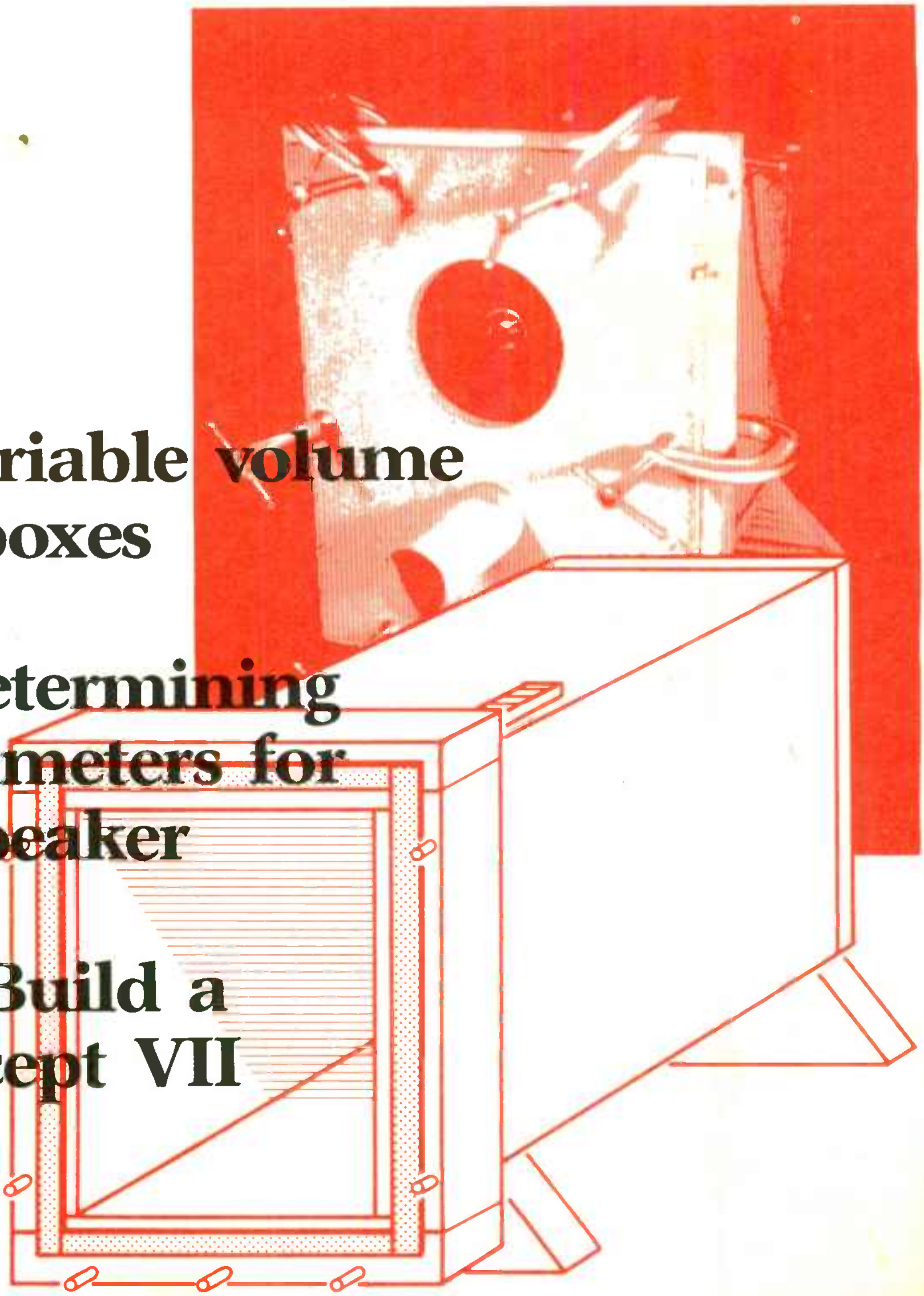
Building a test box to measure driver characteristics

1/1981

SPEAKER BUILDER

US $3.00
UK £1.25 | 15 Fr.



Koonce: Variable volume quick-test boxes

Bullock: Determining design parameters for your loudspeaker

Hayward: Build a Phase Concept VII

Good News

RG Dynamics is offering their new RG X-15 dynamic processor ($255), the company's lowest-priced unit and is among the easiest to use of any on the market, the company says. The RG X-15 offers decibels of dynamic range expansion at full setting. The X-15 employs a four-position expansion setting, including a special one for optimal tape recording, as well as full tape facilities for playback and recording with or without dynamic processing. The RG X-15 employs a harmonic analyzer for each stereo channel to automatically and accurately guide dynamic range expansion. It offers independent left and right channel processing instead of using a compromise signal to control activity on both stereo channels. An image-control circuit is said to enhance left-to-right and front-to-back imaging of voices and instruments. Information is available from 4448 W. Howard St., Skokie, IL 60076.

Coral Electronics is an Italian firm making its full line of bookshelf and turned port loudspeakers available in the USA for the first time. The range includes 13 models two of which are floor standing and one for disco use. The cabinetry is unusually well finished and appears to be of more than usually heavy material. For their tuned pipe floor standing model Cemark 1, a three-way unit for which they claim a ±2.5dB response deviation maximum and less than 1% distortion from 40 to 18,000Hz. Power amp requirements: 40W min; 150W maximum. Information will cost you an expensive air mail stamp to Italy (now 40¢ per half ounce). Direct your inquiries to: Coral Electronic, 10043 Orbassano (TO), Strada Rivalta 73, Italy.

Hartley Products Corp's Dick Schmetterer tells us they produce 18" and 24" devices with a new "Equalized Flux Module" which means the magnet structure has an equal flux field throughout its length. Schmetterer says his firm has devised a method for measuring speaker magnet flux which is new and heretofore not practical. With the new device Schmetterer's people discovered severe asymmetry in many speaker magnets and set about designing a way to make balanced magnets for their drivers. Perhaps such devices will begin to sound more like electrostatics—or better. A letter or card to 620 Island Rd., Ramsey NJ 07446 will get you a brochure on their drivers.

A new Acoustic Test Signal Generator is available from **Hall Engineering** (P.O. Box 506, Martinsville NJ 08836) which provides test signals for speaker adjustment or sound level measurements of all kinds. The unit has a number of interesting features. Its bandwidth may be adjusted for one to 1/20th octave and output may be set from 0dBm to −40dBm. Dials are available to match response characteristics of various sound level meters and microphones, or in blank form to be marked for calibration of the user's mike. The maker claims that the instrument is more accurate than many spectrum analyzers since it is adjustable for finer octave segments. The unit retails for just under $300. Full data on it is available from the manufacturer.

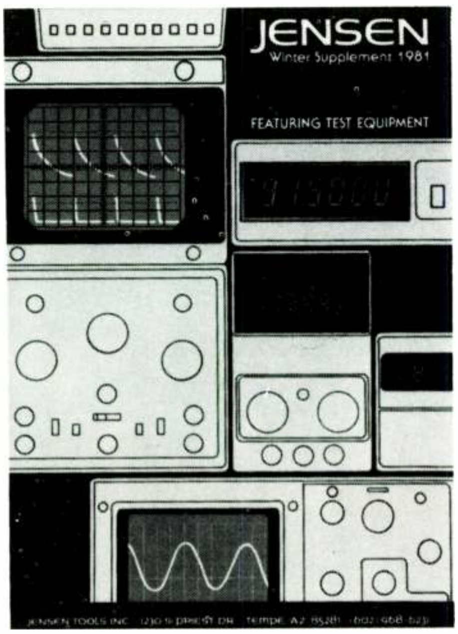
Trumbull Company have a catalog available offering almost everything the amateur builder needs to make his own-etched circuit cards, including some very handy gadgets and fittings. Write to them at Dept. SB, 833 Balra Dr., El Cerrito, CA 94530.

The Speaker Clinic (34 N.E. 74th, Portland OR 97213) has combined a high power ribbon tweeter with a 5¼" bextrene cone mid/bass woofer in a 11¼ x 6¾ x 5" cabinet in a model they have dubbed "The Yankee Reference Mini." The unit also features a 24dB/octave 3.5kHz symmetrical crossover using plastic film capacitors (200V rating or better) bypassed with other types. The manufacturer's catalog is $1 or the speaker manual is $7, both refundable with purchase. The "mike stand" mounting units are $499. per pair.

If you have hash in your system or RFI (radio frequency interference) in your preamp inputs or in your speaker lines **Electronic Specialists** has a filter for you that will probably eliminate it. Ask for their catalog 801 by writing to 171 South Main Street, Department SB, Natick, MA 01760.

Boston Acoustics have two new speaker systems in their growing lineup. A 3-way (A150) is a tall, slim cabinet 30½ x 16½ x 8" deep using a 10" woofer, 4½" midrange and 1" soft dome tweeter. The latter two are treated with ferrofluid® The units cross over at 550Hz and 4000Hz. The two way unit (A60) uses an 8" acoustic suspension woofer and a ferrofluid cooled 1½" cone tweeter crossed over at 3kHz in a cabinet 18" x 11¼ x 7½" deep. This young Boston firm's products are garnering some excellent reviews and they appear to be carrying on the fine traditions of Advent, the company the two principals left to form their own enterprise. For more information on these new units write to 130 Condor St., East Boston, MA 02128.

Nothing is more satisfying than having just the right tool to do a job which you have struggled with, perhaps many times over, using an inadequate or inappropriate one. **Jensen Tools** (1230 South Priest Dr., Tempe AZ 85281) offers a catalog of a very wide range of tools for those interested in electronics and related endeavors. Like many good catalogs, theirs is an education to read. You may not be able to buy the fancy soldering iron you spot in its pages, but you know that some day that is precisely the device you'd like to own. The serious speaker builder will want Jensen's catalog on his resource shelf.



VOLUME 2, NUMBER 1 MARCH 1981

SPEAKER BUILDER
MAGAZINE

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Speaker Builder is published four times a year by Edward T. Dell, Jr., P.O. Box 494, Peterborough, NH 03458.

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

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

FRANCE:
Ainsco (France)
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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.

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

VOLUME 2
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Soup

THIS EVENING WE HAD A SUPPER of old fashioned beef-vegetable soup. It began three days ago with a piece of beef joint which our food service normally does not include with your meat order unless you bother to ask them. The bone, gristle and small bits of beef all go into a large pot we put on the back of the wood stove to simmer for 24 hours.

By that time the meat has separated from the bone, the fat has melted, and the marrow has flavored the whole. The bones and gristle come out and the pot goes into the vestibule where the cold congeals the floating fatty portion on top. The following afternoon you skim off the fat and add seasonings, water and a can of tomatoes before simmering it another day, still on the woodstove. Two hours before dinner you add diced fresh celery and a bag of frozen mixed vegetables and a cup or so of red wine. Serve it with butter and thin-sliced rye bread from the new one-man bakery in the next block.

Campbell's, eat your heart out.

The soup lasts for a couple of meals and is generally better the second time around. Sometimes people ask me for a recipe. It does not exist. I never make it the same way twice. It is always inexpensive, an adventure, and some versions are better than others, but all are delicious.

In a world of chunky beef and fast food that bowl of homemade soup make our day to day reality something thin and shabby.

The do-it-yourself idea has a romantic sound that we want to believe in. The idea remains an abstraction until we put the soup pot on to simmer and, in the end, taste the soup. Doing it yourself is more than an abstract, popular idea. It offers you the taste of good soup at the end of things.

But do-it-yourself is subject to the McDonald's syndrome too. You can buy a soup starter at the grocery store and just add the water and meat: no muss, no fuss, and no bother. None of that simmering and putting in spices. No thinking, either. Easy as pie.

We get letters from some of you querying us about details in articles, mostly good questions that need good answers. And we try to find them for you if we can, or ask the author to answer if he can. Some of them, however, seem to us to come from people who have fallen into the habit of letting other people do all their thinking for them, having been handed too many prepackaged, fool-proof projects that any idiot could do with no danger of failure.

We think that is not the kind of do-it-yourself you want. More and more of the articles in *Speaker Builder* will be of the sort that provide basic theory, tools, calculator programs, design data and provocatively thoughtful ideas. These will not be much good for those who take the mindless, canned approach.

We have had, and still have too much of that. *The New York Times* reported Sunday (Jan. 11) that productivity in the US is declining steadily. Non farm productivity in 1960-65 was rising 3.6% per year. Between 1976 to 1980 it was .2%. There are lots of complex reasons for this decline but we suspect that the "easy way" syndrome has affected managers, politicians, laborers and consumers alike. We are likely in for some times that will teach us all some hard lessons about the necessity for hard work, clear thinking, ingenuity, and doing it ourselves—better than we have ever had to do it before.

Speaker Builder magazine's commitment to do-it-yourself is a whole lot more than mere doctrine or abstract theory with a romantic ring to it. It is *better* in the end. What you understand from the inside is always better. And what you make yourself puts you in a new place from which you experience the world differently. We are, I think, about to become re-acquainted with the world through our hands. And high time too.

How about a nice bowl of hot, savory home made beef-vegetable soup? □

Build A Widget Box to Measure Loudspeaker Parameters

by Richard Saffran

Much of the information needed to design a loudspeaker can be calculated directly from the impedance curves of the individual drivers. This includes the 'Thiele-Small' parameters, and the data needed to design much of the crossover circuitry. Unlike frequency response measurements, these are well within the reach of the amateur who owns or can borrow some basic, inexpensive test equipment.

Two methods of measuring impedance commonly used are: constant voltage and constant current. The more accurate constant voltage method should be used to measure 'Theile-Small' parameters; the faster and easier to interpret constant current method is useful for crossover design measurements. We would like to be able to do both, without having to rewire the test equipment. To this end I built a "widget box" from spare parts. It allows either measurement at the flick of a switch, and has built-in calibration for high accuracy.

The theory behind the measurements is simple, and so is the circuitry. The constant current method uses a large resistance between signal and load; 'large' compared to the load under test—in this case, a loudspeaker. Because the load resistance is insignificant compared to the source resistance, the total circuit resistance remains more or less constant, even as the load impedance varies with frequency.

For a given signal voltage, then, the current through the circuit will be constant, independent of load variations—hence the name, 'constant current.' By Ohm's law, we can say that $R_{load} = E_{load}/I$. Since I is a fixed value, if we measure the voltage across the load, we can calculate the impedance of the load.

YOKING TWO CONSTANTS

In practice no calculations are needed. Instead, we set up a calibrated signal level so we can read (R) directly from a voltmeter. We attach the source resistor to the signal source, and connect a known (small) resistance between the other side of the source resistor and ground. The signal is adjusted to give a meter reading that corresponds to the calibration resistance. For example, if the calibration is 10 ohms, we increase the signal until the meter reads, say, 100 millivolts. A load of 6 ohms will then read 60 millivolts, and so on.

This system is not perfect. The assumption that current will be constant (load independent) holds only when the source resistance is infinite. This would require an infinite voltage to get a usable reading, and is generally not practical for the home experimenter. In practice we will always have some error, which increases as the load departs from the calibration value. So it would be nice to have several calibration resistors, to ensure accuracy over a wide range.

'Constant voltage' means the current through the load is measured at a known voltage, from which impedance is calculated as the ratio E/I. This is done with an ammeter and a voltmeter, so there are no approximations. It has the advantage of being highly accurate, but there is the inconvenience of having to calculate each measurement. In addition it would seem to require an extra meter.

ERROR SOURCES

The trick here is to make one meter serve as both ammeter and voltmeter. This is easy, because an ammeter is only a voltmeter with a current shunt—nothing more than a very low value, high precision resistor. The shunt is in series with the load, so that the current through both elements is the same. The voltage across the shunt is then proportional to the current through the load. $I_{load} = E_{shunt}/R_{shunt}$. If R_{shunt} is some convenient value, say 0.1 ohms, then current can be read directly off the voltmeter—100 millivolts for one ampere, and so on. The shunt should have as low a value as possible so that the signal voltage appears almost entirely across the load, and does not change with load impedance (remember, 'constant voltage'). This is exactly the opposite of the constant current method.

It is no good to use a commercial multimeter with built in current shunts. These do not let you measure the voltage across the load *with the shunt in place*, making exact measurement impossible.

There is another advantage to the constant voltage method, besides its greater accuracy. Loudspeakers are normally operated in a constant voltage mode, not constant current. Speaker impedance depends on voltage as well as frequency; higher drive levels (voltage) usually raise the resonant frequency and Q_t. In the constant current method, drive level depends on impedance: the higher the impedance, the greater the voltage applied to the speaker. As a result, the impedance measurements at different frequencies are also taken at different drive levels. This introduces an extraneous variable, a potential source of error.

WIDGET CIRCUITRY

To be able to perform all the functions discussed, our widget box should contain the following: a high value source

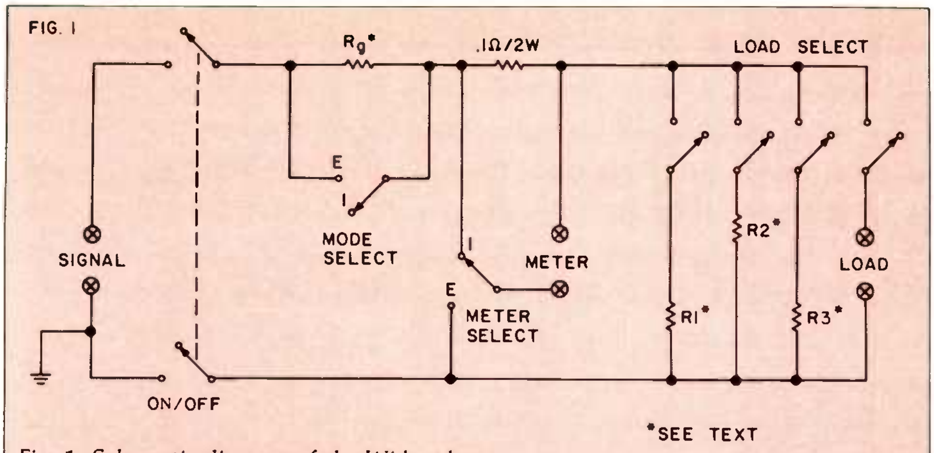

Fig. 1. Schematic diagram of the Widget box.

resistor, which can be switched into the signal path for current mode, or switched out for voltage mode; a multi-position switch to select one of several calibration resistors, or the test load; the calibration resistors; a precision current shunt; a switch for the meter to read either voltage or current. In addition there should be a switch to disconnect the signal source, and of course connectors for signal, meter, and load.

The complete circuit is shown in *Fig. 1.* I have not given exact parts specifications, layout plans, etc., because this project, being very simple, should be built around available parts. Use whatever you can dig up, as long as you satisfy the following requirements.

The accuracy of the unit depends on the accuracy of the resistors, and the stability of the switches. R_g is the only resistor whose precise value is unimportant. It should be set "as high as the traffic can bear." This means the highest value that will still give a useful voltage across the load, given the maximum output of your signal source. If R_g is 1000 ohms, and your signal generator has a maximum output of 8 volts, then a 10 ohm load will have about 80mV across it at full signal.

COMPONENT CHOICES

In order to read ohms directly off the meter, the signal will have to be turned down to 1 volt, reading 10mV/ohm. At this low level there may be some interference from noise. It would be better to use R_g = 700 ohms to allow a 100mV/ohm calibration. The exact value depends on your signal source and the scale markings on your meter. It occurs to me now that it would be nice to have a variable resistor for R_g, say 3k ohms, with a screwdriver adjust (time to get out the soldering iron!).

The most critical resistor is the current shunt. You are not likely to have a 0.1 ohm precision resistor. Combine several resistors in parallel to one very slightly higher than 0.1 ohms. I used ten 1.1 ohm ¼watt units. Be sure the composite resistor has a power rating on the order of several watts; you don't want it to heat up and change value.

I chose three resistors for the constant current calibration (R_{1-3} in *Fig. 1*). These were chosen to correspond to center scale readings of my voltmeter: 5, 15, and 50 ohms. Since error increases to either side of the calibration point, this keeps the average reading comfortably close to the calibration, and cover a wide range. I could have added a 150 ohm resistor to extend the range, but very few speakers have impedances that high.

