

SPEAKER BUILDER



Good News



An indoor-outdoor omnidirectional two-way loudspeaker system, the Model OS-1, has been developed by **OESIGN ACOUSTICS**, an Audio-Technica company. Because of its broad (90Hz to 18kHz) range, the OS-1 is a means of reproducing background sound for a backyard barbecue or party. It is recommended for patios, walkways, decks and atriums.

The cylindrical unit comes in a sturdy weather-resistant plastic case finished in satin black, but it may be repainted to blend with any surroundings. It may be mounted at ground level, held aloft by a pipe or suspended from a standard lamp-hanger (not included). The two loudspeakers used in the system are water-resistant and specially designed for long use under temperature extremes.

Information is available from Audio-Technica, 1221 Commerce Dr., Stow, OH 44224.

FAST REPLY #DG22



Soundfield Imaging is a new technology that improves the spatial perspective of music reproduction in the home. Developed by **dbx INC.**, the Soundfield™ One speaker system is the first product incorporating this technology. The system can reproduce the full dynamic range of digital compact disks and creates a sonic image with a realistic breadth and depth of field that is identical for virtually any listening position.

The dbx Soundfield One is comprised of two 43-inch (H) by 14½-inch-square columnar loudspeaker enclosures and a Soundfield Imaging Controller. The controller provides a flexible means for dealing with room acoustics problems and compensating for various sonic deficiencies of recordings. This outboard line-level analog signal processor connects to the tape monitor, EPL (external processor loop) or preamplifier output jacks of your stereo system. Although the primary purpose of the controller is to provide overall system equalization, additional functions include low and high-frequency compensation, tape monitor, auto bypass, auto balance and rumble suppress.

Each speaker enclosure contains 14 drivers, including four 10-inch woofers and four 4-inch midrange drivers, with

BOSTON ACOUSTICS has introduced a new compact speaker system designed specifically for use with video monitors, color television sets and computers. The Boston A40V is a new version of the Boston A40 with MagnaGuard™ magnetic shielding so that it can be placed adjacent to a color TV without adversely affecting picture quality. The new two-way system is identical in size (13¼ by 8¼ by 7¾ inches) and performance to the standard Boston A40. It features the same ¾-inch ferrofluid tweeter and magnetically shielded 6½-inch, long-throw, acoustic suspension woofer. Recommended amplifier power is 5 to 40W.

For details, contact Boston Acoustics, 247 Lynnfield St., Peabody, MA 01960.

FAST REPLY #DG336

one of each size arranged on the cabinet's four sides. The remaining six drivers are ½-inch dome tweeters, positioned in a hexagonal array in the upper portion of each enclosure.

Each speaker has an impedance of 4½ ohms ($\pm 1\frac{1}{2}$ ohms) from 20Hz to 20kHz, which means the speakers' operation will remain stable with any amplifier. They can be driven to healthy levels with as little as 40W/channel, and 300W/channel will produce a 110dB peak sound-pressure level in most home listening environments.

Write to dbx Inc., PO Box 100C, Newton, MA 02195.

FAST REPLY #DG85



One of this editor's dreams has been to put ten minutes of music on a 7½ ips tape dubbed one-to-one from a good master. In my fantasy, the result is hundreds of audiophiles buying pairs of mikes and rushing out to record live music for themselves. Now Bob Sellman has done all that for the music lover/audio enthusiast. His new **DIRECT-TO-TAPE** catalog features a treasure trove of tape recordings of the highest quality. Serious audiophiles who own a good reel-to-reel deck or cassette machine owe it to themselves to buy at least one of Mr. Sellman's tapes. Direct-to-Tape's address is 14 Station Ave., Haddon Heights, NJ 08035.

FAST REPLY #DG9

The Model 120 active electronic crossover from **DECOURSEY ENGINEERING LABORATORY** is made to each customer's specifications. It contains a circuit board with provisions for up to nine plug-in modules, which may be single or dual filters, subsonic filters, subsonic filters with low-frequency compensation, amplifiers or summers. The board contains a power supply capable of supplying all of these with regulated $\pm 15V$ DC.

The Model 120 can be supplied as monaural or stereo biamp, triamp or quadamp, with subsonic filters and with a summer for single subwoofer output. Customer-specified Butterworth filters of any audio frequency and with slopes of 6, 12 or 18dB/octave are also available, and up to six level controls can be sup-



plied. The unit comes in an 8-by-6.25-by-2.5-inch plastic case.

Contact Decoursey Engineering Laboratory, 11828 W. Jefferson Blvd., Culver City, CA 90230.

FAST REPLY #DG18

The world's first series of professional and consumer digital floppy-disk audio recording and playback systems was recently introduced by **COMPUSONICS CORPORATION**.

The DSP-2000 Series of mixers/recorders will make it possible for recording studios to produce all-digital prerecorded music, either for compact disks or for CompuSonics-formatted high-density digital disks. The professional system is actually a super-micro, multi-processor computer that is configured as a single-user workstation for the audio mixing and recording of live music in a variety of digital formats. The system is designed to replace conventional analog

and near-digital studio recording equipment.

The CompuSonics DSP-1000 system allows you to make home digital recordings on a high-density, specially formatted, 5¼-inch floppy disk. You may use any digital or analog source to make the recordings. The system is compatible with all conventional stereo components. Because the recordings made on the CompuSonics DSP-1000 systems are stored in a digital format, they will never, according to the maker, encounter most of the problems inherent in analog recordings—wear, deterioration, surface defects, tape hiss and dropouts.

FAST REPLY #DG785

MONSTER CABLE has introduced Cable Helpers, a wire-management system for audio, video and computer installations. You may purchase the identification labels, cable ties and ladder straps individually or as a set.

Each package of identification labels contains 144 self-adhesive tabs printed with descriptions such as Audio Out, Phono In, Tape Out, Video In, Amp AC, 3R and 3L. The identification labels are designed to be applied to both ends of a

wire. Cable ties come 50 to a package and are used to bind wires together for an uncluttered look. For optimum organization, ladder straps help route cables down the side of a rack, across baseboards or around corners. They come six to a package and have a strong adhesive backing.

For details, contact Monster Cable, 101 Townsend St., San Francisco, CA 94107.

FAST REPLY #DG664

6000.6 phase correct

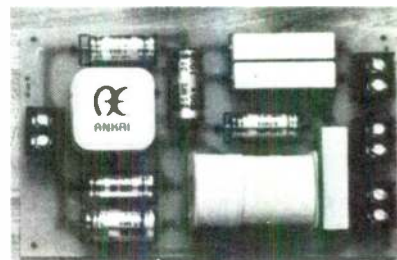


electronic crossover

The new 6000-6 is designed to improve your system by eliminating crossover errors and passing perfect square waves. A plug-in module allows convenient frequency change (from 40-16,000 Hz). Level controls on rear, 1% components used. Model 6000-6 \$175 PPD. Other models from \$16.25. Free folder/reviews. **ACE AUDIO CO.**, 532-5th St., East Northport, NY 11731-2399. (516) 757-8990.

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About This Issue

Speaker Builder's fourth issue of 1984 opens (p. 7) with the work of **Joseph D'Appolito**, who has heretofore been prominent in our Mailbox column. He now shares his elegant design for a pair of genuinely high-power, two-way satellite designs smoothly covering the range above 100Hz and having an unusually wide and even polar response. **Bernhard Muller** gives us a new version of the widely used white/pink noise generator (p. 16) and also shares his extensive experience in using the device for evaluating loudspeaker response in rooms.

The final installment of **G. R. Koonce's** excellent modular test instrument series, Part II of his unique dual impedance meter, begins on page 21. And **Siegfried Linkwitz**, who has become justly famous among crossover theorists and also published his three-box system incorporating a time delay in *SB's* 1980 series, has worked out some clever nomographs (p. 24) to calculate sound pressure levels for any driver working into a half space. *Speaker Builders* will doubtless find this set of tools invaluable in design work.

Tools, Tips & Techniques is rich in fresh information from a number of readers (p. 28), while **Timothy Palmer-Benson** reports on his adventures with the legendary Strathearn ribbon mid-high transducer from Northern Ireland (p. 30). On page 36, **W.L. Ramsay** shows us how he combined two Polydax woofers with four Jordans in his Craftsman's Corner report.

The 1985 *SB* series is coming up right on schedule with a slew of exciting articles. We hope you will all be with us.

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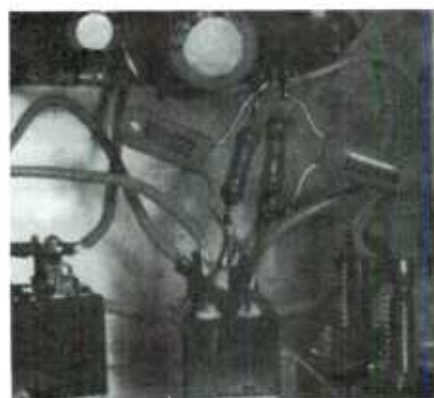
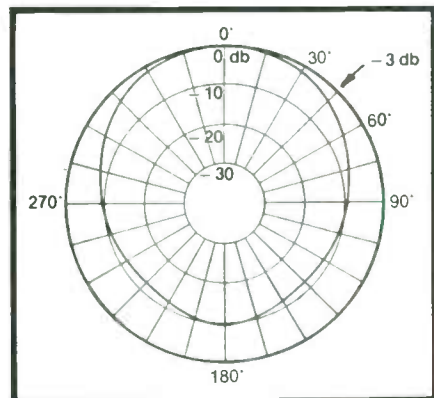
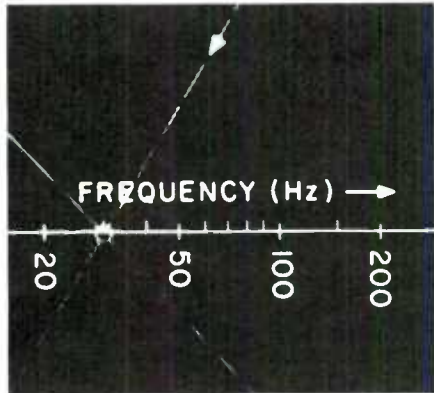
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Retrospective: A Half Decade

This issue completes *Speaker Builder's* first five years. It seems impossible that so much time has passed since this publication's inception, and the time has been packed with surprises. I could not have anticipated that the intricate mysteries of loudspeaker design were at once so engrossing for so many deeply motivated and talented people and that the mysteries were so nearly unexplored.

The first surprise was the impressive backgrounds of those who have volunteered their services to the art and science of speaker building. Our authors work in a wide variety of occupations and places, including the space lab at Berkeley, Hewlett-Packard, a defense hardware design facility and several universities.

Aside from this diversity, our authors have brought the most up-to-date technology to our pages. The complex array of parameters that interact to determine a loudspeaker's performance are difficult to manage all at once. Harnessing the microcomputer's power to this task has been the goal of programs written by Bob Bullock and Glenn Phillips and implemented by Bob White. I encourage those programming in microcomputer BASIC to write versions of these programs for machines other than the Commodore (on the way) or the Apple.

Other outstanding work has come from Bruce Edgar, whose special interest is horns. He has not only given us excellent horn construction projects, plus basic woodworking directions, but has also functioned as our loudspeaker historiographer, having interviewed three outstanding pioneers in the field—P.G.A.H. Voigt, Raymond Cooke and Ted Jordan. Edgar's horn designs are typical of the quality evident in the range of designs it has been our privilege to publish.

Siegfried Linkwitz began our 1980 series with his unique three-enclosure system, which had a delay built into the active crossover. Mr. Linkwitz is back again in this issue with his excursion-limited nomographs. Roger Sanders' updated series on constructing electrostatics also graced the pages of our first series, and he has continued to contribute to the magazine. In 1980, Bob Bullock began his landmark articles based on the Thiele/Small theory of vented and closed boxes. He went on to put the theory into programmable calculators and most recently into the microcomputer.

G.R. Koonce has given us a fine array of devices for loudspeaker project development, including test boxes, theory and test instruments for measuring driver parameters, while Gary Galo has widened our coverage of enclosure types with his series on transmission lines. Ken Rauhen introduced us to the handmade Heil Air Motion Transformer driver and gave us the world's first version of that transducer coupled to a horn.

The variety of information in *SB's* pages on both passive and active crossovers is so wide and various that I haven't room here even to summarize. All this has been enhanced by the many practical builders' reports we have published in these 20 issues of *Speaker Builder*.

All in all, I find it an amazing performance on the part of amateurs who generally earn their living outside the audio industry. Whatever *Speaker Builder* has achieved for its readers is directly attributable to its authors. To be sure, our staff brings professional magazine production and editing skills to the task, and I am proud of every one of them. But the magic in any issue comes from the hands, minds and love of those who write the articles.

What of the next five years? All of us know by now that our universe is still flying apart at an exponential rate as a result of the original "big bang" that started us on our way. In a similar fashion, the technological "big bang" that began so short a time ago is now propelling us into development at a breathtaking rate. As I write this, 3M Company is beginning experiments aboard *Discovery's* space flight that could produce results leading to a film only a few molecules thick that has the strength of steel. How about that for tweeter cones and possibly membranes for a new electrostatic?

Loudspeaker technology in our first five years has moved a relatively short step compared with what the next five years will bring. I hope the prospect excites and challenges you as much as it does me.—E.T.D.

We are pleased to announce the first issue of our new quarterly publication, Computersmith, for people who like to build, modify and enhance microcomputers. The first issue will be mailed on March 1, 1985. Subscriptions are available at \$15 per year, \$25 for two years from Computersmith, PO Box 176, Peterborough, NH 03458.

A HIGH-POWER SATELLITE SPEAKER

BY JOSEPH D'APPOLITO

Satellite/subwoofer speaker systems have become quite popular in recent years. The general design considerations and many advantages of these systems were covered in an excellent series by Siegfried Linkwitz (*SB 2/80, 3/80 and 4/80*). Among these advantages are wide dispersion, excellent imaging, ease of placement and minimum impact on home decor.

Unfortunately, satellite speakers often have one major disadvantage—limited power-handling capability, especially in the critical satellite/subwoofer crossover region. This disadvantage becomes even more important as we enter the "digital era." The small mid-bass drivers usually used in satellite/subwoofer speakers can generate a short-term average sound-pressure level (SPL) of only 92dB or so

around 100Hz, where most of these systems cross over.

The major goal of this project was to develop a satellite speaker that would retain the traditional advantages of this genre while providing substantially increased power-handling capability. In particular, when combined with a suitable subwoofer, the complete stereo speaker system must produce a short-term average SPL of 110dB at any frequency above 40Hz in a typical home environment (a 3000-cubic-foot listening room).

I also had three other goals in mind—a uniform frequency response to at least 16kHz, a uniform horizontal polar response of 90 degrees (-3dB) up to 10kHz, and a sensitivity of 90dB or more at 1 meter and a 2.83V input. (Loudspeaker sensitivity is normally

quoted in decibels SPL at 1 meter for 1W of power input. Modern speakers, however, are designed to be driven from zero impedance or constant-voltage sources and are thus actually voltage-to-pressure transducers. The voltage-to-pressure sensitivity is most useful for predicting the output of multiple drivers in series, parallel or series/parallel connections. A 2.83V input will generate 1W across an 8Ω resistor.) The last requirement would guarantee that a 110dB SPL could be reached with reasonable amplifier power capabilities.

Finally, I decided that the satellite speaker should be a two-way system with a passive crossover network between the mid-bass and tweeter drivers. Accurate passive mid-bass/tweeter crossover networks are rela-

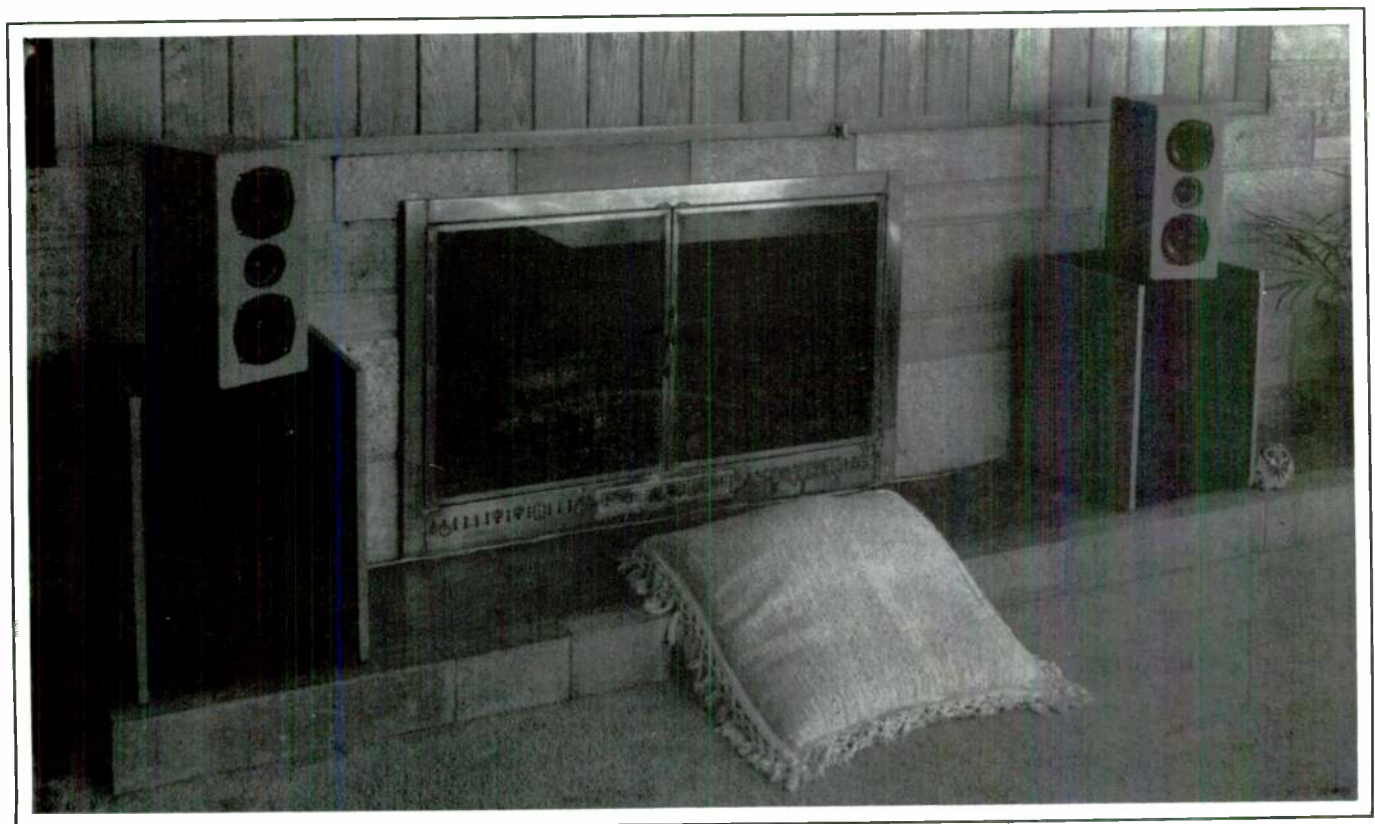


FIGURE 1: Mr. D'Appolito's satellite/subwoofer speaker system is a two-way, three-driver design.

tively easy to build and are far less expensive than triamping. Furthermore, with a passive crossover, the satellite speaker is self-contained, permitting it to be used as a full-range system in smaller rooms.

The satellite speaker system that meets all the above requirements is a two-way, three-driver design (Fig. 1). To obtain higher power-handling capability, I combined two mid-bass drivers with a ferrofluid-damped tweeter in a unique geometry that eliminates the usual problems associated with multiple drivers and guarantees uniform vertical and horizontal polar response.

Each speaker is 7.5 by 16 by 9.5 inches (WHD) in size. When crossed over to appropriate subwoofers at 100Hz, a pair of these speakers can produce peak SPLs of 115dB or more in the average room. This system has evolved in my home over a period of two years and has consistently impressed sophisticated listeners with its musicality, imaging and power-handling ability.

DRIVER SELECTION. Let's examine some of the considerations that influenced my driver selection. The requirement for a short-term average SPL of 110dB around 100Hz is particularly stringent for the small 5 to 6.5-inch mid-bass drivers commonly used in satellite speakers. Fortunately, a single satellite does not have to produce the entire output. In this frequency range, left and right channels are usually in phase, producing a total far-field SPL twice (+6dB) that of a single channel. With an even-order Linkwitz crossover, the satellite and subwoofer will each contribute one-half the total output for another 6dB gain. Thus, a single satellite speaker need only produce a short-term average SPL of 98dB to meet my design goal.

At low frequencies, the SPL generated by a vibrating piston mounted in a small sealed box placed in a normally reverberant listening room can be approximated with the following formula:

$$\text{SPL} = -86 + 40\log f + 40\log D + 20\log A_{pp}$$

where f is frequency in hertz, D is piston diameter in millimeters (mm), and A_{pp} is peak-to-peak excursion in mm.

For a typical 5.25-inch mid-bass driver, the maximum linear excursion

is 6mm, and D is 108mm. At 100Hz, the resulting SPL is 91dB, which is 7dB shy of my goal. Increasing the crossover frequency to 150Hz will produce the desired SPL, but this frequency is too high for satellite/subwoofer systems. Alternatively, adding a second mid-bass driver will double output capability (+6dB) to within 1dB of my goal. Close enough.

The situation with a 6.5-inch driver is somewhat better. Typical values for D and the maximum linear A_{pp} are 130mm and 7mm, respectively. With these figures, an SPL of 95dB at 100Hz is obtained. Pushing the crossover up to 120Hz or doubling up on the drivers will produce 98dB or more.

What effect does our horizontal polar-response goal have on driver selection? The polar-response pattern of a cone driver narrows with increasing frequency. For a simple piston mounted in an enclosure of minimum frontal area, a -3dB beamwidth of 90 degrees occurs when the wavelength of the driving frequency is one-half the piston circumference (Fig. 2). The corresponding frequency is as follows:

$$f = \frac{2c}{C} = \frac{2c}{\pi D}$$

where c is speed of sound (343m/sec), D is piston diameter in meters, C is piston circumference in meters, and π is 3.1416.

Using the values of D already given, the -3dB, 90-degree beamwidths for 6.5 and 5.25-inch mid-bass drivers are 1.7kHz and 2kHz, respectively. Of course, the tweeter will fill in some of the missing off-axis response near crossover, but with sharp cutoff rates, these frequencies can be increased by only 10 percent or so. Thus, the polar-

response requirement places an upper limit on my crossover frequency around 2kHz.

In early 1980, when I first developed this design, the Dynaudio D-28 was the only high-quality tweeter generally available that could generate 110dB SPLs around 2kHz. I purchased a pair of these tweeters and mounted each one on a 7-by-16-inch baffle to simulate the acoustic loading it would see in use. I then ran one-third-octave warble-tone frequency-response plots on each sample. (All frequency responses shown in this article are one-third-octave warble-tone responses taken at a distance of 1 meter on-axis. Each response is plotted as a single point at the one-third-octave band center frequency. The points are then connected with straight lines to form the final graph.)

The average response is shown in Fig. 3. The individual curves were within ± 1 dB of each other. As shown in Fig. 3, the one-third-octave on-axis response of the D-28 peaks broadly in

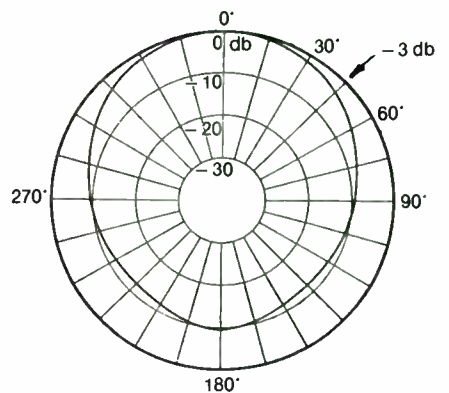


FIGURE 2: Horizontal polar-response pattern for the condition $C = 2 \times \text{wavelength}$, where C is circumference.

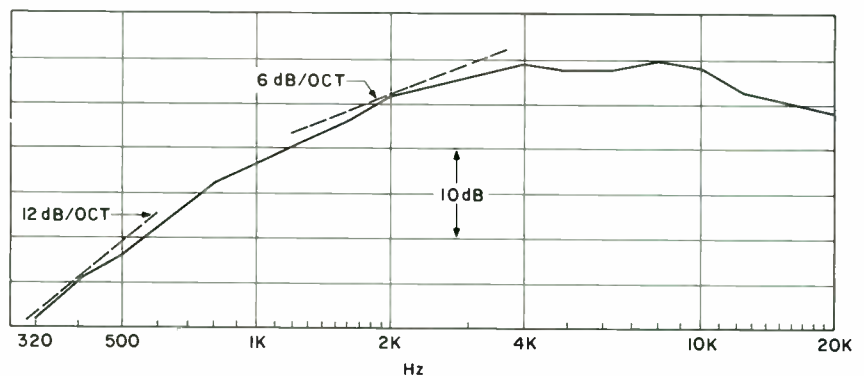


FIGURE 3: One-meter, one-third-octave band, on-axis frequency response of the D-28 tweeter mounted on a 7.5-by-16-inch baffle.

