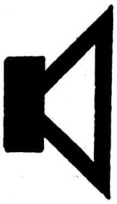
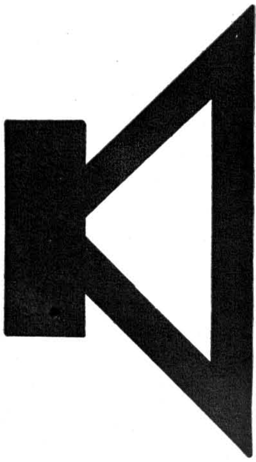
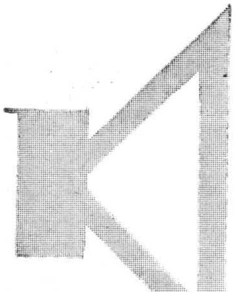




HIGH-FIDELITY LOUDSPEAKERS

Part IV—The enclosure, cabinet, or baffle can be a decisive factor



By H. A. HARTLEY*

EVERY loudspeaker making any pretensions to providing high-fidelity reproduction must be mounted in a way that agrees with its design. Horn-loaded speakers obviously must be loaded with a horn, but direct radiators can be mounted in various types of housings. Not all are equally good, nor can any particular design be chosen as the best mounting for any given speaker. The housing must be designed for the unit which will work in it. The only exception to this rule is the original and simplest mounting—the flat baffle—and it is now generally recognized that this is not the best design, with the sole exception of a hole in the wall. That is very nearly perfect, if the back of the wall is not obstructed.

The baffle

The effective size of any baffle is the shortest path from the edge of the cone in front of the baffle board to the edge of the cone behind the board. Under certain circumstances the speaker can be deliberately mounted off center to reduce interference patterns in the sound waves, but this is a type of experiment that can be done only by trial and error, the mathematical analysis being hopelessly involved. The larger the baffle the better the bass response. Fig. 1 gives the bass loss at various frequencies for different sizes of baffles. Intermediate sizes can be interpolated.

The baffle must be made of thick material. Wood, well braced and backed with sound-absorbent material for deadening purposes, is as convenient as anything. The thickness must be increased with increased size, for the vibration from the speaker can set the baffle in motion at its own natural frequency—it acts like the skin of a drum. The front edge of the speaker cone should be in the same plane as the front of the baffle, for even the short tunnel of the baffle opening can impair results. If the baffle is placed across the corner of a room, the sides should not touch the walls; otherwise air-column resonance will be set up in the triangular space behind the baffle. By the same token, a speaker mounted in a hole in the wall should play into another room, not into a cupboard.

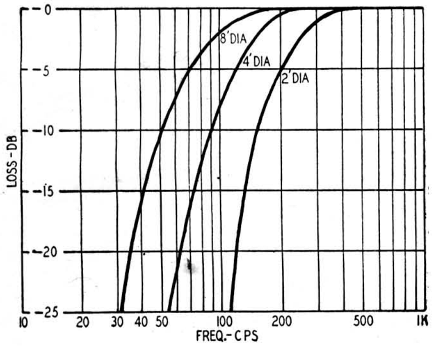


Fig. 1—Bass loss with finite baffles.

The baffle need not be flat. It can be "bent"—even to the point where it becomes a box with open back. The effective size is still the shortest distance from the front to the back of the cone, and the diagram for bass cutoff given for flat baffles (Fig. 1) still applies. However, with a box baffle, complications creep in. If the speaker has no bass resonance—and very few have none—the flat baffle performance will be as shown in the diagram; if it is mounted in a box, two additional resonances will be generated. One is the resonance of the enclosed air; the other is the resonance of the box itself, which is more pronounced than with a flat baffle. The deeper the box the more pronounced is the air-column resonance.

