routed driver mount flange is smooth and without major imperfections) or Mortite© rope caulk[e,1].

5. **Tuning the enclosure.**

a. Check cabinet resonance with an audio signal generator, amplifier, voltmeter and 100 ohm resistor (see *Fig. 5* for wiring details and instructions).

Cabinet resonance between 30 and 40Hz is good. If it is higher, your work is cut out for you. Either you have overstuffed or understuffed. Chances are my

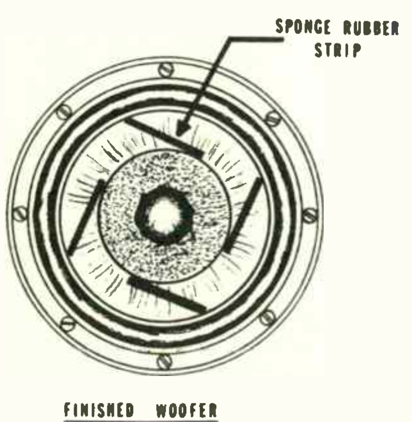

FIGURE 3: Cone resonances are dampened with four sponge rubber strips.

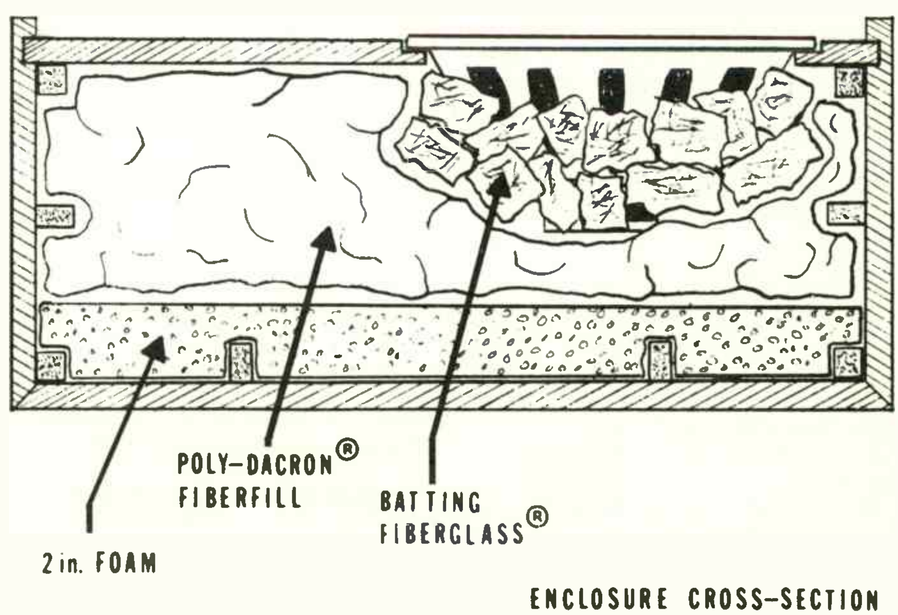

FIGURE 4: Three different materials control cabinet resonances. Cross braces strengthen cabinet.

"fluffy-firm" description was not good enough. Dis-mount the driver, pull out a double handful of the Polydacron,© re-mount the driver and check the cabinet resonance. If the resonance is coming down, remove stuffing a handful at a time until the resonance rises again. Then backstep one double handful. A handful is that amount of Polydacron© you can close your fist around and which, upon relase, springs back to the size of a grapefruit.

Tuning is a frustrating task. A lot of material has been written on the subject with plenty of mathematics to make matters complex. Using plain English, I just attempted to describe the mechanics involved in tuning the enclosure for optimum "Q" (the ratio of reactance to resistance)[4,5]. Real-time analyzers (such as the Ivie unit) save time because you can observe easily a response peak (or bass roll-off) which indicates the need for more (or less) stuffing.

Give the new woofers an ear test. If the cabinet resonance is as low as possible and you feel the bass power could be better, your cabinet may be too air tight. To answer the question why so much care was taken to seal the system in the first place, you can now control the amount of air leakage to fine tune the enclosure. Try drilling a 1/16" hole in the enclosure about two inches from the driver. A second 1/16" hole may help even more if you did a good job sealing the system. Keep in mind that the holes can be easily resealed and redrilled at will for test purposes, hidden air leaks cannot.

If you are going on to a full range system, the highest practical crossover point will be 800Hz. Should these systems be used as sub-woofers for a pair of Magnepans© or electrostatic screens, a crossover of 100Hz will work well. Again, a real-time analyzer can be a tremendous help. Setting levels is important for a cohesive sound.

CONCLUSION. Day to day use of these speakers has revealed the existence of musical information on records and tapes that many audiophiles dream about hearing, without realizing it was always there. As most readers of *Speaker Builder* will probably attest, experimenting with and building speaker systems can be a very rewarding hobby, with a high ratio of improvement vs. dollars spent on their sound systems.

Proper speaker placement can put the finishing touch on that system on which you have worked so hard. Room boundaries have a direct effect on the performance of any woofer system because the intersection of two planes acts as a reinforcer of bass frequencies. The intersection of three planes (such as a corner floor placement) has an even greater effect and should be avoided. A simple change of a couple of inches or a few degrees of angle can sometimes make a striking difference. As a general rule I start by putting speakers 18 inches from the floor and at least two feet from any wall. Naturally, we all have different rooms, so ear testing different speaker placements is the best barometer for finding that final resting place. Happy listening! □

***ACKNOWLEDGEMENTS:** Many thanks to Tucker Cameron and Ed Grotefend for providing additional speakers to work on. Their needs allowed me to test the repeatability of the modification.*

Chuck Hollander played a key role in confirming the repeatability by others. His efforts to duplicate the modification gave birth to the initial outline of this article by helping me identify the instructional problems.

And, last but not least, many thanks to the POOGE for inspiration.

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7. Villchur, "Handbook...," pp. 25, 101, 106.
8. Roy F. Allison, "The Influence of Room Boundaries on Loudspeaker Power Output," *Journal* Audio Eng. Soc., Vol. 1, No. 5, June 1974.

REFERENCE PARTS

a. 3M No. 51135-08001 Super Weatherstrip Adhesive
b. GE No. GEC 421 Silicon Auto Seal (or equal)
c. Thermwell Products No. R538 "Frost-King" sponge rubber weatherstrip tape (or equal by 3M)
d. Valspar 20 clear high gloss Polyurethane© liquid plastic (or equal by Varathane©)
e. Mortell Mortite© weatherstrip and caulking cord
f. Ross No. 44 rubber cement for paper work (or equal)
g. Jo-Ann Fabrics© Hollofil No. A-90333 Dacron batting
h. Owens-Corning Fiberglass© insulation
j. 12-inch woofer such as Teledyne Acoustic Research part No. W 12" 200003

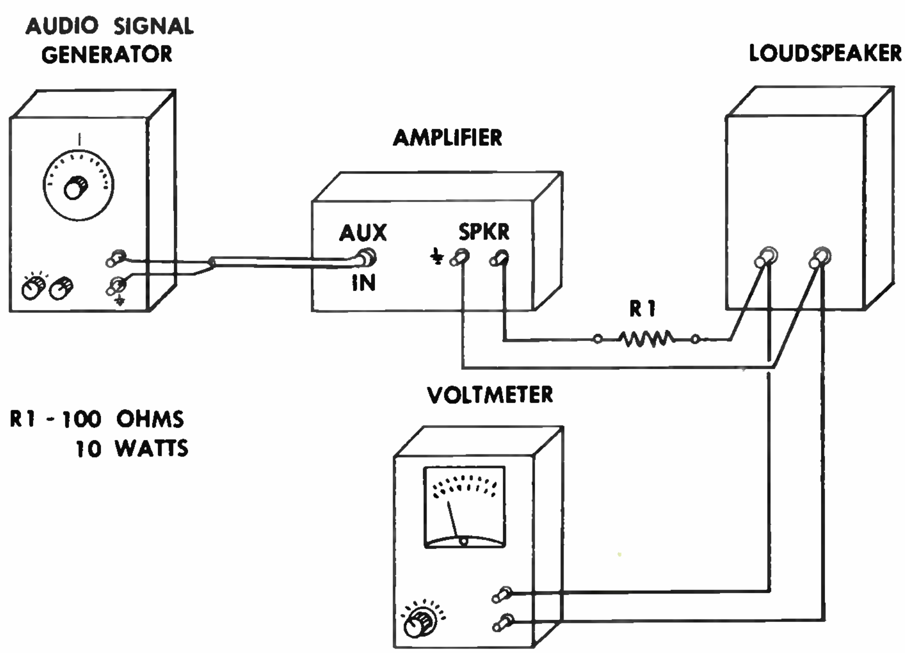

FIGURE 5: Speaker Resonance Test Set-Up

1. Connect an audio frequency signal generator to an auxiliary input of your amplifier.
2. Connect the amplifier speaker output through a 100Ω, 10W sandstone resistor to your speaker system.
3. The voltmeter is simply connected to the speaker terminals.
4. Set the signal generator to 100Hz, turn the generator and amplifier on and set the sound level to a point where you hear the 100Hz signal reasonably well.
5. Turn on the voltmeter and set it to a scale where the voltage reading is in the left half of the scale, as shown.
6. Slowly scan the frequencies between 100Hz and 20Hz to find the frequency that gives the highest reading on the voltmeter. That frequency is the cabinet resonance.

You can also use this test set-up to check the free air resonance of the driver while it is out of the enclosure.

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PHASE COHERENT CROSSOVER NETWORKS

BY NELSON PASS

DRAWINGS BY KIRK RADER

The importance of phase response in the audio chain has been brought to greater focus recently by equipment claims of phase coherency, (the output signal has the same phase relationships as the input signal). It is not particularly obvious that two different frequency components of a signal can go into a device at precisely the same time and emerge at different times, but it is extremely common. All audio components distort the phase of the signal to some degree–even air alters the time alignment of a signal, but the biggest offenders are loudspeakers and their crossover networks. Phase shifts in the audio signal destroy the waveshape of the important attack characteristics of many instruments and hamper our ability to perceive the localization of the image, smearing the apparent source. They can change the steady state waveforms of vocal sounds so that the singer seems to be ten feet wide.

Historically, the phase integrity of the audio signal has been considered much less important than amplitude and harmonic/intermodulation distortions, but as more of those problems are solved and the quality of reproduction improves, phase distortion stands out in greater relief. The question of the audibility of these distortions has become the object of heated discussions regarding the perceivability of absolute phase, frequency dependent phase shifts, and the rate of phase shift. Nonetheless we know that the ear is sensitive to phase and uses phase cues to help determine directionality. In the belief that proper attention to phase does produce better sound, I will discuss the design of crossover networks which have minimum phase distortion.

WHY USE CROSSOVERS? A necessary evil, the crossover network exists solely to ameliorate the inability of most loudspeaker drivers to cover the full audio range. Treated as a mass controlled piston working into an acoustic load, the typical cone loudspeaker derives the flatness of its response from the cancellation of two opposing effects–its excursion (which decreases as the square of the frequency), multiplied by the resistance of the acoustic load (which increases as the square of the frequency). *Figure 1* shows this relationship on normalized logarithmic scales. The two functions cancel each other to create a flat acoustic output between the rolloff points. At some high frequency (where the acoustic wavelength is less than the circumference of the cone) the acoustic resistance levels off to a constant value. Since the cone's excursion decreases by the square of the frequency, the resulting frequency response curve (excursion times acoustic resistance) rolls off at 12dB/octave. At the low frequency resonance of the driver, where the excursion is dominated by the compliance of the suspension instead of the mass of the cone, another rolloff appears, also at 12dB/octave.

Generally cone drivers don't work well over more than about a 10 to 1 frequency range, and to cover the audio spectrum from 20Hz to 20kHz you might need three different drivers, each designed for a specific range–20 to 200Hz for the woofer, 200 to 2000Hz for a midrange, and 2 to 20kHz for the tweeter. You could send a full range signal to all the drivers in parallel, but would discover quickly that they fail to reproduce outside their range. As they struggle to do so, severe distortion and possible damage may occur. The crossover network divides the sound among the drivers. Ideally when the drivers reproduce the signals sent to them, their outputs blend together to form an acoustic copy of the original signal as if the division had never taken place.

SQUARE WAVES SHOW PHASE CHANGES. One of the reasons the square wave is a useful test signal is that its shape is extremely sensitive to any variation in either amplitude or phase. It consists of a rich array of harmonics, and any alteration of their amplitude and phase deforms that squareness. I suppose the perfect high fidelity system would have to pass a square wave test, where a square wave would be encoded onto the appropriate medium and the resulting playback would create an acoustic square wave in the vicinity of the listener's ear. Most parts of the audio chain pass square waves quite well when designed carefully. Loudspeakers have the greatest problem, and although some present good square waves at particular frequencies and angles, to date I have not seen a loudspeaker which passes a general square wave test.

When we send a square wave into a loudspeaker system and observe the resulting image on an oscilloscope screen, we see little resemblance to a

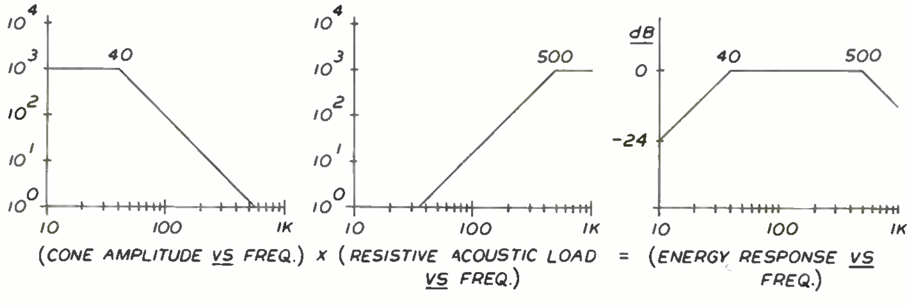


FIGURE 1: When the cone's falling frequency response interacts with its rising acoustic resistance, the result is a flat response in the middle.

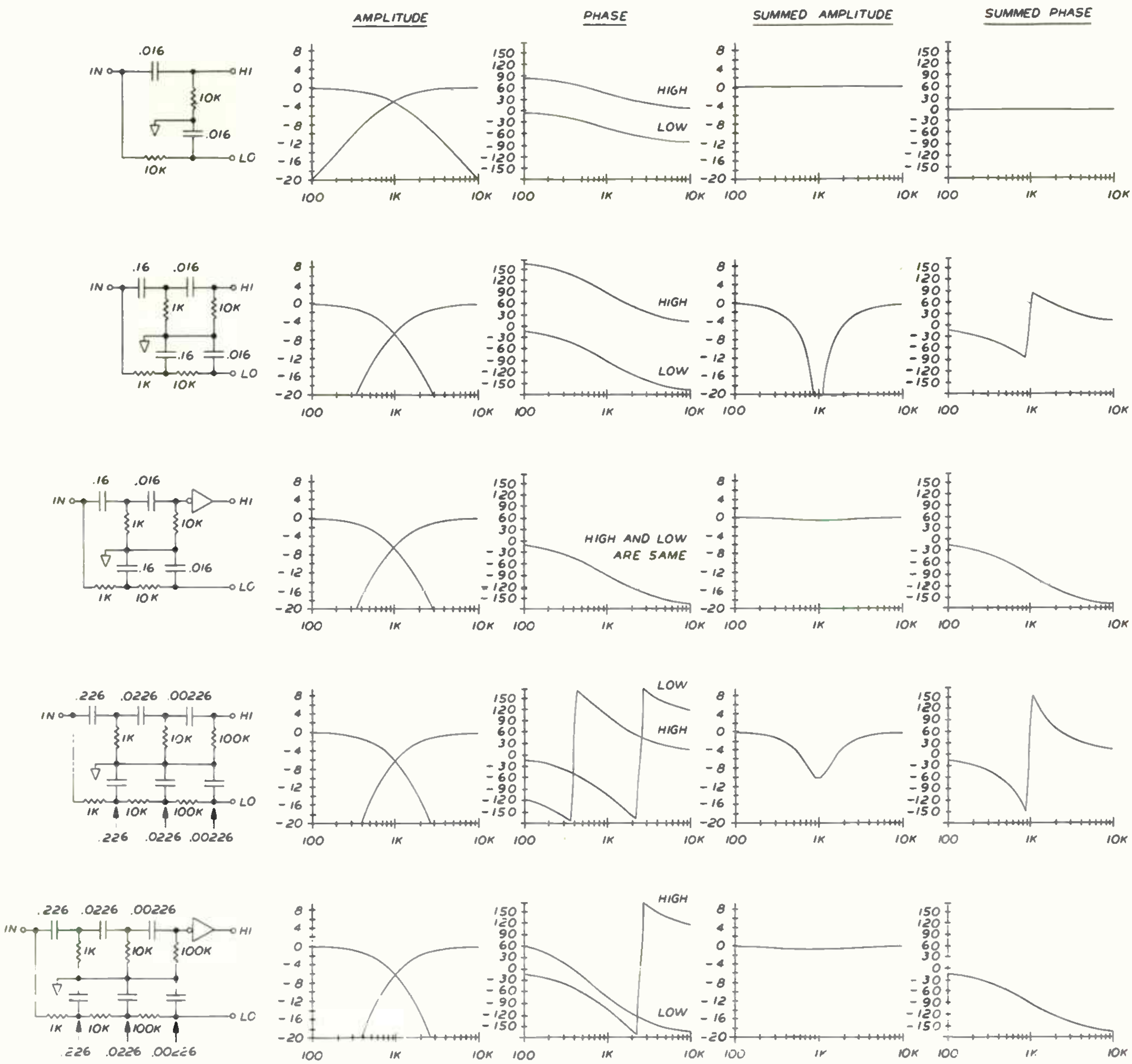


FIGURE 2: Using inverting buffers improves the phase and amplitude response of these typical preamp level crossovers. The 6dB/octave filter is the flattest, but its slope is too gentle for most drivers.

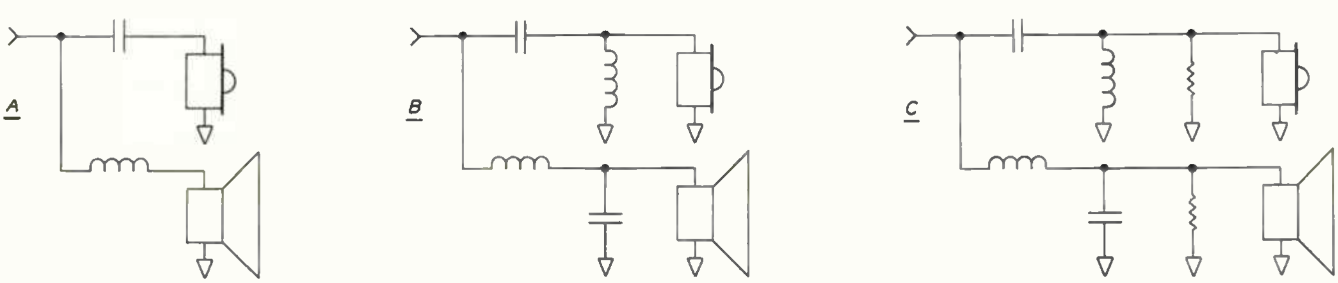
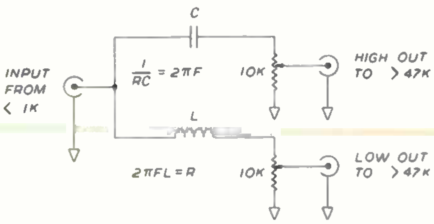


FIGURE 3: Power level translations of Fig. 4 circuits require use of coils, and recalculation of values.



