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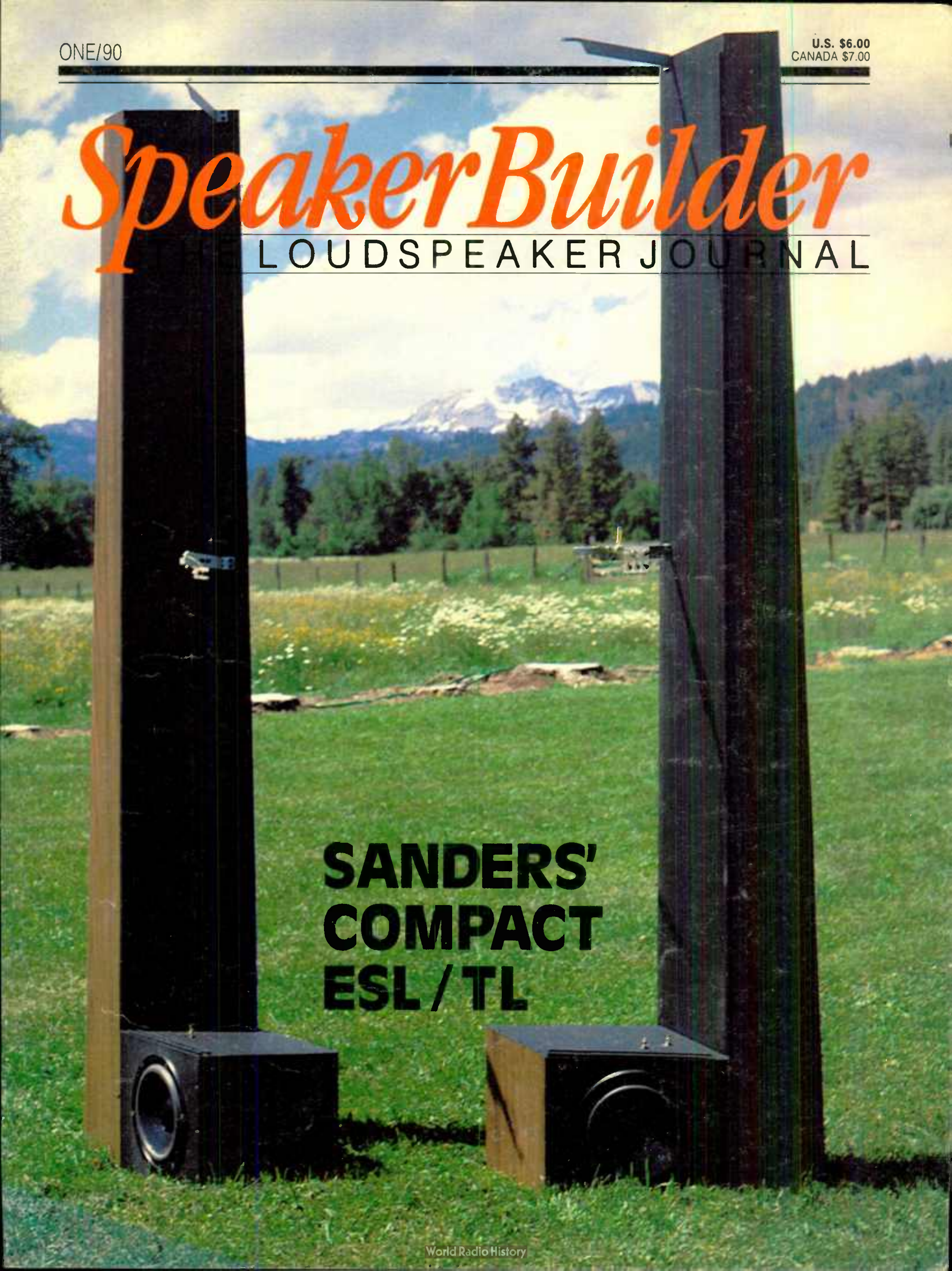
Speaker Builder

LOUDSPEAKER JOURNAL



SANDERS' COMPACT ESL/TL

SB Mailbox

ERRATA

Several readers have called to our attention errors in *SB* 6/89. On page 67, John Levreault's reply to Frank Habrle was in error stating that Analog Devices' AD713 is a direct pin-for-pin replacement for the 4136 op amp. The only direct replacement for the 4136 is Texas Instruments' TL4075.

Tom Tutay points out that two of the capacitor values in James Lin's Table 1 on page 17 of his article are incorrect. C_H values 0.01 and 0.033μF should be 0.1 and 0.33μF, respectively.

SATELLITE CORRECTION

I would like to call attention to an error in my Craftsman's Corner article "Symmetrical Satellite" (*SB* 6/89). The actual value for F_H should be 76Hz. Observant readers may have noticed that the F_L x F_H did not equal FO2 as should be the case.

My system is now biamped with the ports facing out into the room just below the satellites. A Hafler DH120 powers the satellites and I used 12-gauge OFC throughout.

Rod Hickerson
Portland, OR 97206

ABSORBENT TUBES

After going over Allan Millikan's outstanding article, "Dynaudio Drivers and Sheetrock" (*SB* 3/89) for about the 12th time before heading for my shop, I wonder about the fiberglass wool tube absorbers he mentioned near the end of the article. Are these commercially available or the author's contrivance? Probably my biggest headaches are caused by speaker/listening room interaction. I would appreciate Mr. Millikan's comments on his absorbers and their effectiveness.

Dave Schneider
Marion, IA 52302

Allan Millikan replies:

Thank you for your comments and your query about the bass absorbers.

These devices are my home-brew attempt to provide the same function as the commercially available ASC Tube Traps (Acoustic Sciences Corp., PO Box 1189, Eugene OR 97440, (503) 343-9727). The literature states that standing waves in a room produce high pressure nodes in the room tri-corners, and absorbers located in those positions are far more effective than flat panels mounted on the room walls. The tubes are effective to lower frequencies as their diameter increases. I believe my 16-inch-diameter tubes will be useful down to about 40Hz.

I made hollow cylinders from 2″ by 4″ wire fencing stock available in 30-inch-wide rolls at many home supply and garden stores. The cylinder is lined with 6″ unfaced fiberglass building insulation, leaving a hollow core about 4 inches in diameter. The ends of the tube are closed with disks of ¼″ hardboard. To provide improved appearance I have covered the outside of the tubes with natural-colored burlap cloth. I made four tubes in my listening room for approximately $60 in material costs.

The bass response of my system with the tubes in place is smoother and the bass lines of jazz and classical accompaniment are more "tuneful." I am sorry I can't give you more quantitative results but I don't have the necessary measuring equipment.

I have a colleague in Arizona whose listening room is treated with some $3,000 of ASC Tube Traps. He was present when the inventor of Tube Traps optimized that room. They make a powerful difference. ASC Tube Traps are more complex in construction and allow the ratio of mid/high frequency reflection to bass absorption to be adjusted by rotating each Tube Trap. My simple devices seem to help a part of the room problem at much lower cost.

If you decide to experiment in this area, I would be interested in hearing of your results.

RADIO SHACK 40-1022A

I recently began designing an Isobarik type project using the Radio Shack 40-1022A (blue-box) 4″ woofer and I would like to relate my experiences to Contributing Editor John Cockroft.

Since I needed a total of four woofers per channel I chose the inexpensive Radio Shack 4″ drivers. But after reading of your bad experiences (Mailbox, *SB* 4/88), I placed the project on hold. Then Rodney Cavin related his experiences (Mailbox, *SB* 2/89) and I thought, "Well, maybe I'll buy just one woofer and see what happens."

My "break in" consisted of applying enough power to produce a ¼″ peak-to-peak cone excursion for one hour at 15Hz. I then measured F_S and was shocked to find it right on target. I decided to continue purchasing woofers, one at a time, and figured that if I started to get several "losers" I could always scrap the whole project and make a pair of mini-speakers for my garage.

Table I summarizes my findings. I ended up purchasing a total of 11 woofers of which two were rejected. These two exceeded the tolerance listed in the Radio Shack spec sheet which shows that F_S should be 55Hz, ±5Hz. My Radio Shack store managers were glad to exchange my "losers" for fresh drivers.

The woofer marked "turkey" sounded edgy so I bought another driver to replace it. It looked and measured OK so I did not return it to Radio Shack. Maybe I'll cut it apart to examine the voice coil.

The cryptic markings column lists the numbers or letters that were stamped next to the word "Korea" on the back of my drivers. I don't know what these markings mean but perhaps they have something to do with the shipping and/or manufacturing dates.

Table II summarizes my driver parameters when hooked up in the Isobarik configuration. I made a small 2¾″ tunnel,

TABLE I

MEASURED DATA—RADIO SHACK 40-1022A

#	CRYPTIC MARKINGS	MFG LOC.	F_S (Hz)	Q_{MS}	Q_{ES}	Q_{TS}	V_{AS} (ft³)	FINAL STATUS
1	1989.2.2	Korea	55	2.361	.419	.356	.238	OK
2	1989.2.2	Korea	55	2.449	.433	.368	.241	OK
3	1989.2.2	Korea	55	2.381	.429	.363	.234	OK
4a	1989.2.2	Korea	49	2.445	.352	.307	.293	REJECT
4b	1989.2.2	Korea	55	2.386	.413	.352	.242	OK
5	1989.2.2	Korea	59	2.384	.499	.413	.208	OK
6a	8025	Korea	62	2.222	.531	.428	.184	REJECT
6b	1988.12.8	Korea	51	2.301	.446	.373	.282	OK
7	1989.2.2	Korea	58	2.263	.432	.363	.219	OK
8	1989.2.2	Korea	57	2.284	.427	.359	.224	TURKEY
9	7D16	Korea	51	2.397	.380	.328	.255	OK
Manufacturers' Specs			(55)			(.350)	(.230)	

TABLE II

COMPOUND WOOFER DATA

Driver #'s	F_{SB} (Hz)	Q_{MS}	Q_{ES}	Q_{TS}	V_{AS} (ft^3)
1, 3	54	2.474	.449	.380	.116
2, 4b	54	2.516	.452	.383	.122
6b, 9	50	2.451	.448	.379	.143
5, 7	56	2.466	.477	.399	.114

wired the drivers in series, and measured the compound woofer parameters in free air. It is interesting how this data compares to that of a single driver.

I am very impressed with these little Isobarik wonders. The sound is exactly the way you describe it in your articles. I can't believe I am listening to a pair of inexpensive Radio Shack drivers. Thanks to your inspiration, I intend to do much more testing and building of Isobarik speakers.

Bill Schwefel
Jackson, WI 53037

John Cockroft replies:

Thank you for sharing the encouraging results of your experiences with the Radio Shack 40-1022As. Adding your data to that of Rodney Cavin creates a picture of hope that Radio Shack has solved the 1022's problems. I'm very happy about it because the 40-1022 is one of my favorite driver units. Perhaps it's time to thank Radio Shack.

It's also gratifying to see that someone is still interested in the Isobarik concept. To some, "A free lunch does not a speaker make." Some of us are willing to put off a few calories to attain the sound qualities we desire. Over the years since I first ran across the concept and wrote about what I thought the Isobarik system was, I have noticed an occasional spark flickering in the pages of *SB* Mailbox. It makes me happy to see this. The concept is as good a tool as any other in the audio field and when correctly used in the right place can produce excellent results.

I am sometimes dismayed to find many speaker builders more interested in theory of design than in quality of sound. The sound of my systems is my only stimulus for creating them. In an attempt to achieve that sound I go in any direction I think might help (even if the direction is contraindicated by the prevailing lore). My experiences with Isobarik and compound speaker systems were happy ones and I'm glad to see yours are too. Your letter really made my day. Thanks.

KLIPSCH COMMENTS

I am a cover-to-cover reader of *Speaker Builder*. The recent interview with Paul Klipsch by Bruce Edgar (4/89) was interesting . . . but not too informative. Although the reminiscing put some of the Klipsch history into perspective, it seemed a shame to access a real contributor to the audio art, and get such limited technical insight.

Like Mr. Klipsch, I have had the opportunity to play with his full-sized horn as well as one called a K-Horn, manufactured in the Northwest. My observations were not the same as his. In an irregular room of 103 square meters (275 cubic meters) structured to limit standing waves, both produced reasonably clean output to just below 30Hz. The K-Horn actually went down to about 28Hz, and then stopped abruptly. The Klipsch product had fewer objectionable cabinet resonances and random harmonic vibrations than the other product.

Suppliers of fully horn-loaded products seem obsessed with working the bass end . . . which they still don't get right. They fold the bass horn, expect it to operate over 2–3 octaves, but rarely include properly designed equalizing plugs at the horn throat to attempt some phase coherence at the mouth. Most use mid and high frequency horns of dimensions that de facto make them diffraction horns. The suppliers then proceed to (horizontally) mount these horns in baffles, so as to guarantee the loss of dispersion which had been assured by diffraction. The use of a larger number of horns, each with only one octave to contend with, would measurably improve most "high-end" horn-loaded systems.

If you want to see speakers mounted almost correctly, look at Vandersteen.

Continued on page 53

Fast Reply #EE401

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About This Issue

If you have wondered how to get your speaker into the distortion cancelling feedback mode, **Hans Mortensen** has also. His suggested pathways into this relatively uncharted territory begin on p. 10. All you guitar players who've been asking for a speaker voice for your instrument are about to be gratified. Using paper drums and tubes **Glenn DeMichele** has built a beauty. The specifics begin on p. 22.

Roger Sanders, surely one of the world's leading authorities on electrostatics graces our pages again with a brand-new bass recipe in the spectacular package pictured on our cover. Our four-part series on this handsome realization of ESL/TL coordination begins on page 30.

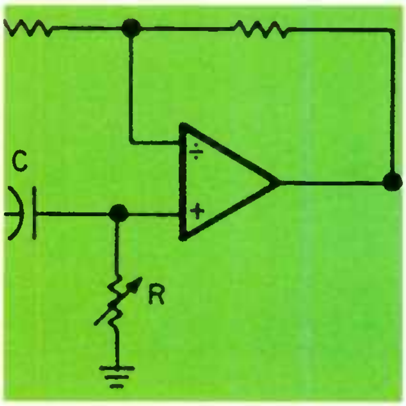
Those nifty little Radio Shack speakers are just too tempting to let alone. **Angel Luis Rivera** suggests a new configuration for the popular pair of poppets (p. 42). **Dick Pierce** not only clarifies Richard Heyser's "time delay spectrometry" concept and such wonders as FFTs—Fast Fourier Transforms to the uninitiated—in his *Ask Speaker Builder* treatise (p. 46), but also he introduces readers to George Augspurger's mordant wit on the topic of speaker patents on p. 78.

To underline the importance of your responses to *Speaker Builder* we've moved a couple of features in this first 1990 issue. *Letters* will lead off our pages in future, but you will find the *Good News* about new vendor offerings beginning on page 73.

Next time you'll be seeing Bruce Edgar's *Show Horn* and how to fix the Klipsch Heresy plus a nifty little two-way design.

SpeakerBuilder
THE LOUDSPEAKER JOURNAL

VOLUME 11 NUMBER 1 FEBRUARY 1990



10

22

On our cover: **Roger Sanders'** compact electrostatic/transmission line speakers without the electrostatic panels. Photo by the author.

FEATURES

DEPARTMENTS

Editorial

MICHAEL AND US

Michael Moore is man of the year around Audio Amateur Publications these days. Not only do we admire his dogged determination to do something about entrenched intransigence and short sightedness so rampant in today's US corporate marketplace, but also we like his scale of values very much indeed.

If the name hasn't become familiar in your household, Michael is the man who made the movie *Roger and Me*, which is all about what has happened (or not happened) at General Motors over the last half decade or so. The Roger of the title is Roger Smith who has recently become a highly controversial item in business circles. As GM's Chief Operating Officer he is presiding over a company whose activities seem to consist of introducing dull new products and closing assembly plants. He and Ross Perot had a *High Noon* shootout a while back over GM performance and efficiency. Mr. Smith bought out Mr. Perot's interests rather than go along with his ideas for improving the giant corporation.

GM's plant closings in Flint, Michigan (the company's birthplace), and the astronomical unemployment rates in that city are Mike Moore's chief theme. Throughout the film he apparently spends most of the footage trying to get past Roger's minions to have a frank talk with him about what's happening to Flint and its citizenry.

Moore couldn't persuade anyone in Hollywood to make the picture, of course. So he made it himself, with his own money. That alone would endear him to us around this establishment, but there's more. Unable to find backers who wanted to risk money on his idea, he sold all his possessions, house, car, furniture, and so on—save one item. His music system. Now there is a central kernel for a myth: a genuine audio folk hero.

I have no idea what his system might have consisted of, or where he parked it while putting *Roger and Me* in the can. But his set of values is certainly in the right order.

The rest of the story really fills out the original promise exemplified in his value choices. The movie has become a rousing success. Warner Brothers, as part of the new Time-Warner complex, has contracted for distribution of *Roger and Me* and is making Moore a well-to-do young man. His contract with the distributor even requires that they show the movie free to the unemployed in specified areas throughout the country. I imagine Michael has been able to buy another house and furnish it satisfactorily. Somehow, I rather hope he has kept his original sound system, whatever his fiscal success.

Despite wide media exposure, Moore continues to dress—baseball cap and all—just as he did before making the movie. He appears to have kept his value system intact. We can all certainly hope so. Naturally Roger Smith has not consented to talk, face to face, with Moore, which neatly confirms what a lot of people are saying about GM's head officer—including a couple of very large pension fund managers who are no happier about Roger than Moore is.

I wouldn't want to bet this David and Goliath rerun is going to make much difference at fortress GM, or within many leaders of corporate America, who are spending most of their energy circling the wagons rather than looking for ways to reclaim our leadership in the industrial world. But it should be a small, eloquent example for corporate boardrooms everywhere that communication power today is a force to be reckoned with, whether we are talking Berlin walls or corporate ossification.

As long as we're meditating on values, it's probably worthwhile to reflect on society's new music values. Music has ceased to be a luxury. The "stereo," as our hero exemplifies, is as necessary today as the bed or the stove. Certainly few cars traveling our highways are without both AM/FM radios as well as cassette players. Music is more pervasive in our society than in any which has come before us.

Many of us have heard more music, live and reproduced, than Johann Sebastian Bach did in his entire lifetime. The variety is greater as well. Although the imagination fails at the thought of what old J. S. might have had to say about contemporary serious music or about Hard Rock. Given the choice, my prejudices suppose he would have preferred the latter.

Scholarly studies completed within the last fifteen years make it clear that music has some kind of evolutionary survival value for humans, since it is quite universal throughout all cultures, past and present. Our brains also have unique mechanisms for processing it. The fact that the right brain is active during music listening activities for those of us untrained in music tells us that the experience is aesthetic or a-rational rather than primarily rational in character. Those of you who see *Audio Amateur* may examine this thesis more thoroughly in the 1/90 issue where we will be reprinting an article from the now defunct *Opus* by Andrew P. Stiller titled "Toward a Biology of Music."

I find it delightful that some, and possibly all, humans have the capability of recording indelibly in their gray matter every scrap of music they have ever heard in some fashion we do not yet fully understand. Neurologists are reporting more and more empirical snippets of evidence to that effect, as in the work of Oliver Sacks, especially in his book *The Man Who Mistook His Wife for a Hat*.

It appears likely to me at least, that modern technology has simply responded to one of our most basic human appetites. Music is not a luxury. It performs some functions we are only beginning to dimly glimpse. Our common search for better loudspeakers in the pages of this periodical is not fueled by mere technical curiosity, craftsmanship or do-it-yourself satisfactions. The satisfaction we seek will, I think, turn out to be something far more profound and primitive in our makeup. How lucky it is all so much fun.

And for our new hero Michael Moore: a tip of an audiophile hat and our thanks.—E.T.D.

ORIGINAL MASTER RECORDINGS

FOR THE SOUND CONNOISSEUR

Mobile Fidelity Sound Lab has been committed to the highest quality in sound reproduction in pre-recorded audio software since the introduction of their audiophile half-speed mastered LP in 1978. Contrary to the conclusions of the music industry, the LP is not dead! Word from audiophiles, collectors, and turntable owners has strengthened Mobile Fidelity's belief in the viability of the analog format

Mobile Fidelity's LP's are the result of careful transference using half-speed mastering which provides a much deeper groove, giving the playback stylus more surface area from which to read the sonic information. Half-speed mastering also eliminates the need for limiting, and allows for greater frequency response. The lacquers are plated in Japan and the resulting LP's are pressed on 120 grams of pure virgin vinyl providing a virtually noise free, anti-static sound. The LP's are protectively packaged in rice paper sleeves, individually numbered and limited to 5,000 pressings each.

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Fast Reply #EE317

AN ACCELERATION FEEDBACK SYSTEM

BY HANS KLARSKOV MORTENSEN

PHOTO 1: The subwoofer with a 12 inch driver.

This article differs somewhat from the standard do-it-yourself (DIY) articles, which usually offer complete construction information. Sometimes I am bored by all the "do this, don't do that"—all of which is necessary for a construction story. I decided to try another type of DIY article, including notes, ideas, formulas and considerations.

INTRODUCTION. Since the invention of the dynamic loudspeaker, we have concentrated on improving this ingenious and imperfect device. I am quite sure if the inventor could listen to the new breed of his device, he would hardly believe his own ears. No doubt we will see still improved versions of the dynamic driver. However, recent years have shown a return of interest in circuitry designed to compensate for various speaker shortcomings. This is partly made possible by the vast improvement of relatively inexpensive, good quality audio circuits which have appeared during the last two decades. Some years ago KEF introduced their K-UBE in connection with some of their high-end products, and recently even B&O has introduced an active equalized loudspeaker system.

In this article we will look at two ways to improve the problematic low-frequency response of dynamic speaker systems.

CHEATING NATURE. The human mind has come up with many ways of "tricking" nature in an attempt to make small speakers reproduce frequencies which are, in theory, impossible for their size. In the following, I will use "low frequency" to signify the register from approximately 120 to 20Hz.

In terms of quality we need linearity

ABOUT THE AUTHOR

Mr. Mortensen lives in Denmark, is a full-time high school teacher with a Masters Degree in Danish and English, and has published some works of literary criticism (in Danish). He has been an active, amateur jazz musician, but during the last couple of years he has devoted most of his spare time to high fidelity design, contributing to the Danish magazine, Hi-Fi & Electronics.

$$Fo = \frac{1}{2*\pi*R1*\sqrt{C1*C2}}$$

$$Qo = \frac{1}{2*R1*R2} * \sqrt{\frac{C1}{C2}}$$

$$\frac{R2}{R1} = \frac{1}{Qo} * \sqrt{\frac{C1}{C2}} - 2$$

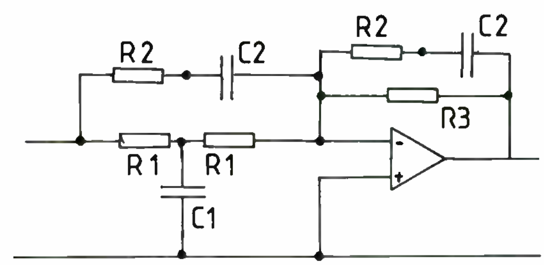
$$F1 = \frac{1}{\pi*R1*C1}$$

$$F2 = \frac{1}{2*\pi*(R2 + R3)*C2}$$

$$Adc = \frac{R3}{2*R1}$$

$$A\infty = \frac{R3}{R2 + R3} < 1$$

$$\frac{Adc}{A\infty} = \frac{R2 + R3}{2*R1}$$



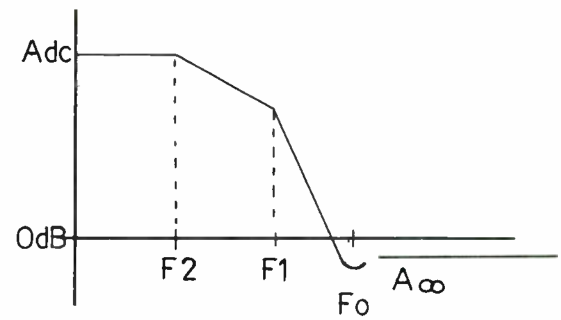


FIGURE 1: The Q compensation circuit developed by Siegfried Linkwitz along with the design formulas. Reprinted by permission from *Electronics and Wireless World.*

```
For C7=0.1µF and C6=0.047µF and C8=0.33µF you get following
resistorvalues for the Fs and Qs as indicated.
  F=  25.0  Q= 0.4  R13=    79685.6  R14= 108323.6  R15=    7720.5
  F=  50.0  Q= 0.4  R13=    39842.8  R14=  54161.8  R15=    3860.3
  F=  75.0  Q= 0.4  R13=    26561.9  R14=  36107.9  R15=    2573.5
  F= 100.0  Q= 0.4  R13=    19921.4  R14=  27080.9  R15=    1930.1
  F= 125.0  Q= 0.4  R13=    15937.1  R14=  21664.7  R15=    1544.1
  F= 150.0  Q= 0.4  R13=    13280.9  R14=  18053.9  R15=    1286.8
  F= 175.0  Q= 0.4  R13=    11383.7  R14=  15474.8  R15=    1102.9
  F= 200.0  Q= 0.4  R13=     9960.7  R14=  13540.4  R15=     965.1
  F=  25.0  Q= 0.6  R13=   119528.4  R14=  72215.7  R15=   11580.8
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  F= 100.0  Q= 0.6  R13=    29882.1  R14=  18053.9  R15=    2895.2
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  F=  75.0  Q= 0.8  R13=    53123.7  R14=  18053.9  R15=    5147.0
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  F= 175.0  Q= 1.2  R13=    34151.0  R14=   5158.3  R15=    3308.8
  F= 200.0  Q= 1.2  R13=    29882.1  R14=   4513.5  R15=    2895.2
  F=  25.0  Q= 1.4  R13=   278899.6  R14=  30949.6  R15=   27021.8
  F=  50.0  Q= 1.4  R13=   139449.8  R14=  15474.8  R15=   13510.9
  F=  75.0  Q= 1.4  R13=    92966.5  R14=  10316.5  R15=    9007.3
  F= 100.0  Q= 1.4  R13=    69724.9  R14=   7737.4  R15=    6755.5
  F= 125.0  Q= 1.4  R13=    55779.9  R14=   6189.9  R15=    5404.4
  F= 150.0  Q= 1.4  R13=    46483.3  R14=   5158.3  R15=    4503.6
  F= 175.0  Q= 1.4  R13=    39842.8  R14=   4421.4  R15=    3860.3
  F= 200.0  Q= 1.4  R13=    34862.5  R14=   3868.7  R15=    3377.7
  F=  25.0  Q= 1.6  R13=   318742.5  R14=  27080.9  R15=   30882.1
  F=  50.0  Q= 1.6  R13=   159371.2  R14=  13540.4  R15=   15441.0
  F=  75.0  Q= 1.6  R13=   106247.5  R14=   9027.0  R15=   10294.0
  F= 100.0  Q= 1.6  R13=    79685.6  R14=   6770.2  R15=    7720.5
  F= 125.0  Q= 1.6  R13=    63748.5  R14=   5416.2  R15=    6176.4
  F= 150.0  Q= 1.6  R13=    53123.7  R14=   4513.5  R15=    5147.0
  F= 175.0  Q= 1.6  R13=    45534.6  R14=   3868.7  R15=    4411.7
  F= 200.0  Q= 1.6  R13=    39842.8  R14=   3385.1  R15=    3860.3
  F=  25.0  Q= 1.8  R13=   358585.2  R14=  24071.9  R15=   34742.3
  F=  50.0  Q= 1.8  R13=   179292.6  R14=  12036.0  R15=   17371.2
  F=  75.0  Q= 1.8  R13=   119528.4  R14=   8024.0  R15=   11580.8
  F= 100.0  Q= 1.8  R13=    89646.3  R14=   6018.0  R15=    8685.6
  F= 125.0  Q= 1.8  R13=    71717.1  R14=   4814.4  R15=    6948.5
  F= 150.0  Q= 1.8  R13=    59764.2  R14=   4012.0  R15=    5790.4
  F= 175.0  Q= 1.8  R13=    51226.5  R14=   3438.8  R15=    4963.2
  F= 200.0  Q= 1.8  R13=    44823.2  R14=   3009.0  R15=    4342.8
  F=  25.0  Q= 2.0  R13=   398428.1  R14=  21664.7  R15=   38602.6
  F=  50.0  Q= 2.0  R13=   199214.0  R14=  10832.4  R15=   19301.3
  F=  75.0  Q= 2.0  R13=   132809.4  R14=   7221.6  R15=   12867.5
  F= 100.0  Q= 2.0  R13=    99607.0  R14=   5416.2  R15=    9650.6
  F= 125.0  Q= 2.0  R13=    79685.6  R14=   4332.9  R15=    7720.5
  F= 150.0  Q= 2.0  R13=    66404.7  R14=   3610.8  R15=    6433.8
  F= 175.0  Q= 2.0  R13=    56918.3  R14=   3095.0  R15=    5514.7
  F= 200.0  Q= 2.0  R13=    49803.5  R14=   2708.1  R15=    4825.3
```

```
10 CLS
20 PRINT " For C7=0.1 µF and C6=0.047µF  and C8=0.33µF you get the "
30 PRINT " following resistorvalues for Fs and Qs as indicated"
40 PRINT
50 FOR Q= .4 TO 2.2 STEP .2
60 FOR F= 25 TO 200 STEP 25
70 LET C8= .1
80 LET CA= .047
90 LET CC=.33
100 LET Y=C8/CA
110 LET RB= 1000000!/((2*3.14*F*CA*(1+Y))*Q)
120 LET N=(Q*Q)
130 LET D=(1+Y)*(1+Y)
140 LET P=N*D
150 LET S=P/Y
160 LET RA=S*RB
170 LET RC=(1000000!*Q)/(2*3.14*F*CC)
180 PRINT "  F= ";
190 PRINT USING "###.#";F;
200 PRINT "  Q= ";
210 PRINT USING "#.#";Q;
220 PRINT "  R13= ";
230 PRINT USING "########.#";RA;
240 PRINT "  R14= ";
250 PRINT USING "######.#";RB;
260 PRINT "  R15= ";
270 PRINT USING "######.#";RC;
280 PRINT
290 NEXT F
300 NEXT Q
Ok
```

FIGURE 2: Low-pass filter component values. Also included is the program which calculates component values for the low-pass filter, written in GW-Basic. It should be fairly easy to rewrite in another Basic dialect.

and low distortion and in terms of quantity we need SPL levels of at least 90dB. Fulfilling these demands is very difficult indeed. Some of the more conventional ways comprise—in order of physical dimension—horns, transmission lines and reflex systems, all of which are very well described.

There is another way: electronic compensation of an "ordinary" dynamic driver for Q and resonance frequency (F_O). Electronic compensation is preferable to passive compensation for several reasons. The most obvious is that you can realize the low register with quite small speakers. Another is that you have a large selection of usable drivers, thus reducing the total cost of the system. Let's look at two different sorts of electronic compensation circuits.

SEMIACTIVE Q COMPENSATION. The circuit in *Fig. 1* was developed by Siegfried Linkwitz and described in *Electronics and Wireless World*[1] along with the design formulas. If you know the Q and resonance frequency of the speaker in question it is only a matter of using the formulas to get the right component values. Of course you must compromise somewhat since the driver's cone excursion is limited, and every time the F_O is lowered by a factor of two the cone excursion is increased four times. But if you have a fairly good driver you should have no problems at reasonable levels.

As I mentioned, you must know the Q and F_O of the complete speaker system in order to use the semiactive compensation circuit. Measure the Q as described below on the actual terminal of the closed-box speaker system you want to compensate. Include the influence of possible crossover components and their influence on Q. Here is how you do it:

1. Measure the DC resistance of the speaker with an ohmmeter.

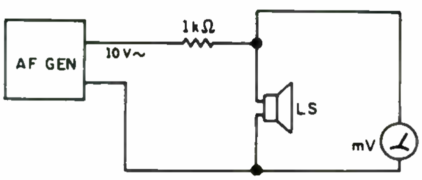


FIGURE 3: Measuring setup for the audio frequency generator.

2. You need a calibrated audio frequency generator which can deliver 10V RMS (you may need a power amplifier if your generator cannot supply this voltage). See *Fig. 3*.

Now you can read the impedance (Z) of your speaker directly since 10mV RMS corresponds to a Z of 1Ω. First, find the frequency where Z is at maximum; this is F_O. Then calculate R_{AV} from

$$R_{AV} = \sqrt{R_{MAX} * R_{DC}}$$

3. Next step is finding F1 and F2, the frequency where $Z = R_{AV}$ on each side of the peak. Now calculate Q:

$$Q = \sqrt{\frac{R_{DC}}{R_{MAX}} * \frac{F_O}{F2 - F1}}$$

(As a check, $F_O = \sqrt{F1 * F2}$)

You are now ready to calculate the necessary component values. See formulas in *Fig. 1*.

The mathematics of the design formula are not complicated, but a bit tedious, since you'll have to do the calculations a number of times to get not only com-

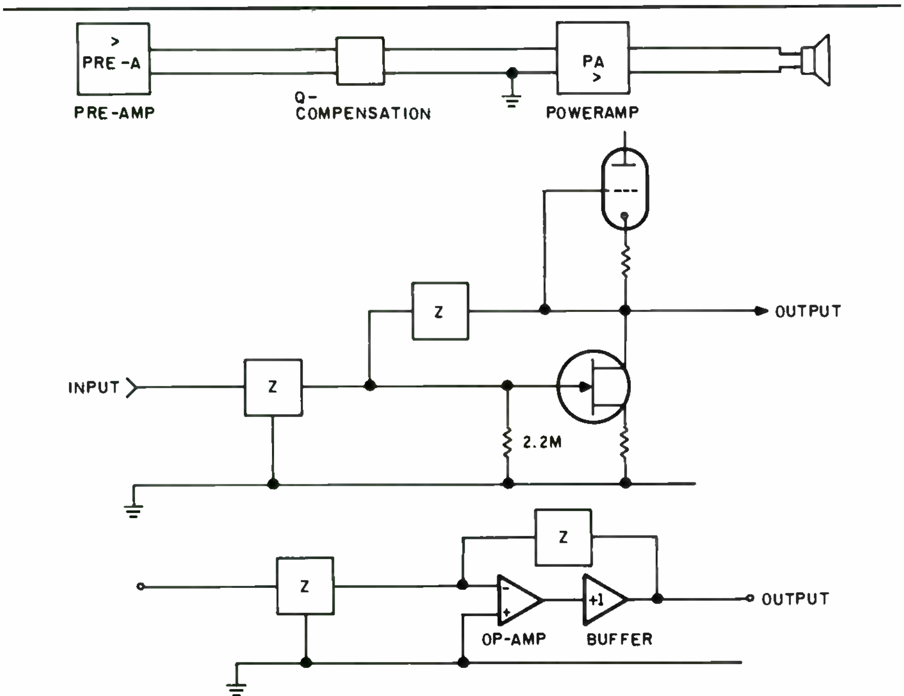
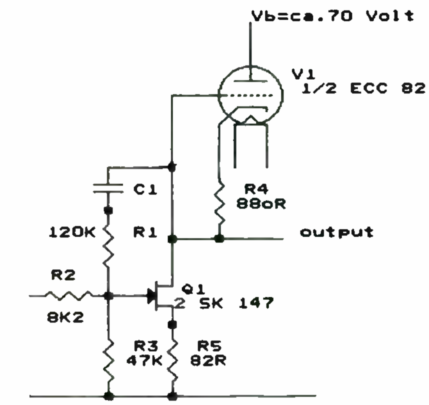


FIGURE 4: Practical details in connection with the use of the Q compensation network.