Choose the number and values of calibrations that suit your equipment. In my case, with R_g = 1000 ohms and the calibrations listed, the maximum error from 0-20 ohms is .5% and from 0-70 ohms, 2%. Again, you may have to parallel several resistors to get the values you need. Power rating is not critical.

CONTACT CAUTIONS

Certain of the switches are just as critical as the resistors. The first widget box I built had nice 1% resistors in it, but was nearly useless because the cheapo load select switch made these values vary widely. The Mark II uses four miniature relays, controlled by a four gang pushbutton row with interlock. I haven't included the relay wiring in *Fig. 1*, but I do recommend this very highly. The SPDT relays, each as large as a dime, came in an inexpensive relay "grab bag." Likewise, less than two dollars for the pushbutton control (but I had to make my own buttons!). If you do use relays, they should be DC actuated; AC current might interfere with low frequency measurements.

The other critical switch is the mode select; it must have reliably low contact resistance. For this, and in fact for all the remaining switches, I recommend mini toggles.

"Five-way" binding posts make the best connectors. They allow you to stack several connections to each terminal. You should also make a binding post to alligator clip patch cord, to connect speakers to the load terminals. The stranded wire should be as short and heavy as is practical, so as not to add resistance.

When laying out the panel, bear in mind that it is most convenient to have the switches closest to the front with the terminals behind, so you don't reach over wires to use the switches. If you plan to use an oscilloscope, you may want to space each pair of binding posts the standard ¾" from its neighbor. This allows an easy connection between signal hot and meter hot (purpose explained later).

CALIBRATION CAPER

Now that you have an assembled, labelled, and lacquered widget box, you still need to calibrate it. You will need: a 10 ohm 1% resistor, a low impedance sine wave source, and an AC millivoltmeter.

First, calibrate the ammeter. Connect signal source and meter. Firmly connect the 10 ohm resistor to the load terminals. Set mode select to E, meter select to E, and load select to load. Turn on the signal and adjust the level to exactly 1 volt. Change meter select to I and note the reading. It should be 10mV. If it reads less, snip out one of the paralleled resistors, and start over. If it reads more, the current shunt is too large, and you will have to add another parallel resistor. Calculate the value needed:

$$R = 1/(10 - 1/(10 \cdot E))$$

where R is the value of resistor to add, and E is the meter reading in volts. Add the new resistors and repeat the calibration until you get within 0.1mV of 10mV.

Now use the ammeter to calibrate the calibration resistors. Of course if you have an impedance bridge you may just connect it to the meter terminals with the meter select at E. In this case use $1/R_{measured}$ as the final term in the next equation.

Select the first resistor on load select. With mode and meter select at E, adjust the signal to exactly 1 volt. Switch meter select to I and note the reading. Calculate the value of parallel resistor to add:

$$R = 1/((1/R_{ideal}) - (1/10 \cdot E)).$$

This will probably be positive because the switch or relay will add some extra resistance. If you calculate a negative value, your calibration resistor is too low and must be replaced with a larger value. Repeat for the remaining resistors.

APPLICATIONS

That completes the construction. Here is some advice on how to use your widget box.

A variety of equipment may be connected. At the very least, you need a sine wave source with a 10Hz-20kHz range, distortion less than 1%, less than 1% amplitude variation, with buffer amplifier to give low source impedance; and an AC millivoltmeter with comparable specifications, and at least 10mV sensitivity, preferably better. A frequency counter with period function is also extremely useful; this can be stacked onto the signal terminals.

An oscilloscope can be useful when finding impedance maxima and minima, because of the well defined electrical phase angle at these points. Speaker voltage drives the horizontal axis, and current the vertical, generating a Lissajous figure which is often easier to read than hunting for tiny meter deflections.

Connect the horizontal scope input to the meter terminals reversed with scope ground to meter hot. Connect the vertical input to signal hot and meter hot, with the scope ground to meter hot (see *Fig.* 2). Set mode select to I, and meter select to E. The vertical input senses the voltage across R_g, which is proportional to the current through the speaker. Horizontal sensitivity will have to be much higher than vertical sensitivity. Incidentally, if you disable the horizontal input and use a triggered sweep, you will see the current waveform. This should not appear distorted; if it does, the drive level is too high.

Now adjust the frequency and watch the scope. At an impedance maximum, you will see a tilted line; to either side of this frequency, the line turns to an ellipse. At an impedance minimum (ported box resonant frequency), you will also see a tilted line, but this one is longer. The patterns for a ported-box test are shown in *Fig. 3*. The exact angle is unimportant. Should the scope and meter indicate different maxima or minima, the meter theoretically gives the correct reading.

FIG. 2

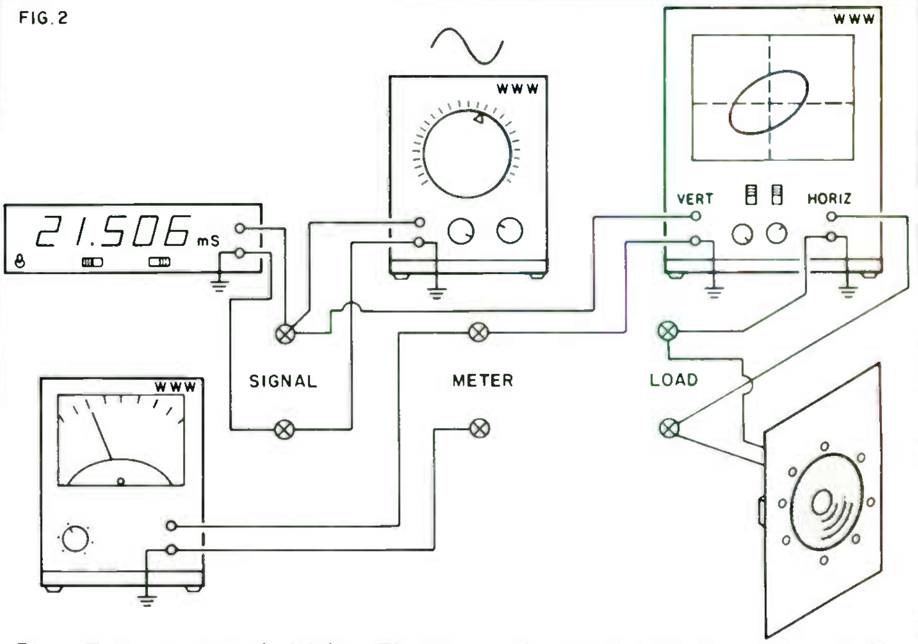

Fig. 2. Test setup using the Widget. The six crossed terminals in Fig. 1 are represented by the six crossed terminals above. The box interconnects meter, frequency counter, audio generator, oscilloscope and driver.

FURTHER POSSIBILITIES

Better than all this fiddling would be a circuit that flashes an LED as you tune through a maximum or minimum. I would be interested to hear from anybody who has such a design.

I have tested dozens of speakers in the past several months, and was going crazy fiddling with patch cords and calibration resistors. I'm sure that the time saved using my widget box has already made up for the time spent building it.

Readers interested in the origin of the term 'widget box' are encouraged to write to the author. My great appreciation to Eric Johanson for helpful suggestions and mostly for help in building the device. □

Appendix: Measuring Loudspeaker Q By the Constant Voltage Method

(1) Connect the speaker to the load terminals. If it is a woofer it should be mounted in a baffle of area similar to a loudspeaker cabinet front, and hung with cone vertical, away from reflective surfaces.

(2) With an impedance bridge connected to the meter terminals and meter select at E, measure the voice coil resistance, and record as R_e.

Continued on page 21

FIG. 3

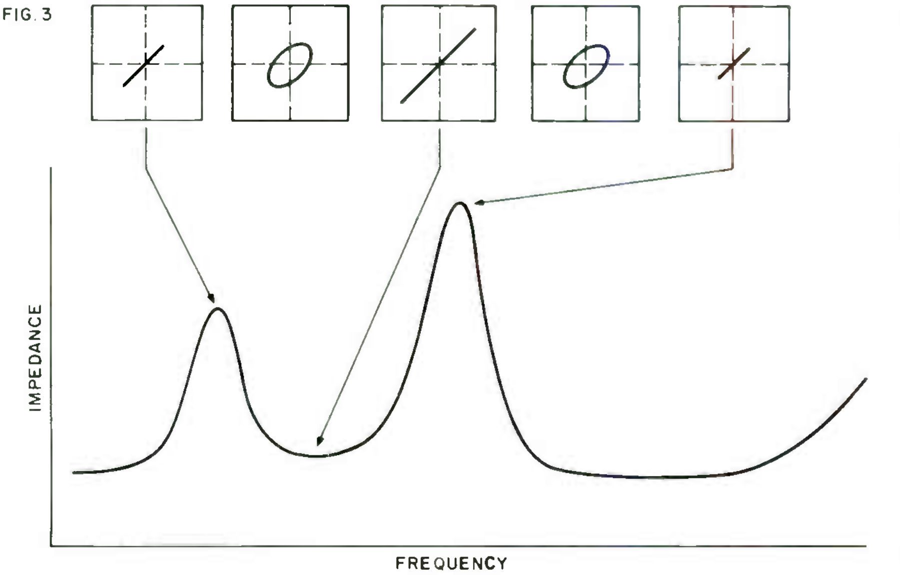

Fig. 3. A typical resonant peak pattern of a driver and the oscilloscope patterns indicating various nodes.

A Quick Opening, Variable Volume Test Box

by G. R. Koonce

When you measure the Thiele-Small (T/S) parameters on a lot of speakers you quickly conclude that you need a variable volume test box with rapid access. *Figures 1* and *2* are drawings of my unit, which works well. I use it for both vented and closed box speaker tests.

The test box is constructed of ⅝" chipboard; inside dimensions are 12" high x 8¾" wide x 15⅝" deep. The front board, which can be removed by releasing six c-clamps (*Figs. 3A* and *3B*), becomes the test baffle for the "free-air" part of the testing. *Figures 2* and *4* show the box's 2"x 2"external front lip; this ensures the needed stiffness when clamping on the front board. The 1/16" foam tape gasket that the front board seats on establishes an airtight seal.

I achieve volume variation by partially filling the box with bricks. I selected the box dimensions to optimize this approach, note that all bricks are not the same size. Maximum box volume is 0.949 cu. ft. with no bricks or speakers. With port duct and speaker installed one can add up to 15 bricks, resulting in a gross box volume of 0.340 cu. ft.

Figure 5 shows an auxiliary array of baffles and tuning ducts. A port hole plug allows closed box tests. When installed in the port hole the duct is outside the test box and thus does not change its volume.

This test box has two functions: to allow T/S parameter measurements, and to "breadboard" an enclosure design by testing the driver in the computed optimum volume and with the calculated tuning if you are considering a vented enclosure. To allow actual driver listening tests I found I needed some damping material to prevent standing waves. I therefore

FIG. 1

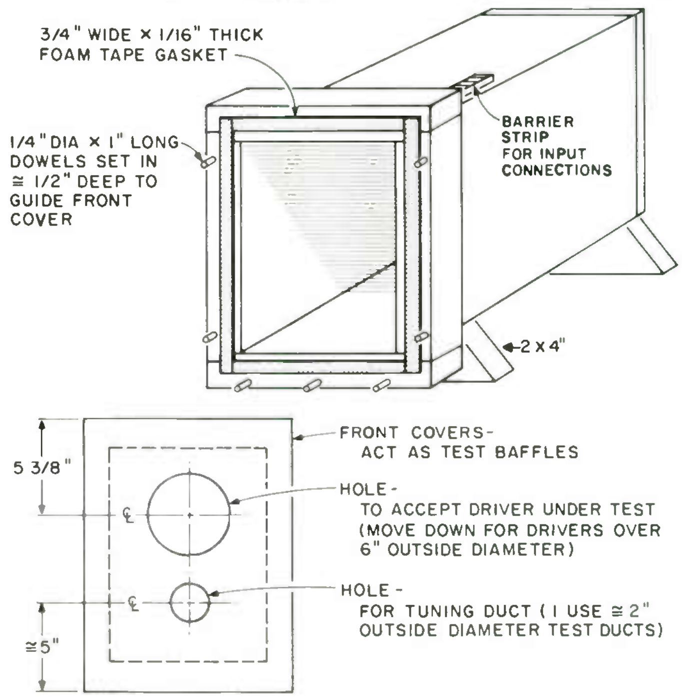

Fig. 1. Isometric view of the variable volume test box and its quick opening front panel.

FIG. 2

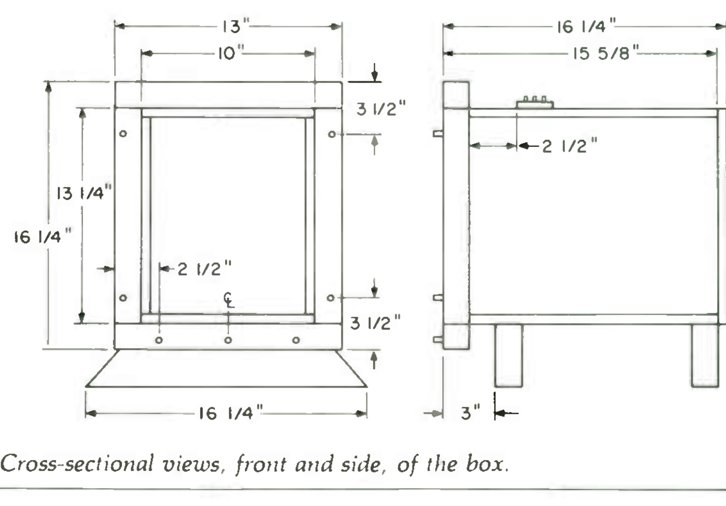

Fig. 2. Cross-sectional views, front and side, of the box.

covered the back, the top, and one side wall with 1" glass wool insulation, which I fitted with nylon grille cloth to prevent the bricks tearing up the glass wool. This much glass wool will scarcely affect the box's acoustic net volume, but you must take it into account when sizing the box for bricks. Leave enough room above or to one side of the brick to let you get your hand in to remove them. I sealed a piece of zip (lamp) cord into the top of the box to allow connections to the driver under test.

While this box will hold 8" drivers, I have mainly used it for testing units in the 3" to 6½" range. You could of course build a bigger version if you had enough bricks and c-clamps available to operate it. □

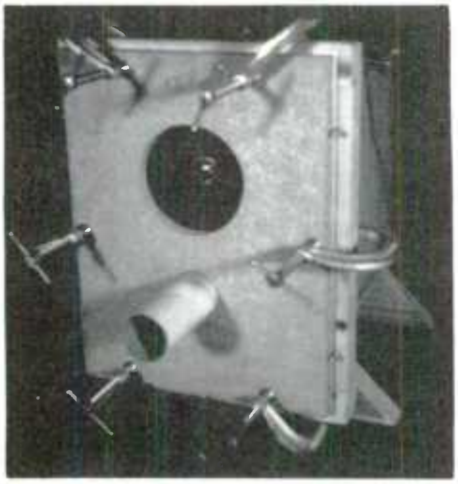

Fig. 3A. Front of the box with clamps in place.

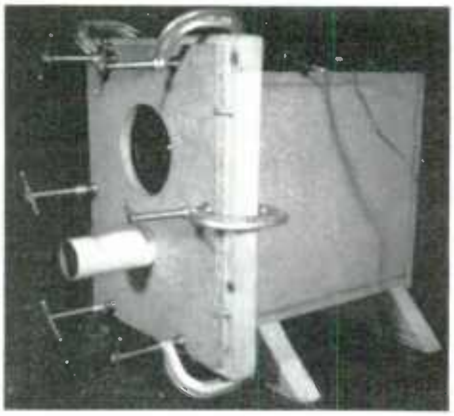

Fig. 3B. Front and side view of box. Note that the tube port is mounted outside so that it does not affect enclosure net volume.

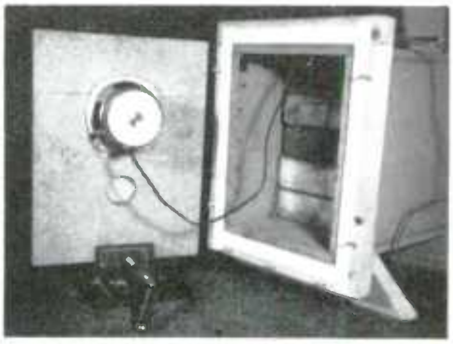

Fig. 4. Open front of the box. Note the bricks inside the box.

Fig. 5. An assortment of front panels and tube ports for the box.

How You Can Determine Design Parameters for Your Loudspeaker

by Robert M. Bullock III

In my first article I described accurate analytic methods for vented box loudspeaker design resulting from the work of Thiele[1] and Small[2]. Using a series of papers by Small, similar analytic methods are available for the design of infinite baffle systems[3], closed box systems[4], and passive radiator systems[5]. All these design methods have one common factor: they are based on values of a certain set of system component parameters. In this article I describe techniques which you can use to find these component parameter values.

For design purposes, a loudspeaker system consists of an amplifier, a driver, crossover/connecting cable, and a driver mounting system (baffle or box). Here we are concerned with determining the design parameters associated with the first three components, which all systems have in common. The amplifier parameter of interest is its source resistance, R_g. The required crossover/connecting cable parameter is the total resistance, R_x, these components have in series with the driver. The necessary driver parameters are R_E, f_S, Q_{MS}, Q_{ES} and V_{AS}. See my first article for a detailed description of each of these parameters.

The seven design parameters listed above can be determined by making various electrical measurements which I describe below. We will begin by describing the necessary test equipment.

TEST EQUIPMENT

We find all the parameter values by making DC resistance and AC impedance measurements. Such measurements require an ohmmeter, a sine wave generator, a voltmeter, and possibly an ammeter. For the best results, the instruments should have the following capabilities.

The ohmmeter should be able to measure very low resistance with a fair amount of accuracy. Since laboratory grade instruments are not available to most of us, I think the next best alternative is a digital multimeter. Many of these devices have an accuracy rating of 1% or less, which is quite satisfactory for our purposes. The meter should be able to resolve to at least .1 ohm; that is, it should be possible to read resistances as small or smaller than .1 ohm. Most 3½ digit meters seem to have this capability. B+K have a model (2815; $150) which will resolve to .01 ohm and has a basic accuracy of .1%; this meter would be an excellent choice if you have the money.

The sine wave generator should have a frequency range extending down to at least 10Hz, and its frequency scale should be as accurate as possible. Small[4] recommends using a frequency counter rather than trusting the generator scale, but accurate counters are quite expensive. The generator output should have low distortion and its voltage should not vary with frequency. Most of us will probably have to settle for less than optimum in these two capabilities, but we can minimize their effects by careful measurement techniques. I have had quite good results using a Heathkit IG-18 ($95) with Williamson's[7] modification which should reduce the distortion to low levels and make the frequency readings accurate to within 2%.

The measurements also require an AC voltmeter and possibly an ammeter. You can make the measurements most conveniently if the voltmeter has a 100 or 200 millivolt range and if the ammeter can resolve to 1 milliamp. If you use a digital multimeter of the type described above, it should be more than adequate.

One potential problem with digital meters is that their AC accuracy is usually given only for frequencies above 45-50Hz, while many of our required readings will be at lower frequencies. I asked Fluke Co. about this; they say accuracy is maintained but the display may be unstable at low frequencies. I have noticed some instability at extremely low frequencies, but it occurred only in the least significant digit, which we can usually ignore. Fluke did recommend a meter modification which would stabilize the display at low frequencies if necessary.

If you are ready to give up because of lack of test equipment or test equipment not up to the above specifications, *don't*. I have used meters with a basic accuracy of only 5 percent which could resolve only to 1 ohm and 10 millivolts, and the parameter values were within 10 percent of those obtained using more accurate equipment. This much error will certainly alter system response, but probably not as much as using the manufacturer's average values. Alternatively, if you have no test equipment and do not want to invest in any, a competent audio repairman should be able to make the required measurements for you using this article. You will have to pay him, but not nearly as much as the cost of equipment. On the other hand, if you plan to make speaker design a hobby, it will be worth investing in your own equipment.

