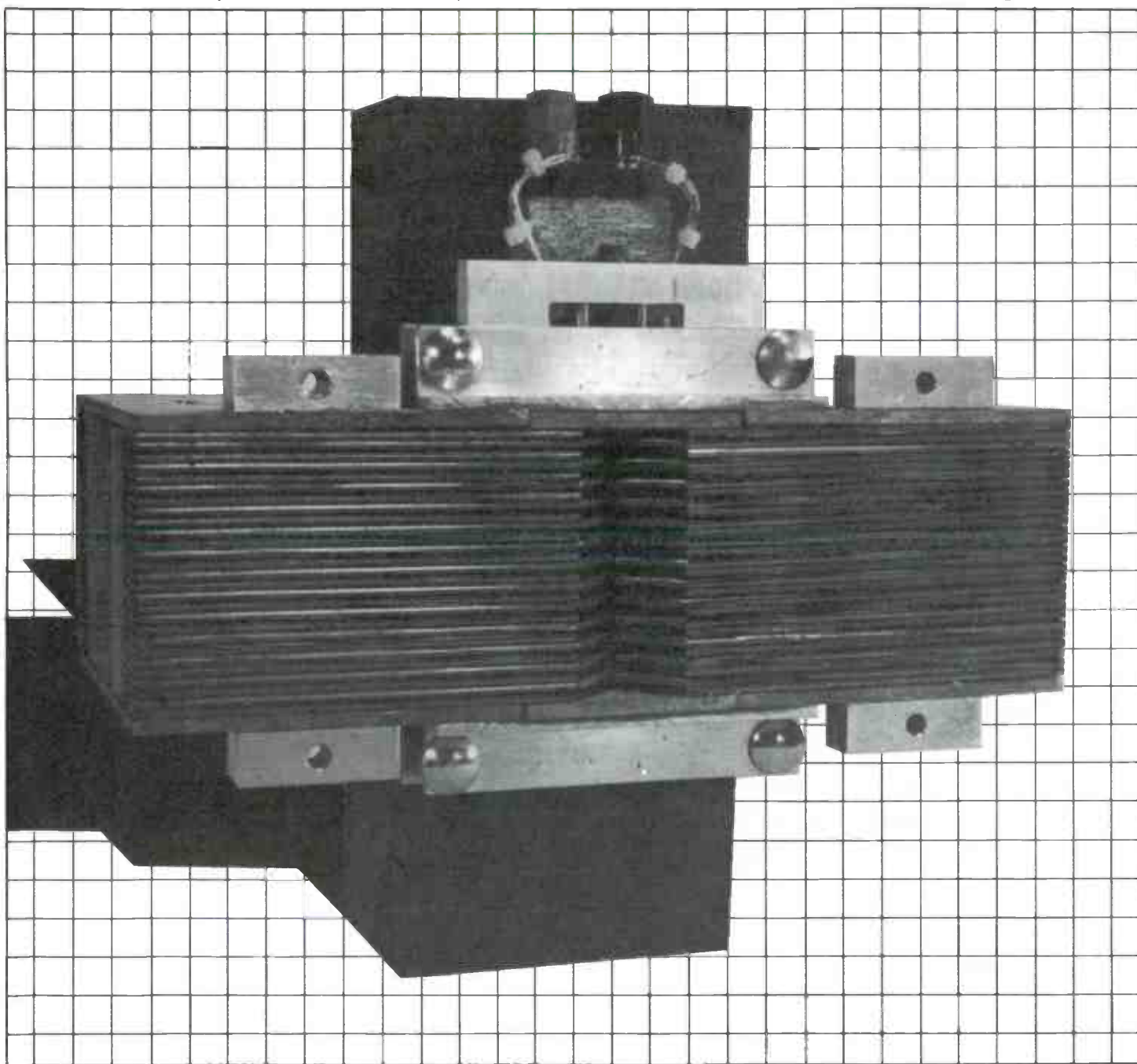


# SPEAKER BUILDER

Crossovers: Phase adjustable, active, series & parallel ◦ A builder's tale ◦ Winding coils ◦ Mating Heil & Horn



# Good News

Among the new auxiliary products for personal computers are some which have application to audio. **IQS** has a fast Fourier transform system which turns the Apple II into a versatile spectrum analyzer. With this, you can measure many aspects of speaker performance including frequency response, phase or group delay, and time delay characteristics. All the required test signals, including tone bursts, are incorporated into the system. Ask the computer to sample only the first few milliseconds of a speaker's response to a tone burst, and you have simulated an anechoic chamber. You also can observe the frequency spectrum of musical instruments, test your phono cartridge, and measure room response. The **IQS 401** generates very clear graphic representations, including a 3D view of frequency response versus time, which may be printed out if desired. Data and waveforms may be stored on disk for future reference and analysis. Complete details are available from **IQS Inc.**, Dept. STB, 5719 Corso di Napoli, Long Beach, CA 90803.

The Sept. 1982 issue of **BYTE** shows how to make the Apple and the **MOUNTAIN COMPUTER** A/D converter function as a digital storage scope. Author Larry Korba provides details and program listings.



Making a suitable face plate after finishing a new project is always a problem. A nice-looking face plate complements the hard work you put into the design and construction with an appearance to match. **3M'S DECORATIVE PRODUCTS DIV.** has an easy to use photosensitive system which enables you to make your own face plates. Lay out your artwork on a transparent sheet, position it on the photosensitive material, expose to ultraviolet light, and within minutes you have the finished material, ready to peel off and stick on your prototype. Backgrounds can be various colors, aluminum or "gold finish." Write to them at **3M Center**, 223-1S, St. Paul, MN 55144 for details and the name of a dealer near you.

An interesting material for sealing speaker cabinets comes from **UNITED MINERAL AND CHEMICAL CORP.** in the form of self-sticking polyurethane foam insulation tape. Very flexible and easy to shape, **TESA 710** can be used around drivers and along cabinet edges to provide an airtight, soundproof, resilient seal. Resistance to most of the common destructive chemicals, including lacquer and paint solvents makes it suitable for speaker enclosures. Look for it at building supply stores and try it on your next set of speakers.



Super lightweight headphones suitable for use with personal stereo equipment or home systems feature powerful samarium cobalt magnets and oxygen-free high conductivity copper wire in the coils and cords. When not in use, these comfort-designed headphones fold and store in their own carrying case. Visit your **SIGNET** dealer for an audition.

The Model 85 aScope from **NORTHWEST INSTRUMENT SYSTEMS, INC.** will turn an Apple II into a fully programmable, digital memory oscilloscope. The system is dual channel, allowing you to compare two waveforms or trigger one with the other, over a frequency range of DC to 50MHz. You can store acquired waveforms on disk for future reference or analysis. Software included with the aScope enables you to perform standard procedures quickly and easily, with provisions for user modifications. You can write your own program, up to 8K. Photos of the display are unnecessary because the aScope outputs to a printer (Silentype, Epson MX80). A demonstration disk is available for \$10; the system sells for \$995. For more information, write to Dept. SB, PO Box 1309, Beaverton, OR 97075.

A price list and spec sheets for raw drivers, speaker kits, crossovers and long hair wool are available from **BRITISH ACOUSTICS SOUND REPRODUCTION EQUIPMENT** Brands carried include Siare, Focal, Audax, Lowther, Jordan, and Falcon. Send 40¢ in US stamps to 1011 Meyerside Dr., Mississauga, Ontario L5T 1K8 Canada for details.

## High Performance Review

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**HERRINGTON** specializes in audio accessories of excellent quality. Their catalog displays tastefully selected items from Signet, Discwasher, Monster Cable, Mobile Fidelity and others. The solid oak cassette storage cabinet on the back cover appears to be well-executed. Write to Dept. ED, 7265 Shadowbrook Dr., Kirtland, OH 44094 for a catalog.

An extremely low cost spectrum analyzer is sold by **RADIO SHACK** in the form of a \$19.95 program pak for the Color Computer. Bar graphs show the power distribution of the input signal from 31.5Hz to 12.5kHz in 1/3 octave segments, at levels of -20, -10, -5, -3, 0, +3, and +5dB. See your favorite Radio Shack dealer for a demo. Although the resolution is not fine enough for precise measurements, the display is useful for checking system and component performance. Using FM hiss as a source, you can measure your speaker's frequency response with a fair degree of accuracy.



**NAKAMICHI** has introduced their SP-7 headphones, featuring a flat diaphragm and a system response calculated to sound flat when worn. Since the shape of the outer ear and the cavities in the middle ear affect frequency response with an extremely close sound source, Nakamichi designed inverse peaks and dips into the SP-7's response curve to make it sound flat in actual use. Special attention was given to damping diaphragm breakup and its attendant distortion. Try them on your own head at your favorite dealer.

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## About This Issue

Crossovers are the theme for this third issue of *Speaker Builder's* 1982 series. **Wilfred Harms** cogently differentiates the pros and cons of series and parallel networks (p. 12) and **Robert Ballard** explores multi-driver polarity problems and proposes an active crossover solution in Part One of his two part series, which begins on page 14. **Pat Coyle** sets out all you need to know to wind your own coils for passive crossovers (p. 20) and the Editor revisits our vintage active crossover which first appeared ten years ago, and offers an update with Walt Jung's assistance (p. 22).

Our leadoff performer this time is **Ken Rauen** who mates Oskar Heil's air motion transformer driver to a horn. The first part starts on p. 7 and the construction details will come along in issue four. The cover photo is by Mark Schlorff.

Finally, **Robert Carlberg** invites us on a journey through years of speaker building and its joys and jarring disappointments beginning on page 28.

We apologize to all readers for the publishing delay, but we do hope to catch up before many months have elapsed. Thanks for your patience.

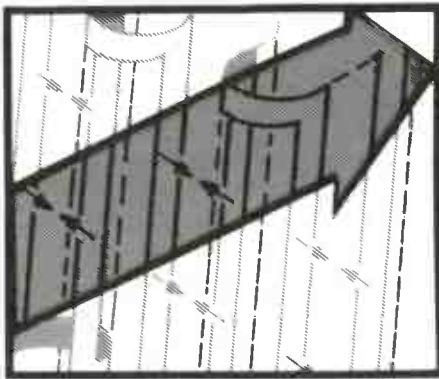
This issue carries an early renewal offer on its outer cover, a Christmas offer on the back cover, and a very special free offer for those of you who have friends who'd like to subscribe to *Speaker Builder*, page 41.

# SPEAKER BUILDER

VOLUME 3 NUMBER 3

OCTOBER 1982

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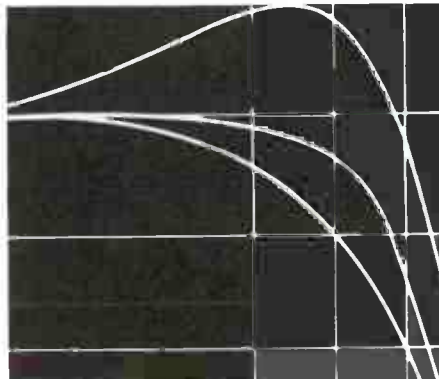
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# SPEAKER BUILDER

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## Editorial

### Harmonic Feedback

The plight of America's auto workers contrasting as it does with the success of the Japanese car manufacturers is giving journalists, management experts and economic analysts a field day. Henry Ford has even gone so far as to admit in public that his family's company made some shoddy cars.

Not only are three out of each ten autos manufactured in the United States in need of repair at the end of the assembly line as compared with two per hundred in Japan, the Japanese car lands on our shores at a lower cost by \$1,000 to \$1,500 each.

In the past, management's goal was production figures high enough to make the managers look good. Union leaders hardly differed since their only thought seemed to be maximum wages—a third higher than those of the Japanese worker.

The three-in-ten defective product rate is eloquent evidence that neither worker nor manager had much reason to care about product quality. Competition has suddenly created a compelling reason to care. Apparently the Ford people have re-opened the communication lines from the top management down through every level to their assembly line workers. A new spirit of cooperation appears to have blossomed in Ford's plants.

I recall standing in the cone production room of Advent one afternoon watching workers dip slurry from continuously agitated five gallon buckets with dippers which were exactly the right size for the cone being fabricated. Every worker knew that Henry Kloss had devised the production technique they were using and that he understood their job. They also knew they could offer suggestions for improving things and that Henry would take them seriously.

Ford's similar new style of relationship between workers and managers augurs well for better cars and better prices. It is a tribute to Ford's people that they have managed such a change. We Americans are, like most of our cousins in the West, highly individualistic and competitive. The Japanese are far closer to their origins and are more cooperative, interactive, and "tribal" in life style. Thus their efficient work patterns have been easier to achieve.

This contrast is, I believe, a basic fact which affects almost all we do. In publishing it matters greatly whether or not one views a magazine staff as super experts who hand down ultimate truth. The magazine is then a vehicle for making experts out of each reader. Our approach has been more like a cooperative. We encourage the individual to do his or her hands-on work, keep good records, and to share the results with others. People learn best by doing, less well by being told all the answers. People who work with their hands know the vital facts about how well or how poorly the product performs. When that knowledge is fed back to the management input, the product gets better.

When we share our knowledge of what happens when we build a speaker system or a crossover in a certain way, we will have better speakers and also one of our most deeply human satisfactions, a smarter, cleverer, more rewarding relationship with our quirky, stubborn, fascinating physical world.

# A HORN LOADED HEIL: Part 1

BY KENNETH RAUEN  
PHOTOS BY MARK SCHLORFF

**A** new driver design, the Heil Air Motion Transformer, appeared on the market in the early 1970's. This intriguing, ingenious invention by Oskar Heil caught many people's attention, including mine. I was impressed both by the AMT's performance and by its new operating principles. In the process of building a pair of wooden horns to use with Altec 405-G midranges, I noticed that when I ran the numbers through the equations, the throat area turned out to be rectangular, with a long vertical axis. Mating this with a round driver has some problems, but suddenly the ideas clicked together: the Heil would be the perfect driver for this horn.

In 1979 I subscribed to *The Audio Amateur* and bought many back issues. Among them was Neil Davis' article (2/77) describing how to build a Heil driver. That was it. I would have to build my own.

**MOVING THE AIR.** Loudspeaker design has always involved limitations and compromise. All electroacoustic transducers operate with solid matter (except the plasma tweeter and the corona wind speaker), and must deal with the characteristic problems of solids and the ways they couple with a gaseous medium of propagation. Traditional design seeks to improve transient response by applying extra power to the vibrating element, and to reduce resonance by damping. My design improves transient response by reducing mass (and resulting inertia) and reduces coloration by moving resonances out of the audio range. The Heil is a good example of the latter approach. But because it couples with the air inefficiently, a horn is needed. Although horns cause coloration, this factor can be minimized with careful design, and actually can be used to advantage, in this case moving the AMT's response down to 300Hz.

A horn is an acoustic transformer. Ideally, it provides an impedance match between the speaker and the air, thus in-

creasing the speaker's efficiency. The air's impedance to the diaphragm is only a small part of the speaker's total impedance. For maximum energy transmission, the source (speaker) and load (air) impedances must be equal. A speaker should work on the air, not its own mass and stiffness. A horn helps accomplish this by presenting the driver with a higher air impedance at the throat. Varying the throat constriction is how we match impedances. If we reduce the throat area in front of the diaphragm, the air particle velocity through the throat increases, creating higher pressure at the diaphragm. Since the

force on the diaphragm is area times pressure, the horn's throat loads the diaphragm with increased force. In this way the radiation force's magnitude can equal the inertia and elastic forces of the diaphragm.<sup>1</sup>

This alone will not transfer more energy to the air. We need a mouth match and transitional flare also. Just as the throat must match the driver's impedance, so must the mouth match the open air. The transitional flare transforms the impedances.

Horns also act as highpass filters, the flare (*ie* conical, exponential, tractrix) and dimensions acting to control its

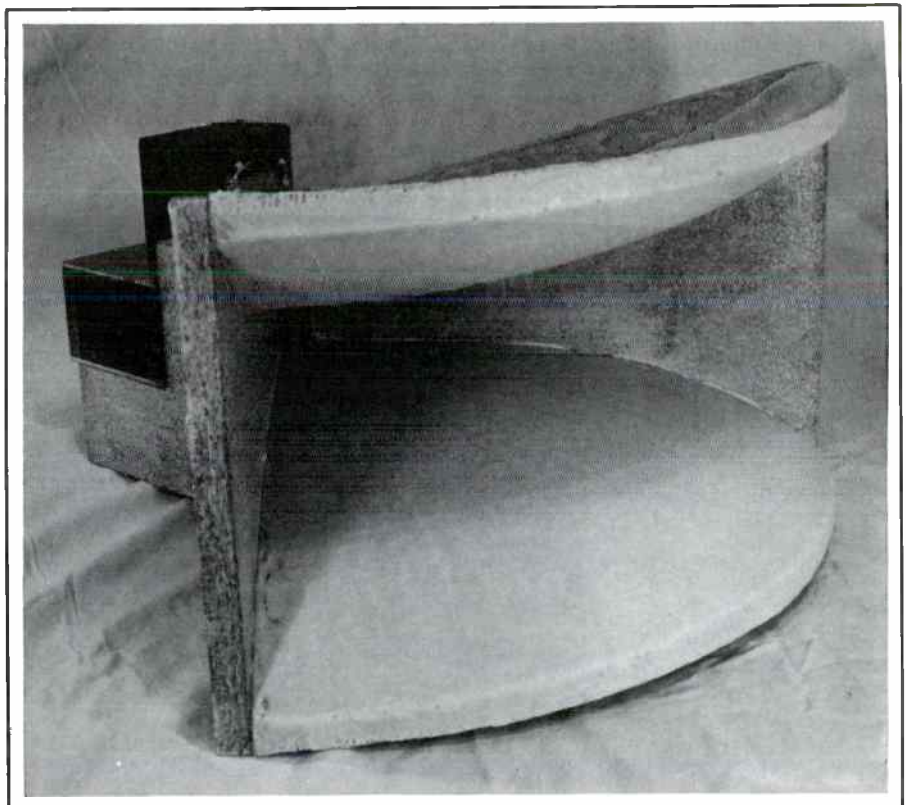


PHOTO 1: Clean, low distortion sound radiates from the assembled horn and Heil driver, with flat response down to 300Hz.

characteristics. Depending on the design, they can act as bandpass filters also.

For a horn to maintain a match to the air and to prevent reflection of the soundwave back to the throat<sup>2</sup>, the mouth area must be greater than the square of the longest wavelength to be radiated, divided by  $4\pi$ , or  $A_m > \lambda^2/4\pi$ . Since I chose a low frequency cutoff of 250Hz (wavelength 54.24in),

$$A_m > 54.24^2/4\pi = 234.12\text{in}^2,$$

and for convenience I set it at 240in<sup>2</sup>.

Each flare has its own impedance characteristics. I used an exponential curve because it is easy to calculate and has good, predictable performance. The cross sectional area of a location ( $A_2$ ) is defined as  $A_2 = A_1 e^{kx}$  where  $A_1$  is the area of a location closer to the throat,  $e$  is the natural logarithm,  $k$  is the flare constant, and  $x$  is the distance between  $A_2$  and  $A_1$ . To find  $k$ , we need the equation  $k = (4\pi\nu_c)/c$  where  $\nu_c$  is the low frequency cutoff and  $c$  is the velocity of sound ( $ca$  1130ft/sec). For a 250Hz cutoff,  $k = [4\pi 250]/1130 = 2.78/\text{ft}$ . In the horn we will build, the exponential flare is used only in the outer  $2/3$  from the mouth to where the top and bottom are essentially parallel. From that point to the throat, the flare is conical (which lowers the impedance loading and raises the cutoff frequency). This flare combination in a sectoral horn has two advantages: maximum horizontal dispersion of the highs and phase coherent wavefront propagation (ie no reflections from the mouth to cause cancellations). Slanting the top and bottom surfaces about  $5^\circ$  breaks up standing waves in the throat area (in this case

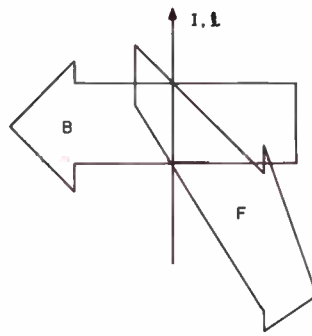


FIGURE 1: When current flows in a conductor it creates a magnetic force  $90^\circ$  from the direction of current flow, which is the operating principle behind all electromagnetic devices.

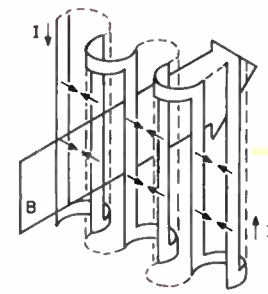


FIGURE 2: In the Heil driver, the magnetic field is oriented from front to back. As current flows through the conductor, the pleats are squeezed together on one side, and spread apart on the other.

$2.5 \times 1.25\text{in}^2$ ) smaller than the diaphragm area to achieve a better impedance match. The transformation ratio is the ratio of the diaphragm to the throat area, and is one of the principal factors affecting efficiency. As you will see, the AMT has its own transformation ratio, and further restriction of the opening or a phasing plug usually aren't necessary.

**HEIL THEORY.** The same equation governs both the Heil and the common cone driver:  $F = B\ell I$ , where force equals magnetic field density times conductor length times current, all in  $90^\circ$  relationships (Fig. 1). Heil used this principle to generate sound in a unique way. Instead of winding the conductor in a coil (as in

cones and domes) or placing it flat in a plane (as in ribbons), he laid it out in a zigzag pattern on a flat diaphragm (as in planar magnetic drivers) and then folded it so the conductor runs up and down the structure. The magnetic field is oriented front to back so it squeezes the pleats together on the front while spreading them apart on the back (Fig. 2).

Because the electromagnetic energy is distributed evenly on the diaphragm, it controls movement and damps resonances much better than the locally energized cone. Ribbon tweeters, electrostatics, and planar magnetic speakers all share this characteristic with the AMT, so what is the Heil's unique advantage? ESS's ads touted the cherry pit explanation. Squeezing it between your fingers will propel it further than simply pushing it with the same force. But this never seemed quite right to me. Looking at it more carefully, Neil Davis (TAA 2/77) described it as an evolution of the ribbon speaker, and concludes that it is a planar magnetic driver folded up and placed in a more powerful magnetic field.

From the patent (US# 3,636,278) comes the essence of the Heil's operation and how it moves the air with less kinetic energy than conventional diaphragms. Figure 3 depicts a flat diaphragm, simplified for clarity, and Fig. 4 is a top view of the AMT, also simplified. Oskar Heil defines a term,  $f$ , the effective mass reduction factor, as the ratio of pleat width to depth ( $f = a/b$ ). The significance of this will follow. Given that the diaphragms in Figs. 3 and 4 displace the same volume of air, the ratios of the diaphragm velocities are  $V_1 = c/t$  and  $V_2 = \text{flat } d/t$ . The ratio of pleat velocity to diaphragm velocity is  $V_2/V_1$ , or  $(d/t)/(c/t)$  or  $d/c$ . Since  $d/c = f$ , we can substitute terms and  $V_2/V_1 = f$ .

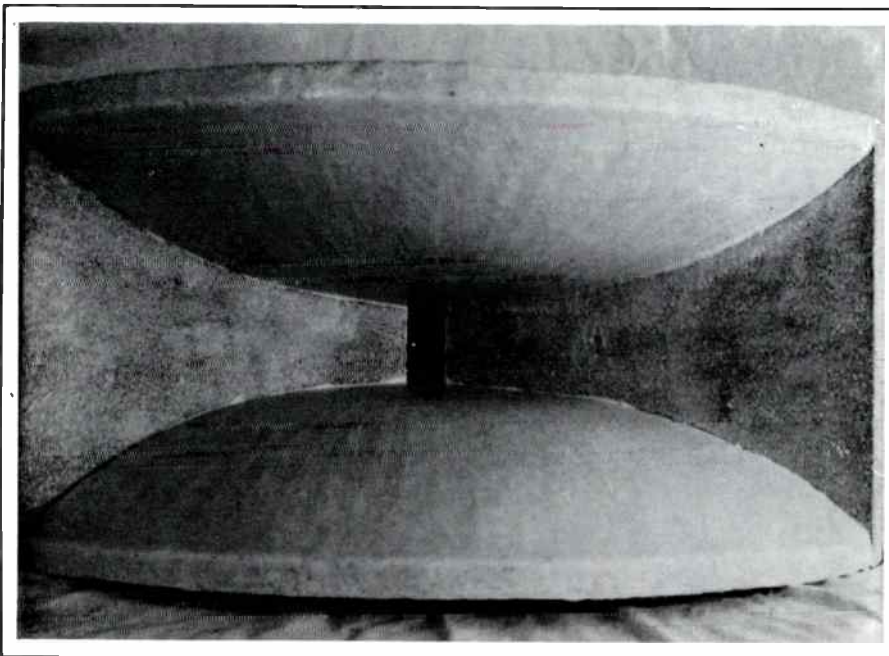


PHOTO 2: The conical-exponential horn provides highly efficient coupling to the air, and excellent horizontal dispersion.