SPEAKER	FREQUENCY	L =	C =
TYMPANI ID	1000 HZ	1.6H	.016 MF
MG IIA	1500 HZ	1H	.01 MF

RATING OF "L" IS ≥ 10MA AND < 500 OHMS

FIGURE 4: For biamping drivers which have inherently good phase coherence, simpler circuits are possible.

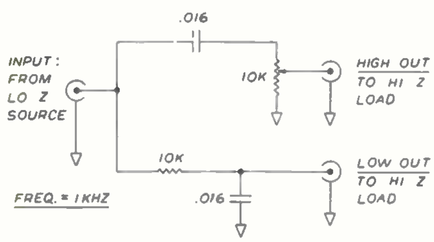


FIGURE 5: Removing the coil in the previous circuit improves performance (if your preamp can drive a 5kΩ load), but with a slight loss of gain.

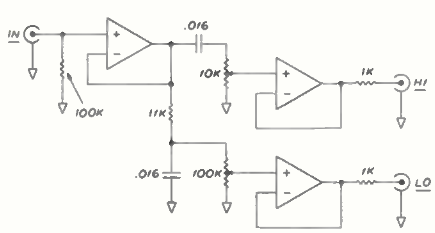


FIGURE 6: Adding impedance buffers restores the gain and presents better input and output impedances. All three circuits (Figs. 4-6) have 6dB/octave slopes and pass good square waves.

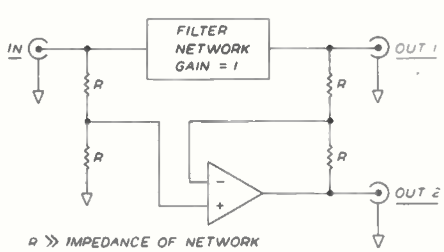


FIGURE 7: An active circuit combines the input and output of a single filter to produce a phase coherent output with flat response.

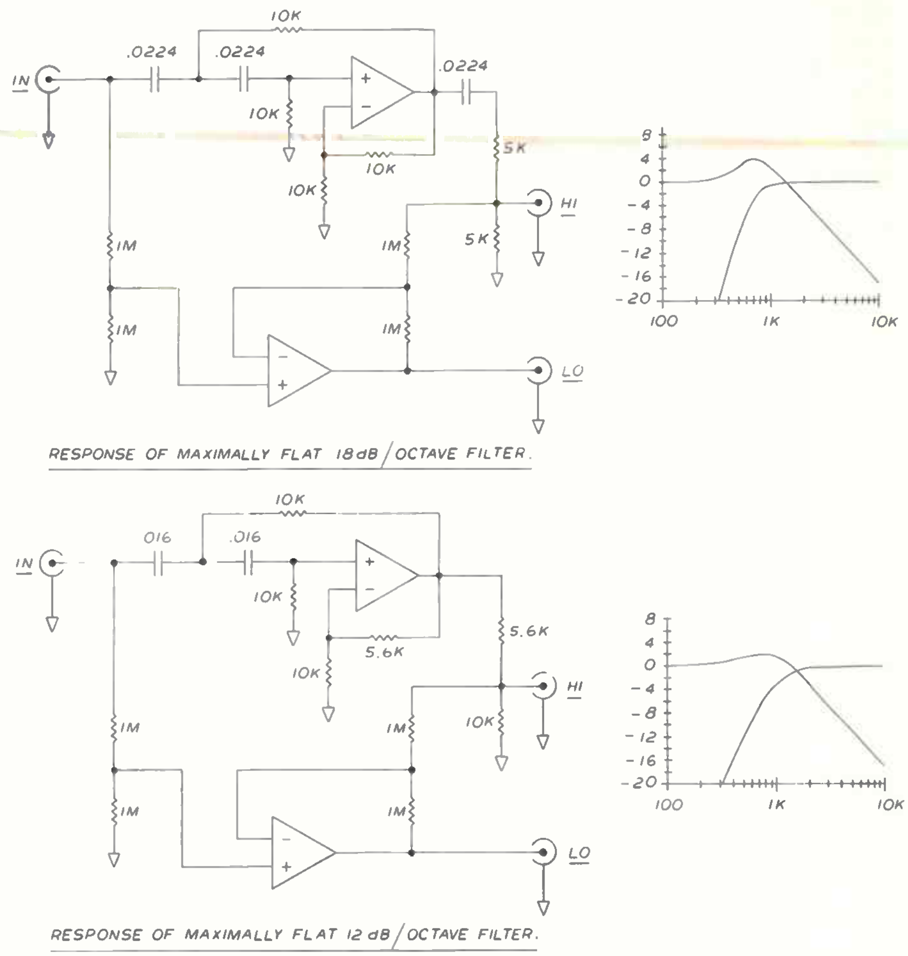


FIGURE 8: A peak develops when using this technique with 12 and 18dB/octave filters.

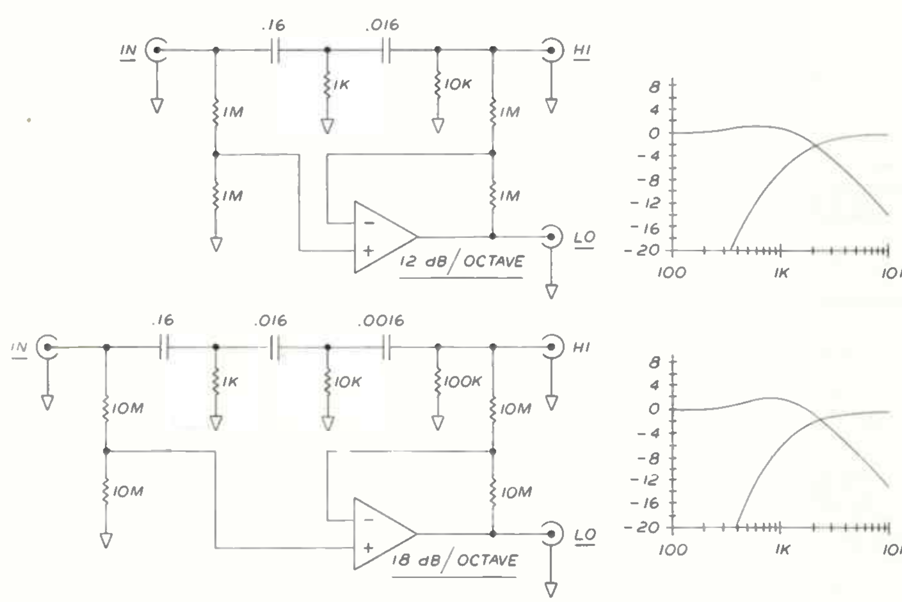


FIGURE 9: Lowering the Q of the filter minimizes the peak.

square wave except the original periodicity. The loudspeaker drivers, the room, and the microphone have all degraded the waveform. If we could eliminate all of these sources of distortion, we still might find our square wave grossly modified, the phase seriously distorted by the crossover network.

CROSSOVERS ALTER PHASE. All filters, active or passive, alter the phase. However, with some types of filters, when the low pass and high pass outputs are mixed back together, the original phase and amplitude relations are recreated precisely. Such crossover filters are phase coherent and their high and low pass outputs are phase complementary.

To evaluate the coherence of a given pair of filters, we measure the electrical sum of their outputs, then mathematically add them; examining the result for amplitude and phase distortion. On some filters we find that inverting the output of the high or low pass filter results in more accurate total amplitude or phase response, and we will examine those possibilities also.

Figure 2 shows the results of such a test with some reasonably common crossover network types. These particular circuits are designed for biamplified systems, with low source impedance

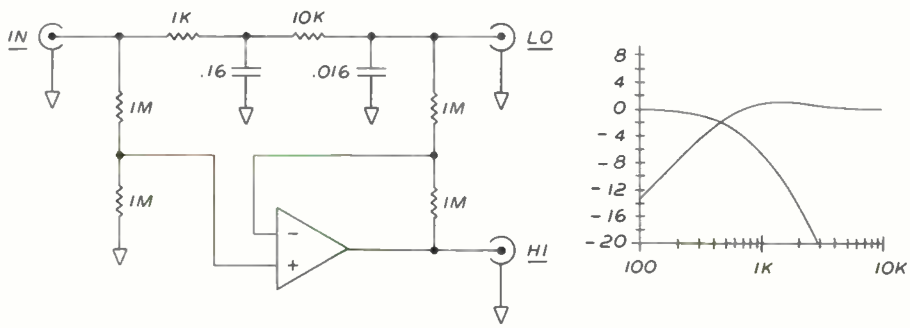


FIGURE 10: When using low pass filters the peak appears on the opposite curve (smoothed out in this circuit).

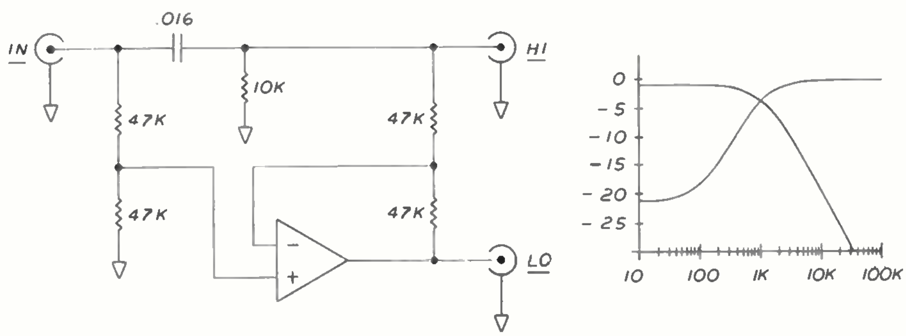


FIGURE 11: Insufficient impedance in the difference amp causes the shelving effect.

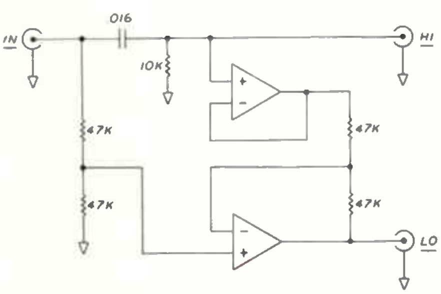


FIGURE 12: Buffering the filter output reduces its impedance almost to zero, which is a better way to eliminate the shelving effect than increasing the difference amp's impedance.

and high load impedance. Note the use of phase inverting buffers to invert the in some cases. (Of course this could be achieved more easily in a real system by inverting the polarity of the loudspeaker terminals.) The topologies in *Fig. 3* are for power, rather than preamp levels, using coils. As the textbooks are fond of saying, calculation of the values is left as an exercise to the reader. The 6dB/octave and the inverted 12 and 18dB/octave examples yield sums which are quite flat, and remarkably, we see that the 12 and 18dB/octave cases both yield identical amplitude and phase results. Of all these filters only one, the lowly

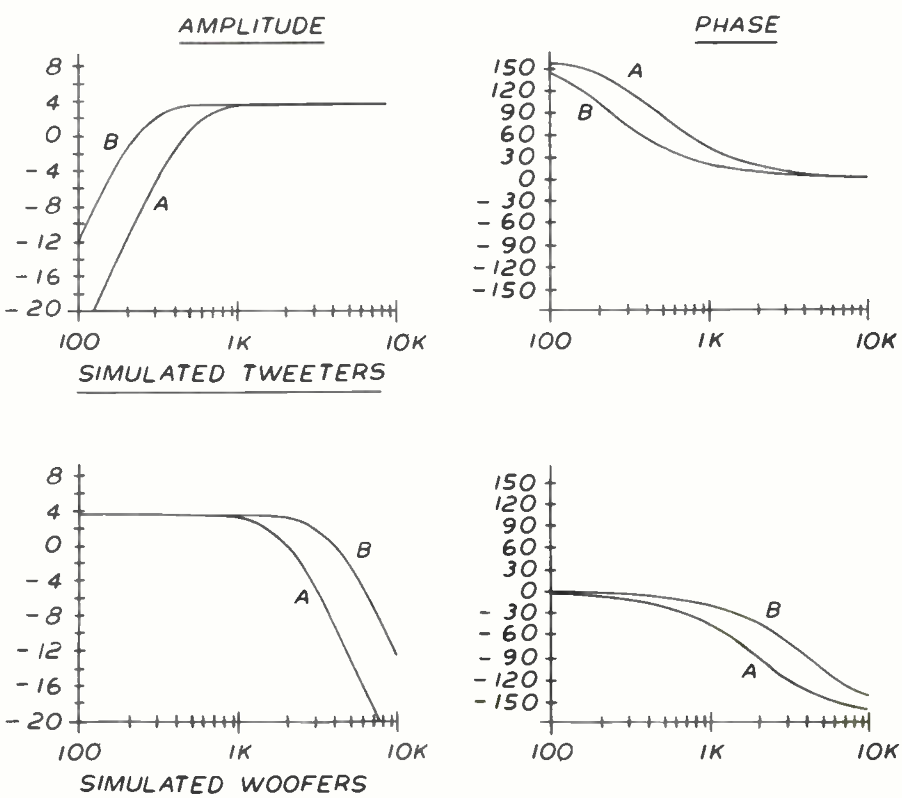


FIGURE 13: Computer models of drivers can be matched with various filters to see total results.

6dB/octave crossover has both accurate amplitude and phase response when the outputs are reassembled.

SIMPLE BUT EFFECTIVE. In applications where the drivers have wide bandwidth and can tolerate the low rolloff rate, the 6dB/octave crossover can give excellent results, particularly with planar drivers, such as electrostatic systems and Magnepans. The circuit of *Fig. 4* has given me excellent results with the Tympani 1D's and MG 2A's and serves as a good example of how well simple inexpensive approaches work. I have not had the opportunity to try it with their newer SMG's, but I expect similar improvements over the stock systems. Using both capacitors and coils, it presents a flat input impedance of 10kΩ or higher.

Those who wish to dispense with coils and whose preamp can drive a 5kΩ load might try the equivalent circuit of *Fig. 5*, which gives the same results with a few decibels loss of gain. The circuit of *Fig. 6* (which uses active impedance buffers to give the circuit a very high input impedance and a very low output impedance) does not have this loss. Various types of buffers are possible. IC buffers (such as the LM 302 or LM 310) op amps (whose output is connected to the inverting input), and simple one-device emitter/source/cathode voltage followers without negative feedback are suitable. The circuits of *Figs. 4-6* all pass our square wave test and all have 6dB/octave slopes.

SUMMING FOR FLAT RESPONSE. Even more interesting is the technique illustrated in *Fig. 7*. An active circuit assembles a phase complementary output from the difference between the input and the output of a single filter. This ensures that the sum of the two outputs will be perfectly flat in amplitude and phase. To be effective, the filter should exhibit unity gain in its passband, or the rolloff characteristic will have a shelf (like a conventional tone control), but otherwise it can be any type of filter.

This approach allows the use of higher order filter slopes in a phase coherent crossover as shown in *Fig. 8*, where we note some interesting phenomena. The precise complement of a maximally flat 12 or 18dB/octave filter has a peak which increases with the slope and Q of the filter, and it always exhibits a 6dB/octave slope. One of these minor drawbacks, the peak, can be reduced by lowering the Q of the filter as in the examples of *Fig. 9* where the less than maximally flat characteristics are those of *Fig. 2*.

Figure 10 shows us that the effect is similar but reversed if you use a low pass filter in this configuration instead of a high pass. Unfortunately, I don't know of a way the complementary output can be made to roll off at a slope greater than 6dB/octave, and you must choose whether it will be the low pass or the high pass based on information about the drivers. Most of the time you should assign the higher slope to the tweeter, since it generally needs more protection from out of band signals.

In such filters, the resistances in the differencing amplifier must be very much greater than the output impedance of the filter. *Figure 11* shows what happens when they are only 5 times greater: the rolloff curve shelves at about −20dB. This is not a very desirable characteristic, but often it is not very practical to place multi-megohm resistances in the differencing circuit because of the noise and the input bias currents of the op amp. *Figure 12* shows an easy solution to this potential problem. Buffering the output of the filter gives it a near-zero output impedance, and completely eliminates thi effect.

TOTAL SYSTEM RESPONSE. So far we have considered only the phase and amplitude performance of the crossover network and how easily you can achieve phase coherency in such a device. However Mother Nature is not going to let us off so lightly. These networks drive loudspeaker elements and while we can make filters perfect, the acoustic sum in-

Continued on page 43

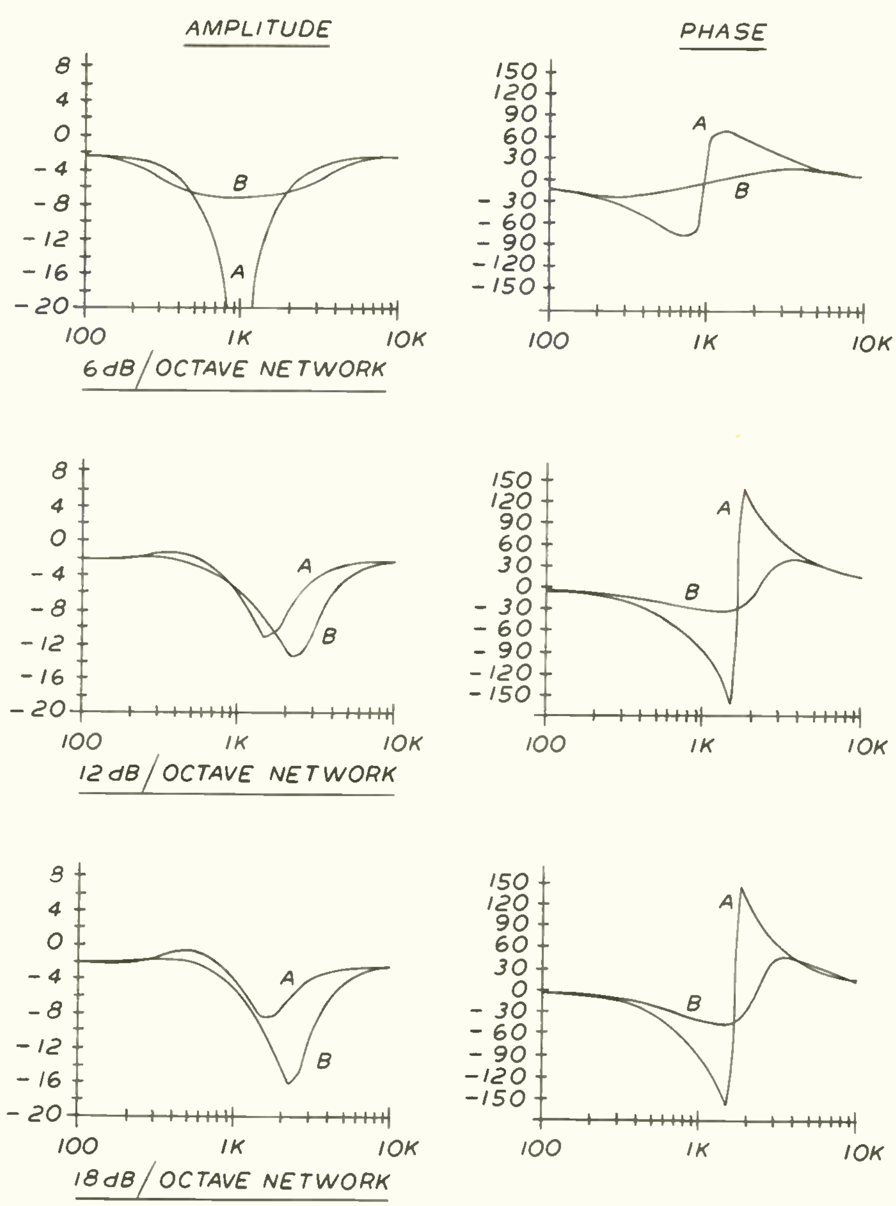


FIGURE 14: Simulated acoustical outputs for several driver and filter combinations reveal that many problems must still be resolved.