RESISTANCE PARAMETERS

The two simplest parameters to determine are the resistance of the driver voice coil R_E and the total additional resistance R_X which will be in series with the driver. Measure these resistances as accurately as possible. If you are not confident of your ohmmeter's accuracy, you can calibrate it by using a 1% precision resistor of known value close to the advertised impedance of

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the driver being used. Just measure the resistor and adjust the meter reading until it reads the exact value of the resistor.

Measure R_E across the voice coil terminals and record the value to as many significant digits as possible.

The best way to measure R_X is to connect everything together as it will be in the finished system: speaker cables, connectors, crossover, driver, and all interconnecting wiring. Then measure the resistance across the amplifier end of the speaker cables. Subtract R_E from this reading and the result will be R_X. The alternative is to measure each resistance contribution separately, but this takes a meter with high resolving power. To see this, suppose a connector measures .04 ohm, a speaker cable lead .04 ohm, and one of the connecting wires .03 ohm. The total contribution to R_X will be .11 ohm; but if you measure each component separately with a meter of .1 ohm resolving power, each will read 0 ohms for a total of 0 ohms contribution to R_X. The first method will give a value of R_X which does include this .11 ohm contribution.

As an example of the first method, suppose the driver has R_E = 5.5 ohms and you plan to hook up the system in *Fig. 1*. If the measured resistance between points *a* and *b* is 6.3 ohms, then R_X = 6.3 − 5.5 = .8 ohm.

AMPLIFIER PARAMETER

You may determine the source resistance R_g of an amplifier in two ways. In one method you use the advertised damping factor D of the amplifier and the advertised impedance R_n of the driver in the formula:

$$R_g = R_n/(D-1) \qquad (1)$$

To find R_g directly from the amplifier use a method described by Small[4]. He claims this method is preferable because R_g can be found for a more appropriate frequency than the 1000Hz at which damping factors are usually given. If the amplifier is to be used in a low frequency system Small recommends finding R_g at 50Hz. To do this you need a voltmeter, a sine wave generator, and a high wattage resistor of R_n ohms. The resistor's wattage rating should at least equal the amplifier's power rating.

Attach the sine wave generator to the amplifier input and apply a 50Hz signal with no load on the amplifier. Adjust the generator output until the amplifier output voltage is what would be needed to deliver its rated power into an R_n ohm load. Calculate this voltage from $E_o = \sqrt{WR_n}$, where W is the power rating of the amplifier. For an 8 ohm driver and a 100 watt amplifier, E_o = 28.3 volts. Now, without changing the generator settings, connect the R_n ohm load to the amplifier and measure the voltage E_L across it. The source resistance of the amplifier is then found from the formula:

$$R_g = R_n(E_o - E_L)/E_L \qquad (2)$$

As a matter of passing interest, you can calculate the damping factor from:

$$D = E_o/(E_o - E_L) \qquad (3)$$

As an example, the ST150 has an advertised damping factor of 80 at 1000Hz. Using formula (1) for an 8 ohm driver, the source resistance would be R_g = .10 ohm. To use the second method, adjust the generator for a no load output of E_o = 24 volts from the amplifier, which corresponds to 72 watts into an 8 ohm load. This is close enough to the rated 75 watts of the ST150. The loaded voltage measured E_L = 23 volts. From formula (2) we obtain a source resistance of .35 ohm, which does not agree with the value found by the first method.

I discovered my ST150's source resistance varied with the output level. For an output of about 5 watts the damping factor was as advertised, namely 80. But at an output just short of clipping, the damping factor had decreased to 14! This parameter is supposed to be constant for design. I solved the problem by calculating the source resistance at the highest power the amplifier would be expected to deliver. The system driver was limited to 50 watts, so I used the amplifier source resistance at this level. It turned out that R_g = .28 ohm and D = 30.

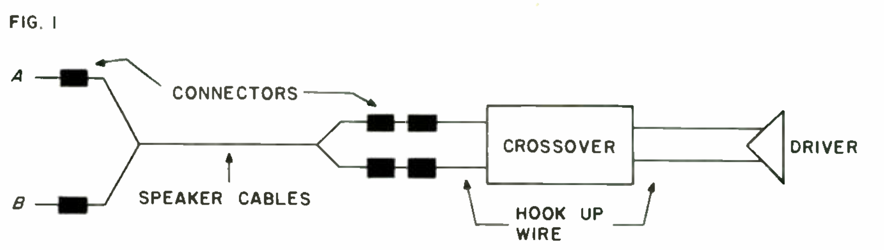

Fig. 1. Typical system hookup for measuring R_x.

IMPEDANCE MEASUREMENTS

We will find the remaining parameters by making various impedance measurements on the driver. I will describe two methods for impedance measurement: one involves constant current, the other constant voltage. Each requires a test setup, of which there are many variants. Those I have chosen to illustrate the methods are, I hope, the least elaborate and most straightforward. A good understanding of these simpler methods should make it possible for you to figure out how to use one of the more elaborate ones.

1. Constant Current

You need a sine wave generator (G), a voltmeter (V), and a resistor (R_{cc}) hooked up as in *Fig. 2* for this method. The resistor R_{cc} converts the generator into a constant current source making readings on the voltmeter proportional to the impedance between A and B. Choose R_{cc} with a resistance eight to 10 times larger than any impedance value you expect to measure. Driver impedances are rarely larger than 100 ohms, so a good choice for R_{cc} is 1000 ohms. A one watt ±5% should work fine.

Calibrate the test by using a resistor R_c of known value between A and B. R_c should have a value in the middle of the range of the expected impedance readings. For driver impedance measurement a 50 ohm ±1% resistor should work well. Calibrate by connecting R_c between A and B and adjusting the generator output until you read a convenient reference voltage V_o on the voltmeter. From this point onward do not alter the generator's output voltage.

To measure a device's impedance, connect it between A and B, adjust the generator to the frequency at which the impedance is to be measured, and read the voltage E on the voltmeter. The impedance Z of the device at that frequency is then:

$$Z = (E/V_o)R_c \qquad (4)$$

Usually you can calibrate the test setup so you are able to read impedances directly from the voltmeter, eliminating the need to use formula (4). To do this choose the reference voltage V_o so its significant digits are the same as those of the resistor R_c. If you have chosen an R_c of 50 ohms, then set V_o at 50 millivolts on a 100 or 200 millivolt meter range and at 500 millivolts on a 1 or 2 volt meter range. For reasons that will be evident later, you will do better to calibrate at the lower voltage.

If your meter is limited to 100

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millivolts on this lower range, then the maximum impedance you will be able to read is 100 ohms. If your meter can display 200 millivolts on this range, then you can read impedances up to 200 ohms. Driver impedances seldom exceed 200 ohms but may sometimes be larger than 100 ohms. If you must measure impedances above 100 ohms and your meter is limited to 100 millivolts, the best thing to do is give up the direct reading capability and recalibrate on the same range. Using R_c = 50 ohms and adjusting the voltmeter reading to V_o = 25 millivolts will enable you to measure 200 ohm impedances. With this calibration, the impedance Z will be twice the voltmeter reading.

When using this method verify that your generator output voltage does not vary with frequency. To do this, put R_c in the test setup and vary the frequency over the range you expect to use, generally from 10 to 100Hz. Note any significant variations in the voltmeter readings and the frequencies at which they occur. Then, when you need to measure an impedance at one of these frequencies, remember to recalibrate the test setup before reading the impedance.

2. Constant Voltage

For this test you will need a generator (G), a voltmeter (V), and an ammeter (A) hooked up as in *Fig. 3.*

In this method you use the ammeter readings to calculate impedance while keeping the voltmeter reading constant at all times. That is, you keep the voltage across A and B constant as the current varies. Readings on the ammeter will be inversely proportional to the impedance.

To calibrate this setup you need a resistor R_c whose known accurate value is close to the nominal impedance of the driver you are measuring. A 5 or 10 ohm precision resistor is a good choice. Connect the resistor between A and B and adjust the generator output until the voltmeter reads some convenient value V_o. *You must maintain this voltmeter reading of V_o for all future readings* by varying the generator output voltage as necessary.

Read the current I_c on the ammeter A with the resistor R_c in the circuit and the voltmeter reading V_o. Calculate:

$$I_E = I_c R_c / R_E \qquad (5)$$

where R_E is the driver voice coil resistance. Then when you connect a driver between A and B and the ammeter reads I (with the voltmeter reading V_o), the impedance Z of the driver at the frequency set on the generator is:

$$Z = I_E R_E / I \qquad (6)$$

You cannot make this a direct reading method.

For either method of impedance measurement you should keep the sine wave generator's output as low as possible, for two reasons. A low level will minimize sine wave distortion, which will improve accuracy; and the driver parameters which you will find are "small-signal parameters," meaning they are defined only for small signals. For these reasons using the voltmeter's 100 millivolt range is best. For the constant voltage method, you may for convenience maintain the fixed voltage V_o at 100 millivolts. I have already discussed appropriate voltage settings for the constant current method.

FIG. 2

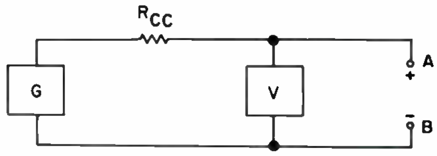

Fig. 2. Test setup for constant current method.

WHICH IS BETTER?

The constant current method is clearly easier to use since it involves less test equipment and can be set up to read impedances directly. However, the constant voltage method has the advantage of more nearly duplicating the usual conditions under which a driver will operate in a system.

FINDING f_S, Q_{MS}, Q_{ES}

Before making any measurements, you should probably operate the driver for an hour or two to break it in, which you can do by applying a low frequency signal at a moderate level. Choose a quiet place and time to make your measurements, since extraneous noise can disturb the meter readings. When taking readings, give the meter time to settle to a stable reading and record it to as many significant digits as possible. Use the full readings to make any calculations, and do no rounding-off except on the final parameter values. These efforts may not improve accuracy, but they cannot hurt either.

Calibrate whichever test setup you are using at a frequency of 50Hz after all the equipment has warmed up. Now hook the driver into the test setup. The resonant frequency f_S of the driver occurs at a frequency where the driver impedance is at maximum. For the constant current method, adjust the generator frequency until you reach a maximum reading on the voltmeter. For the constant voltage method, adjust the generator frequency until the ammeter reads a *minimum*, remembering to maintain the constant reading on the voltmeter. Now record the frequency f_S on the generator. Also record the maximum voltage reading R_M or the minimum current L_{IM}.

Now, for the constant current method calculate (assuming a direct reading calibration)

$$r_o = R_M / R_E \qquad (7c)$$

or, for the constant voltage method, calculate:

$$r_o = I_E / I_M \qquad (7v)$$

where I_E is the current calculated from (5) during calibration. Then calculate:

$$R_1 = R_E \sqrt{r_o} \qquad (8c)$$

for the constant current method or:

$$I_1 = I_E / \sqrt{r_o} \qquad (8v)$$

for the constant voltage method.

The next step is to find two frequencies, f_1 below f_S and f_2 above f_S, such that the driver impedance has the value represented by R_1 or I_1. For the constant current direct reading method this means finding two frequencies f_1 and f_2 such that the voltmeter reading if R_1. For the constant voltage method it means finding two frequencies where the ammeter reading is I_1. Record these two frequencies.

At this stage you can check the accuracy of the measured value of the resonant frequency f_S by calculating $\sqrt{f_1 f_2}$. If this number is within 1Hz of the measured value of f_S then everything is in order. If it is not, either you didn't take the measurements accurately enough or the driver is one to which available system design procedures may not apply. I have measured drivers from several different manufacturers and have yet to encounter one which seems to be in this latter category.

FIG. 3

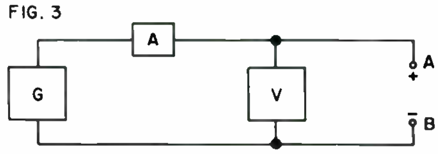

Fig. 3. Test setup for constant voltage method.

If you have to re-measure, try doing so with the driver axis horizontal if it was not so for the original measurement. When I measure f_S, I suspend the driver from the ceiling, using rubber bands to isolate the driver from mechanical vibrations, with its axis horizontal and as far away from any reflecting surfaces as possible. Thiele says precautions like this are not usually necessary, but they make me feel more comfortable.

Using the numbers f_S, r_o, f_1, and f_2 found above, you can now calculate the driver Q's using the formulas:

$$Q_{MS} = f_S\sqrt{r_o}/(f_2 - f_1) \qquad (9)$$

and

$$Q_{ES} = Q_{MS}/(r_o - 1) \qquad (10)$$

You may fear the above methods may not allow you to determine f_S, Q_{MS}, and Q_{ES} with sufficient accuracy for good design. In particular, errors in each measurement may accumulate to produce gross errors in the parameters. Trying to minimize such errors, I determine the parameter values several times, usually on different occasions, and use the average values for design. The crude response measurements I have been able to make on my completed systems indicate the performance is within acceptable limits of that predicted by the theory; and when I have used drivers with manufacturer supplied data, my measurements usually give parameter values within 10 percent of these data.

Now let's consider two examples.

EXAMPLE 1

Use the constant voltage method to find the parameter values of a 6.5" Audax 17HB37 driver with nominal impedance 8 ohms.

The voice coil resistance is $R_E = 6.5$ ohms. Using a calibration resistor $R_c = 5$ ohms, adjust the generator output so the voltmeter reads 100 millivolts. The ammeter reading is $I_c = 20.2$ milliamps. From formula (5), $I_E = I_cR_c/R_E = .0202 \times 5/6.5 = .0155 = 15.5$ milliamps. Now hook the driver into the test setup and adjust the generator frequency until you obtain a minimum value I_M on the ammeter, remembering to maintain the voltmeter reading at 100 millivolts. The minimum current is $I_M = 1.05$ milliamps at a frequency of $f_S = 40.4$Hz.

From (7v) $r_o = 14.7619$; and from (8v) $I_1 = 4.034$ milliamps. Now, find the two frequencies f_1 and f_2 at which the ammeter reading is 4.03, with the voltmeter reading 100 millivolts. These frequencies are $f_1 = 24.6$Hz and $f_2 = 65.3$Hz. As a check on f_S, calculate $\sqrt{f_1f_2} = 40.1$Hz. Since this is within 1Hz of 40.4, everything is fine. Using formulas (9) and (10) we find $Q_{MS} = 3.814$ and $Q_{ES} = .277$.

I have since obtained manufacturer's data on this driver and my numbers are within 10 percent of the manufacturer's except for f_S which is 15 percent off. Even this much error could be due to production tolerance.

EXAMPLE 2

Use the constant current method to find the parameter values of a KEF B139, an oval driver equivalent to a 10" diameter, with an 8 ohm impedance.

The voice coil resistance is $R_E = 6.9$ ohms. With an $R_c = 50$ ohm calibration resistor, adjust the generator output so the voltmeter reads 50 millivolts on the 200 millivolt scale. With the driver connected, vary the frequency until you reach a maximum voltmeter reading of $R_M = 146$ millivolts at a frequency of $f_S = 24.2$Hz. If the meter can read only to 100 millivolts, you can recalibrate on this range to 25 millivolts. The impedances would then be double the voltmeter readings; hence the 146 ohm impedance would correspond to a reading of 73 millivolts.

Now, using (7c) and (8c), calculate $r_o = 21.1594$ and $R_1 = 31.74$. The two frequencies at which the voltmeter reads 31.7 millivolts are $f_1 = 17.5$Hz and $f_2 = 33.6$Hz. The check of resonant frequency gives $\sqrt{f_1f_2} = 24.3$, which is within 1Hz of 24.2. Finally, using (9) and (10) we find $Q_{MS} = 6.914$ and $Q_{ES} = .343$.

I have not seen any manufacturer supplied data on this driver, but the values found here are close to those given by Stamler[8].

Again, I emphasize that you should run these tests more than once and use the average value for all the tests as your design value.

DETERMINING V_{AS}

V_{AS} is the most difficult parameter of all to find with acceptable accuracy. It varies not only with atmospheric conditions, but also with time even in the presence of constant atmospheric conditions. So take readings with care and run the tests more than once. Luckily, this parameter's value is not as critical as the others: that is, a system's response will not be as sensitive to errors in V_{AS} as it will to errors in the other parameters.

I will give two methods for finding V_{AS}, each of which is also useful for making other system measurements needed for design. Both methods use a test box of known internal volume V_{TB}, but in one case the box is closed and in the other it is vented. You could use the same box by fitting it with two different baffles, one with a port and one without. As a matter of fact, it would probably improve accuracy if you determined V_{AS} both ways and used the average value for design.

CLOSED BOX

A closed, unlined, air tight, unfilled test box of known net internal volume V_{TB} is required. For this reason, mount the driver on the box with the magnet assembly outside to make wiring holes unnecessary and so the driver does not alter the box's internal volume. Glueing battens the length of each joint to ensure air-tightness is also a good idea. Use a gasket of some sort in mounting the driver to assure that no air can escape around it. To check air-tightness, Small suggests applying a 10Hz signal at a moderate level and listening all around the enclosure and driver for "breathing" indicative of a leak.

Once you have mounted the driver

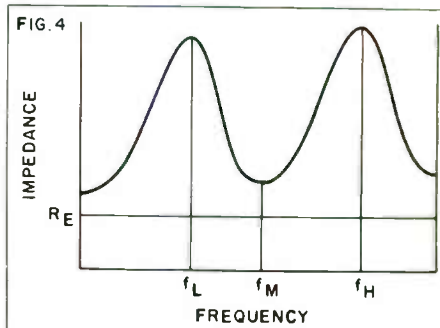

Fig. 4. Graph of driver impedance in vented box.

and connected it to the test setup, you must find the resonant frequency and Q's of this "system." We can do this in exactly the same way as when we measured them in free air. The box's resonant frequency is denoted by f_C and the Q's by Q_{MC} and Q_{EC}. The value of V_{AS} is then calculated from the formula:

$$V_{AS} = V_{TB}([f_CQ_{EC}]/[f_SQ_{ES}] - 1). \qquad (11)$$

Another formula for finding V_{AS} can be found in Colloms[9] and EMS's catalog[10]. However, it is based on an assumption that may lead to a less accurate value for V_{AS}, so the preferable formula is (11). For the record, the other formula is:

$$V_{AS} = V_{TB}(1.15[f_{CC}/f_S]^2 - 1).$$

2. VENTED BOX

For this method you need a vented, unlined, unfilled test box of known net internal volume V_{TB}. The same comments regarding its construction and mounting the driver apply as in the closed box method. The vent size is not critical, but it should tune the box to a frequency of the same order as f_S. Since most woofers have a resonant frequency of less than 100Hz, a reasonable box frequency would be 50Hz.

Thiele[11] prefers this method to the closed box method and "uses a terracotta flower pot, with interchangeable timber lids, pierced with holes for various speaker diameters, attached to the otherwise open top. The pot stands on the floor with three rubber feet and the hole in the bottom tunes the 1 cubic foot pot near 50Hz." See what can be done with a little ingenuity!

To return to the matter at hand, mount the driver on the box, making sure it is air-tight, and connect it to one of the test setups. If you plotted this system's impedance with respect to frequency, the curve would look like *Fig. 4*. At one specific frequency, f_M, the impedance is a minimum; at two others the impedance is a maximum. We must find these three frequencies.

The frequency of maximum impedance below f_M will be denoted f_L and the other f_H. We find f_M by varying the generator frequency until measuring a minimum impedance. For the constant current method this will be at a minimum voltmeter reading, while for the constant voltage method it will be at a maximum current reading. The other two frequencies are found by adjusting frequency for a maximum impedance value. Thiele[11] cautions that "since the impedance curve is very flat around f_M, care must be exercised in reading it. The writer habitually takes the mean of five measurements for f_M." Small[3] says a large voice coil inductance can cause an inaccurate value of f_M. If you suspect this problem, Small suggests "carefully blocking the vent aperture and measuring the resonant frequency f_C of the resulting closed box system.... Then:

$$f_M = \sqrt{f^2_L + f^2_H - f^2_C}\ .$$

The point is clear: it is not easy to measure f_M accurately. Once you have obtained satisfactory values for f_L, f_M and f_H, calculate the value of V_{AS} using:

(12)

$$V_{AS} = V_{TH}([f^2_H - f^2_M][f^2_M - f^2_L])/(f^2_H f^2_L)$$

I will now conclude the examples by calculating V_{AS} for each of the drivers.