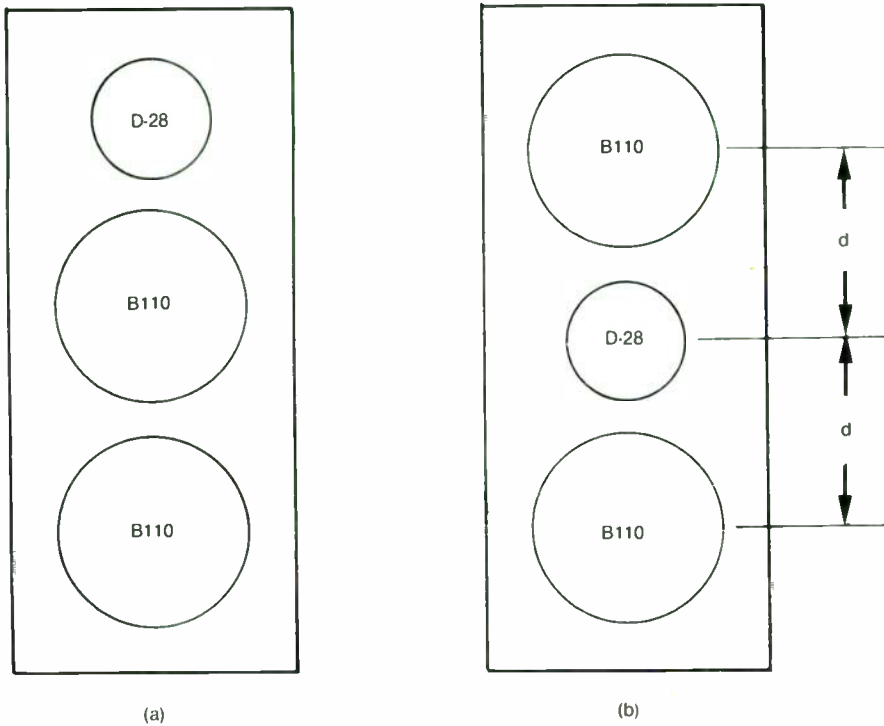


FIGURE 4: Alternative asymmetric (a) and symmetric (b) driver arrangements.

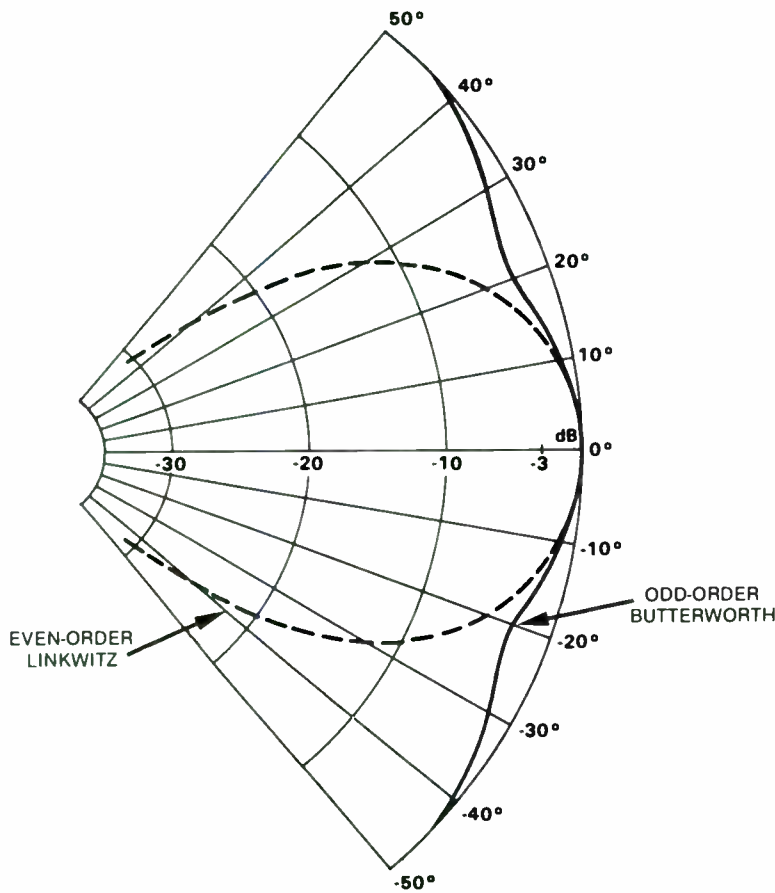


FIGURE 5: Vertical polar-response plot for the driver arrangement of Fig. 4b with an odd-order Butterworth crossover or an even-order Linkwitz crossover, where d equals 4% inches.

the 4 to 8kHz region due to its horn loading. Sensitivity in this region is 94dB. The D-28 is down 3dB at 2kHz and 6dB at 20kHz. The -3dB point of 2kHz sets a lower limit on the D-28's useful range, and the roll-off at 20kHz is greater than I would like. Because of the extra sensitivity between 4 and 8kHz, however, you can remedy both of these "faults" with appropriate crossover design. (The D-28 has one advantage over the flat-flange version, the D-28 AF. The horn assembly places the tweeter diaphragm behind the baffle and into closer time alignment with the mid-bass driver.) With the crossover frequency set at 2kHz by the D-28, you must choose 5.25-inch mid-bass drivers to obtain the desired polar response.

Before making my final driver selection, I had to grapple with the question of interdriver sensitivity matching. The on-axis acoustic output of two identical drivers driven in phase with equal voltages is twice that of a single driver (+6dB, ignoring a small mutual coupling effect). If the voice coils are connected in parallel, the overall sensitivity will be up 6dB over a single driver. In series, the sensitivity will be the same as a single driver. In either case, the maximum output capability is doubled. With passive crossovers, the tweeter sensitivity must be either the same as the mid-bass drivers or 6dB greater, depending on the voice-coil connection.

The venerable KEF B110 has a sensitivity of 84dB. As mentioned before, the Dynaudio D-28 sensitivity is 94dB. Two B110s in parallel will produce a 90dB sensitivity, and the extra 4dB of the D-28 can be used to pull up its high-end response. Thus, I decided to use two KEF B110s with the Dynaudio D-28. Resonances of the paired B110s should be as close as possible and preferably no more than 10 percent apart to guarantee good load sharing.

The drivers must be aligned vertically to minimize horizontal polar-response irregularities and interdriver path delay. Thus, only two choices of driver arrangement are possible—place the B110s together with the D-28 above them or place the D-28 between the two B110s. Both choices are illustrated in Fig. 4.

The first arrangement, Fig. 4a, is asymmetric. It produces frequency-dependent wander of the vertical polar-response pattern and off-axis response irregularities that depend on

interdriver phase differences.¹ The second arrangement is inherently symmetric. It places the effective acoustic center of the mid-bass driver pair coincident with the tweeter. This arrangement yields a stable vertical polar response independent of interdriver phase or magnitude differences. It has many additional features described in my paper presented at the October 1983 AES convention.² I will discuss some of these later in this article.

CROSSOVER SELECTION. Polar response is influenced by the crossover network. Vertical polar-response patterns for the symmetric two-way, three-driver configuration at the 2kHz crossover frequency are presented in Fig. 5. Plots are shown for two crossover network types, the even-order Linkwitz crossover, where all drivers are driven in phase, and the odd-order Butterworth crossovers, where tweeter and mid-bass drivers are 90 degrees out of phase. Interdriver spacing is $4\frac{5}{8}$ inches, which corresponds to two-thirds of a wavelength at 2kHz. Both patterns are symmetric. The in-phase crossover, however, produces a sharp null at ± 46 degrees off-axis. With a 90-degree phase shift, the off-axis response is relatively smooth.

My AES paper shows that the smoothest polar response is obtained at all frequencies when the drivers are 90 degrees out of phase and that the odd-order Butterworth crossovers are best with this geometry. These crossovers also have minimum delay and constant magnitude and power response, which are desirable.³ Vertical polar response is enhanced by keeping interdriver spacing at a minimum. For example, if the driver spacing is increased to 7 inches, the off-axis null produced by the in-phase Linkwitz crossover network in Fig. 5 moves in to ± 20 degrees, and a second null appears at ± 75 degrees.

Having decided on odd-order Butterworth crossovers, I had to pick the cutoff rate. From Fig. 3, you can see that the D-28 is already rolling off (actually rolling up) acoustically at 6dB/octave below 2kHz. To get any additional electrical roll-off, you must go to a higher-order crossover. For example, combining the D-28's 6dB/octave roll-off with an electrical 12dB/octave roll-off will produce an overall acoustic roll-off of 18dB/octave. Because of some peaking in the B110's response above 3kHz, the mid-bass

crossover roll-off rate should also be greater than 6dB/octave. An 18dB/octave roll-off is satisfactory for the B110. Since passive 30dB/octave crossovers are difficult to build and align properly, I chose 18dB/octave acoustic crossovers for the final design.

CROSSOVER DESIGN. Crossover design involves proper tailoring of

electrical response to driver acoustic response to obtain an overall acoustic Butterworth characteristic. The D-28 tweeter uses ferrofluid for mechanical damping and heat removal. The fluid produces an overdamped mechanical response, which causes the tweeter to begin roll-off way above its mechanical resonance of 600Hz.

Acoustic unloading of the D-28's horn below 2kHz also adds to the fall-

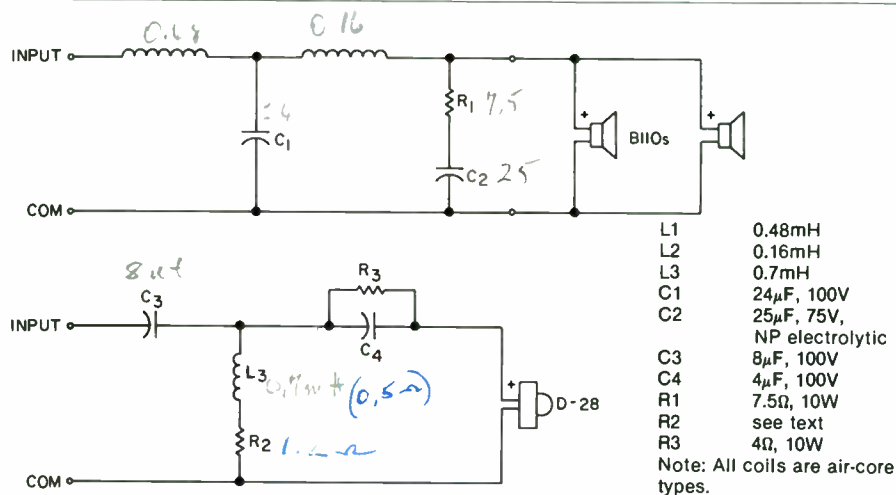


FIGURE 6: Schematic diagram of the author's satellite speaker crossover network.

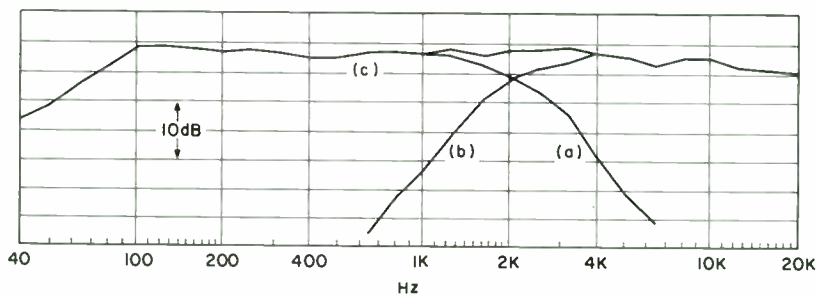


FIGURE 7: On-axis frequency response of the mid-bass drivers (a), tweeter (b) and complete system (c) at 1 meter.

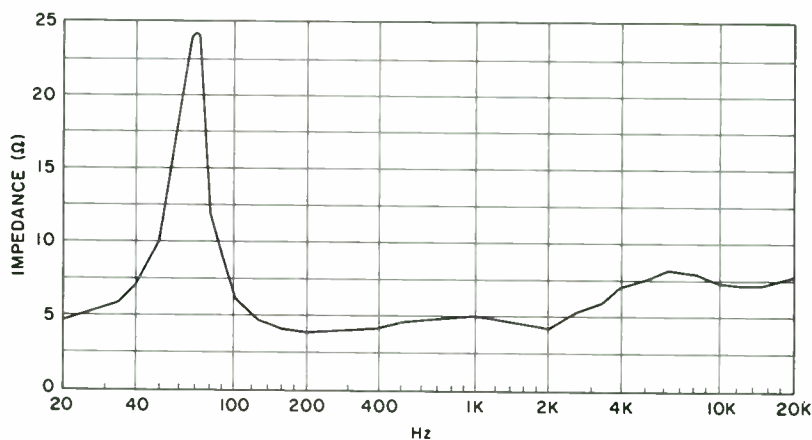


FIGURE 8: Satellite speaker system impedance magnitude.

off. *Figure 3* shows that the D-28 slowly changes from a 6dB/octave roll-off around 2kHz to a 12dB/octave roll-off down around 400Hz. If you want a true 18dB/octave acoustic roll-off, you must design the electrical part of the crossover to start rolling off 12dB/octave at 2kHz and to change slowly to 6dB/octave at around 400Hz. The tweeter crossover must also account for the sensitivity mismatch between the B110s and the D-28. The 4dB mismatch will be used to pull up the high-end response of the D-28.

As you will see shortly, you can easily correct the smooth response variations of the D-28 with a complementary crossover design. The B110 peaking in the 4 to 5kHz region, however, is difficult to complement and is not really necessary. A conventional constant-resistance crossover will simply roll off the mid-bass drivers at 18dB/octave.

The final crossover schematic is shown in *Fig. 6*. L1, L2 and C1 comprise a conventional 18dB/octave third-order Butterworth crossover. R1 and C2 are an impedance-compensating Zoebel, which is required to keep the network properly loaded in the presence of the B110's rising impedance. The Zoebel is actually used in this application to control the Q of the crossover/driver combination. I selected final values for the flattest overall response.

The high-pass crossover section requires some additional explanation. You can obtain the conventional third-order Butterworth crossover by cascading a first-order high-pass with a slightly underdamped ($Q=1$) second-order high-pass. The first-order part is already in the D-28 response. C3 and L3 make up the underdamped second-order high-pass, which gives a 12dB/octave roll-off below 2kHz. R2, however, limits the final roll-off rate to 6dB/octave around 400Hz. The exact value of R2 is not critical. I found it by adding a fixed resistor of appropriate value to the DC resistance of L3.

R3 attenuates the D-28 response by 4dB in the 4 to 8kHz region, while C4 progressively shorts R3 above 10kHz to bring up the high-end response of the D-28. Again, I selected final values for the flattest response. Note that the tweeter is connected in phase. A small, uncompensated delay of the mid-bass drivers relative to the tweeter causes the normally preferred phase-reversed connection to produce a response dip in the crossover region.

The individual driver response and the combined system response on-axis are shown in *Fig. 7*. Notice that acoustic roll-off rates for both low and high-frequency drivers are 18dB/octave. The overall hemispherical free-field response is ± 2 dB from 76Hz to 20kHz, which is quite good for a two-way system. *Figure 8* shows the satellite speaker impedance curve. System resonance is at 72Hz, where the impedance peaks to 24 Ω . The minimum impedance of 4 Ω is reached at 200Hz and rises slowly to 7.5 Ω at 20kHz. The small dip at 10kHz reflects the effect of C4. The system Q at resonance is 0.8, including the effect of the DC resistance of L1 and L2.

CROSSOVER CONSTRUCTION.

All the crossover components are mounted on a 4-by-6.5-by- $\frac{1}{16}$ -inch blank glass epoxy board and wired point to point. Input and output connections are made with solder lugs pop-riveted to the board. You could also use quick-disconnect lugs and solderless connectors. Coils and capacitors are held in place with self-locking nylon wire ties. No coil-winding information is given. You may purchase all the required coils from Madison Speaker Components (8982 Table Bluff Rd., Box 4283, Madison, WI 53711) for about \$9. Unless you have access to 18-gauge magnet wire at bulk prices, you cannot wind your own for less. Order the inductance value nearest to that given in *Fig. 6*. Note that all coils are air-core types.

You can build the required capacitors by paralleling smaller standard values. I used three 8 μ F, 100V Mylars in parallel for C1. C3 is an 8 μ F Mylar, while C4 is a 3.3 μ F Mylar in parallel with a 0.68 μ F polypropylene. R2 is a 1.5 Ω , 5W resistor. In series with the 0.5 Ω DC resistance of L3, this yields the total value needed for R2. (You can delete R2 with little measurable effect on overall response.)

CABINET CONSTRUCTION.

I constructed a prototype cabinet of $\frac{5}{8}$ -inch high-density particle board for initial system testing. I made an accelerometer from an old moving-magnet phono cartridge and used it to measure panel resonances and vibration. Frequency sweeps revealed substantial side-panel vibration in the 200 to 500Hz range, sometimes producing a calculated spurious acoustic output only 15dB below the direct output of the system. Further tests showed that

these vibrations were mechanically coupled to the box through the mid-bass driver chassis and *not* acoustically coupled into the box panels. The final box design attacks panel radiation on two fronts. First, the side panels are treated with a damping compound. Second, the mid-bass driver chassis is mechanically decoupled from the enclosure.

I also made the final enclosures of $\frac{5}{8}$ -inch high-density particle board. The overall dimensions are 7.5 by 16 by 9.5 inches (WHD). The interior sides, top and bottom of each enclosure are covered with $\frac{1}{2}$ inch of a dense sand/asphalt mixture. This mixture is made by combining roughly equal parts per volume of roofing cement and clean sand, which are available at local building supply houses. The sand adds mass to the enclosure walls, while the cured asphalt matrix provides high mechanical loss (damping) to kill panel vibrations. Precoat the enclosure panels with a thin layer of the roofing compound to improve adhesion of the heavy sand/asphalt mix. Almost two weeks are required for this mixture to cure.

I installed a central internal brace between the side panels and glued (100 percent coverage) half-inch acoustic foam to the back panel. The crossover network is screwed to the back panel and the remaining internal volume filled with about 6 ounces of high-loft Dacron fiber. Do not overstuff!

The front baffle is made of $\frac{3}{4}$ -inch 13-ply Baltic Birch plywood for ease in machining. Front-baffle layout is illustrated in *Fig. 9*. The D-28 is rabbeted flush with the baffle. To minimize interdriver spacing, the B110 rims overlap the D-28 flange by about $\frac{3}{8}$ inch to yield a $\frac{4}{8}$ -inch center-to-center spacing. The entire front panel is glued to the enclosure with a thick layer of non-hardening panel adhesive to provide some mechanical vibration isolation between it and the enclosure.

The B110s are vibration isolated from the baffle to reduce mechanical noise transmission into the speaker side panels. The isolation scheme I chose permits easy removal of the B110s—a requirement for SB readers who like to modify their gear. The B110 mounting holes are reamed out slightly to accommodate $\frac{1}{8}$ -inch ID rubber grommets. I placed a $\frac{1}{16}$ -by- $\frac{3}{8}$ -inch dense, self-sticking, polyfoam weather stripping around the B110 mounting hole. The mid-bass driver is

gently snugged to the baffle with #6 self-tapping screws, which pass through the grommets. Flat washers between the screw head and grommet produce uniform compression of the grommet. The screws are tightened just enough to make a positive seal. With this construction, all spurious panel responses are at least 35dB below the direct output, which is a good figure.

The front baffle is covered with half-inch acoustic foam for high-frequency diffraction control. The foam pattern is shown in Fig. 9. Use the B110 frame as a template and cut the foam carefully with a fresh triangle-point X-acto blade. If acoustic foam is not available, half-inch foam carpet padding works well and comes in many colors. The finished satellite speakers are shown in Fig. 10.

ROOM RESPONSES. The response curve shown in Fig. 7 is obtained when the satellite speaker radiates uniformly into a half-space, or hemisphere. This condition is comparable to having the speaker mounted flush in the center of a large wall. In more typical installations, however, speaker response will be altered by diffraction loss and wall reflections. At high frequencies, where wavelengths are short compared to front-baffle dimensions, acoustic energy will radiate largely into the front hemisphere. At lower frequencies, where the smallest baffle dimension is comparable to one-half wavelength (about 900Hz for this project), some acoustic energy will begin to diffract around the baffle and radiate rearward. At very low frequencies, radiation will be omnidirectional.

As the effective volume into which the speaker radiates increases, SPL falls off. At the lowest frequencies, output is down 6dB. The diffraction loss is illustrated in Fig. 11b. I determined this loss by mounting the speaker at normal listening height (tweeter 36 inches above the floor) in the center of a large, mildly reverberant room. Below 1kHz, the response falls smoothly until about 100Hz, where it is down by 6dB. Linkwitz discusses diffraction loss in his SB series and provides a circuit within his electronic crossover to compensate for it. If you are building your own subwoofer/satellite crossover, you can use Fig. 12 in the satellite signal path to compensate for diffraction loss.

It is relatively easy to account for diffraction loss. The smooth curves of Figs. 7 or 11a and 11b, however, are possible only if the speakers are 5 feet or more from any vertical reflecting

surface. Many of us will not be able to place the satellites that far away from the walls in our listening rooms. In my room, the speakers are at normal listening height, but only 18 inches

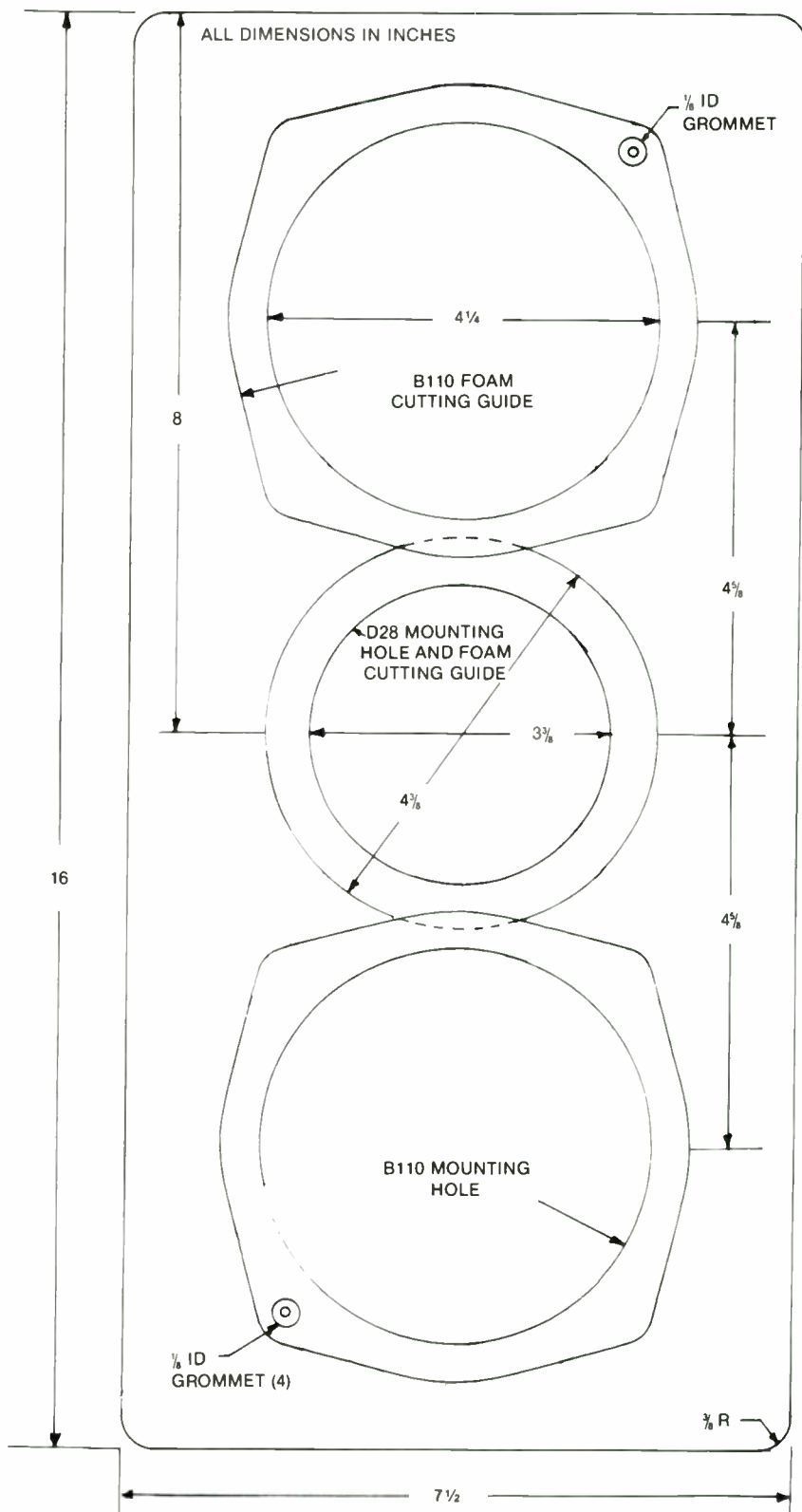


FIGURE 9: Front-baffle layout and foam cutting guide. Rout the D-28 flange flush with the baffle and use the B110 chassis for a bolting guide.

from a highly reflective stone wall. The one-third-octave response plot for this condition is shown in *Fig. 11c*. The wall reflections superimpose alternate reinforcement and cancellation of 3dB

or so on top of the diffraction loss effect. The large peak in the 64Hz one-third-octave band is due to a room-resonance mode, which is not excited in the complete system because of the

high slope crossover between subwoofer and satellite speakers.