Open loop gain:
191x - 45.6 dB
Zud = ca.9000
S-N: 120 uV / -78 dB ref. 1 Vrms

Closed loop
Gain 14.6 x - 23 dB
THD: o.03%, v. 2.5 Volt rms 1 Khz.
SN: 70uV -83.1 dB ref 1Volt rms

FIGURE 5: A modernized version of the SRPP circuit which will work at about 70V. Open-loop condition: R1, 2 and C1 removed, otherwise no changes.

ponent values which are obtainable but also an F1 which is not too low. Mostly for the fun of it, I wrote a Turbo-Prolog program which you can obtain on disk by writing to Old Colony Sound (see parts list).

Using this circuit in a two- or three-amp system with an electronic crossover network is straightforward: The amplifying device is just a very good op amp (*Fig. 4*). Using the system in a single-amp system requires a very good amplifying device. No op amp I tried alone was satisfactory. The loss of dynamics and detail was obvious indeed. I got a far better result with the one in *Fig. 5*—an FET-tube-shunt-regulated push-pull amplifier.

The circuit is based on the well known valve, SRPP, with which Anzai and Jean Hiraga have experimented.[2] The input and output impedance of this circuit are so high and low, respectively, that the error you introduce by disregarding them is irrelevant, provided you use an R1 between 47 and 150kΩ and a C1 between 0.22 and 0.56μF. In my system this didn't affect the tonal balance or the sense of dynamics outside the low register at all.

I have tried the Q compensation circuit with two systems. The first one was a three-way single-amp system, where I compensated the KEF B200G woofer. The result was quite astonishing: a far better transient response and a much richer low register. In this case I used the FET-tube amplifying device.

The second system was my old ESS Amt 1. This speaker is extremely ambitious and in many respects still very good, mainly because of the excellent Heil driver. It is also well built with a strong cabinet, and the crossover network is stuffed with lots of heavy and expensive copper wiring.

The slave-woofer system, also ambitious, sounds horrible, mainly because of a strong peak around 50-60Hz and a very poor transient response. To make things even more interesting it's almost impossible to fit the speaker into ordinary living rooms. For quite a while I had been looking for a replacement, but the upper midrange and treble of the Heil are very difficult to live without, whereas it is nearly impossible to live with the horrible bass reproduction.

So I removed the passive slave radiator and closed the hole with a piece of chipboard, adding more damping material to lower the Q and improve the woofer's transient response. The resulting Q turned out to be 0.8 with a resonant frequency around 45Hz. Then I calculated a Q compensation circuit. This time I used an op amp and the superb homespun video buffer described in *Audio Amateur* 2/88, p. 24. For further details see *Fig. 6*.

And the result? A remarkable improvement of the woofer's transient response and a much cleaner bass reproduction. The only snag is a heavy loss of sensitivity, which is, however, easily compensated for with the controls on the speakers. With this update I feel a better speaker would cost at least three times the original price.

However good this idea is, it still has one problem: The increased cone movement in the low register will cause greatly increased distortion. Even though

Continued on page 15

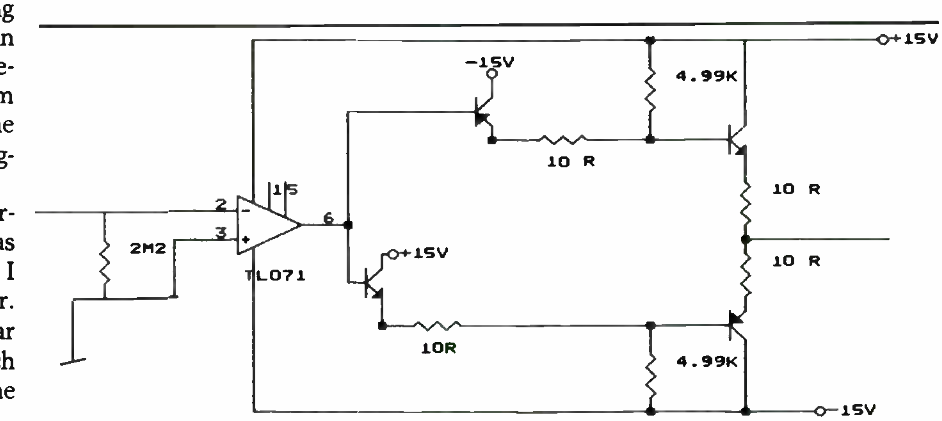


FIGURE 6: Another amplifying device for the Q compensation network. The buffer compensates for the op amp's poor performance under near-unity gain conditions.

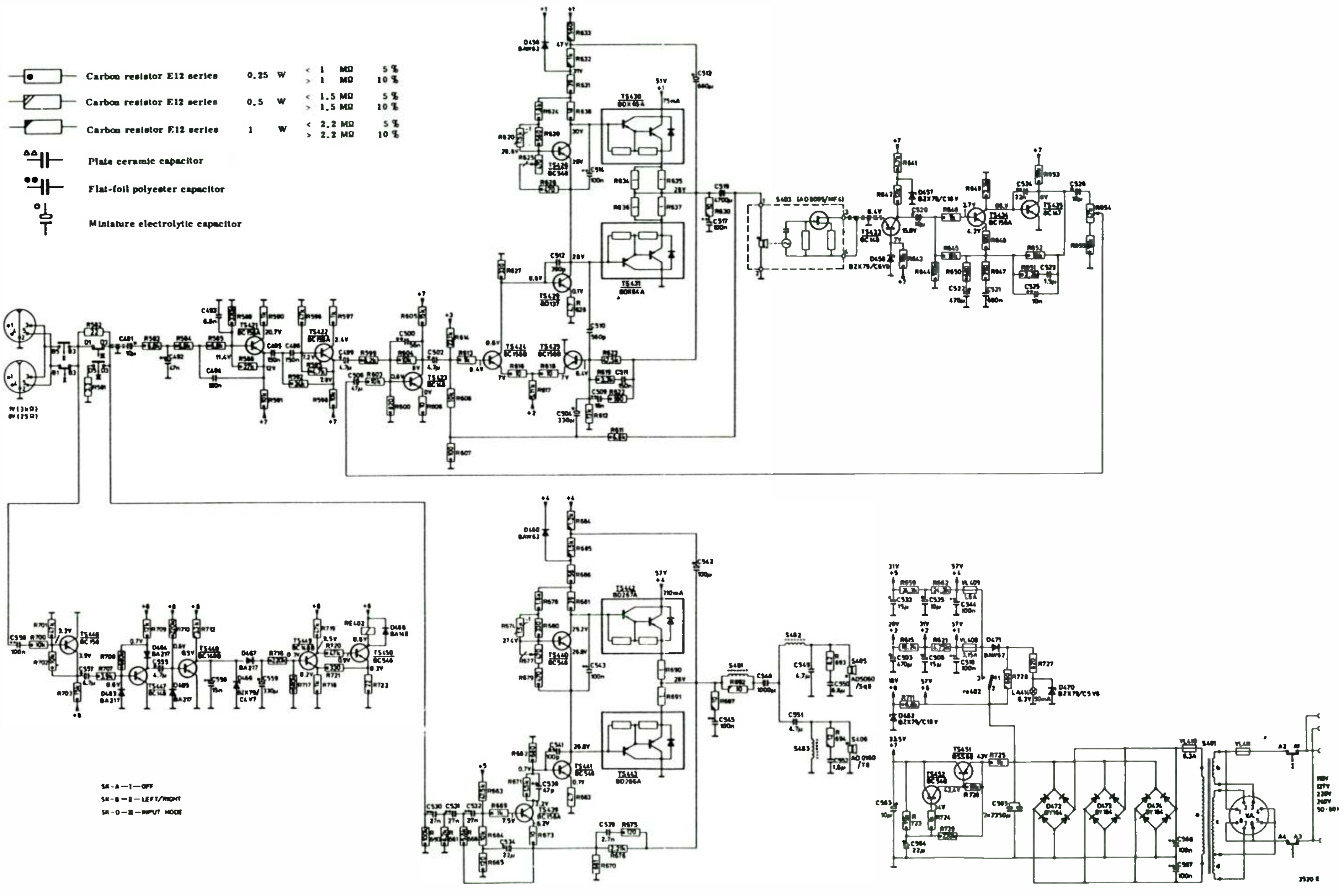


FIGURE 7: The Philips motional feedback loudspeaker system.

Continued from page 12
a couple percent distortion at 50Hz is not important it is nevertheless undesirable, and 10% at 30Hz is decidedly unwelcome. This distortion may be eliminated in two ways: very expensive drivers in fairly large cabinets or via electronics. We'll look at the latter.

ACCELERATION FEEDBACK. Nowadays the most well known feedback system is probably Infinity's servo-system in (among others) their IRS5. Other manufacturers have experimented with servo/feedback systems as well. Several years ago Philips marketed a "Motional Feedback" loudspeaker system (*Fig. 7*). The bass unit of this active system was unique in that it had a small piezo accelerometer and an FET impedance converter mounted on the cone. The accelerometer's output was then returned to the input of the power amp and thus created a feedback loop. The feedback circuit (*Fig. 7*) is marked by quite heavy phase and filter compensations around R647, 652, 651 and C521, 523 and 525, and the feedback path of the low-frequency power amp is also heavily compensated. Another author[3] gave the reason for some of these compensations:

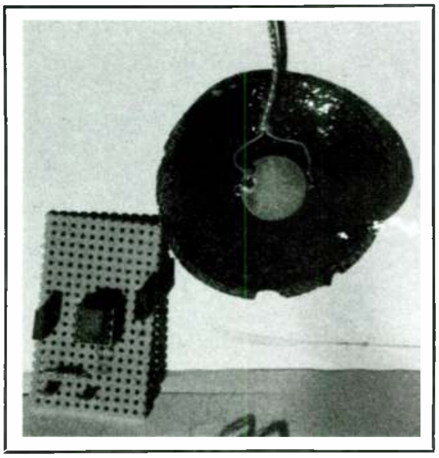


PHOTO 2: Left, the impedance converter. Right: the piezo transducer glued onto the inside of the dust cap.

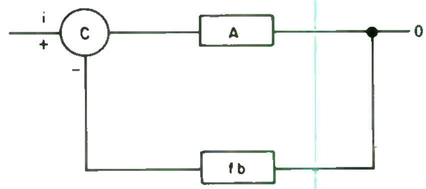
The piezo is far from linear. Part of this nonlinearity, however, was due to the limited input impedance of the Philips FET.

On the basis of the Philips speaker, Mr. D. De Greef and J. Vandewege[4] (*Fig. 8*) succeeded in designing a single-amp system with "motional feedback" compensation of the bass unit. Looking at this design from the low-frequency viewpoint it is interesting to notice that the piezo is hardly compensated at all. In fact, the De Greef and Vandewege circuit is remarkably simple.

The idea reappeared in a new version by R. Conell.[5] Conell's idea was to modify an ordinary driver by adding a simple piezo accelerometer and a vastly improved impedance converter. This is a very good idea, and it makes it possible for us to experiment with many drivers other than those from Philips.

Cone movements can be monitored in other ways. Elbert Hendricks has described a version using a coil whose inductance is like that of the speakers in a bridge configuration.[6] The function of the bridge is to separate the drive signal from the driver's "error" signal. Mr. Hendricks' circuit does, however, require quite a lot of adjustment and modification to suit drivers other than the ones he used.

The basic principle of the motional feedback system can be seen in the block diagram below:



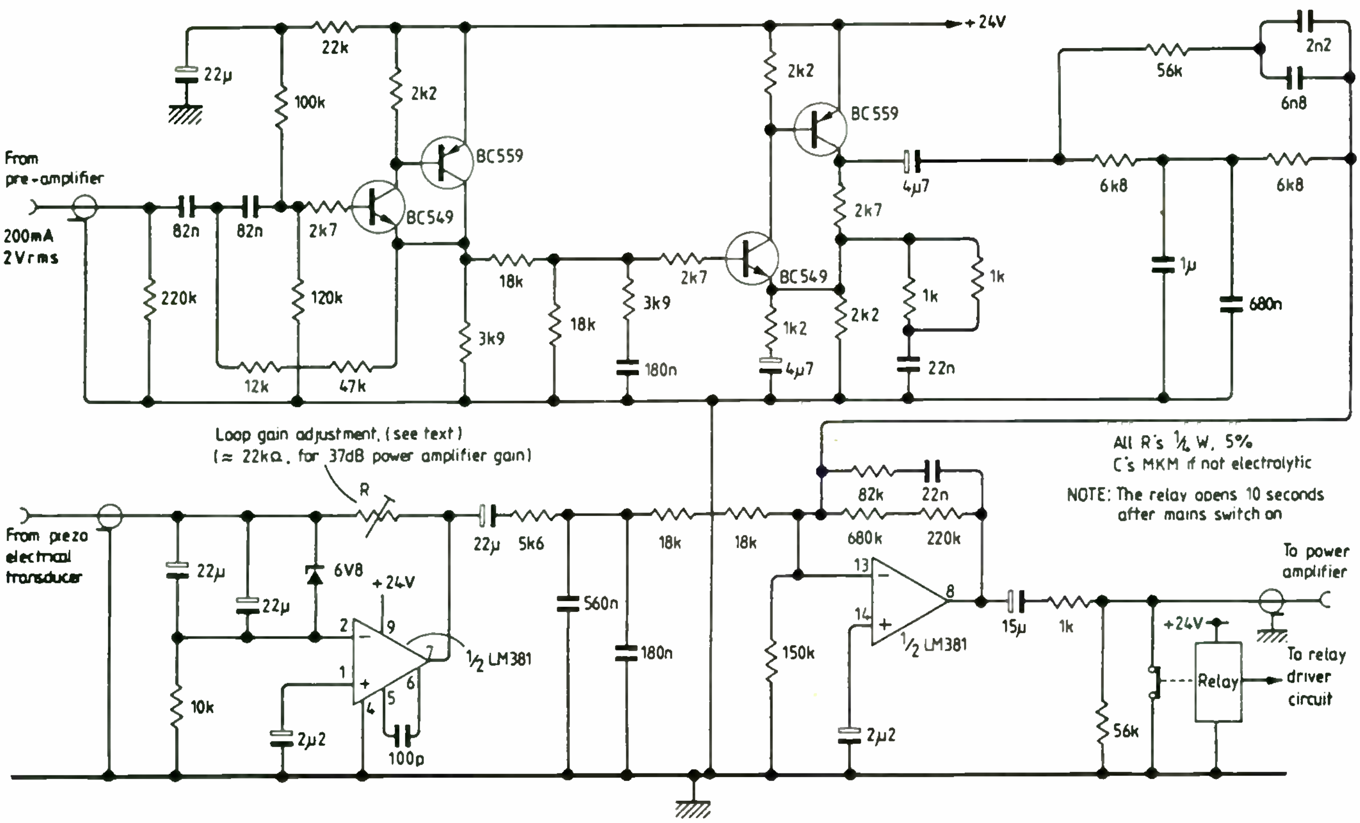


FIGURE 8: The De Greef and Vandewege single-amplifier acceleration feedback loudspeaker. Reprinted with permission from *Electronics and Wireless World.*

A represents the power amplifier and fb the feedback path. At point C the feedback signal is deducted from the incoming signal so the actual output at point O is the difference between the incoming signal and feedback signal. If fb*A is much higher than unity then O will be equal to 1/fb*i. This fact means that the resulting sound pressure level (SPL) is independent of the driver, provided that the entire system is stable.

In practice we cannot do as well, but with luck a mode t driver can be persuaded to give this performance: in a small cabinet (I used approximately 40 liters), I obtained a ±3dB response from 15–250Hz, with a few percent distortion. The price is modest: an extra amplifier and a feedback network.

DRIVER CHOICE. In choosing a driver for this system you need not look at its specifications. They will quite likely change significantly when the unit is modified. Three parameters you should consider critical are: the unit's power rating, cone excursion limit and driver Q.

The first parameter is easily taken care of: 50W is enough for most applications in ordinary living rooms.

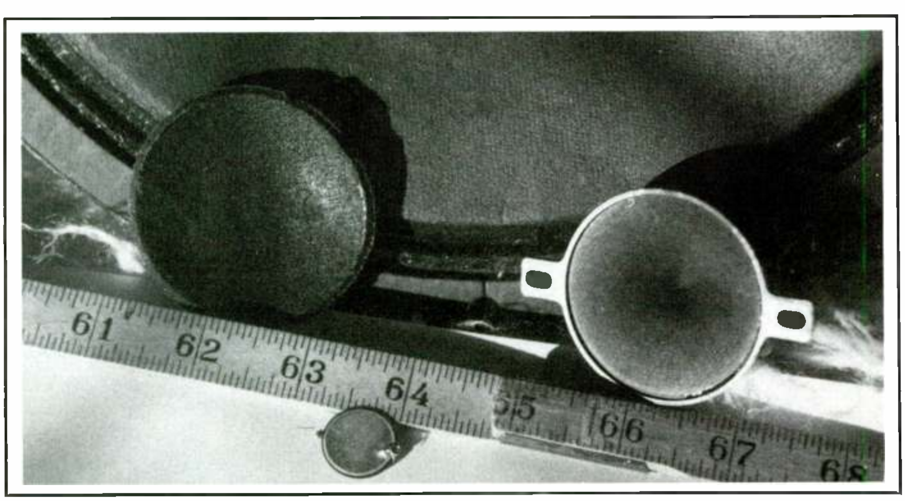


PHOTO 3: From the left: the dust cap, the piezo disk and the piezo speaker.

The second is more problematic: If you want high SPL at 20Hz out of an 8 inch speaker you will need large cone movements. One of my prototypes used two 8 inch speakers with 1cm maximum cone excursion limits. This system does reproduce 20Hz notes, but not very loudly. Three or four 8 inch drivers per system should perform quite well. You can also increase the size of the drivers. A second prototype uses a 12 inch unit with maximum 6–7mm cone movement. This one gives somewhat richer sound, and the actual levels are a bit higher than the 8 inch units. When planning a system along these lines remember that the cone amplitude is constant above the resonance frequency. It increases with a factor of four every time the frequency is lowered by a factor of two. Therefore a low resonance frequency is preferable.

The third parameter, Q, affects the transient response. You should aim at a low total Q. A total Q of 0.5 is good, but somewhat higher quality factors will work.

Keep in mind that loud 20Hz notes demand large cones and large amplitudes. Infinity's biggest system uses five 12 inch drivers.

DRIVER MODIFICATION. The first problem: You need a small piezo disk (*Photo 3*). I found mine inside inexpen-

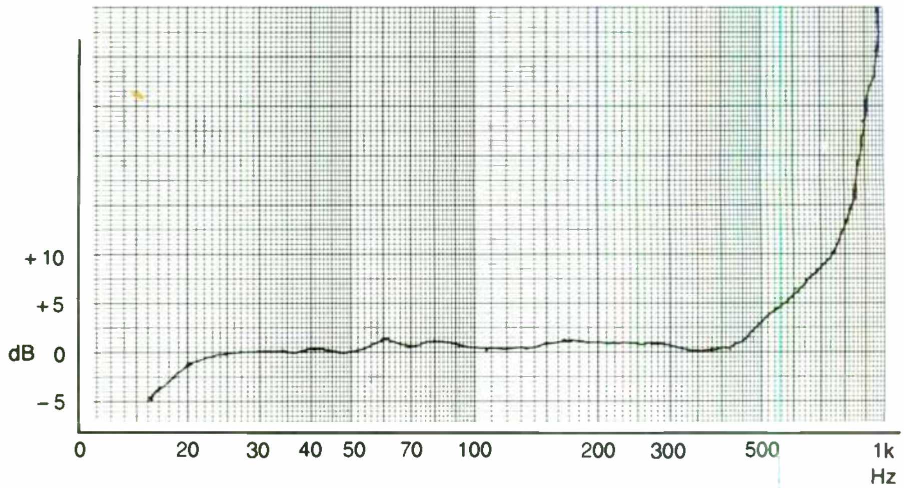


FIGURE 9: Typical transducer response. The curve was made keeping the output from the speaker constant and by plotting the transducer response picked up at point B in *Fig. 10*. The power amplifier for the speaker was fed directly from the audio frequency generator, and the signal picked up with a Bruel & Kjaer condenser microphone.

sive piezo loudspeakers, see example in the same photo. I saved the small piezo disk and threw the rest away. Unfortunately you cannot use the ever-beeping computer types as they are too stiff. Conell used a similar type of piezo, bought in Great Britain; I bought my two different looking piezo drivers in Denmark, but their performance seemed uniform. Since they are used to record frequencies far below any of their numerous resonances they perform well. This doesn't prove you'll be able to get one with the same performance in the US, but it is likely.

Once you have found the piezo disk you proceed to the driver. It's best to mount the accelerometer inside the dust cap which is normally glued to the cone with thermoplastic glue. This can be lifted with a hot knife. If you cannot do it this way you'll have to cut off the dust cap; gluing it back in place is not difficult.

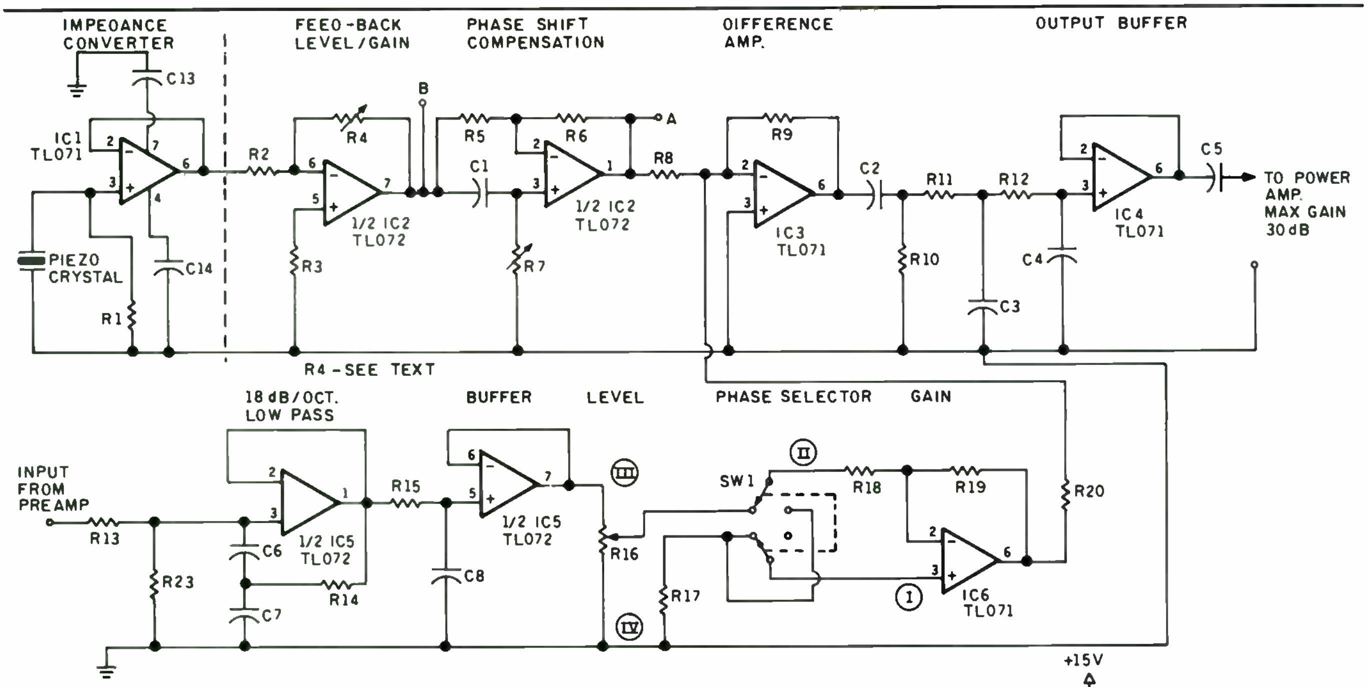
With the dust cap removed you are ready to mount the accelerometer whose edges must be free of the dust cap so you'll need a small block of wood or acrylic (3 x 3 x 2mm) to lift the piezo disk from the surroundings. The dust cap must be stiff; coat it with a thin layer of epoxy resin, the same as you use to glue the piezo in place.

When the epoxy has hardened, solder some thin flexible wires to the piezo's terminals. You can either twist the leads together firmly and fix them inside the dust cap, or use shielded wire. The latter is preferred because it minimizes the risk of hum pickup.

Now punch a small hole in the cone for the leads from the piezo and replace the dust cap with thermoplastic glue.

This modification should be done carefully—anything loose will rattle horribly.

While the glue is drying proceed to the impedance converter. It can be built on a small piece of vero-board or the like. Drill one or two holes in the driver chassis, but be careful not to glue the converter onto the chassis. This also must



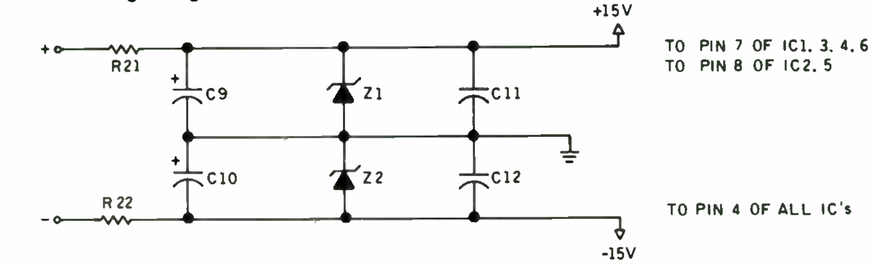


FIGURE 10: Schematic of acceleration feedback system.

PARTS LIST (electrical components only)

Resistors

R1	2.2M
R2, 3	10k
R4	See text
R5, 6	95.3k 1% metal film
R7	20k multi-turn trimmer (Bourns 3299W1)
R8	33k
R9	120k
R10	1.5M
R11	10k
R12	220k
R13, 14, 15	See text
R16	4.7k potentiometer
R17	6.8k
R18	22k
R19	100k
R20	4.7k
R21, 22	See text

All 5% metal film, unless otherwise indicated

Capacitors

C1	0.15μF, 100V, MKT
C2	0.680μF, 100V, MKT
C3	1μF, 100V, MKT
C4	2,200pF, film, f. eks. Philips KS
C5	1μF, 100V, MKT
C6, 7, 8	See text
C9, 10	100μF, 25V, electrolytic
C11, 12	0.470μF, 100V, MKT
C13, 14	0.1μF, 100V
IC1	TL071, JFET op amp
IC2	TL072, dual JFET op amp
IC3, 4, 6	TL071, JFET op amp
IC5	TL072, dual JFET op amp
D1, 2	15V, 0.4W zener
SW1	two-pole, make before break switch
X1	piezo transducer, see text

OCSL DISK

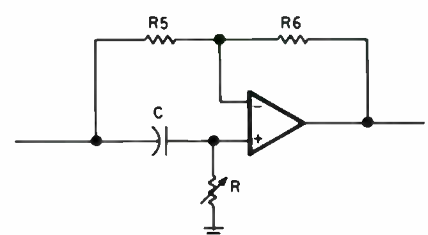
SOF-ASF-1 disk contains the design formula for calculating Q. Format 5¼″, DSDD, 360K, IBM compatible. The price is $12.50 from Old Colony Sound, PO Box 243, Peterborough, NH 03458.

be done with care. As a result of this modification the resonance frequency of the 8 inch driver went down 5Hz, whereas the stiff suspension of the 12 inch unit kept its resonance frequency almost unchanged.

FEEDBACK SIGNAL. Our aim is to get as good a replica of the cone movements as possible, which means the amplitude of the output from the piezo must follow the amplitude of the cone movements. I have modified two sizes: an 8 inch and a 12 inch. In *Fig. 9* you see a typical response curve of the relative output from the transducer. I kept the near-field SPL constant while recording the output of the transducer. It appears that the linearity in the region of interest is very good, so good in fact that I didn't find any further compensation necessary.

So far so good, but amplitude is not everything in audio. Phase is also important. In my case a rough estimate of the phase response suggested some 90° phase shift around 70Hz. The other versions along these lines have included quite complex phase-shift compensations, but since you are going to use your own drivers the components I could suggest wouldn't work. Though manipulating phase shift in feedback circuitry is risky because of the danger of oscillation, we do need some sort of adjustable phase-shift network.

The phase-shift circuit is shown below:



The phase shift is given by:

$$0 = 180^\circ - 2{*}\tan^{-1}(f/F),$$

where 0 = the resulting phase shift in degrees at frequency f and where

$$F = 1/(R{*}C{*}2{*}\pi)$$

On the complete schematic, *Fig. 10,* you'll find it around IC2. I will return to the practical adjustment procedure later.

In *Fig. 10* you will notice the differential point at the junction of R8 and R31 in combination with IC3. The filter network around R11, 12 and C3, 4 is necessary to ensure stability. The buffer IC4 prevents the power amplifier's input impedance from interfering with this network.

CROSSOVER CONSIDERATIONS. Many a small closed-box speaker has a rolloff around 12dB/octave. Adding a simple first-order filter will give a rolloff of 18dB, which indicates that the subsystem should be equipped with a third-order 18dB/octave filter. You can see this around IC5. At the end of the article you'll find component lists for various crossover frequencies and Qs. This should make it possible for you to match the subsystem quite closely with your side systems. The extra first-order filter for the side system is best implemented by adding an extra capacitor in series with the input of the power amplifier. It may be calculated from:

$$C = 1/2\pi * Z_{IN} * F$$

where C is the capacitor, Z_{IN} is the input impedance of your power amp and F is the required crossover frequency. (The units used are ohms, hertz and farads.)

Since it is difficult to invert the true phase of this subsystem I found it necessary to provide a simple 180° phase selector. This is seen around S1 and IC6. Apart from the influence of the series resistance of R17's wiper, the gain of this stage is unity, both in and out of phase (the difference between the inverted and noninverted gain is maximum 1dB).

THE BOX. I'll leave the box dimensions to you. Remember, the bigger the box the higher the SPL. I have only experimented with boxes of approximately 40 liters.

The box must be absolutely airtight. Any leak will increase distortion and lower the maximum SPL. Fill the box with damping material to reduce the total Q. A total around 0.5 is ideal, but I haven't experimented with it. The resonance frequency is irrelevant (see block diagram under Feedback Signal).

THE POWER AMP. Any good power amplifier will do as long as it has a gain of not more than 30dB and a frequency response down to 3–5Hz. The Hendricks system uses a power amp with no more than 19dB gain. Higher gain and higher cutoff frequency will reduce the feedback system's stability margin. I have used a simple 60W bipolar device. Slew rate and distortion are not important in this case. LSI integrated power amp ICs should work very well.

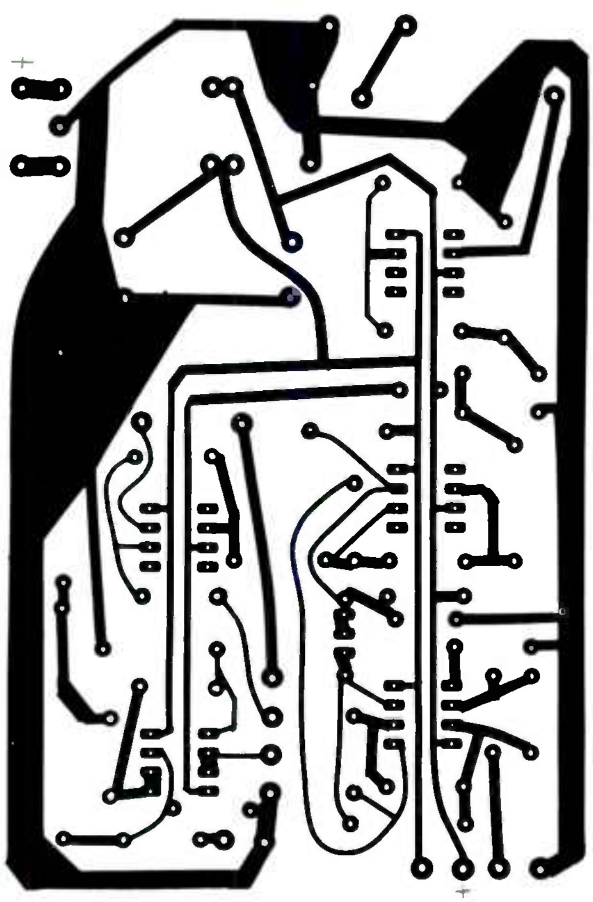


FIGURE 11a: Circuit pattern for the acceleration feedback system.

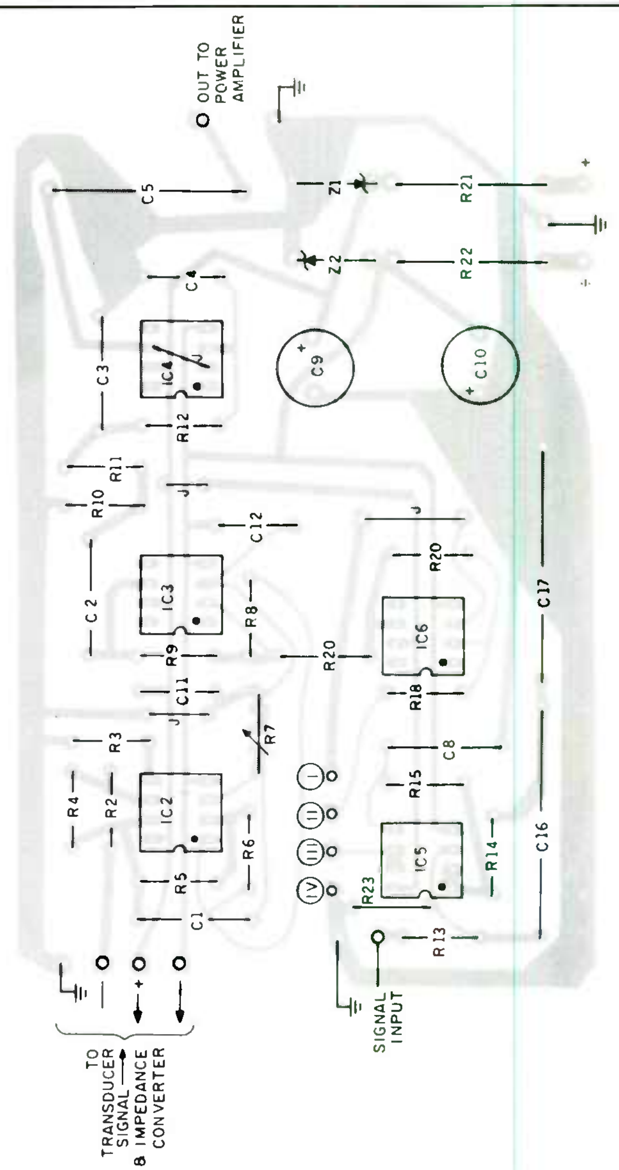


FIGURE 11b: Stuffing guide.

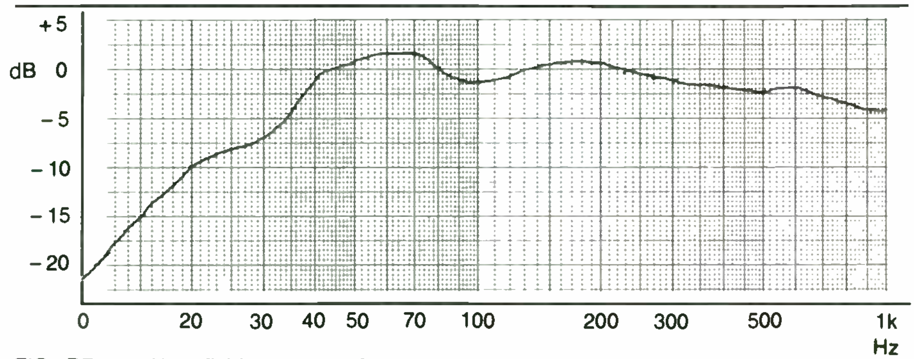


FIGURE 12a: Near-field response of one 8 inch driver in a 40 liter cabinet without feedback.