Lining the box with absorbent material will help to deaden box resonance, but it seems to be very difficult to convince some people that this does nothing to kill the air-column resonance. This latter is resonance of the air itself, and it can be overcome only by introducing specially designed absorbent screens or by eliminating the air. Such is clearly impossible, but an equivalent effect can be got by packing the whole of the interior space with lightly compressed sound-absorbent material. A recently published book on high-fidelity reproduction states that "such . . . resonance can be eliminated simply by closing the rear opening of the box, thus completely enclosing the loudspeaker." Such a statement cannot be justified. If there is air inside the box, open or closed, it will resonate at its own natural frequency when set in motion by the movement of the speaker cone.

A unique method that I developed uses what are, in effect, acoustical filters. Fig. 2 shows a section of the

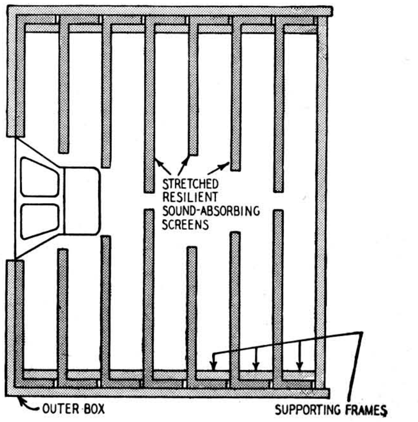


Fig. 2—The author's nonresonant box baffle makes use of acoustic filters.

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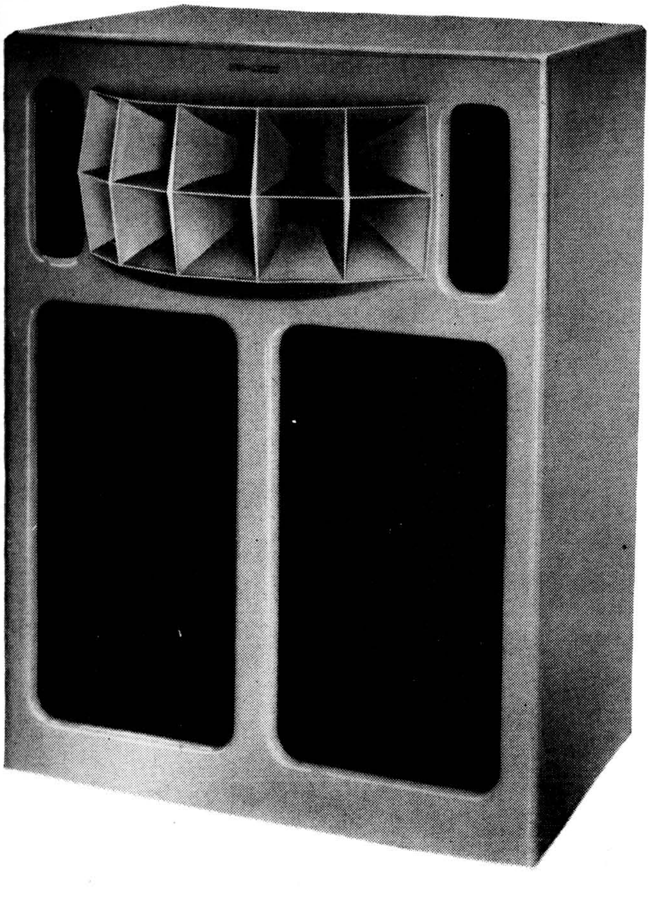
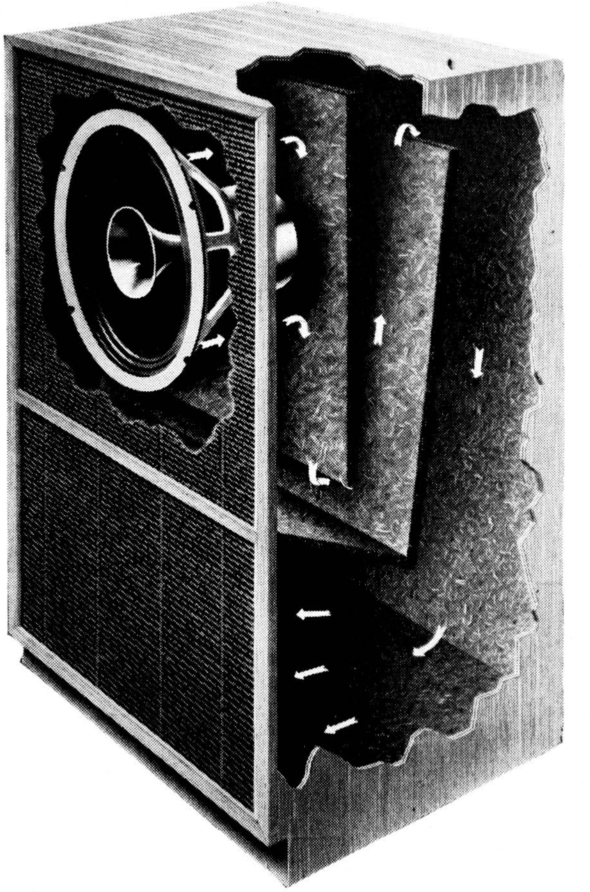


