

Practical Aspects of the R-J Speaker Enclosure

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A further discussion of the enclosure which has created so much interest and which was the forerunner of the current flurry for small cabinets.

COMMERCIAL HIGH-FIDELITY reproducing equipment has for some time been available at prices low enough to permit widespread use in home installations. Tuners, amplifiers, cartridges, and speakers which can handle the range from 50 to 10,000 cps are today quite reasonably priced, and equipment handling 30 to 15,000 cps is available in the higher-price range. Speaker development has reached the stage where the former range can now be handled by single-cone speakers and the latter by two- or three-way speaker systems. Most of the progress taking place in speaker development over the last decade has been mainly in extension of the treble range, since low bass reproduction in speaker techniques preceded the development in the treble range.

Reproduction of the low bass end, however, is a function not only of the speaker but of speaker enclosure as well. As almost all 12- and 15-in. speakers designed for the high-fidelity market are capable of reproducing down to 50 cps and below, the responsibility for low bass reproduction today rests almost entirely on the enclosure. Unfortunately, space limitations in the modern home mitigate against the use of large enclosures and in most home systems the octave below 100 cps is generally missing or is strongly curtailed. While such systems would sound balanced and pleasing before the full treble range became available—and do indeed sound better if the amplifier treble control is cut back—it is generally found today that home systems are operated with the treble control flat and with the bass control considerably boosted in an attempt to improve balance. While this boost in the 100- to 200-cps range may help matters somewhat, there is actually no true bass "feeling" to such reproduction. It was considered worthwhile, therefore, to attempt to develop a small enclosure which would permit extending the bass range to at least 50 cps, and if possible to attempt to attain this result without resonant peaks, yet with good damping and transient response. Resonant peaks in the bass range produce "boom" and "barrelly" speech reproduction, while poor transient response "muddies up" the bass.

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A brief consideration of existing systems required to provide 50-cps response will be pertinent in tracing the development of the R-J system and the following types of speaker housings will be considered:

1. Flat Baffle
2. Open-back Box
3. Closed Box
4. Horns
5. Bass Reflex
6. The R-J Enclosure

The Flat Baffle

To reproduce 50 cps adequately, a flat baffle must be eleven feet square. If the speaker itself resonates at 50 cps, there will be a hump in pressure-response curve at this frequency and the response will fall off below this point at the rate of 18 db per octave.

The Open-Back Box

Open-back boxes are not suitable. A 7-cu. ft. open-back box 4 in. from the wall produces a walloping "boom" at 100 cps¹ and response drops off below at the rate of 18 db per octave. Below 100 cps, frequency-doubling and tripling is extremely objectionable.

Closed Boxes and Horns

Completely enclosed boxes need to be very large. A 15-in. speaker will require

¹ Daniel Plach and Philip Williams, "Loudspeaker enclosures." *AUDIO ENGINEERING*, July 1951.

12 to 18 cu. ft. of air, depending upon speaker compliance.

Horns provide high efficiency and good transient response. For 50 cps, the horn works out to a mouth diameter of 6 ft. 8 in., or its area equivalent, and a length of about 8 ft. This is a little bulky for use in the average home. However, Klipsch² has been able to fold the horn ingeniously so as to require only 13 cu. ft. of space.

The Bass Reflex

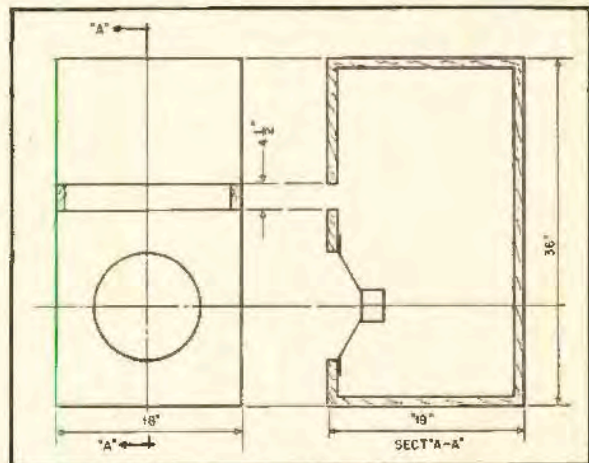
In pursuing small enclosure design, it was felt that the most fruitful field for investigation lay in the direction of resonating systems. A resonating column³ or chamber will produce sound with very little energy to activate it. Consequently, proper design may achieve useful sound output at some point in the register where system response would otherwise fall off. The bass-reflex enclosure⁴ is an example of this kind of system which, until recently, offered the closest approach to meeting the space problem. The typical bass-reflex enclosure shown in Fig. 1 consists of a box with a speaker mounted in it and a port hole in the front near the speaker opening. The first