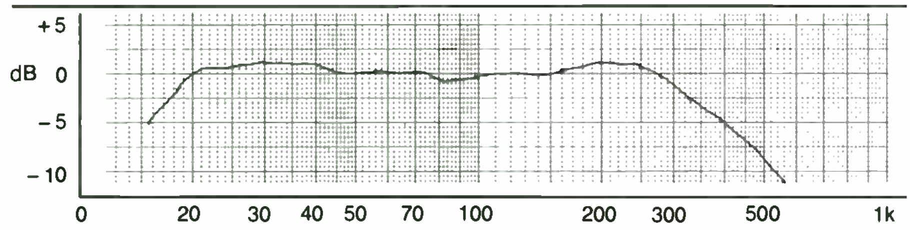


FIGURE 12b: The 8 inch driver in a 40 liter cabinet with feedback.

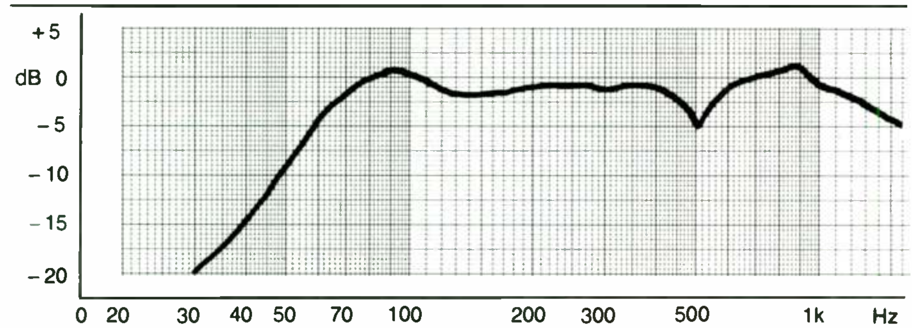


FIGURE 12c: Near-field response of one 12 inch driver in a 35 liter closed box, without feedback.

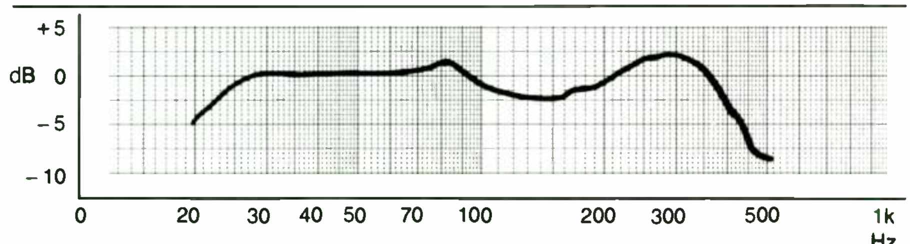


FIGURE 12d: The 12 inch driver under the same conditions but with feedback.

POWER SUPPLY. The feedback circuit consumes about 25mA. On the board I have provided space for two 15V/1W zeners and two electrolytic capacitors along with further high frequency decoupling. It goes without saying that these capacitors are not critical at all. The only thing to notice is the inclusion of high frequency decoupling of the impedance converter around IC1. Leaving these out will cause severe problems.

The idea is to get power for the feedback circuit from some other unit. Zener diodes greatly simplify the power supply and you can get the current you need from any source in the audio chain. Resistors R21 and R22 are given by Ohm's law:

R = (input voltage − 15)/0.025 (ohms).

ADJUSTMENT. Complete the circuit board but instead of R4 use a 220kΩ trimmer. Connect the phase and level controls with a three-lead shielded wire. Notice that R18 should be connected between the switch and potentiometer. This arrangement saves one long lead. Connect the feedback circuit to the amplifier. Make sure that R4 is as close to 0Ω as possible.

Turn on the power. If you are lucky and everything is done correctly nothing should happen. If you get a very low frequency oscillation reverse the connections to the speaker (or to the piezo, but that is difficult since you'll have to take the speaker out of the cabinet).

Next, apply a small signal of 70–90Hz. Turn the level control till you hear the signal softly. Now try to apply a little feedback by turning R4. This will increase the gain of IC2 and the signal from the transducer will be allowed into the feedback path. Increase the feedback level until you sense the first small sign of oscillation, and try to keep the oscillation so that it is just barely audible. When you apply feedback, the output from the speaker should decrease. It is now possible to compensate for the phase shift which is the root cause of this oscillation by adjusting R5. When oscillation disappears, increase the feedback level still more, until you sense beginning oscillation again. Remove the oscillation by adjusting R5. Continue in this way until you cannot get rid of any more oscillation.

My system has been stable up to 17dB feedback, but it is not a good idea to take it to the limit. I suggest you experiment with feedback around 7–12dB, as higher feedback levels tend to produce a subsonic peak (around 10–15Hz).

You are not through yet. The whole system will need some playing to "burn in" the suspensions of the driver, and the temperature changes of the amplifier need some time to settle. Connect the units to your system and use it extensively for a week or two. After this period you should readjust the drives and replace the trimmer with the value which gives the feedback level you want.

SONIC MERITS. In *Figs. 12a–d* you see the results of my systems, both before and after the modification. These speak for themselves. Unfortunately I do not have a line writer, so I have plotted the curves instead, but there were no peaks which I haven't plotted.

Measurement is one thing, sound another. Two observations may be of interest: It is striking how little recorded information is present below 40Hz and equally striking as to how much is subjective. Adding bass units of this type is like standing the music on its feet and placing it firmly on the floor of the room. Traditionally, the transient response of feedback systems is their weak feature, but to my ears this properly adjusted system makes it very easy to distinguish, for example, a low bass guitar note from the bass drum. And it is this fundamental you hear, not the second harmonic which we are so used to from pop recordings. But organ music is the genre where this system really comes into its own.

The fly in the ointment? You'll be surprised at the amount of VLF garbage

Continued on page 66

CYLINDRICAL SYMMETRIC GUITAR TLs

BY GLENN DeMICHELE

I am an electric bassist, and when practice fails to yield any discernable results, I work on my equipment. In a performance situation, technical flaws in the amplifier/speaker system can be positive attributes. A contemporary lead guitarist, for example, relies heavily on amplifier clipping and cone breakup to achieve a desired sound. A band's public address system may sound great when people are singing through it, but any recorded music played through that system during the band's break may reveal a less than ideal frequency response.

Musical instrument amplifiers are producers, not reproducers, of sound. This fact makes it difficult to design a musical instrument system using the same goals you would use in the design of a high-fidelity system. Fortunately, the bass guitar sound in today's music often has a very pure and hi-fi quality.

You might say the same of most synthesized keyboard sounds. In the recording studio, these instruments often feed directly into the mixing board, arriving at the tape uncolored by any artifacts of mechanical origin. Thus, the sound of the bass guitar is often produced for the first time by speakers which have been designed to audiophile criteria. My goal in the design of my bass guitar system was, in effect, to build a giant pair of stereo speakers.

NEW DEMANDS. Recently, I made the transition from a four to a five string bass. The addition of the low B string (30.9Hz) has placed new demands on my sound reinforcement system. My electronics are DC coupled all the way up to my Carver PM-1.5 power amp which is capable of delivering 450W/channel into 8Ω at 20Hz, and has a −3dB frequency of 3Hz. I had

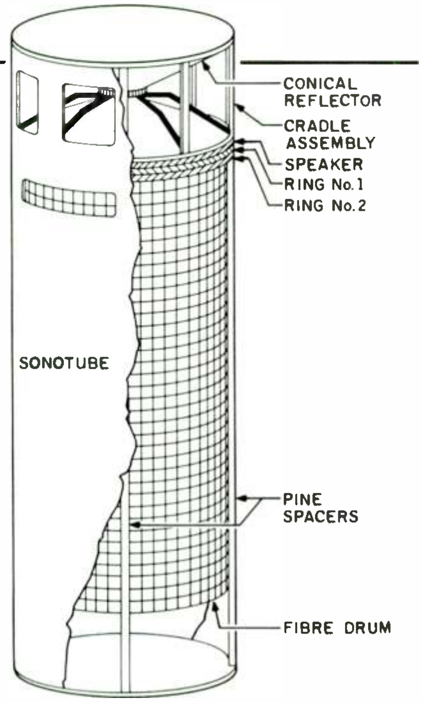


FIGURE 1: Drawing of completed cabinet.

been using a single JBL EB-140 15 inch driver in a 5 cubic foot ported enclosure made of half inch particle board. With a 6dB boost at 30Hz, the speaker sounded fine at moderate volumes, but when the band was really cranking, the boost bottomed out the driver, causing a loss of clarity in the midrange without a substantial enhancement of the low end. At high SPLs, I therefore had to remove the 30Hz boost.

Any speaker I was to design for this application must meet the following criteria:

1. The smaller the better. I generally use only one cabinet (and one power amp channel) on a job, but for the big gigs, I would like to use two cabinets. This also allows me to electronically alter one side for stereo effects, such as chorus or delay. I must therefore be able to fit two completed cabinets, as well as my guitar, my electronics, and myself, into my car. A large cabinet is difficult to roll through the finer hotel kitchens (on the way to the party) without eliciting some kind of snobbish remark from the chef. On stage, there are often width and depth restrictions, but I can always go as high as the ceiling. This implies a tall narrow structure rather than a cube.

2. The lighter the better. I use a two-wheeler (a dolly), but I must sometimes carry my equipment up and down stairs.

3. Efficiency is important. I often have no idea how big the band or the room is until I arrive at the job. Since I do not want to carry around both cabinets all of the time, an efficient design will enable a single cabinet to cover a greater variety of performance situations. The driver must be capable of handling the full power output of my amplifier.

The Electro-Voice EV18B 18 inch driver can conservatively handle 400W RMS, and weighs only 22 pounds. The Theile/Small parameters as supplied by Electro-Voice are:

Q_{ES}	= 0.376	Q_{MS}	= 8.37
V_{AS}	= 18.22 cu. ft.	f_S	= 33Hz
R_E	= 5.2Ω	S_D	= 176.7 sq. in.
n_0	= 4%	X_{MAX}	= 0.13 in.
P_E	= 400W		

The BOXRESPONSE program (*SB* 1/84)

ABOUT THE AUTHOR

Glenn DeMichele, the Midwestern Field Applications Manager for Harris Semiconductor, is currently pursuing his MSEE at the Illinois Institute of Technology in Chicago. In addition to music and electronics, he manages to find time to eat and sleep. His goals include getting a social life and making his audio equipment smaller and louder.

indicated that a vented-box design which would give me reasonable output at 30Hz would have to have a volume of about 18 cubic feet. I figured out a way to fit this into my car by making it out of three smaller boxes which fit inside each other, and telescope to full size upon arrival at the job. This idea however, was discarded after imagining the horrified look on the hostess' face as this monster expanded to refrigerator size at her society cocktail party. The optimum closed-box alignment yields a smaller box, but the low frequency corner would be around 50Hz.

LINE TAPERING. Even after eight years of listening, the set of transmission line (TL) loudspeakers (DCM Time Windows) in my living room continue to impress me with their bass accuracy. A quarter wavelength at 30Hz in free air is 9.4 feet. If one follows the rule of thumb that the TL cross-sectional area should be at least equal to the diaphragm area, the total volume of a 30Hz TL enclosure for the Electro-Voice 18 inch speaker would be about 11 cubic feet. In practice, sound travels more slowly in the stuffed line than in free air, so the line may be physically shortened, yet still satisfy the quarter wavelength requirement. A further volume reduction may be realized by tapering the line to a smaller cross section as the line moves away from the speaker.

Any vibration of the enclosure walls is undesirable. In this application, any cabinet resonances in the bass and low midrange regions are readily apparent, and I have found them difficult or impossible to control with equalization. The walls of a woofer enclosure must be particularly rigid, and big woofer cabinets are often constructed of ¾ inch or thicker particle board with extensive internal bracing. This type of construction however, produces very heavy cabinets. At lower frequencies, the internal walls are subjected to pressure variations which are evenly distributed across the internal surface area of the cabinet walls.

In a cabinet with a rectangular cross section, any increase in internal pressure will cause the sides to bow. In a cylindrical enclosure however, the resistance of the walls to pressure-induced motion is dependent upon the material's tensile elasticity rather than its stiffness. Aside from threading problems, this is why high pressure pipes do not have a rectangular cross section. The high internal rigidity of a cylindrical structure may be easily demonstrated by speaking into a cylindrical garbage can or a cardboard paper tube. The sound produced is far more resonant than that produced by similar materials fashioned into a rectangular shape.

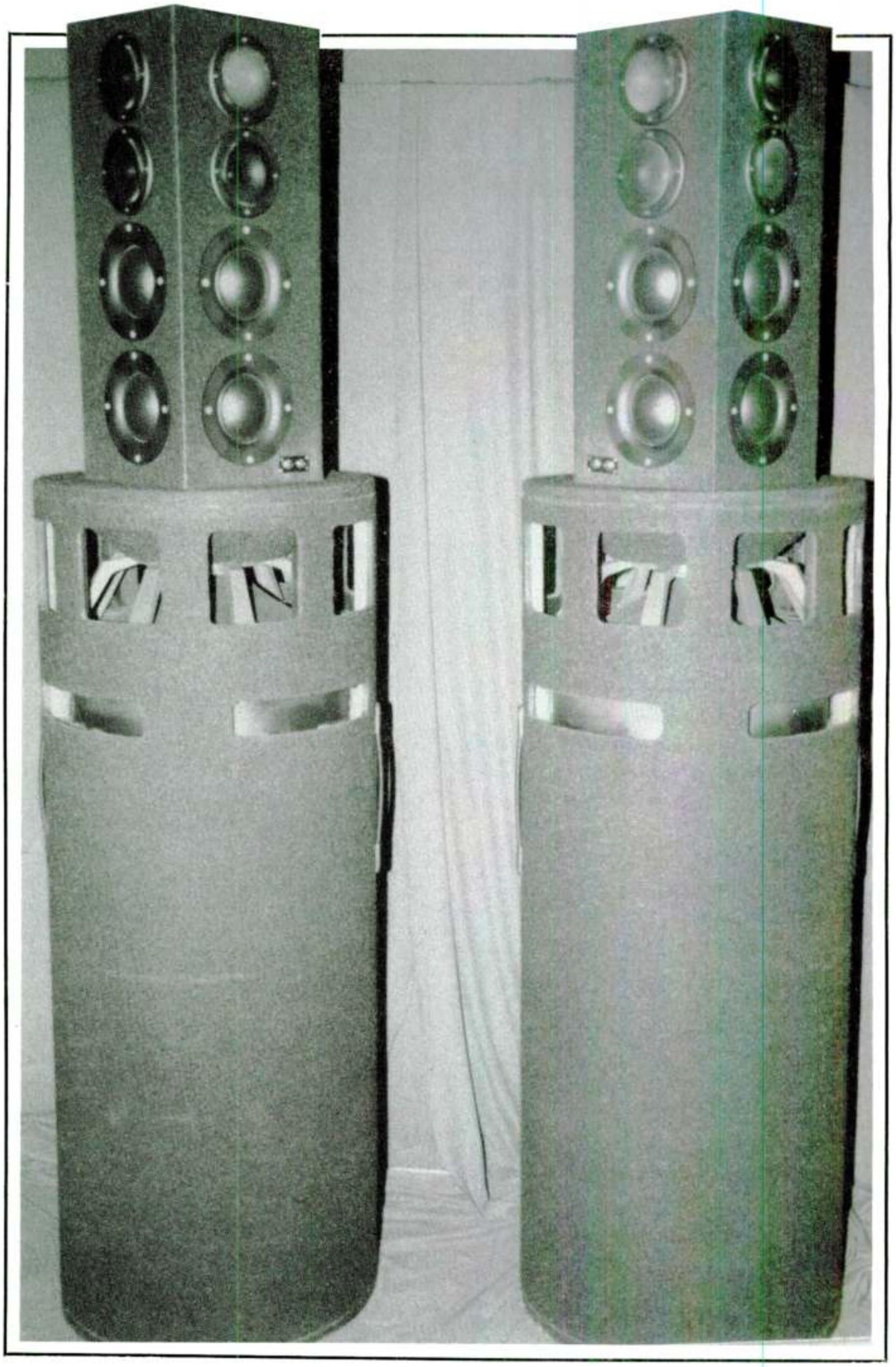


PHOTO 1: The completed pair of speakers, with tweeter cabinets.

CYLINDERS. This resonant quality is indicative of a high Q, and therefore low loss structure. In a rectangular enclosure, you may excite and hear the resonances of the various panels by tapping on the panels with your finger. Tapping on the side of a cylindrical enclosure however is not a valid test, since the asymmetrical application of force causes an acoustic wave to be sent around the circumference of the tube. These resonances would not be induced by the evenly distributed audio pressures normally present in a low-frequency speaker enclosure.

In my search for a suitable cylinder, I investigated plastic garbage cans, storage drums, large diameter PVC pipe, wooden musical drum shells, and even a hot water heater. Any cylindrical object was fair game. I finally discovered fiber drums, and thanks to Mr. Muller's tip in *SB* 2/85 (Tools, Tips & Techniques, p. 45), Sonotubes.

Fiber drums are normally used to hold dry goods. These ⅛ inch thick cardboard cylinders come in a wide variety of sizes and are inexpensive (a 15 inch diameter by 3.5 foot high cost me $3). The fiber drums are rigid enough to function well acoustically, but too flimsy to be used as an outer shell for a transportable cabinet. Sonotubes are ¼ inch thick, wax-impregnated cardboard tubes used as molds for concrete pillars. With an appropriate cloth covering, the Sonotubes withstand the rigors of transportation if moved carefully. They come in 12 foot lengths in diameters from 6 to 48 inches. The inner diameter of an 18 inch Sonotube fits exactly the outer diameter of the EV18B woofer.

My basic design consists of the driver radiating downward into a 15 inch inner tube. The sound wave hits the bottom of the cabinet, travels upward between the 15 inch inner tube and the 18 inch outer tube and escapes from vents cut in the outer tube. Although I initially had misgivings about using the rear of the speaker as the radiating surface, this mounting arrangement offered several distinct advantages.

First, I am a "measure once, cut twice" kind of guy, and this mounting arrangement eliminated an additional spacing ring necessary to keep the speaker basket from interfering with the 15 inch inner tube. Second, I surmised that the rear of the cone would be more effective in directly radiating any midrange output to the listener. Mounting the speaker in a horizontal plane preserves cylindrical symmetry, and hence produces an omnidirectional system. A directional speaker does offer an efficiency advantage when one is playing outside to a localized audience, and sometimes you may aim it to minimize the excitation of room resonance modes.

In most performance situations I have my back to a wall (literally and figuratively), so a lack of efficiency due to the omnidirectionality of the system would not be apparent. This nondirectional pattern would also allow any other band members to clearly hear me even if they were sitting beside or behind my cabinet.

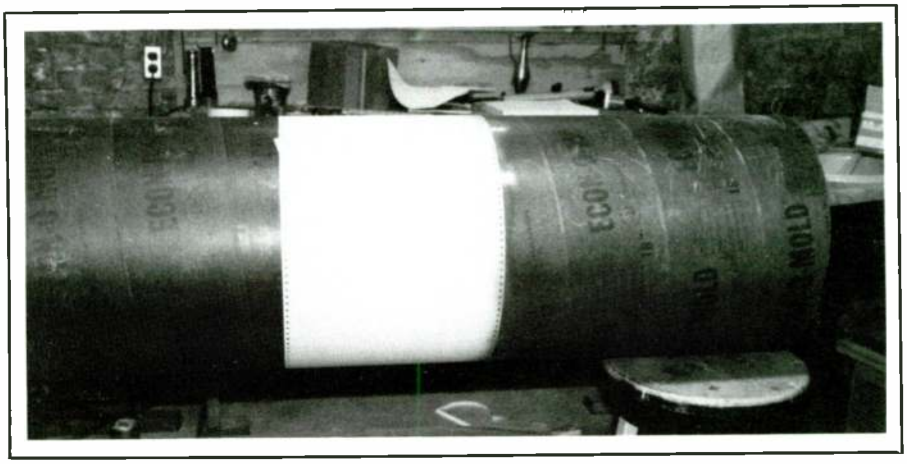


PHOTO 2: To cut the large diameter tubes squarely, use a piece of computer paper, spray paint, and a jigsaw.

CONSTRUCTION TIPS. The Sonotubes may be purchased from many construction supply companies. I asked around for Sonotubes, and everybody knew what I meant, but I ended up with "Econ-O-Mold" tubes made by the Deslauriers Company in Bellwood, IL. These are functional equivalents. To find the fiber drums, just look in the Yellow Pages under "Fiber Drums."

To cut these large diameter tubes squarely, I wrapped a large piece of continuous form computer paper tightly around the tube and carefully lined up the edges of the overlapping ends of the paper. I marked the cutting line with spray paint, using the paper as a mask.

Continued on page 26

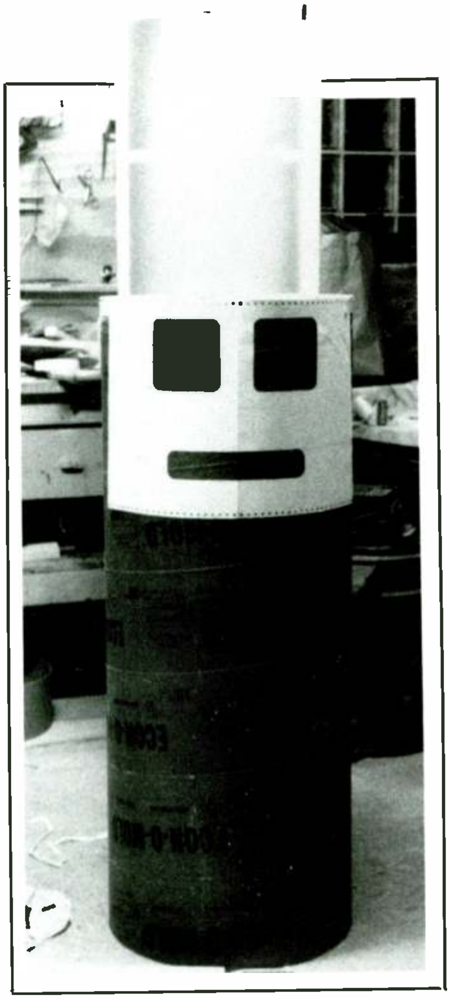


PHOTO 3: Use this template for cutting the vents in the outer tube.

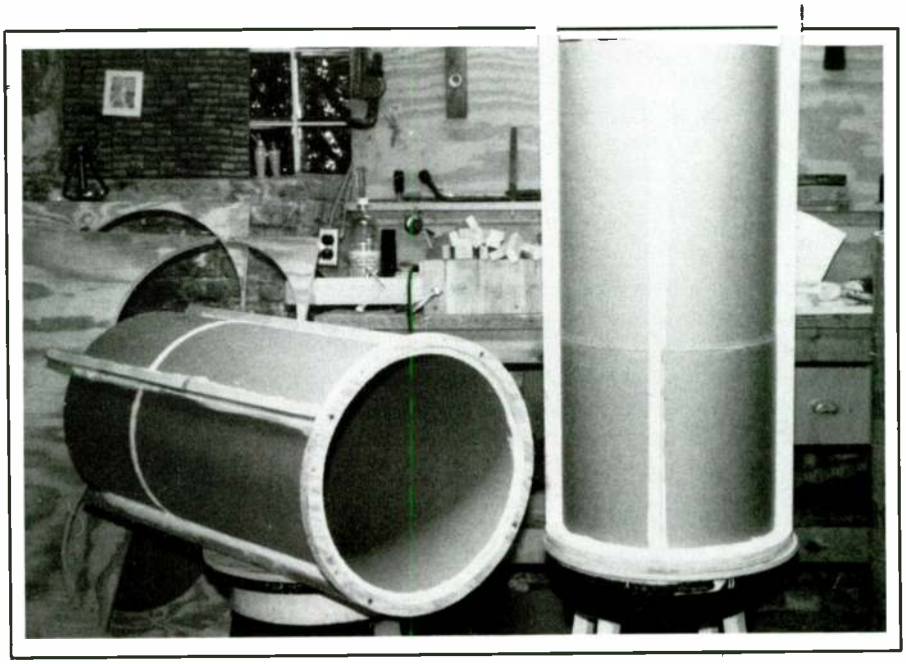


PHOTO 4: The inner tube assemblies, complete with pine spacers, ready for installation into the outer tubes.

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PHOTO 5: The outer shell and inner assembly. The speaker cradle, driver, and inner tube will eventually mount inside the outer tube.

Continued from page 24

My plans indicated that the outer cylinder was to be 48 inches long, but I failed to account for the bad end on my tape measure, and they came out an inch short. I used 0.75 by 1.5 inch pine boards for the spacers between the inner and outer cylinders, as well as for the internal bracing struts. The bracing struts are required only for rigidity during transport, and not for sonic reasons. I also attached handles to the cabinet to facilitate transport.

The construction of the cylinders proceeded as follows:

Cut the Sonotubes to the correct length, and cut the vents.

Make the speaker mounting ring from two plywood rings, and affix the four spacers with screws and glue.

The fiber drums I used came with a thin steel bottom and clips at the top to hold a cover. After I cut off the bottom and removed the clips, the "raw" cylinder was only about 30 inches long. I therefore had to use two fiber drums to produce one 35 inch long inner cylinder. Affix the two fiber drum sections to the speaker mounting ring/spacer assembly with silicone sealant. Also seal the seam between the two fiber drum sections. Immediately slide the entire assembly into the Sonotube, making sure the inner tube is not out of round, and the spacers are spaced evenly. While the Sonotube acts to hold everything in place, let the silicone cure.

Make the speaker cradles.

Apply silicone sealant to the spacers and slide the inner assembly into the Sonotubes, making sure the vents line up. Screw through the Sonotubes into the spacers, thereby affixing the inner assembly to the Sonotubes. The silicone does not stick very well to the Sonotubes, but it serves as a gasket and eliminates any rattles.

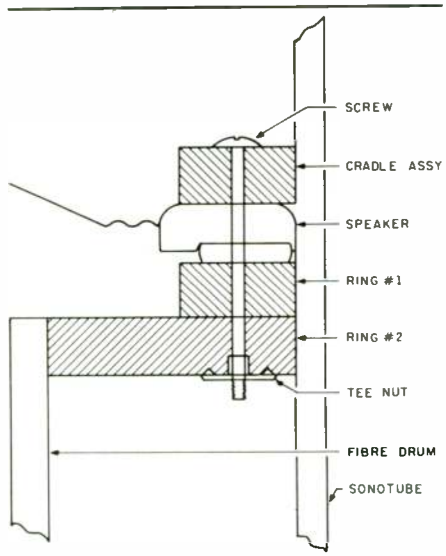

FIGURE 2: Mounting detail of speaker.

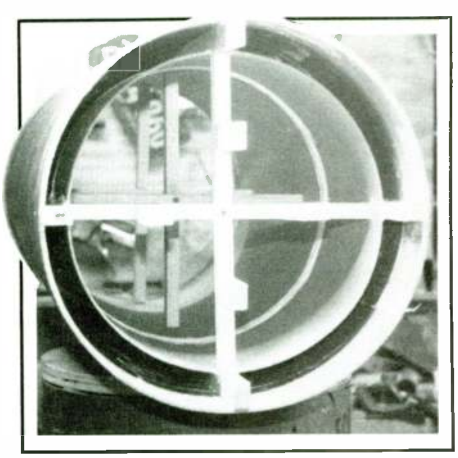

PHOTO 7: A bottom view of the interior of the cabinet after the inner tube assembly has been mounted, and the pine structural supports have been installed.

Using contact cement, glue the fabric to the outside of the cabinets. Also apply cement to the inside of the enclosure and stuff it with long fiber wool. Don't forget to put wool in the space between the two cylinders. I stuffed the cabinet with wool at a rate of 1.4 pounds/cubic foot (ten pounds of wool per cabinet).

LISTENING TESTS. After I assembled the cabinets, I ran several frequency response and listening tests. The low frequency response was smooth enough, but I measured and heard a large peak around 400Hz. This peak was apparently due to standing waves being generated between the speaker cone and the flat inside surface of the speaker cradle. I added a conical reflector to this inside surface, which nearly eliminated this peak. The conical reflector was made with cardboard from a fiber drum, and covered by fabric for aesthetic reasons.

PHOTO 6: The author on his way to the maiden bar mitzvah. Note the absence of the reflecting cones above the woofers.

With this modification in place, I took one of the cabinets out on its first gig. It was an afternoon bar mitzvah with a seven piece band, and my audience was 200 caffeine- and sugar-fed 13 year olds who I'm sure immediately recognized the clarity and acoustic perfection of my cabinet. The transient response of the cabinet was very good, and it produced a tight, well controlled bass. Since the majority of the high frequencies are radiated by the metal dust cover on the front of the 18 inch driver, the high frequency response left something to be desired.

I compensated for it with equaliza-

PHOTO 8: A top view of the cabinet with the driver and speaker cradles removed, showing the packing of the long fiber wool.

PHOTO 9: A completed revised speaker basket with the reflecting cone epoxied in place. The interior of the cone is stuffed with wool, and black grille cloth holds the wool inside the cone. Note the input jack and wire terminations for attachment to the woofer.

tion, but to get the hi-fi sound I was looking for, it was apparent that I needed to add some tweeter cabinets. In addition, the EV18B driver has an unmanageable response peak at about 1kHz. This is fine for a musical instrument application (EV states that the EV18B is designed to produce "a traditional bass sound"), but hi-fi demands that I cross the cabinet over at about 800Hz.

The omnidirectionality of the cabinet produced an unforeseen effect. I placed the cabinet about a foot from the rear wall, and stood 3 feet in front of it. Everybody in the band could hear me well, and the sound in the audience was excellent and well balanced. Our drummer however, who was sitting only a foot from the rear wall, and a full 6 feet from my cabinet, claimed to be deafened by my output. My cabinet was generating very high sound pressure levels along the rear wall.

Moving my cabinet four feet away from the wall dramatically reduced the SPL at the drummer. Also, I placed the speaker upside down, with the driver on the floor. This helped a little, since the speaker was no longer at the drummer's ear level. I have seen this effect in many rooms. The high levels along the rear wall do not seem to be frequency dependent, and I suspect they are due to horn-like interactions between the driver and the wall.

TWEETERS. Omnidirectionality in a midrange/tweeter enclosure offered no apparent construction or sonic advantages, so it was decided to proceed with a more conventional design. I have always been of the opinion that industrial strength midrange horns sound harsh and metallic. This bias prompted me to use dome midranges and horn loaded dome tweeters in my design. The tweeter enclosure has a triangular cross-section and is constructed of quarter inch plywood internally braced by left-over segments of the pine spacers used in the woofer cabinets.

The two front surfaces are 9.5 inches wide, and the back of the cabinet is 13 inches wide, with the enclosure being 24 inches tall. The enclosure is then equipped with four Vifa D75MX-31 3 inch midrange domes and four Vifa H25TG-35 horn loaded tweeters. The driver aggregate should easily handle 400W of program material. These particular drivers were chosen for their comparable efficiencies and similar acoustic centers in an attempt to minimize time alignment problems.

The two faces upon which the drivers are mounted are at right angles. This simplified construction of the cabinet, and the angle also allowed the two halves of the radiation pattern to merge without any noticeable amplitude ripples when standing directly in front of the cabinet.

The crossover network is a three-way, two-pole design, mounted in the tweeter cabinet. The crossover frequencies are 500Hz and 6kHz. Two jacks are mounted on the tweeter cabinet. I fed the power amplifier output to the input jack and connected the woofer cabinet to the low output jack. I used a stereo type jack for the woofer connection to prevent the power amplifier from driving the undamped low-pass filter section if a woofer is not connected to the crossover.

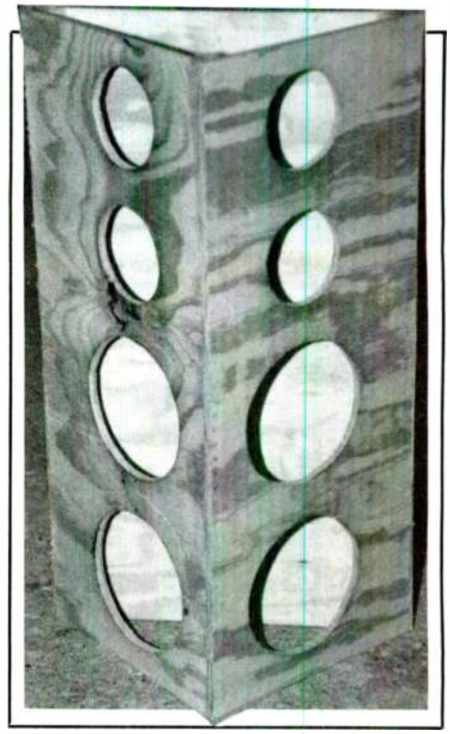

PHOTO 10: A tweeter cabinet in the early phases of construction.

When the woofer is plugged in, the sleeve of the phone plug connects one end of the capacitor in the low-pass LC filter to ground through the ring connection on the stereo jack. This allows the stand-alone operation of the tweeter cabinets for use in a biamped system. I stuffed the tweeter cabinets with long fiber wool and covered them with the same fuzzy material as the woofer cabinets.

PERFORMANCE. I set up my new pair of speakers in my 20 by 15 foot liv-

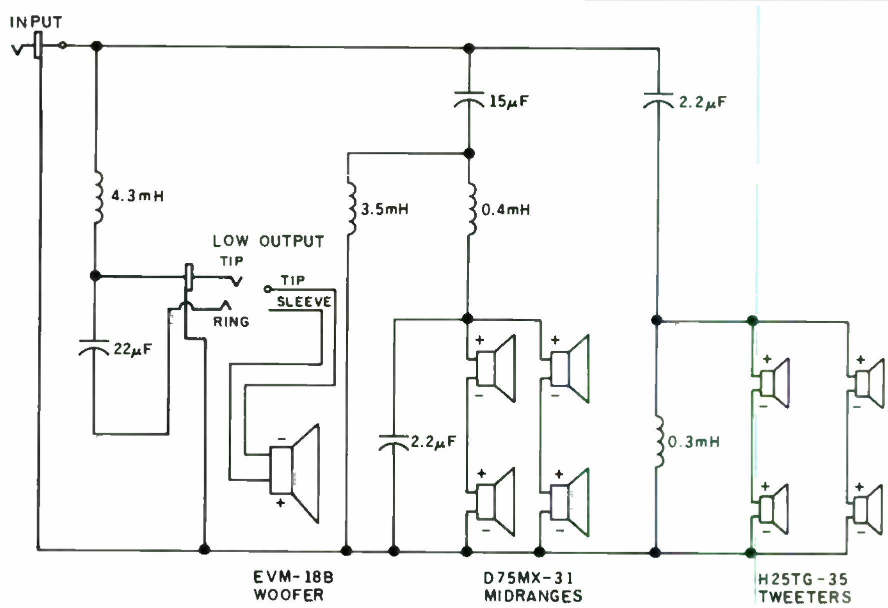

FIGURE 3: Crossover schematic.

PHOTO 11: A completed tweeter cabinet.

ing room, hooked them up to my Hafler DH-220 (100W/channel) and listened to some music. They are loud. The bass was tight, but I think the tweeters were a little too loud for the woofers—nothing an attenuator couldn't fix. Percussion sounded terrific, and the vocals and brass were very clear. The speakers imaged well, but everything sounded "larger than life" perhaps due to the sheer size of the system. The efficiency of the system is impressive, being 6 to 10dB better than my hi-fi transmission lines. I had succeeded in building a pair of giant stereo speakers, fit for a king (and his king-sized living room).

Their performance in the situation for which they were designed is even more surprising. The completed woofer cabinets weigh only 60 pounds each, and the tweeters each weigh only 20 pounds. The system is noticeably more efficient than the 15 inch cabinet I had been using, and the high end produced was very clear without sounding forced or edgy.