Treatment of nearby reflecting surfaces with acoustic foam or other sound-absorbing material will smooth response to some extent, but will not absorb the lower frequencies completely. Try to keep the speakers far from vertical walls if they are highly reflective and compensate for diffraction loss as required.

My complete system is shown in *Fig. 1*. Two 12-inch subwoofers increase the low-frequency output capability and hold up the satellite speakers. The subwoofers are equalized flat to 27Hz, and the system is bi-amped. The satellite/subwoofer crossover at 100Hz properly accounts for satellite roll-off below 76Hz. The circuit is similar to the one given by Linkwitz (*SB 4/80*), without the mid-bass to tweeter crossover. You may switch the diffraction loss circuit in or out, since its boost, together with wall reflections, tend to thicken male voices on some recordings. A 100W/channel amp drives the subwoofers. The satellites are powered with a 300W/channel amp, since most of the power demand is actually in the satellites' range.

HOW DOES IT SOUND? My satellites are about 10 feet apart on the long wall of an 18-by-28-foot listening area with a 9-foot ceiling. In this volume, the complete system can generate short-term average SPLs of 110dB at any frequency above 35Hz and peak SPLs greater than 115dB. More important, the system can play at these volume levels without any sign of strain or breakup. With sufficient power, there is no compression or loss of inner detail at high volume levels.

Many large, high-efficiency systems (e.g., those of "theater" heritage) can play loudly, but they make soloists and small ensembles appear larger than life. The satellites do not distort spatial perspective. Symphony orchestras spread across the entire sound stage, while small ensembles and soloists sound intimate.

The system retains all the traditional advantages of a satellite/subwoofer combination. Frequency response is smooth and non-fatiguing. Imaging is precise, stable and even three-dimensional with good source material. With proper toe-in, it produces a precise image over the entire area between the speakers. Vertical dispersion is relatively broad. There is

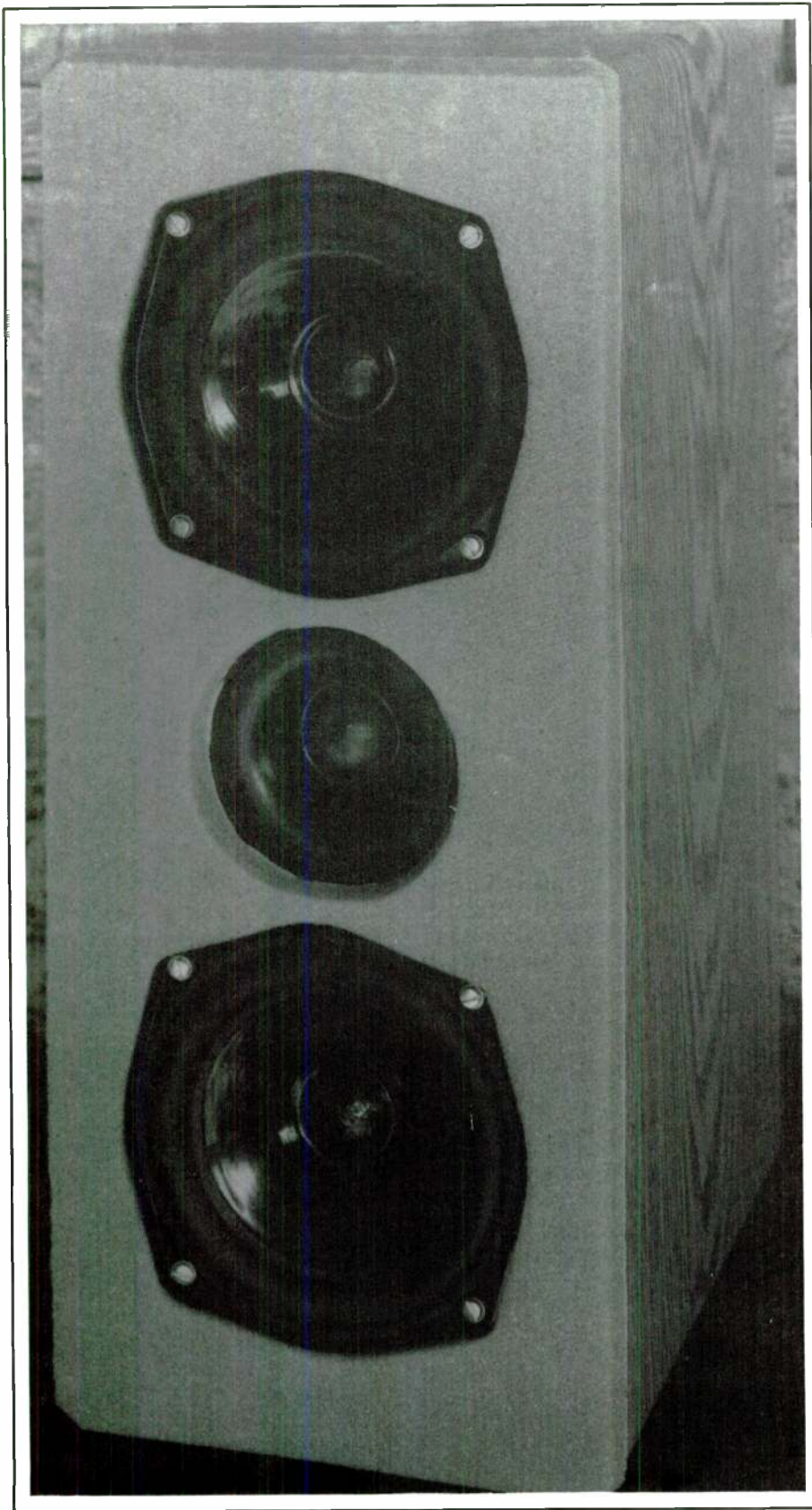


FIGURE 10: Mr. D'Appolito's finished satellite speakers.

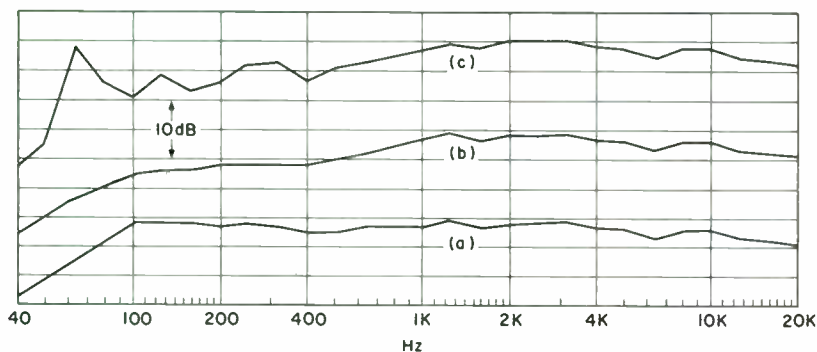


FIGURE 11: One-third-octave frequency response of the system in the following positions: (a) free-field hemispherical, (b) 36 inches off the floor in the center of a large room, (c) same as (b) but 18 inches from a reflecting wall. All responses were measured at a 1 meter distance from the loudspeaker.

no discernible difference in response between standing or sitting on the floor. In summary, the system is basically neutral, reproducing all source material with equal ease and having the ability to play as loudly as new technology demands.

ALTERNATIVE DESIGNS. The three-driver, two-way (3,2) symmetric geometry has many acoustic advantages. I would encourage you to experiment with other drivers in this configuration, but I think some general words of advice will help.

Proper matching of mid-bass drivers is very important. You will not obtain increased output capability with multiple drivers unless they share the load equally, especially in the first octave or two above resonance. To maximize load sharing, driver free-air resonances should be matched to 10 percent or better.

You should mount mid-bass drivers in a common volume to improve tracking of driver in-box resonances. (You can control undesirable high-frequency interference within the common volume by filling the enclosure with Dacron or another suitable damping material.) Use the parallel

voice-coil connection whenever possible. With the series connection, any voice-coil impedance differences will cause unequal voltage division and correspondingly unequal outputs. If you use the series connection, put drivers with the closest in-box resonances together. In all designs, remember to keep the interdriver spacing as small as possible—preferably no larger than one wavelength at the crossover frequency—to ensure uniform vertical polar response.

Although I have not tried them, several other drivers appear suitable for this project. The 5.25-inch Bextrene drivers from Audax and Dalesford should work well. Focal has recently introduced a dual-voice-coil mid-bass driver that looks quite attractive. With a proper crossover, you can use the second voice coil to correct for diffraction loss. Tweeters that can produce very high SPLs at 2kHz are still rare, but Morel has introduced a line of Dynaudio look-alikes, which should work well. Dynaudio and Morel offer flat-flange versions of their tweeters, which are said to have much flatter frequency responses than their horn designs. To use these

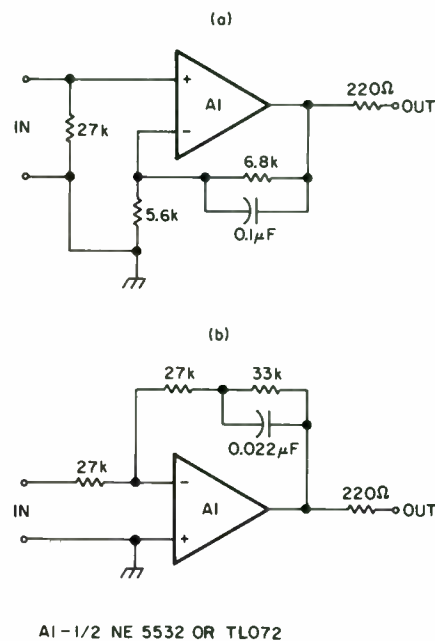


FIGURE 12: Non-inverting (a) and inverting (b) diffraction loss compensation circuits.

tweeters, however, you must redesign the present crossover, which is optimized for the horns.

A full-range system with the (3,2) geometry looks especially attractive because of its potential for low cost, small size and the ease with which two-way passive crossovers can be built and aligned. For a full-range system, I would use long-throw 6.5-inch drivers crossed over between 1,600 and 1,800Hz to a matching 28 to 32mm dome mid-tweeter unit. A typical closed-box design might have an internal volume of about 1 cubic foot and an f_3 around 60 to 65Hz. A bass-reflex design would typically require 1.5 cubic feet and perhaps would go as low as 45 to 50Hz.

ACKNOWLEDGMENTS

I would like to thank Bob Pyle, a good friend, fellow engineer, semiprofessional photographer and audio enthusiast, for taking, developing and printing the photographs for this article.

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A STEREO NOISEMAKER

BY BERNHARD MULLER

We have all read articles detailing the ins and outs of various white and pink-noise generator circuits, but my unit is different. What makes it special is its ability to generate subjectively uncorrelated stereo, mono and reverse-polarity mono signals at the flip of a switch. In addition, the pink filter circuit is specifically tailored to the audio band.

WHITE vs. PINK. White noise contains equal energy at every frequency—that is, there is as much energy at 100Hz as at 10kHz. Pink noise, on the other hand, contains equal energy per octave. The octave from 100 to 200Hz has as much energy as the octave from 200 to 400Hz. Since an octave band spans twice as many discrete frequencies as the band just below it, white noise can be converted to pink noise by halving the energy every octave as frequency increases. This is equivalent to passing the white noise through a 3dB/octave low-pass filter. While white noise has as much energy at 10kHz as at 100Hz, pink noise has 20dB less energy at 10kHz than at 100Hz.

Why use pink rather than white noise? First, it more nearly matches the frequency characteristics of the noises we hear as music. Second, most filters we use to analyze noise (including our ears) have a constant Q . This means that their bandwidth, as a fraction of an octave, is constant as the filter frequency is varied, while the bandwidth (measured in hertz) varies with frequency. Q is equal to the geometric center frequency of the filter divided by the bandwidth.

For example, one one-third-octave filter might cover the 25Hz range from 100 to 125Hz, while another one-third-octave filter might cover the 1,250Hz range from 5,000 to 6,250Hz.

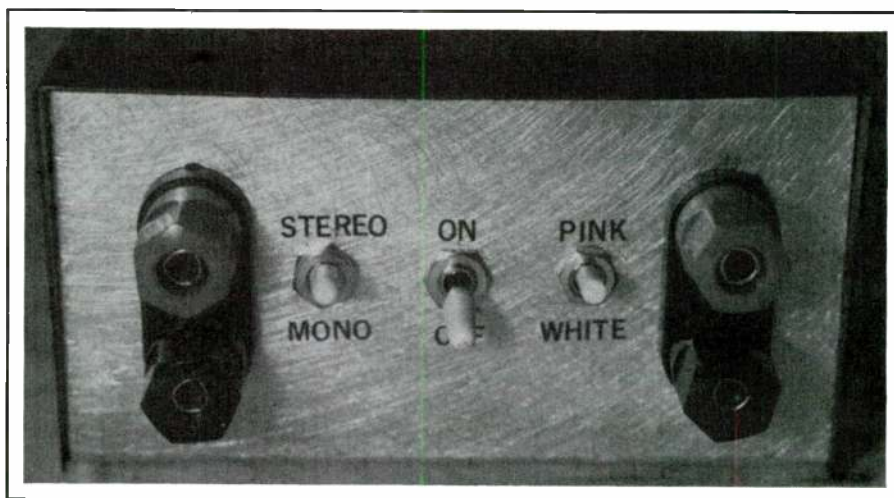


PHOTO 1: The author's pink-noise generator features a stereo/mono/reverse-polarity switch that distinguishes it from other generators.

These filters have a Q given by the following formula:

$$Q = \frac{(100 \times 125)^{1/2}}{25} = \frac{111.8}{25} = 4.47$$

Thus, a pink-noise source gives a constant output as it is analyzed by a constant- Q filter.

Wave analyzers and some Fourier analyzers operate on a constant-bandwidth basis. If their bandwidth is 25Hz, they might cover the range from 100 to 125Hz or from 5,000 to 5,025Hz. Their Q increases with increasing frequency, and they would give a constant output if they analyzed a white noise and a decreasing output (3dB/octave) for pink noise.

A pink-noise filter is comprised of many elements and is never perfect. By judicious selection of parts values, however, you can make it close to ideal. For a rigorous discussion of the math involved, see the *Journal of the Audio Engineering Society* Preprint 1777, 1981.

While I was developing a subwoofer analyzer several years ago, it became evident that the low-frequency end (below 100Hz) of the modified General Radio filter (Petzold, *TAA* 3/76, p. 3) deviated several decibels from ideal, while the high-frequency end extended into the hundred-kilohertz region. The pink filter shown in *Fig. 1* has a 3dB/octave slope from 16Hz to 20kHz ± 0.5 dB and rolls off gradually below and above this range (*Fig. 2*). This permits more accurate subwoofer measurement without taxing the system with supersonic signals.

CIRCUIT DETAILS. The signal generator itself (*Figs. 3-5*) is a 31-stage shift register with a cycle time of more than two hours instead of a few seconds like most integrated units. The longer cycle eliminates "thumps." The relatively high clock rate of approximately 220kHz ensures that reasonably true white noise is present all the way to 20kHz. IC1a and IC1b

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KL-3R: INVERSE RIAA. [1:80] Resistor/capacitor package complete. Contains stereo R₂/C₂' alternates. Each 25.00

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

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

● **KG-2: WHITE NOISE/PINK FILTER.** [3:76] All parts, circuit board, IC sockets, 1% resistors, ±5% capacitors. No batteries, power supply or filter switch. CLOSEOUT Each \$11.50

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

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

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

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

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

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

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

SBK-E4: MUELLER PINK NOISE GENERATOR. [SB 4:84] All parts, board, 1% MF resistors, capacitors, IC's, and toggle switches included. No battery or enclosure. Each \$27.50

SYSTEM ACCESSORIES

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

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

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

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

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

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

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

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

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

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

KS-7: SCOTCHCAL® PANEL KIT. [2:84] One 10 x 12" sheet each of 4 types of pressure sensitive panel material (blk on aluminum, blk on transparent poly, blk on white poly, matte clear overlay), one pint of developer plus pads, and instructions. Requires a simple frame and a light source: ultraviolet, photofloods or the sun, plus your own press-on lettering materials. Postpaid. Each \$34.50

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

are parts of a 4070 device whose pin-outs are shown in Fig. 6a. They form a 220kHz oscillator, which drives the clock inputs of shift registers IC2 and IC3, which are 4006 devices (Fig. 6b). Thirteen of IC2's and 18 of IC3's stages are connected in series for a total of 31 shift-register stages.

The outputs of stage 13 and stage 31 are fed to the inputs of EXOR gate

IC1c (Fig. 6a). An EXOR gate puts out a one if either input is one and puts out a zero if both inputs are either zero or one. The output of IC1c feeds the first stage of the shift register with the pseudo-random sequence of ones and zeros that constitute the noise signal. Since there are 2^{31} possible combinations, it takes more than two hours to run through all of them at 220kHz.

The loop can lock up if the input contains all zeros, so the 1M resistor and 1μF capacitor in IC1c's output ensures that at least one "one" is injected, after which the sequence begins. Remember that the sequence of ones and zeros produced by IC1c is clocked through the entire register so that any two outputs differ by only a short time delay. (An interesting experiment is to listen to two of the shift-register outputs with earphones. You hear the sound predominantly in the ear listening to the earlier register output.)

In the stereo mode, IC1d (Fig. 6a) is driven by two different shift-register outputs. Therefore, it generates a pseudo-random sequence that is totally unlike the sequence being clocked through the shift register. You can produce mono and inverse-polarity mono by tying one IC1d input to either

ground or B+, respectively. The stereo/mono/reverse-polarity switch is a "center-off" toggle switch. In the center position, the 100k resistor to B+ is sufficient to ensure a one at the input of IC1d, without interfering when the switch is set to either of the other positions.

I used C-MOS devices, which should be handled with reasonable care. I have never destroyed one of the modern devices with static electricity, and I suspect the manufacturers are being overly cautious with their constant reminders to avoid static electricity, use grounded workbenches and ground the person installing the device. Reasonable caution is warranted, however.

Any enclosure will work, but a metal one will produce hum and RF (radio-frequency) shielding. The photograph of the front panel of my prototype (Photo 1) shows a pink/white switch, but this is unnecessary. In three years of use, I have never found an application for the white-noise source. The schematic for the switch is shown in Fig. 7. For convenience, the circuit is powered by a 9V battery.

WHAT TO LOOK FOR. Pink noise is used most precisely in conjunction

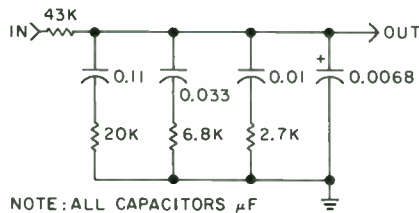


FIGURE 1: The pink filter circuit is specifically tailored to the audio band.

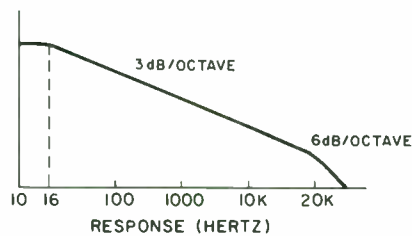


FIGURE 2: The response of the pink filter circuit rolls off below 16Hz and above 20kHz.

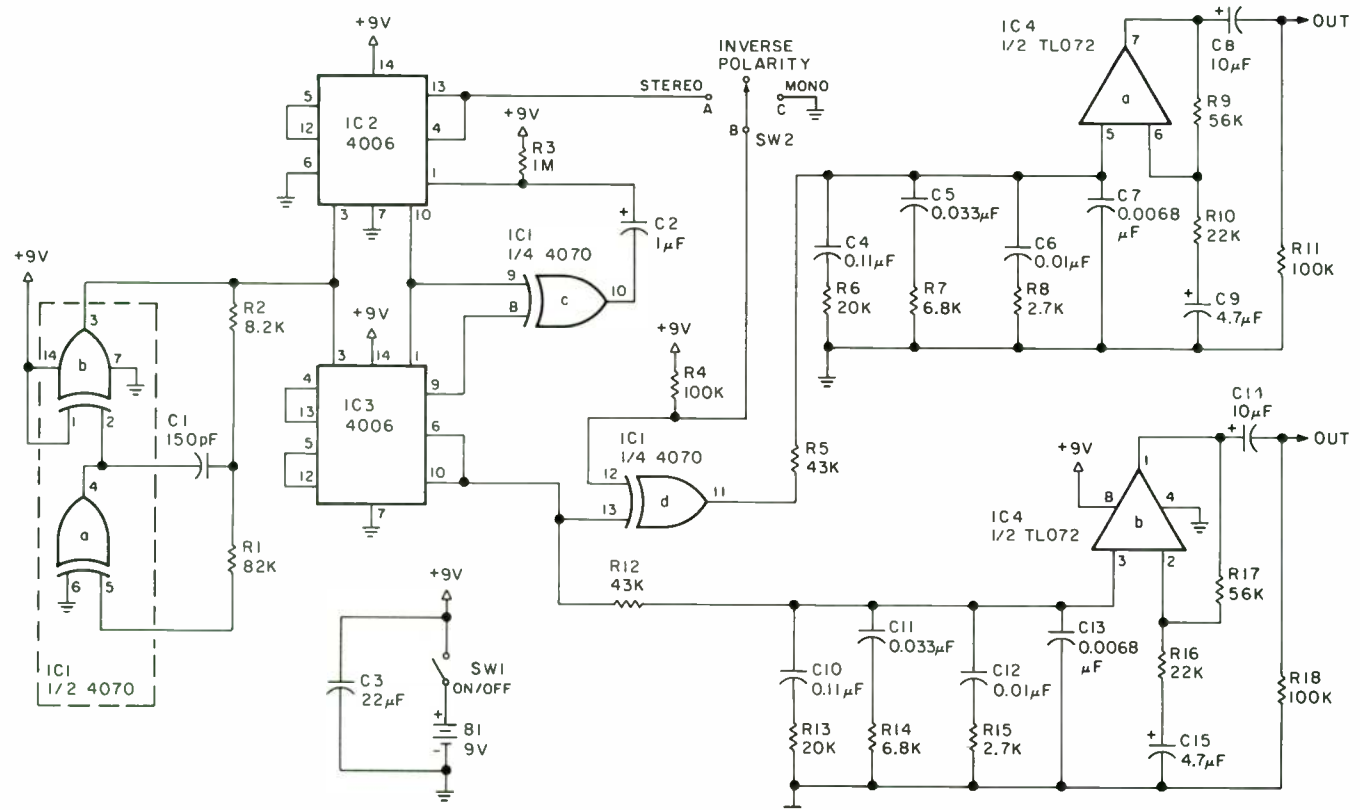


FIGURE 3: The schematic diagram of the pink-noise circuit.

with a real-time analyzer. One-third-octave and one-octave units are most common. Although you can set the frequency response of a system fairly accurately with this gear, the ear, when moderately trained, can derive a great deal of additional information from a pink-noise signal. I use pink noise extensively in the initial evaluation of loudspeakers.

I usually listen to noise first because the ear is far more sensitive to frequency response, poor dispersion characteristics, inadequate stage, poor imaging and incorrect polarity matching than when music is used. With noise, I can make as many observations in a few minutes as I might make in several hours using a variety of music. Of course, I always finish by listening to music to confirm my impressions.

Response. The first thing I listen for is smoothness of response on each speaker. Since pink noise contains all frequencies, a response dip or peak is immediately noticeable from the "nasal" or "honk-like" character of the sound.

