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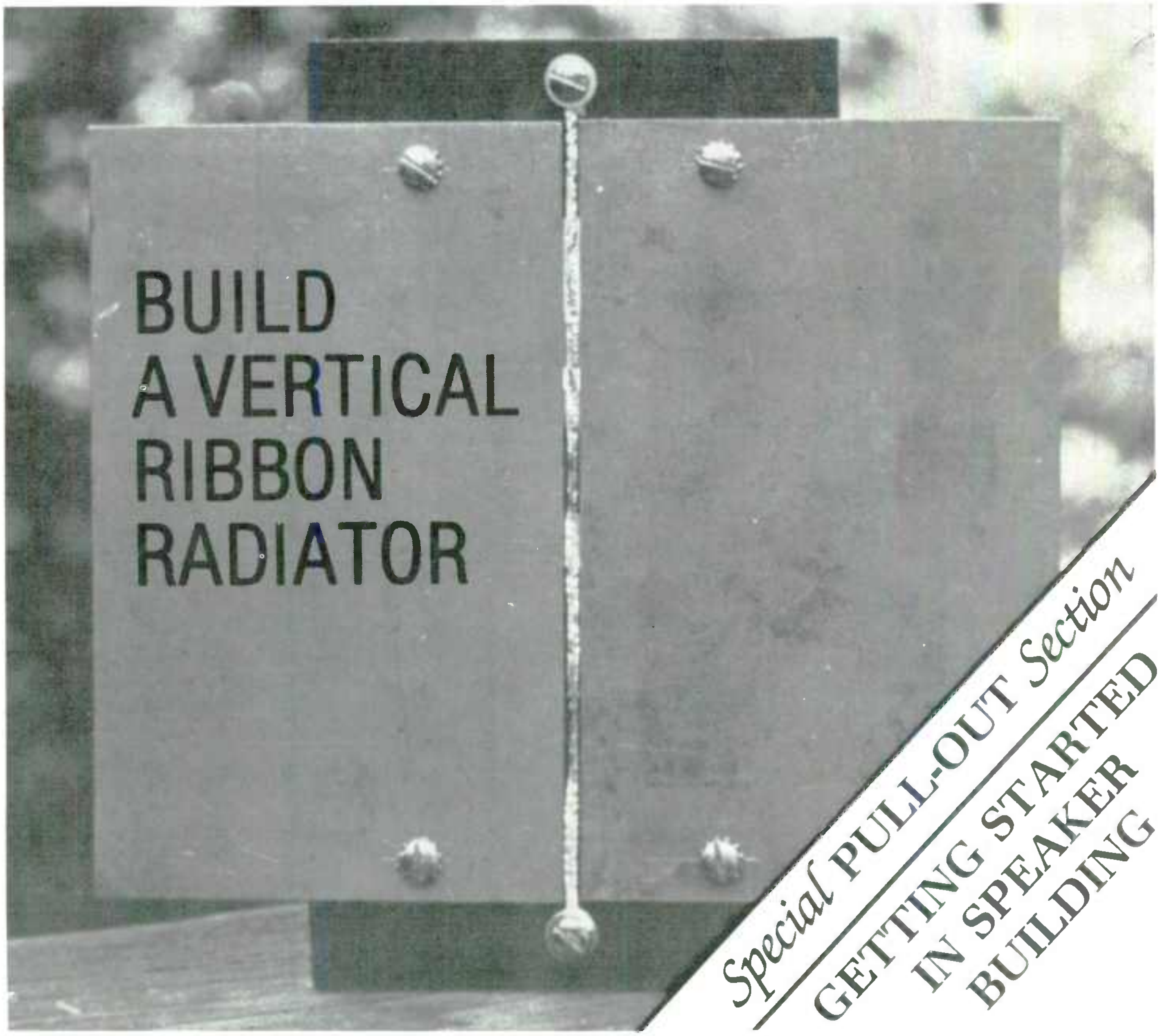
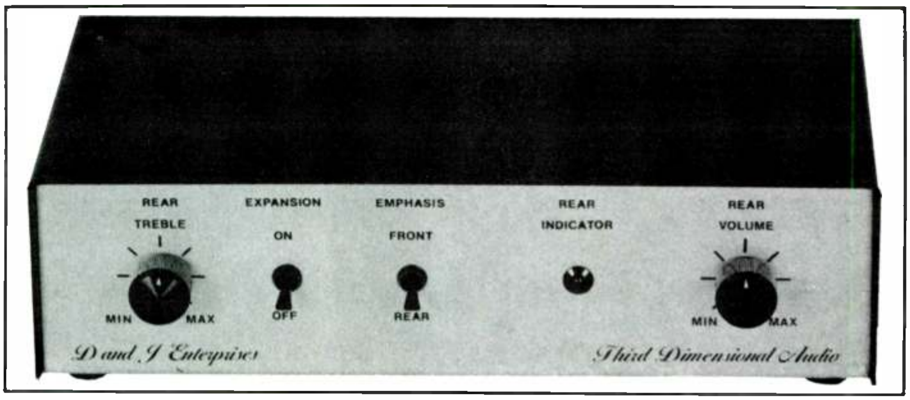


BUILD A VERTICAL RIBBON RADIATOR

Special PULL-OUT *Section*

GETTING STARTED IN SPEAKER BUILDING

Good News



D & J ENTERPRISES has recently begun production of a new product to enhance home viewing and listening enjoyment of motion pictures made with stereophonic sound. The Third Dimensional Audio unit uses unique circuitry to reproduce the special-effects audio channel heard from the rear of movie theaters. This audio channel is already embedded in the stereo sound tracks of most motion pictures. The expansion circuitry provides excellent front-to-rear acoustic isolation and further enhances the performance of the rear channel.

To connect the Third Dimensional Audio unit, just place it between the final amplifier output and the speakers. No other connections are necessary. You can use your present stereo system plus one or two additional rear speakers. You do not need any other special-purpose equipment or an extra amplifier. The unit works with any videocassette recorder (VCR), videodisk, cable or satellite source that delivers motion pictures in stereophonic sound.

A prerecorded VHS-format videocassette comes with each unit to verify proper setup operation. It contains reference tones in the center-front, rear, left and right channels. A video picture describes the direction and relative loudness of each tone. If a VHS videocassette recorder with stereo capability is not available, you can use an alternate setup procedure.

The brushed aluminum front panel with black trim and black aluminum cover is designed to complement video equipment, and the entire unit is designed for durability.

Contact D & J Enterprises, 19 Sandia Heights Dr. NE, Albuquerque, NM 87122.

Fast Reply #CG782

PYLE INDUSTRIES, manufacturer of Pyle Driver® speakers, has announced two new high-compliance car stereo woofers in 10-inch and 6-by-9-inch configurations. These woofers complement the smaller woofers currently in the Pyle Driver line.

In general, high-compliance woofers have a very low resonance and are specifically designed for efficient operation in small, sealed enclosures. These woofers were designed using Thiele-Small parameters to refine their performance.

The 6-by-9-inch woofer, model number W69C200-F4S, was designed for use in a 0.25-cubic-foot sealed enclosure. It is rated at 65W RMS with a 25 to 1,500Hz response. The 10-inch woofer, model number W10C200-F4S, was designed for use in a 1-cubic-foot sealed enclosure. It is rated at 75W RMS with a 20 to 1,000Hz response. Both feature a high-temperature, 1½-inch, four-layer voice coil and are available from Pyle Industries, PO Box 620, Huntington, IN 46750.

Fast Reply #CG128

ACOUSTIC RESEARCH has recently introduced the AR30B, the newest addition to its two-way bookshelf loudspeaker line. The 30B includes the company's 10-inch woofer design and newly developed 1-inch liquid-cooled dome tweeter. It is housed in a walnut vinyl veneer cabinet. The AR30B is the fourth speaker in the series from Teledyne Acoustic Research, 10 American Drive, Norwood, MA 02062.

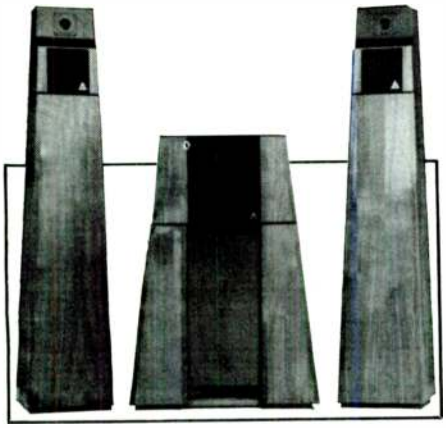
Fast Reply #CG324

AUDIO-TECHNICA has announced the third and most compact member of its Design Acoustics Point Source loudspeaker series, the PS-6. The new system achieves pinpoint stereo imaging by reducing diffraction with a small front baffle area.

Measuring only 8⅛ by 12 by 11½ inches, the system delivers smooth, clean sound over a 50Hz to 20kHz frequency range with a sensitivity of 88dB at 1W at 1 meter. It is designed for use with amplifiers ranging from 10 to 100W per channel. The driver complement of the PS-6 includes a 6-inch long-throw woofer. The other driver is a ¾-inch soft-dome tweeter, which handles all frequencies above the 3kHz crossover point. The system's nominal impedance is 8 ohms. Additional features include push terminals to accept virtually any thickness of speaker cable.

For details, contact Audio-Technica, 1221 Commerce Drive, Stow, OH 44224.

Fast Reply #CG22



The Triad 70 three-piece speaker system combines high-quality sound reproduction with realistic imaging, small size, handsome styling and moderate price. Its small, two-way, phase-aligned satellites provide excellent imaging. The midrange has a 3½-inch treated paper cone, while the ¾-inch Mylar dome tweeter is ferro-fluid cooled. The compact woofer operates effectively below its resonance point, yielding accurate low-frequency response down to 24Hz. The woofer measures 8½ by 8 by 13 inches and weighs only 14 pounds. A 70W bass amplifier powers the woofer, whose 6½-inch polypropylene cone has a single voice coil. The cabinet comes in walnut or oak wood veneer. Wood or metal stands are also available.

Write to **ACOUSTIC DESIGN GROUP**, PO Box G3, Aspen, CO 81612.

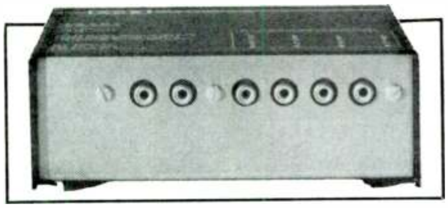
Fast Reply #CG261

The Ace 6000-SF electronic crossover is designed for biamping and features a 12dB/octave slope, with low-distortion active filter circuitry. Crossover points are available at any frequency from 200Hz to 18kHz. The crossover frequency is controlled by precision metal film resistors and polystyrene capacitors, and you can easily change the crossover frequency with a plug-in module. Distortion is in the 0.002 percent region at a 2V output level.

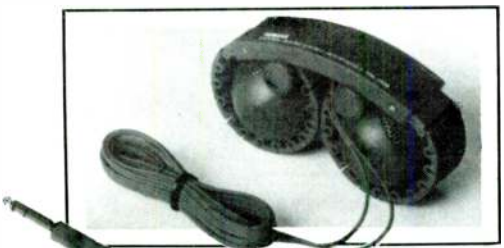
The 6000-SF incorporates a new Bessel infrasonic filter circuit, which removes infrasonic "garbage" below 15Hz at 18dB/octave. This effectively removes subsonic disturbances, which can interfere with good sound reproduction. It also eliminates ringing on pulse-type signals typically found in music programs. Options include a mono woofer output and level controls on either the woofer or tweeter outputs.

Contact **ACE AUDIO CO.**, 532 5th Street, E. Northport, NY 11731.

Fast Reply #CG11

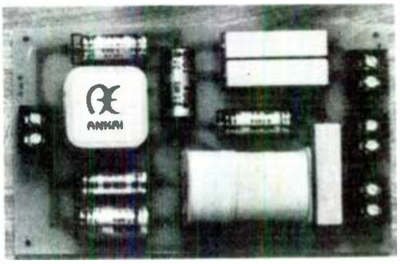


Who says headphones have to be dull? Not **YAMAHA ELECTRONICS**. The company has introduced the YHL-006 and the YHL-003, styled by the Porsche Design group with the idea of combining excellent sound, high fashion and human engineering. These lightweight headphones curl up into a palm-sized package for easy portability. Uncurled, they wrap comfortably around your head and fit snugly on your ears.



The YHL-006 comes with a vinyl carrying pouch, while the YHL-003 utilizes a wider-range diaphragm for extended frequency response and comes with a leather carrying pouch. Both have mini-plugs for portable use and phone-plug adapters for home listening. Contact Yamaha Electronics, 6660 Orangethorpe Ave., Buena Park, CA 90620.

Fast Reply #CG406



SPEAKER BUILDER
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About This Issue

Mike Lampton and **Henry Primbsch** lead off our third 1984 issue with almost all you need to know about building a ribbon tweeter (p. 7). I say "almost" because although Mike and Henry did all the homework and built a working prototype, Mike used a commercially available unit in his speaker system (*SB* 3/83, p. 7). The research and experience gained in the exercise are invaluable, however, and should enlighten and inspire many.

G.R. Koonce introduces part four of his instrumentation series (p. 16), which describes a dual impedance-measuring device that simultaneously reads the size of the driver's impedance and its phase angle.

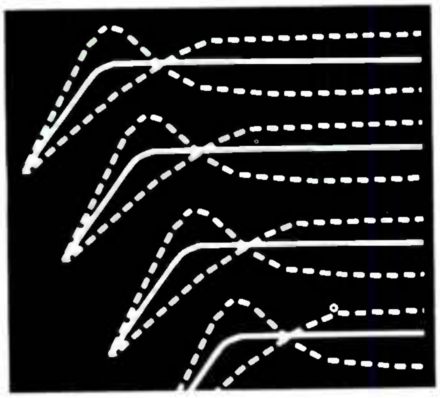
The concluding section of **Bruce Edgar's** interview with Ted Jordan begins on page 26, while readers **Meraner, Kaufman, Ball** and **Cabaniss** offer some useful "Tips" beginning on page 32.

David Davenport reports on his assembly and listening experience with the Audio Concepts Model C kit (p. 34), and **Claude Manning** steps through his "Showcase" adventure building a mini-monitor system from the same vendor and adding a subwoofer to it (p. 36).

We are also including a special pull-out section (between pages 24 and 25) for current subscribers only. It includes a reprint of **David Baldwin's** fine article on building your first speaker system, which originally appeared in *SB* 3/82. **William R. Hoffman's** "Loudspeakers from A to Z" is a step-by-step review of loudspeaker basics. Many of you are obviously well beyond this stage, but if you have a less-sophisticated friend who might be interested in this avocation, pull out your supplement and give it to him or her. We will be glad to supply extra copies.

SPEAKER BUILDER

VOLUME 5 NUMBER 3 AUGUST 1984



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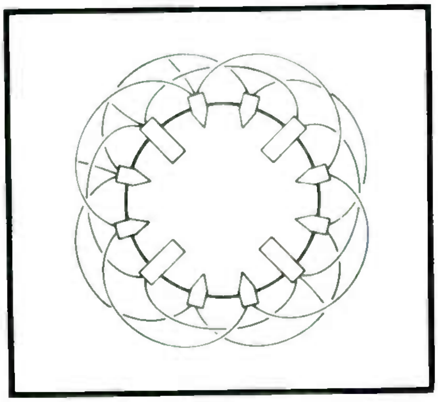

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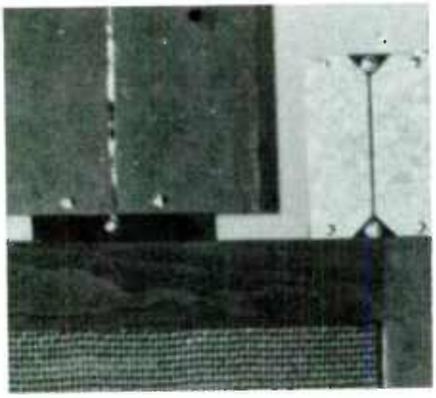


9

Special Pull-Out Section

FEATURES

DEPARTMENTS

Editorial

Speaker Building's Other Pleasure

A new loudspeaker in prospect is always a pleasure. The exploration of the new possibilities and the triple adventure of building the enclosure combine with the satisfaction of seeing it come together and the penultimate pleasure of the finished units being carefully put into place in the listening room.

Finally, you experience the heart-stopping delight of discovering what new treasures have been hidden all this time in recordings you might have owned for years. The new system lures you into a ceaseless frenzy of listening with anticipation to old favorite after old favorite just to catch heretofore hidden intricacies, explicitness, definition.

You know what I'm talking about if you have built one pair of speakers. The pleasure of executing a well-thought-out design becomes a kind of travail as the building process wears on. The long, patient work required for precise, accurate execution is tiresome toward the end, and as completion approaches, you fight the impatience to be done with it all. But completion day does come, and with it comes the double reward of this avocation – the pleasure of the maker and of the music listener.

There is a third pleasure I hope all of you will add for yourselves. Plan beforehand to share your experience with your fellow speaker builders. Make notes as you go. Pause, however hard it may be to do so, to write down your problems, your procedures and your surprises. Load your camera with black-and-white film and buy a couple of photofloods to put plenty of light on a crucial step in the building process. Keep good records. Make notes about supplies and suppliers. List your materials. Make scaled cutting guides on graph paper.

Write down the better ways of doing things that come clear only after you have done it the awkward or wrong way. Mistakes related help everyone else. Pull it all together in a first rough draft as a letter to a friend who wants to do the same project. Let it sit for a week or so, then revise, revise and revise, each time from a different viewpoint – style, grammar, spelling, paragraphing, order.

But most important of all – get it onto your pad and into your camera so you can share it with other *Speaker Builder* subscribers. Doing so can only add to the pleasure you derive from this extraordinarily rewarding hobby. – E.T.D.

Basic Maintenance

Ears remain our preeminent test instruments for audio quality. Setting aside the issue of subjective bias, the human ear is our most sensitive and valuable means of evaluating reproduced sound. The experienced listener who reflects often on listening events – of live and reproduced sound – can often build a basis for discriminative judgment, which allows him or her to decide whether or not a system is improved by adding a new loudspeaker, changing crossover topologies, substituting new drivers or switching from passive to active crossovers.

Most of us would probably agree with the above propositions without too much argument. We would also doubtless agree that a valuable instrument is no better than its level of maintenance. I was rudely reminded of this truism recently during a routine checkup in my family doctor's office. You know the usual features of those encounters. The mirrored light for examining your eyes – looking into the cornea, watching as you look to the left, up, to the right and then down. Next comes that smaller cone-shaped gadget for peering up your nose and then into your ears.

Imagine my surprise when my doctor began to dig, tentatively at first and then with more vigor. Fifteen minutes later, I had a sore ear, and the doctor had removed an astonishing quantity of wax from my left outer ear canal. Seeing my chagrin, he assured me that ears can normally produce widely varying amounts of wax over time and what he had removed could be normal for even as little as six months. The only sensible ear care, therefore, involves periodic checks, preferably by a relative or a friend.

If you haven't a doctor to clean a nearly blocked ear canal, do *not* tackle the job yourself – particularly do not do so with metal or other rigid implements of any kind. You should not ask your friend or relative to operate with improvised tools either. Eardrums are irreplaceable. Fortunately, quite effective ear-cleaning products have recently appeared on the market. Your druggist has them, and they will clean your ear passages safely and thoroughly.

Good ear maintenance is an obvious prerequisite for lovers of good sound, but how many of us bother to think about it? There's no better time than now to begin systematic care of two of your most valuable input transducers. – E.T.D.

SIMPLE RIBBON TWEETERS

BY MICHAEL LAMPTON and J. HENRY PRIMBSCH

Editor's Note: Mike Lampton and Henry Primbsch began this project with high hopes of building a ribbon tweeter for Mr. Lampton's three-way system (SB 4/82, p. 7). With most of the preliminary work completed, they discovered SRC's 1980 announcement of the JVC ribbon (Model HSW1101-01A) and decided that most speaker builders would prefer to spend $25 to $35 for the unit than to construct one themselves. Still, we felt that the background information on the design of such a unit would be helpful to our readers. Here is a description of their preliminary work.

Perhaps the simplest kind of tweeter is the vertical ribbon radiator. A ribbon tweeter shares many of the advantages of other high-quality reproducers such as electrostatics because it operates on a direct-drive principle and requires no cone or dome to couple the driving energy to the surrounding air. Compared with an electrostatic, it has the further advantage of a small, flat, resistive electrical input impedance for convenient drive from common power amps, and it has no need for a high-voltage bias supply.

On the other hand, unless the ribbon tweeter is rather tall, it will be inefficient. Readers hoping to lay down a solid 100dB on the disco dance floor had best look elsewhere. A modestly sized ribbon tweeter will have a rather small radiating area and very little output below 2 to 3kHz. Its best use is as a top-end driver crossing over above about 4kHz, where you can take advantage of its extreme transient speed, smooth high-end frequency response and broad horizontal angular coverage.

Before going into details, it is worthwhile to look at the ribbon tweeter in the context of contemporary loudspeaker development trends. During the past few years, audiophiles have seen a proliferation of loudspeaker designs generally directed toward improved transient and spatial performance. These developments have been inspired by the growing realization that older loudspeaker designs, largely evaluated with on-axis, anechoic-chamber sine-wave testing, are inadequate. Often, they do not illuminate the listening area uniformly or exhibit good time-domain performance.

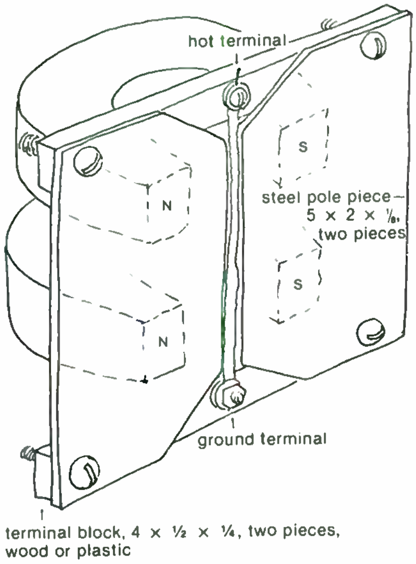


FIGURE 1: Layout of a ribbon tweeter using two alnico magnets.

Both problems usually stem from a common set of design features found in popular cone and dome tweeters. First, the radiating diaphragm is flexible and rather massive. When driven by its voice coil, it stores mechanical energy in the forms of elastic stress and motion. This energy, after a brief propagation time delay, is radiated as sound. Such a delay blurs transient detail. Second, the diaphragm's size and flexural patterns combine to produce a directional radiation pattern, which depends on frequency in a complicated way, leading to a nonuniform and position-dependent frequency-response curve.

One way around both of these problems is to adopt a tweeter design in which the sound radiator is itself the electrodynamically driven element. If this element is mechanically flexible and limp, it will not store mechanical flexural energy. If it is also very light, it will store a minimum of kinetic energy. This is the motive for choosing a ribbon tweeter. First, it eliminates the mechanical "rise time" and "decay time" associated with coupling vibrational energy through a separate radiator dome. Second, it minimizes the directivity-pattern irregularities characteristic of such radiators.

The simple ribbon tweeter is ideally suited for the adventurous home constructor. Its few parts are available from a hardware store, an electronics supply house or your own junk box, if you have done much tinkering. Once built, the tweeter can fit into almost any low-efficiency loudspeaker system to improve its high-end performance and treble detail.

The basic design is shown in *Fig. 1.* Here, one or more permanent horseshoe magnets establish a magnetic field in a narrow gap. A very thin conductive ribbon is suspended in the gap. It is held in place at each end by screws, which enter terminal blocks located at the top and bottom of the gap. In a biamped system, the tweeter is connected to its power amplifier through the terminals. In a single-amp-per-channel reproducing chain, it is connected to the high-pass output of the crossover network at this point.

Although the ribbon tweeter avoids some of the problems of cone and dome tweeters, it introduces a few limitations of its own. First, the small ribbon radiator has a low efficiency of about 0.1 percent, which is roughly one-quarter the efficiency of common small woofers and midranges. This means that it is not suited for high-SPL sound-reinforcement applications. It also means that a reasonably large power amp ought to drive it. In our experiments, we have had excellent results with a 40W-per-channel biamplified rig.

A second limitation, already mentioned, is that its small radiating area gives very little output in the midrange. We have achieved good performance crossing over around 4kHz. Finally, because its ribbon is light and gently suspended, the tweeter is liable to distort if placed too close to the woofer's powerful low-frequency sound field. For example, this tweeter *(Photos 1* and *2)* ought not be mounted in the woofer's baffle board. It seems to work best sitting on top of the enclosure housing its associated woofer and midrange *(Photo 3).*

GENERAL TRANSDUCER. The primary design goal in making a practical ribbon tweeter is to achieve an adequate efficiency. Our ribbon design is a direct radiator—i.e., it has no horn. A horn could be used to boost efficiency (the commercially available Decca ribbon tweeters do this), but horns are hard to build, and they introduce a variety of frequency-response problems and directivity complications.

Any electrodynamically driven direct radiator, be it a woofer, tweeter or whatever, has an efficiency governed by the following approximate expression:

$$E = \frac{0.01\, A^2 B^2 F}{M}$$

where E is the transducer efficiency in percent, A is the radiator's area in square centimeters, B is the magnet field strength in tesla (one tesla is 10,000 gauss), M is the moving mass in grams, and F is the fraction of that moving mass that is the electrical voice-coil conductor. (In deriving this expression, we have made the usual assumptions that the transducer radiates into a 2π steradian half space and that the voice coil is aluminum.)

This formula shows very clearly that small loudspeakers are extremely inefficient unless the total moving mass is very small. For example, a $1 cm^2$ tweeter with a 1g voice coil in a one-tesla field will have an efficiency of only 0.01 percent. Efficient loudspeakers tend to be big: they make use of the area-squared factor in the formula. In our ribbon tweeter, we wanted to avoid the high-frequency directionality that large radiator areas cause. To regain the lost efficiency, we were forced to reduce the total moving mass to a few milligrams. These efforts also turned out to be a tremendous benefit in achieving wideband response.

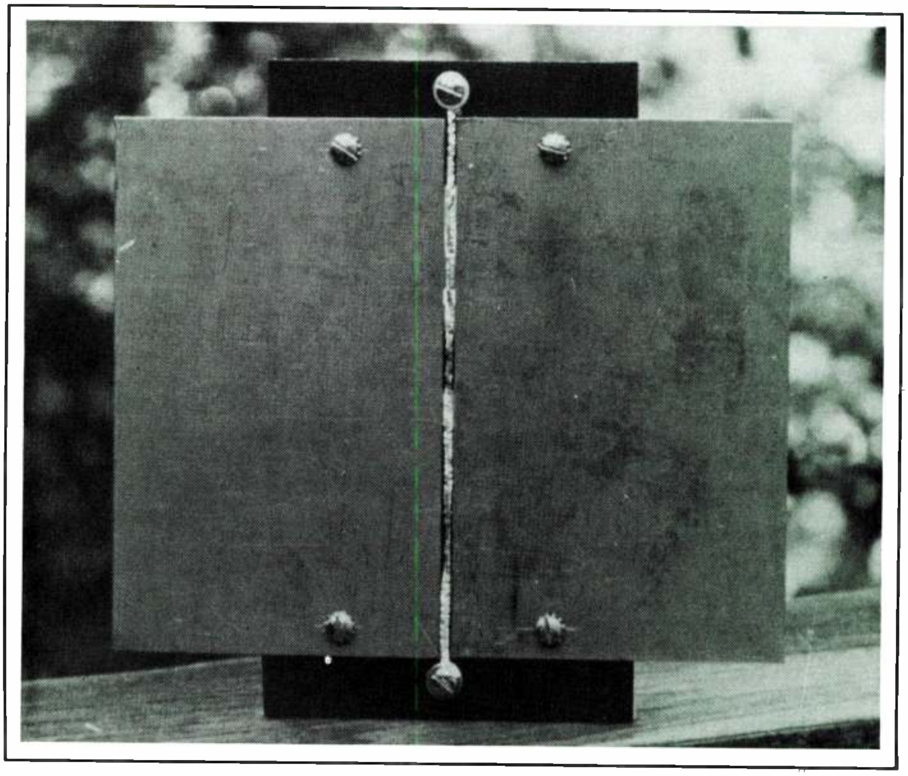


PHOTO 1: Front view of the author's experimental ribbon tweeter.

This formula illustrates another trade-off in coming up with an acceptable design. Suppose, for example, that you use an extremely light ribbon, one that is much less massive than the air in the slot. Because of this light-motor, heavy-load combination, the mass fraction will be very small, and the efficiency will be low. Alternatively, if the ribbon conductor is much more massive than the air load, F will essentially equal one, but the overall efficiency will be low because of the large total mass factor in the denominator. The best efficiency occurs when the conductor mass fraction is about 0.5—i.e., when the conductor's mass is approximately equal to the mass it has to drive.

Note that the air-load masses encountered in designing ribbon radiators are extremely small. A good approximate formula for air mass (in grams) is:

$$\text{air mass} = 0.004\ W^2 h$$

where the slot width (W) and height (h) are expressed in centimeters. For the unit shown in *Fig. 1,* which has a width of 0.25cm and a height of 10cm, air mass is equal to only 2.5 milligrams.

