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Speaker Builder

THE LOUDSPEAKER JOURNAL

BRUCE EDGAR'S SHOW HORN

SB Mailbox

CORRECTION

While looking back at my Unline article (*SB* 4/88), I noticed an error in equation #4 on page 29. It should read:

$$D_L = 0.5(Q_{TL}/Q_{TS})^2$$

The factor of 0.5 was left out. In the worked example however, it was included.

John Cockroft
Mountain View, CA 94041

HIGH-PASS FILTER

I am at least halfway through my latest endeavor, a derivation of the Swan IV, and find a problem with the Pedal Coupler I built. Specifically, I want to use a smaller bass enclosure with my 12″ driver in lieu of the original twin-driver bass cabinets. My problem is in modifying the equalizer (boost) circuit.

My present Pedal Coupler is per the *SB* plans (4/88, p. 19) with the exception of having 12dB Linkwitz-Riley crossovers (as currently employed in factory Swan IVs). I would like to determine the equations for modifying the equalizer Q and F_P.

I've searched through all my data books, and *SB* back issues, and can't find this "non-inverting high-pass filter with gain."

Matthew Honnert
Carol Stream, IL 60188

Joe D'Appolito replies:

The design equations for the non-inverting high-pass filter with a gain of two (6dB) are shown below. The circuit (*Fig. 1*) should not be used for gains greater than two, since it uses positive feedback which may lead to instability for higher gains. Higher gains also make the circuit very sensitive to small errors in component values. It is very reliable at a gain of two and is useful where a little extra gain is needed. Capacitors should be 2% tolerance and resistors 1% tolerance for best performance. If you require larger gains, use the circuit of *Fig. 2*. Feedback in this circuit is taken from the op amp inverting input which has a gain of −1 relative to the filter input so all the conventional unity gain non-inverting filter equations apply.

Returning to *Fig. 1*, first, for a desired boost of B dB compute the constant K, where

$$K = 10^{B/20}$$

Then compute the required filter Q, where

$$Q = \sqrt{(K^2 + K\sqrt{K^2 - 1})/2}$$

Next, for the desired boost frequency, F_B, compute the filter cutoff frequency, F_C, where

$$F_C = F_B\sqrt{1 - 1/2{\cdot}Q^2}$$

Note that F_C is always less than F_B. Pick a convenient capacitor value, C, and compute the resistance, R, using

$$R = 0.1592/(F_C \cdot C)$$

Finally the resistor values, R1 and R2 are computed using

$$R1 = R(1 + \sqrt{1 + 8{\cdot}Q^2})/(4{\cdot}Q)$$

and

$$R2 = R^2/R1$$

Note that the equations for K, Q, F_C, and C apply to high-pass filters of any gain. Only the values R1 and R2 are specific to the gain-of-two high-pass filter.

An example at this point should help. We are currently recommending 5dB of boost at 25Hz for the Swan IV bass modules when using the Eclipse 10″ drivers. The required calculations look like this:

$$K = 10^{5/20} = 10^{0.25} = 1.778$$

$$Q = \sqrt{(1.778^2 + 1.778\sqrt{1.778^2 - 1})/2} = 1.700$$

$$F_C = \sqrt{1 - 1/(2{\cdot}1.700^2)} = 0.909 \cdot 25 = 22.7\text{Hz}$$

Now let C be 0.1μF or 10^{-7}F. Then

$$R = 0.1592/(10^{-7} \cdot 22.73) = 70.04\text{k}\Omega$$

and

$$R1 = 70.04(1 + \sqrt{1 + 8 \cdot 1.700^2})/(4 \cdot 1.700) = 60.9\text{k}\Omega$$

and

$$R2 = (70.03)^2/60.9 = 80.6\text{k}\Omega$$

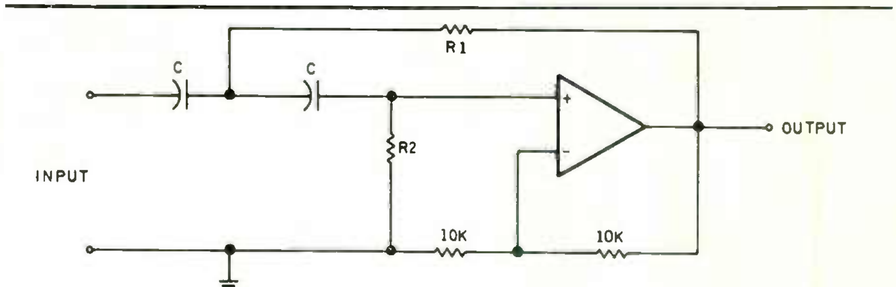

FIGURE 1: Non-inverting high-pass filter with gain of 2.

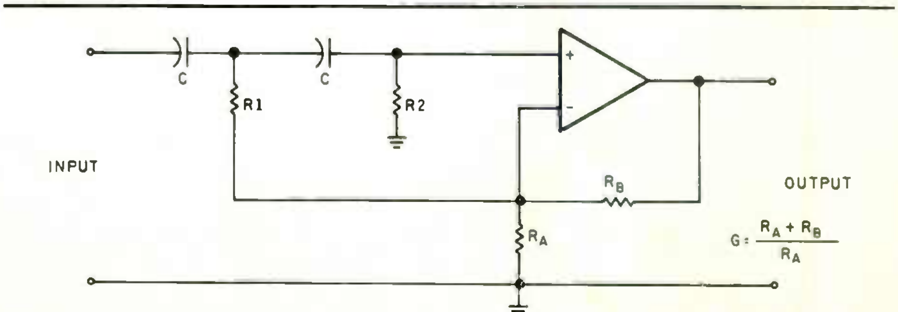

FIGURE 2: Non-inverting high-pass filter with gain of G.

CONTOUR CIRCUIT

Can the D-28 contour circuit be added to an active crossover? Falsely assume that

I have operational capability from two Jung boards, the ability to modify an AC Richter Control, and the intelligence to put together assembled kits from Marchand, DeCoursey, or Ace, of course using a Sulzer regulated power supply.

M. Thompson
St. Catharines, ON
L2T 1R4 Canada

Joe D'Appolito replies:

By the D-28 "contour circuit," I assume you mean the parallel RC circuit in series with the tweeter. The circuit function can, of course, be synthesized actively, but it is rather complex. The parallel RC network interacts with both the resistive and inductive portions of the tweeter impedance to provide a second-order lift which almost perfectly compensates for the D-28's high-frequency droop. It also compensates for the tweeter-to-tweeter variations.

Frankly, I see no reason to redesign the satellite for active crossover use. The Swan IV satellite passive crossover has been computer optimized, carefully accounting for both driver response and impedance variations. Without the voltage transfer function curves you cannot begin to develop the proper active crossover. Even with these curves, the correct active crossovers will not be standard circuits. A hit or miss active crossover design may lead to poorer rather than better performance.

OUT OF PHASE

I recently built a seven-foot transmission line speaker system using two Dynaudio 21W54 8" woofers and a D28af 1" dome tweeter arranged in an MTM D'Appolito configuration. The system biamped and crossed over at 2,000Hz. The two woofers are wired in parallel which causes a 7dB SPL mismatch between the woofers and the tweeter. I am using a Marchand XM6 active crossover, an Adcom GFA 555 amplifier for the low end, and an Adcom GFA 535 for the high end. The Marchand crossover is capable of adjusting the level between the low and high outputs and can reverse the phase of the low output.

I have an Audio Control "Ten Plus" warble tone equalizer-analyzer. I adjusted the high and low level controls on the crossover by getting equal readings at 1,000 and 4,000Hz on the analyzer. The microphone was positioned on the tweeter axis, 30" in front. I noticed the 2,000Hz analyzer reading was 6dB down. When I reversed the phase of the low output, the analyzer read 1dB down. This indicates the woofers and tweeter are out of phase at the crossover frequency.

First I checked my speaker wires for reversed hookup. This was OK. I contacted Marchand. He said his crossover is a fourth-order Linkwitz-Riley and the outputs are in phase at the crossover frequency. Adcom said both amps do not

Continued on page 58

Speaker Builder

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Speaker Builder is published bi-monthly by Edward T. Dell, Jr., PO Box 494, Peterborough, NH 03458.

All subscriptions are for the whole year. Each subscription begins with the first issue of the year and ends with the last issue of the year. A sample issue costs $4 in the US, $5 in Canada.

Subscription rates in the United States and possessions: one year (six issues) **$20**, two years (twelve issues) **$35**. All sets of back issues are available beginning with 1980. Canada add **$4** per year for postage. Overseas rates available on request. Subscribers residing outside the US and Canada are served by air.

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Speaker Builder (US ISSN 0199-7920) is published bi-monthly at $20 per year; $35 for two years, by Edward T. Dell, Jr. at 305 Union St., Peterborough, NH 03458 USA. Second class postage paid at Peterborough, NH and additional mailing office.

POSTMASTER: Send address changes to **SPEAKER BUILDER**, PO Box 494, Peterborough, NH 03458. Return postage guaranteed.

About This Issue

The horn is loudspeaker technology's oldest enclosure format, yet it's the least used in listeners' living rooms. With the exception of Klipsch and company, no manufacturer makes horns for homes. Contributing Editor **Bruce Edgar** is determined to change that if he can. His continuing search for the perfect, small horn for home use continues. Details of his bass unit, dubbed The Show Horn, begin on page 10.

Fred Thompson chronicles his adventure with a small, simple system which many new readers have been asking for. For details on a good place to begin your own speaker odyssey, see page 24. **Carl E. Richard**, wanting a quick way to do Helmholtz resonator formulas, turned to that popular computer design tool, the spreadsheet. His discoveries are detailed on page 26.

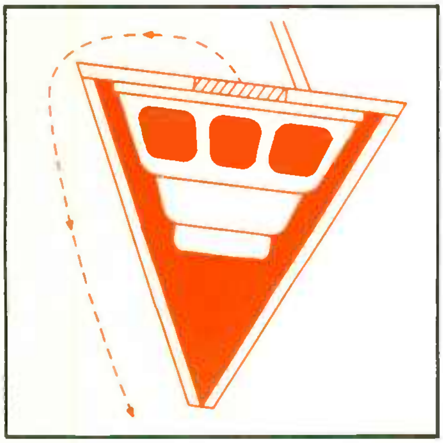
If your local public radio station needs studio monitors and the gift horse is a pair of venerable Klipsch Heresies, what do you do? **Paul Stamler** achieved surprising results doing some basic upgrades (p. 28).

Feelings about proper electrostatic hardware run deep. **Roger Sanders** and **Barry Waldron**, both devotees of the ESL, differ on what type of panel is best. Wisely, they decided to present both methodologies so you may choose for yourself. The fun begins on page 36.

And don't miss **Bob Bullock**'s software review (p. 49), two full pages of *Tools, Tips & Techniques* and **Dick Pierce**'s advice on how to use an old driver (p. 54) as well as his usual acerbic comments in *Pox Humana* (p. 86).

SpeakerBuilder
THE LOUDSPEAKER JOURNAL

VOLUME 11 NUMBER 2 APRIL 1990



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FEATURES

DEPARTMENTS

On our cover: Contributing Editor **Bruce Edgar**'s Show Horn. Photo by Manfred Buechler.

Editorial

Unhandy Heads

One of our advertisers, the colorful Elliot Zalayet of Zalytron Industries, has been serving for some time as midwife attempting to bring to these pages a wonderful story of a high school teacher's loudspeaker building course. A number of the author's more pressing concerns have kept the article from being written up to now, but we're still trying.

In one of New York City's many suburbs, a teacher offers a semester course in building a pair of loudspeakers. It fills quickly, and has overflowed regularly into two sessions. Although highly popular with the students, such student responses are a problem. As Elliot points out, "In high school teaching, no good deed goes unpunished."

If a course is successful, and students like it, can it really be academically respectable? Such is one guise the jealousy takes. No cooperation is available from the woodworking department, of course, since speaker cabinetry is so much more complicated than broom holders or tie racks. And the electronics are too simple for the technical arts teacher to become involved.

On reading *The New York Times'* recent special section on science education (Jan. 7, 1990) my thoughts inevitably wandered to Elliot's teacher friend. The lead article, by K.C. Cole and titled "Science Under Scrutiny," quotes the National Science Foundation's report on science education in the schools. In sum, the report shows that science education has been made tough, elitist, and a turnoff for the average student.

It isn't that young kids don't like science, it's just that between the fifth and eighth grades, their interest is destroyed. US fifth graders rank 8th among the industrialized nations in science, ninth graders rank 15th.

To quote just one paragraph from the report: "What's happening from grade school to grade school is the suffocation of curiosity under an avalanche of raw fact. Mary Budd Rowe, professor of science education at the University of Florida, estimates that more new terms are introduced in a typical high school biology text than in the first two years of foreign language."

The current demand among educators for achievement tests, combined with textbook publishers afraid their books will not be bought unless they include "everything," and the teacher's breathless race to "cover everything" the kids will need to know for good SAT grades, are all the evident reasons why science teaching fares so badly that we are seriously short of people trained in science.

In some reports I see, 60% of the new science jobs in the US are going to nationals from other countries. And considering the parlous state of US science education, the situation is unlikely to change very rapidly. One large company operations manager recently scoffed at IBM's offer of maintenance programs for mainframe and minicomputers because he could not believe that even the giant computer maker could find enough good people to reliably deliver such service.

Considering these facts it is little wonder we have lost our leadership role as the scientific innovators of the world. And unfortunately, we must couple that sad situation to another which has been a recurring theme, perhaps boringly so, of mine over the years. Far too many of our industries are being run by people who know nothing about science and precious little about how they manufacture the products they sell.

When Peter Sprague, the quintessential bean counter, took control at Advent years ago, his chief qualification for the job was possessing enough money to cover the financial mistakes and misjudgments made by that technical and manufacturing wizard, Henry Kloss. The company quickly failed, simply because Sprague did not understand what made the company great. It now exists as part of a larger complex but its products are simply one more set of low end speakers competing for sales at your local shopping mall. Not the truly innovative, cleverly manufactured products Kloss designed and built.

The same situation occurred when Tyco bought Dynaco and within four years dumped it for one twenty-fifth its purchase price to ESS who made a tax write-off of it. Business management in the US is being done by "lawyers, accountants or other financial types" to quote another article from the March 4, 1990 edition of *The New York Times.* Happily, the article chronicles the discovery by Lewis Cullman, famed leveraged buyout artist, that when a company head knows something about manufacturing methods as well as about managing money, he or she is apt to dramatically increase the profitability and growth of the company. Amazing discovery, eh? Incredibly novel concept.

Quoting some of the facts from the article, "According to Meyer Feldberg, Dean of the Columbia Business School, fewer than 4 percent of all college students in the United States will graduate this year with degrees in engineering, while about 25 percent will earn business degrees." And those latter degrees will provide nothing in the way of genuine understanding of how things are made, or the basis of their quality.

Mr. Cullman was so impressed by the effects of putting G. Thomas Hargrove in charge of one of his companies that he decided to do something about finding and helping to educate such people. Hargove took on a business that in 1980 was grossing $16 million a year in sales. Today revenues are at $120 million annually.

Cullman looked around for a place where aspiring managers could get a taste of such manufacturing know-how and bypassed big schools like Yale and Harvard whose business curricula are almost totally "case method" and financial management oriented. In discussing his search for possible candidates Cullman said, "The people I see now running businesses are all steeped in finance. No one seems to have any manufacturing qualifications or ability to understand what goes on out on the floor of the plant." Finally, Mr. Cullman settled on endowing a $1 million chair in manufacturing management at the Krannert School of Management at Purdue University, in the middle of the "rust belt."

I remember clearly the excitement and enthusiasm I sensed in Henry Kloss as he proudly showed me an old photocopier he had modified to transfer circuit board patterns and a prototype cassette master recorder one of his MIT student-technicians was building. Henry not only conceived a new product idea, he seemed able to visualize the means of manufacturing and marketing it as well. His skills were, to some extent, doubtless bred in the bone. But his obvious pleasure in making things himself, with his own hands, was a vital element in his spectacular success at Acoustic Research, KLH, Advent and today, Cambridge Soundworks. I'm not sure Henry would like being professor of manufacturing techniques at Purdue, but he surely has the qualifications for a seat in their newly endowed chair.

Perhaps the day is not far off when the industrial leaders of this country will rediscover the values of hands-on experience. Every company with the wit to listen to those who do the work benefits spectacularly. If the top management is led by people who understand the hands-on experience, our economy will snap out of its present economic malaise.—E.T.D.

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Fast Reply #FE317

THE SHOW HORN

BY BRUCE EDGAR
Contributing Editor

Every speaker project has a stimulus. In this case, *Speaker Builder* and Madisound sponsored a room at the 1988 Stereophile Show in Los Angeles. I saw this as an opportunity to display audiophile horn technology to the public and the audio industry. However, one problem existed: Although I had midrange and tweeter horns ready to use, I didn't have a suitable bass horn. Luckily, I had a paper design for a one-eighth-size 50Hz bass horn. Since the show was two months away, I was forced into a fast paced building program. Several friends helped build and finance the project, and we were able make the show deadline with some cushion. Thus, the Show Horn (*Photo 1*) was built.

PHOTO 1: The Show Horn.

Reactions to my system varied. I saw many jaws drop as people came into the room. A sample comment was, "I can't believe you would display a horn at the show." But it was gratifying to talk with many audiophiles/speaker builders who, after getting over their initial surprise, began to show interest in the possibility of horns for their own systems. Some people were enthralled by the sound and kept returning. After three days, I was exhausted, but all the feedback from listeners stimulated me to do further research and design work. So for all those enthusiastic builders I met at the 1988 Stereophile Show, I now give you the theory of how the Show Horn was designed and construction details so you can build it.

INTRODUCTION. For a very old design, the horn loudspeaker literature does not give the amateur any clear step-by-step method of how to design a bass horn. In contrast, there have been a good many expositions on designing vented- and closed-box loudspeakers. Keele probably presented the first comprehensive and simplified design methodolgy for bass horns.[1] He showed most horn design parameters could be calculated from the Thiele/Small parameters for the driver. Leach extended Keele's work by introducing losses into the model.[2] However, Leach's math formalism makes the paper very hard to follow.

The principal problem in bass horn design is maximizing the bandwidth response. Most ad-hoc horn designs yield efficiency but not always a smooth response over several octaves. For example, I designed a tractrix corner horn (*SB* 2/83) which, while sounding good, did not achieve the design objective of a good response down to the flare frequency, 70Hz. Instead, the response died below 100Hz. After some thought and experimentation, I have concluded that the prime limitation on bass response is what acoustical designers call throat reactance.

You can think of a horn as a transformer which transforms the low impedance air load into a high impedance that a driver likes to see at the throat. At the flare frequency, the throat reactance peaks, whereas the throat resistance is zero and rises to its maximum value above the flare frequency (*Fig. 1*). Theoretically, a bass horn should give response down to the flare frequency, but the throat reactance will choke off any response near the flare frequency.

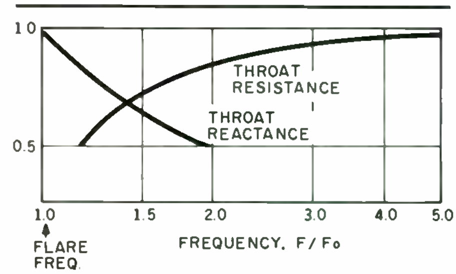

FIGURE 1: Normalized acoustical throat impedance of an exponential horn.

Over the years, Wente and Thuras at Bell Labs and Klipsch[3] independently found you could cancel out the throat reactance by using a sealed back chamber. This technique, which Plach[4] termed "reactance annulling," allows for bass response right down to the flare frequency. Leach showed that, for a number of exponential horn examples, reactance annulling does not occur at the flare but at a higher frequency.[2] In a follow-up letter,[5] Leach concluded that reactance annulling works best with the hyperbolic-exponential horn as discovered by Salmon (US Patent #2,338,262).[6] And it is the difference between a horn with reactance annulling at the flare rate frequency and one without that spells the difference between superb and marginal bass response.

ABOUT THE AUTHOR

Dr. Bruce Edgar is a project engineer/scientist at a Los Angeles aerospace company. His interests include horn design, woodworking, and the history of loudspeakers.

Here, I present a simple comprehensive method of designing a hyperbolic-exponential bass horn, combining the best of the Keele and Leach approaches. I have successfully applied it to a number of driver and horn combinations. This approach, using the hyperbolic-exponential horn contour, supersedes my earlier efforts using exponential and tractrix horn contours. The latter make good midrange and tweeter horns but in my experience suffer near the flare cutoff due to throat reactance problems.

DESIGN. The Edgar design method can be outlined as follows:

1. Select a suitable driver.
2. Measure driver F_S, Q_{ES}, and V_{AS}.
3. Calculate the throat area (S_T) and mass cutoff frequency (F_{HM}).
4. Calculate α (V_{AS}/V_B, V_B = back volume).
5. Determine M (hyperbolic-exponential horn parameter) and flare rate.
6. Decide on wall or corner placement and specify mouth area.
7. Calculate area expansion of the horn with linear distance.
8. Work out folding geometry.
9. Experimentally determine the back volume.
10. Integrate bass horn response and SPL sensitivity with the rest of the loudspeaker system.

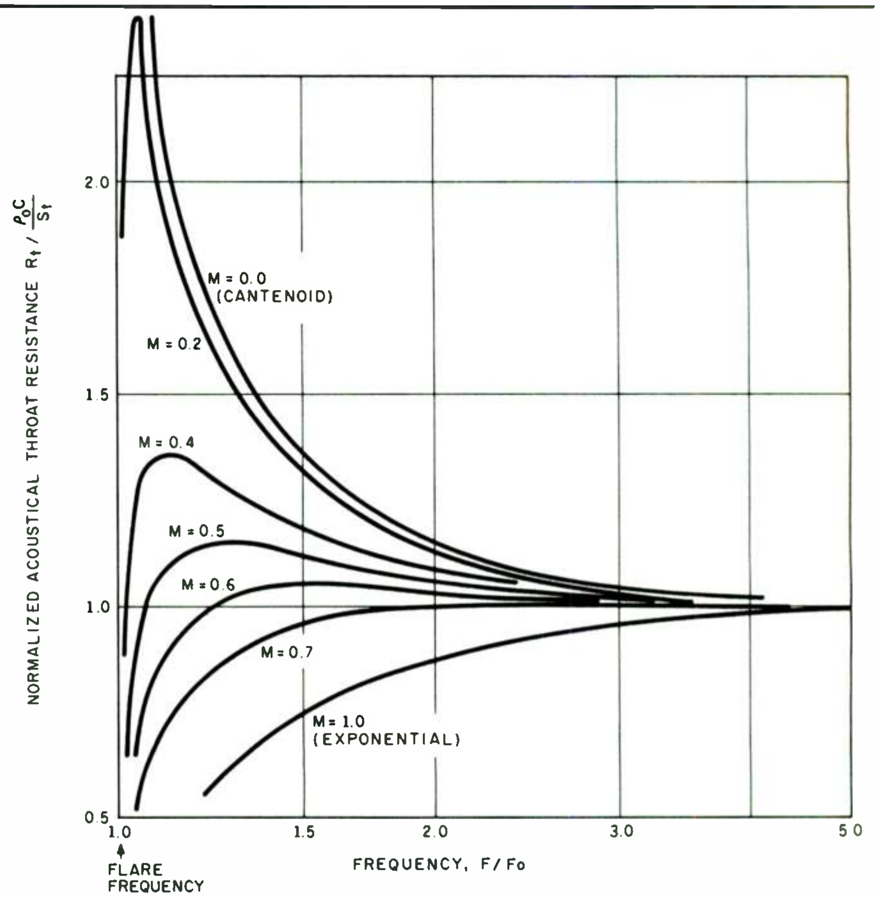

FIGURE 2: Throat resistance for hyperbolic-exponential horns.

SUITABLE DRIVERS. Actually, driver selection is predicated on the lowest desired frequency. With the hyperbolic-exponential horn, the flare rate is usually set close to the driver resonant frequency, F_S, so driver selection and flare rate are somewhat tied together. The old myth that you can take any bass horn design for a 12″ speaker, stick in any good looking 12″ driver, and expect good results is simply not true. I don't mean you shouldn't try other drivers; sometimes through serendipity you find combinations that work unexpectedly well.

For bass horns, we require drivers with relatively high F_S (40–80Hz) and a low Q_{ES} (0.2–0.3). The bandwidth can be specified as being between the flare rate (or F_S) and the mass rolloff frequency, F_{HM}. As derived by Keele,[1] $F_{HM} = 2F_S/Q_{ES}$. For proper mating to a midrange horn, F_{HM} must be above 300Hz, preferably near 500Hz for best results. S_T, the optimum throat area,[1] is defined as:

$$S_T = 2\pi F_S Q_{ES} V_{AS}/c,$$

where c = velocity of sound, or

$$S_T = 0.8 F_S Q_{ES} V_{AS},$$

where S_T is in square inches and V_{AS} is in cubic feet.

In *Table I*, I have listed several 12″ drivers with their given Thiele/Small parameters, SPL sensitivities, throat sizes, and mass rolloff frequencies. The first two Audax *[Polydax in the USA—Ed.]* drivers yield almost the same throat sizes and rolloff frequencies even though their F_S and Q_{ES} vary widely. The throat sizes are comparable to the area of a 12″ driver, but the rolloffs of the Audax drivers are too low to mate to a typical midrange horn. However, you could use them in a subwoofer horn with 1:1 coupling up to 100Hz.

The EVM12L has a throat size a third of that for the Audax drivers, and the rolloff is up in the 400Hz region. The FORCE 12 is a cousin of the EVM12L, but it has a heavier cone and voice coil giving a higher Q_{ES} and consequently a lower rolloff of 250Hz even though both drivers have comparable SPL ratings. The FORCE 12 is marginal for this application.

We can do the same comparison for the JBL 2202H and 2204H drivers. The 2202H has very high rolloff frequency but a very small throat size. The 2204 has a low rolloff but a good throat size. The last driver, the JBL E-120, is similar to the 2202H, with a high rolloff and a small throat. Thus you can observe from these examples, as the mass rolloff frequency goes higher, the throat size be-

TABLE I

PARAMETERS OF CANDIDATE 12″ DRIVERS

DRIVER	F_S	V_{AS} (cu. ft.)	Q_{ES}	EFF (dB)	S_T (sq. in.)	F_{HM}
Audax HD30P	17	25.0	0.27	95	91	126
Audax PR30ST100	40	5.0	0.69	95	110	116
EVM12L	55	3.3	0.25	98	36	440
FORCE 12	55	3.0	0.44	99	58	250
JBL 2202H	50	3.0	0.17	99	20	588
JBL 2204H	45	3.0	0.44	95	48	204
JBL E-120	60	2.8	0.19	103	26	632

comes smaller. The EVM12L seems to be the best compromise between a reasonable throat size and a sufficiently high mass rolloff freqency.

The EV and JBLs in this comparison are professional musical instrument drivers, characterized by very heavy magnets, high (greater than 100dB SPL ratings) sensitivities, moderate resonant frequencies and low Qs. They will produce very high sound levels when mounted in small boxes. However, there will be no response below 100Hz. But when mounted in a properly designed bass horn, you regain the bass response below 100Hz with about 10dB additional sensitivity. Beware of any surplus or other driver advertised as a "musical instrument" driver. While it may be suitable as a direct radiator, using it in a horn may give unsatifactory results. You must still go through the comparison as given in *Table I*.

ALPHA CALCULATION. In Leach's formulation the α parameter (ratio of V_{AS} to the back volume) is calculated from the bandwidth.[2] The bandwidth frequencies are essentially the flare cutoff at the low end and the mass rolloff frequency at the upper end. Leach calls these two frequencies F_L and F_H, respectively. Then alpha is calculated by the formula:

$$\alpha + 1 = F_L F_H / F_S^2$$

Taking the EVM12L parameters from *Table I*, assuming a 50Hz flare frequency, and substituting them into the above formula, we come up with an alpha of 6.2.

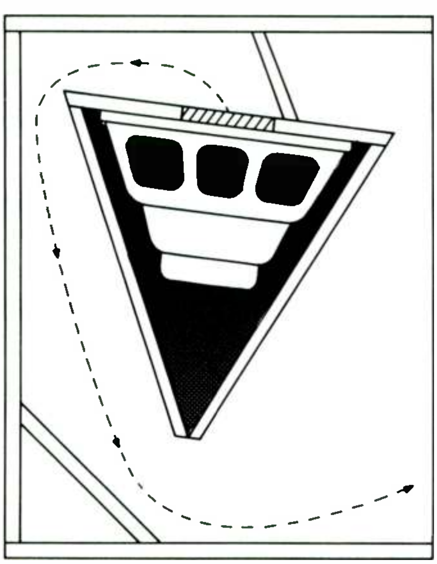

FIGURE 3: University Classic horn folding configuration.

TABLE II

MEASURED EVM12L DRIVER PARAMETERS

DRIVER	F_S	Q_{ES}	V_{AS} (cu. ft.)	F_{HM}	S_T (sq. in.)
1	56.4	0.20	3.30	564	29.9
2	53.2	0.19	3.98	560	26.7
3	55.2	0.21	3.71	525	34.4
4	54.6	0.20	3.76	546	32.9
5	55.0	0.22	3.88	500	37.6
6	52.2	0.23	4.33	453	41.6

M CALCULATION. The hyperbolic-exponential horn formula has a free parameter M that allows reactance annulling at the flare frequency. Leach[4] gives the formula for M as:

$$M = \frac{2\pi F_O V_{AS}}{(\alpha + 1)\, S_T c}$$

where F_O is the flare frequency. This formula makes two assumptions. First, the horn is an infinite hyperbolic-exponential horn. If you don't use this assumption, the mathematics become very messy, and besides, if you take the horn expansion out to the proper mouth size and don't try to foreshorten it, the assumption is fairly good. Second, the formula assumes that the capacitive reactance of the back chamber is exactly cancelled by the inductive throat reactance at the flare frequency, F_O.

Again substituting the EVM12L parameters into the above formula, we obtain a value for M of 0.51. In fact, if you place the flare rate anywhere near the driver resonant frequency, you will always obtain an M of 0.5 with Leach's formulation.

The real part of the throat impedance tells us how the horn should load, given a proper mouth size. R_T, the throat resistance for the infinite horn case, is given by:

$$R_T = \frac{R_{AL}\sqrt{1 - \left(\frac{F_o}{F}\right)^2}}{1 - (1 - M^2)\left(\frac{F_o}{F}\right)^2}$$

where $R_{AL} = \rho c / S_T$, F = frequency, and ρ = density of air. The throat resistance is plotted out in *Fig. 2* for several values of M. M = 1 corresponds to an exponential horn, and M = 0 corresponds to the cantenoid horn. For values of M between 0 and 1, you have a hyperbolic-exponential horn. Notice that for M between 0.5 and 1.0 in *Fig. 2*, you have fairly uniform throat resistance behavior. But for M below 0.5, the throat resistance peaks severely; so avoid values of M below 0.5. For M between 0.5 and 0.6, you can obtain response very close to the flare rate and uniform loading above the flare frequency.

After examining *Fig. 2*, I decided an M of 0.5 might have a slightly peaky bass character and 0.6 would sound better. However, such a change in M would violate the alpha calculation in Step 4. But after reviewing Leach's assumptions for his alpha formula, I'm not sure it exactly applies to a horn design. In any case, you may also regard alpha as an independent variable. I will clarify the matter in Step 9.

HORN PLACEMENT. When most builders think about a bass horn, they almost immediately think of a corner horn, *a la* Klipsch. The corner horn offers distinct advantages over other placements. For example, it allows a mouth size one eighth of what it would be in free space. The smaller mouth means a shorter horn length and overall smaller size. The one disadvantage of a corner horn is that few people have free corners for horn placement, and usually those corners are too widely spaced. (See the Klipsch interview, *SB* 3/89, for Paul's solution to this problem.)

Thus, for reasons of simplicity, I chose

Continued on page 14

TABLE III

AREA EXPANSION FOR THE 50Hz M = 0.6 HORN

x (in.)	A (sq. in.)
0	40.0
4	45.0
8	51.0
12	58.4
16	67.3
20	78.2
24	91.2
28	107.1
32	126.2
36	149.2
40	176.8
44	210.0
48	250.0
52	298.9
56	357.0
60	427.1
64	511.7
68	610.3
72	735.9

Continued from page 12
for this initial work a one-eighth-size corner horn design. For a free space horn with a circular mouth, the proper mouth size is one whose circumference is equal to a wavelength (c/F_O) at the flare frequency, F_O. Thus, if r is the radius, this condition may be expressed as:

$$2\pi r = c/F_O.$$

The area for the free space horn is:

$$A = \pi r^2, \text{ or}$$

$$A = \frac{1}{4\pi}\left(\frac{c}{F_o}\right)^2$$

The mouth area, S_M, for a one-eighth-size horn is:

$$S_M = \frac{1}{32\pi}\left(\frac{c}{F_o}\right)^2$$

For a one-eighth-size 50Hz horn, S_M is 725 square inches, assuming a speed of sound (c) of 13,500 inches per second.

DRIVER VARIATIONS. When you try to generate a speaker design, it pays to look at a number of drivers to check the production tolerances. *Table II* lists the measured Thiele/Small parameters and calculated mass rolloff frequencies and throat sizes of six EVM12L drivers. As you can see, the resonant frequencies are fairly close to the spec of 55Hz, but the Qs are much lower, which gives mass rolloff frequencies which are mostly higher than 500Hz. A large variation in the V_{AS} between drivers gives a corresponding wide variation in the calculated throat sizes. I decided to use drivers 5 and 6 and to use a common throat size (S_T) of 40 square inches.

HORN EXPANSION CURVE. The hyperbolic-exponential horn curve is given by the following equation:

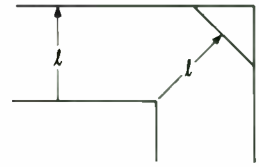

FIGURE 4: Radius corner reflector.

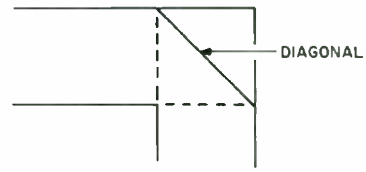

FIGURE 5: Diagonal corner reflector.

$$S = S_T\left(\text{COSH}\frac{X}{X_o} + \text{MSINH}\frac{X}{X_O}\right)^2$$

where:

$X_O = c/2\pi F_O$
S = cross-sectional area
X = linear distance along the horn
COSH = hyperbolic cosine function
SINH = hyperbolic sine function

A simpler alternative form is:

$$S = \frac{S_T}{4}\left((1 + M)e^{X/X_o} + (1 - M)e^{-X/X_o}\right)^2$$

which is easily programmed on a computer or a hand calculator. The horn expansion is listed in *Table III* for the case of F_O = 50Hz, M = 0.6, S_T = 40 square inches, and S_M = 725 square inches. These parameters give alphas of 5.5 and 6.25 and calculated back volumes of 1,227 and 1,197 cubic inches for drivers 5 and 6, respectively.

FOLDING GEOMETRY. George Augspurger once remarked in one of his patent reviews, "Of a thousand ways of folding a horn, this is one of them." He was implying there are a great many ways to fold a bass horn, and unfortunately, most are wrong from a wide bandwidth viewpoint. Most designers in the past were forced by economics and marketing to engineer the most compact volume for a given horn. But this design philosophy will give you many 180° turns which tend to roll off the response above 300Hz. If you have a driver with a mass rolloff of 300Hz, 180° bends in the horn are not a bad choice. However, if the mass rolloff frequency is above
Continued on page 16

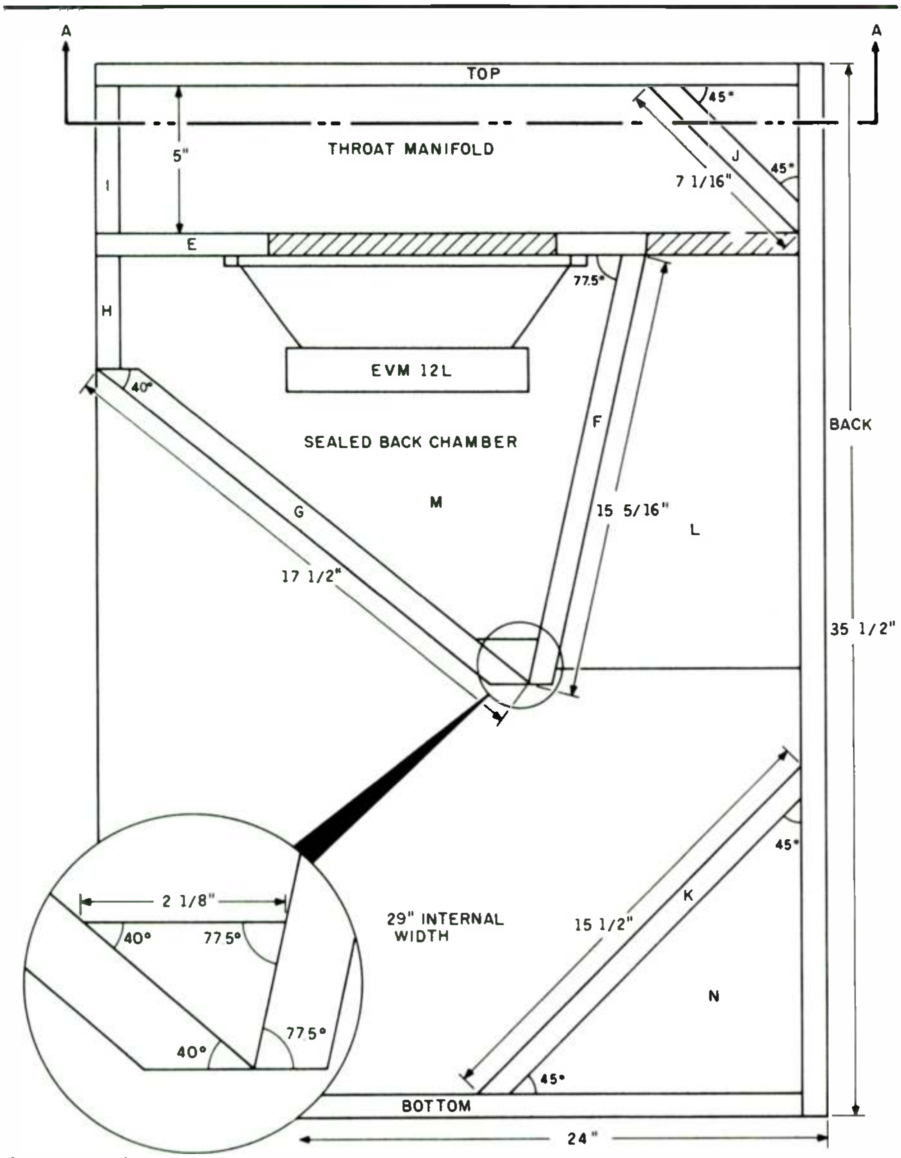

FIGURE 6: Side view of the 50Hz horn.