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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 x 8½. Requires ±15V supply, not supplied. Use the Sulzer supply KL-4A with KL-4B or KL-4C. Per channel **$64.00**
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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**

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BENCH AIDS & TEST EQUIPMENT

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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**

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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**

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Loudspeaker Networks

BY WILFRED F. HARMS

This article examines aspects of networks often recommended for use with multi-unit loudspeaker systems. Over the years books and articles have recommended standard dividing networks, usually referred to as "crossovers," the component values for which are determined from simple formula to achieve attenuations of 6, 12, or 18dB/octave, as shown in *Fig. 1*. Often extensive tables and graphs are drawn to assist this end, and most are based upon what are called "constant impedance" networks. Taking as an example a lowpass filter with a 12dB/octave attenuation, this takes form as in *Fig. 2*, in which a −3dB point at frequency f is obtained provided:

$$L = \frac{\sqrt{2}R}{2\pi f} \text{ and } C = \frac{1}{2\sqrt{2}\pi fR}$$

where R is the resistive termination.

We have known for a very long time that this type of filter is applicable to a resistive termination and it has been known for an equally long time that a loudspeaker unit is far from being purely resistive—and yet the suggestions for the use of these formula persist.

MYSTERIES. Many misleading statements are made concerning networks causing misunderstandings which are then often repeated. For instance, a description of a satisfactory network mentioned that "A theoretical crossover is worse than no crossover at all" and included a test diagram to prove it. The meaning was of course, that the constant impedance formula was not satisfactory but since no explanation was given as to why it should fail to be effective, the statement could be misconstrued. After all, the fault lies not in the theory but in the incorrect application of a theory and little guidance has been given as to the limitations of this type of network when the termination of it is changed to an actual loudspeaker (LS) unit.

The electrical properties of a LS unit are very complex and are the result of interaction between the electrical and mechanical systems. Equivalent circuits for speakers consisting of inductors, capacitors and resistors are sometimes shown but these can be complex and dif-

TABLE I

	EQUIVALENTS	
Frequency	R(Ω)	L(mH)
1k	8.9	0.71
1.5k	10.8	0.67
2.0k	12.3	0.61
3.0k	12.3	0.49
4k	12.6	0.42
5k	13.6	0.38
7k	16	0.4
10k	18.2	0.35

TABLE I: Using the voltage/current phase angle, you can determine the "apparent impedance" and "apparent inductance" of the driver. The wide range of values will alter the sound considerably.

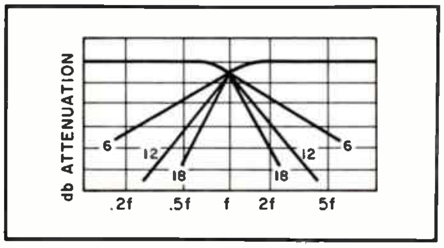


FIGURE 1: The usual attenuation curves for dividing networks do not work with real drivers.

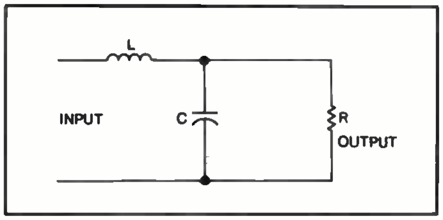


FIGURE 2: This 12dB/octave low pass filter circuit is often suggested, but since actual speakers do not have purely resistive loads, will not produce the intended results.

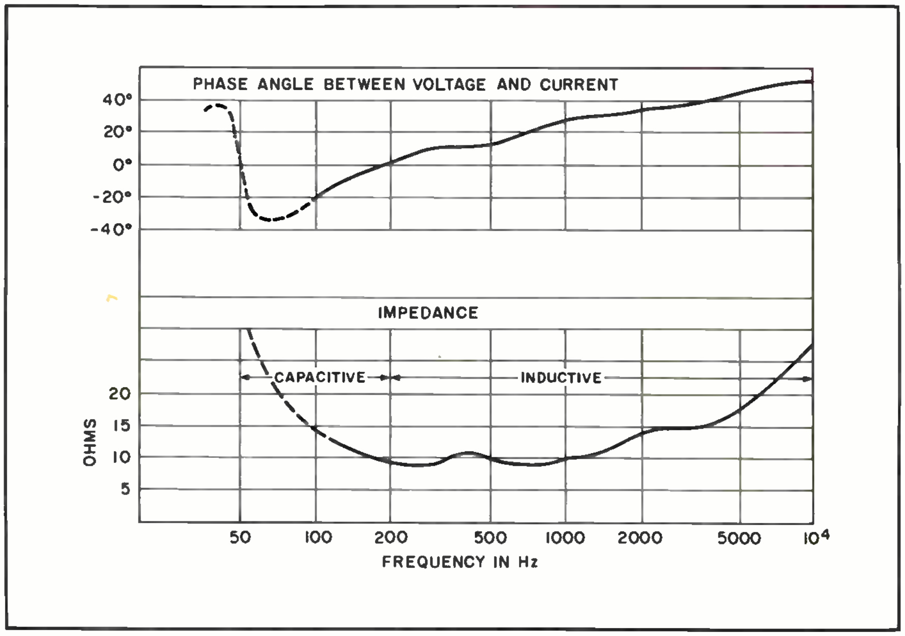


FIGURE 3: A typical 8″ driver has wide fluctuations of impedance at different frequencies.

ficult to understand. Generally the impedance of an 8″ bass/midrange unit may vary with frequency as in *Fig. 3*, and ignoring the peculiarities at the lower frequencies, from 500Hz and above (the region where the divider frequency may be), it has some semblance to the impedance of a resistor/inductor combination. However, from the voltage/current phase angle ϕ also shown, it is possible to determine the "apparent resistance" (= impedance x cos ϕ) and the "apparent inductance" (= impedance x sin $\phi/2\pi f$) at different frequencies. *Table 1* illustrates that these vary considerably.

CIRCUMSTANCES MATTER. The constant-impedance formula has no provision for these variations and it is for this reason that it should not be used for the dividing network for a loudspeaker without regard to the circumstances. To illustrate the point in detail, a constant impedance network for an 8 ohm resistive termination at 300Hz (12dB/octave) would be as *Fig. 4* and the characteristic is as *a* in *Fig. 5*.

The formula for the dB drop at frequency f for the combined resistive/inductive termination of *Fig. 6* is:

$$20\log_{10}\sqrt{\frac{\left(D-\frac{AD}{B}\right)^2+\left[A+C-\frac{AC}{B}\right]^2}{D^2+C^2}}$$

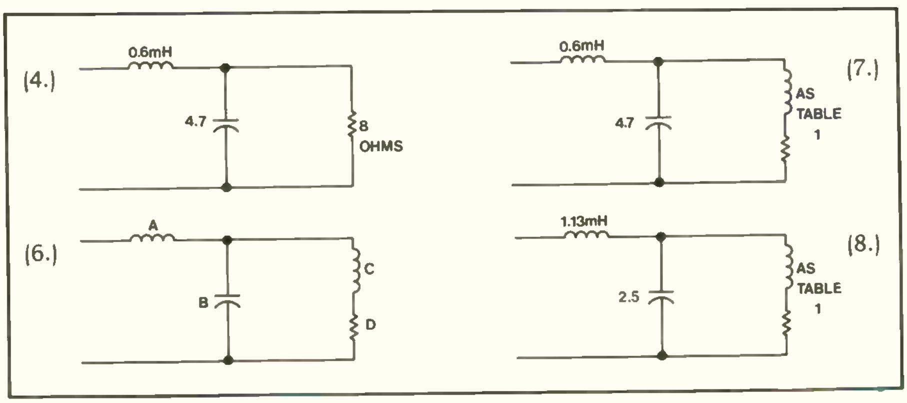
where A, B and C are the *impedances* and D the apparent resistance at the specific frequency. If the values for the capacitor and inductor of *Fig. 4* are combined with the apparent resistance and inductance in *Fig. 7*, a characteristic can be obtained such as *b* in *Fig. 5*. You will see that the characteristic rises at the point where it should be dropping as in curve *a*, and is altogether far from target and quite unsatisfactory.

Another writer, in trying to offer a helpful suggestion to meet this problem recommended "that the impedance of the LS unit be determined at the desired dividing frequency and that this impedance be used instead of the nominal impedance for inclusion in the standard formula." It is pertinent to compare the results that ensue. The impedance of the unit under consideration at 3kHz is 15.2 ohms and the values of L and C for a constant impedance network to suit this value if it were a pure resistance would be 1.13mH and 2.5μF. Substituting these values in *Fig. 8*, the result is curve *c* in *Fig. 4*. Although this differs materially from *b* in that the "hump" is eliminated, it can hardly be considered to be a very effective cut-off at 3kHz, and I think it is not a very good alternative.

BETTER ANSWERS. Having shown what is not satisfactory, how do we find something more effective? This "variable resistance and inductance" does not permit a simple formula to satisfy all conditions. If we consider attenuation at frequencies between 200 and 500Hz where the phase angle is relatively low, the error incurred by using the simple formula is not great.

Bearing in mind the difference between curves *b* and *c* in *Fig. 5* in relation to the components used, it seems that increasing L reduces the "hump" whilst reducing C raises the cut-off frequency. Consider a network with L equal to 1.2mH (twice that in *Fig. 4*) and a C with the original value of 4.7μF, as in *Fig. 9*. The characteristic determined for this network is curve *d* of *Fig. 5* which can be considered a rough compromise solution. In the circumstances we might say that if the phase angle exceeds 10° at the dividing frequency, the value of the capacitor as obtained from the simple formula based on the nominal impedance of the unit should be used, but the value of the inductor obtained therefrom should be multiplied by a factor (up to 2 or more) depending on the actual frequency.

Ideally, if measures are taken to eliminate the effect of the unit's variable properties, the use of the simple formula becomes valid and this will be considered in a later article.



FIGURES 4, 6, 7, 8: These typical variations on a 12dB/octave constant impedance filter generate the response curves of Fig. 5, all of which are unsatisfactory.

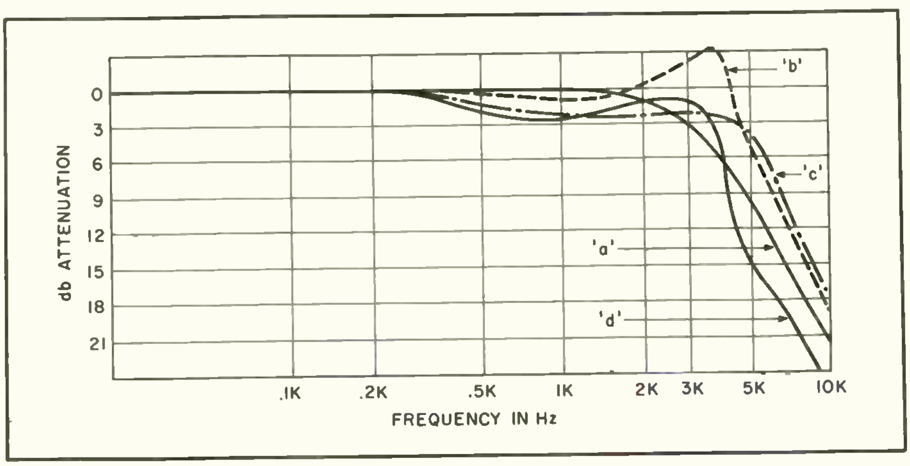


FIGURE 5: Frequency response curves (a, b, and c) for an 8Ω driver, when used with constant impedance filters, are all poor.

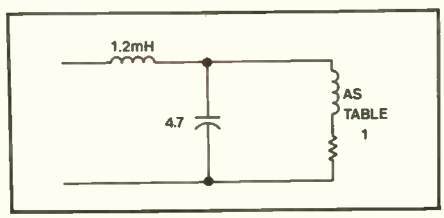


FIGURE 9: This circuit generates curve d in Fig. 5, which has the best compromise between flat response and rolloff point.

Note that the above considerations are in respect to the attenuation defined in *Fig. 1* and have no relation to steps which might be necessary to compensate for the response characteristic of a unit. However, the depression at frequencies lower than the cut-off frequency as shown in *d* of *Fig. 5* may assist this need. □

Mr. Harms is a civil engineer with a special interest in loudspeaker design. He lives in Bexhill, East Sussex, England.

A Beginner Builds His First Speaker

BY DAVID BALDWIN

I am now finishing construction of my first set of speakers. A year ago I would have never thought it possible for someone who knew as little as I did about woodworking and electronics to design and build a pair of speakers. I knew nothing about either. Now I know a little about each. If you are also a beginner, you may be intimidated by all that you must learn. However, you don't need a computer to design decent speakers. Your mind paired with a calculator can do a great deal.

About a year and a half ago, I contracted what my wife calls *Stereo Madness*. [A too rare malady well documented in medical circles. –*Ed.*] It came on as I shopped for our first stereo. I read the standard consumer magazines such as *Stereo Review* and *High Fidelity* and learned all I could. As I learned, they seemed more and more repetitive, so when I spied an ad in *Audio* for *Speaker Builder*, I sent in a subscription order. It was money well spent. I learned all that I could understand from *SB* and read an electronics text also.

DESIGN TAKES FORM. When Robert Bullock's article on bass reflex cabinet design appeared I became excited. It was the clearest discussion of the subject that I had seen up to that time. I had some catalogs, so I did some calculations on some drivers that I saw in Transcendental Audio's catalog. When I got a little extra money I took the plunge and bought Polydax's HD17-B25J2C12 woofer and their HD100-D25A/HR tweeter, plus a crossover advertised as being designed for those drivers.

Words cannot describe my excitement when the drivers arrived just nine days later. *Stereo Madness* had completely destroyed my mind's balance by this time. I could hardly sleep that night. As I studied Bullock's article further and kept redesiging the enclosures, my planned pair of minispeakers grew larger and larger. Finally I thought I had it right. I showed my little drawing to a woodworking friend. He started to ask questions about types of joints, bracing, glue vs. screws, etc., etc. I couldn't answer any of his questions satisfactorily, so I crept back to the drawing board.

I did a scale drawing and that made a world of difference. I became aware of many things I had not thought of or accounted for, such as the amount of space taken up by the bracing. I had estimated it, but when I did exact calculations it became clear how far off I had been. Who knows what my speakers would have sounded like if I

PARTS LIST

Particle board: 1.9cm thick
Glue blocks: 1.9 x 1.9cm (length as indicated)
Bracing: 3.8 x 3.8cm (length as indicated)
Woofer: Polydax HD17B25J2C12
Tweeter: Polydax HD100D25A/HR
Crossover: Recommended by Transcendental Audio

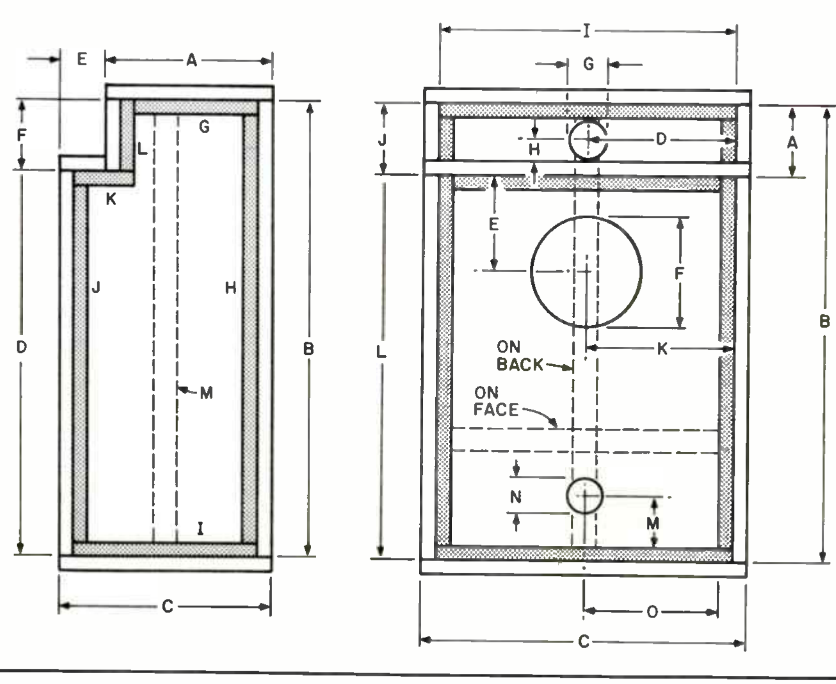


FIGURE 1: A scale drawing helps to clarify the concept, often solving problems before they occur in construction. The letters refer to dimensions in the lists.

had not recalculated, not to mention the wasted wood. Therefore friends, do a scale drawing. You don't need to know much about drafting; I didn't. I avoided the issue of perspective entirely by doing a front view and a side view with exact dimensions showing each and every cut. With care you can do the same thing.

Before I started cutting, I was lucky enough to buy David Weems' *How to Design, Build, and Test Complete Speaker Systems,* (Tab $7.95). After reading his book, I realized that the specifications in the Transcendental catalog contradicted each other. They could not all be correct. What a dilemma! I have seen those same faulty spec sheets in other catalogs, so I suspect that they were supplied by Polydax. I gritted my teeth and invited a friend over who brought his test equipment. We spent an evening testing the woofers. Weems' procedures are very clear and easy to follow. Even a novice can do it if he/she can follow directions. Test your woofers if at all possible. My enclosures would not have yielded the bass they do if I had not gone to the trouble, and I would not have known why. If you are going to design your own crossover, test your tweeters also. You will be able to design a better one.

Side Dimensions **Outside letters are panels** **Inside letters are glue blocks**	**Front Dimensions**	**Specifications**
A = 22.7 cm	A = 12 cm	Polydax HD17B25J2C12
B = 66.2 cm	B = 66.2 cm	F_s = 45Hz
C = 29.2 cm	C = 44.8 cm	R_e = 6.5Ω
D = 54.2 cm	D = 20.5 cm	Q_{ts} = .48
E = 6.5 cm	E = 13 cm	V_{as} = 32.094 liters
F = 12 cm	F = 15 cm	
G = 15.1 cm	G = 7.5 cm	F_B = 37.2Hz
H = 62.6 cm	H = 5 cm	V_B = 59.4 liters
I = 21.6 cm	I = 41 cm	F_3 = 33.2Hz
J = 52.6 cm	J = 10.1 cm	L_v = 3.48cm
K = 6.5 cm	K = 20.5 cm	d_v =5cm
L = 10.1 cm	L = 52.3 cm	
M = 62.6 cm	M = 7 cm	
	N = 5.4 cm	
	O = 20.5 cm	

I did yet another scale drawing using the new specs, and after much time in the wood shop figuring out which end was up, got one speaker together. While in the shop, measure *perfectly*, account meticulously for the width of the saw blade, and dry clamp the enclosure before gluing to make sure it fits. I came up with some weird joints because I made them airtight with a lot of silicon-rubber sealant, but cosmetically they leave much to be desired. Take things slowly, don't hurry.

