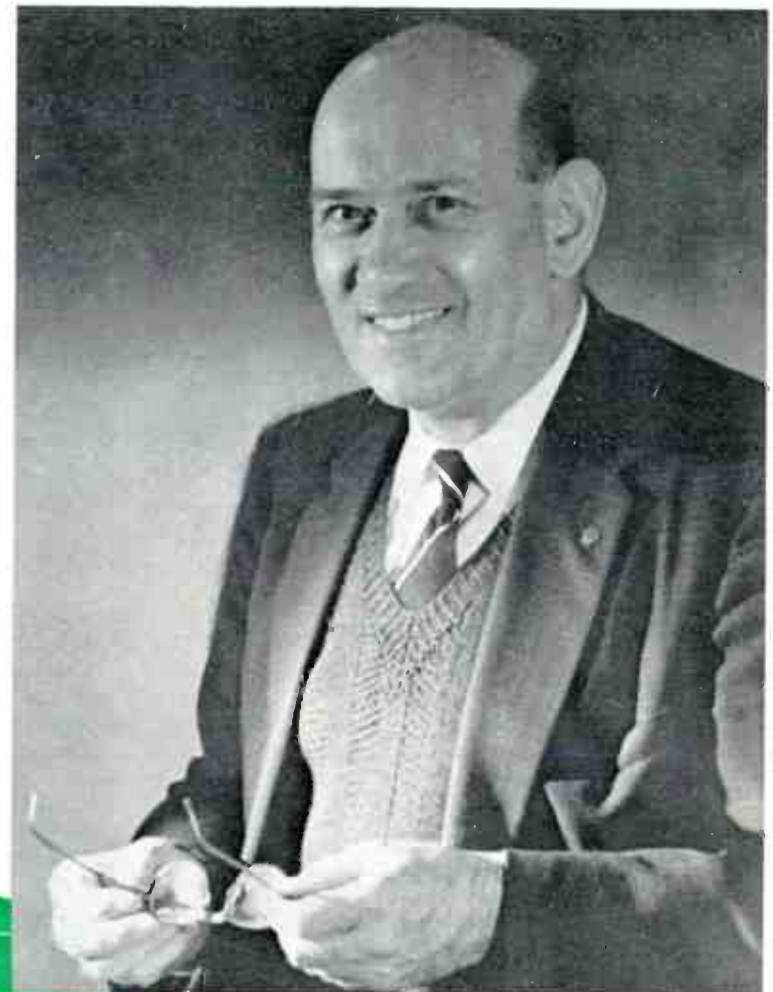
Petite Pipe ∘ Closed vs Vented ∘ Improved Tweeters ∘ Calibrated Pads ∘ Particle Points

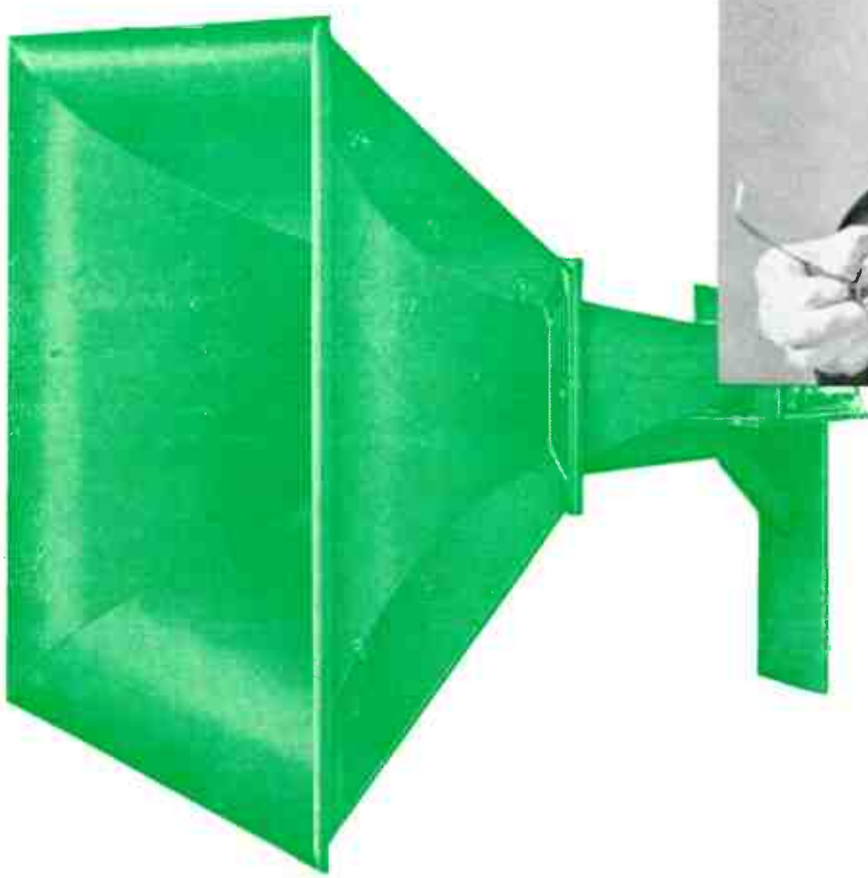
3/1981

SPEAKER BUILDER

US $3.00
UK £1.25 | 15 Fr.

P.G.A.H. Voigt
1901—1981
Loudspeaker Pioneer





Good News

Manufacturers who have heretofore been content to offer only built, finished and tested loudspeakers are discovering the do-it-yourself enthusiast and responding to his needs. **American Acoustics Labs** (629 West Cermak Road, Chicago IL 60616) are offering a range of 26 drivers in a special display which they have dubbed *Blasters*. Suited for home or car, the drivers may be purchased with or without cabinetry and crossovers. Dealers should have information about the new line but a query to AAL will get you full information.

Electronic crossovers are appearing in all sorts of places. **ElectroVoice/Tapco** have a new one designated EX-18 which is stereo two- or three-way. It can be set easily for any point between 100 and 16kHz with 18dB/octave Butterworth filtering. For more information write to EV/TAPCO, 3810 148th Ave., N.E., Redmond WA 98052.

Crossover technology moves forward these days into more and more sophisticated levels. **DB Systems** (P.O. Box 347, Jaffrey NH 03452) are offering a new two-way design with a 24dB per octave slope and with phase coherency at all frequencies. That means flat response without interactions at the crossover point, which the manufacturer sets to order. THD is less than 0.003% in the 20Hz to 20kHz range with noise at -100dB referred to 1 volt. Outputs have level controls. A common bass option is available and an additional power supply is required. A standard version of the crossover set at 100Hz with common bass option is $316. Power supply is $62. additional.

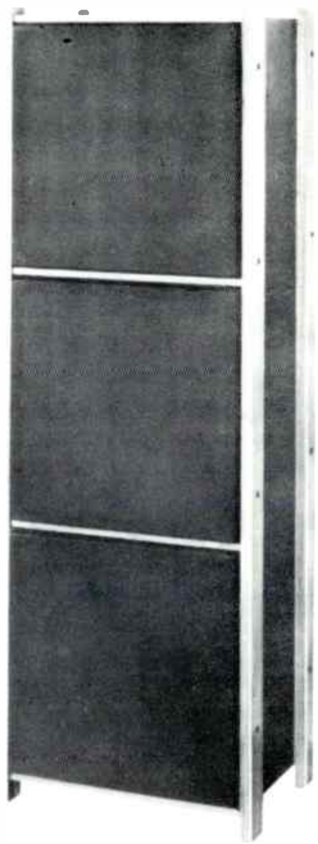
A Belgian based manufacturer has some new ideas about achieving control of a loudspeaker's radiation patterns and some measure of ambience reproduction. **KM Laboratories** introduced a new three-way passive bass-reflex system which as a rear-firing tweeter with an ellipsoid dome and controls for both high end and low end to compensate for room problems. The model AC 550 is one of three speakers in the KM line which delay some signals to achieve greater clarity, according to the manufacturer. Looks like a source of some interesting variations. For more information write, KM Laboratories, 342 Madison Ave., New York NY 10017.

Audio's newest and most lucrative fad appears to be the automobile stereo system. **Visonik** (701 Heinz Ave., Berkeley CA 94710) announces a new driver for door mount in cars. The Alphasonik D-3200 is two-way, mounts flush and has a cast aluminum frame and aluminum grille. The open back of the unit utilizes the door's space as an "enclosure," according to the manufacturer. Frequency response is claimed to be 60-22, 000Hz ±3dB.

If you like what special cables did for your home system, you may want them in your car system as well. That seems to be the rationale behind a decision by **Monster Cable** to offer *Hotwires* for speakers in automobiles. The manufacturer claims the special wires offer increased power, dynamic range and musical clarity due to maximum signal transfer. For more information write 101 Townsend St., San Francisco CA 94107 (415) 777-1355.

One of the delightful things about the do-it-yourself speaker movement afoot in the USA these days is the large number of local dealers who are stocking components for the enthusiast. One of those, **Audio Concepts** (1919 So. 19th St., LaCrosse WI 54601) offers a catalog of parts for $1 and the Jordan manual for $2.00 (a bargain, in our view). They stock Rowland, SEAS, Dalesford, Jordan, Foster, Audax, Philips, and JVC. They also offer a wide range of supplies and kits. Tell them SB sent you.

If you have dreamed about having the ability to thoroughly test and evaluate your listening room to find the best spot for the speakers and to adjust a fine-tuned equalizer so that the room's problems are compensated for, **Hall Engineering** has a dream machine for you. Their SLM-201 is a calibrated sound level meter, usable with a pink noise generator or test disc. They also offer the ATS-401 which is a complete Acoustic Test Set with all the tools needed for the job. Their handbook *Handbook on the Acoustic Testing of Audio Systems* is available for $6. Information on their instruments is free for the asking. Write: Dept. P-2-SB, P.O. Box 506, Martinsville NJ 08836.



It begins to look as though the sub-woofer idea has finally arrived. **Heath's** Model AS-1320 is a floor-standing device and has a 15″ driver with a 2″ long throw voice coil in a vented enclosure measuring 64.5″ H x 21.5″ W x 17″ D. Range is 15Hz to 750Hz but the +3dB response is 22Hz to 500 Hz. The $300 price does not include a crossover. Heath has a passive version for $45 and an electronic one for $195. The crossovers are designed for common bass operation. The subwoofer is rated for 250W max input at 8 ohms. For more information write to Heath at Benton Harbor MI 49022.

We received a very interesting flyer the other day from **Phase Matrix** (P.O. Box 101, Bethlehem CT 06751) offering a wide range of goodies including capacitors, resistors, and what appear to be come heavy duty music drivers. In addition they are offering six assembled speaker systems at about half price. Their flyer is free for the asking.

VOLUME 3, NUMBER 2 AUGUST 1981

SPEAKER BUILDER MAGAZINE

Editorial and Circulation Offices:
P.O. Box 494
Peterborough, New Hampshire 03458 U.S.A.

ADVERTISING REPRESENTATIVE
Robert H. Tucker
316 St. James Place, Philadelphia, PA 19106
Telephone (215) 627-5326

SUBSCRIPTION RATES
In the United States and Possessions
One Year (four issues) $10
Two Years (eight issues) $18

Elsewhere
Special Rates available on application in:
UNITED KINGDOM:
J.L. Lovegrove, Leazings, Leafield, Oxford, OX8 5PG, England

FRANCE:
Ainsco (France)
17, rue Saint Louis-en-l'Ile,, 75004—Paris.
Tel. 329-45-20.

ALL SUBSCRIPTIONS are for the whole year only. Each subscription begins with the first issue of the year and ends with the last issue of the year.
To subscribe, renew or change address in all areas outside the UK or France write to Circulation Department, P.O. Box 494, Peterborough, NH 03458. For subscriptions, renewals or changes of address in the UK or France write to addresses above. For gift subscriptions please include gift recipient's name and your own, with remittance. Gift card will be sent.

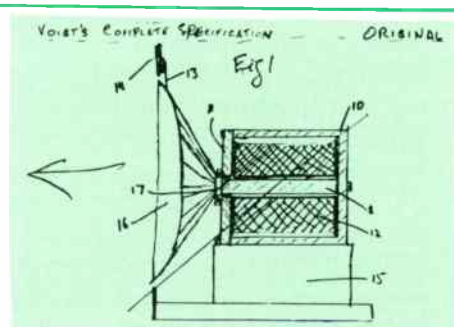
A NOTE TO CONTRIBUTORS:
We welcome contributions for possible publication in the form of manuscripts, photographs or drawings, and will be glad to consider them for publication. Please enclose a stamped, addressed return envelope with each submission. While we cannot accept responsibility for loss or damage, all material will be handled with care while in our possession. Receipt of all materials is acknowledged by postcard. Payment is on receipt of author's approved proof of materials. Contributions should be sent to Editor, *Speaker Builder*.

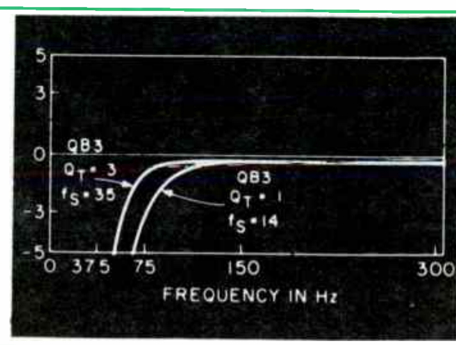
SPEAKER BUILDER MAGAZINE (US ISSN 0199-7920) is published four times a year at $10 per year; $18 for two years, by Edward T. Dell, Jr. at 5 Old Jaffrey Road, Peterborough, NH 03458 U.S.A. Second class postage paid at Peterborough, NH and pending at additional mailing offices.
POSTMASTER: If undeliverable send PS form 3579 to P.O. Box 494, Peterborough, NH 03458.

VOLUME 2
NUMBER 3

AUGUST
1981

SPEAKER BUILDER





About this issue

The Editor is very pleased to welcome three new contributing editors to the staff with this third issue of 1981. **Robert Bullock, Bruce Edgar** and **G. R. Koonce** have made remarkable and extensive contributions to the life of *Speaker Builder* with benefits for every reader. **Richard Saffran** leads off the issue with a tiny driver housed in a piece of plastic pipe which looks like fun and useful as well. **G. R. Koonce** follows with a discussion of efficiencies of closed versus vented boxes —as well as two offerings in the *Tools, Tips and Techniques* section beginning on page 28. **Bruce Edgar** has done a monumental job of gathering the materials for part one of his landmark "interview" with the late Paul G.A.H. Voigt. This remarkable man may well become accepted as a co-inventor of the moving coil loudspeaker and Edgar's research gives *Speaker Builder* readers a fascinating profile of the man. **Robert Bullock** is back this time with another of his explorations of Thiele and Small with lots of invaluable data. We found we had a large and growing collection of items for *Tools, Tips and Techniques* this time so we expanded the feature to nearly four meaty pages. Bob Bullock's reviews of two important books follow. Especially vital is his review of the AES's superb volume of loudspeaker articles from the past 50 years. **John Levreault** leads off our *Craftsman's Corner* this time with a homebrew system with debts to KEF, Linkwitz, and Jon Dahlquist. This third issue brings us to our annual early renewal offer with a way for you to save money and reduce our circulation director's headaches during the year-end renewal flood. And believe me, you will not want to miss 1982. We have a full bin of exceptionally excellent articles in store for *Speaker Builder* readers.

Leave it to Murphy

THE WORLD ACCORDING TO Murphy has become a national "in" joke. We all smile ruefully and accept as inevitable that "whatever can go wrong, will." We celebrate Murphy with everything from T-shirts to toilet paper. The joke has its use, of course. It helps us to accept the daily instances where Murphy's dictum appears to be have a headlock on reality.

That is where the trouble begins. I don't know about you but I find myself more and more discouraged about the state of a good deal of our life together. Ineptitude and carelessness seem the rule whether you are talking about company performance, labor, government, or institutions generally. As a nation we have a steadily falling productivity quotient. We don't seem to make things work and lately the economic situation appears to have taken off on its own with no means of controlling direction or purpose.

But the most serious part of our current relation to Murphy is that we begin to see ourselves as a society dominated by a fatalistic resignation to murphyism. A deadly miasma of hopeless helplessness seems the mood of many people we talk to. Dispiritedness is the prevailing outlook and we have come to expect less and less of each other and of our life together.

Underlying it all, murphyism has begun to seriously affect our attitudes toward ourselves. A recent article in *Folio* magazine reports that the primary obstacle to the massive changeover to electronic editing now taking place in the nation's publications is what the author dubbed "technophobia." Fear of machines is a widespread phenomenon in the USA, an ironic state of things when you consider our position in the world as producer of sophisticated technology.

At the bottom of each individual's fear of technology and machines is a lack of trust of himself. We are, I suspect, applying murphyism to ourselves. "I'm not good with machines. When it comes to anything mechanical, I'm all thumbs." All trembling, jello-like apprehension is more like it. It shuts down our eyes so we are unable to see. The fear of possible failure becomes *de facto* inability. It is self-induced incapacity.

The "Man vs. machine" myth that is the theme of so much popular entertainment is a virulent weed growing out of the sour soil of self mistrust. Such "modesty" about our personal way with machines conveniently allows us to be quite irresponsible about them as well. If consumers weren't so scared of machinery, they'd never buy half the rubbish they do. They'd know better.

This same miasmic cloud demeans do-it-yourself as generally hamfisted ineptitude. Sounds more like defensiveness to me. Our evident national crisis of self confidence is real enough. Its deepest roots, I believe, lie in each of us and our unwillingness to establish our own faith in ourselves. And it is a matter of faith. Not a very popular concept in these days of cool cynism—or realism, if you prefer. But that detached, hard, objective style so many of us are pleased to affect is, in my view, only a cover for a profound lack of confidence. Faith, on the other hand, is something else altogether. A person with faith in himself isn't whistling in the dark. He doesn't start by assuming he can do everything. He is eager to try whatever looks possible. He sees with excitement and analyzes with delight.

Fear and murphyism will give us momentary safety but in the long run they will destroy us. Confidence born of faith in our abilities is the only foundation for hope and a future.

Build a Mini-Pipe Speaker

by Richard Saffran

There is something fascinating about building miniatures; so when in my studies of driver catalogues I came across a three-inch full-range driver, I knew I had to try a mini speaker. I particularly wanted to see the results of using a properly aligned ported enclosure. All the mini speakers I'd ever seen were sealed, with only a "false" bass end and no real output below 150Hz.

This Panasonic driver is truly the smallest woofer I've ever seen: the cone measures only two inches in diameter, the same as a cone tweeter! The published frequency response is astoundingly flat to 10kHz, and doesn't roll off until 15kHz. The only electrical parameters Panasonic gives are the free air resonance, 90Hz, and the efficiency, 92dB/1W/1m. I had no idea if the driver would be suitable for a ported enclosure, so I ordered one to test. Getting very encouraging results, I bought three more to find consistent parameters.

I came up with the values in *Table 1.* A litte calculation suggested a box volume of at least 60 cubic inches, so the next step was to construct a suitable enclosure.

Speaker enclosures don't have to be wooden boxes; in fact, building such small-scale boxes is rather laborious. I found the solution in the plumbing section of a bargain store: a 4″ diameter PVC elbow tube, used for connecting sewer pipes. It is inexpensive ($2.50), strong and acoustically dead, and has a distinctive appearance.

Using ruler and calculator, I found the internal volume to be 105 cubic inches. Adjusting this for the space taken up by the driver, I came up with the alignment in *Table 2.*

The next problem was to find a suitable port. It had to be small, because of the height of the pipe and the limited baffle space. I finally settled on two ports made from ¾″ plastic plumbing pipe, bought at the same store.

Testing the system's near-field frequency response showed the manufacturer's ultra-flat curve to be either wishful thinking or an outright lie. A large peak centered around 1500Hz, and was certainly audible. Everything sounded annoyingly honky and nasal.

The speaker needed a notch filter, which was not hard to design. The circuit appears in *Fig. 1.* The extra resistor, R_g, brings the driver Q_t up to the correct value. The driver requires a total of 1.3Ω, distributed among three places. I leave .4Ω to be supplied by the amplifier and hook-up wire. The remaining .9Ω comes from the inductor and R_g. You can wind the inductor to have the proper DC resistance, in which case you won't need an extra R_g. If you buy the inductor, though, or wind it out of the usual 18 gauge wire, its resistance will be about .3Ω. In this case you will need R_g = .6Ω. If you wind the coil yourself with 18 gauge wire, try a ¾″ diameter, ¾″ long core, and wind 160 turns.

The value of each circuit element is not at all critical, and a tolerance of ±10 percent is fine. If possible, have the inductor and the capacitor err in opposite directions; for example, if the capacitor is 18μF (10 percent low), wind the inductor to .55mH (10 percent high).

Those are the technical details. Now here's how to build it.

Cut the baffle and bottom pieces. *Figure 2* shows the baffle. The bottom is six inches square, with a center cutout for the terminal plate. Use half-inch particle board or plywood. I recommend particle board for its neat appearance when painted.

Cut the holes in the baffle before cutting out the baffle itself. A ⅞″ spade bit is ideal for cutting the port holes. If you use a saber saw, make sure it's sharp. Cut the woofer hole on the outside of the circle, so that the hole will

TABLE 1:
Thiele-Small parameters for Panasonic 3″ woofer

R_e: 7.5Ω f_s: 90Hz efficiency: .4% (= 88dB/1W/1m)
Q_{ms}: 4.2 Q_{es}: .377 Q_{ts}: .346
V_{as}: 100in³ f_{sb}: 87Hz excursion: ±4mm

TABLE 2:
System parameters for Panasonic 3″ woofer

V_b: 95 in³	Q_l:8
∝: 1.1	h: 1.0
f_b: 87Hz	f_3: 87Hz
Q_t: .40	R_g: 1.3Ω

Alignment type: B4
Efficiency: 87dB/1W/1m
Minimum impedance: 8.8Ω

FIG. 1

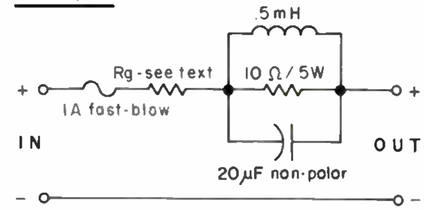


Fig. 1. The crossover network for the pipe.

be slightly larger than 2¾". The hole in the bottom depends on which terminal plate you use. The round plate supplied with the Spectrum Loudspeakers kit takes a 3¼" hole. If your terminal plate has no hole for the fuse holder, drill one. In either case be sure to drill pilot holes for the screws.

File away part of the baffle's inside face so when you mount the driver its rear openings are not blocked. Use a wood rasp at an angle in four places, as shown in *Fig. 3*. Fit the driver in the baffle to make sure the openings are clear.

Cut two pieces of one-inch fiberglass: a 12"x7½" rectangle and a 4" circle. Peel each in half so they are about half an inch thick.

Cut two 4½" lengths of the ¾" plastic pipe, and clear the plastic chips from inside the tubes. Make sure they fit into the baffle; use a wood rasp as needed to enlarge the holes. *Figure 4* shows all the parts except the fiberglass. Roughen up the ends of the enclosure pipe with a file or rasp. The object is to provide more surface area for the caulk to adhere to.

FIG. 2

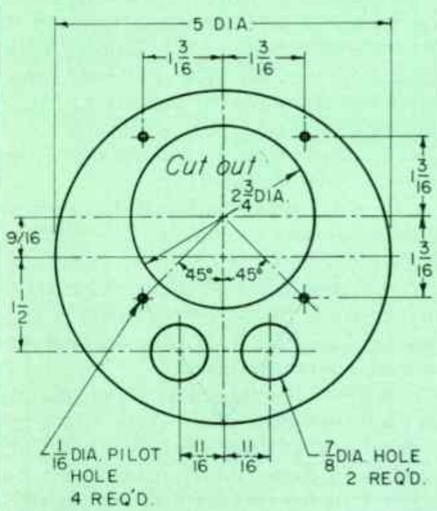


Fig. 2. Baffle cutting diagram for the driver and its pair of vents.

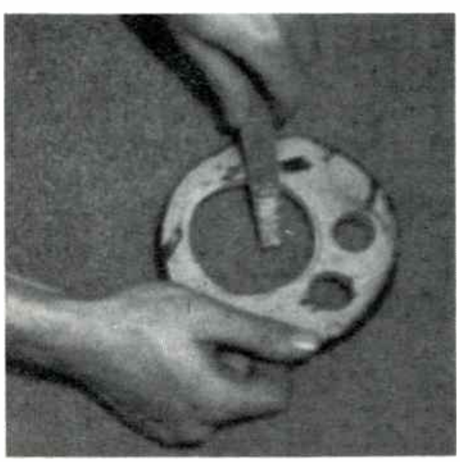


Fig. 3. Use a rasp to clean the edges of the baffle.

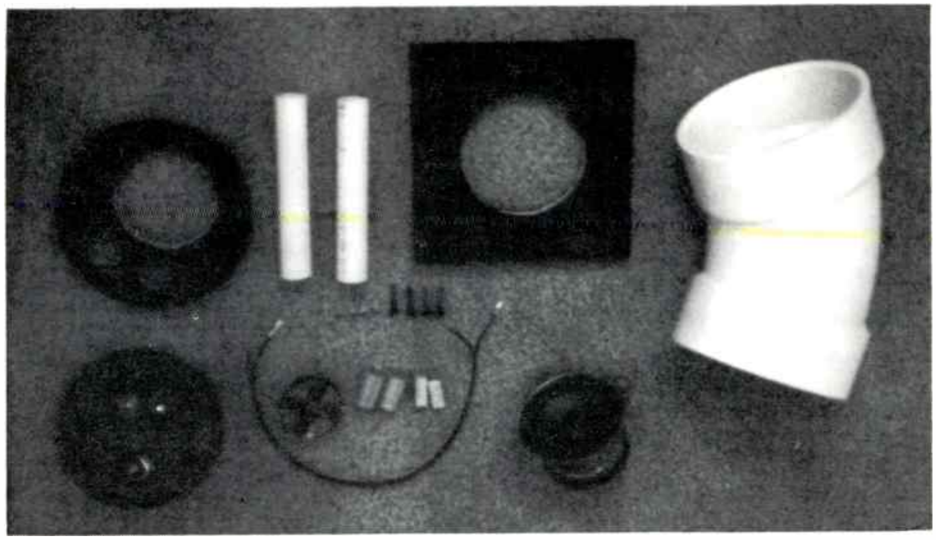


Fig. 4. Total parts for one pipe speaker.

Plug in your soldering iron. While it is heating up, assemble the baffle. Roll a thin bead of non-drying putty, such as plasticine, 3M strip caulk, or Duxseal, and press it onto the driver basket. Insert the driver into the baffle and screw it in place. Tighten the screws enough to make the driver snug, but don't tighten them all the way; this just bends the mounting tabs. Put a bead of latex caulk around the ports, half an inch from the end, and insert them into the baffle from the other end. Push them through the baffle until the caulked end is flush with the baffle top. The completed assembly is shown in *Fig. 5*. Note how the baffle has been filed away.

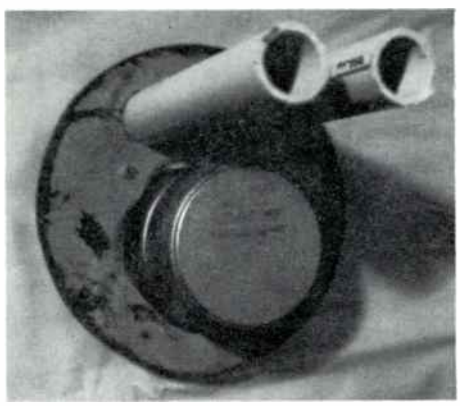


Fig. 5. Baffle with driver and vents mounted.

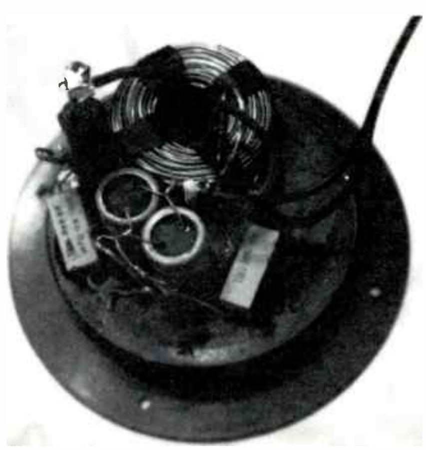


Fig. 6. The base with the crossover components in place.

Attach the terminal plate to the bottom with latex caulk or putty, and screw it in. If you have a separate fuse holder, caulk it in place. Now you are ready to wire up the filter.

Arrange the parts to follow the *Fig. 1* schematic, glueing them to the bottom with caulk. Make sure no parts stray outside a 4½" diameter circle, or you won't be able to center the pipe. The wire to the driver should be about a foot long. If you are using push-on terminals, crimp them onto the wire. The completed electrical assembly appears in *Fig. 6*.

Note that if you are using more than one capacitor to make up the right value, they must be connected *in parallel* to add values (*Fig. 6*). Solder all the wires in place.

Put a bead of caulk on one end of the

Fig. 7. Final mount of the baffle board in the damped enclosure.

pipe, and center it on the bottom. Any excess caulk on the outside can be lifted off with a knife and wiped away with a damp rag.

Put the fiberglas circle into the bottom of the pipe. Roll up the rectangular piece and insert it into the pipe, pressing it to fit the sides. Trim away any excess.

Put a bead of caulk on top of the pipe. Solder or push the wires onto the driver (double-check the polarity). Hold the baffle assembly over the pipe with the ports on the bottom, as shown in *Fig. 7*, and push the baffle onto the tube, being careful not to catch any fiberglass on the ports. Wipe off any excess caulk.

Latex caulk is one of the few adhesives that will stick to PVC pipe. It takes a day to dry, so don't put any stress on the speaker for a while. Once dry it is very strong, and you can mount the speaker on the wall or ceiling.

Attach the rubber feet. If you have none, you could try the adhesive-backed pieces of rubber sold to protect walls from doorknobs. If the fuse holder protrudes, you will need to glue on short legs first, cut from scrap or dowel.

The finished pipe speaker is shown in *Fig. 8*. I find it quite attractive as is, but you may want to make a grille. The unusual baffle precludes a normal grille design, so use your ingenuity. I have used grille foam trimmed to fit and held on with hot glue. This works well, but requires some investment in materials. You can also spray paint the pipe. Silver gives a striking space-age appearance.