The Swan 305 Woofer

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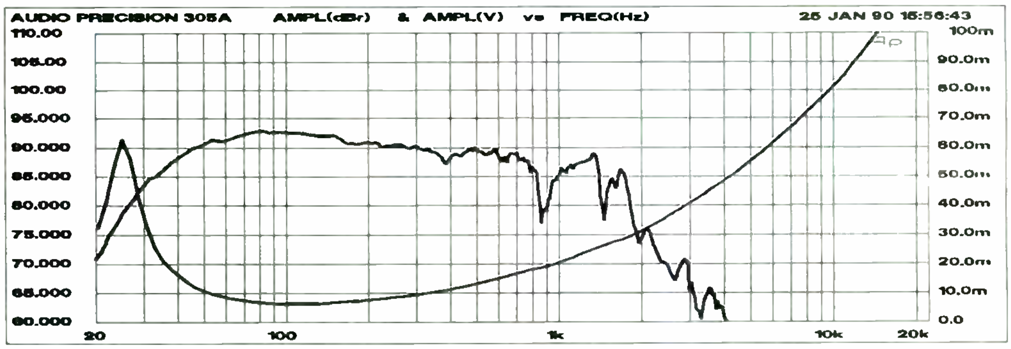

Swan 305 Specifications	
Fs	24.53
Mmd	111 Grams
Cms	380 m/n
Vas	167 Liters
Rscc	5.2 Ω
Zmin	6.3 Ω
Zmax	63 Ω
vcL	2.4mh @ 1K
Bl	16.05 Tm
Qms	3.66
Qes	.344
Qts	.314
Xmax	7.3 mm Peak
VD	408 cm^3
Surround	Foam
Magnet	40 oz.
Voice Coil	2 Inch
Power Handling	200 watts
Freq. Response	30—1500 Hz
Efficiency	90 db 1w/1m
Uses	Home Hi-Fi, Auto
Price	$50.00

	Swan 305 Suggested Alignments			
Box Volume	56 Liter	70 Liter	85 Liter	100 Liter
Bass ½ Power F3	39 Hz	35 Hz	33 Hz	31 Hz
Box Vent Freq. Fb	34 Hz	31 Hz	32 Hz	31 Hz
Port Diameter Inches	3	3	3	3
Port Length Inches	6.15	5.85	4.0	3.43

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Continued from page 14
500Hz, as in the EVM12L driver, it would be wise to keep the number of 180° folds to a bare minimum.

Is there a right way to fold a horn for wide bandwidth? Yes, if you use only 90° folds. The best example of this design criterion is Abraham Cohen's old University Classic horn design introduced in 1956[7] (*Fig. 3*). Unfortunately, Cohen had to use a 15″ driver with a mass rolloff below 300Hz, so his beautiful folding geometry went for naught.

Another consideration is the design of the corner reflector in a 90° bend. In previous horn designs, I had approximated the corner reflector position to be tangent to the arc of the radius (*Fig. 4*). But subsequent wave front calculations showed that the corner reflector should be aligned along the diagonal (*Fig. 5*). For reasons I will not discuss here, a wave front will remain intact going through a 90° bend if the corner reflector is aligned along the diagonal, but it will be distorted if the reflector is smaller.

50Hz HORN DESIGN. *Figures 6* and *7*, are the sectional views of the bass horn. As you can see, I tried to use the University Classic folding geometry as much as I could in *Fig. 4*. But because a hyperbolic-exponential horn is quite long, I had to compromise with a quasi-180° bend to fit all the throat manifold in the enclosure. Another compromise was the shortening of the horn from 72 to 70 inches because the folding worked out better. But I'm not sure how and where these compromises affect the overall response. The parts are shown in *Fig. 8* with a gross dimensions list in *Table IV*. You can cut out one bass horn from two 4 by 8′ sheets of ¾″ plywood. I used a good grade birch that was fairly void free. At the lumberyard where I buy my plywood, I paid a mill charge to have them make the coarse width cuts of 29 and 24″. I made the rest of the cuts on my table saw. *Figure 9* is a cutout diagram. You can make the horn out of

Continued on page 18

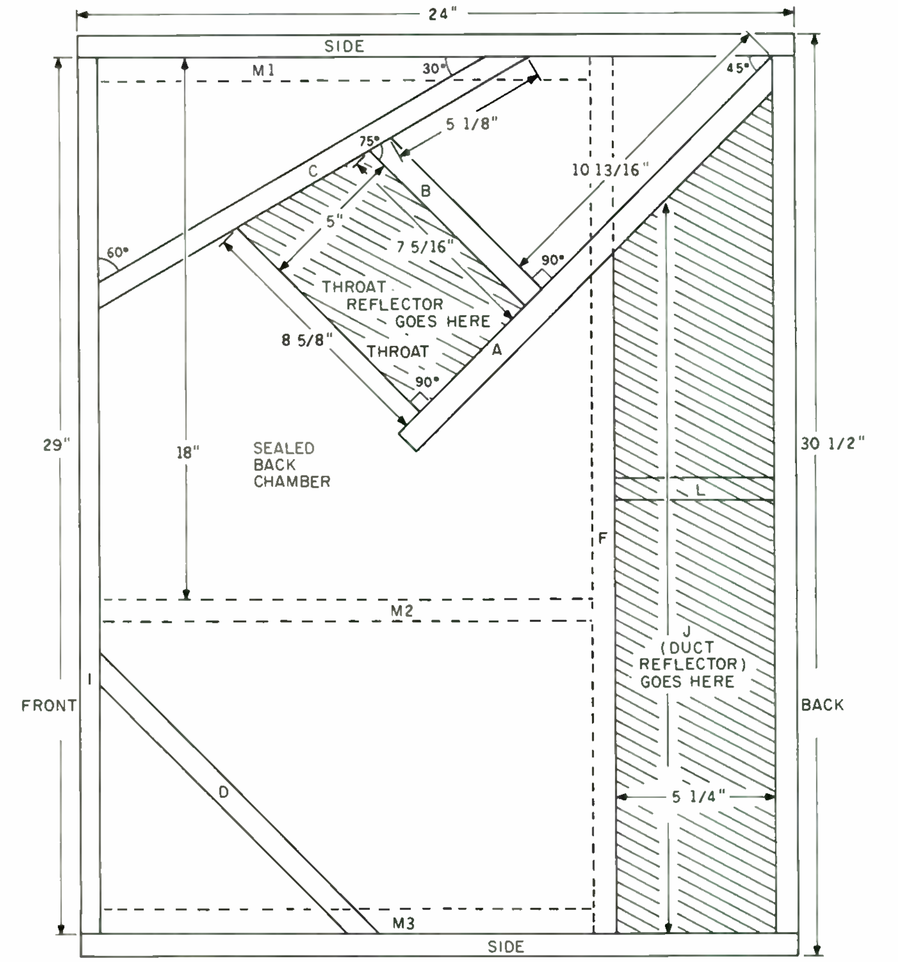


FIGURE 7: Top view of the throat manifold.


PHOTO 2: Attaching the pattern to part M.

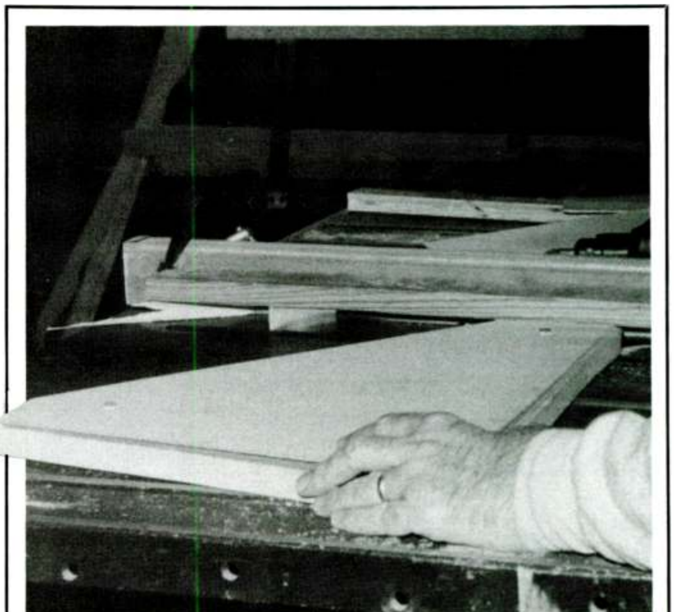
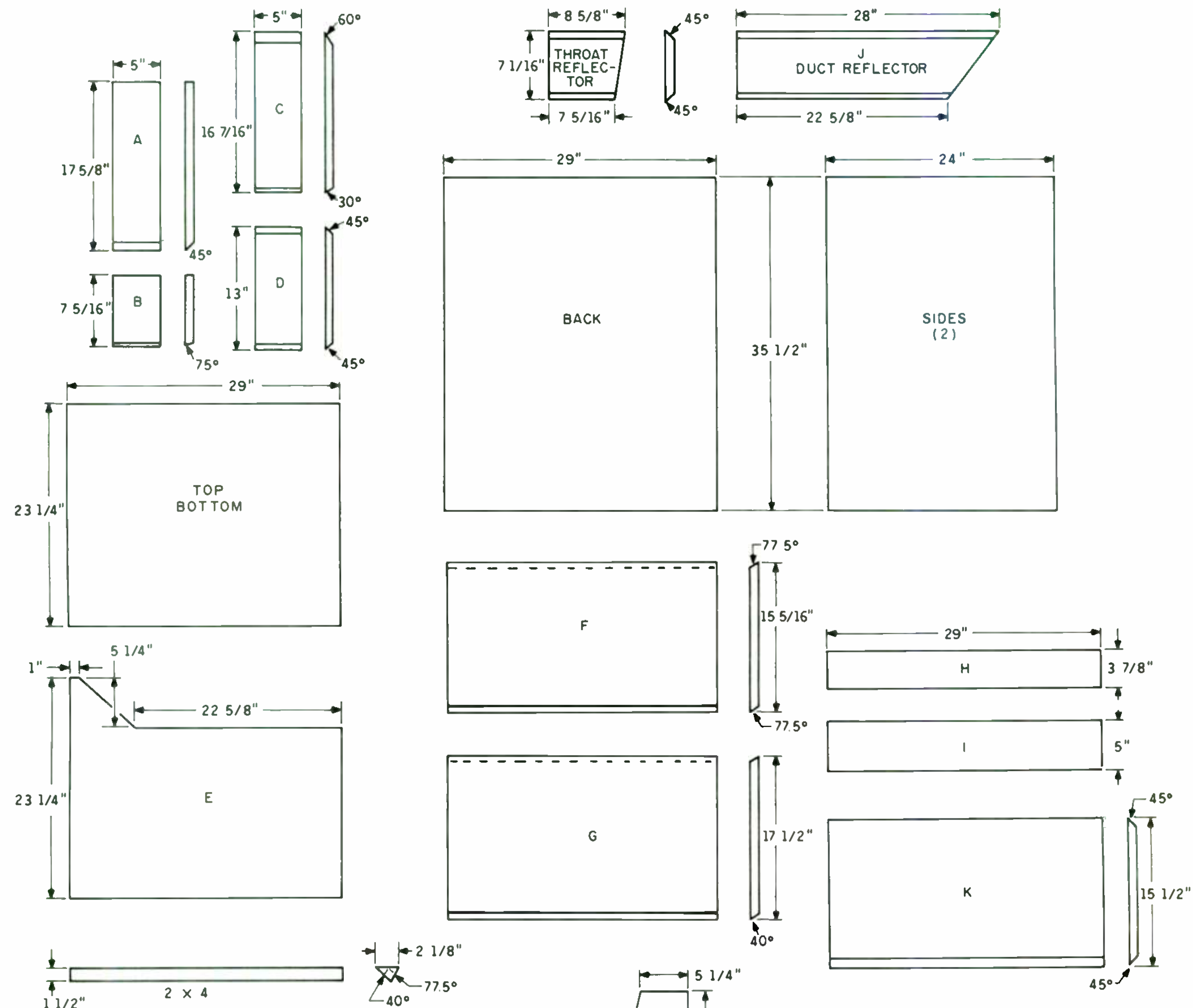


PHOTO 3: Using a feeler gauge for pattern sawing.



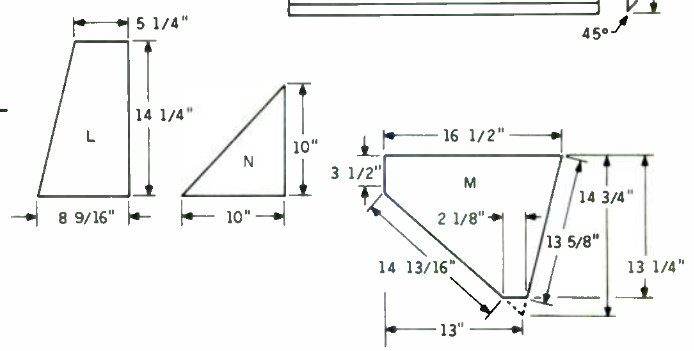


FIGURE 8: 50Hz horn parts description.

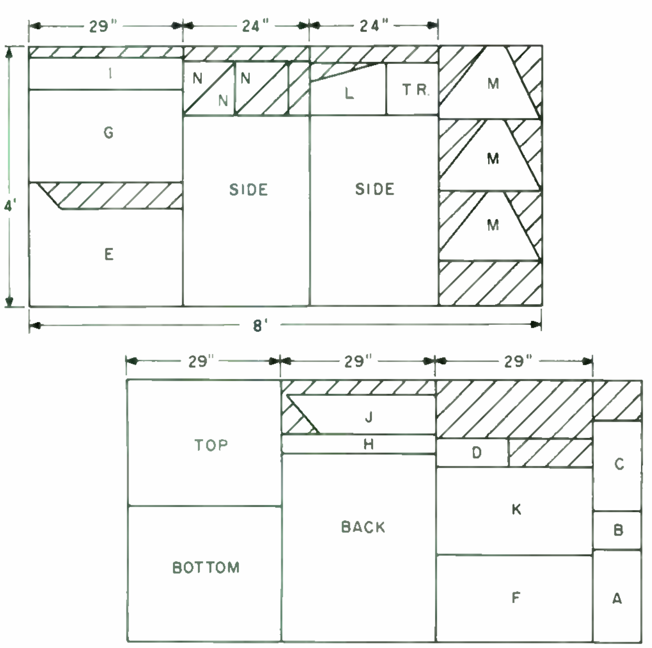


FIGURE 9: Sawing guide for ¾″ plywood.

TABLE IV

PARTS LIST AND DIMENSIONS

PART	SIZE	PART	SIZE
A	5″ x 17⅝″	K	29″ x 15½″
B	5″ x 7⁵⁄₁₆″	L	14¼″ x 8⁹⁄₁₆″
C	5″ x 16⁷⁄₁₆″	M(3)	16½″ x 13¼″
D	5″ x 13″	N(3)	10″ x 10″
E	29″ x 23¼″	Top, Bottom	29″ x 23¼″
F	29″ x 15⁵⁄₁₆″	Back	29″ x 35½″
G	29″ x 17½″	Sides(2)	24″ x 35½″
H	29″ x 3⅞″	Throat reflector	7¹⁄₁₆″ x 8⅝″
I	29″ x 5″		
J	28″ x 7¹⁄₁₆″		

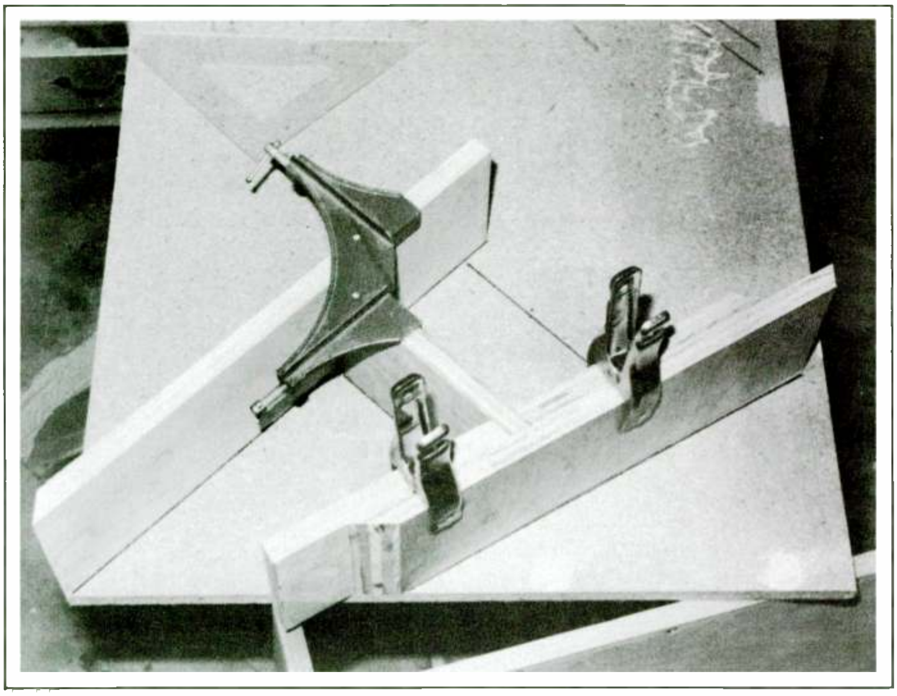


PHOTO 4: Aligning parts A, B and C on the top board.

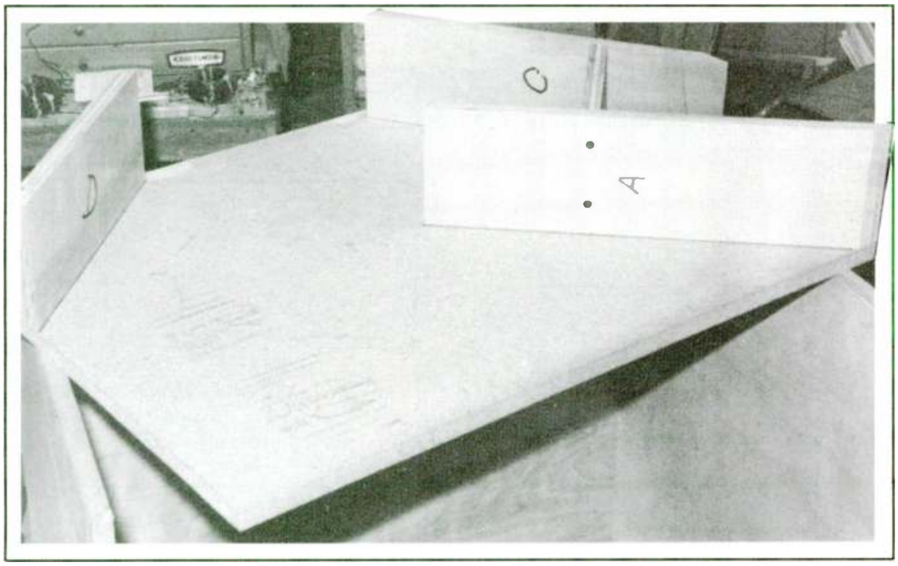


PHOTO 5: Parts A, B, C and D on the underside of the top board.

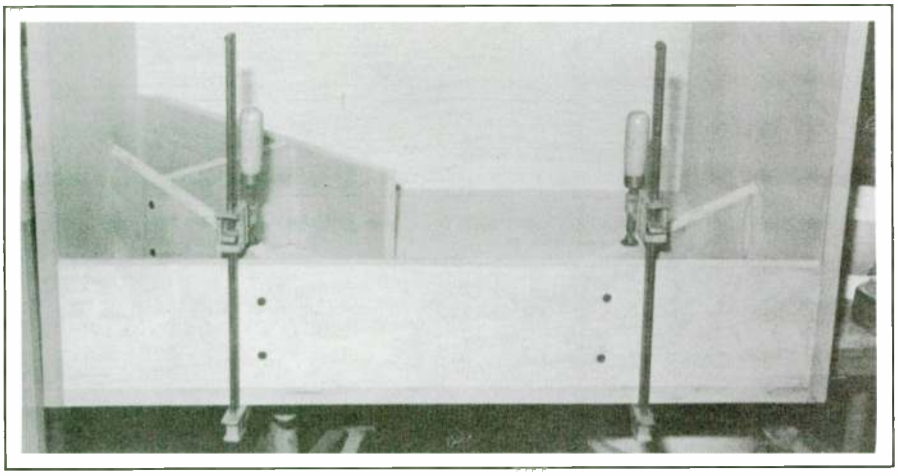


PHOTO 6: Fitting in piece I.

Continued from page 16

heavier particle board, but I chose the lighter plywood to make it easier to bring to the Stereophile Show.

As you can see from *Figs. 6* and *7*, most of the joints are butt type. I used hardened furniture screws and a cordless power screwdriver (*SB* 1/89) to join most of the pieces. Glue and nails will work just as well, but screws allow you to disassemble a part to change a partition. For exposed plywood edges, I glued a strip of solid birch to the edge and recut the board to the original size.

To aid in assembly and lining up the parts, I plotted *Figs. 6* and *7* to full scale on inch-scale transparent engineering graph paper. This procedure allows checking of parts dimensions and angles. I traced the critical angles, glued the tracings to poster board and cut the angles out with a sharp knife. These templates became my angle guides for setting up the saw.

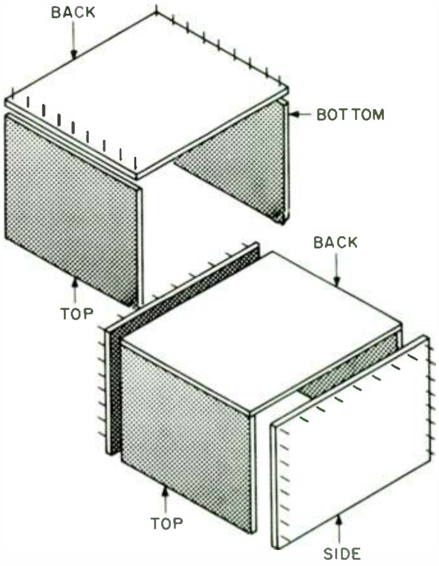


FIGURE 10: Attaching the back to the top and bottom, and attaching the sides to complete the box.

For parts such as pieces M and N, I also made templates for pattern sawing. I screwed these templates to boards cut just larger than the exact dimensions (*Photo 2*). I mounted a feeler gauge board to the saw fence and set it up so its vertical edge lined up exactly with the saw blade edge on the left side. I aligned the lower edge of the feeler gauge so it would index against the template but just clear the top of the board (*Photo 3*). To cut out the piece, I ran the template/board through the saw on one side, rotated the piece to the next cut, repeated the process, and so on. If you have the feeler gauge set up well, you

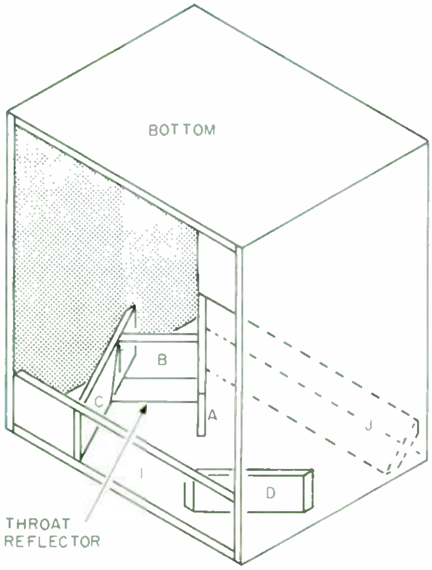


FIGURE 11: Fitting in the corner reflectors.

can reproduce the same part as many times as required.

HORN ASSEMBLY. Using a template based on *Fig. 7*, draw off the alignment lines for parts A, B, C and D on the top piece. Then attach parts A, B, C and D to the underside of the top piece (*Photos 5* and *6*). For this procedure, it helps to have a variety of clamps. Attach the top, bottom, back and side pieces together (*Figs. 10*). Using clamps as demonstrated in *Photo 6*, fit part I in the front. Avoid gaps between the top piece and part I.

Now you do some cut-to-fit operations. As shown in *Fig. 11*, the throat reflector and part J each require cutting a compound angle on one side. Because accuracy in parts cutting and assembly vary from builder to builder, I did not specify the exact dimensions of the two corner reflectors. Take some scrap stock and cut a length with the same cross section as part J and the throat reflector. Then try some approximate cuts on short sections of the scrap stock and check the fit as shown in *Photo 7*. If you get the fit somewhat close but there are still gaps, use Mortite or other caulking material to fill in the gaps.

Use the top template to transfer the throat opening position and placement of parts A, B, C and D onto part E. Cut out the throat opening with a saber saw. Fit part E into position and attach to parts A, B, C and D and to the sides and the back. After this step, the box should look like *Fig. 12*.

Next comes the back chamber assembly. First, attach parts F and H to the three M pieces with glue and screws/nails because the back chamber has to

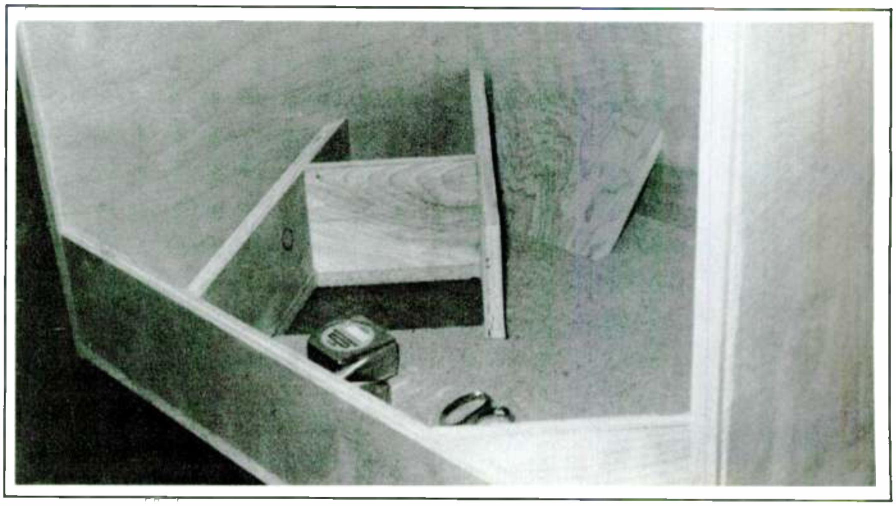


PHOTO 7: Trying a trial compound angle for the corner reflector J. Note: The throat opening, shown cut on a temporary top piece, is for experimentation purposes.

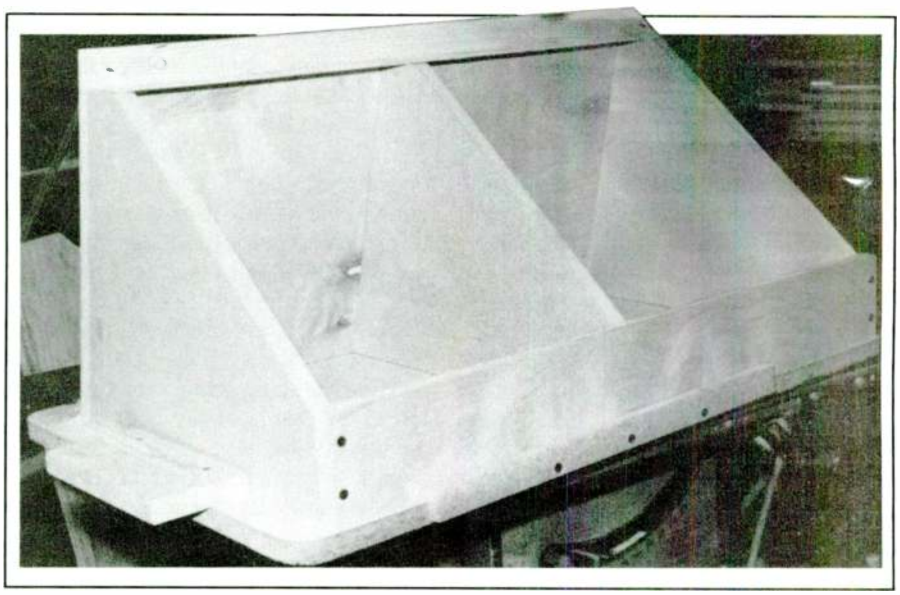


PHOTO 8: Back chamber assembly on a jig.

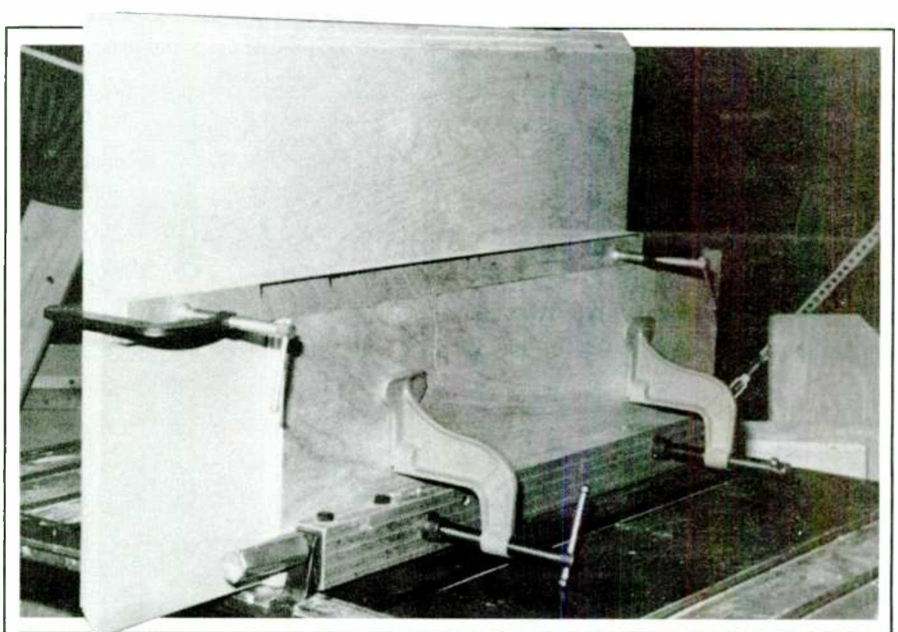


PHOTO 9: Auxiliary fence for table saw to aid cutting part G.

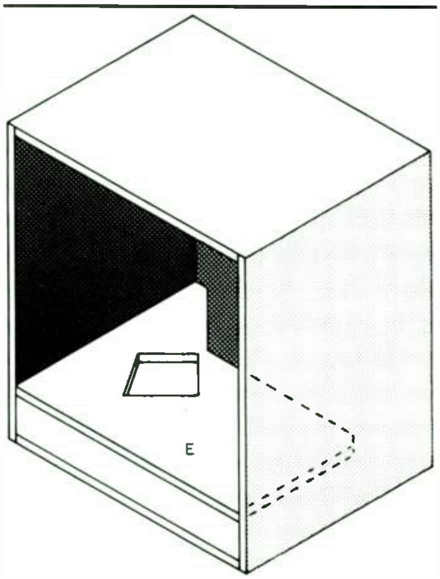


FIGURE 12: Part E in place.

PHOTO 10: Finished back chamber with speaker mounting board.

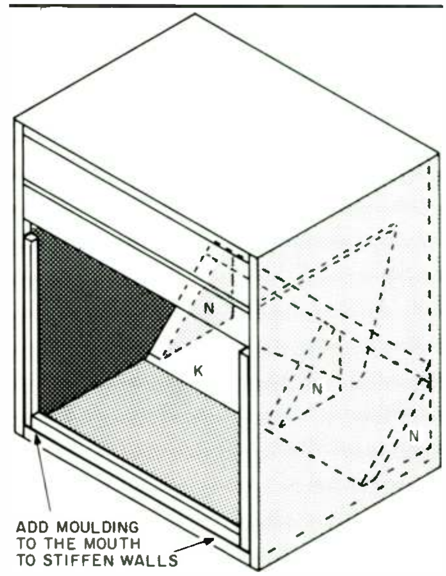


FIGURE 14: Installing the K corner reflector.

be sealed. Then attach the beveled 2 by 4 to the top of the M pieces and to part F. It helps to build a jig (*Photo 8*) to keep all the parts properly aligned. It is especially hard to cut the 40° angles on part G because you must keep the board vertical on the table saw. To solve the problem, I made an auxiliary fence (*Photo 9*) clamped to the regular fence with hold-down clamps made by Pony. I clamped a straight 1 by 1 piece to part G, allowing it to ride on top of the auxiliary fence in a level fashion. Check to see if part G fits properly but don't mount it. Attach divider piece L to F with screws.

You are now ready to install the back chamber assembly. Slide in the assembly to check on fit as shown in *Fig 13*. Draw lines on part E where it contacts the back chamber. Lift up the assembly so you can spread glue on those contact areas. Slide the assembly back in and attach it to E with corner L brackets. Make sure the divider (part L) is flush against the back. Attach the divider to the back with screws. Screw parts M1 and M3 to the side pieces.

Next take some scrap 1 by 1 stock and frame the inside of the back chamber, making a slight inset while mounting the pieces for a foam tape gasket. I recommend drilling a 2″ diameter hole through the side piece and M1 for a banana connector cup. As an optional procedure I also made a board with an 11″ diameter cutout to mount the driver (*Photo 10*). Also fill the extra cavity with fiberglass to prevent any extra resonance problems. Part G is now ready for mounting with screws. Make sure you have a sufficient number of screws around the foam gasket.

Turn the box over and install the K corner reflector (*Fig. 14*). I used the triangular pieces N to help the proper alignment and stiffen the reflector. As you can see in *Photo 1*, I framed the mouth with

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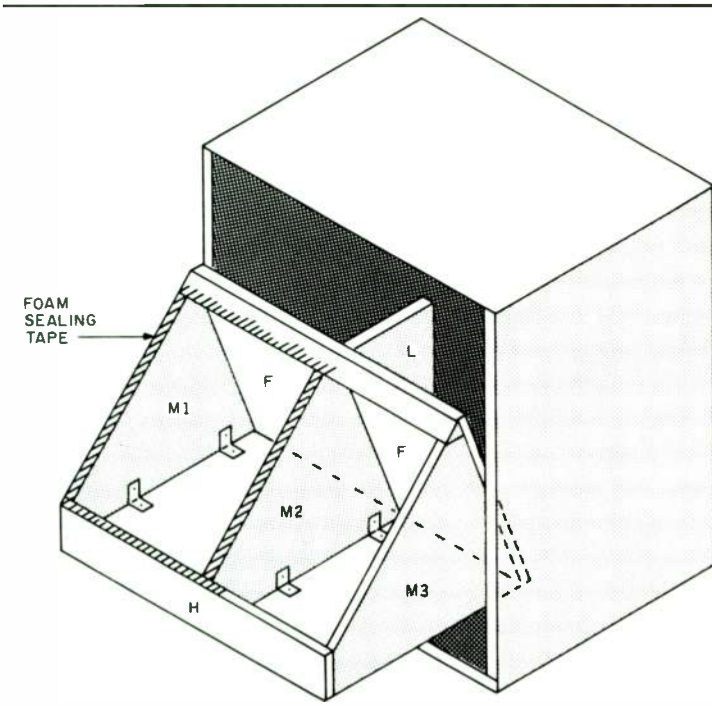

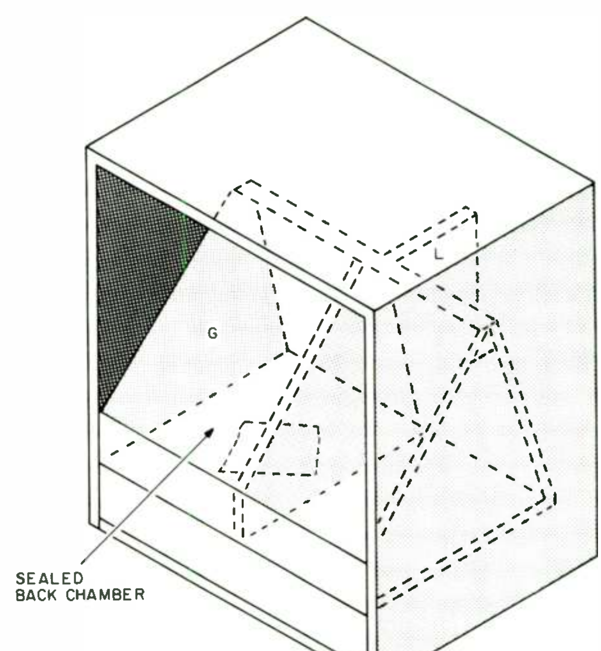

FIGURE 13: Installing the back chamber assembly.

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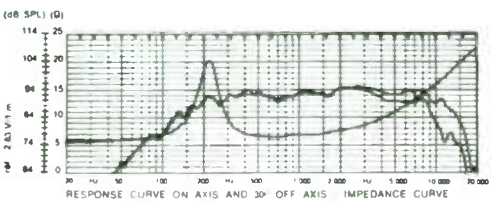
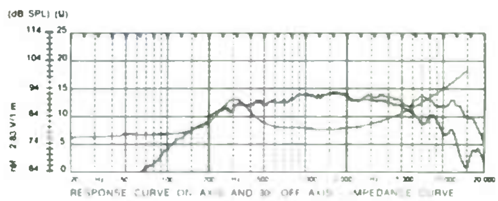


210	f_S (Hz.)	300
0.68	Q_{TS}	1.05
0.62	V_{AS} (1.)	0.30
93.6	Sensitivity	93.6



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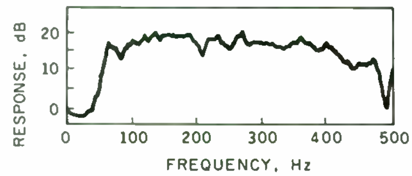


FIGURE 15: Response of the 50Hz horn against a wall.

Continued from page 20

some 1 by 2 birch stock, leaving a gap at the top to slide part G in and out.

STEP 9. You might wonder how I determined the back chamber volume. When I constructed the first prototype, I made an identical top piece from particle board and cut the throat opening in it (*Photo 9*). I didn't cut the throat in part E until later. Then I mounted the EVM12L driver on top and fitted several trial back volume boxes until I found one that resonated at 50Hz. *Photo 11* shows the test setup. I determined the test volume to be 2,644 cubic inches including driver volume, about twice the calculated volume. The reason for the discrepancy is our formula was derived for an infinite horn and this model is a one-eighth size. For quarter-size horns that I have built, the experimental back volume approaches the theoretical value.

Photo 12 shows the EVM12L driver installed in the back chamber. After installation attach part G to the back chamber with screws and measure the system resonance. It should be about 50Hz. If it is higher by a few Hz, put more stuffing in. But the stuffing will lower the resonance by only a few Hz. Normally I tack a layer of fiberglass to the back of part G just to damp the panel and cut down any back radiation. If the resonance is too low by a few Hz, the volume is too large. Reduce the volume experimentally by putting polyethylene bottles filled with water in the back chamber. When the system resonance is raised enough, approximate the volume of the bottles with blocks of wood attached to the sides of the back chamber. If the system resonance is very low, say 35Hz, you have a serious air leak in the back chamber. Go back and recaulk any suspicious voids along the joints.

STEP 10. Many builders have arrived at the system integration step and faltered because many of the normal speaker building rules of thumb don't apply to horn systems due to their high efficiencies and bandpass characteristics. Depending on the location of the horn in relation to corners and walls, you can obtain a 3 or more dB variation in apparent sensitivity. Normally, in a corner you will measure almost 110dB SPL sensitivity.

Pull the horn away from the corner but still against a wall, and the sensitivity will go down 3dB. You can get good bass response with a wall position (*Fig. 15*), and in many situations a wall position may be the only solution. But the bass will sound deeper with a corner position. Try another variation: turn the horn on its side to see whether the response sounds better. A hand-held pink noise analyzer, such as the Audiosource RTA (*SB* 4/86), will help sort out the sensitivity levels.