FIRST SOUNDS. When I got the first speaker hooked up I put on a record and sat down to listen. The first sounds were awful! What could be wrong? I discovered that the tweeter was producing nothing, so I put in the other one. Much

better, although the balance was not right. Investigation revealed that I had misassembled the crossover, putting the wrong values of resistance into the L-pad. I put it back together again, wrong again. It was only after several tries that I got it right.

There is always a reason for a failure. It is probably a wrong calculation or a bad connection. Be patient and double check everything. If your temper gets the best of you, take a walk.

As for the broken tweeter, I figured it was no good to me as it was, and that I couldn't make it any worse [not always a safe assumption—*Ed.*], so I took it apart. Sure enough, it had a bad connection. I resoldered it and had two tweeters again. Speaker of soldering, it is easy. I was afraid of it because I had never done it. A beginning electronics text can give you directions, or you can get a friend to show you how.

After what seems like forever, I got the second speaker working and was able to listen in stereo. The speakers had excellent bass, which was clean, detailed, and extended. The treble was good, but the midrange was honky. This was most noticeable on string quartets.

I reduced the honkiness partly by buying an alignment protractor and aligning my cartridge properly. Not all your problems need be in your speaker. I also redesigned the crossover using the procedures outlined in Weems' book. I found the woofer was crossing over at 2500Hz and the tweeter at 3600Hz. I replaced the cap across the woofer, raising the crossover to 3600Hz, and more complete, natural sound resulted, just as predicted by theory. When you are experimenting, mount the crossover outside the box. I got very tired of removing the woofer every time I made a change.

Putting a felt ring around the tweeter to reduce the effects of diffraction also reduced the peak. When I do these experiments, I modify one speaker at a time and compare it with the unmodified speaker. This way I can be sure that I am not imagining the difference.

Now the speakers have the same good bass, a smooth (but not perfect) midrange, and clear highs. The power handling and sensitivity are both low so the dynamic range is fairly constricted, but I find that it is adequate for most music in small rooms. The speakers are satisfying to listen to and do not cause listening fatigue unless the program material is bad.

When your friends learn what you are trying to do, they will tell you that you can't possibly know enough to build good speakers, and that speaker design is an art that only large companies have mastered. Your friends are right in one respect, you must know what you are doing to design a good set of speakers. What they don't realize is that the technology is available and learnable. If you are willing to do some studying, you can build good speakers on your first try, so don't let your friends intimidate you. Go ahead and do it. □

VOLUME

Int. Height =	66.2 cm
Int. Width =	41.0 cm
Int. Depth =	25.4 cm
	68940.1 cm³
(tweeter notch)	−3198.0 cm³
	65742.1 cm³
(woofer vol.)	−318.0 cm³
	65424.1 cm³
(glue block vol.)	−1967.0 cm³
	63457.1 cm³
(bracing vol.)	−3468.0 cm³
	59989.1 cm³
(vent vol.)	−82.6 cm³
	59906.5 cm³

FIGURE 2: The calculation of the internal volume must account for all the parts which occupy space.

Transmission Line Loudspeakers

PART II: APPLICATION

BY GARY GALO

To avoid confusion, I've assigned the "model numbers" TL-10, TL-8, and TL-5 to the three transmission line loudspeakers I'm about to describe. The numbers indicate in inches the size of each system's woofer. The TL-10 is the largest: six feet tall, with a 10″ woofer. The TL-8 is four feet tall with an 8″ woofer; and the TL-5 is a "bookshelf" size system, 19½″ tall, with a 5″ woofer. All three systems have 8Ω drivers throughout.

TL-10 AND TL-8. My first system was designed to provide bass response to 25 or 30Hz. The original employed a Philips 10100W woofer with a free-air resonance of 25Hz; line length was therefore 11.3 feet. I have since changed the woofer to an Audax HD24B45 Bextrene driver. This woofer's free-air resonance is also 25Hz, so I didn't need to change the line length.

The TL-10's mid-range and tweeter drivers are four each of Philips' 0211/SQ8 and 0163/T8 textile domes, wired in series/parallel (see *Fig. 1*) and mounted in a "line-source" arrangement. The woofer, midrange, and tweeter drivers' voice coils are closely aligned to improve phase response (*Fig. 2*).

I based the TL-8 design on the TL-10, but reduced its size to accommodate an 8″ woofer with a 40Hz free-air resonance. I have replaced the original Philips 8066/W with an Audax Bextrene driver (HD20B25H4C12). The driver has an actual free-air resonance of 25Hz, but the line is still a ¼ λ, 40Hz design; the system's low frequency cut-off therefore remains at 40Hz. The TL-8 employs the same Philips midrange and tweeter drivers as the TL-10, but only one of each per system.

I designed the TL-8 because several of my friends wanted bass performance like the TL-10 in a smaller enclosure (apparently not everyone wants six-foot loudspeakers in the living-room!). The 40Hz cut-off produces a seven-foot line length, reducing the enclosure to a more manageable size.

CROSSOVERS. You can choose between two crossover networks for the TL-10 and TL-8 systems. If cost is important, the stock Philips 600/5000/8Ω crossover at about $14.00, from Madisound, provides very satisfactory results. It is a 6dB/octave constant resistance Butterworth device, except that the high pass (tweeter) section is 12dB/octave, and has been the most popular crossover for the 11 TL-8 systems so far built. If you pick this crossover, change the electrolytic capacitors to mylars of the same value for best performance. *Figure 3* shows the wiring diagram.

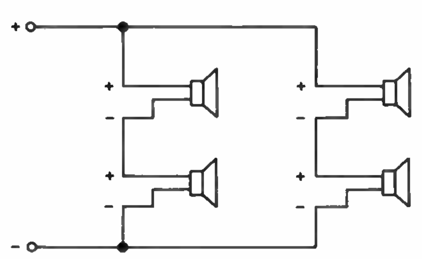


FIGURE 1: This series/parallel wiring scheme for the line source array of four tweeters is also used for the midrange.

Since the midrange and tweeter drivers are far more efficient than the transmission line woofer systems, we'll attenuate their output with a 6dB fixed attenuator (the 4Ω and 8Ω resistors) and L-pad, as shown in *Fig. 5*. I can highly recommend Madisound's 100-watt L-pad, (terminal diagram in *Fig. 4*). Correct setting for the L-pads will be around 9 or 10 o'clock; use your ears as the final judge to determine the settings for the most natural tonal balance.

I designed a better, more expensive crossover for the TL-10 systems (*Fig. 5*) which will also provide superior results in the TL-8. It is a 12dB/octave Butterworth design at 700 and 5000Hz, using Hull's constant resistance parameters.[6] I have no intention of embroiling myself in the crossover rolloff debate at this time. Do experiment with other rolloff rates; I'll be interested in hearing about your results.

PHASE PROBLEMS. The 12dB/octave design is attractive since it allows excellent phase response at the crossover frequencies. In this design, the woofer output at 700Hz and the tweeter output at 5000Hz are both 180° out of phase with the input. The midrange output is in phase with the input at these frequencies, and 180° out of phase with the woofer and tweeter. By reversing the midrange connections, we can bring the midrange output acoustically in phase with the woofer and tweeter at the two crossover frequencies. This provides a more coherent transition among the drivers.

In a 6dB/octave design, the various outputs are actually 90° out of phase with each other. While reversing the midrange terminals can help improve phase response, it cannot completely correct the situation. I therefore recommend that you use the 12dB/octave crossover if you can afford to: current prices, parts for a pair will run $75 to $100 from Transcendental Audio or Madisound. Use mylar capacitors, not electrolytics, throughout. The crossover components can be mounted on a ⅛″ piece of masonite and hard-wired together.

The 12dB/octave crossover will also require a 6dB attenuator (R_1 and R_2) and an L-pad. The L-pad's correct setting will be somewhere between 10 and 12 o'clock; again, your ear must be the final judge.

SOUND QUALITY. The TL-8 and TL-10 systems are both moderately efficient—approximately 92dB at one meter with one watt of pink noise. A minimum of 50 to 60 watts per channel is necessary for good transient response and dynamic range. The Hafler DH-200, at 100 watts per channel, is superb with either system. These speakers reveal the characteristics of all associated equipment. They will not mask distortions caused by mediocre tone arms, turntables and cartridges. Hard, sizzly electronics will sound hard and sizzly, and bad recordings will sound bad. On the other hand, with clean, accurate associated gear, the speakers will sound convincingly like live music. A few "receiver" owners who have built the TL-8's soon realized how inadequate their mass-market electronics were, and upgraded to at least Hafler-level gear.

To realize fully the bass definition and transient capabilities of these speakers, clean solid-state amplifiers with high damping factors are essential. Any amplifier using an output transformer (tube-type, solid-state McIntosh, etc.) will sound slow and poorly defined in the bass region on transmission line loudspeakers.

You undoubtedly will want to know what the audible differences are between the TL-8 and the TL-10. The two systems have similar overall characteristics, as you would expect. However, the TL-10's have better definition and transient response,greater power-handling capability and smoother frequency response throughout the midrange and treble regions, greater front-to-back depth, and deeper bass fundamentals. The TL-10 sound overall is more "three-dimensional." One positive characteristic of both systems is that they do not increase the apparent size of solo instruments. The TL-10 can reproduce the size of a full orchestra very convincingly, but small solo instruments such as guitar or flute have proper proportion.

ACTIVE CROSSOVERS. Personally, I believe even the best passive crossovers are turkeys. I recommend bi-or even tri-amplification, if you can afford the expense and time. The results are well worth the effort. If you bi-amplify either system, the electronic crossover should handle the woofer to midrange crossover; retain the passive crossover to handle the midrange to tweeter crossovers for the remaining drivers.

Tri-amplification, of course, requires no passive crossover at all. My TL-10 system is now tri-amplified, using a modified Old Colony crossover powered by a PAT-5/WJ1A supply. Southwest Technical Products' Tiger .01's (with power supplies rebuilt by me) drive the woofers. The midrange amplifier is a Hafler DH-200 with its idle current increased to 375mA; the tweeters are fed by a Pass A-40 Class-A amplifier built with parts from Old Colony Sound Lab. A Jung-White PAT-5/WJ1A preamp, Netronics 350F turntable with "Platter-Matter" mat, Mayware Formula 4 tone arm (modified), and Shure V-15 IV cartridge complete my basic phono system.

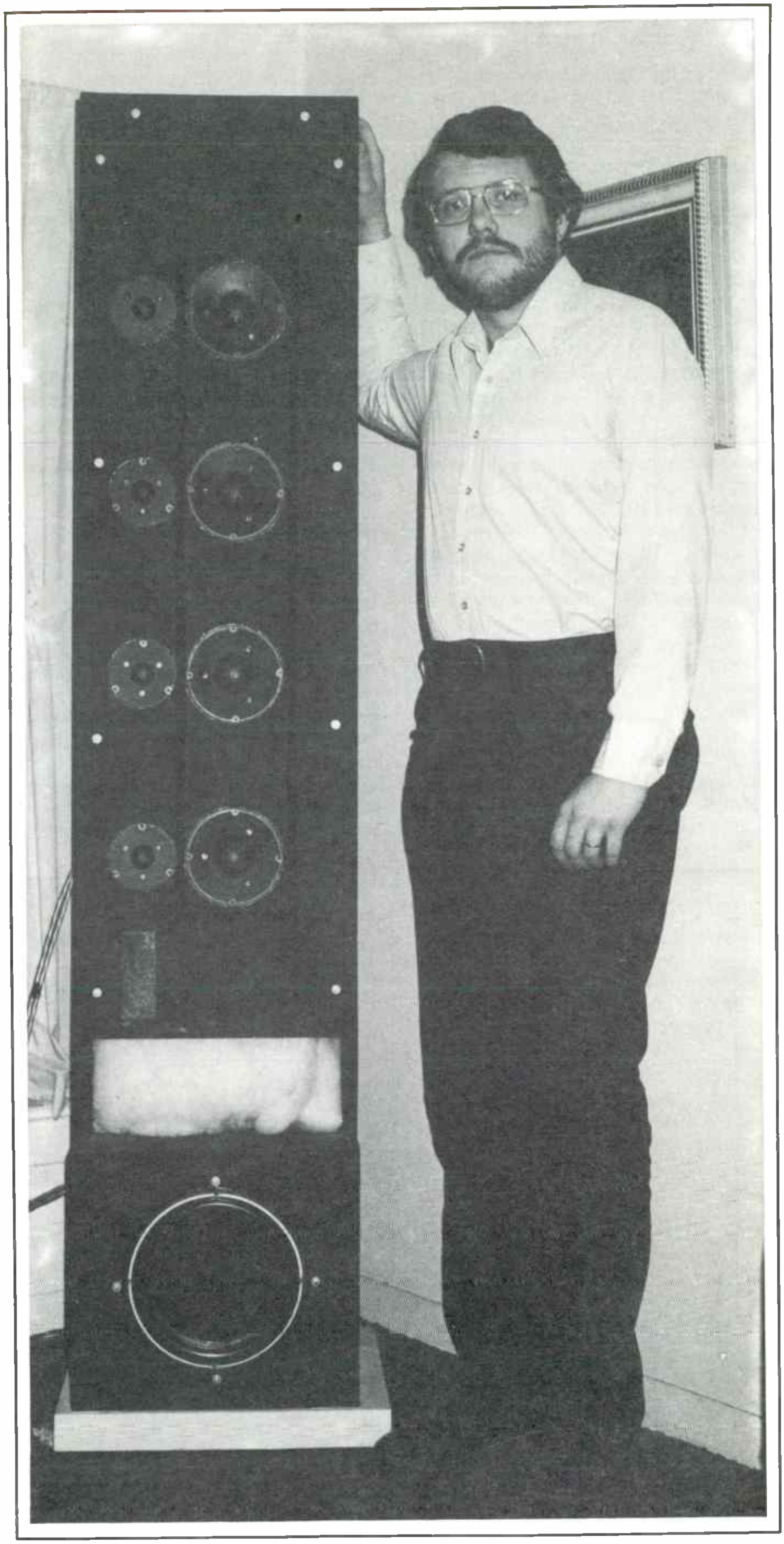


FIGURE 2: The completed TL 10 rests on a 2" thick marble block to suppress feedback, and at 6' nearly dwarfs its maker. Mounting the midrange drivers on ½" masonite improves phase response.

THE TL-5 SYSTEM. I wanted to determine just how good a high-compliance 5" woofer could sound if unrestricted by "trapped-air-in-a-box" colorations found in acoustic suspension systems using similar drivers. After some experiments with crossover frequencies and woofers (the original was a paper cone, PVC-surround Audax), I achieved a two-way system of quite remarkable capabilities for its size.

The present TL-5 uses an Audax HD 13B25H2C12 Bextrene woofer and a Philips 0163/T8 textile dome tweeter with a crossover frequency of 1800Hz. Although the Audax woofer has a free-air resonance of 35Hz, the line is ¼ λ at 60Hz, this system's low frequency cutoff. The crossover frequency may seem low, but it is the best compromise for this combination of drivers. In the prototype I used a 3000Hz crossover frequency. Due to this driver's sharply rising impedance at higher frequencies (it is already 15Ω at 3000Hz), designing a crossover with smooth response in this region is difficult. The prototype's response was very rough around the crossover frequency; lowering the frequency to 1800Hz (woofer impedance is 10Ω here) provided a much smoother blend at the crossover point.

TL-5 CROSSOVERS. Again you have two options when selecting a crossover network for the TL-5. The Philips 2000/8 crossover works very well in this system; its slightly higher crossover frequency (2000Hz instead of the "ideal" 1800Hz) is not really of much consequence. It has a 6dB/octave rolloff on the woofer and 12dB/octave on the tweeter. *Figure 6* shows a wiring diagram for the Philips unit You'll need a 100-watt L-pad and 6dB fixed attenuator (the 4Ω and 8Ω, 10-watt resistors) to reduce the tweeter's high output. Change the electrolytic capacitor to a mylar.

Figure 7 shows my 12dB/octave constant resistance network. It is more expensive than the Philips—about $40 per pair. Use mylar capacitors for C_1. You'll need the 100-watt L-pad and 6dB fixed attenuator (R_1 and R_2) for the tweeter.

The correct L-pad setting with either crossover network is around 10 o'clock. Most builders have used the stock Philips 2000/8 crossover with this system; it is a very satisfactory alternative to my more costly design, and I recommend it for the average builder.

TL-5 SOUND. This system will deliver smooth, natural bass, with fundamentals not possible using such a small driver in a "box" loudspeaker. This small system is accurate enough to reveal differences between power amps, pre-amps, etc. "Rockers" and disco freaks may not like it, however, since it was not designed to rattle floors and break leases. It will deliver musically convincing reproduction at moderate levels, and the amount of bass information will surprise most listeners. Telarc bass drums sound more realistic on the TL-5, again at moderate levels, than on many acoustic suspension or bass reflex systems with much larger woofers. They will not play the Telarc *1812 Overture* cannons.

Due to the relatively short transmission line required for a 60Hz cut-off, woofer control is less than optimum at infrasonic frequencies. An infrasonic filter in your pre-amp will be helpful. The curve in the stock Hafler DH-101 is ideal for the TL-5's, although it begins too high for the TL-8's and TL-10's: so is the low filter in the Jung-White PAT-5/WJ1A.

The TL-5's are not very efficient. I am using them as extension speakers, powered by a 25 watts per channel SWTP 215. This is probably the minimum satisfactory power level; they are even better when powered by my PASS/A-40 or Hafler DH-200.

This system should also function well as satellites with a common sub-woofer. I have not tried such a scheme; if you do, please report the results. A satellite arrangement crossed over at 100Hz would greatly increase the system's power-handling capability.

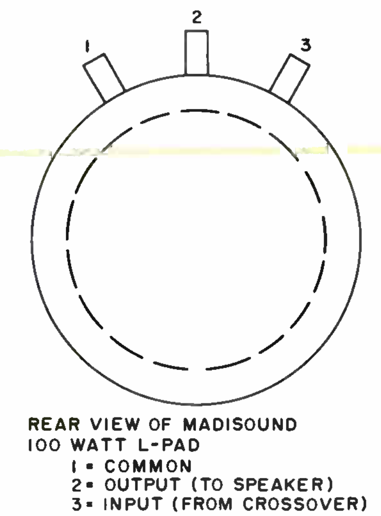


FIGURE 4: Madisound's L-pad permits the user to compensate for room acoustics by adjusting the balance of the three frequency ranges.