Now, how does it sound? Not bad—and that's saying a great deal for a speaker that costs $15 and takes only two or three hours to build. *Figure 9* shows the near-field frequency response to 5kHz. It can produce an impressive quantity of sound. Power handling is of course limited, but I do know these speakers will handle the full output (unclipped) of a 15 watt amplifier. They have enough bass to let you know what is going on (watch for my article, "Build a Cookie Jar Subwoofer").

The high frequencies are well represented, but only on axis—the dispersion is terrible. If you listen off axis, you'll need some treble boost. Probably the speakers' greatest shortcoming is severe distortion on certain complex waveforms: occasionally a French horn may sound like a kazoo.

Continued on page 16

Fig. 8. The completed pipe speaker.

FIG. 9

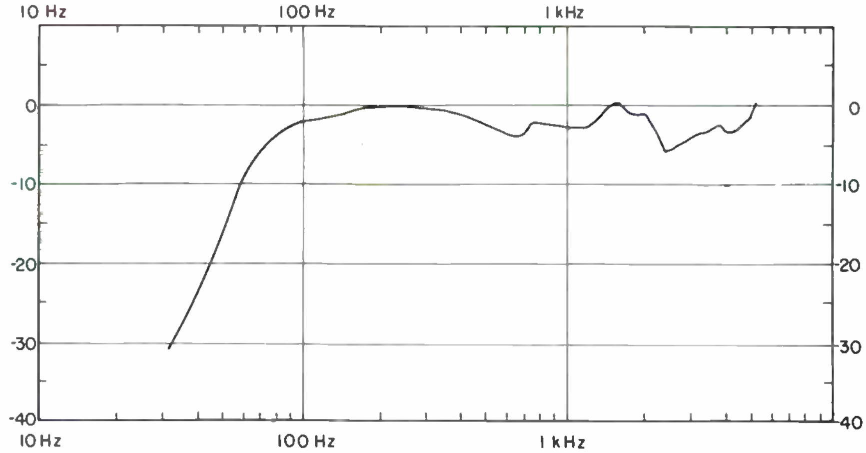


Fig. 9. Response curve of the tiny loudspeaker.

WHERE TO FIND SUPPLIES

PARTS NEEDED	SOURCES
4″ PVC 45° elbow	Bargain store
¾″ plastic pipe	Bargain store
Latex caulk	Bargain store
Non-drying putty	Bargain store
Fiberglass insulation, 1″	Bargain store
Wood screws (4)	Bargain store
Panasonic 3″ woofer	SRC part #433 ($6.02)
.5mH inductor	SRC #363 ($1.38)
10Ω/5W resistor	SRC #266 (.27) or McGee Type HH, p. 162 (.30)
20μF non-polar capacitor	SRC #258 (.97) or McGee Calrad 50-833 16μF plus Calrad 50-831 4μF, p. 79 (2x.49)
.6Ω/5W resistor	McGee type HH (ask for closest value)
Terminal plate	McGee ELCY, p. 78 (.89)
Fuse holder for 3AG fuses	McGee 90-783, p. 168 (3/1.99)
Half-inch plywood or particle board	Scrap from lumber yard
Wire	
1 amp fuse type 3AG	

McGee Radio Electronics Corp.
1901 McGee St.
Kansas City, MO 64108

SRC Audio
3238 Towerwood Dr.
Dallas, TX 75234

The following kit is available for $10.00 from Spectrum Loudspeakers, Box 2774, Toledo, OH 43606.

.55mH/1Ω inductor	1 Amp fuse
18μF capacitor	wire with push-on terminals
10Ω/5W resistor	4½″ ports (two)
round terminal plate & screws	4 black wood screws
fuse holder	strip caulk
4 adhesive rubber feet	

Add 10 percent to any of the above orders for shipping.

Closed vs. Vented Box Efficiency

by G. R. Koonce

Small has demonstrated that a vented box can be up to 3dB more efficient than closed boxes of the same NET volume and with the same −3dB frequency. This fact led me to favor vented boxes when using a driver that would work successfully in either a vented or closed box: I thought any part of that 3dB would give me that little more acoustic output for a given electrical power input.

It doesn't work that way! A specific driver will have the same efficiency in either a vented or a closed box. Any advantage the vented box may have will show up as lower net box volume (V_B) or lower −3dB frequency (f_3) or both, but not as efficiency. Enclosure design can cause peaks and other anomalies at certain frequencies, but the driver's basic efficiency is fixed.

The driver's passband efficiency, in the frequency range above where the enclosure modifies it and below where the driver response starts to fall off, is its reference efficiency. Small[2] has shown reference efficiency to be:

$$N_O = 9.64 \times 10^{-7} \frac{(f_S)^3 V_{AS}}{Q_{ES}}$$

where: N_O = Reference efficiency

$$= \frac{\text{Acoustic Watts}}{\text{Electrical Watts}}$$

f_S = free air speaker resonant frequency
V_{AS} = volume of air equivalent to the speaker acoustic compliance, in cubic meters
Q_{ES} = driver electrical Q

While these parameters are sensitive to changes in air mass load on the driver, they are driver parameters and not parameters for the driver-enclosure system.

I was still unconvinced. A vented box is entitled to three extra decibels and I wanted to find them. I decided to design vented and closed boxes for a specific driver and then compare the finished systems' reference efficiencies. Small[1,3] had developed alignments for the same driver in a vented box and a passive radiator, so it seemed like a logical one to study. This driver's parameters are:

f_S = 33Hz
Q_{ES} = 0.45
Q_{TS} = 0.37 (driver total Q)
V_{AS} = 2.01 FT^3 ($57 \times 10^{-3} M^3$)

Table I shows the results of these designs. Column A is a lossless vented box, arrived at by taking Thiele[4] alignment charts and applying linear interpolation to arrive at an alignment for Q_{TS} = 0.37. Note that the design in Column A cannot be realized in practice.

Column B is the vented alignment from Small[1] with a total box Q of 10. Column C is Small's passive radiator alignment[3] again with a box Q of 10 and with the passive radiator having the same compliance to box volume ratio as does the driver. Column D is a closed box design for a total system Q (Q_{TC}) of 1.0. Column E is another closed box design with Q_{TC} = 0.7. The range of Q_{TC} from 0.7 to 1.0 covers the commonly recommended range for closed box systems.

Note that within the accuracy of my mathematics the efficiencies are all the same. The efficiency N_O = 0.0044 or 0.44% is also the reference efficiency computed from the driver parameters alone. Thus the driver does exhibit its reference efficiency in the various box types and alignments.

Table I shows that the box volume (V_B) and lower −3dB cutoff frequency (f_3) differ considerably for the various boxes. Small[3,5] tells us how to apply decibel amounts to these differences. To calculate the efficiencies of the various driver-enclosure combinations in *Table I*, the equation is:

$$N_O = K_N f_3^3 V_B$$

where K_N is a function of the box type, alignment, and driver parameters.

This equation shows how changes in box volume and lower cutoff frequency relate to efficiency. Since the efficiencies are all equal, the value of K_N is a measure of how well you are using

TABLE I

Enclosure Type	A Ideal Vented	B Vented	C Passive Rad.	D Closed	E Closed
Net Box Volume $(Ft)^3$	1.21	1.30	1.17	0.32	0.78
−3dB Frequency f_3	35	38	42	70	62
Efficiency N_O	.44%	.44%	.44%	.43%	.43%
Enclosure Design Criterion	Max. Flat $Q_B = \infty$	Max. Flat $Q_B = 10$	Max. Flat $Q_B = 10$ $\propto = \delta$	$Q_{TC} = 1$	$Q_{TC} = .7$
Reference For Alignment	Thiele [4]	Small [1]	Small [3]	Small [5]	Small [5]
Relative K_N in dB	O(Ref)	−1.3	−2.1	−3.2	−5.5

the driver's capabilities. The values of K_N appear in the bottom line of *Table I*, converted to decibels and normalized to the value for the ideal vented box, Column A.

The real vented box wastes some 1.3dB of capability due to real losses associated with the box. The passive radiator looses an additional 0.8dB of capability due to lossses in the passive radiator, which had the same suspension as the driver.

A closed box's efficiency is a function of Q_{TC}, and Small[5] shows the maximum occurs at $Q_{TC} \cong 1.1$. Thus, Column D with $Q_{TC} = 1.0$ should be close to an optimum closed box for this driver. The relative K_N shows it down 3.2dB from the ideal vented box—so those 3dB really do exist! The closed box with $Q_{TC} = .7$ is very ineffective, being down 5.5dB from an ideal vented box and down 2.3dB from a closed box of $Q_{TC} = 1.0$.

To summarize: If you do not play games with the air mass load on a specific driver, it will deliver the same passband efficiency in any properly aligned vented or closed box. This efficiency (N_O) is the same as the driver reference efficiency and can be computed from the driver parameters alone. Any advantage a vented box may offer will appear in f_3 or V_B improvement.

How effectively a driver's capabilities are being used can be compared among various enclosure designs by computing:

$$K_N = \frac{N_O}{V_B(f_3)^3}$$

You can express V_B in any units as long as you use the same units for all enclosures. The largest K_N indicates a better combination of lower V_B and lower f_3. (Note that in any enclosure selection you must also consider acoustic power capability, transient response, and other characteristics not addressed in this article.)

REFERENCES

1. R.H. Small, "Vented-Box Loudspeaker Systems," *Journal of the Audio Engineering Society*, Vol. 21, p. 363 (June 1973); p. 439 (July/Aug. 1973); p. 549 (Sept. 1973); p. 635 (Oct. 1973).
2. R.H. Small, "Direct-Radiator Loudspeaker System Analysis," *Journal of the Audio Engineering Society*, Vol. 20, p. 383, (June 1972).
3. R.H. Small, "Passive-Radiator Loudspeaker Systems," *Journal of the Audio Engineering Society*, Vol. 22, p. 593 (Oct. 1974); p. 683 (Nov. 1974).
4. A.N. Thiele, "Loudspeakers in Vented Boxes," *Journal of the Audio Engineering Society*, Vol. 19, p. 382 (May 1971) and p. 471 (June 1971).
5. R.H. Small, "Closed Box Loudspeaker Systems," *Journal of the Audio Engineering Society*, Vol. 20, p. 798 (Dec. 1972); Vol. 21, p. 11 (Jan./Feb. 1973).

An Interview with P.G.A.H. Voigt

Part One

by Bruce C. Edgar

Introduction

I was talking with our Editor Ed Dell about horn loudspeakers when he mentioned the British audio pioneer P.G.A.H. Voigt. Ed had received Voigt's address from Geoffrey Wilson during a chance meeting in London, outside a car rental agency in Heathrow. Prof. Wilson was returning to the U.S. after his father Percy's funeral. Since Percy Wilson was one of the most outstanding and venerable of English audio authorities and a horn enthusiast—it was natural that Paul Voigt's name should come up. The brief interchange elicited a letter from Wilson, without which our contact with Voigt would not have been possible. Ed supplied Voigt's address in Canada, and in April, 1980, I wrote to him about his tractrix horns. In August *Mrs.* Voigt wrote to me; however, since her letter covered none of my questions, I called Voigt, and this was the beginning of many letter and telephone exchanges.

Ed and I asked Voigt if he would allow me to interview him for *Speaker Builder*. At first he refused, saying he had too many projects and immediate worries to deal with. But he gradually relented, and we planned the interview for January, 1981. However, over Christmas he developed a painful hernia which required surgery, and we postponed our meeting.

During January, while awaiting the surgery, Voigt wrote several long letters on many of the speaker subjects I'd been asking about. He went into surgery on February 3; all seemed to go well, and he came home five days later to recuperate. But on February 9 he suffered a heart attack and died.

Mrs. Voigt sent me all the letters he'd been working on. It seems to me, from their volume, that he sensed his time was running out and wanted to "set the record straight." So I have edited them and other material to create the "interview" Voigt in person was never able to give us.

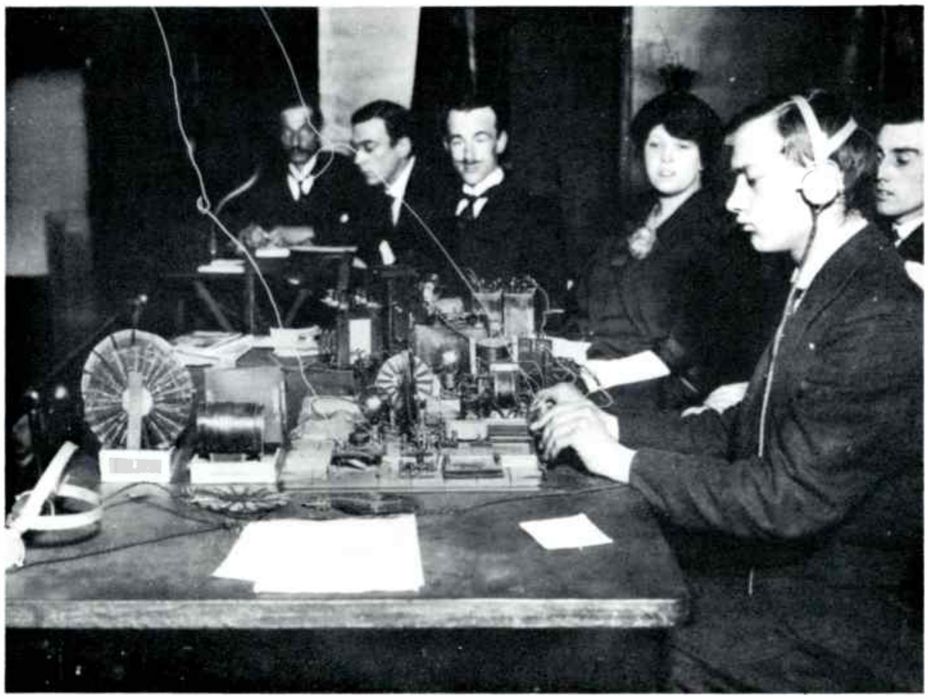


Fig. 1. The young Paul Voigt (with earphones) demonstrates a reflex (dual high and low frequency) amplifier circuit for the Wireless and Experimental Association of Peckham in 1922.

Paul Gustavus Adolphus Helmuth Voigt was born on Dec. 9, 1901, in London, England, of German parents who emigrated and became naturalized British citizens in the late 1800's. His father was a buckram importer; his mother, says Paul's widow Ida, was the "real brains of the family" and a constant source of encouragement to her son. She lived to be 103, and Voigt expected to emulate her.

Paul Voigt's approach to loudspeaker design was to use intuitive physical reasoning, in the style of many researchers of the early 1900's. Though he had many friends he was a loner who persisted towards a goal of audio perfection in the face of contrary contemporary thought and wisdom. Peter Baxandall said of Voigt in *Audio Amateur* (4/79, p. 15), "He was a splendid chap....He demonstrated his corner horn loudspeaker. I heard that evening a standard of music reproduction I'd never heard before." He was a hero to many British audiophiles of the first half of this century, but relatively unknown in the U.S.A.

Voigt was an audio "systems" engineer before the term was invented. He developed and/or invented velocity and capacitor microphones, amplifiers, transformers, moving coil cutters and pickups, and horn loudspeakers, all for the quality reproduction of sound. By the end of his career he held 32 patents. In many areas he was ahead of his time, and by the time the world caught up with him, his contributions were either ignored or forgotten. So as you read this interview, see how many modern hifi concepts and ideas had precursors in Voigt's work.

SB: Where were you educated?
Voigt: I was a "born" inventor and for that reason wanted to learn engineering. My parents could afford to send

me to Dulwich College [a private high school], two miles from home. It had an engineering side. And so during World War I, from the age of 13, I was learning basics of engineering. In 1922, I graduated in Electrical Engineering from University College, London.

By then, with the war over, radio was permitted again. I was experimenting on the subject, and my first article appeared in *Wireless World*, Dec. 10, 1921, before I had even graduated. I wrote it when I was 19. [See *Fig. 1.*]

SB: What was your first job?

Voigt: My first paid employment was at J.E. Hough, Ltd., Edison Bell Works in 1922. They made gramophone records and plastic mouldings for the radio and other trades. The firm were afraid the B.B.C.'s advent would damage the record market, so they sensibly decided to enter that market themselves. I was one of those taken on to get the radio side started.

I knew I was an inventor. There was no way of knowing ahead of time how valuable my ideas might be, and employees were normally obligated to sign away their patent rights. But I insisted that my patents should remain my property (I to pay the cost of patenting), giving the firm preferential rights as regards licensing. There never was a better incentive to invent things of direct use to the company.

Apart from my work designing radios and test gear, etc., by late 1926 I had developed the first British-designed electric recording system to last for years under practical working conditions. Our competitors were ahead of us, only because they were using U.S.-designed equipment.

I had not been with Hough for long before I realized that if the artists and musicians played and sang as they did for the B.B.C., into a mike whose output was amplified and fed into some kind of electric cutter, then a better master should result than we could get from using an assortment of large trumpets. Hough encouraged me. And before the end of 1926 I had designed a moving coil cutter system which meant that records did not have the hysteresis distortion natural to moving iron devices. Hough put the system into commercial use and, with minor improvements, it remained in use until Edison Bell, Ltd., (the later name of the company) died in the slump in April 1933.

SB: Tell us about your early experiments with microphones.

Voigt: Although my initial function was to develop radio components and sets for manufacture, I soon became interested in electric recording. Just when that interest crystallized I cannot say without my notes, but a brochure entitled "The History of Edison Bell" shows a picture of the recording studio in which a swan neck horn Browns loudspeaker is clearly to be seen. I had it fixed there and was using it as a "backwards" mike. The electrical people had put in a connecting phone-type circuit to my lab, where I had a similar loudspeaker used in the right way. No amplification was needed, and while the speaker mike (perhaps the 120Ω winding) may not have matched the connecting circuit, that was short and the mike certainly matched the output speaker. At one time I tried carbon mikes, but the amplitude distortion made me scrap the idea.

SB: How did you build and set up your first good microphone?

Voigt: I had a portion of the wall between the studio and the lab removed and a shelf put across the opening. On that shelf I put a specially designed mike, which I'll describe in a minute, and I hid the opening with thin silk or something. The mike's square frame did not fit the opening, so I closed the space around it with strips of carpet. The face of the mike was in the plane of the partition wall, simulating a closed window.

From what I learned from the excursion requirements, any velocity operated mike, moving iron or moving coil, already had to be free to move about without any appreciable restraint. The ordinary arrangement of a diaphragm clamped around its edge was *out*.

The special mike's diaphragm was the size and shape of a saucer and spun of very thin aluminum. Tangential spokes from its edge met at the hub on the convex side. The curved diaphragm was suspended in a circular hole in a square frame with about ⅛" clearnace around its periphery, on two threads about 1½" long spaced about 45° either side of the vertical center line. To stop it from flopping about, two rubber threads pulled it down; each was at about 45° on either side of the lower part of the center line. I may have stuffed cotton into the clearance between the diaphragm and the frame.

The transducer part consisted of a flat elongated coil mounted with its plane vertical and on an extrapolation of the diaphragm spin axis. Using magnets (at first permanent magnets out of a magneto, but later we used an electro-magnet) fitted with poles that provided a plane vertical air gap, the end of the coil was located within the pole piece jaws and free to move. Thus as the diaphragm vibrated, the coil vibrated, inducing a voltage in that part of its coil within the magnetic field. This arrangement was not efficient, but as a mike it was easier to put in some amplification than to devise a freely supported circular coil and magnet system.

SB: How did you become interested in loudspeakers?

Voigt: We badly needed a good speaker to use in the studio. Musicians wasted much time in the recording studio because they could not tell from the gramophones in use at the time just how good or bad the recording was.

For laboratory test purposes, I wanted a perfect loudspeaker, or at least as close as possible. On April 30, 1924, when the B.B.C. was about 18 months old, Capt. P.P. Eckersley, an ex-Marconi engineer who was then the B.B.C.'s Chief Engineer, lectured to the Radio Society of Great Britain on how they coped with the B.B.C.'s early problems. I had already considered what perfect mono sound should be like if ever we could produce it, and in the discussion which followed the lecture was able to ventilate my hole in the wall theory. The lecture was reported in *Wireless World* of May 28, 1924, and the discussion in the next week's issue.

SB: Can you give a brief description of your hole in the wall theory?

Voigt: In those early days, I had done a mental preliminary survey, not of what bits and pieces should be put together to get good audio, but more fundamentally of what good audio would be like if we ever got it.

My 1924 answer was my hole in the wall theory, which was controversial for a long time. Some people thought perfect reproduction should sound as though the sound originated in the room you were in. This overlooks the fact that your room has one set of reverberations and the studio or concert hall a totally different one. The latter set can easily be made negligible by having the announcer come right up to the hole on his side of the wall and, as it were, talk direct to you through that hole. That theory and the consequent understanding of what to aim for has been fundamental to my outlook.

Incidentally, a non-technical musical expert, visiting a friend having a demonstration of my corner horn wrote up his experience for some musical journal without using the word "hole": he described his experience as listening through a window.

SB: What was the "state of the art" of gramophones and loudspeakers in the early '20's?

Voigt: When I asked leading gramophone designers what perfect reproduction would sound like, I found "forward" tone was apparently the idea. One of Edison Bell's slogans at the time was, "It rings out loud and clear," so we have a clue to 1920 ideas of perfect reproduction! Now, having some scientific knowledge, I could not quite understand how a mechanical instrument could be expected to produce a tone which would appear to originate at some point six inches or so in front of the mouth of the horn, unless this effect were achieved by resonance or some form of forward reflection which would give a focal point there.

In the 1920's loudspeakers for radio, etc., mostly began with an enlarged headphone mechanism coupled to a horn. The general idea had developed that the horn was the reason why the audio quality was so poor. I myself looked upon horns as an unknown quantity, with the introduction of extra resonances into the system as a most probable disadvantage. [*Editor's note:* This attitude changed rather drastically later.]

With my hole in the wall concept in mind, it was obvious to me that for bass it was necessary to provide for the free oscillation of air volume through any such real or imaginary hole; therefore the standard type of reproducer based upon the idea of a "blown up" earphone with trumpet attached would not meet the end requirements. Even the so-called hornless devices, with large diaphragms, were driven by some electromagnetic mechanism which would be inefficient if adjustable and adjusted to be well clear of the pole piece, and would collapse onto the pole pieces if too close. To prevent either occurence, the diaphragms had to be stiff, with no freedom of movement. After World War I I had seen a Magnavox with a 20" or so horn and moving coil drive; but it sounded like the flat bottom of an enamelled army mug of those days. I do not suppose for a moment that its diaphragm *was* made out of a mug, but that's what it sounded like, and with an iron diaphragm clamped around its edge that is just about what you can expect.

SB: What is your normal approach to research?

Voigt: My normal way of trying to achieve progress is to get to grips with a problem and work out the answer. Then I compare that answer with the established ideas when such already exist. If my answer fits the established ideas, then I have discovered I can safely use those ideas. If, on the contrary, my result does not fit the established ones, then arises the question: which is correct, or are both wrong?

Since I am rotten at math, my approach is rarely the mathematical one. The usefulness of math depends upon the accuracy of the assumptions on which that math is based.

SB: How did you start designing moving coil loudspeakers?

Voigt: At Edison Bell I was experimenting with moving coil systems. Using my knowledge, I designed the moving coil cutter for the recording system. I was familiar with the consequence of applying various magnetic field strengths to current carrying conductors.

One major result is that the greater the field strength, the greater the electromagnetic force for a given current. In those days undistorted audio watts were expensive; that was one reason for pushing up the flux density. Another was that the greater the flux density, the greater the electromagnetic damping on the moving coil (other things being unchanged). And there was a more subtle result, theoretical but partly imaginary.

Suppose you could make the field strength so high that the electro-acoustic efficiency would average 100 percent over the whole audio scale, would it not have a flat energy response curve with no peaks or troughs? While 100 percent efficiency is unattainable in practice, there was no question in my mind that the nearer you could get in that direction the better would be the ratio of average to peak. For example, if the average was one quarter of 100 percent, i.e., 25 percent, any energy peak beyond 6dB would provide the missing part for a perpetual motion machine!

The fact that in my lab I had both DC and AC mains meant that if I designed a huge magnet with electrical excitation, in those days when valve rectifiers were still unreliable, providing the excitation presented no difficulties.

SB: What did your first loudspeaker designs look like?

Voigt: I designed for high flux density on the electromagnetic moving coil drive. The company blacksmith provided a U-shaped soft iron core bent, as I recall, out of 2" diameter bar. Onto its straight portions went four separate coils, each with a carbon lamp across it to take care of the "splash" when switching off, and so, for my earliest high power magnet experiments, I had a quarter kilowatt excited field U magnet to experiment with. In due time, I arranged for a pole-tip system suitable for a cylindrical coil. (In my school text book at Dulwich, such coils were called "Solenoids." Nowadays that word describes such a coil plus iron cores to operate switches, etc.)

In my case the coil actuated a lightweight saucer-shaped aluminum diaphragm, driven through aluminum spokes and supported so as to be able to move very freely. It was surrounded by strips of mother's old carpets to act as a non-resonant baffle.

You will notice that my diaphragms (see *Fig.* 2) are based on the "cap of a sphere" shape, with "spokes" tangential to the surface. I used this arrangement on the moving coil mikes I experimented with while developing the recording system, and on the early moving coil loudspeaker drives. It never went into production, as I had no satisfactory method of making the spokes adhere to the spun aluminum diaphragm. When the adhesive between the spokes and the diaphragm gave way, it would rattle under working conditions. When I had overhauled it carefully and had my moving coil system working, I would "turn up the wick" and alas, within five minutes it would be rattling again!

By the time the patent examiners had my complete loudspeaker specification under study, they were aware of the work of Rice and Kellogg. That anticipated my concept so completely that I removed from the complete specification and the claims any mention of the moving coil system. Such removal meant that manufactuie for sale was out, but not that I had to give up my

FIG. 2

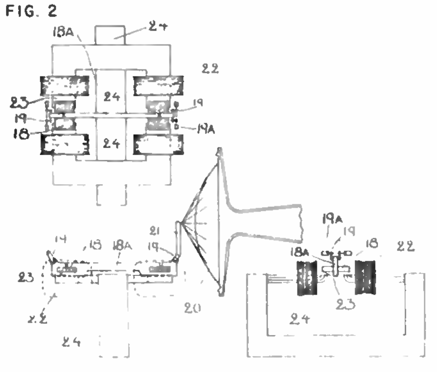


Fig. 2a. Early Voigt moving coil loudspeaker portrayed in a patent drawing. (British Patent #238,310.)

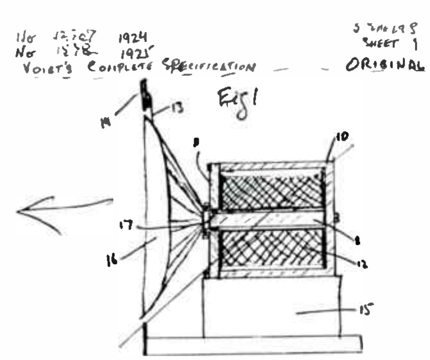


Fig. 2b. Voigt's original drawing of the moving coil loudspeaker which he had to remove because of the prior claims of Rice and Kellogg.

hole in the wall concept or stop experimenting with moving coil systems.
SB: Was this your first patent application?
Voigt: No, I had six previous patents granted to me, all on wireless devices. I was eventually granted British Patent #238,310 for "Improvements to Sound Reproducers." That is the one which would have anticipated Rice-Kellogg if it had been two months earlier. My application date was May 20, 1924, so the Rice-Kellogg application should be in March of that year. I was quite unaware of their work at that time; the news had not reached Britain.
[*Editor's note:* Rice and Kellogg were American engineers working for General Electric who developed the first good electromagnetic moving coil loudspeaker? Kellogg's patent application was filed on March 27, 1924.]
SB: How did your first loudspeaker perform?
Voigt: When it was all ready for test, I was looking forward to hearing something vastly better than any previous loudspeaker. Upon switching on I was very, very disappointed. I had never had anything sounding so "tinny." The highs were strong and the lows very poor.

On thinking it out, I realized that when calculating the load into which I assumed the square inches of diaphragm area (piston equivalent) were working, I had used the mechanical ohms figure for a plane audio wavefront.

The disappointing result I was getting, I realized, was due to that assumption being approximately right for frequencies so high that the wavelength was small relative to the dimensions for the diaphragm, but totally wrong under reverse conditions when the diaphragm dimensions were small relative to the wavelength. Under those conditions, instead of reacting with back pressure when exposed to the peak pressure of low frequency sound, the air simply escaped sideways out of the compression region; and that happened in reverse during the suction half of the sound cycle.

Evidently, I had to find some means of preventing those lateral component motions, and that is how I came to design my horn. The obvious way to prevent lateral motion, is close to the diaphragm is to fit a large diameter pipe. But analysis of that obvious way shows that while the to and from flow of the air propagating the sound is prevented from lateral motion, it will propagate with a *plane* wavefront, at right angles to the inner surface of the pipe, until it reaches the end of the pipe. At that point it abruptly escapes transversely and thus a coupling takes place into an air resistance totally different to the mechanical ohms resistance at the diaphragm.

FIG. 3

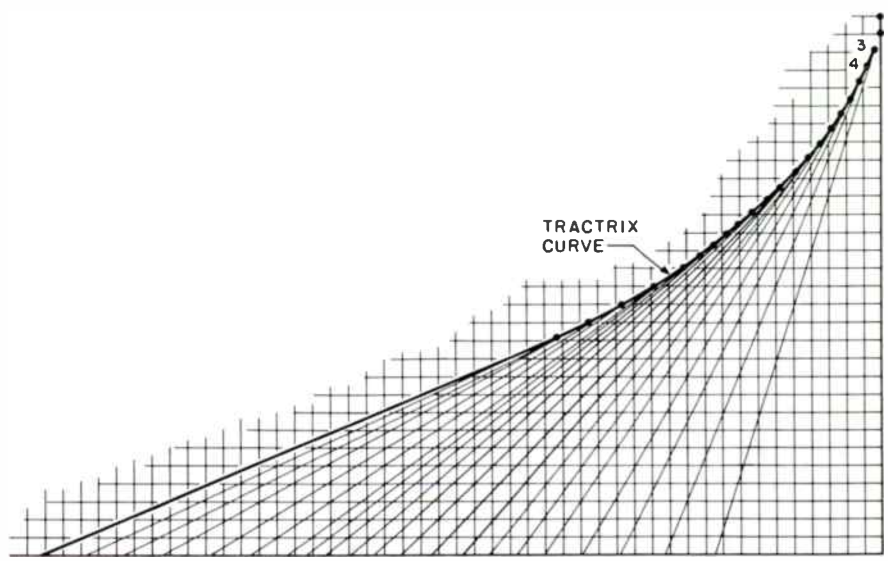


Fig. 3. Drawing of the Tractrix curve from Voigt's instructions.