You can train your own ears to listen for these characteristic sounds by listening to pink noise through a good system and manipulating the controls

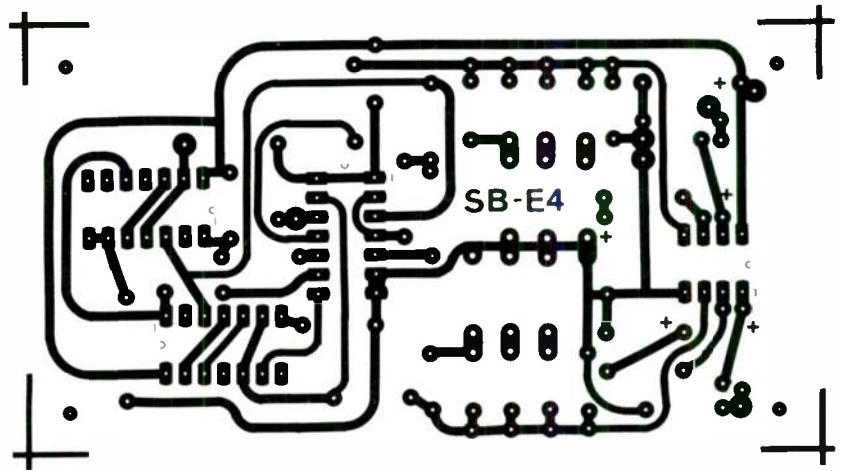


FIGURE 4: The circuit board for the pink-noise generator.

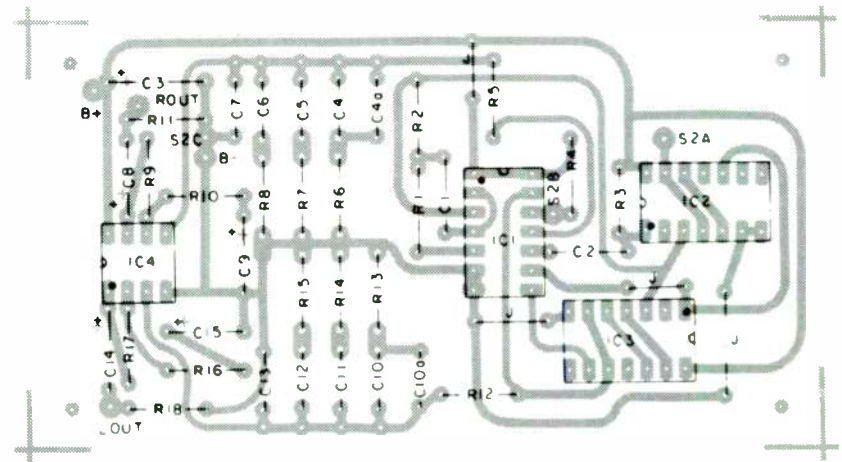


FIGURE 5: The pink-noise circuit stuffing guide.

PARTS LIST

Capacitors

- C1 150pF, 50V polystyrene
- C2 1 μ F, 15V electrolytic
- C3 22 μ F, 15V electrolytic
- C4, C10* 0.11 μ F, 50V polyester
- C5, C11 0.033 μ F, 50V polyester
- C6, C12 0.01 μ F, 50V polyester
- C7, C13 0.0068 μ F, 50V polyester
- C8, C14 10 μ F, 15V electrolytic
- C9, C15 4.7 μ F, 15V electrolytic

Resistors**

- R1 82k
- R2 8.2k
- R3 1M
- R4, R11 100k
- R5, R12 43k
- R6, R13 20k
- R7, R14 6.8k
- R8, R15 2.7k
- R9, R17 56k
- R10, R16 22k

Misc.

- IC1 4070
- IC2, IC3 4006
- IC4 TL072
- SW1 SPST switch
- SW2 SPDT, center-off switch
- B1 9V battery

*You can make C4 and C10 by paralleling a 0.1 μ F and a 0.01 μ F capacitor.

**All resistors are $\frac{1}{4}$ W, 5%.

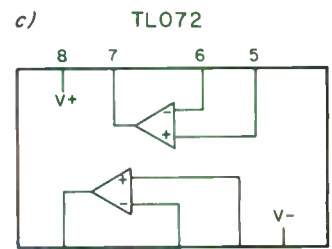
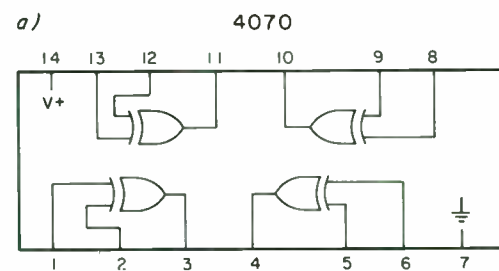
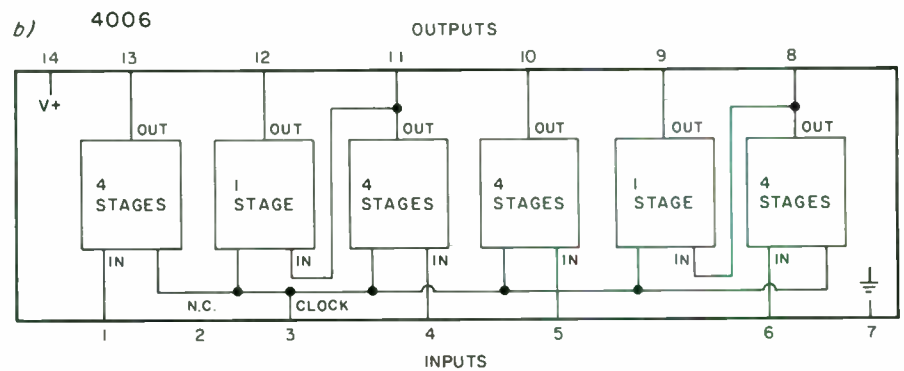


FIGURE 6: Pin-outs for the 4070 (a), 4006 (b) and TL072 (c) devices.

of a graphic equalizer. At full boost of a one-octave band, you will hear an obnoxious sound, remnants of which you can still hear when the band is boosted only 1 or 2dB (depending on frequency). Response dips give different, but equally obnoxious, sounds. Music will sound just as rough, honk-like or colored as the pink noise.

Dispersion. If the speaker sounds smooth and uncolored on-axis, walk around the intended listening area, again listening to only one speaker. Listen standing up and sitting down. You should hear only a slight reduction in level off-axis, with overall sound character and smoothness preserved throughout the intended listening area. The farther you can move off-axis before the sound changes appreciably, the wider the speaker's dispersion will be. Even speakers designed to have narrow dispersion should not change in sound color.

A slight loss of highs is common and is less objectionable than other aberrations, but it will cause "hot spots" in the listening area. Response irregularities caused by wall reflections may also be apparent and usually produce a swishing sound that you can hear while you are moving around the room. You might alleviate these irregularities by moving the speaker a little.

Stage. After listening to the speakers individually, listen to them together,

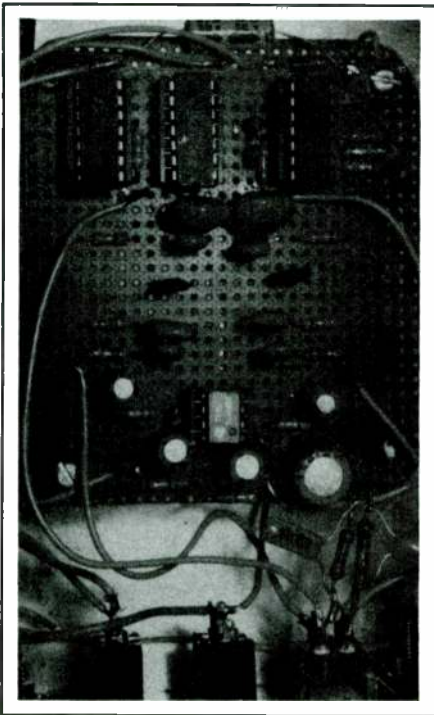


PHOTO 2: An inside look at Mr. Muller's pink-noise generator.

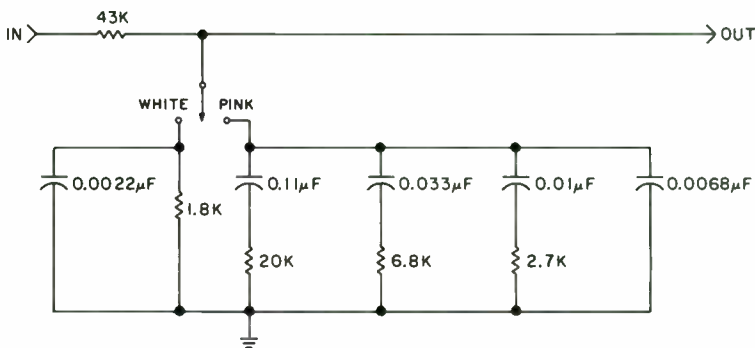


FIGURE 7: The white/pink switch circuit. The 1.8k resistor reduces the overall level so that the average white voltage equals the average pink voltage. The 0.0022µF capacitor rolls off frequencies above 20kHz.

with the generator in the stereo mode. You should hear what appears to be a broad curtain of sound stretching between and perhaps even beyond the speakers. Hearing two separate sound sources is indicative of a "hole in the middle" or possibly extreme frequency-response differences between the speakers. While you are walking around the listening area, the sound should not appear to jump abruptly from one speaker to the other. If it does, this is indicative of dispersion problems. You might be able to correct these problems by changing the angles of the speakers in relation to the listening space.

Test the area sitting and standing, unless the speakers are intended exclusively for seated listening. You should detect no abrupt changes in the overall sound quality while you are moving around the room. The sound should appear to come from the speaker plane. Frequency-response aberrations, especially in the mid-range, can make the sound appear to come from behind or in front of the speaker plane.

Imaging. Now switch the noise source to mono. The broad curtain of sound heard in stereo should collapse to a very narrow source heard between the speakers. Any differences in frequency response or dispersion between the two speakers, due to either the speakers themselves or their environment, will lead to a weakening of the center image.

Because of different path lengths from the two speakers to your ears, various frequencies cancel, resulting in swishing sounds as you walk around the room. Despite the swishing, which is normal in this mode of operation, a stable center image should remain. In highly reverberant

rooms, this swishing effect is considerably weakened.

Turning the balance control on the preamplifier should cause the image to move smoothly from the center to one side, then the other. The two speakers should sound similar, but do not usually sound identical because of their different acoustic environments.

Polarity. If you could not obtain a good center image in the last test, try the reverse-polarity mode on the generator. If a center image occurs now, one of your speakers is connected in the wrong polarity. A failure to get any center image in either switch position could be due to gross speaker inequalities or perhaps one misconnected driver.

The above series of tests is so sensitive that I have never heard a system pass them all with flying colors. The correlation with music listening is generally very good because a speaker system that does well on these tests will reproduce music well. Speakers that have failed one or more of these tests might still sound acceptable, even though they always sound better when the problem is resolved. In some systems that sound vaguely "wrong" in music reproduction, the problem is often instantly identifiable when you listen to the system with pink noise. If the speakers demonstrate good imaging and sound stage with the tests, any problems you hear with music are probably due to a poor multimiked recording.

Old Colony is offering the board and the kit for Mr. Muller's stereo noisemaker. The board (SB-E4) costs \$8.50 and the complete kit (SBK-E4) \$27.50. Send your order to Old Colony, PO Box 243, Peterborough, NH 03458.

BUILD YOUR OWN Z METER

PART IV-B IN A SERIES ON MODULAR TEST INSTRUMENTS

BY G. R. KOONCE
Contributing Editor

In the last issue, the author provided construction details about the Z meter. This time, he offers information on testing and calibration.

TESTING & CALIBRATION. After you have constructed layer one, stop and verify power-supply operation. At connector P1 (not mated to S1), use pin 8 as a reference. You should get the voltages listed in Table IV-10 at other pins if all is well. If you tie P1-9 to P1-2, the relay should shut off, P1-3 should go high (approximately +28V), and P1-5 should go to approximately -28V. This verifies A/I board operation.

After installing the circuitry in layer two, calibrate the VCA board by applying a sinusoid of about 1kHz to BNC J1 with the test-cal switch in test and an AC voltmeter connected to posts J3 and J4 (J4 is low side). For safety, set P2 on the PM board to maximum resistance (full counterclockwise), then with the magnitude range switch in the 10Ω position, adjust the signal input until your voltmeter shows 10mV RMS between J3 and J4. On the VCA board, adjust P1 until 4V RMS appears at point D. The easiest output measurement point is at connector P5, with P5-6 as low and P5-3 as high on your meter. Verify the other range positions and operation of the range-indicating LEDs at this time. If your AC voltmeter does not read to 10mV, you can calibrate in the 100Ω (100mV J3 to J4) position.

The next step is PM calibration. Do this by switching the test-cal switch to calibrate and the range to 10Ω, then applying a 1kHz sinusoid input and adjusting the level for 10mV across the calibration resistor. This drives both comparator inputs to full scale, calibrating the phase meter as indicated in Part III. Note that shorting J3 to J4 in "test" and setting the range to 300Ω will drive only the I comparator,

which should produce a reading of about 90 degrees (bottom scale) in the 0-180 range and about -180 degrees (top scale) in the ±180 range. Remember, crosstalk can confuse this test.

Finally, you can install and calibrate the voltmeter, layer three, per instructions in Part I. Note that raising the voltage at test point TP-3 to about 4.5V via P3 on the VM board will disable the meter overload protection. This allows calibration without removing the overload LED. Disconnecting or short-circuiting the Z_{mag} meter will protect it. Driving with the same setup you used to calibrate the VCA, the 10mV at J3 to J4 is used to set +4V at test point TP-2 on the VM via P1. If all works well, this will also set the Z_{mag} meter to full scale (1) via P2. The meter protection level is then reset (see Part I) and protection verified, along with blanking of the range LEDs and lighting of the overload bulb.

SERVICING. As I mentioned before, the Z meter's layered construction should facilitate servicing. Unplugging S5-P5 allows you to remove the VM board (on its mounting bracket) and the attached overload LED for servicing or access to the VCA calibration pot. Likewise, unmounting the needed controls and indicators, the I

TABLE IV-10

PIN VOLTAGES FOR CONNECTOR P1**

Pin #	Voltage	Source
1	≅ -15V	neg. P.S. out
2	0V	ground
3	+3 to +4V	point C*
4	0V	ground
5	open circuit	point J* (relay on)
6	less than +0.5V	point D*
7	≅ +15V	pos. P.S. out
9	+3 to +5V	point A*

*A/I board

**Pin 8 is used as a reference for measurements.

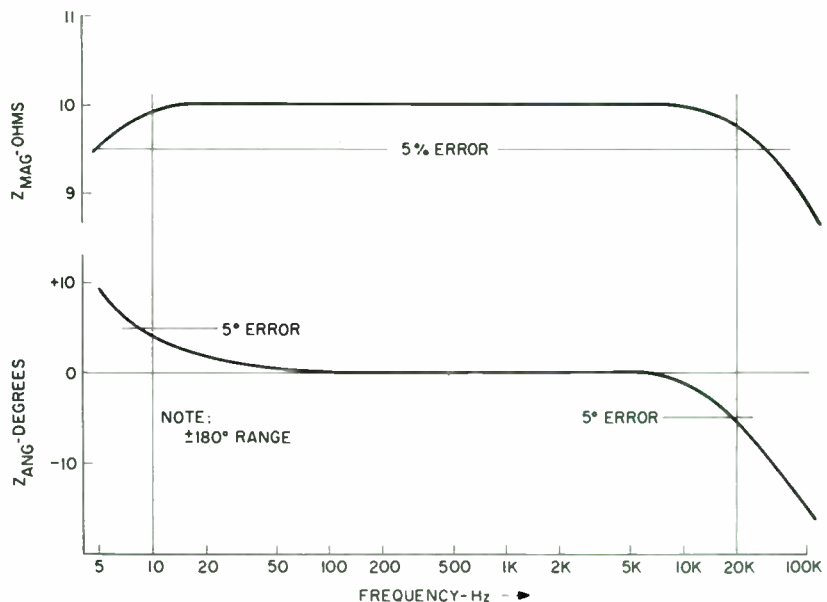


FIGURE IV-22: Z meter readings of a 10Ω, 1% resistor versus frequency.

comparator and the power-supply shield allows removal of the layer two circuitry for repair or access to layer one circuitry. You must unplug connectors S1-P1, S2-P2, S3-P3, S4-P4, S6-P6 and S7-P7.

When doing the AC power-supply wiring, leave some slack. This will allow you to swing the two power-supply boards out together for servicing. Unmounting all three circuit boards in this area, along with transformer T1, should allow access to anything that needs repair.

In four years of use, my Z meter has

never failed. I have not recalibrated the unit, as it is essentially calibrated every time I adjust the input signal level and phase zero trim. I rarely use the latter, as the PM's stability has been fine.

PERFORMANCE. In my performance tests, I used V_{in} from a Heath IG-1271 function generator via a $400\mu\text{F}$ non-polar capacitor to block DC offset. Figure IV-22 shows the performance of the Z meter as a function of frequency looking at a 10Ω resistor (Rc). Over the frequency range 10Hz

to 20kHz, the indicated Z_{mag} is within 2 percent of actual, and the indicated Z_{ang} is within ± 5 degrees of zero.

Figure IV-23 shows the Z_{mag} performance at a test frequency of 1kHz when looking into various resistance values. Measured results agree well with calculated performance—less than 5 percent error for any resistance up to 260Ω and less than 2 percent error for resistances of 1 to 100Ω .

Figure IV-24 shows computed (plotted) and measured (data points) values of Z_{mag} and Z_{ang} with a series R-C circuit. Computed versus measured Z_{mag} values track almost exactly. The Z_{ang} results are also outstanding, except at the frequency extremes, where additional error is expected. Clearly, the Z meter properly characterized this series R-C circuit.

Figure IV-25 shows the computed (plotted) and measured (data points) performance of the Z meter looking into a series tank circuit. Again, the Z meter does an excellent job of characterizing this circuit. The advantages of having phase-measurement capability in locating the resonant frequency of a low-Q circuit is clearly demonstrated in Fig. IV-25. At resonance, Z_{mag} versus frequency is nearly flat, while Z_{ang} versus frequency has its maximum slope.

The above results demonstrate the Z meter's capability to measure impedance (Z_{mag} and Z_{ang}) accurately. Over the frequency range 100Hz to 5kHz (where most crossover designs occur), performance is excellent. Over the full audio range and where Z_{mag} equals 1 to 200Ω and Z_{ang} equals -90 to $+90$ degrees, performance is good.

Figure IV-26 shows the measured impedance looking into a vented box with an 8-inch driver. Note how the phase shift goes through zero at the two magnitude peaks and at the dip between the peaks (called f_m by Small). You can, therefore, use phase to help locate these critical points accurately, but certain effects can cause displacement of the amplitude maximums and minimums and the zero-degree phase points. See Small^{IV-2} for clarification.

ALTERNATE PLANS. I have described the Z meter as I built it, but you might want to consider a number of variations.

1. R_{in} Selection. I used an R_{in} of $5.1\text{k}\Omega$, requiring a sinusoid source capable of more than 5V RMS. You can change R_{in} , noting that V_{in} equals

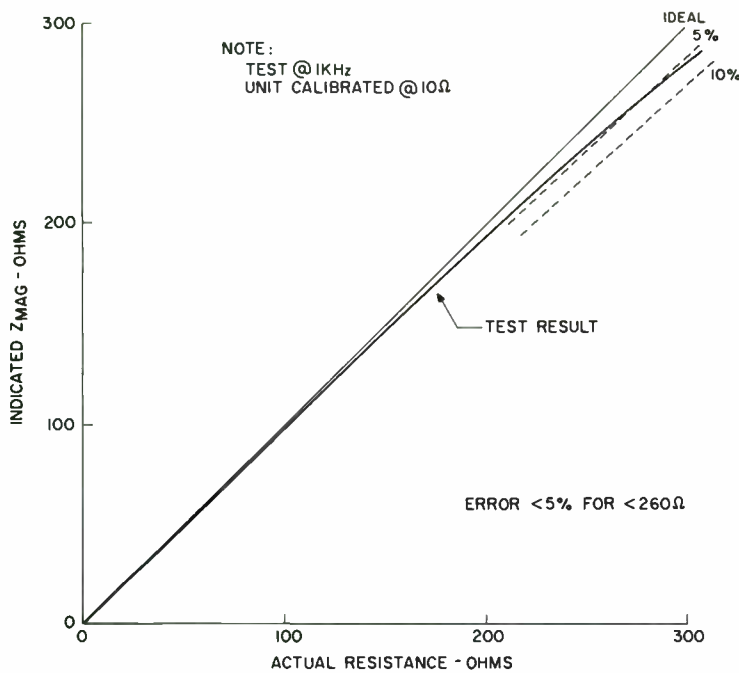


FIGURE IV-23: Z meter magnitude reading versus actual resistance.

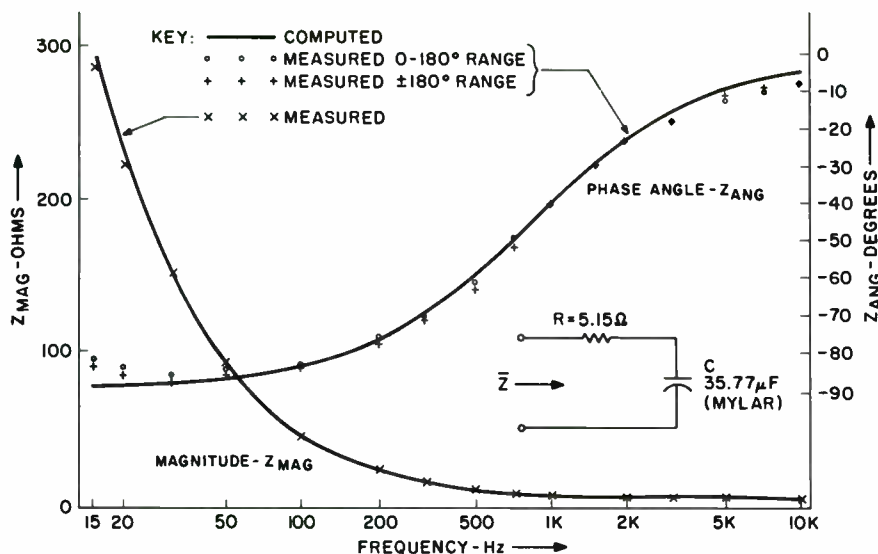


FIGURE IV-24: Z meter performance with a series R-C circuit. Note the proximity of the measured and computed values of Z_{mag} and Z_{ang} .

0.001 times R_{in} and that lowering R_{in} will reduce the Z meter's accuracy.

2. *All Circuit.* You can omit the entire alarm and range-indicating system and mount the VM overload LED on the front panel.

3. *DC Blocking.* DC offset on your sinusoid-signal source (V_{in}) will saturate the VCA when you are testing AC-coupled loads. You can eliminate this problem by adding a capacitor in series with V_{in} , either internal or external, to the Z meter. I would recommend a minimum of $46\mu\text{F}$.

4. *Alternate Sensitivity.* Acoustic pickup will cause problems with the PM on the ± 180 -degree range. (See Part III for a complete explanation.) Modifying the VCA to have 20dB less gain and changing R_{in} to use a test current of 10mA (rather than 1mA) will correct this problem, but will result in lower Z-meter accuracy and an increase in driver loudness during testing.

5. *PM Variations.* It is possible to omit portions or even the entire PM system. Check Part III for a detailed discussion of possible options.

6. *Remote Alarm.* Some of the units I have built in this series have a remote-alarm output. The A/I circuit board (#251X) can implement a remote-alarm system. It should be powered by +25V or less, and you should wire all remote-alarm inputs to point A, with returns to N on the A/I board. Wire the relay to light or sound the desired alarm when it is off (NC contacts).

OPERATION. Although detailed operational information on the Z meter is beyond the scope of this article, I would like to make some general comments. The Z meter is driven by a sine-wave source, which must maintain a constant output over the frequency band. At a convenient frequency, in the calibrate mode and the 10Ω range, adjust V_{in} via the signal source for Z_{mag} at 10Ω (full scale). If you have used the phase zero trim,

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

you would then set it to zero degrees on the ± 180 phase range.

To overcome acoustic interference problems on the ± 180 -degree phase range (FF PM), move the DUT away from any acoustic noise sources. Also try moving up one or two steps in the Z_{mag} range to reduce interference and establish the phase's sign. Returning to the correct Z_{mag} range, the 0-to-180-degree Z_{ang} range will give you an accurate value for the phase.

Several authors have discussed some fundamental uses of the Z meter. To use the meter in determining Thiele/Small parameters, see refer-

ences IV-2 through IV-6. You can also use the Z meter to measure a driver's impedance around a desired crossover frequency and to develop impedance-correction networks to make the driver approximate a resistive load. References IV-6 through IV-8 can help here.