Even with this low mass, the ribbon tweeter efficiency is going to be low for two other reasons. First, although woofers can and do have narrow magnetic gaps in which the flux density is easily made rather large (usually around one tesla), the gap in a ribbon tweeter has to be wide enough to accommodate the radiating width of the ribbon. This wider gap will have a much weaker magnetic field for a reasonable magnet size. Second, the electrical impedance of a few inches of aluminum ribbon is very low. Unless you are willing to make a custom step-down transformer to match the power amp to the ribbon, a series resistor will be necessary. This resistor will cost additional efficiency.

KEY DESIGN FACTORS. The practical question of how to raise the electrical resistance of the tweeter, while keeping the transducer efficiency as high as possible, deserves some discussion. The current sensitivity of a ribbon tweeter is given by the following equation:

$$\frac{P}{i} = 0.053B \times \frac{h}{W + 750T_a + 260T_p}$$

This formula gives the sensitivity, in pascals of sound pressure per ampere, of drive current at a reference listening distance of one meter. B is the magnetic field flux density in the gap, in tesla, while h is the ribbon height in centimeters. The three quantities in the denominator come from the three contributors to the total moving mass: the air load introduces the slot width term (W) in centimeters; the aluminum conductor's mass is included by means of its thickness (T_a) in centimeters; if the conductor is carried on a plastic film, its mass appears in the expression as the film's thickness (T_p) in centimeters.

From this equation, it is clear that the ribbon tweeter sensitivity is improved by increasing the height of the radiator, increasing the flux density in the gap and reducing the width and thickness of the ribbon. Notice that three of these factors—height, width and thickness—raise the electrical ribbon resistance, while boosting efficiency. This indicates that for an effective design, you should strive for the practical limits of all these factors.

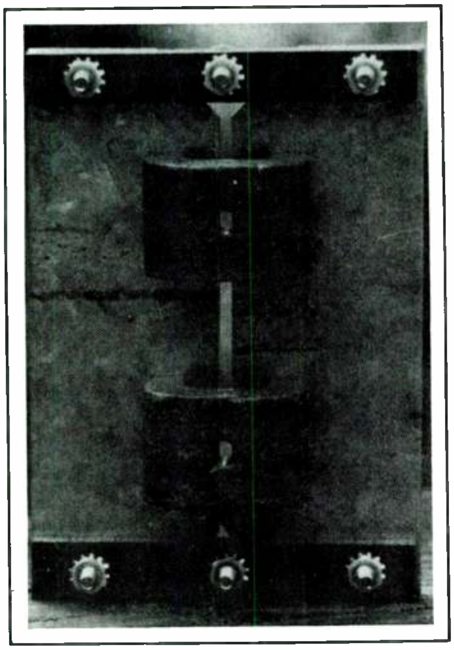


PHOTO 2: View of the back, or magnet, side of the tweeter.

PHOTO 3: The best spot for the experimental tweeter was on top of Mr. Lampton's corner speaker system.

LIGHTWEIGHT MATERIALS. What lightweight ribbon materials are also good conductors? Ordinary aluminum foil has a thickness of about 15 microns (0.6 mils), making it far too heavy (4 milligrams per square centimeter) for efficient tweeter operation. Thinner foils are available, however. For example, some tubular capacitor types are wound with two alternating layers of plastic film and aluminum foil. For compactness, this foil is rather thin (typically around 5 microns, or 1.4 milligrams per square centimeter). Although somewhat fragile, it can be unwound with care. From a Sprague-type 0.5μF, 50V unit, it is possible to recover two pieces of foil measuring about 1cm by 50cm by 5 microns. With a sharp hobby knife, slice the ends off the capacitor, then slit the jacket down the side and unwind the foil.

The only problem with these thin aluminum foils is that they are considerably thicker than is necessary, making them less efficient. For instance, the 5-micron foil has a resistance of around 0.006Ω per square centimeter, so a piece with a length-to-width ratio of 50 has a resistance of only 0.3Ω. We are thus faced with the alternatives discussed earlier in connection with the general transducer problem: either adopt an impedance-matching step-down transformer (but we were trying to avoid complications such as transformers in the first place!), add a 3.7Ω series ballast resistor (and give up a factor of 13 in efficiency) or boost the length-to-width ratio to 1,000.

The third possibility leads to some intriguing tall tweeters, which reach from floor to ceiling. We will discuss these briefly later in the article. For now, let's stick to the goal of making a small ribbon tweeter and recall the one cheap way to boost current sensitivity, while increasing the ribbon resistance: use a thinner conductor.

It is possible to go considerably farther in obtaining a lightweight ribbon material. Certain types of tubular capacitors are wound with two pieces of metallized plastic film. This film, which is the capacitor's dielectric, can be amazingly thin and light. For example, a 50V Mylar cap will have a film thickness of only 2.5 microns (0.1 mil) and weigh only 0.25 milligram per square centimeter. The conductor evaporated onto one side of this film is extremely thin and contributes very little mass. We have measured the resistances of some of these films and have found them to be rather high, in the range of 1 to 100Ω per square centimeter. Hence, ribbons having length-to-width ratios of, say, 50:1 have a resistance of 50 to 5,000Ω end to end. This is too large to be efficiently driven by conventional power amplifiers without some sort of a step-up device.

Another ribbon with which we have experimented is made by sticking a few strands of fine enameled copper wire onto a thin plastic film such as Mylar or polyethylene. We have made ribbons having two and three strands of 44-gauge copper removed from a length of Litz wire. Forty-four-gauge wire measures 0.085Ω per centimeter. (Litz wire is typically 60 strands of #44, but unlike ordinary stranded wire, the strands are enameled.) In our experiments, the base film has been polyethylene dry-cleaning-bag material, which measures 12 microns thick and has about 1 milligram per square centimeter.

To glue down the strands, pull each strand across the tip of a glue stick and then press it against the plastic. By having two or three strands mechanically in parallel, but electrically in series, the overall resistance is 3 or 4Ω, which is very comfortable for the power amp. The fact that the strands are electrically in series helps the efficiency, too, because the same current gets used several times in the gap. It is like having a multiturn voice coil as a ribbon. Two problems with ribbons made in this way are that the glue job does not have much of a heat tolerance, and #44 wire has a rather low fusing current (about 0.1A). These factors make us nervous about the reliability of ribbons made in this way.

We have also examined the possibility of using decorative Christmas tinsel as a ribbon material. It comes conveniently pre-slit to a uniform width of a few millimeters and appears to be shredded metallized plastic film, which could pass for waste material from capacitor manufacturing. The sample we examined was rather massive, about 2 milligrams per square centimeter. This gives it good strength for decorating trees and wreaths, but low efficiency in tweeter service. Its high resistance is the worst problem, however. The 1.5mm-wide strip is metallized on both sides, giving about 500Ω per inch on either side. We did not pursue this idea further.

RIBBON WIDTH & LENGTH. The second and third key factors in making a reasonably efficient ribbon tweeter are ribbon width and length. Although larger widths might at first seem to help the efficiency through increasing the acoustic radiating area, they are actually detrimental because of the quadratic increase of air-load mass with width and because an increased magnetic gap invariably leads to a weaker gap magnetization.

Moreover, wide ribbons become horizontally directional at high frequencies. If you keep the slot narrow, the horizontal dispersion is good out to very high frequencies. For example, a 2.5mm slot has no forward pattern and nulls below 140kHz. Both these factors indicate that you ought to concentrate on reducing the ribbon width to the narrowest practical value consistent with retaining reasonable ruggedness, power dissipation, reliability and ease of assembly. Widths of 2 to 3mm (around one-tenth of an inch) appear practical and are not too difficult to make.

Because the ribbon material is somewhat weak and extremely limp, you cannot cut it with scissors. It is best to immobilize a length of film on a hard surface, beneath a layer of plastic wrap, and to use a heavy steel straightedge to guide the blade of a very sharp hobby knife or razor blade.

The cut edges define the sides of the ribbon, which must be as straight as possible so that you can bring the magnetic gap pole pieces (described below) almost into contact with the edges of the ribbon. The objective is to allow the ribbon to move freely without rubbing against either pole piece, while ensuring that essentially no air can leak past the ribbon. Because the pole pieces in our design are adjustable, it is not important that the ribbon be any particular width or even that the edges be exactly parallel. What matters is the straightness of the two edge cuts. If your knife is a little dull, you will find numerous nicks along the edge of the cut. Avoid these as much as possible, as they will weaken the ribbon and possibly lead to failure in service. One final caveat is that you should not scratch the side of the film bearing the aluminum coating, lest a weak spot or open circuit occur in the conductor. Plan on making plenty of extra ribbons and choose the best-looking ones for use in the tweeter.

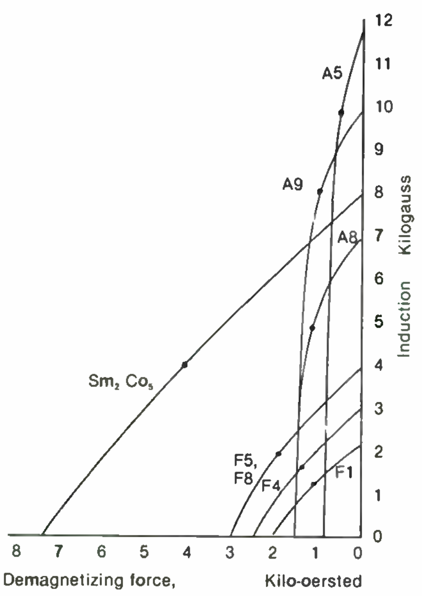


FIGURE 2: Induction versus demagnetizing force for some common permanent magnet materials. A5, A8 and A9 are alnicos 5, 8 and 9. Curves marked F are the ferrites: F1 is Arnox 1, Indox 1, Genox 1, etc. F5 is Edmund 41799. On each curve, a dot marks the best operating point, at which the delivered energy product is maximum.

In our simple design, the radiating area is determined by the width and length of the ribbon. The length controls the tweeter's efficiency, but also has an impact on its vertical radiation pattern. A taller tweeter will be more efficient, but will have a smaller vertical radiation pattern coverage. The compromise we have adopted is a 10cm length, but you might wish to experiment with other lengths. It might also be possible to stack several modules, inclined at different angles to the vertical, to approximate a curved vertical ribbon with an improved vertical coverage angle. We have not tried this.

MAGNETIC STRUCTURE. The fourth key factor in the ribbon tweeter equation is the magnetic flux density (B) in the gap. This field acts directly on the power amplifier's output current to yield the mechanical force driving the gap's acoustic load. The more magnetic flux, the more sensitive the transducer becomes.

How much field strength can we reasonably expect to get? When a permanent magnet is connected to a magnetic load such as our pole piece and gap assembly, you can calculate the resulting field with the help of magnetic circuit theory. Magnetic circuits are closely analogous to electric circuits, with total magnetic flux behaving like current and magnetomotive force (mmf) behaving like voltage. These terms are explained in the accompanying glossary of magnet design concepts (see p. 11). Accordingly, it is appropriate to think of establishing a desired magnetic "potential drop" between the two pole pieces and of asking how much flux the gap draws.

Suppose that you would like a gap field of, say, 3,000 gauss. In the air gap, this is an intensity of 3,000 oersteds. Across a 0.25cm gap, the potential drop would be 750 gilberts. Also, the total flux in a 10cm-high gap and pole piece assembly would be, including fringing corrections, about 50,000 lines. The ratio of these numbers, 0.015, is termed the reluctance of the load and is analogous to an electrical load resistance. Just envision the task of efficiently energizing the magnetic gap as finding an arrangement of permanent magnets that delivers the required flux and mmf at a reasonable cost.

The different types of permanent magnet materials can be contrasted by their differing dependences of flux density (B) with respect to demagnetizing force (H). In *Fig. 2,* we have graphed the B versus H curves for several permanent magnet materials. The most concentrated form of magnetic energy currently available is from the compound samarium cobalt. Its high price, which is now around \$350 per pound, means that you can obtain a lot more magnetic energy per dollar from other materials.

A better choice in terms of energy per dollar would be any of the alnico alloys. These are mixtures of aluminum, nickel and cobalt, which are available in several different formulations. For example, alnico 5 delivers about one-quarter the magnetic energy of samarium cobalt, but costs only \$20 to \$40 per pound at the retail level. On a per-dollar basis, it is about twice as energetic as samarium cobalt.

To develop an mmf of 750 gilberts, an alnico 5 magnet length of at least 1.5cm is needed, since its flux starts to drop off rapidly above 500 oersteds. An alnico 5 magnet can supply the desired 50,000 lines if its cross-sectional area is at least 5cm². This means that the flux density in the magnet would be about 10,000 gauss, which is a reasonable value. You can easily meet these magnet dimensions by paralleling a couple of quarter-pound alnico 5 horseshoe magnets as shown in *Fig. 1.* Increasing the number of magnets in parallel will, of course, raise the gap field further, thereby boosting the efficiency of the ribbon tweeter.

Even more economical sources of magnetic energy are the barium ferrite and strontium ferrite compounds. These have become popular in the past ten years because they do not contain cobalt, whose price has been rising continually. The ferrites do not have as high a flux density as the alnicos, but they offer magnetizing forces several times greater. Consequently, they have energy products that are nearly as good as the alnico alloys. Their cost is a lot lower, typically \$10 to \$20 per pound at the retail level for finished magnets. Due to their large H/B ratios, these ferrite ceramics are seldom used in the long bar or horseshoe forms. Instead, they are usually cast into rectangular slabs.

To get the 750 gilberts desired for the ribbon tweeter, you would need a ferrite slab less than 1cm thick. The 50,000 lines desired would require a slab with a cross-sectional area of about 15cm². You can meet the requirements for mmf and flux by cementing at least four 1-by-2-by-5cm barium ferrite blocks together in a series/parallel arrangement, as shown in *Fig. 3.* These blocks are available (at \$7.50 per dozen) from Edmund Scientific Corp., item number 41799. This material is essentially equivalent to Indox 5 or Arnox 5. You can almost certainly substitute other size blocks and other ferrites, provided you meet the requirements for mmf and flux.

Perhaps by now you have multiplied the values for the gap field and gap dimensions together and have found an inconsistency. With a gap field of 3,000 gauss and gap dimensions of 0.3cm deep by 10cm high, there are only 9,000 lines in the gap. Why, then, must our magnetic supply be nearly 50,000 lines? The answer is fringing, which is the unwanted dispersal of magnetic flux away from the gap. Although excellent conductors of magnetic flux exist (iron or permalloy, for example), no practical insulators do. As a result, the pole pieces and the magnets themselves are surrounded by a field whose flux must be supplied by the magnets, but this flux must never reach the working gap. We have derived an approximate formula for the reluctance of our magnetic pole piece geometry, including all these fringing effects, as well as the desired gap flux:

$$R = \frac{1/h}{1.637 + d/w + 1.466 \log(x/w)}$$

In this formula, all dimensions are in centimeters: h is the vertical height of the pole pieces, w is the gap width, d is the gap depth (i.e., the thickness of the sheet metal from which the pole pieces are made), and x is the total width of the magnetic assembly. Using the rough dimensions from *Fig. 1* ($h = 12.5$cm, $w = 0.25$cm, $d = 25$cm, and $x = 10$cm) we found a reluctance value of 0.016 gilberts per maxwell (i.e., 0.016Ω). Therefore, at 750 gilberts, we must supply a total flux of nearly 50,000 lines.

MAGNET MOUNTING. So far, we have discussed the requirements imposed by the magnetic gap and the ability of common magnetic materials to supply these needs, but we have not yet addressed the question of how to

Glossary of Magnet Design Concepts

Flux: The total number of lines of magnetic force passing through a circuit branch. Flux is analogous to current. In the CGS system, flux is measured in maxwells or lines. Its symbol is ϕ. A quarter-pound alnico 5 horseshoe magnet can deliver about 25,000 maxwells when shorted out with an iron keeper.

Flux density or induction: The degree to which lines of flux are concentrated. In CGS units, flux density is measured in gauss. One gauss is one maxwell per square centimeter. Its symbol is B.

Magnetomotive force (mmf): The magnetic potential difference between two points in a magnetic circuit. It is analogous to voltage. In CGS units, mmf is measured in gilberts. Its symbol is F. A quarter-pound alnico 5 horseshoe magnet will have an mmf of about 3,000 gilberts between its poles when disconnected from its keeper.

Magnetic intensity: The gradient of F—i.e., the rate at which F varies with position. In CGS units, magnetic intensity is measured in oersteds. An oersted is one gilbert per centimeter. Its symbol is H.

Permeability: The ratio of induction to magnetic intensity—i.e. B/H. Most substances, including air, have permeabilities of almost exactly one. These are called nonmagnetic. Iron and soft steel have a permeability of several thousand and so are useful for hooking up the elements of a magnetic circuit. Its symbol is μ. Permeability is analogous to conductivity.

Reluctance: The ratio of mmf to flux. It is, therefore, analogous to resistance, and the Ohm's law for linear magnetic circuits is written as $F = \phi R$, where R denotes the reluctance. If an air gap has a reluctance of 0.1 gilberts per maxwell—i.e., 0.1 "magnetic ohms"—then driving a flux of 30,000 lines through it will require a magnetomotive force of 3,000 gilberts.

conduct the flux to the gap. Ordinary iron or low-carbon steel is an excellent DC magnetic conductor because it has a high permeability and a high saturation flux density.

We recommend that the pole pieces be made from flat strips of soft low-carbon steel sheet metal. The thickness is not critical, as values from 1/16 to 1/8 inch are satisfactory. The overall length of each strip should equal the working height of the ribbon radiator, as shown in *Fig. 1*. The width of each pole piece should be a couple of inches. Again, this is not critical. The two pole pieces are fastened together by means of the insulating terminal boards at the top and bottom of the unit. The screws' clearance holes should be generously oversized to allow some adjustment for the exact ribbon width when the ribbon is installed.

If you choose horseshoe alnico magnets, no mounting fixture is necessary. The horseshoes are normally cast and ground so that their feet come out flat, accurately parallel and coplanar. This allows them to stick to the pole pieces and energize the pieces efficiently without any additional parts. This is a terrific advantage when you are experimenting, and even though the quarter-pound magnets cost about $10 apiece in hardware stores, their mounting convenience prompts us to recommend them over the ferrite units.

For a more permanent job of assembly, you may apply a drop of cement under each horseshoe foot. Remember, however, that if the ribbon needs replacement, the gap width will probably need readjustment, so don't use too powerful an adhesive. The horseshoe magnets seen in the accompanying photographs are made of an alloy called Alcomax (related to the alnicos) and are distributed by the General Hardware Manufacturing Co., part number 370-4. In our tweeter, a pair of them gives about 2,000 gauss, as measured with a Bell Model 110 gaussmeter.

If you choose ferrite block magnets, you must use some additional iron to complete the flux path. One way to do this is shown in *Fig. 3*. Here, the block magnets are applied flat against each pole piece. The polarity is important and will be explained below. There is room for up to four blocks per side, although three per side are shown and work well. The flux path is completed across the rear with a single flat iron plate about 1/4 inch thick or with several thinner sheets stacked together. The space behind the ribbon is vented by a bunch of 3/8-inch holes, which minimize the formation of a resonant acoustic chamber. It is also helpful to line this space with felt. The six block magnets shown in *Fig. 3* give about 2,500 gauss in a 3mm gap.

An assembly like this will stick together pretty well without any adhesives, but for a more permanent job, it might be advisable to use some epoxy or Eastman 910 on three of the four magnetic joints, as indicated in *Fig. 3*. Sliding the fourth joint allows adjustment of the gap width for each ribbon. It will be held securely when the pole pieces are tightened against the terminal plates.

RIBBON MOUNTING. Due to the ribbon's fragile nature, it is important that the mounting hardware clamp the ends of the ribbon without cutting it or risking damage to its metal or plastic part. One safe way to do this is to fold each end over a few times to build up some thickness and then clamp this wad between a pair of washers on the terminal screw. If you use metallized plastic film, be sure that the folding puts the metallized side on the outside of the folds to achieve electrical contact.

For the following procedure to succeed, you should start with the pole pieces separated as far as the corner-hole clearances allow and the terminal bars as close together as the clearances allow. Snug all four corner bolts and install the ribbon into its terminal screws with as little slack as possible. Tweezers help here, especially non-magnetic ones. When you have secured both ribbon ends and have checked the continuity with an ohmmeter, put the ribbon under gentle tension by loosening the top pair of corner bolts and raising the top terminal bar. Snug these bolts.

Next, loosen the left pair of corner bolts and slide the left pole piece over until it is almost in contact with the left edge of the ribbon. Tighten the left bolts. Loosen the right pair and adjust the right pole piece. Finally, tighten everything. This is all a lot easier without the magnets in place because tools behave normally. It is only a little trickier than it sounds.

TWEETER POLARITY. Unlike many loudspeakers, the ribbon tweeter is very easy to phase. In most setups, you want a positive power amplifier voltage to give a positive sound pressure signal. This will automatically be the case if you put all the magnets' north poles on the side

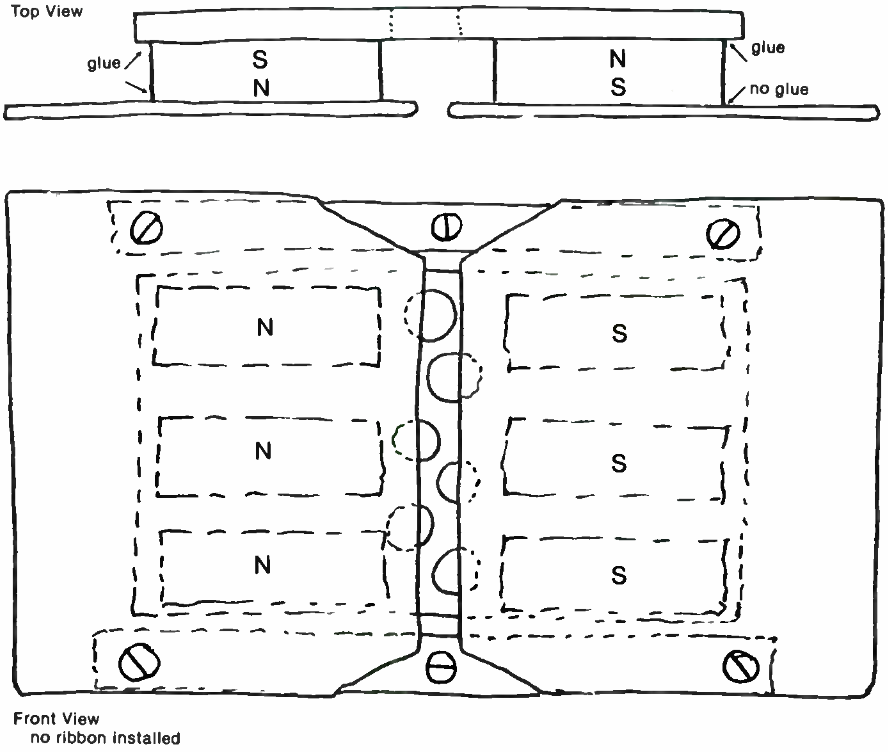
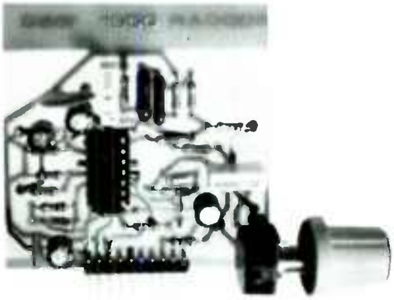


FIGURE 3: Top and front views of a series/parallel arrangement of barium ferrite blocks.

Sound Strategy



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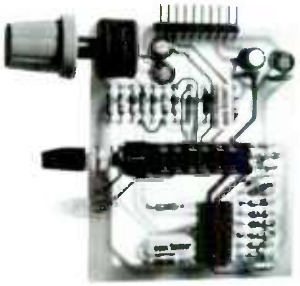

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A unique signal processing circuit, the #1650 Image Enhancer widens the stereo image to surround you with sound and heighten your sense of "being there." All program material, stereo or mono, will benefit from the increased ambience and depth provided. A perfect way to bring concert hall realism to small rooms and acoustically dead environments. This dramatic effect is not restricted to playback, but may be utilized in the recording process as well.

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toward the listener's left and connect the hot power amp output terminal to the top tweeter terminal, grounding the bottom. If you want a reverse tweeter polarity, don't change the magnets, just reverse the electrical connection.

When receiving a shipment of magnets, it is a good idea to determine the north pole of each one and mark it with a dot. Get a long piece of fine sewing thread and tie one end to a sturdy rubber band, then snap the rubber band around one of the magnets so that its magnetic axis is horizontal when dangled from the thread. A horseshoe magnet will hang with its feet down. You now have a magnetic compass. Hang it in a room at least a few meters away from loudspeakers, crates of magnets, steel furniture, and so on, and in a few minutes, its north pole will have stabilized pointing north—unless you live in Baffin Bay. Mark this north pole with a dot of paint or ink. With one magnet done, it is easy to do all the others because like poles repel.

When combining several magnets in parallel or series/parallel, follow the same rules you would in connecting batteries. Be sure they are all oriented the same way. By combining smaller magnets, you are essentially trying to create one big magnet in which all the dipoles point the same way along the magnetic circuit.

THE BACKWAVE. As you probably know, a ribbon element is a dipole radiator—that is, when it makes a positive pressure wave on the front, it is emitting a negative pressure wave out the back past the magnets. Therefore, a listener seated out front will hear the desired "right-side-up" musical waveform, while a hypothetical listener seated behind the tweeter will hear an inverted, or upside-down, version of the same waveform. Psychoacoustic research has shown that inverting a waveform can make it sound different from the original. If you are to achieve accurate reproduction, you cannot allow this backwave to be radiated.

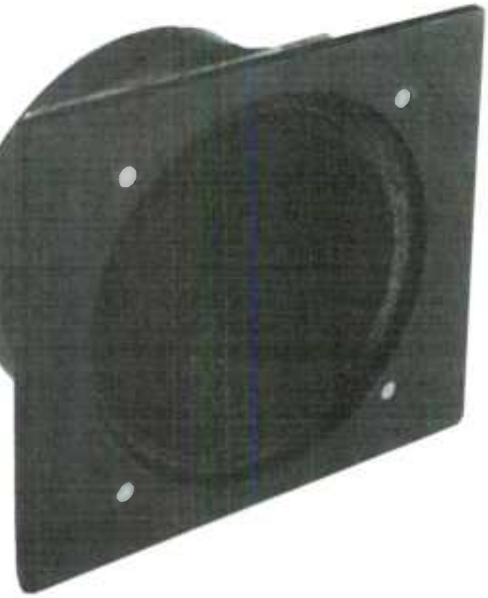
There is a second and more compelling reason to make sure the backwave is absorbed rather than emitted. A loudspeaker is not usually located in the middle of a listening room, but is placed with its back against a wall. If the tweeter radiates much sound toward the back, some will get reflected from this wall. Every impulse will then arrive at the listener twice: first, the initial frontwave arrives, then, after a couple of milliseconds round-trip travel time, the echo arrives. Even though this delay is too brief to be perceived as a separate echo, the transient blurring and frequency-response irregularities it causes are audible, particularly with a high-definition tweeter.

The cure is to eliminate the backwave. This can, of course, be accomplished by enclosing the entire rear of the tweeter in a rigid wooden box. In our experiments, we have found that heavy carpeting is an excellent absorber in the frequency band radiated by this tweeter. We wrapped a 4-by-8-inch piece of carpet around the magnets and cemented or tied it in place. A temporary lash-up of this sort seems well suited to experimenting.

And that's where our work ended. The JVC unit arrived on the scene, and we decided to put the project on the back burner, where it has been sitting ever since. Although chances are slim that any of you will rush out and attempt to build your own ribbon tweeter, we hope that this discussion has given you an "engineer's-eye view" of this type of project.

SUPPLIERS

1. Arnold Engineering Co., Marengo, IL 60152. Manufacturing. Alnico alloys, Arnox ferrites.
2. Colt Industries, Crucible Magnetics Division, PO Box 100, Elizabethtown, KY 42701. Manufacturing. Alnico alloys, Ferrimag ferrites, Crucore samarium cobalt.
3. Edmund Scientific Co., 101 E. Gloucester Pike, Barrington, NJ 08007. Sales. Alnico alloys, ferrites, samarium cobalt.
4. Electron Energy Corp., 329 Main St., Landisville, PA 17538. Manufacturing. Remco samarium cobalt.
5. General Magnetic Co., 10005 Erwin Ave., Detroit, MI 48234. Manufacturing. Genox ferrites.
6. Hitachi Magnetics Corp., 7800 Neff Pkwy., Edmore, MI 48829. Manufacturing. Alnico alloys, ferrites, Hicorex samarium cobalt.
7. Indiana General Magnet Products, 405 Elm St., Valparaiso, IN 46383. Manufacturing. Indox ferrites, alnico alloys, Incor samarium cobalt, misch metal.
8. Magno Ceram Co., 2612 S. Clinton Ave., S. Plainfield, NJ 07080. Manufacturing. Magnite 5 ferrite.
9. Owen Morris & Co., 39 W. 32nd St., New York, NY 10001. Sales. Alnico alloys, ferrites.
10. Permag Sierra Corp., 3721 Haven Ave., Menlo Park, CA 94025. Sales. Hitachi, Indiana General, Crucible and Arnold products.
11. SRC Audio, 3238 Towerwood Dr., Dallas, TX 75234. Sales. JVC Model HSW1101-01A ribbon tweeter.