The parallel pipe thus basically only transfers the discontinuity which permits the lateral "escape" near the diaphragm to a more distant location. It does not eliminate the discontinuity. What is worse, at the discontinuity a reflection analogous to that in a transmission line travels back to the diaphragm, and tends to make the pipe behave rather like an organ pipe!
SB: How did you make the transition from a pipe to a horn?
Voigt: Part of the "trick" necessary to improve the situation at the output end of the straight pipe is to scrap that shape and put a slight, expanding taper at the diaphragm end. If that taper is gentle enough the lateral motion can be reduced till it is too slight to introduce any major loss of reaction pressure.

In a pipe which tapers slightly outward, the sound wave will no longer travel with a perfectly flat wavefront. Where the wavefront travels along the surface of the taper, it will quite naturally travel parallel to that tapered surface and to the surface on the opposite side. Thus, the wavefront edges will diverge to fit the expanding taper, and the normal spherical expansion of a sound wave has begun.

As the area increases, its relation to the lower frequency wavelengths improves. This is beneficial when these wavelengths reach the end of the horn, but they have already suffered a little because of the poorer relationship near the smaller diaphragm. And, if the taper remains gentle, the wavefront will only expand slowly, making the horn inconveniently long if that benefit is to be preserved.

The practical solution is to increase the outward taper as the distance from the diaphragm increases. This too is desirable. We increase the taper gradually to a 90° angle to the axis, and if possible, place a flat baffle around the opening. Then by the time the wavefront reaches the opening, instead of an abrupt discontinuity it passes a rounded surface leading to the baffle, and the ill effects of the enclosure ending are greatly diminished.
SB: How did you draw the horn curve?
Voigt: The curve (see *Fig. 3*) is easily plotted on drawing-board paper by starting with deciding on the semi-mouth size at the 90° to the axis taper. Suppose that size is to be near 30cm. Place a rule at 90° to the axis and mark the approximate position of the mouth at 30cm from the axis (point *#1*). Mark clearly the first cm from that point toward the axis (point #2). Keep the lower end of the rule on the axis and move it along the axis, keeping the 30cm rule point near the clearly marked top cm. In fact, let the edge of the rule pass over point #2 (which is 29cm from the axis). When point #2 is at 30½ cm along the rule, step the motion along the axis and mark the next point, #3, at the 29½cm mark on the rule. This point will be some 28cm from the axis. Move the axis end of the rule along the axis again so that point #3 is at 30½cm along the rule and mark point #4 at 29½cm along the rule.

A curve will develop. Continue the above procedure. As the curve flattens out, the steps can be made longer. The curve we want is the curved line through the points.

As I drew out this curve to make the smoothest possible transition from the nearly parallel taper near the diaphragm, to a 90° angle to the axis, I wondered if I had re-invented the standard logarithmic (exponential) curve mentioned in some advertisements in the mid '20's. When I plotted the latter, I found that at the throat, where the taper was very slight, the difference was negligible. As I approached the mouth, however, the taper increased faster than the logarithmic curve, and the 90° was reached quite soon. Later I heard from our draftsman that the curve was known in the mechanical world as a Tractrix.

SB: How did you come to the conclusion that the wavefronts in a horn must be curved instead of flat?

Voigt: I was familiar with basic engineering principles. It follows from the most elementary of these, that where the edge of the wavefront rubs on the inside surface of the horn, the wave surface has no alternative but to orient itself at right angles, to that surface.

Try and imagine the pressure face of a wavefront endeavoring to propagate parallel to the axis. It will have to leave a gap between its own circumference and the expanding inner surface of the horn. The further forward that wavefront goes, the bigger will the gap become, and the wavefront will automatically spread sideways to fill that gap.

This sideways spread reduces the volume moving forwards and thereby slows it down. In time this slows down the wavefront, the effect being greatest where the gap is being filled and least at the furthest distance from the gap. With a circular horn, the expanding gap exists all around the circle, and the furthest distance available to the wavefront is in the middle, i.e., on the axis. Thus inevitably the wavefront will bulge forward. With a circular horn, that bulge will not be 100 percent spherical. This will surprise most readers, but it is not a serious matter.

To sum up: the difference between the tractrix and the exponential with its flat wavefront (theory) is that one was designed by a 24-year-old engineer familiar with the elementary mechanics of nature, the other by a skilled mathematician. Take your choice! [*Editor's note:* On July 5, 1926 Voigt applied for a patent, and he was granted British Patent #278,098 for the Tractrix Horn in 1927.] □

REFERENCES

1. Voigt, P.G.A.H., A Controversial Idea from England, *Audio Engineering, 24,* pp. 40-41, Oct. 1950.
2. Rice, C.W. and E.W. Kellogg, Notes on the Development of a New Type of Hornless Loudspeaker, *Trans. A.I.E.E., 44,* pp. 461-480, 1925.
3. Voigt, P.G.A.H., Letter to Editor, *Radio-Electronics, 30,* pp. 16, 20, 22, Mar. 1959.
4.________, All About the Reflex Enclosure, *Radio Electronics 30,* p. 38, Feb. 1959.
5. Wilson, P., Cabinets for Speakers—II, *Gramophone, 14,* p. 354, Jan. 1937.
6. Olson, H.F., *Acoustical Engineering,* D. Van Nostrand, N.Y., 1940, p. 128.
7. Augspurger, G.L., Horn-Type Speaker Systems, *Radio-Electronics, 26,* p. 82-86, May 1955.
8. Chave, D.M., Letter to Editor, *Radio-Electronics, 26,* p. 16, July 1955.
9. Voigt, P.G.A.H., Text of Address to British Sound Recording Assn., Sept. 21, 1957. *Gramophone Record Review,* p. 966-967, Oct. 1957.
10.________, Velocity of Electromagnetic Waves and the Expanding Universe, *Proc. I.E.E.* (London), Electronics and Power, (March) p. 109, 1965.
11. 49th A.E.S. Convention, *J.A.E.S., 22,* p. 712, 1974.
12. Voigt, P.G.A.H., A Box for Your Speaker, *Radio-Electronics, 30,* p. 51, Jan. 1959.
13.________, All About the Reflex, *Radio-Electronics, 30,* p. 82, Nov. 1959.
14. The Voigt Loudspeaker, *Gramophone, 10,* p. 298, Dec. 1933.
Voigt Loudspeaker, *Wireless World, 33,* p. 274, Sept. 29, 1933.
15. Wilson, P. and G.L. Wilson, Horn Theory and the Phonograph, *J. Audio Engineering Soc., 23,* pp. 194-199, 1975.
Voigt Domestic Loudspeaker, *Wireless World, 35,* p. 561, Dec. 29, 1934.
16. Voigt Permanent-Magnet Loudspeaker, *Wireless World, 55,* p. 103, March 1949.

Other Works by P.G.A.H. Voigt on Audio

1. Voigt, P.G.A.H., Comments on "Faithful Reproduction by Broadcast" by P.P. Eckersly, *Wireless World,* p. 290, May 28, 1924.
2.________, Discussion of "Some Acoustic and Telephone Measurements" by Harbottle, *I.E.E., 71,* p. 632, 1932.
3.________, *Sound Reproduction, Proc. Brit. Kine. Soc., #7,* Jan. 4, 1932.
4.________, How Near Are We to Perfect Sound Reproduction, *Proc. Brit. Kine. Soc., #30,* Nov. 26, 1934.
5.________, Sound Distribution in PA Work, *Wireless World, 38,* p. 293, Mar. 20, 1936.
6.________, Collaborating with the Architect, *Wireless World, 40,* p. 118, Feb. 5, 1937.
7.________, Getting the Best From Records, *Wireless World, 46,* p. 141, Feb.; p. 177, Mar.; p. 210, Apr.; p. 240, May, 1940.
8.________, Sound Reproduction, *J. Brit. Inst. Radio Engr., 1,* p. 74, June 1940.
9.________, Some Design Considerations on Pickups, *Audio Engr., 36,* p. 64, 1952.
10.________, Future Sound and TV Developments, *Trade Builder (Canada), 28,* p. 46, June 1951.
11.________, All About the Reflex Enclosure, *Radio-Electronics, 30,* p. 38-40, Feb.; p. 24, 26, 82, 83, 88, 90, 93, 94, Apr.; p. 56-58, May; p. 55-58, June; p. 76, 80-82, July; p. 39-41, Aug.; p. 72-75, Sept.; p. 28, 50-52, Oct., p. 78-82; Nov., 1959.
12.________, How I Was Nearly the Inventor of the Moving Coil Loudspeaker, *Electron (Canada), 10,* p. 47, May 1973.

Reference Works on Paul Voigt

1. Beckett, L., Lowther and Voigt (letter), *Radio-Electronics, 26,* p. 10, Dec. 1955.
2. Briggs, G.A., Briggs Speaks Up (Letter), *Radio-Electronics, 27,* p. 14, Jan. 1956.
3. Hartley, H.A., Voigt and Lowther (Letter), *Radio-Electronics, 27,* p. 14, Jan. 1956.
4. Wilson, P., Paul Voigt and Edison-Bell, *Gramophone, 43,* p. 269-270, Nov.; p. 326-327, Dec. 1965.
5. Paul Voigt's Contributions to Audio. *British Kinematography, Sound and Television, 52,* p. 316-327, Oct., 1970.

Acknowledgements

I thank the following people for their support in putting together this interview: Mrs. Voigt for her generosity in loaning me original photographs and papers from Paul Voigt's files; Prof. Geoffrey Wilson for copies of Voigt's letters to his father, Percy Wilson, and for many conversations; Dr. Robert Edgar, Debe Arsenych, Karen Olds, and Celine Walker for tracking down many of the old references; Joe Paul for the fine photo-copying and retouching; and Yvonne Owens for retyping many of Voigt's old letters.

The Interviewer

Dr. Bruce C. Edgar is a Space Scientist for the Aerospace Corporation and is a Contributing Editor for Speaker Builder *in the areas of horn design and the history of loudspeakers.*

BUILD A MINI PIPE SPEAKER

Continued from page 9

This is no problem with pop music.

Fuse-protected and nearly unbreakable, these are excellent extension speakers. Floor, wall, or ceiling mounting helps bring up the bass end, and the angle bend aims the driver towards the listener. They mount easily with four long screws.

They also work well as rear channel speakers in a Dynaquad® arrangement. Connect the rear speaker across the two hot terminals of the amplifier. You can connect a second rear speaker in series with the first, out of phase. To balance the system, disconnect the front speakers, and with a mono signal source, adjust the balance control for minimum output from the rear speakers. The result is very pleasant with many recordings. If the rear speakers are too loud, wire a 20Ω/20 watt variable resistor in series.

I might add that one or two of these would be a fine gift from the enthusiastic speaker builder. Most people are happy to have music in their kitchen or bedroom. As my friend and associate Eric Johanson once said, "Everybody needs loudspeakers."

My thanks to Larry Perault and Eric Johanson of Spectrum Loudspeakers for competent assistance, and to Murray Saffran for the fine photographs. My next construction project will be an uncompromising two-way system for about $70. □

TIME ALIGNED AND NONDIFFRACTIVE

It makes no sense to build a speaker system that imitates all the design errors and compromises of commercial speakers. Our speaker designs are unique in the following ways:

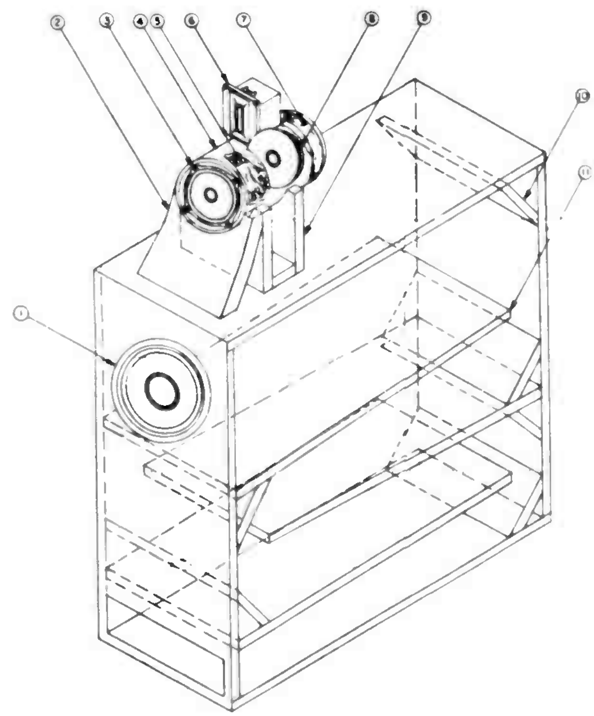
(1) ALL OUR DESIGNS ARE NON-DIFFRACTIVE. As you know your midrange driver must never be mounted in the middle of a baffle that is part of a box. This destroys imaging, causes harmonic inaccuracy and blurring. All of our midrange drivers fit into your our custom made **TUBULAR MIDRANGE ENCLOSURES** that give higher rigidity, minimal baffling (¼″ around driver) and eliminates diffraction distortion.

(2) TIME ALIGNMENT. If your speakers aren't time aligned you are destroying the phase relations that you worked so hard to preserve with your electronics. All of our kits are designed so that ALL drivers are time aligned. Without this feature it is an impossibility to have accurate imaging, depth, and clarity.

(3) OPTIMAL WOOFER ENCLOSURES-all of our woofer enclosures-transmission line, ported or infinite baffle are designed for a Q of .7 to 1 for optimum transient response. The construction is heavy duty, braced and formica veneered with minimal frontal area to eliminate mid bass reflection distortion.

(4) BALANCED DRIVERS. If you bought the best drivers and they weren't balanced to each other you would have a junk sound. We don't give you many choices of drivers, but we have spent lots of money and time giving you the right combination of Audax, SEAS, Peerless, RTR, and Panasonic leaf tweeters.

(5) HOW TO BUILD IT RIGHT—OUR SPEAKER BIBLE is an instruction book on how to build-do it right-cabinet construction, decoupling driver mounting, tubular midranges, time alignment, 29 pages of essential design information that is unique. Check it out. Our SPEAKER BIBLE and catalog is the best investment in speaker building you have ever made. Send $2.00.



This is our TL10.4 Speaker Kit. It consists of a tapered transmission line with narrow fronted baffled, Tubular midrange enclosure for Audax midrange, dome upper midrange, and modified Panasonic Ribbon Tweeter. All the drivers are time aligned. The entire system is modular and has external crossovers so you can easily switch from passive to electronic designs. Our SPEAKER BIBLE has more information about this system.

New York Audio Labs.

33 North Riverside Avenue Croton-On-Hudson, New York 10520

914-271-5145.

Thiele, Small and Vented Loudspeaker Design, Part IV

Alternative Alignments

by Robert M. Bullock III

Now that you are experts in vented loudspeaker system design, construction, and adjustment, it's time to examine some additional alignment possibilities. You may have the impression that once you've selected the drivers you are locked into the unique design spelled out by the tables in my first article (*SB* 4/80, p. 7). But in loudspeaker design as in life, things are not that simple. In fact, there are many reasonable alternatives. I will discuss some of the unequalized possibilities here and go into equalized alignments in a later article.

OLD AND NEW ALIGNMENTS

Recall that the tables in my first article list what are called fourth order quasi-Butterworth (QB3) and fourth order Chebyshev (C4) alignments which yield QB3 and C4 responses. If you visualize each point in the rectangle in *Fig. 1* as corresponding to a possible fourth order response, then the QB3 and C4 responses will all lie on the curves indicated. Many other points in the rectangle represent good loudspeaker responses; the problem is to distinguish them mathematically from the bad ones. I have chosen several alternatives for which alignment tables are relatively easy to construct, and will show you a representative response curve for each alternative alignment type, comparing them so you can decide which alignments are acceptable by your criteria.

Two new response types can be obtained by extending the QB3 and C4 alignments to other Q_T values. The extension of the C4 is called a sub-Chebyshev (SC4), and Small mentions it[1] as a possibly attractive alternative. The QB3 extension has not been mentioned in the literature; so I will call it a super-quasi-Butterworth (SQB3) because it covers higher Q_T values. These

FIG. 1

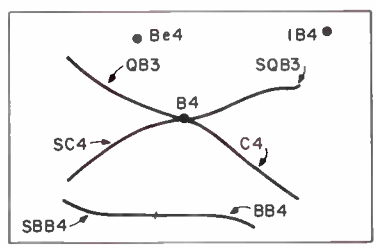


Fig. 1. The universe of possible fourth order responses.

FIG. 2

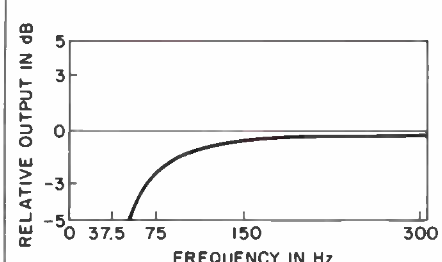


Fig. 2. Simulated response of a SBB4 alignment with f_S=35 Hz., Q_L=7 and Q_T=.30.

FIG. 3

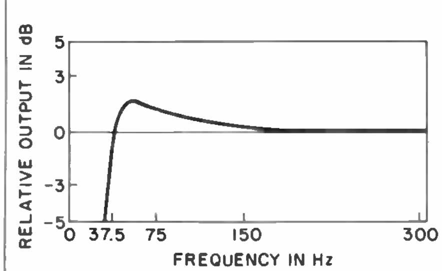


Fig. 3. Simulated response of a BB4 alignment with f_S=35 Hz., Q_L=7 and Q_T=.50.

TABLE I
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS: Q_L = 3

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	5.4444	3.5401	
.21	1.0000	4.9031	3.3255	
.22	1.0000	4.4355	3.1280	
.23	1.0000	4.0290	2.9454	
.24	1.0000	3.6736	2.7761	
.25	1.0000	3.3611	2.6186	
.26	1.0000	3.0850	2.4718	
.27	1.0000	2.8399	2.3347	
.28	1.0000	2.6213	2.2068	
.29	1.0000	2.4257	2.0873	
.30	1.0000	2.2500	1.9759	
.31	1.0000	2.0916	1.8724	
.32	1.0000	1.9484	1.7763	
.33	1.0000	1.8114	1.6876	
.34	1.0000	1.7002	1.6060	
.35	1.0000	1.5924	1.5313	
.36	1.0000	1.4938	1.4632	
.37	1.0000	1.4035	1.4014	
.38	1.0000	1.3205	1.3456	
.39	1.0000	1.2441	1.2952	
.40	1.0000	1.1736	1.2499	
.41	1.0000	1.1085	1.2091	.01
.42	1.0000	1.0482	1.1724	.05
.43	1.0000	.9923	1.1394	.12
.44	1.0000	.9403	1.1096	.20
.45	1.0000	.8920	1.0828	.30
.46	1.0000	.8469	1.0585	.41
.47	1.0000	.8049	1.0365	.53
.48	1.0000	.7656	1.0165	.66
.49	1.0000	.7289	.9982	.79
.50	1.0000	.6944	.9815	.93
.51	1.0000	.6621	.9663	1.08
.52	1.0000	.6318	.9523	1.23
.53	1.0000	.6033	.9394	1.38
.54	1.0000	.5765	.9275	1.54
.55	1.0000	.5512	.9165	1.70
.56	1.0000	.5274	.9063	1.86
.57	1.0000	.5048	.8968	2.02
.58	1.0000	.4836	.8880	2.18
.59	1.0000	.4635	.8797	2.34
.60	1.0000	.4444	.8720	2.50
.61	1.0000	.4264	.8649	2.66
.62	1.0000	.4093	.8581	2.82
.63	1.0000	.3931	.8518	2.98
.64	1.0000	.3777	.8458	3.14
.65	1.0000	.3631	.8402	3.30
.66	1.0000	.3492	.8349	3.46
.67	1.0000	.3359	.8299	3.61
.68	1.0000	.3233	.8252	3.77
.69	1.0000	.3113	.8207	3.92
.70	1.0000	.2999	.8165	4.08

two new response series appear in *Fig. 1* as extensions of the QB3 and C4 curves.

As an example of a completely different series I picked Hoge's[2] fourth order boom box responses which cover the high Q_T range and are abbreviated BB4. This series also has an extension to lower Q_T's which I will call a sub-boom box and denote SBB4. These two series are represented by the third curve in *Fig. 1*.

As well as response series, there are discrete responses corresponding to a single point in *Fig. 1*. A discrete response can be realized for only one value of Q_T once Q_L is fixed. Probably the best known is the fourth order Butterworth (B4). From its position in *Fig. 1* you can see it may be considered as a transition between quasi-Butterworth

FIG. 4

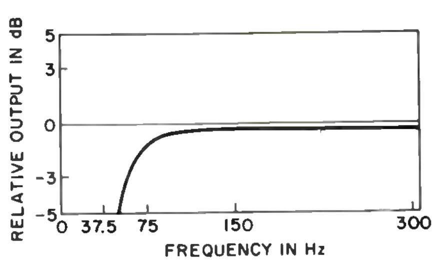


Fig. 4. Simulated response of a QB3 alignment with f_S=35 Hz., Q_L=7 and Q_T=.30.

FIG. 5

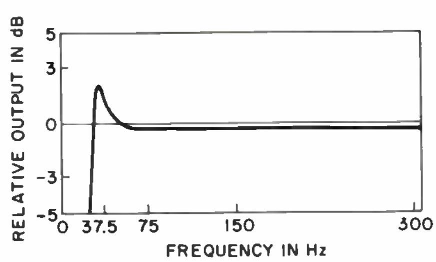


Fig. 5. Simulated response of a SQB3 alignment with f_S=35 Hz., Q_L=7 and Q_T=.50.

FIG. 6

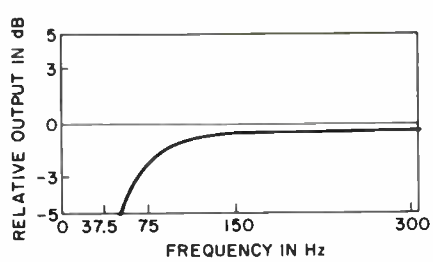


Fig. 6. Simulated response of a SC4 alignment with f_S=35 Hz., Q_L=7 and Q_T=.30.

TABLE II
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS: Q_L = 5

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	5.7600	3.4202	
.21	1.0000	5.2027	3.2041	
.22	1.0000	4.7207	3.0051	
.23	1.0000	4.3011	2.8210	
.24	1.0000	3.9336	2.6502	
.25	1.0000	3.4100	2.4914	
.26	1.0000	3.3236	2.3435	
.27	1.0000	3.0690	2.2057	
.28	1.0000	2.8416	2.0774	
.29	1.0000	2.6378	1.9582	
.30	1.0000	2.4544	1.8476	
.31	1.0000	2.2889	1.7456	
.32	1.0000	2.1389	1.6519	
.33	1.0000	2.0027	1.5664	
.34	1.0000	1.8785	1.4887	
.35	1.0000	1.7651	1.4185	
.36	1.0000	1.6612	1.3555	
.37	1.0000	1.5659	1.2991	
.38	1.0000	1.4781	1.2487	
.39	1.0000	1.3972	1.2037	.02
.40	1.0000	1.3225	1.1637	.07
.41	1.0000	1.2533	1.1280	.15
.42	1.0000	1.1891	1.0961	.25
.43	1.0000	1.1295	1.0676	.36
.44	1.0000	1.0741	1.0420	.50
.45	1.0000	1.0223	1.0189	.64
.46	1.0000	.9741	.9981	.79
.47	1.0000	.9290	.9793	.96
.48	1.0000	.8867	.9622	1.12
.49	1.0000	.8472	.9467	1.30
.50	1.0000	.8100	.9324	1.47
.51	1.0000	.7751	.9194	1.65
.52	1.0000	.7422	.9075	1.84
.53	1.0000	.7113	.8965	2.02
.54	1.0000	.6822	.8863	2.21
.55	1.0000	.6546	.0770	2.39
.56	1.0000	.6286	.8683	2.58
.57	1.0000	.6040	.8602	2.77
.58	1.0000	.5807	.8526	2.96
.59	1.0000	.5587	.8436	3.15
.60	1.0000	.5378	.8390	3.33
.61	1.0000	.5179	.8329	3.52
.62	1.0000	.4991	.8271	3.70
.63	1.0000	.4812	.8217	3.89
.64	1.0000	.4641	.8166	4.07
.65	1.0000	.4479	.8118	4.25
.66	1.0000	.4324	.8073	4.43
.67	1.0000	.4177	.8030	4.61
.68	1.0000	.4036	.7989	4.79
.69	1.0000	.3902	.7951	4.97
.70	1.0000	.3773	.7915	5.14

TABLE III
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS: Q_L = 7

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	5.8980	3.3686	
.21	1.0000	5.3339	3.1518	
.22	1.0000	4.8457	2.9521	
.23	1.0000	4.4204	2.7674	
.24	1.0000	4.0478	2.5960	
.25	1.0000	3.71t4	2.4366	
.26	1.0000	3.4286	2.2883	
.27	1.0000	3.1699	2.1503	
.28	1.0000	2.9388	2.0220	
.29	1.0000	2.7315	1.9031	
.30	1.0000	2.5448	1.7932	
.31	1.0000	2.3761	1.6922	
.32	1.0000	2.2233	1.6000	
.33	1.0000	2.0843	1.5162	
.34	1.0000	1.9576	1.4406	
.35	1.0000	1.8419	1.3728	
.36	1.0000	1.7357	1.3122	
.37	1.0000	1.6392	1.2583	
.38	1.0000	1.5484	1.2104	.01
.39	1.0000	1.4656	1.1679	.06
.40	1.0000	1.3890	1.1302	.14
.41	1.0000	1.3181	1.0966	.24
.42	1.0000	1.2523	1.0667	.37
.43	1.0000	1.1911	1.0399	.51
.44	1.0000	1.1341	1.0160	.66
.45	1.0000	1.0809	.9944	.82
.46	1.0000	1.0313	.9750	1.00
.47	1.0000	.9849	.9574	1.17
.48	1.0000	.9414	.9415	1.36
.49	1.0000	.9006	.9270	1.55
.50	1.0000	.8622	.9137	1.74
.51	1.0000	.8262	.9015	1.93
.52	1.0000	.7923	.8904	2.13
.53	1.0000	.7603	.8801	2.33
.54	1.0000	.7302	.8706	2.53
.55	1.0000	.7017	.8619	2.73
.56	1.0000	.6747	.8537	2.93
.57	1.0000	.6493	.8462	3.13
.58	1.0000	.6251	.8391	3.33
.59	1.0000	.6022	.8325	3.53
.60	1.0000	.5805	.8264	3.73
.61	1.0000	.5599	.8206	3.93
.62	1.0000	.5403	.8152	4.12
.63	1.0000	.5216	.8102	4.32
.64	1.0000	.5038	.8054	4.51
.65	1.0000	.4869	.8009	4.70
.66	1.0000	.4708	.7967	4.90
.67	1.0000	.4554	.7926	5.09
.68	1.0000	.4407	.7889	5.27
.69	1.0000	.4267	.7853	5.46
.70	1.0000	.4133	.7819	5.65

TABLE IV
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS: Q_L = 10

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	6.0025	3.3290	
.21	1.0000	5.4333	3.1125	
.22	1.0000	4.9405	2.9122	
.23	1.0000	4.5110	2.7270	
.24	1.0000	4.1344	2.5551	
.25	1.0000	3.8025	2.3954	
.26	1.0000	3.5094	2.2469	
.27	1.0000	3.2467	2.1087	
.28	1.0000	3.0127	1.9805	
.29	1.0000	2.8027	1.8619	
.30	1.0000	2.6136	1.7527	
.31	1.0000	2.4427	1.6527	
.32	1.0000	2.2877	1.5617	
.33	1.0000	2.1467	1.4794	
.34	1.0000	2.0181	1.4056	
.35	1.0000	1.9005	1.3397	
.36	1.0000	1.7926	1.2810	
.37	1.0000	1.6935	1.2291	.00
.38	1.0000	1.6022	1.1831	.04
.39	1.0000	1.5180	1.1424	.11
.40	1.0000	1.4400	1.1063	.21
.41	1.0000	1.3678	1.0743	.33
.42	1.0000	1.3007	1.0458	.47
.43	1.0000	1.2383	1.0204	.63
.44	1.0000	1.1802	.9976	.80
.45	1.0000	1.1260	.9771	.98
.46	1.0000	1.0753	.9587	1.16
.47	1.0000	1.0279	.9420	1.35
.48	1.0000	.9834	.9268	1.55
.49	1.0000	.9417	.9130	1.75
.50	1.0000	.9025	.9004	1.95
.51	1.0000	.8656	.8889	2.16
.52	1.0000	.8309	.8783	2.37
.53	1.0000	.7982	.8685	2.58
.54	1.0000	.7672	.8595	2.79
.55	1.0000	.7380	.8512	3.00
.56	1.0000	.7104	.8434	3.21
.57	1.0000	.6842	.8362	3.41
.58	1.0000	.6595	.8295	3.62
.59	1.0000	.6359	.8233	3.83
.60	1.0000	.6136	.8174	4.04
.61	1.0000	.5924	.8120	4.25
.62	1.0000	.5722	.8068	4.45
.63	1.0000	.5530	.8020	4.66
.64	1.0000	.5347	.7975	4.86
.65	1.0000	.5173	.7932	5.06
.66	1.0000	.5007	.7891	5.26
.67	1.0000	.4848	.7853	5.46
.68	1.0000	.4696	.7817	5.65
.69	1.0000	.4551	.7783	5.85
.70	1.0000	.4413	.7751	6.04

and Chebyshev responses. As such it marks the change from QB3 to C4 in the first article's alignment tables. The fourth order Bessel response (Be4) is said to have superior time delay behavior; however, this is not necessarily true since the time delay property is attributable to a low pass Bessel filter, not to the high pass filter used to model loudspeaker response. The inter-order Butterworth (IB4) is a discrete response used by Thiele.

TABLES AND SHAPES

I have generated alignment tables for each of the responses described above using the Q_L values 3, 5, 7, 10, 15, 20, which should cover any box loss encountered in practice.