² Paul W. Klipsch, "Design of compact two-horn loudspeaker." *Electronics*, Feb. 1946.

³ Benjamin J. Olney, "Acoustical labyrinth." *Electronics*, Apr. 1931.

⁴ A. L. Thuras, "Sound translating device." U. S. Patent 1869178.

Fig. 1. Typical bass-reflex cabinet, and the one used in the comparison measurements described.



step in the design of the enclosure requires that the air resonance of the box occurs at the free-air cone resonance of the speaker.

The air resonance of the bass-reflex enclosure can be closely determined:

$$f = \frac{c(A)^{1/4}}{2\pi(V)^{3/4}} \quad (1)$$

where A = the area of the port

V = the volume of the enclosure

c = the speed of sound in air

This bass reflex cabinet, later used as a comparison enclosure, employs a 12-in. speaker with a free-air cone resonance of 63 cps. To determine the volume V required, the formula may be rearranged to read

$$V = 2070 \left[\frac{(A)^{1/4}}{f} \right]^4 \quad (2)$$

where V is in cu. in.

A is in sq. in.

f is in cycles per second.

Using A of 75 sq. in. and f of 63 cps, V comes out to be 9400 cu. in. Adding another 400 cu. in. for the speaker, the total internal volume required is 9800 cu. in. or 5.7 cu. ft.

Bass reflex enclosures must be carefully tuned after mounting the speaker to produce optimum results. Since the enclosure is generally purchased separately and the speaker mounted within it without further adjustments, it is seldom that proper results are obtained. This is one of the major drawbacks of the bass reflex. When properly tuned, a bass-reflex enclosure will exhibit two impedance peaks in frequency above and below the speaker free-air cone resonance. The impedance curve of the comparison enclosure with a 12-in. 8-ohm speaker mounted in it is shown in Fig. 2.

Exploring the possibilities for appreciable reduction in size of the bass-reflex enclosure, it becomes evident from inspection of equations (1) and (2) that this may only be accomplished by reduction of the port area. Basically, the enclosure air resonance must occur at the free-air cone resonance of the speaker. The enclosure air resonance, being out of phase with the speaker, restricts the tendency for large movements of the speaker cone while at the same time sound radiation from the port area takes over and helps to provide acoustic output at this frequency.

If the port area is reduced, acoustic

radiation—which is proportional to the port area—drops off correspondingly and the desired sound output is not obtained. In addition, if the port area becomes too small the enclosure begins to approach closed-box performance. There is, therefore, a law of diminishing returns in operation and as a result, ports are generally compromised to about 75 per cent of the speaker area. Sometimes the further addition of a duct added to the port is employed. By this means a further small reduction in volume can be obtained.

The R-J Enclosure

In pursuing the design of a small enclosure, various types of resonant principles were explored and an adaptation of the Helmholtz resonator was finally adopted. In this type of resonator, Fig. 3, the mass of air in the opening A swings back and forth at resonance and the air in the cavity V acts as a resisting spring against the movement of the air in the opening. The combination sets up a system analogous to the weight on a spring and has a resonant frequency determined by the mass and the compliance of the arrangement. The equa-

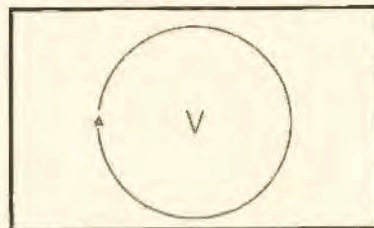


Fig. 3. Basic diagram of Helmholtz resonator.

tion for the resonant frequency of the resonator is the same as that for the bass-reflex enclosure, equation (1).