EXAMPLE 1 (cont.)

Find V_{AS} for the Audax driver using the closed box method.

Mounting the driver on a test box of volume V_{TB} = 900 cubic inches, you find that f_C = 59.3Hz and Q_{EC} = .426. Recalling that f_S = 40.4Hz and Q_{ES} = .277, we have, using formula (11):

$$V_{AS} = 900([59.3X.426]/[40.4X.277]-1)$$
$$= 900X1.2574$$
$$= 1132 \text{ cubic inches}$$

EXAMPLE 2 (cont.)

Find V_{AS} for the KEF driver using the vented box method.

Using a test box of volume V_{TB} = 4520 cubic inches, the impedance minimum occurs at f_M = 26.8Hz and the maxima at f_L = 13.5Hz and f_H = 45.1Hz. Using formula (12):

$$V_{AS} = 4520([45.1^2 - 26.8^2][26.8^2 - 13.5^2])/(45.1X13.5)^2$$
$$= 4520X1.9025$$
$$= 8599 \text{ cubic inches}$$

Depending on the type of system you plan to design you may need additional parameters. The impedance measurement techniques discussed here can often be useful for this purpose. For example, when designing a vented box system, you need a box loss parameter Q_L. The required measurements to find Q_L are the same as those used to find V_{AS} by the vented box method. I plan to discuss finding this parameter in a later article devoted to the details of vented system design.

In order to facilitate measurement and calculation, I include two sample worksheets which should help you do the work in an orderly fashion. Worksheet I is for finding f_S, Q_{MS}, and Q_{ES} using the constant current method, while worksheet II is for the constant voltage method. Similar worksheets for finding V_{AS} can easily be devised on the basis of these two samples. ☐

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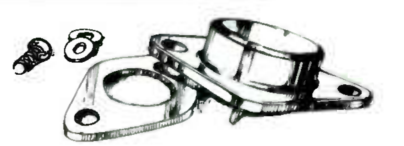
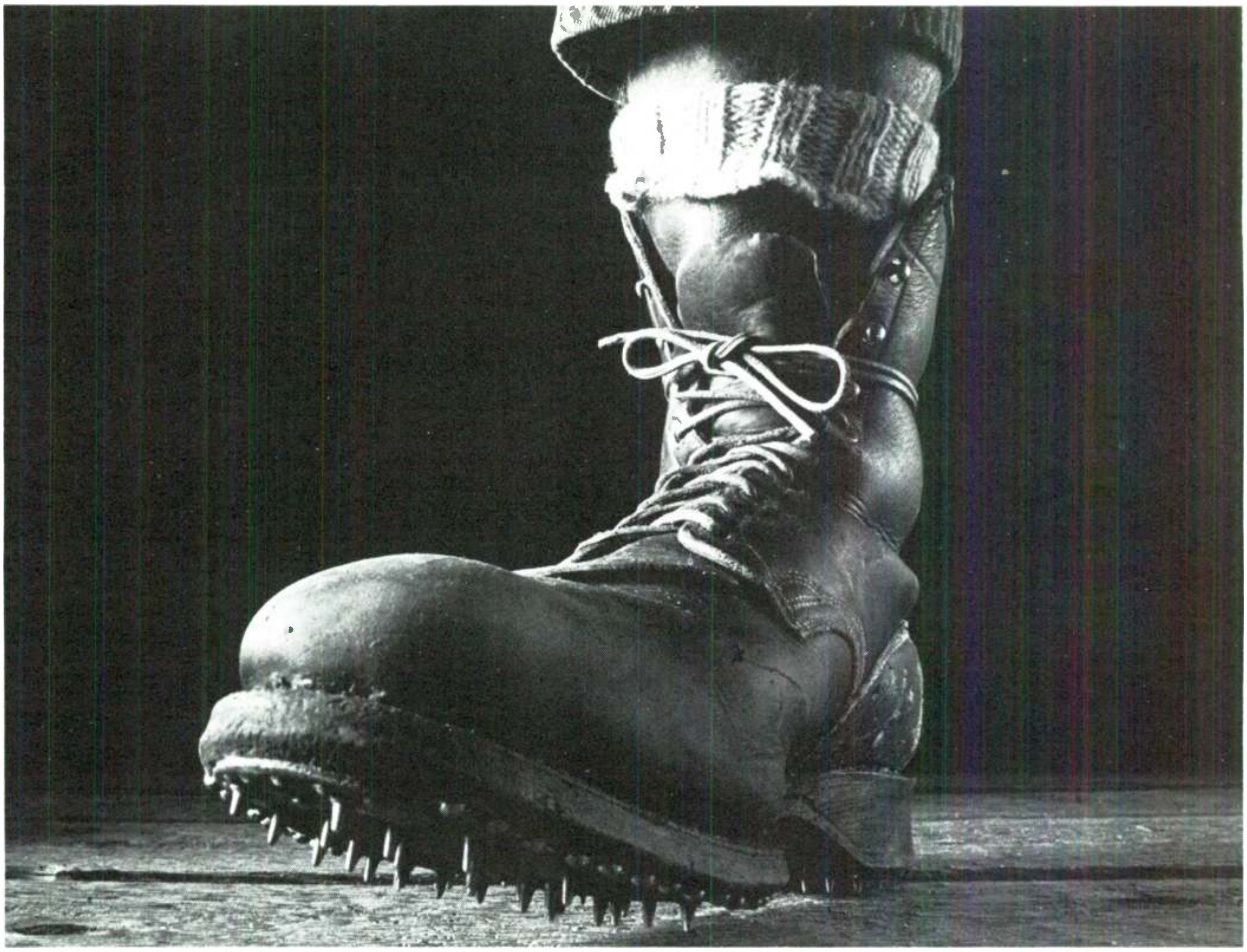


I. CONSTANT CURRENT PARAMETER DETERMINATION WORKSHEET

1. Measure voice coil resistance	R_E	=
2. Value of calibration resistor	R_c	=
3. Voltmeter calibration reading	V_o	=
4. Driver resonance	f_S	=
5. Impedance at resonance (assuming direct reading)	R_M	=
6. Calculate $r_o = R_M/R_E$	r_o	=
7. Calculate $R_1 = R_E\sqrt{r_o}$	R_1	=
8. Lower frequency f_1 where impedance is R_1	f_1	=
9. Upper frequency f_2 where impedance is R_1	f_2	=
10. Calculate mechanical Q, $Q_{MS} = \sqrt{r_o}f_S/(f_2 - f_1)$	Q_{MS}	=
11. Calculate electrical Q, $Q_{ES}\ 2 = Q_{MS}/(r_o - 1)$	Q_{ES}	=
12. Check value of f_S, calculate $\sqrt{f_1 f_2}$	$f_1 f_2$	=

II. CONSTANT VOLTAGE PARAMETER DETERMINATION WORKSHEET

1. Measure voice coil resistance R_E	R_E	=
2. Value of calibration resistor R_c	R_c	=
3. Voltmeter calibration reading V_o	V_o	=
4. Calibration current reading I_c	I_c	=
5. Calculate $I_E = I_c R_c/R_E$	I_E	=
6. Driver resonance	f_S	=
7. Minimum current reading I_M	I_M	=
8. Calculate $r_o = I_E/I_M$	r_o	=
9. Calculate $I_1 = I_E/\sqrt{r_o}$	I_1	=
10. Find lower frequency f_1 where ammeter reads I_1	f_1	=
11. Find upper frequency f_2 where ammeter reads I_1	f_2	=
12. Calculate mechanical Q, $Q_{MS} = \sqrt{r_o}\ f_S/(f_2 - f_1)$	Q_{MS}	=
13. Calculate electrical Q, $Q_{ES} = Q_{MS}/(r_o - 1)$	Q_{ES}	=
14. Check value of f_S, calculate $\sqrt{f_1 f_2}$	$\sqrt{f_1 f_2}$	=



Bookwork

Martin Colloms has made an enviable reputation for himself, particularly in the area of loudspeaker design. This British author is being read avidly on this side of the water. Because of his importance, we present different views of his work by two reviewers. Messrs. Saffran and Bullock have differed in our pages before and the interchange is salutary. Herewith both their reviews.
—Ed.

Reviewed by Robert M. Bullock

High Performance Loudspeakers by Martin Colloms (2nd ed., 245 pp., $24.95, 1980) is an ideal primary reference for anyone interested in loudspeakers because of its encyclopedic coverage and extensive bibliography. This excellently written book is not to be merely read, but to be studied and referred to frequently. On any given topic it may well supply all the information you desire, but if not, the generous lists of up to date references will give you sources for further study. I have had the first edition for little over a year and it is already well worn from use. I have found no other book on loudspeakers as useful as this one.

The book commences with an interesting review of the progress of loudspeaker system performance since the 1960's. Two chapters follow, devoted to both the theoretical and practical aspects of diaphragm radiators, including cones, domes and film transducers. A chapter examines the structure and design of moving coil drivers. These three chapters will give you a good insight into the capabilities and limitations of the basic building blocks of loudspeaker systems.

The chapter on low frequency design begins with some useful material relating system performance to room speaker interaction and system type. Subsonic interference and transient response are are also dealt with effectively. His treatment of the design of closed box systems is detailed enough to use in practice. Equalized alignments, motional feedback, vented system design, transmission line design and horn loading also receive attention. For my personal interests, this chapter alone would have been worth the cost of the book had it been available when I started my study of low frequency design. The reference list contains almost all the articles I eventually accumulated, but it took me months to discover their existence.

The crossover chapter contains a wealth of useful information on both active and passive types. Valuable comments are given on crossover frequency selection, network order selection, sensitivity matching and passive crossover mistermination. This chapter led me to the conclusion (later verified by my ears) that a home builder can get better performance from an active rather than a passive crossover. Specifically, a description of how a particular crossover was developed by a manufacturer made me appreciate the sophisticated analysis and measurement techniques that are required. The home builder is not equipped to duplicate these techniques, whereas the construction of an active crossover is fairly straightforward, especially using kits available from Old Colony Sound.

The chapter on the enclosure is also a gold mine of information. Most of my enclosure construction techniques resulted from a careful study of this chapter, where everything from material selection to resonance damping to driver mounting is covered.

The book's concluding chapter deals with loudspeaker system evaluation using both objective and subjective methods. The author provides an extremely detailed treatment of objective methods, including some very sophisticated ones used by manufacturers. The chapter concludes with a quite rigorous set of standards recommended for conducting subjective evaluations.

This book contains no misprints that I can identify and only one statement of fact that I question. On page 100 Colloms states: "For each halving of frequency the required excursion for constant power is doubled..." I believe the excursion must be quadrupled to maintain the same power.

High Performance Loudspeakers is excellently written, is wide ranging and has an extremely high information density. Anyone with an interest in loudspeakers should not long remain without his own copy. □

Reviewed by Richard Saffran

Loudspeaker design brings together a remarkable number of areas of specialization. The design of drivers encompasses the study of vibrating surfaces, properties of fibers and plastics, magnet structures, and acoustic transmission lines. The crossover network necessitates familiarity with electronic network theory, as does enclosure design. Beyond design principles, the loudspeaker designer must work with a wide variety of analog and digital test equipment and know the subjective worth of each measurement.

All this, and much more, is quite a bit of material to cover in one book. Martin Colloms touches every subject without writing a thorough textbook on loudspeaker design. After reading *High Performance Loudspeakers*, 2nd Ed. (Wiley, 245 pp., $24.95) you would not be able to draw up a blueprint for a quality loudspeaker; you would have a very good idea what is necessary to do it right. The excellent bibliographies are the key to the necessary details.

The book is divided into eight chapters: a historical overview, followed by six major design areas, and a concluding chapter on testing and subjective evaluation. Half of the six design chapters are devoted to driver theory and construction, reflecting Colloms' British origin and his country's dominance of driver design (KEF, B&W, Quad). A good deal of the illustrative material comes from the files of KEF.

The remaining three chapters treat the low frequency system (sealed box, bass-reflex, et al.), crossovers, and enclosure design. This last is another peculiarly British concern. Rarely do American manufacturers boast that their cabinets are damped with car underbody sealant and roofing felt.

As an example of Colloms' thoroughness, consider his chapter on low frequency systems. A typical book on loudspeaker designer might discuss sealed systems, bass-reflex, transmission lines, and horns, with some design charts or equations for the first two. Colloms begins by considering the speaker and room as a system (with references to designs by Allison and

AR). Then, as in other chapters, he sketches the basic mathematical theory, deriving electrical parameters and response curves from equivalent electrical circuits. This theory is mixed with a generous amount of practical detail essential to truly high performance: distortions due to the non-linearity of air compression and harmonics generated in vents of reflex systems.

Other sections, beyond the discussions of the traditional systems, include computer design of low frequency drivers, the "Ace-Bass" system (an integrated amplifier/bass-reflex subwoofer), and motional feedback. The comprehensive bibliography gives testimony to the chapter's completeness: twenty-nine references and seventeen additional listings.

Nevertheless, the chapter is only thirty-six pages long. Compare this to Benson's articles on the same topic, totalling over two hundred pages. You would not want this to be the only loudspeaker book on your shelf, but it does give the most comprehensive collection of design considerations available in any one place.

Other topics, chosen at random, include: every non-moving-coil driver except, curiously the Walsh driver, bextrene and polypropylene cones, cabinet wall resonances, spectral decay testing, 'target-function' crossover networks, impulse testing.

The book is rich in graphs, tables, and illustrations. Each of the topics I mention above is accompanied by at least one graph or drawing—often a reproduction of manufacturer's data or a central figure from a references work. The section on cabinet damping, for example, includes two pages of charts on the absorbtive characteristics of various materials. This may not be enough information to base a design on, but it does give an essential taste of the kind of information that is essential to design.

At about ten cents a page, this is an expensive book. And if you are an amateur loudspeaker designer, it may lead to the expenditure of even greater amounts of money. □

Reviewed by Bruce C. Edgar

Three years ago while perusing the bookshelf in a local electronics store, I ran across these two small paperbacks on loudspeakers. The *1st Book of HiFI Loudspeaker enclosures* and the *2nd Book of HiFi Loudspeaker Enclosures* by Bernard B. Babani (Bernards, Ltd., The Grampians, Shepards Bush Rd., London W6 7NF, 1974, 95 pp. each, $2.50 each) are a part of a whole series of small pamphlets on electronic gadgets, speakers, etc. The availability of the loudspeaker books (hereafter referred to as the *1st Book* and the *2nd Book*) probably depends on whether your electronic emporium carries the other books in the series.

The format of the *1st Book* consists of 39 pages of discussion on loudspeakers (mostly non-technical) followed by a series of 20 line drawings typifying most of the speaker designs of the 1950's. Readers familiar with old *Radio TV News* issues would recognize many of the drawings.

The author has a bias towards horns and horn variations. I counted four horn loaded port-bass reflex designs including the Klipsch "Rebel" corner enclosure popular in the 1950's. The horn designs include the Altec "Voice of the Theater" and 80Hz front loading horn for two 12" speakers, a rear loaded horn for two 15" woofers (still marketed by JBL in their professional series), a simple rear loaded corner horn which I think was taken from an old *Audio* article, and the Gately "super horn".

To balance the emphasis on horn enclosures, Babani includes design table for simple bass reflex enclosures which are now dated in the light of more recent books. The Karlson enclosure, several labyrinth enclosures, and the G.E. distributed port bass reflex enclosure, all popular in the 1950's, are also shown.

The value of the *1st Book* is historical in nature. For experimenters interested in what has been tried in the past, the *1st Book* is very interesting. The drawings are well done with most of the pertinent dimensions, but one would have to do more work to obtain a set of working construction drawings. Badmaieff and Davis (*How to Build Speaker Enclosures*, Sams, 1975) give more detailed drawings of the Altec "Voice of the Theater" and 80Hz front loading horn and the Klipsch "Rebel" enclosures.

The *2nd Book* details some of Babani's own speaker enclosure designs. He begins with a version of the Voice of the Theater enclosure and a companion mid-range horn. The construction of the horns is interesting in that the horn contour is built up with 1" wide particle board strips nailed to a form. Other designs include the Leslie rotating speaker for organ tremelo effects and two omni-speakers. One of the latter used a tapered pipe which was based upon an old Voigt design from the 1930's. The rest of the book is devoted to several p.a. and guitar speaker enclosures.

Both the *1st Book* and *2nd Book of HiFi Loudspeaker Enclosures* are useful to the experimenter because the diverse collection of old designs might provide stimulus for new designs.

The collector would also be interested in the two books for the 1950's period designs, but as a general book on loudspeakers, the widely available Badmaieff and Davis book (reviewed in *Speaker Builder*, 2/80) covers the subject better. □

BUILD A WIDGET BOX TO MEASURE LOUDSPEAKER ELECTRICAL PARAMETERS

Continued from page 9

(3) Set mode to E, meter to E, and load select to load. Turn on signal, and adjust to 1 volt.

(4) Set meter to I. Adjust frequency for minimum meter reading. Set meter to E. Turn off signal at source (do not disconnect) and note residual noise voltage. Turn on signal and readjust level to 1 volt + noise voltage.

(5) Set meter to I, and note value. Turn off signal and note noise reading. Subtract noise reading from signal on value to get correct value. Write down frequency as f_0, and current (=meter reading • 10) as I_0.

(6) a. Calculate $1/R_e$ and write this down as I_e.

b. Calculate I_e/I_0 and write this down as r_0.

c. Calculate $\sqrt{I_e \cdot I_0}$ and write this down as I_r.

(7) Reduce frequency until current = I_r. Set meter to E, and adjust signal to 1 volt. Remeasure current as in 4 and 5 to correct for noise.

(8) Repeat 7 until current is exactly the value desired. Write this down as f_1.

(9) Repeat 7 and 8, this time raising the frequency above f_0. Write down the new frequency as f_2.

(10) Calculate $\sqrt{f_1 \cdot f_2}$. This should agree closely with f_0. If the difference is more than 2%, repeat your measurements.

(11) Calculate:

$$Q_m = \frac{\sqrt{r_0 \cdot f_1 \cdot f_2}}{f_2 - f_1}$$

$$Q_e = \frac{Q_m}{r_0 - 1}$$

$$Q_t = \frac{Q_m}{r_0}$$

Sample notebook entry:
Wonderwoof (8"). Source: McGee Radio ($4.95) 3 oz. magnet, foam suspension, chrome dustcap.

R_e: 6.9 ohms	f_0: 35.4Hz
I_0: 26.8mA	I_e:145
r_0: 5.41	$\sqrt{I_e I_0}$: 66.3
f_1: 29.2	f_2: 42.3
$\sqrt{f_1 f_2}$: 35.1	Q_m: 6.24
Q_e: 1.42	Q_t: 1.16

by HUNTER KEVIL

Loudspeaker Literature

APRIL-JUNE 1980

(1) THEORETICAL AND GENERAL

Ashley, J. Robert. *Group and phase delay requirements for loudspeaker systems.* ***IEEE International Conference on Acoustics, Speech, and Signal Processing,*** held in Denver, CO., April 1980, pp. 1030-1033. 1 ref. "No need for phase delay linearity can be justified for music signals. The actual requirement is a tolerance on 2mS for group delay through the parallel channels (woofer and squawker of a speaker." "Group delay in the highly desirable 3rd order Butterworth crossover network is found to be identical in high and low pass channels. Phase shift in transducers causes the phase troubles in speaker systems." "The usual ideas of time alignment" will not solve the problem. A solution incorporating the transfer characteristics of the transducers into the crossover characteristic in a bi-amplified system is proposed. The author is with Koss Corp.

Atkinson, Brian. *On the use of operational amplifiers in loudspeaker analogs.* ***IEEE International Conference on Acoustics, Speech, and Signal Processing,*** held Denver, CO., April 1980, pp. 1037-1039. 3 refs. A signal flow graph model is used to derive an analog computer circuit to simulate the performance of a vented speaker. Changes in driver or cabinet tuning are made by means of potentiometers.