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PART IV-A IN A SERIES ON MODULAR TEST INSTRUMENTS

BY G. R. KOONCE
Contributing Editor

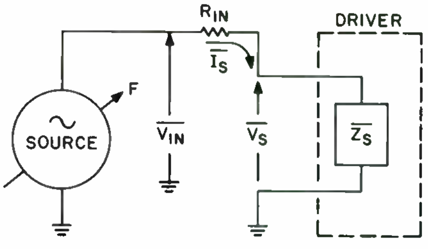
Last time, Mr. Koonce took a break from his construction series to discuss the Thiele/Small parameters. This time, he will show how to use the circuit boards developed in Parts I and III to build a speaker impedance, or Z, meter.

Many of you might not consider the Z meter a useful tool, but I believe it is the most important speaker-related test instrument. It allows you to determine Thiele/Small parameters and evaluate a driver's useful frequency range, while establishing the exact load the drivers place on a crossover. It can also help you to establish the performance of finished enclosures.

The impedance of a speaker is a complex quantity—i.e., it has both a magnitude (Z_{mag}) and a phase angle (Z_{ang}). A detailed discussion of impedance is beyond the scope of this work, but McVeigh^{IV-1} and numerous engineering texts offer more in-depth information.

Although there are several methods of measuring impedance, my unit uses the approach shown in *Fig. IV-1.* A constant-voltage source (V_{in} and external to the Z meter) drives the speaker under test through a large resistor (R_{in}) approximating a current source. Within the limits of this approximation, the magnitude of the driver impedance is directly proportional to the magnitude of the voltage across the driver (V_S). Also, because the signal current (I_S) is approximately in phase with V_{in}, the phase angle of the driver is the phase angle between V_{in} and V_S. When I_S is set to a known value, therefore, measuring V_S gives driver impedance magnitude (in ohms), and measuring the phase angle between V_{in} and V_S gives the driver impedance phase angle (in degrees). The Z meter makes these two measurements and displays ohms and degrees directly.

OVERALL FUNCTION. The overall functional block diagram for the Z meter is shown in *Fig. IV-2.* R_{in} is 5.1kΩ, requiring greater than 5V RMS for V_{in} and using an I_S of 1mA. This yields an impedance sensitivity of 1mV per ohm—i.e., a V_S of 95mV means Z_{mag} equals 95Ω. A test-cal switch accesses a 10Ω, 1 percent calibration resistor instead of the driver under test (DUT). This allows you to calibrate the unit by adjusting V_{in} to show 10Ω on the Z_{mag} meter without having to disconnect the DUT.



ASSUMPTION: R_{IN} IS MUCH, MUCH GREATER THAN THE MAGNITUDE OF Z_S.
NOTE: OVERBAR INDICATES A VECTOR QUANTITY.

FIGURE IV-1: Basic impedance measuring circuit.

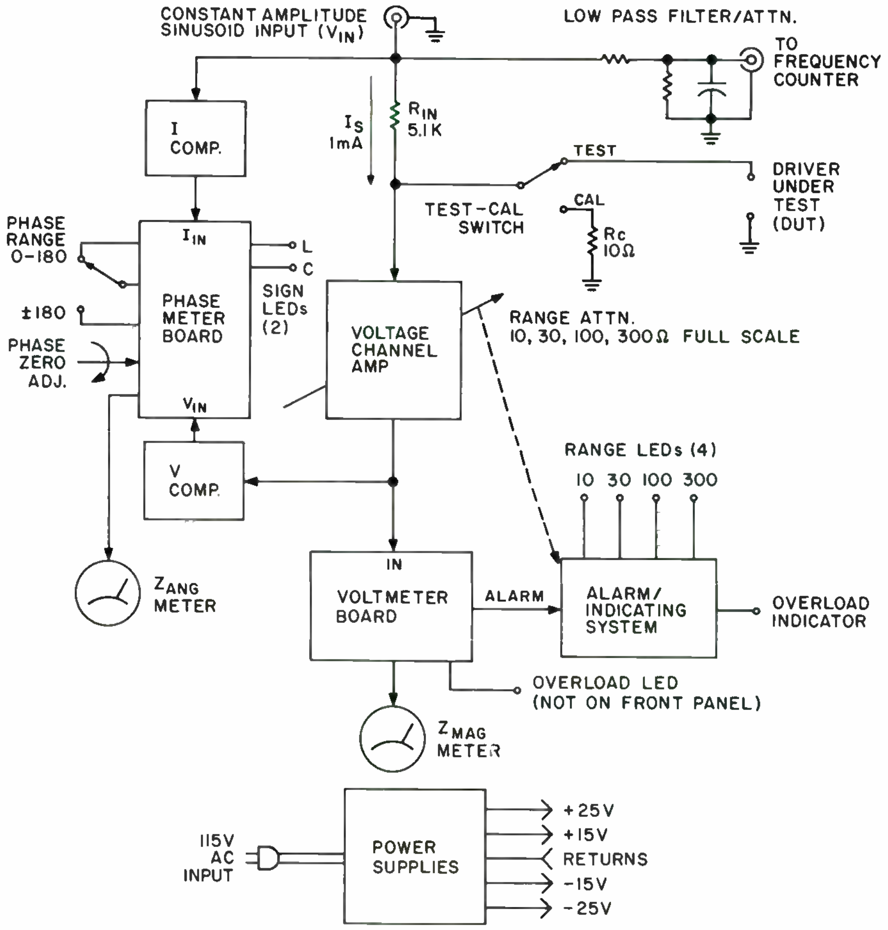


FIGURE IV-2: Overall Z meter function block diagram.

A low-pass filter/attenuator drives a counter, while preventing it from seeing erroneous high-frequency signals. V_{in} drives one comparator of the phase-measuring group (called the I comparator) to give a phase reference. The second comparator (V comparator) monitors an amplified version of V_S at the voltmeter board input. The phase meter (PM) is essentially the full system developed in Part III of this series (*SB* 1/84, p. 23), complete with both phase ranges, the front panel zero trim and the LEDs to indicate the phase angle's sign.

A voltage channel amplifier (VCA) increases V_S to 4V, which allows it to drive a standard voltmeter (VM) board (Part I, *SB* 3/83, p. 12). The VCA gain is switchable so that a 10, 30, 100 or 300mV input (V_S) provides 4V output and yields Z_{mag} ranges of 10, 30, 100 or 300Ω full scale. *Figure IV-3* shows the scales I developed for my Z_{mag} meter.

To fit my application, I added a second pole to the Z_{mag} range switch to drive remote range-indicating LEDs. Coupled to this is circuitry that lights a bright red indicator and blanks the range-indicating LEDs if a VM board overload occurs. These provisions prevent an erroneous impedance reading, with its possible severe consequences in enclosure construction.

The power-supply system used in the Z meter comes from Part I of this series.

INDIVIDUAL FUNCTIONS. The power-supply function uses the AC components and wiring from *Fig. I-10*

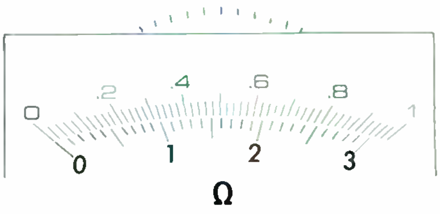


FIGURE IV-3: Meter scale for Z_{mag} meter.

TABLE IV-1

POWER SUPPLY INFORMATION*

+15V Power Supply (7815 type; for 93mA max.)
R6—40Ω, 5W (0.34W actual)
Heatsink—Thermalloy #6030
Other parts per Table I-6
Parts size list—Table I-7
Schematic—Figure I-14a
Stuffing guide—Figure I-15a**
Circuit board #249Z—Figure I-17

−15V Power Supply (7915 type; for 53mA max.)
R6—82Ω, 5W (0.25W actual)
Heatsink—Thermalloy #6030
Other parts per Table I-6
Parts size list—Table I-7
Schematic—Figure I-14b
Stuffing guide—Figure I-15b**
Circuit board #249F—Figure I-17

AC Power System—parts and wiring per Figure I-10

*Refer to Part I, SB 3/83, p. 12 for figures and tables.
**A corrected stuffing guide appears in SB 1/84, p. 37.

TABLE IV-2

VOLTMETER BOARD INFORMATION*

R12—6.2k, ¼W (≅0)
C6—omit
Other parts per Table I-2
Parts size list—Table I-3
Schematic—Figure I-4
Circuit board #246—Figure I-5
Stuffing guide—Figure I-6

*Refer to Part I, SB 3/83, p. 12 for figures and tables.

TABLE IV-3

PHASE METER INFORMATION*

R5—omit
R20—33MΩ, ½W (0.01mW)
Other parts per Table III-4
Parts size list—Table III-5
Schematic—Figure III-9
Circuit board #247—Figure III-10
Stuffing guide—Figure III-11

*Refer to Part III, SB 1/84, p. 23 for figures and tables.

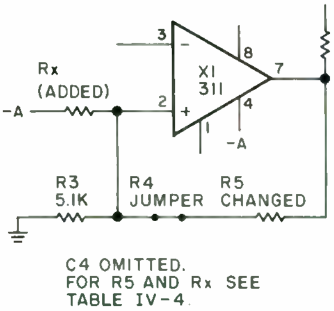


FIGURE IV-4a: Revised portion of the comparator schematic, including Rx.

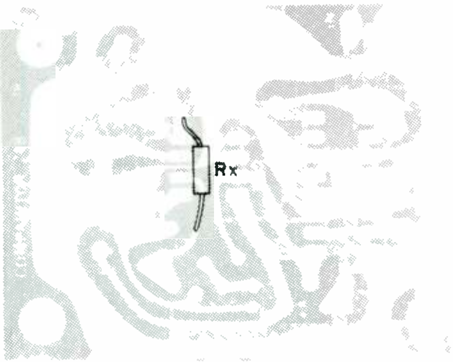
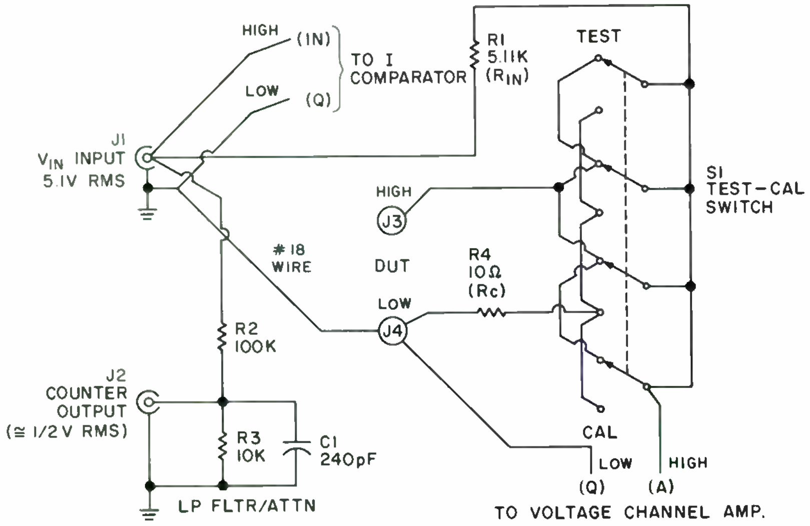


FIGURE IV-4b: Note the position of Rx on the board copper—from the large −A pad by 311 pin 6 to run from 311 pin 2.



S1	4-pole, double-throw shorting rotary	R2	100k, ¼W (0.6mW)
J1, J2	chassis mount BNC connectors	R3	10k, ¼W (0.06mW)
J3, J4	5-way binding posts	R4	10Ω, 1% RN-60 (<1mW)
R1	5.11k, 1% RN-70 (<20mW)	C1	240pF, dipped mica (1V)

FIGURE IV-5: Schematic and parts list for the Z meter input circuitry.

(*SB* 3/83, p. 19). The information needed to build the circuit boards is shown in *Table IV-1*. Note that you should add holes to these circuit boards to tap off preregulated voltage across the filter capacitor (C6 on each supply). A convenient location for these holes is illustrated in *Fig. IV-15.*

As already noted, the VM is from Part I. *Table IV-2* contains the information necessary to build the board. I discussed the requirements for the

TABLE IV-4

COMPARATOR INFORMATION*

	I Comparator	V Comparator
R4	replace w/ jumper	replace w/ jumper
R5	100k, ¼W	240k, 5%, ¼W
C4	omit	omit
Rx (Fig. IV-4)	270k, 5%, ¼W	620k, 5%, ¼W

Other parts per Table III-1
Parts size list—Table III-2
Schematic—Figure III-5 (also see Figure IV-4)
Circuit board #248—Figure III-6
Stuffing guide—Figure III-7 (also see Figure IV-4)

*Also refer to Part III, SB 1/84, p. 23 for figures and tables.

TABLE IV-5

VCA PARTS LIST (Board #251)

R1	100k, ¼W (0.1mW)
R2, R6	1k, 1%, RN-60 (0.9mW)
R3	17.4k, 1%, RN-60 (15mW)
R4	4.7M, ¼W, (0.06mW)
R5	22k, ¼W (13mW)
R7	20.5k, 1%, RN-60 (13mW)
R8	240k, 5%, ¼W (1mW)
D1-D4	1N914 (≅3V, ≅20mA)
C1*, C3*	5pF, NPO disk ceramic or dipped mica (17V)
C2*	11µF, 15V, non-polar tantalum (≅0V normal, 17V worst case if X1 fails), Kemet T11B116M015AS
C4*, C6*	10µF, 25V stand-up electrolytic (17V)
C5*, C7*	0.1µF, 25V disk ceramic (17V)
P1	2k multiturn trimpot, type B only, per Figure I-1L (SB 3/83, p. 13)
X1, X2	LM-301A op amps, mini-DIP case

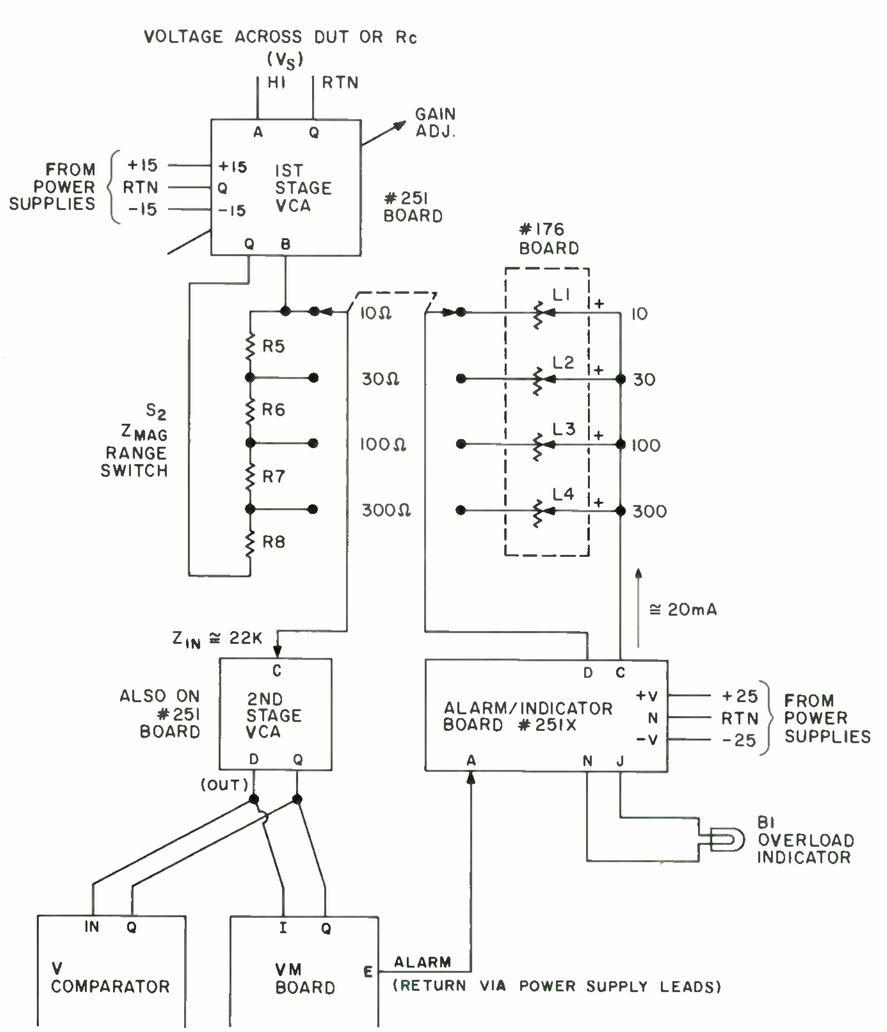
*See parts size list, Table IV-6.

TABLE IV-6

VCA PARTS SIZE LIST

Comp.	Type	Dimensions¹—in inches		
		1	2	3
C1, C3	D	0.15 max	0.46 max	0.25
C2	A	0.2	1.1	1.2
C4, C6	C	0.25	—	0.1
C5, C7	D	0.1	0.5	0.42

¹Refer to Figure I-2 (SB 3/83, p. 14) for definitions.



R5*	2.105k (48mW)
R6*	724.1Ω (16mW)
R7*	219.4Ω (5mW)
R8*	100Ω (3mW)
L1-L4	red LEDs, 20mA
B1**	24V, ≅40mA indicator
S2	2-pole, 4-position non-shorting rotary

*Ideal values. See Fig. IV-17 for actual resistors.
**Catalog No. SP-341A, Meshna, PO Box 62, Lynn, MA 01904.

FIGURE IV-6: Voltage channel amplifier (VCA) and alarm/indicating (A/I) systems. Note that L1-L4 are the author's special LED signals.

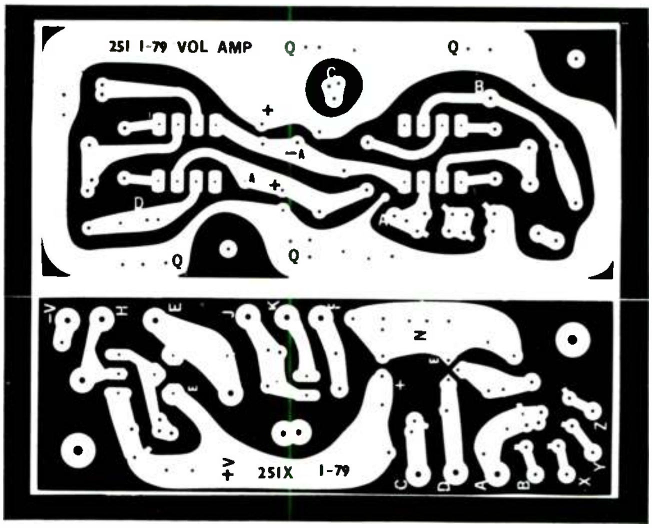


FIGURE IV-8: Circuit board for the VCA (Board #251) and A/I (Board #251X) systems.

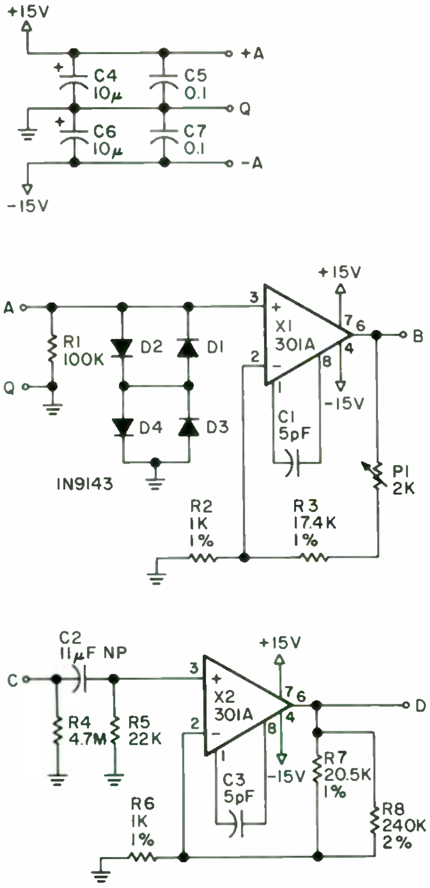


FIGURE IV-7: Schematic diagram of the VCA.

TABLE IV-7

A/I PARTS LIST (Board #251X)

R1, R2	10k, ¼W (R1 = 87mW, R2 = 0.1mW)
R3	470, ½W (334mW worst case, 188mW typical)
R4	330Ω, ½W (234mW worst case, 132mW typical)
R5	1k, ¼W (64mW)
R8	56Ω, ½W (115mW worst case, 90mW typical)
C1*	0.1µF, 10V, disk ceramic (1V)
C2*	0.22µF, 35V, dipped tantalum (32V)
Z1	≅3.5V zener, 1N747, 1N5227 (10mW)
Z2	≅3.1V zener, 1N4372, 1N5225 (88mW)
D3	1N914 (8V, 12mA)
Q1	2N2222 or equivalent, NPN (35V, 26mA, $\beta \geq 15$)
RL1	Elec-Trol RA30571121, 6V, SPDT relay

Optional

D1, D2, D4, D5	1N914 extra OR inputs
R6, R7, R9, R10	½W resistors
Q2	PNP transistor, TO-5 case

*See parts size list, Table IV-8.

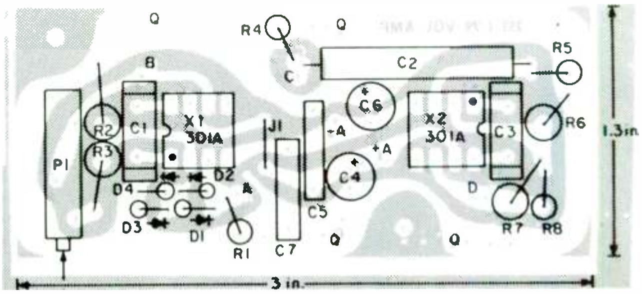


FIGURE IV-9: Stuffing guide for the VCA.

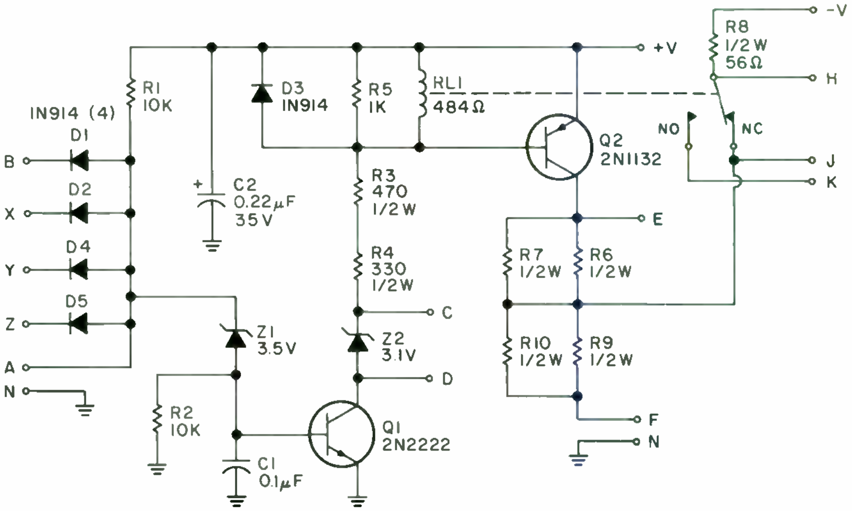


FIGURE IV-10: Schematic diagram of the A/I system.

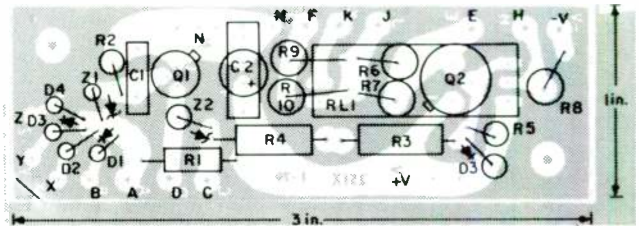


FIGURE IV-11: Stuffing guide for the A/I system (Board #251X in Fig. IV-8).

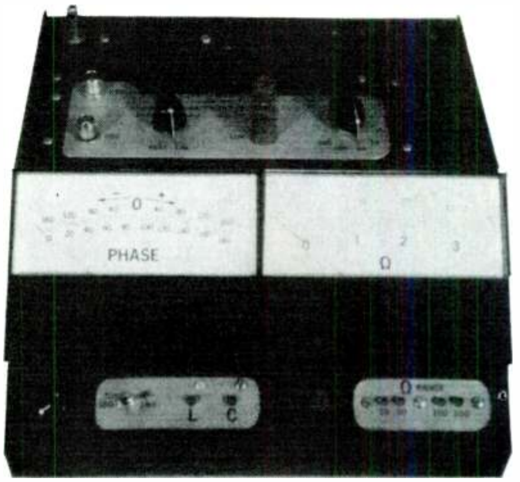


FIGURE IV-12: External view of the Z meter.

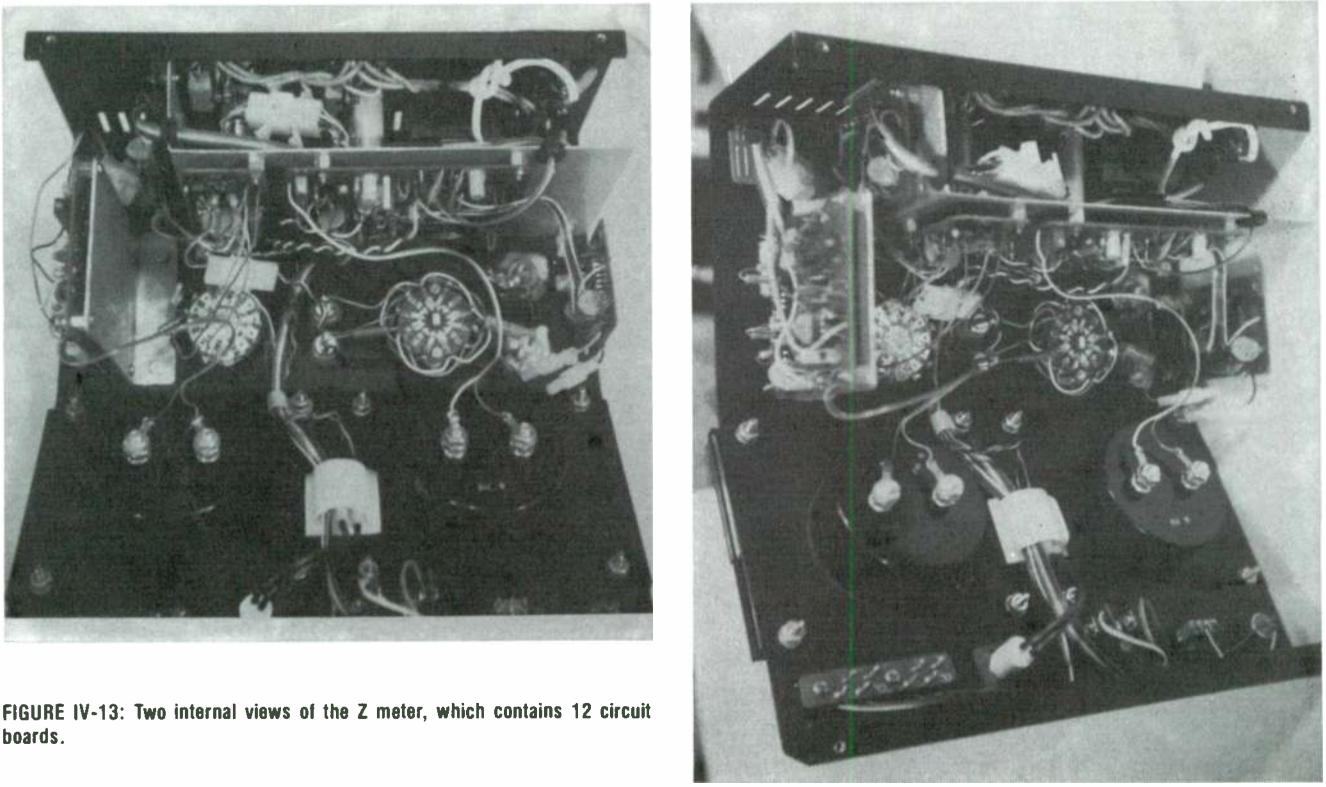


FIGURE IV-13: Two internal views of the Z meter, which contains 12 circuit boards.

overload LED (kept in the circuit, but not visible) and the meter in Part I. Since the Z meter always works with sinusoidal signals, only the fast-mode time constant is provided.

The phase meter function is shown in *Fig. III-12* (*SB* 1/84, p. 29). It contains two comparators (modified), one PM circuit board, two sign LEDs, a meter, a range switch (SPDT miniature toggle) and a zero trimpot. (P0 equals 500Ω for my 1mA meter.) See *Table IV-3* for information on building the PM board. I modified the two comparator boards to have reasonably high symmetrical DC hysteresis. Different values are used to match different input voltage requirements. Unfortunately, the comparator board has no provision for the resistor needed to make the hysteresis symmetrical.

Figure IV-4a shows the schematic for the revised portion of the comparator, while *Fig. IV-4b* is a sketch of where the added resistor (Rx) is tacked onto the board copper. *Table IV-4* contains the other information needed to build the two comparators. Just a reminder—remember to mark which is which. Part III of this series can clarify the effects of this modified hysteresis (approximately 120mV on the V comparator and approximately 300mV on the I comparator) on phase accuracy.