Helmholtz resonators are characterized by extremely high Q and if a speaker is placed within such a resonator the response curve will exhibit a very high peak at resonance. If, however, some means to control the Q can be incorporated into the system, a small enclosure could conceivably be designed which would permit flattening the peak. A practical form of enclosure which attains this end takes the form shown in Fig. 4.

The system still acts as a Helmholtz resonator with the further modification imposed by the creation of a duct sys-

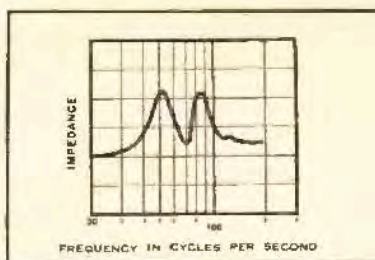


Fig. 2. Impedance curve of the speaker mounted in the cabinet of Fig. 1.

tem, indicated by arrows in the figure, between the back cavity and the frontal opening. The resonant frequency of an enclosure with a volume of 4800 cu. in. and a frontal opening of 64 sq. in. calculates out as follows:

$$f = \frac{(1080 \times 12) \times (64)^{1/4}}{2\pi(4800)^{3/4}} = 84 \text{ cps.}$$

Actually, close calculations require several refinements to take into account the effect of duct length and the end corrections.

Control of the circuit Q is obtained by varying the spacing of the duct produced between the frontal board and the speaker board. By decreasing this spacing it is possible to introduce acoustic resistance to lower the Q and increase damping. The acoustical resistance of a slot is expressed by the equation:

$$R_a = \frac{kl}{t^3w}$$

where k = a constant

l = the length of the duct passage

w = the width of the duct passage

t = the thickness of the duct passage (the spacing between the frontal board and the speaker board).

The acoustic resistance is a function of the third power of the spacing and becomes quite critical as t becomes small. Halving the spacing increases the acoustic resistance by eight times. By experimenting with the spacing it was found possible to reduce the circuit Q and broaden the resonance so that with a speaker of 63 cps free-air cone resonance, this system extends smoothly to 50 cps without any peak at resonance.

The introduction of the acoustic resistance also has a strong effect upon speaker loading. This is very desirable in improving speaker damping and the magnitude of damping obtained may be judged from the amount of lowering in frequency of speaker resonance below the free-air cone resonance. As shown in the impedance curve of Fig. 5, the speaker resonance in the R-J enclosure is 32 cps, as against 50 cps for the same speaker in the bass-reflex enclosure, Fig. 2. It is believed that a 32-cps loaded speaker resonance, as against a 63-cps free-air cone resonance, is considerably lower than can be achieved by other systems.

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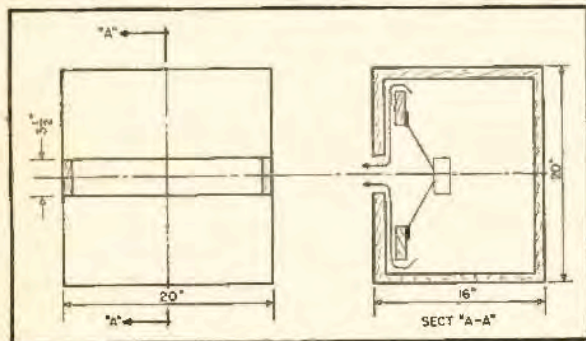


Fig. 4. Front and sectional views of R-J speaker enclosure.

R-J SPEAKER

[from page 20]

Construction

The internal construction of the R-J speaker enclosure is shown quite clearly in *Fig. 4*. All wood used in the construction is $\frac{3}{4}$ -in. plywood, with the external surfaces veneered with suitable hardwood to provide an attractive finish. The dimensions shown will suffice for either 12- or 15-in. speakers, since the speaker size is not critical. The principal requirement is that the free-air cone resonance be relatively low, and the suspension is "soft" enough to provide a high compliance. In the cabinet of *Fig. 4*, a net internal volume of 4500 cu. in. is provided, exclusive of the internal padding. It will be noted that the speaker board is spaced from the frontal board by such a distance as to reduce the peak caused by the resonance of the enclosure so that the sound output is flat, essentially, from a frequency of 150 cps, let us say, down to 50 cps or less. As previously mentioned, the spacing between the speaker board and the frontal board determines the Q of the enclosure, and effectively eliminates the peak due to the Helmholtz resonator effect.

