A Three-cabinet suspended design | All about electrostatics

2/1980

SPEAKER BUILDER

US $3.00
UK £1.25 | 15 Fr.

Good News

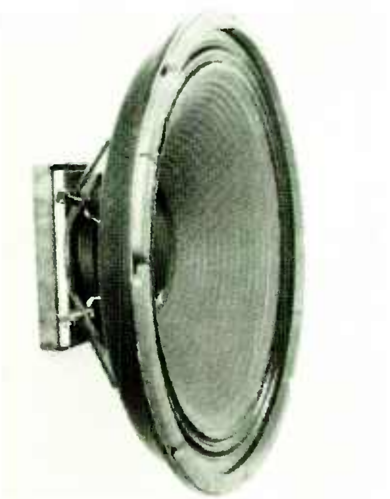
Boston Acoustics may well turn out to be as important a name in speakers as Advent, Acoustic Research or KLH. The two principals of the company provided production and marketing know-how to the Advent organization before Henry Kloss left the firm. They have formed their own manufacturing organization and have two speakers available: The A200 and the A100. The latter is the smaller of the two and the most recently introduced. The two-driver unit is 30½x16½x8" and will work well from a floor location or next to a wall. The designers claim that the relatively large front panel and the shallow depth maintains the 10" woofer's ability to radiate a full hemisphere of mid-frequencies giving the reproduction smooth response. Some most interesting design theory has gone into this unit and appears to be well worth exploring by the speaker enthusiast. A brochure is available by writing to **Boston Acoustics** 130 Condor St., Dept. SB, East Boston MA 02128.

Six speaker kits plus two stands, one for speakers and one for equipment are offered by **Lazer Audio** (45383 Industrial Pl., No. 5, Fremont CA 94538). They also offer a wide selection of drivers and crossovers including, Polydax, the Jordan 50mm module, the Decca DK30 ribbon tweeter as well as a number of bextrene units and woofers of 5" to 12" size. They have a brochure and price list for the asking by writing to Lazer at the address above.

Classics Only is a new catalog of digitally recorded music on discs. The first issue is a dozen pages with fifteen or so offerings per page. The recordings listed may be ordered from the publishers for what appear to be standard prices plus shipping. The price of the catalog is 50¢ and may be ordered from CLASSICS ONLY at Box 14186, Columbus OH 43214.

Here's a little number the manufacturer describes as a Dual Tapered Acoustical Trapezoidal Line which sports two 5" bextrene drivers and a 1½" dome tweeeter in a cabinet that measures 17½x10½x9". The enclosure is mounted on a stand that tilts the box backward at an angle, presumably for better dispersion. The STAT is made by **Kinetic Audio., Ltd.** 6624 W. Irving Park Rd. Chicago IL 60634. They have a descriptive brochure for the asking. Tell them SB sent you.

Merry olde England has a long and ardent history of do-it-yourself—and particularly in audio pursuits. For that reason suppliers of really excellent parts for the home constructor are much more numerous in that happy isle than in the USA. U.S. dealers are catching up, especially with relation to speakers, but some British suppliers offer an exceptional range of drivers, crossovers and parts as well as reprints of interesting articles from British publications to help the builder construct his own. **Badger Sound Services Ltd.** is one of these. Barry Hughes, a principal of that firm, offers a special "export catalogue" designed for the American speaker constructor. It looks to weigh about 6 ounces and is full of useful and interesting information. Badger likes to send these by air so they ask respondents to send a $5 bill to cover costs of postage mostly. Badger's address is 46, Wood Street, Lytham St Annes, Lancashire FY8 10G England. Badger also offers first class export of many lines of English and European drivers, cabinets, and crossovers and parts.



One of the country's largest driver manufacturers **CTS of Brownsville** has a new 15" woofer designated the 15D154. It features a cast aluminum frame, a 2½" voice coil and a vented motor for cool operation. A full catalog of the very extensive CTS line is available by writing to CTS of Brownsville, Inc., 3555 East 14th St., Dept. SB, Brownsville TX 78521.

Anybody who has been thinking steadily about speaker design since 1961, has worked steadily at designing a 50mm driver with a moving mass of only 1.3 grams which covers the frequency range 100Hz to 22kHz must be either deluded or a genius. **E. J. Jordan** is doubtless rightly classed in the latter category. The Jordan units are available from a number of US dealers at about $135. the pair, but the brochure about the Jordan units is almost as interesting and valuable as the speaker itself. Anyone contemplating building a speaker owes it to himself or herself to get hold of a copy of the manual provided by the Jordan organization. Ask your dealer about the Jordan manual. If he hasn't a copy, see whether you can obtain one by writing to Wilmslow Audio, Swan Works, Bank Square, Wilmslow, Cheshire, England. □

About this issue

Nelson Pass leads off our second issue with a study of the effects of speaker wire which subject turns out to be far more complicated than it may have first seemed. Siegfried Linkwitz follows with the first of three articles on an original system which combines extensive knowledge of cabinet design, diffraction, phase, electronic crossovers, and time delay. Mr. Linkwitz has revised the article and updated it from the original form in which it first appeared in *Wireless World*, London. Roger Sanders is an enthusiast for the electrostatic means of reproducing sound and has worked steadily at it since the first articles about hand-made units appeared in our sister publication *Audio Amateur* back in 1972. His article, the first of three, represents not only good design capability but a really remarkable amount of knowledge gained from experience and experimentation.

Our book reviews this time are the first of many. Your letters follow in the Mailbox.

We hope those of you who have systems to show off will photograph them and send them along for use in these pages. Black and white is best but color photos with good contrast are also acceptable. We also welcome your tools, tips & techniques offerings for speaker construction, shortcuts, special tools and suggestions for sources of supply. And by all means keep those cards and letters coming in.

Next time we will be publishing Dick Marsh's intriguing article on a design by George Augspurger. This one uses two chambers and three ports to get low, low bass out of an eight inch driver. The second part of the Linkwitz series will appear as well as the second section of Roger Sander's opus on building those electrostatic panels. We expect the issue to be in the mail to you by September 12. □

VOLUME 1, NUMBER 2 MAY 1980

SPEAKER BUILDER
MAGAZINE

EDWARD T. DELL, JR. *Editor/Publisher*
NELSON PASS *Contributing Editor*
W. MARSHALL LEACH *Contributing Editor*
JUDITH CADIGAN *Associate Editor*
KAREN HEBERT *Editor's Assistant*
ANNARAE HUNTER *Production*
NANCY NUTTER *Circulation Director*
TECHART ASSOCIATES *Drawings*

Editorial and Circulation Offices:
P.O. Box 494,
Peterborough New Hampshire 03458 USA.

ADVERTISING REPRESENTATIVE
Robert H. Tucker
316 St. James Place, Philadelphia PA 19106
Telephone (215) MA-75326

SUBSCRIPTION RATES

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

Elsewhere
Add $2 for each year to remittance.

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 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 USA. Applications to mail at second class rates pending at Peterborough NH and additional mailing offices.
POSTMASTER: If undeliverable send PS form 3579 to P.O. Box 494, Peterborough NH 03458.

VOLUME 1,
NUMBER 2

MAY
1980

SPEAKER BUILDER

SPEAKER CABLES: Science or Snake Oil

by Nelson Pass

AUDIOPHILES RECENTLY BEGAN re-examining the performance of every link in the audio playback chain, and before long their attention turned to the lowly loudspeaker cable. In response to demand, a number of companies are producing or distributing new and exotic cables claimed to improve audio power transmission from amplifier to speaker. Pointing to lower resistance and inductance, proponents of the newer cables insist they sound significantly better ("better than an expander!"); however, the subject is controversial, and some hi-fi notables claim performance increase is negligible and the higher capacitance of some new cables can cause amplifier instability and damage.[1-4]

Neither view is completely correct: the new cables are neither panacea nor placebo, but components whose characteristics must be evaluated in the context of their usage. Hoping to shed some light on the subject, I obtained samples of various cables, performed a number of tests, and drew a few conclusions.

Almost everyone seems to agree that ideally the amplifier should be so intimately coupled with the loudspeaker that the cable can cause no power loss or distortion. This corresponds to a wire having no resistance, inductance, or capacitance, which in real life translates to an infinitely short cable. I treat this premise as fundamental, because in general it results in the best performance. (It may not do so in some specific situations; for example, one could imagine a special case where some resistance or inductance might improve the sound.)

Regardless of the cable type, the effects it introduces to a signal are proportional to its length: the shorter the cable, the more intimate the connection between amplifier and loudspeaker. Subtle differences between cable types become more dramatic with increasing length and shrink toward zero as the cable gets shorter; thus the audiophile whose amplifiers sit close to his speakers need be less concerned than he whose cables are 40 feet long. To this end, some manufacturers have installed amplifiers within their loudspeakers, exchanging speaker cable problems for preamp ones; commercial sound distribution systems have resorted to higher voltages, which improve transmission much like the high voltage utility lines which carry power many miles.

Fig. 1 shows a fairly simple first order model of a loudspeaker cable. The inductance, resistance and capacitance are approximated as components in a circuit, sectioned off per unit of length. In this example, the values are for simple 18 gauge "zip" cord and one foot lengths, so that L is the inductance per unit foot, R is the resistance, and C is the capacitance, measured in Henries, Ohms, and Farads respectively. As a practical matter, the values of these elements represent tradeoffs against each other: for example, low inductance is easily achieved with high capacitance and vice versa, and the ratios of these values give rise to the cable's characteristic impedance, as I shall discuss later.

Researchers have chiefly concentrated on the cable's inductance and resistance, for they impede the flow of electrons between the amplifier and the loudspeaker. Resistance causes loss at all frequencies while inductance causes

Fig. 1

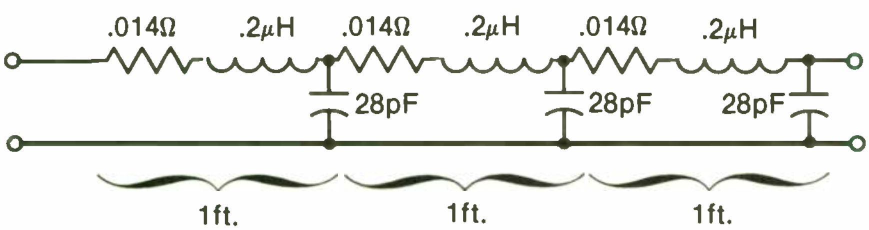


Fig. 1 Simple model 18G loudspeaker cable.

FIG. 2

Cable Type	Ω/ft.	pF/ft.	μH/ft.
24 ga. Zip	.05	16	.24
18 ga. Zip	.014	28	.21
Lucas	.0055	20	.25
Monster	.0034	24	.21
Fulton	.001	28	.19
Polk	.0075	500	.026
Mogami	.0042	170	.023
Audio Source Hi. Def.	.013	280	.037
Audio Source Ultra-Hi. Def.	.012	600	.029

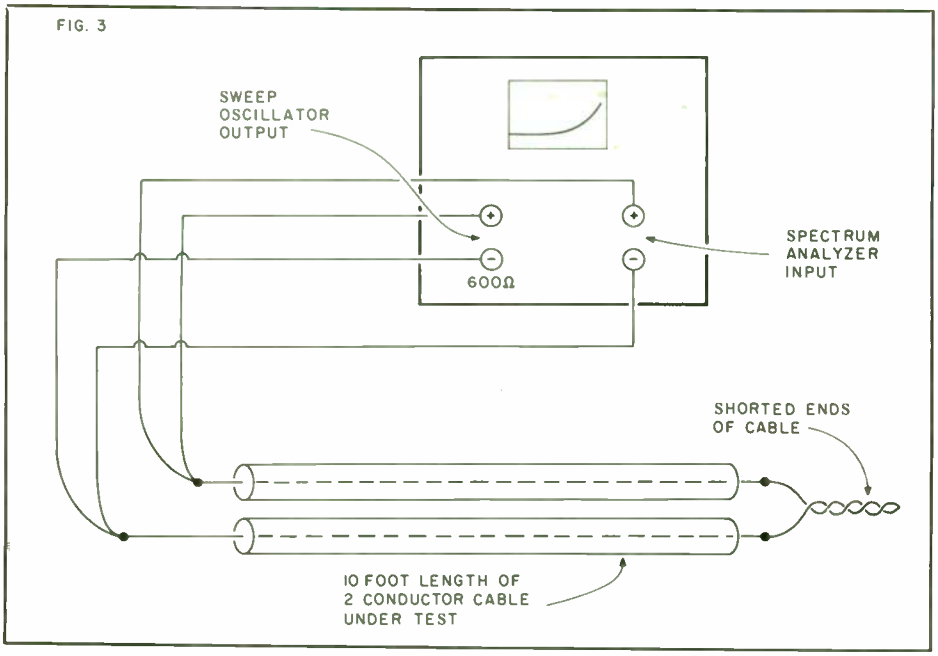


Fig. 3 Series Impedance Test

cables were virtually indentical at higher frequencies.

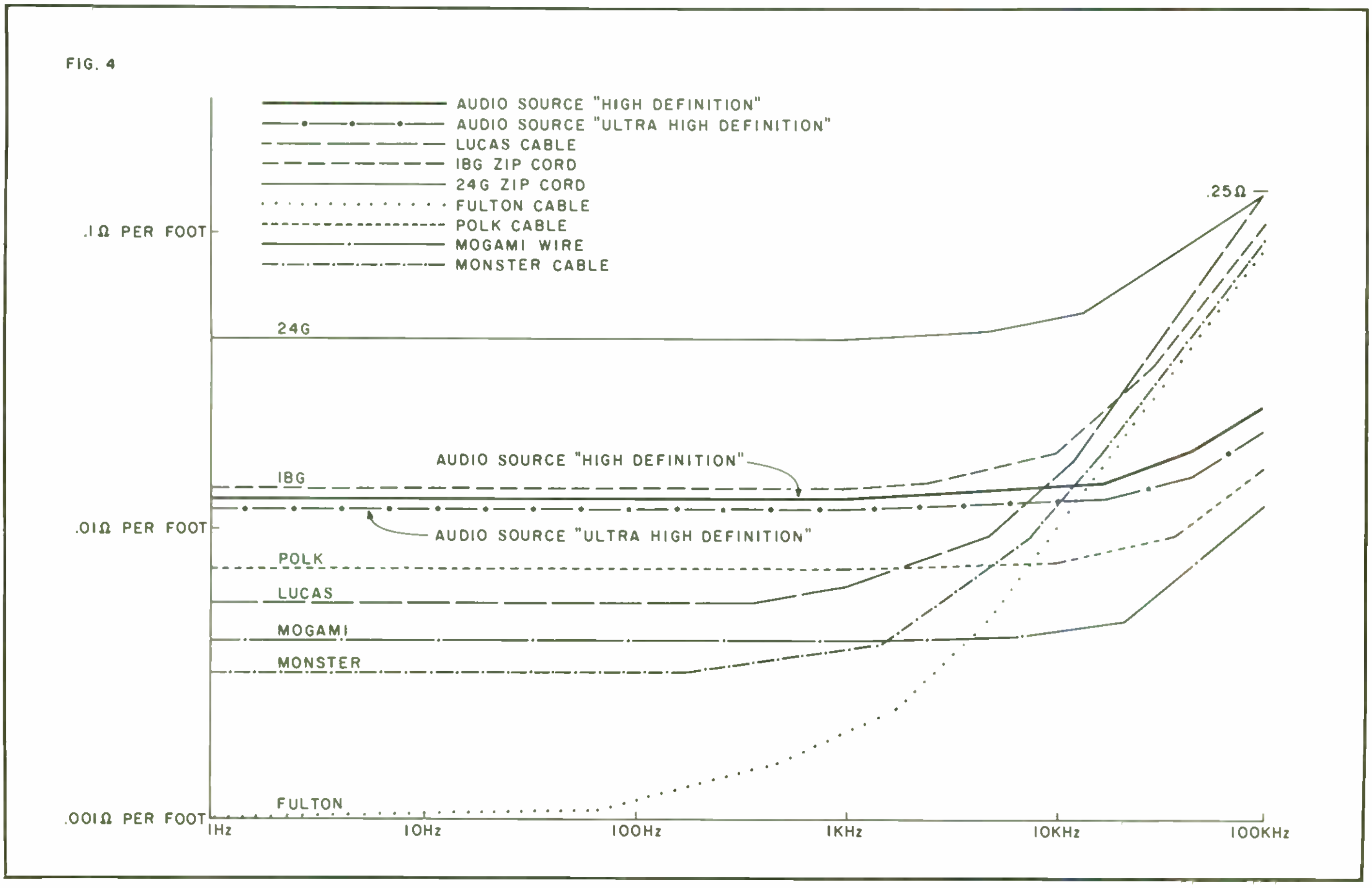
I tested five different types of twin lead cables: 18 and 24 gauge "zip" cord and three specialty cables, "Monster", Lucas cable, and Fulton wire (gold). I bought two samples of each of 18 and 24 gauge wire off reels at a local Radio Shack and a hardware store. All the cables tested were 10 feet in length.

"Monster" cable, marketed by Audio Sales Associates in San Francisco, California, is an approximately 11½ gauge twin lead, similar in construction to very large lamp cord with a thick clear plastic jacket, with large spade lugs at each end for attachment to large screw terminals on "five-way" binding posts as commonly supplied on loudspeakers and amplifiers. Lucas cable is approximately 14 gauge, jacketed in green plastic with a ribbon shape, and is marketed by S.O.T.A., Halifax, Canada. Fulton "gold" cable, available from Fulton Musical Industries with dual banana and other connectors, is an extremely large gauge twin lead having by far the lowest resistance of any cable tested; it is also useful for pulling up tree stumps or jump starting locomotives. Fulton also

loss proportional to the frequency. Capacitance has not usually been considered significant because its values do not impinge upon the audio band. However, we will see later that it may sometimes important.

The new kinds of cable seek to reduce resistance and/or inductance and thus improve the amplifier-speaker connection. They fall into two categories: multistrand twin lead of various gauges (lamp or "zip" cord being an example) and low inductance-high capacitance coaxial or interwoven types. Their measured performance also falls into two categories, 0-100kHz effects and 100kHz - 40MHz effects, which for convenience I will treat separately. My analysis was greatly simplified by the fact that within the two cable categories performances were very similar; indeed, many of the

Fig. 4 Series Impedance



make a "brown" version similar to Monster cable.

The four samples of low inductance cable I tested boasted more exotic construction than zip cord. Two colorful types, Polk Sound Wire and Audio Source Ultra High Definition Wire, use large numbers of separately insulated strands closely interwoven in such a way that the wires cross at an angle to each other instead of running parallel. This reduces the magnetic induction between strands and lowers cable inductance, at the cost of higher capacitance.

High definition cables, another variety of low inductance cable from Audio Source, consists of eight twisted pairs of wire arranged into a flat ribbon. Mogami wire is a large coaxial cable consisting of a grey plastic housing containing two concentric "shells" of wire strands, the inner conductor enclosing a plastic core. "Smog Lifters," another tested cable, is distributed by Disc Washer. It bears a resemblance to Audio Source's high definition cable, with loosely woven braids of conductor.

Fig. 2 shows the relative values of resistance, capacitance and inductance of each of these cables.

SERIES IMPEDANCE TEST

I tested a 10 foot sample of each cable type using the *Fig. 3* setup. I drove the cable by a high source impedance and measured the voltage across it, showing its series impedance. This voltage, referenced to a .1Ω non-inductive resistor and measured from DC to 100kHz, clearly shows the cable impedance's resistive and inductive components (*Fig. 4*). For the twin lead types, inductive and "skin effect" (an additional high frequency resistance effect) components begin to show up at about 1kHz; they increase the impedance, causing high frequency loss in addition to the cable's resistive losses. Interestingly, all the twin lead types have similar cable inductance values, approximately 2μH per 10 feet, and in the region just above the audio spectrum they are nearly identical. Below 20kHz they fan out to their respective resistance values. The lightest wire, #24, clearly has the most loss, while Fulton cable has the least.

The series impedance test differentiates the low inductance cables from twin lead as they exhibit an order of magnitude less impedance at 100kHz. Of these, Mogami Wire had the lowest series impedance, by virtue of its lower resistance; but each of these types has to all intents and purposes inductance effects. The series impedance is a more or less linear function of the length of the cable, so a one foot length will have one-tenth the series impedance shown while 100 feet would have 10 times the amount.

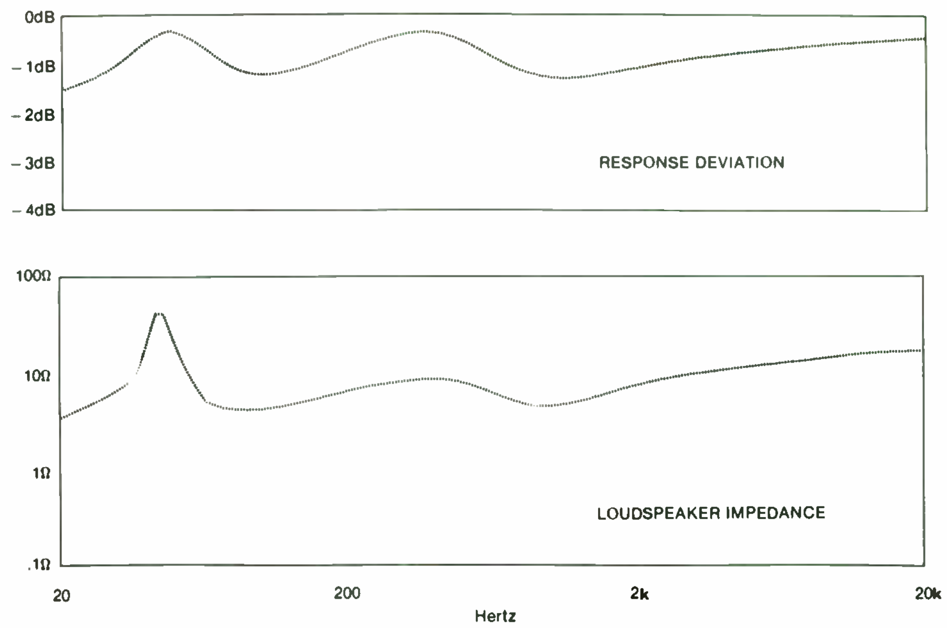


Fig. 5. Effects of 40ft 18 gauge cable on frequency response.