Most midrange horns I build (*SB* 1/86) have sensitivities between 100 and 105dB, so to integrate the bass horn with these midranges you must either attenuate or biamp. I have had reasonable success with L-pads made from high power sand-filled fixed resistors. My limited attempts to biamp have resulted in degraded sound quality. However, readers are invited to experiment with biamping and report their results to *SB*.

Because horns have steep mechanical rolloffs in their responses, they are bandpass loudspeakers. Horns trade off wide band response and lower efficiency for narrow band response and high efficiency. The steep mechanical rolloffs also produce many 360° phase rotations that make it almost impossible for higher order passive crossovers to function properly. But the simple 6dB crossover at 400Hz works nicely between a bass and midrange horn as found by Klipsch many years ago (Klipsch interview, *SB* 4/89).

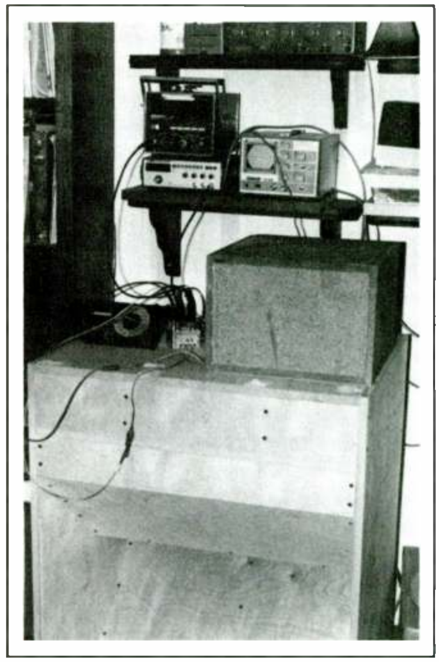


PHOTO 11: Experimentally determining the back chamber volume.

RESULTS. As shown in *Fig. 15*, the response as measured against a wall is quite flat between 60 and 400Hz within ±3dB. Unfortunately I was not able to move our furniture away from the corners to make a corner measurement. But take my word, the response goes deeper in a corner. I measured the reponse with a Spectrum Dynamics FFT analyzer operating in an averaging mode with white noise input to the speaker. The absence

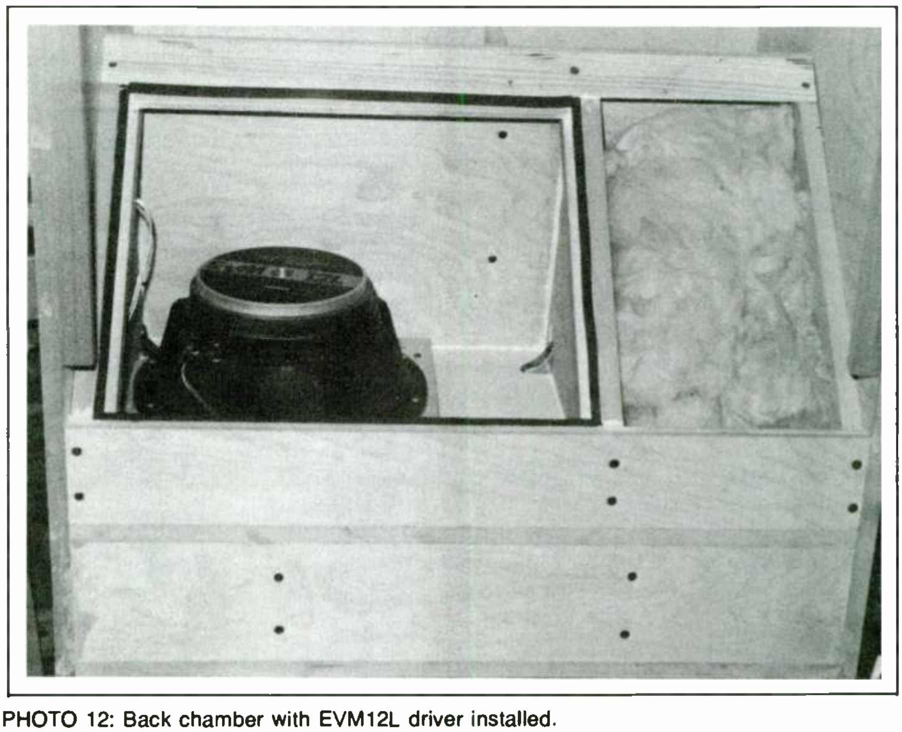


PHOTO 12: Back chamber with EVM12L driver installed.

of any major spectrum anomaly indicates that the horn folding design was done properly.

The bass response sounds tight and smooth. The large bass drum on the Telarc recordings (Holst: *Suites for Winds* CD-80038 and Prokofiev: *Alexander Nevsky* CD-80143) has real impact and character. The Sheffield recording of the *Firebird Suite* by Stravinsky (CD-24) also has physical impact. However, depending on how the recording was miked, on other recordings the bass may sound hollow since most of the frequency components are below the sharp lower horn cutoff of 50Hz.

The bass is only half the story. Most of an orchestra's large brass, woodwind, and string instruments have fundamentals in the 100-400Hz region. This bass horn makes those instruments sound real, as one friend told me. All you need do is put on a good recording of Dvorak's *Serenade for Winds* to be convinced.

CONCLUSIONS. As you can see, I've come a long way from my initial horn articles in *SB* (3/80 and 2/83). This project is a culmination of a number of experimental horns where I made mistakes in design and found out how to correct them. In this article I have given the reader a road map that can be applied to any bass horn loudspeaker. The 50Hz horn project is complicated but well within reach of any competent woodworker with a table saw. Those who attempt and finish the project will be rewarded with a unique loudspeaker presently unobtainable on the commercial market.

ACKNOWLEDGMENTS. I thank Rich Roberts for untiring assistance during the horn building and for most of the photos, Manfred Buechler for *Photo 1*, Effrain Gonzales for financing the project, Vincent Salmon and Ed McClain for technical discussions on horn design, and Larry Hitch of Madisound and Ed Dell for the opportunity to display the Show Horn at the Stereophile Show.

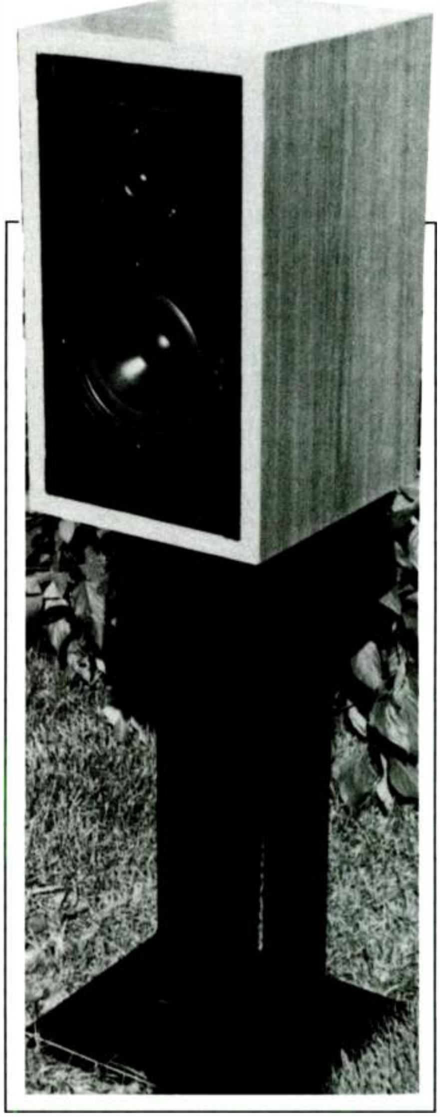
REFERENCES

1. Keele, D. B., "Low Frequency Horn De-

Continued on page 75

A SMALL TWO-WAY SYSTEM

BY FRED THOMPSON



I have been interested in loudspeaker design and construction for about ten years, during which I have built or modified a number of systems. My most recent project is a pair of relatively small (17″ x 11″ x 10″) two-way acoustic suspension designs. My goal was compact speakers with good imaging. I wanted them to reproduce midrange and treble with good resolution and accuracy. The enclosure needed to be well damped so it would be free of boxy colorations. Low bass extension was not essential, since I planned to use them with a separate subwoofer.

I designed the system with a low Q_{TC} of about 0.7, resulting in very good transient response and detail in the bass and mid-bass region. I also wanted to keep the cost of these speakers fairly low without sacrificing too much sound quality. Therefore, I selected drivers that offered very good performance and quality construction without the high price.

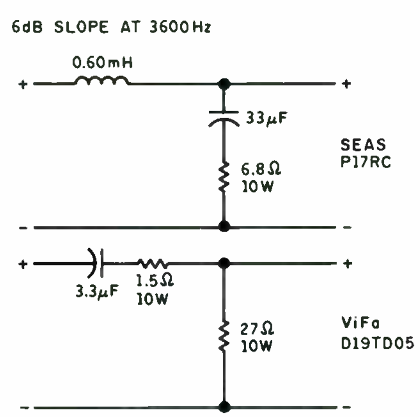


FIGURE 1: Crossover network.

DRIVERS. For the tweeter I chose the Vifa D19TD-05 ¾″ soft dome unit, for a number of reasons. I have heard it in many commercial designs and like the way it sounds. It's fairly smooth with good detail and excellent dispersion. Because the magnet gap is filled with ferrofluid, resonances are well controlled. This allows for the use of a simple crossover network. Another big advantage is its low price.

For the woofer I decided to use the 6½″ SEAS P17RC, a well built unit with a cast magnesium basket, polypropylene cone and PVC surround. It suits my design perfectly as it has been optimized for use in a small closed box with a Q_{TS} of 0.33, a V_{AS} of 36 liters and an F_S of 37Hz.

CROSSOVER. The crossover (*Fig. 1*) is a computer optimized first-order network, utilizing high quality parts. All the capacitors are Solen Chateauroux polypropylene types. The inductors are Solen perfect lay windings. The tweeter section has an attenuation circuit to drop its output level, so it matches that of the woofer. I used a Zobel on the woofer for impedance equalization. The Zobel network also works in conjunction with the inductor to smooth out the rise in frequency at the upper end of the woofer's response. I separated the high- and low-pass sections, giving each its own input terminals, which allows them to be used in a biwire configuration. I made all internal connections with high quality, audiophile grade wire.

BOX CONSTRUCTION. To ensure good damping, I used high density fiberboard. With great care, I made sure the box was completely airtight. The side panels have sand-filled compartments covering about 75% of their interior surfaces. This technique[1] works extremely well for deadening panel resonances. To reduce vibration even further, I installed a sturdy cross brace from side to side. I stiffened the front baffle by making part of it double thick. Lining five interior surfaces with acoustic foam helped lessen internal standing waves.

I loosely stuffed the inside cavity with Dacron. For the exterior finish, I veneered the cabinets in light natural oak.

Continued on page 75

ABOUT THE AUTHOR

Fred Thompson is 27, married, and has been interested in sound reproduction and electronics for many years. He has worked as an audio salesman as well as a car stereo installer and is currently employed by a large audio/video retail store.

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A HELMHOLTZ SPREADSHEET

BY CARL E. RICHARD

I have recently developed a spreadsheet to perform a number of useful variations on the basic Helmholtz vent length formula given by Vance Dickason in his *Loudspeaker Design Cookbook*.[1] I did this because I wanted to look at the interaction between the four variables that make up the following basic equation:

$$L_V = \frac{1.463 \times 10^7 \times r^2}{V_B \times F_B^2} - 1.463r \qquad (1)$$

where:

- r = vent radius (inches)
- V_B = box volume (cubic inches)
- F_B = vent tuning or resonant frequency (Hz)
- L_V = vent length (inches)

```
FIND VENT LENGTH
KNOWING:
RESONANT FREQ. (Hz)
BOX VOLUME (CU.INS.)
VENT DIA. (INS)
************************
INPUT:
RES. FREQUENCY  =     93
BOX VOLUME      =    622
VENT DIAMETER   =      3
************************
OUTPUT:
VENT LENGTH     =    3.9
```

FIGURE 1: Vent length calculation.

I was in the process of designing a Margerand symmetrical bandpass subwoofer[2,3] and wanted to see how changes in some of the Helmholtz parameters would affect the alignment. The way the formula is arranged, the calculations soon became very tedious with my hand-held calculator. Previous *SB* articles on spreadsheet calculations[4,5] have shown the advantage of being able to look at all the variables at one time, which is exactly what I wanted to do.

My spreadsheet is divided into four basic calculation boxes. The first box (*Fig. 1*) does a straightforward vent length calculation and uses equation (1). The upper part of the box requires you to input the desired resonant frequency, box volume and vent diameter. Once you've done this, the vent length is displayed upon completion of the calculation command, which can be either manual or automatic.

```
FIND REASONANT FREQ.
KNOWING:
VENT LENGTH (INS.)
BOX VOL. (CU. INS.)
VENT DIA. (INS.)
**************************
INPUT:
VENT LENGTH    =    3.9
BOX VOLUME     =    622
VENT DIAMETER  =      3
**************************
OUTPUT:
RES. FREQUENCY =     93
```

FIGURE 2: Finding resonant frequency.

The second calculation box (*Fig. 2*) determines the resonant frequency after you input the vent length, box volume and vent diameter. This box is particularly useful if you have the volume fixed and want to play with the vent size to see the effect on resonant frequency. It uses the following algebraic rearrangement of equation (1):

$$F_B = \sqrt{\frac{1.463 \times 10^7 \times r^2}{V_B\,(L_V + 1.463r)}} \qquad (2)$$

The third and perhaps least useful calculation box (*Fig. 3*) finds the box volume if you input the vent length, vent diameter and resonant frequency. Obviously, box volume calculations must be based on driver parameters, not vent parameters. However, you may someday acquire a vented loudspeaker and want to ascertain the internal volume without

```
FIND BOX VOLUME
KNOWING:
VENT LENGTH (INS.)
RES. FREQUENCY (Hz)
VENT DIA. (INS.)
************************
INPUT:
VENT LENGTH       3.9
RES. FREQUE        93
VENT DIAMET         3
************************
OUTPUT:
BOX VOLUME        624
```

FIGURE 3: Finding box volume.

taking it apart. You can start by simply measuring the vent length and diameter with a carpenter's rule. Then find the resonant port frequency using a function generator and a VOM as discussed in previous *SB* articles and explained in reference 1. You can then find the box

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ABOUT THE AUTHOR

Carl Richard is a group leader in the R&D department of the Dexter Nonwovens Division of Dexter Corporation. He received a BS from Western New England College and an AS from Springfield Technical Community College. He is a member of the Connecticut Audio Society and an associate member of Sigma Xi. He became hooked on loudspeaker design and construction after reading David Weems's book on the subject.

EVALUATE VENT SIZE FOR A RANGE OF RESONANT FREQUENCIES

(single and dual vents) Lv= VENT LENGTH (INCHES)

INPUT BOX VOL.	RESONANT FREQUENCY	Lv @ (1) 2" DIA	Lv @ (2) 1.5" DIA	Lv @ (1) 2.5" DIA	Lv @ (2) 2" DIA	Lv @ (1) 3" DIA	Lv @ (2) 2.5" dia	RESONANT FREQUENCY
622	20	57.3	64.5	90.0	114.8	130.1	181.5	20
CU. INS.	25	36.2	40.7	57.0	72.8	82.5	115.2	25
	30	24.7	27.8	39.0	49.9	56.6	79.2	30
	35	17.7	20.0	28.2	36.1	41.0	57.5	35
	40	13.2	15.0	21.1	27.2	30.9	43.4	40
	45	10.2	11.5	16.3	21.0	23.9	33.8	45
	50	7.9	9.0	12.9	16.6	19.0	26.9	50
	55	6.3	7.2	10.3	13.4	15.3	21.7	55
	60	5.1	5.8	8.4	10.9	12.5	17.9	60
	65	4.1	4.7	6.9	9.0	10.3	14.8	65
	70	3.3	3.8	5.7	7.5	8.6	12.4	70
	75	2.7	3.1	4.7	6.2	7.2	10.5	75
	80	2.2	2.6	3.9	5.2	6.1	8.9	80
	85	1.8	2.1	3.3	4.4	5.1	7.6	85
	90	1.4	1.7	2.7	3.7	4.3	6.5	90
	95	1.1	1.4	2.2	3.1	3.7	5.6	95
	100	0.9	1.1	1.8	2.6	3.1	4.8	100
	105	0.7	0.8	1.5	2.2	2.6	4.1	105
	110	0.5	0.6	1.2	1.8	2.2	3.5	110
	115	0.3	0.4	1.0	1.5	1.8	3.0	115
	120	0.2	0.3	0.7	1.2	1.5	2.5	120
	125	.0	0.1	0.5	0.9	1.2	2.1	125

FIGURE 4: Vent size evaluation over a range of frequencies.

***** HELMHOLTZ VENT RESONATOR CALCULATION SPREADSHEET *****

by CARL RICHARD 9 HILLSIDE AVE. ENFIELD, CT. 06082 (SEPT 1989)

based on a formula from Vance Dickason's 'LOUDSPEAKER DESIGN COOKBOOK" 3rd Ed.(pg. 19 sect. 2.70)

FIND VENT LENGTH
KNOWING:
RESONANT FREQ. (Hz)
BOX VOLUME (CU.INS.)
VENT DIA. (INS)
****
INPUT:
RES. FREQUENCY = 93
BOX VOLUME = 622
VENT DIAMETER = 3
****
OUTPUT:
VENT LENGTH = 3.9

FIND REASONANT FREQ.
KNOWING:
VENT LENGTH (INS.)
BOX VOL. (CU. INS.)
VENT DIA. (INS.)
****
INPUT:
VENT LENGTH = 3.9
BOX VOLUME = 622
VENT DIAMETER = 3
****
OUTPUT:
RES. FREQUENCY = 93

FIND BOX VOLUME
KNOWING:
VENT LENGTH (INS.)
RES. FREQUENCY (Hz)
VENT DIA. (INS.)
****
INPUT:
VENT LENGTH 3.9
RES. FREQUE 93
VENT DIAMET 3
****
OUTPUT:
BOX VOLUME 624

EVALUATE VENT SIZE FOR A RANGE OF RESONANT FREQUENCIES

(single and dual vents) Lv= VENT LENGTH (INCHES)

INPUT BOX VOL.	RESONANT FREQUENCY	Lv @ (1) 2" DIA	Lv @ (2) 1.5" DIA	Lv @ (1) 2.5" DIA	Lv @ (2) 2" DIA	Lv @ (1) 3" DIA	Lv @ (2) 2.5" dia	RESONANT FREQUENCY
622	20	57.3	64.5	90.0	114.8	130.1	181.5	20
CU. INS.	25	36.2	40.7	57.0	72.8	82.5	115.2	25
	30	24.7	27.8	39.0	49.9	56.6	79.2	30
	35	17.7	20.0	28.2	36.1	41.0	57.5	35
	40	13.2	15.0	21.1	27.2	30.9	43.4	40
	45	10.2	11.5	16.3	21.0	23.9	33.8	45
	50	7.9	9.0	12.9	16.6	19.0	26.9	50
	55	6.3	7.2	10.3	13.4	15.3	21.7	55
	60	5.1	5.8	8.4	10.9	12.5	17.9	60
	65	4.1	4.7	6.9	9.0	10.3	14.8	65
	70	3.3	3.8	5.7	7.5	8.6	12.4	70
	75	2.7	3.1	4.7	6.2	7.2	10.5	75
	80	2.2	2.6	3.9	5.2	6.1	8.9	80
	85	1.8	2.1	3.3	4.4	5.1	7.6	85
	90	1.4	1.7	2.7	3.7	4.3	6.5	90
	95	1.1	1.4	2.2	3.1	3.7	5.6	95
	100	0.9	1.1	1.8	2.6	3.1	4.8	100
	105	0.7	0.8	1.5	2.2	2.6	4.1	105
	110	0.5	0.6	1.2	1.8	2.2	3.5	110
	115	0.3	0.4	1.0	1.5	1.8	3.0	115
	120	0.2	0.3	0.7	1.2	1.5	2.5	120
	125	.0	0.1	0.5	0.9	1.2	2.1	125

FIGURE 5: Printout of entire spreadsheet.

HERESY UPON A HERESY

BY PAUL STAMLER

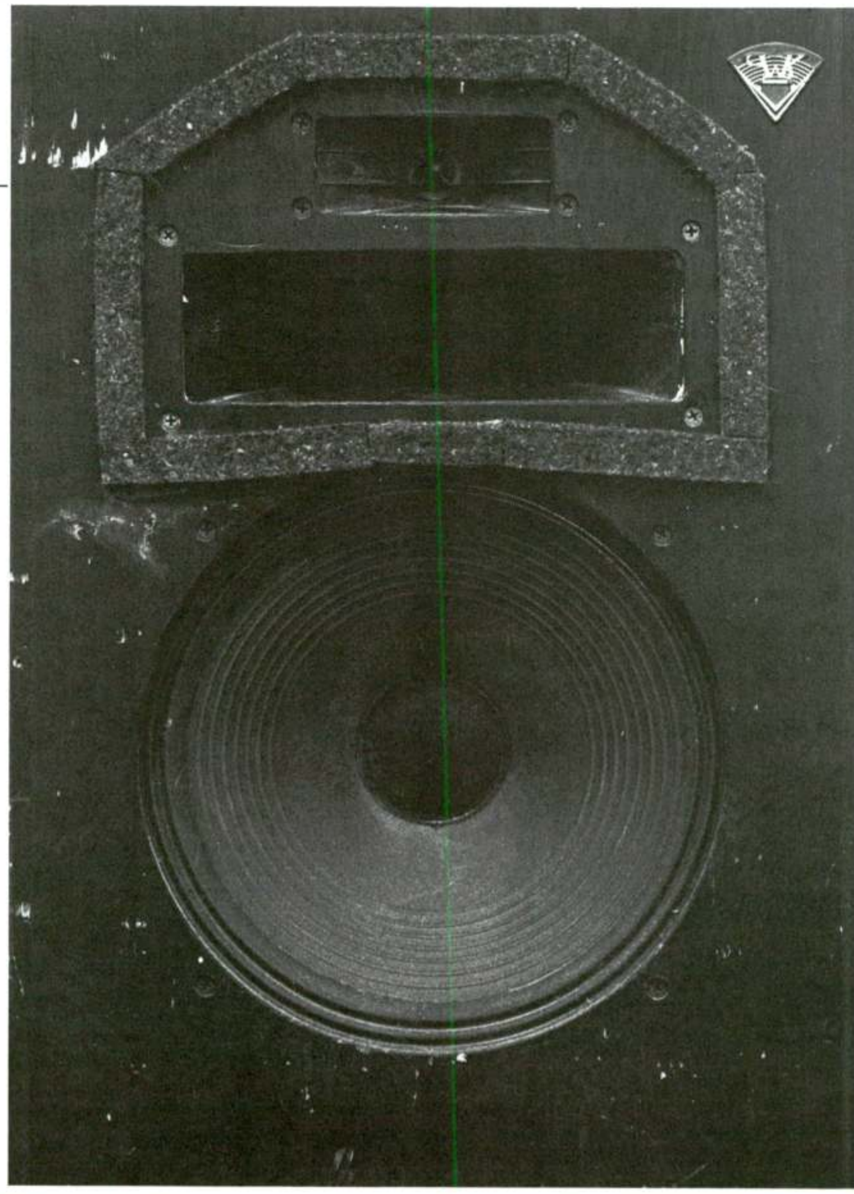

PHOTO 1: The completed unit, showing placement of the diffraction controlling felt strips.

Sometimes you have to play the hand you're dealt. The community radio station I work with (KDHX-FM) had budgeted for a pair of new monitor speakers. We wanted to buy something snazzy—Spendor SP-1s, perhaps, or Rogers LS3/5a's. But the money fell short (such is life in community radio) and there were other, more pressing needs. Thanks to a gift from another community station, we got a pair of 1950s-vintage Klipsch Heresy systems.

The mainstream audiophile press has always treated Klipsch speakers badly; *Stereophile* included the Klipschorn in its list of "Unrecommended Components" several times. And these speakers certainly sounded their age—weak, flabby bass, harsh and peaky treble, and nonexistent imaging. But a stubborn core of Klipsch adherents, have always valued the high efficiency, low distortion and liveliness of these horn-based systems. The drivers seemed reasonably good—the tweeter appeared to be a rebranded Electro-Voice unit, and the midrange and woofer were certainly solidly made. In short, we could have done far worse, and besides, they were free.

It seemed to me these speakers might well profit from upgrading. Surprisingly, the very magnitude of their departure from modern design practices was a good sign, for these departures might explain their sonic deficiencies, and correcting the shortcomings would bring them up to modern standards. This proved to be true: the modifications described below turned the Heresies into remarkably respectable speakers, despite their age.

I will describe the modifications in some detail, to provide a blueprint for Klipsch-owning readers. But my purpose is broader: The overall methodology can be applied to many older speaker systems, provided the drivers' inherent quality is good enough to warrant the work. Some of these older systems may be eligible for a new lease on life.

PLAN OF ATTACK. Heedless of our staff ex-rabbinical student, who thought "Klipsch" sounded like a Yiddish curse, I planned a three-pronged attack. First, I analyze the behavior of the three drivers, as well as the stock crossover.

ABOUT THE AUTHOR

Paul J. Stamler is a free-lance audio engineer and producer. After an eight-year stint in public television, he now produces records and radio programs of folk music and public affairs. In his spare time, he plays the guitar and mandolin, and sings in a loud voice.

It's always a good idea to know your starting point. Second, I upgrade the cabinet to modern standards, within reason. And finally, I rebuild the crossover—a lot has been learned since the 1950s.

There is a stopping point, though. I don't have the tools for major cabinet modifications. And the budgetary constraints that kept Spendors out of our reach also precluded fourth-order, resonance-compensated, all-polypropylene-capped crossover networks. Besides, we had a time limit. The station was using my pair of LS3/5a's until the Klipsches were ready, and I wanted them back. I'm a free-lance engineer/producer, specializing in folk music and jazz, and most of my recording is done on location. The LS3/5a's are my remote-recording speakers, and I didn't relish schlepping the Heresies to a gig.

First, let's attack the obvious lack of bass. The Heresies, with 12″ woofers, had poorer bass than most mini-monitors. The explanation for this became clear when I opened them up and found the input terminals on one system wired in reverse phase. This error, probably attributable to the previous owner, was quickly remedied, and lo, there was bass. (The imaging problems of the stock systems were such that the midrange and treble sounded about the same, in or out of phase.) But the bass was still flabby, boomy and poorly defined.

EXAMINATION. The first step of the modification process itself was analysis: I measured the frequency responses of the three drivers, along with their impedances, and the frequency response of the crossover network when actually connected to the drivers. I also examined the cabinet for problems and possible improvements. Here is what I found:

1) The cabinet was devoid of acoustic treatment: no stuffing—no fiberglass, no foam, no long-fibered wool—in short, nothing to absorb standing waves or in-cabinet reflections.

2) The cabinet sides, made of standard-grade plywood, were unbraced and undamped. They were free to vibrate, and they did.

3) The midrange and tweeter horns, made of metal, were also undamped and free to resonate. The midrange horn, in particular, rang like a bell.

4) The drivers were all rear-mounted on the main baffle, causing cavity resonances.

5) The midrange and tweeter both had severe resonances—the tweeter at 7kHz, the midrange at 9kHz. The crossover did not roll off the top end of the midrange electrically, relying instead on the driver's acoustic rolloff (*Figs. 1* and *2*). The midrange's 9kHz peak meant that at this frequency, the midrange was contributing nearly as much output as the tweeter.

6) The rising impedance of the woofer with increasing frequency, caused by the woofer's voice-coil inductance, decreased the effectiveness of the crossover's low-pass section. The woofer remained active well into the midrange and tweeter regions.

7) The crossover was of unusual design, using a tapped inductor for midrange and treble attenuation. The crossover did not match the schematic obtained from Klipsch. *Figure 4* shows the crossover actually used, as well as I could reconstruct it. The capacitor types

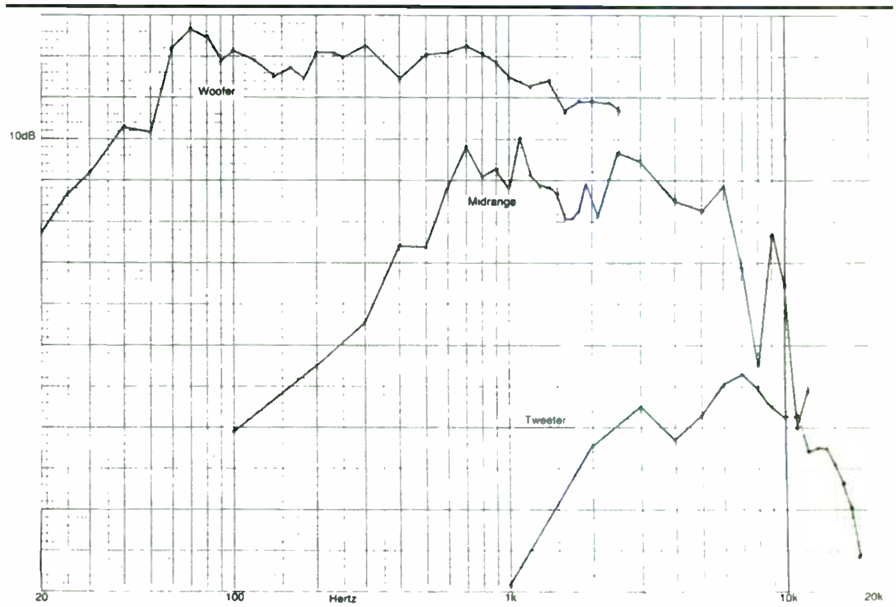

FIGURE 1: Frequency responses of the three drivers. They are measured near-field, using sine waves, and hence are somewhat rough, but overall trends are clear. Note peaks at 9kHz in midrange driver and at 7kHz in tweeter. Curves vertically displaced for clarity.

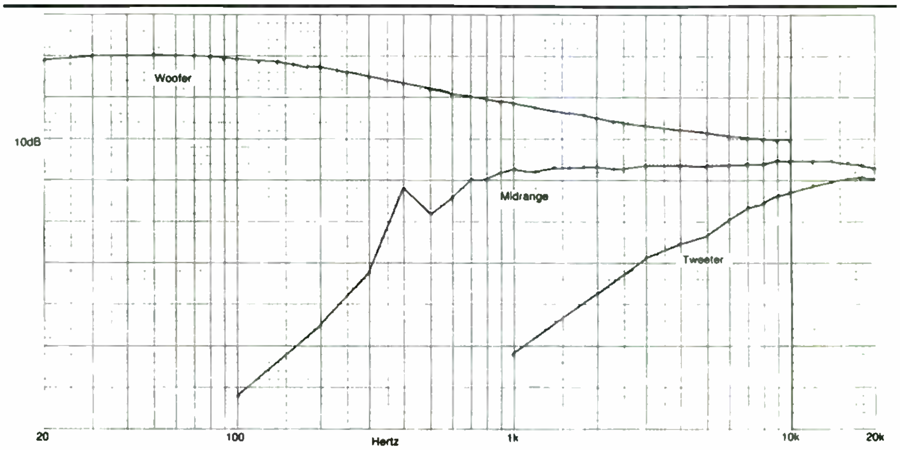

FIGURE 2: Frequency response of the stock crossover, as connected to the drivers. Note that the woofer section is barely effective.

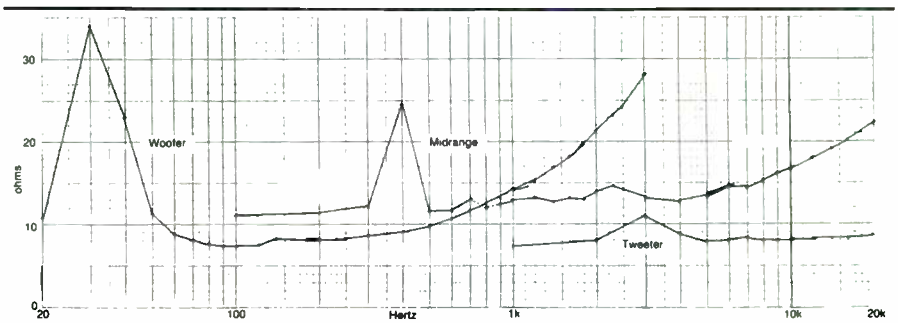

FIGURE 3: Impedances of the three drivers, measured by the constant current method. The rising impedance of the woofer explains the crossover's ineffectiveness.

were hard to determine, but they certainly were not plastic film units.

8) The drivers were all loose on their mounting bolts.

9) The staggering of the drivers meant that the system could not be close to alignment-in-time (pardon the awkward phrase; the more felicitous expression is trademarked).

I decided not to tackle 4) and 9). To remedy these would require a new and rather fancy cabinet, which was outside my self-imposed limits. On the other hand, the other problems seemed eminently fixable.

Continued on page 32

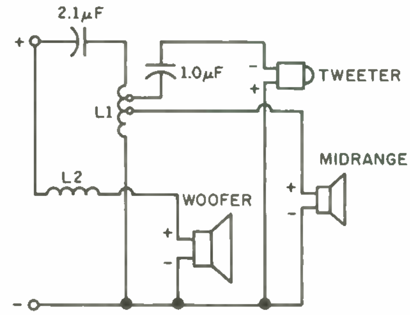

FIGURE 4: Stock crossover. The actual configuration of the tapped inductor is frankly guesswork.

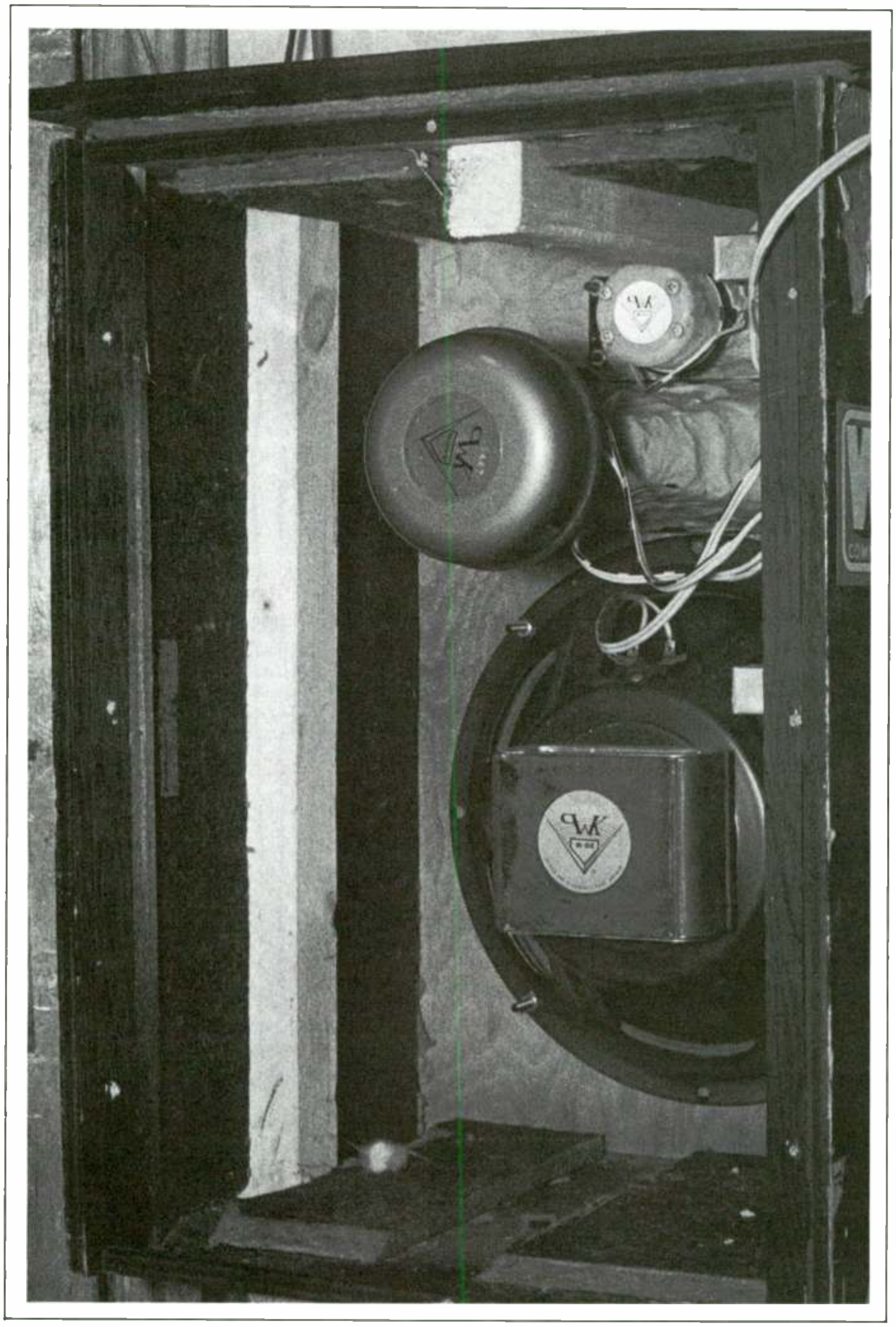

PHOTO 2: Rear view of the modified cabinet. The asphalt-impregnated felt pads and the 2 x 2" braces are both glued to the side wall and top; the putty-coated midrange horn is also visible.

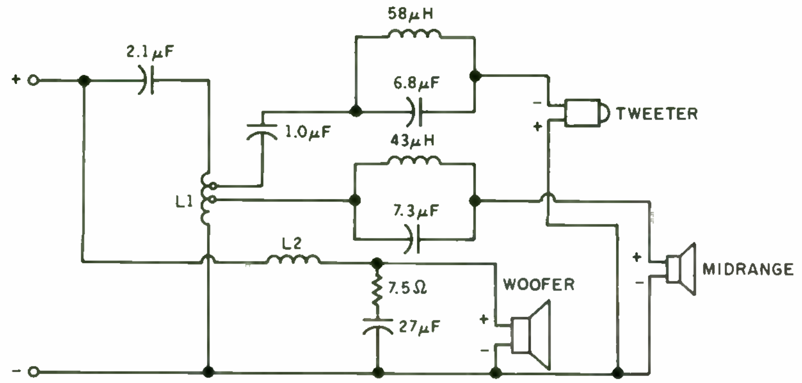

FIGURE 5: Improved crossover network. This is essentially the same design as the stock network, with added notch filters in the midrange and tweeter sections, and a Zobel network in the woofer section.

PHOTO 3: The fiberglass insulation is bunched in the center of the cabinet, where it is most effective.

Continued from page 30

CABINET IMPROVEMENTS. I began by tightening the woofer mounting bolts and nuts, using a Phillips-head screwdriver on the outside and a nut driver on the inside. I discovered that the cabinet holes themselves were threaded to match the bolts, so I tightened them first; I then held the bolts stationary with the screwdriver while I tightened the nuts. To avoid warping the woofer frame, I didn't tighten each nut all at once. Instead, I tightened the nuts partially, one at a time, going around the circle several times until each one was fully tight. I listened again: The bass was now tight and clean.

COATING. I then unscrewed the midrange driver from its horn and removed the horn from the cabinet. To damp the metal horn's sharp internal resonances, I coated its outside (not the throat) with a 3⁄16″ layer of Solder-Seal (Sealmaster) stainless putty. This marvelous, nonhardening substance, found in the plumbing section of well-equipped hardware stores, provides an excellent combination of mass-loading and damping. I also coated the outside of the tweeter horn. The pair of speakers used up about two pounds of putty.