Berkovitz, Robert. *The conflict between sound and specs: II. The subjective view.* ***Popular Electronics*** 17:4 April 1980, pp. 41-46. No refs.

Bruneau, A.M. and M. Bruneau. **Sur la réponse en fréquence des haut-parleurs.** ("The frequency response of loudspeakers") ***Acustica*** 44:4 April 1980, pp. 308-313. (in French) 9 refs. The first part shows how the velocity of the voice coil is determined by the speaker's mechanical parameters & acoustic loading; the second how sound pressure can be calculated from the diaphragm's velocity.

Bruneau, M. and G. Venet. **Mesure des caractéristiques des haut-parleurs électrodynamiques dans des conditions normales de fonctionnement.** ("Measurement of the characteristics of electrodynamic loudspeakers in normal working environment") ***Acustica*** 44:4, April 1980, pp. 314-322. (in French) 7 refs. Complements the author's preceding paper (see above); three mechanical impedances are studied.

Leach, W. Marshall, Jr. *The spatial alignment of loudspeaker drivers on a baffle—effects on system amplitude and phase response.* ***IEEE International Conference on Acoustics, Speech, and Signal Processing,*** held Denver, CO., April 1980, pp. 494-497. 4 refs. Spatial alignment is important in achieving successful acoustic crossover between drivers. A constant-pressure crossover network of nearly ideal characteristics is proposed.

Martikainen, Ilpo. *A systematic approach to monitoring loudspeaker design.* ***Audio Engineering Society,*** 65th convention, preprint No. 1592. Approach of the Finnish Broadcasting Co. to design of monitor loudspeakers.

Queen, Daniel. *The conflict between sound and specs: I. The objective view.* ***Popular Electronics*** 17:4, April 1980, pp. 38-41. No refs.

(No author given.) *Designs for living with loudspeakers: six experts talk about sound propagation, speaker measurement, and listening rooms.* ***High Fidelity.*** 30:6, June 1980, pp. 50-53. The experts are Roy Allison, Raymond Cooke, Mark Davis, Tim Holl, Daniel Queen, John Wawzonek, and Peter Mitchell. An interesting article.

(2) LOUDSPEAKER DRIVER UNITS

Barcus, Lester M. and John F. Berry. *Sonic transducer mounting.* U.S. Patent No. 4,204,096. ***Official Gazette of the United States Patent & Trademark Office,*** May 20, 1980, p. 1060. The Barcus-Berry plate.

Barlow, Donald A. and others. *The resonances of loudspeaker diaphragms.* ***Audio Engineering Society,*** 65th convention, preprint No. 1590. Using BOSOR 4 and the finite-element method, it is possible to calculate diaphragm response. This has been done for domes and for normal cones, of paper and sandwich construction, with interesting results.

Bost, Jonathan, R. *A new piezoelectric driver enhances horn performance.* ***Journal of the Audio Engineering Society,*** 28:4, April 1980. pp. 244-249. 9 refs. The author is employed by Motorola, Inc.

Bertagni, Jose J. *Planar diaphragm and supporting frame assembly.* U.S. Patent No. 4,184,563. ***Official Gazette of the United States Patent & Trademark Office,*** January 22, 1980, p. 1252. An improved suspension for Bertagni's planar speaker.

Dubbleday, Pieter S. *Application of ferrofluids as an acoustic transducer.* Naval Research Lab, Memorandum Report NRL-MR-4030; report No. AD-E000 343. Pp. 30. $6.00 from National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161; order No. AD-A079 314/1. "Properties of ferrofluids are given, basic equations developed. Power transfer calculations are performed for a piston-type transducer."

Freeman, Miller L. *Circuit for electrostatic transducers.* U.S. Patent No. 4,207,442. ***Official Gazette of the United States Patent & Trademark Office,*** June 10, 1980, p. 692.

Hope, Adrian. *Audio Patents.* ***Hi-Fi News & Record Review,*** 25:5, May 1980, p. 81. No refs. Brief discussion of U.K. patent application No. 2,015,300, by Tannoy, for use of a ring of non-magnetic material to achieve different magnetic flux densities at the voice coils of a coaxial speaker.

Hope, Adrian. *Audio Patents.* ***Hi-Fi News & Record Review,*** 25:6, June 1980, p. 55. No refs. Response to a letter published on p. 67 of the same issue critical of Hope's earlier article on the patent application for polypropylene-diaphragm drivers. (See *Loudspeaker Literature,* No. 1, rubric No. 2.)

Sony Corp. *Fluid-flow control speaker system,* U.S. Patent No. 4,194,095. ***Official Gazette of the United States Patent & Trademark Office,*** March, 18, 1980, p. 1063. According to George Augspurger in *JASA* (68:4, p. 1239), "This peculiar looking maze of pumps and pipes will probably achieve historical importance as the world's first loudspeaker system which responds directly to PCM-encoded audio signals."

Raj, K. and R. Moskowitz. *A review of damping application of ferrofluids.* ***IEEE Transactions on Magnetics,*** 16:2, March 1980, pp. 358-363. 11 refs. The authors are with Ferrofluidics Corp. The paper does not treat speaker applications, but the references give four papers in this field.

Sony Corp. *Peripherally reinforced laminated loudspeaker diaphragm.* U.S. Patent No. 4,198,550. ***Official Gazette of the United States Patent & Trademark Office,*** April 15, 1980, p. 1058. Sony's flat honeycomb-mesh diaphragm.

U.S. Philips Corp. *Optical motional feedback.* U.S. Patent No. 4,207,430. ***Official Gazette of the United States Patent & Trademark Office,*** June 10, 1980, p. 688. Uses a light source and a detector element; the latter generates "a voltage which substantially corresponds to the displacement of the diaphragm."

(3) CROSSOVER NETWORKS, PASSIVE AND ACTIVE

Cizek Audio Systems. *Compensated crossover network,* U.S. Patent No. 4,198,540. ***Official Gazette of the United States Patent & Trademark Office,*** April 15, 1980, p. 1054. Compensation to make a speaker a less reactive load; formulae are given. Cf Colloms, *High-performance loudspeakers,* 2nd ed., pp. 142-6.

Hiraga, Jean. **Japon: les nouveaux composants audio de haut de gamme.** ("New Japanese high-end audio components") ***L'Audiophile 16,*** June 1980, pp. 57-65. (in French) no refs. Discusses new Japanese transistors, capacitors, resistors, diodes, cables, cases, pcb's, & solder. Pp. 58-60 treat new capacitors made specially for audio use.

Deboo, Gordon J. *An RC active filter design handbook.* NASA Ames Research Center report, NASA SP 5104. 176 pp., 1977. Cited in ***Monthly Catalog,*** January, 1980, entry No. 80-3119. Available from National Technical Information Service; no price given.

Johnson, David E. *A handbook of active filters.* N.Y.: Prentice-Hall, 1980. Pp. 244. $15.95. Standard book number 0 1337 2409 3. Cf.Johnson's earlier book, *Introduction to filter theory* (1976).

Jones, A. and M.J. Hawksford. *Computer-aided design of lossless crossover networks.* ***Audio Engineering Society,*** 65th convention, preprint No. 1589.

Leach, W. Marshall, Jr. *Loudspeaker driver phase response: the neglected factor in crossover network design.* ***Journal of the Audio Engineering Society,*** 28:6, June 1980, pp. 410-421. 8 refs. A phase lead in tweeter response can cause irregular output in the crossover region, if the tweeter cut-off frequency is close to the crossover frequency.

Marchand, J.F.P. *A 3-way driver system for speakers.* ***Popular Electronics,*** 17:4, April 1980, pp. 46-50. No refs, parts list, diagrams. Construction project for active network.

Marec, Guy. **Mise au point des filtres séparateurs passifs; 1—du reve à la réalité.** ("Passive dividing filters, refinements to theory; part 1, from dream to reality") ***L'Audiophile*** 16, June 1980, pp. 27-33. (in French) no refs. Some problems in second-order filters: impedance rise at fundamental resonance of the driver, voice coil resonating with the capacitor of the filter, impedance mismatch in a midrange filter of cascaded high-pass & low-pass sections, and phase delays in midrange caused by time constant of the driver. Some solutions are proposed. In the second part of the article, a fully worked-out example of a successful second-order filter is promised.

Neveu, Ives. **Application des condensateurs à l'audio; 1—les condensateurs non polarisés.** *("Audio applications of capacitors; part 1, non-polarized capacitors")* ***L'Audiophile*** 16, June 1980, pp. 45-55. (in French) no refs. Discusses the physics of capacitors, including dielectric materials and mechanical construction. P. 54 gives a summary table of different types of capacitor, properties, and recommended uses. A nice complement to Jung and Marsh, *Picking capacitors,* ***Audio,*** Feb. 1980, pp. 52-62, & March 1980, pp. 50-63.

Ravichandran, S. and K. Radhakrishna Rao. *A novel active compensation scheme for active RC filters.* ***Proceedings of the IEEE*** 68:6, June 1980, pp. 743-4. 4 refs. A method using two internally compensated op amps with unmasked gain-bandwidth products to obviate matching the op amp or trimming to reduce pole Q and pole frequency error.

Tedeschi, Frank P. *The active filter handbook.* Blue Ridge Summit, PA: Tab Books, 1979. Pp. 280. $9.95 hardbound; $6.95 paper. Tab order no. 1133. Standard book no. 0 8306 9788 8. Discusses op amp realizations of Butterworth and Chebyshev transfer functions. Only two pages on loudspeaker applications, but still a very important book for constructors and those who wish to understand how active filters work.

(4) CABINETS

Blevins, Robert D. *Formulas for natural frequency and mode shape.* N.Y.: Van Nostrand Reinhold, 1979. Pp. 492. $29.95. Standard book number, 0 4422 0710 7. "Highly recommended" (*JASA*, 67:5, p. 1849); "provides formulas for the natural frequencies and mode shapes of a wide range of structures in easily used form" (New technical books). Discusses the finite-element method.

Delaleu, Charles-Henry. **Lutte contre les vibrations parasites dans les enceintes acoustiques.** ("Preventing panel resonance in loudspeakers") ***L'Audiophile*** 15, April 1980, part 1, pp. 35-41. (in French) no refs. ***L'Audiophile*** 16, June 1980, part 2, pp. 17-25 (in French) no refs. Part 1 discusses problems of choice of material, shape of cabinet, magnitude of panel vibrations, and simple ways to measure & damp the vibrations. In part 2 more sophisticated measuring techniques are discussed & practical designs for a 4½ cubic foot bass-reflex woofer cabinet, a separate midrange cabinet, and a tweeter receptacle are presented. Techniques to inhibit or damp resonance include: use of concrete, T-shaped braces, roofing tar, lead sheet, and hardboard liners.

Fox, D.W. and V.G. Sigillito. *Bounds for frequencies of rib-reinforced plates.* ***Journal of Sound and Vibration*** 69:4 (22 April 1980), pp. 497-507. 6 refs. "Rigorous upper and lower bounds are presented for the frequencies of vibration of a thin elastic plate reinforced by an elastically attached rib." This rib or brace is T-shaped, like the braces recommended by Delaleu in ***L'Audiophile*** (see entry above.)

Lento, Robert. *Woodworking: tools, fabrication, design, and manufacturing.* Englewood Cliffs, N.J.: Prentice-Hall. 1979, pp. 543. $16.95. Standard book number: 0 1306 2514 3. The author is with City College of New York.

(5) MEASUREMENTS, TEST EQUIPMENT, AND SPEAKER EVALUATION

Abbagnaro, L.A., B.B. Bauer, and E.L. Torick. *An acoustic power monitor for loudspeaker testing.* ***Journal of the Audio Engineering Society*** 28:6 (June 1980), pp. 402-409. 5 refs. The authors are with CBS Technology Center. Development of a monitor to measure acoustic power response (or frequency response) in half or full space in an anechoic chamber.

Alteiri, Gustavo. **Le placebo acoustique, existe-t-il?** ("Is there an acoustic placebo?) ***L'Audiophile*** 16 (June 1980), pp. 87-91. (in French) no refs. Preconceptions and visual cues can confuse listeners during listening tests: the factor of psychological conditioning cannot be ignored.

Cable, Cecil R. and J.K. Hilliard. *The practical application of time-delay spectrometry in the field.* ***Journal of the Audio Engineering Society*** 28:5 (May 1980), pp. 302-309, 5 refs. Techniques for using a spectrum analyzer to quantify the behavior of speakers in real rooms. "Subtleties of sound behavior not written in equations or included in laboratory simulations are automatically included in measurement results."

Fryer, Peter and Richard Lee. *Absolute listening tests—further progress.* ***Audio Engineering Society,*** 65th convention, preprint No. 1567. Different ways to compare the output of a speaker under evaluation with the input.

Fryer, Peter and Richard Lee. *Use of tapped delay lines in loudspeaker work.* ***Audio Engineering Society,*** 65th convention, preprint No. 1588. The lines can be used to simulate any impulse response desired, and notably the inverse of a speaker's impulse response so as to cancel out all linear distortions. The authors are with Rank Hi-Fi.

Ianniello, C. *A proposed method for measuring the steady-state pure-tone directivity factor of loudspeakers in ordinary rooms.* ***Acustica*** 44:5 (May 1980), pp. 68-71. 15 refs. A simplified method that does not require a free-field measuring environment.

Keele, Don B., Jr. *Automated loudspeaker polar response measurements under micro-computer control.* Audio Engineering Society, 65th convention, preprint No. 1586. Disk-stored spectral data generate polar/frequency response curves and beam width/directivity data. "This paper emphasizes the practical aspects and problems encountered." The author is with James B. Lansing Sound, Inc.

Linkwitz, Siegfried. *Shaped tone-burst testing.* ***Journal of the Audio Engineering Society*** 28:4 (April 1980), pp. 250-258. 10 refs. Use of a 5-cycle tone burst in a raised cosine envelope permits easy determination of the transient behavior of a speaker and in particular of local resonances. Frequency response can also be determined. In an appendix, details for construction of a simple generator and receiver are given.

McClellan, Gary. *Build this synthesized function generator.* ***Radio-Electronics,*** part 1, 51:6 (June 1980), pp. 51-55; part 2, 51:7 (July 1980), pp. 65-69. No refs. High harmonic distortion, but constant output level with frequency and precise determination of frequency, by means of four thumbwheel switches. "An advanced project."

Orlowski, Adrian. *A rational basis for subjective evaluation.* ***Hi-Fi News & Record Review*** 25:4 (April 1980), pp. 49, 51, 53. No refs. Four criteria for use in assessment of reproduced sound.

Pukhona, S.M. and I.E. Tsukernikov. *Method of calculation of the directivity pattern for an acoustic radiator of arbitrary shape from near-field pressure measurements on the surface of a finite circular cylinder.* ***Soviet Physics—Acoustics*** 26:1 (Jan.-Feb. 1980), pp. 64-66. 7 refs.

Sank, Jon R. *Improved real-ear tests for stereophones.* ***Journal of the Audio Engineering Society*** 28:4 (April 1980), pp. 206-218. 27 refs.

Schroeder, Richard. *Wide range audio generator.*

Literature

Continued from page 23

Radio-Electronics 51:5 (May 1980), pp. 76-81. No refs. 10Hz to 50kHz audio generator that can be constructed for "about $30."

Thomsen, Carsten and Roger Upton. *New capabilities of FFT analyzers.* ***Sound and Vibration*** 14:4 (April 1980), pp. 10, 12. No refs. On the Bruel & Kjaer 2033; the authors are with B&K.

Tokyo Shibaura Denki Kabushiki Kaisha. *Method and apparatus for measuring characteristics of a loudspeaker.* U.S. Patent No. 4,209,672. ***Official Gazette of the United States Patent & Trademark Office,*** June 24, 1980, p. 1466. Use of an impulse signal and Fourier transform of speaker response.

(No author given). *Survey: test equipment (Part 1).* ***Studio Sound and Broadcast Engineering*** 22:4 (April 1980), pp. 50-70 (even numbers only). List of commercially available test equipment. This part includes spectrum analyzers, reverberation timers, audio test sets, oscillators, mics, meters, chart recorders, acoustic polarity testers, and sweep generators. Part 2 is given in vol. 22, No. 5 (May 1980), pp. 48, 51-52. It covers handheld sound-level meters, test discs, and test tapes.

(6) INTERFACE OF SPEAKER, CABLE AND AMPLIFIER

Greiner, Richard A. *Amplifier-Loudspeaker Interfacing.* ***Journal of the Audio Engineering Society*** 48:5 (May 1980), pp. 310-315. No refs. Speaker cables should be considered as lumped-parameter equivalent circuits, not transmission lines. Normal cables are satisfactory for audio purposes, and cable thicker than 12 gauge is unlikely to be of benefit for runs less than 30m. Fuses are nonlinear resistors and can introduce distortion.

Pass, Nelson. *Speaker cables: science or snake oil?* ***Speaker Builder*** 1:2 (May 1980), pp. 6-11. 11 refs. "money spent for high quality cables and connectors is a reasonable investment."

(7) INTERFACE OF SPEAKER AND ROOM

Altieri, Gustavo, Acoustique et conditionnement de la salle d'écoute; présentation des problèmes et exemples pratiques. ("Acoustics and acoustical treatment of the listening room: problems and practical cases") ***L'Audiophile*** 15 (April 1980), part 1, pp. 61-67. (in French) no refs. Effect on frequency response of placing speaker in different parts of a room; use of curtains, rugs, wall-mounted absorbants, and equalizers in 3 different sample rooms.

Altieri, Gustavo. Acoustique et conditionnement de la salle d'écoute; matériaux absorbants. ("Acoustics and acoustical treatment of the listening room: absorbants;;) ***L'Audiophile*** 16 (June 1980), pp. 67-73. (in French) no refs. Treats reverberation time, absorption coefficient, resonantors, and panels; a table gives coefficients for 23 materials.

Davis, Don and Carolyn. *Time, energy, and frequency measurements for sound definition.* ***db*** 14:6 (June 1980), pp. 37-41. No refs. Application of Heyser's measurement techniques to "the interface of electroacoustic sources with architectural spaces." Very useful for control of boundary effects or reflections.

Everest, F. Alton. *Helmholtz resonators for studio use.* ***Recording Engineer-Producer*** 11:1 (February 1980), pp. 60, 62, 64, 69-73. 10 refs. Control of reverberation time & room modes in the 50 to 250Hz range, where porous absorbers are not effective. For further discussion at a more elementary level, see the author's book, *How to build a small budget recording studio from scratch...with 12 tested designs.* Tab Books, Blue Ridge Summit, PA. 1979. 335 pp. $12.95 bound; $8.95 paper. Tab order No. 1166.

Rettinger, Michael. *A live-end environment for control-room speakers.* ***db*** 14:6 (June 1980), pp. 42-43. 1 ref. Disadvantages of an absorbent environment near control-room speakers.

Rettinger, Michael. *the LEDE acoustical concept.* ***Recording Engineer-Producer*** 11:2 (April 1980), pp. 14, 16. 6 refs. Reservations about the new studio designs based on LEDE (live-end, dead-end) methodolgy.

Woram, John. *Books on architectural acoustics for the would-be studio designer.* ***db.*** 14:6 (June 1980), pp. 54-55. No refs. 8 books discussed.

(8) HORNS

Cho, Y.C. *Rigorous solutions for sound radiation from circular ducts with hyperbolic horns or infinite plane baffle.* ***Journal of Sound and Vibration*** 69:3 (8 April 1980), pp. 405-425. 20 refs, appendices. "The solutions are valid for the whole frequency range including frequencies above and below the cut-off frequencies of the duct modes involved."

Salava, Tomas. *Measurements of the input impedance of loudspeaker horns.* ***Audio Engineering Society,*** 65th convention, preprint No. 1587. Two methods are described, and measured results from conventional and constant-beamwidth horns are given.

Shure Bros., Inc. *Loudspeaker horn with adjustable angle of dispersion.* U.S. Patent No. 4,194,590. *Official Gazette of the United States Patent & Trademark Office,* March 25, 1980, p. 1251. A 60° horn within a 120° one; a valve in the throat determines whether the smaller horn or both horns are used.