FIG. 7

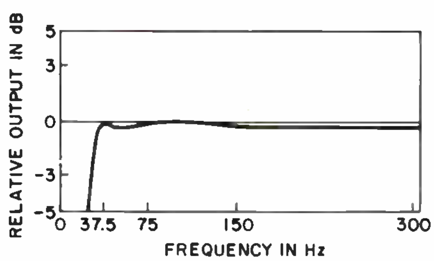


Fig. 7. Simulated response of a C4 alignment with f_S=35 Hz., Q_L=7 and Q_T=.50.

FIG. 8

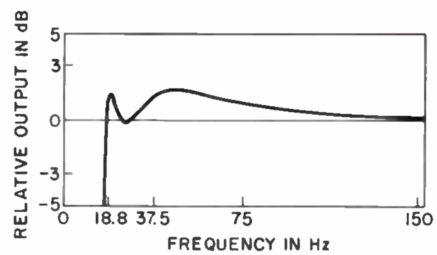


Fig. 8. Simulated response of a C4 alignment with f_S=35 Hz., Q_L=7 and Q_T=.80.

FIG.9

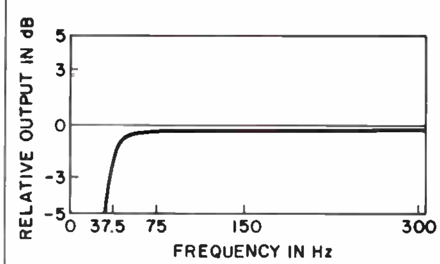


Fig. 9. Simulated response of a B4 alignment with f_S=35 Hz.

TABLE V
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS:
Q_L = 15

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	6.0844	3.2996	
.21	1.0000	5.5113	3.0818	
.22	1.0000	5.0149	2.8811	
.23	1.0000	4.5821	2.6955	
.24	1.0000	4.2025	2.5233	
.25	1.0000	3.8678	2.3633	
.26	1.0000	3.5711	2.2146	
.27	1.0000	3.3070	2.0764	
.28	1.0000	3.0708	1.9483	
.29	1.0000	2.8588	1.8301	
.30	1.0000	2.6678	1.7214	
.31	1.0000	2.4950	1.6222	
.32	1.0000	2.3384	1.5323	
.33	1.0000	2.1958	1.4514	
.34	1.0000	2.0657	1.3790	
.35	1.0000	1.9467	1.3146	
.36	1.0000	1.8375	1.2576	
.37	1.0000	1.7372	1.2071	.01
.38	1.0000	1.6447	1.1626	.07
.39	1.0000	1.5593	1.1233	.16
.40	1.0000	1.4803	1.0886	.27
.41	1.0000	1.4070	1.0577	.41
.42	1.0000	1.3390	1.0303	.57
.43	1.0000	1.2757	1.0059	.73
.44	1.0000	1.2167	.9840	.91
.45	1.0000	1.1616	.9643	1.10
.46	1.0000	1.1101	.9466	1.30
.47	1.0000	1.0619	.9305	1.50
.48	1.0000	1.0167	.9160	1.71
.49	1.0000	.9743	.9027	1.91
.50	1.0000	.9344	.8906	2.13
.51	1.0000	.8969	.8795	2.34
.52	1.0000	.8616	.8693	2.56
.53	1.0000	.8282	.8599	2.78
.54	1.0000	.7967	.8513	2.99
.55	1.0000	.7670	.8432	3.21
.56	1.0000	.7388	.8358	3.43
.57	1.0000	.7121	.8289	3.65
.58	1.0000	.6868	.8224	3.86
.59	1.0000	.6628	.8164	4.08
.60	1.0000	.6400	.8108	4.29
.61	1.0000	.6183	.8055	4.51
.62	1.0000	.5977	.8006	4.72
.63	1.0000	.5781	.7959	4.93
.64	1.0000	.5594	.7916	5.14
.65	1.0000	.5415	.7874	5.35
.66	1.0000	.5245	.7836	5.55
.67	1.0000	.5083	.7799	5.76
.68	1.0000	.4927	.7764	5.96
.69	1.0000	.4779	.7731	6.16
.70	1.0000	.4637	.7700	6.36

TABLE VI
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS:
Q_L = 20

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	6.1256	3.2844	
.21	1.0000	5.5505	3.0665	
.22	1.0000	5.0523	2.8656	
.23	1.0000	4.6178	2.6797	
.24	1.0000	4.2367	2.5074	
.25	1.0000	3.9006	2.3472	
.26	1.0000	3.6027	2.1984	
.27	1.0000	3.3374	2.0602	
.28	1.0000	3.1001	1.9323	
.29	1.0000	2.8871	1.8142	
.30	1.0000	2.6951	1.7059	
.31	1.0000	2.5214	1.6072	
.32	1.0000	2.3639	1.5178	
.33	1.0000	2.2206	1.4375	
.34	1.0000	2.0897	1.3659	
.35	1.0000	1.9700	1.3023	
.36	1.0000	1.8602	1.2461	.00
.37	1.0000	1.7592	1.1964	.02
.38	1.0000	1.6661	1.1527	.09
.39	1.0000	1.5802	1.1141	.19
.40	1.0000	1.5006	1.0799	.31
.41	1.0000	1.4269	1.0497	.45
.42	1.0000	1.3583	1.0228	.61
.43	1.0000	1.2946	.9988	.79
.44	1.0000	1.2351	.9773	.97
.45	1.0000	1.1796	.9581	1.17
.46	1.0000	1.1278	.9407	1.37
.47	1.0000	1.0792	.9250	1.57
.48	1.0000	1.0336	.9107	1.79
.49	1.0000	.9908	.8977	2.00
.50	1.0000	.9506	.8858	2.22
.51	1.0000	.9128	.8749	2.44
.52	1.0000	.8771	.8650	2.66
.53	1.0000	.8435	.8558	2.88
.54	1.0000	.8117	.8473	3.10
.55	1.0000	.7816	.8394	3.32
.56	1.0000	.7532	.8321	3.54
.57	1.0000	.7262	.8253	3.76
.58	1.0000	.7007	.8190	3.98
.59	1.0000	.6764	.8131	4.20
.60	1.0000	.6534	.8076	4.42
.61	1.0000	.6315	.8024	4.64
.62	1.0000	.6107	.7975	4.85
.63	1.0000	.5908	.7930	5.07
.64	1.0000	.5719	.7887	5.28
.65	1.0000	.5539	.7847	5.49
.66	1.0000	.5367	.7808	5.70
.67	1.0000	.5202	.7772	5.91
.68	1.0000	.5045	.7738	6.12
.69	1.0000	.4895	.7706	6.32
.70	1.0000	.4751	.7675	6.52

TABLE VII
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS:
Q_L = 3

Q_T	H	Alpha	F_3/F_S	PK(dB)
.1000	4.3303	31.2904	5.6709	
.1100	3.9371	25.6824	5.1456	
.1200	3.6096	21.4169	4.7069	
.1300	3.3325	18.0974	4.3348	
.1400	3.0950	15.4635	4.0150	
.1500	2.8892	13.3386	3.7371	
.1600	2.7092	11.5994	3.4932	
.1700	2.5504	10.1581	3.2772	
.1800	2.4092	8.9502	3.0844	
.1900	2.2830	7.9280	2.9113	
.2000	2.1694	7.0552	2.7548	
.2100	2.0666	6.3041	2.6125	
.2200	1.9733	5.6531	2.4824	
.2300	1.8881	5.0851	2.3630	
.2400	1.8100	4.5866	2.2528	
.2500	1.7381	4.1467	2.1508	
.2600	1.6719	3.7566	2.0559	
.2700	1.6105	3.4090	1.9674	
.2800	1.5536	3.0980	1.8845	
.2900	1.5006	2.8186	1.8065	
.3000	1.4512	2.5666	1.7331	
.3100	1.4050	2.3386	1.6636	
.3200	1.3617	2.1317	1.5978	
.3300	1.3210	1.9432	1.5351	
.3400	1.2828	1.7712	1.4754	
.3500	1.2467	1.6136	1.4183	
.3600	1.2127	1.4690	1.3636	
.3700	1.1806	1.3360	1.3110	
.3800	1.1501	1.2133	1.2605	
.3900	1.1213	1.0999	1.2118	
.4000	1.0939	.9949	1.1649	
.4100	1.0679	.8974	1.1198	
.4200	1.0431	.8069	1.0763	
.4300	1.0195	.7225	1.0346	
.4400	.9970	.6439	.9947	.00
.4500	.9755	.5704	.9568	.00
.4600	.9550	.5016	.9210	.02
.4700	.9354	.4372	.8875	.06
.4800	.9166	.3767	.8563	.14
.4900	.8986	.3199	.8276	.27
.5000	.8813	.2665	.8014	.45
.5100	.8647	.2161	.7775	.70
.5200	.8488	.1686	.7558	1.00
.5300	.8336	.1238	.7363	1.36
.5400	.8189	.0814	.7186	1.77
.5500	.8047	.0413	.7027	2.25
.5600	.7911	.0033	.6883	2.78

Table I through *VI* cover the SBB4-BB4 series. The alignment is a BB4 if there is an entry in the peak column; otherwise it is a SBB4. The representative response curves are given in *Fig. 2* (SBB4) and *Fig. 3* (BB4). All of the BB4 responses have a peak whose height is in the peak column.

The QB3-SQB3 alignments are given in *Tables VII* through *XII*. If the peak column is empty the alignment is a QB3; otherwise it is an SQB3. *Figure 4* shows a typical QB3 response and *Fig. 5* an SQB3.

The SC4-C4 series is covered by *Tables XIII* through *XVIII*. Here the alignment is SC4 when the ripple column is empty and C4 otherwise. *Figure 6* is an SC4 and *Fig. 7* a C4. The ripple is not very apparent in this figure, so I have also included a high Q_T C4 as *Fig. 8*.

FIG. 10

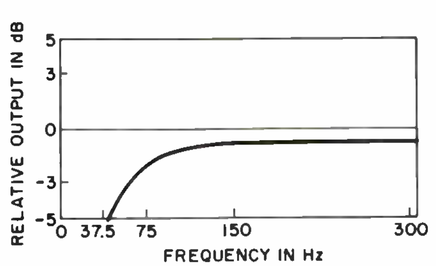


Fig. 10. Simulated response of a Be4 alignment with f_s=35 Hz. and Q_L=7.

FIG. 11

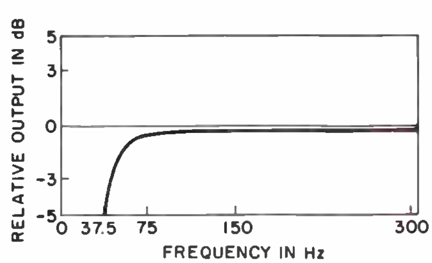


Fig. 11. Simulated response of an IB4 alignment with f_s=35 Hz. and Q_L=7.

FIG. 12

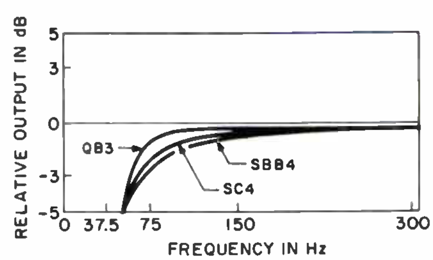


Fig. 12. Comparison of QB3, SC4 and SBB4 for f_s=35 Hz., Q_L=7 and Q_T=.30.

TABLE VIII
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS:
Q_L = 5

Q_T	H	Alpha	F_3/F_s	PK(dB)
.1000	3.9737	33.5256	5.3464	
.1100	3.6143	27.5207	4.8505	
.1200	3.3149	22.9534	4.4364	
.1300	3.0618	19.3989	4.0851	
.1400	2.8449	16.5786	3.7831	
.1500	2.6571	14.3032	3.5205	
.1600	2.4929	12.4409	3.2900	
.1700	2.3482	10.8975	3.0858	
.1800	2.2196	9.6040	2.9035	
.1900	2.1047	8.5093	2.7397	
.2000	2.0014	7.5746	2.5914	
.2100	1.9080	6.7702	2.4566	
.2200	1.8232	6.0730	2.3332	
.2300	1.7459	5.4646	2.2198	
.2400	1.6751	4.9306	2.1151	
.2500	1.6101	4.4594	2.0180	
.2600	1.5502	4.0415	1.9276	
.2700	1.4948	3.6691	1.8430	
.2800	1.4434	3.3358	1.7637	
.2900	1.3957	3.0364	1.6889	
.3000	1.3512	2.7663	1.6183	
.3100	1.3097	2.5220	1.5514	
.3200	1.2708	3.3001	1.4877	
.3300	1.2344	2.0980	1.4269	
.3400	1.2003	1.9134	1.3687	
.3500	1.1681	1.7444	1.3129	
.3600	1.1378	1.5893	1.2592	
.3700	1.1093	1.4464	1.2074	
.3800	1.0823	1.3147	1.1576	
.3900	1.0568	1.1929	1.1095	
.4000	1.0326	1.0801	1.0632	
.4100	1.0097	.9753	1.0189	
.4200	.9880	.8779	.9766	.00
.4300	.9673	.7872	.9366	.01
.4400	.9477	.7025	.8992	.04
.4500	.9290	.6233	.8646	.13
.4600	.9113	.5492	.8329	.27
.4700	.8943	.4796	.8043	.49
.4800	.8782	.4144	.7785	.79
.4900	.8628	.3530	.7555	1.16
.5000	.8481	.2951	.7351	1.62
.5100	.8341	.2406	.7170	2.16
.5200	.8207	.1891	.7010	2.79
.5300	.8078	.1404	.6868	3.50
.5400	.7956	.0944	.6742	4.32
.5500	.7839	.0507	.6631	5.25
.5600	.7727	.0092	.6533	6.31

TABLE IX
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS:
Q_L = 7

Q_T	H	Alpha	F_3/F_s	PK(dB)
.1000	3.8416	34.3925	5.2233	
.1100	3.4947	28.2341	4.7386	
.1200	3.2058	23.5499	4.3337	
.1300	2.9615	19.9046	3.9902	
.1400	2.7524	17.0120	3.6949	
.1500	2.5712	14.6784	3.4381	
.1600	2.4129	12.7685	3.2126	
.1700	2.2743	11.1855	3.0128	
.1800	2.1495	9.8589	2.8345	
.1900	2.0388	8.7361	2.6741	
.2000	1.9393	7.7775	2.5289	
.2100	1.8494	6.9524	2.3968	
.2200	1.7678	6.2372	2.2759	
.2300	1.6935	5.6132	2.1647	
.2400	1.6254	5.0655	2.0620	
.2500	1.5629	4.5822	1.9667	
.2600	1.5054	4.1535	1.8778	
.2700	1.4522	3.7714	1.7946	
.2800	1.4029	3.4295	1.7165	
.2900	1.3571	3.1223	1.6429	
.3000	1.3145	3.1223	1.5732	
.3100	1.2748	2.5944	1.5070	
.3200	1.2376	2.3667	1.4439	
.3300	1.2028	2.1594	1.3836	
.3400	1.1702	1.9699	1.3258	
.3500	1.1395	1.7964	1.2702	
.3600	1.1106	1.6371	1.2167	
.3700	1.0834	1.4905	1.1651	
.3800	1.0578	1.3552	1.1153	
.3900	1.0335	1.2300	1.0674	
.4000	1.0106	1.1141	1.0214	
.4100	.9889	1.0065	.9776	.00
.4200	.9683	.9064	.9362	.01
.4300	.9488	.8131	.8975	.05
.4400	.9303	.7260	.8618	.14
.4500	.9128	.6445	.8294	.31
.4600	.8961	.5682	.8001	.56
.4700	.8802	.4966	.7741	.90
.4800	.8651	.4294	.7510	1.32
.4900	.8507	.3661	.7307	1.85
.5000	.8370	.3065	.7129	2.46
.5100	.8240	.2503	.6972	3.18
.5200	.8116	.1971	.6835	4.01
.5300	.7998	.1468	.6715	4.97
.5400	.7886	.0992	.6610	6.08
.5500	.7779	.0540	.6518	7.36
.5600	.7677	.0111	.6438	8.87

TABLE X
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS:
Q_L = 10

Q_T	H	Alpha	F_3/F_s	PK(dB)
.1000	3.7493	35.0129	5.1363	
.1100	3.4111	28.7446	4.6594	
.1200	3.1296	23.9771	4.2611	
.1300	2.8915	20.2667	3.9231	
.1400	2.6877	17.3226	3.6325	
.1500	2.5113	14.9474	3.3798	
.1600	2.3570	13.0033	3.1578	
.1700	2.2212	11.3921	2.9611	
.1800	2.1006	10.0418	2.7855	
.1900	1.9928	8.8990	2.6275	
.2000	1.8960	7.9232	2.4845	
.2100	1.8085	7.0834	2.3543	
.2200	1.7292	6.3554	2.2351	
.2300	1.6569	5.7202	2.1255	
.2400	1.5908	5.1627	2.0241	
.2500	1.5301	4.6706	1.9299	
.2600	1.4742	4.2342	1.8421	
.2700	1.4225	3.8452	1.7599	
.2800	1.3747	3.4971	1.6826	
.2900	1.3303	3.1843	1.6097	
.3000	1.2890	2.9022	1.5406	
.3100	1.2505	2.6469	1.4748	
.3200	1.2146	2.4150	1.4121	
.3300	1.1809	2.2038	1.3521	
.3400	1.14t3	2.0109	1.2945	
.3500	1.1197	1.8342	1.2390	
.3600	1.0918	1.6719	1.1855	
.3700	1.0656	1.5225	1.1339	
.3800	1.0409	1.3846	1.0841	
.3900	1.0175	1.2571	1.0363	
.4000	.9955	1.1389	.9906	.00
.4100	.9747	1.0292	.9474	.00
.4200	.9549	.9271	.9069	.03
.4300	.9363	.8320	.8695	.12
.4400	.9186	.7431	.8355	.28
.4500	.9018	.6600	.8049	.53
.4600	.8859	.5821	.7778	.87
.4700	.8707	.5091	.7538	1.31
.4800	.8564	.4404	.7329	1.86
.4900	.8428	.3757	.7146	2.51
.5000	.8299	.3148	.6986	3.27
.5100	.8176	.2572	.6848	4.16
.5200	.8059	.2028	.6727	5.20
.5300	.7949	.1513	.6623	6.40
.5400	.7844	.1025	.6532	7.82
.5500	.7744	.0562	.6454	9.52
.5600	.7650	.0121	.6387	11.60

The discrete response alignment data is in *Table XIX*; *Fig. 9, 10* and *11* give the relevant response curves.

I have included several other figures with multiple response plots on the same axes for purposes of comparison. In *Fig. 13* one graph is a natural QB3 and the other is the response obtained with the vent blocked. This will give you an idea of the low frequency extension achievable by venting. *Figure 14* compares an extremely low Q_T alignment with a more moderate one. You can see that even though the low Q_T driver has a much lower resonance than the other, the latter will give a wider bandwidth in a vented box. Finally, *Fig. 15* compares a B4 response with an IB4.

RESPONSE COMPARISONS

With more than one alignment possible, it is important to find out how they differ so you can make the best choice for your circumstances. The tables show explicity that box size, box resonance, response "flatness," and cut-off frequency distinguish the alignments from one another. Generally, the alignment choice with the best combination of these four characteristics is found in the composite QB3-C4 tables of my first article. The new tables do allow us to extend the usable Q_T range up to .80 and down to .10.

Alignments also differ in their transient response, which deteriorates with increasing Q_T. Even more, equal Q_T alignments will not necessarily exhibit the same transient behavior. I will make specific comparisons below. According to Thiele[3], the ringing in a vented box alignment should be imperceptible except in the case of very high Q_T alignments. Now for some specific comparisons.

RESPONSE FLATNESS

Responses are either flat (SBB4, QB3, SC4, B4, Be4, IB4) and correspond to low Q_T values, or nonflat (BB4, SQB3, C4) and call for a large Q_T value. Because of this the driver you use will almost always determine whether your system will have a flat or nonflat response. Consider this point carefully before selecting drivers, and keep in mind also that the flat alignments will have better transient response. Having compared flat and nonflat, we are now ready to compare alignments within these two groups.

NONFLAT ALIGNMENTS

The C4 is the standard in this group. The principal advantage of the BB4 alternative is that a smaller box and higher tuning can be used for a given Q_T, although the cut-off frequency will be higher and the response variation greater. The SQB3 is quite similar to the BB4, but available Q_T values are lower and it requires a much larger box. However, the SQB3 cut-off fre-

Text continued on page 26

TABLE XI
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS: Q_L = 3

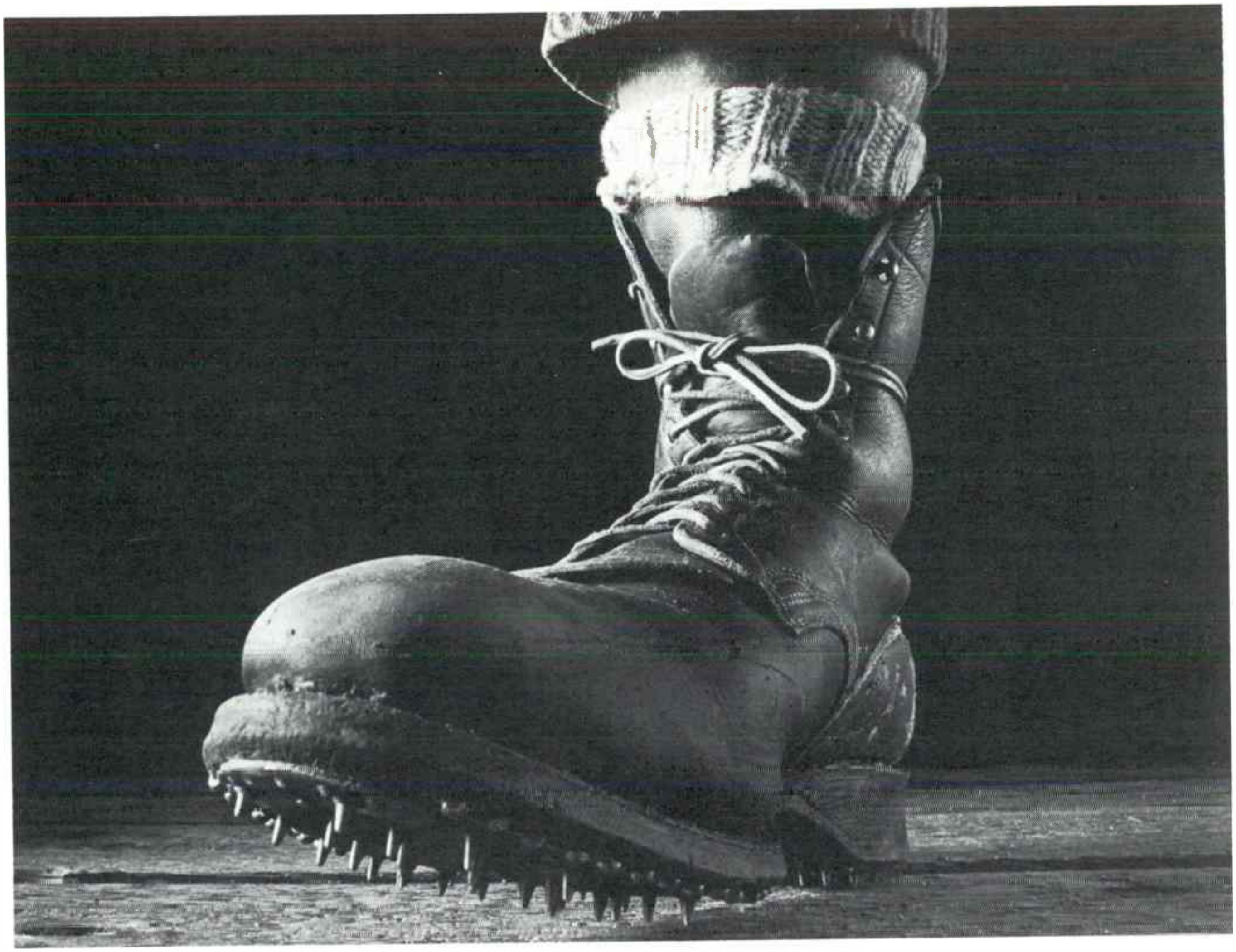
Q_T	H	Alpha	F_3/F_S	PK(dB)
.1000	3.6841	35.4793	5.0715	
.1100	3.3494	29.1286	4.6004	
.1200	3.0732	24.2984	4.2069	
.1300	2.8398	20.5392	3.8730	
.1400	2.6400	17.5563	3.5859	
.1500	2.4670	15.1498	3.3362	
.1600	2.3158	13.1802	3.1169	
.1700	2.1826	11.5478	2.9225	
.1800	2.0644	10.1797	2.7488	
.1900	1.9589	9.0218	2.5926	
.2000	1.8640	8.0331	2.4512	
.2100	1.7784	7.1822	2.3225	
.2200	1.7007	6.4446	2.2045	
.2300	1.6299	5.8010	2.0960	
.2400	1.5652	5.2361	1.9956	
.2500	1.5058	4.7375	1.9023	
.2600	1.4512	4.2952	1.8153	
.2700	1.4007	3.9011	1.7338	
.2800	1.3540	3.5484	1.6571	
.2900	1.3106	3.2314	1.5846	
.3000	1.2703	2.9455	1.5159	
.3100	1.2327	2.6867	1.4504	
.3200	1.1976	2.4517	1.3880	
.3300	1.1648	2.2376	1.3281	
.3400	1.1341	2.0420	1.2705	
.3500	1.1052	1.8629	1.2151	
.3600	1.0781	1.6983	1.1615	
.3700	1.0526	1.5468	1.1099	
.3800	1.0286	1.4070	1.0602	
.3900	1.0059	1.2777	1.0125	
.4000	.9845	1.1579	.9672	.00
.4100	.9643	1.0466	.9245	.02
.4200	.9452	.9430	.8849	.08
.4300	.9272	.8464	.8488	.21
.4400	.9101	.7562	.8162	.43
.4500	.8939	.6719	.7872	.76
.4600	.8786	.5928	.7618	1.18
.4700	.8641	.5185	.7395	1.72
.4800	.8503	.4488	.7202	2.36
.4900	.8373	.3830	.7034	3.13
.5000	.8249	.3211	.6889	4.04
.5100	.8132	.2625	.6764	5.09
.5200	.8021	.2072	.6656	6.33
.5300	.7916	.1547	.6563	7.79
.5400	.7817	.1050	.6483	9.56
.5500	.7723	.0577	.6416	11.80
.5600	.7635	.0128	.6359	14.70

TABLE XII
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS: Q_L = 20

Q_T	H	Alpha	F_3/F_S	PK(dB)
.1000	3.6482	35.7075	5.0399	
.1100	3.3196	29.3166	4.5717	
.1200	3.0460	24.4556	4.1806	
.1300	2.8148	20.6726	3.8487	
.1400	2.6169	17.6708	3.5632	
.1500	2.4455	15.2490	3.3150	
.1600	2.2959	13.2669	3.0969	
.1700	2.1640	11.6240	2.9036	
.1800	2.0470	10.2473	2.7310	
.1900	1.9425	9.0820	2.5757	
.2000	1.8486	8.0970	2.4350	
.2100	1.7638	7.2307	2.3069	
.2200	1.6869	6.4884	2.1896	
.2300	1.6169	5.8407	2.0816	
.2400	1.5529	5.2721	1.9817	
.2500	1.4941	4.7703	1.8888	
.2600	1.4401	4.3252	1.8022	
.2700	1.3902	3.9286	1.7210	
.2800	1.3440	3.5735	1.6445	
.2900	1.3011	3.2545	1.5722	
.3000	1.2613	2.9667	1.5037	
.3100	1.2241	2.7063	1.4384	
.3200	1.1895	2.4697	1.3760	
.3300	1.1571	2.2542	1.3162	
.3400	1.1267	2.0574	1.2587	
.3500	1.0982	1.8770	1.2032	
.3600	1.0715	1.7114	1.1496	
.3700	1.0463	1.5589	1.0980	
.3800	1.0226	1.4181	1.0483	
.3900	1.0003	1.2879	1.0007	
.4000	.9793	1.1672	.9556	.00
.4100	.9594	1.0552	.9153	.03
.4200	.9406	.9508	.8742	.11
.4300	.9228	.8536	.8387	.27
.4400	.9061	.7627	.8069	.53
.4500	.8902	.6777	.7788	.89
.4600	.8751	.5980	.7542	1.36
.4700	.8609	.5232	.7328	1.95
.4800	.8474	.4529	.7143	2.65
.4900	.8347	.3867	.6983	3.49
.5000	.8226	.3242	.6845	4.47
.5100	.8112	.2651	.6726	5.62
.5200	.8004	.2093	.6624	6.98
.5300	.7902	.1564	.6537	8.61
.5400	.7806	.1062	.6463	10.62
.5500	.7715	.0585	.6401	13.20
.5600	.7629	.0131	.6348	16.80

TABLE XIII
FOURTH ORDER SC4 AND C4 ALIGNMENTS: Q_L = 3

Q_T	H	Alpha	F_3/F_S	Ripple (dB)
.2500	1.0093	3.4080	2.6083	
.2600	1.0322	3.2301	2.4391	
.2700	1.0529	3.0516	2.2860	
.2800	1.0703	2.8731	2.1473	
.2900	1.0871	2.6952	2.0217	
.3000	1.1004	2.5188	1.9078	
.3100	1.1109	2.3447	1.8042	
.3200	1.1187	2.1738	1.7097	
.3300	1.1236	2.0068	1.6232	
.3400	1.1255	1.8448	1.5437	
.3500	1.1244	1.6885	1.4703	
.3600	1.1203	1.5387	1.4023	
.3700	1.1133	1.3961	1.3390	
.3800	1.1034	1.2616	1.2798	
.3900	1.0909	1.1356	1.2244	
.4000	1.0758	1.0187	1.1724	
.4100	1.0586	.9110	1.1236	
.4200	1.0394	.8128	1.0778	
.4300	1.0188	.7238	1.0348	
.4400	.9770	.6439	.9947	.00
.4500	.9744	.5726	.9572	.00
.4600	.9515	.5093	.9222	.00
.4700	.9286	.4533	.8898	.00
.4800	.9059	.4040	.8597	.00
.4900	.8837	.3605	.8318	.00
.5000	.8621	.3223	.8060	.01
.5100	.8412	.2885	.7822	.02
.5200	.8212	.2586	.7601	.02
.5300	.8021	.2321	.7397	.03
.5400	.7838	.2084	.7208	.05
.5500	.7664	.1872	.7033	.06
.5600	.7499	.1681	.6871	.08
.5700	.7341	.1508	.6720	.10
.5800	.7192	.1350	.6579	.12
.5900	.7049	.1205	.6447	.14
.6000	.6913	.1072	.6324	.17
.6100	.6784	.0948	.6209	.20
.6200	.6661	.0832	.6101	.23
.6300	.6543	.0723	.5999	.26
.6400	.6430	.0621	.5903	.29
.6500	.6322	.0524	.5812	.32
.6600	.6218	.0431	.5726	.35
.6700	.6118	.0343	.5644	.39
.6800	.6022	.0258	.5567	.42
.6900	.5929	.0175	.5493	.46
.7000	.5840	.0096	.5423	.50
.7100	.5754	.0019	.5355	.53



HOW TO DESIGN THIS INTO YOUR NEXT SPEAKER.