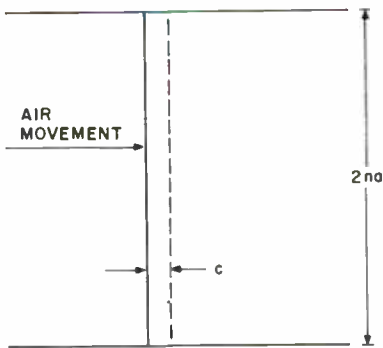


FIGURE 3: A flat radiator moves air by pushing and pulling to create pressure waves.

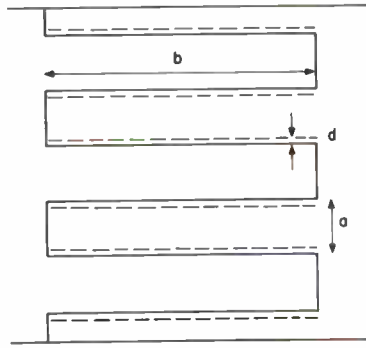


FIGURE 4: The Heil AMT has a larger diaphragm area which moves a shorter distance to set up pressure waves in the air. The pleats introduce the mechanical advantage of a lever, which the flat diaphragm lacks.

If the two diaphragms are of equal thickness and density, then the relative masses are determined by the dimensions, and  $m_1/m_2 = 2na/2nb = a/b = f$ . Even though the AMT's mass is greater than the planar's by a factor of  $1/f$ , the kinetic energy needed to move the AMT diaphragm is  $f$  times smaller. The ratio of the two KE's is  $[\frac{1}{2}m_1(v_1)^2]/[\frac{1}{2}m_2(v_2)^2]$  or

$1/f$ . Remember that  $f$  always will be a fractional value. The energy needed to cause the flat radiator to displace the same amount of air is always greater than for the Heil driver. Expressed another way, the AMT is equivalent to a planar of  $f$  times less mass: hence the name, the Effective Mass Reduction Factor.

Heil gives the effective mass as  $2nahf$ ,

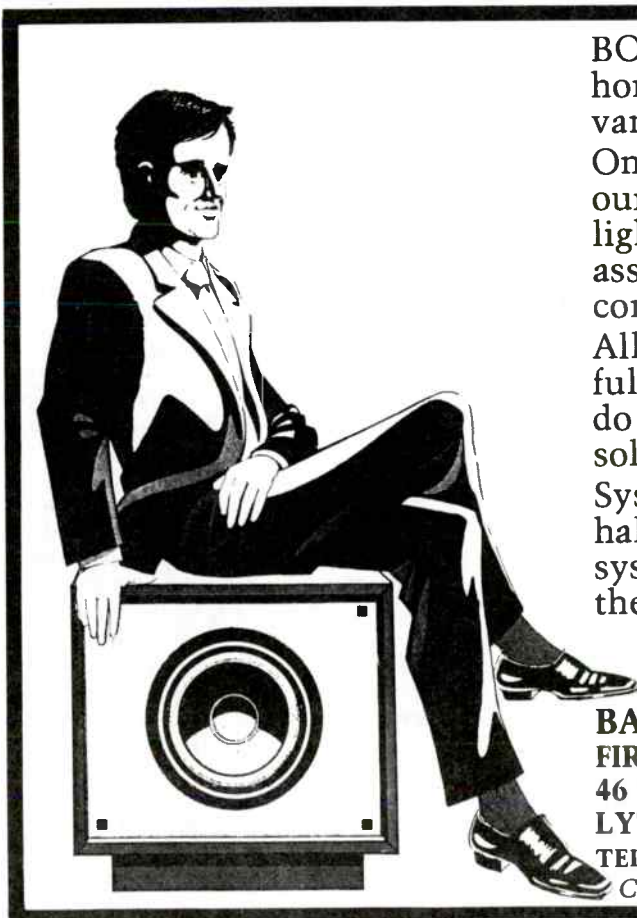
which also can be written as  $(2nha^2)/b$ . The actual AMT mass is  $2n(a+b)h$ , so the the ratio of AM to EM:

$$\begin{aligned} [2n(a+b)h]/[2n(a^2/b)h] &= \\ (a+b)/(a^2/b) &= \\ (b/a) + (b^2/a^2) &= \\ (1/f) + (1/f^2). \end{aligned}$$

In the driver we will construct,  $f = 1/3.7$ , making the 900mg mass equivalent to a flat diaphragm of 52mg.

So the Heil is a large flat diaphragm folded and placed in a more powerful magnetic field. Leaving the diaphragm loose minimizes resonances, which also average out from pleat to pleat. From the opposite point of view, a planar magnetic driver is a Heil stretched and placed under tension to move the resonances out of the audio range. Since it is flat, it lacks the mechanical advantage of the pleats.

**HORN: DAMPER & COUPLER.** The AMT and horns work together as a system quite well. The pleat depth to width ratio,  $1/f$ , is also a velocity transformation ratio, perfect for horn loading. The Heils project a low distortion, phase coherent waveform into the horn, which in turn provides the necessary damping. The ESS AMT's cover most of the audio range, working



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down to 700Hz in the best versions. Neil Davis' drivers go down to 1000Hz before they rattle, and mine, with the benefit of horn loading, will go down to 300Hz (A horn loaded AMT woofer? How about that Mr. Klipsch?!) The dispersion characteristics of a sectoral horn complement the Heil's dispersion, and they work together beautifully.

**A PRACTICAL DESIGN.** The next article will cover all the construction details, so I'll just describe the general outlines. I made my horn shapes from wood, sawdust, yellow glue, and styrofoam, and then made a steel reinforced plaster mold of the curved surface. From these I made the fiberglass reinforced polyester panels for the actual horns, and completed them with particle board side panels.

I built the Heil drivers from ceramic magnets, aluminum stock, and 13 gauge steel stock, bonded totally by epoxy cement and stuffed with long hair wool. For the diaphragms, I made three different types, mounted in rigid aluminum frames, to observe the differences in performance. The first was 3.7:1, constructed of one mil aluminum foil sandwiched between two layers of one mil polyethylene, and fastened with rubber cement—essentially Neil Davis' technique. The second was similar, but I used ½mil polyethylene and coated the exposed metal with vinyl repair compound. Finally I made a 2:1 diaphragm with the techniques I used for the second one.

To allow better breathing of the enclosed rear wave, I enlarged the rear enclosure twice. These baffle extensions

appear in some of the photos. Reflections of the rear wave through the diaphragm caused frequency response peaks and dips, so I changed the shape and volume of the enclosure twice to flatten out the curve.

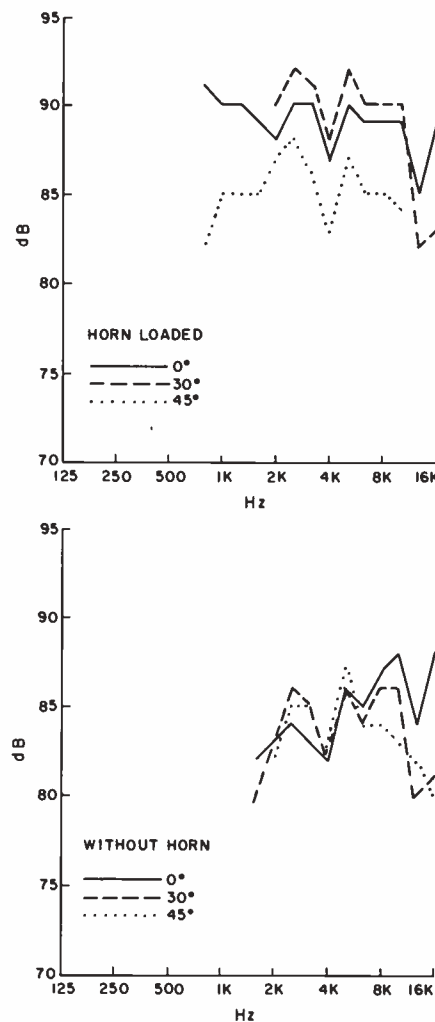
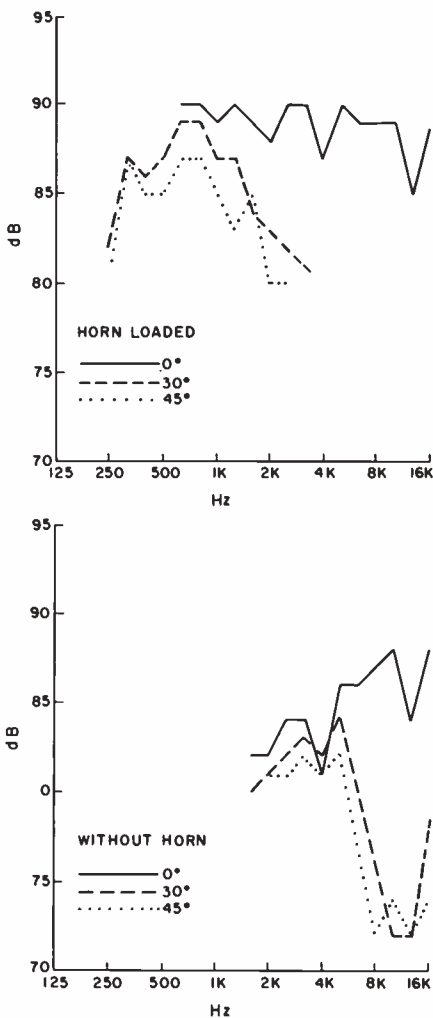
**PERFORMANCE COMPARISONS.** The three motors had different characteristics. For simplicity, I'll refer to the 2:1 construction as R2, the 3.7:1 using my techniques as R4, and the 3.7:1 using Neil Davis' methods as D4.

Measuring impedance is difficult because the values are so low. The R2's DC resistance is .7Ω. The AC impedance in the magnet gap is .8Ω and horn loaded it's .8Ω. The values for R4 and D4 are 1.0Ω, 1.1Ω, and 1.2Ω. Since they are constant from 200Hz to 20kHz, the load is resistive. Note that horn loading increases the driver's electrical impedance by about 10%. Neil Davis achieved over 50% with his. These low impedances present little problem to the amplifiers in my system because they are resistive and I use low power levels, and a Marantz 8B on its 4Ω tap.

Efficiency is high. I measured only relative numbers, using a pink noise 10Ω source. R4 and D4 produce the same SPL with a given drive signal. Apparently the differences in mass (1750mg for R4 and 890mg for D4) are not significant. R2 draws 1.5dB less power than the other two, which explains why it measured 2dB down. Efficiency differences with other types of drivers are difficult to measure. A horn loaded R4 was significantly more efficient than a dome tweeter (which had an efficiency of 2%) and a few dB less efficient than an ElectroVoice T350 tweeter (30% efficiency). Crossed over at 300Hz to a pair of EV SP12's tuned to 45Hz in 7ft<sup>3</sup> enclosures, they generated an SPL of 95dB at 10ft in a large living room with doors and windows open and 15 people in it. The AMT's consumed about 1W average peak power, so exploring their upper power handling limits may be a tortuous task.

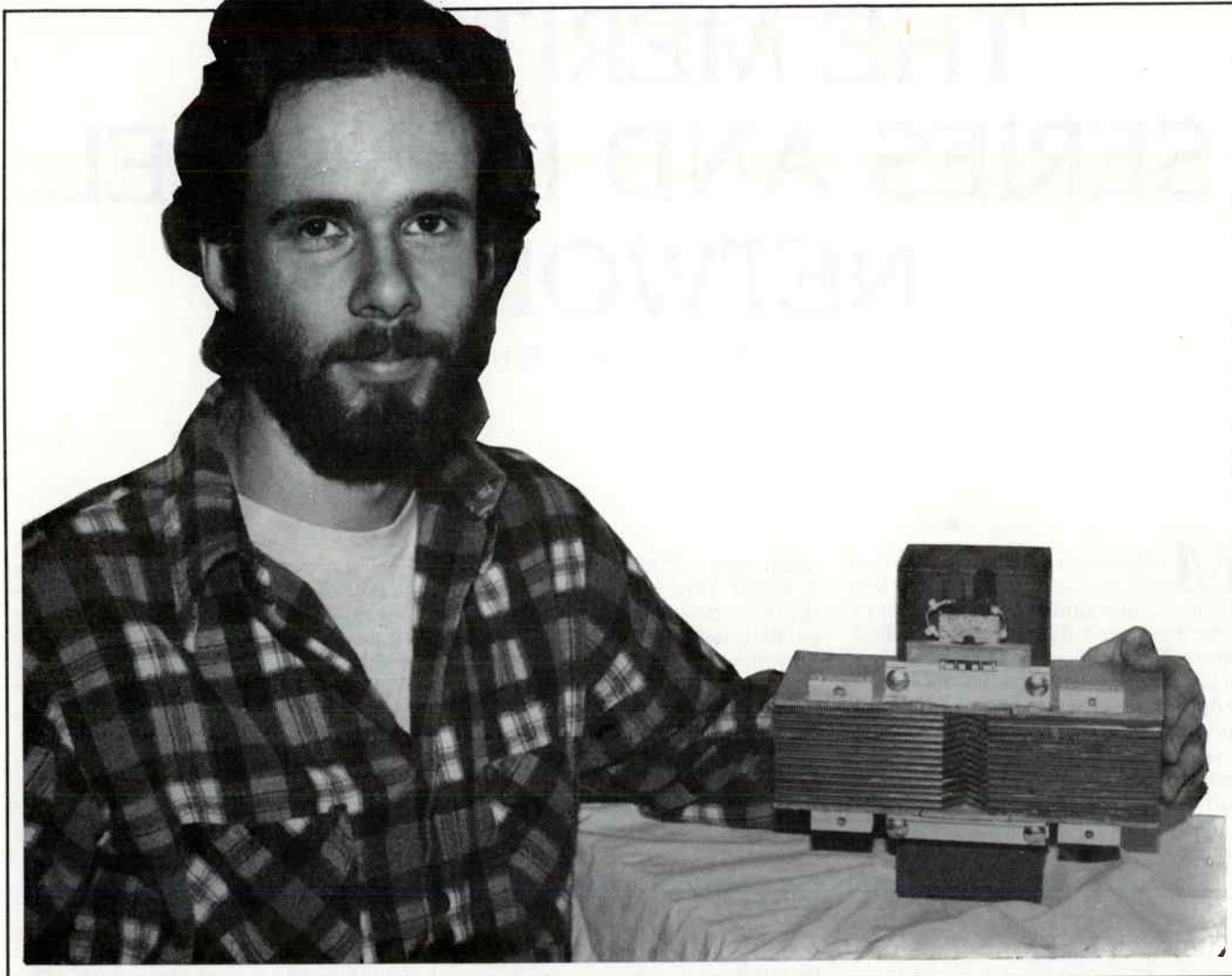
Frequency response varied considerably among the three. D4 produced the flattest curve. R4 was not as good and R2 was horrible. The graphs show the R4 only after the enclosure extension from 17in<sup>3</sup> to 34in<sup>3</sup>. I suspect the dips at 2, 4, and 12.5kHz are caused by the standing waves between the driver and the rear of the enclosure. Because the dips are strongest in R2 (which has the least absorbing material) and nearly absent in D4 (which has the most), and the distances are perfect for those frequencies, this seems to be the most reasonable explanation.

After increasing the baffle to 44in<sup>3</sup> and making the walls non-parallel to break



**FIGURE 5:** Vertical dispersion frequency response curves for the 3.7:1 diaphragm (with the first enclosure enlargement) shows the effect of horn loading is to transpose the curves downward. Very little coloration is added by the horn.

**FIGURE 6:** Horizontal dispersion curves show the excellent consistency at various angles, which results in good imaging.



**PHOTO 3: Author Rauen proudly displays the finished Heil driver. In the next installment, he tells you how to build it.**

up standing waves, I found no difference. Why this happened needs an explanation I haven't found. Maybe the improved construction techniques unbalance the pleat to pleat frequency response averaging Neil Davis speaks of, or cancelling random individual pleat response may not be random in this case. The dip at 12.5kHz is partly caused by a malfunction in the  $\frac{1}{2}$  octave equalizer, which I later corrected, although I didn't remeasure the curves.

The good news from the response curves is that horn loading does improve the Heil's output, and that diaphragm types affect performance. You can see that this horn does not add undesirable colorations of its own but simply transposes the Heil's curve to a lower range. At high frequencies the horn adds only 1dB to the on axis output, but this may be due to slightly greater vertical directionality over 10kHz. At 2kHz where the R4 drops off, the horn provides 5-6dB boost (more below this point).

R4's dropoff is caused by the stiffness

of the trapped air. R2's curve showed a lower cutoff than the others, but when horn loaded, has a 300Hz cutoff. With the small (17in<sup>3</sup>) enclosures, R4 and D4 had an audible cutoff of about 700Hz, which moved down to 400-500Hz and to 300Hz (the horn's limit) with successively larger enclosures.

The horn makes the horizontal dispersion more uniform. Off axis the intensity drops, but uniformly for all frequencies, until  $\pm 40^\circ$  where everything falls off rapidly. Vertical dispersion remains poor, and is unimproved by the horn. Useful intensities are within  $\pm 5^\circ$ .

**SUBJECTIVE QUALITIES.** This system creates a convincing sonic illusion similar to the Magneplanar Timpani 1D's and substantially better than an ElectroVoice system (T350, 8HD, 1823M, and X36). Apart from vertical dispersion, the most serious problem is finding a woofer good enough to match their quality. Their sharply defined transients and low distortion are their most immediately enjoyable aspects. Playing

M&K's *Flamenco Fever* or the clocks and chimes of Pink Floyd's *Dark Side of the Moon* leaves most people speechless. Cat Stevens' voice is clear and free from sibilant distortion, with a pleasant, natural timbre.

The R2 and R4 technique is not durable. The foil eventually lifted off under high acceleration. I rebuilt the drivers in the Davis style and they work just fine. For lower horn cutoff frequencies, you need a larger rear enclosure. An unenclosed rear wave should work well, adding high frequency ambience to the room. Another possibility is to use a transmission line enclosure to absorb all or most of the rear wave without raising the horn's cutoff frequency. □

**NEXT ISSUE:** Step by Step Construction Details

**ACKNOWLEDGEMENTS,** I thank my cousin Robert C. Rauen for his help with the machining work, Dave Clark for the frequency response curves, and Mark Schlorff for the fine photos.

# THE MERITS OF SERIES AND PARALLEL NETWORKS

BY WILFRED F. HARMS

Most amateur speaker constructors follow a published design, but the numerous enthusiasts who wish to experiment with their own designs find little information available. Recently I saw a remark that series configurations reduce the power requirements for the inductors compared to parallel arrangements. I began to wonder if this is a general truth or applicable only to that particular circuit. The current in the circuits is relevant though seldom mentioned.

cond order (12dB/octave) crossing over at 500Hz. Notice that the inductors for the series circuit are smaller than for the parallel, but that this does not indicate how much current they must carry.

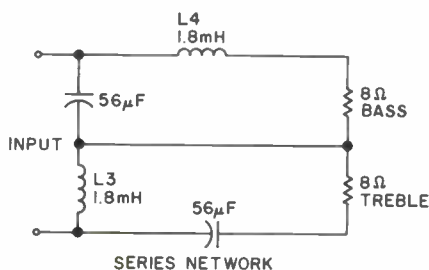
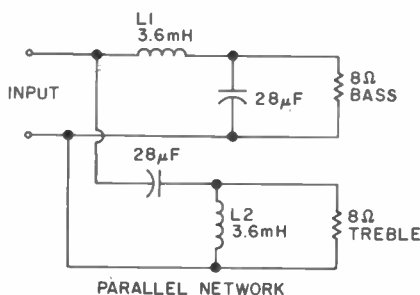
Figure 2 shows the variation of current with frequency in the various inductors for an input signal of 10V (applicable for any dividing frequency). At lower frequencies, the current in L1, L3, and L4 is the same, but in L3 it rises 25% as it approaches the dividing frequency. The current in L2 however is lower than any of the others and its maximum is about half of L1's. Because of this, L2 could be wound with a smaller gauge wire.

For ferrite core inductors another factor is the core's size, which is determined by the amount of current and the number of turns. Since L3 is half the value of L1 it requires only 71% of the turns L1 does. But L3 has higher current, so the cores are the same. L4 is similar, but L2 has less current and needs a core of only half the area. Falcon's high power, high power-low loss, and standard crossovers are applications of this idea. No particular difference exists among them in performance, and no cost savings occur.

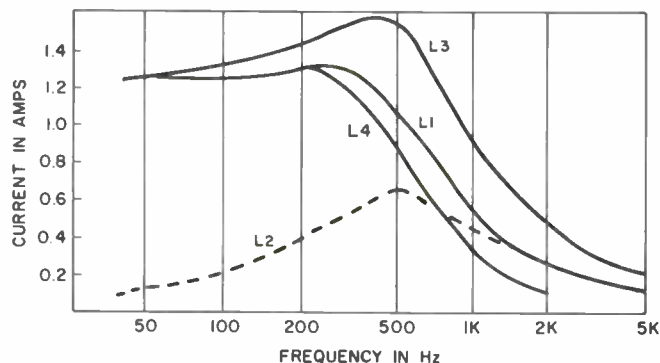
Current and cost are not the only issues of significance, however. The inductor's DC resistance can give rise to losses comparable with those of speaker cables. At low frequencies the bass section is effectively in series with L3 and L4. Because the total resistance of the inductors is always more than a single inductor of twice the value, the parallel network has a small advantage.

An important and often overlooked parameter is the overall impedance of the network. Although the constant-impedance formulae for both types ensure uniformity (provided the drivers behave resistively) this can change considerably if they have appreciable reactance at the crossover frequency. With the parallel arrangement, the impedance rises, which is usually beneficial. With the series type, the impedance falls, lowering the overall impedance.

In conclusion, a change in the value of any component in the series network affects the response of both the bass and treble sections to a degree. In the parallel, the sections are independent. Speaker builders will find the parallel circuit's flexibility very useful for fine tuning their systems. □



General use of "constant impedance" networks is not good because of the impedance variations in individual speakers. They can be used over a frequency range where the driver behaves (or is made to behave) as a resistor. For an example of how this works, look at the two networks in Fig. 1, which are se-



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**STR 130 RIAA FREQUENCY RESPONSE TEST RECORD.** Provides RIAA frequency characteristics for the calibration of professional recording equipment and for testing the response of professional and consumer record reproduction equipment. This record is suitable for use with a graphic level recorder to provide permanent, visible records for precise evaluation. Spot frequency bands for use without automatic equipment are included.

**STR 140 RIAA PINK NOISE ACOUSTICAL TEST RECORD.** Designed for acoustical testing of systems and loudspeakers and for psychoacoustic tests on reproduction equipment. With the STR 140 it becomes possible to test loudspeakers in the room in which they will be used. Spot frequency tones with voice announcements facilitate the testing procedure. Continuous glide-tones in 1/2-octave bands cover the frequency range from 30 to 15,000Hz and are synchronized with a graphic level recorder.

**STR 151 BROADCAST TEST RECORD.** Developed especially to meet the needs of broadcast engineers, audiophiles, and other professionals seeking a convenient signal source for the testing and adjustment of all audio equipment. Tests include: phonograph pickup response and separation, speed accuracy at 33 1/2 and 45 rpm, wow and flutter, rumble and hum detection, ballistic test of V. U. meters and many others.

**STR 170 318 MICROSECOND FREQUENCY RESPONSE TEST RECORD.** Provides pickup designers and recording studios with a high-level, easily-equalized signal for frequency response and channel separation measurements. The STR 170 employs a 318 microsecond characteristic corresponding to the "test" or "flat" mode common to most disc recording equipment. Constant amplitude recording is employed in the region below 500Hz with constant velocity recording in the region above. The transition is smooth, in contrast with the STR 100 which employs a sharp breakpoint at 500Hz. The record is suitable for use with a graphic level recorder to provide permanent, visible records for precise evaluation.