Stephens enclosure with tweeter horn.



Stromberg-Carlson speaker enclosure using an acoustic labyrinth. Arrows show air path from rear of the cone.

speaker box in which there are two series of sound-absorbing screens. The screens are made up of absorbent material stretched across wooden frames, the material being carried around the frames so that it is nipped between the frames and the cabinet. This dodge not only keeps the screens in place but damps out vibration in the sides of the box. The distance between screens should be about 2 inches, and the back of the box is not closed. The scheme can be used in any square or rectangular container; the effective baffle area is about half as great again as an ordinary unfilled box, and there is neither air-column resonance nor cabinet resonance.

Electrical filters are made up of inductors, capacitors, and resistors. The components of acoustic filters are masses, springs, and friction. In this design, the air between the screens forms the masses, the stretched screens themselves are the springs, and the absorbency of the screens represents the friction. The holes in the screens, tapering in size, control the slope of the filter; Fig. 2 shows a two-stage filter. The action is somewhat as follows: The enclosed air is broken up into small sections, each of which has a rather high resonant frequency. The energy of the moving air in each section is absorbed by the screen immediately behind it. The first section gets the greatest impact from the moving air, so the first screen has a rather large hole to allow most of the moving air to escape into the second section; the smaller hole in the second screen allows the same *proportion* of air to escape into the third section, and so on, to the end of that stage in the filter. The process can be repeated several times if the cabinet is so deep as to form a real tunnel.

Absorption of the lowest frequencies can be made complete, but experience has indicated that a total volume of about 4 cubic feet is all that is necessary for a 10-inch speaker. The box should not be placed closer than 4 inches from a wall.

Completely closed boxes, so-called infinite baffles, have quite different properties. As already explained, the enclosed air will resonate at its own frequency and this produces a peak in the impedance curve of the speaker. Standing waves inside the box cannot be absorbed by soft lining, because their wavelength is much greater than the thickness of the lining. A perfectly smooth surface reflects a sound wave perfectly, a soft absorbent surface will absorb a wave up to the limit of its absorption movement. Properly designed anechoic test rooms have a lining some feet deep, usually arranged in wedges to break up the standing waves. The thin lining of a closed box can only help to deaden the box structure itself.

If the box is so dimensioned that the enclosed air resonates at some frequency which makes good a lack of response in the speaker, then the air-column resonance can be turned to good purpose; apart from this the presence of it is nothing more or less than a nuisance. In particular the air-column resonance must not coincide with the bass resonant frequency of the speaker, otherwise distortion and boom at this frequency will be very bad. The simple rule is that the box size should increase as the speaker resonance falls. Some suitable figures are given:

Speaker bass resonance in c.p.s.	**80**	**70**	**60**	**50**	**40**
Box size in cubic feet	**1.5**	**2**	**3**	**5**	**10**

Cabinets

Phase-inverter or bass-reflex housings are deservedly popular because they minimize one of the most common defects in speakers—the bass resonance due to tight suspension. On the other hand, if the selected speaker has no bass resonance, a phase-inverter cabinet will spoil its performance. This type of housing can be used as a carefully designed cabinet for a given speaker, when it is called a matched phase-inverter, or it can be used in an unmatched condition, when it is not designed to fit the speaker but is adjusted to make a pleasant noise. These applications must be considered separately.