(9) METHODS OF BAFFLING WOOFERS

Mahul, Jacques. Principe de la ligne acoustique et applications. ("The acoustical line: theory and applications") ***L'Audiophile*** 16 (June 1980) pp. 35-43. (in French) 2 refs. Largely consists of discussion of two important articles on transmission-line baffling, by A.R. Bailey (*The Transmission-line loudspeaker enclosure,* ***Wireless World,*** May 1972, pp. 215-217) and by Robert Fris (*The Daline, a decoupled anti-resonant line loudspeaker,* ***Hi-Fi News and Record Review,*** Nov. 1974, pp. 117, 119, 121, 123; *Daline plus B110,* ***HFN***, May 1975, pp. 77, 79, 81, 83, 85, 87; revision of crossover in ***HFN***, Oct. 1975, p. 182).

(10) PROFESSIONAL SOUND SYSTEMS

Electro-Voice, Inc. *The PA Bible; addition No. 6—the constant-directivity white horn paper.* Pp. 4. No refs. See *Loudspeaker Literature* No. 1, rubric No. 10, for the basic guide and the first five supplements. Cf. the paper by D.B. Keele, Jr., then of E-V, *What's so sacred about exponential horns?,* ***AES*** preprint No. 1038 (1975).

(11) CONSTRUCTION PROJECTS

Atkinson, P. *A 'Midi-Line' transmission-line design.* ***Hi-Fi News & Record Review*** 25:6 (June 1980), pp. 74-75, 79. No refs. Construction article for a speaker intermediate in size between Atkinson's two-way 'mini-line' (***HFN***, Nov. 1978, pp. 124-127) and his four-way, five-unit 'State-of-the-art loudspeaker' (***HFN***, April 1976, pp. 73, 75, 77). Uses three Dalesford units & the KEF DN12 network in a very complex cabinet.

Linkwitz, Siegfried. *A three-enclosure loudspeaker system with active delay and crossover: Part 1.* ***Speaker Builder*** 1:2 (May 1980), pp. 12-18. 6 refs. Revised from original article published in ***Wireless World*** (May 1978, pp. 52-56; June 1978, pp. 67-72). Important, among other things, for treatment of radiation patterns.

Lipschutz, Heinz. *A below-resonance loudspeaker.* ***Hi-Fi News & Record Review*** 25:4 (April 1980), pp. 61-63. No refs. Four KEF B139 woofers in a very small enclosure with resonance at 110Hz; use of additional DC biasing coils to compensate for excessive stiffness of the enclosed air.

Sanders, Roger R. *An electrostatic speaker system, part 1.* ***Speaker Builder*** (May 1980), pp. 20-29, 36. No refs.

Weems, David B. *21 custom speaker enclosure projects you can build.* Tab Books, Blue Ridge Summit, PA. 1980. Pp. 251. $12.95 hardbound; $7.95 paper. Standard book Nos. 0 8306 9962 7 and 0 8306 1234 3, resp. Tab order No. 1234. Will be good for those who find Weem's earlier book, *How to design, build, and test complete speaker systems (1978),* too difficult and who need practical advice and tips for construction procedures. Less good for others who would object to use of cheap drivers and general-purpose crossovers and who are concerned with the subtleties of speaker design.

(12) STEREO, AMBIENCE, AND SURROUND SOUND

Cooper, Duane H. and Jerald L. Bauck. *On acoustical specification of natural stereo imaging.* ***Audio Engineering Society,*** 65th convention, preprint No. 1616. Takes into account the diffraction of sounds around the head; flat frequency response is apparently incompatible with natural imaging.

Gerzon, Michael. *Practical periphony: the reproduction of full-sphere sound.* ***Audio Engineering Society,*** 65th convention, preprint No. 1571. "Periphony is the recording and reproduction of a full sphere of sound directions covering the whole of 3-dimensional acoustical space." This paper discusses decoding periphonically encoded recordings made with the soundfield mic.

(No author given). *Application note; bucket-brigade delay-line enhances sound reproduction.* ***Electronic components and applications*** 2:2 (Feb. 1980), pp. 80-82. Two refs. Use of the Philips TDA 1097 device with 1536 "buckets" to achieve delay up to 75ms with no insertion loss.

(No author given). *Periphonic sound: first public demonstration of periphony at AES convention. Wireless World* 86:1533 (May 1980), pp. 50, 75. No refs.

(13) HEADPHONES

(14) MISCELLANEOUS AND UNCLASSIFIABLE

Baxandall, Peter J. *Loudspeakers as high-quality microphones.* ***Audio Engineering Society,*** 65th convention, preprint No. 1593.

Bullock, Robert M. *Loudspeaker Design Cookbook. Speaker Builder* 1:2 (May 1980), pp. 30, 32. 5 refs. Review of *Loudspeaker Design Cookbook*, available from Speaker Research Associates, 1505 S.E. 32nd St, Portland, Oregon 97214. Both review and book were the subject of critical commentary in a letter from Richard Saffran published in ***Speaker Builder*** 1:3 (Sept. 1980), pp. 40-41.

Miller, Ron. *Speaker Books.* ***Speaker Builder*** 1:2 (May 1980), p. 30. No refs. Very brief reviews of 4 books: G. A. Briggs, *Cabinet Handbook* (out of print, still available for $6.95 from Old Colony Books), Alexis Badmaieff & Don Davis, *How to build speaker enclosures* (1966, $4.95, Sams order No. 20520). Abraham Cohen, *Hi-Fi Loudspeakers*

Continued on page 27

Old Colony KITS

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

CROSSOVERS

ELECTRONIC

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

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

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

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

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

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

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

PASSIVE

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

FILTERS & Speaker Saver

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

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

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

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

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

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

SYSTEM ACCESSORIES

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

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

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

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

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

BENCH AIDS & Test Equipment

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

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

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

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

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

E-2: JUNG REGULATED POWER SUPPLY. ±15V @ 1.5A. [4/74] Lab quality device but excellent for powering system components. Includes board, all board mounted parts plus two LM395K regulators. Transformer and filter caps not included. Each **$35.00**

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

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

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

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

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

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

PROPOSED KIT: Linkwitz Crossover. Those interested please send your name and address on a postcard. Probable price, one channel **$70.00**

ORDERING INFORMATION

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

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Tools, Tips & Techniques

TUBE TIP

I have noticed, in speaker building articles in your publication and others, the usage of cardboard mailing tubes recommended for making ports in reflex-type enclosures. I suggest trying some PVC pipe, which is readily available at most lumber yards. It would probably cut a little smoother than cardboard, and would be a cinch to "dress" once installed. I have found that by putting a generous amount of PVC glue on the pipe (being very careful not to breathe the fumes and avoiding contact with the skin), that it will glue nicely to wood as it actually seems to melt the pipe. Of course, a snug fit is recommended.

After the glue has set, you can sand off any rough edges and paint it any desired color. One can usually purchase PVC pipe in 1½", 2", 3" and 4" diameters, and it is actually cheaper than cardboard tubes. For example, as of today, our local blueprint shop wanted $1.75 for a 2' length of cardboard mailing tube, and a 10' length of the same diameter PVC pipe was $4.29. And that 10' length would be a lifetime supply of reflex ports!

Glenn J. Behrle
Milford, CT 06460

FINDING f_b

Measuring the resonant frequency of a ported enclosure (f_b) involves finding the minimum of a broad, shallow impedance trough. This is difficult to do accurately and repeatedly. In addition, the frequency of minimum impedance usually does not correspond exactly to f_b; there is an error due to box losses.

These problems are circumvented if f_b is measured as the frequency of minimum diaphragm motion, rather than minimum impedance. The technique is the same as that for near-field measurements. Place a microphone as close as possible to the cone, and read the output on a voltmeter. Sweep the drive signal around the expected f_b until you find the frequency of minimum output; this will be very sharply defined. This is the true value of f_b, and needs no correctionfor box losses.

Richard Saffran
Ann Arbor MI 48104

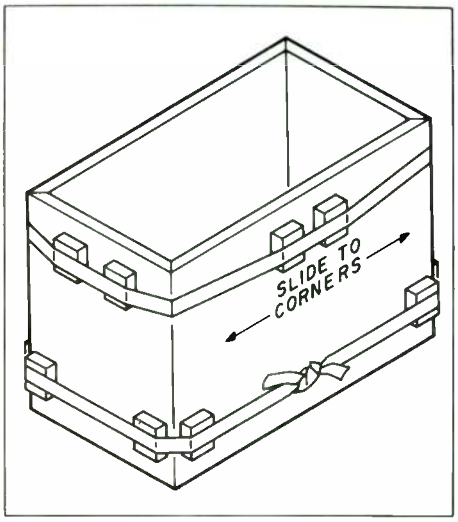
KICKBOARDS & DAMPERS

One big problem in building your own loudspeakers is locating sources of materials. *Speaker Builder* goes a long way towards solving the problem but herewith are two minor suggestions.

Closed cell foam kickboards alone or in combination with other materials are an economical way to get some speaker/floor isolation. The boards raise the cabinet a couple of inches and can be sawed to size and pointed for cosmetics.

A cheap source of thick felt for diffraction control can be had by cutting the back off an ordinary blackboard eraser. The 31" wide strips can be easily split to desired thickness.

Brian Dettling
Akron, OH 44304



GLUE GUIDE

To assemble rectangular cabinets with miter joints at all corners, obtain a length of seat belt material (often available thru surplus outlets). Any other non-elastic belting material will also work. The length will have to be at least 12" longer than the circumference of the boxes. Eight feet is a handy length for boxes up to the size of Advents. You will need two lengths for most boxes.

Glue the joints and using props, (paint cans or whatever is handy) stand the sides on your work bench and wrap the belt tightly around the box. The joints will come together loosely. Tie a square knot in the belt. Repeat with the second belt is the box is over 6" deep. To focus adequate pressure on the miter joint until the glue dries, slide small wooden blocks under the belt and out to the corners. If you do not have a consistently tight flue line, use slightly larger blocks. I have used this technique at least fifty times and have never had a joint break apart.

Rion Dudley
Seattle, WA 98119

Literature

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and Enclosures (1968, $8.95, second revised edition, Hayden order No. 07213), and David B. Weems, *How to design, build and test complete speaker systems* (1978, $7.95 paper, $10.95 hardbound, Tab Books order No. 1064).

Preis, D. *Measures and perception of phase distortion in electroacoustic systems.* ***IEEE International Conference on Acoustics, Speech, and Signal Processing,*** held Denver, CO., April 1980, pp. 490-493. 15 refs. Studies phase and group-delay distortion; "a frequency-dependent tolerance on group-delay distortion is developed based on numerous perceptual studies."

Recklinghausen, Daniel R. von. *Dynamic equalization for loudspeakers.* ***Audio Engineering Society,*** 65th convention, preprint No. 1617. An analog electronic control circuit adjusts the input signal to prevent distortion and damage to the driver. The author is with KLH Research and Development.

White, Frederick, E. and D.C. Teas, editors. *References to contemporary papers on acoustics.* ***Journal of the Acoustical Society of America*** Vol. 67, supplement 2, summer 1980. A classified bibliography of current literature on acoustics (1977-early 1980). Section 43.88J (pp. 303-4) covers "loudspeakers and horns; section 43.88M (p. 305) "Sound recording and reproducing systems, general;" and section 43.88T (p. 307), "Public address systems."

With this issue of *Loudspeaker Literature,* five new journals have been added to the periodicals list given last time. These new journals are given below. Each journal on the list will be consulted issue by issue, beginning with January, 1980. Most of the important articles will be picked up later by one or more indexing and abstracting journals, but if each issue is scanned as it comes out, relevant articles can be cited here much more quickly and reliably.

The Audio Engineering Society preprints mentioned in some of the notices above consist of unrefereed papers given at the Society's 65th annual convention, held at London, February 25-28, 1980. Some of these papers will be published in the ***Journal of the Audio Engineering Society.*** Copies of all the preprints are available for $2.50 each ($2 to members) from:

Audio Engineering Society
60 East 42nd Street
New York, NY 10017

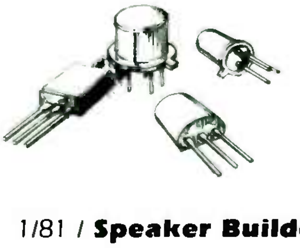
NEW PERIODICALS

Applied Mechanics Reviews
American Society of Mechanical Engineers,
345 East 47th St.
New York, NY 10017. $250. Monthly.

New technical books; a selective list with descriptive annotations. New York Public Library, Science and Technology Research Center, 5th Avenue & 42nd St., New York, NY 10018. $7.50 Monthly (except Aug. and Sept.)

Recording Engineer-Producer
Box 2449
Hollywood, CA 90068. $9 Bi-monthly.

Shock and Vibration Bulletin and ***Shock and Vibration Digest.***
U.S. Naval Research Lab, Shock and Vibration Information Center, Washington, D.C. 20375. The former is an annual, n60; the latter monthly, $100.



Craftsman's Corner

The Phase Concept Model VII

by Tom Hayward

THESE ENCLOSURES ARE quite large (49½ x26x16), but their attractive appearance and sonic attributes are worth the construction effort.

Construction drawings (*Fig. 1*) and crossover schematics (*Figs. 2a* and *2b*) are shown using easily obtainable parts and networks, however, we have made some modifications in the crossover point between the woofer and mid-range drivers. The change is not essential, but we noted improvements in the bass "tightness" in our particular listening room. We added 30 turns of 18 gauge enameled wire to the woofer choke (lowering the bass roll-off to 575 Hz. We also added a 2μF non-polar capacitor in parallel with the 22μF shown to lower the mid-range units to cover the gap.

The photographs indicate an additional two ¼" phone jacks attached to our plexiglass terminal board for the future installation of Tri-Amping if desired. Of course, five-way binding posts may be used in lieu of ¼" jacks, if preferred.

Initial listening tests amazed us with respect to imaging definition and clarity. A real-time analyzer indicated virtually flat response except in the 60–100hz range which has always been a problem in our particular room. This range was up about 2dB, but was next to inaudible in our "hearing tests." We were so pleased that we called several of our "purist" friends to compare what we were hearing to their systems.

Bringing in a pair of Dahlquist DQ-10's, a pair of Vandersteins and a pair of Infinity 4.5's, we assembled a panel of judges to make some fair evaluations. The Model VII's received majority votes of preference over the DQ-10's and the Vandersteins and were equally divided between the Infinity 4.5's. I'm not really sure what this might prove, except that five individuals agree the Model VII's have an excellent sound.

For those interested in the other units used in the test link: they consisted of a Marantz 6300 direct-drive turntable (standard arm) with a Shure V-15 Model 4 cartridge, an Audio Research SP-3A preamp and a Hafler DH-200 Power amp.

Photo 1. Front view of the completed Model VII.

The drivers in the Model VII consist of:

1- Eminence 15QFHL-8G 15Hz free-air resonance 50 oz. magnet, freq. response 16–2000Hz, 95 watts RMS, 180 watts peak. $32.50.

4- BP Electronics 1000-6 Full range 6" speakers, freq. response 50–15Hz. $6.95.

1- Long Engineering Inc. L-15F tweeter 2–22Hz, 4", 50 watt. $11.95.

1- Motorola Piezo electric tweeter (flush flange) 35V RMS input max. $6.50.

1- McGee MG-S-1033 700Hz and 4500Hz crossover. $14.95.

All of these units except the 15" 15QFHL-8G are available from McGee Radio Electronics. We order the low frequency woofer from Eminence direct, and we will be happy to supply any builders at the above cost (plus UPS).

Materials cost (including drivers) should run the constructor no more

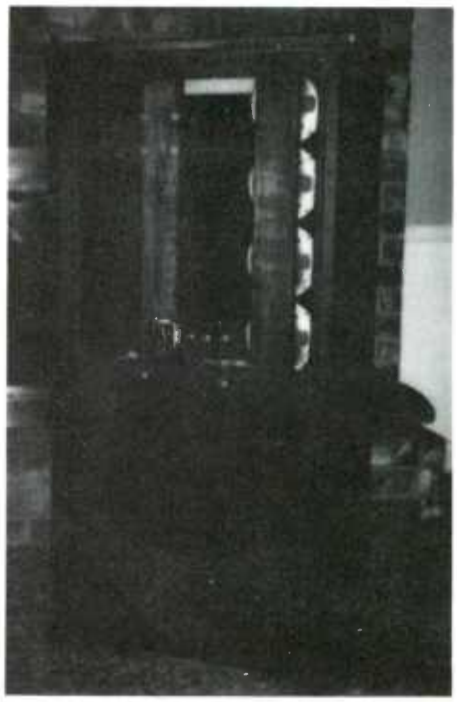


Photo 2. Overall rear view of the Model VII.

than $150 per cabinet which is more than reasonable considering their comparison to store units costing $450. up each.

☐

Model VII Construction Hints

Use ⅝" particle board for cabinet and assembly except top and bottom, which are ¾" birch finished particle board with birch veneer tape on edges. Tape has a heat sensitive reverse side and may be ironed onto the side surfaces.

Stain and varnish top and bottoms to finish desired.

Woofer is bolted to interior 14¼" baffle board with 10-24 bolts and tee-nuts. Outside hole is 15¼" to allow woofer to front mount without protruding past front surface.

All surface except rear is covered with black burlap pulled tight and anchored under walnut-stained strips shown in *photos 2, 3,* and *4.* Rear surfaces are routed vertically ⅛" deep and 1" wide full length of cabinet to accommodate ⅞" walnut anchor strip screwed into back every 4" by ¾" phillips countersunk screws.

All vertical edges are routed with

Continued on page 32

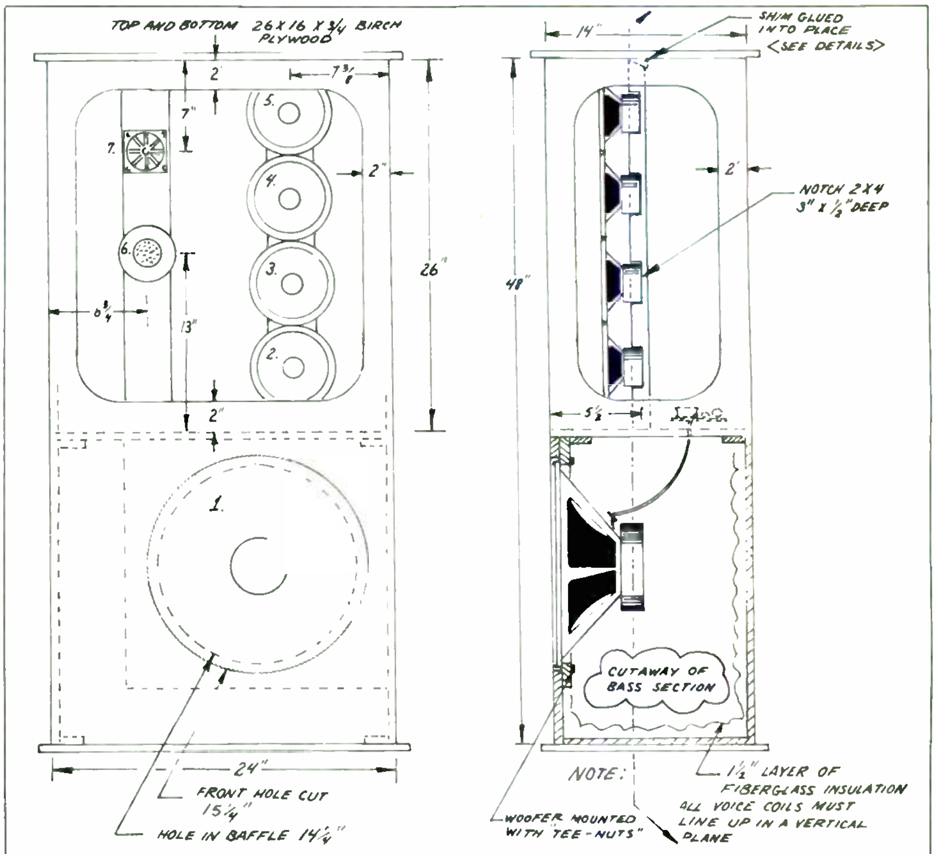


Fig. 1. Front and side views of the Model VII. Drawings by the author. Note the alignment of the voice coils of all drivers. Speaker units should be mounted in mirror image fashion for left and right versions. Woofer is off center to avoid diffracttion.