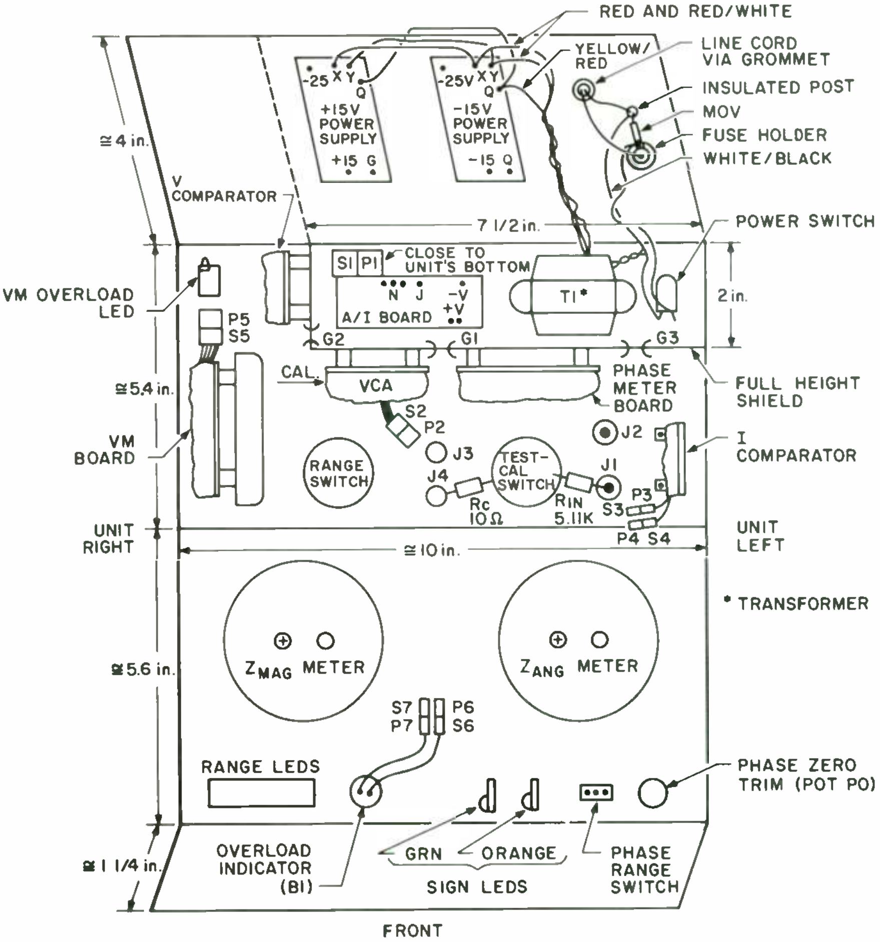


FIGURE IV-14: Parts placement of the Z meter, which contains three construction layers.

Figure IV-5 is a diagram of the functions associated with the input (V_{in}) to the Z meter and contains information about the parts involved. Pay attention to grounding. The only place where the Z meter electronics ground to the case is at the input BNC connector J1. BNC J2 is also grounded to the chassis, but it is tied to the circuitry only by R2. I used a piece of 18-gauge wire to connect the input BNC to the low side (J4) DUT post. The ground return for the I comparator is to J1, while the ground return for the VCA and calibration resistor (R4) is at J4. Note that I used a four-pole, two-position shorting rotary switch for the test-cal switch (S1). This ensures good contact resistance versus the 10Ω calibration resistor and no open circuit as you switch between test and calibrate.

The VCA and alarm/indicating (A/I) systems are shown in *Fig. IV-6*. The range switch (S2) contains an extra pole to run the range-indicating LEDs. *Figures IV-7, IV-8* and *IV-9* show the schematic diagram, circuit board and stuffing guide for the VCA (Board #251). *Tables IV-5* and *IV-6* contain the parts list and parts size list, respectively. Both stages of the VCA have a voltage gain of about 26dB, with the first stage gain being adjustable. This is sufficient to take 10mV to 4V (52dB).

Figure IV-8 also contains Board #251X, which packs the A/I system. *Figures IV-10* and *IV-11* show the

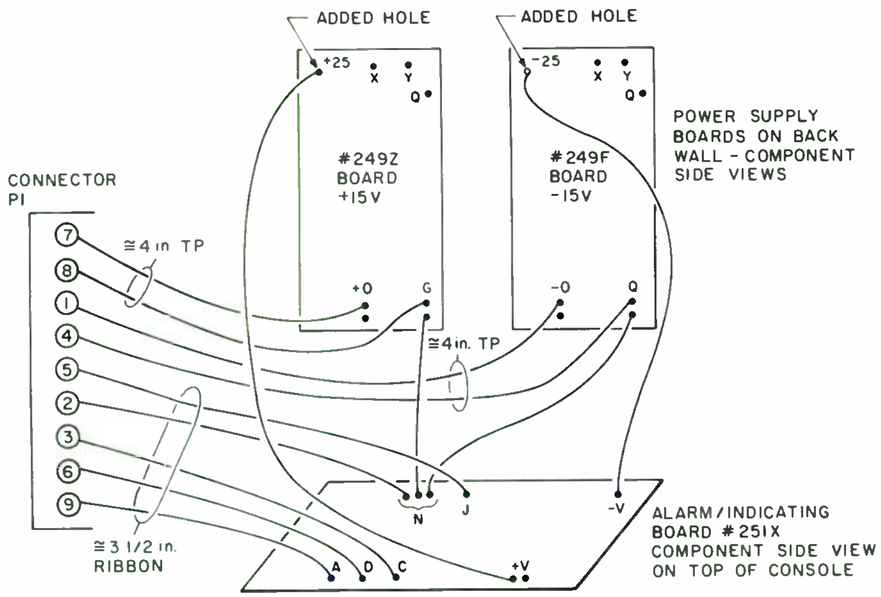
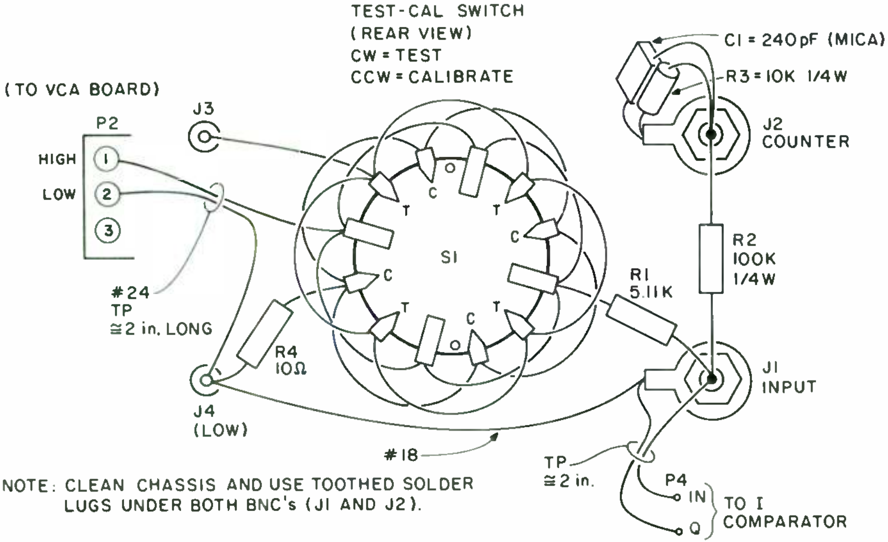


FIGURE IV-15: Power supply and alarm section wiring.



NOTE: CLEAN CHASSIS AND USE TOOTHED SOLDER LUGS UNDER BOTH BNC's (J1 AND J2).

FIGURE IV-16: Fixed chassis wiring of the input circuitry.

TABLE IV-8

A/I PARTS SIZE LIST

Comp.	Type	1	2	3
		Dimensions¹—in inches		
C1	D	0.1	0.4 max	0.25
C2	C	0.25	—	0.1
	or D	0.1	0.55	0.1, 0.4, 0.45

¹Refer to Figure I-2 (SB 3/83, p. 14) for definitions.

TABLE IV-9

CONNECTOR LIST*

Connector Set #1 (9 pins, #1625-9PRT*)

Plug P1—Female Pins	Socket S1—Male Pins
−15V from neg. P.S.	to −A on PM board
N on A/I board	to P6 overload bulb
C on A/I board	to B5 on range switch
Return to neg. P.S.	to Q on PM board
J on A/I board	to S7 overload bulb
D on A/I board	to B0 on range switch
+15V from pos. P.S.	to +A on PM board
Return to pos. P.S.	to Q on PM board
A on A/I board	to P5-1 (alarm on VM board)

Connector Set #2 (3 pins, #1625-3PRT*)

Plug P2—Female Pins	Socket S2—Male Pins
high from test-cal sw.	to A on VCA board
low from J4	to Q on VCA board
spare	spare

Connector Set #3 (1 pin, #1625-1PRT*)

Plug P3—Female Pin	Socket S3—Male Pin
Q on I comparator	ground at input BNC-J1

Connector Set #4 (1 pin, #1625-1PRT*)

Plug P4—Female Pin	Socket S4—Male Pin
input BNC-J1 (hot)	to "IN" on I comparator

Connector Set #5 (6 pins, #1625-6PRT*)

Plug P5—Female Pins	Socket S5—Male Pins (to VM board)
from S1-9 (alarm)	E (alarm)
Q (from VCA board)	Q (power return)
D (out) (from VCA bd.)	I (input)
+A (from VCA board)	+15 (power)
−A (from VCA board)	−15 (power)
Q (from VCA board)	Q (signal return)

Connector Set #6 (1 pin, #1625-1PRT*)

Plug P6—Female Pin	Socket S6—Male Pin
from S1-2	to overload bulb B1

Connector Set #7 (1 pin, #1625-1PRT*)

Plug P7—Male Pin	Socket S7—Female Pin
overload bulb B1	to S1-5

Extra Pins

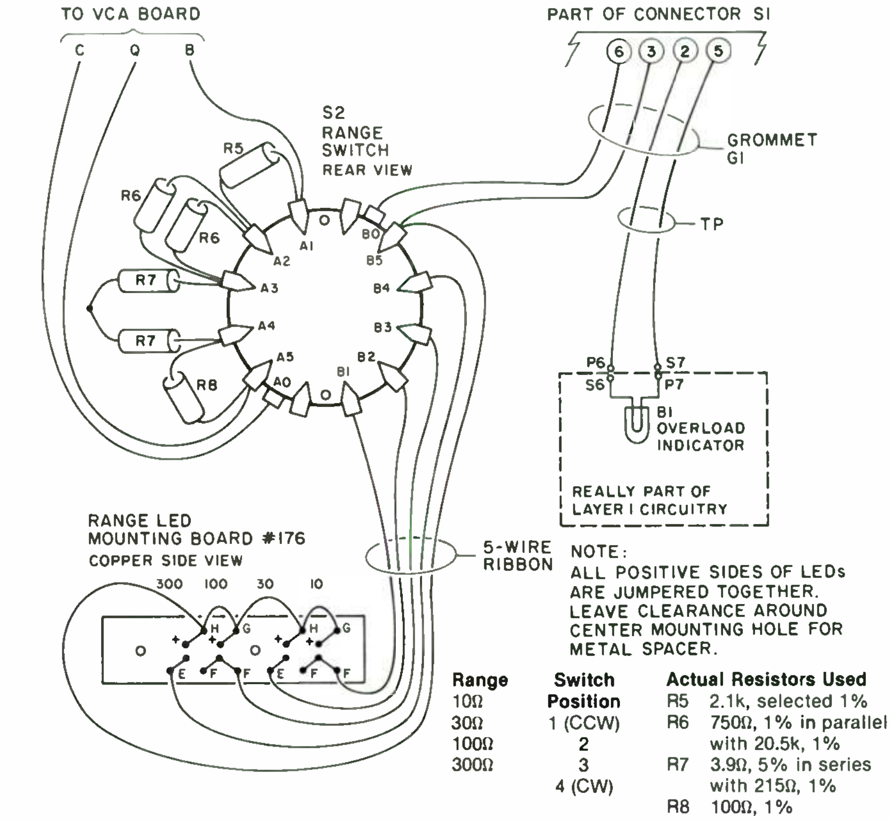
0.062-inch terminal pins (crimped)—#1561-60
Male and female 18-24 wire (I use with #26 wire.)

*Numbers shown include complete connector—both halves and male and female terminal pins. These nylon connectors by Molex are available from Tri-Tek Inc., 7808 N. 27th Ave., Phoenix, AZ 85021. Also note that although the pin numbers are not shown, they are listed in sequential order.

schematic and stuffing guide for the A/I board. These might be a bit confusing, as transistor Q2 shorts out relay RL1 and seems to occupy the same physical location. The board has a dual purpose, however. You would use *either* RL1 or the Q2 stage, but not both. *Tables IV-7* and *IV-8* are the parts list and parts size list for application of this board to the Z meter.

As long as no overload occurs on the VM board, point A on the A/I board can stay high and will keep Q1 on. This means that RL1 is also on, and along with R3 and R4, it puts a "fixed" current (about 20mA) through the range-indicating LED (points C to D on Board #251X). Zener Z2 keeps the relay on while switching ranges. If the VM board goes into overload, its point E lowers point A on the A/I board and shuts off Q1. The range LED then shuts off, and RL1 opens, lighting the 24V overload-indicator bulb (B1 in *Fig. IV-6*). Resistor R8 prevents excessive voltage on B1 and limits the current at turn-on. The positive power supply runs the relay and indicating LEDs, while the negative power supply lights the overload-indicator lamp.

BASIC CONSTRUCTION. I built the Z meter in the same miniature aluminum console as I used for the wattmeter in Part II (*SB* 4/83, p. 20). The finished unit is about 11 inches deep (with the fuse holder), 10½ inches wide and 5¼ inches high, varying somewhat with the hardware used. This means the Z meter is packed more densely than the wattmeter, so



NOTE:
ALL POSITIVE SIDES OF LEDs ARE JUMPERED TOGETHER.
LEAVE CLEARANCE AROUND CENTER MOUNTING HOLE FOR METAL SPACER.

Range	Switch Position	Actual Resistors Used
10Ω	1 (CCW)	R5 2.1k, selected 1%
30Ω	2	R6 750Ω, 1% in parallel with 20.5k, 1%
100Ω	3	R7 3.9Ω, 5% in series with 215Ω, 1%
300Ω	4 (CW)	R8 100Ω, 1%

FIGURE IV-17: Layer two wiring for the range switch and LED indicators. Note that the overload bulb, which is really a part of the first layer, is not removable from the bottom. Also note the VCA attenuator implementation.

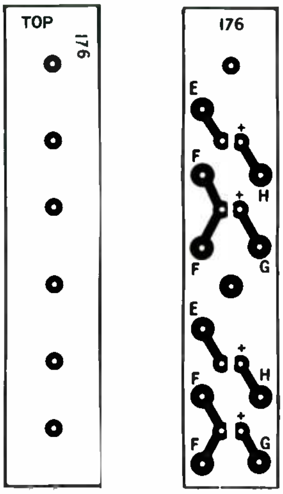


FIGURE IV-18: All the positive LED leads are jumpered together on Board #176. The drilling guide (left) is useful in positioning the four LEDs and two mounting holes.

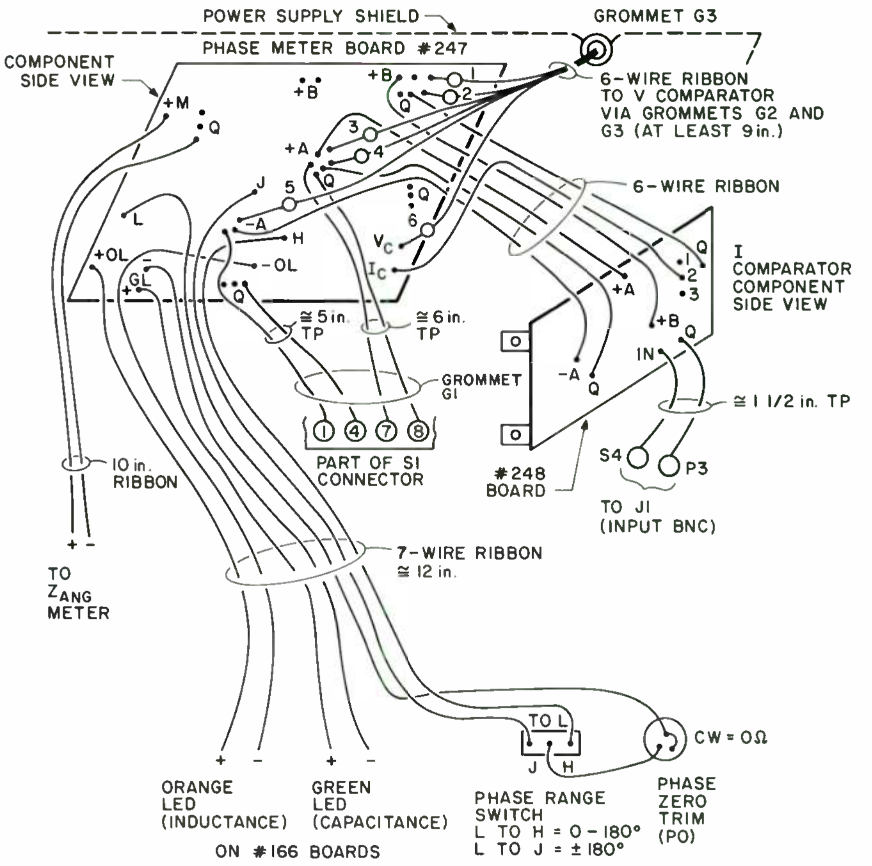


FIGURE IV-19: Left side portion of the layer two board wiring.

you must give special consideration to servicing.

Figure IV-12 shows an external view of the Z meter. See Part II for information on the cabinet and how to label the controls. For the Z meter, I did not paint the aluminum marking sheets and used black transfers to label the controls. *Figure IV-13* shows two internal views of the Z meter, which contains 12 circuit boards of varying sizes.

To facilitate servicing, I constructed the unit in three "layers." The first layer contains the parts that are fixed to the chassis, including the power supplies. The second layer contains all the PM and VCA-related parts, while the third layer is the VM function. To service layer one, you might have to remove layers two and three. You can do this by using connectors between the layers. I used the Waldom-Molex molded miniature series of connectors for this purpose. *Table IV-9* lists information about the connectors, including the connector type, pin type and where the wiring goes.

Figure IV-14 shows the placement of all the components, including connectors, in the Z meter. The three construction layers contain the following components:

- *Layer One* (not removable)—complete power supply, A/I board, four top panel jacks (J1–J4), test-cal switch, Rc and R_{in}, counter filter/attenuator, overload bulb B1, connectors P1, P2, S3, P4, S6 and P7.
- *Layer Two* (removable)—range switch, range-indicating LEDs, both comparators, PM board, VCA board, two sign LEDs, phase-range switch and zero trimpot, Z_{ang} meter, connectors S1, S2, P3, S4, P5, P6 and S7.
- *Layer Three* (removable)—VM board, overload LED mount, Z_{mag} meter, connector S5.

LAYER ONE CONSTRUCTION. The power supplies comprise a large portion of the first layer's circuitry. *Figure IV-14* shows their approximate physical placement and AC wiring. The power supplies and A/I board are allowed a space 2 inches deep by 7½ inches long on the top panel. The line cord (via a grommet), fuse holder and metal oxide varistor's (MOV) mounting insulated post are on the rear wall, along with the power-supply boards, which are mounted with ½-inch 4-40 screws and ¼-inch-OD by ¼-inch-long 4-40 threaded spacers. The transformer, power switch and A/I board are mounted to the top, again using 4-40 hardware for the board.

A full-height, thin aluminum, L-shaped shield is bolted to the top and back wall, isolating the power supply section. Shown in *Fig. IV-14*, this shield, which is removable for servicing, has three grommets notched in from the edge, making them removable also. Grommet G1 is against the top panel, while grommets G2 and G3 are at the free-standing edge of the shield. *Figure IV-15* shows the remaining wiring inside the power-supply area. The open and twisted pair (TP) wire is 24-gauge hookup wire. The "ribbon" is scraps of 26-gauge ribbon cable.

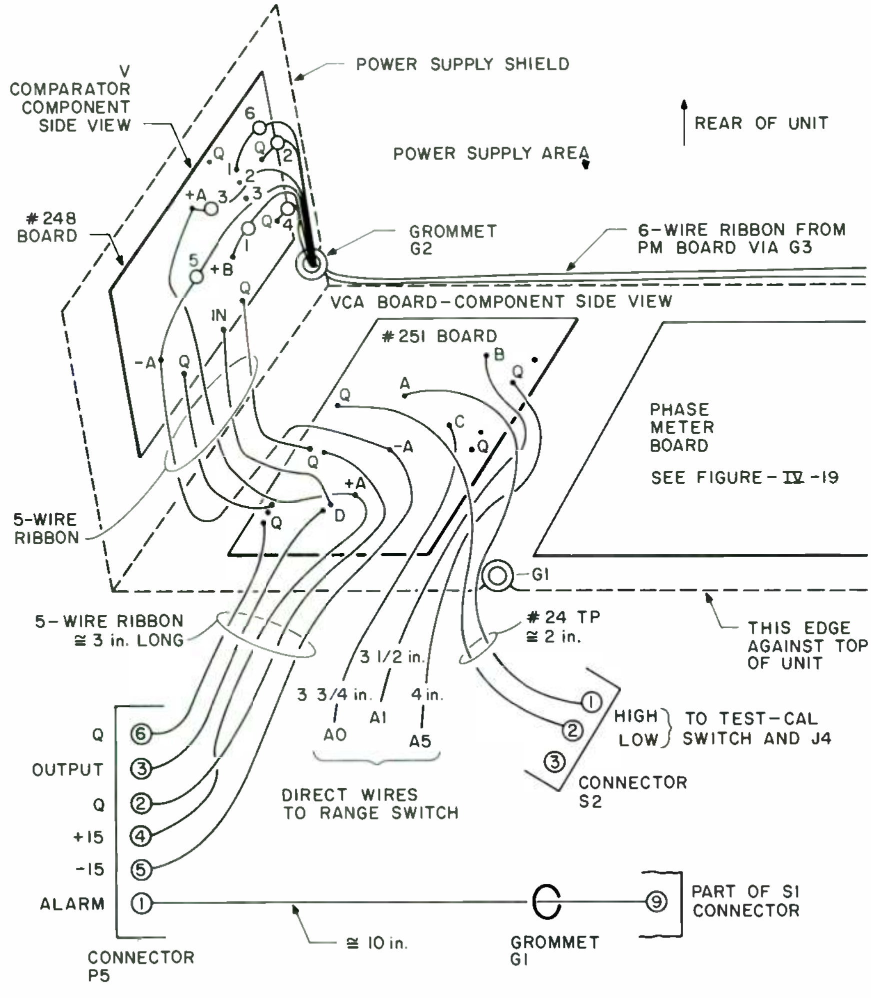


FIGURE IV-20: Right side portion of the layer two board wiring.

Figure IV-16 shows the other main body of the first layer's circuitry. You should ground BNCs J1 and J2 via toothed solder lugs after cleaning the chassis. Do not connect anything to BNC J2 ground except the mica capacitor (C1) and the ¼W resistor (R3). Wire these and the other resistors as shown in *Fig. IV-16*. To minimize resistance and inductance, the range switch has all four poles tied in a complete loop.

The last piece of layer one circuitry is the overload bulb, shown in *Fig. IV-17*. This mounts by a retaining clip and is thus not removable from the bottom. You can omit P6-S6 and P7-S7 if you are willing to cut and repair this wiring, or you can use a single two-terminal connector.

LAYERS TWO & THREE. The first portion of the second layer's circuitry—the range switch and indicators—is shown in *Fig. IV-17*. The indicating LEDs are mounted via Board #176 (*Fig. IV-18*), where all the positive LED leads have been jumpered together. I mounted the LEDs in the board so that they sit flush in the cabinet panel when the board is mounted on ¼-inch-long spacers. *Figure IV-17* also shows the VCA attenuator implementation. Note that only four positions are used, as ter-

CIRCUIT BOARDS

Old Colony's Boards are made of top quality epoxy glass, 2 oz. copper, reflowed solder coated material for ease of constructing projects which have appeared in **Audio Amateur** and **Speaker Builder** magazines. The builder needs the original article (indicated by the date in brackets, i.e. 3:79 for articles in **Audio Amateur** and SB 4:80 for those in **Speaker Builder**) to construct the projects.

C-4: ELECTRONIC CROSSOVER (DG-13R) New 2 × 3½" board takes 8 pin DIPs, Ten eyelets for variable components. [2:72] Each **4.50**

D-1: HERMEYER ELECTROSTATIC AMPLIFIER II. [3:73] Two sided with shields and gold plated fingers. **Closeout.** Each **$5.00** Pair **$9.00**

F-1: BILATERAL CLIPPING INDICATOR. (CB-1) 2 × 2½" [3:75] Single channel. Each **$3.00** Pair **$5.00**

F-6: JUNG 30Hz FILTER/CROSSOVER (WJ-3) 3 × 3" [4:75] High pass or universal filter or crossover. Each **$5.50**

G-2: PETZOLD WHITE NOISE GENERATOR & PINK FILTER. (JP-1) 2½ × 3½" [3:76] Each **$5.00**

H-2: JUNG SPEAKER SAVER. (WJ-4) 3¼ × 5¼" [3:77] Each **$7.00**

H-3: HERMEYER ELECTROSTATIC AMP BOARDS. (ESA-3) Set of three boards with plug-in edges for one channel. [3:77] Set **$19.00**

J-6: SCHROEDER CAPACITOR CHECKER. (CT-10) [4:78] 3¼ × 6" Each **$7.25**

K-3: CRAWFORD WARBLER 3¼ × 3⅜ [1:79] Each **$6.00**

K-6: TUBE CROSSOVER. 2 × 4½" [3:79] Two needed per 2-way channel. Each **$4.25** Four **$13.00**

K-7: TUBE X-OVER POWER SUPPLY. 5 × 5⅝" [3:79] Each **$7.00**

K-12: MacARTHUR LED POWER METER. 5½ × 8¼" [4:79] Two sided, two channel. Each **$16.00**

L-2: WHITE LED OVERLOAD & PEAK METER. 3 × 6" [1:80] One channel. Each **$10.50**

L-6: MASTEL TONE BURST GENERATOR. 3½ × 6⅝" [2:80]. Each **$8.50**

L-9: MASTEL PHASE METER 6⅝ × 2⅝" [4/80] Each **$8.00**

SB-A1: LINKWITZ CROSSOVER BOARD 5½ × 8½" [4:80] Each **$14.00**

SB-C2: BALLARD CROSSOVER BOARD 5½ × 10" [3:82 & 4:82] Each **$14.00**

SB-D1: NEWCOMB PEAK POWER INDICATOR ¾ × 2" [SB 1:83] Each **$2.50**

SB-D2: WITTENBREDER AUDIO PULSE GENERATOR 3½ × 5" [SB 2:83] Each **$7.50**

SB-E2: NEWCOMB NEW PEAK POWER INDICATOR 1 × 2" [SB 2:84] Each **$2.50**

Old Colony Sound Lab
PO Box 243, Dept. SB, Peterborough NH 03458

To order, please write each board's number below with quantity of each and price. Total the amounts and remit by check, money order, MasterCard or Visa. U.S. orders are postpaid. **For charge card orders under $10 please add $1 service charge.** Canadians please add 10%, other countries 15% for postage. All overseas remittances must be in U.S. funds. **Please use clear block capitals.**

Name ____________________

Street & No. ____________________

Town ____________________

State ____________ ZIP ____________

No. Bds.		Price
....	Board No........	$........
....	Board No........	$........
....	Board No........	$........
	Total	$........

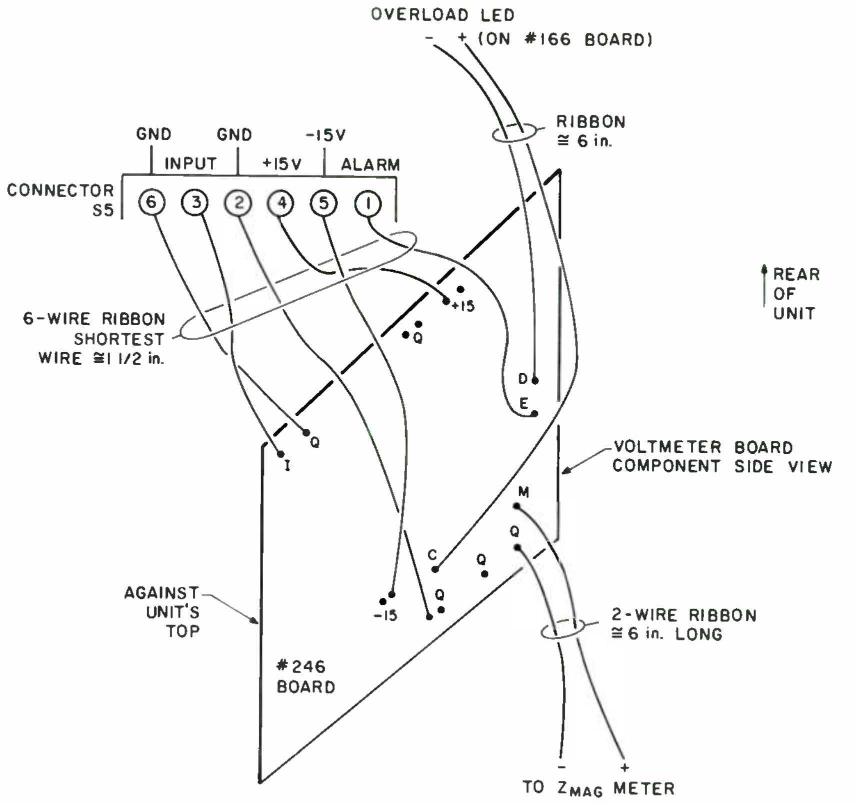


FIGURE IV-21: Layer three wiring for the voltmeter.

minals A5 and B5 are the tie points. Because connector S1 is inside the power-supply shield, all wiring to it must pass through grommet G1.