I then proceeded to the cabinet walls; it's a lot easier to work on these when the midrange horn is removed. I glued pads of "expansion joint" material, an asphalt impregnated felt, to the sidewalls, top, bottom and back, using Liquid Nails™ as the adhesive. You can cut expansion joint, available in 4 x 8′ sheets (½″ thick) at hardware and construction supply stores, with a utility knife and elbow grease. A power saw also works, but it gums up the saw's teeth.

I also used Liquid Nails to attach 2 x 2″ braces to the sides, top and back, lengthwise, to discourage panel flexure.[1] 1 x 2″ braces would probably be sufficient, but I found some scrap 2 x 2s in the basement. *Photo 2* shows the braces and pads, along with the putty coated horns. Incidentally, Liquid Nails is a marvelous damping adhesive, with many possible uses for speaker builders. Use acetone to remove it from your fingers (open the windows and don't smoke).

I stuffed the cabinet with about four square feet of R-11 (3½″) Fiberglas™ insulation, wearing long rubber gloves to avoid "fiberglass itch." I bunched the insulation toward the center of the cabinet, where particle-velocity is highest and the absorbent is therefore most effective. *Photo 3* shows insulation placement.

Continued on page 34

World Radio History

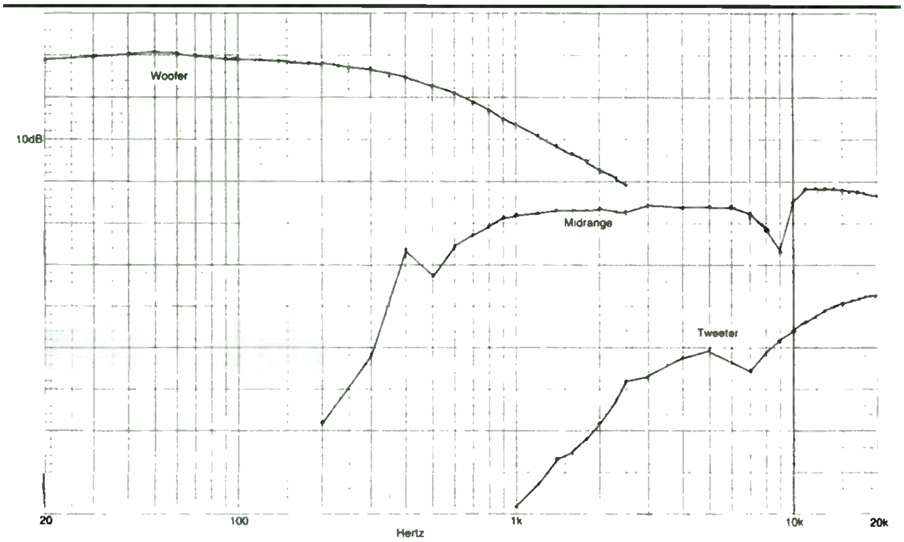

FIGURE 6: Frequency response of the improved crossover network. Note the notches at 7 and 9kHz, in the tweeter and midrange sections, respectively. Also note that the woofer section now works properly.

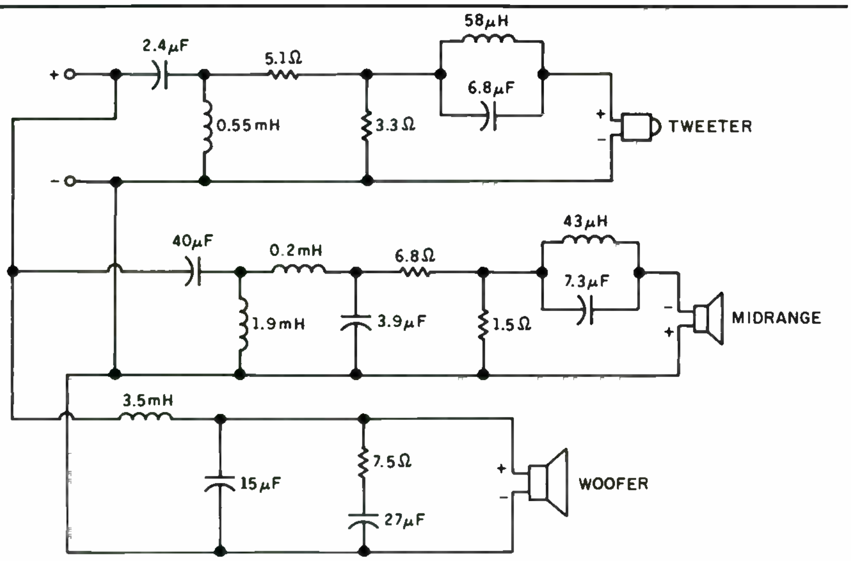

FIGURE 7: 12dB/octave all-pass crossover. This should improve performance further; the L-pads substituted for the tapped inductor flatten out driver impedances, as seen by the crossover, mitigating the effect of the midrange resonance at 400Hz and the tweeter resonance at 2.5kHz.

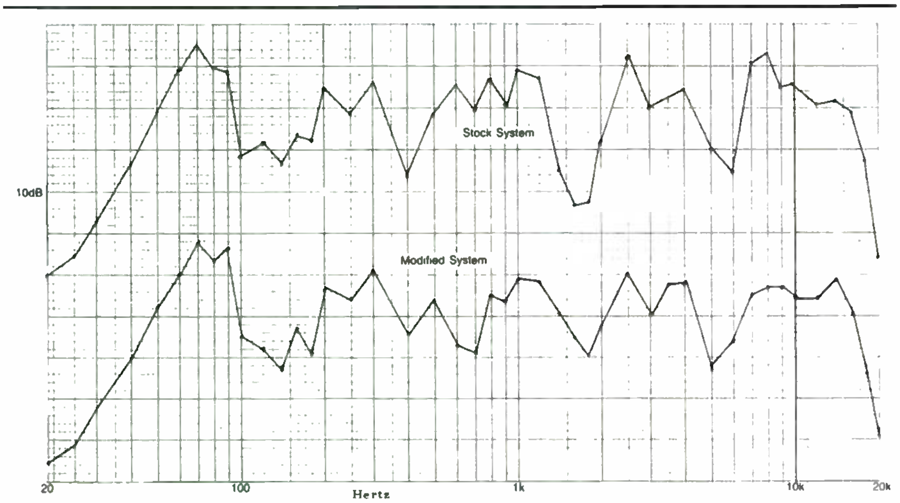

FIGURE 8: System frequency response at one meter, before and after modification. Both curves are pretty rough (this is a limitation of the sine-wave measuring method), but the modified system is clearly smoother than the original. Measurements were averaged from several positions.

Finally, I reinstalled the midrange horn and tightened its nuts and bolts, then screwed on the midrange driver. I also tightened the nuts and bolts of the tweeter.

It was time for an audition. I had only modified one speaker, leaving the other for comparison, so I hooked them up to my (modified) Dynaco ST-70, AR turntable with Grado cartridge, and home-brewed all-tube preamp, and proceeded to compare. Well, there was definitely a major improvement. Listening to Stan Rogers' "Fogarty's Cove," even in mono, there was a distinct sense of depth to the modified system, a sense of an "open window" into the recording studio. On the other hand, the unmodified unit conjured up a paper-thin image, glued to the front of the cabinet. Even without further modifications, the transformed Heresy was beginning to sound like a modern system.

CROSSOVER CHANGES. Feeling encouraged, I tackled the crossover. After much meditation, and a long talk with the station manager, I decided to stay with the original crossover design, but executed more effectively. I made this decision due to time and money limits and with the understanding that it could be reversed with little loss: The new components added to the stock crossover could be recycled into an improved crossover.

Figure 5 shows the revised crossover network. The additional components include notch filters for the midrange and tweeter sections, and a Zobel network for the woofer. In addition, the two crossover capacitors have been replaced with Mylar film caps.

Figure 6 shows the frequency response of the revised crossover network, measured with the drivers connected. The notch filters smooth out the upper-frequency peaks (although the 9kHz filter for the midrange is less effective than I would like), and the tweeter's notch filter reacts with the rest of the crossover to extend the tweeter's high frequency cutoff from 12kHz to about 16kHz. The Zobel network performs in textbook fashion, allowing the woofer to roll off properly with increasing frequency.

CAPACITORS. In keeping with cost limitations, I used paralleled non-polarized electrolytic and Mylar capacitors in the Zobel network, while the notch filter caps are Mylar. The higher-Q achieved with Mylars in the notch filters, along with their smoother overall sound, makes the extra expense worthwhile.

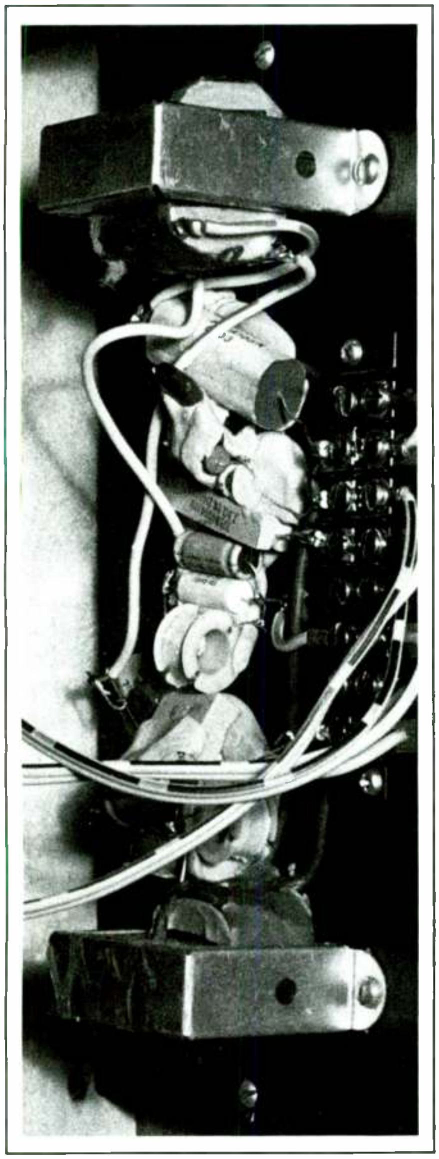

PHOTO 4: The modified crossover; new components are held in place by wads of nonhardening putty. It's ugly; but the parts don't rattle.

Photo 4 shows the revised crossover board. Klipsch hard-wired components together on a sheet of ¼″ plywood (good for them) and made connections using spade lugs and barrier strips. Good for them again—the connections are gas-tight and oxidation-resistant, while remaining easy to change if necessary. I also hard-wired the crossover components, but instead of screwing the new capacitors to the board, I mounted them using wads of stainless putty, in case we needed to change them later.

For those interested in further exploration, *Fig. 7* shows a 12dB/octave all-pass crossover I designed, using Robert Bullock's formulas.[2] This crossover exists only on paper—I haven't had the time or cash to try it yet. As designed, all crossover caps should be Mylar (or better) whenever possible; all inductors should be standard Madisound air-core units, and resistors should be 5 or 10W wire-wound ceramic, available from Digi-Key or Madisound. You can wind the notch-filter inductors at home, using Daniel Coyle's article[3] as a guide.

Figure 8 shows the system frequency response, before and after modification. Neither curve is terribly smooth (such are the limitations of in-room averaged measurements using sine waves), but the modified system measures considerably better than the original.

I compared the two speakers with and without the crossover mods in place (both cabinets upgraded), and again there was a noticeable improvement. The midrange and treble were far cleaner and smoother, with much less glare in the brightness region (7–10kHz). The image improved in depth and spaciousness; a greater sense of an "open window," with real performers behind it.

FINISHING TOUCH. As a final fillip, I glued strips of felt around the midrange and tweeter openings to help control diffraction from cabinet edges and frequency modulation by the woofer cone. I formed the felt strips by slicing up felt blackboard erasers with a utility knife, and attached them with the ubiquitous Liquid Nails. It took about three erasers to treat the two speaker systems. This further tightened up the image.

So how do they sound? Quite good—remarkably good, considering what they sounded like before modification. The bass, while it doesn't go terribly deep, is tight and tuneful; the midrange is clean and clear, and the treble is non-glary, although it lacks "air" at the very top. Perhaps a solid-state power amp will improve that.

On my agenda are more crossover experiments, higher-quality internal cabling, and perhaps an external (passive) equalizing network before the power amp to extend the top and bottom a bit. But in the meantime, well, let me put it this way. I still prefer my LS3/5a's, but if circumstances compelled me to use the revised Heresies as monitors while recording an album, I wouldn't feel unduly put upon. Yes, they are good enough. Now.

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1. Tappan, P. W., "Loudspeaker Enclosure Walls," *Journal* of the Audio Engineering Society, Vol. 10, No. 3, pp. 224–231, July 1962.
2. Bullock, R. M., "Passive Crossover Networks, Part II," *Speaker Builder* 2/85, pp. 26–39.
3. Coyle, D. P., "Custom Wound Inductors," *Speaker Builder* 3/82, pp. 20–21.

Part II

A COMPACT INTEGRATED ELECTROSTATIC/ TRANSMISSION LINE

BY ROGER R. SANDERS

Perforated metal tends to be expensive. The ideal pattern would be 1/16-inch perforations on 3/32-inch staggered centers. Although a possibility, it is too costly for our use. Fortunately, a very good substitute in the form of decorative 2 by 3-foot Alcoa aluminum sheets is available from any Ace hardware store [and other stores stocking Alcoa]. The pattern you want is called Lincaine consisting of 1/8-inch holes surrounded by 1/16-inch holes. Although available in plain aluminum, I urge you to buy the gold anodized version. The plain type has an oily film difficult to clean. The gold type is spotless and costs only a few dollars more. The sheets are only 20 mils thick. The Ace order book lists this material as item number 1215.

This material is soft and thin and can be damaged easily in transit. Often a corner has been bent, but you can straighten that easily. Beware and reject those with a crease across the sheet. You will not be able to remove the crease. The sheets will have a modest bow or warp to them from the perforating process. This is normal and is not usually a problem.

You can cut a sheet in half with a pair of scissors, yielding two stators from one sheet. If you want a perfect cut, have a local sheet metal shop cut it on a sheet metal brake. Because the insulators are narrow to conserve space in this compact design, cut a notch in the metal so it clears the diaphragm contact (*Fig. 1*). Do this after you have drilled the insulating strips so you know exactly where to locate the notch.

The holes have rounded edges on one side and sharp ones on the other. During construction, face the round edged holes toward the diaphragm so you minimize corona problems. A corona is the tendency of a sharp, high-voltage surface to break down the dielectric strength of the air, causing arcing. Smooth, rounded surfaces suppress this. Glue the insulators on the side with the rounded holes.

INSULATORS. The insulators are made from either 1/16-inch acrylic (one brand is Plexiglas) or 80-mil polycarbonate (one brand is Lexan). I have used both but prefer acrylic because it meets my specification for a 68-mil diaphragm-to-stator spacing and therefore produces the highest output. These materials are usually available from home improvement stores or glass shops. Glass shops can often cut the strips you need, but it is not difficult to cut them yourself and doing so will save quite a bit of money.

I have tried many different ways of cutting this stuff, but no method is perfect. Although it is possible to score and break off strips, it is very difficult to do so even with a jig. It is far more practical to saw the plastic into strips. The best tool for this job is a band saw with a very fine blade (a fine-tooth hacksaw blade works beautifully). Clamp some sort of rip fence to the saw and go to it. You can use a table saw, but there are problems. First, fine-tooth blades are not made for them, although you can do an acceptable job with a plywood blade. This will cause considerable chipping along the cut edge, however, which although unsightly, does not affect performance. You also will find the plastic sheet has a tendency to climb the saw blade. To prevent this, clamp a piece of wood on the side of the rip fence about a quarter inch above the table. Run the saw blade about a quarter inch up into the wood, which will prevent the plastic from climbing up the blade.

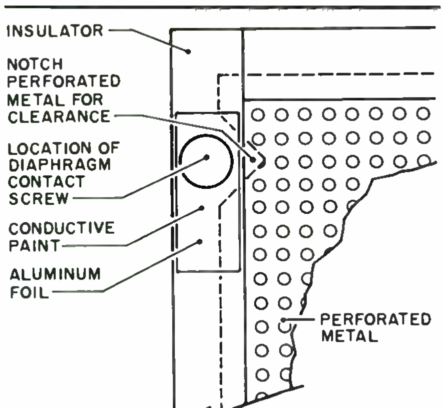

FIGURE 1: Diaphragm contact detail, front view.

Drill the diaphragm contact holes by first clamping two strips together (*Fig. 2*). Drill a 5/32-inch hole (the size of a 6/32 bolt, which you will use for the diaphragm contact bolt) through both strips. Be careful: Conventional drill bits tend to shatter the plastic just as they exit the hole. One way to prevent this is to stop just as the drill point starts to exit, turn the stack over, and finish the hole by drilling in from the other side.

I like Barry's technique (see "The Waldron ESL Panel," opposite page) of using a solder tab for the diaphragm contact because it is simpler and more rugged than my method. It has the disadvantage of sticking out of the edge of the cell, which prevents slot mounting of the completed cell. If you use his design, skip to the next paragraph. If you use my design, separate the two strips and increase one of the holes to ½ inch, so the head of the screw and washer that make up the contact point can pass through one of the strips and make contact with the diaphragm.

CELL CONSTRUCTION. Use a piece of glass slightly bigger than your completed cell upon which to construct the cell. Draw the insulator pattern on the underside of the glass with a felt mark-ing pen (*Fig. 3*). Alternatively, you may lay out the pattern with masking tape. All the stators must be identical so when you glue them together, the insulators match, particularly the center strip insulator, which is very narrow.

The diaphragm must be supported about every six inches for stability: thus, the center insulator. In theory, you have the option of replacing the strip insulator with insulating "dots" about every six inches. The dots allow more of the diaphragm to move and reduce stray capacitance, which should enhance speaker efficiency. I tried this initially, but it was unsatisfactory. The dots gave too little stability to the diaphragm to use high-polarizing voltages. Switching from dots to a strip increased the output by nearly 10dB. This is yet another case where practical experience proved theory wrong.

Obtain two types of adhesives from your local hobby shop. First, you will need a small amount of cyanoacrylate, or instant glue. The gap-filling type is preferable so your joints don't have to be perfect to make a good glue joint. Cyanoacrylates are not instant when used on plastic. You may want to get a "kicker" to make it work instantly. Second, you will need some 30-minute epoxy in a 9-ounce squeeze bottle. Devcon epoxy is preferable because it has the lowest viscosity, but other brands are acceptable. Those of us who build lots of cells use 5-minute epoxy exclusively, but you must use a syringe to apply it and work quickly. Thirty-minute is probably a better choice.

Drill a 5/32-inch hole in one corner of the aluminum sheet for the 6/32 brass nut and bolt used for electrical connection to your amplifier. Carefully remove the burr left by the drill by manually twisting a much larger drill bit or a countersink in the hole. Bend this corner at right angles to the diaphragm *after* the cell is completed and then install the bolt through the hole to attach your electrical connection. The tab needs to be only about a half inch. If you prefer to have all the connections in the same corner of the speaker, remember that the stators will be mirror images of each other.

GLASS CARE. Remove all grit from your plate glass, aluminum, and insulators with a vacuum cleaner. Protect your glass from glue by coating it with car wax or covering it with plastic wrap. Wax paper is porous to epoxy, avoid it. Lay out the insulators and tack them together with cyanoacrylate. When all eight are done, lightly sand the glued areas to remove any high glue spots. Lay one of the insulator frames on the glass and spread a thick film of epoxy where the perforated metal will fit. Omit epoxy in the tab contact area so you can bend it up later. Lay the metal on the insulator frame, remembering to keep the rounded holes toward the insulators, and cover it with plastic wrap.

Place flat weights on this assembly until the glue cures. It is important to have a flat stator, so make sure the weights are flat. If you are using books, select them carefully for flatness. It is a little more expensive, but well worth the cost, to place a second piece of glass or a steel sheet on top and then put books on it. This will ensure a truly flat assembly. Note that when the assembly is lifted from the glass after the epoxy has cured, it will still be warped. Don't worry; it will be flat after it is sandwiched to the other sheet in the final assembly.

Now you need some conductive paint. I use the stuff LocTite sells for repairing rear window defrosters in cars, but any type will do. Take the stator with the large hole and paint a line ¼ inch wide and about six inches long from the hole to the inside edge of the insulator. Go in whatever direction necessary to avoid

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Alternative Method:

THE WALDRON ESL PANEL

BY BARRY WALDRON

This electrostatic panel's architectural design is the result of a similar though wider configuration conceived a few years ago. When Roger asked me to construct the prototype, we discussed the pros and cons of various stator designs. My role was to construct a set of panels to satisfy Roger's overall goals. Since the prototypes were to be offered for sale, it became important to offer a panel which would provide the best possible results.

Roger introduced me to the ESL in 1976. With my first design, I subdivided the original Sanders panel (*TAA* 4/75, p. 18), making the individual sections free standing. The problem with this is the rods are horizontal across the stator, requiring them to be cut, a difficult and time-consuming task.

While building and testing these panels, I found they were structurally unsound, flexing in various places. This caused the diaphragm to become attracted to a stator, and the immediate area then would not emit sound. To correct this, I fashioned and attached Plexiglas longerons to each side of each stator.

After completing the above project (Showcase, *TAA* 4/79), I tried many topologies. I wanted to construct a panel using uncut rods. I made a long, narrow panel with longerons, and added external ribs to support the rods. These give us three advantages: First, more of the diaphragm is usable; second, stray capacitance is reduced, and third, the structural integrity of the frame is enhanced. These are slightly more difficult to construct than the Sanders type.

In the next configuration, I widened the panel and changed the mounts from top and bottom tabs to a peripheral flange. To maintain the 100:1 diaphragm support structure, I strategically placed insulated pads in the first prototype, as shown in David Hermeyer's second design (*SB* 2/77, p. 4). They also have less stray capacitance and more usable diaphragm area. I used a single electrical termination point in each variation.

Roger's initial tests showed that while the pads worked, they failed to adequately support the diaphragm; the panels would only allow 1,800V to be applied, resulting in SPLs of 97dB. Although this is fine for many, we are seeking the best so we eliminated the spot insulator pads and returned to the strip insulator. While stray capacitance is still a valid issue the gain possible by using the strip insulator outweighs the stray capacitance. These panels accept 3,000V and deliver a whopping 106dB.

By following Sanders' articles in *TAA* (4/75) and *SB* (3/80) in addition to the following text, you should have no trouble constructing a suitable set

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ABOUT THE AUTHOR

Barry Waldron, 47, has been tinkering with electronics since the mid '50s and with audio since the early '60s. Another hobby is still-life photography. In addition, Barry holds a commercial pilots license and is an avid ballroom dancer and instructor.

of panels. If you like segmentation, you can easily add this feature by rearranging the bus network.

ESL JIGS. J1 (*Fig. 1*) is a strip of Plexiglas 1/16 inch thick with two alignment holes for uniform placement of the panel electrical terminus holes and to assist in final assembly stator alignment. Size the contact screw hole to fit your hardware. The prototype uses 4-40 screws × ¾" screws. Its location depends on your hardware. To place the hole properly, bend one stator contact (*Fig. 2*) and temporarily place it on the frame. Then place the diaphragm contact over it, making sure it extends a suitable distance from the frame's outside edge. Place J1 over the two contacts and at the junction of the cap strips. Mark, then drill this template hole. Do this anytime prior to attaching the longerons.

Arbitrarily place the second hole on the stators. Locate it in the diagonal corner from the electrical terminus. Use it solely to align the second stator with the first when you attach the diaphragm. This hole and its template counterpart should be just large enough to pass an awl or ice pick.

J2–6 are five strips of balsa wood, 3/16 inch thick, which elevate the rods when affixing the horizontal ribs. Place waxed paper over each strip so the epoxy will not stick to them. Place each under each rib position. Expand the panel frame outward slightly and allow it to droop over the edges during gluing and positioning. A good size is 11 1/16 by ½ inch.

Treat J7–18 as above but make them ⅜ inch thick and cut to fit vertically between any two ribs.

JIG. While not an absolute necessity, you can obtain better panel-to-panel uniformity with a jig than by assembling freehand.

Rest a piece of plate glass the size of the stator (37 by 13 inches) on an oversized piece of plywood. Note: The quarter-inch glass is left with straight, sharp edges. Nail wood strips to the plywood frame base around the perimeter of the glass; then each part of the stator to be glued can be butted to it.

ASSEMBLY. Begin by forming the basic structure. Align and glue strips B and C, using Weld-On 3 solvent or its equivalent available at plastic dealers. Zap™, available at hobby shops, is also suitable. An insulin syringe is best, although dealers sell a plastic bottle with needle that works. Glue the butt joints and hold for approximately 30 seconds, compressing the joints by hand. This is all the drying time needed.

Next, position and glue front cap strips, A. Run the needle along the inside edge of the two strips while rubbing a finger over the top as you progress. You can see the glue run in between the layers and secure the strips. Press and hold the strips together, allowing the solvent to dry. Continue the process affixing D.

Note: If a jobber cuts your material, it might be necessary to trim various strips to exact lengths. A Dremel tool and grinding wheel work fine for this. Alternately, they may be scored and cut, or sawed.

ADDITIONAL GLUING. You can now remove the stator frame from the jig to inspect it. You may need a putty knife to break the attraction of plexi and glass. Should additional gluing be necessary, do it at this time by running the needle along the outside edge of any section. Remember, you can see the solvent line to determine whether it has flowed evenly between the strips. If not, touch up as required.

That wasn't hard, was it? Proceed in the same fashion with the remaining frames. When all have been assembled, position J1 on the cap strip of one frame and drill the two holes. This done, use the front frame as a template for drilling a matching hole in the back frame.

JIG ADDENDUM

Figure	Part	Dimensions	Qty	Total
Jig	Base	4' × 4' × ½" min.	1	1 of 2
	Border			
	top and bottom	¼" × 2" × 6" typical	2	4
	Side	¼" × 2" × 10" typical	3	6
Stretcher (see text)		4' × 4' × ½"	1	1 of 2
	Glass plate (see text)	13" × 37" × ¼"	1	1
J1	Template (see text)	½" × 6" × 1/16" typical	1	1
J2–6	Rib support	½" × 11 1/16" × 3/16"	5	5
	(Balsa wood)	(avail. in 3' lengths)	2+ (as needed)	
J7–18	Center support			
	(as above)	½" × to fit × ⅜"	12	12

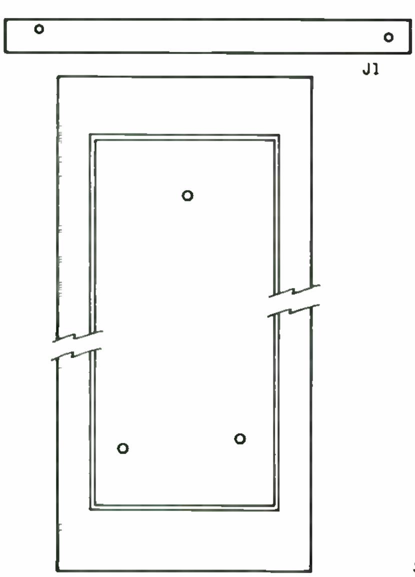

FIGURE 1: Jig.

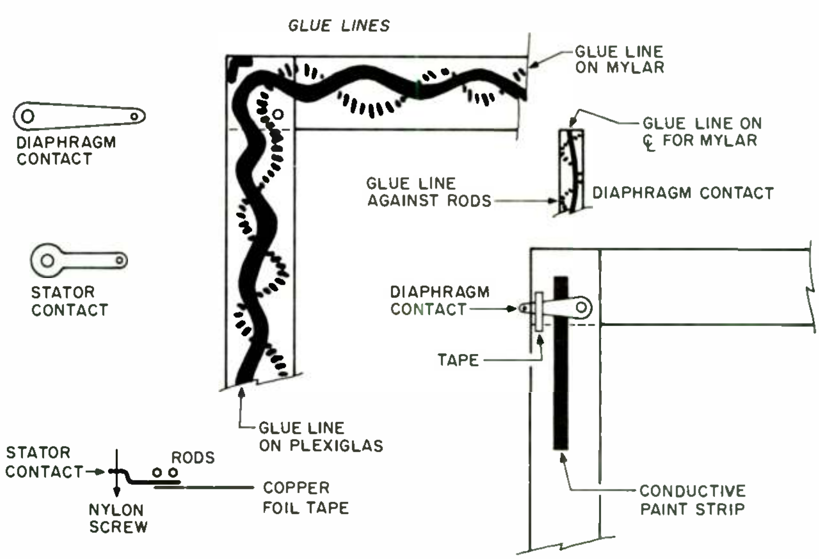

FIGURE 2: Construction details.

Now, scribe a number into each front and back frame so they will not get mixed up and can be used in matched pairs.

Next, take at least six ½-inch-diameter threaded rods (Redi-bolt) cut to a point just after the 110th thread (11 inches). Place a rod top and bottom near the inside edge of B. Place the rest between the rib positions. Use the assembly jig or any convenient flat surface. The threaded rods must be plumb; they position the stator rods, which come next.

PANEL PARTS LIST

Figure	Part	Dimensions	Qty	Total
A	Cap strip top and bottom	½ × 13 × 1/16"	2	16
B	Rod support top and bottom	⅞ × 11 × 1/16"	2	16
C	Gap spacer	1 × 36 × 1/16"	2	16
D	Cap strip left and right	1 × 37 × 1/16"	2	16
E	Longeron	⅜ × 36⅜ × 3/16"	2	16
F	Rib	⅜ × 11⅝ × 3/16"	7	56
G	Center support	⅜ × 36 × 1/16"	1	8

SEGMENTATION. First, place a strip of conductive copper foil adhesive tape along B's top edge, which you designate as the top of the stator and just inside 0 (*Fig. 3*). Now you must decide about segmentation. If you are going to do this, figure out the individual lengths of foil required and lay these down next to each other. Each strip should be long enough to include a pigtail to its respective contact screw. Note: On panels to be segmented, the top rib should be used as a terminal strip for the several contact screws. Further discussion of segmentation is beyond the scope of this article.

Use a screw-type solder lug as a terminal. Bend it to go over the hole in D and rest on the copper foil. Temporarily anchor it with a piece of tape.

Now for the welding rods. Place one hundred ten across the threaded rods after cleaning and testing each for straightness. Use Acetone or lighter fluid to remove the protective oil coating. *Do this using protective gloves (plastic) and in a well-ventilated area. Read the warning on the solvent container.* Now roll each along a flat surface to test for straightness. Discard bent ones.

Place each clean, straight rod on the bolts from one end to the other. When all 110 are in place, line them up. Use a frame, turning it gap side up and using the end without the copper foil to align all the rods.

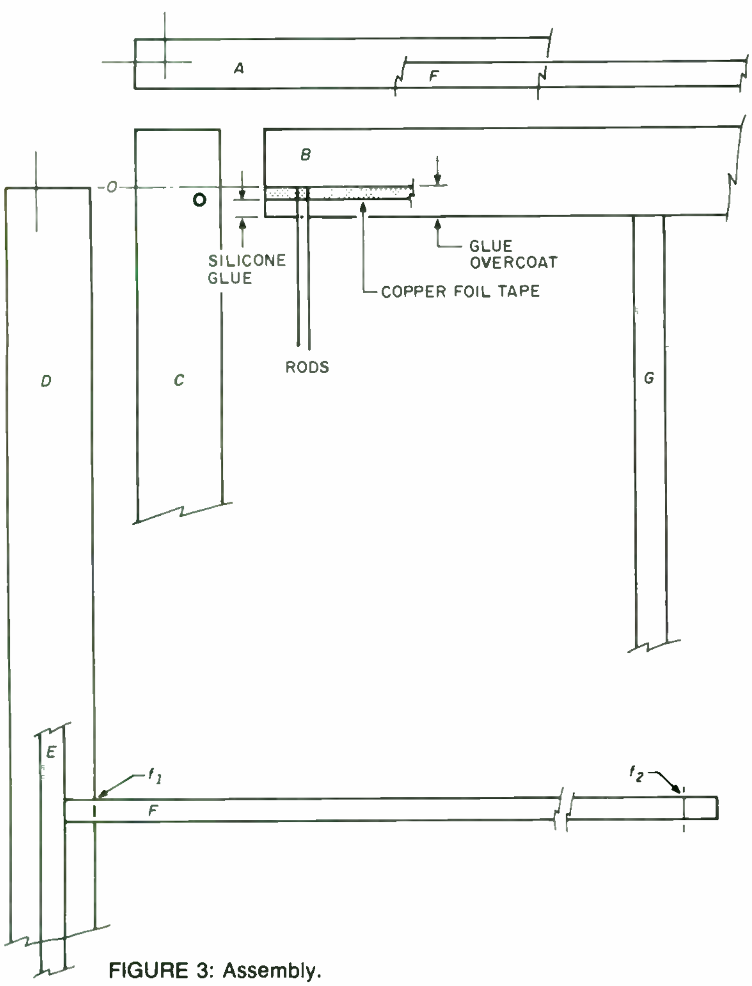

FIGURE 3: Assembly.

GLUE FLOW. To attach a frame to the stator rods you must do two gluings. Do the first with GE Clear Silicone Rubber. Run a narrow but thick line along the inside edge of each B strip. Again turn the frame upside down and position it over the rods resting on the threaded rods. It is easier to position the bottom, B, side first, as you can see rod alignment. Butt the rods up against the line, 0, and *press* the frame down on the rods and into the glue. *Do not rub.* The silicone glue molds itself under and between the rods. Secure the top in a similar manner. Depending on the exact length of the welding rods, you will find a small gap between the rod ends and 0 at the top. This is all right, since an application of conductive silver paint is required and it will flow down into this gap to make a more positive bus.

Allow the glue to set for a minimum of 30 minutes. Then remove the framework from the bolts and turn it right side up.

Liberally apply the conductive paint to the top of the rods. Paint applied to the rods and silicone will also run down in between the rods and onto the foil. Allow the paint to dry thoroughly.

Once the paint has completely dried, cover the whole area on top of the rods between 0 and the inside edge of B with either 5-minute epoxy, Scotch Super Adhesive, or other similar single-part glue. When using the epoxy, try damming up the application along the inside by using a piece of Plexiglas coated with silicone spray lubricant or a balsa strip covered with waxed paper. This will make a neater border. I find the latter to work just fine. Allow the glue to dry.

RIBS. After the final gluing has set up, attach the horizontal ribs. Carefully mark each stator frame near the inside edge of the left and right sides, C/D.

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THE WALDRON PANEL

From the top inside edge of each stator measure down 5 13/16 (5.833) inches on one side, mark it, and continue down until all rib locations have been designated. Do this for the other side and all remaining stators. Add 3/16-inch markings to each point.

Now mark each rib for its respective f1 and f2 positions. Measure in 5/16 inch from each end and mark.

Cut small strips of waxed paper to fit well over each strip, J2–6. Position these jigs on center under the rods for each rib location. Allow the frames, C/D, to expand outward and droop over the edges of the five strips.

Position the threaded rods evenly over the tops of the stator rods and align them so they maintain an even separation along their lengths.

Using Devcon 5-minute epoxy in tubes, measure out 9-inch-long portions of resin and hardener on a sheet of waxed paper and mix with a toothpick. Use flat toothpicks to apply. Each glue line should be no thicker than 1/16 inch. Glue each rib in turn between f1 and f2, then position them on the rods between each of the markings on each side of the stators. Press one rib firmly on the stator rods and hold for a few moments. With all five strips in place, secure each with approximately 25 pounds of weight (concrete blocks, for example) and allow this to set up for a minimum of one hour. Place the plate glass between the blocks and the ribs to distribute the weight.

After the epoxy has hardened, attach the ends of the ribs. Allow the expanded and drooping panel edges to return to normal. Force back any excess epoxy spilled over the f1 or f2 line and secure the ribs to the frame at D/F with solvent. Press and hold each bond for 30 seconds.

LONGERONS. The final framing step is attaching the longerons, E. Proceed as above. Glue each to its respective cap strip, D, and to the end of each rib. Place the longerons on a line ½ inch in from the outside edge of D.

Note: With the type of solder lugs typically available, you may need to shorten the longerons on the contact side near the hole, allowing for the contact(s), washer and screw.

Check the stator gaps to make sure the epoxy has not built up below the level of the rods and overflowed into the gap. If any has, use a Dremel tool with grinding wheel to smooth. The waxed paper on J2–6 will keep the epoxy at rod level.

The vertical diaphragm support strip, G, is now ready for placement. On center, place one waxed-paper-covered jig (7–12) between each of the ribs and the A/B glue line, top and bottom. Remember, the waxed paper goes between the rods and the balsa wood.

With the jigs in position, place the stator, gap side up, on your working surface. Once again, on center, make sure the strip will fit snugly and with no bows. Apply a bead of epoxy to its length using a syringe and refit to the stator rods. Apply weights for an appropriate time, and after the epoxy hardens, remove the weights and jigs.

Next, glue the edges at each end of the strip to each A/B strip with the solvent. This completes the physical stator assembly.

PAINTING. Mask off the gap sides of C, B and G with tape. Three applications of insulation are required. Spray the first coat straight on toward the rods; next spray at a downward angle from the left and finally from the right. Rotate the frame 180° and repeat.

After much thought and experimentation, I recommend either GC 50-12 Red X Corona Dope or GE 1201-A as insulation. Both are available in aerosol cans, and four should be sufficient.

Roger advises that Varathane™ can be applied with a toothpick should you need to cover nicks in subsequent rebuilds.

Each stator front will have a finished and professional appearance if painted with a gloss enamel or lacquer finish. Do this in the same manner as the insulation; again four cans is sufficient. After all stators have been painted, remove the masking tape and any paint from the stator contact with a knife or single-edged razor blade.

Paint a small area around the gap side of the terminal hole of C and down one side for an inch or so with conductive paint. Be certain it does not run into the hole. This patch helps make contact between the diaphragm and the diaphragm contact solder lug.

Use 4-40 by ¾ inch nylon screws and nuts for the terminal support. Base this on your contact hole size. These are available from hobby shops and hardware stores but might have to be special ordered.

DIAPHRAGM COATING. Scrape any dried epoxy off the plate glass with a sharp putty knife. Next, wash the surface with window cleaner. Dr. Lang, in his Amber article (*SB* 6/88, p. 18), advises using a static-suppressant spray, although I did not. The glass must be clean and *lint free*. Any lint on top or underneath the ¼-mil Mylar will cause a cut which, depending on the diaphragm stretching method, might be in the way. Using ½-mil material will alleviate this. For this reason, I prefer the thicker material when using powdered graphite coating. Yes, this material sonically rolls off sooner, but both are well into the ultrasonic region so it is moot.

With the Mylar positioned over the clean, lint-free glass, tension it slightly with small pieces of masking tape around the perimeter.

Use plenty of light for this, as it is *vital* to see any falling or trapped lint. Remove obvious lint with a lint-free cloth both before and during graphite application. Graphite is available in different grades of coarseness. Purchase a tube of extra fine.

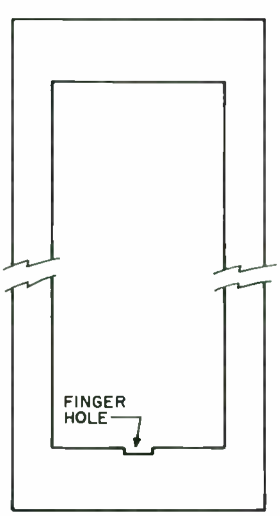

FIGURE 4: Window jig.