Other uses of the Z meter include helping you to establish a driver's upper and lower frequency limits (references IV-6 and IV-7) and offering clues to finished enclosure performance (references IV-2 and IV-4). Finally, a Z meter can help you spot a defective

Continued on page 43

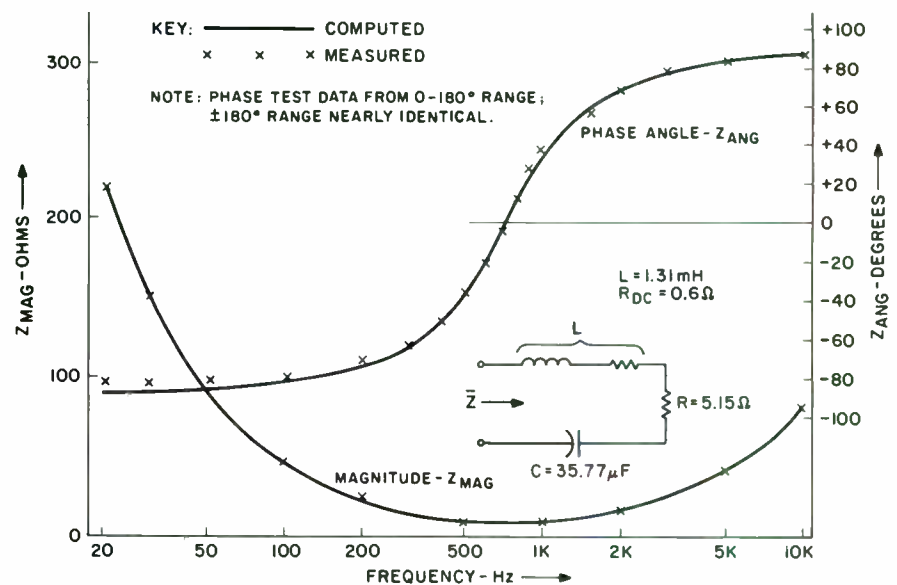


FIGURE IV-25: Z meter performance with a series tank circuit. As you can see, the meter did an excellent job of characterizing this circuit.

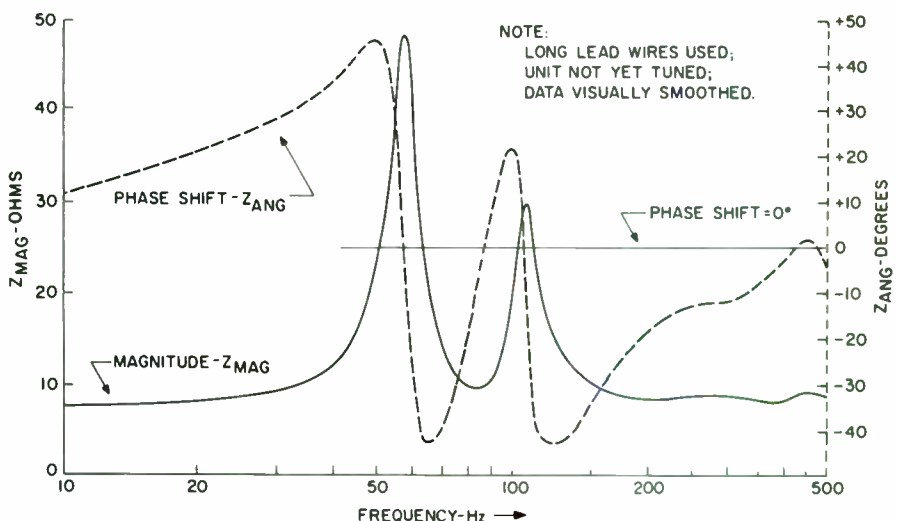


FIGURE IV-26: Measured impedance looking into a vented box with an 8-inch driver.

EXCURSION-LIMITED SPL NOMOGRAPHS

BY SIEGFRIED LINKWITZ

When choosing loudspeaker drivers, you should base your selection on the desired sound-pressure output and the frequency range each driver is required to cover. Low frequencies place the greatest demand on a driver's excursion capability. For a constant sound-pressure level (SPL), the peak-to-peak cone amplitude has to increase inversely proportional to the square of the output frequency. This means that to get the same output at 50Hz as at 100Hz, the cone has to travel four times as far.

Nevertheless, it is feasible to build a small speaker with a 4-inch-diameter woofer and obtain a flat frequency response to 30Hz. Such a speaker will not, however, be able to generate a high SPL at 30Hz. It cannot move a sufficient volume of air because of the small cone area and the limited excursion capability of the voice coil in the magnet gap.

The relationship between the sound pressure for a given frequency, the distance from a source and the volume of air the source must move has been discussed in many books about acoustics. Yet its effect on driver selection is often not mentioned. The nomograph in Fig. 1 shows this relationship for a direct radiator, such as a driver in a closed box, which is radiating into free space without adjacent reflecting walls.

To see what SPL the 4-inch (100mm) driver might generate, assume it is capable of a 7mm peak-to-peak excursion. Draw a line from the 7mm point on the right excursion scale through the 100mm point on the effective piston diameter scale. Note that the line intersects the displaced volume scale at 54 cubic centimeters. This is the volume of air moved by the driver during a full swing of its cone.

To determine the SPL at 30Hz, draw a second line from the 54cc point through 30Hz on the frequency scale. It will intersect the SPL scale at 69.5dB. At 1 meter from the source, this is certainly not a large SPL.

If you wanted 100dB SPL at 1 meter, the displaced volume would have to

be 1,800cc. This is the displacement of a 1.8-liter engine running at 1,800 rpm! The radiated acoustic power, however, would be only 100mW. Two 12-inch (300mm) drivers could move just this much air if they were capable of a 13mm excursion peak-to-peak.

Fortunately, many loudspeakers radiate into less than full space, as at least one reflecting wall is usually nearby. This has the effect of doubling the sound pressure to a level that is 6dB higher than indicated by the nomograph. Thus, in the previous example, the SPL would be 106dB when radiating into half-space, or 2π steradians.

HYPOTHETICAL SYSTEM. Let's take as a second example a loudspeaker system that is supposed to generate at least 110dB SPL at 1 meter into half-space from a frequency of 50Hz and up. The drivers under consideration are the following:

- Becker 912A139 (300mm dia., 10mm p-p) woofer;
- Audax HD13B25H2C12 (100mm dia., 7mm p-p) midrange;
- Audax HD100D25 (25mm dia., 1mm p-p) tweeter.

I determined the useful excursion ranges for these drivers using the shaped tone burst test. Although the manufacturer should specify the

Theory Behind the Nomographs

The sound pressure (p) at a distance (r) from the center of a pulsating sphere in free space equals the following (from L.L. Beranek, *Acoustics*, McGraw-Hill, 1954, p. 92):

$$p = \frac{Uqf}{2r}$$

where U is the RMS volume velocity in m^3/second , q is density of air ($1.19\text{kg}/m^3$), and f is frequency in hertz.

The pulsating sphere is thought to be an enclosure that is small compared to the radiated wavelength and has a circular piston of diameter d , which oscillates sinusoidally with peak-to-peak amplitude x . Therefore, the RMS velocity of the piston (u) is:

$$u = 2\pi f \left(\frac{x}{2} \right) \left(\frac{1}{\sqrt{2}} \right) = \frac{\pi fx}{\sqrt{2}} = \frac{a}{2\pi f}$$

where a is the RMS piston acceleration. Thus, the volume velocity (U) becomes:

$$\begin{aligned} U &= d^2 \left(\frac{\pi}{4} \right) u \\ &= d^2 \left(\frac{\pi}{4} \right) \left(\frac{\pi fx}{\sqrt{2}} \right) \\ &= d^2 \left(\frac{\pi}{4} \right) \left(\frac{a}{2\pi f} \right) \end{aligned}$$

These two expressions for U are inserted into the pulsating sphere equation.

As a function of piston diameter (d) and excursion (x), the sound pressure (p) is:

$$\begin{aligned} p &= \left(\frac{\pi^2 q}{8\sqrt{2}} \right) \left(\frac{d^2 f^2 x}{r} \right) \\ &= a \left(\frac{q}{16} \right) \left(\frac{d^2}{r} \right) \end{aligned}$$

The sound-pressure level (SPL) in decibels is:

$$\text{SPL} = 20 \log \frac{p}{p_{ref}} =$$

$$94.3 + 20 \log x + 40 \log f + 40 \log d - 20 \log r$$

where p_{ref} equals 2×10^{-5} newtons/ m^2 , x , d and r are in meters, and f is in hertz. This expression is nomographed in Fig. 1.

The piston acceleration (a) is:

$$a = p \left(\frac{16}{q} \right) \left(\frac{r}{d^2} \right)$$

With g equal to $9.81\text{m}/\text{sec}^2$ and p equal to p_{ref} times $10^{\text{SPL}/20}$:

$$20 \log \frac{a}{g} = \text{SPL} - 91.2 - 40 \log d + 20 \log r$$

See Fig. 3. Finally, the force relationship (F) is as follows:

$$F = ma = BI$$

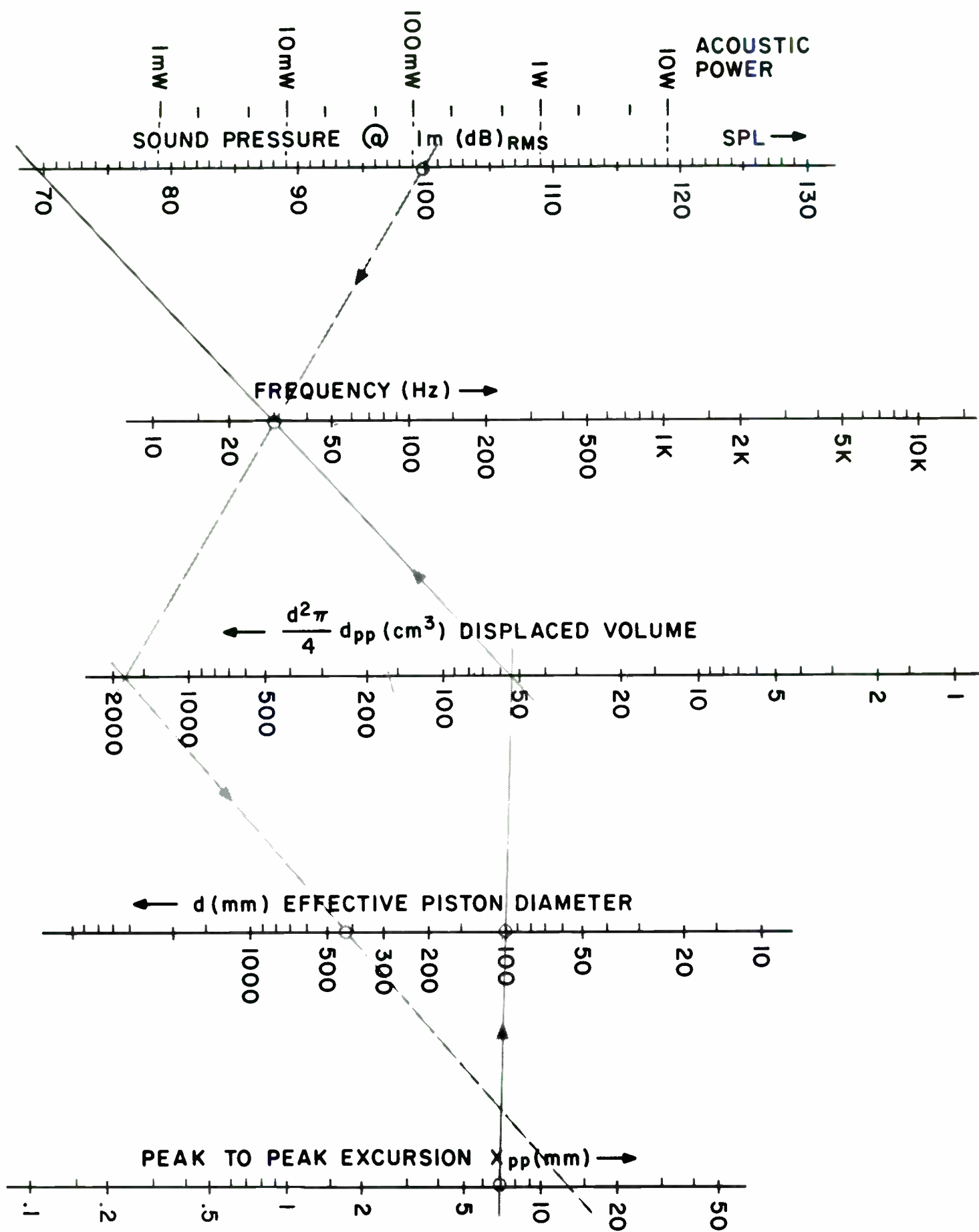


FIGURE 1: Radiation into full space. Add 6dB for half-space.

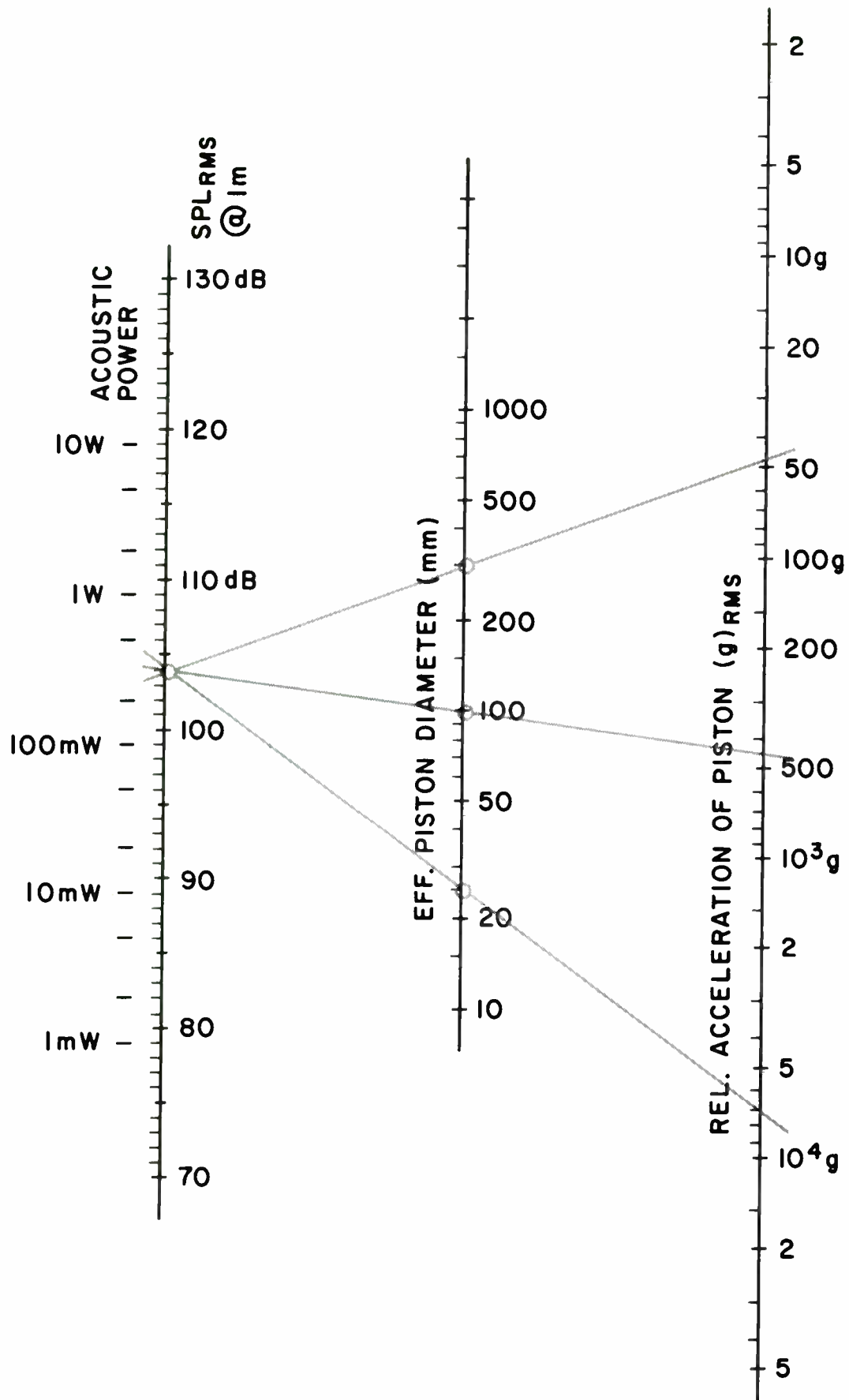


FIGURE 3: Piston acceleration versus SPL. Radiation into full space.

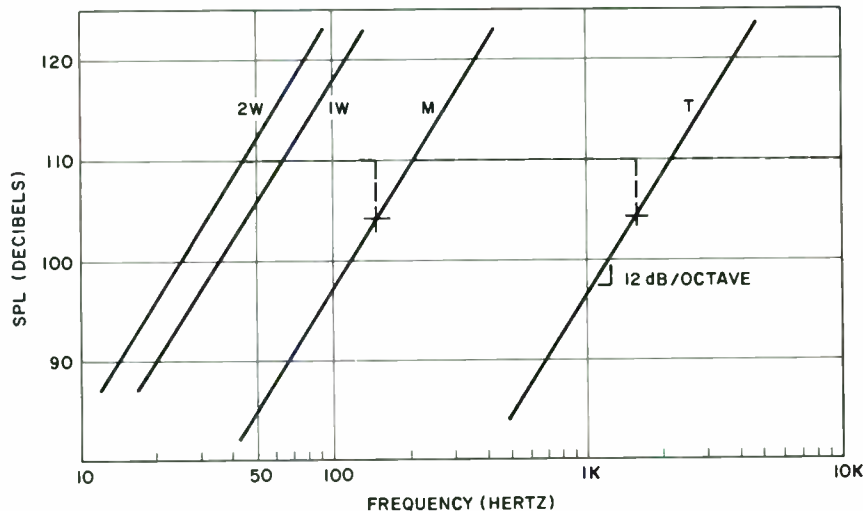


FIGURE 2: The excursion-limited SPL as a function of frequency.

range for a specific harmonic distortion level (e.g., 10 percent), this information is rarely provided. You can obtain some indication of a driver's linear motor range from the voice-coil length and the height of the magnet gap. The difference between these two lengths is the peak-to-peak excursion to a first approximation.

Using the above driver parameters and the nomograph, you can plot the excursion-limited SPL as a function of frequency (Fig. 2). Each driver's capability falls off at 12dB/octave with decreasing frequency. The tweeter can maintain 110dB SPL down to 2.2kHz and the midrange to 210Hz. With a fourth-order LR crossover, where each driver output is -6dB at the crossover frequency, the transition between midrange and tweeter can be as low as 1.6kHz. Similarly, the crossover between woofer and midrange can be at 150Hz or higher. Note that one woofer cannot provide 110dB SPL down to 50Hz, but can go only as low as 65Hz. Two woofers would maintain this level to 45Hz.

The advent of the compact disk will make greater demands on the low-frequency capabilities of loudspeakers. We are used to the restricted low-frequency content of conventional vinyl disks and have designed speakers accordingly. With a CD, you can hear true bass for the first time, as long as the loudspeaker can move the required volume of air.

One more nomograph might help you appreciate the mechanical stresses to which driver and enclosure are subjected as a given SPL is generated. For a direct radiator, the SPL is pro-

portional to the piston or cone acceleration (Fig. 3.) At the 110dB SPL from the previous example, the woofer is accelerating with 48g, the midrange with 450g and the tweeter with an astonishing 7,000g, where g equals 9.81m/sec². The necessary motor force equals piston mass times piston acceleration and might be many pounds.

For example, the midrange driver with a 10-gram cone has to produce a sinusoidally oscillating force derived from the following formula:

$$(0.01\text{kg})(450)(9.81\text{m/sec}^2)$$

This equals 44 newtons RMS (root mean square) or a 14-pound peak force for a 110dB SPL into half-space. This force is also equal to the product of the driver's force factor (Bl) and the voice-coil current (I). With Bl equal to 7.3 newtons/ampere, a current of 6A RMS is required. If the voice coil has an 8Ω resistance, it must dissipate 290W. You may calculate similar numbers for the woofer and tweeter.

Remember that the driver mounting and the enclosure have to absorb the motor forces as reaction forces. They should not set the panels of the loudspeaker cabinet in motion, particularly at the panel resonance frequencies, as this would color the reproduced sound. The majority of commercial loudspeakers suffer from this problem. You should make a special effort to build enclosures that are either extremely stiff—so that the resonances are above the driver's frequency range—or extremely well damped.

OC SOFTWARE BOXRESPONSE

SBK-E3

for Apple Computers by
Robert Bullock & Bob White

Model-based performance data for either closed box or vented box loudspeakers with or without a first or second order electrical high pass filter as an active equalizer.

The program disk also contains seven additional programs as follows:

Air Core: This program was written as a quick way of evaluating the resistance effects of different gauge wire on a given value inductor. The basis for the program is an article in *Speaker Builder* (1/83, pp. 13-14) by Max Knittel. The program asks for the inductor value in millihenries (mH) and the gauge wire to be used. (NOTE: only gauges 16 through 38.)

Series Notch: Developed to study the effects of notch filters in the schematics of some manufacturers. Enter the components of the network in whole numbers (i.e., 10 for 10μF and 1.5 for 1.5mH) and indicate whether you want one or two octaves on either side of resonance. Output is frequency, phase angle and dB loss.

Stabilizer I: Calculates the resistor-capacitor values needed to compensate for a known voice coil inductance and driver DC resistance.

Optimum Box: A quick program based on Thiele/Small to predict the proper vented box size, tuning and -3dB down point. It is only based on small signal parameters, therefore, it is only an estimate of the response at low power (i.e., limited excursion).

Response Function: Calculates the small signal response curve of a given box/driver combination after inputting the free-air resonance of the driver (f_s), the overall "Q" of the driver (Q_{TS}), the equivalent volume of air equal to the suspension (V_{AS}), the box tuning frequency (f_B), and the box volume (V_B). Output is the frequency and relative output at that frequency.

L-Pad Program by Glenn Phillips: Appeared in *Speaker Builder* (2/83, pp. 20-22). It is useful for padding down a tweeter or midrange while still retaining the same load as the driver itself.

Vent Computation by Glenn Phillips: Calculates the needed vent length for 1, 2 or 4 ports of the same diameter. Input box volume in cubic feet and required tuning frequency (f_B), output is vent length and vent area for each case.

Medium: 5¼ SS/DD Disk. Price: \$25.00 postpaid USA (Canada add \$4.00; overseas add \$6.00) Air to other points on request.

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Accurate Acoustic Measurements

If you have been disappointed in the results of acoustic measurements you have taken with your sound level meter and test recordings with announced frequencies, take heart. In certain cases, you can obtain a lot of useful information by *deduction*—not the mental kind, but the mathematical type.

For example, I recently tried to measure the effectiveness of the high-pass section of a crossover network by acoustic means. The design cutoff frequency (-3dB) was $1,500\text{Hz}$. I measured the speaker response with and without the high-pass filter. The

results are shown in *Fig. 1*. I was not as surprised at the ragged response as I was at the apparent crossover frequency—about 600Hz .

After studying this disappointing result for some time, I realized that the effects of the room and speaker characteristics were present in the filtered and unfiltered responses. I also discovered that subtracting the responses would eliminate these effects and reveal the true behavior of the high-pass filter. I performed the indicated calculations (*Fig. 2*), which indicate that the design crossover frequency has been realized.

David J. Meraner
Scotia, NY 12302

Defuse Diffraction Effects

You can improve the imaging and clarity of many speakers by eliminating—or at least decreasing—diffraction effects. Diffraction is the phenomenon exhibited by wave fronts that are modulated by passing the edge of an opaque body. The diffraction of the sound wave results in a secondary sound source at each point of diffraction. This secondary sound source is delayed in relation to the primary source (the speaker). Because it is in another location, it tends to confuse or smear the image, much as multipath reflections cause "ghosts" on a TV picture.

In the case of a driver in a rectangular box, where the wavelength of a sound frequency is less than the distance from the driver to the enclosure edge, the sound wave will be diffracted at the edge of the enclosure, provided the enclosure edge is sharp and the baffle is a smooth, hard surface along which the sound wave can travel without hindrance. The sound wave might also be diffracted from the edge of a grille frame that fits tightly against the baffle.

Many speaker manufacturers have recognized and dealt with diffraction in various ways. These include rounding the enclosure edges; suspending the speaker grilles in front of and away from the baffle; using foam grilles without a frame; using grille frames that fit flush with, rather than resting on, the baffle; installing a material that will attenuate the sound waves that travel across the baffle's surface; maintaining a short distance from the driver to the enclosure edge.

If you consider diffraction effects before you construct a speaker, you can use any of the above methods—or a combination of them—with some degree of success. Your options are considerably more limited if you are dealing with a speaker that is already built. Replacing a grille frame might eliminate diffraction from that source but not solve the problem of the enclosure edges.