IMPLICATIONS OF LOW FREQUENCY TEST

The existing literature covers the subject quite well. However, I think you will find it useful if I briefly touch on the effects of this series impedance as it relates to frequency response and damping factor [4, 5] and [6]. The performance context lies also in the amplifier's source impedance and the loudspeaker's load impedance. The system's performance will depend on the complex sum of the impedances involved:

$$Z_{source} + Z_{connections} + Z_{cable} + Z_{load}$$

The speaker has generally been designed to be driven by a voltage source, so our ideal premise requires source and cable impedance to be very small compared to speaker impedance. In this case, the speaker's design dominates the performance as intend-

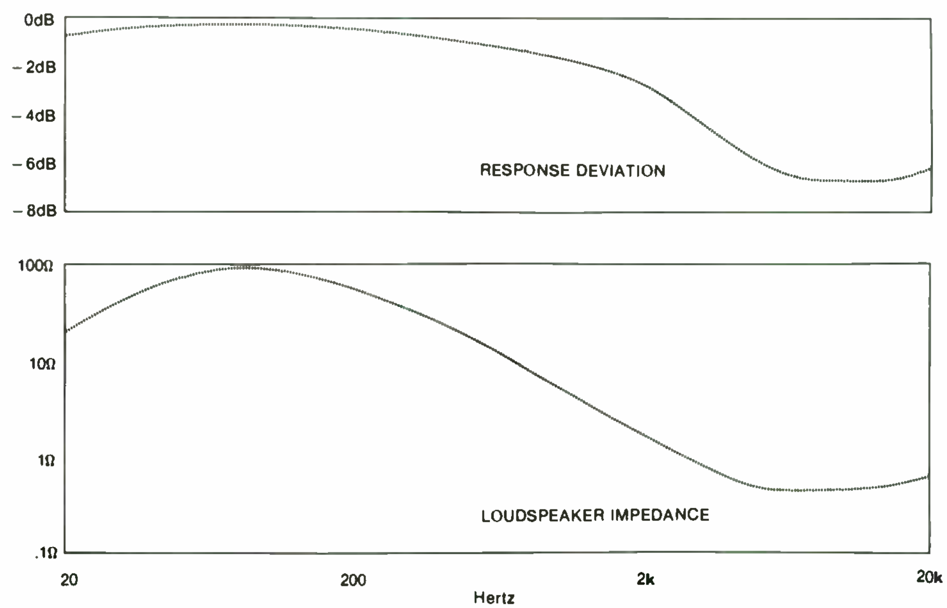


Fig. 6. Effects of 40ft 18 gauge cable on frequency response.

ed, so the variations in the loudspeaker's impedance do not interact to produce frequency response deviations. *Fig. 5* gives an example of such a case, where the aberration is relatively minor; however, *Fig. 6* shows the effects with one particular loudspeaker (which really exists) where the deviation is dramatic.

Just as the cables have an inductive element, so do the amplifiers which drive them. In tube amplifiers the output transformers provide the inductance whereas in most solid state designs the designer has deliberately provided inductance in the form of a coil for added circuit frequency stability. The reason that damping factor (8Ω/output Z) has been traditionally quoted at low frequencies is not only because much of our interest in damping centers on the woofer, but also because this coil destroys the damping factor at high frequencies. In fact, examples exist of solid state amplifiers which quote damping factors of 500 or greater at 20Hz but which have damping factors on the order of 15 at 20kHz. More recently a few designs (Threshold, Audio Research, Yamaha) have dispensed with output coils, giving them more constant damping factors across the audio band. The new IHF test standards call for measurement of damping factor at *all* audio frequencies.

Again, this parameter must be evaluated in the context of the system. For example, most loudspeakers have a considerable inductive component of their own, which may easily provide the desired case of amp Z + Cable Z ≪ speaker Z. Conversely, the source and cable inductances become more important with loudspeakers whose load impedance is resistive or capacitive, especially with some electrostatic designs. Our initial premise does not always hold either, for I have seen "poor quality" cables used to isolate an amplifier from a reactive loudspeaker and thus improve the performance. In general, however, we are looking for amplifiers with low output impedance and cables having low series impedance.

VERY HIGH FREQUENCY TESTS

Ordinarily a discussion of loudspeaker cables would stop here, at 100kHz, where we could safely say that the performance is becoming negligible, if for no other reason than that we cannot hear this frequency (a concept disputed by some audiophiles). However, the advent of wide bandwidth power amplifiers has demonstrated other new effects; several amplifier designs (stable with reactive loads such as capacitors) oscillate into low inductance cables with a variety of results. Threshold, Stax, and Electro-Research designs behave violently, while others acquire oscillation-caused colorations, usually either a hard, etched, high end or warmth and thickness in the vocal range (due to low order intermodulation sidebands and harmonics).

Clearly things are happening above 100kHz; to display them I performed two tests on the cable samples. In the first I swept the frequency output of a ¼Ω resistive source from 100kHz to

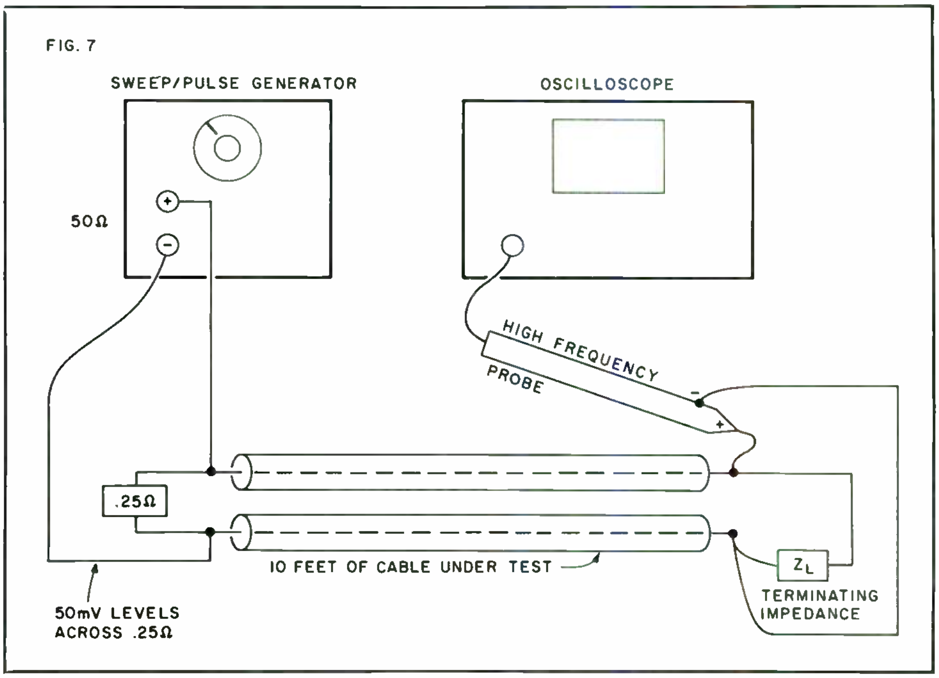


Fig. 7. High Frequency Test

40MHz while measuring the voltage at the other end of the cable with various load impedances. In the second test, I used the same source to send a 5μS pulse down the cable for viewing at the other end. (see *Fig. 7*).

Fig. 8 displays a condensation of over 50 photos showing the test system's response to each variety of cable and load. The unterminated "no load" series shows the equivalent performance of loudspeakers with a substantial series inductive component, while effects of resistive (8Ω) and capacitive (.047μF) loading appear in the following two vertical columns. In the frequency response, we see large peaks occurring in the 1-10MHz region. Remembering that we sent 50mV down the cable from the oscillator, it is surprising to discover amplitudes as high as 5V on the other end—an apparent gain of 100! As shown by the ringing in the pulse waveforms, this highly resonant condition occurs with every variety of cable, but at different frequencies and "Q" factors depending on the source impedance, the load impedance, and the type and length of cable.

The explanation for this resonance is reasonably simple if we consider that it takes a certain amount of time for the signal to travel down the cable. A wave's velocity proportional to its "characteristic impedance," Z_{01} a value expressed in ohms and determined by the inductance and capacitance:

$$\text{as } Z_0 \propto \frac{1}{\sqrt{LC}} \propto \text{velocity}$$

When a wave travelling down a length of cable reaches the end of the cable, it will do one of three things depending on the impedance of the load. If there is a high impedance load, so that $Z_L > Z_C$, the load will reflect energy positively back down the cable to reappear at the source (*Fig. 9*). If the load impedance is less than the characteristic impedance of the cable, the wave is reflected back negatively; and if $Z_L = Z_O$, then the wave is fully absorbed and none is reflected.

This mismatch of load impedance to cable impedance causes the resonance observed in *Fig. 8*, which we see diminish in Polk and Mogami cables when they are loaded with 8 ohms, a value near their characteristic impedance. By contrast, twin lead conductors have a higher characteristic impedance and perform better at multi-megaHertz frequencies with about 50 ohms load impedance. The effect of twin lead cable on a 5μS pulse with an 8 ohm load shows the effect of a load impedance lower than Z_o, where the cable inductance cable rolls off the edges of the pulse, but where the 8 ohm resistance is sufficient to damp the ringing which occurs with $Z_L = 0$ or $Z_L = \infty$. Not so for capacitive loads as shown in the fourth column where another resonance altogether has developed due to the inductance of the cable and the capacitance of the load where:

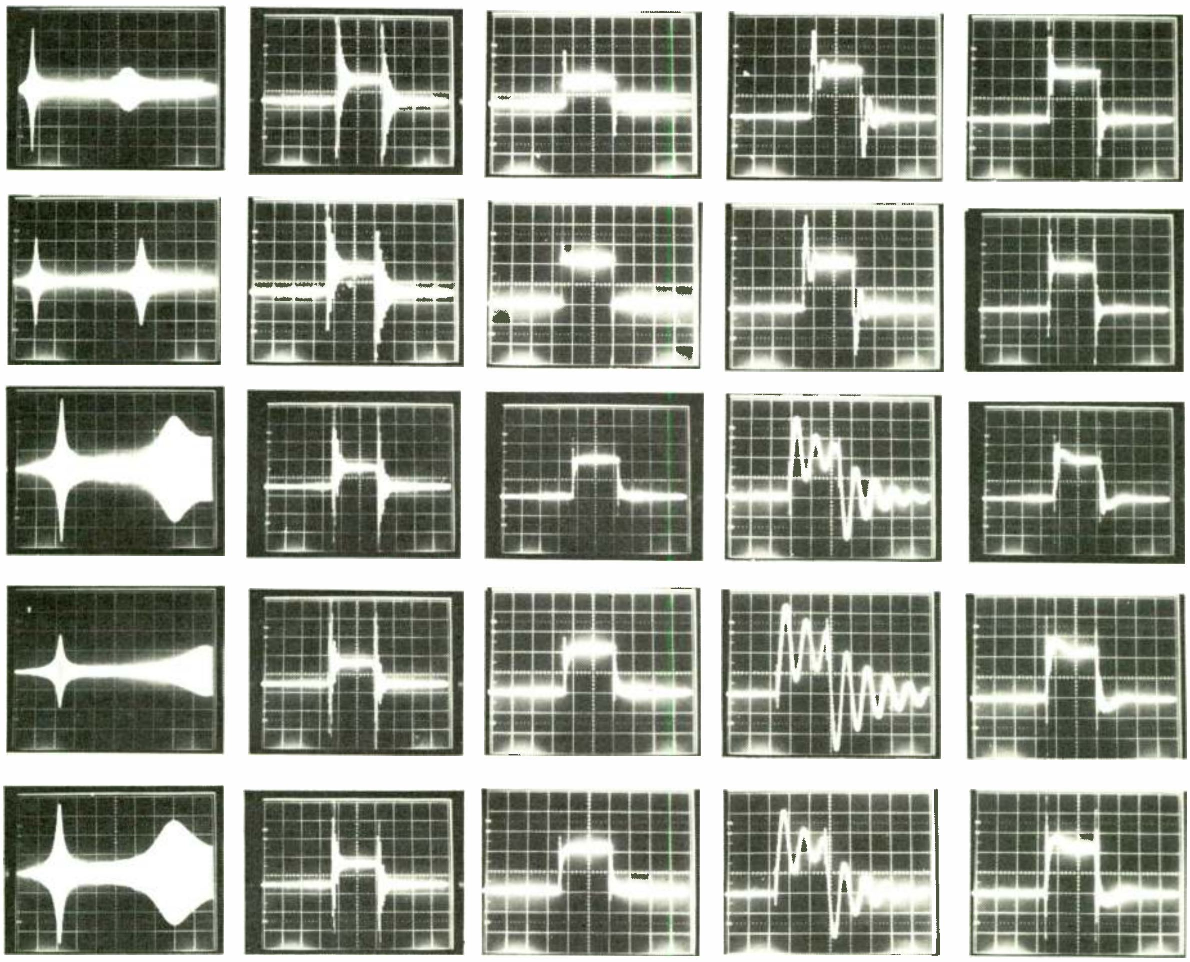
$$2\pi \cdot \text{freq} \cong \frac{1}{\sqrt{LC}}$$

Note that these effects exist with all cables. The fact that only the newer, low inductance cables appear to affect amplifier stability brings us to a point which justifies our examination of a cable's performance in regions which are simply not audible. The lower resonant frequencies of the cables having low Z_o enter into the output bandwidth of the amplifier as it approaches its unity loop gain, and by altering its phase response cause oscillation at the resonant frequency.

Earlier amplifiers as well as some currently available, having slower output stages (less than 1MHz), did not interact with these resonances because they occurred above the cutoff frequency of the active devices by an order of magnitude. However, as the newer cables decreased impedances and as amplifier output stages increased in bandwidth beyond 5MHz, the two effects met and resulted in various forms of sonic problems, fuse blowing, and worse. At Threshold we first ran across the problem with the mating of our 400A and Polk sound cables which caused fuse blowing (due to oscillatory cross-current conduction) with great regularity.

After a period of confusion, Matt Polk and I realized independently that the lack of a characteristic termination was causing the problem. Polk developed and patented a "damper" consisting of a .047μF capacitor and 6Ω resistor in series placed across the loudspeaker, while I used the same network but with .1μF and 5 ohms. The results of this network are seen in *Fig. 8* where the resonance in the pulsed waveform is damped out, restoring stability to an otherwise oscillating

Fig. 8



Polk Cable

Mogami Wire

Fulton Cable

Monster Cable

18G Zip Cord

100kHz to 40mHz swept signal without termination impedance $Z_L = \infty$

5μSec. pulse without termination $Z_L = \infty$

5μS pulse w/8Ω Z_L = 8Ω

5μS pulse w/Z_L = .047μF

5μS pulse w/Z_L = 5Ω, .1μF

amplifier. Since Polk's commercial introduction of the damper circuit we have found it cures oscillation problems caused by the other exotic low inductance cables. It is necessary whenever a reasonably long length (>3 feet) of low inductance cable is mated with any wide bandwidth amplifier. It interacts unfavorably with twin lead conductors (*Fig. 8*) which require higher impedance values (say, .01µF, 60Ω); however, twin lead's higher characteristic impedance and resonant frequencies are in any case unlikely to induce oscillation in amplifiers now available.

With this much information, we might think we have the subject nailed down. However, we could easily install the finest amplifiers, cables, and terminating impedances and achieve 100 times the distortion of the amplifier alone. Loose, dirty, or oxidized connections can, while measuring well with an ohmmeter, cause high amounts of harmonic and intermodulation distortion. When high distortion occurs during an amplifier checkout at Threshold one of the first things we do is replace or tighten the cable from the amplifier to the load; we have thus cured many "defective" amplifiers.

Copper and aluminum oxidize quickly and oils from our fingers find their way to the conductor surfaces, causing poor contact; so on more than one occasion the dramatic improvement provided by an exotic cable has merely demonstrated the extremely poor quality of the previous cable's long neglected connections. Wire connections can age, and anyone wishing to accurately evaluate the newer cable's improved quality should first renew the contacts on his current set. Banana plugs and five-way binding posts make excellent connectors as long as they are kept clean; however, while the connector's plated surface resists corrosion, the wire to the connector interface can become bad and should be periodically checked, especially if it is subject to motion.

OPINIONS

At this point many audiophiles are wondering, "Where are the listening tests?" I have listened to these cables on a variety of amplifiers (mostly my own) and loudspeakers, including Magneplanar Tympani 1 D's, MG II A's, modified Dayton Wright XG 8 MK III's (as shown in *Fig. 6*) Cabasses; I have also heard some examples on Dahlquist and Snell loudspeakers. Frankly, I found it difficult to assess the results except at the extremes of performance. For 10 foot lengths with properly terminated cables and speakers with inductive high frequency characteristics, the differences between low inductance cable and twin conductor are extremely subtle and subject to question. With a low output inductance amplifier and a Heil tweeter (whose impedance is a nearly perfect 6Ω resistive) the difference was discernible as a slightly but not unpleasant softening of the highest frequencies. Fulton or Monster cables were a clear improvement over 24 or even 18 gauge, though a little less subtle than I would have expected, leading me to believe that the effort associated with heavier cables pays off in bass response and in apparent midrange definition, especially at crossover frequencies. The worst case load, the modified Dayton Wright electrostatics, presented some interesting paradoxes: the extremely low impedance involved showed the greatest differences between all the types of cables. However, the best sound cables were not necessarily electrically the best because several amplifiers preferred the highest resistance cable. In one case, I had to use 24 gauge cable to prevent tripping the amplifier's protection circuitry.

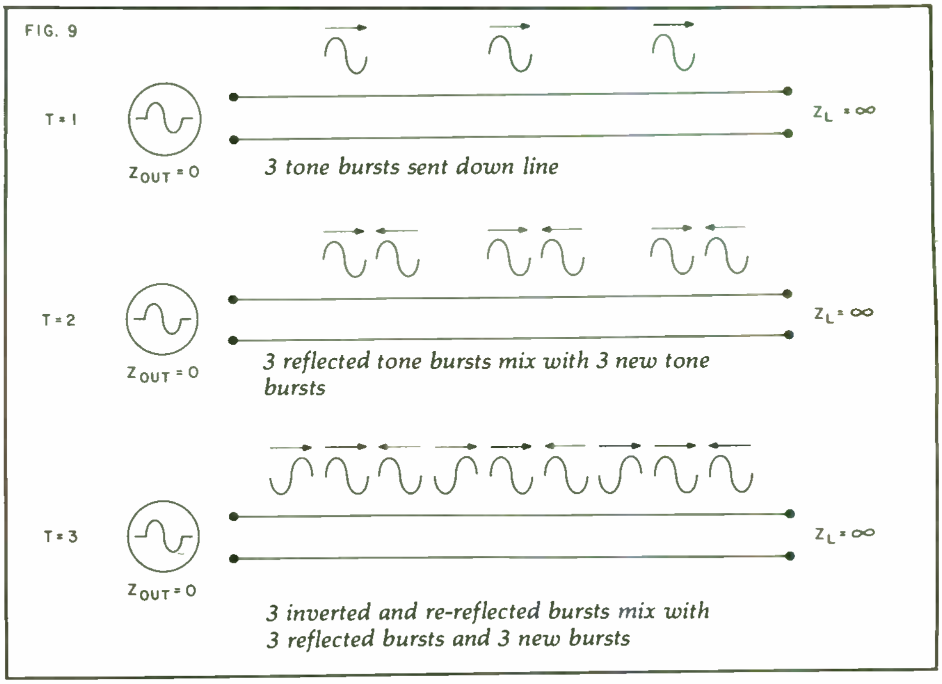


Fig. 9. Wave "pileup" results in resonance at certain frequencies, where the current is high and the voltage is low at the source, and where voltage is high and current is low at the load.

CONCLUSIONS

Who am I to dispute the feelings of audiophiles who, evaluating any cable in the context of program source, amplifier, speaker, and listening room, decide they can hear the difference? A few guidelines have emerged here, but the final judgment belongs to the user. All the special cables mentioned worked well on the test bench and, given the assumption that series impedance should be minimized, all of them work better than 16 gauge wire. If, like many audiophiles, you have spent a small (or large) fortune on your hi-fi system, money spent for high quality cables and connectors is a reasonable investment. □

REFERENCES

1. **Brochures/Pamphlets:**

a. **Fulton Speaker Cable.** Fulton Musical Industries, 4428 Zane Ave. North, Minneapolis, MN 55422.

b. **Mogami Speaker Cable.** At press time we are unable to locate a manufacturer or distributor for Mogami.

c. **Polk Audio Sound Cable.** Polk Audio, 1205 South Carey Street, Baltimore, MD 21230.

d. **Ultra High Definition Speaker Cable.** Audio Source, 1185 Chess Drive, Foster City, CA 94404.