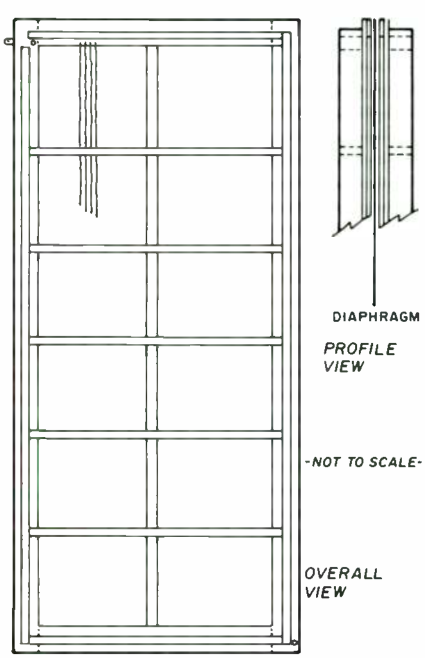

FIGURE 5: Overall and profile views of panel.

Apply the powder sparsely over several cell areas. Use a single cotton ball to rub it around evenly, with only moderate pressure. *Switch to a new cotton ball now and whenever a buildup accumulates.* An accumulation on the cotton ball looks like slate. This can also cut the Mylar.

Rub in small circles over the whole cell area. About three complete rubbings are necessary. Use greater pressure each time. Keep an eye out for lint; any hairline tears void that particular cell unless you can reposition the Mylar to place the cut out of the way.

As you rub, take sample ohmmeter readings. A low resistance border should run around the perimeter under strips C and B. Periodic measurements one inch apart in the radiating area usually show resistances of 50–100kΩ. The higher the readings the better. With practice, using graphite very sparingly, you can get readings on the order of a megohm.

Rub excess graphite to an area outside the cell. After the three rubbings, lightly pick up excess powder with paper towels or cotton balls. Now, give one last hard rubdown.

MISCELLANEOUS

Cotton balls
Extra fine graphite
Paper towels, Acetone, glass cleaner, static spray
¼- or ½-mil Mylar, 20′ minimum (DuPont)
One-part adhesive or 5-min. epoxy
5-min. epoxy in 15-oz. bottles (Devcon)
Toothpicks (flat)
Masking and duct tape (see text)
Rods (Oxweld #7 or equiv.) 36″ × 1/16″ × 880, 35/1 lb., 26 lb. typical; available in 50 lb. cartons for straightness
Pens (felt tip, permanent marker)
Paint (GC 50-12 Red-X Corona Dope or GE 1201-A) 4 aerosol cans
Paint (Rustoleum™ or equiv.) 4 aerosol cans in gloss black lacquer or enamel
Plastic or waxed paper cups
Adhesive solvent (Weld-on 3 or Zap™) (see text)
Conductive paint (GC) silver
Conductive tape (GC) copper
Adhesive Silicone RTV (any brand, clear)

Special Tools

Threaded rods (Redi-bolt) six
Heat gun (Mono Kote or equiv.) 900W
Adhesive applicator syringes (Stylex or equiv. 10cc needleless) (Insulin or OEM from jobber)

STRETCHING. Stretching bars are out. Heat shrinking is in. Stretchers have certain disadvantages:

1. They will not allow for any degree of controlled stretch.
2. You cannot determine what tension has been screwed in.
3. They do not allow for deviations in longitudinal tautness.
4. Not everybody has ready access to steel bars or equipment necessary to cut, drill and tap them.

To handle these problems and for further assembly simplification I offer the following two techniques.

In the first method, retension the Mylar over the plate glass; duct tape lets you apply greater tension than masking tape. Pull the Mylar as taut as possible and free it from any attraction to the glass.

Secure diaphragm contact near the outside edge of the panel with a small strip of tape.

DIAPHRAGM GLUING. Mix a syringeful of Devcon 5-minute epoxy in a plastic cup and apply it with a 10cc needleless syringe in serpentine pattern to B and C (*Fig. 2*). Stay ¼ inch away from the inside edges, apply spots in each outside corner and use it sparingly around the diaphragm contact and hole. Roger questions the need for this kind of glue line as opposed to a simple line down the center using less epoxy. Either is acceptable, but I believe you realize more structural integrity with the first method since it covers more surface area. In all cases, the glue lines must be thin so as not to add unduly to the gap size.

Because center strip G is quite narrow, apply a thin bead of epoxy along its center length only.

Hold the stator with the diaphragm contact away from you and at the opposite corner from the one that first comes in contact with the Mylar. Lower that corner of the stator onto the Mylar by positioning the stator along the edge of the plate glass. Work your way across the short side of the stator first, then along the long side closest to you. Finally let the rest of the stator contact the Mylar.

With J7–12 in place, weight down the assembly as before and leave for at least one hour.

After securely attaching the diaphragm, remove the weights and free the stator by cutting the Mylar all around an inch or so away from the edges.

Flip over the assembly with the Mylar on top and, using the mixing and application instructions above, apply a second glue line in a reverse serpentine (180° out of phase to the first) but to the border area of the Mylar instead of the stator frame. Likewise, apply epoxy to the Mylar over the center strip following the procedure outlined above. Using an awl, poke openings in the Mylar through the contact and alignment hole.

Lower this stator onto the Mylar following the above technique but with two awls, one for each hole. The awls will help align the two stators, since the edges of the other stator are insufficient as a guide.

After joining the two stators, remove the awl in the contact holes, replacing it temporarily with a metal screw. Add jigs J13–18 and weights to the assembly and leave it for a minimum of one hour. After five minutes, remove the second awl, and the screw when the panel is finished.

You can call this assembly a panel.

ALTERNATE METHOD. This method allows you to glue both stators at once, saving valuable time. You must enlist the aid of an able-bodied assistant and procure a piece of plywood large enough on which to tension the Mylar. The ½-inch thick plywood must have a window cut in its middle (*Fig. 4*). Size the window just larger than the stator and place finger cutouts to place and remove the stator and panel.

Place a stator, gap side up, in the window, along with J7–9 appropriately placed for added support. Place your clean plate glass over this.

Following the steps above, tension the Mylar and apply the conductive coating. Loosen three sides and fold the Mylar back, then remove the plate glass. Mix a batch of epoxy and apply it to the stator frame and center strip.

Carefully replace the Mylar, and using duct tape, apply maximum tension. While you are doing this, have your assistant mix a second batch of epoxy and apply it to the top of the Mylar as previously described. Next, poke the two openings in the Mylar and attach the diaphragm contact to the other stator.

With an awl for each of you and each holding the top stator on an end, position this unit above the Mylar and align it to the bottom stator with the awls as it is lowered to the Mylar.

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THE WALDRON PANEL

Set the remaining jigs (13–18) in place between the ribs of the top stator, then position the glass on top of the assembly and weight it down. Remove the awls and insert metal screws as above.

FINAL VENTURE. With weights and jigs removed, trim and clean the panel edges using an X-acto knife or single-edged razor blade.

Remove the metal screw if you haven't already and prepare to replace it with one of nylon. Before inserting the electrical hardware, determine which of the panels will be left, right, top and bottom. Pair up left and right and orient them so the contact holes of each set will be one above the other. This done, insert the screws, washers and any additional solder connectors to the front and rear portions of each panel and tighten down with a nut.

Note: Even though the metal screw keeps the contact hole open and provides more accurate alignment when mating the two stators, I found it necessary to clean the contact holes by running a drill bit through them prior to inserting the nylon screw.

Hair dryers do not heat Mylar enough to tension the diaphragm. Heat guns are better for the shrinking and final tensioning. Industrial varieties are available, but hobby shops market more reasonably priced machines.

Final tension the diaphragm by placing the panel on a chair, stool or other suitable surface and holding it upright with light reflecting off the Mylar. Run the gun from side to side directing the air downward or upward toward the Mylar. Applying the heat straight on does not work well. It takes only six seconds, or about two inches per second, to cover the span. As you do this, you will see wrinkles disappear.

You also will see the diaphragm tighten up as you move toward the bottom using slightly overlapping passes. Dallying in any one area will burn a hole in the Mylar. Several quick passes are better than one slow pass. Once the gun has covered the entire surface, set this panel aside and do the others. Note: Two or three separate sessions will probably be required for each panel. Touch up any wrinkles.

The ESLs are now ready for testing and mounting to the bass enclosure.

Continued from page 37

the joint in the insulators at the corner. I discovered the hard way that the joint usually has a void into which the conductive paint can run and touch the stator, resulting in a shorted cell. Keep close to the inside edge of the insulator, but be extremely careful not to get any paint on the edge of the insulator or drip onto the metal stator. Be particularly careful that the paint does not run down inside the hole. Put no paint near the outside edge of the insulator because you will need that area for gluing things together. If paint drips or runs, clean it off with a cotton swab soaked in acetone or paint thinner, or sand it off with sandpaper after it dries.

CONTACT TESTING. When the paint is dry, take an ohmmeter reading between the stator and the paint using the meter's megohms position. Any meter movement represents a short, which is easier to fix now than after you have assembled the cells. You can test the contact by connecting one side of your polarizing supply to the paint and the other to the stator. If it arcs, you will know exactly where the short is.

Your stators are now finished. Most builders believe they need to insulate them, since all the books on the subject recommend it, but I have found this neither effective nor necessary. Specifically, I have found no spray-on insulation that cannot be arced when I use very high polarizing and drive voltages, particularly when there are foreign objects such as insects in the speakers. I have found that uninsulated cells work beautifully and arcing does not damage them any more than it does insulated cells. Neither will be damaged by an occasional arc or a collapsed diaphragm, but both will develop a hole in the diaphragm if arced persistently by a foreign object. Fortunately, a few holes do not affect the sound. Insulation reduces cell efficiency, is expensive and troublesome to apply, so why bother? If you want to insulate your cells anyway, consult Barry's instructions.

For cosmetic reasons, you may wish to paint the outside of the stators flat black so they are essentially invisible behind a moderately sheer grille cloth. On the other hand, some gold showing through a black grille cloth is attractive.

DIAPHRAGM FABRICATION. Only Mylar, made by DuPont, is acceptable for the diaphragm. Imported imitations do not hold a high diaphragm tension and therefore do not allow a high polarizing voltage, which grossly reduces output. Mylar comes in many forms, but the ultrathin films we use (either ¼ mil or ½ mil) come only in types S and C. I have used type S with splendid results, but DuPont advises me that type C has the same characteristics. Type C is made to tight dimensional tolerances for use in capacitors, but this is unimportant for our use. Although Mylar is rather inexpensive, in recent years it has become nearly impossible to obtain in small quantities.

Mylar film is an insulator and therefore must be made slightly conductive for our use. The diaphragm must be slightly conductive so we can get an electrostatic charge on it. In theory, charge migration is a problem with low-impedance diaphragms. This means the electrostatic charge on the diaphragm will tend to move toward the area where the stator is closest to the diaphragm. This problem is worse at bass frequencies, since charge has more time to migrate and the diaphragm is driven closer to the stators.

Ideally, the conductive coating should be highly resistive (several thousand to

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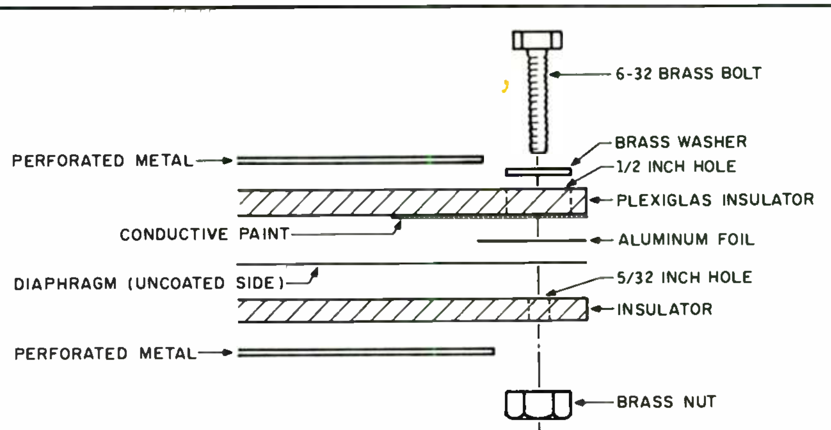


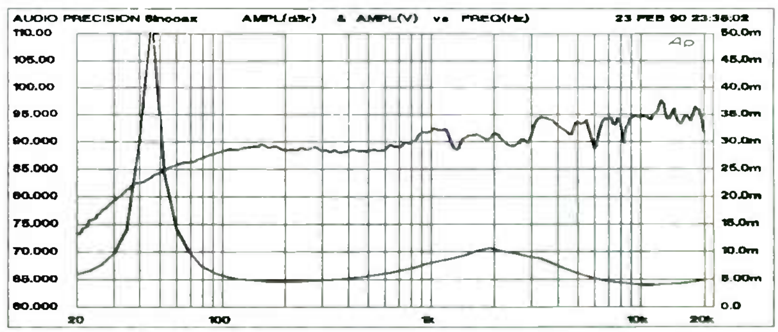
FIGURE 2: Diaphragm contact detail, side view.

Europa 8 Coax

For several years Madisound has been trying to develop a high quality eight inch coax. There were several prerequisites that an ideal drive unit would possess. It had to have a 1.5 inch voice coil for high power handling; it should produce good bass in small boxes and acceptable bass mounted in open air. It was important that this unit be efficient, but we could not achieve this by sacrificing low resonance. We had designed a bass drive unit that had many of these characteristics (our 81524), so we were able to work out an excellent bass section.

The tweeter required special attention, because all the small dome units available had sensitivity below the level of the woofer. The Europa 8 Coax became a reality when Audax of France released a series of very high energy tweeters. These units have a low resonance of 2000 Hz. The pole piece extension is a new type made from unbreakable solid aluminum. When coupled with a quality film capacitor, the sound is smooth and very precise.

The Europa 8 Coax is a fine high fidelity reproducer on one frame. It should give precise reproduction from 50 to over 20K hertz. It incorporates a gentle rise in output, making it very useful for autosound reproduction. Moreover its high power handling should make in-the-wall stereo a reality.



Europa 8 Coax Suggested Alignments					
Box Volume Liter	14	21	21	28	35
Bass ½ Power F3	71	70	51	44	39
Box Vent Freq. Fb	Sealed-No Fill		36	36	28
Port Diameter "			2	2	2
Port Length "			7.4	5.15	7.29

Europa 8 Coax	
Fs	38.4
Mmd	26.6 grams
Cms	627 m/n
Vas	39.9 Liters
Rscc	3.62 Ω
Zmin	4.7 Ω
Zmax	51 Ω
vcL	.6 @ 1K
Bl	7.3 T/M
Qms	7.46
Qes	.44
Qts	.41
Xmax	2.5 mm pk
VD	50 cm^3
Surround	Foam
Magnet	20 oz.
Voice Coil	38 mm
Power Handling	75 Watts
Freq. Response	40-21KHz
Efficiency	90 db
Uses	Auto, home
Price	$49.00
8 Inch Auto Sound Steel Grill	$7.50

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Fast Reply #FE593

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several million ohms depending on the lowest frequency of interest) to prevent this. Peter Walker (designer of the QUAD ESLs) refers to this as constant-charge operation.

Although this has been accepted as gospel in the past, it has become somewhat controversial recently because aluminum coated diaphragms also can work very well, and they are very low impedance as demonstrated by the Beveredge ESL. However, I do not recommend aluminum coated diaphragms because they are too massive and may burst into flames if they arc. This is not a problem with high impedance diaphragms.

Since low impedance diaphragms work very nicely (another case in which practical experience supersedes theory), we need not worry about exactly what diaphragm resistance we get. Graphite-coated diaphragms, as outlined below, typically have impedances between 10 and 100kΩ per inch and work beautifully. Thus I believe you can safely ignore everything you may have heard about trying to achieve some particular resistance.

GRAPHITE COATINGS. Diaphragms may be coated with many materials. Almost anything works—for a while. Most of the spray-on antistatic coatings work very well initially, but the adhesive eventually evaporates, vibration causes the coating to come off, and the cell dies. Experiment if you wish, but if you want to use a coating that has withstood the test of time, use graphite. Fine powdered graphite is available for a dollar or so from any hardware store, commonly used to lubricate locks. Pencil lead rubbed against fine sandpaper also is an excellent source of powdered graphite. Rather than relying on some type of adhesive (very few of which adequately bond to Mylar), you can grind graphite into the Mylar surface so you know it will not come off. Despite the fact that many builders seem intimidated by this process and prefer to use some type of liquid or spray coating, making graphite-coated diaphragms is a simple task. The following directions are very detailed because of all the calls and questions I have received in the past about diaphragm coating.

The main hazard to graphite rubbing is tearing the film on grit between the glass and the Mylar. Both materials must be very clean. If you clean the glass and the Mylar with acetone on a paper towel, you should have no problems. Acetone is the only acceptable cleaning agent because it cuts grease, will not dissolve Mylar, evaporates without a trace, is an effective epoxy solvent, and is nontoxic in small quantities. This is particularly important because you will be working indoors. Acetone is also inexpensive and available from any hardware or paint store. I cannot stress too strongly that *acetone is extremely flammable*. Treat it accordingly.

The only other solvent I might recommend is distilled water. It is not as good as acetone because it is slow to evaporate and does not cut grease or epoxy. However, it is nontoxic, will not burn, and doesn't stink.

Keep windows closed and fans off during cleaning so you don't stir up dust. It is also a good idea to damp-mop the floor and the work area to pick up as much dust and grit as possible before starting. Vacuum cleaners are forbidden, as they only blow dust around.

HANDS OFF. Cut a piece of Mylar a little larger than your glass. Fingerprints do not accept graphite very well, so keep your hands off the surface you will be making conductive. Dave Lang (*SB* 6/88, pp.18–25) recommends cotton or thin latex gloves to solve this problem. You can always wipe fingerprints off the Mylar with acetone if necessary. Wipe the glass with a paper towel wetted with acetone. If you feel any lumps of epoxy or anything else on the glass, scrape them off with a single-edge razor blade and wipe again with acetone.

Lay the Mylar over the glass. Unless the glass is much larger than the cell, give yourself a couple of inches of Mylar border. With a dry paper towel, gently rub the Mylar with about one pound of pressure from the center to the edges of the glass while gently pulling on the edge of the Mylar with your other hand. The object is to smooth it out, get rid of the major wrinkles, get it to stick to the glass, and find the grit.

When the wrinkles are out, wipe with about five pounds of pressure. Using a strong light will reveal little "tents" in the Mylar caused by grit trapped between the Mylar and the glass. Lift the edge of the Mylar and wipe away any grit that forms a tent larger than about ⅛ inch across. Smaller ones are okay unless they are very sharp or pointed. Incidentally, you may notice creases in the Mylar that appear as fine lines. Ignore these; heat shrinking will remove them.

Tape down the Mylar every four to six inches all the way around. Tape the corners first, then put tape halfway between the corners, then tape halfway between that, then halfway between that until you have a piece of tape about every six inches. Now there should be no wrinkles in the Mylar. It is easy to pull the diaphragm quite tight as you tape it down. You need not get it perfectly smooth at this stage because the heat shrinking will do this for you later. It takes me less than five minutes to lay out the Mylar, smooth it, remove the grit, and tape it down.

Sprinkle a little graphite on the Mylar and rub it in gently with a clean, dry paper towel. A light-colored tablecloth or white paper under the glass will make it easier to see the graphite on the diaphragm.

ELBOW GREASE. Now it is simply a matter of rubbing hard to grind the graphite into the Mylar. It is not as difficult as Barry makes it sound. I just use a paper towel and the heel of one hand placed beneath the other and rub hard back and forth, making sure I cover the entire area. The key is to rub hard. I lean on my hands with virtually all my weight. Unlike Barry, I don't worry about slate buildup, and I don't care what resistance the diaphragm has. I don't even bother to measure it anymore. If the diaphragm looks gray and I've rubbed hard, I know it will work perfectly and indefinitely.

Remove the excess graphite with a clean, dry paper towel. Don't be afraid to rub hard. You won't be able to rub off all the coating. If you can, you didn't rub it in hard enough to begin with. Wipe a couple more times with clean paper towels until no more graphite comes off. If you don't clean off the excess, the cell will hiss when first placed in operation until the excess graphite burns off.

Cut a piece of aluminum foil about ¾ inch by two inches. This will be placed under the diaphragm contact screw.

Epoxy is easiest to mix in a one-ounce plastic medicine cup obtained from a doctor's office or a hospital. Some hobby shops also carry them. If you can't find any, use a small plastic cup or the top of a spray-paint can. Do not mix epoxy in a waxed paper cup, as the wax often comes off and contaminates the epoxy, resulting in a loss of bond strength. Use a small Popsicle stick for mixing. Mix about 10cc and stir for at least one minute. A heat gun can reduce the epoxy viscosity if you wish, but this will increase the reaction rate and reduce the pot life, so work rapidly if you use heat.

EPOXY. If possible, use a 10cc dispos-

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Have information plus MC/VISA available.

Continued from page 44
able syringe without a needle to suck up the epoxy. Squirt a small bead (about ⅛ inch wide) down the center of each insulator on one of the stators that has the large diaphragm contact hole with conductive paint. When you get to the diaphragm contact area, move the bead of epoxy to the outside edge so that the paint is free to contact the diaphragm rather than being coated with an insulating film of epoxy. Avoid the tendency to use a lot of epoxy because it will form a thick film and tend to run down the edges of the insulators. I mix about 10cc, am able to suck up about 6cc in the syringe, and actually use about 5cc per stator.

After you have applied the epoxy, put the aluminum foil over the diaphragm contact hole. It should cover the width of the insulator and it will lie on the bead of epoxy. Do *not* allow the foil to extend past the inside edge of the insulator, or it might short the cell. Carefully flip the stator over and set it on the diaphragm. Press hard on the insulators all the way around and up the middle. The object is to squeeze the epoxy into a thin film. Be careful that you do not slide the stator around and smear the epoxy. Put the glass or steel sheet on top, weight it, and let the epoxy catalyze.

The epoxy cures much faster in the cup or syringe than it does in a thin film, so be sure it has cured well before removing the assembly from the glass. To free the Mylar from the glass so you can lift the assembly, cut it along the perimeter of the glass with a razor blade. Then carefully lift one end of the assembly to allow air to enter; otherwise, the assembly will tend to stick to the glass. Even though the Mylar was free from wrinkles when you glued the stator to it, you will probably find that it now has a few small wrinkles. Don't sweat it; you're in good shape.

With your thumb, gently press on the Mylar at the diaphragm contact hole. This will clearly outline the hole. The next step is critical. Use a sharp pencil, awl, or other sharp object to gently puncture the aluminum foil at the diaphragm contact. Puncture from the diaphragm towards the insulator so you don't tear the diaphragm away from the insulator. Remember that you did not put epoxy between the Mylar and the aluminum foil, so this area is vulnerable to disruption if you are not careful. The hole you make should be only as large as the shank of your diaphragm contact screw. It must be centered in the hole in the stator. Be careful to keep it small. If you make it as big as the hole in the stator, you will have no place to contact the diaphragm after the cell is assembled, and you will have to put in a new diaphragm.

HEAT SHRINKING. A heat gun will shrink the diaphragm so it is tight and wrinkle-free. Guns are available from a hobby shop or hardware store for about $20, or if you ask around, you can probably borrow one. Do not substitute a hair dryer, as they simply don't get hot enough. Heat guns vary in power and heat. The common hobby type is rated at 900W and has little vents on the back that can sometimes be adjusted to control the heat output.

Test your gun by having someone stretch a scrap of Mylar between their hands while you heat it with the gun. The object is to determine how much heat you can apply without melting the Mylar. Effective heat shrinking requires that you almost, but not quite, melt the Mylar. I generally find that leaving the vents wide open while holding the gun one to two inches from the film is about right. You have it right when you can hold the gun stationary and the Mylar will not melt. By adjusting the distance from the film and the vent openings, you can easily determine the safe zone.

Hold your stator/diaphragm assembly vertically while passing hot air from the heat gun over the diaphragm in a slow, uniform motion. I move the gun at about four inches per second and cover about a two-inch path with each pass down the cell. This is really very easy to do and takes less than a minute. One pass will do the job unless you have huge wrinkles in it. Feel free to heat and shrink repeatedly until you get the diaphragm smooth and tight. There is a limit, as the Mylar will shrink only about 10% maximum. This is plenty for all but the sloppiest construction. Forget anything you might have heard about exactly how much tension you should have on the diaphragm. You can't get it too tight, but you sure can get it too loose! Get it as tight as you can, since more tension allows you to use higher bias voltages, which gives you more output.

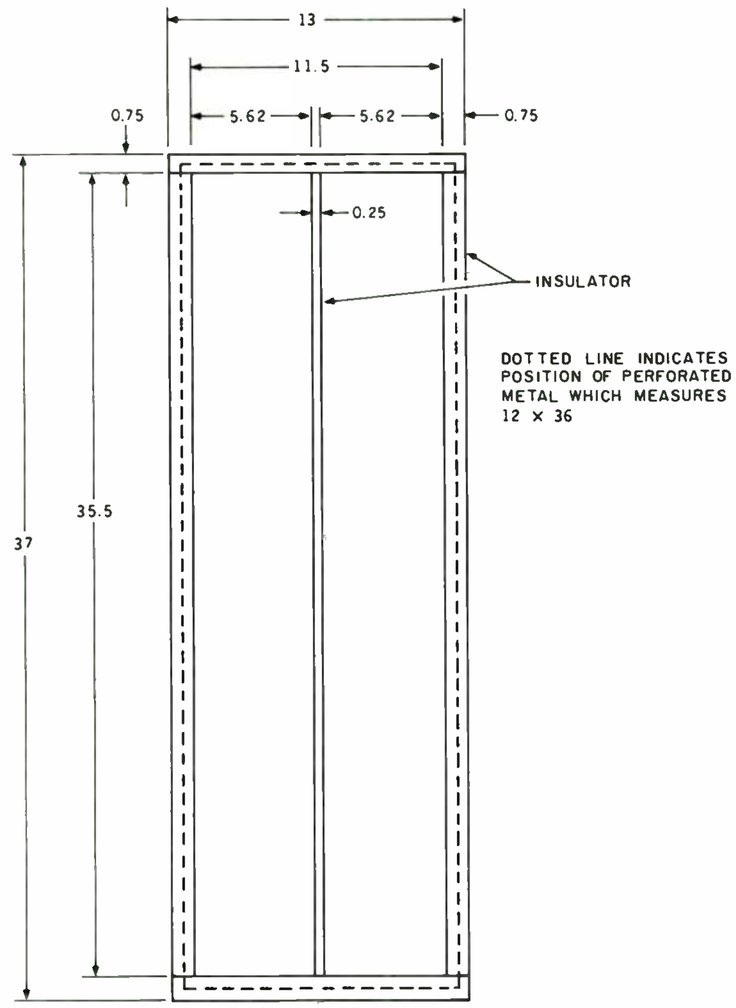

FIGURE 3: Insulator pattern and dimensions.

REHEATING. The diaphragm may relax a little after the first application of heat. It is a good idea to reheat it about a day later, after which it will stay tight. Some builders use mechanical stretching devices to tension the diaphragms. These work, but generally you cannot get the diaphragm as tight as with heat shrinking and the diaphragm will still tend to relax, although to a lesser degree.

You can always touch up the diaphragm in the future by heating it when the cells are mounted, although this is not normally necessary. Once the diaphragm is thoroughly shrunk, it will remain so. Problems occur if the cell is stressed during shipment or by accident, causing the diaphragm to go slack. It is wonderful to be able to retension the diaphragm rather than having to replace it.

If you are using steel wire stators, simply heat the diaphragm on one side as though there were no stator present. If you are using perforated aluminum stators, the aluminum will expand from the heat, which will cause the cell to bow and break glue bonds. The ideal way to handle this is to use two heat guns, one on each side opposite each other. It is possible to use one heat gun by briefly heating one side, then quickly switching to the other side, and then back again. Both these techniques will result in fairly even expansion of the aluminum and prevent broken glue bonds.

When you are satisfied with the diaphragm, put epoxy on the other stator in the matched pair and set it on top of the diaphragm. Look *very* carefully at the diaphragm contact hole. The puncture you made in the Mylar must be centered under the hole in the second stator so that you can put the diaphragm contact screw through it. Again, put the glass over the assembly and weight it. Before leaving, double-check the alignment of the diaphragm contact to be absolutely sure that the two holes are centered on each other.

TRIMMING. When the epoxy has cured, gently lift the assembly. Nothing sticks to graphite-coated Mylar very well, not even epoxy. The glue joints are adequate, but they can be broken if abused. The assembly will be amazingly rigid and flat and will have no give, so if you force the assembly into a curve, the glue bond will fracture. Use a sharp new single-edge razor blade to trim the Mylar. The Mylar will quickly dull the blade, so you should throw it away after trimming one cell. Use a new blade for each cell. You can remove the last fragments of diaphragm from the edges by rubbing a medium-grit sandpaper along the edge, but this is not usually necessary.

Bend up the stator contact tabs and insert 6/32 brass contact bolts. Using a small washer under the head of the diaphragm contact bolt, carefully push it through the diaphragm hole. This goes through the large hole first so that the head and washer contact the aluminum foil. Add the nut and gently tighten. When connecting wires to these contact bolts, avoid excessive tightening or rotating of the bolts, which could damage the contacts on the diaphragm or stators. Your cells are now complete.

When you first fire them up, they will make a faint hissing sound. I believe this hiss is caused by excess graphite on the diaphragm and it is temporary. If you test them with music alone, without equalization, woofers, and the baffling effects of the TL cabinet, you will be disappointed in the SPLs and frequency response. Hang in there; there is nothing wrong. This is a *system*, and when all the parts are working together, the sound will be splendid.

TROUBLESHOOTING. The foregoing instructions have 17 years of mistakes behind them. I have tried to advise you of all the pitfalls involved in constructing your cells, and it is unlikely that the cells will not work if you follow the directions closely. Writing a troubleshooting section suggests that the speakers are going to be difficult to build and operate and you are going to have problems. Actually, the cells are quite reliable and easy to construct, but I know how frustrating it is to have something not work and not have the slightest idea of what the problem is or how to fix it.

If the cell does not work, only three things can be wrong. First, make sure you have polarizing and drive voltages at the connections to the cell. If you do, there are only two possible problems with the cells themselves. The most common is that you have a short between the diaphragm and one of the stators. This is usually a foreign object and can usually be removed by vacuuming the cell with a soft brush or blowing out the cell with compressed air. Possibly conductive paint ran down the edge of the stator insulator or into the hole. If you painted the stators with insulation, it is possible that you have some conductive object embedded in the paint.

The other problem may be caused by something conductive on the outside. Keep in mind that even though you trimmed off the diaphragm, it is easy to make electrical contact with the diaphragm anywhere along the edge. Look closely for something touching the edge of the cell that is also touching a stator. That something may be quite insignificant and still cause problems. Usually the short is fairly easy to find and correct, but if it isn't, you must tear down the cell and put in a new diaphragm.

SHORTED DIAPHRAGM. It is rather easy to determine which stator has the short. Connect only the two stator connections (you need not play music, but it doesn't hurt to do so during testing). With the polarizing voltage on, bring the diaphragm contact wire slowly up to the diaphragm contact. Almost, but not quite, touch the diaphragm contact with the wire. In a properly operating cell, there will be a slight momentary arc as the current charges the diaphragm. In a shorted cell, the arc will be much larger and will persist. You will usually hear a pronounced pop from the speaker when it is first connected as well.

You can tell which stator is shorted by removing one of the stator connections and again bringing the polarizing voltage wire slowly to the diaphragm contact. Alternately connect and disconnect one stator at a time. The shorted stator will cause persistent arcing. You can usually tell by connecting an ohmmeter between the diaphragm contact and the stator contact. Keep in mind that the short may be several megohms and still render the cell inoperable. Ohmmeters don't always identify the problem, as the foreign material may not actually be making contact between the diaphragm and stator. The meter, which measures at low voltage, will see an open circuit. But when a high voltage is applied, it will arc and prevent the use of the necessary high voltages.

It is also possible that you have a stator in which the aluminum is not flat or a wire stator in which one or more wires are bent or detached from the support structure. You can prevent warping by

Continued on page 77

ESL PARTS LIST

Qty.	Description
16	1/16″ acrylic insulators, 0.75 × 35.5″
16	1/16″ acrylic insulators, 13″
8	1/16″ acrylic insulators, 0.25 × 35.5″
4	Lincaine perforated aluminum sheets, 24 × 36″
1	Mylar film, 0.5 or 0.25 mil, 48″ × 20′
1	Epoxy, 5 or 30 minute, 9 oz. bottles
12	Bolt, washer, nut, brass, 6-32 × 1/2″
1	Conductive paint, LocTite "Quick Grid"

KITS from OLD COLONY

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FILTERS & SPEAKER SAVER

KH-2: SPEAKER SAVER AND OUTPUT FAULT DETECTOR [3:77]. This basic two-channel kit includes board and all board-mounted components for control circuitry and power supply. It features turn-on and off protection and fast optocoupler circuitry that prevents transients from damaging your system. The output fault detector has additional board-mounted components for speaker protection in case of amplifier failure. **$65**

KF-6: 30Hz RUMBLE FILTER. [4:75] This kit implements a 1975 design for a low frequency garbage filter. The filter knee is set to 30Hz. Roll-off below that knee is the 18dB/octave characteristic of its three pole design. Gain for the filter is unity (0dB) but can be simply adjusted for up to 12dB of gain. The reprint of the article explores the use of the filter with other components in crossovers (see kits SBK-C1A, C1B). It shows how to obtain slopes of 6, 12 or 18dB in high and low pass filters. The kit contains all parts for building a two channel HPF including a board (3" × 3"), quad op amp IC, precision resistors and capacitors. Requires a bipolar supply of ± 15V, the KE-5 is suitable. **$30**

AIDS & TEST EQUIPMENT

KK-3: THE WARBLER OSCILLATOR [1:79]. This unit will produce a swept signal covering any ⅓-octave between 16Hz and 20kHz. The total harmonic distortion at the output is less than 1.5%. The output voltage is adjustable from 0 to 1V. When used with a microphone it is as effective as a pink noise source in evaluating speaker system performance. It also reveals the listening environment's effect on sound through reflection and absorption. The sweep rate is set at about 5Hz. The kit includes 3¼" x 3⅞" circuit board, transformer, all parts and article reprint. **$70**

KH-7: GLOECKLER PRECISION 101dB ATTENUATOR. [4:77] All switches, 1% metal film and 5% carbon film resistors to build prototype. Chassis, input/output jacks are not included. **$65**

KC-5: GLOECKLER 23-POSITION LEVEL CONTROL. [2:72] All metal film resistors, shorting rotary switch and two boards for a two-channel, 2dB per step attenuator. Choose 10k or 250kΩ. **$48**

KL-6: MASTEL TIMERLESS TONE BURST GENERATOR. [2:80] All parts with circuit board. No power supply. **$24**

KP-2: TWO TONE INTERMODULATION TEST FILTER. [1:82]. This filter is designed to isolate the two high frequency tones at an amplifier's input from low frequency intermodulation products present at the output. The high pass filter corners at 2kHz and rolls off at 24dB/octave. A 5kHz signal at the low pass input will be down at the output by 80dB. An article reprint detailing design and use is included with the kit. All parts are supplied including quad op amp IC, circuit board and precision resistors and capacitors. **$26**

SBK-D2: WITTENBREDER AUDIO PULSE GENERATOR. [SB 2:83] All parts, board, pots, power cord, switches and power supply included. **$80**

SBK-E4: MULLER PINK NOISE GENERATOR. [SB 4:84] All parts, board, 1% MF resistors, capacitors, ICs, and toggle switches included. No battery or enclosure. **$35**

CROSSOVERS

KC-4A: ELECTRONIC CROSSOVER, KIT A. [2:72] Single channel, two-way. All parts including C-4 board and LF351 ICs. Choose frequency of 60, 120, 240, 480, 960, 1920, 5k or 10k. KE-5 or KF-3 supplies are suitable. **$14**

KC-4B: ELECTRONIC CROSSOVER, KIT B. [2:72] Single channel, three-way. All parts including C-4 board & LF351 ICs. Choose two frequencies of 60, 120, 240, 480, 960, 1920, 5k or 10k. **$18**

KK-6L: WALDRON TUBE CROSSOVER LOW PASS: Single channel, 18dB/octave, Butterworth, [3:79] includes three-gang pot. Choose 1: 19-210; 43-465; 88-960; 190-2100; 430-4650; 880-9600; 1900-21,000 hertz. **$60**

KK-6H: WALDRON TUBE CROSSOVER HIGH PASS: Single channel, 18dB/octave, Butterworth, [3:79] includes three-gang pot. Please specify 1 of the frequencies in KK- 6L. No other can be supplied. **$62**

KK-7: WALDRON TUBE CROSSOVER POWER SUPPLY. [3:79] Includes board, transformer, fuse, semiconductors, line cord, capacitors to power four tube crossover boards (8 tubes), 1 stereo bi-amped circuit. **$110**

SBK-A1: LINKWITZ CROSSOVER/FILTER. [SB 4:80] Three-way crossover/filter/delay. 24dB/octave at 100Hz and 1.5kHz and 12dB/octave below 30Hz, with delayed woofer turn-on. Use the Sulzer supply KL-4A with KL-4B or KL-4C.
Per channel **$75** Two channels **$140** SBK Board only **$25.50**

SBK-CIA: ELECTRONIC TWO-WAY CROSSOVER. [SB 3:82] 30Hz filter with WJ-3 board & 4136 IC adapted as one channel crossover. Can be 6, 12 or 18dB/octave. Choose frequency of 60, 120, 250, 500, 1k, 2k, 5k or 10k. The KL-4A/KL-4B or KW-3 are suitable supplies. **$32**

SBK-C1B: THREE WAY, SINGLE CHANNEL CROSSOVER. [SB 3:82] Contains 2 each SBK-C1A. Choose high & low frequency. **$60**

SYSTEM ACCESSORIES

KW-3: BORBELY IMPROVED POWER SUPPLY [1:87] This single channel, low impedance supply was designed for the exacting requirements of Erno Borbely's moving-coil preamp [2:86, 1:87]. The design utilizes polypropylene caps and 1% metal film resistors. LM317/337s are used in the preregulator and Signetics NE5534 in the op amp regulator. The kit includes a low profile 24V toroidal transformer, 4¼" × 5½" circuit board and all board mounted components. Chassis and heatsink are not included. **$135** Two or more **$128**

KE-5: OLD COLONY POWER SUPPLY. Unregulated, ± 18V @ 55mA. **$20**

KF-3: GATELY REGULATED SUPPLY. ± 18V or ± 15V @ 100mA. **$52**

KL-4A: SULZER POWER SUPPLY REGULATOR. **$40**

KL-4B: SULZER DC RAW SUPPLY. ± 20V @ 300mA. **$60**

KL-4C: SULZER DC SUPPLY w/toroidal transformer. **$85**

KH-8: MORREY SUPER BUFFER. [4:77] All parts, 1% metal film resistors, NE531 ICs, and PC board for two-channel output buffer. **$22**

SBK-E2: NEWCOMB NEW PEAK POWER INDICATOR. [SB 2:84] All parts & board, new multicolor bar graph display; red, green & yellow LEDs for one channel. No power supply needed. **$14** Two for **$22**

KL-2: WHITE DYNAMIC RANGE & CLIPPING INDICATOR. [1:80] One channel, including board, with 12 indicators for preamp or crossover output indicators. Requires ± 15V power supply @ 63 mils. Single channel. **$58**
Two channels. **$110** Four channels. **$198**

KW-1: MAGNAVOX CD PLAYER MODIFICATION. Improves frequency response. Includes two Signetics NE5535s, two Panasonic HF series 330μF capacitors and four 3.92k, 1% metal film resistors. **$12**

KW-2: MODIFICATION. As above, but with two AD-712 op amps in addition to the NE5535s. **$16**

KX-1A: DISC STABILIZER. Set of 3 Sorbothane feet, 3 Tiptoes and Mod Squad's Disc Damper with 15 centering rings. **$70**

KY-1: BEERS' BUDGET CD MOD. [1:89] Kit provides POOGE-4 improvements without additional wiring or circuit boards. Complete parts for assembling amplifier modules and replacing DAC components. Article reprint included. Soldering skills required, not recommended for beginners. **$95**

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, faceplace, 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 *TAA* and *SB* are helpful guides. Articles 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.