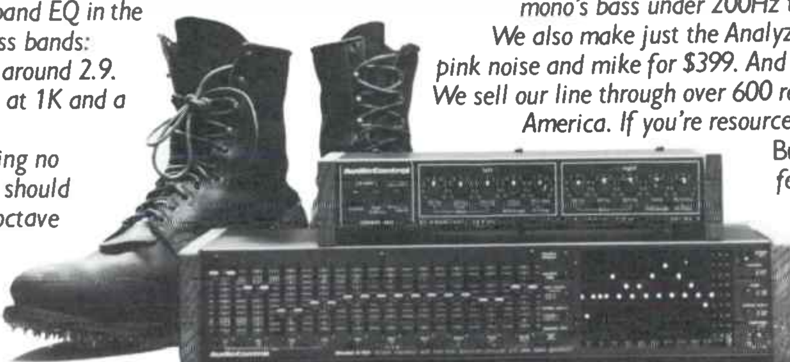
This is the graphic for our consumer and regular trade advertising and might seem a little glossy for you hard-core speaker builders but the point is still this: Your speakers should kick butt.

And after you get through with flux density calculations, Theile formulas, crossover nomographs, vent cutting, damping, cutting, sawing, screwing and wiring, the best way to make make sure your speakers kick butt is with an equalizer.

We make the only five-band EQ in the world with three octave bass bands: 36, 60 and 120 with "Q"'s around 2.9. (We throw in a wider band at 1K and a sizzler at 15.5, too.)

We also include something no builder of speaker systems should ever be without: An 18dB/octave Tchebechev subsonic filter.

And the 520B Equalizer costs just $119.



On the other end of the spectrum (excuse the pun) is our C-101. An octave equalizer with built-in Realtime Spectrum Analyzer, built-in Pink Noise Source and phantom-powered Measurement Mike. All for just $549.

We don't even have to tell you what use that combination can be to the speaker designer/builder. And it also has the 18dB/octave subsonic filter and a special Rumble Reduction circuit which mono's bass under 200Hz to cut audible low-end crud.

We also make just the Analyzer portion of the C-101 with pink noise and mike for $399. And the equalizer only for $249. We sell our line through over 600 reputable hi-fi dealers across America. If you're resourceful enough to enjoy Speaker Builder, you'll have no trouble ferreting out your local Audio Control dealer.

It's worth it to get speakers that truly kick butt.

AudioControl

6520 212th SW, Lynnwood, WA 98036 in the Heart of the Northwest Rainforest.

FIG.13

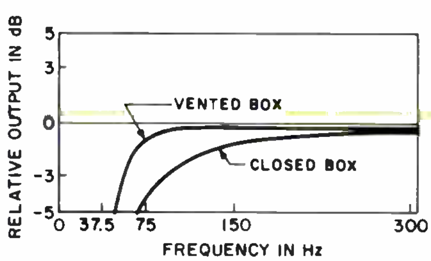


Fig. 13. Simulated response of a QB3 compared with the closed box response obtained by blocking the vent.

FIG. 14

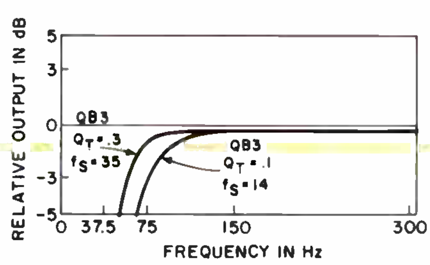


Fig. 14. A very low Q_T alignment compared with a more moderate one. Note that even though the driver resonant frequency of the low Q driver is less than half that of the other, the cut off frequency of the low Q system is higher.

FIG.15

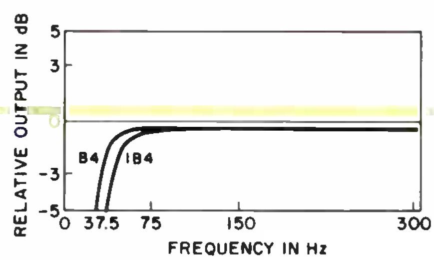


Fig. 15. A comparison of the B4 and IB4 responses plotted separately in Figs. 9 and 11.

TABLE XIV
FOURTH ORDER SC4 AND C4 ALIGNMENTS: Q_L = 5

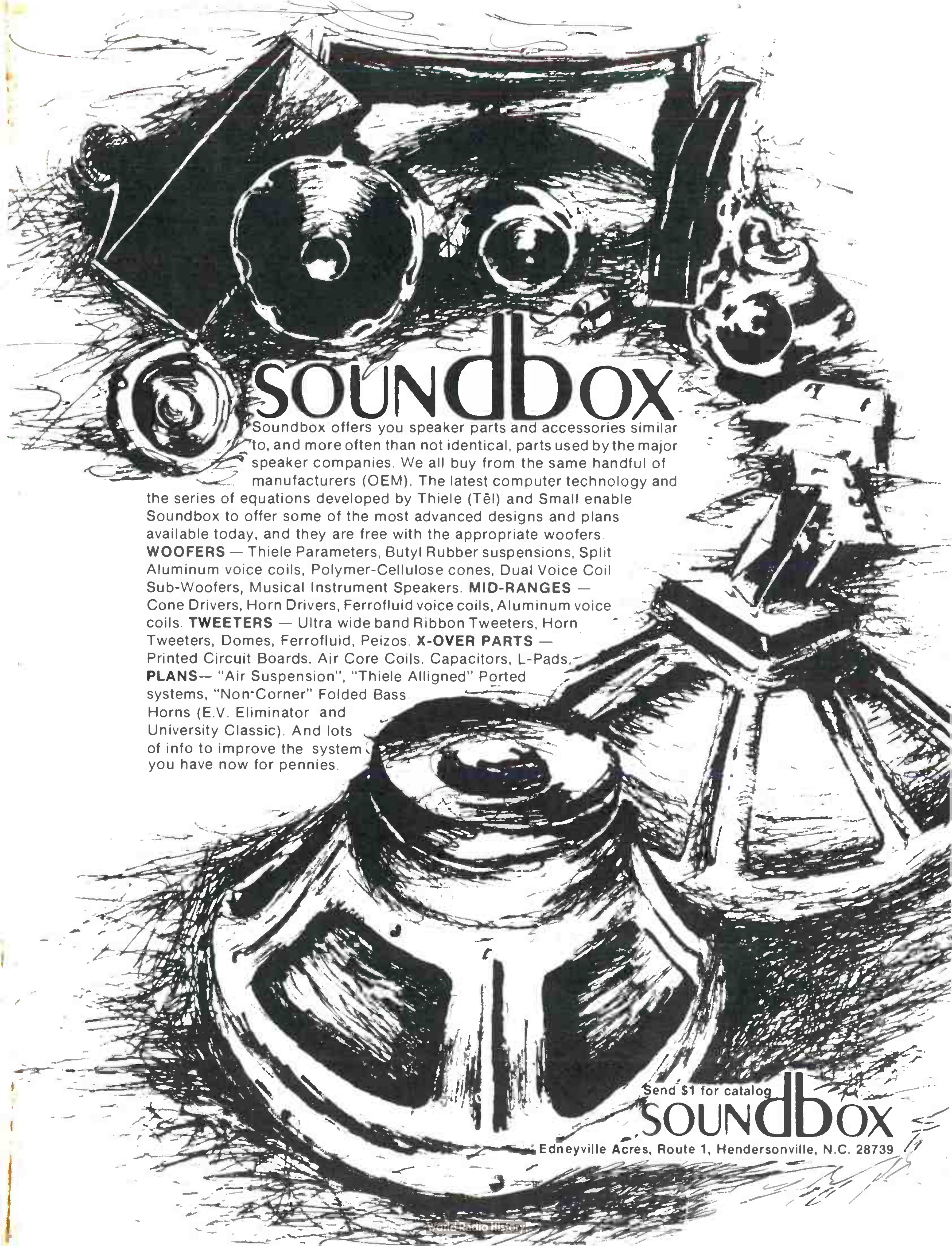
Q_T	H	Alpha	F_3/F_S	Ripple PK(dB)
.2500	1.0271	3.7503	2.4589	
.2600	1.0478	3.5430	2.2912	
.2700	1.0658	3.3356	2.1402	
.2800	1.0812	3.1290	2.0042	
.2900	1.0936	2.9242	1.8816	
.3000	1.1031	2.7223	1.7708	
.3100	1.1095	2.5242	1.6705	
.3200	1.1127	2.3311	1.5791	
.3300	1.1120	2.1441	1.4957	
.3400	1.1096	1.9641	1.4191	
.3500	1.1033	1.7923	1.3485	
.3600	1.0939	1.6296	1.2831	
.3700	1.0817	1.4769	1.2225	
.3800	1.0667	1.3347	1.1660	
.3900	1.0495	1.2036	1.1134	
.4000	1.0303	1.0840	1.0645	
.4100	1.0095	.9757	1.0190	.00
.4200	.9877	.8785	.9767	.00
.4300	.9652	.7920	.9377	.00
.4400	.9425	.7154	.9016	.00
.4500	.9200	.6480	.8684	.00
.4600	.8979	.5889	.8379	.01
.4700	.8766	.5370	.8100	.01
.4800	.8560	.4915	.7844	.02
.4900	.8364	.4516	.7609	.03
.5000	.8178	.4166	.7395	.04
.5100	.8002	.3857	.7198	.06
.5200	.7836	.3583	.7017	.08
.5300	.7680	.3340	.6852	.11
.5400	.7533	.3122	.6699	.13
.5500	.7394	.2927	.6558	.16
.5600	.7263	.2752	.6428	.20
.5700	.7140	.2592	.6307	.23
.5800	.7024	.2447	.6195	.27
.5900	.6915	.2314	.6091	.31
.6000	.6811	.2192	.5994	.35
.6100	.6713	.2080	.5903	.40
.6200	.6620	.1975	.5818	.44
.6300	.6531	.1878	.5738	.49
.6400	.6447	.1787	.5663	.54
.6500	.6367	.1701	.5592	.59
.6600	.6290	.1621	.5525	.64
.6700	.6217	.1544	.5462	.70
.6800	.6147	.1472	.5402	.75
.6900	.6079	.1403	.5346	.80
.7000	.6015	.1337	.5292	.86
.7100	.5953	.1274	.5240	.91
.7200	.5893	.1213	.5192	.96
.7300	.5835	.1155	.5145	1.02
.7400	.5780	.1098	.5100	1.08
.7500	.5726	.1044	.5057	1.13
.7600	.5674	.0991	.5016	1.19
.7700	.5623	.0939	.4977	1.24
.7800	.5575	.0889	.4939	1.30
.7900	.5527	.0840	.4903	1.35
.8000	.5481	.0792	.4867	1.41

TABLE XV
FOURTH ORDER SC4 AND C4 ALIGNMENTS: Q_L = 7

Q_T	H	Alpha	F_3/F_S	Ripple (dB)
.2500	1.0338	3.8961	2.3949	
.2600	1.0534	3.6755	2.2282	
.2700	1.0703	3.4551	2.0784	
.2800	1.0842	3.2360	1.9439	
.2900	1.0951	3.0193	1.8229	
.3000	1.1028	2.8062	1.7137	
.3100	1.1073	2.5977	1.6149	
.3200	1.1086	2.3952	1.5251	
.3300	1.1065	2.1997	1.4431	
.3400	1.1012	2.0125	1.3679	
.3500	1.0926	1.8347	1.2986	
.3600	1.0810	1.6672	1.2345	
.3700	1.0667	1.5109	1.1751	
.3800	1.0498	1.3665	1.1200	
.3900	1.0309	1.2343	1.0689	
.4000	1.0103	1.1146	1.0215	
.4100	.9886	1.0070	.9777	.00
.4200	.9662	.9113	.9373	.00
.4300	.9436	.8266	.9001	.00
.4400	.9212	.7521	.8660	.00
.4500	.8992	.6868	.8348	.01
.4600	.8780	.6297	.8064	.01
.4700	.8578	.5798	.7804	.02
.4800	.8385	.5361	.7567	.03
.4900	.8203	.4978	.7351	.05
.5000	.8031	.4642	.7155	.07
.5100	.7870	.4345	.6975	.09
.5200	.7719	.4083	.6810	.12
.5300	.7578	.3849	.6659	.15
.5400	.7445	.3640	.6520	.19
.5500	.7321	.3453	.6393	.23
.5600	.7205	.3284	.6275	.27
.5700	.7096	.3131	.6166	.31
.5800	.6993	.2992	.6065	.36
.5900	.6896	.2865	.5971	.41
.6000	.6805	.2749	.5883	.46
.6100	.6719	.2641	.5802	.51
.6200	.6638	.2542	.5726	.57
.6300	.6561	.2449	.5654	.63
.6400	.6488	.2363	.5587	.68
.6500	.6418	.2283	.5524	.74
.6600	.6352	.2208	.5465	.80
.6700	.6289	.2136	.5409	.86
.6800	.6229	.2069	.5355	.92
.6900	.6171	.2006	.5305	.98
.7000	.6116	.1946	.5258	1.05
.7100	.6064	.1888	.5212	1.11
.7200	.6013	.1833	.5169	1.17
.7300	.5964	.1781	.5128	1.24
.7400	.5917	.1731	.5089	1.30
.7500	.5872	.1682	.5051	1.36
.7600	.5829	.1636	.5016	1.43
.7700	.5787	.1591	.4981	1.49
.7800	.5746	.1547	.4948	1.55
.7900	.5707	.1505	.4917	1.62
.8000	.5669	.1465	.4886	1.68

TABLE XVI
FOURTH ORDER SC4 AND C4 ALIGNMENTS: Q_L = 10

Q_T	H	Alpha	F_3/F_S	Ripple (dB)
.2500	1.0385	4.0048	2.3469	
.2600	1.0573	3.7740	2.1811	
.2700	1.0731	3.5437	2.0325	
.2800	1.0860	3.3150	1.8992	
.2900	1.0965	3.0893	1.7794	
.3000	1.1020	2.8677	1.6715	
.3100	1.1051	2.6515	1.5739	
.3200	1.1048	2.4419	1.4853	
.3300	1.1012	2.2403	1.4044	
.3400	1.0942	2.0479	1.3303	
.3500	1.0840	1.8658	1.2620	
.3600	1.0708	1.6950	1.1990	
.3700	1.0550	1.5366	1.1407	
.3800	1.0368	1.3909	1.0867	
.3900	1.0168	1.2584	1.0368	
.4000	.9954	1.1390	.9907	.00
.4100	.9732	1.0325	.9482	.00
.4200	.9507	.9381	.9092	.00
.4300	.9282	.8550	.8736	.00
.4400	.9062	.7822	.8410	.01
.4500	.8848	.7187	.8114	.01
.4600	.8644	.6632	.7844	.02
.4700	.8451	.6148	.7600	.03
.4800	.8269	.5725	.7377	.05
.4900	.8097	.5355	.7175	.07
.5000	.7937	.5029	.6991	.10
.5100	.7787	.4742	.6823	.13
.5200	.7648	.4487	.6670	.16
.5300	.7517	.4261	.6529	.20
.5400	.7396	.4059	.6401	.24
.5500	.7282	.3877	.6282	.29
.5600	.7176	.3714	.6173	.34
.5700	.7077	.3565	.6072	.39
.5800	.6983	.3431	.5979	.44
.5900	.6896	.3308	.5892	.50
.6000	.6814	.3195	.5812	.55
.6100	.6736	.3092	.5737	.61
.6200	.6663	.2996	.5667	.68
.6300	.6594	.2907	.5601	.74
.6400	.6529	.2825	.5540	.80
.6500	.6467	.2748	.5482	.87
.6600	.6409	.2677	.5428	.93
.6700	.6353	.2609	.5376	1.00
.6800	.6300	.2546	.5328	1.07
.6900	.6249	.2487	.5282	1.14
.7000	.6201	.2430	.5239	1.20
.7100	.6155	.2377	.5198	1.27
.7200	.6111	.2326	.5159	1.34
.7300	.6068	.2278	.5122	1.41
.7400	.6028	.2232	.5086	1.48
.7500	.5988	.2188	.5052	1.55
.7600	.5951	.2146	.5020	1.62
.7700	.5915	.2105	.4989	1.69
.7800	.5880	.2066	.4960	1.76
.7900	.5846	.2029	.4932	1.83
.8000	.5814	.1993	.4905	1.90



soundbox

Soundbox offers you speaker parts and accessories similar to, and more often than not identical, parts used by the major speaker companies. We all buy from the same handful of manufacturers (OEM). The latest computer technology and the series of equations developed by Thiele (Têl) and Small enable Soundbox to offer some of the most advanced designs and plans available today, and they are free with the appropriate woofers. **WOOFERS** — Thiele Parameters, Butyl Rubber suspensions, Split Aluminum voice coils, Polymer-Cellulose cones, Dual Voice Coil Sub-Woofers, Musical Instrument Speakers. **MID-RANGES** — Cone Drivers, Horn Drivers, Ferrofluid voice coils, Aluminum voice coils. **TWEETERS** — Ultra wide band Ribbon Tweeters, Horn Tweeters, Domes, Ferrofluid, Peizos. **X-OVER PARTS** — Printed Circuit Boards. Air Core Coils. Capacitors, L-Pads. **PLANS**— "Air Suspension", "Thiele Alligned" Ported systems, "Non-Corner" Folded Bass Horns (E.V. Eliminator and University Classic). And lots of info to improve the system you have now for pennies.

Send $1 for catalog

soundbox

Edneyville Acres, Route 1, Hendersonville, N.C. 28739

THIELE, SMALL AND VENTED LOUDSPEAKER DESIGN

Text continued from page 22

quency is lower than the corresponding C4 for Q_T's below .50. In terms of transient response the BB4 is best, the SQB3 is worst, and the C4 occupies the middle ground. Both the BB4 and SQB3 alignments should be appropriate for electric bass loudspeakers, since a large bass emphasis is usually designed into such units.

I used a BB4 alignment to design a system for my parents. They wanted it built into their enclosures, which fixed the V_B parameter. I ordered woofers with Q_{TS} = .33 and had in mind a QB3 alignment. But the samples I received showed a measurement of Q_{TS} = .50. This eliminated my original plan, since the customary C4 alignment would have required a much larger V_B than my parents' boxes provided.

Luckily, the box-driver combination fitted a BB4 alignment almost exactly. The 2dB peak in the upper bass response is very noticeable in my opinion, but the overall sound is comparable to commercial units I have heard costing $300 apiece. My parents are extremely pleased with the results of their $80 investment. (Of course, their opinion had nothing to do with the fact that their son built the system.)

FLAT ALIGNMENTS (SBB4, SC4, QB3)

The QB3 is the standard alignment in this group, but both the SC4 and SBB4 will give better transient response; the SBB4 is best. For a given Q_T the SBB4 requires the largest box and the QB3 the smallest. For very low resonance drivers the SBB4 may call for an exceptionally long vent since the box tuning is so low. The vent constraints of the SC4 are a little less stringent and the cut-off frequency is lower. In my opinion any of these alignments should give an excellent sounding system, but as yet I have used only the QB3. If you use one of the other two I would appreciate your impressions of performance.

DISCRETE ALIGNMENTS

These alignments (B4, Be4, IB4) are all flat. On the basis of Q_T values the Be4 will have the best transient response and the B4 the worst. I recommend you not use any of these alignments, because the target is fixed once Q_L is known and what may appear to be a correct driver initially may be incorrect in the final system. This is not a problem with the alignment series because you can always shift to a new target in the series.

MAKING THE CHOICE

In summary, you must consider several trade-offs in choosing an alignment. By selecting a low Q_T driver you can attain a flat alignment and the best transient response. On the other hand, a high Q_T driver may allow you to realize a system with a very low cut-off frequency.

TABLE XVII
FOURTH ORDER SC4 AND C4 ALIGNMENTS: Q_L = 15

Q_T	H	Alpha	F_3/F_s	Ripple (dB)
.2500	1.0420	4.0890	2.3097	
.2600	1.0601	3.8500	2.1477	
.2700	1.0751	3.6119	1.9970	
.2800	1.0871	3.3757	1.8647	
.2900	1.0958	3.1429	1.7460	
.3000	1.1011	2.9147	1.6391	
.3100	1.1031	2.6924	1.5426	
.3200	1.1016	2.4774	1.4549	
.3300	1.0966	2.2711	1.3749	
.3400	1.0884	2.0748	1.3016	
.3500	1.0769	1.8896	1.2342	
.3600	1.0626	1.7166	1.1720	
.3700	1.0456	1.5567	1.1146	
.3800	1.0265	1.4104	1.0615	
.3900	1.0058	1.2779	1.0125	
.4000	.9840	1.1591	.9675	.00
.4100	.9615	1.0535	.9262	.00
.4200	.9390	.9604	.8884	.00
.4300	.9167	.8787	.8539	.00
.4400	.8951	.8074	.8226	.01
.4500	.8744	.7453	.7942	.02
.4600	.8547	.6911	.7684	.03
.4700	.8361	.6439	.7451	.05
.4800	.8187	.6027	.7239	.07
.4900	.8025	.5666	.7047	.09
.5000	.7873	.5348	.6873	.12
.5100	.7732	.5068	.6714	.16
.5200	.7601	.4820	.6569	.20
.5300	.7479	.4599	.6437	.24
.5400	.7366	.4402	.6315	.29
.5500	.7260	.4225	.6204	.34
.5600	.7162	.4065	.6101	.39
.5700	.7070	.3921	.6006	.45
.5800	.6984	.3789	.5919	.51
.5900	.6903	.3670	.5838	.57
.6000	.6828	.3560	.5762	.63
.6100	.6757	.3459	.5692	.70
.6200	.6690	.3366	.5626	.77
.6300	.6627	.3281	.5565	.83
.6400	.6567	.3201	.5508	.90
.6500	.6511	.3127	.5454	.97
.6600	.6458	.3058	.5403	1.04
.6700	.6408	.2994	.5355	1.12
.6800	.6360	.2933	.5311	1.19
.6900	.6314	.2876	.5268	1.26
.7000	.6271	.2823	.5228	1.33
.7100	.6230	.2772	.5190	1.41
.7200	.6190	.2724	.5154	1.48
.7300	.6152	.2679	.5120	1.56
.7400	.6116	.2636	.5087	1.63
.7500	.6082	.2595	.5056	1.70
.7600	.6049	.2556	.5026	1.78
.7700	.6017	.2519	.4998	1.85
.7800	.5986	.2483	.4971	1.93
.7900	.5957	.2449	.4946	2.00
.8000	.5929	.2416	.4921	2.07

TABLE XVIII
FOURTH ORDER SC4 AND C4 ALIGNMENTS: Q_L = 20

Q_T	H	Alpha	F_3/F_s	Ripple (dB)
.2500	1.0436	4.1309	2.2912	
.2600	1.0614	3.8879	2.1266	
.2700	1.0760	3.6458	1.9793	
.2800	1.0875	3.4058	1.8476	
.2900	1.0957	3.1694	1.7294	
.3000	1.1006	2.9379	1.6231	
.3100	1.1019	2.7126	1.5270	
.3200	1.0998	2.4949	1.4398	
.3300	1.0942	2.2863	1.3603	
.3400	1.0853	2.0881	1.2875	
.3500	1.0753	1.9014	1.2205	
.3600	1.0583	1.7274	1.1587	
.3700	1.0409	1.5668	1.1017	
.3800	1.0214	1.4203	1.0491	
.3900	1.0003	1.2879	1.0007	
.4000	.9783	1.1695	.9562	.01
.4100	.9557	1.0645	.9154	.01
.4200	.9332	.9721	.8782	.01
.4300	.9111	.8912	.8444	.01
.4400	.8898	.8206	.8137	.01
.4500	.8694	.7592	.7859	.02
.4600	.8501	.7057	.7607	.03
.4700	.8319	.6591	.7379	.05
.4800	.8149	.6184	.7173	.08
.4900	.7991	.5827	.6986	.11
.5000	.7844	.5514	.6816	.14
.5100	.7708	.5238	.6662	.18
.5200	.7581	.4993	.6521	.22
.5300	.7463	.4774	.6393	.27
.5400	.7354	.4579	.6275	.32
.5500	.7252	.4404	.6167	.37
.5600	.7157	.4247	.6067	.43
.5700	.7069	.4104	.5976	.49
.5800	.6986	.3974	.5891	.55
.5900	.6909	.3856	.5812	.61
.6000	.6837	.3748	.5739	.68
.6100	.6769	.3649	.5671	.74
.6200	.6705	.3557	.5608	.81
.6300	.6645	.3473	.5549	.88
.6400	.6588	.3395	.5493	.96
.6500	.6535	.3322	.5441	1.03
.6600	.6484	.3254	.5392	1.10
.6700	.6437	.3191	.5346	1.18
.6800	.6391	.3132	.5303	1.25
.6900	.6348	.3076	.5262	1.33
.7000	.6307	.3024	.5224	1.40
.7100	.6268	.2975	.5187	1.48
.7200	.6231	.2929	.5152	1.56
.7300	.6196	.2885	.5120	1.63
.7400	.6162	.2843	.5088	1.71
.7500	.6129	.2804	.5059	1.79
.7600	.6098	.2766	.5030	1.86
.7700	.6069	.2730	.5003	1.94
.7800	.6040	.2696	.4978	2.01
.7900	.6013	.2663	.4953	2.09
.8000	.5987	.2632	.4929	2.17

TABLE XIX
UNIQUE FOURTH ORDER ALIGNMENTS

Q_L	Q_T	h	alpha	f_3/f_s
Butterworth:				
3	.4386	1.0000	.6543	1.0000
5	.4144	1.0000	.9316	1.0000
7	.4048	1.0000	1.0613	1.0000
10	.3979	1.0000	1.1629	1.0000
15	.3927	1.0000	1.2444	1.0000
20	.3901	1.0000	1.2861	1.0000
50	.3856	1.0000	1.3624	1.0000
Bessel:				
3	.3535	.9696	1.4036	1.4911
5	.3376	.9725	1.7488	1.4933
7	.3312	.9735	1.9076	1.4941
10	.3266	.9743	2.0311	1.4947
15	.3230	.9749	2.1296	1.4951
20	.3213	.9751	2.1797	1.4953
50	.3182	.9756	2.2713	1.4957
Butterworth Inter-order (3½)				
3	.3835	1.1397	1.1722	1.2432
5	.3647	1.1241	1.5206	1.2347
7	.3572	1.1184	1.6802	1.2315
10	.3513	1.1145	1.7998	1.2294
15	.3477	1.1117	1.9030	1.2278
20	.3457	1.1103	1.9533	1.2270
50	.3421	1.1079	2.0450	1.2257

If you must still pick an alignment after choosing the driver, you must consider the trade-offs among box size, box resonance, cut-off frequency, and transient response, according to your criteria.

EXTREME Q_T ALIGNMENTS

Extreme Q_T alignments present special problems. It can sometimes be difficult or impossible to design a satisfactory vent for a very low Q_T alignment, since the box volume may be too small to permit using a vent of adequate cross-section and reasonable length. This problem is most likely to occur with a small diameter, low resonance driver.

At the other extreme, a large Q_T alignment can call for a box size many times larger than the driver V_{AS}. Usually this leads to an enclosure which would be obtrusively large in most listening rooms. A recent experience underscores the problem. A student asked my advise on designing a system using a pair of Radio Shack 12" woofers. The woofer parameters were Q_{TS} = .70 and V_{AS} = 18 cu. ft. A standard C4 alignment would have required a 92 cu. ft. enclosure, assuming Q_l = 7. A cubic enclosure of this volume would have to be 4½ feet on a side! Even a BB4 alignment would call for a 43 cu. ft. box, still much too large to fit comfortably in a typical dormitory room. I finally advised him to use a closed box of as large a volume as possible. He seemed to think 6 cu. ft. would be tolerable, which would give a response with a 3.5dB peak in the upper bass, or about half that which would result from using a BB4 alignment.

Considering all factors it is my opinion that the best results will be obtained by starting with a driver whose Q_{TS} is in the range from .20 to .50. This will give a reasonable box size in most instances and avoid excessive peak or ripple in the response. Personally, I usually try to choose a driver with Q_T no higher than .40 so I can use a flat alignment, and no lower than .20 so that the advantages of venting are still significant. □

Acknowledgement: The tables and graphs in this article were generated with the use of the computing facilities of Miami University, Oxford, Ohio.

REFERENCES

1. R.H. Small, "Vented Box Loudspeaker Systems-Part I: Small-Signal Analysis," *JAES*, Vol. 21, 1973, pp. 363-372.
2. W.J.J. Hoge, "A New Set of Vented Loudspeaker Alginments," *JAES*, Vol. 25, 1977, pp. 391-393.
3. A.N. Thiele, "Loudspeakers in Vented Boxes," *JAES*, Vol. 19, 1971, pp. 382-391, 471-483.

READER'S CHOICE

In these inflation fighting days we look for ways to keep our operating costs down. One means is finding other sources of income from our operations which reduce overhead and keep the inevitable price increases in subscription rates to a minimum. We are approached from time to time by various firms asking if we would make your name available for direct mail promotions of their products. For many years we have refused all such requests, knowing that many of you would prefer that we do so.

Recently we have had letters, quite unsolicited, from several readers suggesting that if we wished to make their names available to those vendors whom we consider might be of some interest to them, they would have no objection to rental of our list for such purposes.