My cure for diffraction effects is to add sound-attenuation material to the baffle surface surrounding the high-frequency driver. The sound-absorbing material on the commercial speakers I have seen appears to be a thin sheet of some synthetic foam, such as polyethylene. I made a lengthy but fruitless search for a similar

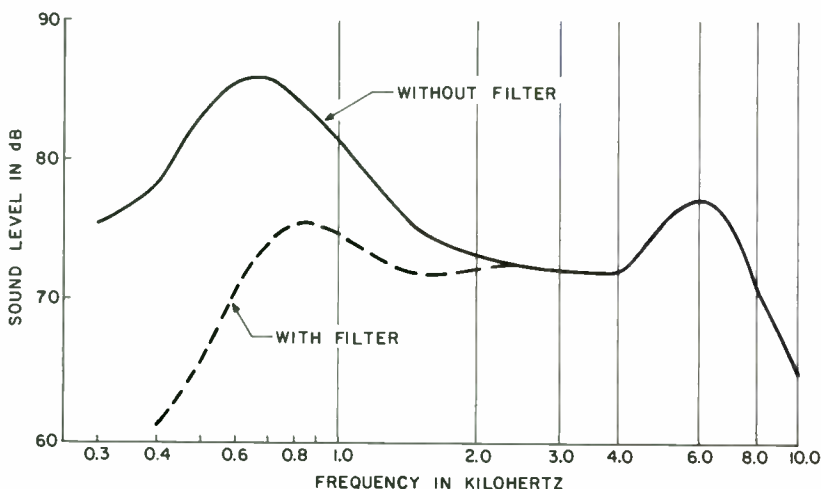


FIGURE 1: Speaker response without the high-pass filter.

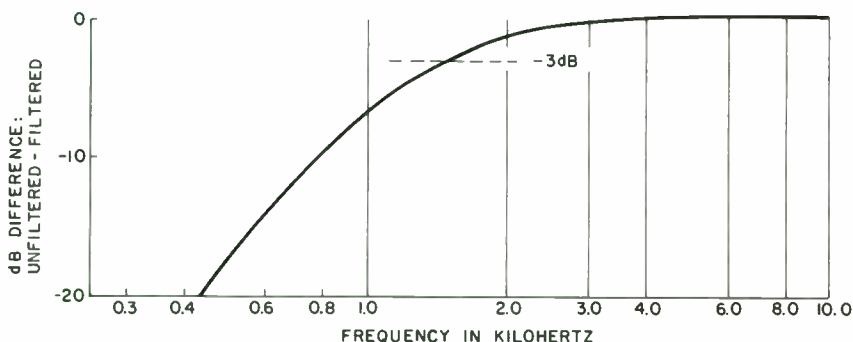


FIGURE 2: Results of the difference between the filtered and unfiltered responses.

material that is thin enough (approximately $\frac{1}{16}$ inch) not to cause dispersion problems. The characteristics of such a material are diametrically opposed to those of a good grille cloth. The logical choice would be a material that is dense, optically opaque (if it won't pass light, it probably will be a good sound attenuator, providing it does not resonate), and fibrous (fibers disperse and attenuate sound waves and amp resonances). I finally found a dense black felt that is approximately $\frac{1}{16}$ inch thick. I applied it to the baffle surrounding the tweeter, using silicone rubber cement as an adhesive.

Subjectively speaking, installing the material resulted in a definite improvement in sound clarity, both with and without the grilles installed. With the grilles removed, the sound was slightly better than with them installed, indicating that some diffraction was still occurring at the edge of the grille frame, which rests against the baffle and creates an obstruction between the driver and the cabinet edge. The grille frame is $\frac{3}{8}$ -inch-thick particle board. I installed $\frac{1}{8}$ -inch-thick foam weather-stripping tape on the inside grille frame edge near the tweeter, which resulted in some additional improvement.

In all, the changes I made cost less than \$5 and substantially improved sound clarity. I would recommend experimenting with the changes I have outlined, as

they are easily reversible if they do not improve your system.

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K010 Mounting Specs

The old Peerless K010 DT tweeter still does a pretty respectable job in two-way

systems, crossing over at about 3kHz. It is specified in many DIY projects and is available for less than \$15 from McGee Radio (1901 McGee St., Kansas City, MO 64108). The mounting holes for this unit are tricky to achieve without spoiling the baffle. *Figure 1* shows the specifications that have worked for me.

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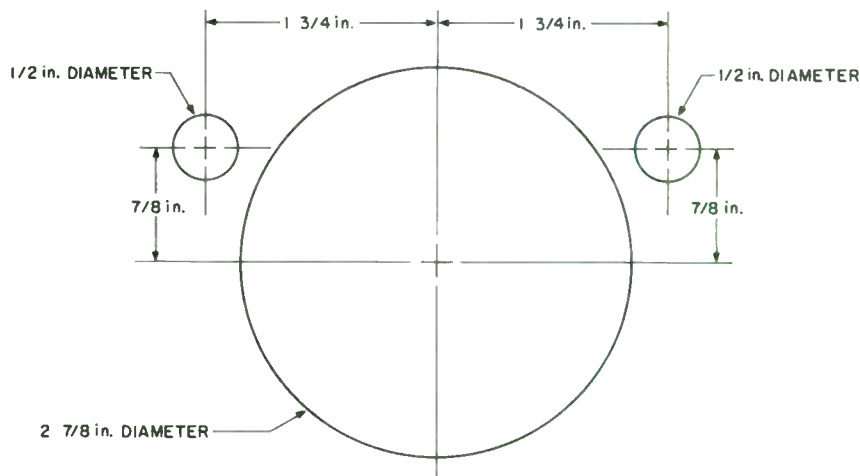


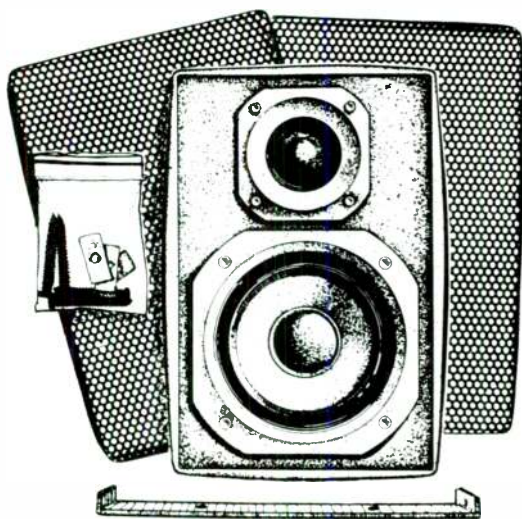
FIGURE 1: Mounting-hole specifications for the Peerless K010 DT tweeter.

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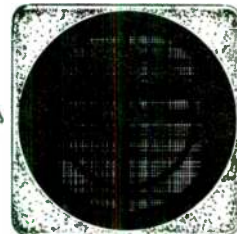
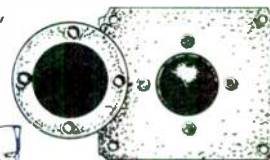
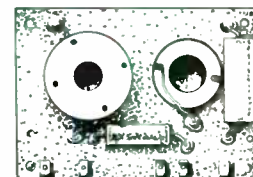
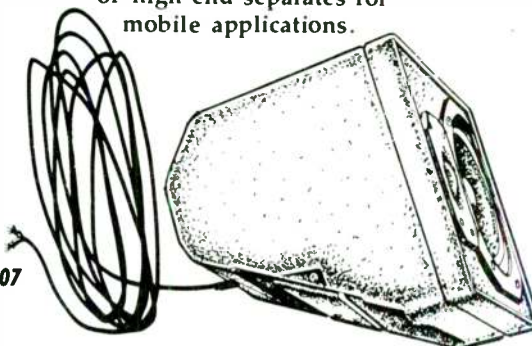
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Kit Report

JCRS Rejuvenation

About a year ago, I decided it was time to change speaker systems. I had lived with a pair of IMF MK-3 Professional Monitors for about ten years. Their bass was always impressive, but their midrange and high end lacked the presence of modern speakers. I spent more than a year shopping and experimenting and ended up with the Jack Caldwell Ribbon System (JCRS) from Audio Concepts (1631 Caledonia St., La-Crosse, WI 54601).

On the Hunt

My search began with a trip to a dealer who was experimenting with the Strathearn ribbon. This driver, used by Infinity some time ago, is made in Northern Ireland. It is a midrange, high-frequency unit, 23 inches high, 5 inches wide and about 2½ inches deep (Fig. 1). Impedance is 0.5Ω. A toroidal transformer is available from Audio Concepts to match this impedance to an amplifier.

The dealer's system consisted of three Strathearns wired in series for each channel. The drivers were mounted in a simple frame, without enclosures and without baffles or wings. He considered three units a minimum impedance for his Conrad Johnson power amplifier without using matching transformers. KEF B139 woofers in transmission-line enclosures provided the bass.

The sound was airy and provided a sense of reality, but the Strathearns tended to produce a snapping sound on transients. The dealer insisted that you must use these drivers with tube equipment to avoid a metallic sound. He also said he had tried the Strathearns with transformers and had found that their transient response was poor. I believed the real answer to be a high-current transistor amplifier, as long as you did not use them with transformers.

I looked at other speaker systems before making a decision. These included the most expensive Magneplanar Tympanis, which cost more than \$4,000 in Canada. I did not find anything attractive on the market that cost less than the Tympanis. Since I was not about to spend that kind of money, I opted to order three pairs of Strathearns from R.F.R. Dowling (11 Bachelors Walk, Lisburn, Northern Ireland). The cost was £300 sterling, plus another £45 for air freight to Toronto. (£1 = approximately \$1.40 US at present.—Ed.)

When the units arrived, I unpacked

structured two chipboard frames out of ¾-inch material to hold the Strathearns. The frames were open in the back and stood on a small box for stability. I wired the drivers in series and connected one toroidal matching transformer to each array. The transformers provide taps of approximately 4, 8 and 16Ω. I used the 4Ω tap because it seemed to provide the most gain when connected to my POOGE-2 Hafler DH-200 powered by four Boak regulators. I adapted a Walt Jung rumble filter to provide a 6dB roll-off at 175Hz on the Strathearns. I chose this frequency as the crossover point because the drivers'

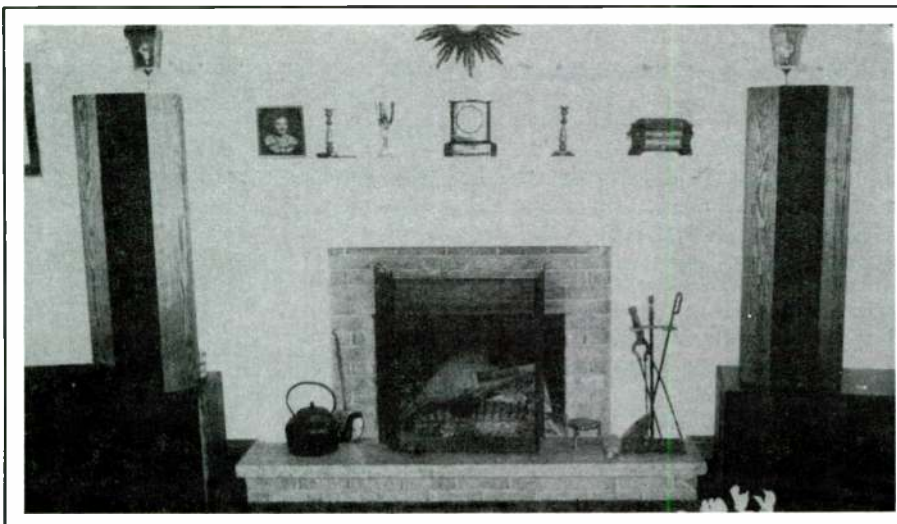
one-page brochure states that two or three Strathearns connected in series can provide response down to this point if there is adequate baffling. The brochure does not provide any details about what is considered to be an adequate crossover point.

I then connected a Borbely 60W MOSFET amplifier to the KEF B139s in their IMF cabinets, disconnecting the wiring to the other drivers and crossover board. I adapted

the remaining half of the Walt Jung rumble filter to roll off the bass at 175Hz, 18dB per octave, which I chose at a friend's advice. Both of us were working in the dark; we had no idea what would happen.

ABOUT THE AUTHOR

Timothy Palmer-Benson is a CBC National Radio News editor. He has been with the CBC News Service for ten years, and hi-fi is one of his hobbies. His system consists of a Koetsu Black cartridge, mounted in a Fidelity Research 64S arm. He uses an Oracle Delphi turntable, a Marsh pre-preamp, a Marsh preamp and the amps mentioned in this article. He also owns a Hitachi 25M dual trace scope, digital and analog meters, and an HP generator. He has no formal training in electronics, but has gleaned most of his knowledge from Audio Amateur, Speaker Builder and his friends.



The author's completed Audio Concepts Jack Caldwell Ribbon System incorporates Strathearn drivers.

each driver carefully, as they are easily damaged. Metal objects can be easily drawn into their diaphragms. I measured continuity on each unit with an ohmmeter, but then disaster struck. One of the drivers measured open. I pressed hard on the speaker's terminal with my probe. It slipped and pierced the ribbon.

I sent a pleading letter to Mr. Dowling explaining what had happened. Within one month, a new driver arrived with only the air-freight costs to pay. I later found out that dirty speaker-terminal contacts were to blame for my difficulty. I also learned that in some cases, the ribbons can be repaired using conductive silver paint (the type used for repairing rear-window defrosters on cars).

In the meantime, a carpenter con-

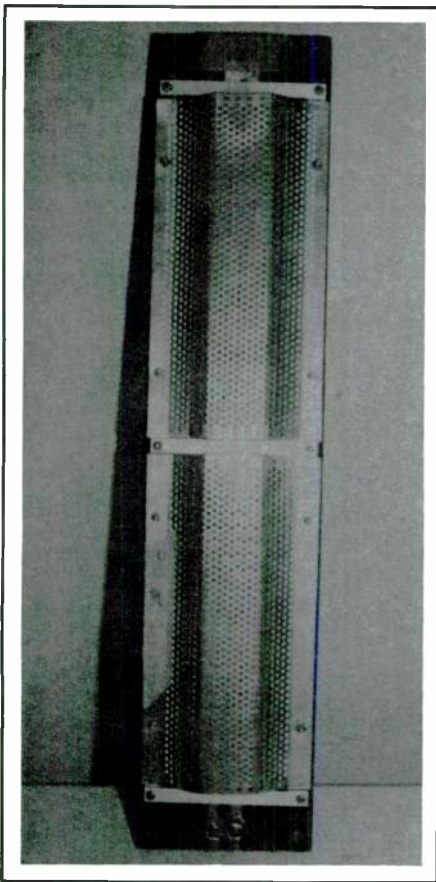


FIGURE 1: The Strathearn driver is a midrange, high-frequency unit.



FIGURE 2: Here you can see the JCRS oak enclosures for the Strathearn units before driver mounting (left) and after the drivers are in place (right).

I placed the Strathearns beside the IMF cabinets on the inside, and as I had suspected, the midrange was much better than the IMF midrange. Still, something was missing in the sound spectrum from about 300Hz to about 150Hz. I decided to install 9-inch wings on piano hinges on either side of the Strathearns, leaving the backs open. The wings definitely helped the Strathearns to go down a bit lower, but not enough. Also, they had to be placed at least 2 or 3 feet from a wall.

While trying to find a permanent arrangement, I experimented with various crossover points, eventually settling on 275Hz with a 6dB roll-off to the Strathearns and an 18dB roll-off on the B139s. Various listeners were concerned that the bass was not fast enough and noted a lack of coherency. The Strathearns did not seem to blend into the bass, and there was no line source for the whole frequency spectrum. I tried putting the IMFs on their sides, but this was disastrous for the decor of the living room. I also tried driving the Strathearns directly with the modified DH-200. The amp distorted on transients, but I was able to solve this problem with some extra bypass capacitance across the MOSFETs.

At about this time, an Audio Concepts catalog arrived describing the awe-inspiring sound of the Jack Caldwell Ribbon System (JCRS). This system offers a line-

source configuration with bass response down to 40Hz, using two Strathearn ribbons and a push-pull, compound-bass module with 8-inch Dynaudio woofers. I decided to take the plunge, ordering two enclosed cabinets for the Strathearns and two bass modules that were not yet listed in the catalog.

The modules incorporate 12-inch woofers to provide response below 30Hz. Audio Concepts was unable to provide the manufacturer's name for these 12-inch units. Friends warned against ordering something unknown, but I reasoned that the Strathearn performance was a known quantity.

Audio Concepts recommends using its Shadow Engineering crossover for the JCRS. To set the crossover point, it uses TL074 ICs and resistors in a Ziff Lock assembly. I ordered the board and a 50k Alps dual linear pot for setting the low-pass level. I did not order the case or the $\pm 15V$ power supply because I intended to use the Sulzer supply. The total cost came to \$1,275 Canadian, including shipping.

The New Arrival

The system arrived in six boxes, which were well wrapped. The bass module and Strathearn cabinets (Fig. 2) were already assembled. The kit included pre-cut acoustic foam, duxseal, high-quality acoustic wire, dry-wall screws and speak-

er terminals. The enclosures for the Strathearns are impressive. They are made of 3/4-inch solid, unfinished oak (Fig. 3). The joinery is excellent. The bass modules are made from 3/4-inch chipboard with 3/4-inch unfinished oak ends. These modules are



FIGURE 3: From the back of the enclosure, you can see how the Strathearns have been mounted.

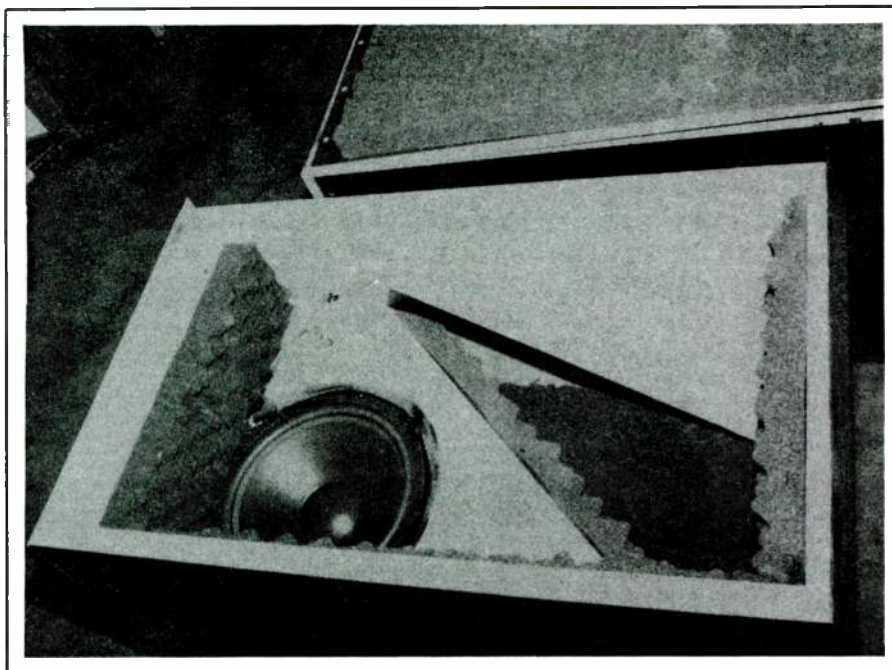


FIGURE 4: You must mount the speakers one at a time, using liquid silicone to hold them in place. Here, one 12-inch driver is in place in the low-frequency enclosure.

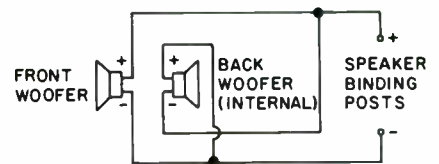


FIGURE 5b: JCRS woofer hookup.

21 inches high, 34½ inches wide and 20½ inches deep. Cutouts for the two 12-inch drivers in each cabinet are already made.

I began by staining the cabinets with a Danish oil walnut finish. To get the right effect, you must rub the oil into the wood, then wipe off any excess with a clean rag. After about 24 hours, you may apply a second coat if necessary. About one-half quart of oil is plenty for four cabinets.

My next step was installing the drivers. Here I ran into difficulty. The cutouts on the bass modules are designed so that you drop the drivers into them. The drivers rest on the modules' flanges (Fig. 4). There is insufficient clearance for mounting with screws or bolts. The only way to mount the speakers is with silicone, which makes removing the speakers difficult once the silicone has set. The Audio Concepts instruction sheets say nothing about this, so I had to phone the company for directions. After talking with them, I mounted the internal woofer first, leaving it to cure for 24 hours, with the bass module resting upside down.

After the silicone had set, I wired up the speakers. The front, or exterior, woofer is wired in parallel but out of phase with the interior one, and their leads are brought back to the rear of the cabinet (Figs. 5a and 5b). I drilled holes to allow routing of the wires through the interior baffle of the bass module. I sealed these with silicone. It is important to get an airtight seal because this is a push-pull, compound-bass system. Although the speaker terminals supplied in the backboard are stainless steel, I opted for five-way, gold-plated terminals from Old Colony. After connecting the coded wires from the speakers to the terminals on the backboard, I applied duxseal to the rear edges and fastened the backboard to the cabinet with dry-wall screws. The kit includes a pre-stretched grille cloth on a wooden frame for the bass modules. It snaps into place easily.

The Strathearn cabinets are 47 inches high, 17 inches wide and about 9 inches deep. The sides are raked back at 45 degrees on either side of the drivers. Brackets hold the cabinets securely on top of the

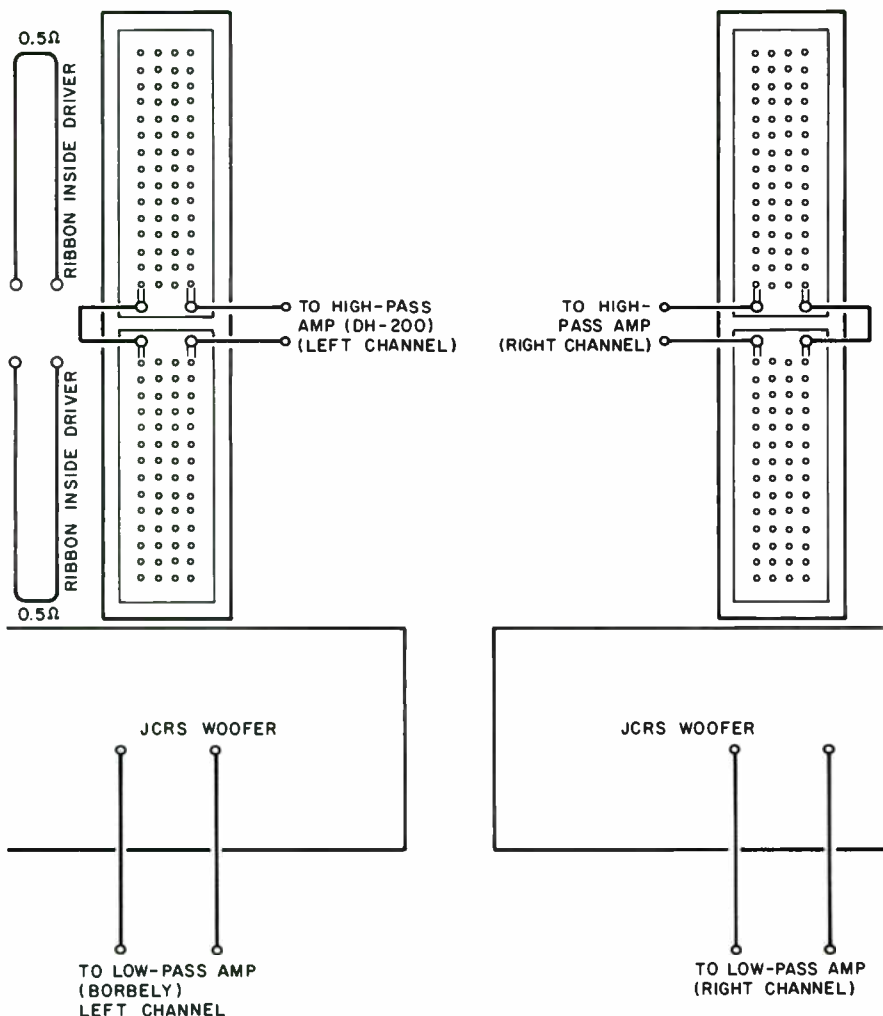


FIGURE 5a: The JCRS as viewed from the back. The Strathearn backs were removed to illustrate hookup.

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The CONSEQUENCE is the combination of many years of development of the finest loudspeakers by the DYNAUDIO organization.

The internationally famous Danish designer, Eivind Skaaning, who has for years been as a consultant for major American and other speaker system manufacturers, has conceived the DYNAUDIO CONSEQUENCE as the ultimate speaker system for the enthusiast who wants a performance available in no other way.

The bass portion of the CONSEQUENCE consists of two chambers, separated from each other by a bass driver which is designed specifically in cone mass and in resonant frequency so that it will absorb and smooth the back radiation from the forward-facing bass driver. This unique concept makes possible a tremendous dynamic range, with a linear response free from the problems of boominess and coloration which otherwise arise from the back pressures of air waves within the cabinet.