This new assertiveness in the low end and clarity in the high end has even altered my playing style. Every nuance of my playing (both positive and negative) is accurately projected to the audience. Drive them with 400W per side, and people have to dance. Although the quality of the sound they produce is remarkable, their appearance tends to elicit the most comment. When I wheel my black fuzzy cylinders into a party, people invariably say "What are those?" and run right up to touch them.

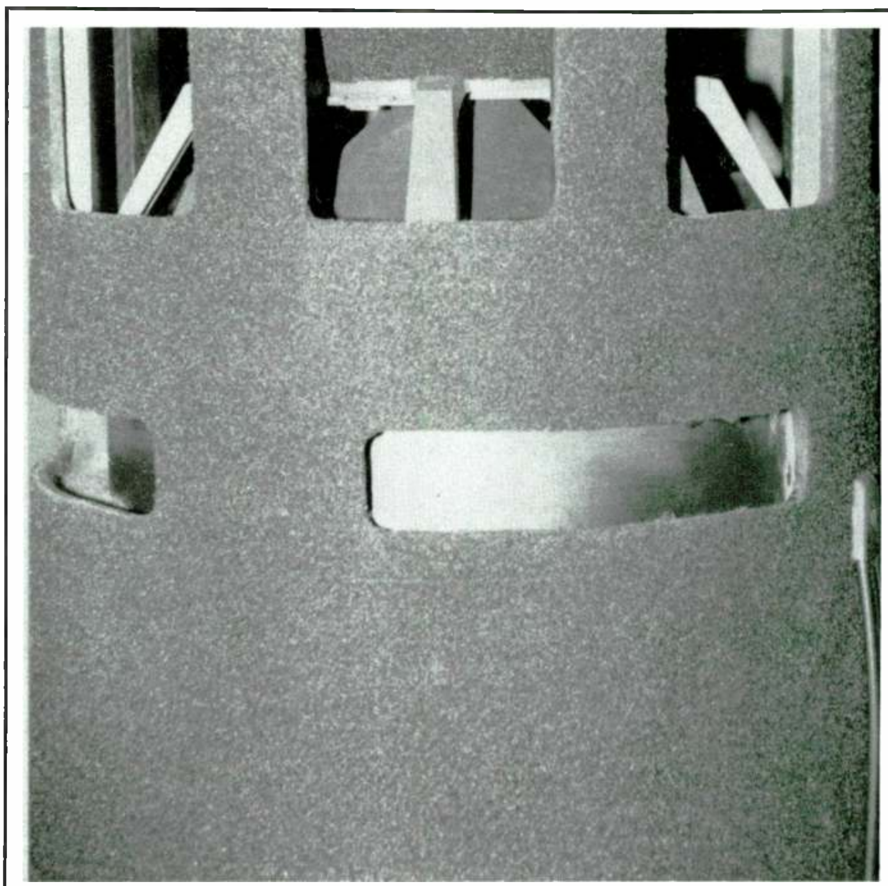

PHOTO 12: A close-up of woofer and tweeter. Note the reflective cone mounted at the rear of the woofer, and the pair of jacks on the tweeter cabinet.

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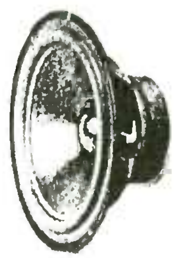
CONE EDGE: Foam
RESONANCE: 25 Hz
VAS: 180 Liters
QTS: .330
POWER RATING: 150 Watts



SPEAKER DIA: 8 Inch

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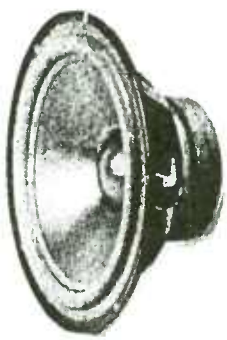
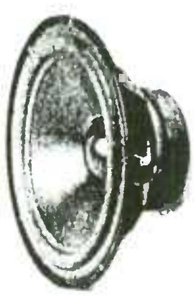


SPEAKER DIA: 12 Inch
MAGNET WT: 38 oz.
VOICE COIL DIA: 2 Inch
SENSITIVITY: 90.7 dB
IMPEDANCE: 8 Ohm
CONE BODY: Grey Polypropylene
CONE EDGE: Grey Foam
RESONANCE: 22 Hz
VAS: 188 Liters
QTS: .332
POWER RATING: 100 Watts

SPEAKER DIA: 6.5 Inch
MAGNET WT: 14 oz
VOICE COIL DIA: 1.25 Inch
SENSITIVITY: 90 dB
IMPEDANCE: 8 Ohm
CONE BODY: Polypropylene
CONE EDGE: Foam
RESONANCE: 48 Hz
VAS: 22.7 Liters
QTS: .331
POWER RATING: 50 Watts



SPEAKER DIA: 10 Inch
MAGNET WT: 28 oz
VOICE COIL DIA: 1.5 Inch
SENSITIVITY: 91 dB
IMPEDANCE: 8 Ohm
CONE BODY:Grey Polypropylene
CONE EDGE: Foam
RESONANCE: 25 Hz
VAS: 152.9 Liters
QTS: .268
POWER RATING: 75 Watts

SPEAKER DIA: 5 Inch
MAGNET WT: 14.4 oz
VOICE COIL DIA: 1 Inch
SENSITIVITY: 88.9 dB
IMPEDANCE: 6 Ohm
CONE BODY: Polypropylene
CONE EDGE: Foam
RESONANCE: 63 Hz
VAS: 8.1 Liters
QTS: .349
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Part I

A COMPACT INTEGRATED ELECTROSTATIC/ TRANSMISSION LINE

BY ROGER R. SANDERS

The sonic advantages of electrostatic loudspeakers (ESLs) have been well recognized for over forty years. Anyone who has ever heard one is forced to agree that magnetic speakers are still a long way from being able to match the detail, smoothness, and delicacy of electrostatics in the critical midrange. The reasons for this superior performance are quite clear: First, ESLs have essentially no mass. They will therefore respond to the audio drive signal instantaneously. Equally important is the fact that they will stop instantly.

By comparison, magnetic speakers are more massive, making them hard to start and stop. Powerful magnetic motors have managed to greatly reduce the start time, but do not stop the cone. The unavoidable result is overshoot and ringing with distressing effects on sound quality. The massless nature of an ESL means the mass of the air in the room damps any potential speaker resonances, so extremely smooth frequency response is automatically achieved.

Unlike the cone of a magnetic speaker which is driven only at its center, causing cone flexure, ESLs are driven uniformly over their entire surface. Distortion is therefore negligible. In an attempt to improve magnetic speaker performance, ribbon and planar magnetic types have been built. In many ways these are superior to the cone drive, but have numerous problems which have prevented their widespread acceptance. Furthermore, they are still far from matching electrostatic performance because they remain much more massive and are not driven uniformly over their entire surface. If one desires the finest in sound reproduction, I believe there is no choice but to use the electrostatic format.

DRAWBACKS. While difficult for commercial manufacturers to build, ESLs are simple, easy, and cheap for the home constructor. They virtually guarantee magnificent performance. Yet, they have drawbacks that have severely limited their widespread use. Ask most audiophiles why they don't own ESLs, and one of the most common reasons is the typical ESL's large size and ugliness is incompatible with their wives' living room decor. My design is aimed squarely at this problem. It is the latest in a long series of extremely high performance speaker designs that began in 1972.

Over this 17 year period, I have learned much about the construction and operation of ESLs. Some of this work has been published (*TAA* 4/75, *SB* 2, 3, 4/80) resulting in communication with engineers, amateurs and others who had many good ideas which I incorporated into later versions. The design I present here utilizes all I have learned over this period and is well proven. One of the things I learned is there is no magic. ESLs are simple, predictable, and offer superb detail. There are often many ways to accomplish the same goal. I will outline a variety of options you may choose.

My goal is to achieve the highest performance possible, considering the aesthetic restrictions of a quality living room environment. Previous designs are no-compromise performance devices consisting of floor-to-ceiling ESLs up to two feet wide which must stand away from the walls. These are combined with large transmission line woofer systems in boxes at least 4 feet tall and 1.5 feet deep. While the resulting sound is spectacular, their large size, multiple sections, and free standing requirements make them unacceptable in most homes. Clearly the challenge now is to build that kind of performance into a small, pleasingly shaped speaker that can be placed against a wall.

Building a small, attractive, full-range, flat frequency response ESL is a piece of cake. All you have to do is pick a convenient size, determine the phase cancellation and fundamental resonance frequencies and magnitudes, build a mirror image equalizer, hook it up and you're in business. They would be cheap (surely less than $100 for the pair) and you could build them in an evening. They would have marvelous detail, perfect frequency response, great imaging, and if done right, you could even hang them on the wall to make them virtually disappear.

If you suspect I'm deliberately overlooking something, you're right. The above speaker has one small problem: You could barely hear it. Obtaining high sound pressure levels (SPLs), particularly in the deep bass, is a serious problem and must be compromised against all other design parameters. This need for high output is *the* challenge for ESL designers. It is important to realistic sound reproduction and is the main failing of most ESL designs.

HIGH OUTPUT. To give you some idea of the output required, if you measure the SPLs of commercial source material (virtually all of which is heavily compressed), you will discover "ear shattering" levels (which I define as uncomfortably loud with loss of hearing sensitivity for a while after exposure) are about 95dB.

ABOUT THE AUTHOR

Roger Sanders is a 41-year-old inventor/designer. His interests and designs span all types of mechanical and electrical products. He maintains a particularly keen interest in electrostatic transducers and will be publishing a book on the subject this year.

Because commercial source material is generally of poor quality, I make my own recordings.

I have been fortunate enough to record live performances of good symphony orchestras and pipe organs for more than 20 years. Measuring "Row A" sound levels while recording these, the highest level I encountered was the finale of Mahler's "Resurrection Symphony" with full orchestra, pipe organ, brass choirs, extra percussion, 500 voice chorus, and soloists. I saw momentary peaks of 105dB, although I am sure some were very short peaks which the meter wasn't quick enough to display.

The ability to reproduce "Row A" SPLs in my home is a fundamental requirement of any audiophile quality speaker. To realistically reproduce such uncompressed material requires prodigious amounts of speaker output. My no-compromise system will do that. No full-range ESL can even come close. But can levels of that magnitude be accomplished in a small ESL system? Let's have a look at how it might be done.

The ESL's operating principle is the attraction of an electrically charged object. You experience this when you comb your hair on a dry day and feel the electrostatic charge on the comb pull gently on the hair on your arm or attract bits of paper. Our speaker operates by placing an electrostatic charge on a diaphragm which is suspended between two electrically conductive grids, perforated so air may pass through them. The audio amplifier drives alternating high voltage onto these grids so the diaphragm feels a net force, moves, and drives the air producing sound.

High SPLs are difficult to achieve with electrostatic designs since, unlike magnetically driven speakers, electrostatic forces are weak and travel only short distances. Speaker output is the product of driven area times excursion. Either one may be increased to increase SPLs. Large excursions in ESLs are difficult to obtain because they require very high operating voltages. Not only is it difficult to supply the speaker with such voltages, but if you do, it is difficult to prevent the speaker from arcing internally and destroying itself.

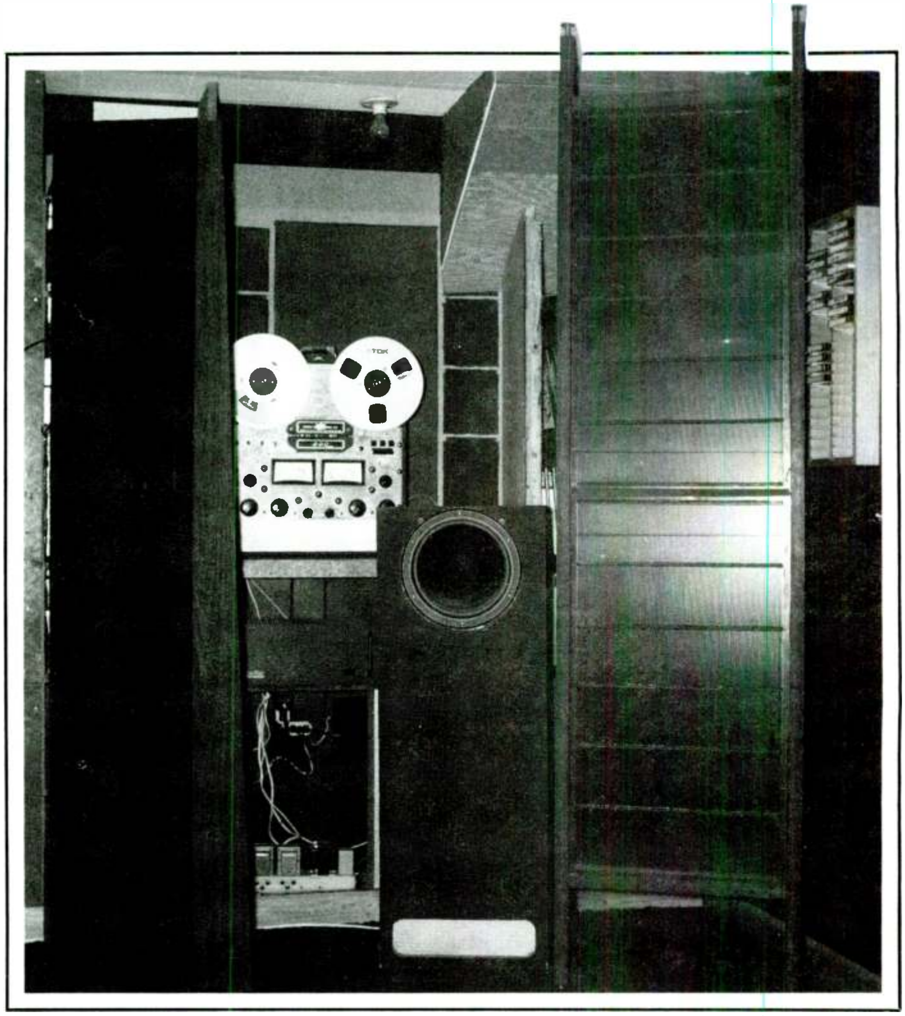

PHOTO 1: The original speaker, right, compared to the new, compact version.

DRIVE VOLTAGE. Electrostatic forces in speakers require several thousand volts to be effective. This requirement rises as the distance between the moving diaphragm and the stationary conductive grid (stator) is increased. To further complicate matters, the voltage required is squared as the distance is doubled. I use a relatively small diaphragm-to-stator spacing of around one sixteenth of an inch (often referred to as 63 thousandths of an inch or 63 mils in the literature). Even so, a total of around 7,000V is required to drive them to SPLs I consider adequate. Obviously, larger spacing requires higher voltages. Where does one get 7kV of audio drive voltage? The typical 100W amplifier is capable of an output voltage of only around 100V, and we need about 100 times that amount. This problem may be solved by either using a high voltage step-up transformer between the speaker and the amplifier, or by designing an amplifier which will deliver several thousand volts directly to the speaker.

High voltage amplifier designs are available ("An Electrostatic Speaker System," by David Hermeyer, *TAA* 4/72, p. 9 and "The Sanders Electrostatic Speaker," by Roger Sanders, *TAA* 4/75, p. 18) as well as commercial amplifiers used by Beveridge and Acoustat. However, they are expensive, parts are hard to find, tend to be unstable, radiate RF, generate large amounts of heat, use vacuum tubes, and still don't deliver as much voltage as a good hybrid system (conventional amp with transformers). Their greatest asset is that they usually will measure better into an electrostatic load, but even if this is audible (it isn't in my experience), a good transformer system will produce much higher SPLs which makes it audibly far superior. Furthermore, a transformer/conventional solid-state amplifier is cheaper than a high-voltage amplifier, easier to assemble, is stable, and runs cool.

Amplifier sound is a controversial subject. I have done a considerable amount of double blind "A-B" amplifier testing and have come to the conclusion if two properly operating high quality amplifiers sound different, the difference is always due to different distortion products produced during some type of overload condition. Amplifiers are usually driven into at least modest clipping at SPLs most audiophiles enjoy. "Tube sound" for example, may possibly be explained by the fact that few odd-order harmonics are generated by a clipping tube amp, while a solid-state one produces an edginess or harshness due to a high percentage of odd-order harmonics when clipped.

SURPRISE. When clipped subtly so the ear does not perceive gross distortion, the two amplifiers do in fact sound different. It is truly amazing how much power and headroom is needed to avoid clipping an amplifier in most listening situations. However, if you set up double blind tests which require that neither amp under test be allowed to overload at any time, you will be surprised by two things: 1) You will be unable to play your speakers as loudly as you thought you could, and 2) both amplifiers sound the same.

I realize many audiophiles simply do not believe this. However, even skeptics will agree that if such differences exist, they are subtle. If not, then there would be no controversy about it. One issue is *not* subtle: Inadequate power is extremely obvious. In short, the most important amplifier parameter, particularly when driving ESLs, is adequate amplifier power. Don't sacrifice power for some subtle (or imagined) sonic difference between amplifiers.

I have abandoned the direct drive types for the conventional amplifier/transformer setup. I can hear no reduction in sound quality between the two in a double blind test, but the hybrid system will play much louder resulting in a system which seems much more "at ease" and is far superior for meeting my goal of high output.

VOLTAGE. Transformers have their problems which I will not discuss here except to say that from a practical standpoint, the highest feasible step-up ratio ("turns ratio" in engineering jargon) in the wide bandwidth transformer my design requires is about 1:50, or about 5kV from our 100V conventional amplifier. While this voltage is quite usable, it isn't quite enough.

A larger amplifier is one answer. Personally, I use the Hafler 500 which will swing nearly 180V with plenty of amperage, for a drive voltage of around 7kV. Add a diaphragm polarizing voltage of around 3kV for a total voltage of around 10kV. This level drives an ESL with a diaphragm-to-stator spacing of around 60 mils extremely well. But to double the excursion to 120 mils you would have to square the voltage. It is difficult enough to develop the 10kV. How would you generate several times that amount?

Furthermore, even if it were practical, preventing arcing within the speaker would be difficult. Dayton-Wright even replaced the air between the stator and diaphragm with sulfur hexafluoride gas which has six times air's insulating qualities. Thus, increasing diaphragm excursion is impractical.

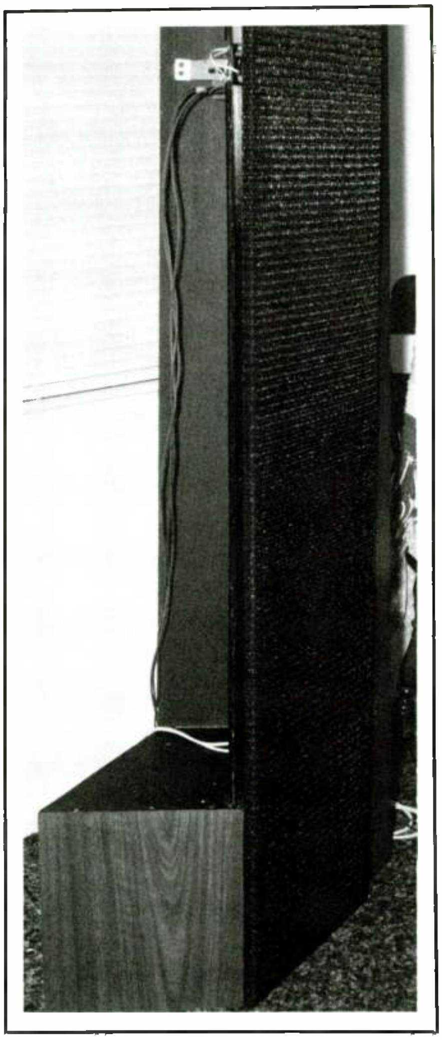

PHOTO 2: A peek around the inside edge of the speaker.

PHASE CANCELLATION. Phase cancellation at low frequencies is the biggest problem with obtaining high output from ESLs. ESLs are usually used as dipoles, i.e., they are free to radiate in both directions. The speaker's pressure waves leak around its edge to the other side. When this occurs, the pressure wave magnitude is reduced, thereby reducing output.

The "leak's" seriousness is determined by how far the air must travel and how much time it has to get there. Distance is reduced as the driver gets smaller, and time is increased as the frequency is reduced. Hence, small speakers suffer severe low frequency losses. These losses start when the sound's wavelength is about twice the minimum dimension of the speaker and the output falls quite dramatically with lower frequency.

Imagine that the ESL is a canoe paddle and the air in the room is a bathtub full of water. If you put the paddle in the water and move it rapidly back and forth (high frequency sound in the ESL), you get big waves (high output in the ESL). But if you move the paddle very slowly (bass frequencies in the ESL), the water has time to travel around the side of the paddle and cancel most of the wave energy, hence there are almost no waves in the water (low bass output from the ESL).

CONTROL. We can control phase cancellation in many ways. Most magnetic drivers are simply placed in some type of enclosure which effectively isolates the frontwave from the rear. This causes all sorts of problems with resonances and diffraction effects. One of the reasons ESLs sound so clear is they avoid the problems associated with enclosures. Placing the ESL in an enclosure does not solve the problem because its low mass results in a high fundamental resonance with rapid output loss below that.

Other solutions are to increase driver size, increase excursion at low frequencies, or increase radiating area at low frequencies. Since one of my goals is to keep the size small, increasing it is unacceptable. Increasing the radiating area at low frequencies again requires us to increase the size or give up SPLs, both of which are unacceptable. Increasing excursion at low frequencies gets us back to the problem of needing very high drive voltages.

There is no magic, the laws of physics cannot be circumvented. There is simply no known way to make a small full-range ESL with flat frequency response *and* high output. Some compromises are possible. I have a reputation as a designer of ESLs but, in fact, that's the easy part. Any *real* success of my designs is based on carefully selecting the best compromises to achieve my goals of electrostatic detail coupled with very high output. That and the difficulties in developing adequate woofer systems have occupied most of my design efforts. The importance of working out the compromises cannot be overestimated.

BASS SOLUTIONS. The first of several compromises required for high output is to avoid ESLs for producing bass. Conventional magnetic drivers are quite capable in the bass, and are much smaller. The trick is to mate them to an enclosure that does not color the sound and blends well with an ESL. High quality magnetic drivers mated to transmission line (TL) enclosures are quite satisfactory for this purpose. Such enclosures are typically rather large and difficult to build, but are more resonance free and have deeper frequency response than other enclosure designs.

TRANSMISSION LINE THEORY. A TL is a long tapered tube ("line") into which the woofer's rearwave is directed. Tapering the tube results in an infinite number of insignificant resonances rather than the two or three large ones typical of most box enclosures. Stuffing the line with damping material absorbs most of the sound energy except for the deep bass.

By the time the deep bass exits the line, it has been considerably delayed which shifts its phase so that instead of canceling the woofer's frontwave, it augments it. This extends and supports the deep bass response which by that time is falling due to reduced radiation resistance. The resulting woofer system is essentially free of audible resonances and coloration, is reasonably efficient, has linear frequency response, and has remarkably extended deep bass performance.

TLs are capable of producing the same type of clean easy sound typical of ESLs so there is a seamless match between them. While much smaller than ESLs of similar bass capabilities, TLs are not necessarily small since they must be several feet long. The exact length is controversial; I'll not get into all the arguments here. In my experience the ideal is in the range of eight to ten feet, which I chose here.

HIDING THE TL. The challenge was to somehow stuff an eight-foot TL into a size small enough for a compact ESL/TL system. At first glance this seems impossible. Where can we hide eight feet of transmission line? As can be seen from the photographs, the solution was to run the line up the side of the ESL. I also made the line more compact than usual by making the cross-sectional area smaller than usual.

Conventional TL design says the cross-sectional area of the line immediately behind the woofer should be 125% of the woofer area. This will taper to 100% of the woofer area at the port. Some English engineers believe it unnecessary to have such large areas although unquestionably they work. Because this line needs to be crammed into the smallest space possible, I reduced the cross-sectional area to near 100% immediately behind the woofer, and tapered it to 70% at the port. I reduced the damping material density from the standard ½ pound per cubic foot to about ¼ pound to compensate for the reduced area.

If you choose a reasonably small woofer, the line can be quite narrow, and you can use it to mount the ESL which will need some kind of support in any case. Added benefits are that the rearwave of the ESL must travel around the side of the TL so the problem of phase cancellation is reduced, and you can use the TL as a beam splitter to improve casual dispersion characteristics which I will discuss shortly.

CROSSOVER LOGIC. The bass cancellation problem could be avoided if the ESL were crossed over to the woofer at a high enough frequency (several kHz, depending on size). However, crossovers are fundamentally evil devices and listening tests demonstrate that the ear can detect the effects of even the best crossovers as the crossover frequency rises above 500Hz. On the other hand, my tests produced no evidence that the ear can detect well-designed crossovers if they are used with excellent woofer systems below 500Hz.

Of course, the biggest problem with high crossover points is that magnetic drivers, particularly woofers, are simply incapable of high quality midrange sound reproduction. After all, isn't that the reason we are building ESLs? The larger the ESL, the lower it can be crossed over. This design is fairly small, but we can still cross over to the woofer as low as 550Hz if we use some modest equalization to support the midrange to that level. This crossover point is low enough, and the woofer system is good enough that audible problems with crossovers and the limitations of woofers operated into the midrange are not a problem. The crossover greatly helps the problem of phase cancellation as does using the TL as a baffle to increase the sound wave path, but neither completely resolves the issue.

EQUALIZATION. Electronic equalization is needed to boost the frequencies in the range from 500Hz to 5kHz. This equalization is on the order of 7dB, moderate enough for us to still attain very high SPLs with currently available drive voltages. Please avoid the technofreak gut reaction of omitting this small bit of electronics in the interest of purer sound.

The electronics are extremely clean, and if the ESL is not equalized it will have that thin, bright, unnatural sound so typical of most ESLs. This is because you will adjust the woofer to the ESL in such a way as to have a full sounding midrange. But if the ESL is unequalized, the low range of the ESL will be markedly attenuated due to phase cancellation. When you adjust the levels for a full midrange, the upper regions of the ESL will be exaggerated. The net result will sound much as though you had turned up the treble on a preamplifier. In short, the equalization is essential, don't omit it.

SPACING. Diaphragm-to-stator spacing is critical for high output and must be carefully selected. Larger spacing offers potentially greater output, but requires more voltage as previously discussed. Smaller spacing produces higher outputs for a given set of voltages, but arcing occurs more easily and acoustic coupling becomes a problem.

Acoustic coupling occurs when the diaphragm is driven into the stator by sound waves from the woofer and often exaggerated by room resonances. At high SPLs, you can see the ESL diaphragms move by observing your reflection in them. If you turn off the ESLs and only operate the woofers, they still move, proving that the air in the room is driving the diaphragms. If the room has large resonances, such acoustic coupling can be a major problem. I chose 68 mil spacing because it maximizes the output that can be obtained with 7kV drive systems and arcing is rare. This dimension is usually wide enough to prevent problems with acoustic coupling unless your room resonances are horrible.

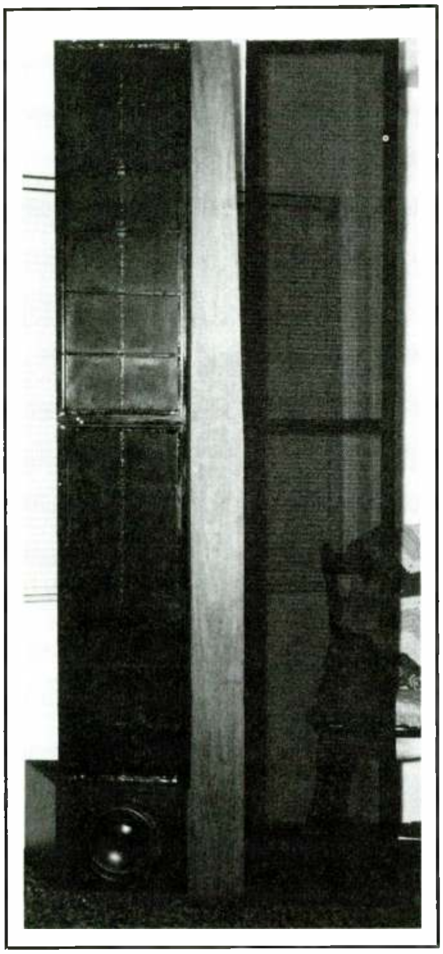

PHOTO 3: Speaker with grille removed.

OUTPUT DETAILS. Finally, your careful attention to a number of little details will add up to improved output. Each individual factor may not seem important, but when combined, they make a significant difference. This reminds me of the first rule of lightweight backpacking: "Pay attention to the ounces and the pounds will take care of themselves."

The small quality factors include:

- Narrow insulators since they do not produce output but take up valuable limited space
- Thin glue bonds so the diaphragm-to-stator spacing is not needlessly increased
- Closely spaced stator wires or holes to achieve high field density
- Careful diaphragm preparation to produce uniform surface conductivity to avoid output voids anywhere on the speaker's surface
- Develop the highest possible diaphragm tensions so maximum polarizing voltage can be used
- Run the polarizing voltage as high as practicable
- Use high power amplifiers and high turns ratio transformers for maximum drive voltages
- Keep interconnecting wires separated to minimize stray capacitance
- Build highly directional cells to concentrate output energy in the first arrival wave front
- Listen in a spot close to the speakers so the sound energy is not dissipated before reaching you.

ESL DIMENSIONS. The free-standing ESL's minimum size is determined by the wavelength of the lowest frequency we wish the ESL to produce. With the techniques above, we can use a minimum ESL dimension of only 12 inches and still produce SPLs in excess of 100dB. If we want to be able to hear the speaker in both standing and sitting positions, be able to produce very high SPLs, and have some place to put the TL, it must be taller than 12 inches. Fortunately, height does not take up floor space, the main problem with speaker size. A tall, thin speaker can be very attractive and also have superb sonic performance.

DIRECTIONALITY. I invented a smoothly curved free-standing wide-dispersion ESL and have done much testing and comparing of curved cells and flat (planar) cells. Despite the perfect dispersion characteristics of curved ESLs, I consider the planar cells superior. Therefore I specifically designed my system to be extremely directional. Most audiophiles seem to desire wide dispersion, because they apparently believe they must be able to listen to their system from almost anywhere in the room and have it sound wonderful. Unfortunately, the laws of physics do not allow this.

Wide dispersion speakers are unavoidably compromised in several ways, the most important of which is the ability to resolve detail. Remember your first headphone experience? There may have been faults, but you were surely impressed by how clear and detailed they were. Why are even poor headphones nearly as detailed as the best loudspeakers? This mostly has to do with room acoustics.

Consider the wide dispersion speaker. It sends sound directly to you, but simultaneously bounces sound off nearby walls and objects which then reaches you after a very slight delay. This delay is too short for the ear to separate it as an echo. The audible result is that this delay "smears" the detail and affects the frequency response by phase cancellation and augmentation.

Headphones avoid room acoustics. Highly directional speakers barely excite room acoustics. Furthermore, they get their sound to your ears *before* exciting room acoustics, and then after a considerable delay, you finally hear some room acoustics. Your ear can easily tell the difference between the direct sound and the delayed sound with the result that the sound is much more detailed than any wide dispersion speaker can be.

SPL. Sound pressure levels are subjectively much higher in directional speakers. With an SPL meter I have measured planar and curved ESLs with the same dimensions, side by side with the same drive amp. Both registered the same loudness. However, the planar sample subjectively seemed much louder and needed a higher woofer drive level for the system to have subjectively linear frequency response. I believe the meter was registering the total energy in the room, while psychoacoustically, the brain was responding to the first arrival wave front.

The wide dispersion cell was radiating only a small percentage of its energy toward the listener as a first arrival wave front, while sending the largest percentage away to produce room reflections. The directional cell was radiating virtually all of its energy as a first arrival wave front therefore seeming louder. We need more studies in this area to precisely identify this phenomenon, which doubtless exists.

Planar ESLs project a much more realistic and believable image than wide dispersion types. The image from such a speaker has often been compared to a laser holograph. When listening to this form of ESL you will be able to visualize the stage with incredible detail in three dimensions (if the recording has been done in true stereo). If you have experienced only standard wide dispersion speakers, the above statement may seem akin to advertising hype. However, once you have heard a planar ESL for comparison you will understand.

DIMENSIONS. Directional speakers are phase coherent. The sound does not seem artificial since it doesn't appear to come from the speakers, but rather floats between them. Wide dispersion speakers by contrast create an image that is diffuse and spatially ill defined. This sound seems to come *from* the speaker (although the best ones have a transparent quality that makes the sound seem to be coming *through* them). When the sound comes from the speaker, your mind seems to be able to tell that the image is artificial and two, rather than three dimensional. When further confused by all the room reflections, the image simply isn't precise enough to convey much of the third dimension.

This can be a two edged sword however. If your source material is only recorded in two dimensions, then neither type will transmit a three dimensional image. A good example of this is the typical recording studio that uses a single microphone to record a singer and then "pans" that signal to "center stage." With only one microphone, your ear lacks the clues necessary to determine the third dimension, and no amount of artificial reverberation can change that.

On the other hand, a simple concert hall recording done with just two high

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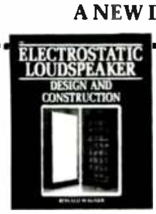

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Continued from page 35
quality microphones will produce amazingly three dimensional images. The pop singer recorded with one mike and loaded with artificial reverb will sound bloated and as though she is singing inside a 30 foot pipe, while the opera singer recorded with two mikes and no artificial reverb will appear to have a voice of normal size inside a concert hall.

Should we blame a speaker that is accurately reproducing poor recording techniques for the unnatural image of the pop singer? Or should we use wide dispersion speakers that are incapable of precisely reproducing the recording so that the recording faults are not so obvious? You might want to use the wide dispersion speakers on the pop singer, but you would then sacrifice the superb realism offered by the directional ones when good source material is available.

BEAM SPLITTER TECHNOLOGY. For casual listening and background music, superb imaging is not necessary and the compromises involved in wide dispersion speakers are not a problem. At the same time, wide dispersion is highly valued so you can use the room freely and hear the speakers acceptably everywhere. Planar dipole radiators have very poor dispersion. We need a speaker with perfect imaging for serious listening, and wide dispersion for casual listening that simultaneously does not harm the image at the focal point ("sweet spot"). The two seem mutually exclusive, but my design incorporates a novel idea to solve this dilemma.

A dipole sounds poorly off axis because the highs are lost. So long as you are in the main or rear reflected beam, the sound is acceptable, but these beams only cover very narrow areas. The rear beam from a dipole radiator does not harm the image since it has long delay times and is mostly decayed by the time it reaches the focal point. Therefore, the problem could be solved if we had a multitude of rear beams going in many directions so we would be in a beam no matter where we were in the room, while at the same time being careful to avoid directing any of the beams into the focal point.

To test this theory, this speaker uses the TL's vertical column's shape as a beam splitter to reflect the ESL's rearwave in three different directions. None of the beams intersects the focal point. This beam splitter is much like—dare I say it—a Bose speaker, except that it does not influence the focal point.

REFLECTIONS. Listening tests revealed that the three beams produced by the beam splitter produced much better tweeter beam coverage than the conventional dipole's single beam, although admittedly some voids remained. Dispersion covered a full 180 degrees. Interestingly, once you are distanced from them about four times the speaker's width, they sound about as coherent as the typical wide dispersion speaker at a similar distance.

I designed this system with only two extra reflections, yet this concept worked well. Additional work in this area utilizing curved or multiple angle reflecting surfaces could produce a speaker that has essentially perfect coverage, yet uses the highly directional beaming qualities of dipoles to *avoid* putting any of these reflections directly into the focal point which is what ruins imaging and detail for serious listening. This is an exciting development that offers a real solution to the compromises and controversy surrounding the dispersion issue. Many of you will undoubtedly expand this idea. I would appreciate hearing news of your results.