2. Hiraga, Jean, "Can We Hear Connecting Wires?", *Hi Fi News and Record Review*, August 1977.

3. Retsoff, Alexander, "Retsoff's Remedies," *Stereo*, Fall, 1978.

4. Klipsch, Paul, "Speaker Wire," *Dope From Hope*, Sept. 13, 1978.

5. Pass, Nelson, "Loudspeaker Damping," *Audio Magazine*,

6. Gailus, Mark, "Speaker Wire: What Size is Sufficient?", *Audio Forum*, Aug.-Sept.,

7. Greinier, R. A., "Another Look At Speaker Cables," *Speaker*, The Boston Audio Society, Dec. 1978.

8. Gross, T. A. G., "Multistrand Litz Wire Adds "Skin" To Cut AC Losses in Switching Power Supplies," *Electronic Design*, Feb. 1, 1979.

A Three-Enclosure Loudspeaker System with active delay and crossover: Part 1

by Siegfried Linkwitz

This detailed description of a multiple-driver loudspeaker design is in three parts and covers driver selection, enclosure design, the active crossover, equalization and positioning. Sufficient information is given to duplicate the system or to improve existing systems by equalizing the low-frequency response or adding a separate woofer box.

The system described evolved over years and out of experimentation with many different configurations and types of drivers and enclosures. Many people have contributed their ideas. It is not "the ultimate loudspeaker", but it reveals enough about microphone placement and recording practices to suggest that the recording studio is the next weak link in the chain between original and reproduction. The few recordings with good spatial definition are proof that the full potential of stereo has not been exploited. Possibly this potential has gone unnoticed because hardly any commercial loudspeaker reproduces the depth perspective adequately, giving either a diffuse or thin-walled stereo image.

Every driver becomes more directional as frequency increases. The radiation pattern of a rigid piston mounted at the end of a long tube[1] is omnidirectional at frequencies where the ratio of piston diameter d to the wavelength λ of radiated sound is small, *Fig. 1*. As d/λ increases the on-axis pressure increases but the pressure at 45° off-axis decreases relative to it. Experience shows that wide dispersion of sound is desirable for natural reproduction. Allowing for a maximum 6dB drop-off at 45° off-axis requires that a driver be only used over a frequency range where its equivalent piston diameter is less than one wavelength. This is an idealized assumption because real drivers do not behave exactly like rigid pistons but the general principle still holds that uniform, wide dispersion can only be expected for frequencies where $d/\lambda \leq 1$.

In all loudspeaker designs the physical dimensions of driver, box and room have to be compared to the wavelength of the radiated sound to determine whether a dimension is acoustically small, as when $d/\lambda < 0.5$, or large, *Fig. 2*. A 200mm diameter driver for example should only be used up to 1.5kHz to maintain wide dispersion. This is indeed a popular crossover frequency but it is also well within the critical frequency range of fundamentals and lower harmonics of many musical instruments. It is unavoidable that some change in the radiation pattern is introduced around the transition frequency from a larger to a smaller driver. In the design described a 100mm diameter driver is chosen which crosses over to a 25mm diameter unit at 3kHz. The radiation pattern change occurs therefore an octave higher in a relatively less critical frequency range, but still care has been taken in the design of the crossover circuitry to minimize irregularities in the transition region.

Revised from articles first published in Wireless World, London.

Photo A. Author's system on location. The satellite/midrange tweeter enclosures hang from the ceiling by curtain cord, and remain oriented by the signal cable at the rear of each.

MULTI-DRIVER HAZARDS

Some designers try to obtain wide dispersion or "omni-directionality" by using multiple drivers, covering the same frequency range. The fallacy in this approach can be seen by comparing the radiation pattern of a single driver to the resulting dispersion when two of these units radiate together, *Fig. 3*. If the distance d between the driver is greater than half a wavelength signal cancellation can occur. The two outputs will be 180° out of phase whenever the path lengths from each of the drivers to the listener differ by an odd multiple of a half wavelength. As frequency increases the two units move relatively further apart (*Fig. 2*) and the locations for which the outputs cancel become more frequent. Such a system can only be described as multi-directional. Additional drive units further destroy the phase coherence of the direct sound output from the speaker system. This imparts the illusion of wide dispersion to all program material but lacks the accuracy in sound perspective which can be obtained from a single drive unit.

After establishing from the cone diameter the highest frequency up to which a driver can be used with good dispersion, the lower frequency limit will be determined from the cone excursion capability of the drive unit and the desired sound pressure level.

The radiation from the piston in a long tube was found to be omnidirectional for low frequencies where $\frac{d}{\lambda} \ll 1$ *Fig. 1*. If the piston moves with a peak-to-peak excursion a_{pp} at frequency f and radiates into free space, then pressure p at a distance r from the source is:

$$p = \frac{\pi^2 p_o}{8\sqrt{2}} \quad \frac{a_{pp} f^2 d^2}{r}$$

Normalizing the pressure with respect to the reference pressure $p = 2 \times 10^{-4}$ μbar yields an expression for the more familiar sound pressure level (d and a_{pp} expressed in mm)

$$SPL = 20\log(p/p_o) = -86 + 40\log f - 20\log r + 40\log d + 20\log a_{pp}$$

Assuming a_{pp} is 6mm and f 70Hz a direct pressure level of 83dB at 1m can be obtained from the 100mm driver and 95dB from a 200mm unit.

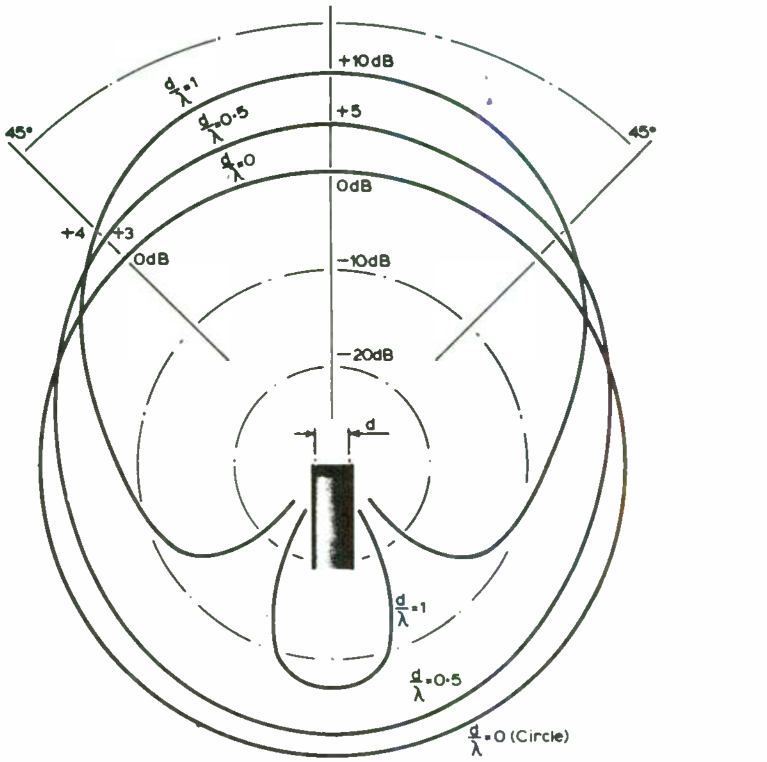


Fig. 1. Directivity pattern for a rigid circular piston in the end of a long tube as function of d/λ (d is piston diameter, λ is radiated sound wavelength). Wide dispersion can only be obtained for frequencies where d/λ = 1.

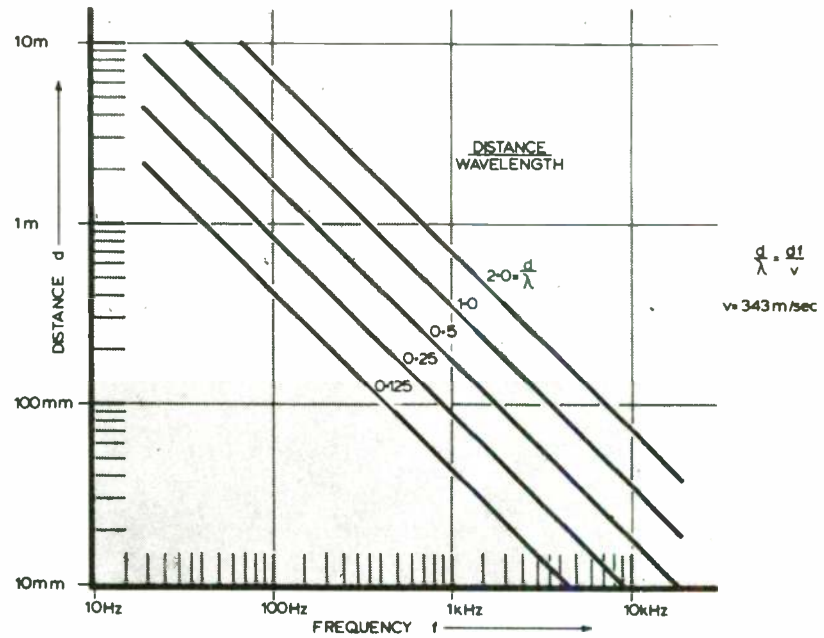


Fig. 2. Dimensions (d) of driver, box or room must be compared to wavelength of sound to determine whether a dimension is acoustically small.

MAXIMUM SPL'S

These sound pressure levels may not seem very high but crossing over to a woofer at 70Hz will double the maximally obtainable sound pressure (+6dB) and because signals from the left and right channels of a stereo system are predominantly in phase at such low frequency, a further increase of approximately 6dB can be expected. Therefore from a stereo system with 100mm drivers a direct free-field s.p.l. of about 95dB can be expected. Furthermore the normal listening environment is a semi-reverberant room where sound is reinforced by reflections from walls and objects.

Practical experience confirms that a 100mm unit can handle program material down to 70Hz at adequate levels and low distortion. This moves the crossover to the woofer to a less critical frequency range and a single large woofer can be used to cover the remaining frequency range below 70Hz. The large woofer enclosure can be placed separately from the relatively small midrange and tweeter enclosures and still be acoustically close because d/λ is small. Further consideration is given to this aspect of the system design later.

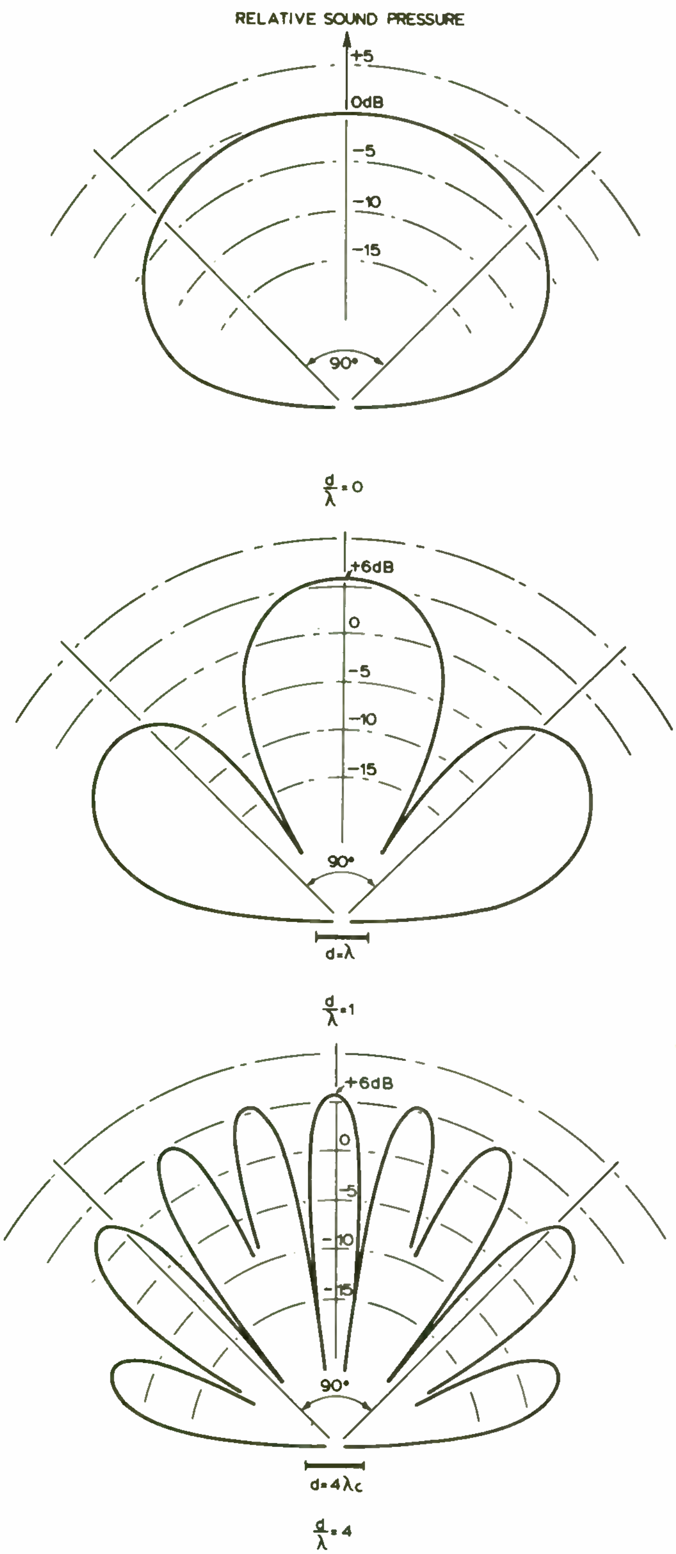


Fig. 3. Use of multiple drivers to give wide dispersion produces interference effects for d>0 (a) single driver (b) two drivers one wavelength apart, (c) two drivers four wavelengths apart, all with same signal.

The frequency range below 70Hz could be covered by two 200mm units which will generate 90dB of direct s.p.l. at 35Hz and 1m or two 250mm diameter drivers with 94dB s.p.l. assuming 6mm peak-to-peak excursion capability.

DRIVER CHOSEN

The particular drivers chosen for this design are the 100mm KEF B110 low frequency/midrange unit, the 25mm KEF T27 tweeter and the KEF B139 woofer. A different unit like the KEF B200 or some other make with adequate excursion capability and linearity could be substituted for the B139.

There are of course considerations other than dispersion and cone excursion which must enter into the selection of a drive unit, such as smoothness of frequency response, freedom from high Q resonances, minimum phase behavior, and low non-linear distortion. Unfortunately, manufacturers publish scant useful data. Knowing the magnet weight and flux density is of little help. With some training though the ear can sort out those drive units that seem worth further investigation and the units chosen for this design proved to be very satisfactory.

I was primarily guided in the selection of drivers by the desire for wide, uniform dispersion and crossover frequencies as high and low as possible. Had I chosen to put emphasis on high power output capability or lower non-linear and Doppler distortion then I would have chosen larger diameter drivers, or shifted crossover frequencies to a more critical frequency range. Wide dispersion can only be obtained from a small drive unit which will also have higher distortion than a larger unit. It appears though that psychoacoustically the increased distortion is outweighed by an improved sound perspective which gives a greater sense of realism. Some further investigation of this subject is needed.

SPEAKER ENCLOSURES

Usually the size of a loudspeaker enclosure is dictated by the required low frequency response and efficiency. I took a different approach here where the enclosure is optimized for minimum secondary radiation over as

Continued on page 16

A THREE-ENCLOSURE SPEAKER SYSTEM

Continued from page 13

wide a frequency range as possible. The low frequency output capability is treated as a separate problem

My enclosure's purpose is to control the radiation from the back of the cone. A closed box design is the simplest form of enclosure. If the largest box dimension is less than a quarter wavelength at the highest frequency from the driver then the box is acoustically small and the air volume inside the enclosure will act like a uniform spring. The box walls must be made sufficiently stiff so the internal air pressure changes will not deflect the walls and cause secondary radiation. The woofer enclosure can be made small relative to the 70Hz maximum frequency. It will therefore have no internal air volume resonances and box panel resonances can be pushed above 70Hz by crossbracing.

The B110's enclosure presents greater difficulties because of the wider frequency range covered. The volume inside the enclosure will exhibit cavity resonances which have to be eliminated. Acoustic energy is stored whenever one of these resonances is excited and gradually released after the excitation has been removed. Most of this acoustic energy exits through the cone: the speaker regurgitates its own characteristic box sound. Fortunately it is not difficult to dampen cavity resonances. The technique of filling the enclosure with long fibre wool is well established and very effective.[2,3]

Another form of undesired secondary radiation comes from the enclosure walls themselves. The walls can be excited to vibrate by the internal air volume pressure changes, but more serious is the direct transmission of the mechanical vibration of the driver's cone to the enclosure. The walls then radiate the transmitted mechanical energy as sound, particularly when its frequency coincides with a panel resonance.

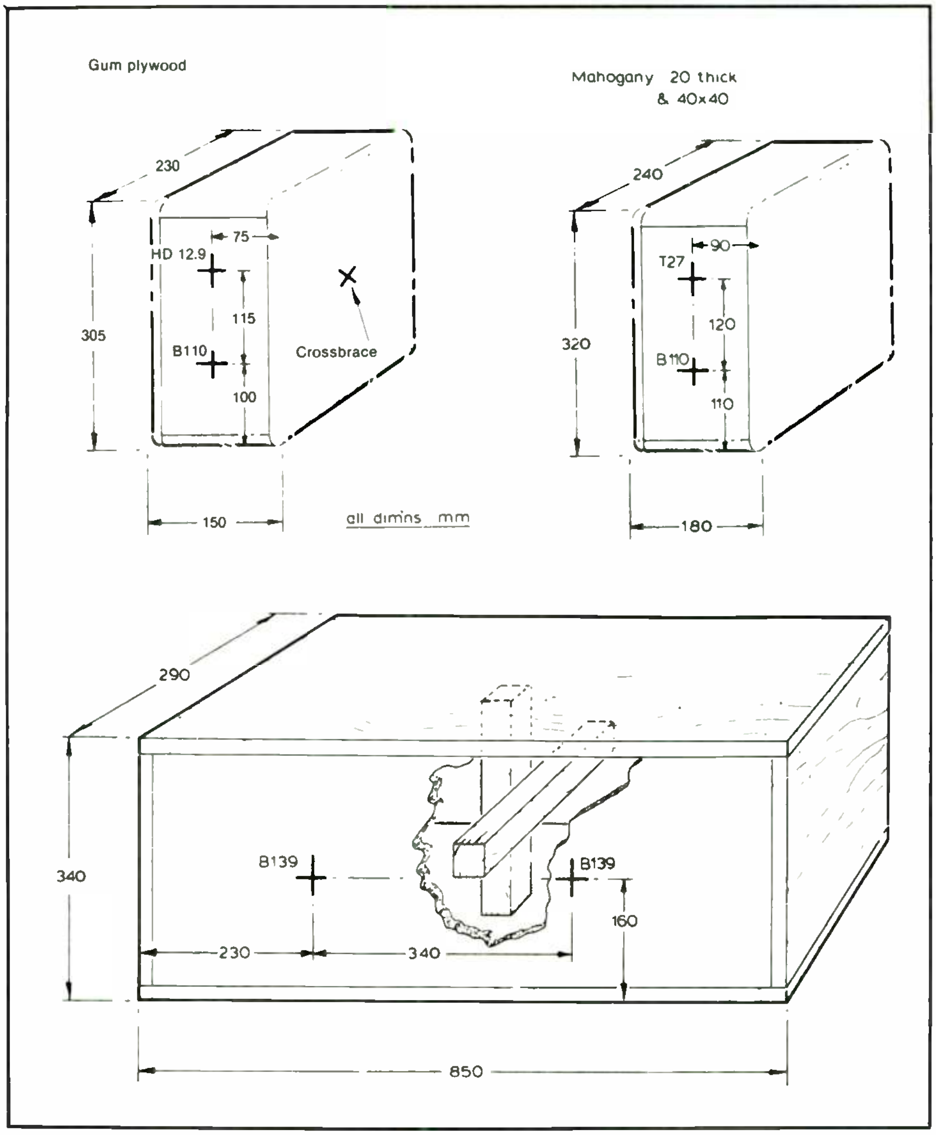


Fig. 4. Loudspeaker enclosure dimensions. As there is little stereo information below the 70Hz limit of the enclosures (above), a center woofer covers the remaining range down to 25Hz (below). The revised enclosure (above left) has minimum width and optimum tweeter position for reduced diffraction from cabinet edges. The gum plywood construction allows only minimum bevelling.

Enclosure Design Objectives

- Narrow frontal area for optimum horizontal dispersion; tweeter mounted directly above the midrange unit.
- Box edges rounded to reduce scattering.
- Drivers mounted to minimize direct transmission of vibration to the panels.
- Panel resonances attenuated with damping layers of sufficient stiffness and loss.
- Air cavity resonances attenuated with filling materials to eliminate delayed re-transmission through cone.

WALLS & MOUNTS

It is not unusual for more energy to be radiated directly from the enclosure walls than from the cone at resonance frequencies. If, for example, the vibrating enclosure surface has ten times the area of the cone then its acoustic output will already equal that of the cone if it has only one tenth of the cone excursion. The output of most loudspeakers is colored by the radiation from the enclosure walls.

It has been verified experimentally that vibration coupling between the driver and the walls occurs primarily through the rigid mounting of the driver to the enclosure. Vibration-mounting the driver to the enclosure with some form of compliant suspension will significantly reduce the wall excitation, but it poses some difficult mechanical design problems. The natural frequency of the driver mounting should be well below the acoustical output frequency to avoid frequency response irregularities. The mount must seal the enclosure air tight and provide sufficient mechanical support for the driver. Another approach might be to enclose the box to which the driver is mounted by a second box

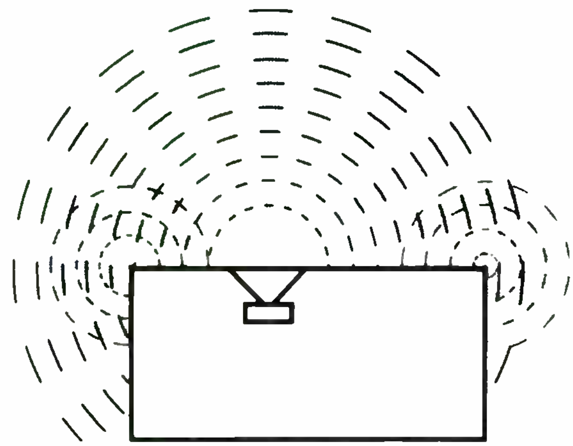


Fig. 5. Sound scattering from the sharp corners of a loudspeaker enclosure producing a smeared out transient behavior of the system.