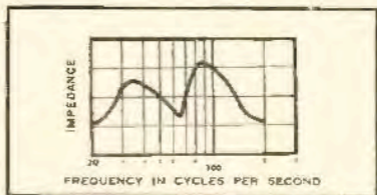


Fig. 5. Impedance curve of the R-J enclosure with the same type of speaker as used in the cabinet of Fig. 1.

The opening in the speaker board is the same as the free cone area of the speaker used— $10\frac{1}{2}$ in. for a 12-in. speaker and $13\frac{1}{2}$ in. for a 15-in. speaker. The opening in the frontal board was shown to have an area of 64 sq. in.

If the enclosure is to be used as a woofer exclusively, a rectangular slot—as shown in *Fig. 4*—would be perfectly satisfactory, and adequate performance would be obtained over the frequency range from the lowest transmitted frequency up to 400 or 500 cps. However, if the enclosure is to be used for a wide-range speaker, without the addition of any other speaker or horn for the high range, then the frontal opening must be modified. While the shape of the opening must be determined specifically for each individual cabinet type, it may be described roughly as resembling a "skinny lemon." It may be approximated by laying out a diamond-shaped opening with its major axis about 25 deg. from the vertical—at an azimuth of 025, for the nautical-minded—and with its minor axis at an angle of approximately 15 deg. from the horizontal, or at an azimuth of 295. The minor axis should be one half the length of the major axis, and the total area should be the calculated 64 sq. in. Then, after the diamond shape is laid out, round off the obtuse corners, and extend the acute corners so that the "skinny lemon" shape is attained. From this description, it is obvious that it would be difficult to prescribe the actual opening, but bear in mind that the low-frequency performance is a function of the enclosure volume and the area of the frontal board, and the high-frequency performance is a function of the shape of the frontal opening. The spacing between the speaker board and the frontal board adjusts the *Q* so as to avoid a peak in sound output throughout the range from 50 to 100 cps.

From the foregoing, it is seen that the low-frequency performance is not as dependent upon the speaker as it is with some other types of housings. It is only important that the free-air cone resonance be relatively low—from 40 to 70 cps. Since the object is to resonate the enclosure somewhat above the cone resonance, and since the volume and the size of the frontal opening determine the resonant frequency, it is readily possible to design a satisfactory cabinet for speakers smaller than the 12- or 15-in. models for which the cabinet of *Fig. 4* was calculated. This has been shown by the performance of the 8-in. enclosure, which is $23\frac{1}{2}$ in. long, 11 in. high, and 10 in. deep. The design of this cabinet is the same as for the larger one, being modified only by the differences in size and resonant frequencies.

Comparative Measurements

To show the performance of the system, and to evaluate it in comparison with a conventional bass-reflex box, the equipment shown in *Fig. 6* was set up. The amplifier is a modified Williamson employing two 5881's in the output stage, and with 30 db of feedback. The internal output impedance of the amplifier was approximately 0.5 ohms. The

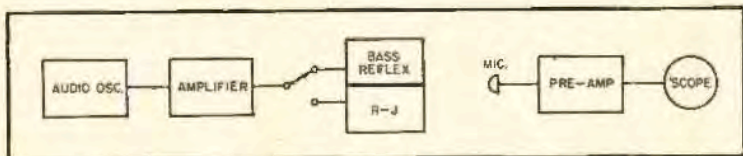


Fig. 6. Block diagram of the test set-up used to compare acoustic outputs of the two types of enclosures.