Finally, even wide dispersion speakers have only one sweet spot. It is exactly equidistant between the speakers. Anywhere else is a compromise of phase and image coherency because the sound will be arriving at your ears at different times from the different channels which is certainly not what occurs when you hear live music. You can get away with it with wide dispersion speakers because their phase coherency is so poor you can hardly tell the difference. Because I don't like to compromise performance, I chose planar cells. They are also much easier to build than curved ones.

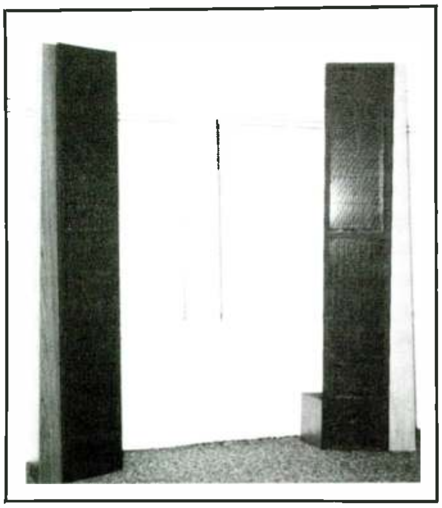
COST CONSIDERATIONS. Cost was not a design restriction, hence this is not an inexpensive project. However, from the standpoint of quality sound versus money these speakers are a bargain. The ESLs are quite cheap; you should be able to build them for well under $100. However, you can expect to spend at least $200 for the TLs when you consider the cost of materials, drivers and fancy finish work. The added costs are in grille cloth, connectors and miscellaneous hardware. The prototypes cost around $400. Associated electronics (EQ, crossovers, power supplies, chassis and transformers) are costly and may match the cost of the speakers themselves. Also, you will probably need at least one additional amplifier.

ELECTROSTATIC CELL DESIGN. Before the development of modern plastics, reliable ESLs were difficult to build. Now we are blessed with many different ways to build them. Builders have strong and varying opinions about the best way to build ESLs. I believe all ESLs of similar dimensions sound the same. For those who disagree, I offer five different construction techniques from which you may choose. All utilize quarter or half mil polyester film (Mylar) diaphragms and acrylic (Plexiglas) or polycarbonate (Lexan) insulators. The main differences are in support structures and stator construction techniques.

The construction types are as follows: 1) Steel rod stators as designed and built by Barry Waldron for this project (to be published in *SB* 2/90). 2) Steel rod stators as designed by the author. Suitable plans can be found in *TAA* 4/75. This construction is somewhat simpler than Barry's design. I used 50 mil music wire spaced 12/inch.

Some modifications to my original design will make construction easier. First, you may prefer to use copper coated 1/16 inch welding rod spaced 10/inch. Welding rod is cheaper and more readily available than music wire. You can also omit the insulation, and use a heat gun to shrink the Mylar tight as will be outlined later in this article, rather than using the stretcher specified in the original article. It would also be a good idea to use some conductive paint to improve the diaphragm contact point. Rather than using a clock gear to space the wires, use a long piece of threaded rod as Barry outlines in his instructions.

3) Insulated tensioned wire stators called "A Sheathed Conductor ESL" by David Lang (*SB* 6/88). 4) Perforated aluminum stators similar to those originally described in my *SB* '80 articles, but modified for more reliability and easier construction. 5) Perforated plastic stators by Ronald Wagner and described in his book *Electrostatic Loudspeaker Design and Construction* (Tab Books No. 2832).



All the designs have various advantages and disadvantages. Remember that in the following comparisons, all critical dimensions will be the same for all cells. Specifically, the diaphragm-to-stator spacing will be about 68 mils (63 mils for the insulators and 5 mils for the glue), and the overall size of the cells will be 13 by 36 inches regardless of the construction technique used.

To aid you in choosing the construction method best suited to your needs, I offer my observations on them. Some will disagree with my comments, but they are an accurate report of my well controlled testing experiences. Briefly, the sound *quality* will be identical for all the cells. The differences are in the *quantity* of sound (cell output), ease of construction, and cost. Unquestionably, perforated aluminum cells are the cheapest and easiest to build. Mr. Wagner's perforated plastic cells are the most expensive and difficult with the lowest output. The various wire types lie somewhere in between.

STATOR INFLUENCES. Output at a given combination of voltages and diaphragm-to-stator spacing is essentially a function of electrostatic field density. Field density is directly affected by how far apart the conducting parts of the stator are. In other words, highest output will be obtained with wires that are close together in a wire stator, or tiny holes in a perforated one. The point of diminishing returns is reached when the distance between the conductors approximates the diaphragm-to-stator spacing.

Obviously then, the ideal stator for a diaphragm-to-stator spacing of 68 mils will be wires about 1/16 inch apart, or 1/16 inch holes. This specification is constrained by three factors. The optimum percentage of open area is about 42%, the thickness of the stator, and the physical strength of the cell. It is easy to see that for 1/16 inch spacing, the wires should be about half that diameter, or 1/32 inch. This would give 50% open area, a thin stator, and very high efficiency.

However such small rods are not stiff enough to avoid sagging between insulators. Tensioned wire with the recommended insulation is too thick to maintain the required 42% open area. Perforated metal with 1/16 inch holes on 3/32 staggered spacing is ideal, but is neither readily available nor inexpensive. So as usual, compromise is in order.

Stator thickness is important, particularly in perforated designs. A thick stator with small holes will be seen by the air as having "tunnels" rather than "holes." Tunnels have resonances. A thick stator causes distressing Helmholtz Resonator effects. Stator thickness should not be greater than the spacing between conductors.

IDEAL DESIGN? You can judge for yourself how closely the various designs offered approach the ideal. You may have to modify your ideal selection based on cost and construction effort. The best stator of all has not yet been built to my knowledge. If I didn't already have a fine set of speakers, I would try building a tensioned wire stator using medium-sized tined or silver coated copper wire spaced 16 to 20 per inch. This would offer excellent charge density with smooth rounded wire to reduce corona effects.

If I desired an insulated stator, I would use magnet wire which would offer a thin, but high quality film of insulation. The general design offered by David Lang would be a good starting point for such a stator design. If you build such

Continued on page 66

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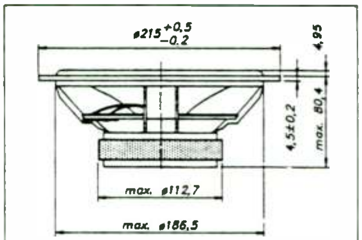

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SENSITIVITY (1W, 1m)	91	dB
EFFECTIVE CONE AREA	235	cm²
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VOICE COIL INDUCTANCE	0,9	mH
OPERATING POWER	3,2	W
VOICE COIL DIAMETER	40	mm
VOICE COIL HEIGHT	14	mm
AIR GAP HEIGHT	6	mm
FREE AIR RESONANCE	28	Hz
MOVING MASS (incl. air)	22,5	g
FORCE FACTOR, B x l	7,4	Txm
MAGNET WEIGHT (24,6 oz)	698	g
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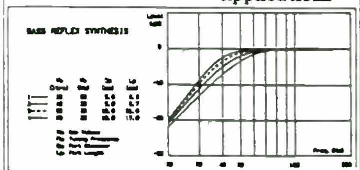
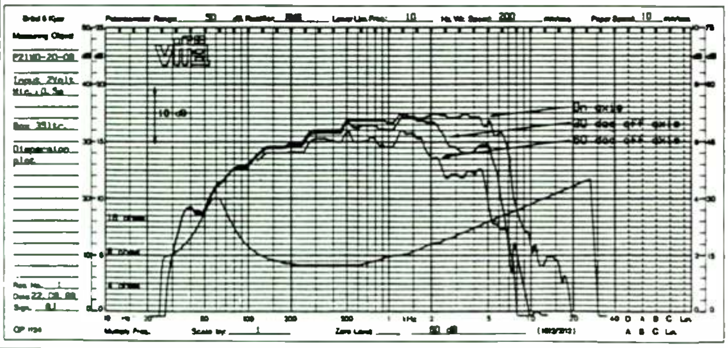
Qes	0,41	
Qts	0,33	
Vas	113	ltr

P21W0-20-08 Applications





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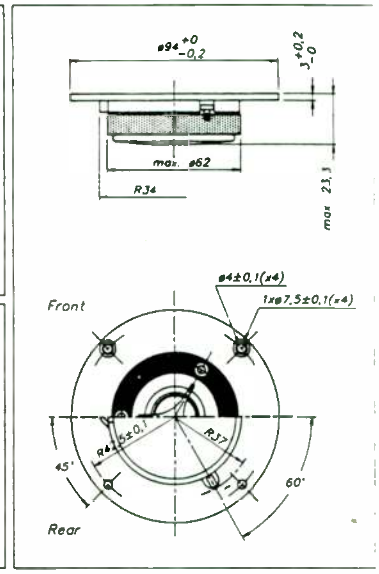
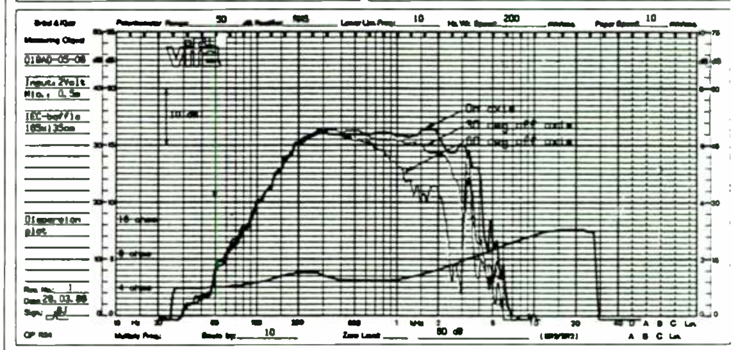


NOMINAL IMPEDANCE	6	Ω
NOMINAL POWER (IEC 268-5)	100	W
FREQUENCY RANGE	3-20	kHz
SENSITIVITY (1W, 1m)	87,5	dB
EFFECTIVE DIAPHRAGM AREA	4,4	cm²
VOICE COIL RESISTANCE	4,2	Ω
OPERATING POWER	7,1	W
VOICE COIL DIAMETER	19	mm
VOICE COIL HEIGHT	1,3	mm
AIR GAP HEIGHT	2	mm
FREE AIR RESONANCE	1700	Hz
MOVING MASS (incl. air)	0,2	g
FORCE FACTOR, B x l	2,2	Txm
MAGNET WEIGHT (3,7 oz)	105	g



1" DOME TWEETER D25AG-05-06

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- "BUTTERFLY" VC ASSEMBLY
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- HIGH LOSS SUSPENSION
- PISTON MOVEMENT TO ABOVE 20KHZ
- HIGH PRECISION PHASE SHIELD
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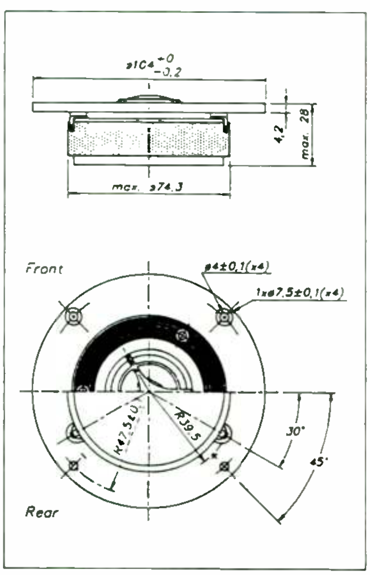

NOMINAL IMPEDANCE	6	Ω
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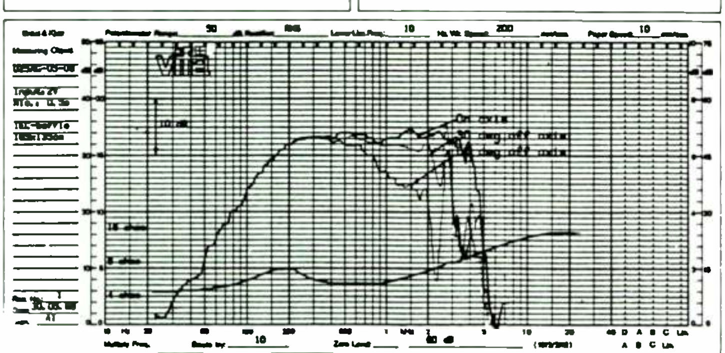
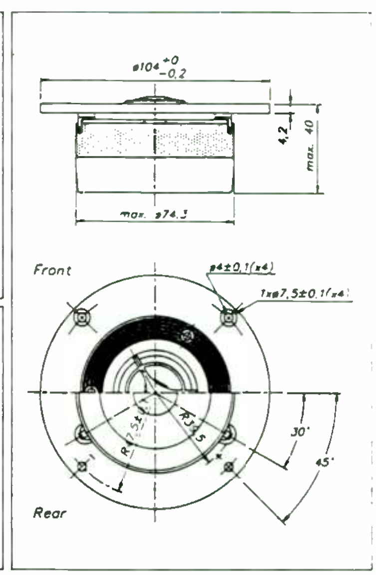
FREQUENCY RANGE	2,5-35	kHz
SENSITIVITY (1W, 1m)	90	dB
EFFECTIVE DIAPHRAGM AREA	7,1	cm²
VOICE COIL RESISTANCE	4,6	Ω
OPERATING POWER	4	W
VOICE COIL DIAMETER	25	mm
VOICE COIL HEIGHT	1,6	mm
AIR GAP HEIGHT	2	mm
FREE AIR RESONANCE	1500	Hz
MOVING MASS (incl. air)	0,3	g
FORCE FACTOR, B x l	3,5	Txm
MAGNET WEIGHT (8,5 oz)	240	g



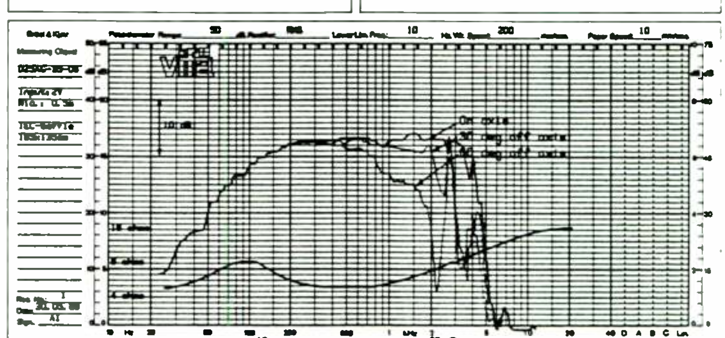
1" DOME TWEETER D25AG-35-06

SPECIAL FEATURES

- ALUMINIUM ALLOY DIAPHRAGM
- "BUTTERFLY" VC ASSEMBLY
- MAGNETIC FLUID
- DOUBLE CHAMBER
- FLEXIBLE VOICE COIL BRAIDS
- PISTON MOVEMEMT TO ABOVE 20KHZ
- HIGH PRECISION PHASE SHIELD



NOMINAL IMPEDANCE	6	Ω
NOMINAL POWER (IEC 268-5)	100	W
FREQUENCY RANGE	1,5-35	kHz
SENSITIVITY (1W, 1m)	89	dB
EFFECTIVE DIAPHRAGM AREA	7,1	cm²
VOICE COIL RESISTANCE	4,6	Ω
OPERATING POWER	5	W
VOICE COIL DIAMETER	25	mm
VOICE COIL HEIGHT	1,6	mm
AIR GAP HEIGHT	2	mm
FREE AIR RESONANCE	850	Hz
MOVING MASS (incl. air)	0,3	g
FORCE FACTOR, B x l	3,3	Txm
MAGNET WEIGHT (8,5 oz)	240	g



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D26TG-35	1"Dome[1,2,3]	6	18	940			100	12@3K	90	**$18.00**
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H25TG-31	1"Horn[2]	6	18	750			100	12@4K	94	**$16.00**
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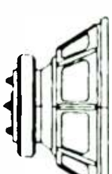

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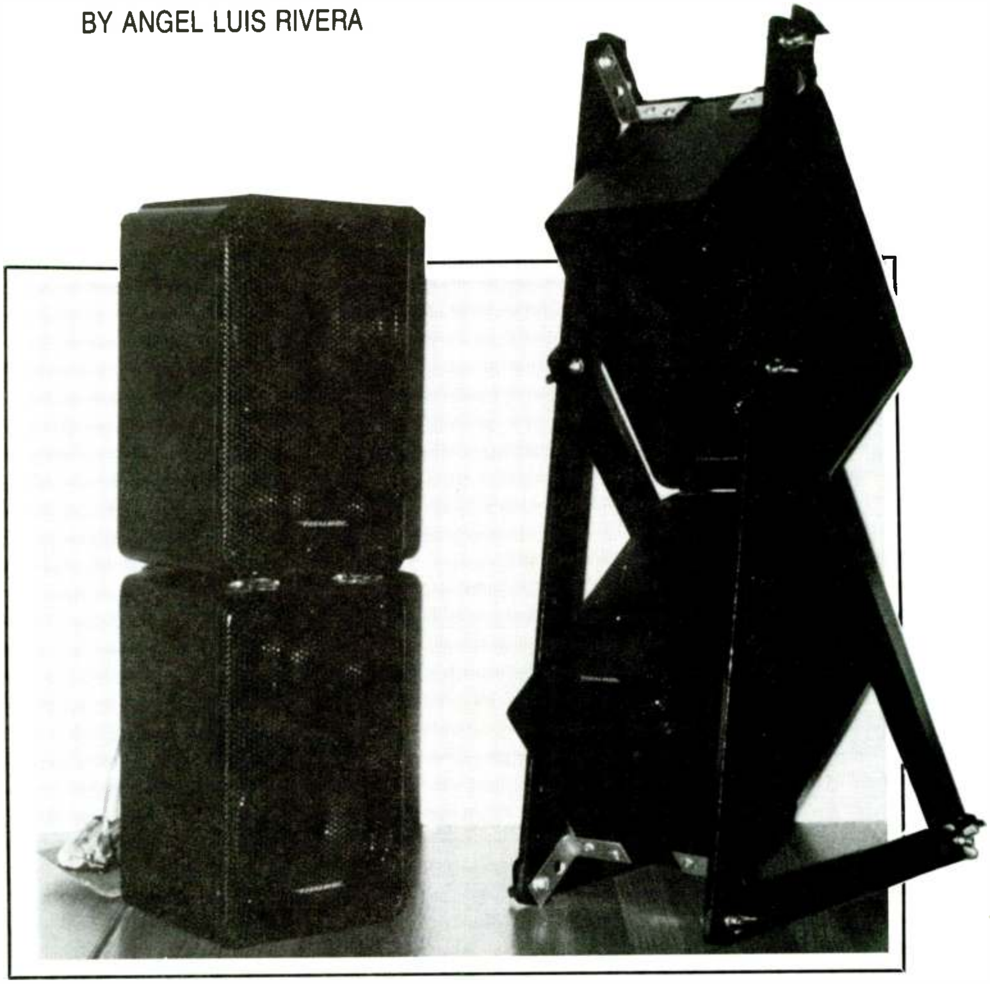
MINIMUS-7 SUPER MOD

BY ANGEL LUIS RIVERA



The diminutive Minimus-7 loudspeaker by Radio Shack has long been considered a great little speaker by many hi-fi aficionados, especially regarding value for your dollar. Regularly sold for $49.95 each, Tandy usually puts them on sale in late spring/early summer for $29.95, a true sonic bargain. Their sound quality is amazing, given the price, with respectable bass output for such a small woofer, and reasonably flat response down to 100Hz. In their black metal enclosures, they are reminiscent, both physically and sonically, of the Braun Output Cs, which at $224 per pair cost two to four times as much back in 1977.[1]

The Minimus-7 does have some inherent limitations and problems, but what do you expect for only $30–50?

For one thing, the stock crossover network is fairly primitive. The little 4 inch woofer is allowed to run full-range with no low-pass inductor (one way to cut cost) and the tweeter has a second-order LC (inductor-capacitor) network. William R. Hoffman explored and resolved this item in *SB* 1/88, providing insight into the Minimus-7's design strengths and flaws. He provided an alternative to the stock filter via a new crossover design that smoothed out the problem areas of the drivers and improved the system response considerably.

Never one to leave well enough alone, I began to think about what else I could do to improve Bill Hoffman's design. Looking at the impedance plot in the final system curve, I decided to use more "classic" Zobels (impedance compensating circuits) in order to completely flatten the system impedance and provide a more resistive load for the driving amplifier. I also thought Linkwitz-Riley (LR) (fourth-order) filters would provide more sophistication with steeper slopes and thus grant greater power-handling capacity to the drivers over their limited operating ranges.

I corresponded with Bill and shared my musings with him. What he had to say was both instructive and revealing.

REALITY. To begin with, he explained that a formula-derived Zobel and crossover design simply would not deal with the reality of the Minimus-7's woofer response beyond 1.7kHz and the tweeter response irregularities throughout its range; he reiterated that the response deviations require *different crossover points* for each driver, effectively *one full octave apart* (2kHz and 4.5kHz).

He also furnished graphs which revealed the tweeter to be similar in its frequency response to the cheap ones included in transistor radios and the like; both have the same double peaks, at resonance and higher up, with a subsequent falling response above the second peak (*Fig. 1*).

Mr. Hoffman also showed that in the region of 70–125Hz, the Minimus' total harmonic distortion ranged from 4–9% at 1W and 5W, respectively (*Fig. 2*). My impression is that despite its subjective bass output, this small woofer could use a subwoofer to give it some support and to lighten its low frequency burdens. More on that later.

Their flaws aside, these little speakers

ABOUT THE AUTHOR

Angel Luis Rivera is a 37-year-old physician's assistant currently working in surgical research at Maimonides Medical Center in Brooklyn, NY. He built test prototypes for Richard Kaufman for his book, Enhanced Sound.

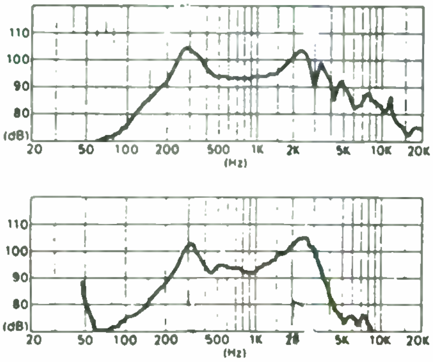


FIGURE 1: Resonant peaks representative of Minimus-7 tweeter.

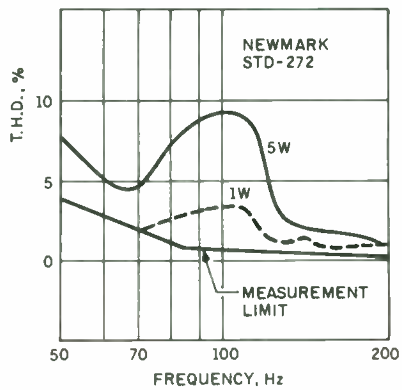


FIGURE 2: Measured total harmonic distortion of Minimus-7 woofer at 1 and 5W input.

PHOTO 2: The bracketed, time-aligned Minimus-7s.

sound so good it's hard to believe they have such humble origins. Hoffman describes this as "a minor miracle." They're just too good to give up on, so I forged ahead.

ANOTHER APPROACH. In light of Hoffman's information, I decided to abandon the original idea of modifying the Minimus-7 with more extensive Zobels and LR fourth-order crossovers. My mind was already working on another approach, an idea which had occurred to Hoffman as well.

By turning one Minimus-7 upside down and placing it on top of the other so that the tweeters are head to head, so to speak, I would have a D'Appolito-like configuration. I reasoned that both tweeters are small enough and in close enough proximity to appear acoustically as one driver. By doubling them in this way, they would be able to handle twice as much power as a single-driver system; their efficiency and output would also increase. And of course, there would be that marvelous D'Appolito vertical polar pattern.

In D'Appolito's articles and responses in *SB* Mailbox (4/84, 2 and 4/85), he prescribes an odd-order filter with its attendant 90° phase shift working in conjunction with his unique woofer-tweeter-woofer configuration so as to yield that constant vertical polar pattern. As Hoffman states in his article, his crossovers are effectively 6dB/octave, thus fulfilling D'Appolito's requirement (in part anyway, as D'Appolito preferred a higher third-order network).

I had several alternatives:

1. Since Hoffman had already worked out the values of the necessary crossover elements for the Minimus-7s in his design, it would only be a matter of using those same values and building four separate crossovers, one for each driver. This would be the easiest design approach. But considering it would require four 3.5mH inductors, this seemed unnecessarily costly.

2. Since the paired drivers would be wired in parallel, this would reduce their total system impedance by one half. Thus, according to Weems, as impedance at a given frequency is halved, the capacitor value doubles and that of the inductor is halved.[2] By recalculating Hoffman's component values as noted, I would have the proper values for this configuration *for a stereo pair* without building four individual sets of crossovers; furthermore, the inductors would be smaller and thereby less costly. Hoffman recommended deleting resistor R1 (mistakenly labeled R2 in *Fig. 7* of his article).

3. The third option would be to design a new third-order passive network. I decided this would be too costly and possibly too complicated.

I chose option #2 as the most practical approach and proceeded with the modification. Component values are L1 = 1.75mH; C1 = 8μF; C2 = 4μF; delete R1 (*Fig. 3*).

UNDER THE GRILLE. Hoffman suggested prying up gently at the four corners with an ice pick (fork tines could also be used) to remove the Minimus-7

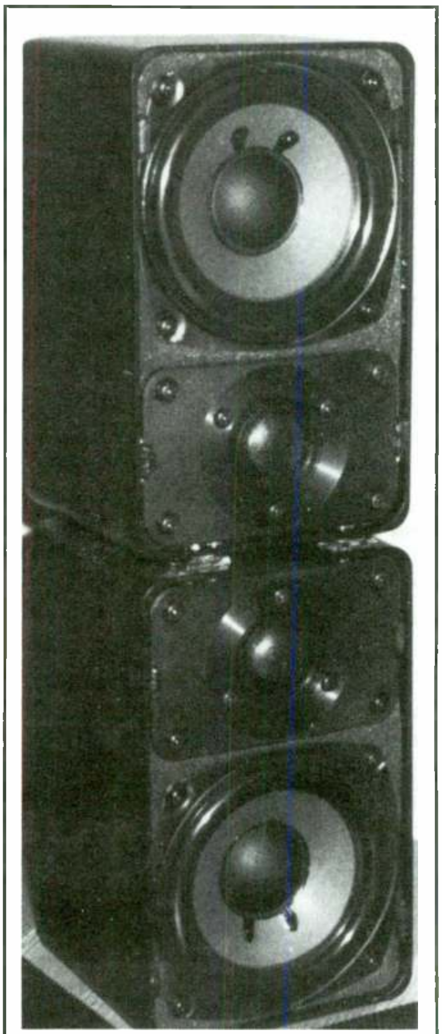


PHOTO 1: The paired Minimus-7s in the D'Appolito configuration.

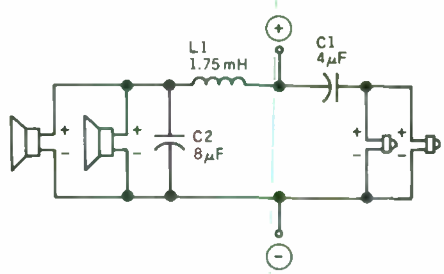


FIGURE 3: Crossover schematic.

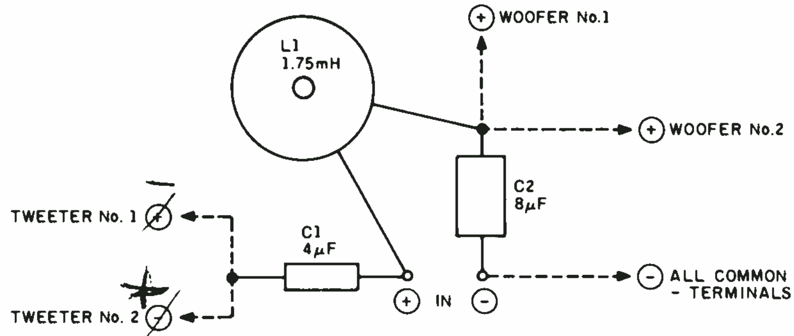


FIGURE 4: Crossover board component layout.

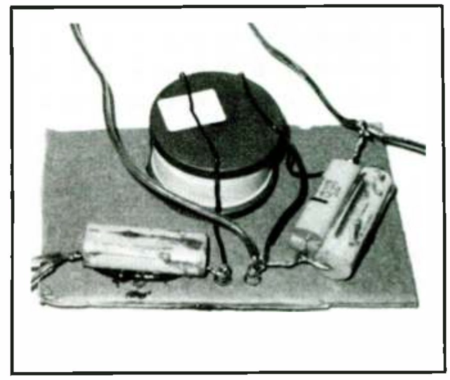


PHOTO 3: Close-up of the crossover.

grilles to gain access to the woofers. To avoid scratching and damaging the grilles, I threaded dental floss through the grille perforations at one of the corners and pulled up gently; the entire grille came loose easily. I subsequently found out that even a fat toothpick can be used to accomplish this.

Remove the woofers and disconnect the crossovers, leaving the woofer input terminal wires intact. Drill new holes on the back of the enclosure for separate direct access to the tweeters via new input terminals (Radio Shack #274-315 or #274-663). This enables you to make changes easily in passive crossover components; it also makes bi- or even tri-amping much easier later. The crossover circuit is kept external to the loudspeaker enclosure. Note that each output to the woofers and tweeters will require two sets of wiring in order to be in parallel (*Fig. 4*).

Hold the enclosure up to a light to look for leaks and seal them with silicone, especially at the input terminals.

Reassemble the speakers making sure they're airtight. To secure the enclosures to one another, lay down a bead or layer of silicone; this will also prevent the metal enclosures from rattling against each other. The speakers will be upright and stand approximately 14⅝ inches tall. Since the tweeters then measure a total of 4 inches across vertically, this would not do in terms of imaging for the crossover point of 4.5kHz (see alternatives).

In actual listening, though, this did not appear to limit its imaging capabilities; even with the systems upright and the tweeters farthest apart, soundstage presentation is excellent and quite natural. Aural images are rock stable, without any apparent frequency-dependent wander as you change position from sitting to standing and vice versa. In experimenting with speaker positioning, an odd effect occurred when I toed them in more than 75°: The soundstage seemed to become almost mono, similar to that which you get with Richard Kaufman's "Shuffler" circuit.[3] It appears that the dispersion characteristics are so good they easily blend together in the middle when toed in to such an extreme.

For a given volume setting, I immediately notice the increase in efficiency and power handling, as the doubled Minimus-7 plays louder than its single counterpart. It accomplishes this effortlessly and without strain. Further listening reveals the previous "zippiness" and roughness is gone. Thanks to Hoffman's crossover design, highs are now smooth and more natural sounding, with remarkably good inner detail. Piano, that most difficult of instruments to reproduce believably, sounds incredibly realistic with most CDs I've played and it was achieved at very convincing volume levels—no shattering of notes occurred whatsoever.

ALTERNATIVES. As I corresponded with Bill Hoffman, another idea occurred to us. We decided to build a bracket to hold the cabinets together in such a way as to allow the speakers to be angled in and aligned by time. The tweeters, being in the center, would be further away from the listener, with the woofers at the top and bottom closer to the listener.

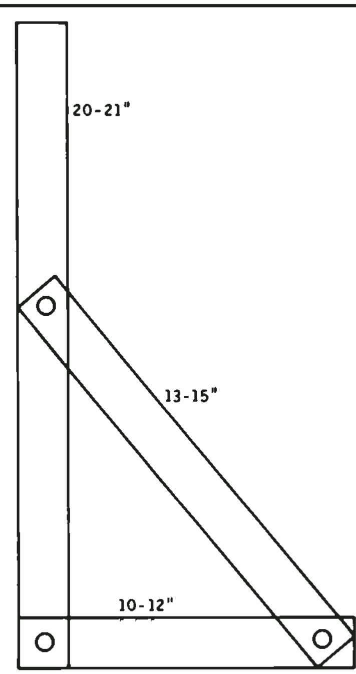


FIGURE 5: Supporting alignment brackets.

I attached two small hinges to the junction of the tweeter ends of two speakers by placing them face to face (woofer to woofer/tweeter to tweeter) on a flat surface, centering the hinges, drilling pilot holes and screwing the hinges in place with sheet metal screws. Unfortunately, neither silicone nor crazy glue would secure the heavy metal enclosures to the hinges reliably.

Then, I repeated the procedure with two metal 1.5 inch L-brackets, each at the top and bottom (the woofer ends) of the enclosures. I placed the L-brackets at the back of the enclosures so the bottom speaker's back would "clear" when angled backward. I experimented with pointing the L-brackets down instead of up, but found that the center of gravity was displaced anteriorly too much for my peace of mind. The advantages would be aesthetic and practical since the L-brackets would no longer stick up in the air like Batman's horns and there would be more leeway for angling the speakers. I'm satisfied with the final configuration, however.

Slide a bolt through the L-brackets and secure it with a nut. You then must find or build metal or wooden brackets to hold the speakers in place and allow you to angle them. A friend used flat 1 inch wide lengths of steel to build brackets for me. He drilled holes 1 inch apart for approximately 18 inches. Instead of holes, a track would be more convenient for sliding the speakers up and down by loosening wing nuts attached to the L-bracket bolts. The measurements for the brackets should be: 20–21 inches for the long upright (vertical) one, 10–12 inches for the flat (horizontal) bracket, and 13–15 inches for the angled (diagonal) one (*Fig. 5*).

Angling the enclosures backward

allows for alignment of the drivers relative to one another but it also makes the acoustic center area of the tweeters smaller and more acceptable for the 4.5kHz crossover point.

RESULTS. The difference in perceived sound? I must say that I found the aligned configuration produced more focused images. The virtues of the woofer-tweeter-woofer D'Appolito arrangement continue to hold true to form. Aural images maintain their respective positions regardless of listener position, sitting or standing. An old way to test a speaker's dispersion abilities was to stand several feet in front of or to the lateral side of one speaker and see whether you could hear the speaker on the opposite side.

The super modified Minimus-7 goes beyond that. You hear everything the other speaker is contributing as the soundstage stretches between, behind, and beyond the two speakers. Sonic images remain embedded in place in the sonic fabric; even as you walk from one speaker to the other side, the stability of the soundstage is apparent. The speakers are non-directional and seem to disappear. There is a new dimensionality of increased depth, ambience and improved imaging. The soundstage is better than before and very natural sounding.

Remember the awful "stereo" of the early Beatles albums? Believe it or not, even the "soundfield" of each pseudo-stereo channel is improved, since the sound source appears to be coming from behind the speaker with a sense of ambience. There is no beaming whatsoever and no boxy sound coming directly from the speaker.

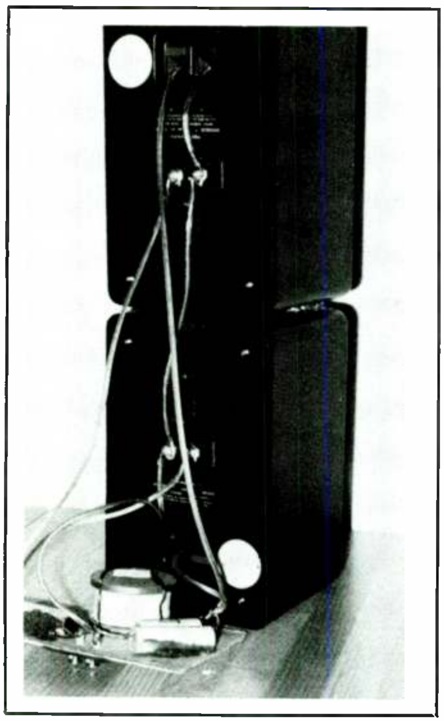


PHOTO 4: The crossover wired to the speakers.

In addition, the aligned enclosures place the drivers off-axis to the listener—this might also be responsible for the natural, smooth sound quality and the lack of harshness in the upper frequencies.