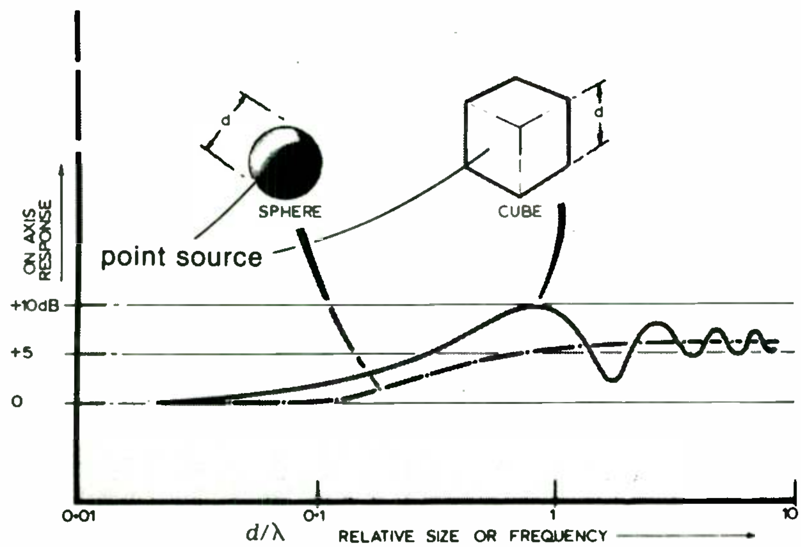


Fig. 6. On-axis frequency response of a point source mounted in different enclosures shows smoother response of sphere (after ref. 6).

Siegfried Linkwitz *became interested in sound reproduction as a hobby, recognizing the many dualities between the propagation of microwave and acoustic fields. "A 1GHz electrical wave and a 1kHz acoustical wave have about the same wavelength." After modifying and equalizing several commercial loudspeakers, he set about designing his own system—out of frustration with available units.*

He is section manager for signal analyzer developments with Hewlett-Packard. He has been program manager for the 8566A high performance microwave spectrum analyzer and he's been involved with the design of signal generators (608E), a vector-voltmenter (8405A) and was project leader for the 8554L RF analyzer. He joined Hewlett-Packard Company in California as a development engineer for r.f. test equipment following graduation in 1961 from Darmstadt University.

avoiding all rigid coupling between the two.

For the design described here I chose a single, totally enclosed box, *Fig. 4*. The B110 driver was attached to it with soft rubber grommets in the four mounting holes of the basket which slide on the mounting bolts. The sealing foam gasket is barely compressed. Comparing this to a directly mounted driver by tapping on either basket indicates a significant reduction in coupling to the box. Some further investigation of this subject is in progress.

WOOL & TAR

The relatively small size for the B110/T27 assembly has the advantage that the internal air volume resonances occur at high frequencies where they can be damped effectively with wool filling. The lowest cavity resonance occurs at 600Hz, the next ones at 800, 1000, 1200Hz etc. the resonances are measured easily with a small omnidirectional electret microphone protruding into the box and applying a sweep signal to the B110. Filling the boxes rather tightly with long-fibre wool attenuates all the resonances to a smooth frequency response inside the box and at the outside cone surface.

My original enclosures were constructed of 20mm mahogany board with the internal surfaces coated with tar-based damping layers. I have since built new versions using 6mm plywood with a 15mm damping layer consisting of a 3:1 mixture of water based asphalt emulsion (Henry's 107) and sand, which gave optimum results.[4] The original enclosures had panels which were quite stiff. The lowest panel resonance was observed at 430Hz using a magnetic phono pickup in a makeshift tonearm as vibration transducer. A 430Hz tone was measured to decay b y 40dB in the rather long time of 120msec indicating a Q of 36 which is typical of undamped wood panels. By applying damping material the decay time could be reduced to 40msec corresponding to a Q of 8.4 at 300Hz. This is a low Q for a mechanical structure.

The basic difficulty consists in finding a damping material which has adequate stiffness to control the motion of the panel and which at the same time has sufficient loss to dissipate the mechanical vibration energy as heat. A

Photo B. Overall view of the author's system. The comfortable chair evidently gets moved to a sonically less active position during listening sessions.

better match between available materials is achieved by using thinner walls of correspondingly less stiffness so that a softer damping material can reduce wall flexures. A simple and quite revealing test is to knock on any box to hear how dead it is acoustically.

A small box presents a small obstacle to omnidirectional sound propagation. This is a clearly audible advantage when properly placed in the room. As the box is only marginally wider than the B110 driver it can be assumed that the radiation pattern for a piston at the end of a long tube is an adequate first order approximation to its sound dispersion, *Fig.1*. The T27 tweeter is mounted as close as possible to the B110. At the crossover frequency of 3kHz the spacing corresponds to a distance of one wavelength. In the vertical plane therefore the radiation pattern at the crossover frequency should follow the previously discussed behavior of two drivers contributing equally, *Fig. 3b*.

RESPONSE RESULTS

Ideally the sound from the T27 should be able to disperse freely in all directions, but because of the large width of the front panel relative to the cone diameter a wave emanating from the cone will initially be blocked by the panel and then encounter an abrupt transition where it ends, *Fig. 5*. A second wave is generated at the cabinet edge which will interfere with the original wave. If a pulse is radiated from the T27 then a secondary pulse of lower amplitude is generated at a time $t = d/c = 260\mu S$ later, the original pulse is smeared out. This scattering of sound should be avoided by eliminating sharp discontinuities through bevelling of the cabinet edges.[5]

Fig. 6 shows the on-axis amplitude response of a small driver mounted in the center of a cube and of a sphere.[6] Clearly the sphere with its surface gradually receding from the source produces a much smoother response than the cube with its sharp edges. Therefore the larger the box relative to the driver the more closely should it approach the shape of a sphere. It follows that the midrange/tweeter enclosures might be further improved by reducing their size and constructing a more curved driver mounting area. Papier mache, cardboard or epoxy fiberglass with damping materials applied to it rather than wood might be more suitable materials for the unconventional contours of such an enclosure.

For the given design the frequency range extends down to 70Hz where the B110 has its enclosed resonance. As there is little useful stereo information below this frequency a single center-channel woofer box can cover the remaining range down to 25Hz, *Fig. 4*. This is built with internal bracing to stiffen it and to push panel resonances to frequencies above 70Hz. In addition 25mm-thick heavy felt is glued to all panels to reduce direct transmission. The box is loosely fitted with long-fibre wool. □

REFERENCES

1. Beranek, L. L., Acoustics, McGraw-Hill 1954.
2. Bailey, A. R., Non-resonant loudspeaker enclosure design, *Wireless World*, October 1965, p. 483.
3. Bradbury, L. J. S., Use of fibrous materials in loudspeaker enclosures, *JAES*, Vol. 24, April 1976, p. 162.
4. Harris, C. M. and Crede C. E., Shock and Vibration Handbook, 2nd edition. McGraw-Hill 1976.
5. Heyser, R. C., Energy-time test, *Audio*, June 1976, p. 74.
6. Muller, G. G., Black, R. & Davis, T. E., Diffraction produced by cylindrical and cubical obstacles and by circular and square plates, *JASA*, vol. 10, July 1938, p. 6.

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 electro-mechanical 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**

OLD COLONY SOUND LAB

American Radio Relay League

AR-1 THE RADIO AMATEUR'S HANDBOOK. A basic introduction to electronics and an unequalled guide to good construction practice, it is also rich in basic data. Fully revised for 1979 in a new 8½x11" format. Softbound.
Each **$9.75**

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 bo build his own one-of-a-kind test gear especially tailored for highest performance. A wealth of circuitry including a $40 harmonic distortion analyzer, an AC voltmeter, a breadboard electronic load, and much more. 140pp., softbound.
Each **$5.95**

The PENGUINS

P-1 PENGUIN STEREO RECORD GUIDE(2ND ED.) *by Edward Greenfield, Robert Layton, and Ivan March.* Drawing on profound technical knowledge and on vast musical and historical learning, this newly revised and updated guide to recorded classical music deals with over four thousand discs, giving details of title, performers, record number, label and price range. For record buyers in a hurry, a starring system (from one to three) is provided; while, for the enlightenment of browsers, there is a short but informative discussion of each record. The authors are long-time reviewers for *The Gramophone* the world's oldest phonograph review medium. "The authors' scope and zeal are stunning, their standards of judgement and accuracy high. . .what an achievement."—*Sunday Times*(London)."The answer to a record collecting browser's prayer."—*High Fidelity.* 1,169pp., softbound.
Each **$8.95**

P-2 A DICTIONARY OF ELECTRONICS *by S. Handel.* This remarkably compact reference covers electronics from A-Battery to Z-parameters with succinct, concise definitions and illustrations. A quick reference by a man who spent thirty years in electronics and believed the future world will be one where electronics is increasingly important. 413pp., softbound.
Each **$3.95**

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**

TAB BOOKS

T-2 ELECTRONIC EXPERIMENTER'S GUIDEBOOK *by Don Tuite.* How to move from kit builder to scratch builder. Construction principles and techniques, finishing the package, troubleshooting, and component selection are all part of this helpful guide. Softbound.
Each **$4.95**

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**

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**

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**

Sagamore Press

SG-1 MICROPHONES: DESIGN AND APPLICATION *by Lou Burroughs.* The co-founder of Electro-Voice has produced a comprehensive handbook on microphone usage which is eminently practical, easy to read and use. 26 chapters. Paperbound.
Each **$12.95**

Howard W. Sams

S-5 AUDIO ENCYCLOPEDIA, 2ND EDITION, *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.* The bestselling, authoritative, best introduction to practical op amp usage available. 591pp., softbound. Each **$12.95**

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**

HOWARD W. SAMS' complete catalog of all titles is available from *Old Colony.* Ask for a copy with your next order—and Old Colony can supply any Sams book (except Photofact®).

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/Bank-Americard. All prices are postpaid in the 50 states. *$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.	$ ....
	Total	$ ....

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

An Electrostatic Speaker System

Part 1

by Roger R. Sanders

Since the publication of my speaker design in *The Audio Amateur* (Issue #4, 1975, p.18), hundreds of readers have contacted me and scores have built speakers. From this and from continued investigation on my part several new designs have been built and tested and many small bits of worthwhile information have been learned. The purpose of this series of articles is to make it possible for the average audiophile to construct his own speaker that will exceed the performance of the finest commercial systems.

I shall discuss theory, construction, and custom tailoring. If you build the proven design without modification, I can virtually guarantee you superb results. I'll present various modifications to allow for individual preferences, but all modifications have been tried and studied and I have chosen the best combination of compromises for the "ultimate" system; modifications will degrade performance in one area or another.

Electrostatic loudspeakers (henceforth called ESL's) offer improved detail and clarity compared to conventional dynamic loudspeakers. The reasons for this are clear. Essentially, the dynamic loudspeaker has a great deal of mass compared to the air it is driving, while the ESL has essentially no mass compared to the air it is driving. This offers much better transient response; more important, no resonances are present above the ESL's fundamental resonance because the speaker is air damped.

Sonically this means the sound is very smooth as well as detailed. The ESL is driven over its entire surface, rather than at just one point as in a dynamic speaker; therefore the driving surface is scarcely distorted. Because of the lack of moving mass, the driven surface response is exceedingly linear and therefore essentially perfect frequency response should be available from the system.

DRAWBACKS

Well, it certainly sounds good; there must be a catch or else everybody would be using it. There is a catch—in fact several. To understand one must understand the speaker's working principle. Unlike the magnetic forces that drive a dynamic speaker, the ESL is driven with electrostatic attraction. This is the force you feel when you run a comb through your hair on a dry day and feel the comb attract the hair on your arm or have little bits of paper stick to it.

The force is developed by high voltages (problem #1), and it is very weak (problem #2), it is only available across very short distances (problem #3), and tends to migrate across the surface of the charged object (problem #4). Electrostatic force decreases with the square of the distance which causes non-linear motion (problem #5).

We can take a thin piece of non-conductive film such as the cellophane found around cigarette packs, and place several thousand volts on it. It will have an electrostatic force if placed within a few thousandths of an inch (hereafter called "mils") of another object. If that other object is conductive, like a perforated metal plate, a voltage (hereafter called "charge") can be easily placed on it or removed from it by an audio amplifier. If the non-conductive film (hereafter called diaphragm) has 2000 volts (2kV) positive on it and the amplifier is causing the perforated metal plate (hereafter called "stator") to have 3kV negative charge, then the diaphragm is going to be strongly attracted to the stator. It will be more attracted to a 3kV negative stator than to a zero volt one. If our stator is changing voltage as directed by our audio system amplifier, then the diaphragm will move back and forth and you will hear music as the air moves through the holes in the stator.

HIGH VOLTAGE

The principle is simple, but the solution to the problems are not. Let's examine the problems and possible solutions.

The first problem is that we need high voltages. This means the speakers have to be built with insulation in mind and some safety precautions are needed. Conventional audio amplifiers generate only approximately 100 volts of output swing (peak to peak), and we need several thousand volts. The diaphragm voltage is reasonably easy to develop: we used about 2kV and essentially no current is required. An easy way to get this voltage is to connect a surplus copy machine power supply to the diaphragm.

The amplifier voltage problem is usually solved by driving the speaker through a transformer with a high turns ratio in order to step up the voltage. Transformers don't really like this because the speaker does not draw current: electrically the transformer sees the speaker as a capacitor. This makes for problems with transformer resonances, goofed-up frequency response, and instability in some amplifiers. Good transformers of this type are also rather expensive.

Several people have tried to build a high voltage amplifier directly connected to the ESL stator. These are not without problems, the biggest one being instability (see my article in *The Audio Amateur*, issue #1, 1976, p. 12, and David Hermeyer's articles in the same publication, issues 2 and 3 of the 1977 series). They are also costly to operate because they are generally class A devices, and they are quite an undertaking to build. With the correct transformer, I believe a transformer coupled system with a conventional amplifier is still the best compromise. More discussion of this later will make my reasoning clear.

PHOTO BY REG WILLIAMSON.

Photo A. The author's system including two transmission line woofers with KEF drivers and four 2'x3' electrostatic panels. The speakers are driven by two stereo amplifiers with electronic crossovers and equalizers.

SHORT FORCES

The second problem: the forces are small; the third: they are available only across very small distances. It therefore becomes impractical to drive the diaphragm over large excursions, which severely limits how loudly the speakers will play. The frequency spectrum of music is such that a great deal of energy is needed in the midbass and lower midrange (100-500Hz by my definition). This is particularly unfortunate because also in the lower frequencies we run into problem #6, phase cancellation or the tendency for the sound pressure levels (hereafter called SPL's) to decrease even though the diaphragm motion is linear. This is caused by "leakage" of the pressure waves from one side of the speaker to the other.

To demonstrate, pretend a canoe paddle is the diaphragm and put it into a tub of water and pretend that it is air. Move the paddle rapidly back and forth in the water and you get big waves (loud high frequency sound). Now move it very slowly the same distance back and forth: you get little waves or none (weak bass). You can see the water has more time to move around to the other side of the paddle and cancel out the pressure waves at low frequencies. The same is true of an ESL and air.

FIG. 1

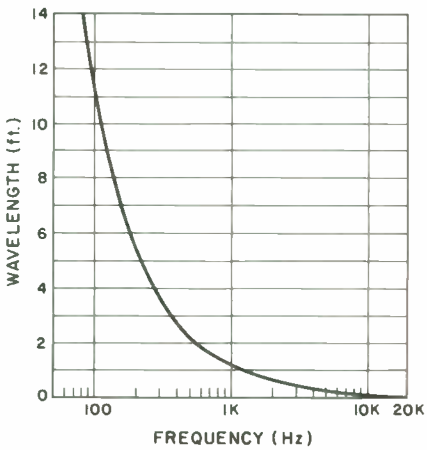


Fig. 1. The wavelength of sound versus frequency.

To compensate one can equalize the bass and make the speaker go through large excursions, which is difficult to do because of the weak forces, small distances, and large voltages required. Essentially the compromise here is that you get bass at the expense of SPL's. Alternatively, we can increase the speaker area. This works well up to a point; after all, if the speaker completely seals off the end of the room, no air can get around it. In free space, the speaker would have to be at least 30 feet across the smallest dimension to reproduce 30Hz linearly—see the sizes required in *Fig. 1*.

Not only is it impractical to make such large speakers, but they are also very difficult to drive: the load they present to the amplifier and transformers (if used) becomes unmanageable. Imaging also becomes a problem with the sound arriving from such large areas. The most practical way to get the bass response required is to use conventional dynamic woofers. A *good* woofer in a good enclosure (either a transmission line or a large horn system) can be made to sound clearly superior to a full range ESL in direct A-B tests.

WHICH IS BETTER?

Now, I realize that comment is going to make the "techno-freaks" say I am crazy: a crossoverless ESL just has to be superior to a hybrid system. Well, "techno-freaks" generally don't have hands-on experience and so aren't realists; I know, I used to be one. The point is, just because theory says something should be better doesn't mean it *is* better.

I can't tell you how much time I have spent with readers who insist on operating the ESL's full range or at least down to 100Hz because "it should sound better." It is *not* better. I have demonstrated in A-B tests on several occasions that the full range system is inferior to the hybrid system. Tests were done with the ESL equalized to achieve reasonably linear bass response to about 70Hz (one just can't get a dipole of this design to produce really *deep* bass). I used transmission line woofers rolled off at 70Hz to approximate the ESL response, alone with 18dB/octave crossovers with an effective crossover point at 400Hz. I matched levels with an SPL meter.

All listeners were clearly biased in that they expected the full range ESL to easily outperform the hybrid system, particularly with regard to mid-bass detail and clarity. At no time during the test were the ESL levels so high as to produce obvious distortion. The test results converted the listeners without question to thinking the hybrid system was clearer and more at ease than the full range system. Of particular interest was the fact that the critical mid-bass/low midrange was actually clearer with the hybrid system than with the ESL operated full range. The logical question is, "Why?"

It's difficult to be certain, but my best guess is the ESL diaphragms are being driven so far that the diaphragm is changing tension significantly and in a non-linear fashion, and also that the amplifier is being asked to deliver tremendous voltages which it cannot easily do. This is not to say the full range ESL was not good; it was very clear and detailed, considerably more so than conventional box speakers. The point is that if the woofer system is done right, you can have your cake and eat it too—you *can* have clear bass and high SPL's using a hybrid system.

BIG PICTURE

I must emphasize the term "system." I have spent nearly as much time working with woofer systems as I have with ESL's. They are equally important. Crossovers are also important. You can't take an iron core inductor, passive, high level, 12dB/octave, conventional crossover and make a clean hybrid system: you must use "electronic crossovers" at 12dB/octave or, better yet, 18dB/octave and bi-amp the system. You can't take a little, boomy, cheap "woofer in a box" and get a good hybrid system, either; it really takes transmission lines or horns to do the job.

Now, this doesn't mean that none of the above will work. I have had readers who listened only to chamber music or gentle popular music and were ecstatic over the sound of their full range systems, but they didn't need deep bass or high SPL's. Others are finding so much improvement over their conventional systems even when using poor woofer systems that they are quite satisfied to continue. But most readers are interested in the best possible reproduction, and they will get such reproduction if they are willing to listen to experience, do what has been proven to work, and not let their "techno-freak" ideas stand in their way.

My personal standards are severe: I want to be able to play my live concert recordings from uncompressed master tapes at "row A" levels, with no apparent distortion, in a system I can afford and would be able to put in my living room. I require SPL's in excess of 103dB at my listening location four meters from the speakers. Frequency response must be essentially linear from 20Hz to 20kHz. I find my system is adequate to these tasks; if you wish to make modifications, please do, but the suggested system is proven.

BOXED ESL'S?

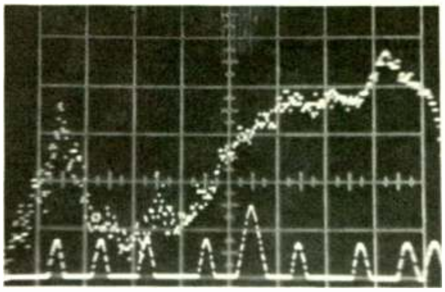
I tried one other way to get full range from an ESL: I enlcosed it in a box to isolate the front from the back and prevent low frequency cancellation. This did not work. The enclosure produced all kinds of colorations from resonance effects, but worse still, the bass was not there. After some head scratching and measurements I realized the problem was the ESL's fundamental resonance. Because the ESL was rather small (about 18" x 34"), the resonance was at about 300Hz. Without the mass of a conventional dynamic woofer, the system was simply reaching fundamental resonance and the output was falling rapidly below that.

It appears it is not possible to achieve bass in a reasonably sized ESL with the use of an enclosure. This does not mean this is not a useful technique, and readers who wish to pursue it are referred to Peter Walker's famous articles, "Wide Range Electrostatic Loudspeakers," in *Wireless World*, May, June, August, 1955. The first article deals with the concept of constant charge operation which solves our problem #4 involving charge migration. The second covers enclosures for ESL's, and in the third, on loudspeaker/room relationships, Walker makes a very strong case for using the dipole radiator.