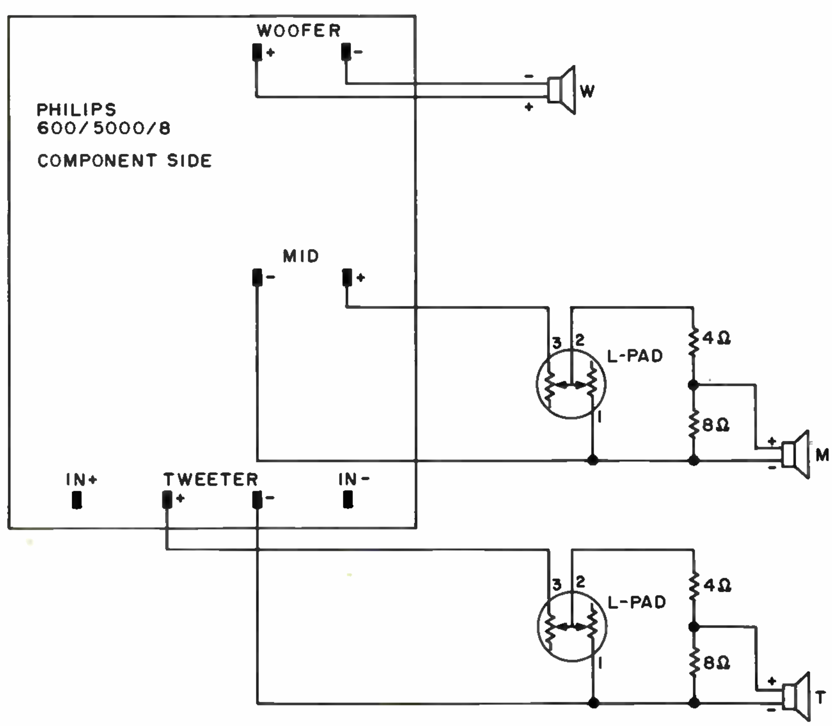
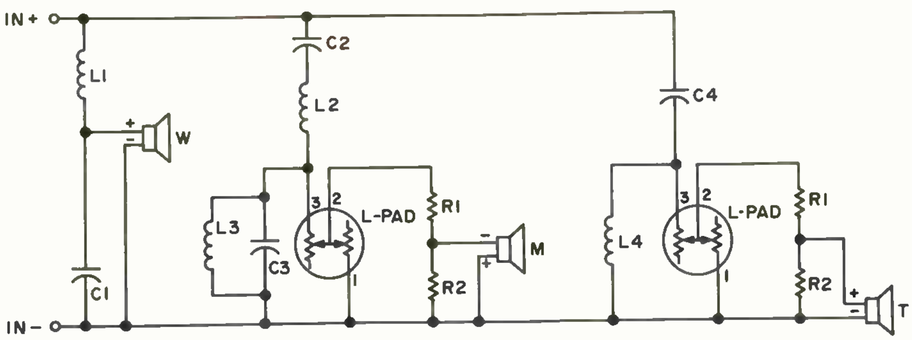


FIGURE 3: With the stock Philips crossover, better sound results when mylar caps replace the electrolytics. The L-pads reduce the outputs of the tweeters and midranges to match woofer.

CONSTRUCTION PROCEDURE

I. TL-8 and TL-10 Systems. Since these loudspeakers are identical in construction details, apart from the dimensions and layout of the midrange/tweeter baffle board, I will discuss them together.

Look at the parts lists for both systems. Use ³/₄" particle board, two-inch #8 flat-head screws, and Titebond glue throughout. Space the screws about six to eight inches apart. I do not recommend screwing the pieces together by



L_1 = 3.2mH
L_2 = .49mH
L_3 = 2.9mH
L_4 = .45mH

C_1 = 16mFd
C_2 = 15mFd
C_3 = 2.5mFd
C_4 = 2.25mFd

R_1 = 4Ω 10W
R_2 = 8Ω 10W
(or 2-4Ω in series)

L-pad = 8Ω, 100W (Madisound Spkr. Components)

FIGURE 5: Galo's crossover moves the woofer rolloff point up to 700Hz and uses 12dB/octave slopes.

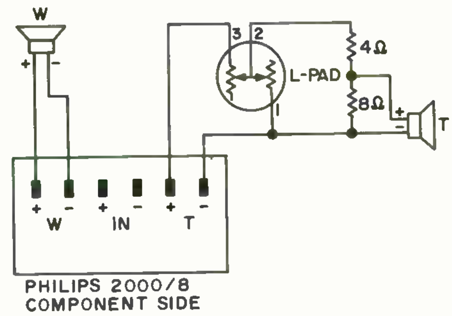


FIGURE 6: This crossover has 6dB/octave response for the woofer and 12dB/octave for the tweeter. An L-pad adjusts the tweeter level and mylar caps improve the sound.

hand. Use a variable speed electric drill with a flat blade screwdriver bit and drill pilot holes with a Stanley "Screw Mate," which drills, counterbores, and countersinks in one operation. You'll save a lot of time if you use two electric drills, one for the "Screw Mate" and the other for the screwdriver bit. *Figure 8* shows the layout and dimensions.

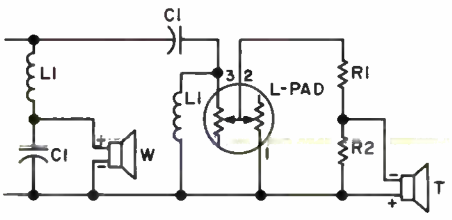
STEP BY STEP. 1. Begin with what will be the right side piece. Attach the back (A), the top (B), and the bottom (C) to the side piece.

2. Cut the woofer hole in its baffle board (D) and attach it to the side piece.

3. Fasten the step (E) to the line divider (F). Now fasten this assembly to the side piece and the woofer baffle.

4. Attach the right angle piece (H). This can be a piece of 2″ x 6″ (for the TL-10) or 2″ x 4″ (TL-8) with the edges beveled 45 degrees.

5. Mount the terminals (five-way binding posts, or any other terminals you choose) on the back panel, behind the woofer. You can do this most easily by attaching the binding posts to a 6″ x 6″



L_1 = 1.25mH
C_1 = 6.25mH
R_1 = 4Ω 10W
R_2 = 8Ω 10W
(or 2-4Ω in series)

L-pad = 8Ω, 100W (Madisound Spkr. Components)

FIGURE 7: An alternative crossover offers 12dB/octave on both drivers and moves the rolloff point down to 1800Hz, but is more expensive.

piece of ¼" masonite. Then cut a round 3½" hole in the back piece (A). Now mount the masonite terminal assembly from the inside with glue and short screws. If you are planning to bi-amp or tri-amp at some future time, install the extra terminals and wiring *now*.

6. Do the preliminary wiring at this time, using heavy wire throughout—#16 minimum, preferably #14, #12, or Monster Cable. Solder a pair of wires to the back of the binding posts; drill a hole through the step (E) and pass wires through it. You'll be mounting the crossover and level controls behind the midrange/tweeter baffle (G), not yet installed, so make the wires long enough to reach. Another pair of wires must also pass through the step (E) to connect the crossover to the woofer. Seal around the wire holes with GE silicon rubber glue to prevent leaks. Sealing around the binding posts is also a good idea.

7. With a staple gun, fasten a one inch layer of fiberglass in the area behind the woofer shaded in *Fig. 8*. You need cover only one of each parallel surface—ie, put one piece on the side and another covering the bottom (C), the right angle (H), and the back. Extend this fiberglass no higher than the step (E). Its purpose is to prevent reflections in the area immediately behind the woofer. Some European designs use carpet felt or short fiber wool for this purpose, but fiberglass works fine; besides, carpet felt is hard to find (rubber underlayments are more popular) and short fiber wool seems to be nonexistent in the United States.

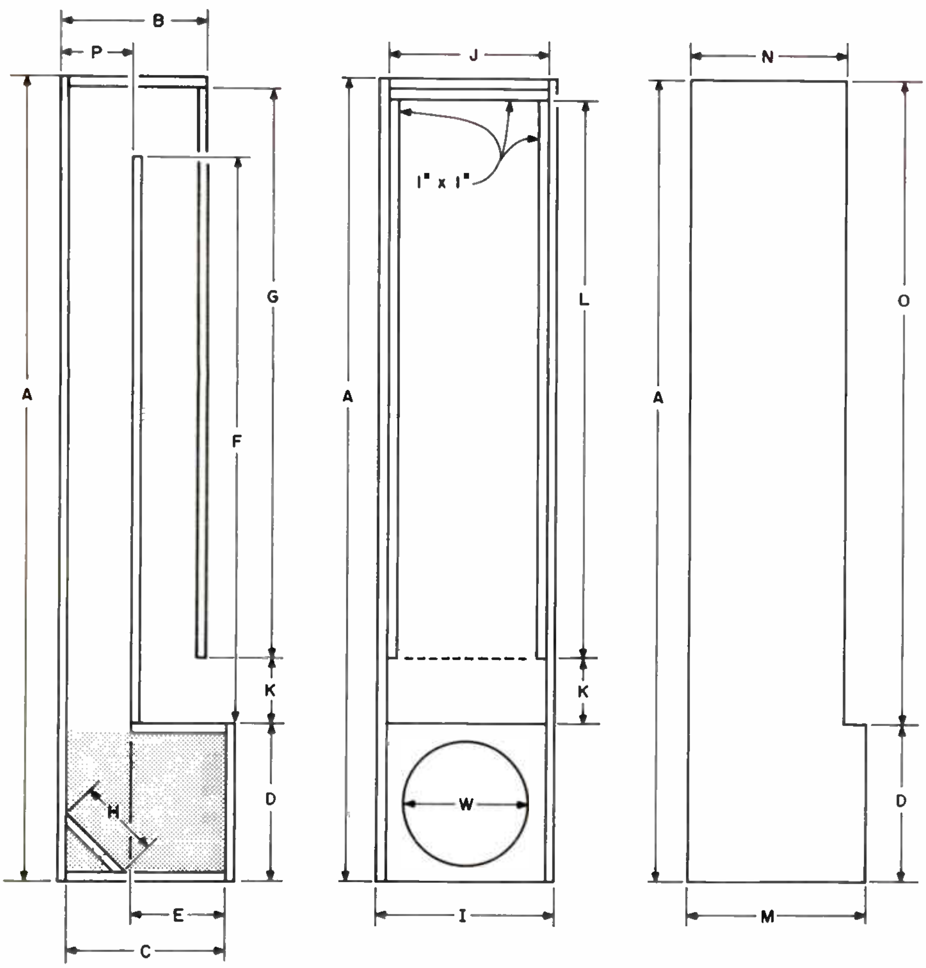
8. Fill the area behind the woofer and the rear portion of the line, between (A) and (F) with long fiber wool. A TL-10 will need three pounds, a TL-8 one and a quarter pounds. Save an appropriate amount for filling the area between (F) and (G) later Distribute the wool evenly, using staples to support it. Most long fiber wool clings to particle board, so staples are usually enough to prevent settling.

9. Fasten the remaining side piece to the existing assembly.

10. We're going to attach the midrange/tweeter baffle boards so they can be removed easily. A 1" x 1" strip of pine (*Fig. 9*) supports the baffle, with a ⅛" layer of foam or felt weather-stripping to ensure no air leaks around the board.

Attach the 1" x 1" inside the enclosure's side panels and top as shown in *Fig. 9*, using 1¼" x #8 screws and glue. Recess the 1" x 1" far enough from the front edge of the side panels to allow for the thickness of the baffle board plus weather-stripping (remembering the weather-stripping will be compressed when the baffle board is screwed in place).

11. *Figure 10* shows midrange/tweeter baffle board dimensions and details. Cut the baffle board to the indicated outside



DIMENSION	TL-10	TL-8
A	72"	48"
B	13¼"	9¼"
C	14½"	10½"
D	14"	14"
E	9⅝"	6⅝"
F	51¼"	29"
G	51¼"	29"
H	6"	4"
I	15½"	11½"
J	14"	10"
K	6"	4¼"
L	50½"	28¼"
M	16"	12"
N	14"	10"
O	58"	34"
P	6⅝"	4⅝"
Woofer hole	8⅜"	7⁷⁄₁₆"

FIGURE 8: Side and front views of TL-10/TL-8 enclosure show internal details and dimensions before the side piece is put into place.

dimensions, and if necessary trim it to fit easily in the enclosure, remembering to allow for paint build-up later on. To align the midrange and tweeter voice coils, the midrange drivers are mounted on a half-inch thick piece of particle board. See *Figs. 9* and *10* for the board's outside dimensions, and bevel its edges in about 30 degrees.

Cut holes for the midranges and tweeters in the baffle board and half-inch piece and attach the half-inch piece with 1¼" x #8 screws and glue, drilling holes where indicated to accommodate the L-pads. Madisound's 100-watt L-pads have threaded sleeves well over ¾" long, so they will mount easily in ¾" material. (Do not mount them yet, however.)

12. Fill all holes, rough edges, etc. in the main enclosure and baffle board with Savogran, Red Devil, or a similar water-mixed wood filler. Sand and finish the enclosure with black paint, veneer, or whatever you prefer.

13. Solder leads (*never* use slip-on speaker connectors!) to midrange and tweeter drivers now to facilitate wiring after they are mounted. Observe speaker polarity. With a single edge razor blade, remove the rear foam gasket attached to the Philips 0211 midrange drivers. Mount the midrange and tweeter drivers on the baffle boards, using GE silicon rubber glue. Lay the boards horizontally between two chairs or boxes. Run a generous quarter-inch bead of silicon glue around the back edge of each driver and press it into place on the baffle board. You needn't use screws. The silicon glue requires 24 hours curing time before the baffle boards can be moved. Once cured, it provides a superior seal. The drivers will not fall out!

14. With the main enclosures lying flat

PARTS LIST

ITEM	Quantities needed per system TL-10	TL-8	TL-5
Audax HD24B45 10" Bextrene woofer, 8Ω	2	-	-
Audax HD20B25H4C12 8" Bextrene woofer, 8Ω	-	2	-
Audax HD13B25H4C12 5" Bextrene woofer, 8Ω	-	-	2
Philips AD-0163/T8 dome tweeter, 8Ω	8	2	2
Philips AD-0211/SQ8 dome midranges, 8Ω	8	2	-
Crossover networks (see text)	2	2	2
100 watt L-pads	4	4	2
4Ω, 10 watt power resistors	12	12	6
Five-way binding posts (speaker terminals)	4	4	4
¾" particle board (4' x 8' sheets)	4	2	1
½" particle board (2' x 4' sheet)	1	-	-
½" particle board (2' x 2' sheet)	-	1	-
2" #8 flat head wood screws	200	100	60
1¼" #8 flat head wood screws	50	30	-
2" #8 pan head screws with flat washers	20	14	-
8' pieces of clear pine 1" x 1" (actually ¾" x ¾")	4	2	-
Bottle of "Titebond" glue or "Elmer's" carpenter's glue	1 large	1 large	1
Caulking tube of GE clear silicon rubber glue	1 large	1 large	1 small
⅛" x ¾" foam or felt weather stripping	25 ft.	15 ft.	-
Long fiber wool	6 lbs.	2½lbs.	1¼lbs.
Radio Shack speaker fiberglass #42-1082	2 pkg.	1 pkg.	1 pkg.
Wire (see text for preferred type)	Indef.	Indef.	Indef.

on their backs, solder the wires previously installed for the woofer to the woofer's terminals, again observing polarity. Run a bead of silicon glue around the back of the woofer and press it into its hole. Allow 24 hours curing time.

15. Mount the L-pads and crossovers next to each other on the backs of the baffle boards. Connect the crossover inputs to the wiring previously installed, and the woofer outputs to their waiting leads. Using the diagrams in *Figs. 3* or *5* (depending on which crossover you use), connect the L-pads, attenuator resistors, and drivers as shown, first connecting the TL-10's midrange and tweeter drivers in the series/parallel arrangement shown in *Fig. 1*. The attenuator resistors can be contact-cemented to the back of the midrange and tweeter units.

16. Attach the weather-stripping to the 1″ x 1″ pieces.

17. Fill the remainder of the line with the remaining long fiber wool.

18. Drill pilot holes and fasten the front baffle boards in place with 2″ x #8 pan head screws and flat washers.

If you wish to use grille cloth to cover the woofer and midrange/tweeter baffle boards, you can make frames of 1″ x 1″ pine with grille cloth stretched over and stapled to the backs. In my opinion, no grille cloth is completely non-reflective. With the best associated equipment, any high-accuracy loudspeaker will sound better without grille cloth. You'll have to decide whether decor is more important than better sound.

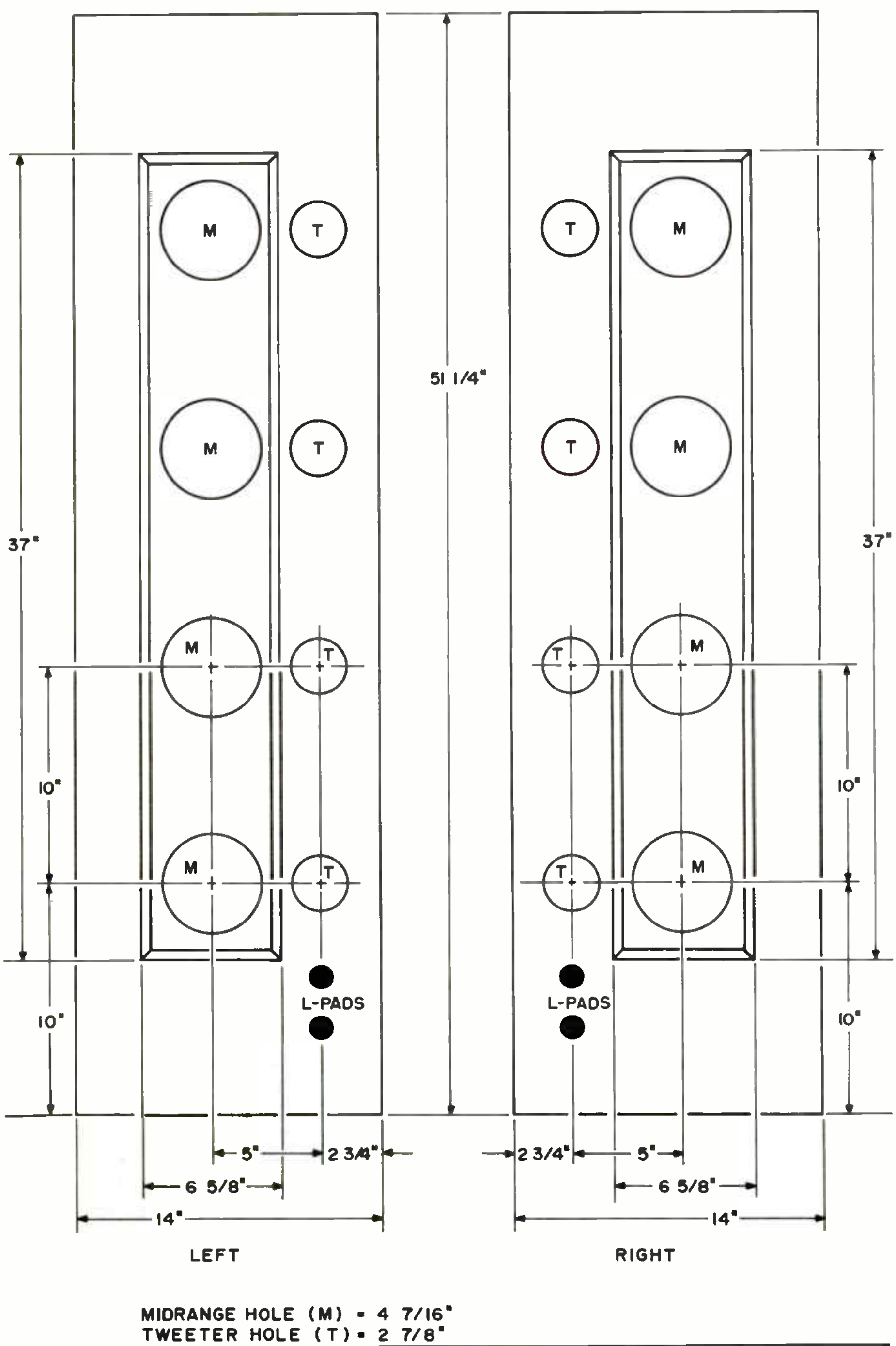


FIGURE 9: The TL-10 uses mirror-imaged tweeters and midranges, the latter raised by a ½″ mounting for phase-alignment.