WHERE'S THE BASS? Despite the system's robust and natural sounding lower end (given its size), it cannot lay any real claim to low frequencies. As I implied earlier, the Minimus-7's tiny woofer should not be called upon to make the large excursions required by low bass notes; this will only raise its intermodulation distortion level, along with limiting output level and power handling. The little woofer can be destroyed if one plays low bass content at too high a listening level. Because of its small size, it is really more suited for midrange reproduction.

For low bass, biamping with an electronic crossover and subwoofers is the way to go; this will allow the Minimus-7 to perform at its best.

Continued on page 67

Ask Speaker Builder

HEYSER EXPLORED

By Dick Pierce

Over the last two or three decades, the fundamental theories explaining and predicting loudspeaker system performance have come to fruition. The pioneering work of Thiele and Small on enclosure design, the work by Bullock and others on crossovers, all have brought loudspeaker design out of the dark ages of black magic, endless tweaking, and empirical guesstimation. Now, with the design and simulation tools at our disposal, we can complete a paper design, perform any necessary tweaking with a couple of simulator runs, and end up with a design which has a pretty good chance of success on the first construction attempt.

Some have such supreme confidence in their designs, they are willing to go ahead and build, presuming it *will* be right, and nothing could possibly go wrong between design and construction. These people are the latest in a long succession of engineers, some of whom are responsible for such notable achievements as unsinkable passenger liners now resting peacefully at the bottom of the North Atlantic, suspension bridges that gallop about wildly in moderate winds, sophisticated anti-tank missiles which can be completely fooled by a burning wad of newspaper, and others too numerous to mention. Results range from mildly amusing to the ultimate in tragedy.

All this because, too often, the designer failed to verify the validity of the design in actual practice. The best modeling and design tools in the world make the blind assumption that they have been handed the right set of data to begin with. The accuracy of these tools depends as much on the representativeness of the input data as it does on the basic models themselves.

Scientific Theory

During my years of experimentation and design, I spent as much time measuring (and sometimes more) as I did designing and constructing. These measurements helped refine my models. In some cases, they forced me to abandon some models entirely. Science is (and must be) an evolutionary, self-correcting process. Through observation and experimentation, we develop, refine, reject and reinforce our theories. The acid test of a theory is its ability to make accurate predictions, and the only way to test the validity of those predictions is through careful experimentation and measurement.

Never has a successful scientific theory been developed in isolation from observation, experimentation and measurement. The most successful ones have withstood barrage after barrage of experimentation. As examples, relativity and quantum physics are two of the most successful modern scientific theories. They have shown an uncanny ability to make sometimes bizarre and incredible predictions, only to have them borne out to the limits of experimental accuracy.

Well, enough of the philosophical rambling, what does this have to do with loudspeakers? A fair amount, I believe. This issue's column is triggered by a letter from John Jenkins:

"Could you please describe, basically, how to achieve Heyser's measurements without an anechoic chamber..."

TDS

Heyser's technique, developed nearly a quarter century ago, is one referred to as "time delay spectrometry," or TDS. It is one of several loudspeaker measuring techniques in which the room influence does not completely overwhelm the data we're trying to gather. I'll try to touch on this and other techniques. What I will assiduously avoid, though, is a justification for anechoic measurements in the first place. Maybe that's meat for another article.

We'll assume, for the moment, that we do have a problem with the room influencing our measurements, and that we want to measure the speaker's performance independent of the room. There are two basic techniques: set up the measuring conditions so that the loudspeaker data completely overwhelms the room (or the effects of the room are at least minimized, possibly at the expense of resolution) or gather all the data before the room has a chance to get involved. We'll deal with the latter here.

Heyser's TDS system is quite straightforward. He used a swept sine wave tone to excite the loudspeaker, although the tone was swept at a rate much faster than other techniques, often covering the entire audible range in just a few seconds. On the measurement side was what amounted to a fairly conventional narrowband spectrum analyzer (a very narrow tunable bandpass filter) synchronized to the sweep oscillator. Here the similarity to conventional techniques ends.

Heyser introduced a "delay" between the oscillator and the analyzer, so the analyzer, rather than being directly synchronized exactly with the oscillator frequency, was synchronized with what the analyzer had produced some time in the immediate past, say a few milliseconds. He timed this delay so the analyzer frequency was tuned to correspond to what the speaker had produced, delayed by the time it took that frequency to traverse the air path to the microphone.

Selective Analyzer

Sound travels at a speed of about 1 foot per millisecond. If the microphone and the speaker are placed 1 meter apart (about 3 feet) the delay is 3 milliseconds, because of the time the sound takes to travel that distance. Let's say the oscillator is swept at a rate of 10kHz per second (or 10Hz per millisecond). In that 3 milliseconds between when the speaker produces, say, 1kHz, and the time that 1kHz reaches the microphone, the analyzer, if it was exactly synchronized with the oscillator, would be tuned 30Hz too high, and would miss the signal.

Introducing a delay of 3 milliseconds (or a shift of 30Hz) would mean that the analyzer would now be receiving the signal the loudspeaker produced 3 milliseconds ago. It also means that the analyzer would normally reject all other frequencies. More importantly, it would ignore signals at its tuned frequency that were emitted by the loudspeaker and had to travel longer paths (or, for that matter, shorter ones) to get to the analyzer because they would be arriving at a point when the analyzer was tuned to some other frequency.

The implications of this are fairly profound. It means that only the delayed signals are actually measured. All others are rejected. We could for example, measure only the first, direct signals from the loudspeaker. Or we could measure only those signals that were emitted by a driver and reflected off a specific point on the enclosure (because these would be delayed by a specific time).

The great power of Heyser's technique

came at a time when other techniques, while known, were either very difficult and expensive to implement or gave results that were extremely difficult to interpret. Heyser's TDS system allowed engineers to probe the minutest details of the response characteristics of drivers and systems.

Acoustic Center

One of the great discoveries that came about as a direct result of TDS was the driver acoustic center concept. This point in a loudspeaker corresponds to the virtual radiating point (in time and space) for the driver. Heyser and others discovered that not only did this point not necessarily correspond to where everyone thought it should (at the voice coil) but also that it moved around with, among other things, frequency. This point could be changed by the crossover as well.

Currently, to my knowledge, two commercial implementations of TDS systems are available. The most popular is the Crown TEF-12, an $8,000 self-contained unit. A fairly sophisticated set of hardware and software, it generally works well. Its major handicap is that it is buried inside an archaic computer system (a fairly mundane 8-bit CP/M portable computer).

The other system, from the Danish Bruel & Kjaer company, is a combination of fairly straightforward analog equipment combined with a purpose-made TDS controller and a real-time spectrum analyzer. Its cost is nothing short of astronomical—the last time I checked it was somewhere in the neighborhood of $60,000.

Heyser caused something of a minor revolution with his TDS measurement technique. In the intervening years, other techniques have reached a level of maturity and sophistication that rivals and often surpasses TDS system capabilities.

Simple Transforms

KEF in England, in cooperation with Hewlett-Packard, developed another system in the early 1970s based on impulse measurement techniques. A true impulse is an infinitesimally narrow pulse of energy applied to the system. The response of the system to this impulse stimulus is its impulse response. Linear system theory predicts that the impulse (energy *versus* time) response, the conventional notion of "frequency response" (energy *versus* frequency) and the phase response (time *versus* frequency) are merely three different orthogonal views of the same phenomenon. They are all related by some relatively simple transforms.

For example, the energy *versus* time response and the energy *versus* frequency response are related by the Fourier transform. The energy *versus* frequency response and the time *versus* frequency response are related by the Hilbert transform. Lest we take over this entire magazine, and several hundred to follow, we'll not go into the math behind these operations.

All you had to do was acquire the impulse, or energy *versus* time response, then apply the transforms to get the other responses. Further, if we set up our acquisition time window such that we open our measuring window just as the beginning of the impulse reaches the microphone, and shut it just before the first of the signals from the room arrives, we will have captured the part of the impulse response that only the speaker produced. Then we merrily send off our impulse response to be transformed into something more to our liking (an amplitude versus frequency curve, or a phase versus frequency curve) with just a bit of computation.

The original KEF system was expensive, probably in the $50,000 to $100,000 region. In the intervening 15 or so years since these early systems, the price of the data acquisition hardware, the supporting computers and display devices have dropped dramatically. You can now get an IBM PC based system that has more horsepower than these early systems for around $5,000. A variety of manufacturers offer measurement systems, including the supporting software packages, that can be added to existing systems.

Problems and MLS

Impulse based measurement systems,

however, suffer from some significant limitations. For example, the high frequency response characteristics of an impulse are dependent upon the width of the impulse: the narrower the impulse, the higher the bandwidth of the energy in the impulse. But making the pulse narrower means reducing the amount of energy in the measurement window. The system is excited for only a very brief time at the beginning, and then is idle for the rest of the time. During this time, the system is measuring not only the speaker's response to the impulse, but any extraneous noise as well.

One way to overcome this problem is to increase the amplitude of the impulse, increasing the signal-to-noise ratio. But it's quite easy to inadvertently drive the system you're measuring into overload, which gives you completely erroneous results. Another way is to make several identical measurements and average them. The impulse response, which should be the same each time, will be reinforced while the noise, varying randomly, will tend to cancel out. But this adds significantly to the measuring time, and is no help if the interfering noise is repetitive in nature (like motor noise).

Using an impulse based system can be very useful if you're very careful in setting it up and using it.

Some of the most significant and exciting systems I have seen in recent years are those based on "maximal length sequence" measurements. These are conceptually very simple. Again, linear signal theory states that if you compare the input to a linear system with the output of the system through a mathematical process called "cross correlation," the result is the impulse response of the system. Theoretically, any input signal could be used. A special type of input signal is used in these systems, a "maximal length sequence." This is a series of psuedo-random values which, while it meets the statistical criteria for true randomness, is also completely predictable. It affords several advantages over other signals.

Hadamard Transformation

First, driving the system with a signal like this involves exciting the system for the entire length of the measurement time window, increasing its signal-to-noise ratio. This also means we can use lower level signals, reducing the possibility of overloading what we are measuring. Also, a maximal length sequence offers us some mathematical efficiencies. Using any old signal, a cross correlation operation involves, among other things, two Fourier transforms and one inverse Fourier transform. This is a lot of time-consuming work for a computer. A maximal length sequence has properties that allow us to take advantage of some extremely efficient matrix operations. It's possible to perform the cross correlation using what's called a Hadamard transformation in a mere fraction of the time it would normally take with other signals.

The result is still the impulse response for the system. From there, to get the other information we want we can apply the same techniques we used in impulse types. What we've bought is a vastly improved signal-to-noise ratio, greater noise immunity and a far more benign measurement stimulus.

To my knowledge, only one commercial MLS system is currently available, DRA's MLSSA system, a less than $3,000 hardware and software system which plugs into normal IBM PCs and provides a complete acoustics analysis system that certainly rivals and often surpasses far more expensive ones. It is quickly becoming the standard research tool for advanced loudspeaker research and design. I have used all of the systems I discuss here, and the MLSSA system performs as well as any of them.

I've merely scratched the surface of loudspeaker measurement techniques. We've not even explored more conventional, but useful, techniques such as ⅓ noise analysis, swept sine waves, close miking and so forth. The measurement realm is extremely broad and multifaceted (and not just a little controversial as well). In future columns, as some of you might request, I can deal with other measurement techniques.

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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 opto-coupler 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″ x 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 **$14**

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″ x 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**

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, faceplate, 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. Article reprints are included with the kits. Our aim is to get you started with the basic parts—some of which are often difficult to find—and let you have the satisfaction and pride of finishing your unit in your own way.

Tools, Tips & Techniques

RECYCLED SPHERES

These former 9½″ ceramic omnidirectional speakers, found at a flea market, have become vent-connected "sphere-odds." I used Madisound 5102 woofers and Vifa D19-05 tweeters.

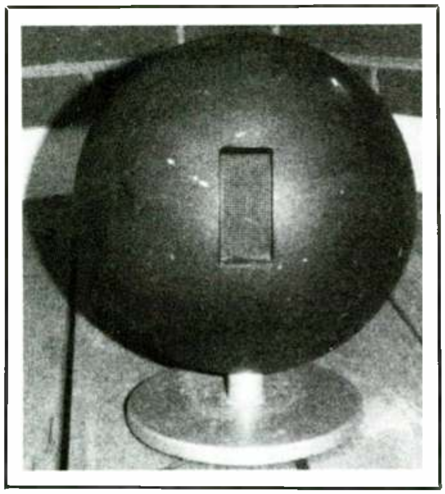
I filled the connecting vent tube with plastic straws, thus lowering internal F_B from 110–120Hz to 65–75Hz. The volume is 0.22 cu. ft., 0.15 net plus overvolume.

The bottom-firing vents are 1.25 x 2.5/2.875, f_S is 67, 71, f_B 71, 75 (theoretical), and f_3 upper 70s (theoretical). F_B was impossible to locate, being a combination of both vents tuned by ear.

The ceramic spheres' walls vary from ¼ to ⅜″ thick. I router mounted each half-sphere into a 10½″ diameter, ⅝″ MDF (medium density fiberboard) baffle board. I used ⅝″ AL foam as damping material.

The crossover point is 3,200Hz, 0/12 Bullock Equal Compromise (BEC), 0.67μH, 3.8μF, 4.25″ diameter adjacent. The 5102s are without Zobel and crossover components for economy and by reason of a gradual rolloff at 2,500Hz. The crossover result is a textbook example of "everyman's blending region," and should work well for others. You might want to add a 0.3μH coil (I didn't) to the 5102 to filter peaks 10dB down between 5 and 8k, or equivalent second or third order.

I have some older, sealed-box KEF Cresta's (B110, T27). The sphere-odds represent from 80 to 100% of their per-



formance in a smaller vented enclosure for under $100 each. In some respects the KEFs' "stuffiness" was lost altogether. Surprisingly, bass is present, possibly reinforced by the interior vent. If true (I have not built a standard vented enclosure for comparison) the volume division is 1:1, the interior vent optimized (number of straws) for F_S presumably, normal vent to F_B, just a theory.

In conclusion, I prefer the sphere-odds to the older KEFs. The idea of raising chickens who laid the "eggs" appeals to me in a historical sense, being into American antiques and things. Unusual appearances are neglected by US manufacturers.

The next logical step is to use two or four 5102s per cabinet, in a standard or 3/2 alignment. The 0.3μH coil might combine with a 10dB vertical drop at 4,500Hz and loosely approximate an 18dB/octave rate, sounding just fine in hacker terms. As two 5102s will sound better than one, you may want to upgrade the tweeter.

Mark Thompson
St. Catharines, ONT
L2T 1R4 Canada

SOURCES

All-Electronics
15004 Oxnard St.
Van Nuys, CA 91411
Mylar caps

Madisound
8608 University Green
Box 4283
Madison, WI 53711
coils

Meniscus
2442 28th St., SW, Ste. D
Wyoming, MI 49509
driver, wire

Radio Shack
binding posts

Interior Vent
2⅞″ PVC (2.4″ i.d.), or 3″ cardboard

CLAMP WITH REACH

I have always found it difficult to install internal cabinet braces. For some odd reason the spots I need to brace are usually located too far into the cabinet to be reached by commercially available C-clamps or wooden type clamps.

One day, browsing through my local bookstore I discovered a tip for inexpensive homemade clamps, submitted in letter form by Larry Humes and published

MATERIALS LIST FOR 3 CLAMPS

Qty	Description
2	8′ 2 by 4s (knot & crack free)
1	3′ length of ⅜″ threaded rod
18	#6 fender washers
18	#6 1″ sheet metal screws
3	⅜″ lock nuts
3	⅜″ nuts
12	⅜″ fender washers
3	4″ long springs
1	Old leather belt (1.5″ wide)

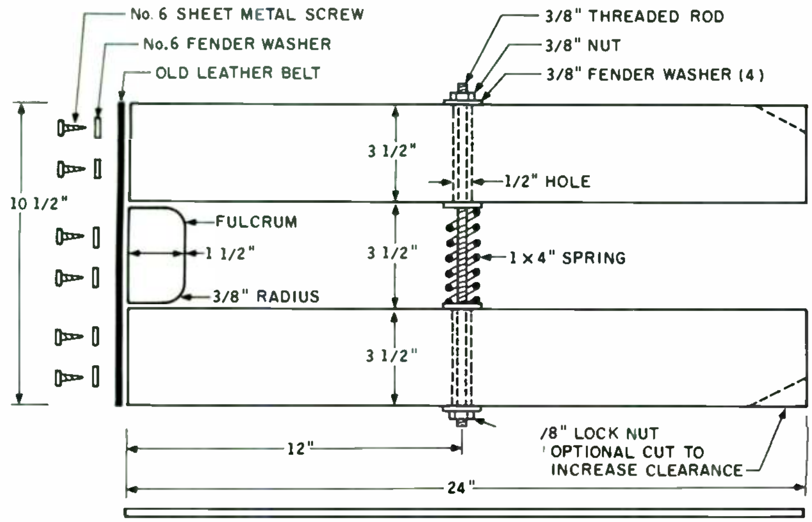


FIGURE 1: Construction detail. (All dimensions in inches).

in *Fine Woodworking On Proven Shop Tips.*[1] I took Humes' design and modified it into a clamping device for 3″ braces with jaws that reach up to 12 inches inside a speaker enclosure (see photo).

Start by cross cutting six 2′ lengths of 2 by 4 and then drill a ½″ hole at the center of each piece (*Fig. 1*). A drill press is the preferred tool for this operation, but I used my hand drill. Make sure you drill exactly on center and straight through the material.

Take the 3′ piece of ⅜″ threaded rod and cut it into three equal parts with a hacksaw. File the rough ends to avoid cutting your fingers. Turn a lock nut onto one end of each rod and then slip a fender washer on top of it.

Insert the rod into the ½″ hole on one of the 2 by 4s, then slip another fender washer over the top. Next, place a 4″ long spring on, then another fender washer, and then slide another 2 by 4 onto the assembly. Finish with another fender washer and nut.

At one end of the 2 by 4s place a short length of scrap to act as the fulcrum. Round the inside edge of this piece to prevent binding as you tighten the clamps. Secure it in place with fender washers, #6 screws, and an old leather belt cut into 10″ lengths.

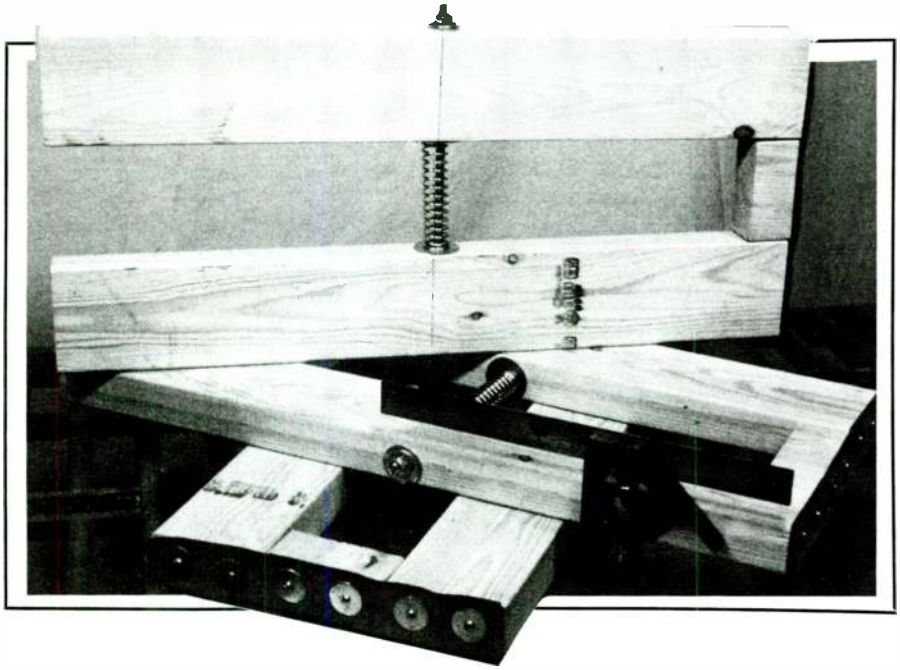
I used the clamps to install some 3″ by 48″ braces about 9″ deep in a large cabinet and they worked very well. I was able to develop a very high clamping pressure, even 9″ past the adjustment. The only drawback is that I had to use two wrenches to tighten and loosen the clamps.

My brother borrowed the clamps for another project and reported that the clamps worked well on his speakers, too.

Bill Schwefel
Jackson, WI 53037

REFERENCES

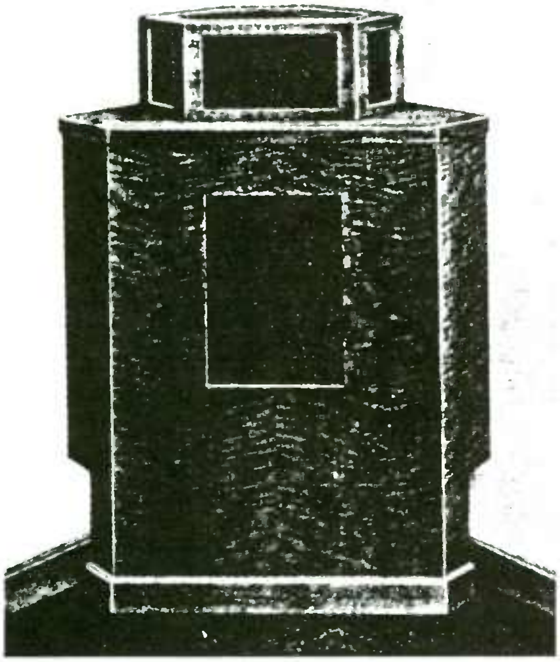
1. Richey, Jim, *Fine Woodworking On Proven Shop Tips*, Taunton Press, Newtown, CT, 6th Edition, 1988, p. 12.



Vintage Designs

Wharfedale Omnidirectional System

Courtesy of Gardiner McCauley, Columbia, MO 65201



3-SPEAKER system

This assembly gives the most natural reproduction so far attained by Wharfedale, and has been demonstrated on many occasions during lectures given by G. A. Briggs in the Royal Festival Hall, London; Philharmonic Hall, Liverpool; St. George's Hall, Bradford, and Carnegie Hall, New York, *et al.*

The front panel is constructed with a double wall and the space between is filled with dry sand so as to obviate panel resonance. The assembly stands against the corner walls and is kept in position by its own weight so that no fixing is required. Where necessary an airtight seal can be ensured, using strips of felt. The Twin Treble Assembly stands on the ¾″ thick wooden top which completes the bass enclosure. The middle and treble units, which are mounted facing upwards, are provided with individual controls so that a satisfactory balance is readily achieved.

To meet the requirements of stereo, the main crossover frequency is now at 400 c/s, giving virtually omni-directional radiation at all frequencies.

Units: **W15/FS or W15/RS, Super 8/FS** and **Super 3.**

Fitted with half-section three-way network with crossover frequencies at 400 c/s and 5000 c/s.

Size: 48″ x 34″. Distance along wall from corner: 26″.

Weight: 160 lb. complete.

Impedance: 12/15 ohms only. Power handling capacity: 20 watts max.

Frequency range: 20-20,000 c/s.

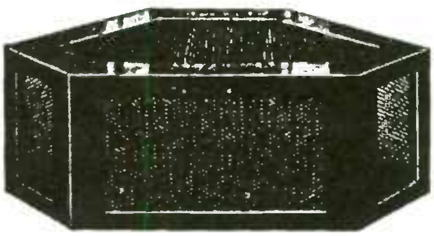
Available in whitewood or fully finished with a choice of walnut, oak, mahogany, or maple veneers.

The sand-filled corner panel is available separately with sub-baffle to take 15″ or 12″ units to order. It is recommended for use with the Coaxial 12 or Super 12/RS/DD units as an alternative to the AF12 Reflex Cabinet.

Where there is no suitable corner, a special model is available fitted with sand-filled back panels.

N.B. The W12/RS unit may be used in place of the 15″ unit giving slightly reduced bass performance and power handling capacity, with a saving in cost.

TWIN TREBLE CABINET



This cabinet provides omni-directional horizontal mounting for two treble speakers in a three-speaker system. The middle unit may be 8″ or 10″ and the tweeter should be a Super 3. Where volume controls are not fitted to the crossover unit, provision is made for fixing them to the back of the Twin Treble Cabinet.

Suitable for stereo systems with common bass enclosure. See SM1 Leaflet.

Size: 23½″ x 12″ x 8″.

Weight: 6 lb. cabinet only.

Available in whitewood or fully finished in walnut, oak, mahogany or maple veneers.

Mailbox

continued from page 5

This is not an endorsement for the selection or quality of components offered by Vandersteen, just an observation that someone out there seems to remember what diffraction is all about . . . leave off the baffling baffle!

Great magazine. Keep up the good work, and let's see lots of good construction ideas from readers.

Ernie Guerri
Barrington Hills, IL 60010

Bruce Edgar replies:

Thank you for your comments. Interviewing Klipsch was both a pleasure and a difficult job. After much effort to draw Paul out into a freewheeling discussion and then have him clam up on me, I thought it best to have him talk about the history of his speakers. Remember Klipsch is in his mid-eighties and is essentially out of speaker development. In his earlier years he would have entered into an intellectual discussion much like Keith Johnson. I know this to be true because I've heard a tape of Klipsch talking to an extended Sunday afternoon meeting with the Los Angeles AES section in which he had a lively discussion with the likes of Peter Sutheim, the late Dick Heyser, and others.

Your comments about high freqency horns are especially appropriate. As you very well know, all high frequency horns on Klipsch speakers are mounted horizontally, i.e., with their widest dimension horizontally aligned. But as you point out, they are diffraction horns and need to be mounted vertically. However, that change would require a complete redesign of their front baffles.

FEEDBACK CONTROL

I read "Servo-Controlling the AR-1," by Arthur Brown in *SB* 3/89, p. 24. I agree that the Velodyne is great and had hoped, as you did, to simulate this feedback control more reasonably. I am using a pair of DAK subwoofers. I made two channels of your circuit but am having difficulty with their use. I hope you can help me get them working.

The output of the setup is very low. Is there some way to get the gain higher? I don't get much, if any, effect from the unit. Howling feedback comes on extremely easily and I wonder how I can control this. Your comments and help will be most welcome. Many thanks for your help.

Marvin Shuster
North Brunswick, NJ 08902

Arthur E. Brown replies:

You state that you made two channels of my circuit. I assume you mean two complete servo control systems with all parts shown in *Fig. 4* of my article, including dedicated power amplifiers for

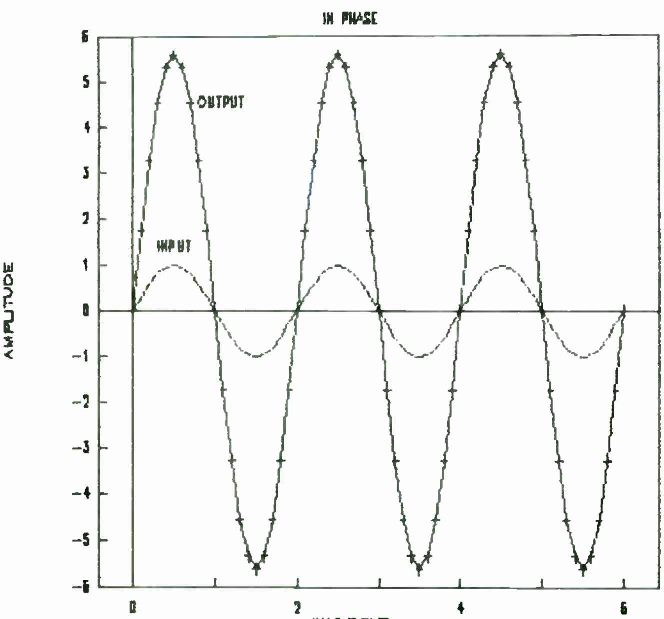


FIGURE A: Input and output signals, in phase.

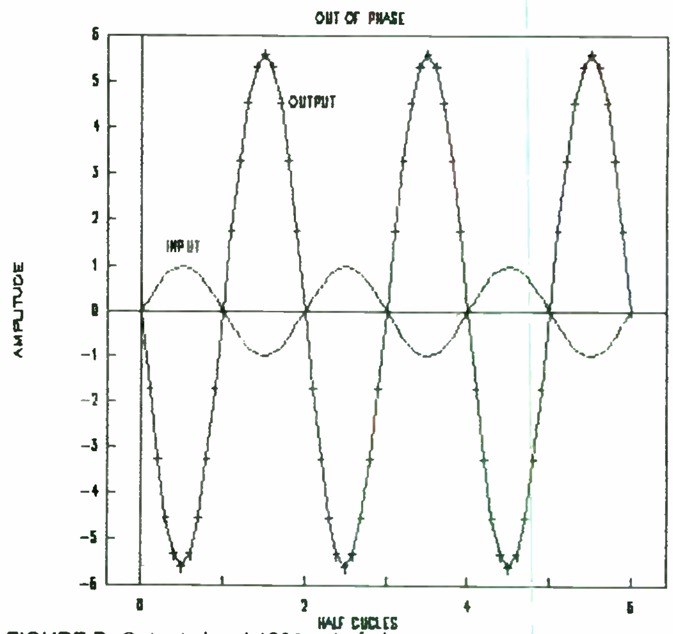


FIGURE B: Output signal 180° out of phase.

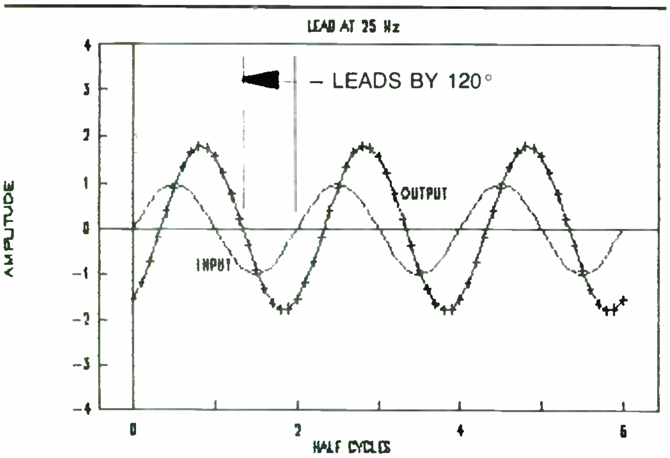


FIGURE C: Output signal leads by 120°.

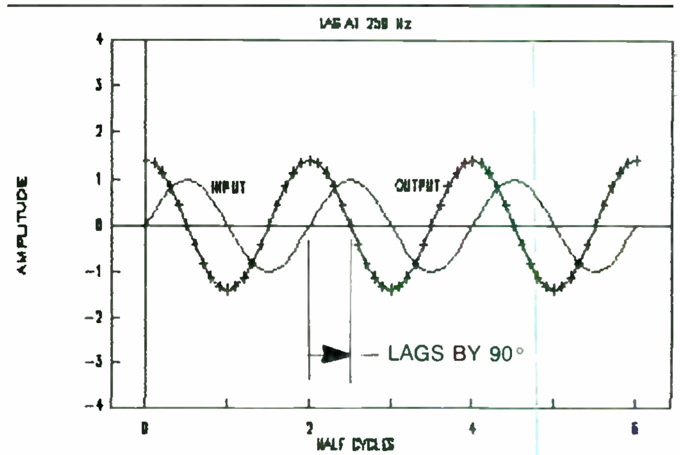


FIGURE D: Output lags by 90°.

each subwoofer. You also state the output is very low, and howling feedback comes on extremely easily. This suggests that you have tried to close the loop. I surmise that as you closed the loop you got the howling, and you reduced the gain to avoid it. This resulted in very low output. If this is the case, you have the feedback phase wrong and need a very low loop gain to avoid the howling. Let me review some specifics.

I assume you have a diagram similar to my *Fig. 4*. First, note that the summing amplifier has two inputs: the signal coming from the input amplifier and A. The signal that eventually gets to B from either input will be the same. You may therefore send a signal at A and receive it at B to get the loop gain and phase relationship. As I stated in the article, you want the feedback signal (from B) to be subtracted from the input signal. This is done by making the B signal out of phase with the input signal.

I measured the open loop gain and phase and determined that they were correct, by sending a signal into the circuit at A and reading it at B. I observed these two signals on a dual channel oscilloscope. I have generated several curves to illustrate this relationship. *Figure A* shows an input sine wave (at A) of unity amplitude and an output wave (at B) of 5.6 times (RMS or peak-to-peak) the input signal. The output signal is in phase with the input, i.e., each goes positive and negative in the same parts of the cycle.

Figure B shows the same data *except* that the output is now 180° out of phase from the input. As the input goes positive, the output goes negative and vice versa. *This is the proper relationship between the two signals.* If you do not have this relationship, reverse the connections at the speaker terminals of the subwoofer driver before trying to close the loop. This signal amplitude was approximately correct for my setup at the mid frequency of 63Hz (*Fig. 5* of my article).

While you are looking at *Fig 5*. note that at 25Hz (log freq. 1.4) the open loop gain is lower (the output is about 1.4 times the input) and the phase shift is about +120°, not the same phase relationship as at 63Hz. In reality, the output signal at 25Hz leads (gets there before) the input signal by about 120°. This is shown here (*Fig. C*). Compare *Figs. B* and *C*. Also looking at 250Hz (log freq. of 2.4) you will see that the gain is again lower than at 63Hz (about 1.8 gain) and the phase is about −90°. In this case the output lags (gets there later than) the input by about 90°. This is illustrated in *Fig. D*. Again compare *Figs. B* and *D*. The data of *Fig. 5* comes from the computer study but actual data in *Fig. 6* of the article is very similar.

If you have obtained similar data to that shown in the article and *Figs. B, C* and *D* then I need more information on your system to help you. If you have not taken this data, I recommend that you take it. When you have data of similar gains and phase as I illustrate in *Fig. 5* (of the article) and *Figs. B, C* and *D* you should have a system that is reasonably stable with sufficient output. The loop gain is adjusted with the pot within the loop after the compensating amp (my circuit). If the subwoofer sound output does not match that of your satellites you should adjust your gain outside of the loop, my 100k pot at the output of the preamp. I wish you the best of success.

TANDEM LINE

I have purchased and read Martin Collom's *High Performance Loudspeakers* and Vance Dickason's *The Loudspeaker Design*

If you should have a *TECHNICAL QUERY...*

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.

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	Change effective

Please let us know 4–6 weeks in advance so you don't miss any issues.

Thank you.

Cookbook. Both have given me great project ideas. I am about to start a short transmission line using the D'Appolito configuration. How will the dual (compound) woofers affect the cross-sectional area and stuffing density of the line?

I would like to make the line about 40–55 inches long with wool as a damping material. As Dickason suggests, I should use dowels or netting to keep the wool from settling. I plan to use 6″ by 8″ Dacron sheets spaced about 12″ apart to hold the sections in and keep it from settling. Is this a good idea?

I am planning to use two Morel MW 164 woofers and an MDT 33 tweeter. I have considered using the Dynaudio Twynn crossover system but am unsure whether it will interact correctly with the Morel drivers.

George B. Gritt, Jr.
Tucson, AZ 85705

John Cockroft replies:

I think the D'Appolito configuration would work well. I have considered such a project myself. Unfortunately, I've had to shelve it (temporarily, I hope).

When you refer to the two woofers of this configuration as compound, you are in error. These are two discrete drivers, each doing its own thing, in what might be thought of as a tandem arrangement. A compound speaker is generally two speakers fastened together (usually face to face) to work as a single unit. My Mini-Dancer system (*SB* 3/86) was an example of this. I believe Morel makes a compound woofer on a single chassis, but this is unique as far as I know.

The cross section of your line would have to reflect the areas of both the cones. This would give twice the area of a line designed for a single cone. For a line in the length range you speak of, a cross section of about 1.25 times the area of the two cones would be a reasonable starting (and we hope, an ending) place.