Problem #5, non-linearity of the diaphragm motion is solved by what is commonly called the "push-pull" ESL. This requires placing a second stator on the other side of the diaphragm. Now when we place voltage on one stator we place an opposite charge on the other. As the diaphragm moves toward one stator and is attracted non-linearly, it moves away from the other whose force is decreasing non-linearly in a mirror image fashion, the forces on the diaphragm are then linear.

BIPOLAR BEHAVIOR

Large planar speakers are highly directional. This is a physical characteristic of large areas whose smallest dimension is as large or larger than the wavelength of the sound being reproduced



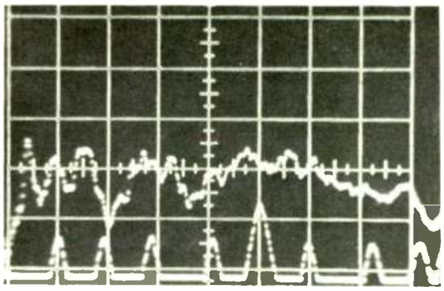


Fig. 2. Top photo, a storage oscilloscope trace of what ⅓-octave pink noise looks like fed into a real time analyzer measuring the unequalized response of Sanders' ESL panels indoors with a mike at five meters. The lower photo is the effect of an equalizer on the panels with a crossover at 120Hz. The large baseline marker in both photos is 1kHz, and the horizontal markers represent 5dB.

(a 20kHz wave is about one quarter of an inch long). Most audiophiles believe this directionality is undesirable and therefore a problem; this point is highly debatable. There are those who believe a highly directional loudspeaker is superior to wide dispersion types. [See: J. Newman, "Dipole Radiator Systems," *Journal* Audio Engineering Society, Jan/Feb 1980; Vol. 28, Nos. 1 & 2, pp. 35-39.]

Personally, I prefer the highly directional types: they minimize room resonance effects, image better, and are easier to build. Even with wide dispersion speakers one needs to be an equal distance from both, so one must listen to music seriously at only one location in the room anyway. Background music listening off-axis is no problem because the sound bounces around the room.

The image from a conventional box loudspeaker can be described as coming *from* the speaker, while the image from really superb conventional dynamic loudspeakers and from wide dispersion ESL's can be described as coming *through* the speaker: it has "transparency." However, the sound fron highly directional ESL's is different from all the others. It appears not to be associated with the speakers at all. The image seems to float in the room; it is three dimensional, and its exact location depends upon recording techniques used in producing the source material.

Some very unnatural effects are created this way. For example, a pop vocalist recorded with a great deal of artificial reverberation and a single microphone (a monophonic recording passed off as stereo) is "panned" to the center of the sound stage. The singer will appear to be singing slightly inside a very deep 30' diameter pipe; the image will be huge and very unrealistic. On the other hand, a singer recorded in a concert hall with a pair of microphones in proper stereo will appear to be of normal size and sound entirely natural.

IMAGE, SPEAKERS & MIKES

A common complaint is that planar speakers "cause" soloists to sound 10 feet wide. This is simply not true. Planar speakers accurately reproduce the poor recording techniques commonly used. Naturally recorded music sounds natural through them. If you insist on wide dispersion speakers, you can easily make them by angling several ESL strips to each other around the imaginary surface of a cylinder. This is not completely satisfactory in that the dispersion is not uniform: each narrow cell has its own narrow beam and moving about in front of the speaker causes a "venetian blind" effect. You can minimize this by using small angles between the strips; I recommend less than eight degrees.

Robert Unterbrink and I have developed a method of forming a smoothly curved ESL cell with perfectly uniform dispersion. Patents are pending on the design, and we expect commercial development. The design of this speaker will be presented at a time when I can devise good fabrication techniques for the home builder.

Reliability has been a problem with commercial ESL's. I am pleased to say my original speakers, built in 1974, are still running fine and I have never replaced a diaphragm since working out their "bugs." I attribute this to the availability of better materials such as polyester film. I did not put grille cloth on my speakers because tests indicated this ruined their high frequency response. Foam grille didn't hurt the frequency response but messed up the phase response. I have therefore had some problems with insects getting into the speakers and causing arcing, which eventually burns pinholes in the diaphragms. I have probably several hundred pinholes, but the speakers still sound fine, and I cannot detect this has harmed their performance in any way.

I have since found some grille cloth that doesn't mess up the sound, and would use it in the future. It is a plastic fiber cloth marketed by Mellotone. While it is quite expensive, the smooth fibers do not harm the high frequency response and the weave is fine enough to keep out bugs. There is absolutely no need to use dust covers. I even sand balsa wood in my listening room and it gets into everything, but the speakers do not seem to care. Occasionally I blow out dust with compressed air or gently vacuum them, but I do this only for appearance, not for performance reasons.

LINEARITY PROBLEMS

The typical commercial ESL does not have linear frequency response even though theory indicates the diaphragm should be very linear. The reasons for this are numerous. First of all, the high frequencies have a narrower dispersion than does the midrange, which effectively makes the speaker sound

Continued on page 24

AN ELECTROSTATIC SPEAKER SYSTEM: Part 1

Continued from page 23

"bright." The low frequency phase cancellation previously mentioned begins at a considerably higher frequency than you might expect. For example, the minimum dimension of a cell of my design is 24". Looking at *Fig. 1*, it would appear the wave length of a 500Hz tone would equal the speaker's minimum dimension and that the low frequency rolloff would begin there. Well, it obviously begins much higher than that: it becomes noticeable at 2kHz.

Fig. 2 demonstrates early tests with a spectrum analyzer: the frequency response (1 cm. from diaphragm center). *Fig. 4* is a composite of theory and objective measurements that I feel accurately reflects the true behavior of the ESL alone at far field (my listening location).

Fig. 5 reveals the techniques I used to flatten the frequency response. The ESL's bass is severely attenuated and is highly irregular because of phase cancellation and fundamental resonance. The best way to correct this is to simply avoid using the ESL in that region. This also makes high SPL's possible, as I discussed above.

The ESL response above 400Hz is still rising, and the system will still sound bright and thin unless something is done to correct this. With modern electronics it is possible to make a high quality equalizer that presents a mirror image depression to the high frequencies. I described this in my 1975 article, and I am sorry to say many readers felt this would degrade the high frequencies and so did not use it. The fact is the equalizer attenuates the high frequencies, but then the entire ESL section level is raised until the highs are back to normal balance. The net effect of this is that the midrange is elevated to its proper level and the sound is now properly rich and full.

EQUALIZATION: YES OR NO

"Techno-freaks" will be loth to put an equalized signal into the speakers because they believe it degrades the sound. However, there is simply no question that the system is far more natural with the equalizer, and once one hears the system with the equalizer, no listener has been willing to do without it. It adds no detectable sonic distortion.

I went to considerable effort to minimize the "modern" distortions such as TIM and SID. I discarded the

FIG. 3

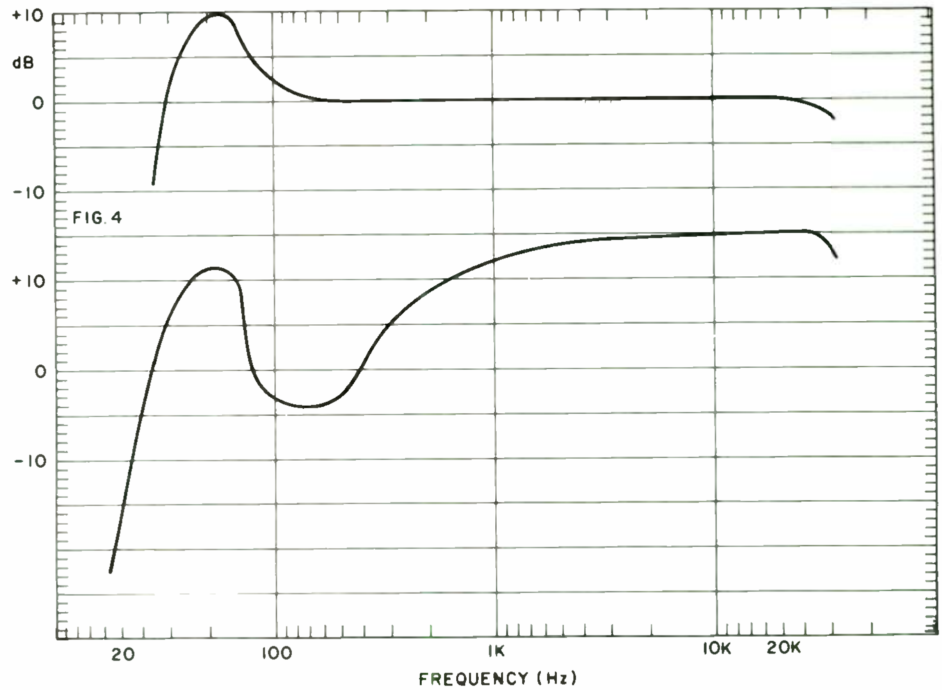


Fig. 3. Near field ESL response.

Fig. 4. Far field ESL response.

FIG. 5

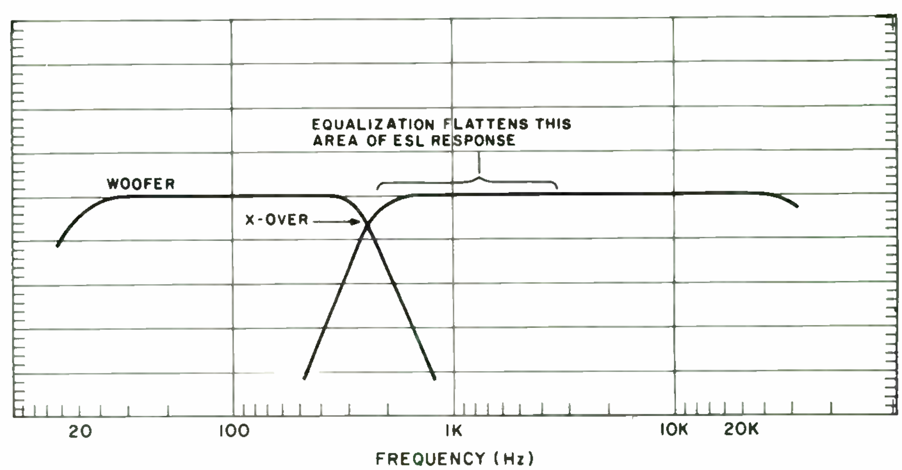


Fig. 5. Composite system response.

FIG. 6

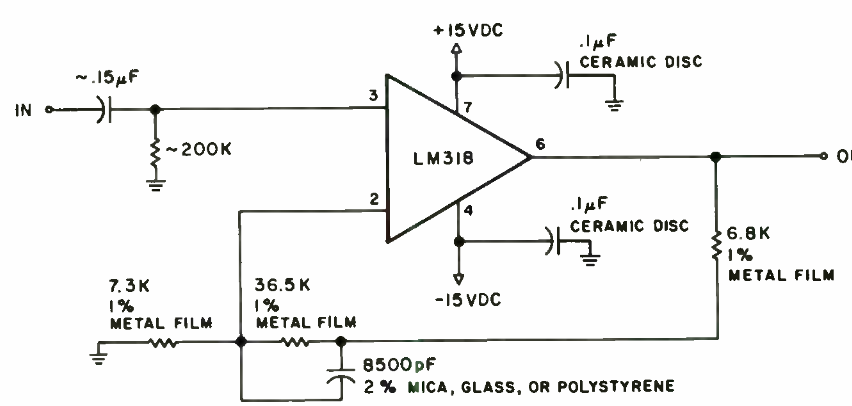


Fig. 6. Schematic for one channel of an equalizer with gain for the electrostatic panels.

earlier equalizer in favor of a much simpler one utilizing the very high performance LM318 IC, and placed the equalization in the ICs feedback loop in order to isolate it from the impedance loading effects of the associated equipment, which had been a problem in some installations with the earlier passive system. In addition, the equalization stage has 18dB of gain, making the system's sensitivity equal to a typical loudspeaker system.

Fig. 6 is the revised schematic of the eq/gain stage. For those of you who have preamp gain to spare and are able to measure electrical frequency response, I have included the schematic of a passive equalizer (*Fig. 7*) with an adjustable high frequency corner which will allow you to "tweak" it to the correct frequency response curve. The insertion loss of this is nearly 20dB, so you will probably have enough spare gain to use it unless you listen only at low levels. I personally don't use a preamp at all, just a passive attenuator for level control of high level circuits, so I had to have additional gain in my system offered by the gain section of the equalizer. *Fig. 8* shows the frequency response of the eq/gain section alone.

FIG. 7

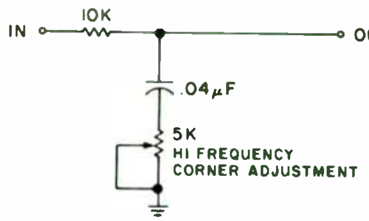


Fig. 7. A passive equalizer with 20dB insertion loss for use before the power amp driving the ESL panels.

CROSSOVERS

Electronic crossovers are a must. Beside the fact that they are audibly superior to passive high level crossovers, the ESLs capacitive characteristic makes it very difficult to get proper response from passive crossovers. You have several crossover choices. You can make passive 6dB/octave crossovers, but the slopes are really not steep enough even though in theory they are superior to any other type. I have used them and they work, and I have included a suitable schematic in *Fig. 9*. This, like the passive equalizer, has a large insertion loss so if you use it you had best have an extra 20dB of gain available. You will also have to "tweak" to the correct crossover points based on the im-

Continued on page 26

FIG. 8

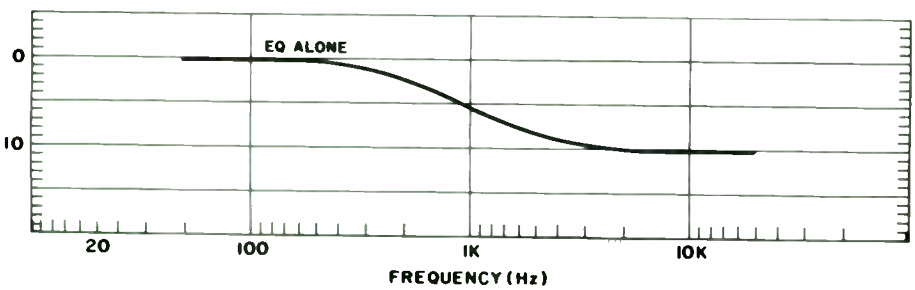


Fig. 8. Response curve of the effect of the active equalizer/gain circuit shown in Fig. 6.

AN ELECTROSTATIC SPEAKER SYSTEM: Part 1

Continued from page 25

pedances you are driving with it.

The Old Colony crossover kit is 12dB/octave and active, works very well and has no insertion loss. It is also very cheap, and being quite small you can build it and the eq/gain stage on the same small chassis and drive them by the same power supply. Several authors have tested crossover slopes and the general consensus of opinion is that odd order Butterworth filters are better than even order ones—in other words, each "order" in the filter is 6dB, and therefore a 6dB filter is 1st order, 12dB is 2nd order, 18dB is 3rd order, 24dB is 4th order, etc. In theory the Old Colony crossover should not be best because it is even order. However, I could detect no obvious problems with it with one exception: I could not determine the correct phase between woofer and ESL.

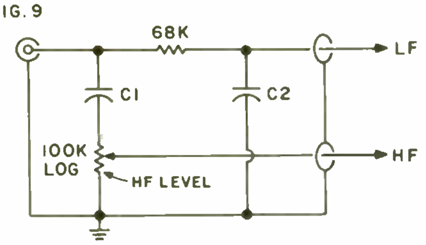
Clearly, there should be a difference, and with 18dB/octave filters there was one. The upper bass/lower midrange sounded properly full in one phase and thin and incoherent in the other phase. One phase was obviously correct. I therefore feel 18dB/octave crossovers are superior to 12dB/octave crossovers. However, the fact remains that unless you make a direct comparison the Old Colony units have no detectable problem. A complete article concerning these crossovers appears in *The Audio Amateur*, issue #2, 1972, p. 10.

I personally use crossovers by DeCoursey, who offer them in various forms and slopes. I simply bought completed boards and installed them in my eq/gain stage. They are about two inches square and cost about $40 per channel. I did not make my own because the precision components required are not readily available to the amateur constructor. (DeCoursey Engineering Laboratory, 11828 Jefferson Blvd., Culver City, CA 90230.)

PERFORMANCE

Fig. 10 is the total system electrical response with the eq/gain and 18dB/octave crossovers. Note that the correct crossover point is 460Hz. When this is combined with the equalization the actual crossover point is reduced to 400Hz which I have tested extensively and found to be optimum for this system. Please resist the urge to cross over lower: this causes a large depression in the frequency response in the 200 to 500Hz region, and the clarity and detail in the bass and lower midrange are definitely *not* improved.

FIG. 9



	C_1	C_2
500Hz	0.0039μF	0.0056μF
1kHz	0.0022μF	0.0022μF
2.5kHz	560pF	0.001μF

Fig. 9. A passive 6dB/octave crossover with adjustable high pass gain control. Values in the chart set crossover points at various frequencies.

Fig. 11 is a block diagram of the system as well as a schematic diagram of the correct connections for transformer coupling the ESL to a conventional amp. If you want high SPL's, use a modern "super amp"—not that the speakers require a lot of power, but rather that they need a lot of voltage and large amplifiers have higher voltage power supplies than low powered ones. The amplifier should run no warmer when driving the speakers at high levels than it does when it idles. If it gets hot, that indicates you are getting DC in the output, usually because the amp is one of the DC coupled types and is getting a little bit of DC at the input from one of the crossover IC's.

Most IC's have a small DC offset, usually around .05 volts. When this is amplified, you may have a volt or so of offset in your power amp. Into essentially a dead short such as the primary of a low impedance transformer, lots of current will flow and the amp will overheat. The solution is simple: install a small capacitor between the crossover and the amplifier. For the ESL amp, .01μF is adequate. The capacitor should be a non-polarized type such as polycarbonate, polyester, mica, or glass; do not use electrolytics for coupling. If the problem also exists in the woofer amp (usually noted because the woofer moves away from its center and stays there when the amp is turned on), then use a .5μF capacitor.

TRANSFORMER MATCH

Finding suitable matching transformers is difficult. The problems are two: first, finding high enough turns ratio transformers is not easy, and second, high frequency response is usually poor. The problem with the frequency response seems to be leakage inductance in the transformer resonating with the capacitance of the ESL. This puts a 3 or 4dB peak in the response with a rapid rolloff above that. I have tested many transformers and find few of them will perform above 8kHz with ESL loads. This problem worsens with larger speakers, as the turns ratio increases, and as the transformer's power rating increases.

What you need is a transformer with both a turns ratio and frequency response as high as possible. In two years of searching I finally found transformers with 44:1 turns ratio with a frequency response of 20-50kHz. They will drive an ESL with a capacity of 2400pF essentially linearly to 20kHz. You can buy them through me—see the end of this article.

You may be able to use audio output transformers from a good tube amplifier. Ideally they should have a very high primary impedance—8kΩ if possible. Install them backwards: connect the transformer's 4Ω taps to your

FIG. 10

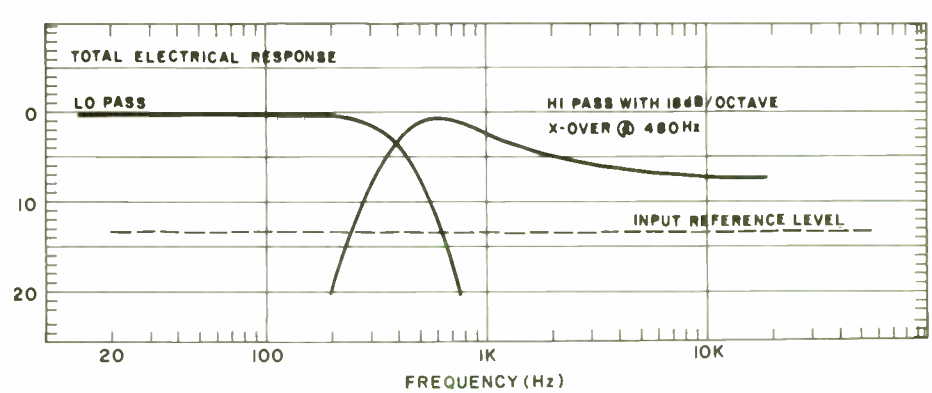


Fig. 10. Total system electrical response with the author's equalizer/gain control in place and using 18dB/octave crossovers.

amplifier and the 8kΩ taps to your stators. Test the frequency response by connecting a high impedance voltmeter (at least 10MΩ) to the 8kΩ leads and drive your amplifier with an audio generator so it puts out between 1 and 10 volts. Be careful not to get the voltage too high or you can arc your meter's guts. Run a frequency response sweep. You may see some irregularities in the area from 10kHz to 20kHz, but so long as this does not result in severe rolloff of the highs. You can consider it superb performance.

The transformer's power rating should be about 15 watts. This will take all the amplifier power you want to feed it and is small enough to have good frequency response with minimum leakage inductance. Larger transformers may work, and lower turns ratios will work, but achieving good frequency response and high SPL's becomes progressively more difficult. If you are using tubed amplifiers, try connecting the 16Ω amplifier taps to the 4Ω transformer taps; this will give you the highest voltages but sacrifice good power transfer. Since the speakers do not use power, this is no problem.

CAPACITIVE AMP LOADS

Some amplifiers may be unstable with capacitive loads. I have found problems only with a Leach low TIM amp; Crown, Williamson, Perkins, Dyna, Phase Linear, and Quad amps have all worked without difficulty. If you should have a stability problem or your amp blows fuses, try adding some series resistance: 1-10Ω seems to work OK. You may also want to try using the transformer's 8Ω or 16Ω taps; however, this will decrease your SPL's to some extent.