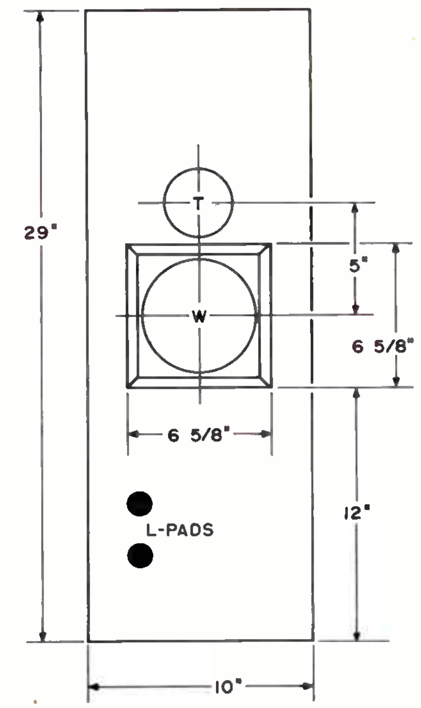


FIGURE 10: For simplicity on the TL-8 the mirror-imaged baffle boards are not used.

II. THE TL-5 SYSTEM. This is the easiest to construct. *Figure 11* gives the front and side views and internal details. The back and front panels are both 13½″ x 19½″. All the other pieces are six inches wide and fit between the front and back panels. See the TL-8 and TL-10 section above for comments on tools, drills, etc. Space 2″ x #8 screws about six inches apart.

STEP BY STEP. 1. Begin with the back piece. Attach the top, sides, and bottom pieces. Then attach the inside pieces and the three-inch, 45 degree angle piece. Note that the left and right loudspeakers are mirror images of each other, as shown in *Fig. 11*.

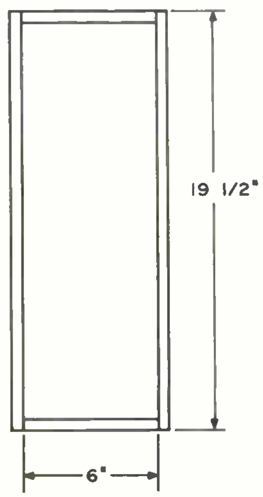
2. Mount binding posts or other suitable terminals on the back panel near the tops of the enclosures, as in step 5 in the TL-8/TL-10 procedure above.

PARTS SUPPLIERS:
Philips and Audax drivers, crossovers, crossover components, L-pads: Madisound Speaker Components, Box 4283, 537 Holly Ave., Madison, WI 53711. Telephone: (608) 256-7337.

Crossover components, Audax drivers, many other components: Transcendental Audio, 6795 Arbutus St., Arvada, CO 80004. Telephone: (303) 420-7356.

Long fiber wool: J. Ebbert, 431 Old Eagle School Rd., Strafford, PA 19087. Telephone: (215) 687-3609.

Speaker terminals, numerous electronic components: Mouser Electronics, 11433 Woodside Ave., Lakeside, CA 92040. Telephone: (714) 449-2222.



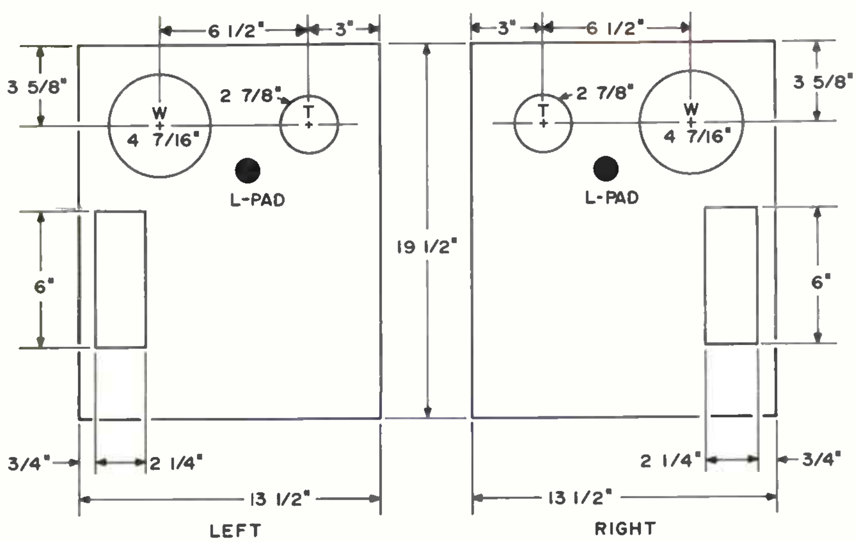


FIGURE 11: Left, right and side views show TL-5 external dimensions with mirror-imaged tweeters.

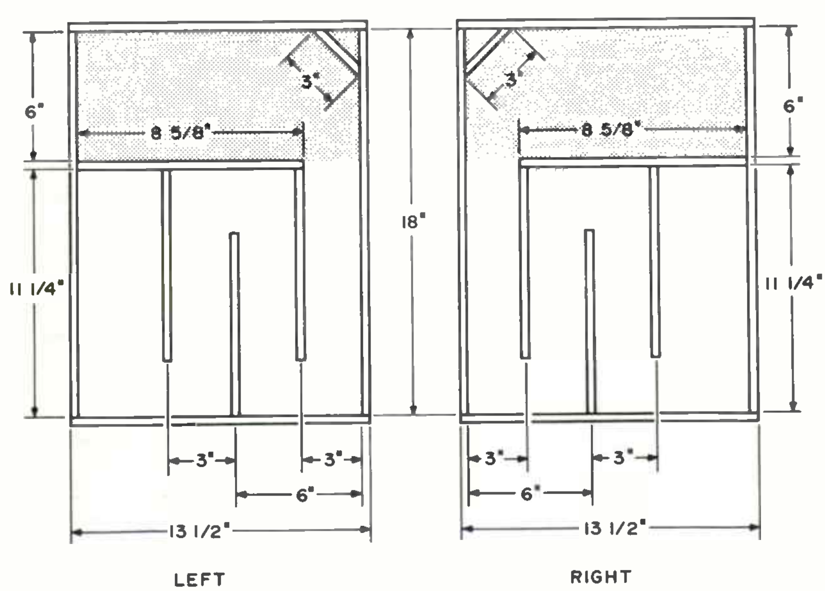


FIGURE 12: Internal details and dimensions of the TL-5 are shown with front baffle removed.

3. Mount the crossovers next to the speaker terminals and connect the terminals to the crossover inputs. Observe polarity. Attach leads to the crossover's woofer and tweeter terminals, using at least #16 wire—see step 6 in the TL-8/TL-10 section.

4. With a staple gun, attach a one-inch layer of fiberglass to the areas shaded in *Fig. 19*. One piece should cover the back area immediately behind the woofer and another piece should cover the side, top, and 45 degree angle piece.

5. Fill the enclosures with evenly distributed long fiber wool. One and a quarter pounds are enough for both speakers.

6. Cut holes for the woofer, tweeter and line exit in the front pieces. The woofer and tweeter are six and a half inches apart, center to center. Check the exact spacing of the line dividers in your speakers. You may have to adjust the line exit size slightly for a neat fit. Note again that the left and right speakers are mirrored pairs.

7. Drill a hole for the L-pad shaft between the woofer, tweeter, and line divider.

8. Fasten the left and right front pieces to their enclosures. Fill all holes, rough edges, etc. as in step 12 of the TL-8/TL-10 construction. Sand and paint or finish the enclosures to your liking.

9. Solder the tweeter crossover output wires to the L-pad and connect the L-pad to the attenuator resistors and tweeter. Observe polarity! (See *Fig. 6* or *7*, depending on which crossover you are using.) The attenuator resistors can be contact-cemented to the back of the tweeter. Mount the L-pad in its hole. Run a bead of GE silicon rubber glue around the back edge of the tweeter and press it into its hole.

10. Connect the woofer leads to the woofer, again observing polarity. Run a bead of silicon glue around the back edge of the woofer and press it into place. Allow 24 hours for the silicon glue to cure, leaving the speakers flat on their backs during this time. Cover them with grille cloth if you must—see my comments on grille cloth above.

I shall welcome comments, questions, etc. on these designs. Please include with any queries a list of the associated equipment used, such as pre-amp, amplifier, turntable, and cartridge. Send questions and comments c/o *Speaker Builder* and please include a stamped, self-addressed envelope; or you may call me after 7:00 p.m. Eastern time at (315) 265-4268. □

I would like to thank Paul Steinberg of Potsdam, N.Y., for his help in preparing the photographs.

Turn page for bibliography

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Tools, Tips & Techniques

WOOLLY BASS

After having built the 10 foot transmission line bass enclosure, I would like to suggest the following method for installing the wool.

First make a frame, just a little larger than the enclosure's inside measurements, and drive in finishing nails about 6″ apart, near the inside edge of the frame. (*Photo 1*)

Cut the fishnet into the number and size of pieces needed. I used five per side, 10 in all, and cut one full-sized piece into three parts for the small spaces around the driver. Divide the wool into appropriate amounts. Soak the fishnet in contact cement, squeeze out the excess, and string it on the finishing nails. While the glue is still wet, apply the wool first on one side, then the other (*Photo 2*). Press it between the front and back sections of the unassembled cabinet while it dries.

When dry, comb out the wool on both sides to fluff it up as much as possible. Remove from the frame and hang it so the wool won't compress before installation (*Photo 3*). Staple it securely to the inside of the enclosure.

Emil Stan
San Francisco, CA 94131

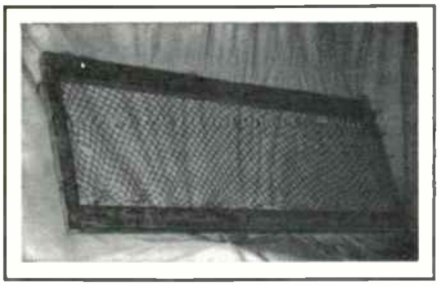

PHOTO 1: Installing wool in a transmission line speaker is easy if you apply it to this frame and fishnet first.

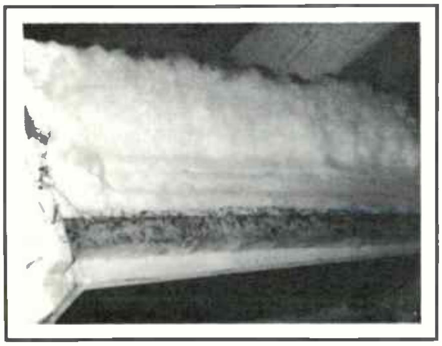

PHOTO 2: Glue the wool to both sides of the fishnet.

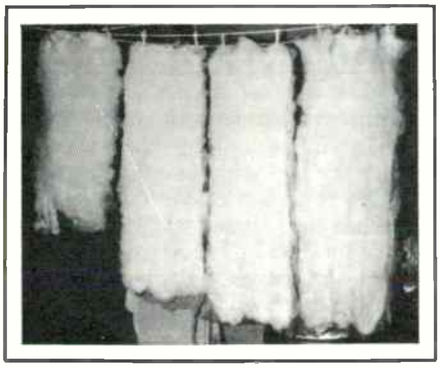

PHOTO 3: After drying, hang the wool, comb and fluff it before installation.

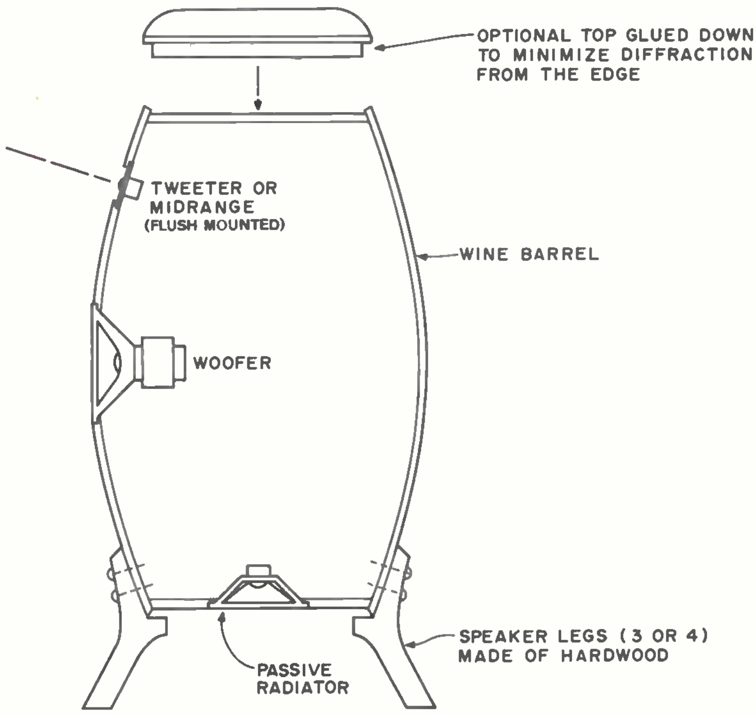

FIGURE 1: A barrel's shape has many advantages as a speaker enclosure. If it doesn't sound right, you can always put new drivers in old barrels.

BARREL BASS

Building speakers is a serious business but it can also be a lot of fun. There have been many designs to minimize cabinet diffraction, to time-align and to reduce the secondary radiation from the panel vibration.

Using an old wine barrel might solve those problems and barrels can be an interesting aspect of interior decoration, and it is fun or shall I say "it's a barrel of fun?"

Obviously a barrel is a near ideal shape for a speaker enclosure as we learned from Dr. Olson's study (*SB* 1/80, p. 29). It is fairly easy to time-align the drivers from this shape. What is not so obvious is that if this enclosure vibrates it may not be as harmful as a rectangular box because an ideal sound source is a sphere. Since this is only my speculation, I hope someone will come up with a definite study on secondary vibration effect on this kind of enclosure shape.

I have not given any dimensions in my drawing so that the individual builder can suit them to his available barrel. The

Tools, Tips & Techniques

system can be an acoustic suspension, closed system with bottom firing passive radiator as in *Fig. 1*, or a ported enclosure (as in port wine).

It can be a 2-way or 3-way and single or multi-amped. The Technics 10TH1000 leaf tweeter has a barrel shaped body and is designed to be placed on top of an enclosure. It might match very well as a complement to the barrel.

The optional top indicated in the drawing can be just placed there if you do not want to spoil the appearance of the barrel.

The distance from the floor is very important, and must be determined by experiment because the type of flooring or the floor covering can severely affect the bass response.

You may encounter one serious problem during hole cutting for the large woofer. The barrel may simply fall apart so that you must make sure to glue the affected sections of the barrel beforehand. You may also have to caulk the inside since a dry barrel may not be air tight. Usually they become water tight when a liquid is poured in and wood expands. [*Perhaps readers will experiment with pouring wood sealers, "liquid glass" or tar products into the barrel before cutting and then letting it drain and dry.—Ed.*]

Internal wiring can be done through the woofer hole. Experiment with sound absorbing material. The grille can be just the size of the driver so that you do not spoil the quaint look of the wine barrel.

Happy experimenting and building.
Bottoms up.

Haruka Watanabe
St. Louis, MO 63130

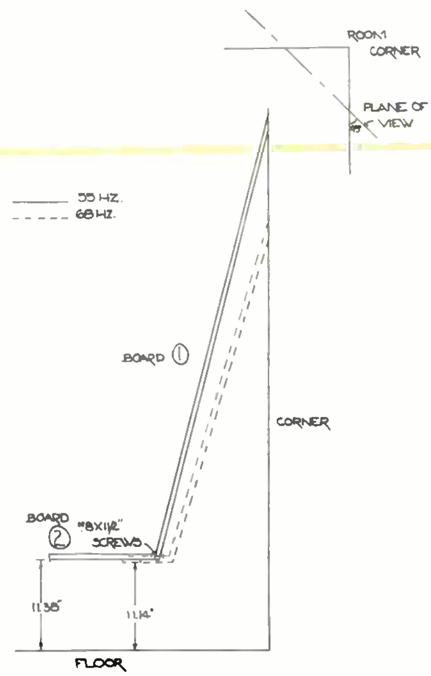

FIGURE 1: An exponential horn can be approximated very easily using just two pieces of particle board and the corner of a room.

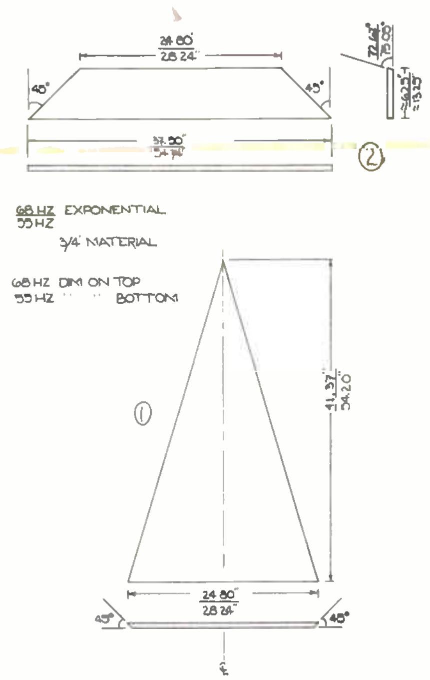

FIGURE 2: The triangular piece fits between the two walls, sloping in toward the ceiling. The flat piece extends outward, parallel to the floor.

WALL HORN

More audiophiles than ever are showing a genuine interest in low frequency horns because of their extremely high efficiency and low distortion characteristics. However, most of us never pursue them past the thinking stage because of the complexity of horn construction and the tools required. But here's a horn design that anyone with a circular saw and a steady hand can build in a few hours.

The sub-family of exponential horns with cut-off frequencies of 40-80Hz can be closely approximated (±5% at any point along the wavepath) with two pieces of high density particle board mounted in the corner of a room. The 55 and 68 cycle designs illustrated maintain an even closer tolerance to a true exponential curve and are composed of parts small enough to be convenient and easy to brace, yet will provide excellent low frequency response. Close attention must be paid to the dimensions and angles involved, and the two pieces must be securely joined to each other and to the corner of the room with glue, screws, and silicone caulking compound to maintain an air seal.

Any size of loudspeaker component can be used with these horns. The proper mounting location is the highest point on the triangular section to which you can flush-mount the driver. Simply stick the thing up there as high as it will go without interference from the walls of the room, cut an opening for the driver having an area half that of the effective cone area, and mount the speaker over the opening. Be careful to avoid air leaks. While not a very scientific method of throat design, this procedure is surprisingly accurate with these two horns.