Software Report

Two-Way Active Crossover Program

by Robert M. Bullock, III

Two-Way Active Crossover Design Program, by **Gary** Galo. Available from Old Colony Sound, PO Box 243, Peterborough, NH 03458, (603) 924-6371; $20.

This program calculates the component values for the active two-way crossover networks described in my article, "Passive Crossover Networks, Part III" (*SB* 3/85, p. 14). I provided some component value tables, but they were necessarily limited to a small number of crossover frequencies. With this program you can now obtain component values for any frequency.

The program is quite straightforward. Simply choose crossover type and order from a menu, provide the crossover frequency and a single capacitor value, and the program takes care of the rest. It not only provides the component values, but also will display the circuit if you like.

I restricted the tables in my article not only as to crossover point but as to capacitor value as well. This program has no such restriction. You can supply any capacitor value, so you are more apt to be able to use what you have on hand. Remember, only two values are used in the circuits. If the selected value is C, then the other value you may need is 10C, which is standard if C is.

The program produces accurate values (as long as you provide the correct input) and will save you a lot of calculation, especially if you want to play with various crossover frequencies and/or types.

If you have not considered using active crossovers, I encourage you to rethink your position. While they are not inherently better than passive networks, they offer the home builder a convenience and versatility in the absence of sophisticated measuring capabilities. Once the active approach is incorporated into your system, you can avoid some load matching problems. You can deal easily with sensitivity matching by adding a gain control or volume stage. You can even add stages to handle various types of response equalization.

If you decide to convert to active crossovers, this program will allow you to obtain acceptable crossover circuits. By keeping your crossover points a decade or more apart, it should even provide acceptable three-way networks by cascading two two-way networks.

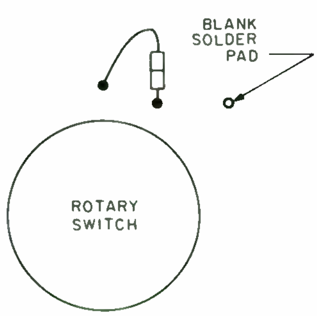
Tools, Tips & Techniques

FLUKE UPGRADE

Owners of the very popular Fluke Model 75 can convert this precision meter to include all the features of the top-of-the-line Model 77. The mod is simple, requiring only a jumper relocation.

If you open the Model 75, you will find a jumper above the rotary switch at about 1 o'clock (display on top, battery below). The jumper in my unit looked like a resistor with a single black band, but others may differ. The jumper has a blank solder pad to its left.

Remove the jumper and move it one space to the left; it will then look like this:



Reassemble the meter and it will operate as before. To access "Touch-Hold," turn the unit off, then turn the switch to any position while holding the center button down for a few seconds. To revert to standard operation, turn the unit off and on again.

Concerning accuracy, both the Model 75 and 77 are produced on the same line with similar components. Technicians at Fluke have advised that accuracy is the same, but guarantees are different.

Matthew Honnert
Carol Stream, IL 60188

WOOFER ALTERNATIVE

Much has been written in recent years about using a compound ("Isobarik") woofer to obtain deeper bass. Given two identical woofers in this configuration, with their voice coils in parallel, you have a compound driver with unchanged F_S

Only real reason?

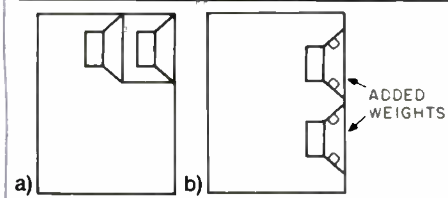


FIGURE 1: a) Compound woofer. b) Alternative woofer combination.

and Q_{TS}, half the previous V_{AS} (meaning you can use a smaller box), half the previous impedance, and unchanged sensitivity (*Fig. 1a*).

Suppose, instead, we put both woofers on the front baffle in a normal configuration, parallel the voice coils, and add weights to double the cone mass of each woofer (*Fig. 1b*). Now, compared to a single unaltered driver, F_S is $1/\sqrt{2}$ times its normal value, Q_{TS} rises $\sqrt{2}$ times, V_{AS} is *doubled*, impedance is halved, and sensitivity is unchanged (since each driver has 6dB lower sensitivity on its own).

Let's compare the results for a typical high-quality 6½″ driver, the SEAS P17RC4. (Notice that with either arrangement, distortion due to suspension nonlinearities can be partially cancelled by monitoring one woofer backwards and reversing its electrical connection.)

	Single	Compound	Alternative
F_S	37Hz	37Hz	26Hz
Q_{TS}	0.23	0.23	0.32
V_{AS}	36 liters	18 liters	72 liters
Sens.	91dB	91dB	91dB
Imp.	8Ω	4Ω	4Ω

Now, given a 28-liter (1-cubic-foot) sealed enclosure, we have these results for the compound driver: F_{CB} = 50Hz, Q_{CB} = 0.3. The alternative driver in the *same* 28-liter enclosure gives: F_{CB} = 48Hz, Q_{CB} = 0.6. This means the compound driver is about −10.5dB at 50Hz, while the alternative approach gives about −4dB at 50Hz, a 6.5dB improvement.

Clearly, in this situation the approach shown in *Fig. 1b* gives significantly better bass than the compound approach, yet has the same sensitivity and impedance.

As a bonus, higher SPLs are possible with the alternative approach, since the total driver surface area is double that with the compound arrangement. (Also you don't need to worry about the compound driver's high frequency problems.)

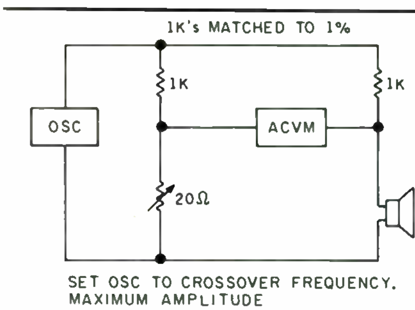
Of course, there may be other situations where the compound arrangement has a genuine advantage. Just be aware that there are sometimes better ways to use your woofers.

Ralph Gonzalez
Wilmington, DE 19803

MEASURING R AND L

We use Zobel networks to make the impedance of a woofer look like a resistor. Since most crossovers are designed to drive resistors, we need Zobels for good performance.

To design a Zobel, you must know the resistance and inductance of the woofer. This procedure is a simple yet accurate way to measure a woofer's R and L using a digital multimeter and oscillator.



- Adjust the potentiometer to give the minimum ACVM reading. Record the AC voltage as V_{NULL}.
- Short the speaker. Record the AC voltage as V_{SHORT}.
- Remove and measure the pot. Record its resistance as R_{NULL}.

$$R = R_{NULL}$$

$$L = \frac{R_{NULL} * V_{NULL}}{2 * \pi * FREQ * V_{SHORT}} \text{ Henries}$$

where FREQ is the oscillator frequency (Hz).

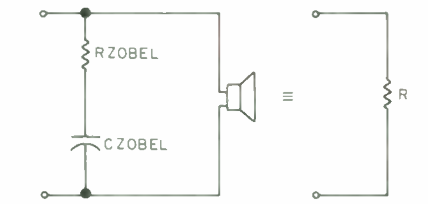
The values of R and L for woofers change with frequency (R is usually larger than the DC resistance of the woofer). By setting the oscillator to the expected crossover frequency, the results will be optimized for your application.

Once the woofer impedance is known,

the Zobel component values are calculated using:

$$R_{ZOBEL} = R$$

$$C_{ZOBEL} = L/R^2 \text{ (Farads)}$$



Mark Rumreich
Indianapolis, IN 46220

REFERENCE
M. R. Knittel, "Impedance Compensating Crossover," *Speaker Builder* 1/83, pp. 11-14.

A STABLE FOUNDATION

Over the past five years, the idea that rigid stands with spiked feet for speakers—as well as for virtually all other audio equipment—improve performance tremendously has spread out from the English audio lunatic fringe to even the great North American mass market. It's a simple idea which is very effective, and very audible, as many *SB* readers can probably confirm. Some enthusiasts would even go so far as to say if your stands are not made of steel and spiked for highest strength and rigidity, then you're not getting the best from your equipment. But simply having spikes is not the point; making a firm stable foundation for your equipment is the objective. Carpets sometimes get in the way of this goal.

Some carpets, especially when combined with a thick underlay, are virtually impossible for spikes (on stands) to penetrate effectively. On such carpets, spiked stands are no better than unspiked ones, wobbling easily with even a gentle touch. This is especially true with smaller, lightweight speakers. The problem is the lack of firm and direct contact with the floor. Here are two solutions, one for a wood floor, and one for cement.

On wooded floors, sink Phillips or Robertson head wood screws through the carpet into the floor so that each spike on the stand sits firmly in a screw head. The slot in the head must be large enough for the spike to fit, and its length adequate to penetrate the carpet and go ¾" (or more) into the floor. From experience, a 1½" long #10 screw works well, and common sense suggests that all things being equal, a larger screw will likely provide firmer support. If you sink them down deep enough, the screws are invisible once the stands are installed upon them. Damage to the carpet is minimal, although you may feel such treatment is unacceptable for your expensive Persian.

Start by determining precisely where you want your stands (and speakers, naturally). Place the stand—with spikes attached—on the carpet and press down hard on the top. You may want to put all your weight on it. When you remove the stand, the spikes will have made indentations in the carpet, where you will install your screws. An electric drill with the appropriate screwdriver bit is very handy here. When all the screws are installed at roughly the same height, check to see if the spikes on the stand fit into the screwheads. Invariably, one or more screws will be slightly off the mark. Use a hammer to tap the screws lightly to the correct position; if a screw is any more than a quarter inch out of position, reinstall it altogether. Checking the stand/screws fit more often, each time after a screw is installed, may provide more precise alignment.

After the screws are correctly aligned, make sure each spike (on the stands) seats firmly in its screwhead. A light lateral force applied to the stand from any direction should not produce a rocking motion. Adjust the spikes on the stands to achieve this result (this is easier than adjusting the height of the screws as the hammer alignment process will have bent some of the screws) and retighten their retaining nuts securely when finished. A final touch is to apply a drop or two of hot glue (from a hot glue gun) onto each screwhead, and then mount the stand onto them so that each spike is seated firmly but cannot rattle against the screw.

With cement or concrete floors, the simplest solution is to drill tiny holes in the carpet and underlay. These holes need to be just large enough for the spikes to go through to the floor below. A drop or two of hot glue on each exposed floor point will help to dampen the cement-to-steel spike interface.

For music/audio aficionados handicapped with plush carpets, this screwing technique may be the only way to experience first-hand the improved transient response, dynamics, clarity, and sheer musicality of rigid, spiked stands.

Mike Chin
Vancouver, BC
Canada V5W 2V7

HOME-BREWED GASKETS

Several different types of gaskets are used to mount woofers on baffles: foam gaskets, rubbery gaskets, and even some that are cardboard-like.

Foam gaskets are made from the same material used for air-conditioner and window insulation and must be compressed tightly between the woofers and baffle to ensure a good airtight seal. The rubbery gaskets are usually paper-thin and fragile. These also require tight pressure against the baffle to be effective. Some feel this tight coupling of the woofer to the enclosure adversely affects sound quality through transmission of vibration and resonance.

Unfortunately, many woofers do not come with the gasket necessary to obtain a good seal when mounted on a system baffle. What do you do if proper gaskets are just not available in your area? My suggestion is make your own.

Latex caulk and silicone are widely available. For a few dollars, you can buy the necessary caulk and caulking gun almost anywhere in the US. Lay your woofer down magnet side up. Assess the width of the woofer frame's edge and determine whether you want to lay down one wide thick strip of caulking on the back of the frame or whether you prefer to lay down two narrower concentric strips. This will determine how much of the caulk container's tip you cut off. Allow to dry at least 24 hours.

You will have a thick rubbery gasket that not only will provide the airtight seal you need, but also will damp vibrations transmitted from woofer to enclosure cabinet and vice versa.

Once you've mounted the woofer on the cabinet and tightened the screws, apply a thin layer of caulking around the circumference of the woofer and smooth this out with your finger.

Remember to seal the woofer's mounting holes as well and you will be assured of an airtight seal at the point of your system's driver(s).

As a final note, to preserve your caulk and prevent it from drying and hardening inside its container (remember, on opening it you've exposed it to the drying effects of air), I recommend clay or duct-seal to seal up the container tip instead of the plastic tip cover that usually comes with caulk.

Angel Luis Rivera
Brooklyn, NY 11204

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Fast Reply #FE588

Ask Speaker Builder

DRIVER RETREADS

By Richard Pierce

Loudspeakers, as everyone knows, have been around for a long time. There is quite a heritage of both knowledge and specimens. Sometimes the urge is strong to reuse and adapt some of these older technologies. Very often, the application of new design techniques can significantly improve an old set of drivers.

I well remember some of the bass reflex designs, for example, from the 50s and early 60s, before the time of Thiele and Small. That's when empiricism, coupled with more than a little black magic and personality, ruled the day. You just went out, found a driver (usually, the selection criteria was little more than size and cost, since choice was limited anyway) and stuck it in your box. With crossover design you were a little more fortunate; there were tables where you could look up all sorts of filter topology values.

You simply multiplied the values by 1,000 or so (we're working in kHz with speakers, not MHz with radios), pretended the loads were resistive, presumed the acoustical outputs were theoretically perfect, and *voila*, you were about 5% done with your design. Next you walked your speaker down to the local engineering college to borrow their anechoic chamber for just a little (six weeks or so) "tweaking." More often than not, the chamber, or college was unavailable. No problem, you just hauled the speaker to the top of a flagpole, or buried it face up in the ground and measured away.

Having said all that, it's remarkable to me that some of the speakers from that era were as good as they were. (I clearly remember Acoustic Research's first product, the AR-1. It had a 12" acoustic suspension woofer and an 8" Altec PA driver for a tweeter.) It's not remarkable, though, how very few were good.

Total System

All this was supposed to have changed when A. N. Thiele first published his landmark articles on bass reflex enclosure design in the early 60s (later reprinted in the early 70s in this country). Thiele proposed that the driver and enclosure must, essentially, be thought of as part of the total system synthesis. Ideally, the design of one should constrain the design of the other. This means there is a narrow set of design parameters for the enclosure, the driver and the resulting system response that constitutes an optimum design.

One of the first groups to recognize the practical implications of Thiele's theory was the British Broadcasting Corporation. They set out to design and license a set of standard loudspeaker designs to be used in high-quality broadcast and recording monitoring. The result is a now legendary series of speakers, manufactured by a variety of companies (KEF, Bowers and Wilkins, Rogers, and others) that established the leading edge of accurate acoustical reproduction. (LS-3-5A)

The secret behind the success was the axiom that the design of the drivers, the enclosures, the crossover, and the intended use must all be considered together. This meant that once an application had been defined, new drivers had to be developed to match the new enclosure, and so on. The era of total integrated design had begun. The "British" standard of loudspeaker design was well established.

Here we are, some 20 years later, and it finally seems the industry as a whole has begun to grasp the basic tenets of those times. Even one of the largest electronic retail chains in this country recognizes the fundamental value of Thiele's and Small's work, and is investing not a small amount of money designing products based on it.

Inheritance

As I said earlier, much has come down to us through the years. Many of us (myself included) have "inherited" older drivers. Again, the urge to try to use them in more modern designs is tempting (it's obviously cheaper to use something you already have than to go out and pay for something you don't). Sometimes it works, sometimes not.

Michael Stanzione has a set of older drivers he would like to try to reuse. He writes:

"... I have an old pair of Altec 416-8a 15" woofers with a measured Q_{TS} of 0.45, F_S of 26[Hz], and V_{AS} of about 19 cubic feet. The optimum box for these drivers in an SQB3 alignment is approximately 29 cubic feet, with a C4 alignment being almost as unmanageable at 27 cubic feet. With such parameters, could you construct a more practical 11-cubic-foot box following the non-optimum Koonce alignments (*SB* 3/87) for a given alpha, in this instance 1.7, but employing the double chamber instead? If not, would basket damping as described by Dickason in *The Loudspeaker Design Cookbook*, page 28, be a realistic method of lowering the Q_{TS} from 0.45 to 0.35, at which point these drivers would then be optimally aligned in the preferred 11-cubic-foot enclosure? What sort of 'acoustically resistive cloth' would be suitable in this application?"

My first urge is to ask, "What do you want the system to do?" Do you want a system that will perform in such and such a fashion, a system that must use a specific set of drivers, or a system that uses a specific design? It's possible to have all three, but it's not very likely, I'm afraid.

Empiricism

First, let's look at the drivers themselves. Older driver designs, such as those from Altec, Electro-Voice, JBL and others, date from the time when empiricism ruled supreme. There was not much knowledge of designing drivers for applications. While some of the specifications might be in the ballpark for a modern design (the Q_{TS} of 0.45 is not that far off for a reasonable reflex design), other specs (like the incredible 19-cubic-foot V_{AS}) make a reasonable design impractical, as you've discovered.

In a driver like this you'll find that the relatively low Q_{TS} is a direct consequence of the relatively high V_{AS}, and normal means of adjusting one (say, lower the V_{AS}) will proportionally affect the other.

The drivers have other problems, though. In all likelihood, the cone is made of a pulp mixture whose characteristics vary markedly with environmental changes. I have found that a normal change in relative humidity from 10% (typical in the winter) to 85% (in summer) can wildly change the parameters of a woofer. The moving mass of the cone can easily change 35% just from absorbed moisture. The V_{AS} can vary just as widely. Subtle effects, those that are harder to quantify simply, can change also. The internal losses in the cone material change, affecting the response of the driver.

These drivers generally were not known for their linear, low-distortion excursion. This is somewhat helped by the fact that they are relatively large, but the problem remains nonetheless.

Exploration

Given the constraint that we must use these drivers, what are we to do? Well, we can explore the possibilities of non-optimum alignments or higher-order systems, such as the double chamber method. I think the latter is potentially dangerous, in spite of its added design flexibility. Given that these multiply-tuned systems require tighter parameter tolerance, it's unlikely you'll find an optimum alignment under a reasonable range of conditions.

How about exploring other designs altogether? For example, if you were to design a sealed-box enclosure with system Q_{TC} of 0.6, you would have a 15-cubic-foot enclosure with a −3dB frequency of about 45Hz. You could then use a mild, first-order boost to lower the −3dB point to the mid to lower 30s.

The idea of lowering the Q_{TS} by adding acoustical resistance appears attractive at first glance but has some problems. In most loudspeakers, it is the electrical losses, measured by the Q_{ES}, that predominate in the total system losses (the Q_{TS}). The other losses arise from mechanical (and acoustical) sources (measured by the Q_{MS}), such as frictional losses in the surround and spider, and so on. Typically, these losses are ten times lower than the equivalent electrical losses. This is why the Q_{MS} is typically ten times higher than the Q_{ES}. You must add a lot of acoustical resistance to make a measurable change in the final driver Q.

How much? Well, with the Q_{MS} figures in hand, we have to guess. Let's presume the Q_{MS} is about 5. That means Q_{ES} is then about 0.5:

$$Q_{ES} = \frac{Q_{MS}\,Q_{TS}}{Q_{MS} - Q_{TS}}$$

$$.495 = \frac{5 \times 0.45}{5 - 0.45}$$

Now, how much do we have to lower the Q_{MS} to lower the Q_{TS} from 0.45 to 0.35? Using the equation:

$$Q_{MS} = \frac{Q_{ES}\,Q_{TS}}{Q_{ES} - Q_{TS}}$$

$$1.16 = \frac{0.5 \times 0.35}{0.5 - 0.35}$$

You would have to lower the mechanical Q from 5 to about 1.2, meaning the acoustically resistive cloth would have to account for the bulk of the mechanical losses. In my experience, it's possible to lower the Q_{MS} by 10 to 20% using this technique, resulting in the Q_{TS} being lowered by 2 to 5%. But I have serious doubts about such a dramatic lowering of the Q_{TS}.

My preferred choice, if I had to use these drivers, would be an equalized closed-box system. It would be relatively insensitive to misalignment, it gives you a more reasonable volume than a vented system, and you have the ability to partially re-align the system simply by changing the electronic boost.

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about an article appearing in this magazine, write it clearly, leaving space for a reply and referencing the magazine, the article and the page about which you are inquiring. Enclose a self-addressed stamped envelope and send these to *Speaker Builder*, PO Box 494, Peterborough, NH 03458.

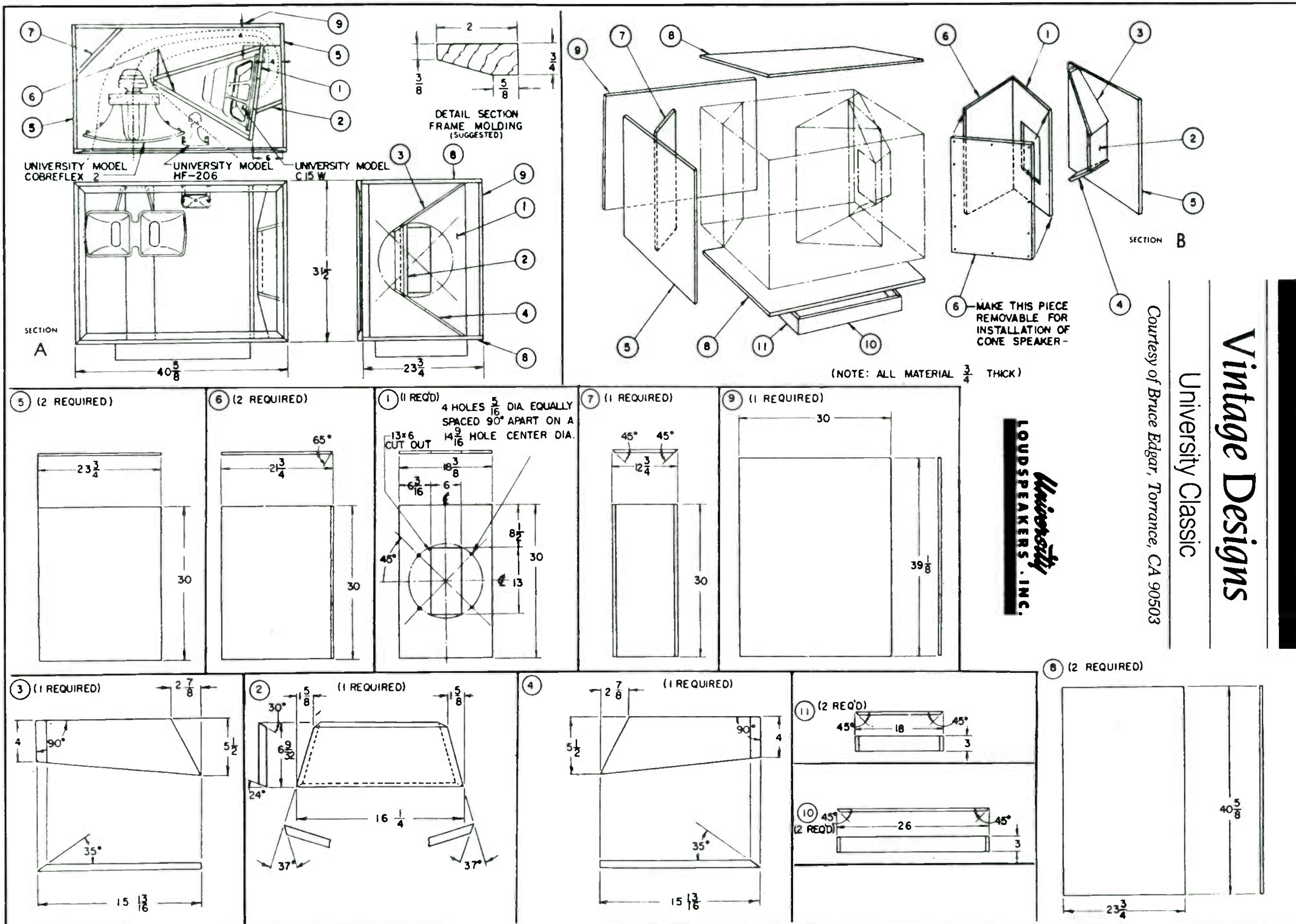
If it's warranted, we will forward your query to the author or a Contributing Editor for a prompt reply.

Help us by not calling in your question. We have neither the staff nor the time to respond to technical questions by phone.

Vintage Designs

University Classic

Courtesy of Bruce Edgar, Torrance, CA 90503



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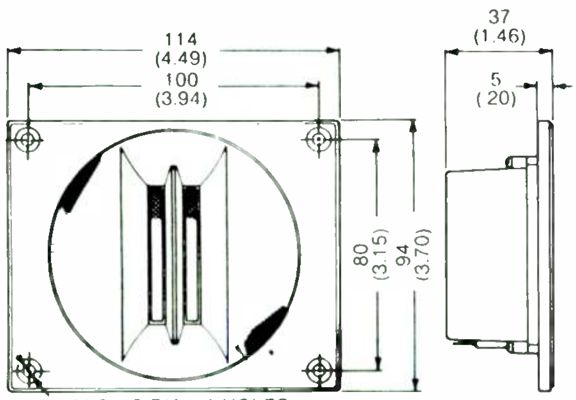
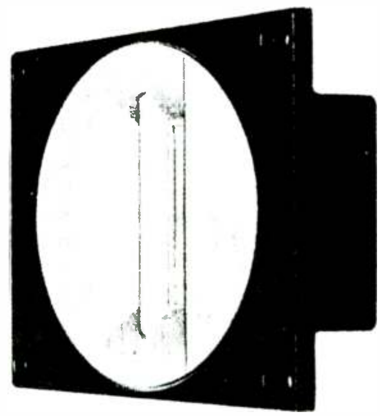
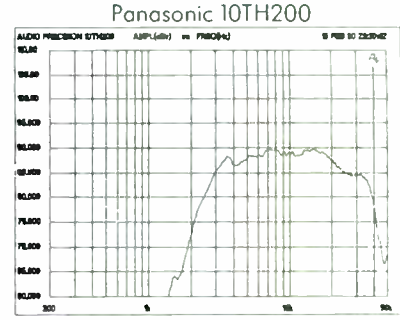
EAS-10TH200D Leaf Tweeter





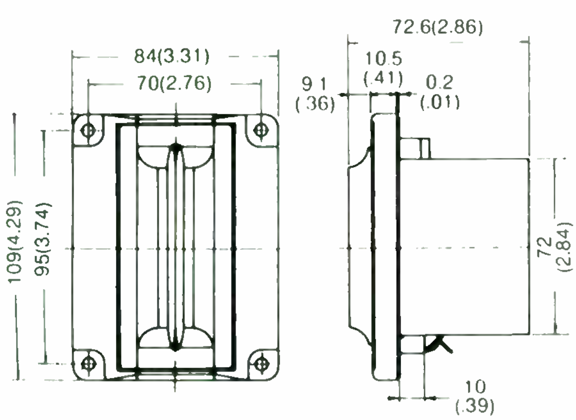
Panasonic 10TH200

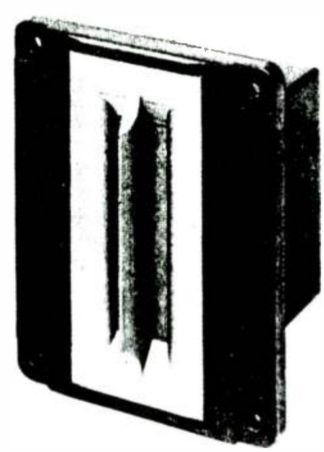


Madisound Price $30.00

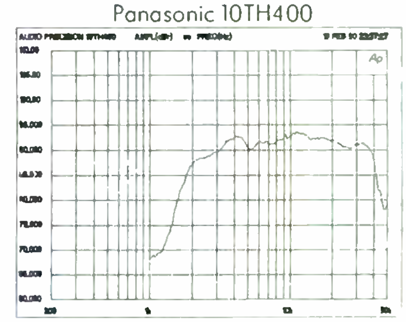
Part No.	Input		Imp. (Ω)	fo (Hz)	Frequency Range (Hz)	S.P.L. (dB/W 0.5m)	Magnet		Net Weight (g)
	Rated (W)	Max (W)					Size (mm)	Weight (g)	
EAS-10TH200D	63	100	8	—	3K∼50K	97	ϕ55 × ϕ31 × 17	284	650

EAS-10TH400A Leaf Tweeter





Panasonic 10TH400

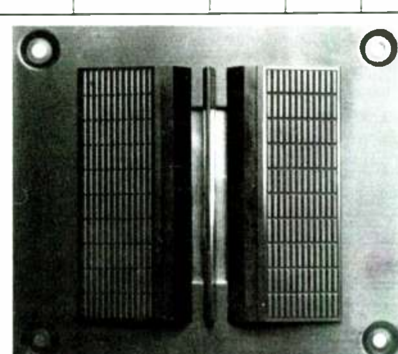


Madisound Price $49.00

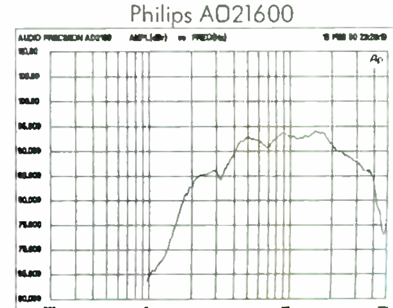
Part No.	Input		Imp. (Ω)	fo (Hz)	Frequency Range (Hz)	S.P.L. (dB/W 0.5m)	Magnet		Net Weight (g)	Remarks
	Rated (W)	Max (W)					Size (mm)	Weight (g)		
EAS-10TH400A	20	100	5.2	—	4K∼85K	97	ϕ65 × ϕ36 × 19	450	1000	Leaf Tweeter

PHILIPS AD21600 Leaf Tweeter

Impedance	8 Ω
Magnet Weight	14 Oz.
Power Handling	75 Watts
Sensitivity	93 db
Usable Frequency Range	5K—25K
Flange size inches	4⅝ X 5¼
Cut out inches	3⅞ X 3⅝



Philips AD21600



Madisound Price $45.00

Fast Reply #FE584

Mailbox

continued from page 4

reverse phase. Finally, I checked the internal wiring of the speakers for correct phase with a flashlight battery. This was OK. I am at a loss to explain why the woofers and tweeter are out of phase at the crossover frequency. Can you help me with this?

Ralph B. Kocian
Oak Lawn, IL 60453

Joe D'Appolito replies:

Do not assume that drivers mounted on a common baffle are in phase. Nothing could be further from the truth, a point which has been discussed countless times in the pages of *Speaker Builder*. Invariably, the woofer will lag the tweeter for three reasons. First, the woofer response, generally falling off just above the crossover point, will produce a lagging phase angle. Second, the tweeter response, generally rising below crossover toward its rated level will produce a leading phase angle. And finally, the zero delay plane of the woofer will be behind that of the tweeter, producing a time offset of the drivers. These points are discussed more fully in my *SB* 4/89 letter.

The simplest solution to your problem at this point is to reverse the phase of the tweeter and spread the crossover frequencies slightly to get rid of the 1dB lift.

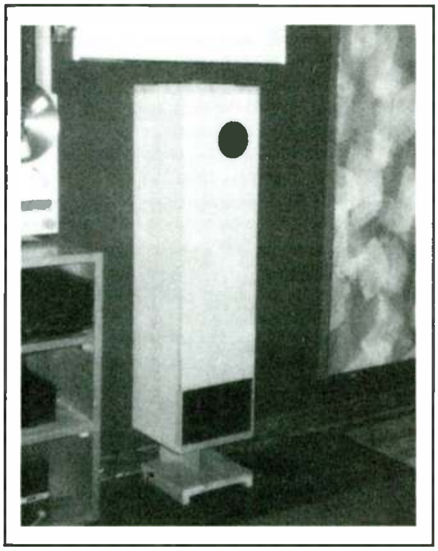


PHOTO 1: Holbrook's Shortline.

SHORTLINES

I thought John Cockroft might like to see one of his Shortlines. The one pictured (*Photo 1*) has just been finished but not yet oiled. I am delighted with the way it sounds, even though it presently serves as only one of the two rear speakers in my living room. If I can figure out how to build a pair using two woofers and a tweeter each for the front sound, I might replace the venerable towers I built over seventeen years ago. The Shortline is the first of the modern speakers I've thought matched the quality I already have.

I do have some questions though. My Radio Shack catalog no longer lists the 540-1021 woofer, so I have installed their 40-1024. Is there any difference that would affect the crossover? In addition, I am using my old Philips tweeter. My present crossover is at 3,000Hz, using only a simple capacitor in the tweeter. What should I do to it? (The crossover is external, up against the back wall of the recessed stand, and can be changed at will.)

The cabinet is solid alder, with a ¾″ ply back. To alleviate frustrating vibrations I have run a ¾ × ¾ shaft between the two side stiffeners. It works. Before building this finished one, I spent a weekend building a trial in solid pine, with a ¾″ ply back. That worked beautifully, too, except that I had to play a lot with the stuffing.

Photo 2 is a model I built earlier, from a remark in your article for another TL design. You mentioned the old model that used layers of circles of ozite behind the speaker, decreasing in size until the back piece which was solid. I remembered having built one many years ago and was quite

PHOTO 2: The Cockroft-inspired TL.

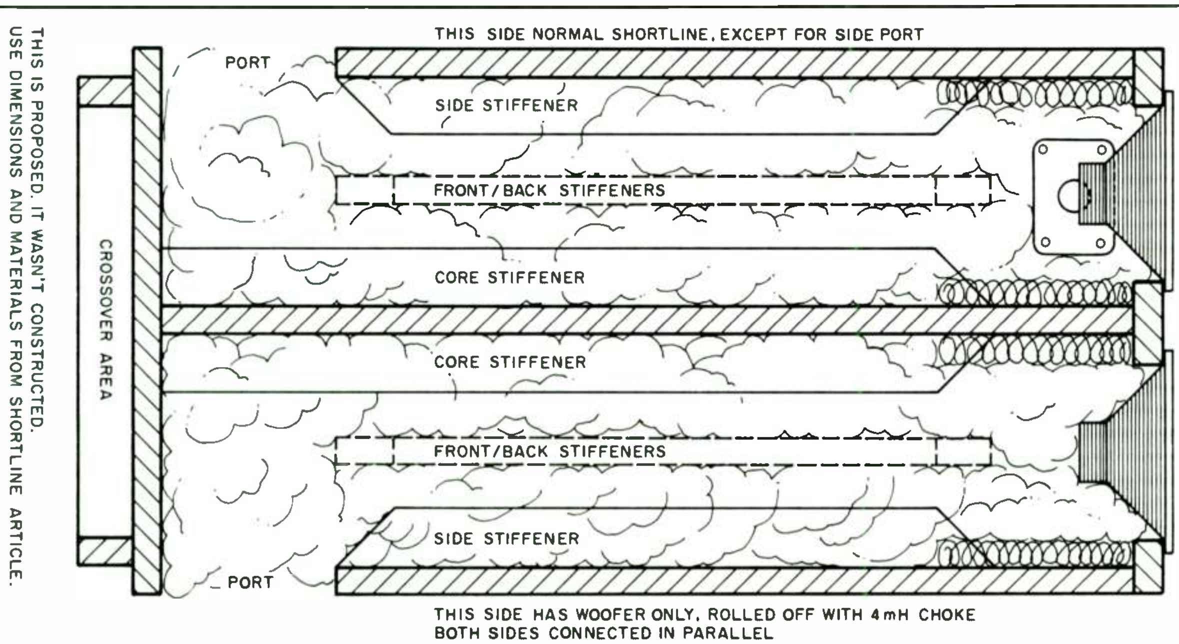


FIGURE 1: Dual Shortline. Make mirror image pair for stereo. Copyright © 1990 by John Cockroft.

happy with it, until I fell in love with horns. Your article stirred many memories, and I was chagrinned at how old they were. Perhaps to relive the past, I built the cabinet pictured, using a 6 × 9″ GS woofer I had and a Radio Shack tweeter.

The design features four 2½″ frames inside, each wrapped with ⅛″ flannel (as used for making bathrobes—baby blue was the only color they had, but I clenched my teeth). Each frame is wrapped around all four sides and up the inside. The first has a 6 × 9″ hole; the second a 5 × 7″ hole; the third a 3 × 5″ hole; the fourth a 2″ diameter hole. They feed into a 6½″ chamber at the bottom which is stuffed loosely with polyester filling, and there is a 4 × 6″ port at the side. It, too, sounds far better than I had a right to expect, what with playing the whole thing by ear. But the Shortline is superior.

Again thanks for the idea and the impetus. I hadn't done any speaker work other than in my head for some time and I enjoyed the project more than I can say.

A. D. Holbrook
Bridgeport, WA 98813

John Cockroft replies:

Thanks for your interesting letter and for the photos. Yours is the most beautiful Shortline I have seen to date. I appreciate your kind words concerning its performance.

Several letters in past *SB* issues cover my feelings and the sum of my knowledge on the various Radio Shack 40-1021 substitutes. Readers have obtained good results with the 1021A and B. I have not personally listened to these results, so I don't know their relative merits. I have no feedback except from you regarding the 40-1024 speaker. I made several attempts to purchase one to try out, but so far I have not found any in the stores.

I had an old Philips (Norelco, actually), of which I don't recall the number. I used it as a direct substitute for the Peerless K010DT. It sounded a bit brighter, as I recall. I used a Zobel circuit across the tweeter terminals, consisting of a 1.5μF capacitor in series with an 8.34Ω resistor. Three 25Ω resistors in parallel will yield 8.34Ω. I had a Peerless tweeter in the Shortline for a while, so at least my old tweeter probably would have worked. Perhaps yours would too. I would try using the crossover as presented in the Shortline article. Beyond that I can't guide you. We live in a world of many variables.

Your other speaker sounds like a lot of fun. I'm glad I was the inspiration for it. I presume you are referring to *Fig. 1* in my Octaline article (*SB* 3/87, p. 10). This was copied from the original Bailey article on transmission lines (TLs), where he used it to show what he meant by Acoustic Labyrinth, when discussing the work others had done prior to his TL loudspeaker system design. Over the years, probably because of a similar name, the Stromberg Carlsen Acoustical Labyrinth became associated with the TL system. Your stuffed chamber and port may have enhanced its sound. With that colored flannel you should have a speaker ideally suited to Bluegrass and Rhythm and Blues. You certainly made a nice looking job of your project.