When deciding what amplifier to use, please ignore all the "techno-freak" ideas you may harbor about amplifiers. Several readers and I have discovered most amplifiers sound identical on the ESL's even though the same amplifiers may sound markedly different on conventional dynamic speakers. The "tube vs. transistor" controversy also becomes meaningless: transistor amplifiers do not sound "harsh" or "edgy" with these speakers. This puzzles me because generally ESL's seem to place more stringent demands on an amplifier and commercial ESL's are very amplifier sensitive.

My only explanation is that these speakers present "pure" loads to the amplifiers rather than the complex

Continued on page 28

AN ELECTROSTATIC SPEAKER SYSTEM: Part 1

Continued from page 27

loads presented by the commercial units with their passive crossovers and woofer systems, often of the dynamic type. The combination of capacity, inductance, and resistance of such a load under dynamic conditions must be just awesomely complex in comparison to a simple 2400pF capacitor. The ESL also essentially requires no current, so the amplifier is working only with voltage rather than with large amounts of both. This is quite different from a conventional speaker, and is also the reason a 200 watt amplifier doesn't overload a 15 watt matching transformer even when the amplifier is clipping.

FIG. 11

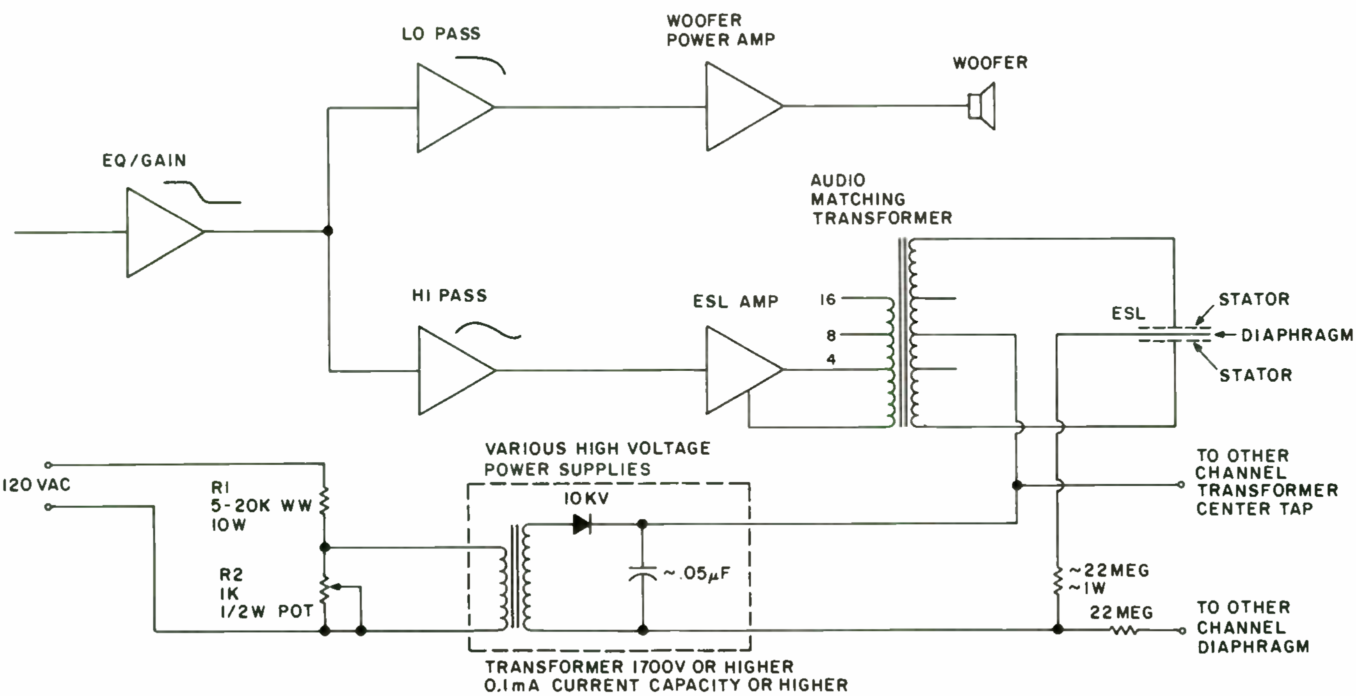


Fig. 11. Block diagram of system interconnections as well as a hookup guide for both an output transformer and a high voltage power supply. Note that each panel requires a 22mΩ resistor in series with the supply. R_1 may also be a 10 to 20W unit. R_2 should probably be a wirewound unit as well.

POWER SUPPLY

Fig. 11 includes the schematic of a typical high voltage power supply. There are several ways to approach this device. Probably the easiest is to buy a surplus electrostatic copier power supply for around $10. These are usually rated around 5-10kV and you need only 2kV, so to reduce the voltage you will have to pad the input. Generally this is done with a voltage divider at the input. If R_1 is a 10 or 20 watt unit designed to do the major part of the voltage reduction, you can place a ½ watt pot across the input to allow a small amount of trimming; if it burns up, you need more resistance in R_1.

If you can get your hands on a small high voltage transformer you can place a 10kV diode in series with it to get DC. It doesn't matter what polarity you feed the diaphragm if you are using transformers. The speakers will usually take about 3kV, but they are marginally stable at that voltage and will sometimes arc, or the diaphragms will "cave in." If this happens simply turn off the power supply, go over to the speaker, and blow the diaphragm away from the stator it is stuck to. This may or may not pop a pinhole in the diaphragm; at any rate it doesn't destroy the speaker.

To be on the safe side, don't run the voltage at the "ragged edge." I find no detectable difference in SPL between 2 and 3kV even though in theory there should be. You may find you can use a flyback transformer from a television set for the supply. A small capacitor is usual at the power supply output, but I think it's unnecessary since the speaker is a capacitor. Do not omit the 22MΩ resistor in the line to each diaphragm, as this helps prevent charge migration. You need only one power supply for several speakers.

High voltage test prod wire makes the best connections from the power supply and transformers to the speakers. Do not tape or otherwise hold the wires close to each other, as this increases stray capacitance; just lay them loosely on the floor. I have used common 18 gauge "zip cord" for connections and have had no arcing problems, but I don't recommend it since it is only rated for 600 volts. I like using banana plugs for connectors. Keep plenty of space between them as the voltages are high enough to cause arcing over at least a quarter of an inch. Getting shocked by the system is not lethal, but I can assure you you'll know when it happens!

DIRECT COUPLED AMPS

You may wish to build a direct coupled high voltage amplifier to drive the speakers. If so, build the high voltage diaphragm supply into the amplifier. I used to use such an amplifier but have since returned to transformers; chiefly because I finally found good ones. The DC amp is a class A device which generates a lot of heat and wastes electricity. You can achieve high SPL's with the right transformers and a conventional amplifier.

Stability is a problem with a DC amp, whose only advantage is that objectively it is considerably better than a transformer. However, the transformers I now use sound every bit as detailed as my DC amp; in fact other users have told me the inner detail seems better with transformers than with an amp! I feel this is due to subtle differences in frequency response rather than to any inherent transformer superiority, but a transformer coupled system can be just as good as a DC amp system.

THE COMPLETE SYSTEM

My recommended and proven system consists of:

1. A pair of ESL's 2'x6' in radiating area.
2. A pair of transmission line woofers.
3. A pair of stereo power amplifiers, one for the woofers and one for the ESL's.
4. A pair of equalization/gain stages.
5. A pair of electronic crossovers.
6. A pair of matching transformers.
7. A high voltage power supply.

I constructed the electrostatic cells as large cells rather than small ones because I didn't want to have to build a bunch of little cells and wire them together. Two 2'x3' cells are used for each channel, stacked and mounted into a narrow wooden frame with both sides completely open. The system in the photographs has wire stators, but for general construction I recommend perforated aluminum. I'll discuss both construction methods later in this series.

FOR THE LOWS

The woofers are KEF B-139 drivers mounted in 10' transmission lines. I have tried many other types of woofer systems, including bass reflex, acoustic suspension, infinite baffle, semi-infinite baffle, and horn. In my opinion only the transmission line and the horn systems were able to produce adequate bass; only they could make the sound coherent so you could not detect the woofer's presence in the system. The entire sound appeared to have the quality of the electrostatic when the woofer system was operating correctly.

An often overlooked point is that the woofer must be in the same plane as the electrostatic. Because the crossover point is above 100Hz, one needs two

Continued on page 36

Bookwork

SPEAKER BOOKS

by Ron Miller

A number of publishers list books which discuss the construction and/or design of loudspeakers for home music reproduction. The following four represent different publishers and different approaches.

G. A. Briggs, a grand old man of British high fidelity and stereo and the founder of Wharfedale Speakers, wrote an interesting *Cabinet Handbook* (Old Colony Books, $3.25) which surveys speaker manufacturing techniques and gives handy hints for home constructors. Briggs, one of the pioneers in the manufacture and marketing of high fidelity speakers, here shared some of his experiences. The book is facinating to read, but was published in 1962 and is beginning to show its age. Briggs' discussions of woodworking and construction techniques still merit attention, however.

In *How to Build Speaker Enclosures* (Sams, 20520, $4.50) Alexis Badmaieff and Don Davis have written an American book technically comparable to Briggs' but without his inimitable style and personality. A liberal supply of photographs, line drawings, graphs, and construction diagrams show the reader how to construct copies of top-of-the-line commercial speakers popular around 1966. If you want to build your own Jensen Imperial Horn or Bozak B310A, for example, you will find everything but where to buy the drivers. The authors give enough additional theory to understand the reasons behind such designs and barely enough construction directions to suggest the reader might want to build his own.

Abraham Cohen, in *Hi Fi Loudspeakers and Enclosures* (2nd edition, Hayden, 07213, $6.85), devotes the bulk of his attention to speaker theory. How and why speaker drivers function, how enclosures work, how the room interacts with one or two speaker systems are some of the major topics he thoroughly discusses. He looks briefly at measurements and construction practices, but the bulk of his attention is given to theoretical material. A good understanding of why things work the way they do is a great help if one is building anything more complicated than a total kit.

Finally, readers who also read the slick, hobbyist magazines will probably remember David Weems as the author of numerous speaker projects. In *How to Design, Build, and Test Complete Speaker Systems* (Tab, 1064, $6.95), he has given us a very useful "cookbook." Rather than start with commercially available systems, Weems tells us how to roll our own.

The chapter on testing speakers and drivers is alone worth the price of the entire book. Weems gives at least one method (frequently two) of measuring things like free air resonance, impedance, the tuned frequency of a ported enclosure, or speaker damping, among a total of 21 tests. Beyond that, he helps the reader design enclosures for individually selected and tested drivers, and discusses the basic types of enclosures in terms of their advantages, disadvantages, and critical design parameters.

Weems' last comment on transmission lines suggest both some scepticism about the design and a sense of humor. "If you run into trouble, use the line as a dog house and design either a closed box or reflex enclosure for your woofer." His book is very useful for its theory and its application hints. Weems also includes as an extremely valuable bonus the details of complete systems which served as his design examples. □

LOUDSPEAKER DESIGN COOKBOOK

by Robert M. Bullock

Loudspeaker Design Cookbook (written and published by Speaker Research Associates, $6.95, 58 pp.) is unique. Most books on loudspeaker design either contain detailed plans for the construction of a particular system or give general qualitative design instruction. *Loudspeaker Design Cookbook* (*LDC* henceforth) present explicit quantative design procedures which yield systems with optimal frequency response.

These quantitative design procedures are based on technical articles by researchers in loudspeaker theory. *LDC* has codified material from many sources into practical techniques for designing direct radiator loudspeaker systems. The book centers specifically on the design of systems which optimize low frequency response. The same procedures can be used to design the midrange part of a three-way system; however, since high frequency response is determined mostly by the tweeter used, the book discusses only frequency equalization in this range.

LDC contains much of the information on low frequency design that took me months to collect and digest on my own. This collected information is what makes *LDC* unique, and therefore essential for those seriously interested in designing their own systems.

The book's style is terse, straightforward, and non-technical. However, the reader is expected to have some minimal mathematical skills, in particular, the ability to read graphs and use formulas containing decimal exponents. The latter involves using either a calculator with an exponential button or a logarithm table. Armed with these skills, anyone should be able to use *LDC* to design quality systems.

Chapter headings are: I. Acoustic Suspension Loudspeakers; II. Bass Reflex Loudspeakers; III. Passive Radiator Loudspeakers; IV. Transmission Line Loudspeakers; V. Unbaffled Loudspeakers; VI. High Level Crossover Networks; VII. Low Level Crossover Networks; VIII. Test Procedures; IX. Cosmetic Technique. The material in chapters VI, VII, and IX can be found in other readily available sources, but the material in the remaining chapters cannot. My review will therefore concentrate on chapters I through V and VIII.

The first three chapters deal with systems for which sophisticated mathematical models based on acoustics and electrical circuit theory have been developed. The design procedures are based on a series of articles by Richard Small (1), (2), (3), (4) in which he analyzed these models in detail. An editor of the *Audio Engineering Society's Journal*, in which Small's papers appeared felt the series would "have a long term impact on direct-radiator loudspeaker theory."

Chapter I, on acoustic suspension systems, gives clear, unambiguous design procedures faithful to Small's work in every detail. Anyone should be able to use them to design an acoustic suspension system tailored to his taste, provided he starts with the appropriate driver (raw loudspeaker). In this regard, I believe the book could be more explicit concerning the limits imposed on possible system response curves by the driver Q parameter. In particular, "flat responses" are not possible with high Q drivers (Q greater than .35).

The design data in this chapter are presented by means of one graph and one formula. If all data had been presented graphically, I think the reader might have found it easier to understand. The formula given is a relatively complicated one used to calculate the system's cutoff frequency (−3dB frequency). The system resonance frequency can be used as a conservative estimate of cutoff frequency if the system Q is greater than .7.

In addition to the actual design procedures, this chapter contains other useful information. Regardless of what type of system interests you, I recommend the section on power handling capacity vs. cutoff frequency vs. enclosure size. It makes good sense. However, in my opinion, the section on box dimensions should be considered as a guideline only. I have seen recommendations different from those given. It is probably a good idea to avoid a box with two or three equal dimensions.

The bass reflex or vented box system is covered in Chapter II, which presents the design data very succinctly in three formulas and a table. The procedure as described is clear and easy to follow. The only possible hitch is that one must evaluate formulas containing decimal ex-

Continued on page 32

The people who publish **The Audio Amateur** welcome your subscription to our NEW publication. . .

SPEAKER BUILDER

IF ONE HALF THE CASH you spend on your audio system should be invested in your speaker, why not build it yourself? Nearly 100,000 Americans will do so this year—why not you too? Your dream speaker just may be possible *only* by doing it yourself. There's a lot of help around already and now this new quarterly publication from the publishers of *The Audio Amateur* promises an assortment of articles that are comprehensive and a mix of both simple and advanced projects about all types of speakers.

- ★ **Bass Reflex**
- ★ **Horns**
- ★ **Electrostatics**
- ★ **Transmission Lines**
- ★ **Infinite Baffle**
- ★ **Specials: Ribbon, Air motion transformers and many others.**
- ★ **All the basic data on passive and electronic crossovers.**

There will be kit reports on building the many speakers and enclosures now available in kit form and a roundup of suppliers of drivers, parts, and kits.

We have articles in hand that range from the ultimate (650 Lbs each) to very simple extension speakers. From time delayed multi-satellites to horn loaded subwoofers. There will be modifications of many stock designs as well as resurrections of great classic designs out of the past.

We'll be doing basic articles on the design theory behind each of the great classical speaker formats. And you'll find lots of reference data on design formulas, crossover coil winding guides and much more. **Speaker Builders** will have a lot to say to each other in the column on tips, photos of systems, in the letters exchange as well as swaps of gear and data in the columns of free classified ads.

Standard format 8½ x 11″ on good book paper, with clear diagrams and photos and all the data you need to build each project successfully and without undue hassle, **Speaker Builder** will be reader-centered and reader supported and NOT a thinly disguised marketing medium catering to advertisers. Ad ratios will never exceed 40% (*the national average is over 60%*). Guarantee: if you are not satisfied with **Speaker Builder** the publisher will refund the unused portion of your subscription.

The price is $10 per year, for the four quarterly issues, or just $18 for two years. Use your charge card to execute your order (signature with order blank below, please) or call our charge card order desk for Speaker Builder at (603) 924-6526 from 8am to 4pm on weekdays and leave your order. Tell your friends about Speaker Builder or include their names with your order and we will send them full information about the publication and how to subscribe.

ORDER BLANK SB-2/80

SPEAKER BUILDER Magazine

P.O. Box 494, Peterborough NH 03458 USA

☐ Enter my charter subscription to **SPEAKER BUILDER** for one year at **$10.00.**

☐ Make that a two year charter subscription at **$18.00.**

☐ Check enclosed ☐ Charge to my ☐ MasterCharge Visa ☐ charge card.

☐☐☐☐ ☐☐☐ ☐☐☐☐☐☐☐☐ ☐ Expire____/____

Name ____

Street & No. ____

Town ________________________ State__________ ZIP__________

I understand that the unexpired portion of my subscription will be refunded after my first issue if the magazine is unsatisfactory for any reason. Make checks and money orders payable to Speaker Builder. Rates above are for USA only. Outside USA add $1.50 per year for postage. Non U.S. checks must be drawn in U.S. currency only.

Bookwork

Continued from page 30

ponents, which requires a calculator with an exponential button or a log table. According to *LDC*, the design formulas are approximations of a design graph found in Small's third paper.

Small's vented system model includes a correction factor to account for box losses, i.e., vent losses, cabinet leaks, leakage around and through drivers, etc. This loss factor is described by a number denoted Q_L. Typical systems, according to Small, have Q_L between five and ten; the number cannot be determined beforehand but must be measured on the completed system. The design can then be modified by changing the vent geometry and box size. (This is a good reason for initially oversizing the box.)

The initial design must therefore assume a particular Q_L value. *LDC* states that its formulas are approximations to Small's charts for $Q_L=7$ with the box size parameter increased by 20 percent. According to my calculations, the formulas also appear to give a box tuning frequency about 5 percent lower than Small recommends. The book asserts that these approximations "do a better job of depicting the 'real world' situation regarding box loss."

I assume this comment is based on the performance of actual systems designed according to *LDC's* specifications, but the reader should be aware that these approximations will give design data different from those Small recommends on the basis of his analysis of the model. If one uses the model to predict the response curve using both data sets, *LDC's* formulas will yield a curve with a lower rolloff at very low frequencies but a slightly decreased output in the mid-low frequency range when compared to Small's charts. However, the difference between the two response curves is usually within one decibel, which I doubt would be perceptible.

According to Small, the response curve is very sensitive to changes in the system resonance frequency. For this reason, a formula for computing vent tube length would have been useful for initially determining more precise lengths. Then less adjustment would be required at the tuning stage.

Designers of vent-box systems should pay very careful attention to *LDC's* discussion of the need for subsonic (frequencies ≤ 20Hz) filtering. Even under nearly ideal conditions, subsonic noise may cause the cone to flap and add significantly to distortion, as has happened with vented systems I have constructed. *LDC* presents a universal passive filter circuit to cure this problem; my cure was to design a sixth order system as described by Thiele.[5] However, I know of no "cookbook" formulas for the design of such a system, which is probably why *LDC* does not discuss it.

This chapter also includes a section titled "Resistive and Distributed Ports" which gives methods for decreasing the system Q. This information should be especially useful if one wants to design a small enclosure using a high Q driver.

Chapter III follows Small and contains all necessary information on design procedures for a passive radiator system. The problem with this type of system is finding a suitable passive radiator. Even after that, tuning is probably difficult. For this reason, I prefer acoustic suspension or vented systems.

Chaper IV gives design details for a transmission line system. This type of system differs from earlier ones in that there is no model to use as a starting point for an analytical design procedure, so these systems are usually designed on a trial and error basis. *LDC* gives the essential features of transmission line design, but I think such a system is best constructed by referring to articles on specific systems which contain actual driver recommendations and system dimensions. *Audio Amateur* magazine has published several such articles.

Chapter V contains some interesting information on unbaffled speakers; however, they are generally of limited use.

The key to the accurate design of an acoustic suspension, bass reflex, or passive radiator system using *LDC's* procedures is determining the resonance frequency, Q, and compliance of the driver(s) to be used. *LDC's* publishers offer a service which includes the determination of these quantities; or Chapter VIII gives the test procedures required. The driver quantity measured in these procedures is its impedance at various frequencies. Only one method is needed to make all required measurements, but *LDC* uses the constant voltage method for others, which makes the procedures needlessly complex. In spite of this, all the information necessary to calculate the required quantities can be found in this chapter.

The book ends with an impressive list of references for further reading.

In conclusion, the book is generally well written, seems to be free of errors, and contains some excellent recipes. As I said above, it is a necessity for those seriously interested in designing their own systems.

□

REFERENCES

1. R. H. Small, "Direct-Radiator Loudspeaker System Analysis," *J. Audio Eng. Soc.*, Vol. 20 (1972).
2. R. H. Small, "Closed-Box Loudspeaker Systems, Part I: Analysis," *J. Audio Eng. Soc.*, Vol. 20 (1972).
3. R. H. Small, "Vented-Box Loudspeaker Systems, Part I: Small-Signal Analysis," *J. Audio Eng. Soc.*, Vol. 21 (1973).
4. R. H. Small, "Passive-Radiator Loudspeaker Systems, Part I: Analysis," *J. Audio Eng. Soc.*, Vol. 22 (1974).
5. A. N. Thiele, "Loudspeakers in Vented Boxes," *J. Audio Eng. Soc.*, Vol. 19 (1971).

□

Above, back view of the enclosure showing the two midrange units and terminal board. Below, the laminated top of the cabinet.