**SQT 1100 QUADRAPHONIC TEST RECORD.** Designed for calibration, verification, and adjustment of SQ<sup>®</sup> decoding equipment. The record provides test bands for pickup measurements, for adjustment of decoder electronics and for channel identification and balance. Each band is described in terms of recorded characteristics and its intended use.

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# An Active Crossover with Phase Correctors: Part I

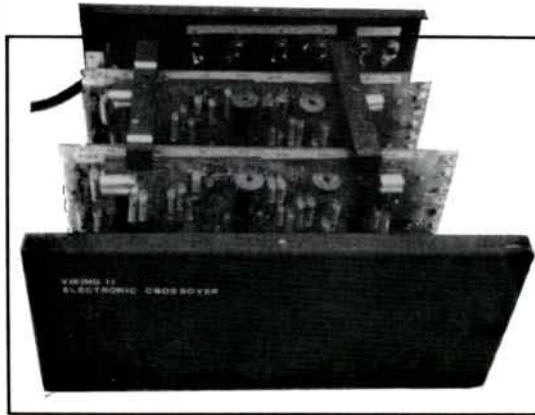
BY ROBERT BALLARD

Phase distortion in speakers has many causes, but the prime culprit is the crossover network. Physical placement of the drivers follows close behind. Other factors include equipment interactions and connecting cables. The result of all these phase disruptions is a vague, diffuse image, with unrealistic size, and frequency response peaks and dips. In this article I will show practical methods for measuring phase shift in circuits and in the actual acoustical output of the drivers, along with a design for an active crossover which permits fine-tuning of system phase alignment from preamp to driver output.

Active filters can be made from a combination of resistors, capacitors, operational amplifiers, and a suitable DC power supply. In an active filter, through the use of a positive feedback circuit, a capacitor takes the place of the expensive wire wound inductor used in passive filters. The landmark paper which made this all possible was by Sallen and Key, *A Practical Method of Designing RC Active Filters*, in *IRE Transistor Circuit Theory* (1955). Further and more detailed information about active filters appears in Walter Jung's excellent series of articles in *The Audio Amateur* (1/75, 2/75, 4/75 and 2/76), and in *Speaker Builder* 2/82, the *Manual of Active Filters* by Hilburn and Johnson, and the *Active Filter Cookbook* by Don Lancaster.

**FILTER TYPES.** In *Fig. 1*, the circuits, vector diagrams, and response curves are shown for first, second, and third order filters both low and high pass. Phase angle at the crossover frequency ( $F_c$ ) for all cases is  $N(45)$  degrees, so a fourth order filter would have a phase angle of  $4 \times 45$  degrees or 180 degrees. This characteristic of fourth order filters causes the output of both low and high pass filters to be in phase with each other, which is exactly what we need for phase alignment within crossovers.

A fourth order filter consists of two cascaded second order filters, requiring two op amps as shown in *Fig. 2*. In the previous examples of first, second, and third order filters with  $F_c$  at  $-3$ dB, the phase angle at  $N(45)$  degrees, and with



unity gain, the  $Q$  of the circuit is  $\frac{1}{2}\sqrt{2}$  or .707 with maximally flat response, which is desirable in first and third order filters used for speaker crossovers. (Note that the third order filter in *Fig. 1* actually is a hybrid designed to avoid using two op amps since a true third order filter should have cascaded first and second order filters.) With fourth order filters, the above no longer holds true. Each second order section of the fourth order filter shown in *Fig. 2* is a duplicate of the one shown in *Fig. 1*. Each section then has a  $Q$  of .707, but when cascaded the total  $Q$  becomes the product of the  $Q$ 's which is 0.5, and  $F_c$  occurs at  $-6$ dB instead of  $-3$ dB with the phase angle remaining at 180 degrees. With the drivers in phase,  $-6$ dB represents  $\frac{1}{2}$  acoustical power from each driver and the combined acoustical power from both drivers is unity, or in other words the response is flat over the crossover region.

However, as we will discover later, midrange  $Q$  needs to be adjustable. A circuit with equal values for  $R$  and  $C$  and variable gain can control the  $Q$  (*Fig. 3*). Gain is controlled by resistors  $R_1$  and  $R_2$  with gain ( $K$ ) equal to  $(R_1 + R_2)/R_1$ .  $Q$  is governed by the relationship of  $Q = 1/(3-K)$  and  $K = 3 - (1/Q)$ . For maximally flat response in a filter the  $Q$  of one section should be .541 and the second should be 1.307. Note that the product of these equals 0.707. To illustrate how  $Q$  affects the shape of the response curve, curves are shown for  $Q$ 's of 0.5, 0.707 and 1.0 in *Fig. 4*. The response curve for  $Q$  equal to 1.0 has about a 3dB rise just before it makes the plunge into negative dB's while those of 0.5 and 0.707 do not. The shape of the curve

shows why a response with a  $Q$  of 0.707 is maximally flat.

**PHASE SHIFTERS.** From *The Manual of Active Filters* by Hilburn and Johnson we will use an all pass filter (phase shift circuit) (*Fig. 5*) to obtain phase alignment. The gain of the circuit is 0.5 and this loss must be compensated for in other ways. The resistor and capacitor values for wide ranges of phase shift angles can be obtained from the extensive charts in this book. In an all pass circuit, the frequency response is absolutely flat, only the phase angle changes. We control the phase angle with a trimpot connected to  $R_1$ .

The strategy in driver phase alignment for a 3-way system is to use the midrange driver as home base. We do not attempt to shift the phase position of the midrange. Instead we shift the woofer and the tweeter to match the phase position of the midrange using the all pass phase shift circuit from *Fig. 5*. The final circuit for a 3-way electronic 4th order crossover will be built around the three circuits shown in *Figs. 2, 3* and *5*. Before establishing component values for the phase shifting circuit, we must know how much phase shift is required for the woofer and the tweeter. The next section shows how.

**MEASURING PHASE ANGLE.** The only equipment necessary to measure phase angle is an oscilloscope and a sine wave generator. The test setup and oscilloscope patterns are shown in *Figs. 6A* thru *6G*. In *Fig. 6A*, "UUT" is the unit under test. *Figure 6A* shows that with both horizontal and vertical sweeps set for equal deflection, the pattern is a straight line inclined at 45 degrees for zero degrees phase shift between inputs to the oscilloscope. *Figure 6C* is also a straight line inclined at 45 degrees but it is in another set of quadrants, which indicates a phase angle of 180 degrees between inputs. These two patterns have no ambiguity. Their preciseness leaves no doubt as to the angle. The measurement of other angles is not quite so easy. For example, *Figs. 6C* thru *6F* show patterns which leave you with an either-or choice. To ascertain which is which we

employ a "phase reference circuit" (PRC), which is simply a resistor and capacitor in series to form a first order low pass filter (Fig. 6G) and connected across the output terminals of the sine wave generator (SWG). In first order filters, R and C must be chosen so that  $R = X_c$  at the measuring frequency (this would be  $F_c$  for the first order filter). If we arbitrarily choose C as .047 $\mu$ F (a standard value), then at 400Hz (arbitrarily chosen measuring frequency):

$$x_c = \frac{1}{2\pi fc} = \frac{10^6}{2\pi 400(.047)} = 8.47k\Omega$$

(use  $R = 8.2k\Omega$ ). We know (see Fig. 1) the phase angle of this PRC is 45 degrees lagging and can use it as a reference point to determine whether the angle we are measuring is leading or lagging. In Fig. 6, first calculate the phase angle by measuring "A" (the Y intercept) and "B" (the height of the ellipse) and then  $\sin \theta = A/B$ . If you set B equal to 2cm and A is 1.414cm then the ratio is .707 and the angle is 45 degrees either leading or lagging. Now move the lead from the scope's vertical sweep to the point between the R and C on PRC. If the new pattern is a straight line (Fig. 6B). The UUT has a lagging phase angle. If it is a circle (Fig. 6F) the UUT has a leading phase angle. The technique applies in like manner for all other angles keeping in mind that the PRC will make the test angle smaller in quadrants 3 & 4 and larger in quadrants 1 & 2. Of course, the values of R and C must be reselected for changes in measuring frequency.

**PHASE BETWEEN DRIVERS.** In addition to phase shift, which may occur in the crossover, phase shift occurs because driver current is seldom in phase with the input voltage (driver current determines the phase of the acoustical output). Another factor which affects the acoustical phase of a driver is its physical geometry (the shape and size of the cone, location of the driver coil, and its location in the speaker cabinet). We assume that all drivers are mounted on the same flat baffle. By using phase shifting circuits we can correct most of the factors which contribute to phase misalignment among drivers.

To measure phase angle between adjacent drivers at the crossover frequency, obtain two identical dynamic mikes. They should be acoustically invisible (as small as possible) but a diameter of about 3/4" will work. Connect each to an audio or microphone amplifier with a gain of about 40dB for a good deflection on the scope. Refer to Fig. 7 for the test setup. The mikes measure acoustical phase angle between drivers. The gauges (Fig. 8) are necessary to get accurate and repeatable spacing between the drivers

and the mikes. At 400Hz, which could be the crossover between woofer and midrange, the wave length is 33". Over this distance the phase shift is nearly 360 degrees (11 degrees per inch). At 3500Hz (the crossover between midrange and tweeter) the wave length is only 3.8" (6 degrees per 1/16"). Precise and careful spacing of the microphones is very important for obtaining accurate measurements. The gauge for the high

frequencies allows 3" between baffle board and mike while the other gauge allows 6". These distances are within the first wave propagated by the drivers (to avoid disturbances from room reflections). Keep any reflecting surfaces well away from the front of the speakers and yourself at least 10' away while making measurements.

Using the setup in Fig. 7, place the mikes in the exact center of the woofer in

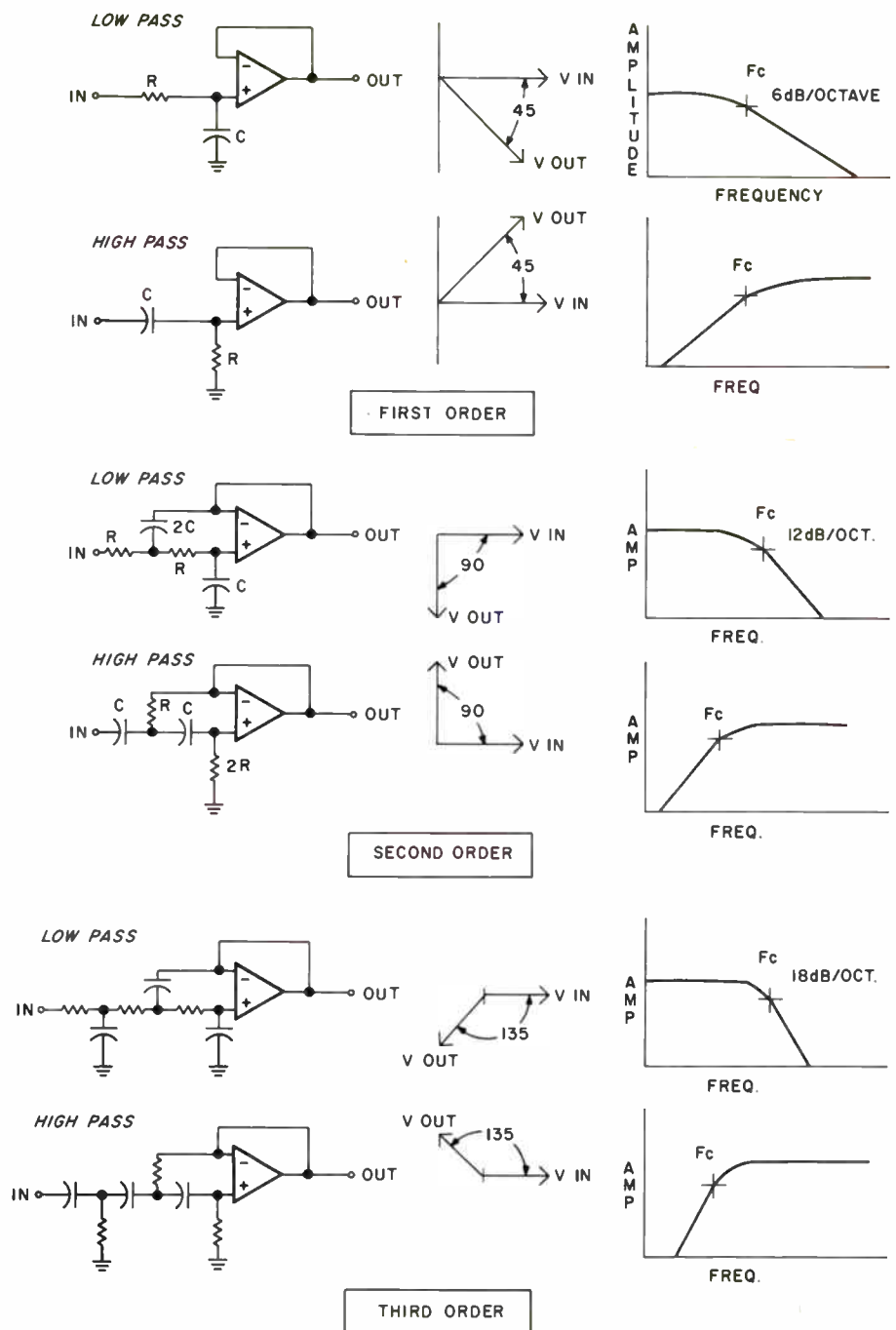
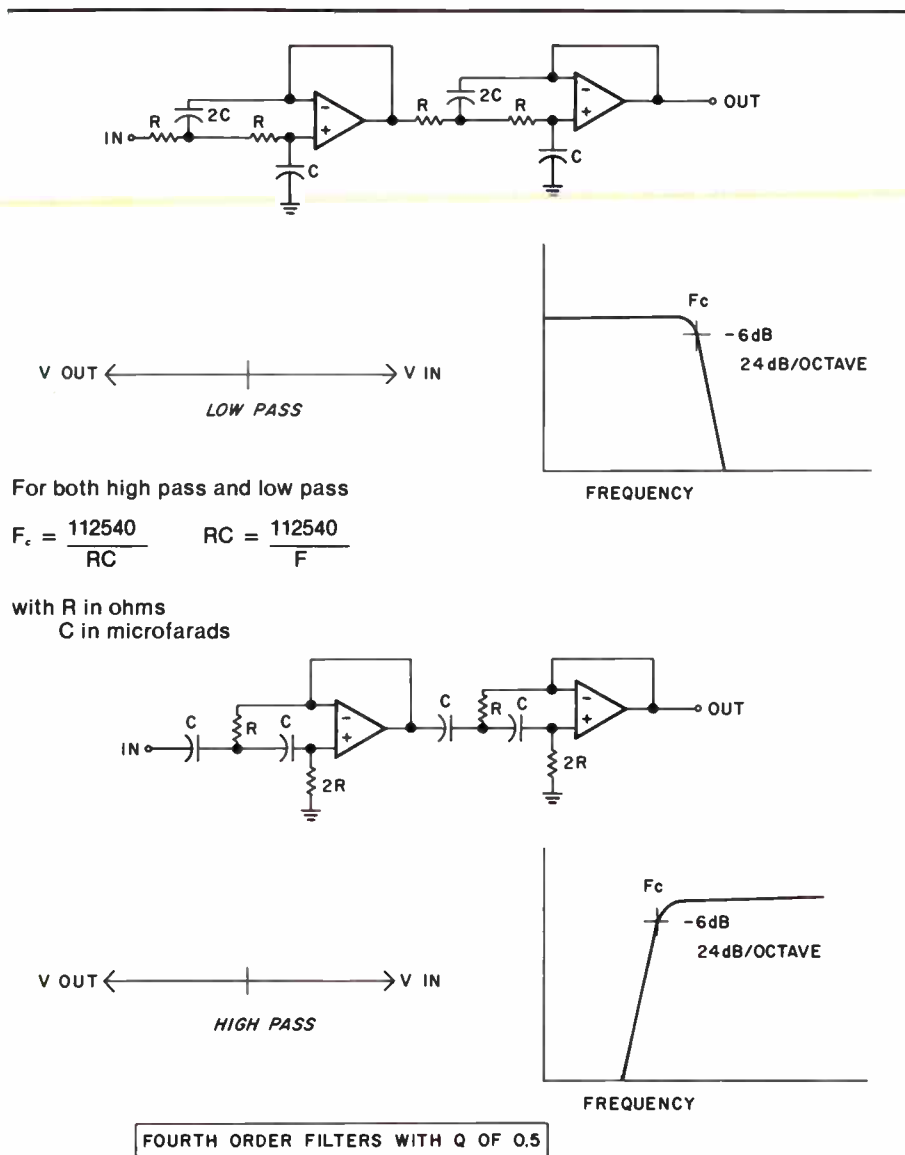


FIGURE 1. The phase and frequency response of first, second, and third order filters all have undesirable characteristics. Phase delay occurs when the phase vector rotates clockwise from  $V_{IN}$  to  $V_{OUT}$ . None of the three has an output with the high and low pass in phase with each other.



**FIGURE 2.** In fourth order filters, a very sharp rollover slope occurs, and the high and low pass outputs are in phase with each other.

the right channel and midrange driver in the left channel. The reason for placing mikes for drivers in opposite channels is to minimize the effect of one driver on the other when close together. Left and right channel speakers should be about 8-10' apart and not facing each other. Set the SWG to the crossover frequency and increase the volume to obtain acceptable deflection. Keep the volume as low as possible to obtain good sine wave output from the drivers and to avoid damage to drivers from a sustained sine wave input. Next connect B to V and D to H, measure and record the woofer's phase angle, and check quadrant location with a PRC (A to V). Next connect B to V and C to H, to measure the midrange's phase angle.

Refer to Fig. 9 for a method of determining phase angle between woofer and

midrange. Woofer phase angle is 70 degrees in the third quadrant while the midrange measures 65 degrees in the fourth quadrant. The sum is 135 degrees, and subtracting it from 180 degrees leaves 45 degrees, the phase shift between woofer and midrange, with the woofer lagging. The values of R and C in the woofer phase shifting circuit must provide 45 degrees leading phase shift to bring it into phase with the midrange.

As a double check of phase angle, connect both microphones to the scope (C to V and D to H). This angle should be 45 degrees, the phase difference between the woofer and the midrange. However, this check does not tell you whether the woofer is leading or lagging. The difference measurement just completed tells you this. Then go through the same

steps to find the phase angle between midrange and tweeter. As is often the case, you may find that the phase angle between dome tweeters and cone midranges is close to 180 degrees. If so, the easiest way to get phase alignment is to reverse the leads to the tweeter and then measure the phase angle, which should be relatively small. Determine if the tweeter is leading or lagging. With all this completed, you have enough information to calculate the proper resistor and capacitor values in the phase shifting circuits for the woofer and the tweeter. Values for R and C also can be obtained from the very flexible charts in Johnson and Hilburn's *Manual of Active Filters*. Leave the midrange drivers in their original position for now. They will be swapped later.

**COMPLETE CROSSOVER.** The complete circuit for one channel of an electronic crossover using the building blocks previously presented is shown in Fig. 10. Three 4136 IC op amps and three 531 IC op amps are used in each channel. A circuit for the power supply is not shown, but it should be a well filtered regulated and balanced  $\pm 15V$  supply. Many excellent circuits are described in *The Audio Amateur* and other publications. Twelve  $0.1\mu F$  capacitors ( $C_{27}$  thru  $C_{38}$ ) bypass the power supply leads at the IC pins. The first section (A1) is an inverting buffer to present correct input impedance (value of  $R_1$ ) to the output of the preceding preamp and to provide low output impedance to the rest of the circuit. Set the gain ( $K = R_2/R_1$ ) of A1 at 2.0 to compensate for the loss in the phase shift circuits (A2A and A6A). The gain could be higher if desired for a particular application but you might suffer loss of bandwidth.

**MIDRANGE SECTION.** Since the midrange driver is the pivotal driver in a phase aligned system, we will consider it first. The 400 to 3500Hz bandpass presents some special problems which require empirical corrections. When the 400Hz high pass is connected in series with the 3500Hz low pass filter to form the bandpass they interact, shifting the 180 degree and -6dB points. The first correction is to add the circuit of Fig. 3, to have a variable Q. Experimentation has shown the following corrections necessary:

1. Frequency  $F_c$  shifts at both ends of the bandpass and the value of R, as determined by  $RC = 159155/F$  (C remains constant), must be increased by  $10^6$  for the low pass and decreased by  $10^6$  for the high pass to maintain the targeted  $F_c$  at 180 degrees.
2. The -6dB point drops to about -7.5 to -8.0dB and Q must be in-

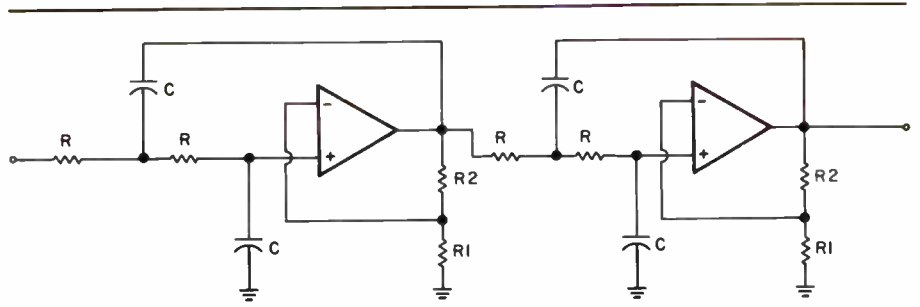


creased from 0.50 to 0.56. In Fig. 10, one of the second order filters in both the low and high pass is connected for unity gain which automatically provides a Q of 0.5 ( $Q = 1/(3-k)$ ). The other second order filters have variable gain, thus variable Q. These must have a Q of 1.12 to have an overall Q of .56 because a Q of 1.12 requires a gain of 2.107 with  $K = (R_{24} + R_{33})/R_{24}$  and  $(R_{33} + R_{32})/R_{33}$ , make  $R_{24}$  and  $R_{33}$  18kΩ and  $R_{33}$  and  $R_{32}$  20kΩ for a K of 2.111 and a Q of 1.125. The overall Q is then 0.5625.

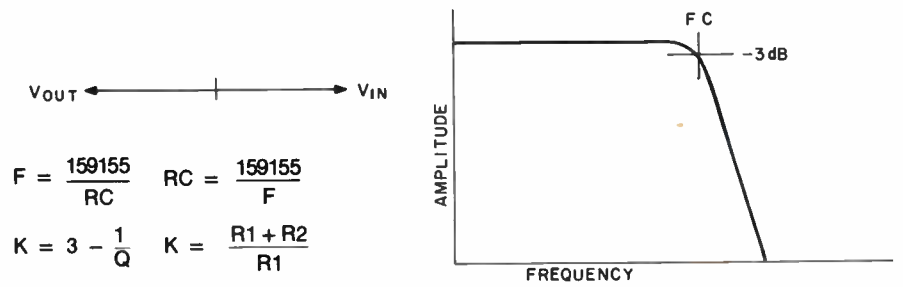
3. With gains of 2.0 in the buffer (A1) and 2.111 in both the low pass and high pass filter, the overall gain is 8.9 (19dB) which will overload the midrange amplifier severely. Therefore, attenuators A3 and A5, inverting amplifiers with gains of 0.237 and .47 respectively, attenuate the signal so the output of A4D has unity gain. Inverting amplifiers provide gains of less than 1.0 and double inversion keeps the signal in-phase. With  $R_{19}$  equal to 4.3kΩ and  $R_{18}$  equal to 18kΩ, k is .239. With  $R_{28}$  equal to 4.7kΩ and  $R_{27}$  equal to 10kΩ, K is .47. The phase angle must be exactly 180 degrees at  $F_c$ . The -6dB point can be  $\pm 0.5$ dB.

**WOOFER SECTION.** The sequence may seem odd with phase shift first, then the low pass, and finally the rumble/bass boost filter, but the final output at trim pot  $R_{19}$ , is not affected by the order in which the various elements are connected. I placed the phase shifter, with its gain of 0.5, first, to keep the signal level reduced. You can toss a coin for the other two. The 400Hz low pass uses the circuit from Fig. 2 for a Q of 0.5, a gain of 1.0 and -6dB at 180 degrees for  $F_c$ . The two feedback capacitors in parallel provide a value exactly twice that of the capacitor to ground so all capacitors have equal values.