The V comparator, VCA and PM boards are mounted on the power-supply shield via 4-40 hardware. The PM calibration pots are then accessible from the unit's bottom and the VCA calibration pot from the unit's right. *Figures IV-19* and *IV-20* show the wiring of these boards and the I comparator, which mounts via L brackets near the input BNC. The two sign LEDs are mounted via Board #166. See Part II (p. 25) for the board negative and use. Along with the SPDT mini-toggle phase-range switch and 500Ω mini-pot zero trim, the sign LEDs are mounted from the bottom near the front edge. Wiring to the Z_{ang} meter solders to the lugs fitting on the meter studs.

A six-wire ribbon goes from the PM board, via grommet G3, into the power-supply area and along the shield to G2, where it exits and attaches to the V comparator. The signal in this ribbon is high-level digital, so it is immune to power-supply noise pickup. This routing also shields it from the low-level VCA. Again, all wiring to connector S1 must pass through grommet G1.

The wiring in layer three (*Fig. IV-21*) involves the VM function. The overload LED is also mounted via Board #166, but it is mounted internally near the VM board. The VM board is mounted on the unit's top via an aluminum bracket, which is slightly larger than the circuit board with all calibration pots facing the bottom. The mounting here is the same as I used for the wattmeter in Part II.

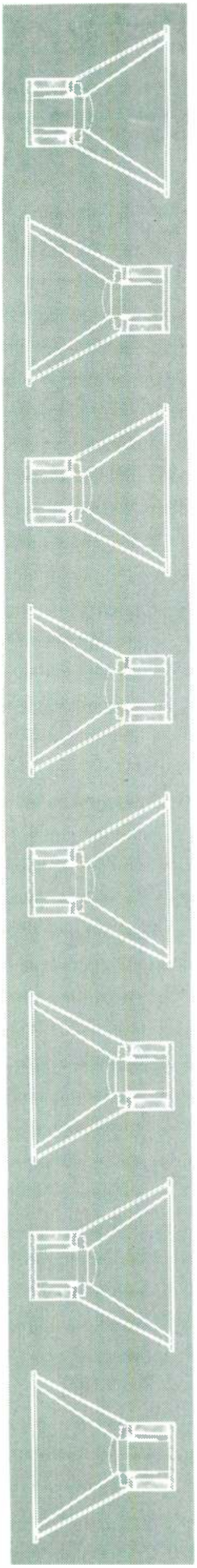
In SB 4/84, Mr. Koonce will describe testing and calibration procedures for the Z meter.

If readers express a substantial interest, Old Colony will offer the circuit board negatives for the Z meter and the other test equipment in Mr. Koonce's series. The estimated cost of the complete set is $6. Send a card expressing your interest to Old Colony, PO Box 243, Peterborough, NH 03458.

REFERENCES

IV-1. J. McVeigh, Hobby Scene Q & A, "Speaker Impedance," *Popular Electronics*, October 1978, p. 81.

World Radio History



LOUDSPEAKERS:

HOW TO BUILD ONE
HOW THEY WORK

A Special Supplement to:

SPEAKER BUILDER MAGAZINE
P.O. Box 494, Peterborough, NH 03458-0494 USA

A BEGINNER BUILDS HIS FIRST SPEAKER

BY DAVID BALDWIN

I BUILT MY FIRST set of speakers about two years ago. Before I began, I would never have 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 might be intimidated by all you must learn, but you do not need a computer to design decent speakers. Your mind, paired with a calculator, can do a great deal.

A few years ago, I contracted what my wife calls "Stereo Madness." (*A too-rare malady that is 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 filled in the gaps with an electronics text.

DESIGN TAKES FORM. When Robert Bullock's article on bass reflex cabinet design (*SB* 4/80, p. 7) appeared, I became excited. It was the clearest discussion of the subject I had seen up to that time. I had some catalogs, so I did some calculations on drivers I saw in a speaker supplier's catalog. When I got a little extra money, I took the plunge and bought Polydax's HD17-B25J2C12 woofer and HD100-D25A/HR tweeter, plus a crossover advertised as having been designed for those drivers. (Polydax equipment is also marketed under the name Audax. It is the same thing.)

Words cannot describe my excitement when the drivers arrived just nine days later. By that time, "Stereo Madness" had completely destroyed my self-control. I could hardly sleep that night. As I studied Bullock's article further and kept redesigning 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, who started to ask questions about considerations such as type of joints, bracing, and glue versus screws. I couldn't answer any of his questions satisfactorily, so I crept back to the drawing board.

I did a scale drawing (*Fig. 1*), which made a world of difference. I would strongly recommend doing such a drawing. You do not have to know much about drafting; I did not. I avoided the issue of perspective entirely by doing front and side views with exact dimensions showing each cut. *Table 1* shows the dimensions and system specifications. With care, you can do the same thing.

In doing the drawing, I became aware of many things I had not considered, such as the amount of space taken up by bracing. I had estimated it, but when I did exact calculations (*Table 2*), I realized how far off I had been. Who knows how my speakers would have sounded if I had not recalculated to account for all the parts that occupy space.

Before I started cutting, I was lucky enough to buy David Weems' *How to Design, Build, and Test Complete Speaker Systems.* (*Editor's Note: This edition of Mr. Weems' book is no longer available. It has been replaced by Tab Books #1364,* Designing, Building and Testing Your Own Speaker Sytems.) After reading his book, I realized that the specifications in the original 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 Polydax supplied them.

I gritted my teeth and asked a friend, who owned some test equipment, for help. We spent an evening testing the woofers. Weems' procedures are very clear and easy to follow. 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, too.

I did yet another scale drawing using the new specs, and after much time in the wood shop figuring out which end was up, I got one speaker together. While in the shop, you should 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 silicone rubber sealant. Cosmetically, they leave much to be desired.

FIRST SOUNDS. When I got the first speaker hooked up, I put on a record and sat down to listen. It sounded awful! What could be wrong? I discovered that the tweeter was producing nothing, so I put in the other one. The sound was 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, but it was still wrong. Only after several tries did I get it right.

Remember that there is a reason for every failure. It could be 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 that it was not any 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

TABLE 1

DIMENSIONS AND SPECIFICATIONS

Side Dimensions Outside letters are panels. Inside letters are glue blocks.	Front Dimensions	Specifications
A = 22.7 cm	A = 12 cm	Polydax HD17-B25J2C12
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} = 0.48
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 = 3.48 cm
K = 6.5 cm	K = 20.5 cm	d_v = 5 cm
L = 10.1 cm	L = 52.3 cm	
M = 62.6 cm	M = 7 cm	
	N = 5.4 cm	
	O = 20.5 cm	

TABLE 2

CALCULATION OF VOLUME

Int. Height =	66.2 cm
Int. Width =	41.0 cm
Int. Depth =	25.4 cm
	68940.1 cm^3
(tweeter notch)	−3198.0 cm^3
	65742.1 cm^3
(woofer vol.)	−318.0 cm^3
	65424.1 cm^3
(glue block vol.)	−1967.0 cm^3
	63457.1 cm^3
(bracing vol.)	−3468.0 cm^3
	59989.1 cm^3
(vent vol.)	−82.6 cm^3
	59906.5 cm^3

PARTS LIST

Particle board:	1.9 cm thick
Glue blocks:	1.9 × 1.9 cm (length as indicated)
Bracing:	3.8 × 3.8 cm (length as indicated)
Woofer:	Polydax HD17-B25J2C12
Tweeter:	Polydax HD100-D25A/HR
Crossover:	Recommended by a Polydax dealer

two working tweeters again. Speaking of soldering, it is easy. A beginning electronics text can give you directions, or you can get a friend to show you how.

After what seemed 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 somewhat by buying an alignment protractor and properly aligning my cartridge. I also redesigned the crossover, using the procedures outlined in Weems' book. I found the woofer was crossing over at 2,500Hz and the tweeter at 3,600Hz. I replaced the cap across the woofer, raising the crossover to 3,600Hz. More complete, natural sound resulted, just as theory predicted. I got very tired of removing the woofer every time I made a change, so I would suggest mounting the crossover outside the box when you are experimenting.

Putting a felt ring around the tweeter to reduce the effects of diffraction also reduced the peak. When experimenting, I modified one speaker at a time and compared it with the unmodified speaker to be sure that I was not imagining the difference.

Now the speakers have the same good bass, a smooth (but not perfect) midrange and clear highs. Power handling and sensitivity are low, so the dynamic range is fairly constricted, but is adequate for most music in small rooms. The speakers 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 accessible. 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. ☐

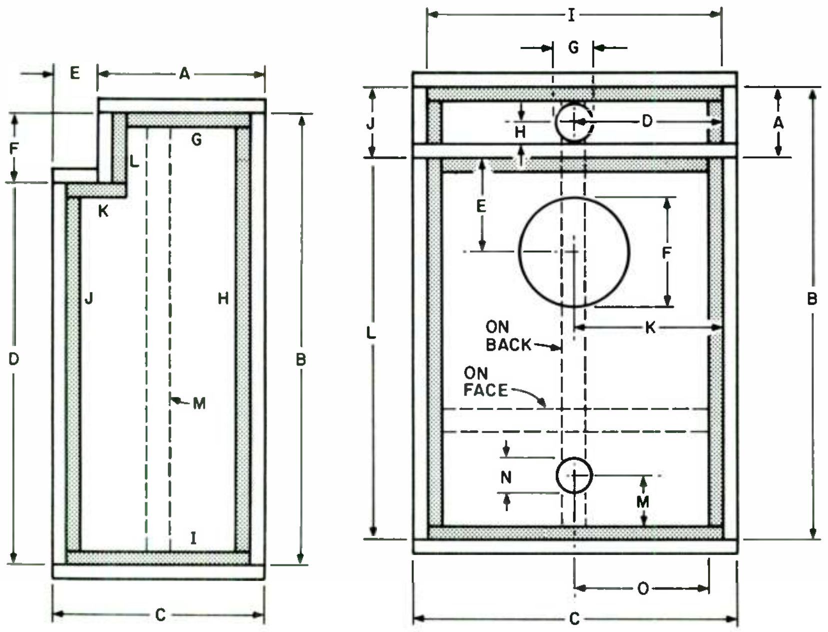


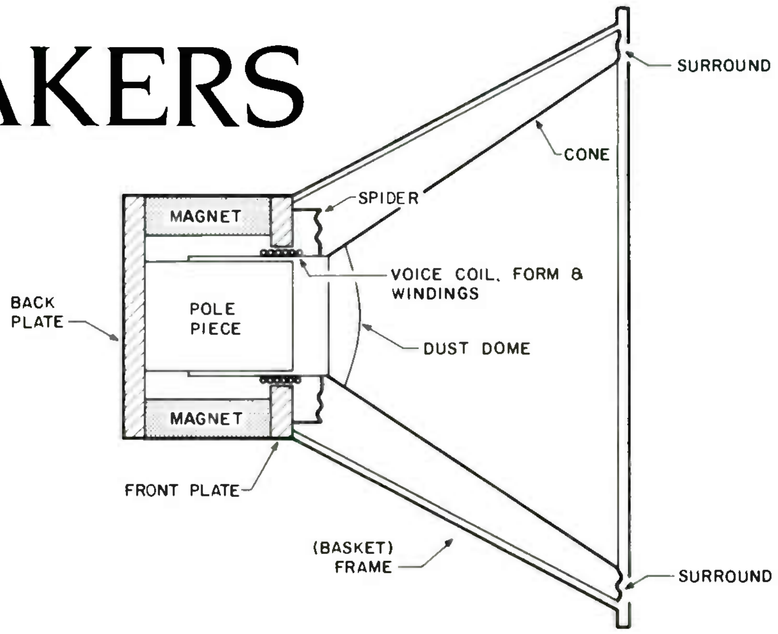
FIGURE 1: A scale drawing helps to clarify the concept, often solving problems before they occur in construction. The letters refer to dimensions in Table 1.

POLYDAX SOURCES

1. A&S Speakers, Dept. DB, PO Box 7462, Denver, CO 80207.
2. Audio Concepts, Dept. DB, 1631 Caledonia St., LaCrosse, WI 54601.
3. Madisound, Dept. DB, PO Box 4283, Madison, WI 53711.

LOUDSPEAKERS FROM A to Z

BY WILLIAM R. HOFFMAN



Although most of us enjoy listening to the sound that emanates from a loudspeaker system, many of us do not understand how that sound is produced. Explaining that process is what this article is all about.

First, let's get a few definitions out of the way. Technically, a loudspeaker system is an assemblage of interdependent electromechanical parts that converts electrical energy to acoustic power. These parts include the driver, the enclosure and a network of electrical frequency-selective components. Let's take a closer look at each of these parts.

THE DRIVER. Almost all currently produced drivers take the form of the basic cone loudspeaker (*Fig. 1*). The front plate, magnet, back plate and pole piece form the *magnetic circuit*, while the surround, cone, dust dome, spider and voice coil form the *moving system*. Together, the magnetic circuit and the voice coil make up the heart of the driver—the *motor* (*Fig. 2*). The common dome tweeter is a slight variation of this arrangement, omitting the cone, basket and surround.

To understand the operation of a loudspeaker, you must first understand the operation of the *motor*. *Figure 2* is an enlarged cross-sectional view of the magnetic circuit and the voice coil.

The permanent magnet creates a magnetic field of fixed polarity across the voice-coil gap (magnetic field conduction between the front plate and the pole piece). The amplifier supplies the voice-coil windings with an electrical signal whose polarity (direction of current flow) pattern changes to match the acoustic waveform to be reproduced. This current flow sets up an electromagnetic field around the windings, which is in direct proximity to the permanent magnetic field.

By the natural laws of physics, like poles repel each other, and opposite poles attract, so the permanent magnetic field and the electromagnetic field interact. Notice in *Fig. 2* the small dotted arrows marked with an S and an N. These indicate the fixed polarity of the permanent magnet. Next to the voice coil is another dotted arrow without markings. This indicates the alternating polarity of the voice-coil field.

Because the polarity of the voice-coil field matches the polarity of the permanent magnetic field, the voice coil and windings are repelled from the voice-coil gap. The amount of this repulsion is proportional to the strengths of the two fields. When the voice-coil field reverses, and the polarity becomes opposite the permanent magnetic field polarity, the voice coil is attracted into the voice-coil gap. The result of this axial motion is then transferred to the cone, which is attached to the voice coil at its truncated end.

The second part of a loudspeaker is the *moving system*. Referring back to *Fig. 1*, the cone, surround, spider and dust dome are the major parts of this system. The axial motion of the voice coil causes a back-and-forth motion of the cone, which in turn causes a compression and a rarefaction of the air immediately around the cone. This pattern of air-pressure changes is the acoustic waveform, or the sound that we hear.

As you can see, the loudspeaker is a conversion device. Two conversions actually take place—electrical-to-mechanical and mechanical-to-acoustic—making the speaker a double-conversion device. As in all mechanical and electrical devices, errors occur. These errors are usually in the form of nonlinearity, which means that the output of the conversion does not correspond exactly to the original input. This distortion occurs in several ways.

DRIVER DISTORTION. The first type of distortion results from a nonlinear relationship between current flowing in a coil and the resulting electromagnetic field. This relationship is generally linear, meaning that the strength of the field is proportional to the amount of current flowing: field strength = (current) × (the number of turns in the coil).

In terms of the motor, this equation becomes:

$$\text{force} = B \times L \times I$$

where B is the flux density in the voice-coil gap (Webers/meters^2), L is the length of the voice-coil windings in the gap (meters), I is the current flowing in the voice-coil windings (amperes), and force is the motor (strength).

Therefore, motion of the voice coil

becomes approximately proportional to the current flowing, as long as the number of coil-winding turns in the gap remains constant. If at any time the motion of the coil takes it far enough out of the voice-coil gap, the force changes because L changes. This causes a corresponding change in the cone's motion, resulting in distortion.

Changes in inductance cause the second type of distortion. All coils have inductance, which, for a coil in free air (not wound around a form of steel or iron), is approximately described by the following equation:

$$\text{inductance(mH)} = \frac{N^2A^2}{\pi(6A + 9B + 10C)}$$

where N is the number of turns of wire divided by 100, A is the radius of the average turn (millimeters), B is the winding length (mm), and C is the winding depth (mm).

Inductance changes the current flowing through a coil in proportion to the rate of change, or the frequency. The coil exhibits not only reactance, but resistance as well. The sum of these two factors changes the current and, therefore, the force. Because the effect varies with frequency, a selective action occurs, and distortion results.

Note that the term "impedance" is commonly associated with loudspeaker specifications. It is related to resistance and reactance in the following way:

$$\text{impedance(Z)} = \sqrt{(\text{resistance})^2 + (\text{reactance})^2}$$

The third type of distortion is known as amplitude distortion. The relationship between the driver frequency and the force required to produce it is not linear:

$$\text{force required} = \text{mass} \times \text{acceleration}.$$

Acceleration (of a loudspeaker cone) is proportional to the peak amplitude (motion) of the cone times the frequency. The formula is:

$$\text{acceleration} \cong 2\pi D\, f,$$

where D is the peak distance the cone travels in one direction, and f is the frequency being reproduced.

The goal is for a loudspeaker to produce all frequencies fed to it with the proper intensities, neither exaggerating nor reducing any tones. To reproduce these tones, the cone must move a certain distance (amplitude) in a given amount of time (frequency).

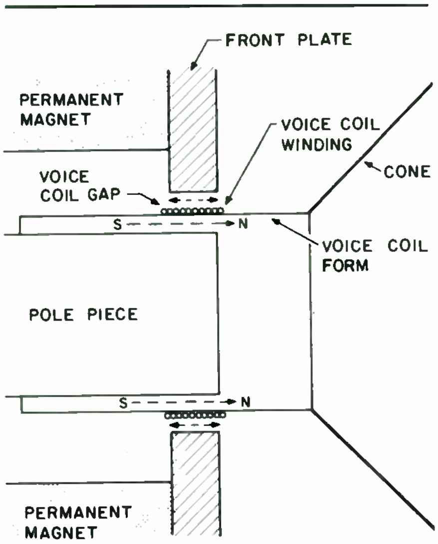


FIGURE 2: Cross-section of the magnetic circuit and voice coil, which together form the motor.

The relationship between time and distance does not, however, remain fixed for a loudspeaker—i.e., amplitude is not equal to 1/f.

Let's look at an example. If f1 equals 1kHz, f2 equals 2kHz, and the amplitude of cone motion decreases with increasing frequency, as the acceleration equation suggests, then:

$$\frac{\text{amplitude @ f1}}{2} = \text{amplitude @ f2}$$

if the acceleration remains constant.

This is not the case, however. In fact, the cone distance of travel must not halve with double the frequency, but instead must be reduced to one-quarter. Despite this, the natural tendency of the cone is to move half as far for each doubling of the frequency to be reproduced. Therefore, the loudspeaker naturally has a rising response. The correct relationship is expressed as:

$$\frac{\text{amplitude @ f1}}{4} = \text{amplitude @ f2}$$

You can see that because D is not a linearly changing quantity, acceleration does not change linearly either. Therefore, while the force required and the mass are constant, the acceleration is not correct, and the result is amplitude distortion.

To clarify this complex relationship, look again at the basic equation for force required, which equals (mass × acceleration), where force is the loudspeaker motor (a fixed quantity), and mass is the mass of the loudspeaker cone (also fixed). As a result, acceleration must also be fixed.

TABLE 1

DESIGN ALTERATIONS

Efficiency	Cone Area	Motor	Mass
increase	increase	same	same
increase	same	same	decrease
increase	same	increase	same
decrease	same	same	increase
decrease	decrease	same	same
decrease	same	decrease	same

TABLE 2

LOW-FREQUENCY LIMITS

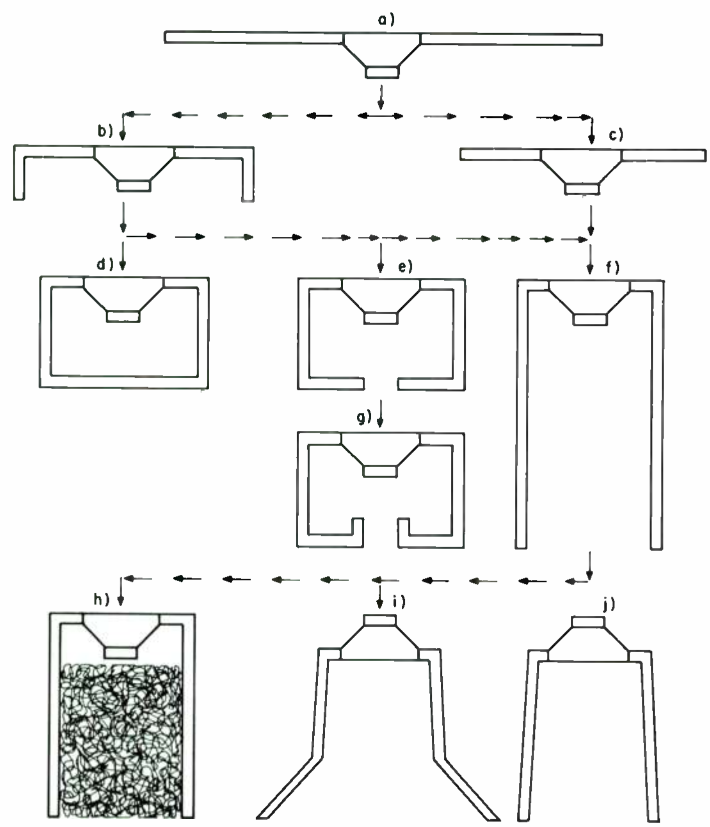
Driver Size	Lower Useful Limit
6"	60Hz
8"	45Hz
10"	28Hz
12"	24Hz
15"	22Hz
18"	21Hz

If acceleration is fixed, the quantities D and f in the acceleration equation above must change linearly—i.e., if D doubles, f must halve, and vice-versa. This is, in fact, a fairly accurate description of what a loudspeaker does and is the cause of rising response, a form of amplitude distortion.

My discussion of the first three types of distortion assumes an "ideal" loudspeaker, in which driver operation closely follows the basic laws of physics and engineering. When considering the loudspeaker cone, however, these rules fail, and the laws governing certain aspects of operation become extremely complex. Without citing specific examples, I can only generalize on the operation and distortion that a cone produces.

The basic problems relating to diaphragm design and operation stem from a lack of perfectly rigid and infinitely light material. Theoretically, a diaphragm (cone) possessing these two qualities would follow the voice coil's motion perfectly and thus transmit to the air an exact acoustic replica of the electrical signal being fed to the loudspeaker. In reality, however, the cone reacts differently.

Because the diaphragm material is not perfectly rigid, it will not follow the voice coil's motion exactly. Modern materials and techniques, though, can alleviate many of the problems. In addition, because the diaphragm material has mass, it will not be able to respond instantaneously to the commands of the voice coil. Obviously, the more massive the cone, the slower the response.



(a) Infinitely large flat baffle (wall)
(b) Open-back cabinet
(c) Finite baffle
(d) Infinite baffle (The acoustic suspension system is variant.)
(e) Bass reflex
(f) Extended tube
(g) Ducted port
(h) Extended tube with acoustic material (transmission line)
(i) Horn (exponential, hyperbolic, parabolic, etc.)
(j) Horn, conical

FIGURE 3: Enclosure types.

Although no hard and fast rules apply to cone design, the following general principles are useful:

- Shallow cone designs are more efficient radiators than deep ones.
- Curved cones tend to behave more ideally than straight-sided cones.
- With loudspeaker designs requiring large cone motions, "roll edge" type surrounds cause fewer problems than "accordion pleated" designs. The pleated types tend to experience a "whipping" motion under large cone excursions.

DRIVER DESIGN. When designing a loudspeaker system, you must consider four things:

- frequency range to be covered;
- electrical power input capacity;
- acoustic power output capability;
- linearity of operation.

In practical systems, all four considerations are interrelated.

To design a system with linear response over a specified range of frequencies, with a given level of efficiency and within a given limit of distortion, requires knowledge of four parameters:

- cone area of the low-frequency driver;
- mass of the low-frequency driver's moving system
- low-frequency driver motor;
- enclosure air volume.

Starting with a basic design in which you have control over these four parameters, you can alter it to achieve the results in *Table 1*, which relates specifically to the bass driver. Note that enclosure volume does not relate directly to system efficiency. Indirectly, it determines the results in many performance areas. This is my second concern.

The air volume stiffness of the enclosure adds to the driver stiffness. The formula forair volume stiffness, as it relates to a sealed box, is:

$$\text{stiffness} = \frac{pc^2A^2}{V}$$

where V is the enclosure volume, p is air density, c is the speed of sound in free air, and A is cone area.

This equation shows the following:

- Increasing the enclosure volume decreases stiffness.
- Decreasing the enclosure volume increases stiffness.
- Increasing driver size increases stiffness.
- Decreasing driver size decreases stiffness.

A second consideration is driver resonance required to reproduce the bass. Resonance frequency determines the lower useful limit of a bass driver. Because of natural acoustic limitations, a driver rapidly loses its ability to produce useful acoustic output below this point. In designing a system, therefore, you must first determine the lowest frequency that it must reproduce and use this as a guide in designing the driver.

The reason for the bass loss below resonance is obvious when you examine the relationship between the cone's amplitude requirements (the distance it must move) and the frequency to be reproduced. Assuming that the driver is to reproduce all tones fed to it in a linear manner, then the following rules hold true:

- When the frequency is halved, the cone's amplitude must quadruple.
- When the frequency is doubled, the cone's amplitude is reduced to one-quarter.

No driver has "infinite" compliance: there is a limit to how far a speaker cone can move. This limit is set by the driver design. The length of the voice-coil winding and the strength of the magnetic circuit are the key considerations. Because cone motion is limited, and because the requirements for cone motion increase with decreasing frequency, the driver reaches its limit at some point. This usually occurs at the driver's resonance frequency, although it might not be directly related to resonance.

The effect of enclosure stiffness on driver resonance is predictable. Use the value for stiffness mentioned earlier and apply it to the following equation to find the proportional amount the bass resonance (and, therefore, the useful low-frequency limit) will rise:

$$\frac{1}{\sqrt{\text{stiffness (increase)}}}$$

From this, you can see that in a typical system, the bass driver must have a resonance, measured outside the enclosure, that is lower than the intended limit for the completed system. Knowing the size of the enclosure, you can calculate the completed-system resonance frequency.

POWER OUTPUT & LINEARITY. The third consideration—the acoustic output of a driver—is approximately proportional to the amplitude of the cone motion. Acoustic power equals

(V^2R), where V is cone velocity, and R is radiation resistance. Using the formula for velocity ($V = 2\pi Df$), where D is the peak distance the cone moves in one direction, and f is frequency, you can see that velocity, amplitude and cone size relate to the amount of power the driver can radiate.

Ignoring for the moment other engineering factors, *Table 2* shows the approximate lower-frequency limits of some common driver sizes. These limits are based on two assumptions:

- the acoustic output is fixed at ¼W for all drivers;
- the peak-to-peak cone excursion is limited to ½ inch.

Both are reasonable assumptions and reflect the current state of loudspeaker design, as ¼W is a fairly loud level in a typical room of 2,500 to 3,000 cubic feet. From this you can see that the bass driver's size is important in designing a loudspeaker system.

The final consideration is driver size versus frequency range covered. Not only is there a minimum useful size for a given bass reproduction capability, but there is also a maximum useful size for a given high-frequency reproduction capability.

As I showed earlier, acceleration increases as frequency increases. As acceleration increases, so must the driving force (motor). Obviously, the motor is not infinitely "strong." (The formula for motor strength appears earlier in the article.) At some point in the high-frequency range of the driver, therefore, the motor becomes too weak, and driver response starts to decline. You can overcome this difficulty in two ways—by reducing the mass of the cone and by increasing the strength of the motor.

Typically, light cones are used in full-range drivers, but this presents a problem. Reducing mass also raises the cone's bass resonance. Consequently, a full-range speaker must be a compromise.

As for increasing the motor strength, this is impractical beyond a certain point, as cost and weight become unmanageable. The only practical solution is to use multiple drivers of various sizes. Larger drivers with heavy cones and low resonances are useful in the bass, while smaller drivers with lighter (less massive) cones are best in the high frequencies. This is one reason for building loudspeaker systems with multiple drivers, each covering a specific range of frequencies, and for using a filter to deliver only those frequencies the driver can reproduce best.

A further advantage of going to progressively smaller drivers is dispersion. For a given size driver, as the frequency increases (and the wavelength becomes shorter), the driver output becomes more confined to the area directly in front of the unit. Conversely, the lower the frequency, the more dispersed is the sound. As the frequency increases, however, so does the tendency for the driver to "beam" the sound directly in front of it.

In practical terms, the driver becomes directional when d is greater than or equal to λ, where d is the cone's effective radiating diameter, and λ is the wavelength. In this case, λ equals V/f, where V is the velocity of sound in air (feet/second), and f is the frequency (hertz).

A practical loudspeaker system is composed of several different-sized drivers with a filter network delivering the frequency range each driver can reproduce best. The advantage of this is that the system can reproduce the broadest range of frequencies, with the widest possible coverage.