SB Mailbox

BUILDERS AHOY

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

LOVE & HARD WORK

IN REPLY to your editorial comment, "Love and Marketing" (4/1980), may I say that part of Acoustic Research's success is a result of Teledyne's unique way of blending the entre-preneurial style of its management team with the business disciplines necessary to succeed in the hard, real world of today. The other part of our success lies in the continued skill and dedication of everybody who works in the company.

RON W. FONE, President
Teledyne Acoustic Research
Norwood, MA 02062

WAVE LENGTH VS. FILTER THEORY

I AM VERY PLEASED to read Mr. Carlberg's letter (*SB* 3/80), as we seem to have arrived to the same conclusions about a couple of points concerning Mr. Linkwitz's speaker system. I find it extremely interesting as we never have met, and we live hundreds of miles apart. This confirms my belief that with careful listening, much can be agreed about.

Having a biamped system similar to Mr. Linkwitz's (Rogers LS/35As and a pair of home built bass units utilizing the KEF B139 drivers), I feel I am in a position to critique Mr. Linkwitz's design approach on a couple of points.

I am still a bit confused about the route that Linkwitz took in designing his bass speakers, even though he seems to be quite familiar with the filter synthesis data papers from both Small and Thiele.

I firmly believe, since I have had actual practical experience with the B139 LF drivers, that his bass unit with such a high cutoff point and consequent high Q, cannot, by what Small's theory predicts for sealed systems, sound accurate. Even if he equalizes it, a Q of 1.2 will have a detrimental effect throughout its assigned frequency response. Transient response will also be compromised. I realize that he is concerned about the piston range linearity of the B139 drivers and the reasons why he wants maximum linearity and low distortion by such a cutoff point and Q factor, but actual, real-world performance is impaired.

A low system Q (.5) stands a better chance for equalization, since it seems to roll off slower than a higher Q and thus lift or boost is easier to achieve. However, greater distortion can be heard, power handling is worse, mid bass is compromised, voice coils bottom easier, and subjectively, bass performance tends to be rather poor, sounding thin and lacking in impact. Bass lines sound "dry" and somewhat over tight (in other words, bass is underdamped). Though a low Q allows a lower cutoff point, extreme low frequencies are highly attenuated.

The other side of coin is true for bass systems having a high Q factor; bass will always sound over prominent, boomy, overdamped, uncontrolled, with poor transient response. He would have optimzied his speakers, and would have made it much simpler for potential builders, I feel, if he had designed them applying the Small data for sealed systems instead of using wave length theory.

The correct Q for a dynamic driver enclosed in a box is a factor of .707 (corresponding to a "Maximally Flat" filter). This is true for both vented and sealed systems. For other types of loadings it may not be true, but that may be questionable and subject to debate. If there is one theory which predicts a correct performance, and correlates quite nicely with the listening experience, that has to be the filter synthesis theory from Thiele and Small. With the possible exception of impulse testing, as suggested by Richard Heyser, there seems to be no other measurement or theoretical prediction which truly correlates with the aural perception of the human ear of the reproduction of music via an audio system.

A proper and correct alignment of the KEF B139 LF drivers in a sealed enclosure is the "B2" alignment from Small. This yields a cutoff point of 47.8Hz, with a Q of .707.

Using the driver's data provided by KEF, and using the Small B2 alignment, the following formulas can be used:

$$Q_{tco} = .707; \frac{Q_{tco}}{Q_{ts}} = \frac{.707}{.37} = 1.911 \text{ liters} = F_c$$

$$= F_3 = F_s\,(1.911) = 47.8\text{Hz}\,(a+1) =$$

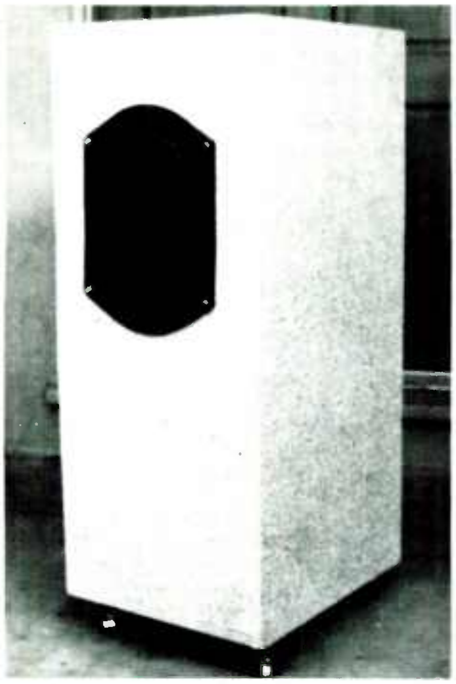
$$1.911 = a = 2.651 = V_{ab} = 164/2.651 =$$

61.9 liters or 3800 cubic inches (2.19 cu. ft.)

It is somewhat unfortunate that even these excellent drivers cannot respond to a lower cutoff point with a .707 Q factor, enclosed in a sealed box. It's possible to obtain a −3dB point of 25Hz on a vented system, but that is beyond the scope of the present discussion.

It is possible to lower the −3dB or resonant point of these drivers in sealed boxes somewhat, and still maintain a sonic level of excellence with the only penalties of compromising power handling capabilities a bit, and somewhat more distortion, by simply increasing the internal volume of each enclosure to a reasonable degree.

It may be of some interest to some *SB* readers to have a description of the bass system I designed (with the kind help of some friends!) to add more octaves of bass to the pair of Rogers LS3/5A monitors. A cutoff point of 47.8Hz though having an ideal Q factor of .707, was not totally



satisfactory for me. I opted to increase the internal volume so that the −3dB point be lowered to 38-39Hz in order to obtain a flat response of 41-42Hz, and still have Q around .7. The internal volume was increased from 3800 cubic inches (2.19 cu. ft.) to 5170 cubic inches (2.99 cu. ft.) in each box. The final total figure takes into account the displacement of volume by the driver, bracing, and damping material used for each panel wall. The effective internal volume is around 2.5 cubic feet.

Overall dimensions of each box are 33½"H x 13¼"W x 15"D, using ¾" high density particle board. Front and rear panels were mounted flush in each box. 1" x 1" battens were used to form a frame inside each box (see photos). For wall damping I used roofing felt material sprayed liberally with car underseal compound. I let this compound dry several days to allow any gas to evaporate to avoid damaging the B139 rubber suspension system.

About 1 Lb. of Dacron pillow stuffing material was used in each box in order to mitigate the effects of standing waves from interacting with the driver. When finished, each enclosure is quite rigid and acoustically dead. Also, each B139 driver was mounted to the front panel with a compliant material to avoid exstraneous vibrations from interacting with the main output. Severl ounces of caulking rope were applied to each driver's inner frame and magnetic structure to dampen vibrations.

The photographs show the method of construction. When these were taken I had not totally finished the bracing and damping of panel walls. Two additional braces running the length of depth of the enclosure from the rear to the front panels were added before installing each front panel.

Listening to the final results of my involved and time consuming efforts proved to be a worthy affair. The fine bass performance derived from the larger enclosures is remarkably articulate, almost tactile. There is good definition of bass lines, and these are well controlled and tight. The power of resolution is indeed excellent; These bass units can let one hear the vast differences of bass contained in different source material. Extension is good down to 40Hz, but lower frequencies are somewhat attenuated (due to the second-order roll off rate of 12dB per octave).

These bass units blend remarkably well with the LS3/5A monitors, a feat not easily achieved in view of the latter system's excellent transient response. Crossed over at no higher than 125Hz, these two systems offer a performance that is hard to equal, and at a reasonable cost, as well.

I believe that these bass units can be successfully used with other speakers of similar performance to the LS3/5As.

I have one caveat for bass freaks: Extremely high sound pressure levels cannot be achieved by these units without voice coil bottoming and possible permanent damage. One can feel bass lines that have true fundamental notes, but don't expect to peel paint off of walls, nor shake the house down. The limitations inherent in the design, and the limitations set by the drivers themselves do not allow this to happen without serious penalties! For the great majority of signal sources, however, these units are more than adequate, offering an excellent sonic performance.

Another point on which neither I nor Mr. Carlberg agree with Mr. Linkwitz is the matter of using a summed bass system. Mr. Carlberg is right in pointing out that Linkwitz's bass unit cannot perform optimally placed where it is. For proper localization and proper bass propagation, bass enclosures must be free-standing. I would add that using a summed bass output will compromise and deteriorate the overall image within the sound field. Though many argue that frequencies below 100Hz are non-directional, some have already found out (and I can aurally perceive it) that even at frequencies as low as 70Hz; the image of the sound field is markedly affected if only one bass unit is utilized in a monoaural or summed mode.

Whatever the benefits resulting from summing may be, these are lost when one seriously compromises the image. Sonic effects such as poor localization of low frequency sound sources, blurred images (yes, even low frequency producing sources have a definite image), and the improper reproduction of low frequency ambience and reverberation, among other things, will occur.

I would like to ask fellow readers just how many discs (or tapes for that matter) have well balanced channels, and good bass blend? Very few indeed! One must realize that the great majority of discs are a very weak link in the audio chain, and with current sloppy quality production, they are far from perfect. I believe those who hear a reduction of noise by using a summed bass system are hearing extreme supression of low frequency ambience.

It's true, however, that subsonic disturbances will tax the power input capabilities of a given audio system, the resultant distortions proceeding from this problem, and the potential of irreparable damage to some or all components. But let us attack the problem at its root! Any one experiencing severe subsonic disturbances should use a good filter. This one should be a stereo type. In most cases, extreme precautions must be taken to isolate a disc playback system from airborne and mechanically induced feedback. Tables should have no

Mailbox

audible rumble, and proper interface between tone arm and cartridge must be taken care of.

The one thing left which is really beyond our power to solve, is the matter of warped discs. We consumers should put greater pressure to disc manufacturers so that these provide us with quality material, and not the current highly priced garbage which they market for our consumption. That is the root of subsonic problems!

I am not in a position to answer any one who manages to find errors in the formulas given for my bass units' design. I leave it to the more industrious among the *SB* readers to come up with the corrections necessary if needed. I felt impelled to relate my personal aural experiences to *SB* readers, and to offer a viable alternative to the Linkwitz design. It is not an ego trip on my part to offer the foregoing. It is instead an attempt to show that most of the time, simplicity is a better route. Let us remember that accuracy is not a matter of taste!

FRANK J. MANRIQUE
Redlands, CA 92373

KEF CROSSOVER DATA

THE FOLLOWING MAY ASSIST contributor Mr. Ballard (*SB* Mail Box 3/1980):

1. KEF's specified crossover frequency for this combination is 3.5kHz. Mr. Ballard's calculated point of 2.3kHz appears to be in error and it may be that he has used theoretical values as opposed to the practical values which would be determined by measurement. The usual pitfall here is to calculate on the assumption of an 8Ω drive unit. A practical drive unit however would rarely exhibit an impedance of 8 ohms at crossover frequency but may vary by one or two hundred percent!

The curves below, prepared by Malcolm Jones of Falcon Acoustics Limited, illustrate this effect quite well. The drive units are the Sonaudax HD20B25H4 8" woofer and the HD129D25 1" soft dome tweeter. *Figures 2* and *4* are curves taken with the Falcon network No. 19 (Badger Sound Services Limited type CN 121) and the smooth, well

Craftsman's Corner

Continued from page 29

¼" round router bit allow burlap to wrap smoothly around cabinet.

Notice that woofer is mounted off-center to avoid standing waves and as high as possible to eliminate any "boominess" from loading into floor surfaces. Use 1½" of fiberglass insulation on inside of woofer enclosure to dampen mid frequencies. Furring strips assure good glue joints to top and bottom of cabinet. Drill ¼" hole for wires from woofer to crossover. Fill in any remaining air-leaks in woofer cavity with an even bead of silicone or butyl caulking.

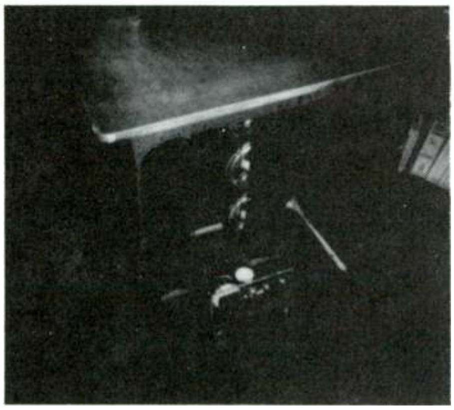


Photo 3. Top, rear view of Model VII showing the plexiglas input panel and tweeter/midrange mount details.

All voice coils must be lined up in a common vertical plane to avoid phase cancellation and distortion.

Mark the top of the woofer enclosure precisely with pencil so that midrange and tweeter supports may be voice-coil aligned. Supports or struts are made from 2x4's cut 1" short to allow fitting them into place in top section. Cut at an angle and cut shims at same angle to assure tight glue support of struts at top and bottom.

Mid-range strut has 3" by ½" dadoed cuts to allow epoxy gluing of 6" drivers to these insets. Cuts should be measured by setting all four 6" drivers on their magnets end to end where outer edges of metal basket frames barely touch. L-15F tweeter is epoxy glued directly to second strut, but piezo-electric tweeter is attached using 2⅞" spacers, 5"-10-24 stove bolts and 10-24 tee-nuts. See picture #4.

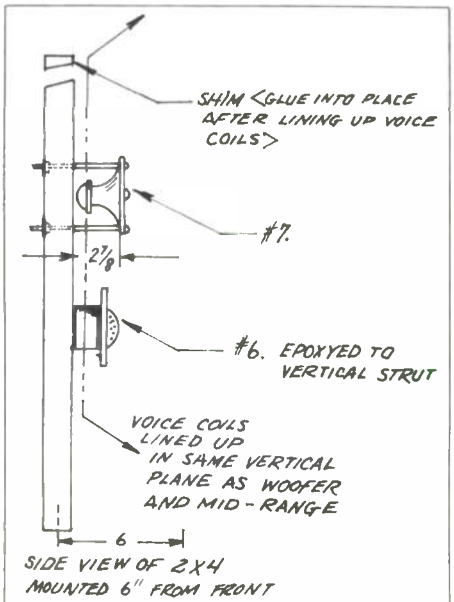


Fig. 2a. Alignment procedure of two tweeters.

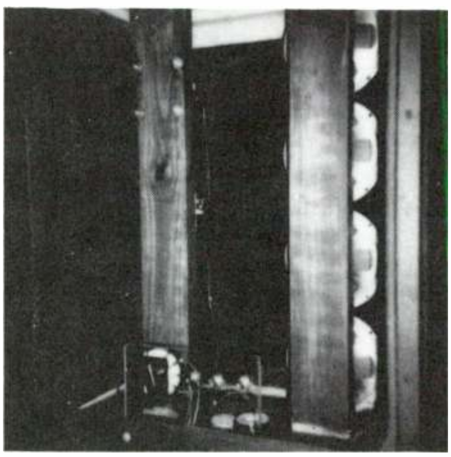


Photo 4. Closeup of input panel.

Midrange drivers are wired in series, parallel to present an 8 ohm load to the crossover.

Patience and care in installing burlap grill-cloth will prevent any sags or folds, but if a slight sag should appear within the first week after assembly, dampening the burlap with a wet rag evenly will cause the sags to disappear. □

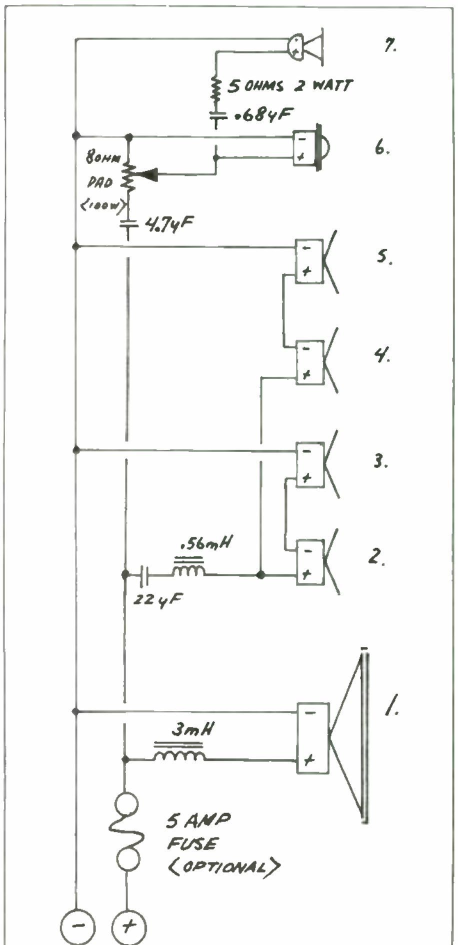


Fig. 2b. Crossover network schematic. See text.

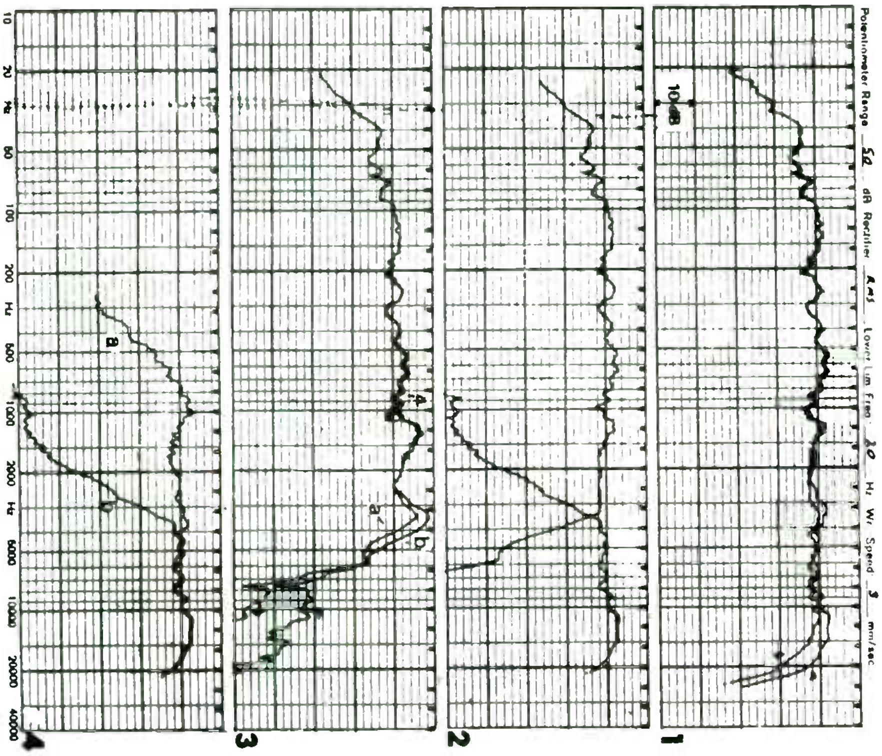


Fig. 1. Overall frequency response curve (a) on axis and (b) 30° of axis.
Fig. 2. Frequency response curve of each drive unit through crossover network, showing unit integration.
Fig. 3. Frequency response of bass/mid drive unit (a) without crossover (b) with 'theoretical' crossover.
Fig. 4. Frequency response of tweeter (a) without crossover, (b) with crossover.

integrated behavior of the combination is apparent.

Figure 3 however illustrates the behavior of the drive units (a) without a crossover and (b) with a "theoretical" network calculated on the assumption that the drive units were a constant 8Ω impedance. It will be seen that the behavior of this "theoretical" system is inferior to the system with no network at all. I am indebted to Falcon Acoustics for permission to publish these curves.

2. The tuned circuit consisting of the 2mH inductor and the 16μF capacitor also contains a "hidden" resistor. The 2mH inductor is wound from five guage wire offering a high DC resistance of about 6.5Ω. Mr. Ballard appears to have overlooked this unseen resistance and consequently the impedance of the circuit cannot become nearly zero.