I have added the rumble filter and bass boost (A2D) to show what can be done with electronic crossovers to tailor driver response for smoother frequency balance. I strongly recommend using an infrasonic filter (especially for transmission line speakers which have minimal damping at the ultra-low frequencies), because excessive woofer pumping will muddy the bass notes and will draw excessive power from the amplifier, causing distortion in the audible range. This high pass filter is a hybrid third order, chosen to obtain maximum attenuation (18 dB/octave) with only one op amp. You can vary the amount of bass boost by altering the values in  $(R_{13}/R_{16})/R_{14}$ . With a ratio greater than two, you obtain bass boost. For example, with a ratio of 13.8 and with  $R_{14}$  equal to 15kΩ,  $R_{16}$  of 2.2 megohms,  $R_{13}$  of 220kΩ and with  $C_{10} = C_{11} = C_{12} = .047\mu F$ , bass boost is 6.8dB at 26Hz and the -3dB point is at 18Hz. The



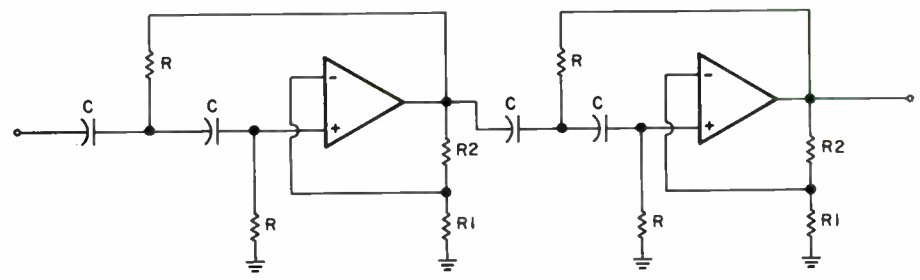
LOW PASS



$$F = \frac{159155}{RC} \quad RC = \frac{159155}{F}$$

$$K = 3 - \frac{1}{Q} \quad K = \frac{R1 + R2}{R1}$$

$$Q = \frac{1}{3 - K}$$



HIGH PASS

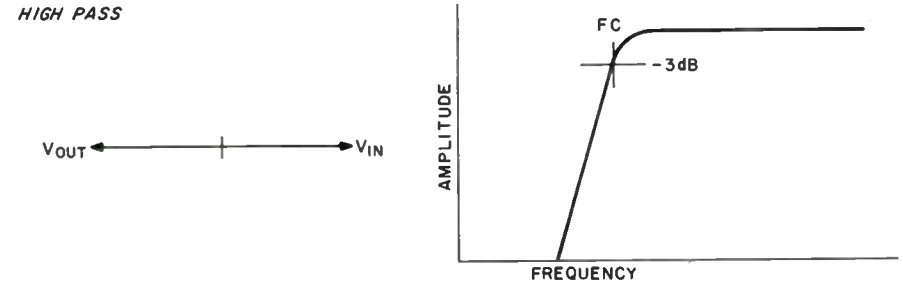


FIGURE 3. By changing the values of resistors ( $R_1$  and  $R_2$ ) the Q (resonance) of the filter can be altered.

frequency response curve for the rumble filter and bass boost is given in Fig. 11. With the realization that 6.8dB of boost results in more than a fourfold increase in power at 26Hz, bass boost of this amount is recommended only if:

1. Woofer can handle extra drive at low frequencies without undue distortion.
2. Woofer power rating is adequate.
3. Woofer amplifier rating is adequate.

If you want the rumble filter without bass boost, then make  $R_{14}$  equal to 33kΩ,  $R_{13}$  equal to 82kΩ, and  $R_{16}$  equal to 560kΩ

with capacitors remaining the same. Since the rumble filter is a high pass in series with the 400Hz low pass filter, some interaction between them occurs as in the bandpass for the midrange. However, since the two cutoff frequencies are more than four octaves apart the effect is not as severe. You can adjust  $R_6$  to set the 180 degree and -6dB point without any further changes.

**TWEETER SECTION.** The 3500Hz high pass filter for the tweeter is more

simple and straight forward. The circuit is from Fig. 2 with  $F_c$  at 180 degrees and -6dB attenuation. Note that no true high pass filters exist using op amps because of the limited bandwidth of the op amps. However, the 4136 in this circuit is flat beyond 80kHz which is more than adequate for audio applications.

Trim pots  $R_{17}$ ,  $R_{30}$ , and  $R_{47}$  provide separate level control for each of the amplifiers. Other trim pots are scattered throughout the circuit for adjustment of phase alignment. Straps  $S_1$  through  $S_4$  can be used to isolate certain portions of the circuit during test and adjustment.

Next Issue: Complete step by step instructions for phase-aligning your system using the crossover's phase adjusters and a simple but effective method of measuring phase differences among driver outputs. The circuit board and parts list will appear also.

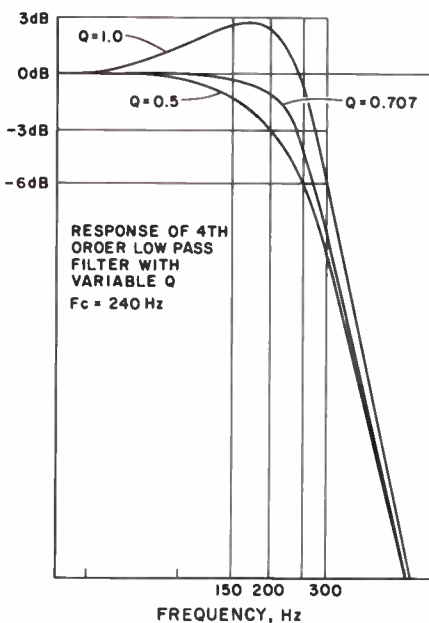


FIGURE 4. Changing the Q alters the response curve. When  $Q = .707$ , the curve extends further along the 0dB line than for any other value, or is "maximally flat."

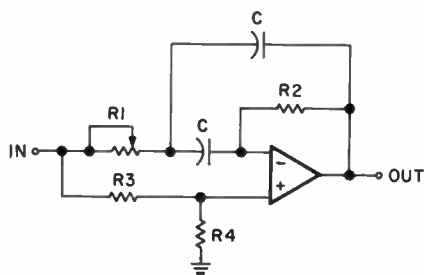


FIGURE 5. An all pass filter makes a good phase shifter. By using a variable resistor for R, the phase shift can be adjusted as desired.

FIG. 6A

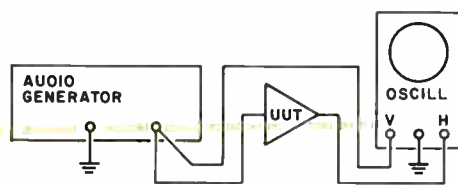


FIG. 6B

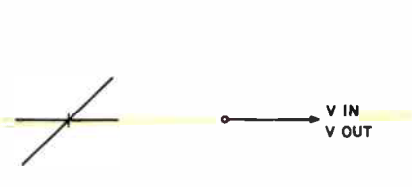


FIG. 6C

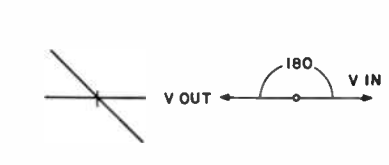


FIG. 6D

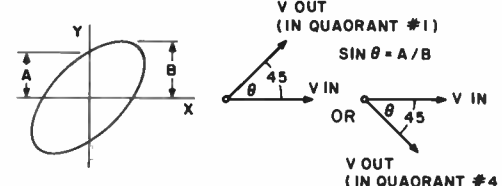


FIG. 6E

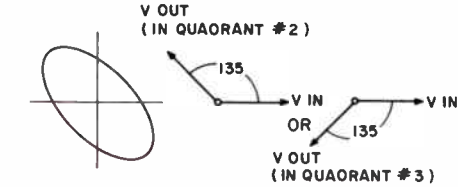


FIG. 6F

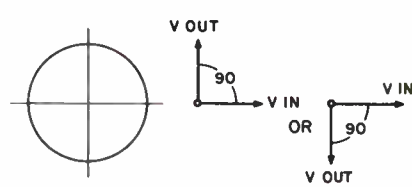


FIG. 6G

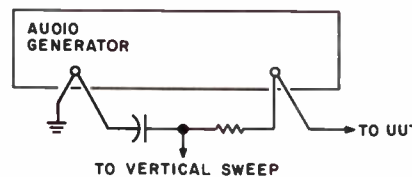


FIGURE 6. Testing phase angle requires only an oscillator and an oscilloscope. When the scope shows the patterns in B and C, phase shift is 0 and 180 degrees respectively. In D and E, the ellipse has poles in two quadrants, so to determine whether phase shift leads or lags, use a "phase reference circuit" with known shift, as shown in G. Leading phase will show a circle as in F, lagging phase, a straight line.

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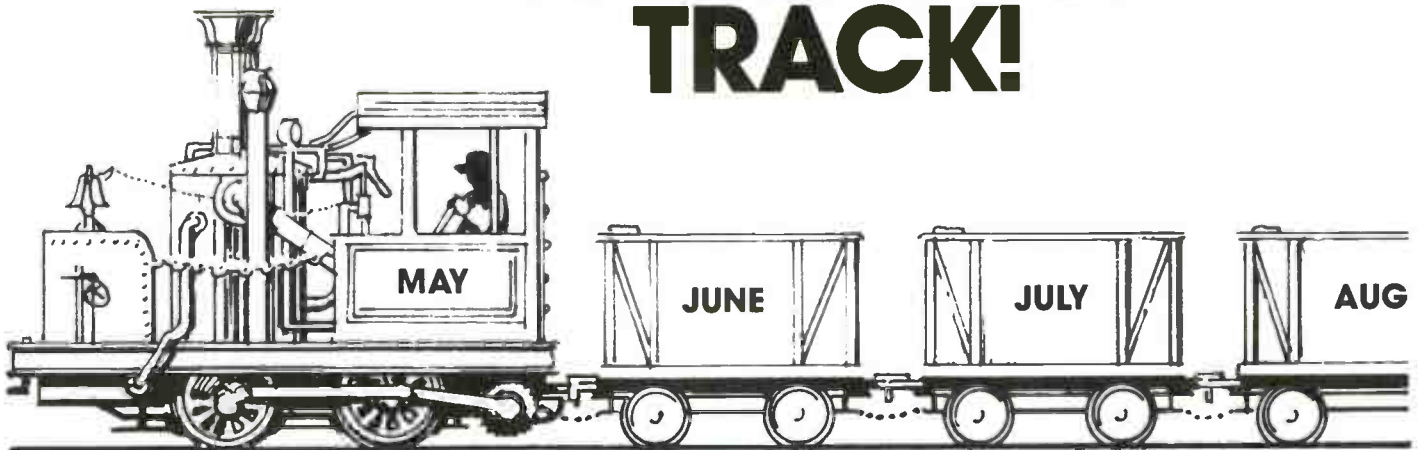
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# CUSTOM WOUND INDUCTORS

BY DANIEL PATRICK COYLE

Most of us who construct our own loudspeaker systems would like to make the crossover, as well. Commercially available high quality passive crossovers are quite expensive and available only in certain frequencies. One solution is to assemble your crossover from scratch, winding your own inductors with wire bought from a local electric motor rebuilder. My experience has been that rebuilders will sell copper wire at \$3.00 per pound on up, quite cheap compared to the electronic parts stores.

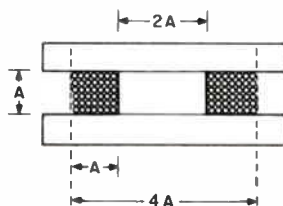
**HOW IT WORKS.** An inductor, in case you have not seen one, is a winding of copper wire on a spool. Its final shape is like a doughnut. The current of the audio signal in the inductor sets up a magnetic field in which the close proximity of one turn of wire to the next causes a mutual reinforcement of the magnetic field. When the audio signal's current reverses its electrical polarity, as it does each audio cycle, the magnetic field's north-south polarity also has to reverse.

Once established, the field does not "want" to collapse and reverse direction. (The mechanical equivalent is inertia.) This property makes it difficult for an AC signal (as audio is) to get through an inductor and presents mounting impedance to the signal as the frequency gets higher and tries to reverse its polarity more often. The overall effect is of passing low frequencies while impeding high frequencies, just what we need for a crossover network. (A capacitor, the other principal component of a crossover network, has the opposite effect, passing highs and impeding lows.)

Adding more turns of wire increases the strength of the magnetic field, as does putting something in the center of the coil that passes magnetic lines of force more easily, such as iron. (This is a description of a voice coil around its steel pole piece, hence a loudspeaker's sizable inductance.) In passive crossover inductors which are subjected to high power

levels, the large magnetic field created can supersaturate an iron core, giving nonlinear performance. For this reason air-cored inductors generally are preferred for high quality, high power applications, even though they require more copper, thus costing more.

**TAKE-APART FORMER.** I have found it easiest to wind inductors on a former that will disassemble to yield the finished coil on its center core. I then re-use the two side plates for the next coil. I have made formers of scrap, using two sheets of  $\frac{1}{4}$ " particle board or plywood, cut in a 5" square, as the outside of the form. Make the center core of the appropriate diameter wood doweling cut to the correct height for the coil (see Fig. 1). Drill a  $\frac{1}{4}$ " diameter hole through the assembled former and along the center axis of the wood dowel. Put a 4" long  $\frac{1}{4}$ " bolt through this hole and run a nut down to tighten the form together. Then put the free bolt end in the chuck of a drill. Precut the wire to length. Wind a random-winding coil. Keep enough tension on the wire to ensure a tight, even wind. Remember, both ends of the wire must be accessible at the finish. When you have finished, tape the outside of the wire bundle and carefully disassemble the former. Then tape the coil radially to



**FIGURE 1.** When winding the coil, these relative dimensions of core size, height of windings and coil width must be observed to obtain the desired inductance. The end plates are removable.

hold the bundle together. You may also use wax, lacquer, or nylon ties to hold it together.

I have found it easiest to leave the wood plug in place in the center of the coil. It becomes a boss for a nonmetallic fastener (nonferrous is not enough), such as a  $\frac{1}{4}$ " wood dowel, sunk into the speaker box or whatever. A large diameter dowel is hard to find. I have added cardboard and tape to 1" dowel to make larger center cores.

**BALANCING INDUCTANCE AND RESISTANCE.** A. N. Thiele, in his article "Air-cored Inductors for Audio,"<sup>1</sup> describes how to size the form on which the inductor is wound. He gives a method to approximate the needed wire length and gauge. I will describe a simplified method, derived from Thiele, for use with a pocket calculator. Our goal is to have a low DC resistance in the coil, because excess resistance changes the "alignment" of the speaker, by altering the total "Q," or behavior at resonance. Thiele suggests that the inductor in the crossover network have a DC resistance no more than  $\frac{1}{20}$  of the impedance of the speaker. For an  $8\Omega$  speaker,  $0.4\Omega$  of series resistance would be a typical value. For a given wire material, the two variables determining the DC resistance are the gauge and the length of wire. Thiele has given a simple description of optimizing the coil's dimensions to get a given inductance from the shortest length of wire, hence the least DC resistance and expense.

**FINDING ELECTRICAL VALUES.** Determine the crossover frequency,  $f_c$ , you want for the speaker. Generally, a midrange or tweeter's lower limit might be at twice the frequency of resonance of the speaker.<sup>2</sup> The upper limit for a woofer or midrange might be  $KA=2$ , or expressed another way, 8556 divided by the actual diameter of the radiator in inches.

Find the time constant of the crossover frequency. The time constant is ex-

Inductor L in  $\mu\text{H} = (Z_L)(T_c)$ ;  
Capacitor C in  $\mu\text{Farads} = (T_c)/(Z_H)$

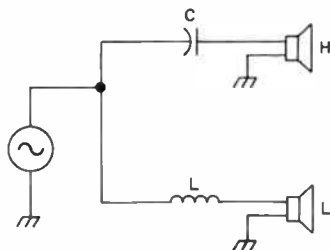


FIGURE 2. A first order, parallel, Butterworth crossover requires only one coil.

$$Z_H = Z_L, L = (Z)(T_c)/\sqrt{2/3}, C = [(T_c)\sqrt{2/3}]/Z$$

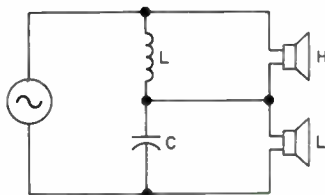


FIGURE 3. To convert the parallel first order to a series Butterworth circuit, you must calculate different values for C and for L.

$$L = Z T_c \sqrt{2}$$

$$C = T_c / Z \sqrt{2}$$

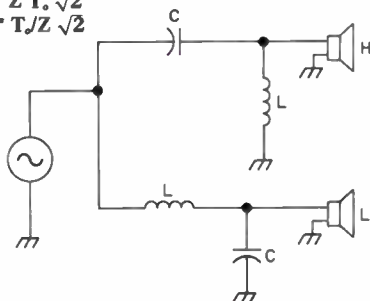


FIGURE 4. A second order parallel filter requires two coils.

$$L_{1L} = (3Z_L T_c)/2$$

$$L_{2L} = (Z_L T_c)/2$$

$$L_H = (3Z_H T_c)/4$$

$$C_{1H} = 2T_c/3Z_H$$

$$C_{2H} = 2T_c/Z_H$$

$$C_L = 4T_c/3Z_L$$

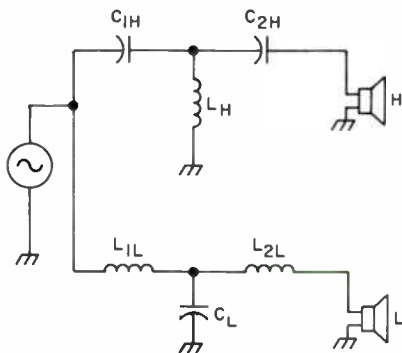


FIGURE 5. Third order crossovers require three coils.

TABLE I  
PROPERTIES OF COPPER WIRE

GAUGE NUMBER	DIAMETER (INCHES)	OHMS PER 1000 FT.
10	.10190	.9989
11	.09074	1.260
12	.08081	1.588
13	.07196	2.003
14	.06408	2.525
15	.05707	3.184
16	.05082	4.016
17	.04526	5.064
18	.04030	6.385
19	.03589	8.051
20	.03196	10.15
21	.02845	12.80
22	.02535	16.14
23	.02257	20.36
24	.02100	25.67
25	.01790	32.37
26	.01594	40.81

pressed in microseconds ( $\mu\text{S}$ ) and is symbolized by  $T_c$ :

$$T_c = (1,000,000)/(2\pi f_c), \text{ or}$$

$$T_c = (159155)/(f_c)$$

Determine the impedance, Z, of the speaker at the crossover frequency. This value is expressed in ohms and often is different from the speaker's nominal value of 8 or  $4\Omega$ . Consult the manufacturer's impedance graph of the speaker, or for more accurate results, test the particular driver to determine its actual characteristics.

Determine the amount of inductance, L, needed. This will vary, depending on (A) the type of crossover configuration (first, second, third order),<sup>3</sup> (B) the impedance of the speaker at  $f_c$ , and (C) in the special case of parallel Butterworth networks as described by R. Small,<sup>4</sup> the actual voice coil inductance, which should be subtracted from the crossover network inductance. A brief schematic and design formulas are given in Figs. 2-5, adapted from E. Baekgaard.<sup>5</sup> For convenience in our calculations, values of inductance are expressed in microHenrys and symbolized by L. (One Henry equals 1,000 milliHenrys, mH, and one million microHenrys,  $\mu\text{H}$ ).

Decide what amount of DC resistance, R, in ohms, is acceptable. Thiele<sup>1</sup> uses 5% of the speaker's nominal impedance at  $F_c$ . Greater resistance affects damping, alignment and power output of the speaker. Less resistance, for low frequency crossovers, rapidly becomes more expensive. [An exception to the lower-resistance-is-better maxim is the special case of an over-damped driver of

great efficiency, where an increase in resistance can help raise the Q to a more usable value].

**HOW MUCH WIRE?** Now calculate the former shape, wire length and gauge. Calculate the dimensions of the coil former, expressed in inches. Once the form's height, A, is found, the coil's other dimensions become fixed.

$$A = \sqrt{(T_c)(Z)/(5590)(R)}$$

2A = inner diameter of form in inches.

4A = outer diameter of form in inches.

Find the length of the wire in feet, W.

$$W = (3.14) [\sqrt{(L)(A)}]$$

(L is in  $\mu\text{H}$ , A is in inches.)

Find the number of turns in the inductor, N.

$$N = (3.94) [\sqrt{(L/A)}]$$

Find the cross-sectional diameter (gauge) of the wire, expressed in inches as  $W_d$ .

$$W_d = (0.841)(A)/\sqrt{N}$$

(see Table 1 to convert to wire gauge.)

Find the weight of wire needed to wind the inductor, expressed in pounds as  $W_{lb}$ .

$$W_{lb} = (1.683)(A^3)$$

These core dimensions assume neatly wound coils, where each winding is next to the previous. For the less fastidious of us, random-wound wire will be the likelihood. In this case, I have found that a slight increase in coil height, about 10%, will maintain the optimum coil shape. Final fine adjustment of inductance values, by adding or removing wire, will not change the coil shape significantly. □

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4. Richard H. Small, "Constant-Voltage Crossover Network Design," *Journal of the Audio Engineering Society*, January 1971.
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# ELECTRONIC CROSSOVERS REVISITED

BY THE EDITOR

Many *Speaker Builder* readers have written to us in the wake of Walt Jung's series in *The Audio Amateur* on IC distortion (Issues 2 and 3, TAA 1978) asking why we don't update past projects which contain IC's, especially those using the 741. Alas, we seem to find time

for only our necessary day-to-day chores, and have little to spare for updating the past to the levels of the present.

The 741 has become an embarrassment and needs replacing by better descendants, especially in the electronic crossover we published in

TAA's issue 2, 1972 (see Fig. 1). We have updated the Old Colony circuit card for this crossover to accommodate dual-in-line eight-pin packages—see Figs. 2a and 2b for the new card. Jung advises using either the National LF 351 or the Texas Instruments TL 071 in this circuit as a direct replacement plug-in for the 741. Table A shows the results of such a change in the two-way version; using the LF 351.

When we come to the three-way crossover, however, we discover a snag. Our little design is a two-pole configuration giving a 12dB-per-octave slope. A growing body of evidence shows the 12dB slope has problems avoided by 18dB and 6dB slopes; so our crossover has that drawback as well as some notch cancellation in the way we derive the center channel by cancellation of 180° out-of-phase frequencies.

Note that in Fig. 2 IC3 inverts the main signal and feeds it to the uninverted low pass and high pass portions of the audio band. The output of IC4 is thus a center channel consisting of the main signal with the high and low signals cancelled out.

You can use the crossover in other ways, however. In Fig. 3 we cascade two DG-13R boards to produce a 12dB/octave, three-way crossover. Values for the two boards should be the two crossover points: for example, card 1 is set for the low frequency, card 2 for the high frequency.

## PARTS

All resistors  $\pm 1\%$  metal film.

C<sub>1</sub>, C<sub>2</sub>  $\pm 5\%$  low leakage polystyrene, polycarbonate

C<sub>3</sub>, C<sub>4</sub>  $\pm 1\%$  Mica

IC1, 2, 3, 4  $\mu$ ALF351N

Solder all terminal posts to copper foil for best long term performance.