ENCLOSURES. For a loudspeaker system that reproduces bass frequencies, it it necessary to have an enclosure. First, the enclosure isolates the radiation from the front and back of the cone. As the driver moves, it creates an area of pressure on one side of the cone and a partially evacuated area on the opposite side. Without an enclosure, the air pressure from one side will quickly move around the driver into the area of evacuation, causing cancellation. This is called acoustic short-circuiting and results in no driver output. It occurs when λ is greater than or equal to d, where λ is wavelength, and d is cone diameter.

Second, the mass of even the lightest loudspeaker cone is many times greater than the mass of an equal volume of air. This creates an inefficient condition because the driver has a difficult time transforming the moving system's mechanical energy to acoustic energy in the air. Some form of "loading" is, therefore, necessary. An enclosed ("trapped") volume of air on one side of the driver serves this purpose. It can take many forms, depending on driver design.

Figure 3 shows several enclosure types. *Figures 3a*–3c are simple enclosures intended to prevent acoustic short-circuiting. They are useful only down to a frequency where the front-to-back air path is approximately one-half the wavelength of the frequency produced.

Figure 3d is an infinite-baffle system, which is the simplest way of preventing acoustic short-circuiting. Unless the enclosure volume is very large, however, the air loading can be too great for some drivers. Certain heavy and compliant drivers specifically designed for this enclosure type make it very useful. In its more compact forms, it is referred to as an acoustic suspension system.

Figures 3e and *3g* are tuned by virtue of their ducts, or vents. They do not load the driver as heavily as an infinite-baffle enclosure, yet they have some advantages. First, by phase-inversion action, they can use the energy radiated by the back of the driver cone, making a more efficient system. Second, being tuned, they can be selectively made to load the driver. This is useful in suppressing the driver bass resonance and in reducing distortion.

Figures 3f and *3h* both function as long pipes, where the length of the pipe determines system tuning. Unlike the ducted, or vented, system, these require large enclosures. For proper action, the length of the pipe should be one-quarter wavelength at the driver resonance, which is typically 6 to 8 feet. Also, the pipe's cross-sectional area should not be less than the driver's cone area. *Figure 3h*, a transmission line enclosure, is a variant of the open pipe and is filled with acoustically absorbent material.

Finally, *Figs. 3i* and *3j* are horn enclosures. Their driver loading is very high over their working range, making them extremely efficient. This type of enclosure is commonly used in sound-reinforcement systems in large auditoriums. To be effective, they must be large, and the mouth's diameter must be about one-third wavelength of the lowest frequency to be reproduced. The horn's shape determines its length and the exact degree of loading on the driver. A general rule is the longer the horn, the better the loading in the bass. Long horns tend to inhibit high-frequency reproduction, though, so a multiway system, employing large bass horn(s) and smaller high-frequency horn(s), is usually necessary.

Properly matching a driver and enclosure requires knowledge of at least two factors—type of loading and efficiency required. Drivers using rather light, low-compliance cones are the best choice for tuned, resonance enclosures or if efficiency dictates, for a horn design. Because the driver's moving system is already very stiff, placing it in a sealed box will add more stiffness (due to the trapped air volume), which will generally restrict cone operation too much.

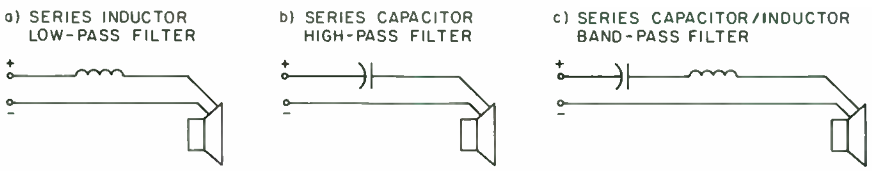


FIGURE 4: Networks for the various types of drivers. Fig. 4a shows a low-frequency speaker (woofer), Fig. 4b shows a high-frequency speaker (tweeter), and Fig. 4c shows a mid-frequency speaker (midrange).

Drivers with relatively massive cones, loose surrounds, spiders and long voice-coil windings work best with enclosures that provide heavy loading (small, tight air volumes). These are the infinite-baffle systems. In their most compact form, where enclosure volume is only a few cubic feet, these create the acoustic suspension system.

NETWORKS. As I mentioned before, good system design generally involves multiple drivers of different sizes and designs. In addition, a means of dividing the audio frequency spectrum into different ranges and feeding them to the proper driver is normally used. You can achieve frequency selectivity in two basic ways:

- driver or enclosure design;
- electrical filtering of the signal from the amplifier, before it reaches the driver.

You have several options for achieving mechanical (design) frequency limiting.

1. By controlling the ratio of cone mass to motor strength, you can limit high-frequency response.
2. Proper selection of cone material is another factor. Cones manufactured of "soft" material tend to be thick and cannot follow the rapid accelerations that are required to reproduce high frequencies. Therefore, the high-frequency response becomes limited. Conversely, small, thin, "hard" cones accelerate rapidly, thus providing the desired high-frequency reproduction.
3. By limiting the moving system motion, you can control bass response or eliminate it altogether. Small drivers also limit low-frequency response.
4. Enclosure design can limit frequency response. For example, if you use a horn enclosure, you can make the horn very long or the throat area very small to limit high-frequency response.
5. Material placed in front of the driver can control response. Fabric, certain types of foam and solid materials such as metal or wood are good mechanical means of frequency control.

The second way to achieve frequency selectivity is with electrical frequency limiting. You can do so with the aid of two basic electrical components—the capacitor and the inductor. First, you must understand the operation and effects of these components. A capacitor is an electrical device for storing electrical *charge*. The higher the capacitance is, the greater the charge-storage capability. An inductor is an electrical device for storing electrical *energy*. The higher the inductance is, the greater the energy-storage capability.

Capacitors and inductors have a common property: they are both frequency-selective devices. They selectively resist a flow of alternating current, which means that their resistance changes with frequency. When a device possesses this property, we say it is reactive, or has reactance. The reactance value for a capacitor is approximately proportional to 1/f, while the reactance value of an inductor is approximately proportional to f, where f is frequency. Notice that one is the inverse of the other—i.e., the capacitor reactance goes down as the frequency rises, while the inductor reactance goes up as the frequency rises. This property allows the design of circuits with an electrical filtering action.

For example, a driver to be used only for low frequencies (a woofer) might have an inductor connected to it. As the frequency rises, so does the reactance value, reducing the higher frequencies. An inductor used in this manner is called a low-pass filter (*Fig. 4a*).

Another example is a driver to be used only for high frequencies (a tweeter). Connecting a capacitor to the driver will allow high frequencies to pass. As the frequencies go down, however, the reactance rises, reducing the lower frequencies. A capacitor used in this manner is called a high-pass filter (*Fig. 4b*).

Finally, you can design a driver requiring both capacitance and inductance. Assume the driver is specially designed to reproduce only a small range of frequencies in the middle of the sound range. Connecting capacitance and inductance to the driver will cause a reduction of both the higher and lower frequencies, leaving only the middle range to be reproduced. A capacitor and inductor used together in this manner is a band-pass filter (*Fig. 4c*).

In practical loudspeaker systems, various combinations of capacitance and inductance are used. A two-way system (one driver for bass, one for high frequencies) uses an appropriate capacitor and inductor for the drivers. You would choose capacitor and inductor values so that the frequency ranges of the two drivers would just meet. Obviously, if the two values were not correct, a gap or overlap in the ranges would occur. This would cause irregularities in sound reproduction.

Another component sometimes found in the electrical system of a loudspeaker system is the resistor. In systems designed for general use, where the designer does not have control over the listening room, it is common to put a resistor in the filter network to one or more of the drivers. The resistor value will usually be variable, either with a rotary adjustment or a switch that selects one of several resistors or fixed values. In either case, this allows adjustment of the driver sound level, which in turn allows adjustment of the tonal balance.

These three components—the capacitor, inductor and resistor—make up a *passive crossover network*. An alternate method of providing frequency-selective signals to each of the drivers is to use the inductors and capacitors in an electronic circuit immediately preceding an individual amplifier. That amplifier is then directly connected to a specific driver. This arrangement is referred to as an *active crossover network*, requiring a separate amplifier channel for each driver.

I hope this has given you a better understanding of how your speaker system produces the sound you enjoy so much. Now just sit back and listen to the music, and when the music doesn't sound just right, you might have some clue to the cause. ☐

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Part II

A VISIT WITH TED JORDAN

BY BRUCE EDGAR
Contributing Editor

Last time, Mr. Jordan described his work at Goodmans Industries and his early efforts in speaker design.

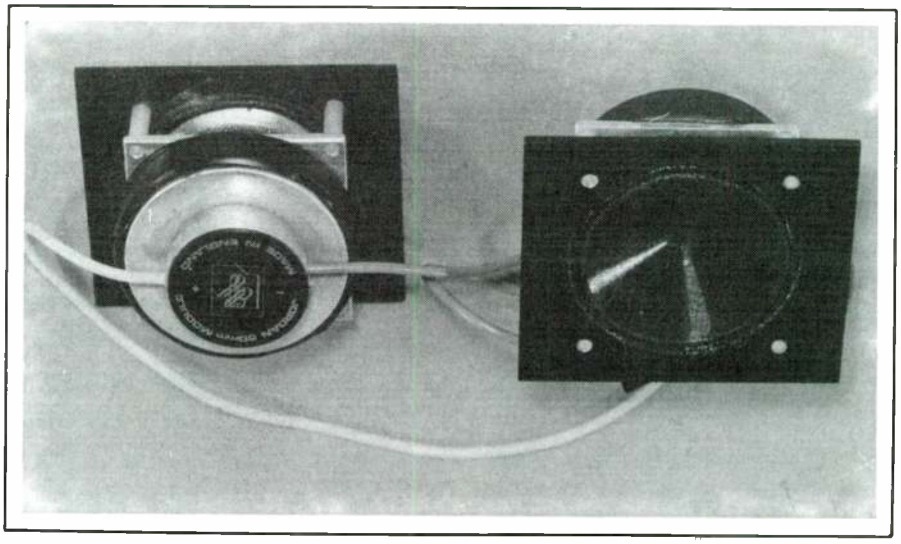

FIGURE 5: The Jordan 50mm Module. The specifications are as follows: frequency range, 100Hz to 22kHz, ±3dB on axis; power rating, 20W (above 200Hz); recommended back volume, 1.5 liters, or 96 cubic inches.

SB: *How did your 50mm modules (*Fig. 5*) evolve?*

TJ: Now that I had production experience—the nuts and bolts of putting a company together—I decided to run my own company. I started from the top end and worked down through the audio spectrum. I worked on the cone—its angle and material—and went right through to the coil. I did a lot of design and experimental work, but the best results for top and midrange were with a 50mm diameter. It gave me the distribution pattern I wanted.

SB: *How was the Jordan 50mm Module first sold?*

TJ: First I made some for myself. Then my friends heard and liked them, so I made some for them. Within 18 months, we were selling them in Australia and had made 1,500 units. We do very little in the way of advertising. We don't have a big market and have expanded very slowly, but that suits me. I'm basically very lazy: I don't want to be the head of a vast organization.

SB: *How are the modules made? I don't see a big factory.*

TJ: There isn't one. They are all handmade by six very experienced and trustworthy women from my neighborhood. It's a cottage industry. They are made on the kitchen table, in the garage, in the workshop.

SB: *What are your production levels?*

TJ: We have always built to order, so we never have much stock on hand. I suppose we average several hundred a month. If we were asked to produce 1,000 per month, we could do it. We are very flexible with low overhead.

SB: *How do you make your surround?*

TJ: That's complicated because each one is handmade. We start off with a basic gauze, which you see on the front of the module. Then we put on several layers of a coating material that we developed ourselves. The surround is very stable, and our reject rate is two out of 1,000.

SB: *Do you maintain very high quality control over the cones?*

TJ: Yes. The cone is foil, which is a very stable, consistent material. Unlike paper and plastics, it is unaffected by temperature variations, so it tends to maintain a far closer standard of stability than most other materials. We also use very good adhesives, which is one thing you have to understand in loudspeaker engineering.

The cone is straight-sided. If we put a curve in it, we could probably get a better response curve, but I do not believe the frequency response curve is important. I have heard many speakers with flat response curves sound really appalling. What *is* important is the pulse response (*Fig. 6*).

If you compare a loudspeaker to a pickup cartridge, you will find the same problems and the same solutions. You are talking about trackability, which I consider the most important feature. A cartridge has to track complex waveforms in the groove. The loudspeaker radiating surface has to track the complex electrical waveform coming into the voice coil. Just as with a cartridge, a flat frequency response says nothing about a speaker's trackability.

We published a pulse response seven years ago, and since then nobody has published a loudspeaker pulse response, despite computer design and related technology. Our response curve in a room is not perfectly flat, but it is pretty flat. The coloration is extremely low. The distortion is very low—about 0.3 percent over most of the band.

SB: *What have you achieved with the Jordan Module?*

TJ: I have achieved a sound I like, which approaches the sound I hear in a concert hall. This is the old-fashioned concept of high fidelity. In addition, I have avoided complexity of design. My system introduces a minimum number of components between the amplifier and the air. If you could connect my amplifier terminals straight through to the air load, you would have the perfect loudspeaker.

Every kind of distortion is due to electrical and mechanical components. The basic components are the mass of the cone, the stiffness in the suspension, and the inductances and capacitances of the crossover. All of these introduce distortion. Mass itself does not introduce distortion, but the suspension's compliance can because it is nonlinear. It is very difficult to make a linear suspension system, but I think we have done as good a job as is possible with the 50mm module. Still, it has nonlinearities throughout.

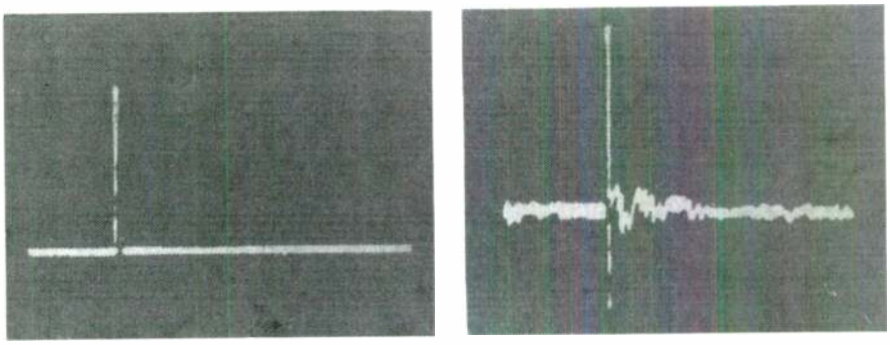
FIGURE 6: The pulse response of the Jordan Module. The pulse width is 50μsec, and the pulse repetition frequency is 700Hz. The input is on the left, while the output is on the right.

SB: *What about your cone's mass?*

TJ: We start by making the cone as light as possible. If we made it any thinner, it would go to pieces during loud passages. We keep the mass to an absolute minimum.

SB: *But you keep a certain rigidity, too?*

TJ: Yes. The favorite chestnut bandied around by loudspeaker designers is that the cone must be rigid. The ideal would be a perfectly rigid cone, but such a cone is not possible. If you had a perfectly rigid cone, it would operate only up to the point where it meets the knee of the radiation resistance curve (*Fig. 7*). The radiation resistance curve has two parts: in the lower piston range, it rises in a linear manner; in the upper range, it flattens out. If you have a mass-controlled cone, it will give you a linear pressure wave right up the sloping part of the curve.

Once you get up to the knee and go beyond where (k × r) equals 2, two things happen. First, because the cone is mass controlled, the output will fall dramatically. Second, since the cone will maintain its full radiation area, its polar distribution will become pencil thin. This would make a lousy loudspeaker. Fortunately, nature has saved us from ourselves by providing no perfectly rigid material.

SB: *So you think that some materials, such as berylium, used in exotic diaphragms to obtain rigidity are way off base?*

TJ: Yes, I do. As I said, no material on earth is infinitely rigid. If you have a radiating surface of, say, 1 inch in diameter, somewhere in the mid-kilohertz region, that diaphragm is going to stop being rigid. If you try to maintain the rigidity beyond the knee in the radiation curve, you are going to have problems in directivity and a fall-off in response.

SB: *What happens to the cone when you get to the flat portion of the radiation resistance curve?*

TJ: It breaks up. It flexes. You do everything you can to work with it and control the flexing. Any cone can go into some sharp resonances, and even my alloy cone can have some very high Q resonances. But the question is how to apply the correct damping in the correct place.

Consider a transmission line. The correct place to terminate a transmission line is at the end with its characteristic impedance. If you get the impedance terms right, your reflections are gone. You don't spread resistances through it in a haphazard way—that's not the way to handle it. If you consider that the coil produces impulses that travel along the cone material to the edge, you must terminate the edge with a surround that presents, as nearly as possible, the correct characteristic impedance. It's virtually impossible to do so perfectly, but you can do it well.

The surround should do so many things. You would like it to be perfectly rigid as far as back pressures from the enclosure are concerned. You would like it to be infinitely flexible as far as cone movement is concerned. And you would like the surround to be properly resistive as far as correct termination is concerned.

SB: *How do you damp out the high Q resonances in the alloy cone?*

TJ: Let me use an analogy. When you tap a wine glass with your finger, it rings nicely. On the other hand, when you tap a plastic beaker, which is a lossy low-Q material, it goes "thunk." It doesn't ring. If you take the wine glass and place your thumb on the rim, the ring changes to a colorless tick. If you hold the plastic beaker and tap it, the sound has a distinct color no matter where you hold or tap it. The point is that it is far easier to eliminate high Q resonances completely by correct termination than it is to eliminate low Q resonances. The analogy holds for loudspeaker cones.

SB: *What other characteristics should a cone have?*

TJ: A loudspeaker cone needs the ability to restore. The cone is going to flex, so if you hit it with a pulse, it will create an acoustical pulse. At that point, the cone becomes momentarily deformed from the mechanical force, and it has to restore as fast as it can because the next pulse is coming fast behind it. If the cone hangs about, you have what I call hysteresis distortion. As you can see, restoration speed is vital, and none of the plastics have a quick restoration speed. If you squeeze the plastic beaker into an eliptical shape, it will take ten minutes to resume its original shape.

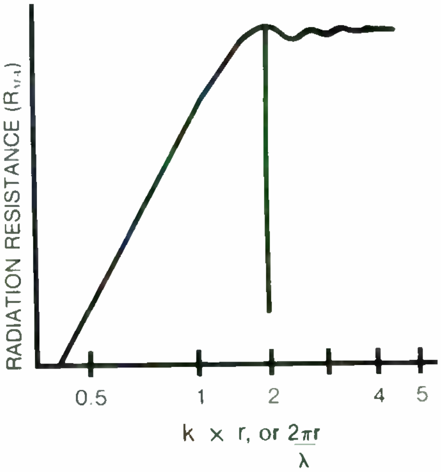

FIGURE 7: The radiation resistance curve for a flat circular piston. A speaker operates in the mass-controlled region until it reaches a frequency whose wavelength (λ) is equal to the circumference of the piston. Note: for non-physicists, k is the wave number, which equals $2\pi/\lambda$.

SB: *Something you haven't mentioned is magnet design. Are you content to use conventional magnets?*

TJ: As far as the loudspeaker is concerned, all it knows is that the coil is immersed in a magnetic field.

SB: *But you have not gone to high-flux magnets to aid transient response?*

TJ: No, I haven't. I disagree with the Lowther and Voigt design concept, which says that the flux should be as high as possible. I agree with most of Voigt's principles, but not that one. The magnet-coil system can be regarded as a transformer. It is an electromechanical transformer, but it has impedance-matching properties, as in a normal transformer. This becomes apparent at the bottom end around the resonant frequency.

Now, we all know that if we can measure the free air resonance of a loudspeaker, it will have a measurable Q. With a small magnet—one with low flux density—the speaker will have a Q greater than one. With a large magnet, it will have a Q less than one. We don't want a Q greater than one because it will produce boom in the bass. I'm assuming the loudspeaker is mounted in an infinite, or flat, baffle, not a box.

Is there any point in making Q less than unity? Some people say that doing so improves the transient response. I disagree. All it gives you is very expensive bass cut. People talk about bass transients, treble transients, and so on. A transient is a transient. It is a burst of broad-banded energy lasting for a short period of time. A loudspeaker splits the transient pulse into the various bands of operation. At very high frequencies, if the cone has to ring, it will ring. At low frequencies, if the cone has to flap about in resonance, it will do that. The magnet cannot possibly damp the high-frequency transient because the cone is into its breakup region, and the electromagnetic damping is negligible.

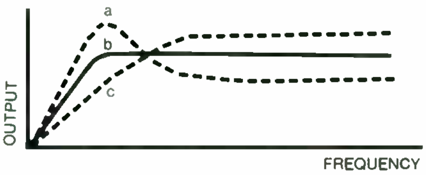

FIGURE 8: Response curve variations as B1 (flux density) is increased from Curve a to Curve c.

You have the surround looking after the high frequencies. What kind of damping would you have to put on the coil end to produce the right characteristic impedance down there? You might try all types of dopes, but the magnetic flux is not going to have any effect on the high-frequency transients. Once you have Q down to unity—and therefore have virtually zero overhang—what is the point of having high-flux magnets when all you get is bass cut?

If you have unity Q, you have Curve a in *Fig. 8*. If you have a smaller magnet and a Q greater than 1, the efficiency at midband goes down, but at resonance the efficiency goes up. With a large magnet, the inverse happens. What you have as you vary flux density is not an absolute increase or decrease of efficiency.

SB: *How does the efficiency of the 50mm module compare to other speakers?*

TJ: The efficiency was chosen to match average bass units. Several people from the States have asked me whether I could make it more efficient. A few others have said that they have had to fit L-pads on to cut down the efficiency. I figure I have it about right.

SB: *Describe the 50mm module's rear suspension.*

TJ: The rear suspension is an unusual feature. The module has a lightweight cone, and part of my exercise was to see how far down I could make the frequency go, bearing in mind the miniature speaker system I developed for Goodmans. This meant making the highest compliance and most linear suspension I could obtain. Instead of using a bit of corrugated rag behind the cone, I have a microtube that passes right through the magnet and the back and attaches to the center of a membrane.

SB: *What's a microtube?*

TJ: It's like the tube used in a pickup cartridge cantilever. It has a low mass and is very rigid. It is 2mm in diameter, which is somewhat larger than a pickup cantilever, and is specially made for us. You can pull out our diaphragm at least 4mm. The displacement runs at ±4–5mm, and the design travel is 1mm. You can see that the rear suspension is highly linear, and the compliance is very high. The low mass and high compliance result in high trackability.

SB: *But you sacrifice bass response.*

TJ: Yes, I wasn't able to do the whole range. For it to go down to 20Hz, it would require an excursion of ±6 inches. My unit crosses over at 150Hz. By that frequency, it is out of the trouble area because it is past the region where coloration, phase and transients are important.

SB: *I notice that in some of your designs, you have a vertical array of modules.* (See *Fig. 1* of Mr. Edgar's sidebar to the Hirsch article in *SB* 2/84, p. 12.—Ed.) *What does that do for you?*

TJ: It develops a better stereo image than we could have achieved by any other means. Once again, it's nothing new. Loudspeaker manufacturers strive for a wide distribution. All of the loudspeakers that have an all-around distribution, such as the upward-facing reflector type, do not produce a good stereo image. They were great for mono, which is exactly what you could have predicted from basic theory. The reasons are as follows.

Take two loudspeakers that have a wide distribution, which presupposes a spherical wavefront. The pressure wave that you hear is inversely proportional to the distance squared between you and the speaker. Therefore, if you move halfway toward one, square law says that you get four times the sound from one speaker and a quarter from the other. Arithmetically, that's probably not quite correct, but you can see the principle. The moment you come off center, you get this tremendous image shift. Stereophonic perception is not just a question of intensity. It also concerns time of arrival, phase, shadowing effects, and so on.

Take intensity, for example. If you put the loudspeakers into a vertical array, your wavefront approaches a cylindrical front instead of a spherical front. the intensity is now proportional to distance rather than distance squared. So you immediately cut down on the intensity jump. I have found that if you space them slightly apart in an array, the image is gone. If you curve them, it is gone again. You can't put it into words, but the solidity of the sound vanishes. The speakers must be in phase and placed as close to each other as possible to achieve that coherency of sound.

SB: *You now have an amplifier (*Fig. 9*) on the market. Can you tell us how you went from speakers to amps?*

TJ: After I began producing the 50mm modules, I decided I needed a very good amplifier. I listened to all the "very good amplifiers," and I was shocked to find that at ten times the price, they did not sound any better than my little 15W amp.

SB: *What is the reason for the "bad" amps?*

TJ: Circuit design. This goes back to my fundamental principle of sticking to an uncomplicated design. When I look at most amplifier circuits, I can count 48 or more transistors and hundreds of resistors and capacitors. I don't understand what all those are for. When I design an amplifier, I design the best output stage I can make. Then I design the driver stage and so on all the way back to the input. Each stage can stand on its own as an operational low-distortion, quality stage. Then I add a touch of overall feedback, and the job is done. It is simple and very economical in components. My little amplifier has six stages between the pickup and the loudspeaker.

Each stage in conventional amplifier design depends on the stage before and the stage after for its DC conditions. Designers put in zener diodes to hold conditions constant. If you design an amplifier stage correctly, the DC conditions will be stable without zeners. The performance will be very wideband, and the distortion can be very low.

That's the approach I took with my little amp. It will out-perform most expensive amps in terms of detail and quality. I

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KC-4A: ELECTRONIC CROSSOVER, KIT A. [2:72] Single channel, 2-way. All parts including C-4 board and LF351 IC's. Choose frequency of 60, 120, 240, 480, 1k, 2k, 5k or 10k. Each $8.00

KC-4B: ELECTRONIC CROSSOVER, KIT B. [2:72] Single channel, 3-way. All parts including C-4 board & LF351 IC's. Choose frequency of 60, 120, 240, 480, 1k, 2k, 5k or 10k. Each $11.00

● **KF-7: CROSSOVER FOR WEBB TLS.** [1:75] Passive 4-way x-over, in pairs, assembled. Components are included for both STC and Celestion tweeters. Made by Falcon of England. CLOSEOUT Pair $50.00

KK-6L: WALDRON TUBE CROSSOVER LOW PASS: Single channel, 18dB/octave, Butterworth, [3:79] includes Bourns 3-gang pot. Choose 1: 19-210; 43-465; 88-960; 190-2100; 430-4650; 880-9600; 1900-21,000 Hz. Each $43.00

KK-6H: WALDRON TUBE CROSSOVER HIGH PASS: Single channel, 18dB/octave, Butterworth, [3:79] includes Bourns 3-gang pot. Please specify 1 of the frequencies in KK-6L. No other can be supplied. Each $45.00

KK-6S: SWITCH OPTION. 6-pole, 5-pos. rotary switch, shorting, for up to 5 frequency choices per single channel. Each $8.00; ordered with 2 kits above, Each $7.00

KK-7: WALDRON TUBE CROSSOVER POWER SUPPLY. [3:79] Includes board, x-fmr, fuse, semiconductors, line cord, capacitors to power 4 tube x-over boards (8 tubes), 1 stereo biamped circuit. Each $88.00

SBK-A1: LINKWITZ CROSSOVER/FILTER. [SB 4:80] 3-way x-over/filter/delay. 24dB/octave at 100Hz and 1.5kHz and 12dB/octave below 30Hz, with delayed woofer turn-on. Use the Sulzer supply KL-4A with KL-4B or KL-4C. Per channel $64.00 Two channels $120.00 SBK Board only $14.00

SBK-CIA: JUNG ELECTRONIC 2-WAY CROSSOVER. [SB 3:82] 30Hz filter with WJ-3 board & 4136 IC adapted as 1 channel x-over. Can be 6, 12 or 18dB/octave. Choose frequency of 60, 120, 250, 500, 1k, 2k, 5k or 10k. Each $24.75

SBK-C1B: THREE WAY, SINGLE CHANNEL CROSSOVER. [SB 3:82] Contains 2 each SBK-C1A. Choose high & low frequency. Each $49.70

SBK-C1C: TWO CHANNEL, COMMON BASS CROSSOVER. [SB 3:82] Contains 2 each SBK-C1A. Choose 1 frequency. Each $49.70

SBK-C2: BALLARD ACTIVE CROSSOVER. [SB 3:82 & 4:82] 3-way x-over with variable phase correction for precise alignment. Kit includes PC board (5⅜ x 9½"), precision resistors, polystyrene & polypropylene caps. Requires ±15V DC power supply—not included. Can use KL-4A with KL-4B or C. Two channel $134.00

AIDS & TEST EQUIPMENT

KH-7: GLOECKLER PRECISION 101dB ATTENUATOR. [4:77] All switches, 1% metal film and 5% carbon film resistors to build prototype. Chassis, input/output jacks are not included. Each $50.00

KL-3C: INVERSE RIAA NETWORK COMPLETE. [1:80] 1 KL-3R and 1 KL-3H with 1% polystyrene capacitors. Alternate 600 ohm or 900 ohm R_2'/C_2' components for 2 channels. Each $35.00

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

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

KF-4: SINE-SQUARE AUDIO GENERATOR. [4:75] Morrey's MOD kit for Heath IG-18 (IG5218). 2 boards and parts to modify the unit to distortion levels of parts per million range. Each $35.00

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

KJ-6: CAPACITOR CHECKER. [4:78] All switches, IC's, resistors, 4½" D'Arsonval meter, x-fmr and PC board to measure capacitance, leakage and insulation. Each $78.00

KK-3: THE WARBLER OSCILLATOR. [1:79] Switches, IC's, x-fmr and PC board for checking room response and speaker performance w/o anechoic chamber. Each $56.00

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

KM-1: CARLSTROM-MULLER SORCERER'S APPRENTICE [2:81] 4 boards and all parts for construction of the first half of a swept function generator with power supply. No knobs or chassis. Each $145.00

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

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

SBK-D2 WITTENBREDER AUDIO PULSE GENERATOR. [SB 2:83] All parts, board, pots, power cord, switches and power supply included. Each $70.00

SYSTEM ACCESSORIES

KH-8: MORREY SUPER BUFFER. [4:77] All parts, 1% metal film resistors, NE531 IC's, and PC board for 2 channel output buffer. Each $14.00

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

KJ-3: TV SOUND TAKEOFF. [2:78]. Circuit board, vol. control, coils, IC, co-ax cable (1 ft.) and all parts including power x-fmr. Each $21.50

● **KJ-4: AUDIO ACTIVATED POWER SWITCH.** [3:78] Turn your power amps on and off with the sound feed from your preamp. Includes all parts except box and input/output jacks. CLOSEOUT Each $35.00

● **KK-14A: MacARTHUR LED POWER METER.** [4:79] 2-channel, 2-sided board and all parts except switches, knobs, and mounting clips for LEDs. LEDs are included. No chassis or panel. CLOSEOUT Each $60.00

● **KK-14B: MacARTHUR LED POWER METER.** [4:79] As above but complete with all parts except chassis or panel. CLOSEOUT Each $70.00

SBK-D1: NEWCOMB PEAK POWER INDICATOR. [SB 1:83] All parts & board. No power supply required. Two for $10.00 Each $6.00

SBK-E2: NEWCOMB NEW PEAK POWER INDICATOR. [SB 2:84] All parts & board, new multicolor bar graph display; red, green & yellow LED's for 1 channel. No power supply needed. Two for $15.00 Each $9.00

KC-5: GLOECKLER 23 POSITION LEVEL CONTROL. [2:72] All metal film resistors, shorting rotary switch & 2 boards for a 2 channel, 2dB per step attenuator. Choose 10k or 250k ohms. Each $36.75

KR-1: GLOECKLER STEPUP MOVING COIL TRANSFORMER. [2:83] X-fmrs., Bud Box, gold connectors, & interconnect cable for stereo. Each $335.00

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

● **CLOSEOUT: KITS NOT AVAILABLE AFTER PRESENT STOCK IS GONE.**

What's Included? Kits include all the parts needed to make a functioning circuit, such as circuit boards, semiconductors, resistors and capacitors. Power supplies are not included in most cases. Unlike kits by Heath, Dyna and others, the enclosure, face plate, knobs, hookup wire, line cord, patch cords and similar parts are not included. Step by step instructions usually are not included, but the articles in ***Audio Amateur*** and ***Speaker Builder*** are helpful guides. Article reprints are included with the kits. Our aim is to get you started with the basic parts—some of which are often difficult to find—and let you have the satisfaction and pride of finishing your unit in your own way.