As you may have gathered from some of my articles and letters, I am not the person to give you information on the intricacies of coddling wool. If you'll pardon me, your stuffing description sounds like you're building a bird apartment house, complete with furnishings. (I wonder if the esteemed Mr. Weems ever considered that conversion?) In my heart I hear the faint murmur, "Don't." As an alternative I suggest Acousta-Stuf (from Mahogany Sound). It is cheaper, a joy to use and requires no support (it would make a perfect ex-wife). Using it will probably help you avoid the unpleasantness of a tic in your old age. Best of all, your ears will not feel cheated.

I suggest about .65 lbs./cubic foot as a ball-park figure for a line in your stated length range. Multiply .65 by the net internal volume of your line to arrive at the amount of Acousta-Stuf (or any other stuffing) in pounds. For ounces, multiply that figure by 16. For grams, divide the ounce figure by .0353.

I have no experience with the Morel drivers. I looked up the specs of the MW 164 in my A&S Catalog and it looks like a reasonable candidate for a line of the length you propose. Other than that, you are on your own, unless someone else is able to help you.

Crossovers are the heart of a speaker system. The prospects would not be very good if you simply took the one you mention from another system using different speakers. Joe D'Appolito mentioned somewhere (I think) that he tried many drivers looking for a substitute for the original one in his system, although I doubt whether he tried 6½" types. Perhaps he has some information that would help you. My only other suggestion is to use the formulas in the Dickason book based on Bob Bullock's third-order crossovers and read what Joe D'Appolito says in his articles concerning his crossovers. I hope some of this helps.

AR-3 UPGRADE

Only recently introduced to *Speaker Builder*, I write to thank you for your AR-3 upgrade article ("A Low-Cost Upgrade for the AR-3," by Bruce Edgar, 3/88). Its clarity and simple instructions were particularly appreciated by one who considers it an evening's challenge to replace a light bulb.

Having wrestled my antique AR-3a boxes from the attic, I find it necessary to replace the woofers. As these have cut-off edges left and right to fit the AR box, I hope to be able to replace them with new units from AR. At $75+ per unit, I realize I am going somewhat beyond a low-cost upgrade, but as I have a failing for the look of the boxes, I am prepared to put more into this upgrade than into a whole new project.

The last paragraph of your article says "variations are possible depending on your wallet and junk box." What further improvements, including alternatives to the Peerless and Audax drivers suggested in your article, would you recommend for my renovation so as to take it beyond a simple historical restoration?

Marc E. DeVos
Kent, CT 06757

Bruce Edgar replies:

The variations to the AR-3 modification that I had in mind were: using high quality midrange and tweeter drivers such as the Dynaudio D76 mid dome and the D28 tweeter, using high quality capacitors in the crossover instead of electrolytics, and lining up the position of the mid and tweeter drivers with the center line of the enclosure to reduce diffraction effects and promote better imaging. I have not done any of these mods, but each should provide a better sounding speaker as a result.

ESL PANELS

Please advise me where I can get audiophile-quality electrostatic panels of various frequency ranges, so I might incorporate them into a system I am building.

R. F. Stonerock, Jr.
Orlando, FL 32806

Roger Sanders replies:

I am not aware of any commercial source of ESLs for home builders. However, you should be able to obtain such panels with a little effort. I suggest the following:

1. Contact commercial manufacturers such as Acoustat and Martin-Logan. They will probably be willing to sell you bare panels, but the price may surprise you.

2. Contact private amateur builders and arrange to have panels made to your specifications. You might try Barry Waldron, who is in contact with many other builders and may direct you to a willing builder, or he may even be willing to build them himself. He has built and experimented with many

cell designs and is competent to assist and advise you.

3. Advertise in the classified section of magazines like *SB*.

4. I would be willing to build them for you, but my spare time is scarce and expensive. My cells would be guaranteed to meet your expectations, but would not be your most cost effective alternative.

In summary, if you look hard enough you will find either complete cells or someone to build exactly what you want. However, I recommend you seriously consider building your own. You can build one of the simpler cell designs such as my perforated metal types very quickly, easily, and inexpensively. *[See "An Electrostatic Speaker System," by Roger Sanders,* SB *2, 3, 4/80 as well as his "A Compact Electrostatic/Transmission Line," page 32 of this issue.—Ed.]*

Building your own will give you the satisfaction of having created your own speakers from scratch, it will be an interesting experience, you will be able to service the cells in the future, you can build them exactly to your standards, you can get the job done quickly and you can save money. You are virtually guaranteed fabulous results. I strongly recommend it.

Barry Waldron replies:

You stated you wanted to locate ESL panels in a variety of frequency ranges to include in a proposed system. You can dedicate panels to specific frequency ranges like cone woofer, midrange, and tweeter drivers, but with the ESL principle, this is unnecessary; moreover, it's undesirable. Early ventures did utilize this approach, but progress in the field over the last decade or so has shown that a unified driver is far superior.

Any time you use crossovers in the midrange and higher frequencies you notice a degradation in the seamlessness of sound. Among the last designs following this approach were the *Telestar* by R. J. Matthys, *Servostatic* by Infinity, and the *1/1A* by Koss. Of course, commercial offerings like the Wilson *WAMM*, on the high end, and the Denneson model, on the lower price end, incorporate ESL tweeters among an array of cone drivers. For wide-range ESL arrays, avoid passive crossovers. The ideal is to have no crossovers, but since ESLs are costly and inefficient as woofers we find an electronic crossover in the upper bass to be completely transparent.

Not all woofer designs compliment an ESL. Roger (Sanders) favors long transmission lines while I lean toward corner horns. A project now under construction uses a variation of the Bose *Acoustimass*. All cross over around 500Hz.

I have no idea whether manufacturers offer raw ESL drivers. Certainly you can inquire. As pointed out, the cost will likely prove prohibitive since each has to recoup their investment in labor, tooling, material, development, operations and advertising, on a prorated basis. Another idea is the used market. The *Audio Mart* classified newspaper is a fine source. The Classified section of this magazine is another. You could conceivably reconfigure a purchase into a custom design.

I agree with Roger that constructing your own ESL is a fun and educational endeavor. The rewards provide a superior product at much less than commercial cost. As a subscriber, certainly you believe that amateurs can and do construct audio projects at a fraction of the cost yet equal or (as in this case) superior to commercial models. Since we do not have price points and profit margins to contend with, we can include much or all of the technical methodology available.

We are active in the ESL Users Group and invite you to join this loose knit organization by writing to the address listed in the Club section of the magazine. These ties provide support and a valuable source of knowledge and information. Researching patents and other literature can give you a solid background in theory and practice.

If your interest has been captured by this philosophy, the next consideration is that of dispersion. We believe narrow dispersion is pure sonic harmony. Speakers using flat panels—full range—provide a solid holographic image when played with proper source material. Practicality being what it is dictates that some will opt for wide dispersion. A paper addressing this issue is available through the club. Also available for those in the wishing or planning stage is an article on *Getting Started*.

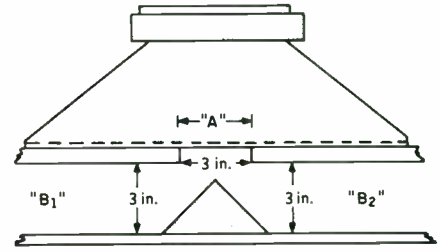
Roger and I have worked years with ESLs in all manner and form. As mentioned, Roger has a new project (see page 32) in which I was privileged to participate. Along with these are two projects by David Hermeyer ("An Electrostatic Speaker System" *TAA* 4/72, and "A High Efficiency Electrostatic Loudspeaker System" *TAA* 2 and 3/77), one by Dr. David Lang ("Amber: A Sheathed Conductor ESL" *SB* 6/88) and several insightful suggestions by fellow experimenters scattered about. All may be constructed as shown or modified to suit.

There's more ☛

HORN FAN

I have just finished reading Bruce Edgar's articles about tractrix bass and midrange horns (*SB* 1/86, p. 7; 2/81, p. 9; 3/80, p. 9). They were excellent and I look forward to future horn articles. I have always been a horn-loaded loudspeaker fan. I especially enjoyed the Klipsch interview (*SB* 4/89), since he is my personal audio hero. I hope to meet and talk with him in person someday.

I have built two sets of loudspeakers to date and am currently working on a third pair. With my version of the venerable Speakerlab SK system, I am confused about how to calculate the slot/optimum throat size (area) and where it starts (*Fig. 1*). Also, what parameters and formula do you use to calculate which woofers are compatible for bass horn use? I used a 3 x 13″ slot for my woofer (the current size in Speakerlab's new K corner horn system). In your interview with Paul Klipsch, he stated that the present woofer slot on his Klipschorns is 6 x 13″. Is this the slot onto which the woofer is mounted or the area figured after it hits the deflector that splits the soundwave into two 3 x 13″ paths, effectively giving it a 6 x 13″ slot or throat?



NOT TO SCALE

FIGURE 1: Is "A" the start of the throat/slot or is B_1 + B_2 considered the throat?

Please define where the throat actually begins. My speakers seem to lack the very low end punch (SPL) of the original Klipschorn. Could it be the slot is too small? Could the smaller slot in any way damage the woofers? Will polyester fiberfill in the woofer cavity aid in smoothing the response of the woofer? If so, how do you calculate how much to use? Will over/understuffing the woofer cavity with polyfill cause any damage to the woofer?

I am planning to build yet another set of bass folded horn speakers and would

CAVEAT CORRESPONDENTS

Things that go bump in our round file:

1. "I'm thinking of building a 16-in, 8-out console in my basement. What tape recorder should I buy?"

2. "Is my Fisher Z-705 receiver worth updating? Where should I begin?"

3. "Although I forgot to enclose a stamped, self-addressed envelope, please answer the following nine questions based on my experiences building your inverted RIAA kit."

4. "Please forward this (unstamped) letter to Ralph J. whose letter appeared in one of the 1970 issues—don't remember which."

5. "I have a Milhous 10W integrated stereo amplifier and a Gesundheit turntable. Which of the following six cartridges would you recommend?"

6. Queries with no stamped, self-addressed envelope or postal coupons enclosed.

7. Letters without return addresses on them whose envelopes have strayed away somewhere.

8. Illegible hand-written letters scrawled on odd scraps of paper. If you have no access to a typewriter, please try to be sure our typesetter doesn't lose his eyesight and his mind in deciphering your writing. (This is especially important if you want us to publish your classified ad.)

appreciate any information. In addition, does anyone have a copy of the plans for the Klipschorn or the original SK, prior to 1977?

I am not using Speakerlab drivers in my horns. Thank you for all your help and keep the fine horn articles coming. I look forward to reading them in future issues of *SB*. My thanks also to any readers who may answer my problems.

Peter J. Groth
Clinton Corners, NY 12514

Bruce Edgar replies:

You are correct in pointing out that the throat on the present day Klipschorn is 3 x 13″. I missed that point when editing the interview. However, the correct terminology is that the throat plate is 3 x 13″ and the throat is 6 x 13″. I now have a math model of how the Klipschorn throat works, and an article is in preparation.

Basically, the 3 x 13″ throat plate expanding to a 6 x 13″ throat boosts the effective mass rolloff frequency of the driver/horn system from under 200Hz (without the throat plate) to over 400Hz (with the 3 x 13″ throat plate). However, not just any driver and throat opening will work. You must use the design formulas in the forthcoming paper to choose a proper driver and throat system for the mass rolloff boost to work.

Your letter also mentions that your horns lack the punch of the Klipschorn. Your drivers (not specified) and your horn are probably mismatched. The best solution is to buy some JBL 2220H 15″ musical instrument drivers and open up the throat to 6 x 13″. An alternative is to buy a pair of replacement K-33E drivers from a Klipsch dealer to use in your present horn (with a 3 x 13″) throat.

Adding foam to the throat will not solve any problems, but foam in the back chamber usually helps. Also make sure your back chamber doesn't have leaks which will rob your bass response.

LICKING LEAKS

I just received my first issue two days ago and have already found an interesting article I can apply to my hi-fi system. I only wish I had been a subscriber long before I built my satellite-subwoofer system. Oh well, better late than never. I received all but one magazine for the year and have reviewed only two books; I'm impressed. This is the most informative magazine I have ever subscribed to.

The main reason I am writing is Randall Bradley's article, "Practical Considerations For Passive Radiator Systems," *SB* 4/89, p. 41. Bradley spoke of some common problems associated with passive designs, and since I own a passive subwoofer, I would like to try some of his simple ideas on alleviating air leaks. Unfortunately, I am not likely to find the driver dope he speaks of for sealing air holes in the surround in this small midwestern town, mainly because I wouldn't know who to ask or what to ask for. Where might I look, or better yet, who could I get in touch with to obtain this product?

Rocky D. Craig
Fort Dodge, IA 50501

Randall Bradley replies:

Locating a supplier of speaker dope is not all that easy. The can I own has lasted about ten years and treated lots of drivers. Once you've got some, the stuff seems to go a long way. That's the good news. The bad news is there is no standard source for these chemicals that I know of. I don't even know of any catalogs which list such materials.

To add to the confusion, there are probably as many types and formulations for speaker dope as there are speaker manufacturers. Maybe some readers know the chemical composition and specifications of these compounds.

The stuff I use never fully hardens, remaining flexible indefinitely. It also appears to be "self leveling," making it impossible to create lumps or high spots.

Since you will not need more than a small bottle of the stuff, going to a speaker manufacturer will probably not work. To say the least, if many of *SB*'s readers suddenly start calling manufacturers and asking for small bottles of speaker dope, they might get upset. In general, most driver manufacturers are set up to deal in large quantities. Forget about chemical companies, they sell products in 55 gallon drums and up.

Your best shot is probably one of the small businesses which specialize in re-coning speakers. That's how I got my quart can of it. Even if you don't know of any such companies locally, many professional sound reinforcement companies either do such work themselves, or send drivers out for repair. A nearby pro sound company might be able to help you get some speaker dope. Perhaps some *SB* advertisers stock it.

Unfortunately, I don't have very much left in my old can or I'd send you some. If enough people want the stuff, it may be possible to make an arrangement to acquire a large quantity of it and distribute it in small quantities to audiophiles like yourself.

If you do finally get some, be sure to apply it only in a well ventilated area. The solvents are generally highly toxic and are intended for industrial or professional use, not consumer use.

In any case, I'd be interested in learning what your before and after results are from your leak "sniffing" and system sealing.

EGG QUESTIONS

I have a few questions regarding your test of the Focal Egg II (*SB* 6/89, page 49).

You report that Focal offers three drivers for the mid/bass of the Egg II, however you only tested the Neoflex and Kevlar coned units.

Admittedly, Neoflex and Kevlar are presently in fashion, but some very talented designers like Dave Wilson (WAMM and WATT) have expressed a preference for cellulose cones in their designs. Wilson claims that polypropylene materials add a coloration he finds consistently audible. This was part of his reasoning for using the paper coned (doped) 6½" SEAS driver in his $5,000 WATT monitors.

This by itself proves very little, but it does make me curious whether you tested the 7C014-DBE (cellulose coned unit) and if so, what did you find. Or if not, why not?

Also you didn't mention any specs for crossover points or frequency response for the system. I'd be curious as to the frequency response for both the vented and sealed system if you have them.

Mark Skiles
Austin, TX 78704

Dave Davenport replies:

In selecting drivers to evaluate in the Egg II, I chose the 7N412-DBE because of its similarity to the driver used in the original Egg, and the 7K011-DBE because it is an example of the latest technology. I did not evaluate the 7C014-DBE because I thought (obviously erroneously) that nobody would be interested in this driver. When I received your letter I thought, "Why not give it a listen—if one person cared enough to write, there may be general interest."

I called Focal and asked Kimon Bellas for a pair of 7C014-DBEs. It turns out that Focal America has not been importing this driver because of a lack of demand for cellulose-cone drivers in general. However, Kimon believes there is a place for cellulose-cone drivers and agreed to provide a pair for me to evaluate in the Egg II. I will provide an addendum to my review after listening to the 7C014-DBE. By the way, Kimon has agreed to start importing the unit if a demand develops. Readers should express interest directly to Kimon Bellas at Focal America, 1531 Lookout Dr., Agoura, CA 91301.

When evaluating a loudspeaker for review, I do not perform extensive measurements or electronic tests as a matter of course. I may perform appropriate tests and measurements in order to help diagnose the cause of some aberration observed while listening. I like to get to the bottom of problems—we learn a lot from our own mistakes as well as the mistakes of others. In the past I have been able to highlight the causes for shortcomings in some speakers I have evaluated with the hope that future designers will not fall into the same traps. As I found nothing wrong with the crossover recommended for the Egg II, I did not perform measurements to determine the response of the filters. Since you asked, I performed the measurements—the crossover point between the woofer and tweeter is about 2kHz.

Long ago I gave up making extended acoustic frequency response measurements at home. Room acoustics get in the way. I think the only way to get an accurate acoustic frequency response of a loudspeaker system in the home environment is to perform a Fourier transform on a pulse. Unfortunately, I do not possess the necessary equipment. However, using what equipment I have indicates a −3dB point of about 43Hz for the vented Egg, and about 51Hz for the sealed Egg.

EVEN vs. ODD

In reference to "Tweeter Q Problems," by Jorge O. F. Oliveira, *SB* 5/89, page 40, odd order passive crossover networks do not have a low generator Z needed to damp high Q_{MS} type drivers at f_S. Please present models of generator Z and "typical" figures of even versus odd network generator Z. Is the low Z of the even order networks a function of the last shunt inductor D.C.R.? Also, what effect do amplifiers of different damping factor have on the generator Z presented to the mid- and high-frequency drivers in both odd and even order passive crossover networks? What about the use of a series resistor such as R_A in Robert Bullock's crossover network program, where R_A is used to attenuate excess gain—might this raise Q_T and invite ringing?

Fred Ireson
Huntington, WV 25701

Jorge Oliveira replies:

Under the simplifications of my article ($f_S > f_C$), the driving source impedance of a first/third order high-pass (HP) crossover may be modelled by a voltage generator in series with a capacitor, while a second/fourth order would be modelled by the generator in series with an inductor.

So, the output impedance of the crossover (at f_S) would be mainly the reactance of the capacitor or inductor (the components the speaker "sees" when looking into the network). As an example, if we use an 8Ω tweeter with a 3kHz crossover (F_S = 800Hz):

First order: C = 6.6μF; Z (800Hz) = 30Ω
Second order: L = 600μH; Z (800Hz) = 3.0Ω
Third order: C = 13.3μF; Z (800Hz) = 15Ω

As you can see, first order provides the lowest damping, second order the best and third is intermediate. However, as I said in my article, low output impedance only (2nd order) may not be enough.

The D.C.R. of the shunt inductor, as well as amplifier output impedance, usually are much less than Z at frequencies of interest and do not matter. Any resistor in series with a speaker will worsen damping and increase ringing (at f_S). However, an L-pad may help if you are using an odd-order HP crossover, since the L-pad will usually have a resistance lower than crossover output impedance.

If you want to be on the safe side, use fourth order or A/B crossover or low Q_{MS} speakers. By the way, all these considerations also apply to midrange speakers. In this case I feel biamping would be the only real solution.

You must analyze the crossover-speaker interactions in two ways. First, the driver must present the correct terminating impedance to the crossover, at least one octave above and below F_C; second, the crossover shall present a very low impedance to the driver, specially at F_S.

The usual way to present a correct terminating impedance to a crossover is through the use of Zobels and L-C-R networks in parallel to the speaker terminals.

However, presenting a low impedance (close to zero) is much more difficult in HP sections.

The HP section must reduce the energy transmission from the amplifier to the speaker as frequency goes below F_C; this means, in practice, at least one capacitor in series with the signal path (first order crossover).

Since the capacitor's reactance increases as we decrease frequency it becomes obvious that at F_S ($F_S > F_C$) the capacitor's reactance is significantly larger than the speaker's impedance and almost no damping is applied to the speaker at F_S, not fulfilling our second condition.

The series L-C-R circuit is of little help here, since typical values of R are bigger than the speaker's impedance and we want to go below that value.

A second order crossover (or any even order) is better here, for besides the series capacitor, we have a shunt inductor which reactance decreases with frequency, almost fulfilling the second condition (almost, because reactance for practical crossover-speaker combinations is higher than it should be).

The A/B crossover takes another route: apply as little energy as possible at F_S so excursion and ringing (due to the lack of damping) will be very small.

You may argue that this is not the best way to solve the problem. True, however it is a simple and elegant solution, without an inductor, and using a small value film capacitor.

If you decide to use a low Q_{MS} speaker, the considerations above about damping are less important, since these tweeters are mechanically damped and even a first order crossover may suffice. Dynaudio and Scanspeak both use it; however, their tweeters are *made* for it.

By the way, my new speakers use the Scanspeak tweeter.

Finally, all these considerations apply to midrange HP sections as well. However, I don't know any low Q_{MS} mid-driver with low F_S, so you must go fourth order (I dislike second order) or, the practical solution, electronic crossover and biamplifier.

HORN-LOADED

Thank you [Bruce Edgar] for the informative article on the Klipsch speakers and factory, in the 4/89 edition of *SB*.

From the letters and your responses in the 5/89 edition, you have surpassed the Klipschorns in sound quality. The question arises: Are plans for your designs available? Price? Are there any good sources of information on designing and building horn-loaded speaker systems? Are there any sonic advantages to having a straight exponential (bass) horn versus a folded once or folded Klipsch style? What about the phase delay between the different drivers?

It seems to me that with the efficiency available (104dB, 1W) there should be no loss of inner detail, unless it is decreased somehow by the horn itself. Could the result of the lower distortion (*Figs. 2* and *3* of your article) and this loss of inner detail be a result of the same thing?

Also, I'm curious about the use of a horn-loaded subwoofer, say 100Hz down. A smaller amplifier could be used because of the increased efficiency. Any thoughts?

Oliver H. Endsley, III
Atlanta, GA 30319

Bruce Edgar replies:

A design for a 50Hz horn will appear in the article "The Show Horn," in *SB* 2/90. As time and effort permits, more horn articles will appear in *Speaker Builder*. My midrange horns are still available. Write me at Box 1515, Redondo Beach, CA 90278 for more details. In the past I have built bass horns on commission, but because of limited building time, I really can't accept requests for commercial sale of bass horns. However, readers are encouraged to suggest horn projects they would like me to consider.

As far as horn design information, I can't really point out any book that will teach you how to design a horn. But in my upcoming Show Horn article I will attempt to lay down some general guidelines of horn design.

In regards to straight horns versus folded horns, a straight horn is preferable to a folded horn. But few of us have room for a straight horn, so a folded horn is an acceptable compromise. The Show Horn article also gives some optimal folding strategies.

Time delays can be troublesome, but you can tolorate up to 5mS of time delay differential below 500Hz. So time delay effects between mid and bass horns are not as big a problem as you might think. Between midrange and tweeter horns it is usually feasible to time align the drivers so no time delay effects are evident.

In a correctly designed horn system, there should be no loss of inner detail. In fact, the reduction of Doppler distortion in a horn will result in more evident detail if the system has not been compromised by design shortcomings.

In terms of realistic bass nothing can beat a bass horn, and a horn subwoofer with biamping is definitely an alternate to the mainstream direct radiator subwoofer. The main drawback is the large size of the bass horn.

RIBBON TWEETERS

The 3/84 issue of *SB* has an article on ribbon tweeters ("Simple Ribbon Tweeters," by Michael Lampton and J. Henry Primbsch). I'm interested in trying my hand at building one. I have a question or two (four):

1. Since 1984, have other sources of suitable ribbon been found?

2. What are the best adhesives for affixing the metal foil to a plastic base?

3. How do commercial ribbon tweeter manufacturers make their ribbon?

4. I guess Gold Ribbon Concepts went out of business. Would they have ribbon left over? (I'd ask them, but they haven't left tracks.)

Thanks very much.

R. F. Stonerock, Jr.
Orlando, FL 32806

Michael Lampton replies:

The ribbon tweeter industry has pretty much adopted the planar voice coil idea for its low and medium priced products. In this scheme, a thin Kapton or Mylar film is metallized and etched to leave a plane spiral conductor pattern. The membrane is then placed against a pair of ferrite block magnets that give a strong leftward field on the left-hand half of the planar voice coil, and rightward on the right-hand half. They are still called ribbons since the membrane is rather narrow (about half an inch) in comparison with its height, which can be two to four inches. The advantage over the classical, straight one-turn ribbon is that the desirable 8Ω impedance can be obtained by the correct number of turns.

Commercial capacitor film companies metallize their film by evaporation in big vacuum boxes. Perhaps *TAA* or *SB* could solicit an informative article on this process from an engineer at one of the big capacitor companies. It would seem to me there must be a wide range of coating resistivities that could be achieved.

Does anyone have any information on the present whereabouts of the Gold Ribbon Concepts people and materials?

PARAMETERS

After receiving *The Loudspeaker Design Cookbook* (*LDC*), by Vance Dickason, and reading it thoroughly I can honestly say it is the most comprehensive piece of speaker literature I have ever seen. I subscribed to *Speaker Builder* about two years ago and after a year I found that too many things were left unexplained. Your book has certainly filled in the gaps. I would like to ask for your assistance on one matter though. You have offered every pertinent formula and design table for closed-box systems and as a result I was able to tailor my own computer program to calculate the many important speaker parameters.

My problem is in the design of a suitable *vented*-box design. Although you offer design tables, it is a bit archaic to use them when a computer can calculate the values faster and more accurately. The specific math functions I would greatly appreciate knowing are for *vented* box, Alpha f_3 and f_B.

Andrew Fioretti
Farmingdale, NY 11735

Vance Dickason replies:

The answer to your question, calculating Alpha, f_B and f_3 for vented enclosures can be either fairly simple or rather complicated. The easiest solution is to use the formulas published in *JAES*, June 1981, titled "Thiele/Small Personal Calculator Programs" by Margolis and Small. These formulas pertain to calculating a flat QB_3 alignment with a $Q_L = 7$, and were presented as good approximations.

$$V_B = 20V_{AS}Q_{TS}^{3.3}$$
$$f_3 = 0.28f_{SB}Q_{TS}^{-1.4}$$
$$f_B = 1.5f_3Q_{TS}^{0.44}$$

Where f_{SB} is the resonance of the driver mounted on a baffle, which includes the air mass load.

The vented-box design tables in the *LDC* are a regrouped set of tables derived by Bob Bullock from Richard Small's design graphs presented in "Vented-Box Loudspeaker Systems," *JAES*, June through October 1973. Notice that the vented enclosure design tables are divided into three paired alignment sets (SBB_4/BB_4, QB_3/SQB_3, and SC_4/C_4), each pair represented by three different loss levels (Q_L of 3, 7, or 15). Deriving the parameters you ask for using this situation gets much more complex, and involves substituting various pole/zero coefficient sets into transfer function equations. My advice would be to rely upon one of the Thiele/Small programs currently on the market, such as Bob Bullock and Robert White's BOXRESPONSE. It is menu driven, easy to use, has graphic output, and is reasonably priced at $50 from Old Colony Sound.

FEEDBACK SYSTEM

continued from page 20

your records and turntables pour out. Some records are not playable with this system unless you include a steep LF-garbage filter. But that is a very different story.

ACKNOWLEDGMENTS. I thank *Electronics and Wireless World* for permission to quote *Figs. 1* and *8* and Philips for permission to reprint the schematic. I owe my wife, children and friends thanks for their support and patience. Continuous low-frequency sine waves at high SPL are a demanding experience.

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COMPACT ESL/TL

continued from page 38

a speaker, I would appreciate hearing about the results.

John Sutton has built a variation on David Lang's design. Using Lang's "egg crate" plastic stator support structures, he glued aluminum 16-wires-per-inch window screen to them rather than wrapping them with wire. It doesn't surprise me that John reports excellent results from this technique and states that the efficiency is comparable to my perforated metal designs.

John has had difficulties attaching the

screen to the egg crate with epoxy. He advises builders to lay out a length of aluminum foil on a flat surface. Fill a syringe with acrylic solvent. Place the egg crate on top of the precut screen. With a continuous motion, inject solvent across every square on the gridwork. Weight it down and wait 24 hours. This welds the screen to the plastic that was softened by the solvent. Be careful, the fumes from two ounces of solvent spread out over an area can be overwhelming.

NO MAGIC. If you are beginning to get the idea that there is no magic to ESLs, you are right. ESLs are such simple predictable devices they can be built in almost any way imaginable and still work splendidly. I have no strong personal preferences so long as the cells are highly efficient, since my main concern is high output.

Unless you are a perfectionist or just want to experiment, I recommend you build the cells of perforated metal. This method is cheap, lightweight, quick, easy, has high output, and the completed cell is only a trace over ⅛ inch thick. While not the most efficient design possible, the efficiency difference between it and the theoretical best is around 1dB and is not audible except in direct A-B tests.

If you are an absolute perfectionist, I refer you to one of the close-spaced wire construction types. The rest of us will be completely satisfied with perforated metal cells. Their construction is outlined in the next issue of *SB*.

MINIMUS-7 MOD

continued from page 45

ACKNOWLEDGMENTS

I thank the folowing people for their help: William R. Hoffman for acting as elder statesman and giving much appreciated advice, Angel Vazquez of Maimonides Medical Center Engineering Dept. for building metal brackets, Peter Damani of Maimonides Medical Center Surgical Research O.R. Lab for advice with photography, and Arjuna Rivera, my 14-year-old son, for drawing of *Fig.* 5 brackets.

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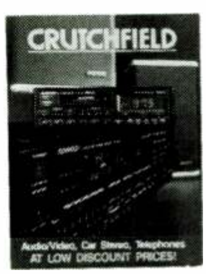

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Classified Advertising

TRADE

LONG HAIR WOOL carded, cleaned for stuffing speakers, $13.50/lb. including shipping. ***J. EBBERT***, 431 Old Eagle School Rd., Strafford, PA 19087, (215) 687-3609. TTF

SPEAKER DESIGN SOFTWARE for PC and Mac. **SpeakerCAD:** graphs predicted performance, calculates woofer parameters, vents. **Filters:** calculates 1-6th order electronic crossovers. **Crossovers:** 1-4th order All-Pass, Constant Power networks. $40 complete. ***Qubix***, 2302 5th NE, Salem,OR 97303, (503) 363-5143. T1/90

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PYLE DRIVERS! Pioneer Industrial Drivers! And now, the incredible 50 to 500W British McKenzie professional drivers. Lowest prices, list on request. Dealer inquiries? VISA/MC/DISCOVER. ***SPEAKER SHOP***, 318 South Wahsatch, Colorado Springs, CO 80903, (719) 475-2545. T4/90

APPLE MACINTOSH OWNERS! Can't find that article or correction? Then get the **Speaker Builder Index on HyperCard**. All articles, letters, and corrections cross referenced. Issues 1/80–6/88. Send $15 to ***DAVID BALDWIN***, 1118 Foster Ave., Lake Bluff, Il 60044.

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"IN PHASE" 24dB/octave electronic crossover minimizes irregularity in radiation pattern through crossover region. 0.0008% distortion, 5 year warranty. Single frequency with power supply (specify), $523. ***DB SYSTEMS***, Main St., Rindge, NH 03461. TTF

WHALE COVE AUDIO is your source for the *SWAN IV* and for complete kits, empty enclosures, the *PEDAL COUPLER*, and Joe Curcio's new elegant rack mount version, the *PEDAL COUPLER II*. ***WHALE COVE AUDIO***, Box 356, Swan's Island, ME 04685, (207) 526-4343. T1/90

SPEAKER CABINET FRONTS custom made—recessed holes. Cost $5 per hole, plus material and shipping. Typical 12-inch 3-way front, $20; 5-inch 2-way, $12. Send details and payment to ***SPEAKER WORLD***, PO Box 14731, Fremont CA 94539, (415) 490-5842. T2/90

MANUFACTURERS' OVERRUNS. Real wood walnut cabinets from major speaker makers. Prices range from $15 to $40 each. Send for complete list of cabinets. ***PHIL BAKER***, 546 Boston Ave., Medford, MA 02155. T1/90

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FALCON ACOUSTICS is one of the largest independent manufacturers of crossover networks and speaker system accessories in the UK, supplying manufacturers, retailers and export. Your guarantee is the trust our manufacturing customers put in the quality and reliability of our networks. **Inductors:** Ferrite (up to 200W), air-cored and transformer; **Capacitors:** Reversible electrolytic 50V/100V, polyester, polycarbonate and polypropylene; **Networks:** choice of over 70 for different unit combinations; **Components & Accessories:** most except for the wood! Please send for details, $2 air, $1 surface, to our mail order retail outlet. ***FALCON ELECTRONICS***, Tabor House, Norwich Rd., Mulbarton, Norfolk, England NR14 8JT. T6/90

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FOR SALE

JBL Alnico speaker components: (2) D123 12″ extended range speakers; (2) 075 high frequency drivers; (2) N2400 crossover networks, $300/best offer for set only. Buyer assumes shipping charges. Johan Granfeldt, 1184 14th St., Los Osos, CA 93402, (805) 528-3273.

Yamaha SR-50 surround processor, mint $250; Bogen C-100B, 100W PA amps, $200 each, $350/pair; Toneff "Fairy Tales" CD $12; JBL2234H 15″ woofers $300/pr., w/cabs $400/pr.; KLH 27 AM/FM receiver $100; Straight Wire 1m pr. interconnects $35/2 pr.; Wanted/Trade: one JBL 075. Steve, 7–10 pm (203) 397-3888 CT, machine on 5th ring, all calls returned.

Two VMPS Smaller subwoofers, oak with brown grilles; one Onkyo T-4087 tuner; one Audio Prism model 9700 FM antenna. All factory sealed. Must sell now. Will consider any offer. Frank, days 9 am-5 pm, (212) 371-9738; nights and weekends (201) 335-2208.

M&K bottom end subwoofers. Pair in real walnut with smoked glass tops. Like new, in carton (early 80s). Original $560, $375; pair Advent (original, not "new") in walnut vinyl, excellent condition, $100. Frank S. Thomas, 47 Signal Ct., St. Louis, MO 63146, (314) 993-3060.

Speakers, custom designed with Dynaudio drivers, a 5-way design using 30W100 in compound loading with D70, D54, D28, D21, using first order slopes 21″ wide, 21″ deep, 53″ high, walnut and linen enclosure. $2,000/pair. Mark, (215) 663-8034.

Tektronix oscilloscope 511 AD with manual. Good condition, $110, must pick up. Walt (516) 334-3144.

Pair of ribbon tweeters, built to *SB* article 4/88, $30 plus shipping and handling. Donald May, 129 Glenridge Rd., E. Aurora, NY 14052.

New Jordan ACT II treble drivers, $75/pr; Jordan bass drivers, $100/pr; Prototype speakers w/Jordan, Focal or Dynaudio drivers; real nice oak and walnut cabinets at parts cost, $600 pair. Marc McCalmont, RR2, Box 334A, Wilton, NH 03086, (603) 654-9826.

(2) Dynaudio D-54AF MIDS, $75 or trade; pair AC compact monitors with nice homemade stands, $375 or best offer. Dan Wenger, 169 S. Knox #2, Monmouth, OR 97361, (503) 838-6628.

Focal SN313 midrange drivers, $65/pr; (2) .15mH, (2) .3mH, (2) 1.0mH, (2) 15µF polypropylene cap (Solen), all $16 plus UPS. Kenney Chan, (508) 460-9872 EST.

Fried monitors, C/2 satellites with 0/2 transmission line subwoofers, oak finish, $725; Sony 620ES CD player, 20 pounds of quality sound, $325; Terk 4500 FM antenna, $25. Doak Wattigney (504) 738-1235. 6–11 pm CST.