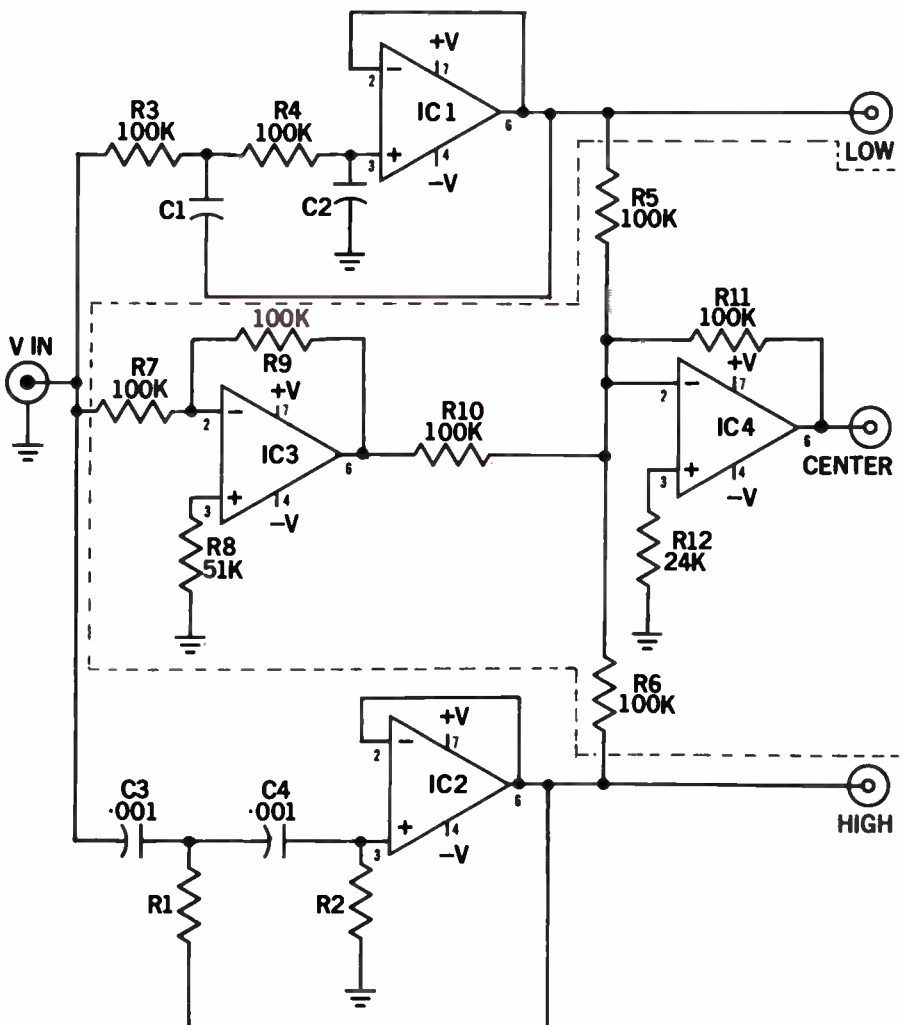


FIGURE 1: The original crossover circuit published in TAA 2/72 can be improved by substituting the National LF351 or the TI TL071 for the old 741's. A much better solution is to modify the Jung 30Hz filter for use as a crossover.

In Fig. 4 we adapt the DG-13R board to a two-way, 18dB/octave configuration. You need only choose one crossover point. The first card omits one resistor/capacitor pair in each active filter, reducing it to a 6dB/octave configuration, with lower distortion and phase problems.

Fig. 5 shows the crossover's ultimate form. Four DG-13R boards and eight IC's produce a three-way, 18dB/octave slope to low, mid, and high pass bands. You'll have to choose two frequencies, one for cards 1 and 2 and the other for cards 3 and 4. See Fig. 3 for the 6dB/octave wiring instructions for cards 1 and 4.

**OTHER CHOICES.** In TAA issue 4, 1975, Walt Jung offered TAA readers far more than a 30Hz filter for eliminating infrasonic garbage. In that article he suggested the dual channel filter as a likely basis for two- and three-way crossovers, using the then-new 4136 IC with its four op amps in a 14-pin DIL package. The TI TL 075 is a worthwhile replacement of the 4136. Jung spelled out ways to set up the same board to make 6, 12, or 18dB/octave low pass or high pass filters, referring back to his comprehensive filter design articles which appeared in the first two issues of that same 1975 series.

We heard little feedback from those articles, but surmised they might be more useful if we digested the material a bit more and presented it here as a reminder to those who want the even better performance of the Jung crossovers.

Figures 6a and 6b (shown on pp. 15-16 of TAA 4/1975, as Figs. 3a and

**\*GAIN PROGRAMMING TABLE A**

	Gain	RF	RI
1	(0dB)	Jumper	4.7k
1.414	(3dB)	4.12k	10k
2	(6dB)	4.75k	4.75k
3.162	(10dB)	4.75k	2.21k
4	(12dB)	6.65k	2.21k

\*\*Let R6 be equal to DC resistance at Az (+) input:

$$R6 = R3 (R2 \text{ or } R1) - \text{HP}$$

$$R6 = R1 + R3 - \text{LP}$$

Old Colony (PO Box 243, Peterborough, NH 03458) will offer two-way and three-way crossover kits based on the Jung design, unity gain, three-pole, 18dB/octave, at the frequencies listed in Table B only. OCSL will also offer common bass units based on the Jung design, with the 6dB gain for each common output. Only the three frequencies in Table C will be offered for these common bass kits.

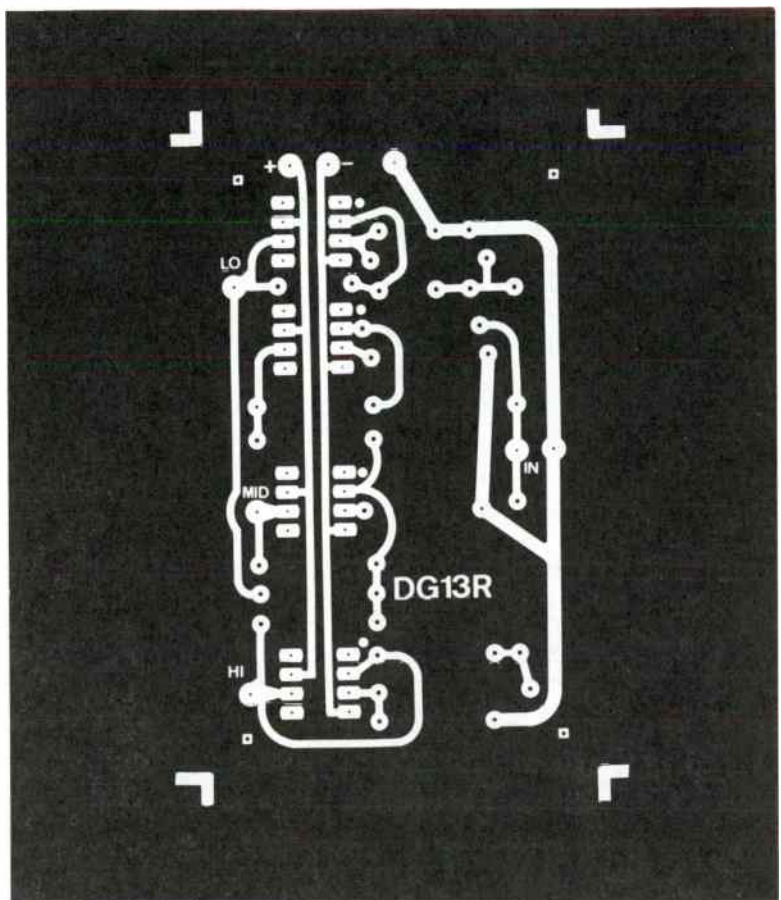


FIGURE 2a: DG-13R board.

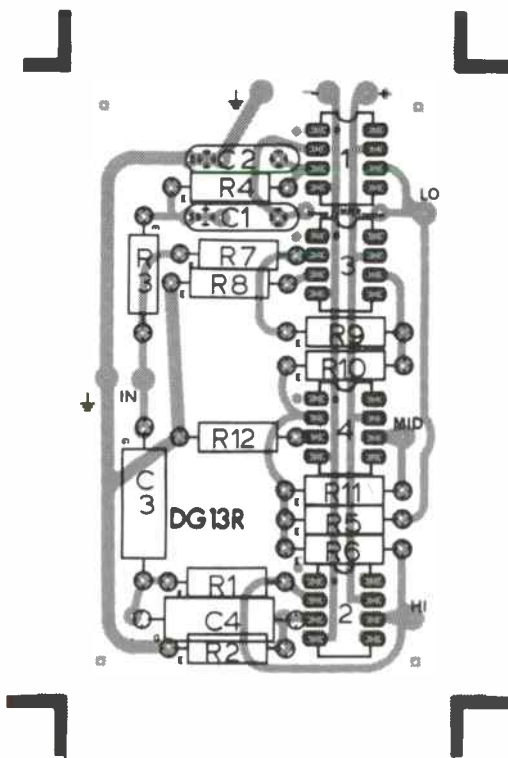


FIGURE 2b: Layout guide for DG-13R board.

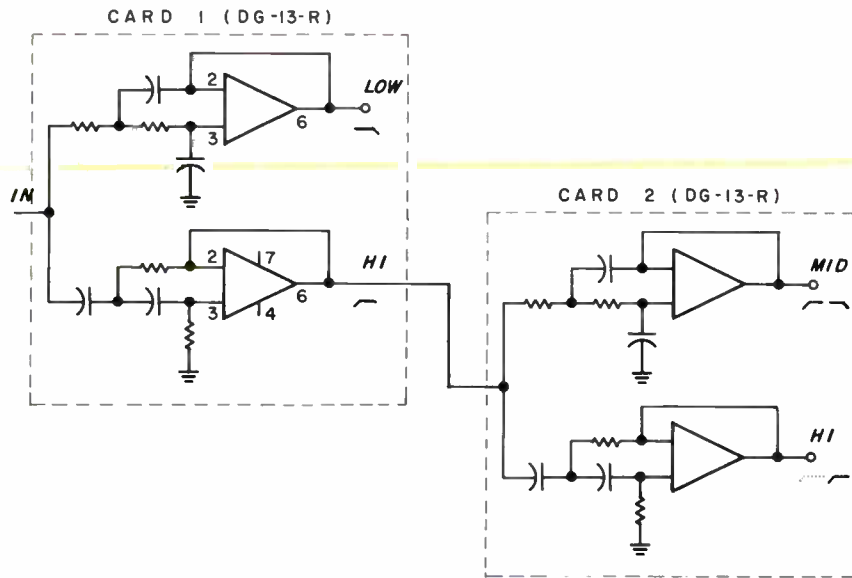


FIGURE 3: 12dB/octave, three-way, one channel Butterworth. All outputs are in phase, and same phase as input.

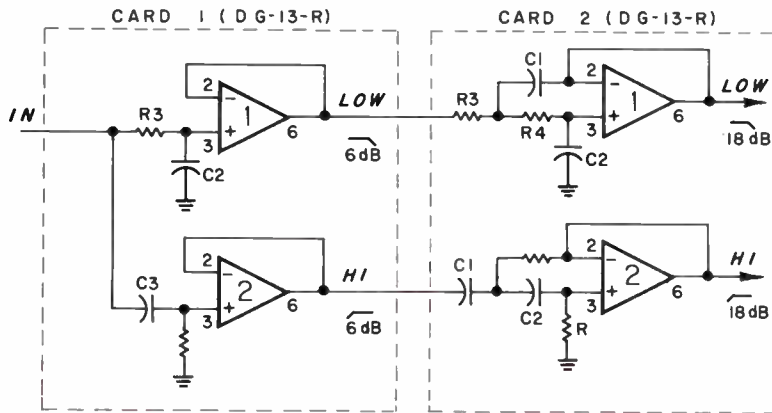


FIGURE 4: 18dB/octave, cascaded, two-way crossover, one channel use jumpers in place of  $R_1$  and  $C_1$ . Omit  $R_2$ ,  $C_2$ ,  $R_3$ ,  $C_3$ . Frequency determining elements are the same for both cards.

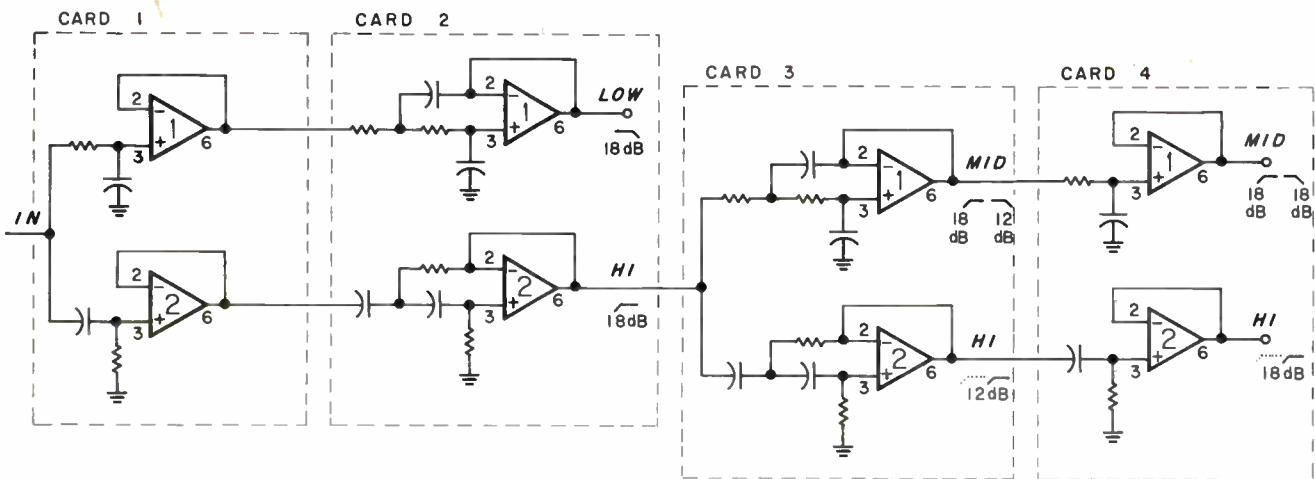


FIGURE 5: Three-way, 18dB per octave utilizes four single channel boards for one audio channel. Boards 1 and 4 omit  $R_2$ ,  $C_2$ ,  $R_3$  and  $C_3$ . Install jumpers in place of  $R_1$  and  $C_1$ . Choose one frequency for cards 1 and 2, the second frequency for cards 3 and 4.

3b) represent the basic filter configuration. Table B gives resistor values for eight frequencies based on making  $C_1$ ,  $C_2$ ,  $C_3$  equal in value and  $.022\mu\text{F}$ . Altering  $R_1$  and  $R_2$  from unity gain to 12dB makes variable gain possible in each filter. Inset is the voltage dropping/regulating network required to convert a  $\pm 15\text{VDC}$  supply to the requisite  $\pm 6.8\text{V}$ .

Figure 7a is a two-way crossover, one channel using a single WJ-3 (F-3) circuit card. The card's two channels are low frequency and high frequency, each set for the same frequency. The 18dB/octave, three-pole configuration is best for this usage. Figure 7b uses two WJ-3 (F-6) cards to develop a three-way crossover. Each card is set at the desired frequencies, with the second card producing both high and low pass for a midrange division. You could develop two midranges (using one card for each midrange and one for low and high) for a four-way crossover such as that in the Webb transmission line speaker (TAA 1/1975, p. 3). Table C details  $R_1$ ,  $R_2$ ,  $R_3$  values for Butterworth response high pass filters, using  $.022\mu\text{F}$  for  $C_1$ ,  $C_2$ ,  $C_3$ .

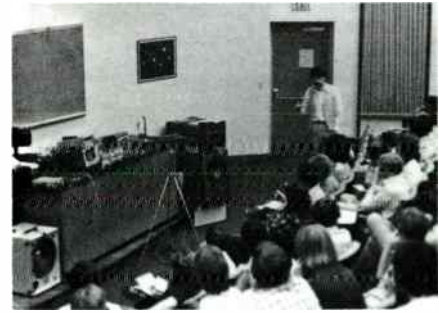
If you want a common bass, Jung suggests using two cards as in Fig. 7c. In this case we thought it wise to move the resistors to a common 100k value. We calculated a set of

TABLE B  
JUNG CROSSOVER PERFORMANCE

Input Z—50k $\Omega$   
Output Z—10 $\Omega$  Non-inverted  
Gain = unity  
Frequency response =  $\pm .2\text{dB}$  30Hz-160kHz  
Voltage  $\pm 15\text{V}$  at 6mA



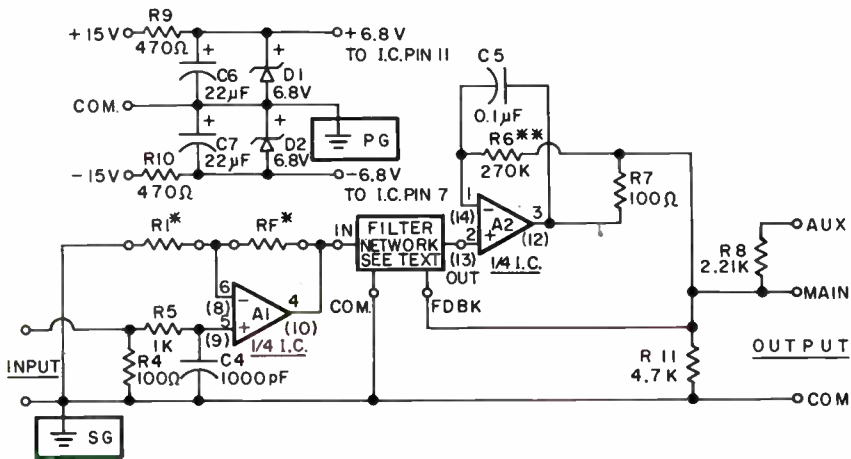
# JOIN AN AUDIO CLUB



**TABLE C**

for  $C_1 = C_2 = C_3 = .022$   
( ) = Nearest E24 values

	$R_1$	$R_2$	$R_3$
60	86.6 (82k)	34k (33k)	596k (620k)
120	43.3 (43k)	17k (16k)	298k (300k)
250	20.788k (20k)	8.160k (8k2)	142.96k (150k)
500	10.394k (10k)	4.080k (3k9)	71.48k (68k)
1000	5.197k (5k1)	2.040k (2k)	35.74k (36k)
2000	2.598k (2k4)	1.02k (1k)	17.87k (18k)
5000	1.0394k (1k)	408Ω (390)	7,148k (6k8)
10,000	519Ω (510)	204Ω (200)	3.57k (3k6)



**FIGURE 6a:** A general purpose VCVS filter configuration (one half shown)

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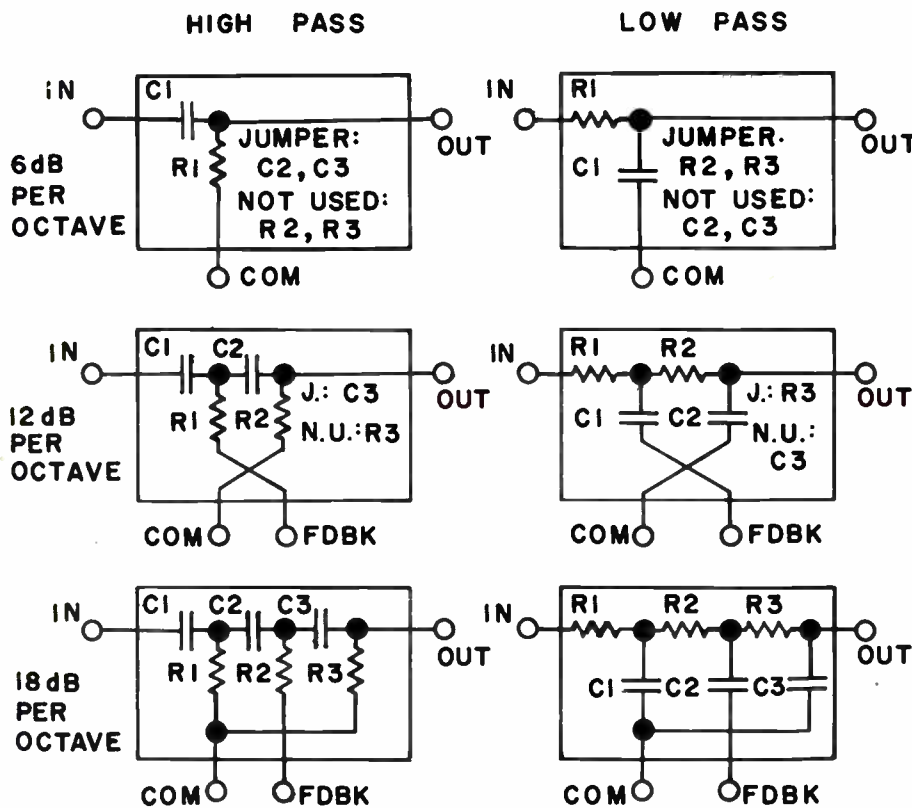
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- **Tours.** Get a behind the scenes look at the equipment and talk with the people who operate it at local TV and radio stations, universities, research labs, recording studios, and factories.
- **Newsletters.** These publications are often of high technical quality and are full of worthwhile information even if you don't attend many meetings. Ads and reviews help you find the right equipment, the latest records, and the dealers who carry them.
- **Evaluation and Testing.** Frequently clubs sponsor clinics so you can bring in your equipment for checkups on test equipment most individuals don't own.
- **Group Buying.** This can be an effective way to obtain obscure items from abroad, including audiophile disks.

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For more information, see the club listings in the Classified Ads of this issue. Clubs exist in many cities, including St. Louis; Calumet City, IL; Boston; Seattle-Tacoma; San Francisco (2); Honolulu; and Minneapolis. Clubs are being formed in Ft. Worth and Central Colorado.



**FIGURE 6b:** Filter networks for 6, 12 and 18dB/octave High and Low Pass filters.

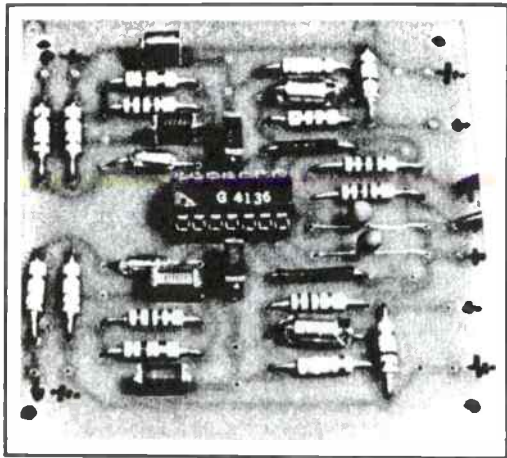


FIGURE 8: Photo of Jung 30Hz filter card.

capacitors for the L.P. common bass configuration as shown in *Table D*. Note that if you set the high pass segments of the two cards for unity gain ( $R_F = \text{jumper}$  and  $R_I = 4.7k$ ), you will need to add 6dB gain to each of the common bass channels to offset the loss by summing them. You can do this easily with 4.75k resistors in place of a jumper in the  $R_F$  position. In this case the  $R_I$  resistors are also 4.75k (see *Fig. 6a*).

**PERFORMANCE.** Crossovers are notoriously difficult to measure for distortion since they divide the frequency spectrum, thus eliminating the possibility of much intermodulation distortion. Harmonics are also difficult to detect. □

TABLE D  
JUNG COMMON BASS CROSSOVER

18dB per octave (Fig. 7C)  
( ) = Nearest E24 values  
( $R_1 = R_2 = R_3 = 100k$ )

	$C_1$	$C_2$	$C_3$
60	0.037 $\mu$ F (0.039 $\mu$ F)	0.094 $\mu$ F (0.1 $\mu$ F)	5370pF (5100pF)
90	0.025 $\mu$ F (same)	0.0627 $\mu$ F (0.062 $\mu$ F)	3580pF (3602pF)
120	0.0183 $\mu$ F (0.018 $\mu$ F)	0.047 $\mu$ F (same)	2635pF (2700pF)

Plus four—4.75k for 6dB gain in LF common outputs.

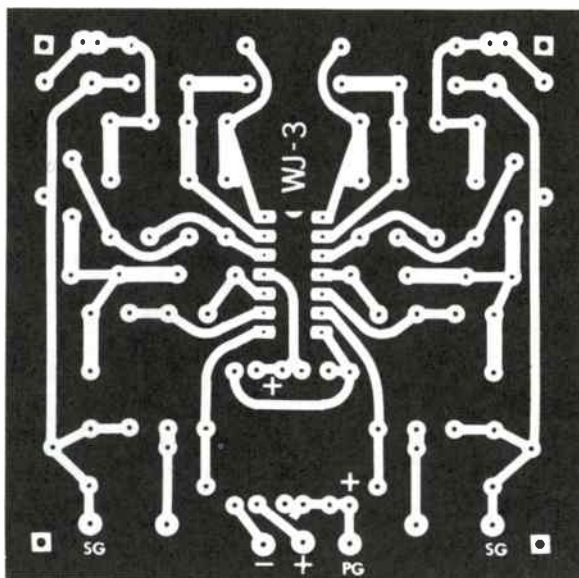


FIGURE 9: Jung filter card pattern.

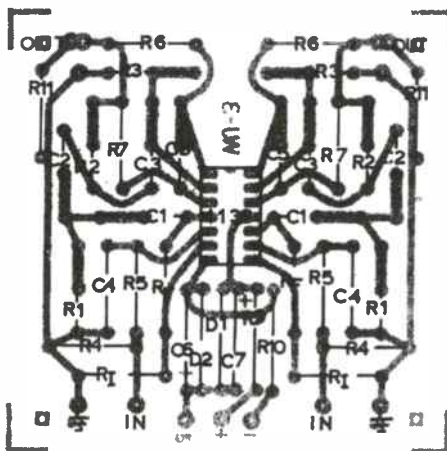


FIGURE 10: Jung filter card layout.