FIGURE 9: The new Jordan amplifier system. It features two power supplies—one for the output stages and the other for the driver and preamp stages. It is rated at 60W into 8Ω.

have taken the same approach in designing my new amplifier. It can't go wrong because I have used power MOSFETs, which have very low turn-on resistances. MOSFETs have problems, but they can be tamed.

SB: *What are the problems with power MOSFETs?*
TJ: Instability (high-frequency oscillations) is the main one. One way to fix that is to put a small inductor in series with the loudspeaker line and a capacitor and resistor to ground. I didn't want any extra stuff in my loudspeaker line, though, so I put the right loss in the right part of the circuit and not in the line.

SB: *What features does your new amplifier have?*
TJ: The output stage is a pair of MOSFETs operating in class AB. They are so simple—you can drive them at 1 percent distortion at full output with no negative feedback. Their input impedance is extremely high, so the driver stage has hardly any work to do. I put a voltage amplifier stage in front of that to get from the 1V input. Three stages is all you need.

The preamp section takes the same approach using bipolar devices. There are no problems in the mid preamp stages. I left out tone controls altogether, as I don't think they are necessary.

The pickup preamp stage is a bit tricky. We have to cater to moving-coil cartridges, as the industry has opted for magnetic or moving-coil input. I have one input for pickup cartridges. A gain control for the input stage adapts itself to whatever cartridge you use.

SB: *What do you do about equalization?*
TJ: It is passive, since I believe that active phono equalization contributes to the loss of detail. Passive equalization also means that you must amplify to a large voltage swing and then attenuate it again.

SB: *Don't you have to be careful that the stage doesn't clip?*
TJ: That's right. I ended up with a design that has phenomenal head room and very low noise. The fact that it has a gain control on the input means that you can adjust between overload and the noise floor and get the optimum for any pickup cartridge.

SB: *Where do you see loudspeaker design headed?*
TJ: Going back to basics, we require electrical energy to be converted into acoustical energy. Can we do this directly? Yes. Finding out how is the future of speaker design. There was a thing called the Ionophone. We know all about it and its problems. I even thought out an electrochemical system. You float a copper sheet on a solution of copper sulfate and then apply AC. The polarity changes deposits or takes off copper sulfate, thereby changing the mass of the copper foil. It is totally inefficient, but it's on the same track. Another possibility is the piezoelectric system, which might be developed further. The problem is that it is basically capacitive and tends to be nonlinear in displacement, which restricts it to the higher ranges.

SB: *Do you have any objections to piezoelectric tweeters?*
TJ: I have objections to tweeters, period. People write and ask, "Should I use a supertweeter with your module?" I have absolutely no commercial interest in putting down supertweeters, but they contain a crossover in the tricky region I try to avoid. I don't know of any tweeter—including the ribbon variety—at any price that can out-perform my module in pulse trackability and low distortion.

SB: *What problems does the ribbon tweeter have?*
TJ: The distortion is higher, and the pulse response is certainly no better. I suppose part of that is due to the transformer in the ribbon. The electrostatic ought to be better, pulse-wise, but in practice it isn't because of the transformer and the nasty capacitive load.

SB: *What about moving-coil speakers?*
TJ: The moving-coil loudspeaker is a very linear device if it is designed properly. I can't see anything replacing it for quite a while. Indeed, why should we replace it if it works?

SB: *Can we look forward to more improvements in your module?*
TJ: If I were a proper engineer, I wouldn't have produced the 50mm module for so long without changes. I won't say that it is the finest loudspeaker on the market, even though I have received a lot of letters telling me that it is. It doesn't seem to have much competition at the moment, so we will let it ride. If someone writes to tell me about a unit like mine, only better, we will have Mark II out the door tomorrow.

To obtain more information about the Jordan 50mm Module, write to [Lindenfels] Spurgrove, Freith, Henley-on-Thames, Oxon, England.

ACKNOWLEDGMENTS

I want to thank C.J. Pyper and Rex Baldock for supplying background material on Mr. Jordan and Manfred Buechler and Joe Paul for photographic help.

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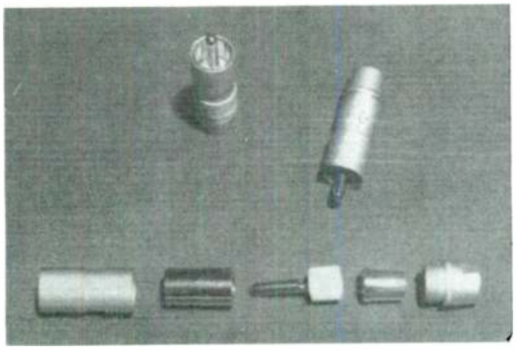

Our new ROYCE RCA-type audio plugs are custom made for Old Colony. They are fabricated from brass with heavy 14K gold plate on all working surfaces and insulated with Teflon®. The outer shell's screw-in top and bottom segments are nickel plated, dull finish. The plugs consist of five parts. The signal pin is a solid brass piece, drilled out at the solder end to accept the signal wire with a cross-drilled hole to confirm a good solder joint. The pin is knurled and force-mounted in a thick Teflon insulating sleeve, which slides into a separate gold-plated grounding skirt which in turn fits inside the threaded outer shell. A smaller flanged gold-plated crown is then inserted into the shell to compress the shield and/or ground wires down against the ground skirt. A threaded top screws into the outer shell to hold the five units together. The crown, whose inner diameter is 0.240 inch, fits over the signal wire's outer insulation. When the shield and ground wires are free, they are fanned upward around the crown and trimmed off just below the top of it. After the shielded center wire is soldered to the center pin, the top may be screwed down to form a solid, strong compression junction between the crown and the skirt. This makes a virtually unbreakable connection, which is far more rugged and dependable than the conventional soldered joint. The Royce plugs will accept Mogami Neglex 2534 audio cables and others up to 0.230 inch in diameter. The Royce plugs come in color-coded pairs (red and white) only. Pair **$9.50.** Two or more pairs **$8.00** pair.

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The most outstanding feature of the Royce jacks is that they mate gracefully with the Royce plug. When plugged together, the Royce units make their sleeve (shield and/or ground) connection prior to the inner pin connection and break that inner pin contact before the sleeve disconnects. Neither the jacks nor the plugs will work in this fashion with ordinary RCA hardware. Our Royce plugs work in this way with the Tiffany jack, but the Tiffany plug does not work with the Royce jack.

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Tools, Tips & Techniques

Improved Impedance Measurement

Perhaps you are using David Weems' Impedance Measurement Method I, as outlined on page 168 of his popular book, *Designing, Building and Testing Your Own Speaker System.* If you are also using a digital VOM (volt-ohmmeter) that starts rolling off at the higher frequencies, you can compensate for the error produced by the VOM's roll-off by repeating the 10Ω precision resistor calibration step each time you change the frequency.

If you are willing to recalibrate each time you change the frequency, you might as well make the following change as well:

1. Measure the precise value of the "500Ω" series resistor.
2. Connect the speaker and the signal generator.
3. With the voltmeter connected across the "500Ω" resistor, adjust the input voltage so that the voltmeter reads 0.001 times the exact value of the "500Ω" resistor.
4. Connect the voltmeter across the speaker and read in millivolts. The millivolt value is numerically equal to the speaker impedance.

This change improves the inherent accuracy of Method I because you have set the circuit current of 0.001A with the actual impedance measured in the circuit. In contrast, with Method I as Weems outlines it, the current value is set when the 10Ω resistor, rather than the speaker, is in the circuit. The change will introduce error to the extent that the circuit current changes when you substitute the speaker impedance for the 10Ω resistor.

David J. Meraner
Scotia, NY 12302

Innovative Electret

The polarizing voltage necessary for an electrostatic loudspeaker (ESL) is usually provided by a separate power supply, which includes a transformer, rectifiers and capacitors. The alternative is to use an electret for the diaphragm. An electret is a material that retains a permanent charge, but has no external voltage source. I am not aware of any electret loudspeakers on the market, although AKG does use electrets in its earphones.

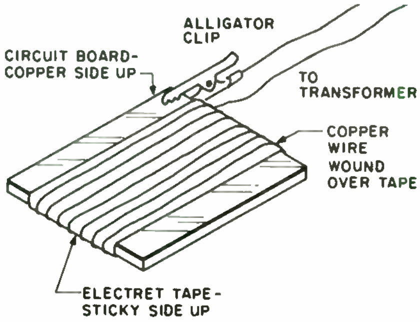


FIGURE 1: This first arrangement produced acceptable results, but suffered from low efficiency.

The main thing that has prevented amateur speaker builders from experimenting with electrets is lack of availability. No longer is that a problem. A plastic film with a permanent charge is available in every hardware store in the country. I discovered this quite by accident when I was building my electrostatic tweeters and was experimenting with various diaphragm materials.

3M makes Scotch-brand plastic package-wrapping tape, which has a negative charge roughly equivalent to an 800V polarizing voltage. This Mylar tape has a brown dye in the glue to make it look like the old-fashioned paper tape traditionally used for wrapping packages. I have also tried some clear versions of the tape, which have the same charge.

Finding out why this tape is polarized took a bit of research. The plastic film is formed by a "web process," in which the molten plastic is formed and carried off by a system of rollers. To make the film stick to the rollers, the molten plastic is given an electrical charge. As it cools, the charge is embedded in the plastic, seemingly forever. I have tested samples of tape more than two years old that have held as much charge as fresh samples.

I have also tried to remove the glue with kerosene and paint thinner. Kerosene does the trick, but is messy and dangerous.

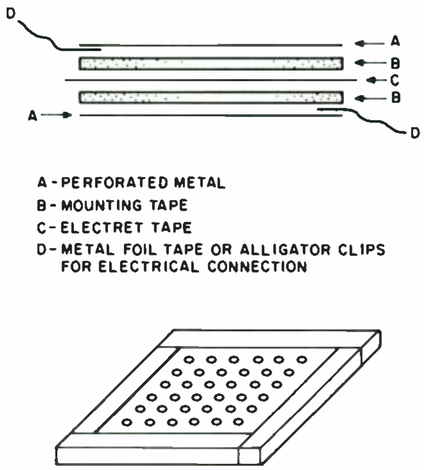


FIGURE 2: A side view (above) of the push-pull electret configuration shows how the materials are stacked. Mr. Kaufman used mounting tape along the edges of the perforated metal (bottom).

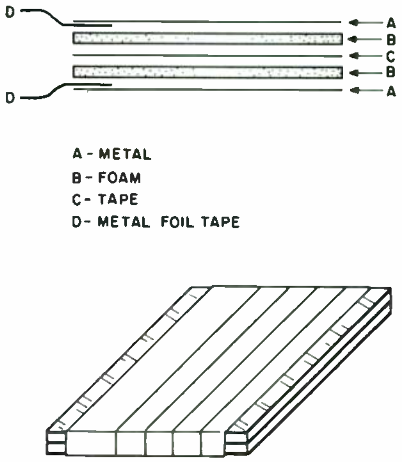


FIGURE 3: Instead of using mounting tape for each segment of electret tape, the author substituted layers of urethane foam filters (top). Here he shows the placement of the tape on the filters (bottom).

Paint thinner also works, but it requires much rubbing and tends to deform the tape. I have determined that it is best to leave the glue on.

In my first experiment (*Fig. 1*), I inserted the tape between two 3-inch-square sheets of perforated metal. For spacers, I used ½-inch-wide mounting tape, a double-sided urethane foam tape that is 1/16 inch thick. Alligator clips provided the electrical connections. I obtained good results with this method, but the efficiency was rather low. I then found the Acro A-3311, a transformer with a higher step-up ratio (50:1). This unit will not take a high enough voltage in the secondary without arcing, so I am experimenting with some toroidal transformers that have a 140:1 step-up ratio.

My second approach was to increase the area of the transducer (*Fig. 2*). I found some 10-by-14-inch perforated metal sheets, which work quite well. While I could have used the same method of construction as I did for the smaller unit—i.e., a row of mounting tape for each segment of electret tape—this seemed too tedious. Instead, I used urethane foam air-conditioned filters (*Fig. 3*). I applied the tape in rows, overlapping about 1/16 inch, completely covering the filter. I then placed a second filter on top of the tape and sandwiched the whole thing between the metal plates. I applied metal burglar-alarm tape (the type used on windows) to the metal sheets to make the electrical connections. (This tape is available through Radio Shack.) Fiberglass strapping tape holds the whole unit together.

The sound quality of this speaker rivals that of an ESL, extending from 300Hz to at least 20kHz. It plays louder than the smaller unit, but still needs a different transformer to be used in a high-fidelity system. Efficiency is comparable to a straight ESL I tried several years ago in a similar configuration with the same transformer.

Richard Kaufman
New York, NY 10025

Routing Unusual Speaker Openings

Routing a speaker opening for a driver that is not round can be a problem. This is usually done freehand with a straight-faced router bit, and the results are frequently less than ideal. It is possible to trace the outline of the driver on paper and then reduce the outline by the necessary percentage so that you can use a rabbet router bit. The only reduction methods previously available were either a photo enlarger/reducer or a camera plate processor such as an Itek or a 3M MR-412/415. Both of these methods require wet developing and tend to be expensive.

A new Xerox copier might be the solution. The Xerox Model 2080 is a large, floor-standing machine that can copy on vellum or bond paper. This $100,000 copier can handle masters 36 inches wide by 500 *feet* long and can print copies up to 24 inches wide and just as long. Best of all, it has a reducing/enlarging capacity of 44 to 142 percent in one pass, in 1 percent steps. Many blueprint companies are now using this copier, and the single copy prices are quite reasonable. In the Austin area, vellum costs $1.35 per square foot, while bond goes for 10¢ per linear inch. Thus, the cost of reducing the outline of a 5-inch Dalesford or Peerless driver on bond paper should be close to 50¢, minimum charges notwithstanding.

Keep the reduced outline of your driver as a master. Make as many full-size copies of the master as required, glue each copy onto a piece of cardboard and cut it out. Using the outer piece of cardboard as a template, draw a reduced outline onto the front of your baffle board. Carefully cut this out with a jig saw, then rout with a rabbet bit. Your driver will now fit on the front of the baffle board with the magnet outside the enclosure. The driver's magnet and/or frame will undoubtedly be larger than the unrouted portion of the opening, however, thus preventing a mounting with the magnet inside the enclosure.

To solve this problem, find the proper size and shape opening that will clear all of the driver except the mounting lip. Glue a drawing of this opening on cardboard, cut it out and mark this shape on the back of the baffle board. Cut this out with a jig saw. Your driver should now fit flush. Be sure to measure the depth of this routing carefully before using the jig saw a second time, or you will have to rout a new depth freehand with a straight-faced bit.

Steve Ball
Austin, TX 78745

SOMETHING NEW

Lots of magazines—most of them, in fact—offer readers special information services for products mentioned in news columns and advertisements. Usually only large magazines offer such services. We think we are one of the first small publishers to do so—and on our own computer.

But we need your help to make it all work. Remember to write your subscriber number (what we are calling your "magic number") on the ***FAST REPLY*** cards you mail in—and on any other correspondence about your subscription or orders for other items. That "magic number" is actually your record number on our computer. We have designed our little system to use that number in addition to the number of the vendor or vendors from which you wish to hear. Our clerk will enter only the numbers from your returned card, and our computer will do the rest.

If you have a friend who wishes to use the second ***FAST REPLY*** card, that's fine with us, even though your friend is not a subscriber. Just ask the person to check the non-subscriber box at the top, and we will take care of the rest.

Packing Particle Pores

Finally, your particle-board cabinets are cut out, nailed, glued and dried. The drivers and crossovers will be in any day. Now is a good time to finish those cabinets. You might not want a veneer (yet), and you definitely don't want to do any more gluing, cutting, measuring, staining, and so on. But the cabinets have to look good. If you are considering a smooth, solid-color finish, read on.

Sealing particle board to an even finish is tough. One way to do so is with a powdered water-putty mix (Durham's is excellent). The steps are as follows:

1. Set all nails, and fill gaps and holes with wood putty. This is also a good time to file or sand corners to minimize cabinet diffraction.
2. Mix the water putty to the consistency of thickened latex paint. Apply it to the cabinet with a 3-inch brush, using even strokes. Let it dry for several hours.
3. Using multigrit sandpapers, sand all painted surfaces smooth to the touch.
4. Paint the cabinet with the desired color.

The nice things about this method are the easy sanding, durability of the finish and cost (about $1.25). Also, you can color the water putty with any water-based paint or powdered dye to match your final coat.

One word of caution: *never* use steel wool around your drivers. It can get into the voice coil structure, rust, rub and ruin the pole piece and former. (*Indeed, it is a good idea to remove drivers from the cabinet and the work area during any finishing operations.—Ed.*)

Doug Cabaniss
Paradise, TX 76073

Kit Report

MODEL C EARNS AN 'A'

I know that you have been wanting that extra pair of speakers for the den, but have not had the money to buy the quality that would satisfy you. Perhaps you have been thinking of building something from scratch, but you just do not have the time. Audio Concepts has the answer for you in the Model C loudspeaker kit *(Fig. 1)*. It is a snap to build, the quality is good, and the price is right.

Kit Contents

The kit comes in two versions. The basic kit ($99 per pair) provides the speakers, crossovers, wire, terminals and polyester fiber stuffing for a pair of loudspeaker systems. The complete kit ($200 per pair), which I built, provides the above plus a pair of enclosures. The only thing you provide is a large tube of silicone adhesive. *Figure 2* shows one-half of the complete kit.

The Model C is a two-way system using SEAS 8Ω drivers for the woofer and tweeter. The woofer is the P21REX, an 8-inch unit with a cast-metal frame and polypropylene cone. The tweeter is the H253, a 1-inch, soft-dome, ferrofluid unit.

Until recently, only the cheapest systems used simple first-order crossover networks. First-order filters do have some good characteristics, however, such as minimum phase shift. With newer drivers exhibiting extended frequency response, many of the finer systems recently introduced use first-order crossovers effectively to obtain phase-coherent output. Audio Concepts adopted this philosophy in designing the crossover network for the Model C *(Fig. 3)*.

The RC network across the woofer is for impedance compensation as described by Max Knittel in *SB* 1/83 (p. 11). Metallized polyester capacitors and air-core inductors are used throughout, and Audio Concepts has saved you money by not etching a circuit board for the few crossover components. Instead, the company attached the components to a piece of fiberboard with silicone adhesive and soldered the component leads directly together. *(Audio Concepts notes that this approach is also better sonically.—Ed.)*

The enclosure for the Model C is a 1ft³ sealed box with external dimensions of 19 by 12 by 10.5 inches. With the complete kit, Audio Concepts provides a pair of assembled and finished real wood, oak-veneered or stained oak or walnut cabinets, complete with snap-on grilles. The cabinets have all the necessary cutouts for driver installation. The quality of these cabinets is impressive for such an inexpensive kit.

FIGURE 1: Audio Concepts' Model C kit is inexpensive, easy to build and pleasing to the ear.

Assembly

Since I built the complete kit, I will not discuss enclosure construction. If you would prefer to buy the basic kit and build your own enclosures, I have included a drawing to guide you *(Fig. 4)*. The enclosure is so simple that you should not have any problems.

You can assemble the complete kit in an afternoon. The only tools you need are wire cutters, a soldering iron and a tube of silicone adhesive. I recommend a caulking gun with a large tube of adhesive, since you are going to use plenty. You will also need about a foot of 18 or 20-gauge solid wire. First, cut the heavy-gauge speaker wire provided in the kit to length. Strip about 1 inch of insulation off one end of the wires and connect them to the crossover network. Strip about ½ inch of insulation off the other end of the wires and terminate the ends with 18 or 20-gauge solid wire. This will facilitate connection to the driver lugs and the terminal strip.

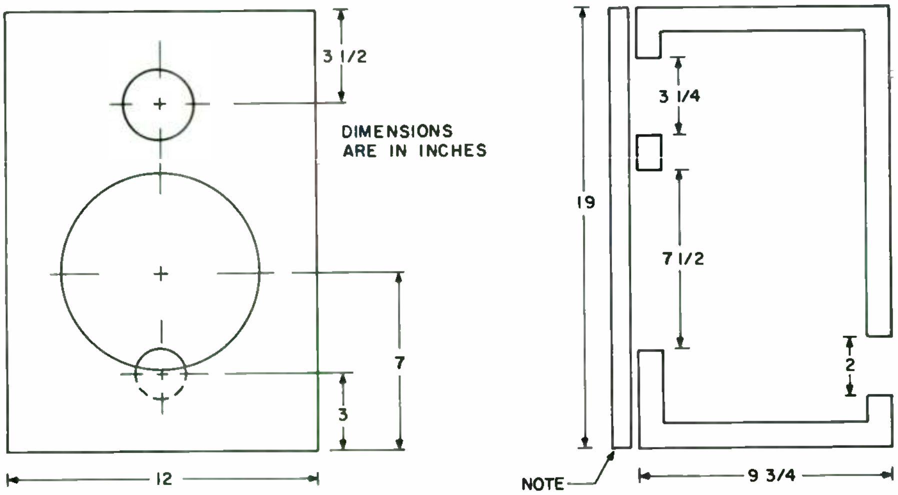
Next, use silicone adhesive to mount the crossover network to the rear of the enclosure, just above the terminal input. Distribute one-half of the fiber stuffing evenly in each enclosure, then solder the wires to the drivers and terminal strip. Now is a good time to test the system to make sure all the connections are secure and correct. Connect the system to a stereo and play it softly to check for good connections. Finally, run a bead of silicone adhesive around each hole and set the drivers and terminal strip in the hole. Let the adhesive set overnight.

That's all there is to it. You are now ready to listen to your new speakers.

Listening Evaluation

My first reaction to the Model Cs was, "Hey, those are very good speakers." Ex-

FIGURE 2: The kit includes these materials for each Model C speaker.



NOTES:
1. MATERIAL 3/4 in. PARTICLE BOARD
2. 3/4 in. THICK GRILLE SNAP-ON, FLUSH FIT

FIGURE 4: Cutting guide for building enclosures to house the basic Model C kit.

tended listening did nothing to change my mind.

Speakers using first-order crossovers tend to beam and are sensitive to room placement, so I thought it would be wise to experiment. I arranged the speakers about 6 feet apart along the long wall of an 18-by-13-foot living room, at ear level and about 18 inches from the wall. I was disappointed with the speakers' imaging, which was only average. I had expected that the phase-coherent crossovers would provide a very sharp image, but perhaps the geometry of the enclosure has more to do with the imaging than the crossover does.

Tilting the speakers back about 30 degrees helped quite a bit, but now the image jumped between speakers as I moved across the sound field. Toeing in the speakers corrected this problem and produced a well-defined, stable image. I also added felt diffraction rings around the tweeters and found that this only slightly affected the imaging. Although it did help, I really had to concentrate to hear the difference. Acoustic foam rings are available from Audio Concepts for $5 a pair.

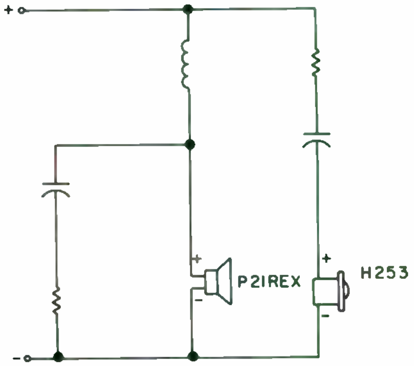


FIGURE 3: The unit's first-order crossover network produces phase-coherent output. Parts values have been withheld at the request of Audio Concepts. Those buying the kit will not be supplied with a schematic listing the values.

Subjectively speaking, the Model Cs are somewhat lively and bright, with good presence and well-controlled bass. Their most notable characteristic is superb detail and definition; individual instruments stand out clearly. Although the upper midrange and lower treble are clear and bright, the very high frequencies seem to roll off. This is evident as a lack of "sheen" in the cymbals. Since the midrange is well balanced, I suspect that the speaker has a slightly exaggerated response in the 3 to 10kHz range.

If I were to build another pair of Model Cs, I would provide a pair of external terminals for the resistor in series with the tweeter. This would allow me to adjust the

Continued on page 43

Craftsman's Corner

Minimonitor/Subwoofer Combination

I have been building loudspeakers for about five years and have benefited much from the advice of others (especially Michael Manz and Max Knittel). Most of my speaker projects have been for friends, but this past summer, I decided it was my turn.

I chose a relatively simple design—a four-way minimonitor/subwoofer system. I used a closed-box design for optimal bass transient response and determined box volumes by measuring the Thiele/Small driver parameters. As much as possible, I limited drivers to signals within their piston range by selecting crossover frequencies of 125, 1,000 and 5,000Hz. I used first-order (6dB/octave) crossovers for best transient response and least phase shift. Crossover design included driver impedance equalization and high-quality components (lots of WonderCaps).

PHOTO 2: The subwoofer consists of a Dynaudio 30W54 12-inch woofer with a polysulfate cone in a 4.5-cubic-foot closed box. The height of the combined systems is 48½ inches.

The minimonitor unit (*Photo 1*) houses a Panasonic EAS400 leaf tweeter, Dynaudio D52 2-inch dome midrange, and Morel MW-160 6-inch midbass. The cabinet is made of 1-inch solid oak (the side panels are ¾-inch oak plywood). In a poor man's attempt at time alignment, I recessed the tweeter mounting to align all the driver voice coils (I don't have an oscilloscope for proper phase alignment). I made the front baffle as narrow as possible to reduce reflections, and I rounded all edges with a router to minimize diffraction.

The subwoofer unit (*Photo 2*) houses a Dynaudio 30W54 12-inch woofer with a polysulfate cone in a 4.5-cubic-foot closed box. (For those not familiar with this driver, it is a beautiful, ruggedly constructed woofer with a specially vented voice coil that results in high efficiency and power-handling capability.) The cabinet is made of ¾-inch, high-density particle board with an outer ¼-inch oak plywood "veneer." I strengthened each subwoofer cabinet with 13 internal ribs and braces, and I applied internal damping material. Measured Q_{TC} was 0.70 for the finished subwoofers.

With the minimonitors positioned on their respective bass enclosures, the combined systems are 48½ inches tall. This places the dome midrange drivers approximately at ear level for seated listeners.

Approximate costs were $400 for the drivers, $150 for crossover parts and $150 for cabinet materials—a total of $700 for the pair. I obtained most of the components through Audio Concepts (1919 S. 19th St., LaCrosse, WI 54601), but they are available from a number of other mail order outlets as well.