3. The 10Ω resistor in series with the 10μF capacitor used in the Webb crossover performs a different function. This is a Zobel network whose purpose, in parallel with the driver, is to present to the amplifier a more resistive load than would otherwise be the case. In the case of the KEF DN13 the 2mH inductor, 16μF capacitor and the inductor's internal 6.5Ω DC resistance form a tuned circuit whose purpose is the correction of midband response.

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England

BOXES, PORT & FUN

I read Part I of Robert Bullock's series on vented-box loudspeaker design with great interest. I have a few comments that may be of interest to your readers. I work as an engineer for a Boston area speaker manufacturer, and all of our present products are closed boxes, but I wrote my M.F.A. thesis on applied vented box design and of course we evaluate our competitors' products, so I'm only moderately biased.

Closed-box designs have several advantages for consumer high-fidelity speaker manufacturers that should at least be understood by amateur builders. For starters, woofer suspension compliance, more than any other driver parameter, unavoidably varies in manufacturing, and is even difficult to measure consistently or accurately. (For more on which, see B.J. Elliott's two Audio Engineering Society papers on the subject.) Compliance definitely can vary with number of hours of use, and may vary with other engineering parameters, like maybe the phase of the moon. Closed-box designs are more tolerant of shifts in driver compliance, or (for amateurs) some inaccuracy in establishing exactly what it is.

The oft-repeated Thiele-Small comparison between closed-box and vented-box designs (i.e., comparatively, vented designs give more efficiency, a lower f_3, and/or a smaller enclosure) is only fully true if you control not only the box design but the woofer design, and can be misleading even then. Thiele and Small are reputedly both nice guys, but they were writing for us manufacturing types, and they might as well have come right out and added "or lower woofer cost."

Now what does that all mean, you ask? Sensitivity is what you listen to, not efficiency, assuming that you design single-woofer direct-radiator systems at reasonable 6-ohm-or-so resistances. Woofer sensitivity is a low-midrange behavior. Up there, the box type doesn't matter, on axis—the driver's motor, suspension and cone are it. Thus a given driver will have the same sensitivity in either a closed or vented box.

The efficiency advantage is obtained by redesigning the woofer version for vented-box use to yield a higher f_3. With the same motor cost, this gives greater sensitivity. The vented box can then be configured to provide the missing response, down to the previous f_3. Alternatively, the vented-box woofer version can be redesigned to have the same sensitivity as its closed-box brother, but at lower cost by cutting down the motor strength.

Either way, there are potential problems: What does the bass sound like below the f_3, and does behavior there show up elsewhere? It may sound rather abrupt, and yes, if you play records. If the comparison is with the equal-sensitivity, skimped-motor vented-box version, what does the midrange sound like above the piston region? Not so good, for equal amounts of engineering tweaking.

Approach two, a lower f_3: here you use the same driver as in a closed-box approach, the vented box providing all of the f_3 gain. No problems with the mid range—it's the same. Also the same potential questions about the bass behavior below f_3. Approach three, a smaller box: same as above, but the box really is smaller, a benefit. On the other hand, the f_3 isn't lowered, so the greater rolloff rate and potential for modulation distortion come in at a higher frequency.

Bullock introduced the speaker-as-filter concept in Part I, and talked about the basic 4th-order filter character of vented boxes. Closed boxes are basically 2nd order. Thus, for equal f_3's, a closed box will have a gentler rolloff and a much lower f_{10}. I think that so many lay listeners have liked the low-end-performance-to-cost ratio ofclosed boxes over the years, not just because some of the comparable vented designs were misaligned, but because music sounds better through a less abrupt filter.

Also, basic vented boxes unfortunately don't adequately load their drivers at frequencies around which record warp and turntable and arm resonances tend to occur. If the amplification system isn't self—or deliberately rolled off, such subsonic signals can modulate the heck out of the above $-f_3$ signal. If the modulation travel is great enough, the woofer will spend significant regions through no fault of the desired signal.

Finally, some vented boxes leak low-level rear-of-cone midrange radiation out the port, obscurely phased and honk-filtered.

So, if I say vented boxes have these disadvantages, I'm some kind of a spoilsport, right? Yes and no. All of the disadvantages of vented boxes *can* be gotten around...if the resulting speaker can have an associated active filter circuit and can be designed for good-to-excellent performance, and if the resulting materials costs and labor requirements are acceptable.

Continued on page 36

CORRECTION:

Two signs became interchanged in formula (5) in Robert Bullock's article on Thiele/Small parameters in 4/80, page 13. The formula should read:

$$L = (1.463 \times 10^7 \times r^2)/(f_B{}^2 V_B) - 1.463 \times r \quad (5)$$

We regret the error. □

BOX TUNING: AGAIN

I see in Robert Bullock's article on bass reflex enclosures that he corrects my formula for box tuning (*Speaker Builder* vol. 1 no. 4). To set the record entirely straight, I would like to offer a correction to end all corrections, a much more accurate version:

$$f_b = f_{sb} * \left(\frac{0.34}{Q_{ts}} + 0.1\right)$$

RICHARD SAFFRAN
Ann Arbor, MI 48104

CORRECTION:

Mr. Bullock writes that there is a typographical error in R.H. Small's paper which went undetected before. The figures that were published in SB were calculated from the formula in Small's paper. Mr. Bullock checked the formula and found a coefficient of 28 which should be 128, obviously a typographical error. The differences, says author Bullock, are probably insignificant but accuracy is important too.

The revised tables appear below.—Ed.

TABLE I
SMALL ALIGNMENTS FOR $Q_L = 5$

Q_{TS}	h	α	f_3/f_S	Ripple (dB)
.2000	2.0014	7.5746	2.5914	
.2100	1.9080	6.7702	2.4566	
.2200	1.8232	6.0730	2.3332	
.2300	1.7459	5.4646	2.2198	
.2400	1.6751	4.9306	2.1151	
.2500	1.6101	4.4594	2.0180	
.2600	1.5502	4.0415	1.9276	
.2700	1.4948	3.6691	1.8430	
.2800	1.4434	3.3358	1.7637	
.2900	1.3957	3.0364	1,6889	
.3000	1.3512	2.7663	1.6183	
.3100	1.3097	2.5220	1.5514	
.3200	1.2708	2.3001	1.4877	
.3300	1.2344	2.0980	1.4269	
.3400	1.2003	1.9134	1.3687	
.3500	1.1681	1.7444	1.3129	
.3600	1.1378	1.5893	1.2592	
.3700	1.1093	1.4464	1.2074	
.3800	1.0823	1.3147	1.1576	
.3900	1.0568	1.1929	1.1095	
.4000	1.0326	1.0801	1.0632	
.4100	1.0095	.9757	1.0190	-
.4200	.9877	.8785	.9767	-
.4300	.9652	.7920	.9377	-
.4400	.9425	.7154	.9016	-
.4500	.9200	.6480	.8684	-
.4600	.8979	.5888	.8379	.01
.4700	.8766	.5370	.8100	.01
.4800	.8560	.4915	.7844	.02
.4900	.8364	.4516	.7609	.03
.5000	.8178	.4166	.7395	.04
.5100	.8002	.3857	.7198	.06
.5200	.7836	.3583	.7017	.08
.5300	.7680	.3340	.6852	.11

Q_{TS}	h	∝	f_3/f_S	Ripple (dB)
.5400	.7533	.3122	.6699	.13
.5500	.7394	.2927	.6558	.16
.5600	.7263	.2752	.6428	.20
.5700	.7140	.2592	.6307	.23
.5800	.7024	.2447	.6195	.27
.5900	.6915	.2314	.6091	.31
.6000	.6811	.2192	.5994	.35
.6100	.6713	.2080	.5903	.40
.6200	.6620	.1975	.5818	.44
.6300	.6531	.1878	.5738	.49
.6400	.6447	.1787	.5663	.54
.6500	.6367	.1701	.5592	.59

TABLE II
SMALL ALIGNMENTS for $Q_L = 7$

Q_{TS}	h	∝	f_3/f_S	Ripple (dB)
.2000	1.9393	7.7775	2.5289	
.2100	1.8494	6.9524	2.3968	
.2200	1.7678	6.2372	2.2759	
.2300	1.6935	5.6132	2.1647	
.2400	1.6254	5.0655	2.0620	
.2500	1.5629	4.5822	1.9667	
.2600	1.5054	4.1535	1.8778	
.2700	1.4522	3.7714	1.7946	
.2800	1.4029	3.4295	1.7165	
.2900	1.3571	3.1223	1.6429	
.3000	1.3145	2.8452	1.5732	
.3100	1.2748	2.5944	1.5070	
.3200	1.2376	2.3667	1.4439	
.3300	1.2028	2.1594	1.3836	
.3400	1.1702	1.9699	1.3258	
.3500	1.1395	1.7964	1.2702	
.3600	1.1106	1.6371	1.2167	
.3700	1.0834	1.4905	1.1651	
.3800	1.0578	1.3552	1.1153	
.3900	1.0335	1.2300	1.0674	
.4000	1.0103	1.1146	1.0215	
.4100	.9886	1.0070	.9777	-
.4200	.9662	.9113	.9373	-
.4300	.9436	.8266	.9001	-
.4400	.9212	.7521	.8660	-
.4500	.8992	.6868	.8348	.01
.4600	.8780	.6297	.8064	.01
.4700	.8578	.5798	.7804	.02
.4800	.8385	.5361	.7567	.03
.4900	.8203	.4978	.7351	.05
.5000	.8031	.4642	.7155	.07
.5100	.7870	.4345	.6975	.09
.5200	.7719	.4083	.6810	.12
.5300	.7578	.3849	.6659	.15
.5400	.7445	.3640	.6520	.19
.5500	.7321	.3453	.6393	.23
.5600	.7205	.3284	.6275	.27
.5700	.7096	.3131	.6166	.31
.5800	.6993	.2992	.6065	.36
.5900	.6896	.2865	.5971	.41
.6000	.6805	.2749	.5883	.46
.6100	.6719	.2641	.5802	.51
.6200	.6638	.2542	.5726	.57
.6300	.6561	.2449	.5654	.63
.6400	.6488	.2363	.5587	.68
.6500	.6418	.2283	.5524	.74

TABLE III
SMALL ALIGNMENTS for $Q_L = 10$

Q_{TS}	h	∝	f_3/f_S	Ripple (dB)
.2000	1.8960	7.9232	2.4845	
.2100	1.8085	7.0834	2.3543	
.2200	1.7292	6.3554	2.2351	
.2300	1.6569	5.7202	2.1255	
.2400	1.5908	5.1627	2.0241	
.2500	1.5301	4.6706	1.9299	
.2600	1.4742	4.2342	1.8421	
.2700	1.4225	3.8452	1.7599	
.2800	1.3747	3.4971	1.6826	
.2900	1.3303	3.1843	1.6097	
.3000	1.2890	2.9022	1.5406	
.3100	1.2505	2.6469	1.4748	
.3200	1.2146	2.4150	1.4121	
.3300	1.1809	2.2038	1.3521	
.3400	1.1493	2.0109	1.2945	
.3500	1.1197	1.8342	1.2390	
.3600	1.0918	1.6719	1.1855	
.3700	1.0656	1.5225	1.1339	
.3800	1.0409	1.3846	1.0841	
.3900	1.0175	1.2571	1.0363	
.4000	.9954	1.1390	.9907	-
.4100	.9732	1.0325	.9482	-
.4200	.9507	.9381	.9092	-
.4300	.9282	.8550	.8736	-
.4400	.9062	.7822	.8410	.01
.4500	.8848	.7187	.8114	.01
.4600	.8644	.6632	.7844	.02
.4700	.8451	.6148	.7600	.03
.4800	.8269	.5725	.7377	.05
.4900	.8097	.5355	.7175	.07
.5000	.7937	.5029	.6991	.10
.5100	.7787	.4742	.6823	.13
.5200	.7648	.4487	.6670	.16
.5300	.7517	.4261	.6529	.20
.5400	.7396	.4059	.6401	.24
.5500	.7282	.3877	.6282	.29
.5600	.7176	.3714	.6173	.34
.5700	.7077	.3565	.6072	.39
.5800	.6983	.3431	.5979	.44
.5900	.6896	.3308	.5892	.50
.6000	.6814	.3195	.5812	.55
.6100	.6736	.3092	.5737	.61
.6200	.6663	.2996	.5667	.68
.6300	.6594	.2907	.5601	.74
.6400	.6529	.2825	.5540	.80
.6500	.6467	.2748	.5482	.87

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*3DB FIGURE BASED ON APPROXIMATE DOUBLING OF DBS (DOLLAR POWER)

Mailbox

Continued from page 34

Amateurs can ignore or get around problems like those.

Manufacturers are subject to all sorts of immutable constraints on costs and market requirements. I marvel at the innocent ignorance exhibited by some amateurs (an occasional *SB* reader included) who react very negatively when a speaker designed and manufactured to offer as much or more value than the competition, and to be sold at the price point preferred by its potential customers, turns out not to have the same bits and pieces in it as another design, which costs more precisely because of those bits and pieces. The value-engineering and cost balancing that the better manufacturers go through to deliver all of the performance that can be squeezed out of a given model's price-set cost is extensive.

An amateur setting out to do a vented-box design should probably select a woofer with good midrange fidelity as high as it needs to go, with all of the usual requirements for motor, suspension and cone. It should have high sensitivity if the design is to have good bass dynamic range. Such a unit will frequently fit into a basic moderate QB3 alignment.

Design for a QB5 (or whatever), with the associated filter, to eliminate modulation distortion problems; and design for an f_3 sufficiently below the lowest content of your musical preference that the rolloff rate will not be an issue. Arrange the box and vent to avoid vent output other than as desired. Otherwise, design as usual. (The hard part.)

And, this being *SB*, have fun.

JOHN W. SCHAEFER
Boston, MA 02114

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FOR SALE: Heathkit IM-18 VTVM $40 and IG-72 sine wave audio generator $60. Both expertly assembled, with manuals, excellent condition, used very little. Bob Shafer, 8460 Marsh Road, Algonac, MI 48001. (313) 794-5400 any time.

WANTED: Dynaco A-50 stereo speakers. Harmon Kardon HK-12, HK-25 stereo speakers. Arnold Wabnick, 5502 14 Avenue, Apt. F-5, Brooklyn, NY 11219. (212) 438-5714. Evenings.

FOR SALE: Leach double barrell amplifier x-former and filter capacitors. Pass A-40 x-former and caps. KEF B-139's $140 pr. Infinity black widow arm $100. High voltage bias power supply for Sanders E.S.L.s $45. Micro-Acoustics MA 2002e cartridge $29. Kent Siegenthaler, 11805 102 Pl. N.E., Kirkland, WA 98033. (206) 823-2165.

FOR SALE: Webb TLS X-overs by Falcon, 2 Celestion HF-2000 tweeters, will separate. Make offer. Neil K. Disney, 1432 Wash. #4, Grand Haven, MI 49417.

FOR SALE: Dyna ST-416, $400; Koss Pro 4-AA phones, $20 ppd. Josh Hill, (212) 867-0330 days (212) 697-6949 evenings.

FOR SALE: Pair of Orthophase speaker systems. Each system contains a set of six uniquely designed flat drivers, mounted on a floor-standing 36x33¼ inch panel, which provides full-range crystal clear sound. Of French origin, still ahead of its time. $275 plus delivery. (201) 444-9587 evenings.

WANTED: Information on the John E. Karlson speaker system. Appeared in Audio Fair of Los Angeles before 1961. Robert E. Fabreguettes, Cours Du Vieux Moulin, Villa Le Patinage 05000 GAP France.

FOR SALE: ElectroVoice 30 inch woofer. Installed in horn loaded Patrician enclosure, with crossover for 100 or 200Hz. Weight 300 lbs. Must provide own transportation. $300. Ed Pelinski, 35 Chubb Rd., Framingham, MA 01701. (617) 875-4289.

FOR SALE: True discrete quadraphonic tape player, Lafayette Model RK-48A, plays 4 channel (or ordinary stereo) eight track cartridge tapes, with owner's manual and set of 22 tapes: demo/test, classical, rock, and jazz. $100 which includes UPS shipping prepaid. (You'll need to borrow an extra stereo power amplifier and pair of speakers for 4 channel effect, though it works fine in stereo without these extras). Dan Shanefield, 119 Jefferson Rd., Princeton, NJ 08540. (609) 639-2572. working hours.

FOR SALE: TEAC 2300S deck, needs heads, $200; Philips 673 tuner, exc. $300; JBL L-65 Jubal spkrs, $500/pr.; SME 3009-S2 arm, $75; call Dave (717) 244-1915.

FOR SALE: 1000 series Two Noise Reduction System, as new $245; Burwen TNE 7000 Transient Noise Eliminator, like new $200; Nakamichi 700-II Cassette Recorder, like new $750; Audio Amateur Vol. 9-10 (1978-79) $16; Altec 838A "Carmel" Speaker System, matched pair, excellent condition, can not ship $750. Darroch, 1807 Elm Crest, Arlington, TX 76012.

ADVERTISING INDEX

WANTED: Info & details for construction of replicas of the LS 3/5A; information for building an electronic feedback motor speed control for a Thorens TD-160; tone arm mods for same. Write M.K. Morgret, 1633 Targhee Dr., Twin Falls, ID 83301.

WANTED: Bozak B207A. FOR SALE: Jensen mid-range spkrs. model P8-RM mint. Pair $50 postage paid. Arthur D. Fisher, 723 N. Oakhurst Dr., Beverly Hills, CA 90210.

FOR SALE: Amber series 70 power amplifier $375; Amber pre-amp one $300; JA Michell hydraulic reference turntable w/Stax U-7M arm, Lescon power amplifier $400; RTR DAC-1 subwoofer $400; Kinetic Audio Stats $600 pr. All mint condition. Franco D'Ascanio, 11450 Overseas Hwy, Marathon, FL 33050. (305) 743-6336.

FOR SALE: DCM Time Windows, latest factory updates, with 8" stands, $500. Denon HA-1000, exc. sounding simple, $300. Walter Clark, 218 Harbor St., Branford, CT 06805. (203) 481-4857.

FOR SALE: Magneplanar Tympani 1U speakers, 6 panels total, mint condition, $650. Dynaco PAS-2X preamp, unmodified, $45. John McBride, 159 Iceland Dr., Huntington Station, NY 11746. (516) 423-2465.

FOR SALE: One pair of Roger Sanders ESL transformers perfect mint $50 pair. Call Rion at (206) 282-6653 or 283-9031.

FOR SALE: Pair KEF 13"x9.5" woofers. Like B139, but with double size magnets from 18" x14" model; never mounted, $150; Pair Celestion HF1300 MK II tweeters, never mounted $35; Pair CTS damped, 10" passive bass radiators unused $24; Pair Trusonic 35Hz $30; Rebuilt dome drivers from classic AR-3 speaker; pair midranges (5 lbs.) $29, tweeters $15. WANTED: working or damped midrange from AR-1. Alex Shaw, La Jolla, CA (714) 454-8661. shipping extra.

FOR SALE: T.R.W. polypropylene caps 4uF 400VDC 10% great for vacuum tube modifications in pre-amps etc. By pass all your funky electrolytics and enjoy great sound. 15 for $1.00 ppd. V. Vogt, 2423 N. Roosevelt St., Arlington, VA 22207.

FOR SALE: Altec Lansing Acousta-Voicette, passive ⅓ octave EQ, $600; SAE Mark 1M preamp, black rack, $300; Marantz 500 amp $725; Ortofon MC20 & MCA 76, MC cart, and ppa, never used $375. F. Zuccaro, (313) 482-1171 days, (313) 485-8925 eve.

WANTED WORKING OR NOT Acoustech 10 E.S.L.s Acoustech preamps mods 2, –4, –6. State price and condition. L. Dyer, 1584 W. Holland, Fresno, CA 93705. (209) 221-8592.

WANTED: Any schematics or information on circuitry of G.A.S. Goliath headamps (powered) and G.A.S. Grandson power amps, and any information on mods. M. Sorensen, 53 Ross Court, Medford, OR 97501.

FOR SALE: 4 Dyna Mk III's $60-$80 ea. Van Alstine "Superpas" preamp $150. Dyna FM-5 (both faceplates) $120. Threshold moving coil amp with separate power supply $130. (408) 629-3466.

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