Hz	BASS (Low Pass)		TREBLE (High Pass)	
	$C_1$	$C_2$	$R_2$	$R_1$
60	0.047	0.022	1.8M	3.6M
120	0.022	0.01	1.8M	910k
240	0.01	0.0047	910k	470k
480	.0047	0.0022	470k	240k
960	.0022	0.001	220k	110k
1920	.001	500pF	110k	56k
5k	470pF	220pF	47k	24k
10k	220pF	120pF	12k	24k

PARTS LIST—WJ3 BOARD

- $R_1$  39k  $\pm$  1%, 1/4W met. film
- $R_2$  15k  $\pm$  1%, 1/4W met. film
- $R_3$  270k  $\pm$  1%, 1/4W met. film
- Above values for 30Hz filter; in general use 1% (or better) stable resistors, metal film recommended.
- $R_4$  100k  $\pm$  5%, 1/8W carbon film
- $R_5$  1k  $\pm$  5%, 1/8W carbon film
- $R_6$  270k  $\pm$  5%, 1/8W carbon film
- $R_7$  100 $\Omega$   $\pm$  5%, 1/8W carbon film
- $R_8$  2.2k  $\pm$  2%, 0.4W metal film
- $R_9, 10$  470 $\Omega$   $\pm$  5%, 1/8W carbon film
- $R_{11}$  4.7k  $\pm$  2%, 0.4W, metal film
- $R_I$  RF Optional—see table and text (general recommendations as  $R_1$ - $R_3$ )
- $C_{1,2}$  and  $C_3, C_5$  0.1 $\mu$ F  $\pm$  5%, 100W polycarbonate Siemens MKM
- Capacitor values for 30Hz filter; in general use MKM polycarbonates or polystyrenes; Siemens MKM B31110 or B31310.
- $C_4$  1000pF  $\pm$  5%, 160V polystyrene
- $C_6, C_7$  22 $\mu$ F 35V, tantalum Siemens
- $D_1, D_2$  6.8V 1/2W Zener  $\pm$  5%
- IC Quad op amp RC4136P (or RC4136D) Raytheon

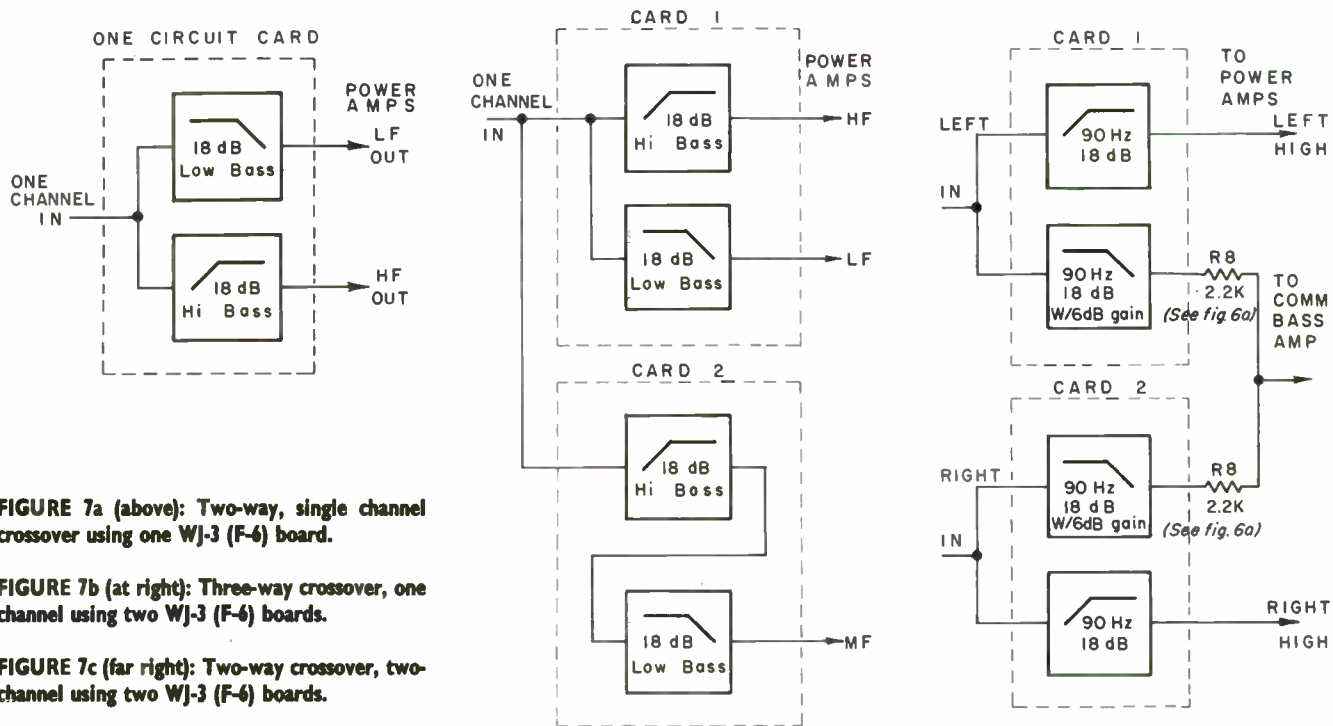


FIGURE 7a (above): Two-way, single channel crossover using one WJ-3 (F-6) board.

FIGURE 7b (at right): Three-way crossover, one channel using two WJ-3 (F-6) boards.

FIGURE 7c (far right): Two-way crossover, two-channel using two WJ-3 (F-6) boards.

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

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# A SPEAKER BUILDER'S ODYSSEY: PART I

BY ROBERT CARLBERG

It might have been inevitable that I would end up building my own speakers. My Christmas presents almost never lasted until New Year's without disassembly "to see how they worked." In addition, my father built a Heathkit amp and a Klipsch-copy cornerhorn in the '50s (when I was growing up), and I was only slightly less anxious to hear about the miters, bevels, resonances and roll-offs as he was to talk of them.

I have built eleven different speaker systems in the last 15 years, and attempted to learn something from each one. My success has been roughly linear in ascent, thanks to ready buyers for previous attempts, and the occasional trusting commissioner. The conclusions I have reached (some commonly held, some not) are therefore solely based on my own trial and error, rather than extensive textbook theory. This was made possible by the fact that, although electronics is surely based on magic, speaker building yields at least partially to a tinkerer's logic.

**SYSTEM 1: COKEBOXES.** I began on Christmas of 1965 when, after much hint-dropping, I received a GE portable phonograph. You know the type: spring-loaded tone arm, 0.5-watt amplifier (10% THD), and 3" speakers—not "Close and Play" but nearly. The molded plastic speaker enclosures, designed for cosmetics rather than sound, were barely 4" deep, which the family's well-thumbed copy of Chone's *Hi-Fi Loudspeakers and Enclosures* said was definitely not enough.

Let's see, if a 15" woofer needs 4ft<sup>3</sup> of internal cabinet volume, and a 12" woofer needs 3 ft<sup>3</sup>, and an 8" needs 2 ft<sup>3</sup>, then a 3" speaker would need 0.75 ft<sup>3</sup>, right? The 5" x 12" x 4" plastic enclosures provided less than 0.14 ft<sup>3</sup>, probably accounting for the tinny, quick roll-off bass

response. True to form, my first attempt at cabinet construction came before the New Year, involving a pair of heavy cardboard Coca-Cola boxes. Somewhat improved response resulted, and the die was cast.

**SYSTEM 2: "SPEAKER CABINETS".** It soon became apparent, however, that Scotch tape and cardboard were acoustically inferior materials. My second attempt followed shortly thereafter.

I used the discarded ½" mahogany doors from my parents' newly-remodelled kitchen cabinets to construct 3x2x1 foot floor-standing cabinets. They housed Radio Shack 12" co-axial speakers, chosen for their ease of mounting (one hole), their ready availability, and mostly their price. They had, as I recall, a ½" voice coil, an 8 oz magnet, and suspension so stiff you could hardly move the cone. Nevertheless, these were an enormous step upward from the Cokeboxes in frequency response, dynamic range, freedom from coloration,

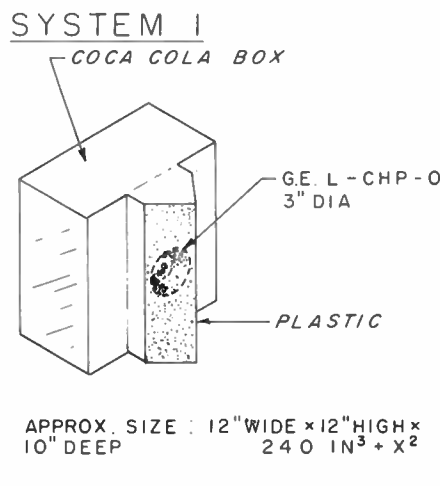
and sound pressure level.

They afforded me several months of experimentation with various baffles, internal labyrinths, port configurations, and fiberglass insulation in attempting to remove the enormous hump in the response at approximately 175Hz. In the end I decided that kitchen cabinet size had little relation to optimum woofer loading. Cohen's formulas had been exceeded by too great a margin, the woofers themselves suffered from lack of displacement, the removable tops rattled at low 'C,' and the ball-bearing casters provided castanet accompaniment. The "Speaker Cabinets" were sold to finance the next project.

**SYSTEM 3: THE EXPERIMENTERS.** The proceeds bought me some much more flexible (literally) components with which to experiment. After considerable shopping around, I settled on Lafayette 8" woofers, made by Utah with distinctive red surrounds. These were chosen for their long excursions and relatively large magnet structures, as well as their reasonable price and availability. The recent pulling back of Lafayette's franchises to a mere eight stores confined to the New York area puts their current availability in question, but Lafayette's catalog service may still offer them.

For the tweeters I chose Calrad 20-267 aluminum domes; excellent little units I'd recommend to anyone. Their sound is crisp without brittleness, their range extended without peaks, and their power-handling sufficient for most applications. I also bought these at Lafayette, although any Calrad dealer can supply them.

Once I felt driver limitations were at a practical minimum, I proceeded to experiment with Cohen's formulas to determine their exact significance. I tried every imaginable cabinet configuration, both in size and in proportion. Tall skin-



ny cabinets, short flat cabinets, long tubular cabinets, teeny tiny cabinets, huge cavernous cabinets—I tried them all. I had learned by now to use 3/4" particle board, which not only worked easily but provided the weight and density necessary for minimum vibration.

I found that cabinet geometries had considerable significance. The front-to-rear dimension is the most important; for minimum standing waves it should be kept as small as woofer clearance (and design stability on the floor) allow. The next most important dimension is the internal volume of the cabinet. For acoustic suspension design, I found about 200 cubic inches of cabinet volume per inch of woofer diameter to be

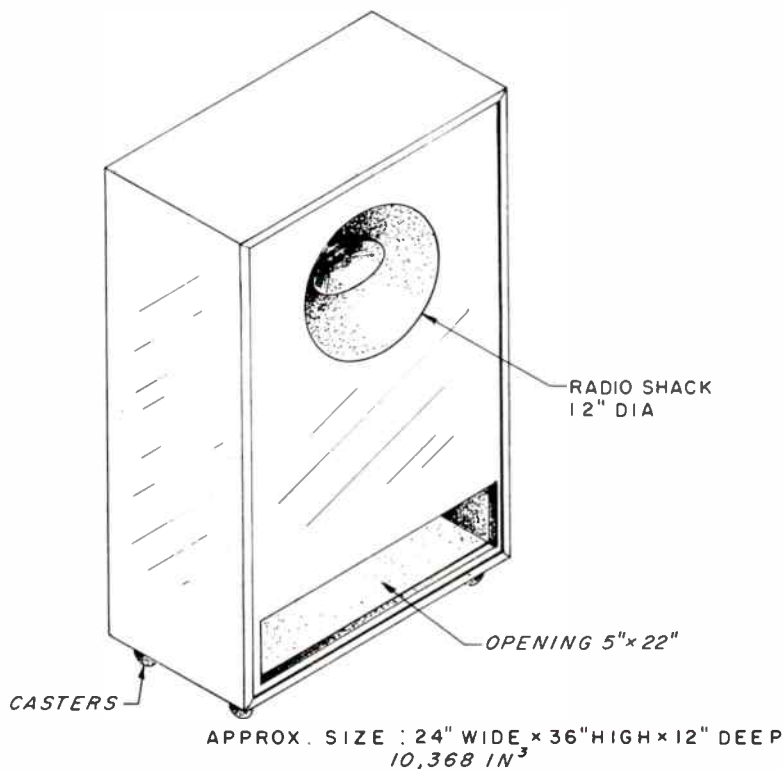
by, I would guess, standing waves within the cabinets, and a compression of loud transients caused by (again guessing) non-linear cone motion due to the resilience of the air spring. My solution to the first problem has already been mentioned: shorten the front-to-rear dimension. But the second problem was more persistent, and it was in attempting to solve this one that I stumbled across the porting idea.

Using a recommendation I had read someplace (I can't remember where), I found that plastic drainpipes did indeed make excellent port material. The effective size of the port could be varied by sliding the tube in or out of the cabinet, without having to alter the initial hole in

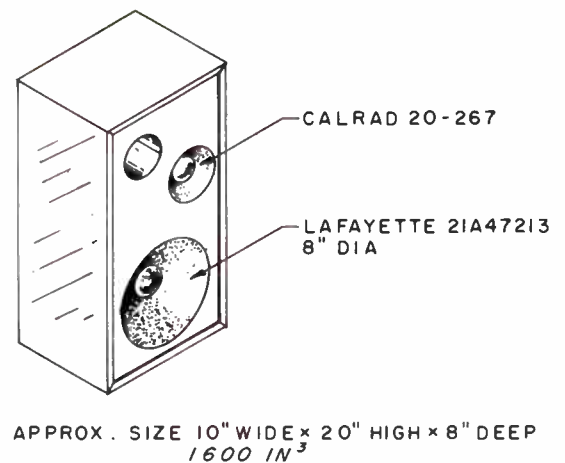
port to the side of the cabinet, or even to the rear, had little effect. JBL, for one, seems never to have done any basic research on port placement—and the unfortunate result is aurally obvious to me, at least.

Porting the enclosures solved the problem of compression from non-linear cone movement, but it left me with another: at high power levels the cones tended to want to flatten themselves to death. My solution to this was to damp the motion of the air inside the cabinet by filling the cabinets with polyurethane "pillow foam." The sponge-like construction of the foam, bought in large rough-cut chunks from the local fabric store, meant that there was still an air

## SYSTEM 2



## SYSTEM 3



ideal. For bass-reflex design, the ratio was more like 450 cubic inches per diameter inch, which is not far from most speaker manufacturers' recommendations.

The Lafayette woofers are intended for acoustic suspension cabinets, with their loose suspensions and large magnets. However, by a judicious accident I discovered that my acoustic suspension cabinets sounded appreciably better if I cut a small port in the face panel. As acoustic suspension cabinets, they suffered two distortions common to almost every acoustic suspension speaker I have heard: a 'boxiness' in the midbass caused

the front panel. Once finalized, the port tube could be cut to length and secured in place. I tried thin-walled and thick-walled tubing (no difference), large diameter and small diameter tubing (the clearance available behind the baffleboard seems to be the only determining factor) and right-angle pipes (too hard to secure).

The placement of the port turned out to be important, also. If too close to the woofer cone, say within a cone-diameter, phase cancellations created odd dips and peaks in the frequency response. Beyond a cone-diameter, this effect was minimized, and moving the

column behind the drivers, but it was inhibited.

There was still considerable acoustic output from the ports, since sound travels in waves of pressure, not air. The hybrid design proved to be the best of both worlds, the open uninhibited sound of bass-reflex woofers with the small size of acoustic suspension cabinets. This particular solution probably depends on the exact characteristics of these woofers, but I'm sure it could be adapted to other drivers with equal success.

In addition to experimenting with the shape of the cabinets themselves, I also played around with cabinet placements in the room. The booming caused by placing them directly on the floor, or against a wall, was not a clean enhancement. I could not imagine a circumstance where this would be a desirable distortion—and in fact there seems to be no practical limit to the distance to the nearest reflecting object. Room limitations prevail.

**Next Issue: Walnut Pines**

# Old Colony Peterborough NH 03458

# KITS

**Box 243**

**POLICY:** OLD COLONY SOUND LAB is a service agency for readers of *The Audio Amateur* and *Speaker Builder* magazines. It attempts to provide circuit boards and the basic, or hard to find, parts for construction projects which have appeared in the magazine. Old Colony assumes that the constructor will use the *Audio Amateur* or *Speaker Builder* magazine article as the guide for building his unit. Kits, with noted exceptions, are not priced to include article reprints or construction instructions. Old Colony kits, with stated exceptions, do not provide metal work, cabinets, line cords and the like. We suggest that before purchase amateurs secure and evaluate the articles, which give details on each unit. Kits vary widely in complexity and required construction skills. A very few can be assembled by the beginner. If you are just starting in audio, get some experience building Heath or Dyna kits before tackling an Old Colony kit, or locate an experienced friend to help in case of difficulties.

## CROSSOVERS ELECTRONIC

For both electronic crossovers: crossover points and  $R_1$ ,  $R_2$ ,  $C_1$ ,  $C_2$  MUST be taken from Fig. 3, p. 11, Issue 2, 1972, TAA. No other values can be supplied.

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

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

Each \$11.00

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

Single channel. Each \$43.00

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

**KK-6-S SWITCH OPTION.** 6-pole, 5-pos. rotary switch, shorting, for up to five frequency choices per single channel. Each \$8.00

When ordered with two kits above, Each \$7.00

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

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

Two channels \$120.00

SBK Board only Each \$14.00

## PASSIVE

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

Pair \$87.50

## FILTERS & SPEAKER SAVER

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

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

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

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

**KK-8: COMPLEX C.** Two channel board with all parts to compress signal, including 1% polycarbonate capacitors and large tantalums. [3:79] Each \$45.00

**KK-9: COMPLEX E.** Two channel expansion board with all parts including precision Rs & Cs. [3:79] Each \$35.00

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

## SYSTEM ACCESSORIES

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

**KH-9: TONE ARM MOUNT BOARD.** For the Thorens TD-124 turntable only. Exact fit, unpainted fine grade hardwood. Three countersunk holes drilled to fit frame. Each \$3.25

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

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

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

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

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

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

Two channels. \$95.00

Four channels. \$180.00

## BENCH AIDS & TEST EQUIPMENT

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

**KB-8: INVERSE RIAA KIT.** Six precision components to shape your audio signal generator's output to the response curve of a recorded disc. Checks phono preamp inputs. Each \$5.75

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

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

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

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

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

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

**KJ-6: CAPACITOR CHECKER.** [4:78] All parts to build an accurate meter for measuring capacitance, leakage, and insulation. Check phono & speaker lead capacitance effects. Includes all parts with 4½" D'Arsonval meter. Each \$68.00

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

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

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

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

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

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# \* OLD COLONY FALL SPECIALS \*

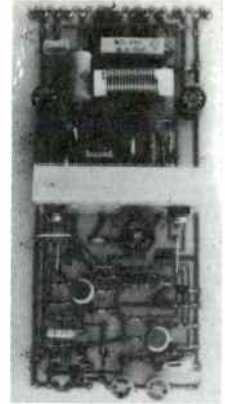
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The kit uses precision 1% metal film resistors and audio grade capacitors throughout. You will need to provide the case, chassis, line cord, and a small handwound "L" choke, but we supply the circuit boards, electronic parts, heat sinks, and power supply with transformer. For best results use OFHC wiring and Old Colony gold plated connectors.

Leave behind the harshness of bipolar transistor amps and enjoy your favorite music reproduced with exceptional purity. Build this 60W amplifier yourself and have the satisfaction of owning better-sounding audio equipment than you can buy off the shelf.



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- Fred Gloeckler's new revision of Advent's classic design

Now you can make clean recordings using this quiet, low-distortion mike preamp. Most tape decks have relatively cheap, noisy mike preamps because few people ever use them, so it's a good place for manufacturers to cut costs. If you've never used your mike inputs, or if you've never made a live recording, you're missing half the fun of owning a tape recorder. And if you've been discouraged by the poor sound quality you get with mikes compared to line level inputs, this outstanding mike preamp is just what you need to enjoy the full benefits of owning a tape deck.

Why bother with live recording? Besides, I don't know any musicians

worth recording, you say. The fact is, you will gain a much deeper insight into your system by doing some live recording. To experiment with mike placement and to solve some of the problems of hall acoustics will provide you with a level of understanding which will increase your enjoyment of your system and record collection many times over. And many young musicians in local schools and churches are eager and willing to let you record them, just for the fun of hearing themselves on tape.

The kit includes audio grade capacitors and resistors, circuit board, and input transformers. You provide the case, chassis, appropriate input/output connectors, and power supply (which could be two 9V batteries, or if you have an Advent 201, use its built-in 18V output).

Construct this updated version of Advent's mike preamp and not only save money, but enjoy the full potential of your tape deck, while learning about recorded sound. You will hear your system with new ears after a few recording sessions.

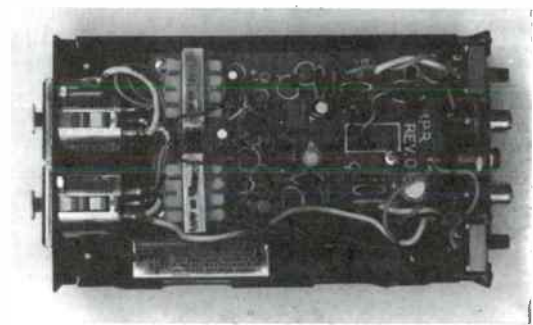
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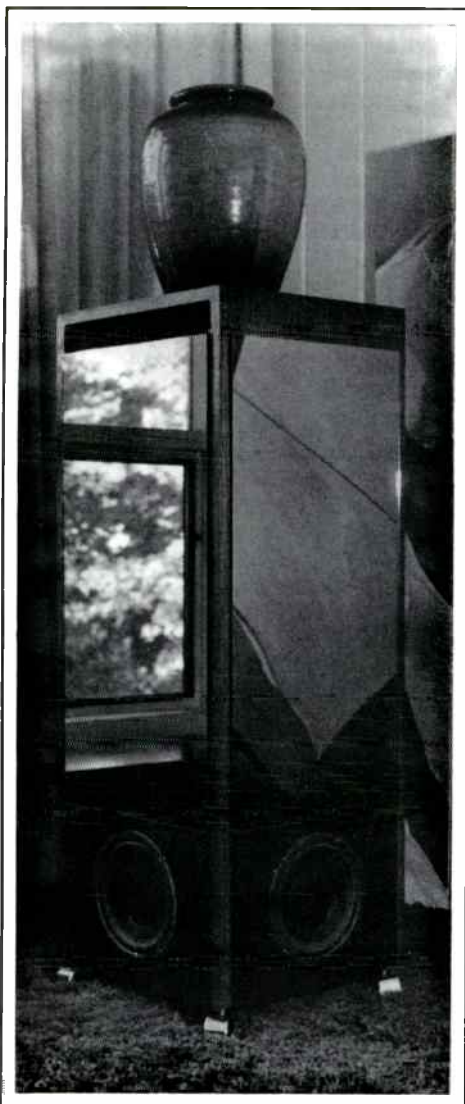
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# Tools, Tips & Techniques



Using mirrors on large speaker cabinets helps to blend them into the room's decor. The reflections on the left panel even capture some outdoor ambience, helping the speakers to seem less dominating or monolithic.

## ROOM REFLECTIONS

Enclosed is a snap of my version of the SAFE. To make a big box in the living room less obtrusive, I used bronzed tinted plate glass mirror. The casters are heavy duty, of course, and removable. The system is bi-amplified and the SAFE is designed to fit on top of a smaller enclosure housing its amp—an ST-150 or smaller. Thanks again for great articles.

Edward T. Wilber  
McClellan, VA 22101

## TIPS RAGOUT

1. Rubber grommets made for running wires through chassis openings are handy for mounting Audax and other drivers on which the mounting tabs do not rest directly on the baffle surface (Fig. 1). The appropriate size grommet keeps the cabinet airtight when using T-nuts to mount the drivers. I built some Gold Sound System One kits, which utilized Audax 5¼" units, over a year ago using the grommets as spacers and seals. The cabinets have remained airtight with no evidence of problems with vibration or the aging of the rubber (Fig. 2).