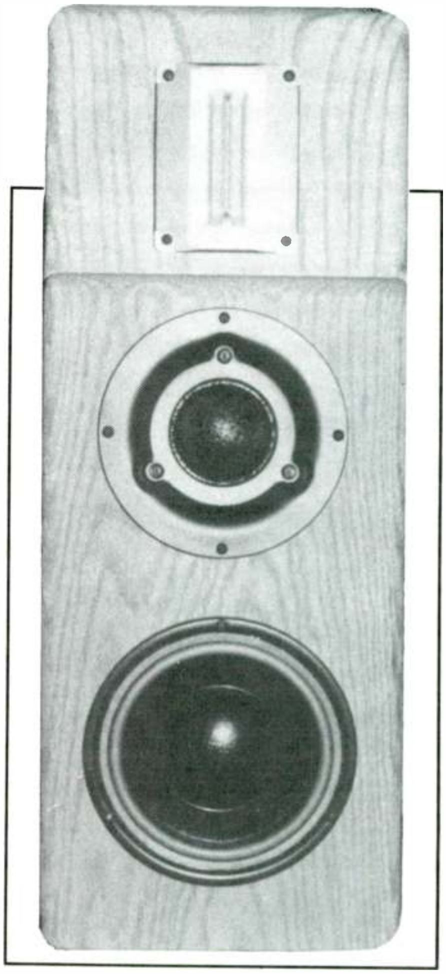


PHOTO 1: The minimonitor's oak cabinet houses a Panasonic EAS400 leaf tweeter, Dynaudio D52 2" dome midrange and Morel MW-160 6" midbass.

I am very pleased with the final product, both musically and visually. The bass is tight and deep ($f_3 = 36$Hz), the midrange is smooth and musical, and the high end is crisp and extended without fatiguing harshness. If any of you is considering building a similar speaker system, I wholeheartedly recommend that you proceed with your plans.

Claude Manning
Spokane, WA 99203

SB Mailbox

FUNCTIONAL FURNITURE

By using a bit of ingenuity and combining furniture functions, it is possible to fit some bulky or otherwise unattractive audio furniture into a small space. I live in a small apartment—the living room is only 10′×12′—yet I have integrated a two-drawer file cabinet for audio literature, a modified W.J.J. Hoge 600 liter subwoofer enclosure, and a 20″ deep × 44″ wide × 76″ high audio equipment cabinet into the decor.

The file cabinet doubles as a coffee table, while the subwoofer acts as a davenport with a backrest that I can pull forward to create a mini electronics workshop. The subwoofer's external dimensions are 17″ high × 37″ deep × 80″ long. It is made of 1⅛″ high-density particle board, and four of the six internal surfaces are non-parallel to minimize resonance.

The equipment cabinet has storage space for 350 LPs and 180 cassettes. I constructed it as two bolt-together modules and can expand it by adding more modules. A false back conceals the wiring and allows easy access through ¾ length hinged doors. I could also adapt the shelf space to rack mounting.

The file and equipment cabinets are made of ⅝″ particle board assembled with dado joints that I nailed and glued together. Pine mill-ends scavenged from a local sawmill cover the outside. This makes for a heavy but stable structure. Casters are almost essential.

All the furniture was inexpensive. The file cabinet cost $25 including hardware, the subwoofer cabinet cost less than $25, and the equipment cabinet cost around $50.

I have also built a pair of pyramidal enclosures for my Philips drivers and crossovers. I originally had the drivers in rectangular enclosures, so when I moved them into the new enclosures, I had the chance to compare the two units. The pyramidal enclosures came out way ahead, as they caused less low and high-frequency distortion.

The front of the cabinet has the minimum surface space for my drivers, and it tilts back to align the voice coils. The rounded edges further reduce high-frequency diffraction. Since only the top and bottom of the cabinet are parallel, low-frequency resonances are considerably less.

Designing a pyramidal cabinet is more difficult, but constructing it is as easy as constructing a conventional rectangular unit.

I am curious why Siegfried Linkwitz did not use a pyramidal enclosure in his speaker system (*SB* 2/80, p. 12; 3/80, p. 9; 4/80, p. 14). It might have solved his cavity resonance problem and would allow the smallest practical front surface relative to the drivers. I intend to build Mr. Linkwitz's satellites with pyramidal cabinets and was wondering if the pyramidal shape requires a reduction or modification of the damping materials. I would appreciate any help in this matter.

By the way, thank you for publishing *Speaker Builder*. It fills a big gap in published information.

Barry Carter
Baker, OR 97814

TL 10 LINE LENGTH

After I read Gary Galo's innovative articles on transmission line (TL) designs (*SB* 1/82, p. 7; 2/82, p. 24), one or two points came to mind. While the basic equation for determining the TL's length is quite accurate, the value given for the speed of sound (1,130 feet/second) is true only in free air. According to Bradbury's fine article in the *Journal of the Audio Engineering Society* ("The Use of Fibrous Material in Loudspeaker Enclosures," April 1976), the speed of sound in a fibrous tangle at low frequencies is given by the following equation:

$$\frac{1{,}130\text{ft/sec}}{\alpha}$$

where, $\alpha = \sqrt{1 + P/Pa}$, P = packing density (kg/m³) of fiber, and Pa = density of air (1.29kg/m³). For the TL 10, the packing density is 3 pounds (1.36kg) divided by the line volume (6.59ft³, or 0.187kg), which equals 7.33kg/m³. In this case,

$$\alpha = \sqrt{1 + \frac{7.33}{1.29}} = 2.58$$

Therefore, the speed of sound in the TL 10's line is

$$\frac{1{,}130\text{ft/sec}}{2.58} = 438\text{ft/sec}$$

This would give a corrected line length of only 4.4 feet for a ¼-wave line at 25Hz.

The success of the TL 10's design might be due to the fact that the line is 0.64 wavelengths long—a value fairly close to ¾-wave, which will also result in a good design. A much smaller design would seem to work as well, however, and perhaps this would explain IMF's use of a shorter line in its systems.

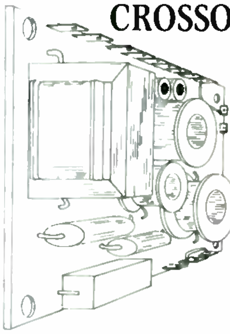
Richard Painter
Ubly, MI 48475

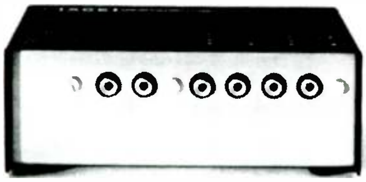
SANDERS' SONIC WONDERS

My Sanders ESL/TL/STL speaker system (*SB* 2/80, p. 20; 3/80, p. 20; 4/80, p. 26) has been pouring forth its sonic wonders for more than a year and, except for a couple of mishaps in the early stages, has been doing so an average of eight hours a day, without any problems.

I used several surplus Celotex ceiling panels to form the inner panels of the woofer and subwoofer. The original drivers were 12-inch Bozak 199BCs, but I replaced them with Radio Shack 8-inch polypropylenes. The sound is at least as good and probably better, at a much reduced cost. In the beginning I used them in push-pull operation, but one day I looked at the sine-wave output on an oscilloscope and discovered considerable distortion. I removed the rear drivers forthwith.

My active crossover is similar to the one appearing in Robert Ballard's article





SB *Mailbox*

(*SB* 3/82, p. 14; 4/82, p. 26), except I used the Sallen-Key equal-component format and the slope is 48dB/octave. I am not certain that such a steep slope is justified, but it does seem that the sound is smoother and more detailed than when I had my 24dB/octave crossover in the system. I am also using the Williamson bandpass filter. The range of the subwoofer is from 30 to 85Hz, the woofer from 85 to 400Hz and the ESLs from 400 to 15kHz.

The ESLs are the piano wire type. I had some slight arcing problems in the beginning, but those have cleared up for the moment. I operate the ESLs at about 1,400V, which is much lower than recommended, but seems to work. When I played Saint Saen's organ symphony at an SPL of 95dB, I could detect no distortion or overload.

A POOGE-II drives the woofers, while a Leach 3a amp drives the subwoofer and a Williamson 40/40 the ESLs. Thus, except for the Leach amp, the entire speaker system is an offspring of *The Audio Amateur* and *Speaker Builder*. By the way, using Cramolin on all the plugs and jacks made a noticeable improvement in the sound. I simply dipped each plug into the solution, worked it into the jack a few times and let it stand.

I have started work on the digital delay line by Jeffrey Borish (*The Audio Amateur* 1/83, p. 7; 2/83, p. 24). Knowing very little about digital electronics, I anticipate a long and difficult undertaking. I would like to hear from anyone interested in exchanging notes on this project. Also, I would be grateful if someone could tell me where to obtain a couple of AM6012 DACs and an AM2504 SAR.

I recently added a Sony CDP 101 DAD and a Sony SL-5200 Beta Hi-Fi VCR to my collection. They provide, in my opinion, the pinnacle of audio performance.

James P. Kitchen
Palm Bay, FL 32905

LISTEN BEFORE YOU LEAP

I recently received literature on the Jordan 50mm module. Since I already had JBL's brochure on the L112, I got out my 4/82 issue of *SB* and reviewed Mike Lampton's "A Three-Way Corner Loudspeaker System" (p. 7). Jordan rates its speaker's sensitivity at 80dB per 1W at 1 meter, while JBL shows the 128H woofer having 89dB per 1W at 1 meter. Further, the L112 response curve shows the bass flat relative to the midrange only when the speaker radiates into a full space (4 pi steradians, solid angle). Radiating into a hemispherical (2 pi) space, the bass response from low-frequency cutoff to above 100Hz is raised 2.5 to 3dB relative to the 4 pi response.

I assume that corner location adds 3dB twice to the low-bass response for a 6dB increase. Since Mr. Lampton makes no mention of what sort of space his WOOF software assumes, there could be a 0 to 9dB increase in low-frequency response when his design is placed in a corner.

In any case, I do not understand how he reconciles two speakers with such widely disparate sensitivities in a passive crossover. Another question concerns the way most low-frequency designs seem to ignore Roy Allison's work on the effects of the proximity of room boundaries on woofer response (cf AES *Journal* index). Are most home walls and floors just too floppy for it to matter?

Although these comments probably seem very negative, I actually enjoyed Mr. Lampton's article. Particularly interesting was his emphasis on sound opaque enclosure panels. I have often wondered if sheets of Sorbothane (or the type of plastic they glue to auto panels), laminated with screws between two layers of particle board would be cost effective and lighter. Perhaps not. As I remember, one of Briggs' favorite enclosures was made out of bricks.

Keep up the good work.

Robert T. Kuntz
Medford, OR 97501

Mr. Lampton replies:

It is always gratifying to discuss the details of a loudspeaker system's trade-offs with other enthusiasts. My three-way corner system has sparked lots of comments, but I would particularly like to respond to Mr. Kuntz's remarks.

My quest for clean sound actually began not with manufacturers' data sheets, but with listening. Long impressed with the capabilities of electrostatic (ES) treble reproducers, I was concerned with finding a means of delivering the clarity and immediacy of a small ES tweeter, without having to accept the usual directivity problems produced by planar ES units. The major problem here is not one of getting the levels right, but rather of achieving a reasonable spatial focus and bandwidth over a range of seating positions/Many ES reproducers do a fine job on axis, but fail to work well at angles off axis.

Through the suggestions of other audiophiles and friends, I began to investigate a few small midrange units and discovered Ted Jordan's 50mm module. In the process, I also learned about the Japanese ribbons and thought that these might complement the Jordans.

A few simple hookups showed the promise of combining these units with a low-efficiency, low-frequency (LF) driver such as the proven JBL. My own test data showed that the midrange unit was about 3dB less efficient than the 2213—i.e., it gives about 85dB at 1 meter compared to the 88dB of the JBL woofer. On the other hand, the ribbon is closer to 90dB and needs attenuation, as described in the SB article. With an attenuator in the ribbon drive path, the sound is reasonably good. The high-frequency (HF) units are not seriously mismatched to the LF unit.

Provisionally, I tried out a first-order crossover and found reasonable overall performance. Still, I expect that using a low-level crossover and biamp will improve things further. I hope to publish details of such a system soon. Of course, a biamp will offer the possibility of setting the LF and midfrequency (MF) levels independently. This accommodates any imaginable ratio of loudspeaker efficiencies. In the article, I chose not to discuss those possibilities and to keep things simple with the proven high-level crossover.

Program WOOF assumes that the space driven has a solid angle of 2 pi steradians (a half space). Of course, real rooms are far more complex than any simple cone: they do not have a solid angle that is constant with respect to frequency. Room resonances complicate things.

I am delighted to hear from others who are experimenting with real-world drive units. We can all benefit from sharing our listening experiences and advice.

POCKET T/S PROGRAM

After making several unsuccessful inquiries about a Thiele-Small program for my Radio Shack pocket computer (PC1 series), I finally sat down and wrote one myself. I used the formulas that David B. Weems included in his Tab publications *Designing, Building and Testing Your Own Speaker System* (No. 1364) and *How to Design, Build and Test Complete Speaker Systems* (No. 1064). My program also includes Robert M. Bullock's vent formula (round ducted type) from *SB* (2/81, p. 20).

The program finds the V_b, F_3, F_b, hump/dip, and ducted vent length and volume for your speaker. You just have to enter accurate values of Q_T, V_{AS}, F_S and port diameter to get a basic design. The program also includes experimentation in V_b versus response. The F_3, F_b and optimum volume values match the ones in the SRC 1982 catalogs and Weems' books, as do the hump/dip and the changes in V_b response.

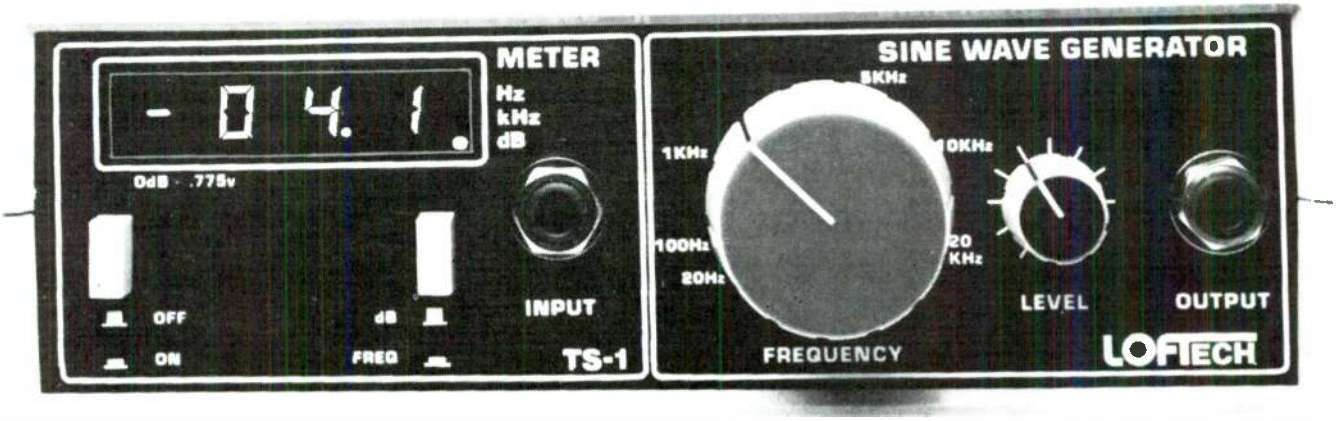
I want to expand this program to include two and three-way crossover design, decibel output at selected frequencies and other important formulas. Unfortunately, I do not have a printer to reproduce the program for distribution, but if you are interested in learning more about it, just drop me a line.

Doug Cabaniss
225 S. Section
Sullivan, IN 47882

FLEX YOUR MOUNTINGS

I would like to see some discussion of the merits (or lack thereof) of flexible mountings for drivers. There seems to be some idea afoot that such flexible mountings isolate the baffle and driver from each other. No one seems to realize, however, that the baffle is going to vibrate anyway from internal pressure (especially in a sealed system) and from vibrations transmitted by the other panels—assuming, of course, that the structure is inadequate in the first place.

A potentially more serious effect might be a detuning or bass loss from the flexible section's acting as an extra vent. I am aware that KEF was among the first



manufacturers to use this technique, but I believe that their approach retains a firm bond between driver and baffle, while a large woofer flange reduces the resonance of the driver frame. It would be interesting to see some A/B tests of systems using flexible mounts to determine if these effects, or others I have not considered, might be taking place.

Scott Ellis
Ocean Springs, MS 39564

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.

BRUTE FORCE UPDATE

Observant readers of *SB* 2/83 might have noticed that my Craftsman's Corner, "Brute Force Bass P.A. Enclosure" (p. 28), violates one of the fundamental guidelines of enclosure design—i.e., the use of cubical or near-cubical dimensions. Instead of many smaller-amplitude standing waves occurring at differing frequencies inside a noncubical enclosure (correctly labeled a right rectangular prism), only one large-amplitude standing wave will occur in a cubical enclosure. A noncubical design, with a shallower depth and greater width, would spread those standing-wave frequencies farther apart, make each one's amplitude smaller and give the driver a larger front board for better acoustic loading.[1] Unfortunately, this shallower depth would turn the enclosure into a less-stable platform for those 250-pound Bozaks, even if they were bolted down. A near-cubical design also makes the most efficient use of enclosure volume (important when hauling equipment around in your pickup truck or van). These factors resulted in the compromise design shown in the 2/83 piece.

I failed to mention, however, that these enclosures were meant to be used with an active crossover in the 80 to 100Hz range. This means that the standing waves' first fundamental frequency (approximately 455Hz)[2] will be 40dB down (with a 100Hz crossover point) or 45dB down (80Hz) using a third-order crossover. The figures for a fourth-order crossover will be 52dB down (100Hz crossover point) or 60dB down (80Hz). I consider the fourth-order figures to be satisfactory for P.A. use.

I should also have covered the following items in that piece.

1. The note in *Fig. 3* that refers to Corner Detail B reads, "All other 2×2s may be cut ¼″ short (or more) for clearance." This might be confusing. If you are using the 2×2 TBs and 2×2 SSs only as glue blocks, cut them shorter than drawn to avoid buzzes. If you are using the 2×2s to build a frame first, as Weems[3] suggests, cut all 2×2s to exact size, then glue and screw them together.

It might be wise to sketch a full-size, three-view drawing of a typical corner to see whether there is room for the long wood screws holding the 2×2s together and the shorter wood screws attaching the particle board to the 2×2s. Counterbored lag bolts might work in the rear corners, but steel angle connectors might be necessary at the front corners to avoid the hanger bolts. Use pipe clamps to ensure a square frame while the glue dries, then attach particle board and plywood. Two layers of particle board would be ideal for a home system, but the rough life of P.A. work demands that the outer layer be plywood. The frame method will result in a stronger assembly, while the glue block method is easier to build.

2. Those hanger bolts are needed only for a removable front or back panel required by rear or push-pull mounting of the drivers. A removable back panel is possible, but without the P.A. column-support option. Front mounting allows permanent panel attachment and eliminates the need for hanger bolts. You can front mount the Altec driver by cutting clearance slots for the driver's radial stiffening members after routing for a flush fit (you may also trim the cork gasket). For use in a P.A. environment, I strongly recommend rear mounting and a wire mesh covering.

3. Too much torque on the hex nuts can pull the hanger bolts' wood threads out of the soft No. 2 pine boards, even after the glue dries. Use just enough torque to get an airtight seal. If you plan to remove the front panel often (for in-

stance, to vary box volume) and would like to use a *small* air-impact wrench to speed things up, use basswood, poplar, birch or another type of hardwood wherever the hanger bolts are permanently installed. You might want to purchase a few extra hanger bolts before construction and test them with scrap pieces of various soft and hardwoods. Use the wood that gives the highest torque reading before the wood threads start to pull out. Hot glue seems to work best on both wood and metal.

Incidentally, the location of Assembled Section B-B *(Fig. 2)* is not shown in *Fig. 3's* Hanger Bolt Installation View. To add it, simply draw a vertical line through the center of the bottom 2×4, then draw two arrows pointing to the right at the top and bottom of that vertical line and label them B and B (the same as the arrows labeled A and A, but rotated 90 degrees counterclockwise).

4. In *Fig. 2,* the detail labeled "Optional 2×4s to Support P.A. Columns" is definitely in error. One 2×4 will go from upper left to upper right, as shown, but the other 2×4 will go from lower left to upper right. Thus, board 3, shown as a 2×4, should be a 4×4 or a 4-inch 0 post instead. The vertical post will withstand 900 pounds per square inch (psi) of compression parallel to the grain (No. 2 southern pine[4]), but each diagonal 2×4 will have compression perpendicular to the grain and thus a 390 psi figure, or approximately 2,300 pounds for the 6 square inches of contact between boards 1 and 3 (or boards 2 and 3). Limit this to 600 pounds as a safety factor.

Also, the end of the caption for *Fig. 3* should read "...add the optional 2×4's to *support* the P.A. columns."

5. I specified ¾-inch plywood in the cutting guide *(Fig. 1)* for the rest of the diagonal bracing. You might want to use pine 1×4s instead. In addition, the dimensions given for those diagonals in the size list *(Fig. 1)* are incorrect. The correct lengths are as follows: 43″ should be 32″, 20″ should be 15¼″, 36″ should be 27¼″, and 38″ should be 28¾″.

6. If you wish, cover all interior surfaces with foam, polyester, fiberglass or some other damping material. Additional damping such as bituminous felt or asphalt/gravel mixtures is not really needed if the system response does not go above 100Hz.

7. As with all closed-box systems, the only adjustable parameters are box volume (real and apparent) and its accompanying total Q. You may add even more bracing to reduce box volume or

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more stuffing (as Tom Nousaine suggested in *SB* 2/83, p. 26) to increase apparent box volume. Try to get a smooth, hump-free response curve down to at least 40 or 50Hz. You can then boost the gentle second-order roll-off with a McIntosh Environmental Equalizer or a ⅓-octave graphic equalizer for flat response down to 20 to 25Hz, or as low as you need to go. The extra power required for this boost explains the use of that 300W Mac amplifier.

8. One of my friends often used his spare time to build enclosures for ZZ Top, Christopher Cross, Point Blank and other bands. His experience with double-thickness enclosures confirms the theory that they will play louder and have a firmer and more detailed bass response than single-thickness enclosures with the same internal volume, drive units, amps and program material. Double-thickness enclosures are heavy (about 200 pounds each), however, which makes musicians and crew members hesitant to use them.

Wharfedale's patented water "sandwich" enclosure technique might sound attractive, but what works in a living room might not work on a dark, cramped, smoky stage. The slightest leak, combined with an improperly polarized microphone or guitar cord or a ground fault with any power amplifier on stage, could have lethal results. Perhaps a single-thickness enclosure will satisfy your bass needs, but if you want that extra crunch in the bottom end and are willing to pay the Charles Atlas tag that goes with it, the "Brute Force" techniques might be the way to go.

Steve Ball
Austin, TX 78745

REFERENCES

1. Cohen, Abraham B., *Hi-Fi Loudspeakers and Enclosures,* 1968, pp. 188–189.
2. Colloms, Martin, *High-Performance Loudspeakers,* 1980, p. 176.
3. Weems, David B., *How to Design, Build and Test Complete Speaker Systems,* 1978, p. 106.
4. Ramsey, Charles G. and Harold R. Sleeper, *Architectural Graphic Standards,* 1970, p. 215.

PIEZO PARADOX

I would like to hear from anyone who has been able to rig up a piezo tweeter to make it sound acceptable. To date, I have been unsuccessful in my attempts to do so. I have used 2-by-5 and 2-by-6 piezo horns without a crossover and also with R-C crossovers. *Figure 1* shows the output/input relationship versus frequency

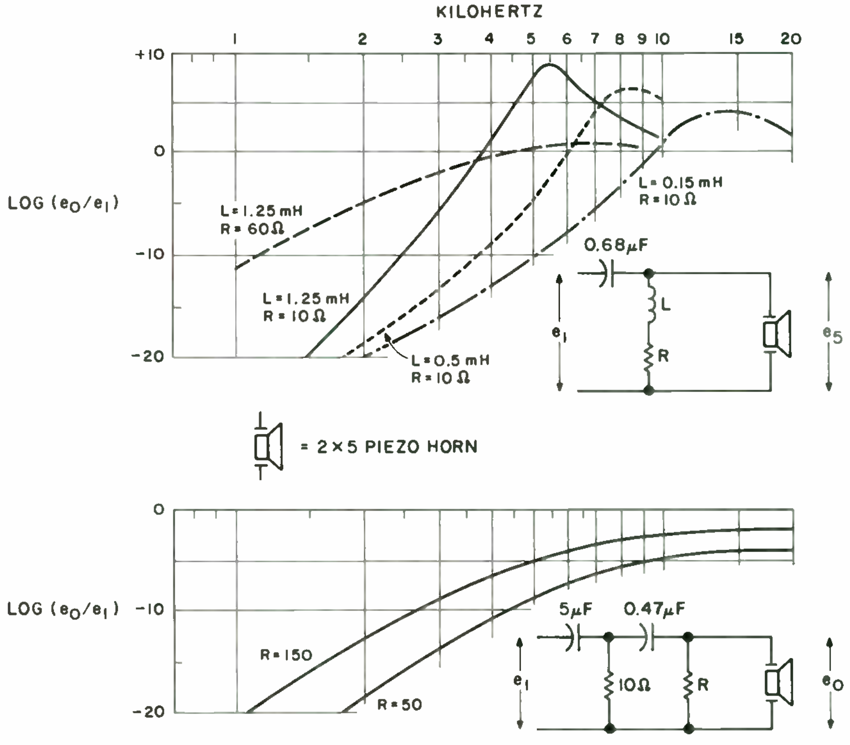

FIGURE 1: Output/input relationship versus frequency for 2-by-5 (top) and 2-by-6 (bottom) piezo horns.

for the two kinds of network. Note the resonant boost and sharp cutoff of the C-L-R circuit and the attenuation and much more gradual roll-off of the C-R/C-R network.

The piezo tweeter circuit comes from David Weems' book, *Designing, Testing and Building Your Own Speaker System* (Tab Books, 1981). He says that some people report better results with a sharper cutoff. I have not evaluated this circuit except to measure volts/division. Because it shows resonant behavior, I am discouraged from pursuing it further.

David J. Meraner
Scotia, NY 12302

SONY 4300 SEARCH

Does anyone have a schematic for a Sony 4300 stereo three-way active crossover? I bought one of these units without an owner's manual or schematic. Now the crossover is on the fritz, and a schematic would be very helpful. I would appreciate any assistance.

Steve Ball
Austin, TX 78745

Kit Report

Continued from page 35

tweeter level and perhaps alter its response by adding a parallel RC network in series. Considering how good the unmodified speakers sound, I expect that the improvement would be slight and is really not worth the trouble of modifying my existing pair.

As you would expect from any 8-inch driver in a 1ft³ enclosure, the bass is limited—no gut-thumping hard rock here. To be fair, the bass response is no worse than other well-designed systems of similar size. It is tight and well controlled, rather than overextended and flabby with a mid-bass hump.

In conclusion, the Model C is a fine speaker at a good price. Its shortcomings are minor for a speaker in its price range. Although Audio Concepts offers a pair of Model Cs assembled for $319, considering how easy the kit is to assemble, I can't imagine why anyone would buy them instead of the kit.

David W. Davenport
Raleigh, NC 27609

Audio Concepts (1631 Caledonia St., LaCrosse, WI 54602) offers several speaker system kits as well as an extensive line of drivers and electronic components. A catalog with a price list is available for $2 refundable.

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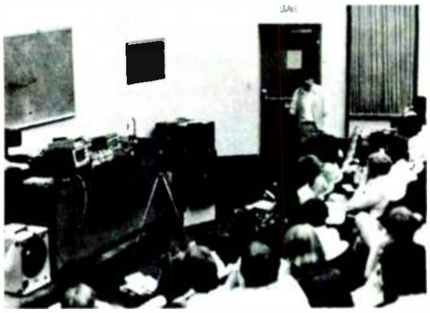

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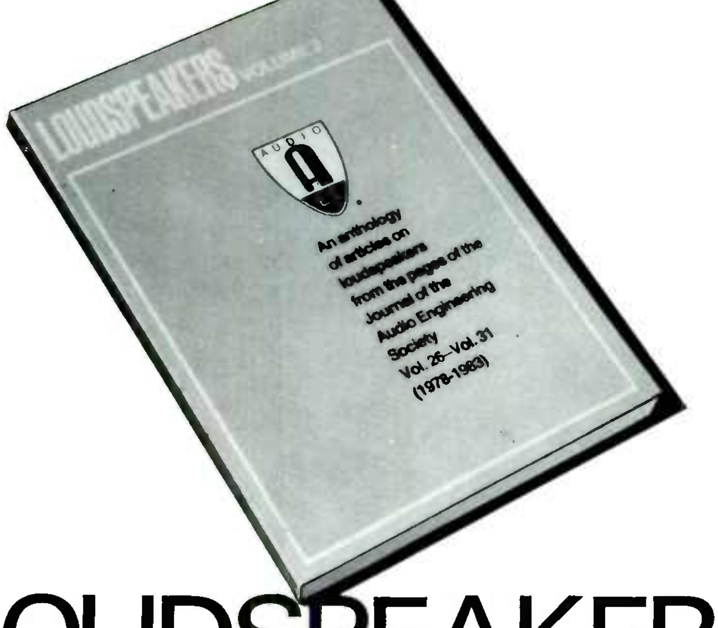

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