two enclosures used were the bass-reflex model of Fig. 1 and the R-J of Fig. 4, both being used with a moderately priced 12-in. speaker with an 8-ohm voice coil, and a free-air cone resonance of 63 cps. Both cabinets were placed side by side with the microphone on a horizontal axis through the two cones and in line with the two adjacent sides of the enclosures. The output of the microphone

was fed through a preamplifier to a 5-in. 'scope. The switch permitted feeding the output of the amplifier to either enclosure and the microphone output could then be observed on the 'scope screen. Thus all variables have been eliminated, with the possible exception of differences between the two speakers—although both were identical as to type and manufacturer. Figures 7 through 12

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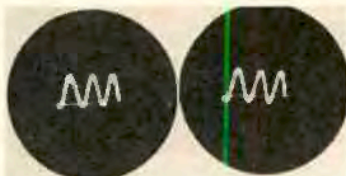


Fig. 7. Acoustic output from the two speaker cabinets as indicated on the 'scope at a frequency of 110 cps. Left, bass reflex; right, R-J.

show the patterns obtained, none of the controls being changed except the main frequency dial of the oscillator and the selector switch. In all of these figures the bass reflex cabinet is shown at the left and the R-J enclosure is shown at the right.

Figure 7 shows approximately the same sound pressure from both cabinets at 110 cps. Figure 8, at 84 cps, corresponds approximately to the cabinet air resonance for both enclosures, as shown by the impedance curves of Figs. 2 and 5. Note the higher output of the bass reflex, resulting in the characteristic "boominess." The R-J output is only slightly increased, and even this could be eliminated by a slight decrease in the spacing between the frontal board and the speaker board.

In Fig. 9, taken at 55 cps, both

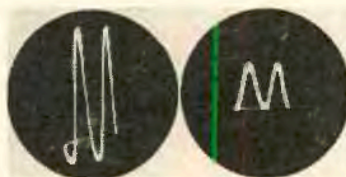


Fig. 8. Acoustic output at 84 cps. Left, bass reflex; right, R-J.

speakers exhibit approximately the same output, but in Fig. 10 at 48 cps, the bass reflex is beginning to exhibit traces of frequency doubling. The R-J is still entirely fundamental. At 44 cps, shown in Fig. 11, the bass reflex has an output which is almost entirely composed of double the frequency of the applied signal—which means almost 100 per cent second harmonic distortion. The difference in pitch is plainly evident upon switching between the two, the bass reflex sounding one octave higher than



Fig. 9. Acoustic output at 55 cps. Left, bass reflex; right, R-J.

the R-J. *Figure 12* shows that the bass reflex is still frequency doubling, while the R-J—although somewhat down in output—still maintains the fundamental tone.

The ability of the R-J system to handle power without frequency doubling at the very low frequencies is due in the main to the air loading on the speaker cone which is the result of the design. This loading is also beneficial in increasing the transient damping of the speaker as well as the power handling capacity. Transient damping which cuts down spurious speaker vibration of



Fig. 10. Acoustic output at 48 cps. Note beginning of frequency doubling from the bass reflex at the left; the R-J is still fundamental.

"hangover" after the signal has ceased may be demonstrated in a simple test. If a small direct current from a battery is keyed on and off, a "click" will be noticed on circuit make, and either a "click" or a "bong" on circuit break, depending on the damping.* It will be noticed particularly with the bass reflex, which exhibits a definite "click-bong" as the circuit is made and broken, while the R-J shows its transient response to be better by responding with a "click-click" for the same treatment.



Fig. 11. Acoustic output at 44 cps. Output from bass reflex is seen to be almost 100 per cent harmonic, due to frequency doubling.

Conclusions

From these comparisons, it may be concluded that although it is based on a resonant principle, the R-J enclosure is a non-resonant system. The response with a 12-in. cone having a free-air resonance of 63 cps is smooth down to 50 cps, and has usable but attenuated output down to 30 cps. It is also shown

* Benjamin B. Drisko, "Getting the most out of a reflex-type speaker." *AUDIO ENGINEERING*, July 1948.



Fig. 12. Acoustic output at 32 cps. Although slightly lower in output, the R-J—at the right—is still fundamental in character.

that the R-J provides air loading which is instrumental in preventing frequency doubling and tripling, and maintains fundamental tones with a 12-in. speaker down to 30 cps. In addition, the R-J offers excellent speaker damping with the result that transient response is maintained.