2. The Illinois Bronze Company (Lake Zurich, Illinois 60047) manufactures *Wrinkle Finish* paint. The paint comes in a variety of colors and leaves a wrinkle texture when dry. I have used this paint on baffle boards and have liked the results. The paint is available in 13 ounce spray cans and larger sizes. One spray can will do the baffles on a pair of medium size enclosures.

3. A convenient way to mount most crossover parts is to use a piece of pegboard and nylon ties. The pegboard provides a variety of attachment points and the ties are quick to install and hold tightly. You can cut the ties if changes need to be made. For a permanent installation, put a bead of silicone sealer on the pegboard before tying the part down. The silicone keeps the part in place while damping vibrations that might cause rattles or buzzes. The exception to this mounting method is ferrite chokes where I have found a machine screw and silicone work well.

4. I have had good luck with a Radio Shack pushbutton terminal connector, part number 274-315. The spring terminal side will accept 14 gauge stranded speaker wire as will the solder terminals with some judicious drilling. The terminals retail for 99¢ each.

5. DAP company has recently introduced an acrylic latex caulk with silicone. I tried it on my most recent speaker project and liked it very well. The caulk has the advantages of silicone sealer without the acid smell, high cost, long curing time, or skin irritation. It also cleans up with soap and water. Overall, it seems to me an ideal product for sealing enclosures—and it has a 20 year guarantee. While I am familiar only with DAP's product, I am sure other manufacturers have similar products.

6. On this same project, I tried rug padding instead of fiberglass as enclosure damping material. The pad I used is quilted fiber (as opposed to foam), about ½" thick. The pad is designed to dampen footfalls where people downstairs would be bothered. I like working with this material a lot better than fiberglass as it cuts with scissors and fits easily to the enclosure walls. It would also be a good material to use as a diffraction damper on baffles. While I cannot evaluate this material in comparison to fiberglass, the results sound good. It certainly seems to be an adequate solution, at any rate.

7. I have found making a template out of light cardboard for any driver I am mounting is worth the time and trouble. Many drivers have little mounting surface and, therefore, little room for error in cutting the hole. Modifying a paper template until it fits is much easier than with a baffle board already cut. Even when you are sure the template is right, slightly undercut your mounting hole.

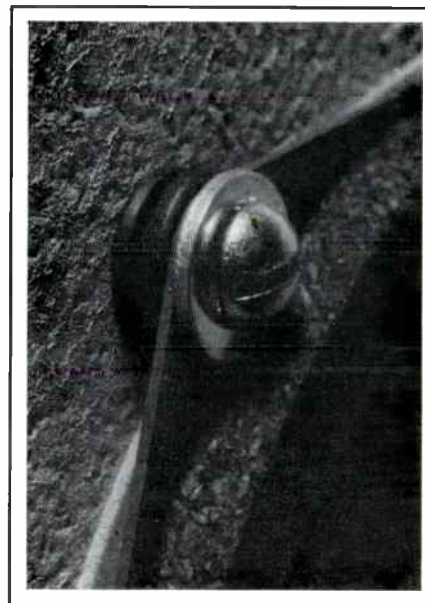


FIGURE 1: An Audax 5¼" driver mounts more easily with a rubber grommet. Notice the wrinkle finish paint on the baffle board.

8. For someone who does only occasional speaker building, investing in clamps and related tools to simplify assembling enclosure panels is probably not economic. A simple holding jig can be made in about ten minutes, however, that will provide the third hand



enclosure assembly requires. You can make it from scrap and tailor it to a convenient size for the panels you need to assemble. You need a flat piece of plywood and some scrap 2" to 3" wide by 1/2" to 3/4" thick by a length slightly shorter than the panels being assembled. Assemble the jig by laying out two parallel "L's" from the scrap pieces on the larger board (Fig. 3). The "L's" should be separated by the thickness of the panels you are assembling. Keep the tolerance tight here. When you insert an enclosure panel into a leg of the jig, it should fit tightly enough that it stands up with very little play. (The amount of play will vary, of course, with wider panels having more play.)

When you have two panels inserted into the jig, they will meet at an exact 90° angle, if you have been careful, and will be firmly held, even with each other. You can nail a stop block behind each panel to keep them from moving away from their joint while you attach them. If the scrap used for the "L's" is the same thickness as the front and rear baffles of the enclosures, the jig will provide a means of marking or attaching any framing that you might be using. While I have used only simple butt joints in my own building, I think this sort of jig would aid

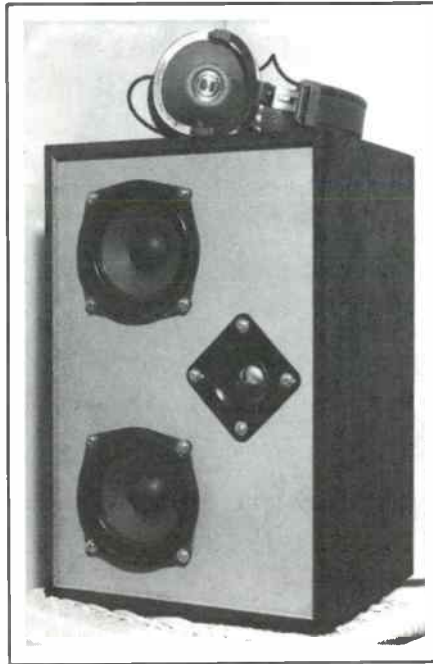


FIGURE 2: The rubber grommet mounts have worked reliably on several of Gold Sound's System One kits.

greatly in holding mitered joints together. The uses or modifications for a simple setup such as this are many and you can tailor it to a particular project.

When you are finished with the jig, reassemble it for another project.

9. A number of speakers are sold as satellite/subwoofer combinations. This design has many advantages in simplifying the placement of speakers in a room. Readers should consider building any speaker as two modules. When you think about it, the requirements for an optimum woofer enclosure can be antagonistic to the needs of the midrange/tweeter. This may be somewhat overstated, but bear with me in a quick look at this situation.

Essentially, all speakers are designed around the woofer. The cabinet size is determined by the woofer parameters, especially in a bass reflex design. Once you make certain design decisions regarding woofer performance, notably  $f_3$ , the cabinet size is set. If you build a cabinet of this volume using a Fibonacci ratio (each term is the sum of the previous two), or 3:5:8, the placement of all drivers will be limited to the resultant area of the front baffle. In an extreme, and admittedly unlikely case, you might have insufficient room on the front baffle for the rest of the drivers. In a more realistic situation, you will have a limited number of locations for the midrange/tweeter drivers, resulting in

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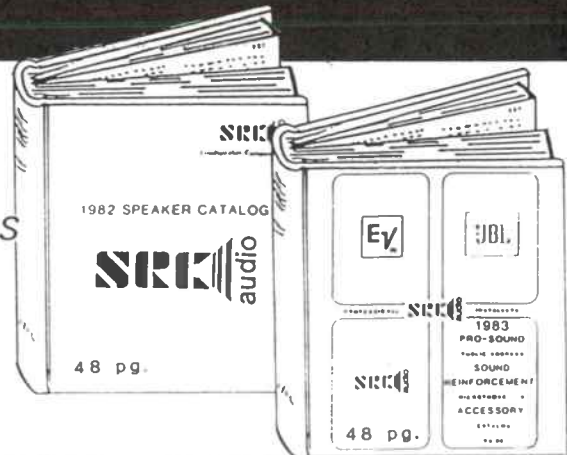
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.0022	.0022	.047	.22
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.01	.0047	.1	.47
.1	.0068	1.0	4.7
	.01	2.2	
	.015	4.7	
	.022		
	.033		
	.047		
	.068		
	.1		
	.47		

## GOLD PLATED CONNECTORS

Our connectors and associated hardware are 23.9K gold plated (0.000020" gold). This plate is high quality, chosen for its suitability in electronic contact applications.

## PHONO PLUG

A shielded (gold plated brass handle) plug that mates well with our gold plated phono jack as well as the gold plated phono jacks commonly used on high quality equipment.

## PHONO JACK A

Mounts from the rear of the panel (up to  $1\frac{3}{64}$ " thick) in a hole  $\frac{3}{8}$ " diameter. The design allows the hex brass body to be held firmly, while the external nut is completely tightened. This avoids the loosening problems commonly encountered in panel mount phono jacks. All hardware supplied in gold plate for optimum grounding continuity.

## PHONO JACK B

Conventional front-of-panel mount with washer, lug, and nut mounting on rear of panel. Requires  $\frac{1}{4}$ " hole. All hardware gold plated.

## NYLON INSULATORS

Sold in sets of ten, each insulator consists of a nylon step washer and flat washer.

$\frac{3}{8}$ " SIZE: Large insulator for our phono jack described above, and other  $\frac{3}{8}$ " connectors. Requires  $\frac{1}{2}$ " mounting hole.

$\frac{1}{4}$ " SIZE: Can be used on phono jacks from H.H. Smith, Keystone and Switchcraft (3501FP). This insulator fits our older gold plated phono jack. Also useful for the insulation of metal banana jacks (H.H. Smith #101, #109; Pomona #3267; E.F. Johnson #108-0740-001.)

Send a stamped #10 self-addressed envelope to **Old Colony Parts, Box 243, Peterborough, NH 03458** for full details and price list.

## NEGLEX CABLE

Make your own high performance interconnect cables with Neglex #2534 cable made of specially drawn and annealed OFHC wire by Mogami. Configuration is two twisted pairs, teflon insulated, with spiral outer shield. Low capacitance, super flexible. Color coded red or blue (specify length and color).

## NEGLEX GOLD CONNECTORS

Finish off your super cables with these high conductivity gold plated connectors. Extra large hole accommodates Neglex and other cables.

## PRECISION METAL FILM RESISTORS

Meet Specs for: MIL R10509 RN55, MIL 55182 RNR55

Tolerance:  $\leq 1\%$

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Max. Voltage: 250 V

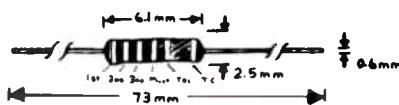
Temperature Coefficient: 50 ppm/C

Current Noise:  $\leq .05 \mu V/v$  to 10k

$\leq .1 \mu V/v$  to 100k

$\leq .25 \mu V/v$  to 1M

## DIMENSIONS



## MIL-BELL SCALE

For those unfamiliar with 1% metal film resistors, note that the values are on the MIL-BELL scale. These are usually within 1% to  $1\frac{1}{2}\%$  of the corresponding IEC E24 values commonly used in domestic equipment. This gives a consistently tighter tolerance to the specified value than a 5% or even 2% carbon film resistor. Metal films provide less than half the noise, much greater temperature, time and load stability, and better linearity than carbon film or composition types.

## VALUES AVAILABLE

10	100	1.00k	10.0k	100k
20	110	1.10k	11.0k	110k
27.4	121	1.21k	12.1k	121k
30.1	130	1.30k	13.0k	130k
39.2	150	1.50k	15.0k	150k
47.5	162	1.62k	16.2k	162k
68.1	182	1.82k	18.2k	178k
75	200	2.00k	20.0k	200k
82.5	221	2.21k	22.1k	221k
90.9	249	2.43k	24.3k	243k
	274	2.74k	27.4k	274k
	301	3.01k	30.1k	301k
	332	3.32k	33.2k	332k
	365	3.65k	36.5k	365k
	392	3.92k	39.2k	392k
	432	4.32k	43.2k	432k
	475	4.75k	47.5k	475k
	511	5.11k	51.1k	511k
	562	5.62k	56.2k	562k
	619	6.19k	61.9k	619k
	681	6.81k	68.1k	681k
	750	7.50k	75.0k	750k
	825	8.25k	82.5k	825k
	909	9.09k	90.9k	909k
				1 MEG

## Tools, Tips & Techniques

less than optimum performance from them. So why fight this limitation? Make two enclosures. Make one enclosure sized and proportioned to optimize woofer performance and make a second enclosure (or simply a baffle) to optimize the performance of the midrange/tweeter.

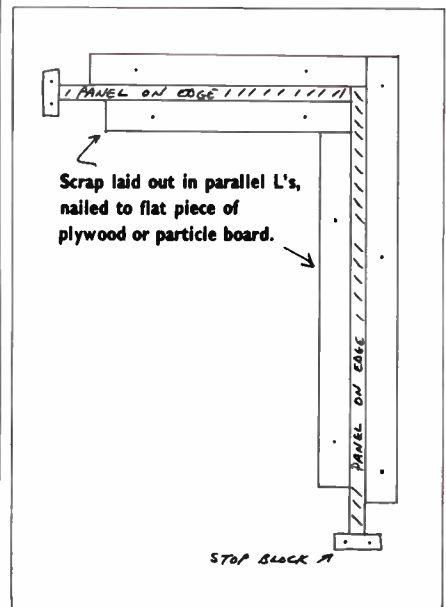


FIGURE 3: You can make a quick-and-easy jig out of scrap for assembling speaker cabinets.

I have already touched on what many builders consider optimal for the woofer. What design criteria are optimal for the m/t module? Get the m/t drivers up to the same height as your listening position. Minimize diffraction by placing the m/t on a baffle of appropriate shape or width. Put the m/t in its best acoustic alignment with the woofer. Put the m/t drivers themselves in their best acoustic alignment as well. These are some thoughts you might want to add other criteria as well.

When you begin to design a two-part speaker, so many more interesting design possibilities arise that a single box design appears extremely limited. This is without considering any advantages that might occur due to making the speaker easier to place in the room.

Kent Johnson  
Denver, CO 80206

# Designer's Corner

Altecs in Oregon

I think all speaker builders like to show off their work. About two years ago I built 12 pairs of these, using formica over particle board, and an Altec 619-8A. The grille fits into the routed groove, held in place by friction. The smaller unit is a Boitz model CP-82 eight-inch two-way. Presently I build speakers mostly with Altec and JBL components, though not in the quantities of two years ago.

Doug Boitz  
Umatilla, OR



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## DEEP BASS DOWN UNDER

As an enthusiastic reader of *SB* from the first issue, I have some comments on the Linkwitz Three Box System, "pirate" LS3/5A's, and Thiele/Small alignments which may be of interest to other readers.

Has anyone built the Linkwitz system? [Yes, several dozen readers.—Ed.] I have, and the sound is magnificent, totally non-fatiguing, easily surpassing any previous system I have built.

Prior to going fully active, I ran two subwoofers, each with a B139 KEF in a Thiele/Small alignment ( $Q_{TS}$  raised from .36 to .41,  $\alpha = 1.007$ ,  $h = .886$ , and  $f_3/f_1 = .9777$ ). These were biamped third order to two pirate LS3/5A's. My next stage was to go fully active, leaving the enclosures and drivers unchanged. Using the layout from the 4/80 issue, I made two circuit boards for the crossovers. The B139 covered the range from 25-100Hz, the B110/SP1057 from 100-3000Hz, and the T27 from 3 to 30kHz. I based my design on the refined system described in Part III. With no woofer equalization, I made op amp U10 inverting unity gain, while in the midrange channels, I used both U7 stages to provide extra delay since my satellites are further forward than in the Linkwitz system. The woofers are placed together at the room boundary, while both satellites are virtually unaffected by room boundaries (apart from the floor). This is as Roy Allison has proposed. The system sounded magnificent, and I preferred the "high frequency tilt."

Some time later, I purchased two Dynaudio D28 tweeters with  $f_s = 650\text{Hz}$  ( $Q_s$  not measurable because of ferrofluid damping). After recalculating the crossover for 1500Hz and rebalancing the system, I heard some coloration from the D28's. I attributed this to the plastic face plate which was a semi-horn, and completely disassembled them. I rebuilt them with a flat aluminum face plate and a new rear chamber. The resultant sound is excellent, rivalling the KEF R105 or the B&W 801. Prospective constructors

should also try the 39mm KEF 752 dome ( $f_s = 600\text{Hz}$ ,  $Q_s = 1.1$ ). I recommend the SP1057/B110 over the SP1003 because of the PVC surround and high temperature voice coil, which alleviate the disturbance in the 1100-1200Hz region and provide better control of the breakup mode around 5kHz. Feedback from other builders of the Linkwitz system would be welcome.

Celestion's laser hologram research has revealed a variety of problems in

resulting in some directivity in the crossover region.

A minor revolution is occurring in driver technology, resulting in drivers that behave as they should, and opening the way to improvements in the sound of speaker systems. We hope these new units will be available to home builders, not just OEM's.

A few tips to Linkwitz system builders:

1. Check your power amps for turn on/



In John Kasowicz' listening room, the Linkwitz subwoofers are against the far wall, and the satellites further forward.

diaphragms, some of which were easy to solve, others requiring complete redesign. This work has produced Celestion's new SL6, which has a one piece cone (no dust cap) woofer with welded surround and minimum overlap. The new copper/aluminum "ultra" dome, which integrates the dome with the voice coil former, has response from 1.5kHz to 20kHz and exhibits perfect piston behavior since no breakup occurs below 20kHz. This tweeter has an  $f_s$  at 1400Hz damped, while the woofer has perfectly controlled breakup to above 5kHz. The SL6 would make a good satellite for the Linkwitz system, although the small (150 mm) woofer and high  $f_s$  of the tweeter suggest a crossover at 2500-3000Hz,

off transients (especially the tweeter amp).

2. Some amps invert phase (*ie* Quad 303, 405) so check the phase output among your amps when mixing brands or models.
3. If you make changes in the Linkwitz crossover, watch the effect on phase, since some stages invert.
4. The balance between the high and midrange units is critical, and if you use mixed amps, the crossover's trim-pots may have insufficient range.

Judging by the letters column, readers have considerable interest in the cloned LS3/5A described by David Davenport (4/81). I have built several of these myself using Badger crossovers (the

Wilmslow and Falcon are also good). Duplication of the original crossover is also possible, and I have done it successfully. However, both test equipment and great care are needed. I doubt that a copied LS3/5A could ever be as good as the BBC's since (I suspect) they match the woofer and tweeter in stereo pairs and also select them for optimum parameters (low  $F_c$  and  $Q_c$  in the T27 and minimal resonance in the B110/SP1003's 1100-1200 region). The crossover permits treble balance and pair matching. I could go on, but this is obviously a carefully designed and built system. An in-depth description of the manufacturing process would clarify a good many points which seem to be unanswered, and which leave quite a few SB readers in doubt.

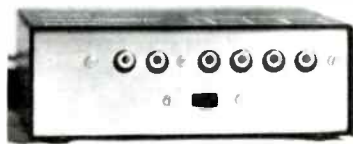
KEF has announced a Constructor Series. Information sheet CS1A covers an LS3/5A monitor, and CS1 describes a replica of the KEF R101. Full details and crossover parameters are available from KEF in England or in the US, write to Intratec, PO Box 17414, Dulles International Airport, Washington, DC 20041. I have duplicated the CS1A and CS1 crossovers for use in systems in other rooms. Results are very good with the CS1A (LS3/5A) replica. At 1200Hz  $f_c$  is nulled in the high pass section, while the 1-3kHz region in the low pass is less colored. Results with the CS1 (R101 replica) are better than with the CS1A because the B110 specified is the SP1057 and both drivers are connected in phase (this appears to be an all-pass fourth order network).

I have read the R. M. Bullock series with great interest and congratulate him. Recently I have been concentrating on woofer parameters for Thiele/Small alignments with rather variable results. I have used a Wien bridge, function generator, digital display frequency meter (with 100X multiplier to improve low frequency resolution), and double beam oscilloscope (for observing Lissajous patterns of  $F_L$ ,  $F_M$ , and  $F_H$ ). Problems are arising from the fact that the B139 and B110 exhibit variation in  $f_c$  according to the drive level (ie the B139 has  $f_c = 26$ Hz at minimum drive level, but at higher levels it becomes 23Hz). The B110's have this problem also. This makes  $Q_E$  and  $Q_M$  and particularly  $V_{AS}$  variable.

Regarding formulae, number 11 on p. 17 of 1/81 and the Colloms formulae agree quite well. However, formula 12 does not agree at all to acceptable limits (test box for B139 = 30 liters, sealed or tuned to 50Hz). This anomaly is rather frustrating. Now that the bass reflex is well documented, some further research into parameter determination would be helpful. Perhaps this is why Linkwitz chose an equalized sealed box, space reasons aside.

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## SB Mailbox

Please continue Hunter Kevil's loudspeaker literature series, which is an excellent and valuable reference source.

John Kasowicz  
Melbourne, Australia

## MELLOWED VOIGT

I was most interested in Bruce Edgar's *SB* articles reporting his interviews with the late P. G. A. H. Voigt just before he passed away. He was a man who applied basic electrical engineering principles to acoustic problems and his keen and inventive mind came up with the solutions, all of 50 years ago. I am writing this on a Braniff 747 on route from London to Dallas to stay with my son for three weeks. He is an electronics engineer with Texas Instruments and like me is keen on Hi Fi. You will gather from this that I am British, strictly I am Scottish, Glasgow being my home town.

In the early 1930's I attended a demonstration of Voigt speakers and the quality was so outstanding I decided there and then to build a corner horn. In fact it took me a few years, but I completed it in 1938. I could not afford a Voigt driver in those days (\$30), and used a BTH Rice Kellogg 6 $\frac{1}{2}$ " ribbed cone from the cinema equipment of those days. It only used a 10W field, so the efficiency was far below the Voigt. I did push up the field by about 50% but insulation began to suffer.

The sound was pretty good for those days, but I felt it had one or two problems, and I corresponded with Voigt about them. You can imagine how pleased I was when he called at our house 20 miles south of Glasgow on the main road, and pointed out where I had gone wrong. It was a most kind gesture to a struggling 25 year old trying to learn the intricacies of acoustic science. You mention his visit to Scotland in your article, and it certainly brought back memories for me.

By 1940 the War came along to interfere with my experiments and it was 1946 before I could resume. I got a Voigt twin speaker and two of his moving coil pickups, all of which I still have. By this time I was into "High Quality" amplifiers (valve of course), such as the *Wireless World* 10W design by the famous D.T.N. Williamson. Isn't it strange that, nearly 40 years on, valve amps and moving coil pickups are all the rage again? In fact I have one or two Class A transistor amplifiers, but I still

love my old valve amp faithfully.

I often wonder what PGAH would have said about the modern ultra-low efficiency speakers, using hundreds of watts to produce a sound intensity he could get from a few watts. I remember him saying if only he could make a speaker 100% efficient, his problems would be over. The speaker to beat for efficiency in the 1930's, I believe, was the Western Electric 555—reputed to be about 55%.

The part of the acoustic spectrum my son and I have paid the most attention to is the two octaves below 100Hz, and the problems of reproducing it in the average home. The rewards are great when you get it about right. As my high frequency rolloff has come down over the years, I can at least pay attention to the other end. As an organ buff, I have some good recordings to test any equipment down there.

Anyway, enough meanderings from me, but I look forward to reading your articles on speakers using the Tractrix configuration in future issues. I am glad that PGAH is still remembered, and if your articles have introduced him to younger generation, that is a job well done.

As a final thought, I can tell you something about Voigt not many people know. His hobby was collecting unusual epitaphs from tombstones all over Britain.

Stuart Abbott  
Garland, TX 75042

## DIGITAL ANALYSIS

I would like to offer a plea to the micro-computer users among *Speaker Builder* magazines to voice their needs, wants, and opinions to the manufacturers, suppliers, and vendors of small computer hardware and software. Notably those who advertise in this publication.

Since my company placed an ad in *SB* for our modified BASIC program, we were flooded with calls and letters from readers and dealers, as to where outside support for the Radio Shack TRS-80 (Models I & III) and other small computers might be obtained. We're still looking too!

Several companies currently are producing computer compatible devices/software but the majority of the products are outrageously expensive (usually made by the esoteric, outerspace/scientific/electronics, government contract types with all hardware/software dedicated to just their own product package) or very limited in application.

The individuals I conversed with all seemed to want the same thing, a

reasonable, cost effective, self contained, acoustical measuring tool that could be used without a BSEE degree. Stereo shop owners wanted something besides a  $\frac{1}{3}$  octave display that the salespeople/employees could operate. Several shop owners had small computers already on hand doing business transactions and bookwork, but the machines sat idle a lot of the time. One owner wanted to be able to document the claims of manufacturers of certain types of equipment for customers.

Many of the amateur and semipro loudspeaker builders fortunate enough to own or borrow a small computer strongly stressed the need to use the computer's power to make repetitive calculations less time consuming. And they wonder why nobody yet makes a decent measuring instrument or interface for their particular micro. A college student called hoping to locate some type of similar unit for the physics department.