I don't have a hard design for a two-woofer Shortline. Such a thing isn't practical in my living environment. However, as the Shortline evolved I gave the idea some thought. *Figure 1* is a sketch of what I came up with. If you should decide to play around with the idea, I'd appreciate hearing about your results. The drawing is undimensioned, but each side is basically the same as the system presented in the Shortline article (*SB* 1/88). The inboard side (left side in the sketch) is a regular Shortline, except that the port is on the side instead of the front. It uses the regular crossover. The outboard side has woofer only, which is rolled off by a choke coil of about 4mH.

The two sides are paralleled at the input jacks. With the two woofers in parallel, the impedance is lowered in the bass range so more power is available with most amplifiers. The remainder of the spectrum and the imaging of the original Shortline should remain intact (no guarantees, of course). The mutual coupling of the two woofers should give a boost of about 6dB in the bass. This should be helpful in overcoming the effects of diffraction resulting from the tendency of wavelengths longer than the width of the enclosure front to wrap around the enclosure rather than radiating in a forward direction as do the shorter wavelengths. Since this enclosure is about 18″ wide this effect will begin to take place starting at about 750Hz, requiring a choke of about 2mH.

With an inductor of this size the low impedance of the two woofers will be retained to a high enough range to interfere with the crossovers causing it to function erratically. As the effect is gradual with frequency (at least in the range where the wavelengths are only slightly longer than the enclosure width and are partially offset in a reverberant room) the 4mH (or even larger) inductor will probably be satisfactory. This is where your efforts come in. The 4mH value came from the fact I actually have such a beast crawling somewhere about my floor. I saw it last week. (And you thought designers made sophisticated decisions.) I would try the same stuffing density as the original Shortline.

I don't know for sure just how this would sound, but it seems a fairly reasonable direction as far as I can see. There's only one way to find out.

ULTIMATE ISOBARIK

In all the correspondence concerning Isobarik or compound speaker designs published in *SB* over the years, one particular variant has never surfaced: a biamped version in which the two woofers are independently driven by identical, separate amps. The advantages are many: increased linearity and control over each driver, increased power and power handling, reduced stress on the amp as load impedance remains nominal—leading to improved sound in many cases, assuredly. Combined with an active crossover, it strikes me this biamping technique represents the ultimate form of Isobarik bass loading.

I am planning to build a pair of full-range 3-way Isobariked bass speakers based on the Linn DMS/PMS design using the biamp mode described above. In final, ideal form, it will require four identical stereo amplifiers. I will be happy to report my experience in due course. Meanwhile, I would like to hear from any readers who have experimented with biamped Isobariks.

I have had extensive experience with the Linn Isobarik speakers—the PMS, the DMS, and the Saras—over the past six or seven years. In my experience, they have few equals when it comes to sheer bass clarity, transient and dynamic power, and musicality; this comment extends to the rest of the musical spectrum with respect to the most recent versions of these models—they are phenomenal in every respect.

Mike Chin
Vancouver, BC, Canada V5W 2V7

HIGH KUDOS

Just a little feedback regarding one of our more interesting advertisers: Zalytron of Mineola, New York. If you stop by this place, you can meet Elliot, bandaged up from his last encounter with a table saw, dressed in his sweats and engaged in his hobby and profession: building loudspeakers. Either by mail or in person, he will build your system to spec, do the cabinet only, or just furnish the parts.

Prior to getting a basement workshop, I asked him to construct an enclosure for a pair of the original D'Appolito monitors. Four days later they were complete, exactly as ordered. If you haven't the time, place or skills, you could do worse than to have your cabinets built here. If you only require drivers and/or crossover components, Zalytron will furnish them, usually from stock, and at very low prices.

I recommend Zalytron highly.

Les Winter
New York, NY 10003

WOOFER HINTS

I have been modifying inexpensive woofers ever since reading "The AR-1 Rejuvenated," by Walter D'Ascenzo (*SB* 2/82, page 7). My success rate has ranged from very good to not worth the time and expense. When Zalytron advertised Philips 10 and 12" woofers for $10 and $12, respectively, I ordered six each and went to work. Here are some comments and suggestions.

The 10 and 12″ models share the same motor structure (10 oz. magnet, 1″ voice coil). The 10 has a Q around 0.65 and the 12 around 0.86. I was able to get good performance from the 10″ by stiffening the cone with Varathane and taming the nasty basket ringing by applying window putty and enclosing the magnet in a plaster of Paris cast. Simply epoxy a 2″-long, 4″-diameter cardboard tube to the basket around the magnet and pour in the plaster.

Do not seal the porous dust cap because this will lower the powerhandling (heat build-up) and introduce a frequency response peak around 2kHz. The best enclosure for the so modified woofer is a 1.6 cubic foot closed box with variovent.

The 12″ was a different story. Q modifications (felt or fiberglass pad behind the basket per David Weems) lowered its sensitivity to the point of very poor power handling. It just doesn't make sense to spend $30 and a lot of time for a woofer that is inferior to, say, a 12″ D.V.C. Madisound (30 oz. magnet, 1.5″ voice coil, 0.38 Q polycone) for $35. However, you can use the 12″ Philips successfully as a passive radiator. Just knock out the magnet, seal the porous dust cap and add weight to the voice coil. At $12, it's a better deal than the $16.50 Madisound PR and works just as well.

Peter P. Manchev
Oklahoma City, OK 73135

WOOFER ADJUSTMENT

I read Brian Smith's article "Adjusting Woofers for High Performance" (*SB* 6/89) with hope of improving my system.

I am writing to ask if this method would work on Pyle Pro 10″ woofers with paper cones. This driver has an F_S of 50Hz. I am an amateur without any test equipment, but I have the polymer kit and BBs. Would this adjustment help these drivers?

The Pyle Pro 10″ woofer has: 2½″ voice coil, 70 oz. magnet, paper cone, 97 SPL, 50Hz F_S, 125 continuous RMS, 250 peak, Q_{TS} = ?.

Russell E. Tinder
Huntington Beach, CA 92647

Brian Smith replies:

I may have found your speaker in a Universal Sound catalog. The model number is MHW10-C700CR. F_S = 46Hz, Q_T = 0.268, V_{AS} = 2.575 cubic feet, magnet weight = 70 oz. If this is your speaker, the following applies:

It will be possible to lower F_S by adding mass to the speaker cone. Q_{TS} will rise as F_S lowers. The Q_{TS} of your speaker is low enough to justify trying it. I experiment by taping weights to the cone to find a weight that produces results I can live with.

You must measure final driver Q to know when you are finished. I cannot predict how much mass will give good results and what those results will be for your speaker.

I predict if we can make this driver play low, it may bottom out at loud listening levels. The advertising hype indicates you can push them hard. However, this probably assumes the driver is being operated with its resonance at around 50Hz and not around 20Hz as it would if modified. I have made 8″ drivers play low and had them bottom out before they played very loud. This is one reason I chose a 12″ woofer for the article. The 12″ Philips driver has never bottomed during 6 months of heavy and loud usage.

If you wish to try the modification, I offer an evaluation/modification service for $20 plus shipping both ways. I will experiment with the driver to determine whether it can be successfully modified. I will modify it if it can be improved. I will then ship it back to you within 3 weeks with new driver specs and a recommended enclosure size and type. The cost is the same whether or not the driver can be modified.

LIN COMMENTS

I would like to make a few corrections,

additions and comments about my article, "A Dipole Subwoofer for Quads" (*SB* 6/89, page 10).

Since the article was written, I have added a grille (*Fig. 1*). It should be made of 3/8" plywood, and the dimensions of the speaker cutout assume that the mounting holes for the driver are located as in *Fig. 1*, that is, with mounting holes centered at the top and bottom.

Since the article was submitted, my driver developed a scraping noise, and I returned it to Hartley for service. They cleaned and recentered it and returned it within a week, for the very reasonable price of $60 including shipping one way. I consider this excellent service. The driver is expensive, but this kind of backup makes the price worthwhile.

I did not receive an advance copy of Hartley's comments on my article and would like to take the opportunity to reply to some of their statements.

When I received my driver back from Hartley, I noted in the accompanying letter that the terminals had been changed to current standards. On rechecking polarity, I confirmed that the driver no longer inverts polarity, i.e., a positive voltage applied to the red terminal now produces a forward movement of the speaker cone, a point which was made in the manufacturer's comment. However, since older drivers, such as mine, may adhere to the older standard, I re-emphasize you should check polarity as described in the setup section of my article, rather than rely on the color of the terminals.

I am glad Hartley has clarified the linear excursion capabilities of this driver. Normally, a driver with a 3/4" length voice coil would not be capable of a 3/4" linear excursion, since the coil would begin to see a decreasing magnetic field once the end of the coil moved into the gap. Given the increase in linear excursion, the output limits would be increased by 3dB over the limits I calculated, assuming a 1/2" linear excursion.

Since I have not measured all the possible Thiele/Small parameters on my driver, I cannot rule out the possibility that some of them may measure abnormally high, as Hartley claims. However, the T/S parameters most useful to amateur speaker builders are Q_{TS}, f_S and V_{AS}, and since these parameters reflect the overall effects of damping, mass and compliance (springiness) regardless of their source, it is difficult for me to understand why measurements of these parameters would give anomalous results.

However, we need not simply argue back and forth about the possible relevance of T/S theory. This difference of opinion is amenable to test; that is, we can measure the T/S parameters and ask whether they predict driver behavior. If so, I am correct, if not, then Hartley is correct.

To give a few more details of how I measured these parameters, I used the constant current method to measure the impedance curve, and then used this curve to derive both f_S and Q_{TS} (see "How You Can Determine Design Parameters for Your Loudspeaker," by Robert Bullock, *SB* 1/81, pp. 12–18). I measured the near-field response of the driver by putting the microphone of the Heath analyzer inside the heatsink of the driver, which was driven at approximately 1/10W. I used the SPL meter portion of the Heath analyzer, set to flat. The fact that the T/S parameters predicted almost exactly the measured response curve suggests to me that these particular parameters can be measured and do describe the response of this speaker, and that therefore T/S theory is relevant to this driver.

In addition, since reading their comment, I have measured V_{AS} as 31 cubic feet, using the added mass method (Vance Dickason, *The Loudspeaker Design Cookbook*, Chapter 8). I did not do so previously, since this parameter is not needed for designing a dipole. Now, if T/S theory is correct, we can use this measurement, in conjunction with the others described in my article, to predict the response of the Hartley driver in a given size box, specifically, the box described in *The Audio Critic*.

First, I will correct a factual error. The homemade box used in that review had dimensions of "4 feet wide by 2 feet deep by not quite 3 feet high, with an estimated internal volume of 18 cubic feet." Hartley's recommended enclosure, in the literature they sent to me, lists dimensions of "48" × 36" × 24" o.d.," and further recommends that "the enclosure should be at least 1¼" thick..." Since, as far as I know, o.d. means outside dimensions, this corresponds to an internal volume of slightly under 19 cubic feet, not counting any internal reinforcements, which would further decrease this.

Thus, the box used by *The Audio Critic* was not "half the cubic volume recommended by our factory," but essentially the same as the factory recommended volume. However, that aside, we can consider the box used in that article as a test box used to derive T/S parameters, which was the sense in which I was using it in the article. In that case, the fact that the box might not be optimum is irrelevant, since all we are interested in is how that volume alters the resonance frequency and damping. Now, if we calculate the response of my driver in an 18-cubic-foot box, using my measured parameters of f_S = 28.4, Q_{TS} = 1.3, and V_{AS} = 31 cubic feet, we find that T/S theory predicts a system resonance of 47Hz and a system

Continued on page 64

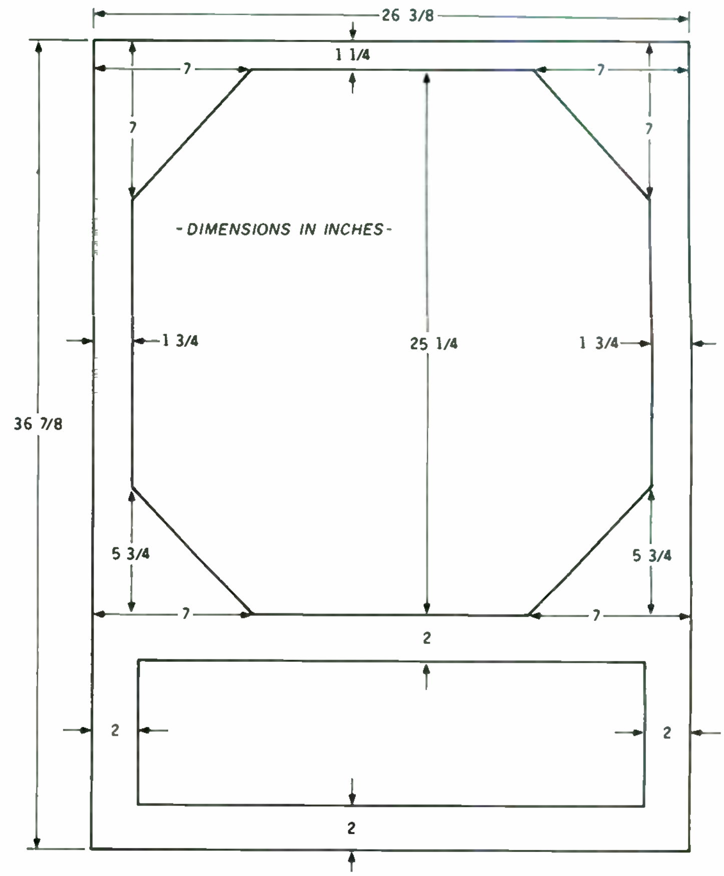


FIGURE 1: Grille frame for Lin's dipole subwoofer.

Continued from page 63
Q of 2.1, as opposed to *The Audio Critic*'s measured 48Hz and Q = 2.

This is as close as you can reasonably expect from any theory, and I believe it fully supports my position that T/S parameters are relevant for the Hartley driver. Furthermore, it should be noted that *The Audio Critic*'s measurements were made on a different driver, at a different time and place, which strongly suggests that Hartley makes a consistent product, and that my particular sample is representative of that product.

This last point is important, since it is really impossible for me to know, given a sample of one, whether my results will be transferable to others. Short of available measurements by others, I must rely on the reputation of the manufacturer. Also, since my driver was used, and presumably several years old (its terminals adhered to Hartley's older standard), I cannot say whether it is representative of current units. Checking through old issues of *Audio* magazine for Hartley ads, I would say it was made after 1975. I note that Hartley's Concertmaster speaker system, which uses this driver, has been unchanged in physical dimensions and specifications since about 1976-77, so I believe that my sample does represent Hartley's current driver. But here again, you must rely on the manufacturer's reputation for consistency.

Since I explicitly praised Hartley's construction and follow-up service, let me be explicit also in my criticism. Any *SB* reader is aware of the many manufacturers who have made available detailed data on their drivers, in the form of T/S parameters, response curves, and even distortion data, either on request or in advertisements. Hartley has chosen not to do so, and even denies their relevance. Except for cone throw and power handling, the raw driver information they provide is almost worthless to the amateur.

For example, the frequency response of the 224HS driver is quoted as 16–350Hz, with no information on the conditions of measurement, and no dB limits (the dB limits cited in the article were for the complete subwoofer system). When many manufacturers are providing much more detailed data on drivers which retail for $20, I believe it is unacceptable to not have such information available on a driver which currently costs $495. In fact, one of the reasons I included so much measured data on my driver in the article, and have provided additional data and supporting arguments in this letter, was to provide other builders with information which, to my knowledge, has been unavailable thus far, information which I believe more useful to the amateur builder than that provided by Hartley.

For example, an amateur builder looking at my data would conclude that this driver is useful only for a dipole or a true infinite baffle (i.e., floor or wall mounting) situation because of the high speaker Q, something which could not have been determined using Hartley's data. I must confess at times to the perhaps unworthy suspicion that the reason Hartley does not believe in T/S parameters is because those parameters do not completely support their performance claims. It is difficult to see how their speaker can be flat to 16Hz given the measured parameters. In any event, if Hartley has technical data which contradicts mine, I encourage them to share it with *SB* readers, so we can all learn something.

As a final note concerning my frustration in obtaining information from Hartley, I also requested a recommendation for fusing the driver. They sent the equation relating watts, ohms and current, which I already knew, thank you very much, and the statement, "The smaller the value fuse, the more protection," with no explicit recommendation. In other words, you're on your own.

Finally, anyone who reads my article and then turns to Robert Camp's contribution on page 53 of the same issue may justifiably wonder how both of us can claim the same rolloff point given the difference in baffle dimensions between his speaker and mine. I cannot speak for Mr. Camp, but I would note that my dimensions were chosen assuming that the floor acts as a sonic mirror to effectively double the baffle size, and further, that I used a fold back of the baffle edges to increase the effective dimensions without increasing frontal area. If the folding is taken into account, 3" in height and 10" in width are added to the frontal area, resulting in an effective baffle area almost exactly the same as Mr. Camp's. I should note that this assumes no folding back for his baffle, whereas in fact he does have a 4½" fold back on each side. I do not know whether this was taken into account when he made his calculations, but if not, his dimensions and mine are in fact compatible.

James Lin
New York, NY 10028

Richard Schmetterer replies:

We appreciate your kind words concerning our service. We pride ourselves on our repair work. However, we would mention that the reason for a misaligned Hartley 24" woofer in 99% of the cases is severe excursion(s) of the moving mass, generally caused by improper back loading or overequalization.

Once again, we must correct your stubbornness when referring to T/S parameters. We stand behind our statement that our magnetic suspension drive units are an anomaly and, furthermore, refute the home measurements made on your Hartley 24″ driver. Your impedance curve shows an F_S of 28Hz which, coincidentally, is almost exactly double the actual "free-field" measurement of the 24″ driver (13Hz, measured outdoors with speaker suspended over a hole in the earth). Thus, you are reading a normal second-order peak.

Measuring near field is also a tricky business. Most microphones are very inaccurate at sub-30Hz readings and we would never recommend placing the microphone inside the confines of our heat-sink/voice coil tube. This type of placement would surely yield very inaccurate readings. We use the finest calibrated Bruel & Kjaer mikes.

The article printed a number of years ago in *The Audio Critic* was certainly a disservice to our company. A Hartley driver was placed in a homemade box of unkown quality, much smaller than factory recommended. This system was reviewed as a Hartley factory unit when, in fact, the system was much too small. Any measurements, comments, or listening evaluation derived from that article was, and still is, totally worthless.

It is unfortunate you are unappreciative of our printed literature. Perhaps next time you undertake a project like this you will contact the manufacturer beforehand, explain the project, and use its expertise and, in our case, share our 60 years worth of accumulated knowledge.

Your further problem with fusing a driver is consistent. According to the Chief Engineer at the Littlefuse Company, the following formula is recommended for selecting fuse size:

For regular blow 3AG (C) type 250V

$$\sqrt{\frac{\text{Watts}}{\text{ohms}}} = \text{trip current}$$

$$\text{Less } 25\% = \text{hold current}$$

This is the information we recommend, including that a fuse is only 70-80% effective. Since a fuse is a non-discriminatory device, its worth would be a function of frequency, input and time.

Finally, we still find your article useful, we just question your means and closed-minded approach to using a driver technology you obviously do not understand.

RIBBON REPLACEMENTS

I have a pair of Decca ribbon "super tweeters," circa 1979, and both ribbons are fried. It would appear to be a fairly simple task to replace the ribbons. Do you know where the replacement ribbons can be found? If not, perhaps the location of the Decca US distributor?

John Edwards
Redwood City, CA 94061

Decca is represented in the US by Townshend Audio, 6776 S. W. Freeway, Houston, TX 77074. Whether they will have replacement ribbons, we do not know.

You might explore replacing them yourself. Michael Lampton and J. Henry Primbsch wrote an article on ribbon tweeters in *SB* 3/84, page 7. Ribbons can be made by unwinding the foil in a Sprague 0.5µF, 50V film capacitor.—Ed.

CALCULATING PARAMETERS

A letter by Paul Graham in *SB* 4/89 offered a program for closed-box calculations written for the Commodore 64. What formula does he use for calculating efficiency and peak displacement volume? I intend to buy my speakers from Madisound; they list a lot of parameters for their speakers (very nice catalogs). However, efficiency and peak displacement volume are not always listed.

Phillip Jacob
Milwaukee, WI 53226

Paul Graham replies:

I did not include the basic calculations for V_D and n_O because these two parameters may be (though rarely are) simply stated in the specifications. True, you very often must calculate these from varied information provided among the other specs. Since you cannot always be sure how the information will be presented, you don't always know what calculation procedure to use.

Let's take peak displacement volume first.

$$V_D = X_{MAX} S_D$$

where X_{MAX} is maximum linear excursion from rest to peak, and S_D is effective piston area. If effective piston area is not specified, use the nominal frame diameter, which is usually the advertised size, calculate the area of the circle, and take 80% of this, or (where r is frame radius):

$$S_D = 2.5 r^2$$

I have found this approximation gives results which seldom differ significantly from those obtained by the specified piston area.

You can find the linear excursion from the voice coil overhang. Subtract the magnet gap height from the length of the voice coil. This gives the peak-to-peak excursion. Half of this is X_{MAX}. You may need to request these specs from the maker. I have tried approximating displacement by using the known specification for similar drivers, but such results must be suspect and should be followed up using known specs.

Free-air reference efficiency, n_O, is easily calculated if you have F_S, V_{AS}, and Q_{ES} (free-air electrical Q). The last is sometimes hard to come by in the ads and short-form catalogs, and you may have to send for it. Small's formula and constant for efficiency is:

$$n_O = [k(F_S{}^3 V_{AS})]/Q_{ES}$$

In this equation, K is a constant having the following value:

9.64×10^{-10} where V_{AS} is in liters,
2.7×10^{-8} where V_{AS} is in cubic feet.

Where a calculation procedure asks you for the efficiency value, make sure to determine whether it requires n_O or efficiency as a percentage (as does my program). If you need a percent expressed value, multiply n_O by 100 (move the decimal point two places to the right).

You could add routines to my program which would include calculation of these parameters, provided you are prepared to accept the specifications in a predetermined form; make sure you've accounted for unit conversions, including the use of the K value, correctly. I thought it was simpler to leave these out of the box calculation.

SHORTLINE CALCULATIONS

As an English teacher interested in speaker building I feel a little like the New Guinea cargo cults who built crude replicas of cargo planes to lure more visits from K-ration and candy bar loaded C-47s. My attempts at building speakers without benefit of technical knowledge are probably not that different, although so far my results have sounded a little better than the cults' planes flew.

Having established my humility, let me pose my questions. I have been interested in building a transmission line (TL) speaker based on John Cockroft's Shortline calculations (*SB* 4/88, p. 28), but have run into a few problems. I already have drivers on hand (Dynaudio 17W75s), which commits me to a Q_{TS} of 0.74. A line folded once to bring the tweeter to ear level gives a line length of about 62″ (I have decided to sacrifice the advantage of putting the woofer in close proximity to the wall to gain some imaging by moving the speaker out from reflective surfaces—sorry). When I try to apply your model to these givens, however, I run into trouble.

What should I use to compute stuffing density? Based on line length it should be 0.54, but if I use the Dynaudio's Q_{TS} (0.74) to calculate d_f, it becomes 1.71. Even lacking any intuitive feel for this stuff, it seems to me a line 86% of the Bailey "Ur-line" shouldn't need three times the stuffing density.

Dickason (*Loudspeaker Design Cookbook*, p. 75) mentions putting material behind the speaker basket to lower Q. Would a region of high-density stuffing have this effect with the balance with the density predicted from line length? Also Dickason's table for TL line area requirements are more constricted than your model—would this have the effect of compensating for the high driver Q_{TS}?

I realize your answers may be educated guesses, given the state of the art in understanding all the variables in TLs, but your educated guess has to be better than my uneducated one.

David A. Gardner
Dubuque, IA 52001

John Cockroft replies:

Your analogy of the New Guinea cargo cults is a profound one that I could have related to many times during the 30-odd years (and I use the word "odd" advisedly) I have been playing with loudspeaker systems.

I think your Dynaudio 17W75 will perform satisfactorily in a TL. Many closed-box speakers function well within a similar Q range of say, 0.6-0.9. This provides a range of relatively flat response. It has been my experience that speakers placed in TL enclosures don't experience as great a rise in Q as do sealed-box speakers, so the enclosure Q should remain fairly close to the free air Q.

The additional (perhaps I should say subtractive) characteristic of greatly reduced enclosure resonance associated with TL enclosures could only enhance the sound. Perhaps my Unline article (*SB* 4/88) may have confused some people. The article wasn't intended to be a definitive way to design a TL system. It was merely an attempt at describing some of my speaker systems and suggesting a design approach for other systems that might have some of the characteristics of my realized designs.

Many, many TL systems with parameters well outside those I suggest in the article would undoubtedly give highly satisfactory performance. My original title for the article included the word, "arbitrary." It somehow got lost along the way. On the other hand, all speaker systems I know of that have been constructed according to the constraints of my article, have performed successfully.

The Q_{TS} of the Dynaudio (0.74) is higher than can be used reasonably while adhering to my equations. They lead to a system with a density (as you point out) of about 1.71 pounds/cubic foot and a line length of 6.147″. This is obviously not a practical realization of a speaker system. (Although the 11″ line mentioned in the Unline article has proved to be very practical.)

The thing to do here is to ignore the Q_{TS} and to design the system according to line length. This (as you also noted) yields a density of 0.54 pounds/cubic foot (say 0.6, as a little overdamping is better than a little underdamping) and a minimum speaker cross-section of 1.08 (1.1)—the minimum that should appear at the downstream end of the line. This factor should be applied to the effective area of the speaker cone and is usually measured from the center of the outer surround on one side to the center of the outer surround on the other side of the cone, with the line going through the center. It wouldn't hurt to have two or more times that figure at the upstream end, behind the speaker.

The speaker with a Q_{TS} of 0.74 will sound somewhat different in the bass range from one of say 0.42, which would probably be close to what my figures come up with, but I would wager that just as many people would prefer the 0.74 speaker as the 0.42. I think the system should be constructed and then evaluated.

There is no need to apologize for moving your woofer to the front of your enclosure, rather than placing it on top of the enclosure, as I often do (this *is* America). I'm not sure you will improve the imaging of your system by doing so, however. (But then, who knows?) I've often been criticized for my woofer location, but never, as far as I can recall, by anyone who has actually listened to my systems.

I wouldn't go to the trouble of trying to lower the Q of your speaker in the manner you state (putting material behind the speaker basket). The amount you could probably lower it would be slight and it may not be necessary. A region of high-density stuffing directly behind the woofer is not a good thing.

Dickason's figures for TL systems reflect the prevailing theory, while mine were derived from several years of my basically empirical approaches to a hybrid TL/aperiodic system. Both sets of figures have led to the production of successful systems.

UNDERESTIMATION

I enjoyed Brian Smith's article, "Adjusting Woofers For High Performance," in *Speaker Builder* 6/89. He sums up the article saying, "...the difference between poorly designed woofers and good ones is attention to detail." I think he underestimates the readers' intelligence.

When Philips designed the $10 woofer he describes, they intended it for low-cost systems with modest performance capabilities. When the designer chooses small magnets, lightweight cone, etc., he also designs small voice coils with minimum overhang and moderate power-handling ability. He did not design the woofer for the high-power, large excursion low-bass applications Smith describes. Increasing the magnet size and adding weight to the cone can only exacerbate the limitation of the moving system.

Using a sealed, 2.9-cubic-foot enclosure with a proposed system resonance of 42Hz and a Q of 1.1 will not yield a –3dB cutoff of 22Hz; moreover, response falls off at the rate of approximately 12dB/octave below resonance, not at 2.9dB/octave. The –3dB point would be closer to 36Hz. A Q of 1.1 also suggests slight underdamping, although this is of minor importance, considering the project as a whole.

Consider, also, that in a direct radiator such as described in the article, cone excursion increases by a factor of four for each lower octave, for the same acoustical output, below the point of ultimate radiation impedance, down to the resonance frequency, at which point the output begins to diminish at the predictable 12dB/octave. Smith's system would require much larger excursions than the woofer was designed to handle, and the result will be greatly increasing amounts of harmonic distortion and coloration. Harmonic distortion may not have been one of his design criteria in changing the woofer's performance.

Using a 12-inch woofer in a 2.9-cubic-foot enclosure, all things being equal, will also yield higher distortion figures than a properly designed acoustic-suspension system of approximately 1.7 cubic feet, if both systems have the same resonance frequency. Too large an enclosure reduces the air-spring effect, and the speaker begins to utilize more of its mechanical suspension than the air of the enclosure for restoring force. Mechanical suspensions are much less linear except for very small excursions.

Finally, therefore, I think Mr. Smith's woofer treatment ultimately degrades the performance of the cheap woofer and triples the cost to the end user. As an engineer he should know that making such a change requires more than a listening test to quantify improvement. He should have made distortion measurements, and then he would realize it is not practical.

Thomas D. Tyson, III
High Point, NC 27262

Brian Smith replies:

My goal was to produce a subwoofer system with a 3dB down frequency below 30Hz in a reasonably sized enclosure at a cost that most builders could afford and with no complicated adjustment procedures. These goals are almost diametrically opposed, yet I believe they are reconciled in my subwoofer system. Doing the modifications yourself and building your own cabinets, you can make a stereo pair of subwoofers for about $100. The cost of a commercial pair of pre-built subwoofers is usually at least $1,000.

The article was not intended to be a dissertation on subwoofer design. It was meant to introduce the builder on a budget to low bass.

As for your claims about the Philips woofer and the intentions of its designer, this driver was designed by Ed Hansen, who passed away three years ago. Unless you worked with him on the design, I don't think you know any more than I do about his design goals. The idea for adding magnet mass to the speaker came from Dick Pierce who is well respected in the audio field. I spoke with him concerning your objections. The bottom line is your objections can be answered only with equations, derivations and other complicated engineering jargon beyond the comprehension of many readers.

Using some design software, the predicted cutoff of this modified speaker in a 3-cubic-foot cabinet is 25Hz. In my article I stated the cutoff to be "about 22Hz." I said "about" because, in calculating, I used an approximation that appeared in *SB* 2/84, page 22, in an article by G. R. Koonce. Design software predicts a cutoff of 25Hz which is about 22Hz, and is still below 30Hz as per my design goal.

I cannot find anywhere in the article where a 2.9dB/octave rate is mentioned.

You are correct that distortion measurements were not a part of my design and test procedures. Instead, I used an A/B test in which I operated a very well designed MK driver side by side with my modified driver. The results were very gratifying. When level compensated, the difference was not easily detectable. When being driven by 150W monoblocks, at no time did the modified driver bottom out, even at very loud listening levels. I agree with your assertions about increasing the distortion products by increasing excursions. My reply to your objection is that if the distortion cannot be heard, why bother trying to quantify it? I try to never let technical details of little importance get in the way of the enjoyment of building and listening to stereo equipment.

If you put my modified driver into a 1.7-cubic-foot cabinet, it would be unbearably boomy, so why bother debating about it?

As far as cost goes, you could make one of my modified drivers for much less than $30. Time and mess are the price you pay if you roll your own. While we are discussing cost, I have seen these speakers in a catalog for about $40. I own a large catalog collection and I try to keep up with the prices. The only reason Zalytron offers this driver for $12 is because they were purchased as a close-out item, possibly well below cost.

My modification allows the owner of modest means to construct a system that opens up a world of bass most people have never experienced. Most people own a stereo system of some sort. The fraction of those systems that produce enough bass below 40Hz to fill an average living room is probably very small. I offer a way for any ambitious builder to explore the world of low bass without breaking the bank.

UNBALANCED SOUND

I modified my Radio Shack Minimus-7s according to William R. Hoffman's article in *SB* 1/88 and was pleased with the results, except that I thought the sound was not well balanced. The tweeter seemed harsh, and spoken voices had a strange, nasal sound to them. In all fairness, I could not permanently mount the speakers against a wall, but that did not account for all of the problems I heard.

Then I read Brian Smith's article in *SB* 6/89 on how to adjust woofers for better sound and deeper bass. I decided to use one of his suggestions and coated the paper mid/bass driver with Enviro-Tex polymer. I also replaced the fiberglass "blanket" with a medium density (one large handful) filling of polyester pillow stuffing, and padded the tweeter down with a 1Ω, 1W metal film resistor. The final touch was a foam rubber diffraction ring around the tweeter, which works best if it lies outside the grooves around the tweeter dome. Be sure to trim the ring down so the grille goes on easily and put the resistor *before* the tweeter's cap.

The difference between the first and second modification is nothing short of incredible. The midrange became clean, clear, and smooth, with much less distortion, and the bass goes deeper. Padding the tweeter down gave a much more natural balance to the sound, and the diffraction ring kept the wide-dispersion dome tweeter from bouncing treble off the walls and smearing the stereo image. Now the soundstage has much larger dimensions, and instruments are better defined. Since I don't have the facilities to measure anything, I cannot supply anything. But if anyone does, and makes these modifications, I would like to see the numbers.

Next I plan to move the Minimus-7 drivers and crossover wholesale to a John Cockroft Shortline TL, which will utilize a Radio Shack paper cone woofer coated with Enviro-Tex, and a first-order crossover; woofer-coil, midrange cap.

I also intend to try TL loading for the

midrange. Although a Q_{TS} of 0.55 might be too high, perhaps Mr. Cockroft's equations and articles will show the way.

David A. West
Kirkland, WA 98033

LEADING PHASE SHIFT

Peter Hillman's article, "Symmetrical Speaker System With Dual Transmission Lines" (*SB* 5, 6/89), is loaded with good ideas and common sense. Concerning leading phase shifts, he touched on an area that I feel could use further explanation. His question, "How can a driver create a sine wave before the input wave arrives?" is a valid one. If a lagging phase shift (at a particular frequency) can be looked at as a simple input-to-output delay, then a leading phase shift must equal a negative time delay or an output that occurs before the input signal. From a common sense point of view, this is trouble. How can the output occur before the input?

There are different ways to interpret this frequency specification in the time domain. With so much analysis done, and equipment built in terms of steady-state responses to sinusoidal inputs (frequency domain), many of the quantities associated with sinusoidal behavior have acquired a real "physical" meaning. It is easy to forget that time is the primary variable.

Whenever I start blundering, a simple RC network usually helps me see things clearer. In this case, a voltage source with a series capacitor into a resistive load will do. Because of the series nature of this circuit, the current through the capacitor is the same (magnitude and phase) as the current that passes through the resistor, creating the output voltage. This first-order high-pass network has a +90° phase lead at low frequencies, a +45° phase lead when the capacitive reactance (1/jwC) is equal to the resistor, and 0° phase shift at high frequencies.

Let's look at the low-frequency case. Basic electronics states that the current through a capacitor is equal to the value of the capacitance times the first derivative of the voltage with respect to time ($i = C\, D_V/D_T$), a perfect differentiator. In other words, the current through the capacitor (which is also the same current that creates the output voltage across the resistor) is proportional to the slope of the input voltage.

Looking at the circuit this way, there is no time lead between the output and the input. The output is a function of the slope of the input at any instant. Since the slope (or the first derivative) of a sine wave is a cosine wave, and the cos (x) =

sin(x + 90), the output appears to lead the input by 90°. When the resistor becomes significant, it changes this perfect differentiator to a slower one, one with less than 90° phase shift, or less than a perfect differentiator. I hope this helps clear up this frequency-to-time-domain confusion.

Paul Marchese
Arnold, MD 21012

Peter Hillman replies:

I'm sure many speaker builders, like myself, appreciate your explanation as to how a driver creates a sine wave before the input wave arrives. Your contribution exemplifies why *Speaker Builder* provides such a unique forum for the fruitful exchange of ideas that an amateur can understand and learn from. Without *SB* I wouldn't have had the information nor the incentive to carry my project as far as I did.

MODEL 30W

In reading James Lin's article on the Hartley dipole subwoofer (*SB* 6/89), the Electro-Voice 30″ driver is mentioned. This driver, the model 30W, is still available through University Sound, which along with E-V is a member of the Mark IV family of companies. Altec Lansing Professional (not the consumer product manufacturer) and Gauss are other speaker manufacturing members. University Sound is located at 13278 Ralston Ave., Sylmar, CA 91342. Retail price on the 30W is $567 in their latest catalog.

I would also appreciate some clarification on the formula used to determine the frequency at which front-rear cancellation rolloff behavior of dipoles begins.

I am planning to build two dipole subwoofers using the 30W and would like to hear from anyone who has built or is planning to build along these lines.

Keep up the good work—*Speaker Builder* is an enjoyable and interesting publication.

Andrew Rutkin
South Pasadena, CA 91030

James Lin replies:

Actually, I was kidding when I referred to possibly using the Electro-Voice woofer in my setup—it's too big to fit in my room. However, I am delighted it is still available and someone else is interested in trying it out. Let me add a note or two of caution though. One of Hartley's advantages is its large cone area is combined with a long cone throw. Both are important, since it is large displacement volume, not cone area alone, which is needed to produce adequate bass levels, especially in a dipole design. You lose a lot due to front-to-back cancellation; for example, with a 100Hz baffle rolloff, only about 6% of the driver's output at 25Hz goes toward producing usable sound, the rest is cancelled out.

It is amazing how much cone movement you can see with what seems like quite moderate sound levels. If the Electro-Voice woofer is a short cone throw design, it may not be capable of producing more, or even as much bass, as the Hartley. In addition, I do not know what the E-V driver's Q is. If it is lower than 0.7-1.0, you will need a boost circuit to avoid a drooping low-end response. Remember, the dipole design does not have a box to boost the low end. Not having access to the E-V driver (I've never even seen one), I can only suggest writing to E-V for the T/S parameters and cone throw before proceeding.

As for the formula for determining the baffle rolloff, R. J. Newman's article (*Journal* of the Audio Engineering Society, Jan/Feb 1980) gives the formula verbally: "This finiteness [of the baffle] causes front-to-back cancellation of the driver output to occur below frequencies for which the average baffle dimension is approximately equal to a half wavelength." Later on, he also describes the use of a ground plane (i.e., the floor) to double the effective baffle area, "thereby causing the average baffle dimension to increase by $\sqrt{2}$." Combining the two, I believe the correct formula is:

$$f_3 = \frac{6750}{\sqrt{(2 \times \text{baffle area in square inches})}}$$

Incidentally, I did not use this formula when I originally calculated my baffle dimensions. Instead, I manipulated the dimensions to come up with the same frontal area Newman recommended for a cutoff of 100Hz. Using this formula actually gives a cutoff of 109Hz or so for my baffle, but fortunately the mild 6dB/octave rolloff makes the consequences of this error quite small. I hope this clears up any confusion.

BASS HORN DESIGNS

As a speaker building hobbyist, I have enjoyed every issue of *SB* immensely. The smaller projects are especially interesting as I can assemble and test them in my apartment.

As my experience and knowledge increase I find myself involved with projects for friends, and now, building fixed low-frequency enclosures in nightclubs. I've encountered many roadblocks in the commercial market (budget constraints, space limitations, overly knowledgeable nightclub owners, and so on). Usually, an owner wants a proven design, something he has seen or heard before. Which brings me to my question. Does anyone have any proven folded horn designs? (especially the Klipsch MWM 1900).

My budget and space limitations simply do not allow me to experiment on this large a scale. Also, I don't have the confidence in my knowledge of folded horn theory to design a cabinet on paper, then cut up three or four sheets of plywood in hope of success. I would appreciate any applicable plans for commercial low-end reinforcement. Also, any suggested reading material would be of help.