IVIE IE-10A spectrum analyzer and IE-20B pink/white noise generator, $370 for both; Ace Audio 6500-DSB electronic crossover, $50; new Magnavox CDB-610 CD player, $199 (sealed carton). Fred Janosky, RD2, Box 3502, Wernersville, PA 19565, (215) 693-6167.

Sony TA-F22Z-ESX integrated amp, European version of TA-F500ES, 90w/channel @ 8Ω, 2dB dynamic headroom, audio/video inputs, two months old, original box, manual and packing, 110/220 volt, $275; EMC 2-way stereo crossover, 100Hz 19″ rack mount, $125. Darrin Tebbe, PSC Box 2032, APO, NY 09223.

Rare and unusual KEF model K-2 Celeste MK-2 two way speakers, made in 1966, from England, real wood construction, first class condition, great sound, never abused, woofer is oval type. These are quality units, $300 for the pair, I pay shipping. Call Ed at (305) 891-2267 (Miami).

JBL K-151 18″ woofer; similar to 2245H or E-155. Good for subwoofer or musical instrument, $175 or best offer. Len, (201) 797-6032 evenings EST.

(4) Focal 8K515, $50 ea; (2) Dynaudio DS4AF, $40 ea; Focal 7N515, $30. Paul Keller, (708) 677-8341.

Audio Concepts pulse subwoofer kit, includes four 10″ drivers, stuffing, foam, plans, etc., $125; 10-ft. transmission line enclosure for 10″ driver, particle board, 12″ x 12″ x 48″, $25. Noah Katz, 2431 Thaddeus Dr., Mountain View, CA 94043, (415) 964-9457.

Two Audio Research EC-21 tube electronic crossovers, one 18dB, 100Hz; one 18dB, 2,000Hz, good condition, includes extra parts for different slopes. $150 each, $275 for both. John Arango (505) 867-3660 anytime.

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

TRW, Microtran, RCA, audio transformers, high voltage high value caps, Penny and Giles slide pots, power supply parts, high current transformers, hybrid power amps, audio ICs, power transistors, various power supplies. Call Don (609) 665-6512 after 6 EST or 112 St. James Ave., Merchantville, NJ 08109.

Apature interconnects: 3/$40 ppd.; new Apature's —CALL!; Souther tonearms: SLA ($850), $350; Junior ($550), $225; Unopened: Sennheiser HD-50 headphones ($80), $45; ADC phono cartridges PSX-30 ($150), $45 ppd.; Motorola KSN-1003A 4/$25 ppd. Andy, 2506 So. 20th St., Sheboygan, WI 53081, (414) 458-2057.

Musical Concepts Epoch CD player $1,200 Canadian; stereo subwoofers, VMPS larger subwoofers $700 US, pair, all new, mint condition; hook-up wire, mil 16878-E, 10 gauge, multi-strand, silver plated, Teflon insulation, $1 US/ft; 25 ft minimum, limited supply. Nick Mastrobuono, 50 Copperfield, Sarnia, Ontario N7S 5K8 Canada, (519) 336-9160.

Dynaco ST-410 power amplifier, excellent condition, 200W/channel $300, plus shipping. Roger Enders, Box 743, Tioga, ND 58852, (701) 664-3609.

Pair modified SpeakerLab Model K corner horn speakers, circa 1976 design; 4Ω woofer, E-V 1823M MR horn & E-V T-35 tweeters, $600 plus shipping; (2) 120/220V 1,500W isolation transformers, $200 each. Send S.A.S.E. for details. Paul Kelly, 7624 Harcourt Dr., Fort Wayne, IN 46835.

NAIM audio power amp NAP 250, $1,400; NAC 32 preamp and SNAPS power supply $800; Linn Sara Isobarik speakers with stands, $700. All in very good condition. Scott Trefethen (713) 721-6975. Leave a message.

Complete Old Colony POOGE-4 kit for modifying Magnavox 16-bit CD players. Never touched. $165 ppd. Joe McQuade (609) 397-8315 EST.

Dynaudio, D54AF, $140 pr.; D52, $50 pr.; 17W75, 4Ω woofers, $50 pr.; B&W 801 driver parts with head units and crossovers, $450 (no base cabinets); Marsh preamp $250; Dyna ST-70 $150; Phase Linear 8000-MK II turntable $150; Eagle 2A amp $550; Electro-Voice LT-12 loudspeaker $100 pr. Bob Smith, 2307-31st Ave. S., Seattle, WA 98144. (206) 722-8003, FAX (206) 722-5778.

WANTED

Original owners manuals for the following equipment: dbx 200, Burwen Research DNF-1201A, Dynaco PAT-5, SE-10, FM-3, Stereo 80 and Wharfedale W60. Would like to borrow them or better yet to buy them. Must be reasonable, I am on fixed income. Rick (303) 431-7404.

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.

Dynaco ST-70 and FM-3 in clean and working condition. C.F. Wong, 61 Shepmore Terrace, Scarborough, ONT M1B 3H3, Canada (416) 299-8438 after 6 pm.

Two TP-63 plug-in wands for Thorens TD126III; Yamaha B-2 amplifier; Shure Ultra 500 cartridge; General Radio impedance bridge 1650A. Dick, 3470 Travis, Simi Valley, CA 93063, (805) 526-7066.

Cassette (metal tape-Dolby B) dub of Helen Traubel singing with Toscanini conducting. Will furnish tape and pay postage. Clyde Bostick, 3390 Blue Rock Rd., Cincinnati, OH 45239

Michael Mossey, where are you? I lost your address. Noah Katz, 2431 Thaddeus Dr., Mountain View, CA 94043, (415) 964-9457.

(2) Philips ADO8066 eight" drivers with fabric dust caps. Will pay cash or trade D-28AFs. Gary Judd, 3457 N. 84th St., Milwaukee, WI 53222, (414) 464-6447 evenings and weekends.

Technics SB 7070 speaker systems. Cabinet must be in good condition. James at (904) 392-0622.

RCA Digital Command CD player MCD141 or Dimensia MCD245 in mint condition with manual and box. Will pay Orion blue book retail plus UPS. Lawrence Kempher, 454 West Greenbriar Lane, Dallas, TX 75208, (214) 942-7369.

Pioneer SF-850 crossover, copy of schematic and manual, pay top dollar. Bob Smith, 2307-31st Ave. S., Seattle, WA 98144, (206) 722-8003, FAX (206) 722-5778.

CLUBS

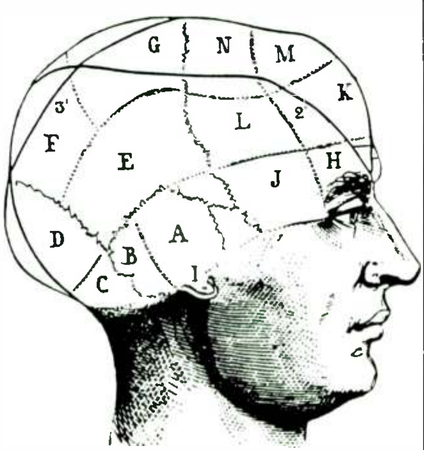
THE ATLANTA AUDIO SOCIETY, a club for men and women interested in high quality home audio/video systems and recordings. Monthly meetings are conducted where special programs and guest speakers are often featured. Guests have been: Jack Renner, Richard Vandersteen, William Conrad, William Johnson, Louis Lane, John Cooledge and others. Monthly newsletter. For information call Chuck Bruce, (404) 876-5659 or write Atlanta Audio Society, PO Box 361, Marietta, GA 30061.

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.

SOUTHEASTERN MICHIGAN WOOFER AND TWEETER MARCHING SOCIETY (SMWTMS). Detroit area audio construction club. Meetings every two months featuring serious lectures, design analyses, digital audio, AB 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.

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.

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.



FILL IN THE BLANKS JOIN AN AUDIO CLUB

Learn about the latest equipment, techniques and recordings through group meetings, tours, and newsletters. Ask questions. Share viewpoints and experiences. Stretch your mind.

If there's no club in your area, why not start one? Our club ads are free up to 75 words ($.20 per word thereafter). Copy must be provided by a designated officer of the club or society who will keep it current.

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.

THE HI-FI CLUB of Cape Town in South Africa send 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 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.

MEMPHIS AREA AUDIO SOCIETY being formed. Serious audiophiles contact J.J. McBride, 8182 Wind Valley Cove, Memphis, TN 38125, (901) 756-6831.

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

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.

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 Dr., Raleigh, NC 27612, (919) 870-5528.

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 CATSKILL AND ADIRONDACK AUDIO SOCIETY invites you to our informal monthly meeting. Join our friendly group as we discuss life, the universe and everything. The meetings usually feature a "show and tell" of members' projects and free-wheeling open dialogs on the subjects of your choice. No matter what your level of interest, experience, or preferences are, you are welcome to join in, or sit back and observe. Meetings are generally held on the second Wednesday of the month, in the evenings. We have been meeting at Rensselaer Polytechnic Institute in Troy, NY, together with the RPI Audio Club. Contact CAAS at 756-9894 (leave message) or RPI Audio Club at 276-5810, or write CAAS, PO Box 144, Hannacroix, NY 12087. See you there!

ESL DIY'ERS: A new electrostatic loudspeaker do-it-yourselfers group is now forming. Our purpose is to share valuable theory, how-to, and parts source information for building our own state-of-the-art electrostatic loudspeakers. For further indormation, please write (SASE please) to: Neil Shattles, 829 Glasgow Dr., Lilburn, GA 30247.

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.

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.

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.

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 Road, Alexandria, VA 22302.

Advertising Index

Good News

RALPH GONZALEZ has added a new product to his loudspeaker design software collection: LMP Professional is for Macintosh computers only. This software's special feature is the ability to view and listen to the square/sawtooth/sine wave response of the system you are modelling by using Mac's internal speaker or audio output jack.

Other features include phase and frequency response prediction, the modelling of driver rolloffs, polarity and delay, as well as crossover definition using component value or transfer function. LMP Professional reads existing LMP/LMP2/LMP3 files and requires at least 512K memory.

You can obtain this product directly from Ralph Gonzalez, PO Box 54, Newark, DE 19711 for $49.50 plus postage. Ralph is offering a $10 upgrade discount to existing LMP owners.

At the request of a *Speaker Builder* reader, Ralph has developed an LMP program for VAX minicomputers. VAX/VMS/BASIC can be obtained for $10 by writing Ralph at the above address.

Fast Reply #EE543

In an effort to contribute to the on-going training of talented young artists, Steve Goldberg, publisher of **AUDIO MAGAZINE**, has awarded the first annual *Audio*-Juilliard Scholarship to Brian Dean Lewis of Kansas. Mr. Lewis, a violinist, is in his third year of studies with Dorothy Delay. As the first recipient of this award, Mr. Lewis will receive a full year's tuition plus a living stipend.

In supporting performers as well as the school, Mr. Goldberg believes *Audio* is participating in musical renewal.

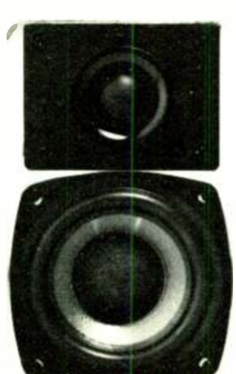
Audio publisher Steve Goldberg, left, and Avery Fisher, right, present the *Audio*-Juilliard Scholarship Award to Brian Dean Lewis.

Acoustical Magic, from **AUDIO CONCEPTS**, is a special paint with a high percentage of titanium, used to coat the inside of your enclosures, and is said to increase the transparency, detail and dynamics. You can also use it on driver chassis, turntable suspensions, speaker stands and the inside of electronics chassis. Recommended usage is about one quart per four cubic feet. You can paint it on with a regular paint brush and, since it is water-soluble, you may add 10–20% water to make it easier to apply. Acoustical Magic is priced at $19.90/qt., $59.90/gal. For more information contact Audio Concepts, Inc., 901 S. 4th St., La Crosse, WI 54601, (608) 784-4570 or (800) 346-9183 (orders only).

The Model LS One compact loudspeaker is available from **AUDIO SOURCE**, featuring a 4″ polypropylene woofer with double wound voice coil. The speaker also includes a 1″ soft dome, ferrofluid-cooled tweeter and a full L/C type crossover. You may choose matte-black, walnut or oak finish and the unit comes with mounting brackets and hardware. The LS One/WT is a weathertight version, designed for outdoor use.

Also available from Audio Source are the LS Eleven and LS Twelve. The Eleven, which offers video compatibility, has two 4″ polypropylene woofers with double wound aluminum voice coils, and a 1″ soft dome, ferrofluid-cooled tweeter. The Twelve contains a 6½″ polypropylene woofer with aluminum voice coil and a 1″ ferrofluid-cooled tweeter. Both speakers are available in real walnut or oak veneer or white enamel or matte-black finish with metal grille. For more information contact Audio Source, 1327 North Carolan Ave., Burlingame, CA 94010, (415) 348-8114.

Fast Reply #EE460



The K 1000 Reference Headphone System was launched by **AKG** at the Winter CES. The new design allows the hinged earphones to be angled away from your ears, eliminating the resonances of the air volume within the ear cushions found in conventional headphones. The angles of the K 1000 transducers are individually adjustable. Unlike conventional headphones, they connect to the loudspeaker terminals of the amplifier. An oxygen free copper (OFC) cable with gold-plated contacts is supplied. Retail price is $895. For more information, contact AKG Acoustics, Inc., 77 Selleck St., Stamford, CT 06902, (203) 340-2121.

Fast Reply #EE289

HART, a small cottage company located in the Pacific Northwest, is now shipping their MS-1000-12, 1,000W Monster subwoofer. Hart has been handcrafting speakers for many years and believes this woofer incorporates all possible improvements and refinements in design, construction and manufacturing to produce the cleanest bass possible.

Retail is $475. Contact Hart Professional, PO Box 186, Kent, WA 98035, (206) 852-4049 to learn more about this powerful subwoofer.

Fast Reply #EE551

Polydax Speaker Corporation, a subsidiary of Audax Industries of France, is proud to announce they have reached a distributorship agreement with **SOLEN INC.** in Canada. With Solen's experience in the loudspeaker industry, Polydax is confident of expanding their marketing position throughout Canada. They look forward to serving their Canadian customers faster and more efficiently.

All future Canadian inquiries will be directed to Solen Incorporated, 5851 Cousineau Blvd., St. Hubert, Quebec, J3Y 7P5, (514) 656-2759.

Fast Reply #EE1063

CELESTION has updated its DL Series of loudspeakers including the DL 4, 6, 8 and 12, each of which feature a 1-inch Celestion 2-piece titanium dome tweeter. The DL 4 is equipped with a 6½-inch treated paper bass driver, while the 6 and 8 each use an 8-inch polyolefin low frequency unit. The DL 12 features dual 8-inch polyolefin bass drivers. The DL 8 and 12 employ a Figure Eight brace construction, a panel-stiffening technique which pins all four sides of the 18mm particle boards.

Suggested retail prices are: $399/pair, DL 4; $439/pair, DL 6; $569/pair, DL 8, and $849/pair, DL 12. For more information, contact Celestion Industries, Inc., 89 Doug Brown Way, Holliston, MA (508) 429-6706.

Fast Reply #EE339

A pocket-sized audio generator with frequency range of 20Hz–150kHz is now available from **B&K-PRECISION**, a division of Maxtec International Corp. Weighing seven ounces, the Model 3001 is ideal for either field service or hobbyist troubleshooting.

The unit features selectable sine- or square-wave outputs with a 23-position rotary switch and x1/x100 slide switch to select one of 46 frequencies spanning its range. A separate sync output provides a fixed-level signal at the same frequency and phase as the main output.

The Model 3001 is supplied with two banana plug-to-insulated clip test leads, a 9V battery and an instruction manual and is priced at $67. For more information contact B&K-Precision, Maxtec International Corp., 6470 W. Cortland St., Chicago, IL 60635, (312) 889-9087.

Fast Reply #EE386

In a continuing effort to upgrade and improve their line of loudspeakers, **PRECISE ACOUSTIC LABORATORIES** has made several changes to its flagship, the Monitor 10. Precise has switched to the gold standard by using high quality, gold 5-way binding posts and gold-plated banana plugs and receptacles that connect the mid/high frequency unit to the bass chamber. They have also added a three-position bass contour switch, which gives the ability to add or subtract low frequency output.

Please contact Precise Acoustic Laboratories directly at 200 Williams Dr., Suite B, Ramsey, NJ 07446, (201) 934-1335.

Fast Reply #EE103

SPARKOMATIC has introduced its 8000 Series, a line of car stereo speakers, designed to replace OEM speakers with or without replacing the in-dash radio/cassette unit. The series includes the 6 x 9-inch 3-way 8690 ($54.95), the 6½-inch 2-way 8650 ($44.95), and the 4-inch 2-way 8400 ($29.95). For more information contact Sparkomatic Corp., Milford, PA 18337, (800) 233-8831 or (800) 592-8891 (in PA).

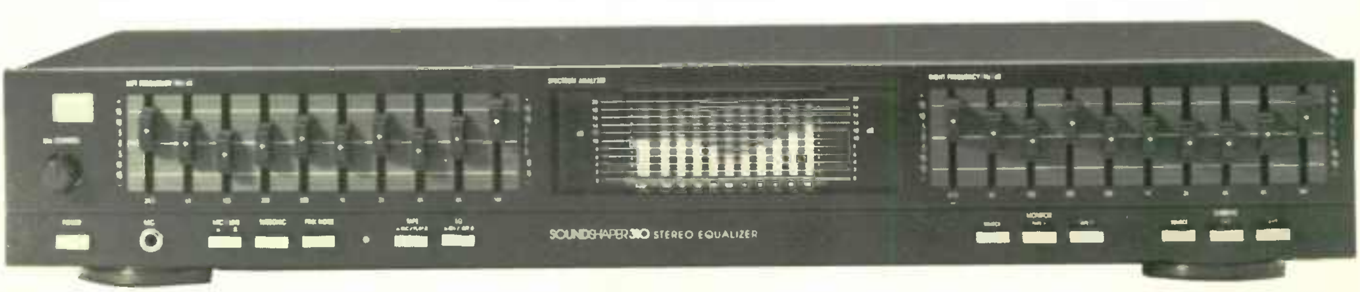
Fast Reply #EE781

A three-piece bookshelf loudspeaker system, which is said to provide stereo imaging from anywhere in the listening room, has been introduced by **ADC**. The Soundshaper 3025 consists of a 2-way mirror-imaging pair of satellite speakers which can be wall mounted, and an omni-directional subwoofer. Suggested retail for the system is $499.95. The satellite pair can be purchased for $269.95 (in white or black) and the subwoofer for $229.95 (black only).

Also available from ADC are three new 10-band graphic equalizers. The Soundshaper 310 features a microphone, a pink-noise test signal and real-time analyzer display, and sells for $199.95. The Soundshaper 200 has fluorescent spectrum analyzer (SA) display, peak hold button, SA sensitivity control, switchable subsonic filter and video/audio inputs. Its retail price is $149.95. The slimline Soundshaper 90, with LED SA display, SA sensitivity control, and EQ record and defeat buttons, is available for $129.95.

For more information on these products contact ADC, 707 E. Evelyn Ave., Sunnyvale, CA 94086, (212) 661-5300.

Fast Reply #EE557



Temporal Continuum™, a loudspeaker cable that can be tuned in an audio system, was previewed at the Winter CES by **TARA LABS**. This cable uses a conductor configuration and a controlling device to optimize the relationship between the loudspeaker and the amplifier. It allows the listener to adjust the damping ratio of the speaker/amplifier interface by controlling application of an electrical force within the cable's design. The Temporal Force is said to control and dissipate unwanted energy within the loudspeaker/amp interface and assist in the delivery of the signal. For more information contact TARA Labs, Inc., 2567 Siskiyou Blvd., Ashland, OR 97520, (503) 488-6465.

Fast Reply #EE555

The second **NEW YORK HIGH END HI-FI SHOW**, co-produced by *Stereophile* magazine and Nelson & Associates, will be held April 27–29 at the Penta Hotel. More than 70 high fidelity, high tech equipment manufacturers and dealers will be present, including AudioQuest, B&W, Dahlquist, KEF, Vacuum Tube Logic and Vandersteen to name a few. Manufacturers will demonstrate pre-production and experimental products as well as units already on the market.

The show will feature live classical and jazz concerts at night and concert soloists performing during show hours. Seminars will be conducted by *Stereophile* audio critics and reviewers John Atkinson, J. Gordon Holt, Sam Tellig, Lew Lipnick and others.

A $25 ticket is good for all three days, seminars and concerts. For ticket information contact Jerran Kingsley, (505) 986-1466.

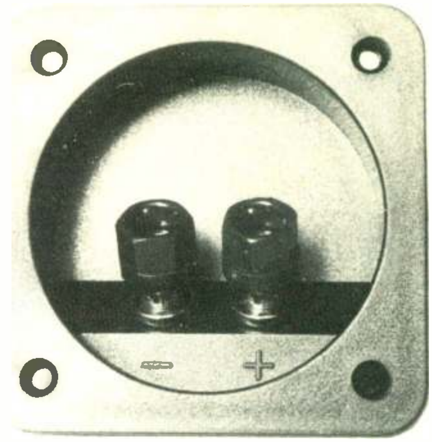
RAPID SYSTEMS has announced R2 software, a new universal software interface for their line of high performance PC-based multichannel waveform digitizers. You can display up to 16 channels on a single screen. Available hardware digitizers offer sample rates from 0.01Hz to 20MHz, data buffers to 128K per channel and 8 or 12 bits of A/D resolution. R2 is a free upgrade to all current Rapid Systems customers and is included with every RS product. The program features digital scope display and can be used with HGA, CGA, EGA or VGA graphics. For more information contact Rapid Systems, 433 N. 34th St., Seattle, WA 98103, (206) 547-8311.

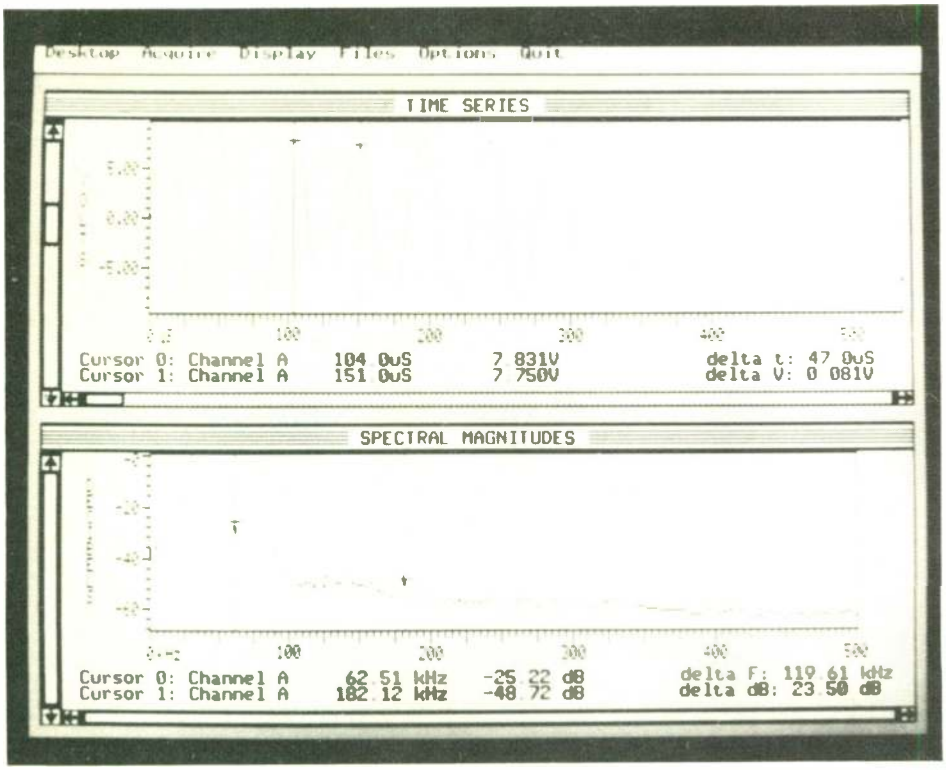
Fast Reply #EE948

MADISOUND has introduced a new line of input cups to their Sledgehammer line. They will now be available with binding posts in either gold or chrome finish. Some of the advantages of these cups are non-flexibility, posts accept 10 gauge cable, gasketing for airtight seal, 2⅝" cutout, flange size of 3½ square inches, and large solder lugs for multiple connections. Hardware is also in the same finish as the posts.

Introductory dealer prices can be obtained by contacting Madisound, Box 4283, Madison, WI 53711, (608) 831-3433.

Fast Reply #EE20





As of January 1, **SHAREWARE** program Perfect Box 4.5 is available for downloading from the following: UCF Health Topics BBS (2400-N-8-1: (407) 281-5522); and Audio Projects BBS (HST/9600-N-8-1: (608) 836-9473). The archive file name is PERF450.ZIP.

New features to the program are QUADplot, a procedure using EGA graphics to allow up to four alignments of the same or different drivers to be compared simultaneously; MicroSoft Mouse on most menus; printer support for LPT1-3, and hot-key search for quick access to the 850+ database files. For more information contact Warren A. Merkel, 2851 Newcomb Court, Orlando, FL 32836.

Fast Reply #EE548

D. W. ELECTROCHEMICALS LTD. of Richmond Hill, Ontario, has announced that Stabilant 22, the world's first liquid semiconductor has received its US and Canadian patent. Its primary use is as a contact enhancement material. A non-toxic liquid polymer, Stabilant 22 is initially nonconductive when applied to an electromechanical contact. Once inside individual contacts the material switches to a conductive state giving those contacts the reliability of a soldered connection. However, it remains nonconductive between adjacent isolated contacts.

For more information contact D. W. Electrochemicals Ltd., 9005 Leslie St., Unit 106, Richmond Hill, ONT L4C 3G4, Canada, (416) 889-1522.

Fast Reply #EE552

In order for serious music lovers to enjoy the rich sound they are accustomed to while not at home, Henry Kloss of **CAMBRIDGE SOUNDWORKS** has designed the Model Eleven transportable component music system. The unit consists of a miniature three-channel amplifier, a pair of compact two-way satellite speakers and the unique BassCase™—a woofer enclosure which doubles as the carrying case. Weighing just 23 pounds and measuring 16½" x 19½" x 6¼", it can easily be carried on an airplane, or toted to any destination.

Model Eleven's amplifier is switchable for use with any AC worldwide electrical system, as well as 12V DC. The satellite speakers (4¼" x 5½" x 3") and the 7" acoustic suspension woofer, which is built into the case, plug into the amplifier. The Model Eleven, retailing for $599, can be ordered using Cambridge SoundWorks' toll free number, (800) 252-4434.

Fast Reply #EE146

MISSION ELECTRONICS has announced its new flagship speaker system, the Mission 767, designed by Henry Azima. Each 55-inch-tall tower of the British-built loudspeakers incorporates five drivers: two active woofers, two passive midrange drivers and Mission's impedance-transforming tweeter. All drivers, the crossovers, and cabinets were designed using CAD systems. Each 767 tower is hand-built from 1-inch MDF board cut by computerized jigs. Cabinets are natural wood veneer finish, or for an additional $1,500, black or white piano lacquer.

Suggested retail price is $4,499. For additional information, contact Mission Electronics USA, Inc., 18303 8th Ave., Seattle, WA 98148 (604) 432-7727.

Fast Reply #EE565

Pox Humana

Patently Stupid . . .

By Dick Pierce

I spend not an insubstantial effort collecting and reading information on loudspeakers, measurement techniques and so forth. One of the richest sources of such information is the *Journal* of the Audio Engineering Society. After I thoroughly read the relevant articles in an issue, I then go searching for the "Review of Acoustical Patents." Here we are privileged to find the cream of the crop of the strange, the bizarre, and the downright stupid. Sometimes I think this section is included only to show that you don't have to be either smart or right to get a patent.

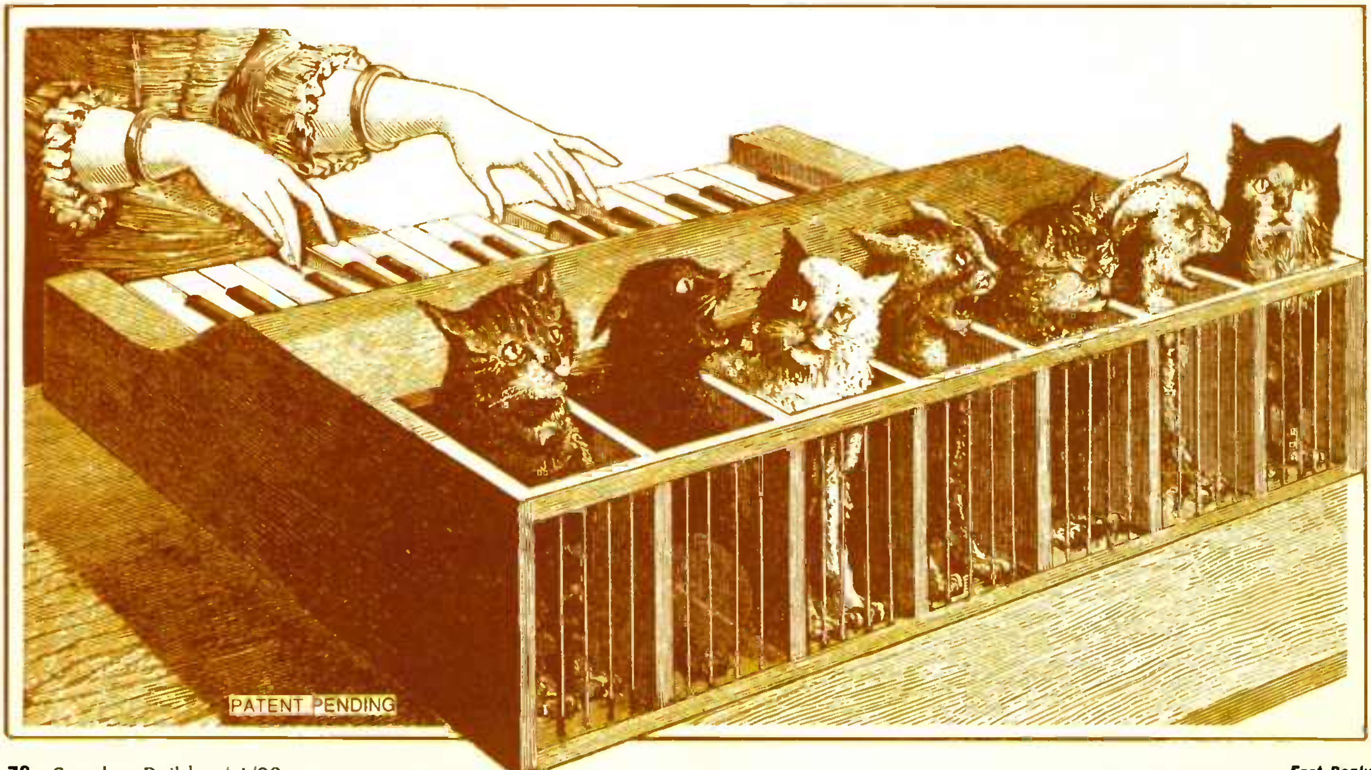
George Augspurger gets stuck reviewing all the crazies, and he seems to take his job quite seriously. Some highlights from recent issues, quoting Mr. Augspurger:

#4,033,430—Speaker enclosure (Edward J. Bolden). What you do is, you take your pyramid and you set it on your bass box and then raise the whole thing off the floor on legs. Now, you put a woofer in the bass box and a tweeter in the pyramid, and for a little elegant touch the tweeter control goes in the middle like a navel. You see what you got? You got a patented speaker enclosure.

#3,967,065—Plexiglas speakers (James M. Ward, deceased). Your reviewer has long given up trying to understand the psychology of spending good money to obtain a patent on some trifling variation of prior art. This patent is a case in point. How many times in the past have loudspeakers been built of Plexiglas, as demonstration models or for decorator effects. To patent the idea would seem to be an exercise in futility. But Mr. Ward's Plexiglas cabinet includes a female phono plug on the back, and that apparently makes all the difference.

#3,912,866—Folded Bass Horn Speaker (Ronald E. Fox). Any bass horn is, of necessity, a variation of some previously used geometry. The "W" configuration is particularly popular since it is easy to build. However, such a nested design can just as well be circular, or quadrilaterally symmetrical as were some of Jack Frazier's designs in the 1950s. This invention belongs to the latter group and claims to be an improvement over the simpler "W" horn because it provides a more nearly flat impedance curve. Your reviewer is not quite sure (a) what this means, (b) why it should be true and, (c) why it should be desirable. No corroborating data is given in the patent.

#4,373,606—Loudspeaker Enclosure and Process for Generating Sound Radiation (Clemens and Smith). This patent belongs to the general class of "ideal" loudspeaker enclosures. It is typical of this class in that it starts by listing the real and imagined deficiencies of horns, closed boxes, and ported enclosures. The patent then takes an unexpected turn, however, by describing a previous design by the inventors, presumably never patented, which is stated to have fairly flat frequency response extending to 41.2Hz at an efficiency of "up to 8 percent" with an enclosure volume less than two cubic feet. One might well ask how such a miraculous loudspeaker could be improved. The patent provides the answer: by eliminating distortion, providing a "longer" bandwidth and a higher "efficiency rate." What is then described is essentially a ported enclosure having a second tuned chamber and lots of absorptive stuffing. Although one has to wade through considerable nonsense about focusing the pulsating column of air and the like, there seems to be no reason why the design should not work almost as well as a properly tuned ported enclosure. The patent says it works better.



morel

high fidelity range

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.

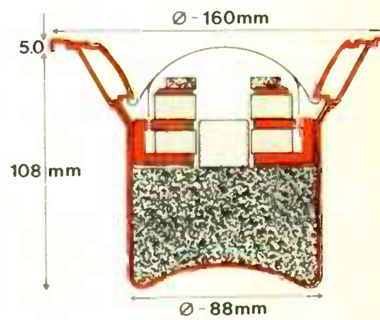
Specification

MDM 85 (with enclosure)

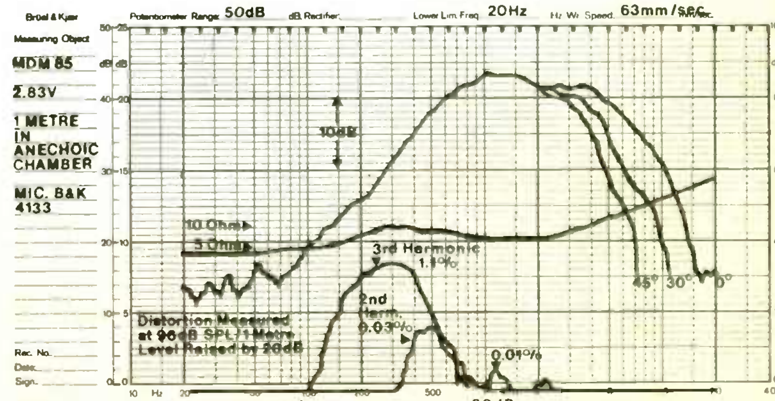
Overall Dimensions	Ø - 160mm × 113mm
Nominal Power Handling Din	300W
Transient Power 10ms	1500W
Voice Coil Diameter	75mm (3") Hexatech Aluminium
Voice Coil Former	Aluminium
Frequency Response	300-5000 Hz
Resonant Frequency	250 Hz
Sensitivity	92 dB (1W/1M)
Nominal Impedance	8 ohms
Harmonic Distortion 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 × 60mm
Frequency Response	250-5000 Hz
Resonant Frequency	170 Hz
Rmec	39.33
Qms	0.19
Qes	1.81
Q/T	0.17
Vas	0.7 litre
Nett Weight	1.05 kg



Specifications given are as after 24 hours of running.



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morel®

Morel operate a policy of continuous product design improvement, consequently, specifications are subject to alteration without prior notice.

Fast Reply #EE142