We have decided to change our policy about mailing list rental and will consider such proposals in the future. We will restrict rentals to reputable firms whose products we consider to be of interest to you. We also exercise strict control on any unauthorized use of our lists by secondary sales of the information to other users.

If you feel strongly that you do not wish your name to be included in such rentals we are able to lock your name and address record out of rental use availability on our computer. All you need to do is drop a postcard to us at *SB, Circulation Dept., P.O. Box 494, Peterborough, NH 03458.* Thanks.

Tools, Tips & Techniques

TIPS GALORE

1. Consider Needle-Punch carpet as a cabinet treatment. It's cheap, durable, and non-resonant. Any major carpet dealer should have some in stock.
2. In your next small speaker where bolts are not necessary—use hex-head screws instead of Philips. Less chance of destroying a driver cone.
3. For filling the end-grain of plywood or particle board before painting the finish, spackling compound, available at any hardware outlet is just the thing. Butter the spackling compound into the end grain with a putty knife, let dry, and paint. Also great for covering counter-sunk screw heads.
4. Radio Shack makes a speaker mounting kit (#40-150) for wall mounting a pair of speakers that will hold up to 50# each for only $4.00 a pair.

Here are a few sources which may interest *SB* readers:

1. For those who use Radio Shack Components: Pan American Electronics Inc., 1117 Conway, Mission TX 78572. 1-800-531-7466. They give a 10% discount on anything in the catalog and accept Visa and MasterCard.
2. As a source for mylar capacitors in large sizes: Allied Electronics, AE Division, 401 E. 8th St., Fort Worth, TX 76102. Catalog $1.
3. If you can use some polypropylene motor run capacitors in 4µF 1660VAC by Sprague: Etco Electronics, North Country Shopping Center, Rt. 9 North, Plattsburgh, NY 12901 has them under Cat. #CC003 for $2.95 each, page 73k of catalog K. They come complete w/mounting brackets.
4. If you need an inexpensive "scope" this one is a surplus RCA 5"—guaranteed excellent condition for $75.00. Herbach & Rademan, Inc., 401 E. Erie Ave., Philadelphia, PA 19134, (215) 426-1708.
5. If you don't have one, get a Speakerlab catalog. Down to earth, well written. Speakerlab, 735 N. Northlake Way, Seattle, WA 98103. They furnish Thiele/Small parameters on all drivers. Be sure to order their technical bulletins, full of good information.

Jeffrey W. Howell
Mission, TX 78572

IMPROVING CHEAP TWEETERS

When I put an inexpensive tweeter into a utility speaker I usually have to pad the tweeter's amplitude response to arrive at a level compatible with the system's other drivers. We can use this padding to "push" the tweeter's high frequency response for improved brilliance.

Figure 1 shows the measured resistance (R_s) and inductance (L_s) looking into the terminals of an inexpensive cone-type tweeter. An ideal driver's acoustic output should be in proportion to the voltage across its terminals; but without special techniques the driver output starts to decrease at frequencies above where the input impedance starts to rise. For the unit in *Fig. 1* the current will be down 3dB relative to the current at 2kHz by about 12kHz. This current falloff is due both to rising input resistance, R_s, and to the inductance component, L_s.

The common approach to padding drivers is to insert an L-pad or the fixed resistor equivalent. This maintains a correct nominal load on the amplifier at high frequencies and makes crossover circuit component values independent of the amount of padding. I first switched to simple series resistive padding for utility speaker tweeters to minimize the crossover capacitor value, so I could use plastic film rather than non-polar electrolytic capacitors. The serindipitous result was increased brilliance as the tweeter's low end response came down into line with the other driver(s) in the system.

About two minutes with pencil and paper shows the obvious: we are simply adding series resistance to a series resistive-inductive circuit, which moves the low pass breakpoint to a higher frequency. *Figure 2* gives the results for *Fig. 1's* tweeter, showing the relative current into the tweeter vs. frequency with various series resistors. The curves are in decibels with the 2kHz no

FIG. 1

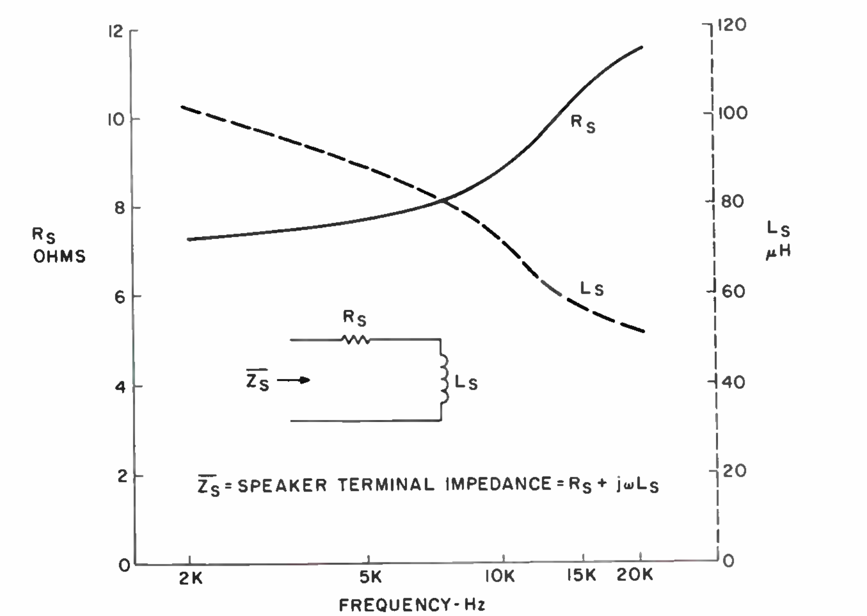


Fig. 1. R_s & L_s vs. frequency for inexpensive cone type tweeter.

added resistance current taken as a reference.

If you believe the acoustic output is current-related, with no padding, this tweeter output drops some 5dB between 2kHz and 20kHz. About 6dB of series padding ($R_1 = 8\Omega$) reduces the falloff over the same frequency span to 2.5dB. The more padding the tweeter needs to match the other driver(s), the greater the benefits of series padding can be in boosting the high frequency response.

If series padding yields too much top end brilliance, try a combination of series and shunt resistive padding; but don't forget to correct the crossover component values. If the top end is still lacking you can try a capacitor or series resistor-capacitor across R_1, the series padding resistor.

D. B. Weems suggests this technique and others for improving tweeters in his book, *How to Design, Build, and Test Complete Speaker Systems* (Tab Books #1064). To me the advantage of simple series padding is it actually uses fewer parts and reduces crossover capacitor size while improving the tweeter's top end performance.

G.R. Koonce
Liverpool, NY 13088

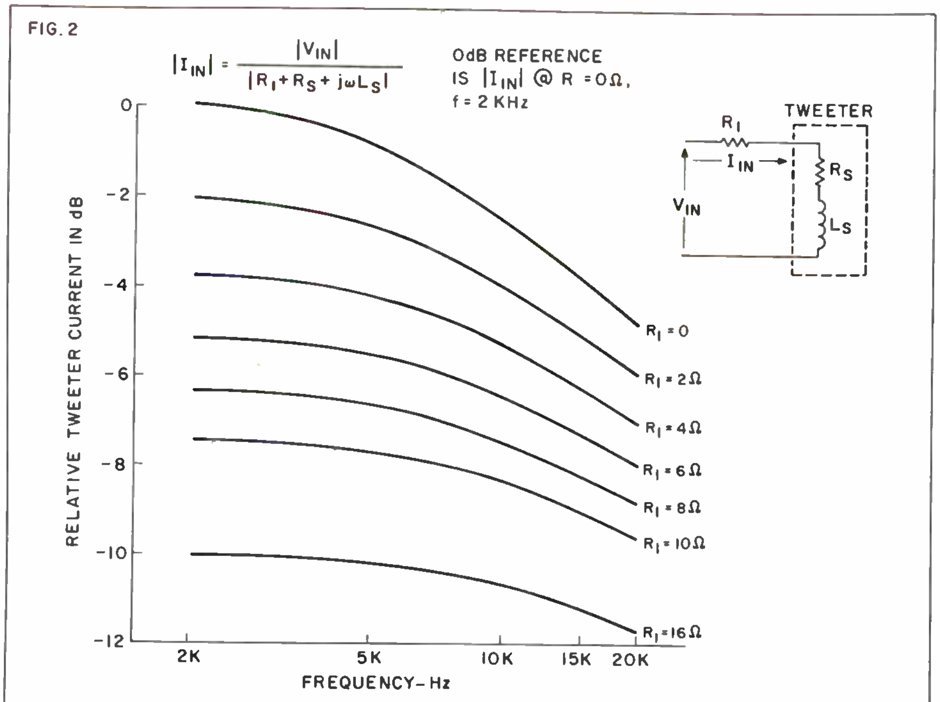


Fig. 2. Relative current into tweeter vs. frequency with various R_1 values.

PASSIVE RADIATORS a la SMALL

ALTHOUGH PASSIVE RADIATOR enclosures exhibit somewhat higher losses, higher 3dB down points and steeper cutoffs (with the consequent degradation of time response) than do vented boxes, these disadvantages seem minor in comparison to the advantages of no wind noises or vent tube resonances that sometime occur with vented boxes, particularly at high listening

Tools, Tips & Techniques

Continued from page 29

levels. More importantly, the passive radiator blocks higher frequencies from escaping the interior of the box. This significantly cleans up the lower midrange of the speaker. Passive radiators are easy to tune, and at least in my experience, seem to more consistantly agree with theory.

Small[1] has published a comprehensive presentation on passive radiators, including an alignment chart. The difficulty with the chart, as with Small's others, is that it is difficult to accurately determine the various parameters from it. Bullock's[2] design tables are a great improvement for vented boxes. Wishing to produce a similar table for passive radiator boxes and not knowing an easy way of generating it from Small's equations, I used an optical X-Y digitizer to tabulate Small's Q_L = 7 passive radiator alignment chart, producing a table in the same format as Bullock's.

The only difficulty with passive radiator boxes is that the designer must find a place on the surface of his box on which to mount both a woofer and a passive radiator. A general rule that I use is that the area of the passive radiator should be about twice that of the woofer. I usually use 12" passive radiators with 8" woofers and 15" passive radiators with 12" woofers. Although I believe it preferable to install the passive radiator on the front of the box with the woofer, this may be difficult with a 12" woofer and 15" passive radiator, and I have built boxes with the passive radiator on the rear with good results.

Once the box is together and the driver and passive radiator installed, the passive radiator must be weighted down to tune the box to the correct box frequency f_B. This is a process similar to that of adjusting the length of the tube in a vented box. Using Keele's[3] method for measuring low-frequency speaker response, a microphone connected to a millivoltmeter is placed very close to the center of the woofer cone and the drive frequency is varied up and down until the frequency of minimum output is found. The microphone is then relocated to the passive radiator and the frequency of maximum output is found.

Initially, both frequencies will be higher than the desired frequency f_B, with the passive radiator frequency the higher of the two. Non-drying modeling clay is then carefully pressed on to the passive radiator cone until the two frequencies decrease to f_B. The modeling clay can then be removed, weighed, and the identical mass of lead fishing wire formed, painted and glued around the passive radiator's dust cap.

PASSIVE RADIATOR ALIGNMENTS FOR Q_L = 7

Q_{TS}	h	∝	f_3/f_S
.20	2.10	8.21	2.65
.21	2.02	7.26	2.51
.22	1.94	6.38	2.36
.23	1.88	5.76	2.26
.24	1.82	5.20	2.16
.25	1.77	4.76	2.06
.26	1.73	4.33	1.98
.27	1.68	4.01	1.90
.28	1.64	3.65	1.82
.29	1.59	3.34	1.74
.30	1.56	3.08	1.67
.31	1.51	2.78	1.59
.32	1.48	2.58	1.53
.33	1.45	2.38	1.49
.34	1.42	2.20	1.44
.35	1.39	2.06	1.38
.36	1.35	1.91	1.33
.37	1.33	1.80	1.30
.38	1.30	1.66	1.27
.39	1.26	1.53	1.23
.40	1.23	1.41	1.19
.41	1.21	1.30	1.17
.42	1.19	1.22	1.14
.43	1.16	1.12	1.11
.44	1.13	1.03	1.08
.45	1.10	0.96	1.05
.46	1.06	0.87	1.01
.47	1.03	0.80	0.98
.48	1.00	0.73	0.95
.49	0.98	0.69	0.92
.50	0.95	0.65	0.90
.51	0.92	0.60	0.87
.52	0.90	0.55	0.84
.53	0.87	0.52	0.82
.54	0.84	0.48	0.79
.55	0.81	0.44	0.76
.56	0.78	0.39	0.72
.57	0.75	0.37	0.69
.58	0.72	0.33	0.67
.59	0.70	0.31	0.65
.60	0.68	0.28	0.62

For example, f_B might be 30Hz and f_D (driver minimum output) and f_{PR} (passive radiator maximum output) might be 45Hz and 50Hz, respectively. As mass is added to the passive radiator, f_D and f_{PR} will both decrease, f_{PR} at a faster rate, until they converge at f_B, assuming no air leaks and correct box volume.

Max R. Knittel
Dept. of Physics/Astronomy
Western Washington University

REFERENCES

1. R. H. Small, "Passive-Radiator Loudspeaker Systems, Parts I and II," *Journal, AES*, Vol. 22, 1974, pp. 592-601, 683-689.

2. R. M. Bullock, "Thiele, Small and Vented Loudspeaker Design: Part I," *Speaker Builder*, Vol 1, No. 4, pp. 7-13 & 30.

3. D. B. Keele, "Low-Frequency Loudspeaker Assessment by Nearfield Sound Pressure Measurement," *Journal, AES*, Vol. 22, pp. 154-162.

CHEAP CALIBRATED L-PADS

CALIBRATED L-PADS are convenient for doing speaker testing so I constructed the simple unit shown in *Fig. 1*. It uses two AT-40 ≅ 8 watt monaural L-pads (if you haven't already discovered it the AT-40 is available for $1.70 in quantity 10 and above from Fuji-Svea Inc., P.O. Box 40325, Cincinnati, Ohio 45240) mounted in a 7 x 5 x 2" chassis with leads brought out to alligator clips. The L-pads have been calibrated by terminating them with an 8Ω resistor and driving them from a stiff voltage source (audio amplifier or filament transformer, etc.).

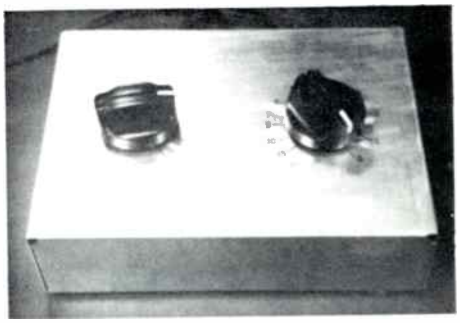


Fig. 1. Calibrated l-pad unit.

With the L-pad turned fully clockwise, the input was set to 1 volt RMS which should produce nearly 1 volt RMS output if the L-pad is any good. The L-pad is then turned until the voltages shown in *Table A, Fig. 2* occur, while holding the input is held constant, and the dB value of padding "marked" on the chassis with transfers. With the AT-40 L-pad you can mark

Fig. 2.
Calibration Data for 8Ω L-Pad-8Ω Load
Based on Holding 1v RMS Input into L-Pad

TABLE A

Padding dB	Voltage Across 8Ω Load-(RMS)
1	.8913
2	.7943
3	.7080
4	.6310
5	.5623
6	.5012
7	.4467
8	.3981
10	.3162
15	.1778

OLD COLONY BOOK SERVICE

Box 243
Peterborough
NH 03458

NEWNES CONSTRUCTOR'S GUIDES

H-1 ELECTRONIC DIAGRAMS *by Morris A Colwell.* A beginner's introduction to electronic diagrams of all sorts: schematics, block, layout, and circuit board. Symbols, interconnections, circuit elements, representational conventions are all explained. Basic symbolic language for the electronics enthusiast. 112pp., softbound.
Each **$6.95**

H-2 ELECTRONIC COMPONENTS *by Morris A. Colwell.* Starting with the minimum basics of electronic building, the author gives a good introduction to the components themselves and all the variety possible in resistors, capacitors, inductors, transformers, semiconductors, ICs, as well as electromechanical devices such as relays and switches. A quick tour of the parts you use for electronic gear to get you started toward knowing your way around. 96pp., softbound. Each **$6.95**

H-4 SIMPLE CIRCUIT BUILDING *by P. C. Graham.* A beginner's approach for simple circuits to step-by-step guidance from the very elementary circuit through increasingly complex circuitry. Circuit board layouts, logic modules, ICs, power supplies, AC amps, and more. A good way to cut your teeth on building if you have no previous experience in electronics. 128pp., softbound. Each **$6.95**

DOVER BOOKS

D-1 REPRODUCTION OF SOUND. *BY Edgar Villchur.* An elegantly simple 92-page paperbound primer on the subject by the man who invented the bookshelf speaker. Loan or give it to friends who want to build a system as good as yours. Each **$2.00**

D-3 MUSIC, PHYSICS AND ENGINEERING *by Harry F. Olson.* A thorough introduction to the physical characteristics of sound and the relationship of sound to musical instruments by the former head of staff at RCA's lab for acoustical and electromechanical research at Princeton, NJ. A classic by one of the giants in the audio field. Good, easy to read chapters on acoustics, mikes and recording, recording and playback systems, as well as an electronic music chapter. 2nd. Ed. (1967) 460pp., softbound. Each **$5.50**

The PENGUINS

P-2 A NEW DICTIONARY OF ELECTRONICS *by R.V. Young.* This remarkably compact reference covers electronics from A-Battery to Z-parameters with succinct, concise definitions and illustrations. A quick reference completely revised and updated with lots of added charts and reference data. 618pp., softbound. Each **$4.95**

P-3 A NEW DICTIONARY OF MUSIC (THIRD ED., 1973; FIRST PUB. 1958) *by Arthur Jacobs* Alphabetically arranged entries covering composers, individual musical works, orchestras, performers, conductors, musical instruments, and technical terms. 458pp., softbound. Each **$3.95**

SCELBI

SC-1 SCELBI'S SECRET GUIDE TO COMPUTERS *by Russell Walter.* An absolutely first rate beginner's book about computers. Explanations about computers that anyone with an IQ over 95 can understand. Written with wit, humor and a secret phone number to call if all else fails. 100 pp. 8½x11, paperbound. Each **$5.95**

SC-2 UNDERSTANDING MICROCOMPUTERS AND SMALL COMPUTER SYSTEMS *by Nat Wadsworth.* A clear, comprehensive introduction to microcomputers with excellent images for visualizing what a computer does and how it does it. Includes a comprehensive glossary and a good chapter on how to choose a system. 306 pp., 5½x8½, paperbound.
Each **$9.95**

TAB BOOKS

T-3 THE BUILD-IT BOOK OF MINIATURE TEST AND MEASUREMENT INSTRUMENTS *by Robert Haviland* is a general electronic constructor's manual as well as a source for test instrument usage, design, and construction. An interesting and different sourcebook. 238pp., softbound.
Each **$4.95**

T-4 HOW TO DESIGN, BUILD AND TEST SPEAKER SYSTEMS *by David Weems.* A cookbook approach to speaker design with some 21 tests for performance. Individual drivers are specified for actual building projects. Weems likes closed box and reflex enclosures but is skeptical of transmission lines. 336pp. Softbound
Each $6.95

HAYDEN BOOKS

H-8 BUILD YOUR OWN HIGH-QUALITY, LOW-COST TEST EQUIPMENT *by M.J. Salvati.* Especially written for the do-it-yourself craftsman who wants to build his own one-of-a-kind test gear especially tailored for highest performance. A wealth of circuitry including a $40 harmonic distortion analyzer, a DC voltmeter, a breadboard electronic load, and much more. 140pp., softbound.
Each **$5.95**

H-10 HI-FI LOUDSPEAKERS AND ENCLOSURES *by Abraham Cohen.* (2nd Edition). Speaker theory covers how and why of drivers, enclosures and rooms. Brief discussions of measuring and building are included along with advice on placement of stereo speakers. 438pp. Softbound.
Each **$9.65**

FONTANA BOOKS

FT-1 INTRODUCING AMATEUR ELECTRONICS *by Ian Sinclair* is a primer of both elementary theory and basic construction techniques. For beginners who want a survey to introduce them to the field. Tools, simple theory, circuits, component descriptions, measurements, and much more. 88pp., softbound. Each **$4.50**

FT-2 HAND TOOLS FOR THE ELECTRONICS WORKSHOP *by Harry T. Kitchen.* An excellent basic introduction to tooling the amateur's workbench for electronics construction. Good chapters on cutting, measuring, drilling, tapping, and soldering. 124pp., softbound. Each **$4.95**

McGRAW-HILL

MH-1 HANDBOOK FOR ELECTRONICS ENGINEERING TECHNICIANS *by M. Kaufman and A.H. Seidman.* A comprehensive compendium of electronic facts. Component selection, circuit analysis, power supplies, IC uses and characteristics, op amps, transistors, batteries and tubes. A one-volume encyclopedia on how components work and how to choose the best of them for your application intelligently. 740pp., softbound.
Each **$26.00**

WILEY BOOKS

W-1 HIGH PERFORMANCE LOUDSPEAKERS (2ND ED.), *by Martin Colloms.* Highly praised sourcebook on loudspeaker theory and construction by a top-notch English authority. 245pp. Hardbound. Each **$24.95**

HOWARD W. SAMS

S-5 AUDIO CYCLOPEDIA, (2nd Ed.) *by Dr. Howard M. Tremaine.* Twenty-five sections covering everything from basic theory to solid state. A complete audio reference library in itself, the most comprehensive and authoritative work on audio available. Covers every aspect of the audio art—from the basic principles of sound to the latest in solid-state equipment. 3,650 entries, 1,760pp., hardbound.
Each **$39.95**

S-11 HOW TO BUILD SPEAKER ENCLOSURES. *by Alexis Badmaieff and Don Davis.* The "whys" and "hows" of speaker enclosures. Drawings and instructions cover infinite baffle, bass reflex, and horn types plus combinations. 144pp., softbound. Each **$4.95**

S-12 IC OP AMP COOKBOOK *by Walter G. Jung. [2nd Ed.]* The revised bestselling, authoritative, best introduction to practical op amp usage available. By *TAA's* op amp columnist and author. 480 pp., softbound. Each **$14.95**

S-14 ACTIVE FILTER COOKBOOK *by Don Lancaster.* A practical, user-centered volume with everything you need to build your own active filters. Explains the various types and how to select the best for your circuit. 240pp., softbound. Each **$14.95**

ORDER BLANK:
Old Colony Sound Lab
PO Box 243
Peterborough NH 03458

To order from Old Colony Sound, please write each book's number below with quantity of each and price. Total the amounts and remit by check, money order, or MasterCharge, or Visa/BankAmericard. Please add 50¢ for postage on the first book; 25¢ per additional book. *$10 minimum order on credit cards.* Canadians please add 10% for postage. All remittances must be in U.S. funds. *Please use clear block capitals.*

Name______________________
Street & No. ______________
Town______________________
State ___________ ZIP________

No. Bks. Price
. . . .Book No. . . . . $. . . . .
. . . .Book No. . . . . $. . . . .
. . . .Book No. . . . . $. . . . .
. . . .Book No. . . . . $. . . . .
Postage $. . . . .
Total $. . . . .

Please add $1 service charge to all charge card orders under $10.

Tools, Tips & Techniques

Continued from page 30

1dB increments up to about 8dB, then things get tight. *Table A. Fig.* 2 shows the values I marked on my units. Don't forget to mark the full clockwise position to establish a reference for reinstalling the knobs later.

This simple box has two major uses in my shop. The obvious is padding midrange and/or high frequency drivers during listening tests or acoustic measurements to match driver efficiencies. The second use is in measuring the impedance the driver presents to the crossover. Once the padding level for a particular driver has been established I measure the driver's input impedance through an L-pad set to this padding. *Figure 3* shows how the L-pad tends to "swamp-out" the reactive portion and the resistance variations giving a much better load for a passive crossover to work into and simplifying the crossover design. In the actual enclosure the L-pad or a fixed resistor equivalent would be included.

While the crossover performance at the L-pad input will be improved, some frequency effects on L-pad attenuation can be expected due to the driver's impedance variations and the driver should not be used any closer to its resonant frequency padded than it would be unpadded. Note that most filter design equations used for crossover work assume a zero ohm source and a fixed resistive load. The L-pad after the crossover helps to meet this approximation.

G. R. KOONCE
Liverpool, NY 13088

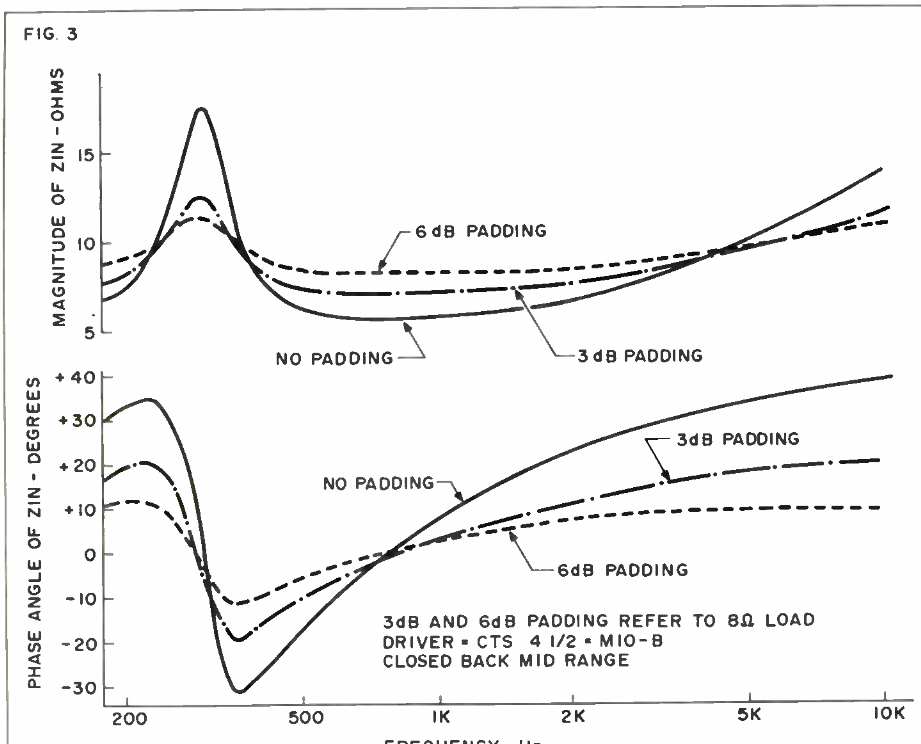


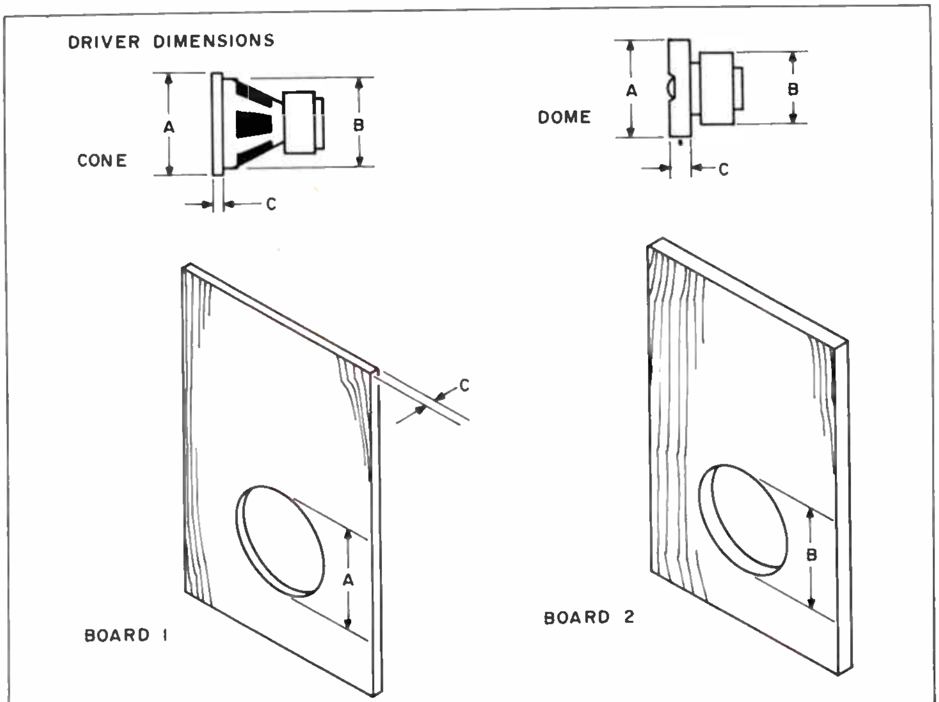
Fig. 3. Effects of padding on driver input impedance.

FASTER FLUSH MOUNT

THERE IS AN EASIER way to flush mount drivers than to make a step down with a router which makes a terrific amount of dust in your work room. You also need a certain skill in handling a router because you will be using it in free hand fashion.

I wish I had a thought about this trick before I built my speakers which have twelve drivers in each enclosure.

HARUKA WATANABE
St. Louis, MO 63130



1. Board 1 and 2 are of equal size and glued together.
2. Board 2 must be sufficiently stiff and as non-resonant as possible.
3. Holes must be concentric when glued together needless to say.
4. For drivers with different dimensions of "C", board 1 can be made with two parts, each with the proper thickness—taper the edge where the two parts meet.
5. Hole "A" may be octagonal for a driver with such a shape.

PARTICLE POINTERS

PARTICLE BOARD IS the commonly preferred material for constructing speaker cabinets. Its advantages over plywood include lower cost, homogeneity, lack of voids or loose plys (as found in all but highest grade plywoods), and relative acoustic deadness. However, when buying particle board, be sure you're getting high density, cabinet grade board, not the cheaper, low density, "underlayment" grade sold by many lumber yards for use as flooring material in new home construction. Density should be rated around 45-50 lbs. per cubic foot. Many lumber yards do not stock this grade unless they cater to cabinet builders.