Crossover and Construction details for the PCL—101A. All capacitors are non-polarized mylar, inductors are air core, using 16 gauge wire. Use 1x2" fir strips for grille frame on edge and vee blocks to reinforce corners. Glue seams of the woofer enclosure of ⅝" particle board covered with veneer or walnut patterned formica. Back and midrange compartment painted flat black; front and sides of mid compartment covered with black, acoustically transparent cloth.

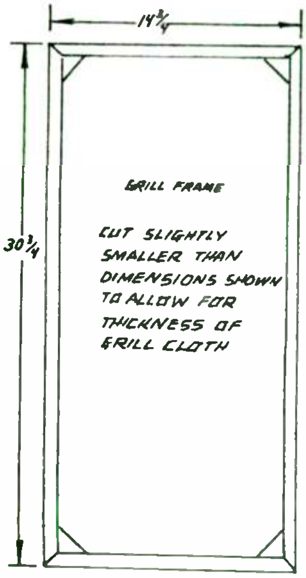
The port tube is a very long 10" because it is tuned to 14Hz to help eliminate turntable warp and rumble. It also adds about 1—2dB in the 20—60Hz range. The port, at builder's option can be shortened to boost the audible bass range (i.e. 2¾" for 40Hz) or eliminated for an acoustic suspension approach.

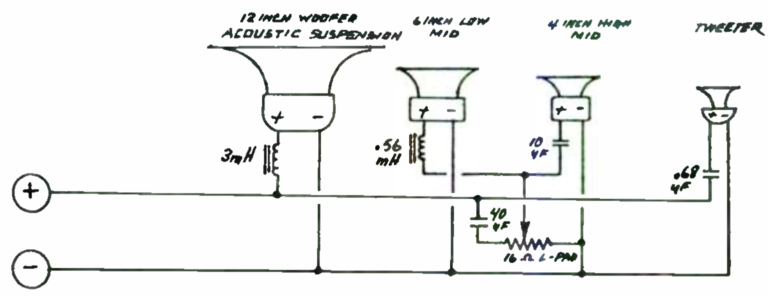
Drivers 12" Eminence, 6" Quam full range, 4" Westwell full range and Motorola Piezo-electric tweeter.

The top is made from 1x2" strips of oak and poplar glued and clamped together to make thick, contrasting grain look. Sand well, round edges, stain and finish with tung oil.

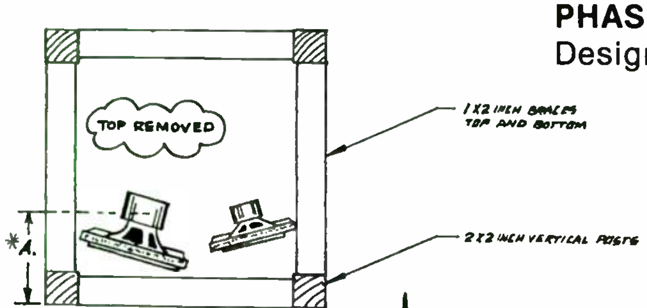
Tom Hayward
Norcross GA 30071

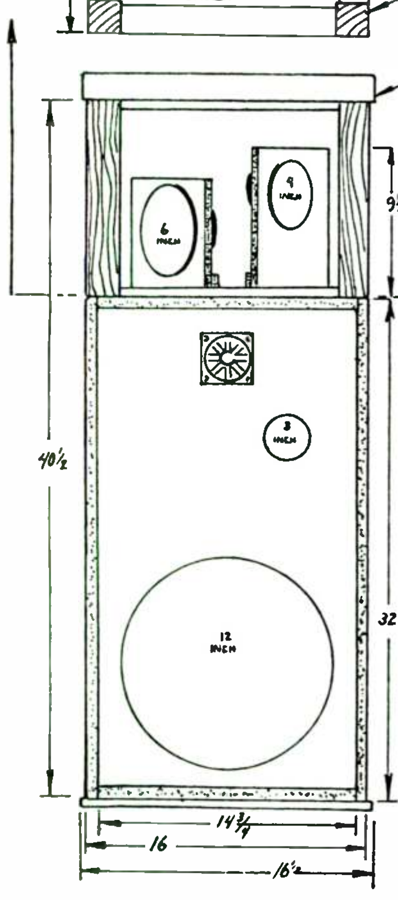
Craftsman's Corner

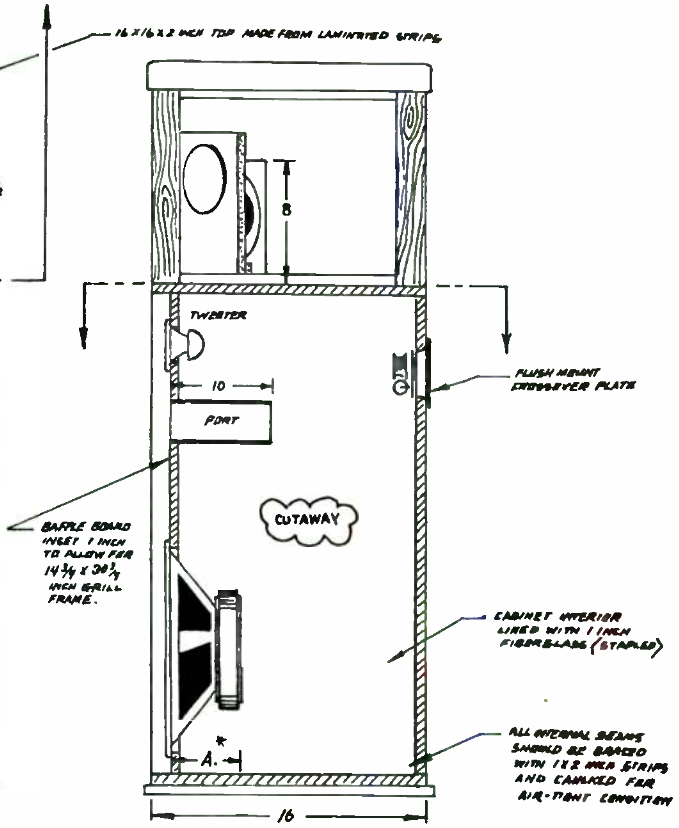




PHASE CONCEPT LTD. PCL—101A.
Designed by Tom Hayward







*Dimension (A) depends on measurement of front of woofer to center of its voice coil. Inset midrange same distance for phase alignment.

SB Mailbox

STAMLER QUERIED

MY APPRECIATION to you for *Speaker Builder* magazine should be expressed; and I'm happy to do just that now. I have been devouring the contents of its first issue, and enjoying every minute of it.

However, I am also writing in regards to Paul J. Stamler's article, which has proven to be of most interest to me. I have found it most frustrating to use his calculations and to come up with substantially different results than his.

I have no quarrels with equations 4 and 5; indeed I obtained the same final figures as he. But equations 1, 2 and 3 just do not compute using the figures he provides both in the article and in table 3. I have enclosed my calculations which show a small deviation for equation 1, and absurd deviations for equations 2 and 3.

It may well be that Mr. Stamler's design is based upon W.J.J. Hoge's calculations (which I do not have access to, and which are not provided within the text of Mr. Stamler's article). However, if this is the case, clearly, the system that Mr. Stamler designed is not even close to being optimized to his own figures. (those in table 3).

I would hope that you might provide some clarification of this disparity in a future issue.

In any case, continued thanks and best wishes to and for what should be a fine and much needed magazine.

GILBERT OWEN PAGE
Ansonia CT 06401

Mr. Stamler replies:

MR. PAGE IS correct in every respect. The small differences in the results of equation 1 are due to differences in data, a subject I shall return to in a moment. The differences in the results of equations 2 and 3 are of considerably greater importance.

The explanation is that the equations as printed in the magazine are pure hash; somewhere in the works a couple of exponents got translated into multiplying factors instead, and although these errors were corrected on the galleys, in the rush of deadline pressure they remained in their incorrect form. The correct equations are:

(Eq. 2) Ripple (dB) =

$$20 \log \left[2.6\, Q_{TS} \left(\frac{V_{AS}}{V_B} \right)^{0.35} \right]$$

$$\text{(Eq. 3)}\ f_B = f_s \left(\frac{V_{AS}}{V_B} \right)^{0.32}$$

Note that in both of these equations the quantity:

$$\frac{V_{AS}}{V_B}$$

(also known as α) is raised to a power (0.35 or 0.32), not multiplied by 0.35 or 0.32, as given in the magazine.

I am very grateful to Mr. Page for catching these goofs, as otherwise someone might have attempted to apply the equations, obtained some hair-raisingly bad speakers, and come after me muttering imprecations. In all seriousness, the moral is clear: before starting a project based on an article like mine, run through the author's own calculations using his or her data, and if you get hash, *write a letter*.

Now for those differences in data. Mr. Page is right; the original design used numbers supplied by Mr. Hoge in his article in *Audio*; specifically, his numbers for the KEF B110 are: f^s = 31, Q^{TS} = .39, and V^{AS} = 27. While the article was in the galley form I received new data from KEF that were substantially different, and pending clarification I decided to incorporate the new data into my Tables 3 and 4.

I have since talked with Mr. Hoge, and he explained that the data in his article were the results of tests by Pro. Ashley of the University of Colorado, a highly respected figure in the world of speaker design. he also said that the only major discrepancies between Prof. Ashley's figures and the manufacturers' figures were for the KEF drivers, and that they had corresponded about it without resolving the differences. Which leaves us a bit up in the air. The performance of my speakers in the lower bass region tends to bear out KEF's figures to little better than Prof. Ashley's, but it seems to me that another set of tests is in order. I plan to undertake a limited series of tests, and will report results as they emerge. Stay tuned.

Mr. Hoge, incidentally, expressed confidence in the manufacturers' data from JBL, CTS and Electro-Voice. For the most part, the data in my tables for these manufacturers came directly from their literature; the Altec, Philips and Polydax data came from tests performed for SRC Audio in Texas.

PAUL J. STAMLER
St. Louis MO 63130

STAMLER TIPS

CONGRATULATIONS on your first issue of *Speaker Builder.*

There are a couple of small problems in Paul J. Stamler's article, "How to Improve that Small Cheap Speaker" (*SB* 1/80, p. 18), that I feel need to be corrected. In Fig. 1 Stamler shows the schematic for KEF's DN-13 crossover network. However, he failed to point out that the 2mH inductor must have a DC resistance of 10 ohms. This

BOXED BOOKS BASS

I HAVE READ Mr. Stamler's article in SB's first issue (p. 18) and it's nice to know that others are as enthusiastic as I am about the Thiele-Small alignment procedure.

In his article, Mr. Stamler expressed concern about the efficiency of his system because of the low cutoff frequency. His numbers were V_B = 36 liters, f_B = 28.4Hz, f_3 = 27Hz. I suggest he decrease the box volume to 27 liters. This is easily accomplished by storing some old books in the box. About four 7" x 9½" books each 2" thick should do the job. Assuming he used f_s = 31Hz, Q_{TS} = .39 and V_{AS} = 27 liters, the box should then be tuned to f_B = 31Hz giving an f_3 = 31Hz. With this alignment there will be a 14% improvement in efficiency.

$$\left[\frac{\nu_{new}}{\nu_{old}} = \frac{K_N(31)^3(27)}{K_N(27)^3(36)} = 1.14 \rightarrow 14\%\ \text{increase} \right]$$

As an additional benefit, the ripple will now be +.12.

$$\left[\text{Ripple(dB)} = 20 \log \left[2.6\,(.39) \left(\frac{27}{27} \right)^{.35} \right] = 20 \log [2.6(.39)] = +.12 \right]$$

If he wishes to have a flat response, i.e. 0dB ripple, he can choose V_B = 28.1 liters giving an f_3 = 30.4Hz with f_B = 30.6.

I would also like to comment on the L-pad formulas. First, there is a subscript typo in the definition of R_P. It should be $R_P = R_2 \| 8$. Second, this circuit is nice to use for other impedances. If the tweeter impedance is R_T then:

$$R_1 = (1\text{-}A)R_T \quad \text{and} \quad R_2 = \frac{A}{1\text{-}A} R_T.$$

$$\left[\text{From } A = \frac{R_P}{R_1 + R_P},\ R_1 + R_P = R_T,\ A = \frac{R_T - R_1}{R_T} \rightarrow \frac{R_1}{R_T} = 1\text{-}A. \right.$$

$$\text{From } A = \frac{R_P}{R_1 + R_P} \text{ and } R_1 = (1\text{-}A)R_T \text{ it follows that } R_P = AR_T.$$

$$\text{Hence, } \frac{1}{R_2} = \frac{1}{R_P} - \frac{1}{R_T} = \frac{1}{AR_T} - \frac{1}{R_T} = \frac{1}{R_T}\left(\frac{1\text{-}A}{A}\right);\ \text{thus } R_2 = \frac{A}{1\text{-}A} R_T \Big]$$

ROBERT M. BULLOCK
Oxford OH 45056

is not mentioned in any of KEF's published literature, but they do use a high-impedance inductor in their pre-assembled crossovers. If someone attempts to build this crossover from scratch, serious frequency response deviations will result if the proper resistance is not used. I cannot stress this strongly enough. If a lower-resistance inductor is used, then the builder must add enough resistance in series with the inductor to equal 10 ohms.

In Fig. 3 Stamler fails to mention that the 0.3mH inductor must have several times a DC resistance between 0.55 and 0.6 ohms. This is mentioned in the KEF literature on the acoustic Butterworth filter. Fortunately most commercially available 0.3mH inductors will fall within this range, but builders should measure their inductors to be sure. Again, if the measured resistance of the inductor is less than 0.55 ohms, appropriate series resistance must be added for the filter to work properly.

I hope these suggestions are printed before too many readers build crossovers from the published plans and end up with bad-sounding speakers. I wish you the best of luck with your new publication.

David Barnett
Little Rock AR 72207

OF SHROUDS & SAVINGS

I have just finished enjoying the first issue of *Speaker Builder*. A magazine of this sort has been sorely needed for many years. It is about time that speaker building came out of the dark ages. Its shroud of mystery, that some manufacturers would be all too happy to continue, should be removed. Several years ago I decided to build my own speakers, long after I had built my own electronics. It was surprising to find out how many $200 list price speakers have $30.00 worth of components in them. After several speaker projects and experimentation, I am thoroughly convinced that building your own is always rewarding, less costly and can provide a tailored level of performance not available or affordable through purchase of ready made units.

I am a graduate mechanical engineer and have worked in a manufacturing engineering capacity for 12 years.

Robert Galler
Altoona, PA 16601

AMBIENCE APPLAUSE

As a member of the design team which developed the Audio/Pulse, ADS, and DeltaLab digital time-delay systems and as the author of their instruction manuals, I applaud Clark & Muller's article on ambience speakers (*Speaker Builder* #1). It correctly focused on two essential aspects of ambience reproduction which are all too frequently ignored—(1) the desirability of pointing the ambience speakers upward or away so that their sound sprays off the walls and ceiling, and (2) the dramatically more subtle and naturalistic ambience which is obtained by using six or eight speakers instead of the usual quad array.

Commercial realities (i.e. the difficulty of persuading people to clutter up their rooms with additional loudspeakers and associated wiring) made it necessary to design and promote time-delay systems primarily as quad systems. But it became clear early on that with six or eight speakers the listening area is enlarged, the setting of delayed-channel levels is less critical, and false localization effects seldom occur since each speaker is operating at a very low volume level.

Two more products should be included in your list of time-delay devices capable of providing high-quality delay without electronic recirculation: the ADS 10-01 (Analog & Digital Systems, Wilmington MA 01887) and the Sound Concepts SD550 (Sound Concepts, P.O. Box 135, Brookline MA 02146). Each retails for $700. As for wideband professional delay lines, DeltaLab makes two models which would be more suitable than the DL-1 listed: the DL-2 ($1750), a stereo delay system with elaborate signal-processing options, and the DL-3 ($750), a minimum-cost highest-quality mono delay. Their correct address: DeltaLab Research, 27 Industrial Ave., Chelmsford MA 01824.

Peter W. Mitchell
West Medford, MA 02155

SAFFRAN, TLS & DALINE

Your first issue is better than I expected, since you have articles of various themes which strike a nice balance. It would have been onerous reading to have only construction projects and crossover design articles. After all, the final aim of the magazine should be twofold: a) speaker production per se, and b) how do speakers fit into the general scheme of music appreciation in the home. Congratulations, and keep it coming!

Richard Saffran's letter is extremely interesting to me, since he mentions his Thiele alignment of the Webb design...*Please* publish the dimensions of his enclosure. I am eager to modify mine in order to get that 20Hz cutoff point!

Transmission line speakers are strongly defended by some authors, but strongly attacked by others. Will somebody give us the real story on this?

I am presently constructing one pair of the Daline + B-110 design by R. Fris. Initial testing with the B-110 alone (no tweeters) has given me a bass response that is, subjectively, on a par with the Webb design, on musical material. The Webbs come out better when the source is an oscillator. Still, this response from such a small system is phenomenal! It is hard to believe, but it's true. The Daline is very strong competition for the Webbs, and it is much less expensive.

Carlos F. Bauza
San Juan, P.R. 00936

AN ELECTROSTATIC SPEAKER SYSTEM: Part 1

Continued from page 29

woofers for best imaging. I have used very large woofers, including 24" Hartleys, but smaller units offer distinct advantages. First, the physical size and expense of large ones is prohibitive. Second, smaller units have better upper bass response because of smaller mass. Third, the T.L. and horn systems will allow the small units to go awesomely deep. Fourth, I suspect the smaller units have less distortion because of relatively stiffer piston with less mass.

Finally, having used "sub-woofers" I feel that there is such a thing as too much deep bass. Even on master tapes essentially no musical information exists below 30Hz, but you sure can hear air conditioning noise, disc rumble, trucks shaking the ground on master tapes, etc. The KEF T.L. system goes well below 30Hz, and I often find myself using a 30Hz garbage filter to clean up the sound. Another advantage to the smaller T.L. system is it is highly efficient; a horn system is even better. I am using a pair of Williamson 20 watt amplifiers on the woofers and a 100 watt Perkins amplifier on the ESL's: the ESL amp distorts before the woofer amp does. I'll present a suitable T.L. system in the construction section of this series.

HOW MUCH?

The system's cost varies and is based more on the cost of electronics than on the cost of the ESL. ESL materials for four cells should run under $100 if you use perforated metal. The cost of frames to mount them is too variable to predict; mine were about $20. Grille cloth will cost about $12 per yard. Transformers are $35 each (from me, 1578 Austin St., Atwater, CA 95301), but you may have some lying around for free, or perhaps you can find some cheaper from a transformer company. You can build T.L. woofer enclosures for around $50 each plus the cost of drivers which may be as high as $100 per channel. Electronic crossovers can be had for about $23 a pair from Old Colony (P.O. Box 243, Peterborough, NH 03458) (plus power supply and chassis), or from DeCoursey for about $80 a pair. Eq/gain stage can be built for $30 the pair, or perhaps somewhat less.

Your largest outlay will be for amplifiers. Presumably you already have at least one to use on either the ESL or the bass. If your amp is suitable for the ESL, then you can get by rather cheaply because a bass amp is not such a problem—the Williamson amps cost under $100 from Old Colony. On the other hand, if you have something like a medium power receiver, you will probably want to use its amp for the woofers and buy a new or used "super amp" for the ESL's. A used Crown DC-300a will go for around $500, and everything goes up from there.

You will see this is no small project; it will cost anywhere from a few hundred to a few thousand dollars depending upon your innovativeness, parts on hand, and general financial condition. You can also cut a lot of corners to save considerable money, space, and time. For example, you can get by with a single ESL cell per channel. You can probably use your present speaker system for woofers. You may be able to build a DC amp cheaper than you can buy a new "super amp." You may find you can be satisfied with an ESL operated full range driven by your present system amplifier. Perhaps you can be satisfied with lower SPL's and save yourself the cost of a "super amp" by using Williamson amps throughout the entire system.

In short, you have lots of options, but unless you build the "full house" system you are going to compromise some aspect(s) of performance: you will still have electrostatic detail and quality, but you will sacrifice either SPL's, frequency response, or bass/midrange detail. In any case, you will have the satisfaction of having built your own speakers, and they *will* sound well. But by spending the time, money, and effort required to build a "full house" system, you will find the sound you can get will exceed anything commercially available; and you will have the satisfaction of having done it yourself. □

Part II of this series includes complete construction details for the ESL's and part III will detail the construction of bass systems. —Ed.

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

ACTIVE ELECTRONIC CROSSOVERS

Plug-in Butterworth (maximally flat) filters in 6 db., 12 db., or 18 db., per octave attenuation, any frequency specified. Filters flat beyond 100 KHz.

Complete crossover in attractive metal cabinet with all terminations and regulated power supply.

STEREO BI-AMP $139

Tri-amp, quad-amp, and monaural types available at comparable prices. Other available features: Summer for "single woofer" systems, Subsonic noise elimination filters supplied with or without bass boost, level controls.