We are aware of only a few companies that produce external, acoustically related measuring hardware for small computers.

Eventide Clockworks Inc., 265 West 54th Street, New York, NY 10019, produces  $\frac{1}{3}$  octave interface boards for three of the more common micros (Pet, Apple, TRS-80 Model I). These hardware units turn the computer into a real time analyzer for acoustical/room related system analysis. The software that comes with each hardware analyzer is cassette based and very limited, but is easily modified by the BASIC language user. Eventide has a sophisticated, machine language, disk based software program for use with the Apple system that will produce 3D, X,Y,Z, CRT/printer plots for RT60 analysis now available in a separate package. Let's hope this same package will be produced for the Pet and TRS-80.

We have been using Eventide's TRS-80 (VTU02) analyzer in our lab for about two years and have developed some pretty neat BASIC programs. The system is very flexible as we never cease to find new ways to modify our programs and applied techniques. Since we are not machine language proficient, our programs probably are not as high powered as the Eventide disk version. Data storage/recall of system plots is very efficient. Give Eventide a call or letter for literature and tell them what you want.

IQS Inc., 5719 Corso di Napoli, Long Beach, Calif., 90803, (formerly INDAC) produces a very sophisticated FFT spectrum analyzer. The Series 401 is for an Apple II with a disk drive and printer such as the Epson MX 80/100 with Graftrax. My phone calls, in December '81, to this company seemed to hint that if demand warranted, this same system

would be available to the other micros on the market. With all the versions (imitations) of the TRS-80 Models I-III available, I am surprised that IQS hasn't produced one for this machine.

I suspect the 401 will be a very hot unit. The price can't be beaten for the power that this unit contains. One of my colleagues has purchased a 401 but as yet has not received it. I am anxious to see the unit demonstrated as I have heard plenty of praise for it. I wish that I had purchased the Apple for my business.

Please IQS, think of all those TRS-80 I-III, LNW80, EPS-80, or any other 80 based micro in the pages of "80 Microcomputing." And all those Heath, Atari, Vic 20, machines that are just waiting to become powerful lab instruments. I hope readers will write or phone IQS directly. But then you will have to wait in line behind me for your unit. I'm first.

These and other companies that produce such items should take note that their market is more than just the loudspeaker manufacturer's lab. As an example, many of the technically oriented dealers who use micros in business would also like to be able to use the same machines as sales tools, to be able to set up showrooms and weed out inferior products etc. Or what about the sound contractor?

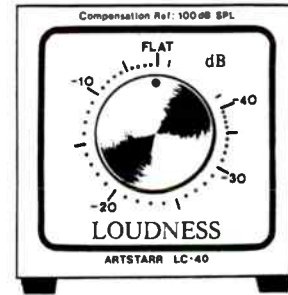
I do not intend to scare SB readers by bringing in the subject of computers. Computers can't really build speakers without the help of people. Computers only make it easier for people to do the creative work. We had to concoct special interfaces into our system to be able to read the "Qs" of the batches of drivers coming through for the manufacturers for whom we design.

Doing the same measurements manually is prone to error and consumes lots of time that could better be spent on other projects. The system does the same measurements you could do with the typical test setup and hand calculator, only faster with tables and charts included. If you are a serious designer and build systems on a casual basis, don't worry about the computer. If you are a semipro or dedicated professional/manufacturer, then you should consider computer assistance.

Before closing I hope SB can provide a "Test Equipment Review" column for its readers. This would help those of us who buy "junk" instruments blindly. I have found many fine devices for my bench that are both cost effective and worked as promised. But for every good unit I had to discard three bad or useless pieces of gear (each from a different manufacturer and after several expensive lessons).

I believe computer users should share

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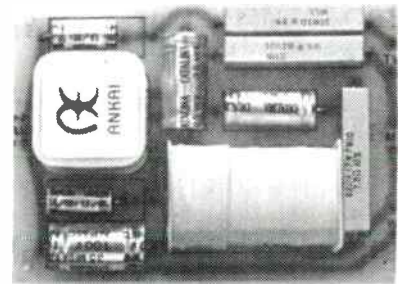
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## SB Mailbox

their experiences with readers about applicable software or hardware they have written or built.

With this I conclude my cry for support for the computer users. I know I want mine to do more than just business functions. I want it freed up so I can increase my skills to chase and gobble up little blobs on the CRT.

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See Bob White's classified ad in *Private Wanted* and the *Good News* column for further information.

## LIGHT AT THE END OF THE TL

Gary Galo's article on transmission line theory (*SB* 1/82) gathers in one place just about all the guidelines necessary to build such woofer systems successfully. But I would like to add that the line length is measured along the mid-line of the labyrinth. Also, his guideline #3 is new to me and it is not clear whether he means for all the initial chamber's surfaces to be lined with fiberglass, or only two specific parallel surfaces. Please explain.

My enthusiasm for this principle stems not from comparison of woofer loading principles, but from actual listening. But comparing the math behind TL's and Thiele alignments, the latter is more impressive. After all, Robert Bullock's been explaining Thiele for endless months, while Gary Galo presented his explanation in one installment. One principle seems logical and fundamental, while the other seems magical and subject to inscrutable dictums. But listen to IMF, Fried, Webb, or Daline systems, and you are hooked on TL systems.

Still, Thiele proponents hold that such alignments will yield better bass than TL's, and that a TL is really an unnecessarily complicated bass-reflex in sheep's clothing. Their main point is, I think, that you can get deeper, flatter bass from an immensely less complicated and less expensive box. And that is a strong assertion.

I don't have the knowledge, equipment, time, or energy to prove whether TL's or Thiele alignment are better for domestic use. But the true designer-artists behind such principles could shed

needed light on this subject by building a definitive case to prove one principle better than the other. And light is what is most needed in audio, where so many myths have been marketed.

Carlos F. Bauza  
San Juan, PR 00936

*Mr. Galo replies:*

*Your comment on measuring the line length is correct. However, TL design does not involve critical tuning, as with other woofer designs, and the line length can be off a couple of inches without harmful effect.*

*Regarding guideline #3, you need to cover only one of each of the parallel surfaces behind the woofer. This normally will be the bottom, back and one of the sides. See Part II, page 28, step #7.*

*Please see my reply to Roy Mallory's letter (*SB* 2/82, p. 40) for comments on Thiele, Small, conventional bass reflex, etc. I certainly agree that the bottom line in any design is how it sounds, and not the technology that produces the sound. I also agree that TL bass sounds musically more natural than that produced by other enclosure designs.*

*I am not at all disturbed by the fact that the mathematics behind Thiele and Small vented loudspeakers is far more complex than for TL designs. The problem of getting true low bass out of smaller enclosures is, indeed, a very complex one. However, if size is not a consideration, I prefer the TL approach.*

*The TL system is not a bass reflex system in sheep's (pun intended) clothing. The classic TL design absorbs the backwave of the woofer completely (or as completely as possible). The Transmission line exit is not a port or a vent. (See part I, p. 8.)*

*With the present state of loudspeaker measurements, to "Prove" why (or if) two speakers with the same frequency response sound different is not possible. The same is true of two preamps with identical RIAA equalization. They usually sound different.*

Gary Galo  
Potsdam, NY 13676

## TIPS AND PLANS

Two things: first a tip for home builders. If you're having a lumber yard cut plywood for you, add 1/4" to all the dimensions. You should then be able to trim the pieces to exact size and 90° squareness with a jigsaw and a large carpenter's square for a guide. This is especially helpful for those with limited space who might find it easier to work on pieces smaller than 4' x 8'.

Second, do you know where I can find the plans for the Electro-Voice Sentry

IVB (TL5050) folded horn? I wrote EV, but they don't seem to have plans available for this enclosure. Any suggestions you may have will be greatly appreciated.

Chris Doering  
N. Bergen, NJ 07047

## SPEAKER RENEWAL

More articles on rejuvenating old speaker systems would be great. My speakers, Heathkit Model AS-1348, are the most expensive parts of my whole system, and leave a lot to be desired. Maybe some day an expert will take on my units and make them right.

Robert B. Jensen  
Reading, PA 19601

## TL REDUX

I enjoyed both of Gary Galo's articles in *SB*. I have built a number of TL's (14 in fact) over the past seven years, but they have all been eight feet long or less and have all used KEF drivers. I am now planning a much larger line—similar to your TL10 and will probably try some new drivers. Crossover will be 200Hz or less.

My question to you concerns the 10" Audax and Dalesford. You apparently have tried both of them. Do you have any comments or recommendations about the sound quality of these drivers? For your information, I generally like a tight, "quick" bass, such as my Fried H has (using KEF B200 and SP1022's). The H just doesn't go deep enough or loud enough.

Also, have you tried the 12" Dalesford or Dynaudio in a TL?

David A. Vorhis  
Salisbury, MD 21801

*Mr. Galo replies:*

*Thanks for your comments on my TL articles. I haven't used the Dalesford drivers in my own systems, but they have been very successful in other TL designs, including some commercial systems (I think Sonikit marketed some of these). I have been very pleased with the Audax bextrene drivers. They have the kind of tight, fast bass you describe.*

*My largest system uses 10" drivers. I prefer them in a 3-way system because they normally will be more linear in the lower midrange than a 12" driver. This is important to good midrange performance if you crossover in the 500 to 1000Hz region. If you use a 200Hz crossover point, then a 12"*



driver will not be subject to these problems. When using a 12" woofer in a TL10 type of enclosure, you must increase the cross-sectional area of the line to accommodate the larger cone area.

Incidentally, Roger Sanders now seems to think the Audax 10" bextrene performs just as well in his woofer system as his original KEF.

Let me know what results you have.

## TL NODES

In the exchange between Messrs. Mallory and Galo concerning transmission lines (SB 2/82), both authors mention the pressure node that occurs at the fundamental resonance of a pipe with one end closed, this node being at the closed end. In fact, the closed (driver) end has an antinode, ie a pressure maximum. The pressure node occurs at the other end of the pipe, which is open to ambient air. Intuitively this makes sense, as damping cone motion at resonance takes high pressure. The node which occurs at the closed end is a displacement node. Pressure and displacement are 90° out of phase.

This may seem a small point, but the lack of rigor which so often characterizes discussions of transmission lines is disturbing. Before you can understand lines, you must understand the resonant behavior of pipes. A lucid explanation is given in:

*The Acoustical Foundations of Music*  
John Backus  
W.W. Norton, pp. 61-65

John Caizzi  
Santa Rosa, CA 95401

## EV POOGE

I read your article in *Speaker Builder* 2/82 with great interest. A need for this type of information exists. My question to you is, what can be done to up-grade a "Voice of the Theater" speaker system. Would it pay to give the woofers your treatment?

Robert B. Jensen  
Reading, PA 19601

Mr. D'Ascenzo replies:

Acoustic suspension speakers have not been the only type that have benefited from the various modifications I described in the article. Any speaker system, regardless of generic type, can benefit from driver modification, optimum enclosure stuffing and tuning. Regardless of crossover point, a system's woofer will put its sonic stamp on the sound. Listen to the woofer alone and you will understand what I mean.

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Term  1 yr.  2 yrs. Remittance \$ \_\_\_\_\_  chk.  Visa or MCard  
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# Circuit Boards



- A-1: WILLIAMSON TWIN 20 POWER AMPLIFIER. (RW-8) 3x5" (1:70) Each \$5.50
- A-2: WILLIAMSON TWIN 20 Power supply board. (RW-9-2) 2½x3" (1:70) Each \$4.50
- B-2: 4 + 4 MIXER Williamson/Wating with staked terminals. (RW-AW) 3½x5" (2:71) Each \$16.00
- B-3: 4 + 4 MIXER POWER SUPPLY. (DG-14) 2x3" (2:71) Each \$4.50
- B-5: WILLIAMSON TWIN 20 PREAMP (RW-11) 3½x8" Stereo (2:71) Each \$10.00
- B-7: V.U. METER (DG-7-A) 1½x3" (3:71) Each \$5.00
- C-1: WILLIAMSON OCTALIZER Components board (RW-13) 2x7" (1:72) Each \$4.00
- C-3: OCTALIZER POWER SUPPLY ± 18V DC. (DG-12A) 2½x3" (1:72) Each \$3.50
- C-4: ELECTRONIC CROSSOVER (DG-13R) New 2x3½" board takes 8 pin DIPs. Ten eyelets for variable components. Parts layout included. (2:72) Each 4.50
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- F-1: BILATERAL CLIPPING INDICATOR. (CB-1) 2x2½" (3:75) Single channel. Each \$3.00 Pair \$5.00
- F-2: GATELY EQUALIZER (EG-1) 4x8" (2:75) Single channel. Each \$12.00
- F-3: GATELY ± 18V POWER SUPPLY. (EG-2) 2½x4" (2:75) Regulated. Each \$4.50
- F-4: MORREY: HEATH IG-18 (and IG-5218) OSCILLATOR MODIFICATION. (WM-1) 4½x5½" (4:75) Each \$8.00
- F-5: MORREY: HEATH IG-18 (and IG-5218) OSCILLATOR: Power supply board for above. (WM-2) 2½x3" Each \$4.50
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- H-2: JUNG SPEAKER SAVER. (WJ-4) 3½x5¼" (3:77) Each \$7.00
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- H-7: GLOCKLER 101DB ATTENUATOR (FG-3) 2x2" (4:77) Each \$2.50 Five for \$9.00
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- J-2: JUNG-WHITE PAT-5 MOD. Power supply. (JW32) 4½x3½" (1:78) Each \$7.00
- J-3: CARLSTROM TV SOUND TAKEOFF. (DC-1) 1½x3½" (2:78) Each \$4.25
- J-5: PASS A-40 POWER AMP. One channel. 3x3" (4:78) Each \$6.00
- J-6: SCHROEDER CAPACITOR CHECKER. (CT-10) (4:78) 3½x6" Each \$7.25
- J-7: CARLSTROM/MULLER VTVM ADAPTER. (CM-1) (4:78) 1½x2½" Each \$4.25
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..... Board No .....	..... \$ .....
..... Board No .....	..... \$ .....
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## SB Mailbox

Specifically, your "Voice of the Theater" system, which I assume is the Altec Lansing model A-7-8, uses the model 416-8A 15-inch woofer which has a pleated surround, a stiff paper cone and a large paper dust cap. That driver has a "woody" sound quality that is exacerbated by the relatively empty enclosure it is mounted in.

A course of action would be to modify the drivers as outlined but to plasticcoat the whole cone instead of part of it, stuff the enclosure and tune for the lowest cabinet resonance possible. Keep in mind that vented systems have two resonant peaks and you will be dealing with a larger internal volume. You also might want to try closing the vent to see how the system operates as an infinite baffle. It has been tried on other systems with good results.

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Magneplanar Timpani III (dark brown) tweeter/midrange with TAA low pass crossover, \$475; Marantz 15.2 x 60 watt amp, \$160; *The Audio Amateur* complete 1980-1982, \$70; *Speaker Builder* complete 1980-1982, \$30 or offer. Rich Davidson, 501 Paige Loop, Los Alamos, NM 87544 (505) 672-1094.

Pyramid MET-7 (list \$305) \$250 with blank warranty card; Symmetry SW-1 subwoofers (list \$800 pr.) \$400, six months old; Luxman SQ68C 30 w/ch (list \$700) \$450 as new with blank warranty card; Luxman L-11 integrated amp (list \$1000) \$500 with blank warranty card, 100 watts channel; Symmetry ACS-1A active crossover (list \$750) \$450 with gold plated inputs; Technics SL-15 programmable turntable (list \$850) \$500 six months old; Nakamichi 700 II with remote control \$500. All items mint or as new. 550 Baker, San Francisco, CA 94117 (415) 921-0870.

1 Pair Webb TLS systems (TAA 1/75), drivers include: KEF B139, B110, T27 and Celest. HF2000. Rosewood veneer, Falcon X-overs, no grilles. \$600/pair. Also these components: two Celestion HF2000 S'tweeters, \$20 ea.; two Falcon Webb TLS X-overs, \$20 ea. All for \$75. Neil K. Disney, 414 1/2 W. Mansion, Marshall, MI 49068 (616) 781-6156 evenings.

Pairs of KEF T-27 (\$40), B-139 (\$175), and Jordan Modules (\$125)—all new in the box with original hardware. Al Schilling, Suite 1900, 10100 Santa Monica Blvd., Los Angeles, CA 90067 (213) 552-4578 (daytime).

Pyramid Met-3's \$950; Denon DP-6000, DK-200 base, \$450; with EPA-100, \$700; Stasis III \$1200; Hegeman Hapi II \$300; Super-PAS, 5751's \$175; Infinity Black-Widow Arm \$75; Grace 704 \$100; KLH-4's \$200; FRT-3G transformer \$125; Integral Systems 200W amp \$175; DB walnut case \$10; Silver Coax \$0.80/ft., Steve (203) 397-4965.

Ampzilla with add-on 100KµF cap bank, excellent condition, \$500; 2 Dyna ST-70 amps, no mods, \$175 the pair; Dyna PAS 3X preamp, \$60; M&K Mil-KX<sub>2</sub> 60-75Hz passive subwoofer crossover, \$50; M&K "bottom end" speaker, \$100; Audionics SQ-106C decoder, \$50. (303) 681-2432.

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Two  $\frac{3}{4}$ " tweeters from AR-3A, \$20 each. One  $1\frac{1}{2}$ " midrange from AR-3A, \$45. AR turntable, no arm, "T" chassis shortened for Mayware arm, extra platter, \$40. Postpaid. Tom Devlin, 17 Cherry St., North Adams, MA 01247 (413) 664-4682.

Advanced Analog Systems. Analog reverb unit, model ARS 911. As seen in *Radio-Electronics* Sept-Oct '81. Assembled and factory aligned. A bit too noisy for my ears. Orig. \$150, now \$125. 15 day trial. Money returned if not satisfied. David Long, 3248 Chatsworth Rd., Dalton, GA 30720.

Tektronix oscilloscope 5" dual beam. Audax H17B25H  $6\frac{1}{2}$ " \$50 pr. unused. Panasonic A11EC 80-02F  $4\frac{1}{2}$ " \$10 pr. unused. Jordan watts 50mm modules \$115 pr. unused. Jordan watts 100 mm modules \$100 pr. unused. Dynaco stereo 80 ex. cond., \$50. William Guidara; 1050 Lake Blvd. No. 8; Davis, CA 95616.



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*The K-Coupler*, a paper on Karlson enclosure theory, by Martin C. Poppe, Jr., appeared in Dec. 1966, I.E.E.E. *Trans. on Audio*. The author stated a sequel would be forthcoming. Does anyone know of the sequel or other theory on the subject? Marvin Weinstein, 3232 E. Stanford Dr., Paradise Valley, AZ 85253.

Teac C3X 2 speed cassette deck. Nak Dolby C cassette deck, prefer 3 heads. Bruce Boyes, PO Box 607, Endicott NY 13760 (607) 785-4630 eves/wknd or leave message.

Older speakers: Goodmans 12" axioms, triaxions. Stentorian 15" coaxials. Racon (N.Y.C.) 15" 15HTX, X-B, 12" HTX. Norelco, Stephens 12"-8" full range. Stephens Coaxial 15" -150 CX, 12" #120 CX 122AX. RCA 15"-12" coaxials. Jensen 12" SG 300, 223, 222. Calrad 8" coaxial #CR-8X, 12" TX4, 1. GE 12" coaxial 1A-401. Stromberg-Carlson 15" Coaxials RF 484, 483. Singles ok. No cabinets. Ask friends. B. Kalish, Box 52, Redlands, Calif. 92372 (714) 792-0220.

Dynaco A-470 output transformer for ST70; Heath AA-121 stereo amp; FR12 arm, will consider trades for above speakers. David Barnett, 8523 Linda Lane, Little Rock AR 72207 (501) 225-4736.

J.B. Lansing No. 45040 exponential horns, also plans for Carlson 12" enclosure. J. W. Madgett, Heiskell, TN 37754 (615) 947-7607.

Schematics and manuals for Crescent Communications ZM-30/U. LCR Bridge, AEL Products AN/USM-206. Semiconductor test set, Tek plug-ins Type G, Type 1A7A, Type CA. Thomas Sahara, PO Box 23283, Honolulu, HI 96822.



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Plans for Electro-Voice TL-5050 folded horn woofer, AKA Sentry IVB LF section. Will pay up to \$5. C. Doering, #G3, 500 80th St., N. Bergen, NJ 07047 (201) 868-4456.

Danish audio amateur needs manual/diagrams/mods for old EICO ST70 integrated stereo tube amp. Will pay reasonable price for originals/copies. Pls. write to S. Hansen, 38 Toften, DK-3450, Allerod, Denmark.

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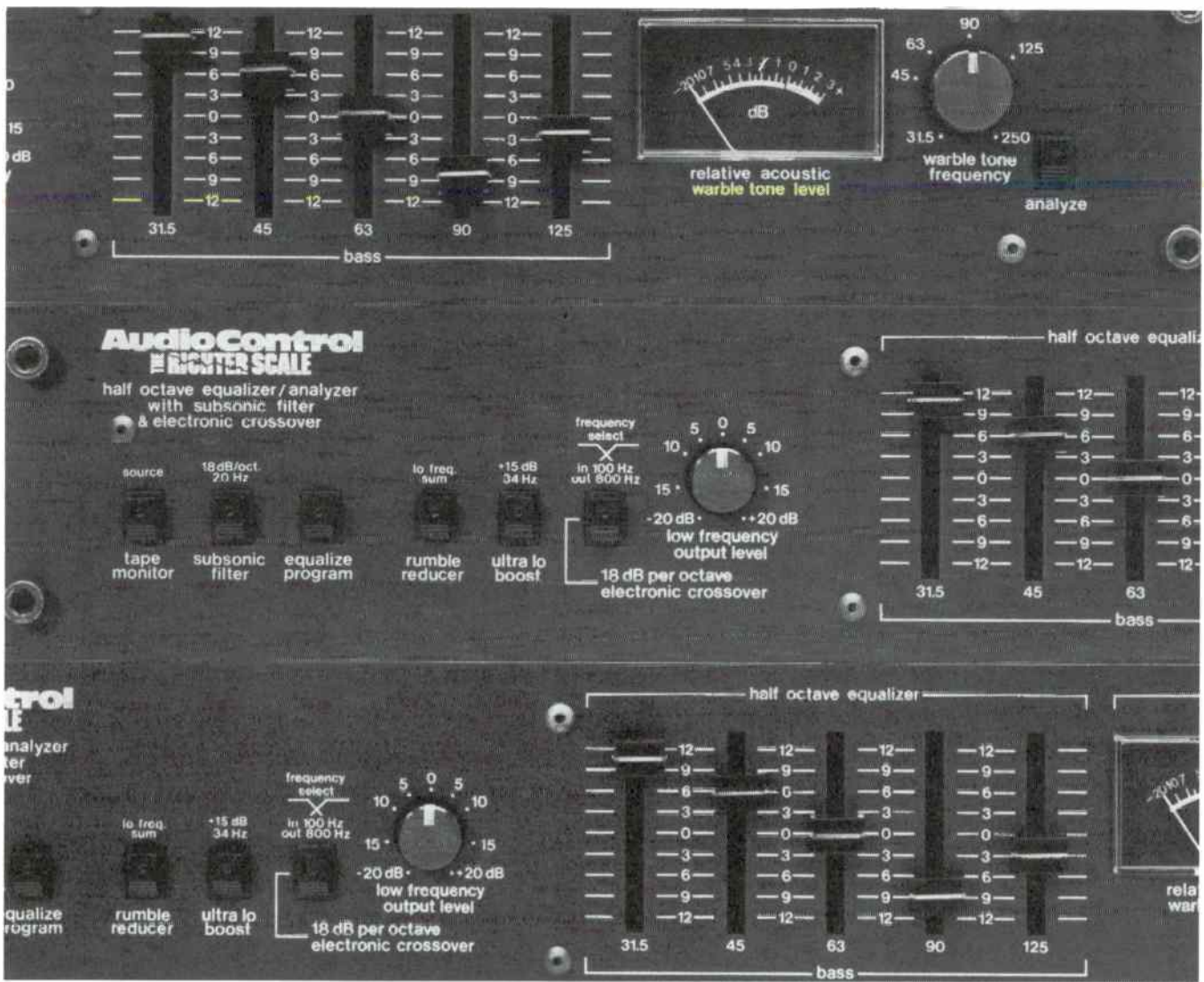
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