I currently live in a concrete block structure at Pine Mountain Observatory near Bend, Oregon, so my room walls are extremely rigid and don't suffer from transmission losses or resonances. I can't guess what the effects would be in a 2" x 4" stud frame building, but some bracing may be necessary. I've built a pair of the 55Hz designs into our living room up here, using 12" woofers from AR-9's built into enclosures of the proper volume to produce the horn reactance annulling condition described by Diel J. Plach in his article, "Design Factors in Horn Type Loudspeakers," published in the AES *Journal* in October 1953. This extends the low frequency response by about a half octave. Analyzed using pink noise and an Audio Control AC-101 analyzer the response was flat from 40 to about 300Hz.

I hope this design concept will open the way for more audiophiles to experiment with low frequency horns in the home. I would be glad to correspond with readers about improvements and strengthening techniques.

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RUBBER MOUNT

Use this easy, non-critical method to mount drivers flush on a baffle.

1. Cut holes slightly larger than the outside of the driver basket (clearance of up to ¼" radius is OK).

2. Tape the driver basket front (or the face of the baffle) to mask off the clearance space between baffle and driver when the driver is centered in its mounting hole. Take care that the tape is in smooth strips and tangent without touching the cone or surround of the speaker.

3. Place the driver and baffle face down on a flat surface, centered and with tape making good contact with baffle and driver basket.

4. Fill the gap between the driver basket and baffle with silicone rubber, glue and seal (I use black but there are 5 other colors). You can use your finger to force good contact between the baffle and the driver basket.

5. Let the rubber cure *fully*, depending on thickness, at least 24 hours, usually more.

6. When you remove the masking tape you will find your driver sitting in a semi-rigid ring of smooth rubber, flush to the baffle and with a substantial amount of isolation between driver basket and enclosure. Needless to say, this is also airtight.

I've found this much easier than routing or trying to cut concentric holes in different thicknesses of stock and gluing together. Usually you can't see where a baffle painted black ends and the black rubber begins so the hole cut for the driver is much less critical. If you cut slightly out of round or chip a piece out of a flakeboard baffle, it will never be noticed or leak. If the driver needs to be replaced it is easy to cut the rubber and pry the driver out.

W. Gabriele
New Haven, CT 06511

TRACTRIX HORN

Please refer to "The Tractrix Horn Contour" by Bruce C. Edgar in the 2/81 *Speaker Builder.*

With the graphs in *Figs. 4, 5,* and *6,* you can obtain x for a given r or an r for a given x. The accuracy obtained is sufficient for building a practical horn but limited by the small size of the graphs and by your ability to interpolate accurately.

The equation for x given in column 1 page 10 can be used to design a free standing horn. That is, the value of x obtained with the equation will agree with the value of x obtained from the graph *Fig. 4.* However the x obtained with the equation will not agree with the x obtained from the graphs of *Figs. 5,* and *6* for wall and corner horns. The correction factor to reduce the mouth area for wall and corner horns is $\sqrt{K}$. The value of K is one for free standing horns, four for a wall horn and eight for a corner horn. (See column 2 page 10 of the 2/81 *Speaker Builder.*)

The work for determining the mouth radius a is reduced if the equation for mouth radius is divided by $\sqrt{K}$.

Hence:
$$a = \frac{C}{2\pi f \sqrt{K}} \quad (1)$$

Tools, Tips & Techniques

$$x = \sqrt{K}\left[a \cdot Ln\left(\frac{a + \sqrt{a^2 + r^2}}{r}\right) - \sqrt{a^2 - r^2}\right] \quad (2)$$

Equation (2) will now give a correct length for any assigned r. The range in r is between the mouth radius a and the radius required to give the throat area required by the driver used. See column 1 page 12 and column 1 page 14.

The work is simpler if you use a calculator having a key for Ln x (Log_e x). The Log x (Log_{10} x) key can be used but requires the use of a correction factor from a math table. The memory keys "Store" and "Recall" are very useful also. A "Slide Rule" calculator has these keys and the calculation for x is one continuous operation once the values of a, r and $\sqrt{a^2 - r^2}$ are obtained.

The horn area at x is πr^2 and is used to determine the dimensions of a rectangular cross section. Equation (2) gives values of x from the mouth of the horn. The x from the throat is easily obtained and is very useful when making a drawing of the horn layout.

Use values of r which give x in increments of 1 to 2 inches. This requires r increments of 0.1 inch near the throat. When the increments in x approach 2 inches, increase the r increments to 0.1, 0.25 or 0.333 as needed. But when r approaches the mouth radius a, use an r increment of 0.5 inch. This results in smaller x increments which may become less than 1 inch. This is OK because the horn area increases very rapidly near the mouth of the horn.

Herbert L. Johnson
Hebron, IN

Muses and Music

Since the music moves you—the muse is almost surely able to do so as well. The writer's muse, that is. Put pen to paper or better yet, typewriter ribbon to paper with a clear, orderly account of your adventure in speaker construction, or any related field of endeavor leading to good listening. Send it along with a stamped, return envelope. We pay modestly for articles, so if your muse move you, write us about it and we'll answer promptly with suggestions and say whether or not we have such an article, whether one is already in preparation, or whether we are interested. Some of our best articles come from people who have never before written for periodicals. And if your muse is as silent as a tomb, don't let that stop you. Write anyway and let's see what develops. We have a nice sheet of suggestions for authors which we will send to nearly anybody who asks for it.

Designer's Corner

Working Wall

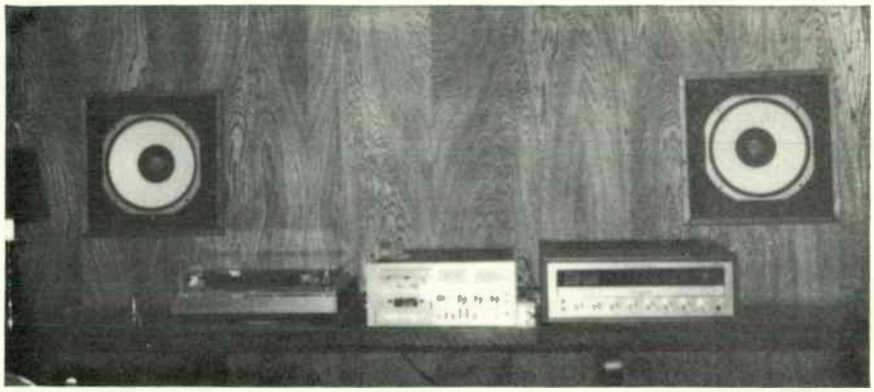


PHOTO 1: Placate your spouse and still enjoy good sound by mounting your speakers in the wall and using the garage as the enclosure.

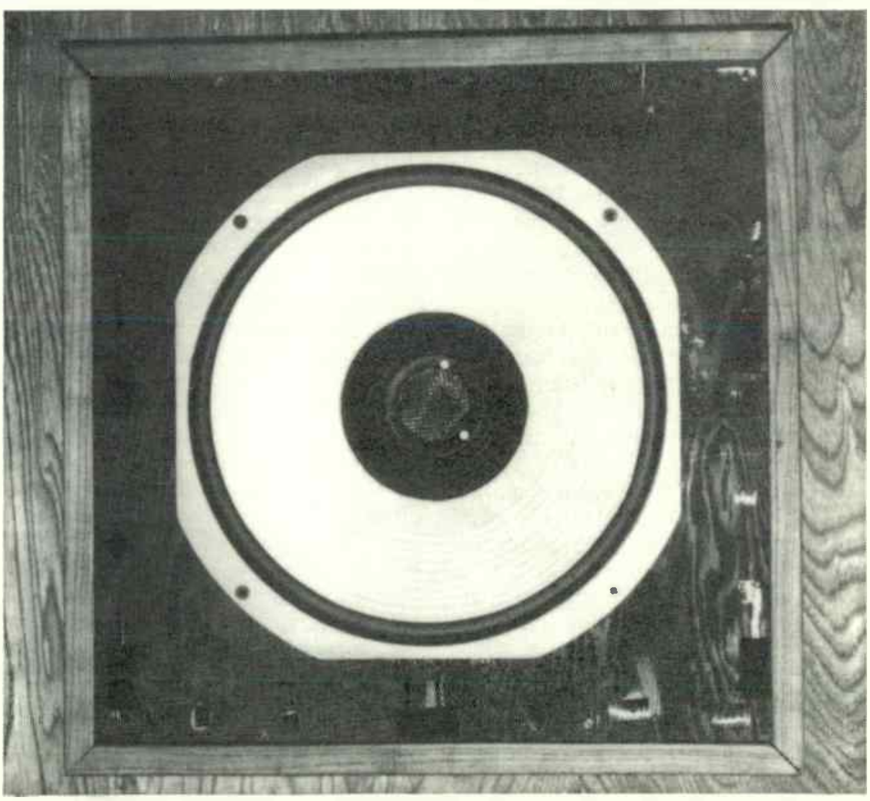


PHOTO 2: Closeup view shows the details of mounting. When in place, the foam grille renders the speakers nearly invisible.

In order to gain some much needed space in my living room, satisfy my wife's aesthetic concerns for speaker placement (they should not be visible), and still enjoy stereo, I installed my speakers in the wall. The speakers are not complete enclosures, but JBL Model LE14C drivers. These are two-way (coaxial) drivers, composed of a 14" woofer and a 1½" cone tweeter crossed over at 2kHz by an external JBL network which employs a continuously variable high frequency attenuator.

The speakers are located in the short wall of a 15' x 22' living room, spaced about 6' apart and 4' above the floor. They are mounted on ¾" thick plywood panels using T-nuts and machine screws. The plywood panels are fastened with screws to the wall studs. The drivers are open in the back to the adjoining garage, which serves as an infinite baffle enclosure. The backs are covered by 3½" of fiberglass batting for thermal insulation and grille cloth to finish the garage side.

Velcro fasteners secure acoustically transparent foam grille to the speaker fronts. The completed installation is visually unobtrusive and performs well acoustically.

JBL has discontinued production of the LE14C drivers, but composite drivers are available from other companies, such as Altec and ElectroVoice. A similar installation can be made using separate (and more complex combinations of) drivers, limited only by your imagination and wallet.

Jim Frane
Orinda, CA 94563

SB Mailbox

FALCON TROUGH

A couple quick follow-up items to my letter in *SB* 1/82 regarding the Falcon Mini-Monitor. First, the trough I mentioned occured between 1000Hz and 1400Hz, not 1 and 4kHz as I had originally noted. Sorry about that.

Secondly, another way of making the felt dam for the tweeter is by cutting the pieces from an ordinary blackboard eraser. It's easier than laminating thin felt.

Charles G. Lyle
Minneapolis, MN 55417

DOUBLE BOSE

I'm complimenting *SB* in an area that may be a first, namely the "Classified–Private For Sale" section. To provide some background details....

In your 4/81 issue, I noticed an ad for a double pair of Bose 901's for sale from an individual in Chicago. After some discussions (!) with the missus (some of which related to my mental stability ie why do we need *another* four speakers????) I wrote a letter offering to purchase the speakers and requesting the seller to make the necessary arrangements for shipping, packing etc. To my complete surprise, the speakers were available and my offer was accepted.

A bit of intestinal fortitude is required to send a money order for a double set of speakers sight unseen (relying only on the word of a complete stranger), to a city 1500 miles away, and to make matters really interesting, to a different country.

The first thing you learn is not, repeat not, to discuss the purchase with your co-workers. Some of the comments you receive:

1. It's a racket, he will probably sell them to 50 poor suckers like you.
2. What beach do you think he will have his holidays at this year?
3. You will probably get four orange crates as speakers.

To make a long story short, in due course the speakers came. They were in immaculate condition, and the way they were packaged you would have thought the box contained the King Tut treasures rather than speakers. My compliments to Protopak of Elk Grove Village, Il for a terrific packing job.

If this is any indication of the type of people who advertise, no *SB* reader should feel hesitant to take some one up on their offer.

In closing, I would like to take this opportunity to thank Mr. Sherwin Janows of Chicago personally for all the time and energy he devoted in getting the speakers to me. I had the easy part, supplying the money.

Bill Landiuk
Calgary, Alberta
Canada T2B 2B3

P.S. My wife thinks the speakers are great.

DUAL COIL Q_S

I recently had a speaker design problem that emphasizes Robert Bullock's comments on not using high Q_{TS} woofers (*SB* 3/81, p. 27). For fun, I decided to build a dual voice-coil subwoofer for my office. Looking through various catalogs unearthed two possible candidates: a 12-inch Eminence driver from McGee Radio and a 10-inch driver from Speakerlab. The Speakerlab catalog lists all Thiele/Small parameters for their driver, and it looked promising. However, although McGee gives no parameters other than $f_s=15$Hz, I chose the Eminence woofer because it costs only half as much.

Unfortunately, the Eminence magnet is really too small, yielding Q_{ts} that is too high. For this driver, I measured $f_s=12.9$Hz, $Q_{TS}=0.61$ and $V_{AS}=882$ liters (29 ft³). This means a LARGE box. *Table 1* shows $Q_{TC}=1.0$ and 1.4 closed box alignments and C4 and BB4 vented box alignments. Only the closed box $Q_{TC}=1.4$ case yields an enclosure that could possibly fit in my office (7 ft³). McGee shows a sketch of a *vented* box for this driver with dimensions for 60″ x 24″ x 18″, yielding 15 ft³. Since this is less than ⅓ the size of the box needed for a BB4 alignment, the speaker must have a ripple much greater than 4dB. You could obtain a much flatter frequency response for this box by simply sealing off the vent, making a $Q_{TC}=1.0$ closed box with about 1db of ripple and no significant loss of low-frequency extension.

The completed speaker turned out to be much as expected. The in-box resonance f_c measured 27Hz (29Hz predicted) with a measured Q_{TC} of 1.39. An attempt to measure the frequency response failed because the microphone rolled off too rapidly to give useful results below 40Hz. However, just listening to sine waves played through the speaker revealed a peak at 26-28Hz with an amplitude of "several" dB. Listening to music showed that a lot of bass was there, but it did not seem as tight, detailed or airy as that produced by my own two 12″ Richard Allan subwoofers in B_4 passive radiator enclosures.

If the Eminence Q_{TS} had been 0.40, then a 5.5 ft³ enclosure would have yielded a closed box Q_{TC} of about 1.0 and $f_3=25$Hz, both satisfactory numbers. In this case, you would be trading a little (and probably unneeded) low-frequency extension for reduced box size (up from 16.6Hz to 25Hz but down from 17 ft³ to 5.5 ft³). This lower Q_{TS} driver would seem much more useful.

TABLE I
Eminence Dual Voice-Coil Subwoofer

$f_s=12.9$Hz $Q_{TS}=0.61$ $V_{AS}=822$ liters (29 ft³)

Closed Box	Closed Box	Vented Box	Vented Box
$Q_{TC}=1.0$	$Q_{TC}=1.4$	C4 alignment	BB4 alignment
		$Q_L=7$	$Q_L=7$
		$\alpha=0.2641$	$\alpha=0.5599$
		$f_3/f_s=0.5802$	$f_3/f_s=0.8206$
$V_B=487$ l (17 ft³)	$V_B=193$ l (7 ft³)	$V_B=3,113$ l (110 ft³)	$V_B=1,468$ l (52 ft³)
$f_3=16.6$Hz	$f_3=21.0$Hz	$f_3=7.5$Hz	$f_3=10.6$Hz
Rip ≅ 1dB	Rip ≅ 3dB	Rip ≅ .51dB	Rip ≅ 3.93dB

The Speakerlab dual voice-coil driver has $f_s=19$Hz, $Q_{TS}=0.38$ and $V_{AS}=340$ liters (12 ft³). The Speakerlab enclosure is a passive radiator design, and the Q_{TS} is very good for a B_4 alignment. *Table II*

TABLE II

Speakerlab W1055B Dual Voice-Coil Subwoofer

$f_s = 10Hz$ $Q_{TS} = 0.379$ $V_{AS} = 340$ liters (12 ft³)

Closed Box	Closed Box	Passive Radiator Box
$Q_{TC} = 0.707$	$Q_{TC} = 1.0$	B4 alignment $Q_L = 7$ $\alpha = 1.66$ $f_3/f_s = 1.27$
$V_B = 137$ liters (5 ft³) $f_3 = 35.5Hz$ Ripple = 0dB	$V_B = 57$ liters (2 ft³) $f_3 = 39.4Hz$ Ripple ≅ 1dB	$V_B = 205$ liters (7.25 ft³) $f_3 = 24.1Hz$ Ripple ≅ 0dB

shows $Q_{TC}=0.707$ and 1.0 closed box alignments and a B_4 passive radiator alignment. The outside dimensions of the Speakerlab enclosure are 18" x 18⅛", yielding an approximate volume of 2.6 ft³. Since this is quite different from the 7.25 ft³ I've calculated, I am a little confused. Is Speakerlab deliberately designing in a ripple in the frequency response for a certain sound character, or are they simply designing the box for a certain size requirement? Or am I missing some point entirely?

You can see that many enclosures are possible, but for high Q_{TS} drivers, few are of any practical value: they are just too large. On the other hand, only the large boxes yield a reasonably flat frequency response and the associated well-damped transient response. Even when you get a good subwoofer built, the problem of a suitable 100Hz crossover remains. An active crossover and second power amplifier are expensive, but passive crossovers use large capacitors and inductors (which would raise the driver Q_{TS} above its already too high value), and then you are left with the problem of how to match subwoofer and satellite sensitivities without using passive resistor attenuators that raise the Q_{TS} (and degrade the transient response) of the woofers. I would be interested in suggestions and comments from anyone who has encountered these problems.

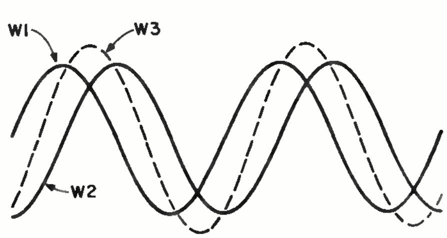
Max Knittel
Dept. of Physics/Astronomy
Western Washington University
Bellingham, WA 98225

BAFFLING TRANS

Your article on transmission line speakers (*SB* 1/82) is fraught with technical errors. First, the author states, "Bass reflex enclosures are...resonant enclosures...incapable of delivering flat, natural bass, free of peaks and other colorations around the region where bass reinforcement from the port takes place." This statement is demonstrably false. As Thiele, Small and Bullock have shown, the driver and enclosure parameters in a bass reflex design can be manipulated so as to produce a smooth frequency rolloff with no passband ripple. This fact has been proven mathematically and empirically. Mr. Galo seems to indicate that the reason bass reflex enclosures cannot be flat is that they are resonant. This assertion of course is not true and shows no understanding of filter theory. At this point in the development of woofer enclosure design, bass reflex, acoustic suspension, and transmission line loudspeakers can *all* be designed to have smooth rolloff characteristics with no passband ripple.

The author's explanation of the labyrinth enclosure's operation is largely incorrect. He states that the pipe length of ¼ wavelength at the woofer's resonance was chosen "to dampen excessive woofer output at resonance" but later states that this design "provides no adequate means of controlling the woofer's excessive cone motion at resonance." He does not explain this contradiction. Secondly, he states that "at ¼λ, the pipe's output is...90° out of phase...and we have partial cancellation of the output from the front of the woofer." The algebraic sum of two waves 90° (or 270°) out of phase is not partial cancellation, but rather a partial reinforcement, as my *Fig. 1* clearly shows.