FOR OEM'S AND HOME ASSEMBLERS

500 Series dual filters and/or plug-in filters, regulated power supplies.

FREE CATALOG & PRICE SHEET
Write to:

DeCoursey ENGINEERING LABORATORY
11828 Jefferson Bl • Culver City, CA 90230
Phone (213) 397 9668

BIG #12 gauge speaker wire twisted with outer jacket 100 ft. $40. C.O.D. ok. Sample $1.00. ***AUDIO HOUSE,*** 4304 Brayan Dr., Swartz Creek, MI 48473. (313) 655-8639 T4/80

GOLD PLATED phono jacks $1.10 plugs 85¢ ea., $1.00 handling. Also custom 1% capacitors, 0.5% resistors. Details SASE. ***REFERENCE AUDIO***, Box 368M, Rindge, NH 03461. T1/81

ALLEVIATE DIFFRACTION with our tweeter damping rings. ¼" thick felt with adhesive backing 2" Id 4" Od for one inch domes $4.00/pair. Check or money order only. ***SPECTRUM LOUDSPEAKERS,*** 2136 Perth St., Toledo, OH 43607. T2/80

AMPLIFIERS, SPEAKERS, CROSSOVERS, wire cables, (shielded and unshielded), noise gates. Send for flyer: ***PHASE CONCEPT LTD.,*** 3975 Omaha Dr., Norcross, GA 30093. (404) 923-1127. T1/81

featuring
Jordan 50 mm Modules & Audax bextrene woofers, patterned after Ted Jordans own design. X-over @ 150 Hz, minimum distortion, excellent detail.

In kit form exclusively from
Lazer Audio
45383 Industrial Pl.
Fremont, Ca. 94538
Brochure: $1.00

DREAM SPEAKER SYSTEMS, drivers, parts, designs, Jordan 50mm Modules, bextrene drivers for woofers & midbass, soft dome tweeters, low DCR coils, film caps to 10uf, systems designs, push-pull woofers. Application notes included in literature, send $1.00. The 26 page Jordan Manual now available send $2.00. ***TRANSCENDENTAL AUDIO, Dept. SB,*** 6550 Indiana, Golden, CO 80401. Polydax, Decca, E. J. Jordan, Eminence, Cylindrical "Un-Box" enclosure systems. (303)420-7356. T1/81

AUDIOPHILE SPEAKER WIRE 65 strand 12 gauge 30¢/ft free shipping. Check or money order only. ***SPECTRUM LOUDSPEAKERS,*** 2136 Perth St., Toledo, OH 43607. T2/80

BASF TAPE: Largest discounts, fastest service. All tapes guaranteed. ***INTERGALACTIC ENTERPRISES,*** 1789 Carr, Troy, MI 48098. T4/80

CROSSOVER COMPONENTS and accessories for the speaker hobbyist. Low prices. Send for free flyer. ***UNIVERSAL AUDIO***, Box 712, Providence, RI 02901. T4/80

COMMONWEALTH LOUDSPEAKERS. Fine quality loudspeakers also drive units, walnut veneer cabinets, air core inductors, mylar capacitors, crossover networks. Choose from famous manufacturers like: Decca, Coles, Dalesford, Richard Allan, Jordan, Schackman, Radford and more. Send $3.00 for design, reprints, plans and catalog (refundable with first purchase): ***COMMONWEALTH ELECTRONICS***, 300 N. Allen, Pasadena, CA 91106. (213) 793-5184. T1/81

ELECTRO-VOICE raw loudspeakers. Audio Control equalizers. Tapco amps, etc. Discount prices with quick response. ***SONIX COMPANY,*** Dept. B, Box 58, Indian Head, MD 20640. T1/81

PRIVATE

WANTED: Electro-Voice Patrician or drivers for same—18WK or 18W, 828HF, A8419, 6HD, T25A, T35 or T350, X2635. Any or all. Richard D. Ridenour, 110 LeRoy St., SW, Cedar Rapids, IA 52404.

FOR SALE: LS3/5A type mini monitors, KEF B110 & T27, Falcon X-over, rosewood finish on all sides but back $300/pr. N. K. Disney, 3225 Devon Brook Dr., Bloomfield Hills, MI 48013. (313) 338-2774.

FOR SALE: (2) CTS 15W54C woofers, $50. each. Eric Weatherman, 2613 29th Ave., N.E., Minneapolis, MN. (612) 781-4123 (days) (612) 788-2559 (nights)

FOR SALE: Tympani III a's mint, $1200; Bozak 929 amp with meters $500; Ariston RD11S turntable new $475; Dynavector DV 505 tone arm unused $250; Nakamichi 1,000 with remote $500; McIntosh MC-240 amp with tube cover $300; Bozak CS-4000A speakers mint $750. (612) 475-1271.

FOR SALE: Hermeyer ESL II amplifier, $275; Leach preamplifier with Holmanson input probe, $125; Sony reel-to-reel deck TC252-D, $50. Andy Catanzaro, 3516 Menomonee River Parkway, Wauwatosa, WI 53222. (414) 466-7211.

CROSSOVERS COILS CAPICATORS
SPEAKER CABINETS & KITS
Send $1.00 for Brochure
KUSTOMIZED SPEAKER SYSTEMS
260-A Glenn Circle
Powell, Tennessee 37849

TOP QUALITY SPEAKERS AND KITS. Send $1.00. ***SPEAKER WAREHOUSE***, 809 North Route 441, Hollywood, FL 33021. T1/81

SAVE 50%. Build your own speaker system. Write: ***McGEE RADIO ELECTRONICS,*** 1901 McGee Street, Kansas City, MO 64108. T4/80

FOR SALE: Altec 511B horns. Purchased new, 10/79. Kenwood L-07M 150 watt monaural power amp for subwoofer; $325 in box. Steve Fritz, 545 El Bosque Rd., Santa Barbara, CA 93108. (805) 969-6925.

EXCITING ADDITIONS TO YOUR AUDIO BOOKSHELF BY

WALT jung

AA-1 SLEWING INDUCED DISTORTION IN AUDIO AMPLIFIERS by *Walter G. Jung, Mark I. Stephens, and Craig Todd* is available as a 32-page booklet. About this landmark series, which appeared in the four 1977 issue of *The Audio Amateur*, Peter Mitchell says: "...clearly the most important work in audio electronics in several years..." Each, pp $4.00

S-12. IC OP AMP COOKBOOK. A big 591 page compendium on understanding and using those tiny miracle packages of gain: the integrated circuit operational amplifier. Voltage and current regulators, signal processing, audio circuits, signal generators, and a wide variety of other useful applications. Schematics give *buildable* parts values. Softbound. Each $12.95

S-16 AUDIO IC OP AMP APPLICATIONS. A new thoroughly updated and larger edition of Jung's earlier work on op amps for audio use. The book includes a general introduction to op amps, the special factors the user must consider in using op amps for audio, building blocks for audio uses, and dozens of practical and buildable circuits. *Second Edition.* 208 pp. Softbound. Each $7.95

S-17 IC TIMER COOKBOOK. A full introduction to the IC timer, the types, and general usage pointers. The applications include 16 monostable timers, 14 astable types and 20 timer systems. Many surprisingly useful audio-related uses. An excellent practical and theoretical volume with lots of reference data added in the mix. 287 pp. Softbound. Each $9.95

Old Colony, *Box 243*,
Peterborough NH 03458

Send me Walt's books:
____ Sid Preprint at $4.00 ____
____ copies *Cookbook* at $12.95 ea. ____
____ copies *Audio IC's* at $7.95 ea. ____
____ copies *IC Timers* at $9.95 ea. ____
Total ____
Name ____
Street & No ____
Town ____ State ____ ZIP ____

All prices postpaid in the USA

Classified

FOR SALE: Audio Pulse Model 1, $325; MC-40 tube, $150; Kenwood KF6011 Denoiser, $36; Speakerlab: 350Htz horn-driver X350/5k net., $115; 2 Klipsch copies (mod) $800; JBL Lancer 77's $150. pr; D130-N2400-075 $135; Garrard Zero 100 changer $40; All mint equip. (916) 885-3163.

FOR SALE: Four KEF B200 SP1022 woofers Available only in England. They have a heavier magnet (handle more power) than the SP1014, are unused and come with the KEF spec. sheet. Plans for a proven four-driver stereo transmission-line subwoofer included. All four for $240. plus shipping. Don Neal, 838 21st Ave S.E., Minneapolis, MN 55414.

FOR SALE: Hartley 24" woofer, new in factory box, $300. Also four 15" woofers, f.a.r. 20Hz, with sheet of Thiele parameters for construction of vented enclosure—new, $35 each. Dick Nelson, 3470 Travis Ave., Simi Valley, CA 93063. (805) 526-7066.

FOR SALE: 2HK Citation II amps. One VGC AT $165. One needs repair, $100. Trade? G. A. Discovitsky, P.O. Box 226, Campton, NH 03223. (603) 726-3724.

FOR SALE: G.A.S. Grandson amp needs a good home. He loves high quality associated equipment, comes with meters and owner's transferable warranty and can provide references as to its excellent condition and sonic performance. $325. Marc Sorenson, 53 Ross Court, Medford, OR 97501.

FOR SALE: Pair Altec 811B horns with 802B drivers with new voice coils—excellent $200. Pair Altec crossovers—very good $50. Pair Altec 515 woofers—fair $50. Extra 811B with 802B—fair $75. Extra crossover—very good $35. Offers. Kent A. Doeling, 2145 1st Ave. SW, Minot, ND 58701. (701) 839-8808 after 5:30p.m. CST.

FOR SALE: Fulton Premiere speakers, Boston Audio Society newsletters from 1974 to present, *Audio* magazines 1974 to present, *Stereophile* magazines volume one number one (1966) to present, *Absolute Sound* magazines volume one number one (1973) to present. Everything is in absolutely mint condition and for sale to the best offer. (617) 593-5937.

FOR SALE: RTR ESR-15 Electrostatic tweeters with built in crossover at 1200Hz $500/pr. Special design limited production 435 watt RMS mono tubed amplifier. Only the very best parts used, $500. Terry Eckert, 33 Greene St., NYC, NY 10013. (212) 226-0199.

FOR SALE: Altec 802D driver with 8 ohm voice coil/diaphragm, $50; University cobreflex horn with driver marked "ovation 9704" 16 ohm $35; Altec N-500-D 16 ohm 500Hz crossover, $25; Bozak N-10102 400Hz/2500Hz crossover, $25; 2-Jensen 6x9 triax speakers, $45; Bozak B-4000A's with N-107 crossovers, best offer (will consider selling parts separately. Don Creevy, 151 Lytton Ave, Palo Alto, CA 94301. (415) 851-0140.

WANTED: PS Audio LCC, Stands for stacking quads. Used or price quote on new. Ed Joyce, 105 W. Crawford, Peotone, IL 60468.

FOR SALE: Dahlquist DQ-10 ($600); Soundcraftsman PE-2217 ($300); Koss Pro-4a ($15) and Pro-4aa ($25). Karl F. Hessler, Center for Alcohol Studies, P. O. Box 969, Piscataway, NJ 08854. (201) 932-3576 weekdays until 4:30; otherwise 249-9519.

FOR SALE: Surplus electronics parts, tubes, power supplies, transformers, test equipment. Back issues of Audio. Send SASE for list to: A. Towbin, 436 Orange St., New Haven, CT 06511.

FOR SALE: Thorens TD 125 MK II 3-speed belt drive turntable, arm board cut for SME, $175. Pair of Acoustic Research AR-3 loudspeakers, oiled walnut, $200. M. H. Clarity, Rt. 1, Monticello, MN 55362. (612)878-2352.

ADVERTISING INDEX

FOR SALE: Altec 416-8B woofers, 511B horns, 1209-8A crossovers and 802-8G high frequency drivers. Purchased new 10/79. (805) 969-6925.

AUDIO CLUBS

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 SOCIEITY 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.

FOUR-QUAD SOCIETY. A worldwide group devoted to four channel sound, has a monthly newsletter on developments in four channel. for information write: J. Frank, 4-Quad Society, 23757 Canzonet St, Woodland Hills, CA 91367.

DELAWARE VALLEY AUDIO SOCIETY? Why not? If you are interested, let us know. Write Jim Elliott, c/o HiFi Hospital, 306 White Horse Pike, Clementon, NJ 08021. (609) 627-1680.

AUDIO SOCIETY WANTED in the Sacramento CA area. Serious audiophiles and dedicated audio amateurs please contact Barry Waldron, 8811 Little Oaks Way, Stockton, CA 95207. (209) 478-9310.

MINNESOTA AUDIO SOCIETY Monthly program—Newsletter—Special events. $10/year. Write: P.O. Box 3341, Trafffic Station, Minneapolis, MN 55402.

☐

Professional, Inexpensive tests for your audio system's performance without instruments...

CBS Laboratories' STR Professional Test Recordings

For over ten years, the original series of these high-precision test records set a standard for the audio industry. Now the new series sets an even higher standard. It's been revised, recut and expanded.

The new series consists of eight records for professionals and one for non-professional audiophiles.

Each record contains a complete series of easy-to-use tests to help you rapidly and accurately evaluate components and systems. Even one of these records can eliminate the need for costly, additional equipment. Each will find productive use and save you hours in the laboratory, on the production line and in field testing.

Take a look what this essential testing series contains:

SEVEN STEPS TO BETTER LISTENING-For only $6.98, you can improve your system with CBS Laboratories' "Seven Steps to Better Listening." This high-precision test record enables you to make sure that your equipment functions properly...to tune your system to your ears and your room acoustics. Included is a detailed 16-page booklet by Audio's Edward Tatnall Canby explaining how to use the record to improve the performance of your system. With the record you can perform the following "ears alone" tests: left-right identification, phasing, loudspeaker balance, tone control setting, alternate phasing, buzz and rattle elimination, lateral tracking, and vertical tracking.

STR 100 STEREOPHONIC FREQUENCY TEST RECORD. Designed for the evaluation of pickups and systems. Provides a constant amplitude characteristic below 500Hz and a constant velocity characteristic above 500Hz. Tests include: Sweep Frequency—with the sweep rate synchronized for use with a graphic level recorder; Spot Frequency—with voice announcements; Channel Separation; Wavelength Loss and Stylus Wear—to pinpoint oversize or worn-out styli, and excessive pickup tracking force; Compliance; Phasing; Vertical and Lateral Tracking: Tone Arm Resonance—to check system performance at low and subaudible frequencies and thus reveal undamped resonance which may cause equipment overloading.

STR 112 SQUARE WAVE, TRACKING AND INTERMODULATION TEST RECORD. Enables detailed study of tracking capabilities of stereophonic phonograph pickups. The square wave modulation allows a rapid appraisal of stylus-tip mass, damping, and tracking. Low frequency compliance and tracking are determined by means of 300Hz bands of progressively increasing amplitude. Intermodulation distortion measurements are made possible by graduated 200Hz intermodulation test bands. The STR 112 has been cut with vertical angle approximately 15°, which is representative of current recording practice.

STR 120 WIDE RANGE PICKUP RESPONSE TEST RECORD. Makes possible the measurement of pickup response at frequencies far beyond the audible range, where elusive distortion elements can cause audible distortion. The low-frequency range includes glide-tones at twice normal level for the detection and elimination of arm resonance, loudspeaker cone and cabinet rattles. Other tests include: silent grooves for measuring rumble and surface noise characteristics; and standard level bands at 0dB for overall system S/N measurements. This record is suitable for use with a graphic level recorder to provide permanent, visible records for precise evaluation.

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

STR 140 RIAA PINK NOISE ACOUSTICAL TEST RECORD. Designed for acoustical testing of systems and loudspeakers and for psychoacoustic tests on reproduction equipment. With the STR 140 it becomes possible to test loudspeakers in the room in which they will be used. Spot frequency tones with voice announcements facilitate the testing procedure. Continuous glide-tones in ⅓-octave bands cover the frequency range from 30 to 15,000Hz and are synchronized with a graphic level recorder.

STR 151 BROADCAST TEST RECORD. Developed especially to meet the needs of broadcast engineers, audiophiles, and other professionals seeking a convenient signal source for the testing and adjustment of all audio equipment. Tests include: phonograph pickup response and separation, speed accuracy at 33⅓ and 45 rpm, wow and flutter, rumble and hum detection, ballistic test of V. U. meters and many others.

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

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

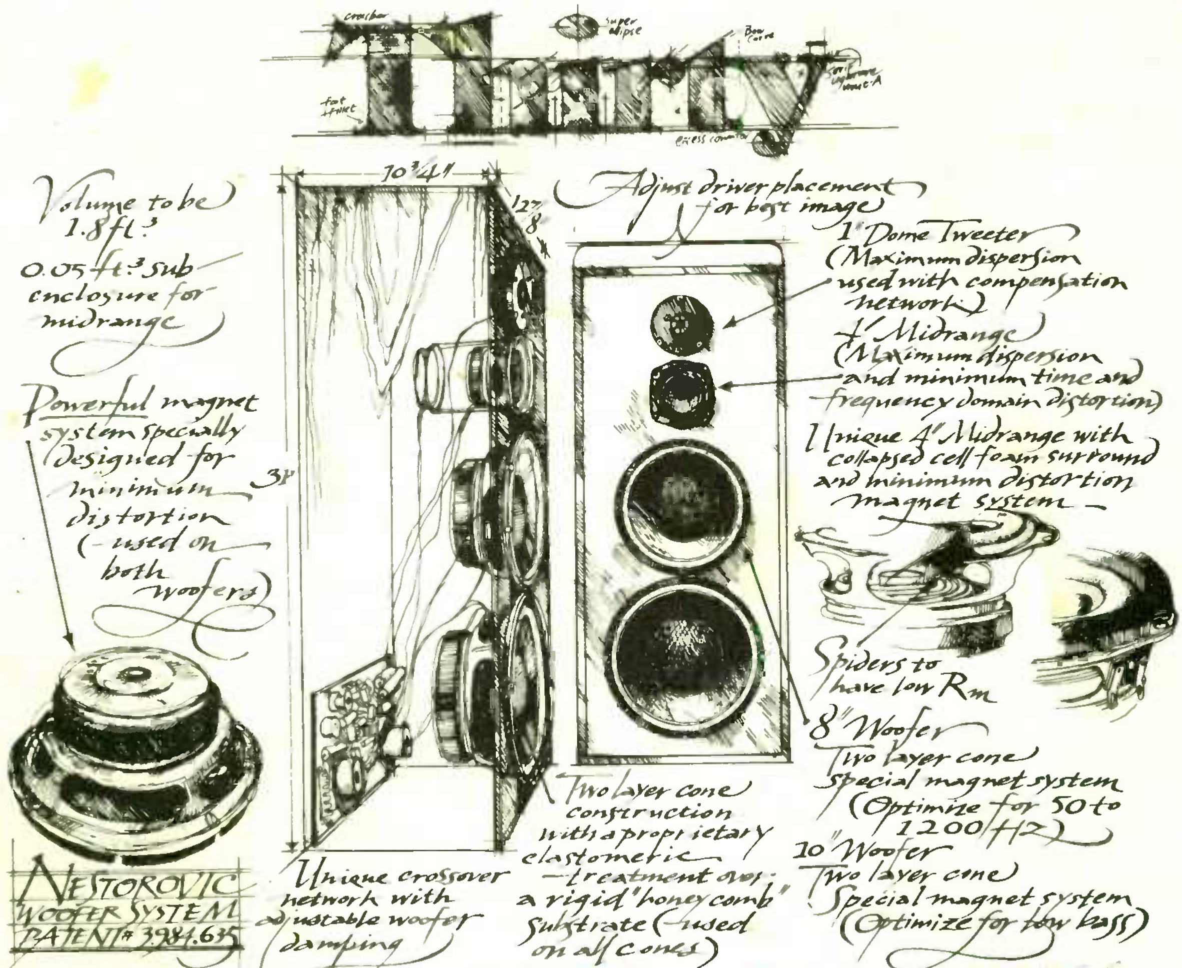
SQ is a Trademark of CBS Inc.

OLD COLONY SOUND LAB
P.O. BOX 243, Peterborough NH 03458
I enclose $________
☐cash ☐check ☐M.O.
Credit card# ☐☐☐☐ ☐☐☐ ☐☐☐☐☐☐ ☐
Expire______ Interbank☐☐☐☐
Signature______________
Name__________________
Street__________________
City________ State________
ZIP________

Quantities are limited. Be sure to order enough for many years of use.

Send me the following test records:

______copies (STR 101) Seven Steps to Better Listening at $6.98 ea.
______copies (STR 100) Stereophonic Frequency at $10. ea.
______copies (STR 112) Sq. Wave, Tracking and Intermodulation $15. ea.
______copies (STR 120) Wide Range Pickup Response at $15 ea.
______copies (STR 130) RIAA Frequency Response at $15 ea.
______copies (STR 140) RIAA Pink Noise Acoustical at $15 ea.
______copies (STR 151) Broadcast Test at $15 ea.
______copies (STR 170) 318 Microsecond Frequency Response $15 ea.
______copies (SQT 1100) Quadraphonic Test at $15 ea.



It's a musical instrument

Our Speakerlab Thirties are the culmination of our acoustic technology and speaker building experience — in collaboration with one of the world's top acoustic designers, Mila Nestorovic. A speaker with better transient response in a smaller enclosure than any system we have ever offered. They're our Stradavarius.

Because our ears receive most information about a musical sound in its very first instant, a speaker's ability to react instantly to an impulse (called transient response) is extremely important. Our Thirties image so well that the speakers themselves actually seem to disappear. The pluck of a guitar string or the snap of a snare drum appear instantly in the Thirties field of sound.

Because they use the patented Nestorovic Woofer System™, Thirties achieve almost a full octave of extra low bass. Through a unique phase-control network and incredibly high flux density 8" and 10" woofers, you get amazingly tight bass transient response. The result is tremendous bass from a relatively small enclosure. Handling up to 350 watts/channel, Thirties are simply unlike any speaker system you have previously heard.

Experience the Thirties: handcrafted, technically precise instruments.

And Thirties are just one of ten different speaker designs from Speakerlab. We also have a wide range of speaker parts available. Send for our free catalog — it'll tell you more about us, our kits and our famous patented Nestorovic Woofer System™, Wave Aperture Drivers™, Polylam™ Cones and Subwoofer Drive Systems.

Dept. SB2

Name

Address

City State Zip

Speakerlab®

Dept. 101, 735 N. Northlake Way
Seattle, Washington 98103