If you find this to be the case in your area and the lumber yard cannot (or will not) order some for you try looking for a specialty cabinet or paneling store. If you still can't find some, go to a local cabinet building shop. They should have some they may be willing to sell you directly or at least tell you where you can get some. (Some places may even be able to supply you with particle board already covered on one or both sides with a decorative laminate such as Formica, vinyl, or real wood such as walnut, oak, rosewood, etc. This makes obtaining a finished appearance easier, but may require 45° miter joints at edges, rather than simpler butt joints.) When buying, look for a fairly tight, dense central core—that's where the strength is. The best grades have very dense cores with little air space, however, due to the way the board is manufactured by compression, the surface will always be denser than the core.

Particle board can be cut using ordinary tool steel saw blades, but will quickly dull these if any extensive cutting is done (anything more than about two speaker cabinets!). Carbide tipped blades are much better providing smoother cuts and lasting almost indefinitely. Those sold by Sears or Wards do an excellent job.

You can glue particle board using white glue (Elmer's) or even better, the newer yellow (aliphatic resin) wood glue (Franklin "Titebond" or Elmer's Professional Carpenter's). However, to obtain a really strong, professional glue joint with these water soluble glues, here's a tip: Particle board, just like any other porous wood, will absorb a certain amount of any liquid or semi-liquid glue. This draws glue away from the joint line thus weakening the resultant bond.

To compensate for this, you should "prime" the joint surfaces before gluing. To do this, add just a little water to a small quantity of white or yellow glue, mixing it to about the consistency of paint (not too watery or runny). Using a brush, saturate both wood surfaces to be joined. Now set the pieces aside until the glue is partially absorbed and begins thickening (about 15-30 minutes—no longer or the glue may dry). This allows the wood to absorb and be saturated with the glue.

Now apply the regular, unthinned glue to one or both surfaces, join, and

Continued on page 37

Bookwork

The Handbook of Electronics Calculations, M. Kaufman and A. Seidman, Eds., McGraw-Hill, 1979.

Reviewed by Robert M. Bullock, III

The Handbook of Electronics Calculations contains exactly what its title promises: a large number of worked electronics calculations in the format of problem, applicable theory, and solution. Only about half the book's 24 chapters have a direct bearing on audio, and I will describe them first.

The first three chapters, "Technical Math Review," "D.C. Circuit Analysis," and "A.C. Circuit Analysis," contain standard information on algebra, trigonometry, Kirchhoff's Laws, circuit analysis, and network theorems, together with problems illustrating the use of various formulas. A chapter on "Selecting R, L, and C Components" includes problems on temperature effects, stray inductance, and stray capacitance as well as the usual information on structure, tolerance, etc. The section on inductors contains formulas that could be used to roll your own.

The chapter on "Selecting Semiconductor Devices," one of the longest in the book, covers 14 different device types with one sample calculation for each. The "Audio Amplifier" chapter covers transistor types complete with biasing and impedance calculations. Problems demonstrate how to find the power gain of different amplifier types.

A chapter on "Feedback gives gain and impedance calculations with various types of feedback, as well as problems dealing with multistage and multiloop feedback, gain and phase margin, and compensating networks. A short chapter covers "Power Supplies," both unregulated and regulated. The "Op Amp Applications" chapter deals only with circuits for instrumentation and mathematical function generation.

The last chapter of interest, on "Filters," approaches filter design from the viewpoint of realizing a prescribed bandwidth and attenuation rate, which is not usually the primary concern in audio. However, the tables for selecting component sizes in both passive and active circuits could be useful.

My overall impression is that this book is intended not for the novice but for someone knowledgeable in electronics who needs to recall a particular computational procedure. The treatment of the underlying theory and the scope of the calculations are generally too narrow to adequately inform a beginner. The book is well written, however, and could serve as a convenient source for the more sophisticated user.

For the record, the chapters not listed above are: "Tuned Amplifiers," "Oscillators," "Battery Uses and Special Cells," "Digital Logic," "Computer Aided Circuit Design," "Analog-Digital Conversion," "Video Amplifiers," "The Microprocessor," "Transmission Lines," "Antennas," " Microwaves," "Communications Systems," "Measurements, " and "Thick-Film Technology." An appendix consists principally of log and trig tables. □

Loudspeakers—An Anthology of Articles, Audio Engineering Society, $22.00.

Reviewed by Robert M. Bullock, III

Since its inception in 1953, the *Journal* of the Audio Engineering Society has published many papers on loudspeakers. The Society has collected 60 of them, covering the period 1953-1977, in one volume under the title *Loudspeakers*. This book will be one of my standard references for the breadth and depth of its information.

Probably at least one article in the collection answers any question that may arise in loudspeaker design. At the very least the accompanying references will lead to additional sources.

To give you some idea of the coverage, I will list several topics and the articles from *Loudspeakers* which I have found relevant.

Direct Radiator System Design:
1. "Loudspeakers in Vented Boxes" by A.N. Thiele
2. "Direct Radiator Loudspeaker System Analysis" by R.H. Small
3. "Vented Box Loudspeaker Systems" Parts I-IV, by R.H. Small

Crossovers
1. "Constant Voltage Crossover Network Design" by R.H. Small
2. "Active and Passive Filter as Loudspeaker Crossover Networks" by J.R. Ashley and A.L. Kaminsky
3. "Active Crossover Networks for Noncoincident Drivers" by S.H. Linkwitz

Loudspeaker Cabinet Resonances
1. "Loudspeaker Enclosure Walls" by P. Tappen
2. "The Theory of Loudspeaker Cabinet Resonances" by J. Iverson

Phase and Time Delay
"Loudspeaker Phase Characteristics and Time Delay Distortion" Parts I, II, by R.C. Heyser

Loudspeaker Measurements
1. "Experimental Determination of Low-Frequency Loudspeaker Parameters" by J.R. Ashley and M.D. Swan
2. "Simplified Loudspeaker Measurements at Low Frequencies" by R.H. Small
3. "The Application of Digital Techniques to the Measurement of Loudspeakers" by J.M. Berman and L.R. Fincham

Other articles cover driver design, distortion, the sound field in home listening rooms, the use of cabinet filling, and much more.

The articles are generally written at an advanced level; many of them require some mathematical ability beyond arithmetic. The information density is often high, so you may have to read an article several times. In other words, this book is not for the casual browser but for someone with a serious and continuing interest in the subject. In spite of this, most of the articles are written in a straightforward enough style so that repeated readings are not tedious.

I strongly recommend this book to the serious student of loudspeakers. It is packed with useful information and even the oldest articles contain ideas still relevant to the problems they address. □

[This volume is one of five offered by AES. Others in the series are: *Disk Recording*, *Microphones*, *Quadraphony*, and *Sound Reinforcement*. Single anthologies are $22 to non-members; $19 to members. Two or more are $20 each to non-members; $17.50 each to members. Full details from AES, 60 E. 42nd St., Dept. SB, New York, NY 10165.—Ed.]

Craftsman's Corner

Xover a la Linkwitz

TECHNICALLY, MY SYSTEM is a reasonably straightforward two-way design with biamplified subwoofers for each channel. The woofer is comprised of two Audax HD20B25J woofers in push-pull, presumably to eliminate second-order distortion effects, housed in a 20″ cube made from 2 thicknesses of ⅝″ particle board lined with a few inches of ordinary fiberglass house insulation. The voice coils are parallelled to provide a nice low 3 ohm impedance for drive from a homebrew amplifier capable of in excess of 15 amperes output. Needless to say, the woofers bottom before the amp overloads! Crossover details are shown in *Fig. 1*.

The midrange is a Dalesford 6.5″ Bextrene cone, type D153/50. This is by far the finest driver I have yet found, easily surpassing the KEF and Audax products. I anticipate trying their 8″ units in the woofer at some future date. I have enclosed the Dalesford in a 8x9.5x9.5″ cabinet of ¾″ particle board lightly filled with more fiberglass. The Dalesford is crossed over at 3500Hz to a JVC ribbon tweeter through standard third order Butterworth filter using impedance equalization on the Dalesford. The JVC is mounted on strips of angled pine for minimum diffraction.

Similarly, the Dalesford baffle is of minimum width, also to minimize diffraction. I believe the 3500Hz crossover is a bit low, since the JVC's are starting to roll off and the breakup modes in the Dalesford are starting to become quite noticeable, especially at high levels. But the blend seems good, tonality is excellent, and imaging is simply unequalled by anything I have ever heard. There still exists a seam between the Dalesford and the JVC, owing to their differing radiation techniques, I'm sure. The woofer blends in quite nicely, owing to the 75Hz transition point, and the Dalesfords do a fine job from the midbass upward.

I should point out that many of my ideas about speaker systems are owed to Mr. Linkwitz. I first received copies of his articles (*SB* 2, 3, 4/1980) in a literature package from KEF. I have chosen to adapt his crossover technique to eliminate the need for high-

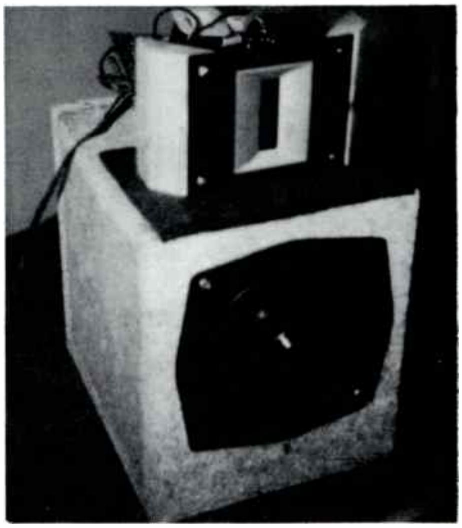


Fig. 2. Closeup of Levreault's midrange and tweeter units.

Fig. 1.

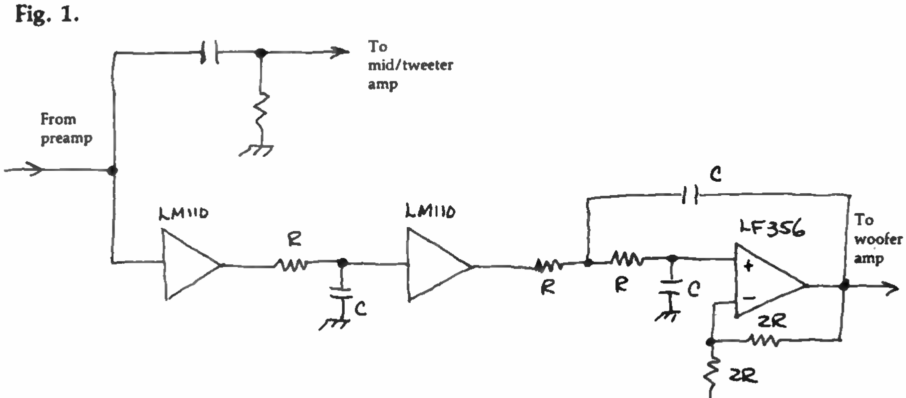


Fig. 1. Active crossover.

Fig. 3. The complete system.

pass active crossover, which I feel unacceptably degrades the sound of the system, not so much because of the active devices, but because of the capacitors.

By aligning the midrange driver, in this case the Dalesford, for a Q of 1, I only need to place a single capacitor in series with the input to its amplifier which will cause the gain of the amp to decrease by 3dB at the resonant frequency of the Dalesford, in this case 75Hz or so, leading to an exact third order Butterworth response. The woofer response can be acceptably generated by cascaded first order Butterworth and second order Q=1 low pass filters for a complementary function. This is the same technique used by Jon Dahlquist in his active crossover, and I therefore make no claims as to its origin. The Dalesford enclosure is, in this case, slightly large, causing a minor audible dip around the crossover region, so more work remains.

John E. Levreault, Jr.
Tewksbury, MA 01876

Tools, Tips & Techniques

Continued from page 33

clamp or weight them for at least 30 minutes. Excess glue may be wiped off with a wet rag. Clamps or weights may be left on as long as you wish, but if you're in a hurry, may be removed after 30 minutes (1 hour under humid conditions). Allow 12-24 hours drying time with or without clamps for the joint to reach maximum bond strength. Use of this technique will always result in joint lines that are stronger than the wood itself.

R. Shaffer
Custom Sound
8460 Marsh Road
Algonac, MI 48001

BUILDERS AHOY

WHILE WE HAVE MANY fine manuscripts in hand for future publication in these pages—we need your contributions too. How about those offerings for our *Craftsman's Corner, Tools, Tips & Techniques*? We also need accounts of your construction adventures with specific projects. Why not plan to take pictures (black and white preferred) and make notes when you're building that next project—or kit. Write it up just as you would a letter to a friend. Send it along to us and we'll give it every consideration. We pay for articles, so you might have a nest egg for that next project you want to try, as well. We have a nice sheet of suggestions for authors which you may have just by asking for it.

MANRIQUE RESPONSE

WE APPRECIATED Frank Manrique's extensive comments (*SB* 1/81) on the audibility of various bass-response design parameters. Finely tuned "ears" are as important for achieving quality audio performance as are precision measuring devices and elegant theory, none of which can be disregarded by the serious audiophile.

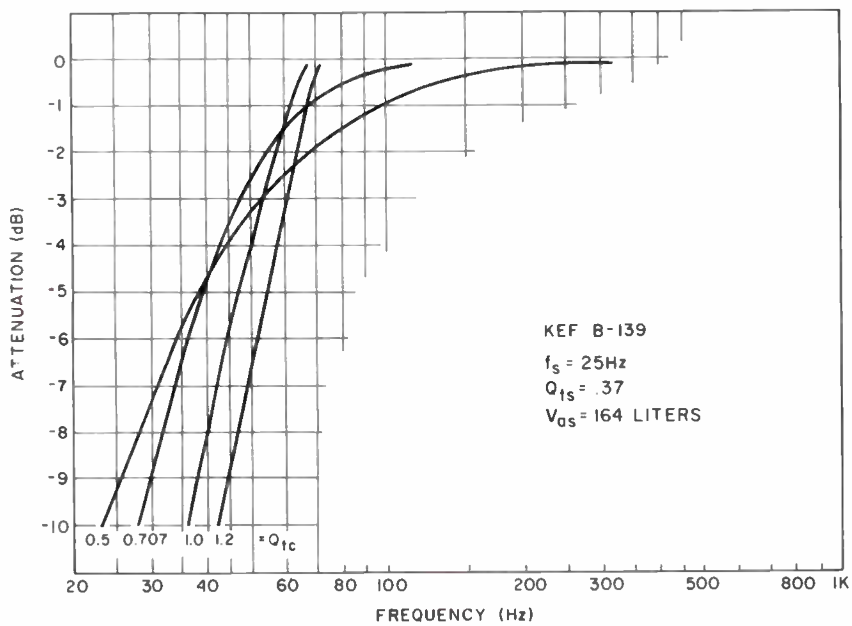
On the theoretical side, we would like to clarify a few misprints and/or misconceptions in Frank's letter. First, the terms "overdamped" and "underdamped" were interchanged. An underdamped woofer might sound "overprominent, boomy, uncontrolled, with poor transient response." The lack of proper damping causes a peak in the amplitude response and overshooting (ringing) in the time response. On the other hand, an overdamped woofer might sound "thin and lacking in transient impact...dry and somewhat tight." Too much damping begins rolling off the amplitude response fairly high in frequency and does not allow transients to build up their full amplitudes. Since Q_{tc} = 0.50 is called the "critically damped" case where no overhang occurs but transients are allowed to build up to their full amplitudes, overdamping would occur only if $Q_{tc} < 0.50$.

Second, "correct Q" depends on which performance parameter is to be optimized. Q_{tc} = 0.707 optimizes flat frequency amplitude response, whereas Q_{tc} = 0.50 optimizes transient response. Other Q_{tc} values could be appropriate because of high driver Q, desire for a smaller box volume or for helping to correct frequency response anomalies such as might be caused by room-boundary interferences.

Third, the relationship between the −3dB point (f_3) and Q_{tc} for a closed box is not a monotonic function, as many audiophiles seem to believe. The formula for calculating f_c, system resonance,

$$fc = fs \frac{Q_{tc}}{Q_{ts}} \qquad (1)$$

FIG. 1



is commonly thought to yield f_3, but it does so only when Q_{tc} = 0.707. For any attenuation point f_{dB}, the proper formula is:

$$f_{dB} = f_s \frac{Q_{tc}}{Q_{ts}} \beta \qquad (2)$$

where the value of β depends on the desired attenuation, as shown in Note 1 below. Working through the calculations indicates that f_3 does indeed decrease as Q_{tc} is lowered toward 0.707, reaches a minimum at that value, but then rises again as Q_{tc} is lowered further. For the KEF B-139 driver, a 0.707 box yields f_3 = 52.4Hz.

Note, however, that this increase in f_3 does not imply that the larger box provides less low-frequency output; more output does occur at lower frequencies, as can be seen by looking at f_{10} (the −10dB point) instead of f_3. For the 0.707 box, f_{10} = 27.6Hz, but for the 0.50 box, f_{10} = 23.0Hz. The

TABLE I: VALUES OF β

	ATTENTUATION (dB)					
Q_{tc}	0.1	1	3	4.5	6	10
1.2	.8693	.8217	.7358	.6818	.6320	.5183
1.0	.9888	.9075	.7861	.7182	.6590	.5314
0.707	2.560	1.400	1.000	.8610	.7598	.5774
0.50	9.292	2.857	1.554	1.213	1.000	.6801

Note 1:

The term in Eq. (2) is obtained from

$$\beta = \left[\frac{(1/Q_{tc}^2 - 2) + \sqrt{(1/Q_{tc}^2 - 2)^2 + 4(p-1)}}{2(p-1)}\right]^{1/2}$$

where the value of p depends on the desired attenuation A in dB,

$$p = 10^{A/10}$$

point is that f_3 is not particularly useful, and possibly misleading, for comparing low-frequency performance of closed-box designs having different Q_{tc} values. The frequency f_{10} is more representative of actual low-bass output since it accurately indicates that low frequencies are less attenuated for low-Q designs (despite the fact that roll-off begins at a higher frequency). More generally, Q_{tc} specifies the complete *shape* of the frequency response curve so that the entire curve rather than just f_3 should be considered for assessing potential bass performance.

Table 1 presents β for four values of Q_{tc} at six different attenuation points. The $f_{4.5}$ point is interesting because it is very close to the frequency at which 0.707 and 0.50 boxes yield equal output for a given driver. Above $\sim f_{4.5}$, the 0.707 box yields greater output, but below, the 0.50-box output is greater. *Fig. 1* shows frequency response curves for the B-139 driver between $f_{0.1}$ and f_{10} for four values of Q_{tc}. It is easy to see why low-Q designs sound "thin" and high-Q designs lack "depth." For example, the 0.50 design has less output than the 1.0 design above 50Hz ("thin"), but the 1.0 design has less output below 50Hz ("shallow"). In addition, the high-Q, steep cut-off designs, being underdamped, will produce transient ringing which is added to the electrical signal entering the woofer. Ringing is heard as a coloration adding excess "weight" to the sound (naively interpreted as good bass performance by some listeners). Overall, the 0.707 design seems to be an excellent compromise between the low- and high-Q designs, producing nearly as much low bass as the 0.50 and nearly as much mid and upper bass as the 1.0.

How can one get greater low-frequency output from a driver such as the B-139? The easiest way is to raise the driver Q_{ts} nearer to 0.707 by placing a power resistor in series with the driver. For example, placing a 1.5Ω resistor in series with the B-139 will raise Q_{ts} to about 0.45, and for Q_{tc} = 0.707, f_3 and f_{10} decrease from 47.8Hz and 27.6Hz to 39.3Hz and 22.7Hz, respectively. The increased low-frequency output is paid for with the enclosure size increasing from 61.9 liters to 111.7 liters with decreased efficiency (the power lost in the resistor).

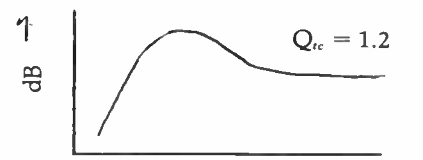
We hope that more *SB* readers will follow Frank's lead in providing finely detailed accounts of the sonic character of their projects rather than merely stating that they sound "good" or "better than Brand X", and that they will also tune-in to the theoretical side of speaker design. We will all benefit in both cases.

ROD REES
MAX KNITTEL

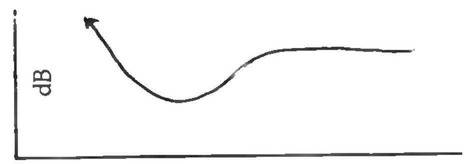
Mr. Manrique (*SB*, 1/81) seems to have failed to understand what Linkwitz is trying to do in his design for the woofer part of his system. With a Q_{tc} of 1.2 there will be some peaking in the frequency response, but the network in the crossover exactly compensates for this.

Linkwitz calculates the amount of room that is available to him for a woofer cabinet and then measures the response in that cabinet. For the home constructor this method is the best as the parameters such as V_{as} vary greatly in production, so that the finished result based on calculations only, might differ greatly from the predicted result. Linkwitz' design compensates for what he ends up with, avoiding all the hassles of misalignment. It can be seen that the home constructor has an advantage over the commercial speaker producer in this respect, because they cannot afford to "tweak" speaker response on this individual basis.

The Linkwitz technique solves the problem of getting good response out of a small box. In Stamler's article (*SB*, 1/80), in *Table 4* where the responses of various woofers



Woofer response f →



Network response f →
(See Linkwitz' Figure 20)

Mailbox

are examined for an alignment of Q_{tc} – 0.707, it can be seen that only three of the woofers have responses below 40Hz, and these responses are obtained in cabinets of volumes 5600, 9152, and 17216 cubic inches. The KEF B200 SP1039 does get a response of 37Hz in a cabinet similar in size to Mr. Manrique's. (Is this woofer commercially available?) I would suggest this woofer for Mr. Manrique's system.
Brian Goodman
Toronto M6P 2X2 Ontario Canada

Mr. Manrique replies:

My face is red with embarrassment! By overlooking certain areas in the formulas and data from the Small and KEF information, I came to the wrong conclusions! I apologize for any inconveniences I may have caused to any *SB* reader who may have considered building the bass units I described in *SB* (1/81). I gracefully accept the corrections of Rees and Knittel and their helpful comments.

Mr. Goodman is also right in his criticism of my letter as far as the conclusions I assumed to be correct on the matter of the frequency response and system's "Q". He's not right, however, in criticizing me for my criticisms on the Linkwitz approach of his design for the bass section of his otherwise very intriguing system.

Most of the corrections offered to my wrong assumptions focus mainly on two points: System's cutoff (–3dB) and "Q". But none of these gentlemen offer an explanation on the matter of what happens in the "large signal" parameters. Changes occur in frequency response and Q with step-drive (at large amplitude levels or under dynamic conditions.) This can and will affect the overall sound of a given speaker system, be it full-range or bass reproducers. Though I did not elaborate on this in my letter, I did say that "The limitations inherent in the design, and the limitations set by the drivers themselves do not allow…" extreme high sound pressure levels without serious penalties. Nor is anyone explaining what happens when speakers are connected to the output of an amplifier. This is really beyond the scope of the present discussion. I hope that other *SB* readers can expand more thoroughly not only about the "small-signal" parameters in loudspeakers, but also about the "large-signal" or dynamic conditions. There is far more than just correct figures, the theory behind the right alignments, a given loudspeaker, etc., to come up with a successful sounding bass system and otherwise…

As far as my criticisms of the approach Mr. Linkwitz chose for his bass design is concerned, I would like to ask Mr. Goodman just how sonically successful will the Linkwitz bass section be in the majority of listening rooms which do not have the same configuration or dimensions as that of the designer? Does he (Goodman) have any actual experience with either Linkwitz' or a system such as mine, from which to draw factual conclusions? Or does he just assume his criticisms and observations from theory alone?

Goodman seems to feel that the Linkwitz bass is sort of a universal bass system, which will be sonically right (but none really is!) in any room. I stand firm and do not recant about what I have to say in my letter. This is so because I have had enough experience with the B139 LF drivers to know better. The design for which I finally opted offers very good performance, and is by far the best compromise in terms of sonics (as Manz and Manning also seem to agree), even though the frequency response may not be as low as I hoped it would be.

It may be worthy noting also that a sealed system is not as critical in alignment (as long as all parameters are considered as a whole) as, say, a vented system. A difference of 1000 cubic inches does not make a lot of difference. The overall alignment for the B139 units, as being correct (refer to the corrections given by Rees and Knittel, plus other data available from Small, etc.), and in a sealed system with a good "compromise" of system's "Q" (0.68, 0.7 or 0.707) will always offer a very natural sound, which is a good match for full-range (?) speakers such as the Rogers/Swisstone LS3/5A's in a biamped mode!

I actually tried the bass set up, with the same drivers, as that suggested by Linkwitz. In my case, the sonic results were terrible, and left too much to be desired. That is also how I came to the conclusions outlined in my letter. Conclusions which, I may add, that agree with the observations of Mr. Carlberg (Mailbox 3/80, p.41.) as well. I tried the "Linkwitz" design in a smaller room in my house, and the sonic results were just as I thought they would be: Not correct for the appropriate propagation of bass reproduction. Of course, my setup does not have the corrective compensation of the Linkwitz crossover. But I am totally sure that a high Q cannot be successfully compensated for regardless of equalization. If Mr. Goodman has built Linkwitz' system, or is planning to do so, fine. But for the great majority of *SB* readers wanting a bass system (or a full range system for that matter) that would complement their audio setup, simplicity will be a better route to take. By simplicity I mean not only approaching the design of any system by utilizing the Small and Thiele data as the case may be, but by having a pair of units which will allow proper stereo reproduction, and which will allow proper localization within the listening environment. A summed bass system cannot, I believe, allow this to happen. If Mr. Goodman's choice of the Linkwitz system is a matter of taste, fine. That's, however, not accurate (accurate insofar as is permissible by the relative accuracy offered by his own audio system).

For those who contemplate building a bass system like the one I described, I believe sonically they cannot go wrong. They should, however, refer to the corrections, and decrease the size of each box to the proper dimensions (considering the amount of internal volume displaced by the drivers, bracing, etc.).

Or the reader interested in such units can follow the suggestions given by Rees and Knittel, increase the internal volume as given, and use the compensating resistors, obtaining then lower cutoff response and Q of 0.707, but also accepting the penalties of greater dimensions, lower efficiency, and more susceptibility to problems in the "large-signal" area.

Many other drivers allow a lower response to be sure, such as the one that Goodman recommends (and cheaper also), but smaller diaphragm area will not allow greater sound output, will be taxed by sound pressure levels of high amplitude, and will be more limited in power handling capabilities.

As a musician I find it extremely amusing to see the response to my errors to be exclusively limited and focused in the theoretical part. Only two respondants commented about the actual sound. It is evident that they used those wonderful instruments of aural perception with which we are endowed, our ears! It's not enough to assume a theory to be correct. We all must listen to ascertain the relative accuracy of audio gear. But we also must have a concrete reference to compare such relative accuracy. As a musician I use the only plausible absolute reference that one should apply for comparisons, live music. Comparing one product to another cannot reveal which is more true to the sounds of live music. Listening is the ultimate arbiter of any audio assessments.

I welcome any communications from interested parties about any matter contained in my letters, be it constructive criticism or sharing of valuable information. Anyone wanting to write me or call me can do so at the following: 1219 Fulbright Ave., Redlands, CA 92373, (714) 793-6252.

Frank J. Manrique

CROSSING KEF'S

I was wondering if any of your other readers have had a similar problem as mine.

I have built a pair of 2-way speakers utilizing the KEF B110 and T29 units. The enclosure is based to a certain extent on the KEF101 speaker system, which I greatly admire; 1" thick plywood is used, thoroughly screwed and glued together, with an internal dimension of about 820 cubic inches. Damping is accomplished with 2 layers of foam (the outer one egg-crate shaped) and the interior is filled with teased wool. The two speakers are electronically crossed over to a mono sub-woofer.

The sound from the speakers is extremely precise and open, however. I believe that there is a problem with the crossover. The KEF unit is used, and it seems to produce harmonic distortion in the 3,000-4,000Hz area (the crossover point), hearable with sine waves played through the system. Thus, there is a harshness and brightness which is similar to the JR speakers, and unlike the smoothness to be found with the KEFs. I have questioned people from KEF about this; they assure me that there are differences between the two crossovers above and beyond their speaker protection circuit, but are quite unwilling to tell me what these are. They also claim that part of the problem is due to their matching of units. However, I still have the problem even when using only one speaker. If any reader has some familiarity with this problem, I would greatly appreciate hearing from them.

Alec Weil
5430 S. Cornell Ave.
Chicago, IL 60615

HORNS & LINES NEEDED

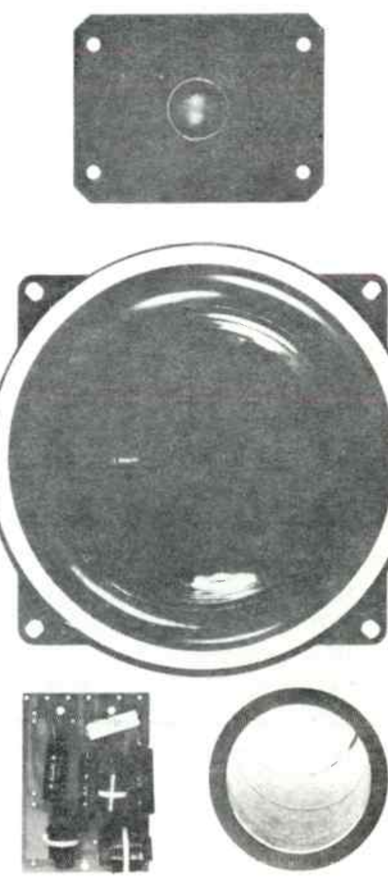
Congratulations on a beautiful magazine. Finally we have a publication that deals seriously with loudspeakers. I would like to see more on bass horns and transmission lines. These types of loudspeakers have never really been covered in detail before. Formulas for designing these loudspeakers are vague and hard to get. From what I have read and heard, these enclosures are the best around. Folded and straight-shot exponential horns are the most interesting of all. I hope you will publish information on these.

Steve Ponder
Huntsville, AL 35811

HORN ADVANTAGES

Mr. Carlberg's reply to Mr. Sanders' reply, in issue 3, contains several misleading comments about bass horn loudspeakers. For example, he says "horns were popular in the days of five and ten watt amps for their obvious amplification characteristics."