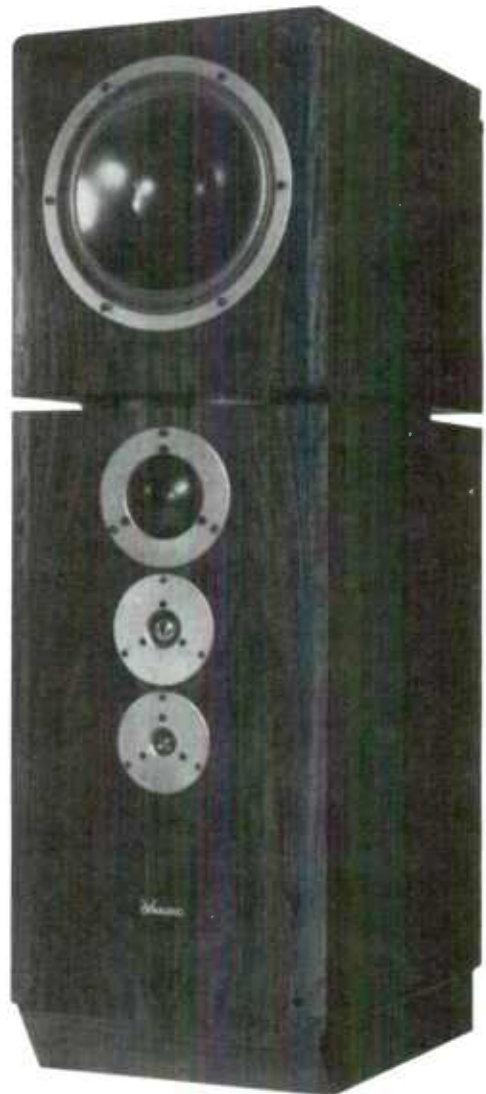
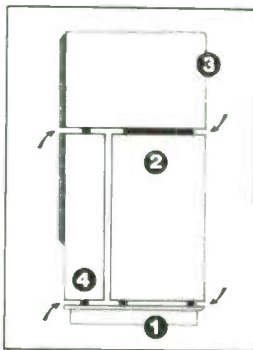
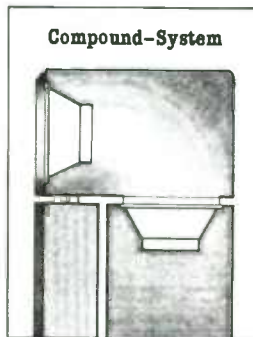
Individual speakers in the system normally exhibit resonances which also deminish the stereo image. Several unique DYNAUDIO developments reduce these resonances to a minimum achieved in no other way.

The midrange and high frequency section is separated by means of resilient damping bearings from the bass chamber. This prevents feedback between the woofer and the midrange and tweeter panel, a particular form of speaker system distortion which is not commonly recognized but has a substantial effect upon performance. Similar resilient damping bearings are used to separate the bass chamber from the floor, to prevent acoustic feedback to the record player.

DYNAUDIO engineering

In 1971 Skaaning developed a new and patented method of forming voice coils. It produces a hexagonal wire which is closely packed and therefore gives greater damping, and more accurate control of the speaker motion from the amplifier. This construction produces such a strong rigid voice coil that it retains its circular form much better than any other type of voice coil. It has enabled DYNAUDIO to use large diameter coils in a tight magnetic gap to retain the damping described above while giving greater power handling capacity and linearity. Because this process is also patented the numerous attempts to copy it are only able to produce marginally similar results.

Distortion in the DYNAUDIO mid-range and treble units is below the traditional methods of measurement and the effects of this are immediately evident. What is most noticeable is that, despite the large voice coils, the speaker system retains its sweet and natural balance in the soft quiet passages as well as in the tremendous dynamic ranges which are possible with this system.



DYNAUDIO loudspeakers, speaker kits, and assembled systems are available from:



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bass modules and directly in line with their woofers.

The Strathearns drop in from the back. Wiring them is a little tricky because the terminals must rest adjacent to a brace that crosses the front of the cabinet on the inside. The best way is to wire the two drivers in series and then carefully lower them into place, securing the corner of each driver with wood screws. I used acoustic foam supplied by Audio Concepts on the cabinet sides and back. Velcro strips hold the front grille cloth in place.

The Shadow Engineering electronic crossover board was somewhat of a disaster. I had to resolder just about every connection. It contains polystyrene capacitors for all signal paths and polypropylene caps for power-supply decoupling. Metal film resistors are used throughout. The leads of the capacitors had been cut so short on the board that extreme care was necessary in resoldering. In one corner of the board, someone had written "6dB," but nothing in the instruction sheets indicated what the crossover point was supposed to be.

This required another call to Audio Concepts. I was informed that the crossover point should be 250Hz with a 6dB roll-off rate. The crossover board would, therefore, be used only for the bass. The roll-off rate for the Strathearns would be passive. Using the following formula:

$$C = \frac{1}{2\pi FR}$$

I calculated that I would need 0.033 μ F of polystyrene for my DH-200, which I had constructed without coupling capacitors on the input. I wired two 0.033 μ F capacitors in series from the input of the elec-

tronic crossover to its output (Fig. 6). Since none of my amplifiers has input coupling capacitors, I can play around with roll-off points without opening them up.

I do all DC blocking in the crossover. In the JCRS, I use a 10 μ F polypropylene cap at the input of the crossover to block any DC entering from the Marsh preamp. The crossover itself has negligible DC offset, so it is connected directly to the low-pass amp. I must admit that I used the Walt Jung Speaker Saver (available from Old Colony) on the low-pass amp just in case.

At Long Last Speakers

At last, everything was ready. I connected the Strathearns to my Hafler and the bass modules to the Borbely 60W amp. I turned on my tuner and sat back to listen at a low level. The results seemed respectable, so I put on a record. After about ten minutes, the Borbely became very hot, and its thermal breakers triggered. Another disaster had struck. I checked all the wiring and waited for the Borbely to cool down before firing it up again. After another 15 minutes, the same thing happened.

The problem turned out to be in one of the bass modules, which was registering a short. It took me a while to discover this, since each woofer is nominally 4 Ω and two wired in parallel do not show much on an ohmmeter. After carefully cutting through the silicone, I removed the front woofer to find that two wires leading to one speaker cone were touching.

With the woofer repaired and reinstalled, I sat back to listen, keeping a careful watch on heat from the Borbely and adjusting the low-pass level to suit my taste. All was well.

The sound produced by the JCRS is as awesome as its brochure suggests. It is also very accurate and has an astonishing

amount of depth. The sound is more defined than what you hear in a good seat at a concert hall, and yet there is no high-end sizzle. The crossover frequency of 250Hz with the gradual 6dB slopes on either side provides coherency, and as Audio Concepts states in its literature, the bass seems to come out of the Strathearns.

Each record tends to sound different, especially classical selections with different recording locations readily apparent. Some multimiked EMI recordings produce a hole-in-the-middle effect. The bass modules go down farther than my IMFs did, yet they match the Strathearns in speed. A 25Hz rumble filter is recommended to deal with record warps and other garbage.

One major drawback of the system is the grille cloths on the Strathearns. They produce a masking effect so that cymbal crashes do not come through. Without the cloths, however, the Strathearn is the only speaker I have ever heard that can reproduce this sound. Another disadvantage is the low impedance of the Strathearns (1 Ω) and the bass modules (approximately 3 Ω). High-current amplifiers are a must. The Hafler DH-200, fully POOGEd, with four Boak regulators, sounds a bit strained on transients, although I have not encountered any overheating problems. The low end could do better with something more powerful than the Borbely 60W amp.

I am working on solving these problems. My first project is a bipolar amp capable of about 20A into 1 Ω . Chris Russell at Bryston in Toronto is giving a hand. I would like to thank *Audio Amateur* readers Murray Allen and John Sloan of Toronto for assisting me in this year-long project and providing me with a good deal of advice and encouragement. I would also like to hear from other readers about their experiences with Strathearns. People who are involved with them for the money are most secretive!

Timothy Palmer-Benson
Aris, Ontario N0B 1B0

Audio Concepts comments:

Overall, Timothy Palmer-Benson does a fine job with the JCRS review. We are very glad that all the work we and Jack Caldwell have done on the system in the past few years has paid off sonically. A lot of folks are also choosing to use the JCRS subwoofers with everything from mini-monitors to electrostats. We are continuing to experiment and look for ways to improve the system. Just recently, we put in a lot of hours redrawing and clarifying the instructions for the JCRS kits. We also spend a lot of telephone time and answer many letters each week assisting builders of the JCRS system.

We do have some specific comments about the review. First, Mr. Dowling will no longer sell the Strathearn drivers directly to US

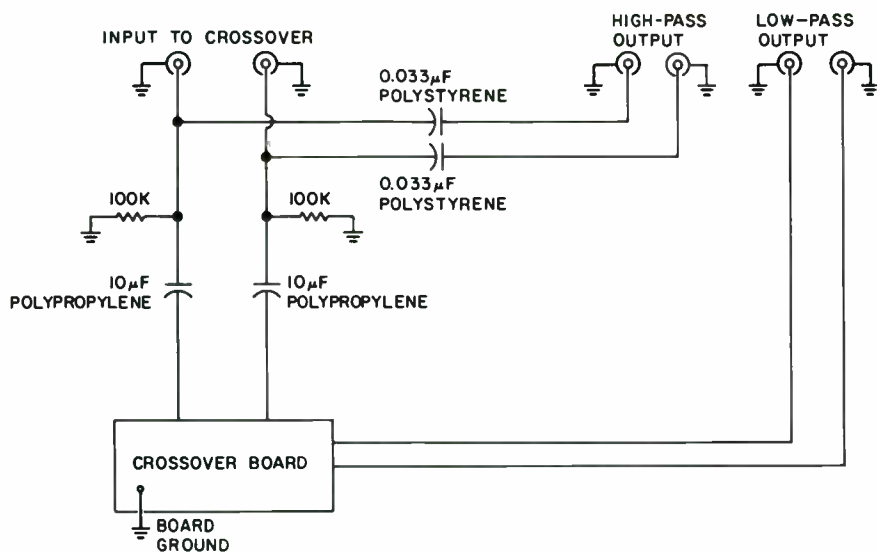


FIGURE 6: Two 0.033 μ F capacitors are wired in series from the input of the electronic crossover to its output. The author used shielded cable throughout, and all grounds go to a star. The capacitors' value will vary depending on type of amp used.



FIGURE 7: A completed JCRC unit with the grilles removed gives you a look at the mounted speakers.

customers. Second, we are sorry Mr. Palmer-Benson had problems with his crossover board, but we would have replaced it gladly at no charge if he had contacted us. Finally, each woofer system is nominally 4Ω, so each of the two drivers is 8Ω. Users may add resistance in series with the Strathearn drivers when their amplifiers are marginal in current capability. This will improve the sound in such cases.

Editor's Note: The Jack Caldwell Ribbon System is also available from other suppliers, including A & K Imports, Main St., Portal, ND 58772; Audio Artistry, 8307 W. National Rd., New Carlisle, OH 45344; Caldwell Audio, 746 Asbury Place, Santa Clara, CA 95051; John Florence, 1502 Smith Level Rd., Chapel Hill, NC 27514; and Salon One Audio, 1921 W. Grand Ave., Wisconsin Rapids, WI 54494.

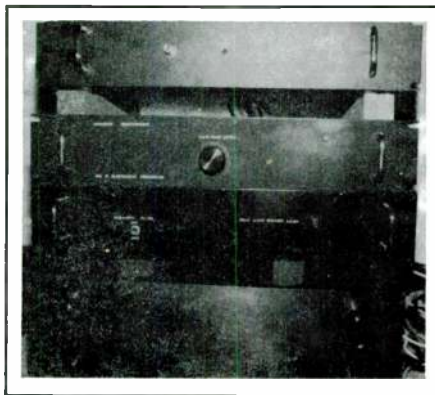


FIGURE 8: The author's custom electronics include, from top to bottom, a Borbely 60W MOSFET amplifier in a Bryston 2B case, the Shadow electronic crossover in a custom case lettered and painted by the author, the Jung speaker saver and Ace subsonic filter, and a OH-200 in a Bryston 4B case.

CIRCUIT BOARDS

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

- C-4: ELECTRONIC CROSSOVER (DG-13R) New 2 × 3½" board takes 8 pin DIPS, Ten eyelets for variable components. [2:72] Each 4.50
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- L-9: MASTEL PHASE METER 6¾ × 2¾" [4:80] Each \$8.00
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Craftsman's Corner

Polydax Perfection

These speakers are a pair of 8-inch Polydax drivers, which are Thiele-aligned and push-pull mounted, crossing over at 150Hz to a line array of four 50mm Jordan speakers. The woofer's -3dB crossover point is 23Hz. The cabinets, which are mirror-imaged, are my own design. You can obtain the Polydax drivers from Speaker Supply (PO Box 48362, Atlanta, GA 30362) or Madisound (8982 Table Bluff Rd., Box 4283, Madison, WI 53711). The Jordan units are available from Soundbox (841A S. America St., Dept. SB, Philadelphia, PA 19147).

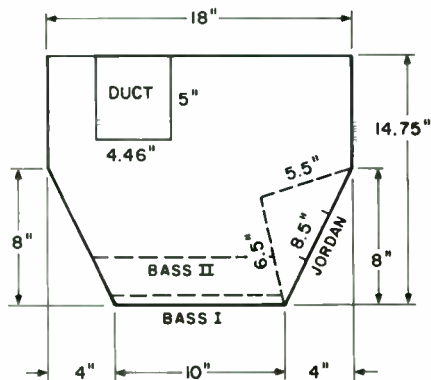


FIGURE 1: Cutting guide for enclosures.

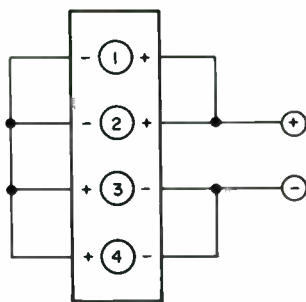


FIGURE 2: Series-parallel wiring for the four Jordan modules.

The cabinet is made of 3/4-inch birch-veneered chipboard. All measurements in the diagrams are internal. To construct the top of the enclosure (Fig. 1), cut a piece of chipboard 18 by 14.75 inches. At both front corners, measure 8 inches toward the back and 4 inches on the front. Draw a line between these points and cut along the line. Since the area of the triangles equals 32 square inches, the area of the top, minus the triangles, is 233.5 square inches. Cut the bottom the same way. The gross volume will then be 8,662.8 cubic inches (233.5 inches times the height, 37.1 inches).

The Jordan chamber is an unequal-sided triangle that measures 8.5 by 6.5 by 5.5 inches and is 22.5 inches long, for a volume of 406.4 cubic inches. It is made of 15mm chipboard. The duct chamber is 5 by 4.46 by 23.6 inches and exits at the top of the cabinet. It is made of 10mm chipboard.

Bass II is recessed into the cabinet about 4 inches. It is wired opposite in polarity to Bass I for push-pull operation. The Jordans are wired series-parallel (Fig. 2). The two drivers occupy 3.88 cubic feet (6,704 cubic inches) for proper alignment, with a duct that is 23.6 inches long and has a 22.3-square-inch cross section. See Fig. 3 for a sketch of the speaker layout.

Driver alignment parameter	6,704in ³
Bass I	130in ³
Bass II	350in ³
Duct	646in ³
Jordan	596in ³
Wood fillets & short braces	64in ³

Added together, these equal 8,490 cubic inches. Subtracting this from the total volume (8,662 cubic inches) leaves 172 cubic inches.

To finish the speakers, brush a 170-cubic-inch mixture of autobody undercoat and sand onto the larger interior panels of the cabinet. Allow it to dry. Two-inch pads of polyester insulation cover the back and bottom. Keep

the duct mouth clear of insulation. A small roll (16 by 6 inches) goes across the cabinet below the Bass II. Loosely fill the Jordan chamber with polyester and fasten the crossover outside on the bottom of the cabinet.

The bass response of the speakers is deep, clean and solid, with no upper-bass recession, as in some transmission line designs. No bass-boost is needed in my room. The Jordans take over above 150Hz, and here the sound is remarkable primarily because of what you do not hear—no audible resonance, boominess, peakiness, shrillness, hangover,

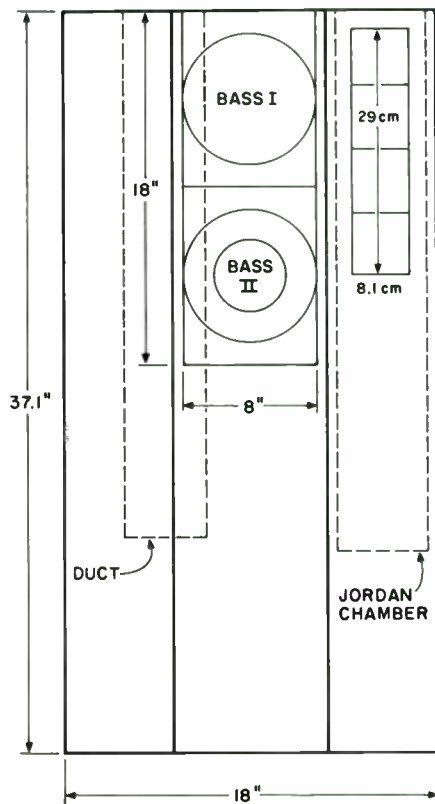


FIGURE 3: Sketch of the speaker layout. Note that all the dimensions are internal.

prominence or recession. The sound spectrum is beautifully balanced and natural, with exceptional smoothness. The speakers are also extremely sensitive to studio and hall ambience. In live, on-stage recordings, the speakers and the area between them disappear as if a wall has opened up to the concert hall.

The music has great depth and exact stereo positioning, while the audience applause is lifelike. In addition, the lack of reverberation in studio recordings or the excess of it in a concert is easily discernible with male and female voices. With some records, I first thought the speakers were deficient in treble, but that was only because the treble does not shrill or peak. When these notes arrive, they have a sheen to them, as in live music. Piano is superb.

The most remarkable characteristic to me is the absence of masking. A single note or voice comes through distinctly, regardless of the volume of the rest of the music. Complex musical scores display a beautiful clarity, and listening fatigue is absent.

These are the best speakers I have built. For those who like the sound of live, unamplified, concert hall music, they are a delight.

W.L. Ramsay
Newcastle, New Brunswick
Canada E1V 2P1

vifa

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We have been authorized by VIFA of Denmark to liquidate loudspeakers that are no longer part of their current production. These are new units with both VIFA warrantee and the MADISOUND guarantee of satisfaction. Quantities are limited to stock on hand. We think that this is an excellent opportunity for you to get the drivers you have wanted to try an idea, create a gift, or to build a design you have read about in Speaker Builder. All units have paper cones, and regrettably, we will be unable to engage in lengthy conversations about suitable applications.

Prices are as following:

15/10 cm oval units \$4.00 each; 17 cm units 5.00 each; 21 cm units 6.00 each; 25 cm units 7.00 each; 30 cm units 8.00 each.

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42	C17WG	35	45	7-15 ltrs	92	Qt.36; VAS 60 L
14	C17WF	60	25	7-12	91	woofer
9	S17WF	60	25	6-20	92	wide range
42	C21WG	50	45	15-25	92	woofer
18	M21WG	35	45	18-25	91	Qt.45; VAS 110 L
3	M21WN	35	100	20-30	92	Qt.37; VAS 80 L
22	S21FG	60	35	20-30	94	wide range
8	S25WN	45	60	25-40	94	wide range
11	M30WN	27	70	60-110	90	Qt.6; VAS 250 L



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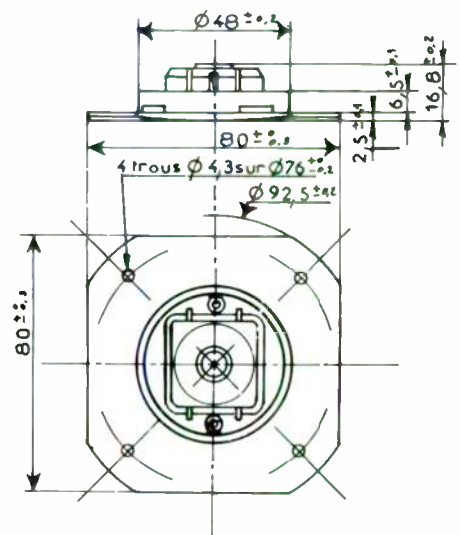
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CORRECTION: TT&T CROSSOVER

My Tools, Tips & Techniques piece (*SB* 2/84, p. 30) contained a slip of the decimal in the crossover circuit schematic (*Fig. 1*). Specifically, the two resistors in the woofer high-pass/boost circuit (R4 and R5) should be 182k Ω rather than 18.2k Ω , which would result in very little low-frequency output (a 260Hz high pass fed by a 220Hz low pass). The equation for determining these values is correct.

I apologize for submitting this error, but I seem to have spent more effort writing the text than checking the drawing. I shall remember this lesson in the future.

B. Kendall Berg
Tempe, AZ 85281

DALESFORD DRIVERS STILL AVAILABLE

I would like to respond to your "Nota Bene" box (*SB* 2/84, p. 11) about the availability of the Dalesford D30/110 5¼-inch Bextrene cone bass-midrange driver. While it is true that Dalesford did recently cease operations, Mission Electronics has purchased Dalesford's patents and tooling and is now producing the D30/110, as well as other Dalesford designs. The new company, which is an affiliate of Mission, is called Cambridge Loudspeakers, and its products are available from A&S Speakers.

Arthur Rosenblum
A&S Speakers
2371 Dahlia St.
Denver, CO 80207

D'APPOLITO DELIVERS THE GOODS

I am writing in response to Joseph D'Appolito's letter, "Rebutting Ballard," in *SB* 4/83 (p. 34). I recently built a four-way crossover and tested it using an op amp to sum the outputs. I measured overall frequency response and found that the all-pass network and "binary-tree" circuit configuration recommended by Mr.

Come Out of the Closet

Fine craftsmanship seems to be in short supply these days, but fortunately, *Speaker Builder* has a large store from which to draw. Most *SB* readers are, by nature, craftsmen who have the ability to build beautiful equipment for their home-listening pleasure.

So what's the problem? Well, we hate to sound like that proverbial broken record, but not enough of you are sharing your craftsmanship with the rest of us. Our Craftsman's Corner bin is nearly empty, and as far as we can see, there's no good reason for it. All we need is a little more "audience participation" to restock our files.

If you have built an especially attractive or distinct piece of equipment, why not take some black and white photos of it and write a description of your efforts? Because this is a "showcase" feature, we can use only high-quality photos, so keep that in mind when planning your piece. If your design does not lend itself to photography, why not share your idea via our Tools, Tips & Techniques department? These, too, are in short supply, and helpful hints are always a welcome addition to the magazine. We pay modestly for submissions to both departments, but fine photographs increase the value of your work.

Whichever vehicle you choose, it's time to come out of the closet and reveal yourself as the talented craftsman you are. It's up to you to keep the craft of speaker building alive.

D'Appolito are the best way to get flat response in three and four-way Linkwitz-Riley crossovers.

First I tried the basic Linkwitz-Ballard filter configuration, leaving out the all-pass networks. The resultant crossover had a midrange dip of 1.5dB, which was about an octave wide. Such a response aberration is audible and has no place in high-quality electronics. Rather than "tweaking" the crossover, I reconfigured it into a "binary tree" and added all-pass correction, as Mr. D'Appolito recommends. This solved my problems with minimum circuitry.

The completed system uses a Cerwin Vega D-189 18-cubic-foot subwoofer in a B6 alignment with f_3 equal to 17Hz, an AR-1W woofer, a Morel MDM-75 midrange and an MDT-27 tweeter. Crossover

points are 100Hz, 550Hz and 8kHz. By operating the drivers an octave within their limits, interdriver phase shift is less than 45 degrees. Many midrange and tweeter drivers have approximate $Q=1$ characteristics, with slight peaking before roll-off. The uncorrected interdriver phase shift produces relatively narrow areas of mild cancellation that flatten overall response.

After I set the levels in each driver's midband, response measured within 2dB from 20Hz to 14kHz—without any further "tweaking." The sound is smooth, full and "up-front," with detailed imaging reminiscent of top-quality full-range electrostatic systems, but without room placement problems. Unclipped output in excess of 110dB is possible using 50W amplifiers, with little chance of driver damage. That's digital-ready!