FIG. 1



W3 = W1 − W2

FIGURE 1. Algebraically, the sum of two waves (W_1 + W_2) 90° out of phase is W_3.

He completely misunderstands the reason for selecting the length of the labyrinth pipe. What is missing from his explanation is that a pipe is a resonant system. A pipe with one end closed resonates at a frequency whose wavelength is four times the length of the pipe. Thus you cannot simply look at the phase relationship in a pipe as a nonreflective transmission line, as the author has done in his *Fig. 2*, because the resonant nature of the pipe will cause phase shifts.

More importantly, the recognition of a pipe as a tuned system gives the real

SB Mailbox

reason why the length of the pipe should be ¼λ at the driver's resonance. At resonance, the pipe has a pressure node at the closed (in this case, the speaker) end. Thus it dramatically increases loading on the woofer cone at its resonance and serves to reduce its motion drastically, contrary to what Mr. Galo states. Note that this action is directly comparable to the effect of the cabinet enclosure resonance of a bass reflex enclosure. And, much as in a bass reflex design, the woofer cone becomes progressively more unloaded with frequencies that fall below it and the pipe's resonance.

In discussing a modern transmission line enclosure, the author states that it "bears a superficial resemblance to the acoustic labyrinth, but they are quite different in operation." Nevertheless he states that the pipe or line should still be "¼λ on the driver's resonance"and, later, "If this frequency makes the line impractically long, you can use ¼λ of a...higher...frequency." However, he offers no explanation for the selection of the line length. My previous description of why a labyrinth enclosure uses a ¼λ pipe gives at least a plausible reason: Although the line is very lossy, it still has a resonance (albeit a self-damped one), and tuning it to ¼λ at the woofer's resonance helps control cone motion by increasing woofer loading at its resonant frequency.

That a transmission line does a better job of controlling cone motion at resonance than a labyrinth is assumed implicitly. This is not so. By reducing the Q of the pipe, woofer loading at resonance would be reduced and therefore cone motion would increase. A true statement might be that a transmission line speaker does an adequate job of controlling cone motion at resonance.

Mr. Galo says that acoustic suspension designs sound boxy due to cabinet reflections. I note that transmission line enclosures can suffer from reflections also. All transmission line designs I have seen have a small area behind the woofer free from stuffing material. Typical linear dimensions of this space often seem to be in the 1-1½ foot range, which would have resonances in the 370-560Hz range.

The author states several other design guidelines for which he gives *no* explanation: "The line's cross-sectional area should be greater than the woofer cone's rear area;" "You may taper the line to conserve space...;" Drivers with "foam surrounds are not as good" as those with butyl or PVC; "Install 45° angle pieces at corners near the woofer; they are unnecessary in the last half of the line."

Transmission line enclosures may indeed have some advantages over box designs:

1) Internal cabinet reflections in the transmission line enclosure would be higher in frequency than in most others because the unstuffed part of the enclosure is smaller.

2) Panel resonances are reduced due to the bracing effect of all the internal baffles.

3) Woofer excursion is controlled below resonance by the lossy line.

4) Matching between cabinet and woofer is probably far less critical than in box type (especially reflex) cabinets because of the lossy, low Q nature of the transmission line.

Roy Mallory
Bedford, MA 01730

Mr. Galo replies:

First of all, my comments on "conventional" bass reflex enclosures, regarding their frequency response, were intended to apply to conventional *bass reflex enclosures only. Prior to the work of Thiele and Small, bass reflex enclosures were characterized by the problems I mentioned. Thiele and Small-aligned "Vented Loudspeakers" are not normally referred to as Bass Reflex loudspeakers these days, probably to avoid confusion between these modern designs and their less refined predecessors.*

I agree with Mr. Mallory's assertion that vented, acoustic suspension, and transmission line loudspeakers can all be designed to have flat frequency response, given today's state of loudspeaker technology. Beyond the frequency response issue, however, I find the low frequency reproduction of Transmission Line speakers to be far more natural (using unamplified live music as a reference) than the other types. Frequency response is but one characteristic of loudspeaker performance. Other coloration problems are more difficult to identify with conventional measurements. As Jung, White and others have shown, the characteristic sound of various preamps and amplifiers cannot be identified by specifications alone (not because measurements are invalid, but because we do not, as yet, have enough measurements to explain every difference that we hear).

The situation regarding loudspeaker measurements is far worse than for preamps and amplifiers. Beyond purely linear measurements (frequency response, phase response), measurements tell us virtually nothing about how a loudspeaker will sound. If all loudspeaker designers used *identical distortion measurements, we would be much farther ahead in this regard.*

Regarding the operation of acoustic labyrinths, I can see how Fig. 2 and its explanation could be misinterpreted. At full wavelength the output of the labyrinth is 180° out of phase with the woofer front radiation, causing total cancellation. At ½ wavelength the output is in phase causing complete reinforcement. A quarter wavelength labyrinth produces a condition which is midway between these two extremes, which we can call partial reinforcement (or partial cancellation, as I did). Mr. Mallory's graph is, of course, correct, as I am fully aware, but my purpose was to compare the effect of the ¼ wavelength size with the other two conditions. I can see how this could have been misinterpreted, and perhaps I should have reworded this in the above manner.

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.

Woofers used in labyrinths (and all other enclosures) during the Stromberg Carlson days had relatively stiff suspensions (ie low compliance). The stiff suspensions resulted in higher resonant frequencies (for a given diameter) and shorter cone excursions at resonance. The pressure node which occurs at resonance in a ¼ wavelength pipe closed at one end was sufficient to dampen the excessive motion of the low compliance woofers used at the time. However, this is not sufficient when using modern, high compliance woofers with very low resonant frequencies. The Audax, Philips, KEF and Dalesford woofers which are popular in transmission line speakers these days would be unsuitable in acoustic labyrinths, due to insufficient control. This is one of the reasons Bailey's original advance over previous designs is so important.

SB Mailbox

The impedance characteristic of a ¼ wavelength pipe closed at one end is the one factor which has been extremely well documented, and I felt it was not necessary to repeat this. Readers should refer to Cohen's Hi-Fi Loudspeakers and Enclosures *for additional information on labyrinths.*

Mr. Mallory questions several of the statements I made. I did not invent these statements. They are based on the previous research in TL loudspeaker design and my objective was to synthesize the information found in the literature. The remainder of my bibliography appears at the end of Part II, and contains the sources I used during the course of my research on TL design.

1) Using long fiber wool as the damping material, at the density described by Bailey, ¼ wavelength is the shortest length which will still absorb nearly all of the woofer's rear radiation. If the line is made shorter, it will transmit more sound through the line at very low frequencies, and will probably show some labyrinth-like characteristics. The ¼ wavelength rationale is discussed in Webb's TL article which appeared in TAA, *1/75. This article, and those by Bailey, are by far the best sources I have encountered on the subject. Certain commercial TL speakers use ⅛ wavelength lines (ie IMF). These do not use long fiber wool as the primary damping material, however, and their operation has never been fully explained in IMF's literature.*

2) Contrary to Mr. Mallory's findings, most TL speakers I have encountered (using long fiber wool as the damping material) fill the line right up to the back of the woofer. For example, Bailey's original 1965 design; The Webb TL speaker; The Rogers Cambridge and Pro-9 monitor (sold in kit form a few years back by Sonikit); Jastak's TL speakers (see TAA *2/78), and finally Roger Sanders TL subwoofer (SB 4/80).*

3) If the line's cross sectional area is smaller than the woofer cone area, particularly in the section of the line closest to the woofer, internal pressure will occur at low frequencies. This is consistent with previous research on TL design. Some designers have tapered the line to conserve space, or to reduce the possibility of internal reflections. I still recommend maintaining the cross sectional area of the line at least as great as the woofer cone area at the line exit. How reducing the area in the last half of the line affects internal pressure is open to investigation.

4) Butyl rubber and PVC surrounds are more linear at the extremes of woofer excursion than foam or cloth-roll surrounds. This, however, is usually at the expense of *maximum power handling capacity. The best of the previous TL designs by Webb, IMF, Dave Berriman (*Practical HI-FI *and* Audio, *Dec. 1975), Sanders, Rogers and Bailey all use rubber or PVC surrounds. The woofers found in most of these systems are KEF B-139's or Audax's.*

5) The 45° angle pieces at the bends in the line reduce reflections due to sharp angles in the line. This is consistent, again, with the best of the previous designs mentioned above. The amount of acoustic activity in the last half of the line is greatly reduced, and the angle pieces are not needed there.

6) The internal bracing reduces panel resonances. They are also less of a problem than in closed box loudspeakers due to the absence of large amounts of internal pressure.

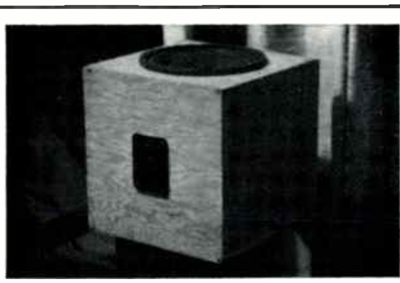
7) Contrary to what Mr. Mallory says, woofer cone motion at infrasonic frequencies is not as well controlled in a TL speaker, as it is in conventional loudspeakers, a fact cited frequently in the literature. This has been one of the major criticisms of TL speakers in the past, but an infrasonic filter in your preamp solves the problem. I mention this in Part II.

8) Yes, matching between the woofer and the TL enclosure is less critical than in box type loudspeakers. Radical departures from the guidelines given will give less predictable results, however.

In conclusion, I would be the first to agree that more research is needed regarding Transmission Line design. My objective was to collect the previous material on the subject and present it in a concise fashion for the reader.

NEW READER

Digging through my old hi-fi junk, I found your ad. I couldn't refuse. What is ten dollars, to the savings of building your own speakers? I built a pair of speakers for $90, and they are *much* better, (A/B comparison) than the Allison 6.



I made mine before Allison made theirs. I just wish I had finished them properly. Maybe you can help. For your records, here is a picture.

Dan Kasha
No. Haven, CT 06518

Crossover Networks

Continued from page 16

cludes the phase and amplitude distortions of the drivers. Robert Bullock's interesting work on the sensitivity of conventional crossover networks to the imperfections of drivers inspired me to examine phase coherent filters for the same phenomena.

The computer model for two different tweeters and two different woofers shown in *Fig. 13* is consistent with our previous analysis of the mass controlled piston. One case allows for a one octave margin between the drivers' rolloffs and the crossover point (500Hz for the tweeter, 2000Hz for the woofer, and 1000Hz crossover), and the second case allows for a two octave margin. The actual acoustical output is the sum of the crossover and driver characteristics. I tried various combinations in the computer model and found (*Fig. 14*) that severe amplitude and phase distortion occur in all cases.

Does this mean that phase coherent crossovers are useless? Not necessarily. Examples of these filters have been known to work well, particularly with planar drivers, which are not precisely modeled as pistons, and do not exhibit the severe amplitude anomalies we might expect. However, note that while the filter may be advertised honestly as phase coherent this does not guarantee the system will be also, and I recommend carefully auditioning such a crossover with the intended loudspeaker. The point is to make the final acoustical response phase linear. The crossovers must be designed to compensate for the drivers' performance if the final output is to be flat.

Much remains to be done in this area. The simulations can be performed using some of the excellent linear circuit analysis programs commercially available for the Apple, Hewlett-Packard, and other microcomputers, and I would be interested in any results readers may obtain. □

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READER'S CHOICE

In these inflation fighting days we look for ways to keep our operating costs down. One means is finding other sources of income from our operations which reduce overhead and keep the inevitable price increases in subscription rates to a minimum. We are approached from time to time by various firms asking if we would make your name available for direct mail promotions of their products. For many years we have refused all such requests, knowing that many of you would prefer that we do so.

Recently we have had letters, quite unsolicited, from several readers suggesting that if we wished to make their names available to those vendors whom we believe might be of some interest to them, they would have no objection to rental of our list for such purposes.

We have decided to change our policy about mailing list rental and will consider such proposals in the future. We will restrict rentals to reputable firms whose products might be of interest to you. We also exercise strict control on any unauthorized use of our lists through secondary sales of the information to other users.

If you feel strongly that you do not wish your name to be included in such rentals we are able to lock your name and address record out of rental use availability on our computer. All you need to do is drop a postcard to us at *SB, Circulation Dept., P.O. Box 494, Peterborough, NH 03458-0494*. Thanks.

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CLUBS

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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.

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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.

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Issue #5 is now available. It contains reviews of the ACM Linn platter assembly, the CARI-A-LIGN alignment protractor, the JMAS moving-coil cartridge, LAST record treatment, the ACM, LEVINSON "Silver", and MENDOTA interconnecting cables, the MAGNEPAN Unitrac I pickup arm, the MARCOF PPA-1 headamp, the ORSONIC DS-250 disc stabilizer, the SUMO "Nine" power amp, and the WIN LABS SDC-10 turntable. Issue #5 also features a survey of 9 turntable mats, and another survey of 19 speaker cables.

Subscription rates to AUDIO HORIZONS for four (4) issues are: U.S.A.-$20 (FIRST CLASS MAIL); Canada and Mexico-$22 (FIRST CLASS MAIL); and outside North America-$26 (AIR MAIL). PLEASE REMIT IN U.S. FUNDS ONLY. Sample copies of all issues are available for $6.00 each (U.S.A., Canada, and Mexico), and $7.50 each (outside North America).

Classified Advertising

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.

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Mayware Formula IV Mk. II tonearm, modified (Gloeckler, *TAA* 2/1978). Excellent condition; includes all original instructions and hardware. $75.00 including UPS. Gary Galo, 49 Pierrepont Ave., #4, Potsdam, NY 13676. (315) 265-4268.

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Dynaco ST-400 power amplifier with meters, mint condition, asking $390. Jim Sofranko, 251 W. Dekalb, A-816, King of Prussia, PA 19406. (215) 337-3862.

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All new, includes shipping double boxed insured. (3) later model Philips AD210/SQ8 2″ domes, $14/ea.; (1) Philips AD5060/W8 5″ mid-bass, $11; (3) Philips AD8067/W8 8″ woofers, $11/ea.; (1) Philips AD12650/W8 12″ woofer, $24; (3) Audax HD17B25J 6½″ mid-bass $12/ea.; (1) Audax HD20B25J 8″ woofer $20; (2) Jordan 50mm enclosures, circular, houses a pair per enclosure—perfect condition, $12/ea.; (16) computer grade 7,300mFd 150VDC near new $4.50/ea. D. Jensen, PO Box 448, Weimar, CA 95736. (916) 637-4054.

Bozak speakers, 2 prs. B-4000 (Symphony I) classics with bi-amp networks & factory upgraded tweeters, $650; B-302A (Concerto) Colonials with custom glass tops, $350; good condition, fine furniture, big sound. Or make offer. John C. Farris, 15913 Moncure Dr., Dumfries, VA 22026. (703) 670-2427 (or daytime Sun.-Thurs. (202) 755-2486.)

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People interested in computer programming for loudspeaker design. Let's share software and ideas. I have some software written in ApPleSoft. What ya' got? Bob White, 13919 Ludgate Pass, Houston, TX 77034. (713) 484-1781.

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Would like to correspond with anyone building electrostatic or Magnepan speakers. V.R. Parker, 463 Chase Rd., Lunenburg, MA 01462.

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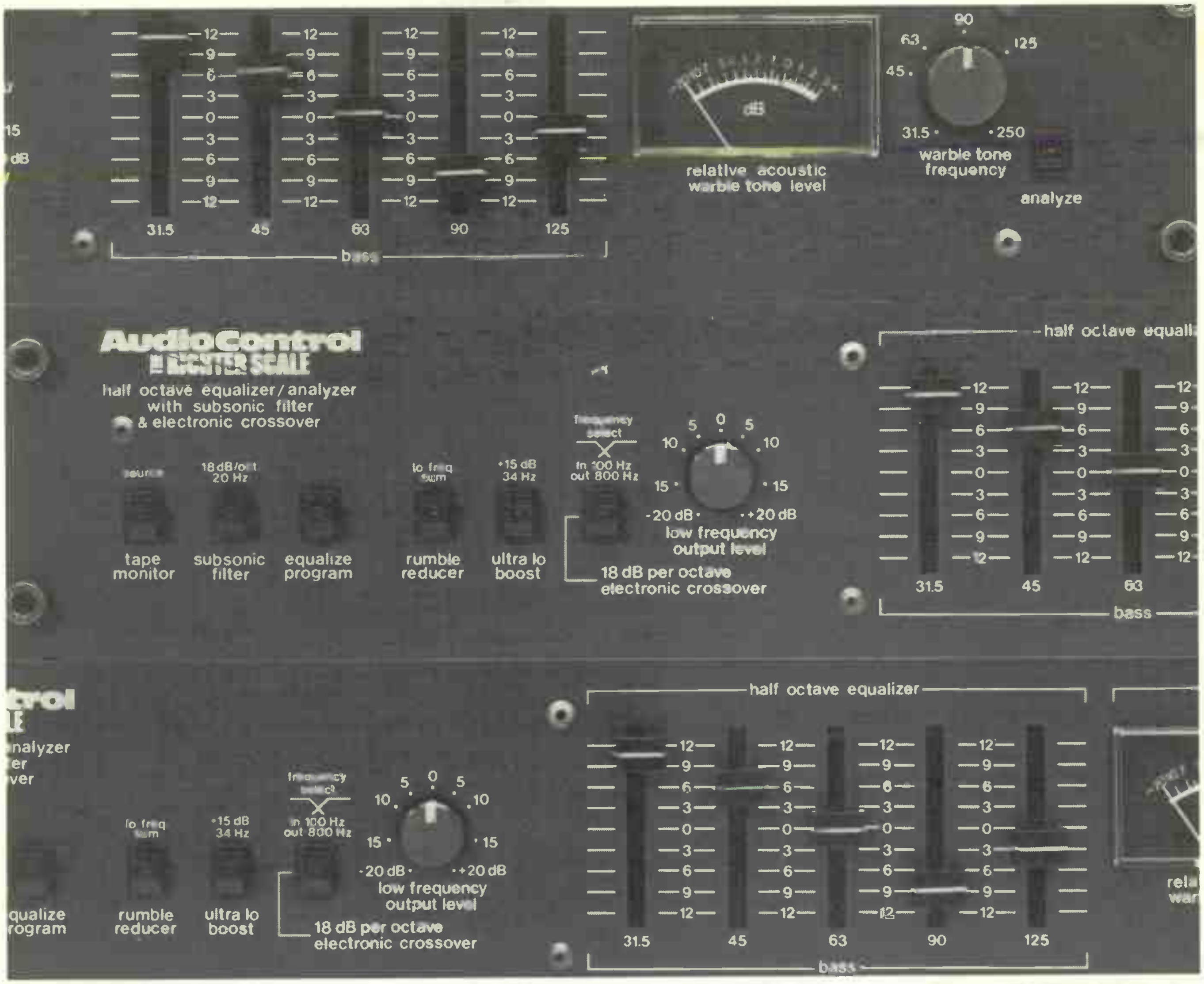

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