Steve Furtick
Columbia, SC 29206

Bruce Edgar replies:

Trying to find proven bass horn designs, especially Klipsch, who does not publish any of theirs, can be a difficult process. I try to publish any good set of horn plans in *SB*'s Vintage Design section whenever I find them. However, the horn is only half the problem. Many old horns were designed and optimized for drivers no longer available; you may have to experiment with several drivers to find the best match.

To my knowledge, the only company that publishes horn designs for its drivers is Electro-Voice in Buchanan, Michigan 49107. They sell plans (TL-4050 and TL-5050) for their EMM12L and EVM15L drivers.

If you have specific design requests, write your desires in another letter to *SB*, and maybe other readers or I can point you to the appropriate design.

SHOW HORN

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sign Using Thiele/Small Driver Parameters," AES Preprint #1250, 1977.

2. Leach, W. M., "On the Specification of Moving Coil Drivers for Low Frequency Horn Loaded Loudspeakers," *Journal* of the Audio Engineering Society (*JAES*), Vol. 27, pp. 950–959, 1979.
3. McClain, E. F., "Comments on Reactance Annulling Horn Loaded Loudspeaker Systems," *JAES*, Vol. 29, p. 523, 1981.
4. Leach, W. M., "Author's Reply to Comments by E. F. McClain," Vol. 29, pp. 523–524, 1981.
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6. Salmon, V., "A New Family of Horns," J. Acoustical Soc. Am., Vol. 17, pp. 212–218, 1946.
7. Cohen, A. B., "Making the University Classic," *Audiocraft*, Vol. 1, pp. 16–18, February 1956.

TWO-WAY SYSTEM

continued from page 24

The front and rear I painted flat black. For input terminals, I used gold-plated binding posts, two sets for each speaker. The grille assemblies are black polyester fabric stretched over a frame constructed of ¼ round moulding. For the final touch, I placed some black felt around the tweeters to reduce nasty diffraction effects. For better imaging, all serious listening would be done with the grille assemblies removed.

SOUND QUALITY. When using these speakers without the subwoofer, they sound very smooth and well balanced with quite pleasing bass output for their size. They present a wide and deep soundstage with superb focus. The sound is clear, allowing me to hear details I had not previously heard in familiar recordings. They also do an excellent job of reproducing voice and string instruments—both sound natural and uncolored. Overall I am very pleased with their performance and feel these speakers compare favorably with some well known more expensive systems.

Continued on page 76

REFERENCES

1. Vance Dickason, "Loudspeaker Design Cookbook," 3rd ed., The Marshall Jones Co., Francestown, NH, p. 44. Available from Old Colony Sound, PO Box 243, Peterborough, NH 03458.

SPREADSHEET

continued from page 27

volume in cubic inches using another rearrangement of equation (1):

$$V_B = \frac{1.463 \times 10^7 \times r^2}{F_B \times (L_V + 1.463r)} \qquad (3)$$

The fourth and largest calculation box allows you to evaluate a variety of single and dual vent sizes over a range of resonant frequencies by simply inputting a box volume. *Figure 4* shows the true strengths of the spreadsheet concept by letting you do "what-if" analysis to see the effects of box volume changes on a large spread of data. Any resonant frequency between the values listed can be input in place of an existing value, and vent lengths will be calculated for that exact frequency.

I toyed with the idea of including Mach number calculations in the vent size evaluation box but decided against it to keep the overall size of the spreadsheet within certain limits. You should be pretty safe if you select from the table the largest vent geometry amenable to your box geometry. Just remember to keep the inside end of the tube at least three inches away from the back wall or any other obstructing surface, even if you have to go to a right-angle bend.

For those of you who don't know how to set up a spreadsheet or don't want the hassle of doing so, I have uploaded it to the Madisound Audio Projects Bulletin Board (608-836-9473) with the file name HELMHZ.ZIP. *Figure 5* is a printout of the entire spreadsheet. It fits nicely on an 8½ by 11-inch format using Sideways software.[6] You can use the spreadsheet on either Quattro[7] or Lotus 1-2-3[8] by assigning the appropriate file name extension (.WKQ or .WK1) *after* you have unzipped the file.

Keep in mind the spreadsheet is based on theoretical mathematical models, and to be safe you should add a couple of inches to the calculated length when you cut your raw material. Then you can gradually shorten it to tune the box to your exact frequency requirements using the techniques described in references 1 and 9.

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1. Vance Dickason, "The Loudspeaker Design Cookbook," 3rd ed., The Marshall Jones Company, Francestown, NH, 1987.
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4. Richard Pierce, "Rapid Loudspeaker Design Using Spreadsheets," *SB* 3/87.
5. Marc Bacon, "The Beauty Of Spreadsheets," *SB* 4/89.
6. A product of Funk Software, Inc.
7. A product of Borland International, Inc.
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COMPACT ESL/TL

continued from page 47

using glass on the top and bottom when building the stators. Either of these problems will appear as persistent arcing whenever the polarizing voltage is applied. The aluminum sheet can be bent away from the diaphragm by inserting a small punch or nail in the ⅛-inch holes along one edge and prying gently. If you used wire, you can figure out what has to be done.

OPEN DIAPHRAGM. A failed diaphragm contact or diaphragm conductivity is easy to identify by bringing the polarizing voltage wire slowly up to the diaphragm contact, as described in the previous section. There will be no arc, pop, or noise—nothing. It is also possible to have the basic cell work but have dead spots in it. This problem is caused by areas of the diaphragm that have no graphite (highly unlikely) or by a coating that has started to come off. This is unlikely to occur with graphite unless you didn't rub it in hard, but it is very common with many other types of coating.

DIAPHRAGM REPLACEMENT. Replacing a diaphragm is not difficult. It requires a sharp putty knife and a metal yardstick (or other long, thin metal object) with the end sharpened. After removing any bolts in the cell, use the putty knife to separate the insulators around the perimeter. Slide the yardstick down the center insulator while lifting one end of the top stator. With the stators now separated, run the putty knife under the epoxy on the insulators. Generally it comes off quite easily. Be sure everything is clean and any problem you might have had is corrected. Now you are ready to install a new diaphragm.

There is an interesting problem with ESLs that I have yet to understand. I have never seen any reference to it in the literature, and I have never heard any mention of it. But I have noticed that as the diaphragms age, they develop holes that gradually get bigger. After 10 to 15 years new diaphragms seem to be in order. The sound quality remains the same, but I don't like looking at holes. It is almost as though the diaphragm material evaporates. I have searched for an explanation but have not found one. Initially I assumed that arcing must have caused them, but this is doubtful because I have looked very carefully at locations on the diaphragm that have arced, and macroscopically I cannot detect any damage. Possibly some type of microscopic damage occurs that eventually results in a larger hole, but this is only a guess. Persistent arcing caused by insects occasionally creates a pinhole, but as near as I can tell, this does not get bigger. If any reader has any factual insight on this phenomenon, please contact me.

The next installment of this article will cover transmission line design and construction, as well as electronics and crossovers.

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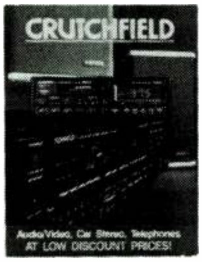

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Test equipment—Scopes, Audio Generators, etc. Write indicating your need. Offer for the lot. Nick Oshana, 101 Treble Rd., Bristol, CT 06010.

JBL 2405H slot tweeters, $195/pair; 2425J horn drivers, $275/pair; Altec 511 horns with Alinco drivers, $275/pair; 604E coaxials with crossovers, $800/pair; Voice of Theatre speakers, loaded, $850/pair; ⅓-octave equalizers, $350/pair; Mastering Lab crossovers, $325/pair; Technics rackmount cassette deck, $350. David, (914) 688-5024.

Mirror II communications software for PCs, new, $35 (currently $89.95 via discount mail order); NCR DMVpc 256K 10MB hard 360K Flex disks 640X400 color noncompatible runs MS-DOS CP/M, extras, $500; Pioneer RT707 reel-to-reel auto reverse both directions, $200; Tektronix oscilloscope with leather case, $150; Simpson 460-2 digital bench VOM, $50; Triplett 310A analog VOM, $30. Tom Bahl, Box 12852, Wichita, KS 67209, (316) 721-8953.

¼ mil aluminum foil for builders of ribbon, planar-magnetic, or Heil systems. Bonded to paper. This allows easy pattern drawing and cutting, while preventing tears. Paper then soaks off in water. From a roll 50 inches wide. $1.00 per foot, $20 minimum, postpaid. Dean Price, (616) 241-5324, evenings.

Marantz 2500C receiver, 250W per channel (RMS) base, mid, treble, high/low-pass filters, built in oscilloscope and fan. All original packaging, owners manual, schematic. Was $1,600 new, asking $400. Excellent condition. Matt Antonucci, 439 Aviation Ave. N.E., Palm Bay, FL 32907, (407) 729-9176.

Swan IV subwoofer/satellite system, beautiful cherry cabinets with tung oil finish, all visible edges rounded with cherry hardwood. Inch thick panels with heavy internal bracing in bass cabinets. Includes Pedal Coupler active crossover. Excellent system as described in *Speaker Builder* 4/88. $2,200 or best offer. Ward Fowler, (414) 347-0820 or 347-1668.

Yamaha DSP-1 soundfield processor, $500; Adcom GTP-500 tuner/preamp with remote, $400. Both in excellent condition with boxes and manuals. Paul Hughs, 3763 1st Ave. North, St. Petersburg, FL 33713, (813) 321-4499.

JBL S7R system LE-15A with passive radiator, LE85 with horn-lens and LX5 in Olympus walnut enclosures. Excellent condition. Also Denon PAO-1500 amp (with meters), PRA-1000 preamp and TU-747 tuner. All have champagne colored fronts. Mint. Speakers $595 per pair, Denons $595 per set. Wesley Kellie, (208) 765-8521.

Crown SX724 studio recorder, rackmount, with manuals and factory individual test results, very clean, $500. SASE for test results. Leo Biese, Murray Hill Rd., Hill, NH 03243.

Counterpoint SA-3000, $1,500; SA-220, $2,000; new, unopened, silver, Teac A4010S reel, $150; Sony TC-355 reel, $100; KLH 24 stereo center, $100. John, (619) 584-8794.

Transmission line speakers have 10″ Madisound drivers, made from braced ¾″ stock, 15Hz–800Hz, 150W power handling, RMS, two available, $195 each. Jim Thornhill, 2112 South Beacon St., Muncie, IN 47302, (317) 284-4826.

Two new Sumo Polaris power amplifiers, still boxed. 100W per channel 8Ω,175 4Ω. Each new cost $750, $350 each; Infinity RS3B speakers, cost $1,500, $750 for pair; Phase Linear 3000 preamp and 400 amplifier, $400 for both. Tim, (305) 344-4415 or 345-0802.

Two Rectilinear Model III 6-driver, three-way ported speaker systems, purchased 1973, original owner, recently reveneered in light oak. Best offer or trade for Richter Scale Series III. Don, NY, (914) 477-2052, evenings or weekends.

Conrad-Johnson PV5 tube preamp, $850; Tandberg 3006A power amp, $450; JBL subwoofer, Model L212 ultrabass, $750. Ralph Hellmer, PO Box 3251, No. Myrtle Beach, SC 29582, (803) 249-7551.

Acoustat Spectra 3, highs 1 section, mids 3 sections, lows full 32″ width, has switchable subwoofer bi-ampable ($3,000 new), $1,750; Counterpoint SA3.1 tube preamp ($1,049 new) $650; Systemdek II turntable Fidelity Research arm Shure V15, $450; Phase Tech PC65 two-way with flat 8″ woofer, $325. Dave, (219) 854-3494 EST.

Amber 5500 programmable audio analyzer with audio check one, HP 3561A, leader FM/AM stereo generator Model 3616, HD 7475A plotter, various meters, load boxes, signal sensors and cables. This is my whole testing lab. Timothy Benson, (514) 933-2133 for pricing and arrangements to inspect.

JBL K-130s, bullet tweeter and 5″ midrange (two each), excellent condition, must sell. John Ianelli, PO Box 307, Randolph Center, VT 05061, (802) 728-4862.

Denon DP-2550 turntable with SME 3990-III arm; Shure V15 cartridge—$450; Yamaha DSP-1 sound field processor—$545; dbx 124 4-channel dbx-II processor—$180; Nakamichi 700-II 3-head cassette recorder—$495; ReVox B77 open reel recorder—$990; Used BASF C-90 chrome cassettes—$12/dozen. Darroch, 1807 ElmCrest, Arlington, TX 76012.

Two each JBL 12" woofer baskets, $150 plus shipping; Harman-Kardon S30 AM/FM receiver, $80; AR XA turntable parts for sale. James Gilmore, (415) 782-2431.

Yamaha M35B 4/2 channel power amp (surround sound or biamp), $140; Sony CDP203 CD player, $110; cast-frame Gauss 15" woofer #4583A (new) 400W RMS, $F_S = 29$, $Q_{TS} = .35$, $V_{AS} = 15.3$, X_{MAX} = ¾" peak, 97dB/1W, smooth response, $110; Hafler XL-280, $525 (new). Fred Janosky, RD 2, Box 3502, Wernersville, PA 19565, (215) 693-6167.

Tandberg 3034 cassette deck, needs help, $75; modified strats with transformers, $170; Dynaco Stereo 35, complete rebuild, new open chassis, premium parts, $150; transformers from HK Citation V amp, never used, $80. All include shipping. Bill, (215) 481-6181, 9–4 EST M–F.

Selector Switch, Grayhill, 2-pole, 5-position, new, $33 ppd. Joe McQuade, (609) 397-8315 (NJ).

Heatsinks: new, large finned, black anodized, drilled for (2) TO-3 transistors, like Aavid 6055, 4.75" W × 5.0" H × 2.75" D, 1.0 degree C/W, suitable for Chater, Borbely projects, etc. $5.50 ea. or 4/$20; Dyna MK IV (2) clean, good chrome, no mods, $120 each, OBO; Dyna PAS2+, with gold front panel, good condition, no mods, $100. You ship all. Randy, (518) 756-9894 (NY) 9 a.m.–10 p.m. leave message if no answer.

(8) Speakerlab 10" woofers. W1048P, V_{AS} 6.89 ft., Q_{TS} .265, F_S 19 polypropylene cone, foam surround, 2" vented voice coil designed for "High Power" use. Good for sealed, vented or TL boxes, $350, or best offer. Include UPS within US. Dexter Jones, (708) 940-8433 evenings and weekends.

Altec, RCA, JBL, W.E. amps, tubes, horns, literature, etc. V. Vogt, 330 S.W. 43rd St. #247, Renton, WA 98055. (206) 251-5420, ext. 247.

Adcom GCD 575 CD player, mint condition, manual box, $450. Mike Phillips, (816) 625-8689 evenings, weekends.

WANTED

Copy of schematic and service or instruction manual for serviscope type S51A from Telequipment Limited of London, England. Please advise copy and postage costs. John Harlan, 9720 S. Prospect Ave., Chicago, IL 60643.

High quality preamp, new or used, good condition. Beau Tedesco, PO Box 17871, Baton Rouge, LA 70893, (504) 334-2693.

Wanted—Job at loudspeaker design/manufacture company. Will soon be graduating with B.S. Engineering Science degree. Please call or write for resume. Gordon Chang, 1750 Prefumo Canyon Rd., San Luis Obispo, CA 93405, (805) 543-3058.

Old Klipsch catalogs, components; *Audio Engineering* volumes 1–5; diaphragm for International Projector LU-1000 high frequency driver; JBL 12" circular perforated plate horn/lens; early Polaroid polarizing film ads, literature; book, *The Throne of Merlin*, by R.C. Schaller; *High Fidelity* volumes 1–5. D. R. Schaller, 6704 Schroeder Rd., Suite 6, Madison, WI 53711.

Metal top cover for Harman-Kardon Citation V tube amp. James Gilmore, (415) 782-2431.

Single Dyna Mark III. Buy or trade Heath AR1500. Paul Leo, PO Box L, Shenorock, NY 10587.

Marantz 8B amp and 7C preamp. Prefer clean, unmodified, working condition, also Lazarus or other classic tube preamps. Mike Howard, 18004 1st St. East, Redington Shores, FL 33708, (813) 393-8875.

Manufacturer's address and number of slider-type potentiometers as used in mixer boards in studios. Steve, 308 North New St., Staunton, VA 24401.

Power transformer for a Dynaco SCA 35 integrated amp. Stanley Grycz, 2935 Crehore St., Lorain, OH 44052, (216) 288-9480.

Need information from anyone who has upgraded or modified the M & K Satellite 1B. Also on Bose 301 II speakers. Pedro Paulino, 1891 S. Capitol Ave., San Jose, CA 95127.

CLUBS

ELECTROSTATIC LOUDSPEAKER USERS GROUP is now a world-wide network for those interested in sharing valuable theory, design, construction, and parts source information. If you are interested in building, or have built, you own SOTA ESL we invite you to join our loose-knit organization. For information, send an SASE to: Barry Waldron, 1847 Country Club Dr., Placerville, CA 95667.

MEMPHIS AREA AUDIO SOCIETY being formed. Serious audiophiles contact J.J. McBride, 8181 Wind Valley Cove, Memphis, TN 38125, (901) 756-6831.

NEW JERSEY AUDIO SOCIETY meets monthly. Emphasis is on construction and modification of electronics and speakers. Dues includes monthly newsletter with high-end news, construction articles, analysis of commercial circuits, etc. Meetings are devoted to listening to records and CDs, comparing and A-B-ing equipment. New members welcome. Contact Bill Donnally, (201) 334-9412 or Bob Young, 116 Cleveland Ave., Colonia, NJ 07067, (201) 381-6269.

AUDIOPHILES IN THE DAYTON/SPRINGFIELD, OHIO AREA: We are forming an audio club. Please contact me if you're interested in construction, modifications, testing, recording or just plain listening to music. Ken Beers, 462 Blose St., Tremont City, OH 45372, (513) 969-8402.

THE HI-FI CLUB of Cape Town in South Africa sends a monthly newsletter to its members and world-wide subscribers. To receive an evaluation copy of our current newsletter, write to: PO Box 18262, Wynberg 7824, South Africa. We'll be very pleased to hear from you.

THE COLORADO AUDIO SOCIETY is a group of audio enthusiasts dedicated to the pursuit of music and audiophile arts in the Rocky Mountain region. We offer a comprehensive annual journal, five bimonthly newsletters, plus participation in meetings and lectures. For more information, send SASE to: CAS, 4506 Osceola St., Denver, CO 80212, or call Art Tedeschi, (303) 477-5223.

CONNECTICUT AUDIO SOCIETY is an active and growing club with activities covering many facets of audio—including construction, subjective testing, and tours of local manufacturers. New members are always welcome. For a copy of our current newsletter and an invitation to our next meeting, write to: Richard Thompson, 129 Newgate Rd., E. Granby, CT 06026, (203) 653-7873.

AUDIO SOCIETY OF MINNESOTA. Audiophiles, music lovers, scratch builders, record collectors, tube freaks, digital freaks — we've got 'em all! Monthly meeting, tours, audiophile concerts, special guests, etc. Now in our 12th consecutive year! Write ASM, PO Box 32293, Fridley, MN 55432.

PIEDMONT AUDIO SOCIETY. Starting an audio club in the Raleigh-Durham-Chapel Hill area of North Carolina. Interested in designing, building, and modifying speakers and electronics (solid state *and* tube). Beginners and old hands both welcome. Kevin Carter, 9009 Langwood Drive, Raleigh, NC 27612, (919) 870-5528.

SOUTHEASTERN MICHIGAN WOOFER AND TWEETER MARCHING SOCIETY (SMWTMS). Detroit area audio construction club. Meetings every two months featuring serious lectures, design analyses, digital audio, A B listening tests, equipment clinics, recording studio visits, and audio fun. The club journal is *LC, The SMWTMS Network*. Corresponding member's subscription available. Call (313) 477-6502 (days) or write David Carlstrom, SMWTMS, PO Box 721464, Berkley, MI 48072-0464.

THE CATSKILL AND ADIRONDACK AUDIO SOCIETY invites you to our informal monthly meeting. Join our friendly group of audio enthusiasts as we discuss life, the universe and everything. No matter what your level of interest, experience, or preferences, you are welcome. Meetings are generally held once a month, on a weekday evening. Contact CAAS at 756-9894 (leave message), or write CAAS PO Box 144, Hannacroix, NY 12087. See you there!

THE INLAND EMPIRE AUDIO SOCIETY (soon to become the Southern California Audio Society — SCAS) is now inviting audiophiles from all areas of southern California and abroad to join our serious pursuit for that elusive sonic truth through our meetings and the IEAS' official speaker, *The Reference* newsletter. For information write or call: Frank Manrique, President, 1219 Fulbright Ave., Redlands, CA 92373, (714) 793-9209.

ELECTROSTATIC LOUDSPEAKER USERS GROUP is now a world-wide network for those interested in sharing valuable theory, design, construction, and parts source information. If you are interested in building, or have built, your own SOTA ESL we invite you to join our loose-knit organization. For information, send an SASE to: Barry Waldron, 1847 Country Club Dr., Placerville, CA 95667.

ORGAN MUSIC ENTHUSIASTS: If live recordings of fine Theatre Organ Music are your thing, SFORZANDO has room for a few new members. We lend you the music on cassettes. All operation is via the mail. SFORZANDO, c/o E.A. Rawlings, 5411 Bocage St., Montreal, Canada H4J 1A2.

PACIFIC NORTHWEST AUDIO SOCIETY (PAS) consists of 60 audio enthusiasts meeting monthly, second Wednesdays, 7:30 to 9:30 p.m. at 4545 Island Crest Way, Mercer Island, Washington. Be our guest, write Box 435, Mercer Island, WA 98040 or call Bob McDonald, (206) 232-8130.

WASHINGTON AREA AUDIO SOCIETY (N. VA, MD and DC) is looking for sincere audiophiles who are eager to devote their time and get involved with the direction of the society and the publication of a monthly newsletter. Please contact: Horacio J. Vignale, 3730 Gunston Rd., Alexandria, VA 22302.

THE WESTERN NEW YORK Audio Society (WNY Audio Society) is an active and growing audio club located in the Buffalo area. We issue a quarterly newsletter and hold meetings the first Tuesday of every month. Our meetings have attracted many local and distant manufacturers of audio related equipment. We are involved in all facets of audio — from building to purchasing at discount prices. For a copy of our current newsletter and information regarding our society, please write to M.A. Monaco, WNY Audio Society, PO Box 312, N. Tonawanda, NY 14120.

THE BOSTON AUDIO SOCIETY invites you to join and receive the bimonthly *B.A.S. SPEAKER* with reviews, debates, scientific analyses, and summaries of lectures by major engineers. Read about Apogee, Nytal, Conrad-Johnson, dbx digital, Snell, music criticism and other topics. Rates on request. PO Box 211, Boston, MA 02126.

THE ATLANTA AUDIO SOCIETY is dedicated to furnish pleasure and education for people with a common interest in fine music and audio equipment. Monthly meetings often feature guest speakers from the audio manufacturing and recording industry. Members receive a monthly newsletter. The society is hosting the 2-day *SUNBELT AUDIO SHOW* in Atlanta on August 18 & 19, 1990. Call: Chuck Bruce, (404) 876-5659, or Denny Meeker, (404) 872-0428, or write: PO Box 361, Marietta, GA 30061.

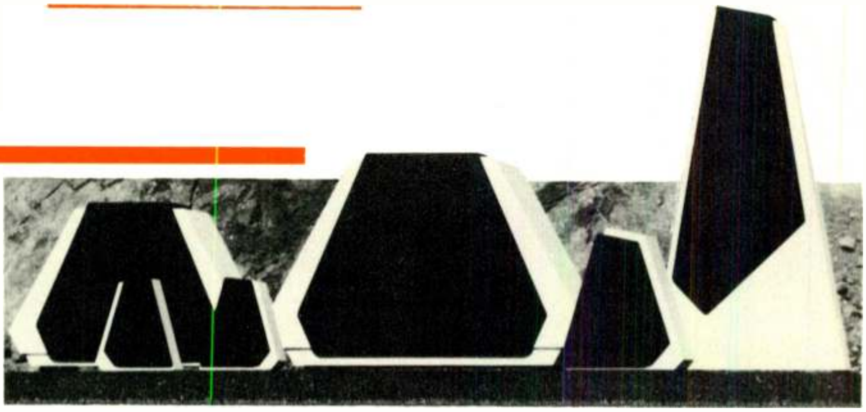
THOSE INTERESTED IN AUDIO and speaker building in the Knoxville-East Tennessee area please contact Bob Wright, 7344 Toxaway Dr., Knoxville, TN 37909-2452, (615) 691-1668 after 6 p.m.

TUBE AUDIO ENTHUSIASTS. Northern California club meets every other month. For next meeting announcement send a self-addressed, stamped #10 envelope to Tim Eding, PO Box 611662, San Jose, CA 95161.

WANT TO START OR JOIN CLUB IN CENTRAL ILLINOIS (Peoria, Bloomington, Champaign, Kankakee area). Speaker building and audio in general. Trade info and parts. (815) 657-8488 evenings or weekends.

Advertising Index

Good News



The Point Series, a new and unusual looking line of speakers, is now available from **ODEON**. The Point Three, 36″ tall, features a 6.5″ butyl-surround polypropylene woofer and a 1″ textile dome tweeter. The Point Four, a 14″ tall shelf- or stand-mount unit, uses a 5.25″ woofer and the same tweeter as the Three. The Zero Three and Zero Four are passive subwoofers without crossovers. All units feature a truncated-pyramid shape and are available in two multicolor finishes. They range in price from $299/pair for the Point Four to $799/pair for the Point Three. For more information contact Odeon, 12461 Tibbetts St., Sylmar CA 91342, (818) 362-3379.

Fast Reply #FE590

The second international symposium on **PERCEPTION OF REPRODUCED SOUND** will be held at the Hotel Faaborg Fjord, Denmark, August 19–22, 1990. Participants will include: T. Holman, E. Zwicker, S. Bech, F. Toole, E. Cohen, G. Thiele, P. Willemoes, H. Staffeldt and M. Colloms. All papers are given in English; no parallel sessions. The symposium fee is 6,000 DKK per person, which includes all symposium arrangements, proceedings and accommodation with full board. Contact Eva Rudolf, Ingeniorhojskolen Aarhus Teknikum, Dalgas Ave. 2, DK-8000 Arhus C., Denmark, phone: 45 86 13 62 11.

PRECISE ACOUSTIC LABORATORIES has introduced their new Beta line of loudspeakers including drivers designed by Keith Johnson. The new speakers feature a baffle/speaker stand design in which the baffle serves as a self-damping surface, with further foam damping beneath the midrange. Crafted of 1½″ high-density fiberboard, the cabinets come in black, walnut or oak finish. For more information, contact Precise Acoustic Labs, 200 Williams Dr., Ste. B, Ramsey, NJ 07446, (201) 934-1335.

Fast Reply #FE103

SKAANINGS ApS has announced a series of drive units called Flexunits. Designed to be variable, they will have specification ranges, but general characteristics include a chassis consisting of a front ring, an intermediate ring for the spider, and a rear ring for the magnet system. The rings are cast aluminium and separated by spacers of variable length, to accommodate the variable voice coil length and air gap height. Voice coils come in 75 and 100mm diameters. Magnets vary from 170 to 220mm. For more information, contact Skaanings ApS, Industrivej 3, Stilling, DK-8660 Skanderborg, Denmark, phone: 45 86 57 15 22.

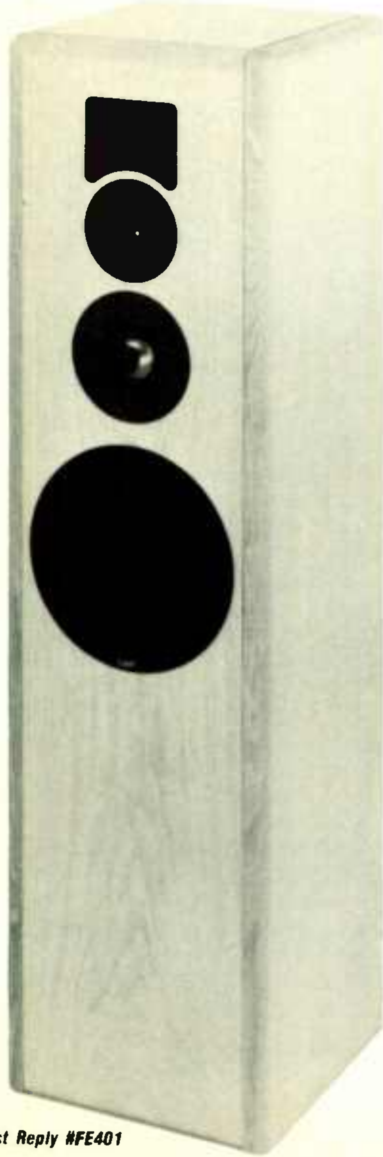
Fast Reply #FE589

RAPID SYSTEMS has introduced the R726, a 6-channel digital-to-analog output board for XT/AT/386 personal computers, providing a way to accomplish servo and process control, programmable voltage sources, function generator or arbitrary waveform functions. The new board is priced at $995 and is available from Rapid Systems, Inc., 433 N. 34th St., Seattle, WA 98103, (206) 547-8311.

Fast Reply #FE948

The new Quart Pure loudspeaker system, announced by **MB QUART**, employs their MCS (moving control system) technology, which combines the advantages of bass reflex and acoustic suspension cabinet designs. The new speakers feature a 1″ titanium dome tweeter, and a 2″ dome midrange and 8″ woofer are flush-mounted mirror image components, in a vertical array. The 44″ high cabinet is available in walnut, oak, black, white or raw oak. Suggested retail is $3,000/pair. For more information contact MB Quart, 25 Walpole Park South, Walpole, MA 02081, (508) 668-8973.

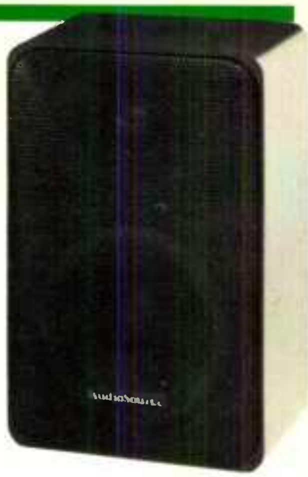
Fast Reply #FE356



Fast Reply #FE401

The LS TWO/A, a new compact speaker from **AUDIOSOURCE**, features a long-throw 5″ polypropylene woofer with double wound voice coil to enhance bass response down to 60Hz. Also included is a 1″ soft dome, ferrofluid-cooled tweeter. Measuring 8½″H by 5½″W by 4½″D, the unit sells for $239.95/pair. A weather-tight version, the LS TWO/A WT, is available for $259.95/pair. Optional, heavy-duty mounting brackets are available for both models at $29.95/pair. For more information, contact AudioSource, 1327 North Carolan Ave., Burlingame, CA 94010, (415) 348-8114.

Fast Reply #FE460

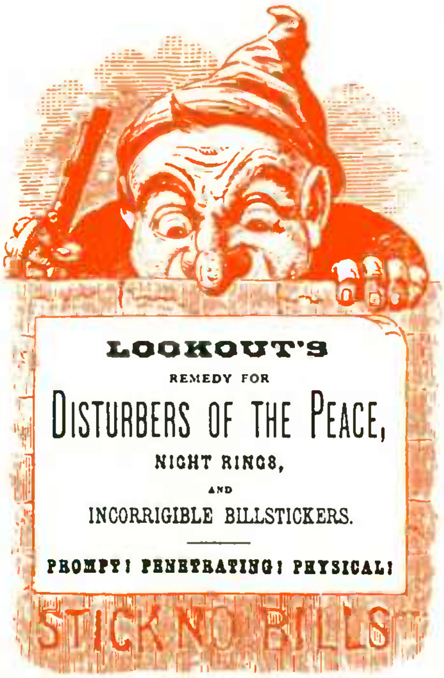


Fast Reply #FE370

Pox Humana

Where is the Tone Coming From?

By Dick Pierce



Back in the days when I was involved with a retail outlet, Nakamichi was just getting started in the US market. They had only a few products, the Nakamichi 1000, 700, 550 and 500. Of interest was the 550, a portable, fairly high-quality cassette unit with Dolby-B.

One customer bought one and, after a week or two, brought it back complaining that he could hear a faint background tone during very quiet passages. Well, after much fiddling and waiting for trucks to pass, yes we could, by straining a bit, hear this tone. Into the lab I went, where I proceeded to measure the S/N ratio. It was supposedly rated at 56dB (or some such figure, only the relative values are important). Well, there on the bench, it was cranking away at some 59 or 60dB S/N. And the scope showed no trace of any regular waveform in the noise. A call to Nakamichi generated an immediate request for the recorder, as they wanted to know what was going on.

After a week or so, Nakamichi called back and said, "There is nothing wrong with the recorder, it meets spec." I asked, "Did you solve the problem?" "It meets spec," came the inappropriate response. "Did you find the tone?" I pushed. "It meets spec," came the obviously practiced reply. "Send it back and I'll check it out," I said. A day or two later, back it came, and by the looks of the screwheads, it had never been opened. Back up on the bench it went, and it did indeed meet spec. I put it back out into the showroom, and sure enough the tone was still there. We decided to give the customer a new unit and try to resolve the issue with Nakamichi. Unfortunately, the new unit, and all others in stock, suffered from exactly the same problem.

Time to bring the heavy weaponry to bear. I fired up the HP narrowband spectrum analyzer. A spectral analysis of the noise revealed, in addition to the perfectly normal noise floor, a nice, sharp, prominent peak at 400Hz. Why 400Hz? Well, that happened to be the frequency of the Dolby calibration oscillator. It seems Nakamichi had designed the calibration oscillator so that when you turned it off, it was not turned off, but merely disconnected from the record amps. The rest of the time, it was oscillating happily away, generating enough cross-coupling to find its way into the playback amps where its microvolt level was dutifully amplified to barely audible levels.

Now, armed with real information, I was able to call Nakamichi service directly and tell them exactly what was wrong. The technicians were very interested in my description. However, Nakamichi as a corporate being said, "If the noise," meaning, I guess, any extraneous information, "is below the spec for signal to noise, then the unit is perfectly OK." Here, we were left high and dry. We had a unit with a definite and identifiable design defect, and the manufacturer was telling us in no uncertain terms they were not interested in the problem.

After several weeks of haggling, Nakamichi simply refused to provide any help in solving the problem. By this time, several units were returned, with the same complaint, so we had a multi-thousand dollar issue to deal with. We had several choices.

1. Tell the customers what Nakamichi told us, and tell them that life is tough all over, and keep their money.
2. Take the units back and give the customers a refund (which, under Massachusetts law they had the right to demand), and bear the loss, since Nakamichi wouldn't take back what they considered good merchandise.
3. Try to solve the problem.

The tack we took involved part of #1 and all of #3, that is, relate to the customer the difficulties of trying to get Nakamichi to handle the problem, and, hoping their sympathies would be in our favor, buy time to solve the problem. The solution was to rewire the Dolby tone switch to disconnect the power from the oscillator, rather than disconnecting the oscillator from the rest of the recorder. This completely eliminated the tone problem, but it took some 30 minutes to effect the repair, and it voided the Nakamichi warranty, even though we were an authorized service station.

The lesson to be learned here is manifold: 1) Highly regarded manufacturers are not always infallible. 2) Some manufacturers, when presented with what they might consider embarrassing information (as Nakamichi later admitted was the case), will stand fast and find anything to defend their position (I believe after many people complained, they finally incorporated my change into the product, but that took several years). 3) Much of the difficulty in trying to solve these sorts of problems is due to the intransigence of the manufacturer, not the dealer (although many dealers are incompetent in this area).

The MDM 85 is a mid range 75mm soft dome unit of extremely high standard, both from a design and technical viewpoint.

It incorporates the renowned Morel double magnet and Hexatech voice coil techniques, and results in a unit of above average sensitivity with extremely low distortion and high power handling capability.

With an output level of 96dB distortion in the area of 400-800Hz is slightly over 1% falling to 0.015% from 1Khz.

There are two different types available, one with a rear enclosure and one without (MDM 85NE). The type with the rear enclosure can be fitted into a cabinet as an integral unit.

The MDM 85NE without the rear enclosure can only be fitted into a system having a separate housing to enclose the unit. A volume of 0.7 litre is recommended for this housing, which is essential to prevent inter-reaction with the bass unit compressions and expansions. This housing must be filled full with damping material, such as fibreglass or rock wool.

The Thiele small parameters are given for both types under specifications. The contribution of this unit to a suitably designed system will be evident in the clarity and detail given in the 500-5000Hz region.

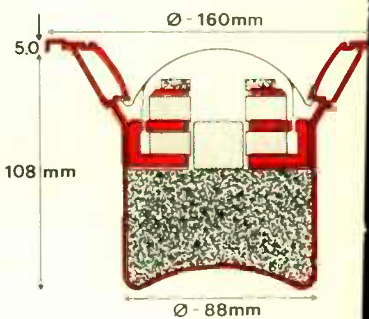
Specification

MDM 85 (with enclosure)

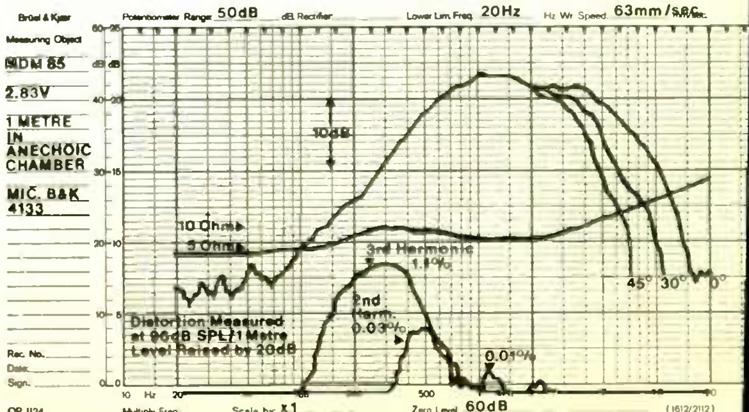
Overall Dimensions	Ø - 160mm x 113mm
Nominal Power Handling Din	300W
Transient Power 10ms	1500W
Voice Coil Diameter	75mm (3") Hexatech Aluminium
Voice Coil Former	Aluminium
Frequency Response	300-5000 Hz
Resonant Frequency	250 Hz
Sensitivity	92 dB (1W/1M)
Nominal Impedance	8 ohms
Harmonic Distortion for 96 dB SPL	<1%
Intermodulation Distortion for 96 dB SPL	<0.25%
Voice Coil Inductance @ 1 Khz	0.2mh
Air Gap Width	1.05mm
Air Gap Height	3.0mm
Voice Coil Height	6.0mm
Flux Density	1.0T
Force Factor (BXL)	4.6 WB/M
Rdc	5.2 ohms
Rmec	37.90
Qms	0.29
Qes	2.66
Q/T	0.20
Vas	0.33 litre
Moving Mass including Air Load	7.0 grams
Effective Dome Area	63.50 cm^2
Dome Material	Chemically Treated Fabric
Nett Weight	1.25 kg

Variations to specification for MDM 85NE (without enclosure)

Overall Dimensions	Ø - 160mm x 60m
Frequency Response	250-5000
Resonant Frequency	170
Rmec	39.
Qms	0.
Qes	1.
Q/T	0.
Vas	0.7 li
Nett Weight	1.05



Specifications given are as after 24 hours of running.



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