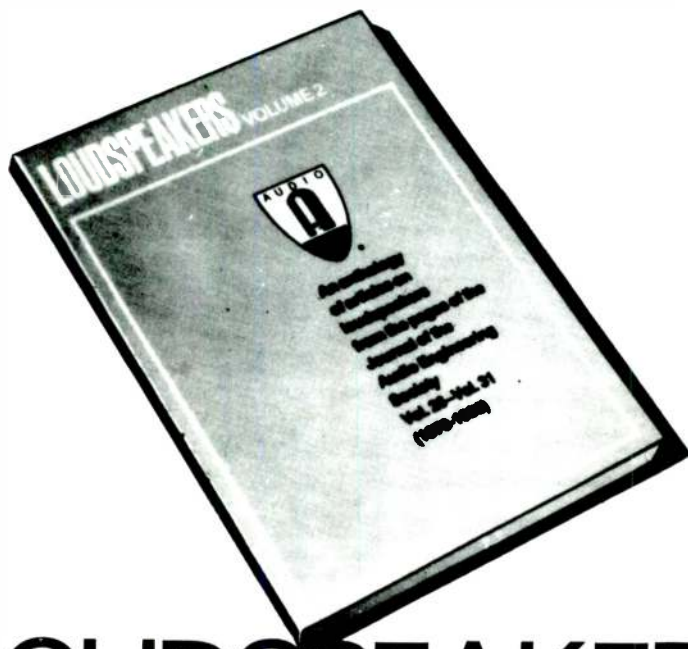
Linkwitz-Riley-D'Appolito crossovers are to multiway systems what Thiele-Small alignments are to woofers. With appropriate drivers and level-setting techniques (third-octave pink noise), they are as close to "cookbook" speaker design as you can imagine. If enough people discover how easy they are to use, I think we will see a sizable increase in home construction of high-performance loudspeaker systems.

A.B. Krueger
Grosse Pointe Woods, MI 48236

BASS SPEAKER SELECTION

For some time now, I have wanted to build a folded horn speaker system. I read Bruce Edgar's article (*SB* 2/83, p. 7) concerning the construction of a 70Hz horn, but I would prefer a bigger enclosure with a bass response of about 35Hz. In fact, I intend to reproduce the Klipsch horn. I have all Klipsch's original articles. Although I find them vague, even with my scientific background, I think I can pull off the project.

The major problem is choosing the bass driver. From what I have read, I think I should get a low-compliance, high-efficiency woofer with a fairly tight suspension and relatively high free-air resonance (about 40 to 50Hz). While it is easy to match a woofer to a cabinet for an infinite-baffle or reflex system, I cannot find much information on matching speakers or choosing speakers for horns.



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The AES, an international organization devoted exclusively to audio technology, publishes its *Journal* to bring professional audio engineers the latest developments in all aspects of audio. LOUDSPEAKERS Volume 2 reproduces forty-nine papers, exactly as they appeared in the *Journal*, authored by international experts on design, construction, and operation of loudspeakers. Computer-aided measurement and testing, crossover systems design, component materials, equalization, and radiation patterns are among the many topics discussed. Editor

Raymond E. Cooke, who also edited LOUDSPEAKERS Volume 1 and is a noted authority in the field of transducers, has written a concise and timely foreword to a publication that offers a comprehensive overview of loudspeaker state of the art.

LOUDSPEAKERS Volume 2 is 464 pages, with the editor's foreword, a table of contents, and a bibliography for further reading listing papers of historical importance from other publications. The book measures 8 1/4 inches (209.6 mm) by 11 1/4 (285.8 mm); it is bound in durable covers and is shrink-wrapped for safety in shipping.

To order this special anthology and its companion book LOUDSPEAKERS Volume 1, please use the order form below. Write Special Publications, Audio Engineering Society, 60 East 42nd Street, Rm. 2520, New York, New York 10165. Or telephone 212-661-2355.

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FAST REPLY #DG43

SB Mailbox

I would appreciate any information concerning speaker choice and cabinet design for low-frequency horns.

Fred W. Wagner
Walton, NE 68461

Mr. Edgar replies:

Mr. Wagner has posed a question that is treated ambiguously in most horn loudspeaker articles, even though choosing a bass driver for a horn is probably as important as choosing the horn shape and configuration. To begin, you want a 10 to 15-inch driver with a Q_{ES} below 0.3. The useful frequency range of a horn driver extends from the resonant frequency (f_s) to the mass cutoff frequency, which is two times f_s divided by Q_{ES} . For instance, a driver with an f_s of 50Hz and a Q_{ES} of 0.3 would have a cutoff frequency of 333Hz, which is about as far as you can push the low-end response of a matching commercial midrange horn.

Mr. Wagner says he wants response down to 35Hz. Theoretically, you can use a 50Hz driver with a hyperbolic horn shape and reactance annulling to extend the response down to 35Hz, but this procedure is very

tricky. The safer way is to select a driver with an f_s of 30 to 35Hz. To maintain an upper mass cutoff frequency above 300Hz means that the driver must have a Q_{ES} of 0.2 or lower. When you start searching catalogs for such a driver, you might not find one. The only candidate I know is an Oaktron FEW12Y2 12-inch power bass speaker with a 108-ounce ferrite magnet, an f_s of 36Hz and a Q_T of 0.16. The upper mass cutoff is somewhere near 400Hz. I have not verified these specifications myself.

If you can find a 12-inch driver ($f_s = 30$ Hz) with a higher Q of around 0.3 to 0.4, the upper mass cutoff frequency will be 150 to 200Hz. To fill in the gap between the bass horn and a midrange horn requires a mid-bass horn such as the small corner horn described in my SB 2/83 article.

LITTLE HORNS, BIG SOUND

I would like to comment on Bruce Edgar's little 70Hz horn in SB 2/83 (p. 7). After reading the article, I told my wife I might build a pair of horns if I had time. I was just kidding because about three years earlier, I had spent \$571 on a set of drivers from Speakerlab for their K-horns. These large 15-inch, three-way,

folded horns are very difficult to build. I am a carpenter and have all the required tools in my wood shop, but it was still quite a project.

After using the K-horns for three or four months, I was not happy with the size. The 15-inch bass horn seemed to be slow and overbearing on the mid and high range. I decided to build Gary Galo's TL-10 (SB 1/83, p. 7; 2/83, p. 24), a very fine speaker that I planned to keep for a long time. No more speakers for me; I was satisfied. But...

Not knowing I was kidding about building the mini-horns, my wife sent to Universal Sound for the Pyle W6C200F woofers and gave them to me for Christmas. I was not in any hurry to do this job, but after a few rainy days, I got bored and started the mini-horns. They were easy to cut out and put together, but I did not have any way to use them. I was getting very impatient with no midrange or tweeter and no money to buy them.

Then I had a brainstorm: I could take the HM350 midrange and the WA4000 tweeter out of the Speakerlab Ks. Since I had no crossover, I could take that from the Ks, too. I figured that I could always put the stuff back, but I just wanted to hear the mini-horns one time. After all, this was a rainy-day project, and so far all I had bought was a little wood and glue.

With the midrange and tweeter just sitting on top of the mini-horn, I hooked the system up to my Hafler 500 and DH-110. I knew this was too much power for the little horns, but I did not turn it up very high. To my surprise, the mini-horns sounded great. I heard things on my records I didn't even know were there. The bass is very clean and fast, and although these horns do not go as low as the Ks, they sound much better. I need not have worried about too much power because the mini-horns play loudly, without any breakup at high levels. I was so pleased with them that I built nice

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enclosures to hold the mini-horns, mid-ranges and tweeters.

The mini-horns are now my main speakers, and I would be hard pressed to put a price on them. I still use my TL-10s in another room, but they cannot compete with the mini-horns.

Jim Eldridge
Frankfort, IL 60423

Mr. Edgar replies:

Mr. Eldridge's experience with the mini-horns echoes those of my friends who have also heard them. The chief virtue of the horns is the fast attack in the mid-bass that makes good piano and other instrumental recordings seem to come alive. In contrast, most box enclosures have a null in the mid-bass region due to room interactions, as demonstrated by Ray Allison's many papers before the Audio Engineering Society. (Mr. Allison was the first editor of High Fidelity magazine and is now head of Allison Acoustics, a loudspeaker firm.). The corner horn, on the other hand, is acoustically matched to the room, so it is no wonder that Mr. Eldridge hears material he never heard before. As an added benefit, imaging in the mid-bass region is also improved.

Mr. Eldridge's experience with the Speakerlab K-horn deserves some comment. Anyone who thinks he is buying a cheaper version of the Klipsch horn is deluding himself. Even though the K-horn copies the folding geometry of the Klipsch horn, Speakerlab's choice of their 15-inch driver is wrong. The driver has a Q_{TS} of 0.45 and an optimum throat size of more than 200 square inches. When the driver is put in a horn enclosure that has a throat size of 39 square inches, a mismatch obviously occurs, and the efficiency suffers a drastic reduction. The end result is an inefficient bass horn that has reactance loading instead of the pure resistance loading found when a low- Q_{TS} (less than 0.2) driver is used. This reactance loading leads to the "slow bass" Mr. Eldridge noticed.

I hope Mr. Eldridge's experience will encourage other readers to try their hand at building the mini-horns.

NEW MAGNET MATERIAL

Science magazine [March 2, 1984 (Volume 223, Number 4639), pp. 920-922] recently ran an article concerning a new magnet material made of a rare earth-iron-boron compound. This compound

has a high coercivity and an energy product of more than six times that of widely used ceramic or ferrite materials. Crumax, the trade name for Crucible's magnet material, has an energy product 14 times that of ordinary ferrite. This development has obvious implications for the audio field. I hope speaker manufacturers are alert and able to take advantage of this technological advance, price considerations allowing.

On another note, I would like to make some suggestions for future articles. How about a discussion of the factors that affect total speaker Q? I would also like to see more interviews with speaker designers, such as the one with KEF's Raymond Cooke (SB 3/83, p.7; 4/83, p. 13).

In addition, passive crossovers still seem a bit mysterious, so an article on

Society Defunct

We regret to announce that the Northern California Audio Society (PO Box 14156, San Francisco, CA 94114) is apparently defunct. The group, led by Gary Hoffman, advertised a monthly newsletter in our classified section. The newsletter appeared for a few issues and then disappeared. We have tried to reach Mr. Hoffman, but his post office box has been closed. We regret the losses readers have suffered and thank those who called this matter to our attention. — Ed.

this subject might be helpful. In Martin Collums' book "High Performance Loudspeakers," the author states that 6dB/octave is too slow, 12dB/octave leads to a 180-degree out-of-phase situation (compared to the source) somewhere beyond the crossover region, 18dB/octave is a good compromise, and 24dB/octave, although in phase at crossover, causes a 6dB dip at crossover and might be unacceptable because of the losses. Yet I see supposedly top-quality commercial systems with 6 and 12dB/octave crossovers. One example is the ADS L1 1290, with 12dB/octave crossovers at 500Hz and 5kHz. It has a group delay of less than 0.2 milliseconds from 1.5 to 20kHz. Also, the Spica TC-50 uses a crossover with a Bessel filter as an "alternative transfer function" to achieve "linear phase" of ± 15 degrees from 350Hz to 4.2kHz. What does this mean?

Because the terms group delay, time alignment and linear phase (the latter is a real misnomer!) enter into crossover consideration, I would like to see some more coverage of this in SB. I have also detected some confusion about phase. As I see it, the goal is a constant time delay across the sound spectrum. Graphing various time delays (for example, 12.5,

25, 50, 100 and 200 microseconds) in terms of degrees of phase shift versus frequency is helpful. I am not sure what all this means for practical speaker construction, as the threshold for human hearing of group delay is close to 1 millisecond (1,000 microseconds) from 500Hz to 6kHz (D. Preis, *JAES*, November 1982).

Concerning active filters, a construction article in which the filter function is achieved by summing would be desirable. By this I mean that original signal minus active filter high pass equals the low-pass signal out. The high-pass signal out is also obtained from the original signal by subtracting an active filter low-pass signal. It would seem that this approach has possibilities.

Robert L. Schultz
Loma Linda, CA 92354

Z-METER

Continued from page 23

driver. Drivers can have a slight rubbing in the voice coil that cannot be heard or felt by pushing on the cone. Such drivers show up clearly on the Z meter, displaying a smooth, flat impedance curve where resonance should occur. Be careful, though, because drivers with fluid-filled voice coils will display low, wide resonance curves that should not be confused with those of defective units. ▶

This concludes Mr. Koonce's series on constructing test equipment.

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DONALD M. CHAVE 1908-1984

On August 19, 1984, noted English loudspeaker designer Donald M. Chave of the Lowther loudspeaker firm died while attending a hi-fi show in Frankfurt, Germany.

Chave came from a family of naval uniform tailors who expected him to follow in the family business. As a teen-ager, however, he became enchanted with wireless radio and attended a technical school for naval apprentices. Eventually, Chave became involved in a Kent radio parts company and worked his way up to regional sales manager. He attended lectures on loudspeakers given by Dr. N.W. McLachlan, a noted mathematician who was an early loudspeaker enthusiast. Chave built his first loud-



speaker from McLachlan's 1927 *Wireless World* plans, and the system was installed in a local cinema.

In the early 1930s, Chave left his sales job and joined with Peter Lowther to design and build high-quality gramophones. (One of Chave's amplifier designs appears in *TAA* 4/84, p. 49.) When Lowther needed a loudspeaker to complete the system, Chave introduced him to P.G.A.H. Voigt, and thus was born the Lowther-Voigt Radiogram (*SB*, 4/81).

After World War II, Chave, who had taken over the Lowther firm, and Voigt agreed that the Voigt high-flux driver, powered by a 40W field coil, had to be upgraded to a permanent magnet version. Voigt continued using his open-frame construction with an internal PM Ticonal slug, while Chave designed an external shell magnet. When Voigt emigrated to Canada after the war, Chave assumed

that no more Voigt drivers would be forthcoming and so introduced the PM-2 driver in a Voigt corner horn. Voigt cut off all relations, and a feud between supporters of the two rivals lasted into the late 1950s.

During that time, Chave made many trips to the US to market

Lowther speakers. He met with many prominent US hi-fi designers, including David Hafler, Arnold Hegeman and Victor E. Brociner. At one of these meetings, Hafler mentioned the need for a tube that would surpass the 6L6. Chave consulted his friends in the British valve industry, and on his next trip to the US, he brought Hafler the KT-88.

Chave continued designing high-flux drivers and horn-loaded enclosures into the 1960s. His PM-6 became the basis for Ralph West's and Rex Baldock's speaker construction articles in *HiFi News*. When I visited Mr. Chave in 1982, I found a delightful old English gentleman who had lost none of his youthful enthusiasm for new loudspeaker designs. In 1983, he revamped his PM-6 to include a 4½-inch cone with a high-flux magnet (16,000 gauss) and came up with a new Lowther C-45 high-performance tweeter.

Donald Chave's contributions to loudspeaker design, tube development and promotion of British audio overseas make him one of the more remarkable unsung figures in audio history. He is survived by his wife, Rhona, a daughter and a brother.

Bruce C. Edgar
Contributing Editor

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A CLUB FOR FM AND TV DXers, offering antenna, equipment and technique discussions, plus updates from FCC on new station data. Monthly publication "VHF—UHF Digest." Annual convention in August. For more info: Worldwide TV-FM DX Association, PO Box 97, Calumet City, IL 60409.

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

HI-FI CLUB OF CAPE TOWN, South Africa issues newsletter monthly for its members and subscribers. Since our audio problems are the same as yours, we'd like to hear from you. Send 2 I.R.C.s for next newsletter (\$16/year) to PO Box 6685, Roggebaai 8012 South Africa.

THE BOSTON AUDIO SOCIETY INVITES you to join and receive the monthly B.A.S. SPEAKER with reviews, debates, scientific analyses, summaries of lectures by major engineers. The BAS was the first to publish info on TIM, effects of capacitors, tonearm damping, tuner IM distortion, Holman's and Carver's designs, etc. Sample issue \$1, subscription, \$16/yr. P.O. Box 7, Boston, MA 02215.

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

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

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

FOR SALE

Pair Sendor SA-1 mini's, walnut with 14" wall mounts, \$350. Chris Gagomiros, (516) 731-3007.

JH Formula-4 tonearm, \$50; ERA MK6C FMI/Pro Musica turntable, \$50; both for \$85. David Barnett, 455 W. 34th, #10E, New York, NY 10001, (212) 695-5482.

ReVox/Studer PR99 HS, two-track, balanced microphone input option, truly mint, hard case available, \$1,550/best offer; Nakamichi NR200 Dolby B/C NRU—new, \$450, asking \$300/best offer; 8Ω speaker coax, 75¢ per foot. UPS additional. Trade for IBM-PC. Bruce Boyes, PO Box 9532, Salt Lake City, UT 84109, (801) 487-7412 evenings.

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MXR 132 expander, \$150; sealed, out of print MFSL records, \$25 and up; "Dark Side of the Moon," \$35; stock Dyna Mark IV amps, \$100 pair; Ace active subsonic filter, \$20; PAS preamp, \$20. Roger Artman, Box 2463, Grass Valley, CA 95945, (916) 272-6427.

New York Acoustics speaker system, four-way transline, put together with screw and glue, no nails, long hair wool glued on fishnet, auto-body underseal used inside enclosures, black melotone grille, oiled walnut, 10" woofer, vampire wire. Will not ship. Emil Stan, (415) 826-6897.

Hartley 24" woofer, brand new, \$350; two pairs Peerless TX-305 12" polypropylene woofers, \$40/pair. Ron Stone, PO Box 741, Lawrence, KS 66044, (913) 749-0133 or (913) 841-9433.

Classified Advertising

SME 3009 Type II, low-mass, fixed headshell, \$90; GE 12AX7 tubes, \$1 each; JBL O66 1" aluminized dome tweeter, \$100/pr; AR3A dome tweeter and midrange, two pairs, \$50 each. All items brand new. All items plus shipping. Charles Walters, 2616 Pine Ave., Manhattan Beach, CA 90266, (213) 679-4927.

JVC QL-50 turntable, Formula 4 tonearm, Ortofone MC-10 head amp and MC-76 cartridge, Silver Audio coaxial, all \$185; Teac 4300 reel-to-reel tape deck, 7" metal reel, demagnetizer, \$185; Mac MR65B VAC FM tuner (good condition), \$100 as is; Dyna MK3 VAC power amp, \$165; pair of Teac AN-80 Dolby decoders, \$60; 150 7" high-quality reel tapes (mint), \$2 each. James Pann, 5818 Santa Cruz Ave., Richmond, CA 94804, (415) 524-5629.

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Audio Research D-60 power amp, \$800; GAS Thoebe preamp, \$420; Litz wire, Perraux PMF 1150B, \$990; SM2 preamp, \$1090. John Sandin, (203) 744-6421.

Hafner DH-200 with rack panel, \$175; Sony CDP-101 digital disk player with remote, \$425; Shure V151V cartridge, \$25. Joe Blackburn, 217 Hanover Hills, Seneca, SC 29678, (803) 882-5491.

RTRs, finest electrostatic amps, \$95 each; Haeco power transformers (68VCT, 6A), \$25 each; Tek scope 361A RM (basic frame), \$40; HP 310A wave analyzer (needs repair), \$50. J.R. Stephens, 41285 Crest Dr., Hemet, CA 92344, (714) 658-9575.

Three pairs Strathearn ribbons with two transformers, \$750; Dynaudio 30W54MPS 12" woofers, \$135/pr; Audio Control Richter Scale II crossover/equalizer, \$235. WANTED: Viking 88 stereo compacts, 87 decks, Fisher FM 200B, FM 1000. Steve Fritz, (805) 964-0245 mornings and weekends only.

Luxman CL34 tube preamp, \$275; MXR 132 expander, \$150; eight unused Tunsram 12AX7 tubes, \$20; Dynaco Mark IV amps, stock, \$100/pr; Pioneer SF850 electronic crossover, \$175; Heath 0-5 oscilloscope, \$50. Roger Artman, Box 2463, Grass Valley, CA 95945, (916) 272-6427.

Two KEF B139 woofers, operationally perfect. Best offer. N. Disney, 416 1/2 W. Michigan, Marshall, MI 49068, (616) 781-6156 after 6 p.m.

Ampex AX300 reel-to-reel deck with remote control, \$185; pair KLH17 speakers, \$65; Sansui PD-30 turntable, \$50; Dual 1215 turntable, \$30; HK400xm, three-head cassette deck, Dolby HX, low hours, \$350; Arkay AM/FM (binaural ca 1960) tuner, best offer, trade. Interested in Leigh "Egg" speakers. William Beasley, 5835 Cove Landing Rd., #302, Burke, VA 22015, (703) 250-2548.

Denon DP-1500 turntable with Oracle mat and much damping added; Signet XK-50 tonearm with spare arm tube; subsonic spring isolation base. All in excellent condition, \$395. P. Bandurian, 139 Lincoln Circle, Louisville, CO 80027, (303) 666-7588.

For sale or trade: mint Fulton FMI 100 in real walnut from defunct dealer. Less than 10 hours use. List \$450 pair. Sell for \$350 a pair or trade for RTR-6 electrostatic tweeters. Other offers invited for items such as one Quad ESL, Ionovac tweeters, test equipment, tubes, etc. Lawrence E. Larsen, (301) 587-8143.

Pioneer RT-707, excellent condition, \$300; dbx 224, \$150; 42 Maxell UDXL35-90B tapes, \$170; 14 dbx disks (5 digital), \$80; dubbing box for dbx, \$20; Rogers Studio 1 stands, \$40; custom-built subwoofer, \$80; Nitty Gritty Record Survival Kit (unused), \$25; modest stereo amp, \$10. Call Bill (415) 321-4857 for more information.

Triplet model 370 sound level meter, calibrated, \$110; Sprague 12µF, 200V DC metallized Mylar film capacitors, \$2 each. J. Carlblom, 2774 Doresta Rd., San Marino, CA 91108, (818) 441-1318.

Bozak B4000 speaker system in walnut cabinets. Perfect condition. Also Bozak B310 system with newly reconed speakers. \$4,000 value. Best offer. Jim Bartholomew, (408) 684-1591.

Dynaudio 21W54, \$40; three D28s with lens, one without, \$20 each; Focal 5N402-DB, \$25; Focal 10N501, \$40; new spare drivers, never used—UPS included. D. Jensen, 12655 W. Brookview Dr., Grass Valley, CA 95945, (916) 273-6738.



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Issues and/or copies of *Listener's Review Finder*, *HiFi Dealer News* (British), *Record World* and *Critical Record Review*. G. Mileon, 14 Border St., Lynn, MA 01905.

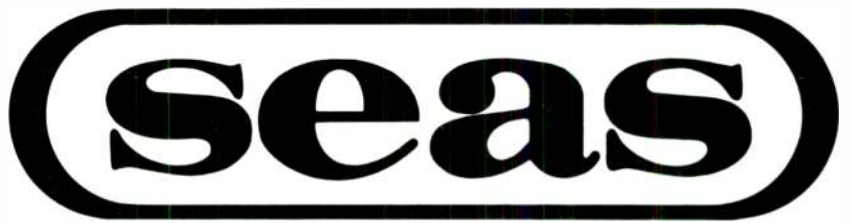
RTR, ESR-15, ESR-6 or replacement electrostatic drivers for these. Ed Modelski, 5341 N. Melvina, Chicago, IL 60630.



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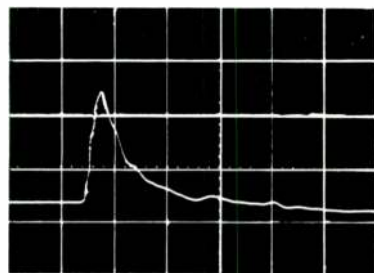
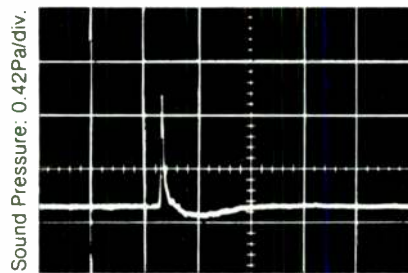
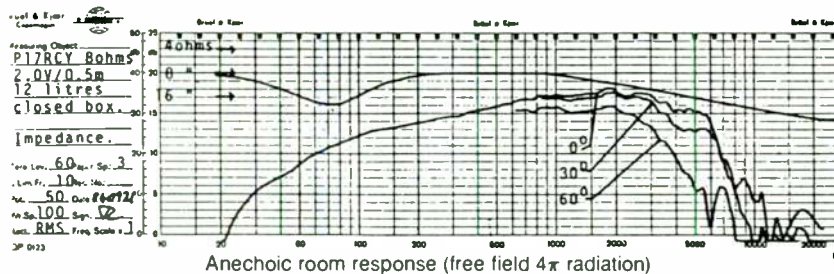
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SPECIFICATIONS

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Frequency range	40-4000 Hz
Free air resonance	37 Hz
Operating power (DIN 45500)	3.2 watts
Nominal power (DIN 45573)	40 watts
Music power (DIN 45500)	50 watts
Characteristic sensitivity	91 dB
Flux density	1.25 T
Force factor (Bl)	7.0 Wb/m
Voice coil diameter	26 mm
Voice coil height	12 mm
Air gap height	6 mm
Voice coil resistance	5.7 ohms
Effective diaphragm area	130 cm ²
Moving mass	11 g
Air load mass in baffle	1 g
Mech. suspension resistance	3.0 Ns/m
Weight	1.12 Kg
Thiele-Small parameters	
Qms: 0.93 Qes: 0.32 Qts: 0.24 Vas: 0.036 m ³	

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