First, horns have no amplification characteristic whatsoever, being purely passive devices. The reason they can produce 10 to 20dB more sound for a given electrical power input than a direct radiator is that they are 10 to 100 times more efficient. Now that is surely an advantage when power is expensive on a per watt basis. But it is also an advantage when power in large quantities is cheap. An efficiency that is 10 to 100 times greater also means that when huge amounts of power



are put into the loudspeaker, for whatever reason, much less of it is wasted in heating up the voice coil, perhaps to its destruction.

Also, high efficiency is always associated with low driver diaphragm motion for the same output level and therefore with low distortion and high peak power output capacity. If a cone moves it produces distortion, regardless of the linearity of the suspension and magnetic circuit. The more a cone moves the more distortion it produces. Horn loading drastically reduces the motion of the cone, typically by a factor of 100 to 200.

Secondly, as I recall, in the days when bass horns were popular they were marketed by Klipsch, Electro-Voice, and University. Those were the days, I believe, of the 20 and 50 watt Williamson and Ultra-Linear amplifier circuits, not the days of 5 to 10 watt amplifiers. And I believe the cost of those 20 and 50 watt amplifiers was only about 1 buck-a-watt.

Mr. Carlberg's current objection to bass horns is the "intermodulation distortion" generated within the horn itself. The single biggest advantage of bass horn loudspeakers over direct radiator woofers is the horn's comparative lack of distortion of all kinds, especially at high output power levels. It is true that the relatively high pressures in the throat of a bass horn produce harmonic distortion. The formula for the amount of first harmonic distortion is readily available, so everyone seems to be afraid of the distortion produced in the throat. The amount of distortion produced in this way is much smaller than the distortion produced by direct radiator loudspeakers at the same output power level.

As a matter of fact, the nonlinearity of the airspring in a sealed box is a large source of distortion in direct radiators (H.D. Harwood. "Non-Linearity of Air in Loudspeaker Cabinet." *Wireless World*, Nov. 1974). The enclosure of a sealed box direct radiator must be more than 1.75 cubic feet in order to keep harmonic distortion from this source alone below 3 percent at an output level of 102dB for frequencies of 40Hz and lower, if the −3dB point is 40Hz. If you require less than 3 percent harmonic distortion at 100dB SPL, then your sealed box must have at least 4 cubic feet. These values are completely independent of the driver size since they are based on sound levels. Three percent is not all that good, and this is only the theoretical *lower* limit to the distortion produced by this one factor.

Some improvement over the closed box can be made, in terms of distortion, by using a vented enclosure if it is carefully designed to minimize the distortions produced by the vent (or passive radiator). But a steep-sloped sub-cutoff high pass equalization must be used as part of the design, to prevent sub-cutoff frequency signals from reaching the driver and producing extremely large diaphragm motion. The other forms of distortion that may be produced by the diaphragm of a bass horn driver are also small compared with the distortions produced by the velocity of the diaphragm of a direct radiator, which must move 100 to 200 times farther than the bass horn driver to produce the same output power level.

In view of the drastic difference in efficiency between bass horns and direct radiators (typically 30 percent compared to 1 percent), it is extremely important to compare distortion levels at the same *output* power level or loudness, not at the same input power level. This is true in all cases, whether distortion is being calculated or whether actual systems are being measured.

Robert J. Feeser
Kernersville, NC 27284

OF PRAISE & PROGRAMS

I have just received issue 4/80 and as usual I am thoroughly delighted. As a direct result of your magazine I am attempting to put together a set of speaker design programs for use on my Texas Instrument TI-59 programmable calculator. The article by Professor Bullock is easily one of the best treatments of Thiele and Small aimed at the average home constructor. I eagerly await the remainder of this article in future issues.

Once the series of articles is completed I will assemble my calculator programs for speaker design and make copies available to any interested readers. I am also a member of TI-PPC notes (a programmable calculator club) and I plan to submit these programs for publication. Any readers with interest in programmable calculators are encouraged to join our club by contacting Maurice E. T. Swinnen, 9213 Lanham Seven Rd., Lanham, MD 20801.

I will continue to support *Speaker Builder* magazine and its advertising contributors as much as possible. I also support and subscribe to the *Audio Amateur*. Mr. Dell and his staff are to be congratulated for both periodicals.

Mark A. Pelletier
Griffith, IN 46312

ESL PARTS SUPPLIERS

For those speaker builders who wish to construct the Sander's ESL's with piano wire, the wire (.051 mils) can be obtained from Schaff Piano String Co., 451 Oakwood Road, Lake Zurich IL 60047. I paid $85 for 1056 pieces or about 8¢ per piece. Allied Electronics has a power transformer, P-8150, 1550 volts AC at 1.5mA which translates to 2185 volts with a .05mFd charging capacitor. It costs $13.36 plus postage.

Completely fill the first cell with the rods. Secure them with masking tape a few inches from each end. Pull every other rod 2 or 3 inches from one end. Glue the rods to the plexiglas and let stand over night. Pull every other rod from the other end, glue, and let stand over night. Remove the unglued rods and glue the remaining rods to the 5 supports. The second cell can be done in the same manner but will have to be done in steps since there aren't enough rods to completely fill it. Be sure to order some extra rods. 50 should be enough. I had no rejects.

James P. Kitchen
Palm Bay, FL 32905

Classified Advertising

PRIVATE CLASSIFIED ADVERTISING SPACE ***up to 50 words in length*** *is open to Speaker Builder's subscribers without charge for personal, non-commercial sales and for seeking information or assistance. The publishers reserve the right to omit any ad. Any words beyond 50 are* ***15 cents per word.*** *Please type or neatly print ad copy on a separate sheet or card with your full name and address.*

TRADE CLASSIFIED ADVERTISING RATES: ***25 cents per word*** *including name, address, and zip code—prepaid only. 10% discount for four insertions.* Speaker Builder *cannot accept responsibility for the claims of either the buyer or the seller.*

TRADE

SPEAKER CABINETS—factory close out of rich walnut vinyl laminated cabinets constructed of ¾" particle board. Shipped assembled with grill frames. Speaker openings can be cut to your specifications. Measurements 24x13x13. Only $19.95. ***FABER***, 1625 Kelley St., Santa Rosa, CA 94501. T4/81

LONG HAIR WOOL carded-cleaned for stuffing speakers. $10.00/lb. including shipping. ***J. EBBERT,*** 431 Old Eagle School Rd., Strafford, PA 19087.(215) 687-3609 TTF

LOOKING FOR a speaker to compliment your SOTA electronics? The Jordan 50mm. module forms the nucleus of a coherent, high resolving, accurate imaging system. The audio amateur can construct a superb, flexible loudspeaker using the Jordan module for a fraction of the cost of comparable commercial systems. If your reference is live music, this could be your system. We also have Audax, Dalesford, JVC and Foster ribbons, SEAS, highest quality crossover components, Falcon crossovers, cabinets and much more. Catalogue $1.00, Jordan manual $2.00. ***AUDIO CONCEPTS***, 1919 S. 19th St., La Crosse, WI 54601. T2/82

OPEN REEL TAPES from studio masters. Philips, Argo, Telefunken, Vanguard, Unicorn. Catalogue $1.00. ***BARCLAY-CROCKER***, Room 1470-L, 11 Broadway, NYC 10004. TTF

CROSSOVER COMPONENTS and accessories for the speaker hobbyist. Low prices. Send for free flyer. ***UNIVERSAL AUDIO***, Box 712, Providence, RI 02901. T1/82

GOLD PLATED phono jacks $1.20 plugs 90¢ ea., $1.00 handling. Also custom 1% capacitors, 0.5% resistors. Details SASE. ***REFERENCE AUDIO***, Box 368M, Rindge, NH 03461. T1/82

RAW SPEAKERS and kits. Specializing in plastic cone drivers and high-end auto systems. Our brands include Audax, SEAS, Becker, Dynaudio, Philips, Foster, Jordan-Watts, Falcon Acoustics and Peerless. Free price list. ***A&S SPEAKERS,*** PO Box 7022, Denver, CO 80207. (303) 399-8609. T3/81

AUDIOPHILE ACCESSORIES

DBP-2J SWITCH BOX.......39.95 AU (gold jacks).......47.95
Selects between up to 4 phono inputs. Used with DBP-6 or 6MC, allows for selectable loading of cartridges.

DBP-6 PHONO EQUALIZATION KIT........................29.95
Allows adjusting the input capacitance of the phono input of every preamp and receiver with low loss Polystyrene Capacitors.

DBP-6MC RESISTIVE LOADING KIT........................29.95
Allows adjusting load resistance from 10 to 200 Ohms for for moving coil cartridges. Gold plated phono plugs in both kits.

DBP-8 SPEAKER WIRE 12 ga., in 3,6, and 9 meter...Inquire.

DBP-9AU BANANA PLUGS Eight gold plated, solderless....10.80

DBP-10 PHONO ALIGNMENT PRDTRACTOR..............19.95
Allows adjusting the lateral tracking error of a mounted cartridge to within ¼ of one degree. Non-technical instructions and case included.

DBP-11 CAPACITANCE LOADING SWITCH BOX..........79.95

DBP-12 AUOIO CABLE 10 meter (33 ft)...................59.95
Low capacitance (400pF) stereo interconnect cable, terminated with rugged gold plated phono connectors.

OBP-13J GOLD PLATED PHONO JACKS (¼") 8 pk...10.80

OBP-13P GOLD PLATED PHONO PLUGS 8 pack 7.20

ELECTRONIC CROSSOVERS...6,12,1BdB,24dB........Inquire

At your dealer or direct. Orders under $45, add $2.00 Handling.

DB SYSTEMS

Box 347G Jaffrey, NH 03452 (603) 899-5121

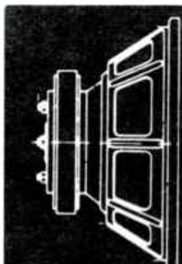
Dealer inquiries invited. Overseas distributors in Benelux, W. Germany, Scandinavia, Japan, Hong Kong, Singapore, Taiwan, France.

METAL FILM RESISTORS, RN55, 0.35 watt, 107 values from 10 ohms to 1 Meg., 25¢ ea., 10 per value/$1.80, 50 per value/$7.50. Send stamped self addressed envelope for list of values and order form. New gold plated brass rear mount phono jack, $1.75 ea. Gold plated shielded RCA type phono plugs, $2.00 ea. Minimum order $10.00, quantity discounts available. ***OLD COLONY PARTS,*** Dept. SB, PO Box 243, Peterborough, NH 03458.

AUDAX 10" BEXTRENE cone drivers for Sanders ESL/T.L. woofer system. Performance equal to KEF B-139, at about ½ the price. $66 each post paid. ***R. SANDERS,*** 1578 Austin St., Atwater, CA 95301. T4/81

NEW GOLD PLATED PHONO JACK. Rear mount, gold plated, solid brass jack w/gold plated ground flag and hardware, $1.75 ea. Will interchange with Audio Research SP3A-1's phono jacks. Gold plated solid brass shielded phono plugs, $2.00 ea. Send stamped self addressed envelope for flyer and order form. Minimum order $10.00. ***OLD COLONY PARTS,*** PO Box 243, Peterborough, NH 03458.

"IN PHASE" 24dB/8ve electronic crossover minimizes irregularity in radiation pattern through crossover region. 0.0008% distortion, 5 year warranty. Single frequency (specify) with power supply: $442.00. ***DB SYSTEMS***, Box 347K, Jaffrey, NH 03452.TTF



Audax and Philips Loudspeakers
— in stock
— competitive prices
— competent service

Suppliers to the Audio community of air core inductors, audio grade capacitors, Falcon crossovers, JVC and Foster tweeters.

Madisound Speaker Components
431 West Gorham, Box 4283
Madison, Wisconsin 53711 (608) 256-7337

SAVE 50%. Build your own speaker system. Write: ***McGEE RADIO ELECTRONICS,*** 1901 McGee Street, Kansas City, MO 64108. T4/83

RAW SPEAKERS AND CROSSOVER PARTS. Send 18¢ stamp. ***MENISCUS SYSTEMS,*** 3275 Gladiola, Wyoming, MI 49509. T2/82

WE ARE ONE OF the largest independent manufacturers of crossover networks and speaker system accessories in the U.K., supplying manufacturers, retailers and export. We have a growing number of outlets in the U.S.A. and Canada. Your guarantee is the trust our manufacturing customers put in the quality and reliability of our networks. If you have supply problems, please send for details: $2 bill Air, $1 bill Surface, to our mail order retail outlet: ***FALCON ELECTRONICS***, Tabor House, Norwich Road, Mulbarton, Norfolk, England. T2/84

RAW FRAME SPEAKERS—All Types—All Sizes. Philips C.T.S. Peerless, Polydax, Dealer pricing. **APOLLO ELECTRONICS,** 1437 Santa Monica Mall, Santa Monica, CA 90401. (213) 393-0794. Mon.-Sat. Stuart. T2/82

DYNACO AF-6, FM-5, FM-3, FM-1 FANS; Scott LT-110 Fans: PLL Stereo Demodulator is assembled and tested and features the KB4437 (Separation: 45dB, THD: 0.04%) with pilot canceller circuit for greatly improved sound quality. Send for free info. ***VSM AUDIO***, PO Box 114, Maspeth, NY 11378. T3/81

AUDIO HORIZONS

P.O. BOX 10973
ST. LOUIS, MISSOURI 63135

Issue #5 is now available. It contains reviews of the ACM Linn platter assembly, the CART-A-LIGN alignment protractor, the JMAS moving-coil cartridge, LAST record treatment, the ACM, LEVINSON "Silver", and MENDOTA interconnecting cables, the MAGNEPAN Unitrac 1 pickup arm, the MARCOF PPA-2 headamp, the ORSONIC DS-250 disc stabilizer, the SUMO "Nine" power amp, and the WIN LABS SDC-10 turntable. Issue #5 also features a survey of 9 turntable mats, and another survey of 19 speaker cables.

Subscription rates to AUDIO HORIZONS for four (4) issues are: U.S.A.- $20 (FIRST CLASS MAIL); Canada and Mexico- $22 (FIRST CLASS MAIL); and outside North America- $26 (AIR MAIL). PLEASE REMIT IN U.S. FUNDS ONLY. Sample copies of all issues are available for $6.00 each (U.S.A., Canada, and Mexico), and $7.50 each (outside North America).

CATALOG OF HARD to find speaker cabinet hardware, crossover parts, tweeters, midranges, woofers, cabinet plans, grille cloth, etc. Over 300 Hi-Fi and Pro Audio items. For your copy send $1.00 to ***UNIVERSAL SOUND,*** 2253 Ringling Blvd., Sarasota, FL 33577. T4/81

TEN GOOD REASONS TO READ T.A.'S NEW CATALOG. 1. The new 8″ polystyrene cone driver that delivers amazingly tight and articulate deep and mid bass in our reflex Push-Pull alignment that is −3dB at 30Hz and non-resonant. **2.** Dynaudio 8¾″ and 12″ woofers. Alot of dynamic headroom and power handling capabilities. Variovents are available. Dynaudio soft Dome midrange and tweeters. All Dynaudio systems available as semi-kit. **3.** The Jordan 50mm module for complete phase coherency from 150Hz to 22k has transient speed and detail like Electrostatics. Sub-woofers are all you need to complete your dream system. **4.** Dalesford 5″ and 6½″ drivers for woofers, midbass and midrange. **5.** "Unbox" semi-kit enclosures for the polystyrene Dynaudio woofers, Dalesford and the Jordan 50mm module. **6.** JVC polymer ribbon super tweeter for detail, extended highs and "air." Also Polydax. **7.** Step Attenuator Volume controls by Alps and Tech Labs for highest accuracy and perfect tracking. The deluxe model has silver contacts, 1% MF resistors as a semi-kit. **8.** Rowland Research Electronics: Electronic crossover, subsonic filter, phono section, strain gauge cartridge boards for Win Labs and Panasonic. Rowland Research preamp all for the highest signal resolving detail. **9.** All products from Rowland Research are made with polypropylene capacitors and Corning MF resistors to achieve sonic purity. They come stuffed and tested as semi-kits or assembled units. **10.** Crossover parts and kits using air core inductors wound with #12 and #16 wire. Dealer inquiries invited. Polypropylene and styrene caps. Mod kits for Hafler amp and preamp and the Dahlquist DQ-10. Jordan Manual text on sound and loudspeaker design $3.00. TA catalog, $1.00. ***TRANSCENDETNAL AUDIO,*** 6796 Arbutus St., Arvada, CO 80004. 9-5 Mountain time, 10-3 Sat. (303) 420-7356. T3/81

GET THE BEST FROM YOUR SPEAKERS with the finest electronics. AudioWorld is the high end connection for those who want the best sounding system for their money. We have competitive prices on whatever you are interested in. ***AUDIOWORLD,*** Box 6202B, Grand Rapids, MI 49506. (616) 451-3868. T4/81

CUSTOM MADE FOAM speaker grills. Any size, thickness, color, or quantity. Bulk foam. Send return postage for information. ***CUSTOM SOUND***—SB, Algonac, MI 48001. T3/81

SPEAKER KITS. Catalog of home, car and sound reinforcement kits, over 100 raw drivers available, Thiele data, JBL, EV, Audax, Peerless, Foster and JVC ribbons, more. $2 refundable. ***GOLD SOUND,*** PO Box 141SB, Englewood, CA 80151. T3/81

AUDIO CLUBS

Space in this section is available to audio clubs and societies everywhere free of charge to aid the work of the organization. Copy must be provided by a designated officer of the club or society who will be responsible for keeping it current. Send notices marked Audio Clubs in care of the magazine.

AUDIO SOCIETY WANTED in the Fort Wayne, Indiana area—for serious audiophiles only—contact: J. D. Reynolds, Jr., 703 Nordale Drive, Fort Wayne, IN 46804. Phone (219) 432-1294.

SAINT LOUIS AUDIO SOCIETY meets monthly for discussion and equipment audition. For information sheet send a stamped, self-addressed envelope to SLAS, 7435 Cornell, Saint Louis, MO 63130.

DO YOU LIKE CLASSICAL MUSIC AND AUDIO EQUIPMENT? Would you like to form a small society mixing music listening with audio equipment discussions? If you live in Nassau or Suffolk County New York in the vicinity of Plainview, contact: Alex Soave, 192 Central Park Road, Plainview, NY 11803. (516) 935-1704.

SERIOUS AUDIOPHILES interested in a central Colorado group (Denver, Boulder, Ft. Collins, Greeley area) contact James S. Upton, 2631 17th Ave, Greeley, CO 80631.

FT. WORTH AREA AUDIO SOCIETY being formed. Would like a diversified group (women welcome), for information send a stamped, self-addressed envelope to Richard P. Machos, 6201 Onyx Drive North, Ft. Worth, TX 76118.

AUDIO SOCIETY WANTED in the Sacramento CA area. Serious audiophiles and dedicated audio amateurs please contact Barry Waldron, 1847 Country Club Drive, Placerville, CA 95667.

Southeastern Michigan Woofer and Tweeter Marching Society

Detriot area audio construction club.

CONTACT: DAVE CARLSTROM 10155 Lincoln Huntington Woods, Michigan 48070 313-54-48453

MINNESOTA AUDIO SOCIETY Monthly programs—Newsletter—Special events, yearly equipment sale. Write: P.O. Box 3341, Traffic Station, Minneapolis, MN 55402.

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

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

THE BOSTON AUDIO SOCIETY INVITES you to join and receive the monthly B.A.S. SPEAKER with reviews, debates, scientific analyses, summaries of lectures by major engineers. The BAS was the first to publish info on TIM, effects of capacitors, tonearm damping, tuner IM dist., Holman's and Carver's designs, etc. Sample issue $1. sub, $12/yr. P.O. Box 7, Boston, MA 02215.

PRIVATE

FOR SALE OR TRADE: Dynaco FM-3 tuner, $50 or trade for home equalizer, UPS shipping included; **WANTED:** one Electrovoice Aristocrat loudspeaker. Steven J. Hohmann, 907 E. Nebraska, Peoria, IL 61603 (309) 686-1169 after 6:30 PM CST.

FOR SALE: Two pair of like new Jordan 50mm midrange/tweeter modules—design date included—$129 per pair (regularly $179. per pair). One mint condition Bose 4401 four channel pre-amplifier with full logic SQ decoder, $350. Ray Cook, 7503 Mowinkle Dr., Austin, TX 78736, (512) 288-0946.

WANTED: Dyna PAS 3 series faceplate, knobs, or blank face plate. **FOR SALE:** Sherwood S-32CP FM/AM tuner $115. R. Pearson, 1080 N.W. 133 St., Miami, FL 33168. (305) 681-0802.

Classified

FOR SALE: "Sleeping Beauty" moving coil cartridge w. Shibata stylus. Threshold pre-preamplifier w. separate power supply. $175 for all. (408) 629-3466.

FOR SALE: Hafler DH-200 power transformer, part #464002, brand new, never used. Use it for new project (88V, 4A, center tap) or in parallel in DH-200 for much improved bass. Evenings (513) 435-7155. $25.

FOR SALE: JVC KD-1770 Mk II top loading cassette deck w/analog & peak LED meters, $150. mint. Sony TC-758 10½ auto reverse open reel deck frequency response 20-30,000Hz, $600. mint. Akai cassette deck 6XC-706D w/dolby & mics input, $110. Moving and don't have room for equipment. I will deal on the prices. (319) 324-0146.

FOR SALE: 1 pair Tympani III-TM (side panel speakers), white grillecloth-mint condition, $590. F. T. Cross, 1817 Birch, Richland, WA 99352. (509) 946-5200 evenings.

FOR SALE: Heathkit AA-1800 power amplifier, 250 watts per channel, unit not assembled and is still in factory sealed boxes, $500. Digital Stereo Delay unit featured in the September 1980 *Popular Electronics*. Both boards complete $150. Free shipping. H. Cohen, 5625 Hempstead Rd., #204, Pittsburgh, PA 15217.

FOR SALE: 4 Altec 416B woofers $100 each. 4 Altec 811B horns with 806-8B drivers $100 each. 4 Altec 800Hz xovers $50 each. All excellent. L. Cartwright, 2723 Darlington Rd., Beaver Falls, PA 15010. (412) 846-7419.

FOR SALE: Fulton Nuance I bookshelf, 3-way, $750; Fulton 42′ gold wire, $190; Fulton FMI-80B new $390; University 303 raw speaker pair coaxial 8 inch; KLH-6 mint, $200; Thorens 145/MK II tt, $150. **WANTED:** EPI-50; AR-7; Spendor SA-1; trade Nuance for Linn Sondek LP 12. Call Bob (212) 721-7380 evenings.

FOR SALE: 400MHz video cable. 20GA silver center conductor with 99.6% shielding efficiency by 2 heavy copper braids. 5MHz signal attenuated 0.69dB per 100′. 3′cable has effectively unmeasurable resistance, capacitance, inductance. Perfect tonearm to preamp to power amp. $4/foot; 3′ pair w/jacks $35. M.E. McClendon, PO Box #3, 200 1st St., Emerson, NE 68733. (402) 695-2509.

FOR SALE: TRW X363UW polypropylene caps, 4mFd, 400VDC, 10%. Fifteen for $100. ppd. or $7.50 each for lower quantities. Vernon Vogt, 5518 Greentree Rd., Bethesda, MD 20034.

FOR SALE: 1 Signet TK9E cartridge $125. (list $275) and 1 Yamaha MC-1X MC cartridge $95 (list $200). Both less than 10 hours use and in perfect condition. I will consider trade for Ortofon MCA-76 pre-preamp. No risk ok if desired. John Soderquist, 385 E. Main St., American Fork, MT 84003. (801) 756-9158 eves. after 5:30 PM MST or on weekends.

WANTED: University Spherecon tweeters and/or 312 with same. Small bookshelf speaker by ADC, AR, KLH, Dynaco, EPI, Rectillinear, etc. for about $50/pr. V. Mogavero, 66-14 51 Rd., Woodside, NY 11377. (212) 446-5918.

FOR SALE: Crown D-150A, $275; DC-300A, $500; wal. cab. SAE 3000 preamp $215; 2200 amp $325, both $490; Sony ST-J60, $270; RAM 203 pre, $125; MAC MX-113, $560 wal. cab. Tandberg TCD-320 w/much added, can convert to 8 into 2 port record studio $200. KEF DN-13 SP1017 $32 pr 3.5k. Wm. Gabriele, 1334 Chapel St., New Haven, CT 06511. (203) 777-1476 mornings best.

WANTED: Contact with anyone who has used the Jordan modules, built a Webb TLS or made a full range system using Double Chamber (*SB* 3/80). Harold Goldman, 241 Central Park West, NYC 10024. (212) 724-9843.

WANTED: Anyone having information re: JVC ribbon tweeter mod known as the JGA mod to Dahlquist DQ-10's; also need information re push-pull subwoofers. Rod Lum, Box 860, 249 Edward St., Chelmsford, Ont., Canada P0M 1L0.

FOR SALE: Two mint PAS2X $65; two mint ST-70 $75; mint FM3 $75; Eico ST-70 needs work $20; HK A300 as is $15; each plus UPS. Also, Koss ESP9B w/energizer $75, bound volumes 1940's-50's Electronics magazine best offer. **WANTED:** Good microphones and reel to reel. B. Boyes, PO Box 607, Endicott, NY 13760 (607) 785-4630.

WANTED: Plans for building the eight inch (speaker size) Karlson speaker enclosure. These used to be sold as kits. William Blum, PO Box 1125, Lake Worth, FL 33460.

FOR SALE: Heath transistorized AC millivolt/dB meter (IM 5238), $100. Sabtronics model 2000 3½ digit multimeter with AC adapter and nicads, $60. Two Beyer M260N(C) supercardioid ribbon microphones, $100 each or $180 the pair. Don Bray, Rt. 2, Box 523, Scottsville, VA 24590. (804) 286-3460 evenings.

FOR SALE: Quad ESL's $1000/pr 2 years old. Quad 405 pwr amp $300. Stax SR5 (SRD-6) headphones, $100. Nakamichi 550 $325. Rick Hiller, 9031 Troulon Dr., Houston, TX 77036.

FOR SALE: H-K Citation 12 60 watt amp excellent $175; Marantz 15 60 watt amp excellent $165; Dyna PAT-4 preamp good $70. **WANTED:** Magnaplanar feet. Rich Davidson, 501 Paige Loop W., Whiterock, NM 87544. (505) 672-109

ADVERTISING INDEX

Old Colony KITS

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

CROSSOVERS

ELECTRONIC

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

KC-4A: ELECTRONIC CROSSOVER, KIT A. [2:72] Electronically divide the signal before the amplifier. Requires one amp for bass; a second for treble (or one stereo amp per channel). Lowers distortion and dramatically increases power capability. Single channel, *two-way*. Values of R_1, R_2, C_1, C_2 must be specified with order. All parts and C-4 circuit board. Includes new LF351 ICs. Each **$8.00**

KC-4B: ELECTRONIC CROSSOVER, KIT B. [2:72] Single channel, three-way. Values of R_1, R_2, C_1, C_2, must be specified with order. All parts and C-4 circuit board. Includes new LF351 ICs. Each **$11.00**

KK-6L: WALDRON TUBE CROSSOVER: Low pass. Single channel, 18dB/octave, Butterworth, [3:79] includes Bourns 3-gang plastic pot, level control, Mullard tubes, board, and three frequency range determining capacitors. *Specify ONE frequency range per kit please.* (Hz.): 19-210; 43-465; 88-960; 190-2100; 430-4650; 880-9600; 1900-21,000. Single channel. Each **$43.00**

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

KK-6-S Switch Option. 6-pole, 5-pos. rotary switch, shorting, for up to five frequency choices per single channel. Each **$8.00**
When ordered with two kits above, Each **$7.00**

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

PASSIVE

KF-7: CROSSOVER FOR WEBB TLS. [1:75] Passive four-way crossover, in pairs, assembled. Components are included for both STC and Celestion tweeters. Made by Falcon of England. Pair **$76.00**

FILTERS & Speaker Saver

KF-6: 30Hz RUMBLE FILTER. [4:75] Rolls off system response at 18dB/octave below 30Hz to eliminate rumble and garbage on discs below 30Hz. Cuts speaker distortion and wasted amplifier power. Two channel universal filter card supplied with WJ-3 (F-6) circuit board and all basic parts, 1% metal film resistors and 5% MKM capacitors for operation as an 18dB/octave 30Hz rumble filter. 30Hz, 0dB gain only. Kit may be adapted as two- or three-way single channel crossover with added capacitors and resistors. Each **$19.75**

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

KH-2B: OUTPUT FAULT OPTION. If the amplifier goes into self-destruct mode, this added feature cuts off drive to output devices quickly. Additional board mounted components for speaker protection in case of amplifier failure. Each **$6.75**

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

KK-8: COMPEX C. Signal compression ina repeatable format for tape recording or signal transmission. Two channel board with all parts to compress signal, including 1% polycarbonate capacitors and large tantalums. [3:79] Each **$45.00**

KK-9: COMPEX E. Signal expansion in tape replay mode or after transmission via limited phone lines. Two channel expansion board with all parts including precision Rs & Cs, [3:79] Each **$35.00**

SYSTEM ACCESSORIES

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

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

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

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

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

BENCH AIDS & Test Equipment

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

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

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

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

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

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

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

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

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

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

KL-6 MASTEL TIMERLESS TONE BURST GENERATOR. [2:80] Highly valuable and useful device for testing speakers and room response. All parts with circuit board. No power supply. Each **$19.00**

NEW KIT: SBK-A1: LINKWITZ CROSSOVER/FILTER. *Speaker Builder's* [4:80] first kit, including all parts and board for one channel of the three-way crossover/filter/delay. 24dB/octave at 100Hz and 1.5kHz and 12dB/octave below 30Hz, with delayed woofer turn-on. Board is 5½ x 8½. Requires ±15V supply, not supplied. Use the Sulzer supply KL-4A with KL-4B or KL-4C.
Per channel **$64.00**
Two channels **$120.00**
SBK Board only Each **$14.00**

ORDERING INFORMATION

Prices, except as noted, are prepaid in the USA and insured. We prefer to ship via UPS, which requires a street address. If you cannot receive UPS delivery, please include an extra $2 for insured service via Parcel Post. We cannot accept responsibility for safety or delivery of uninsured Parcel Post shipments. PLEASE ADD $1 service charge for all orders under $10.

CHARGE CARD
TELEPHONE ORDER SERVICE
MON. THROUGH FRI. 9AM—4PM
(603) 924-6526
MasterCharge/Visa Cards Welcome

OLD COLONY Box 243 Peterborough NH 03458