A matched phase inverter improves the bass, decreases the bass-resonance impedance, increases power-handling capacity above the bass-resonant frequency, and reduces the movement of the cone at bass resonance. The construction must be substantial and free from resonances in the component parts of which it is made. As with a horn the ideal construction would be precast concrete, but this is inconvenient for household use. The port opening should have the same area as the speaker diaphragm, and the tunnel behind the port may be as short as the thickness of the front of the cabinet or as long as 1/12 wavelength of the bass-resonant frequency; the length of the tunnel affects the design of the cabinet. If the cabinet is too small it will behave as a completely closed box. Regardless of how it is designed it will have two defects inherent in the idea: introduction of two resonant peaks, above and below the bass-resonant frequency, and phase shift at resonant frequency.

There will be loss of treble through reflections and absorption; a single wide-range speaker used in such a cabinet therefore will not be as good as on a flat baffle. However, if the phase-inverter is used to house a bass unit, this is an advantage, and the interior may well be lined with soft material to provide a further treble loss; this will, in some small degree, help to reduce phase distortion at crossover frequency. Design of the complete housing is simple, using the following equation:

$$V = \pi r^2 \left(\frac{1.84 \text{x} 10^8}{(2\pi f)^2} \times \frac{1}{1.7r + l} + l \right)$$

where V = volume in cubic inches; r = radius of cone in inches, l = length of tunnel in inches, f = vent resonant frequency (which can be taken as the speaker bass-resonant frequency). The vent area is obviously equal to πr^2.

If internal bracing is used to strengthen the cabinet, allowance must be made for the volume of this in computing the total volume, and it must be remembered that the figure for volume is the volume of enclosed air, *not* the external size of the cabinet.

The unmatched phase inverter is, as indicated, an experimental device, in which the resonances of the cabinet are used to fill out defects in the speaker response or to introduce some synthetic bass to give body to the reproduction. Some reasonable size of cabinet is selected, the tunnel is predetermined, and adjustable vents are used to get the desired effect. Once the cabinet has been built, the vent is the only way of altering the speaker characteristics.

From the outside, an acoustic labyrinth looks like a phase inverter in that there is a speaker at the top and a hole at the bottom; generally, however, the speaker will be displaced from the center and the bottom opening will be larger than a bass-reflex port. The acoustic labyrinth behaves like an organ pipe. It is of little importance how the pipe of the labyrinth is shaped, provided the form is as simple as possible. Whether the enclosure is called a labyrinth, an air column, or something else, it is virtually putting the speaker at the end of a wooden pipe of constant cross-section. For minimum distortion the construction should be as simple as possible, and as rigid as possible, and the length of the pipe should be one-quarter of the wavelength of the bass-resonant frequency of the speaker. The unique property of the acoustic labyrinth is that it lowers the bass-resonant frequency of the speaker; all other cabinets dependent on acoustic jugglery raise it to a greater or lesser extent.

Folded horn enclosures *must* be properly designed to be effective; if they are not, electroacoustic efficiency will be impaired, phase distortion will be excessive, and harmonic distortion will be generated in the throat, and the sound chamber will undo all the good that might result from good design. Constructional diagrams of the better-known folded horns have appeared many times and there is no need to repeat them here; the mathematical design is beyond the scope of the present series. For those who wish to design their own horns the following basic formulas apply:

Exponential horns. $A = A_t e^{mx}$ where A = area of cross-section (in any convenient unit of area) at any point x feet along the axis; A_t = area of throat (in the same units); e (epsilon) = 2.71828; m = flaring constant (which determines the total bulk of the folded horn).

Hyperbolic exponential horns. $A = A_t (\cosh mx + S \sinh mx)^2$ where the symbols are the same as in the previous formula and S is the shape parameter, which may be anything from zero to infinity. A usual value is between 0.5 and 0.7.

(TO BE CONTINUED)