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 cps[1] 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 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, Klipsch[2] 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 column[3] 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 enclosure[4] 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

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

[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.

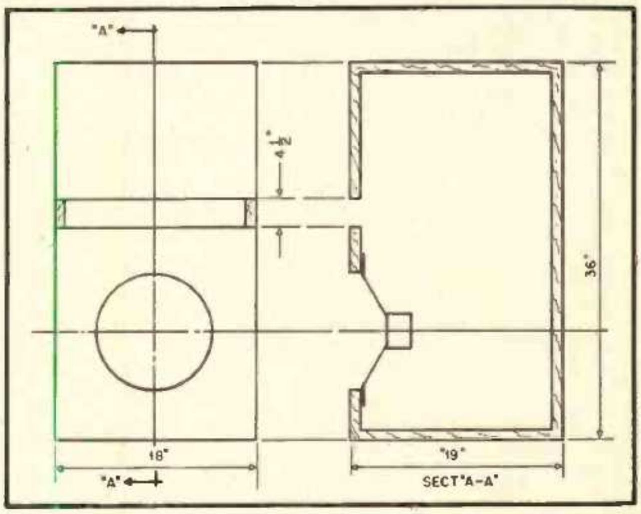

Fig. 1. Typical bass-reflex cabinet, and the one used in the comparison measurements described.

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:

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

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

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

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 of equal amplitude, equally spaced 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 equation for the resonant frequency of the resonator is the same as that for the bass-reflex enclosure, equation (*1*).

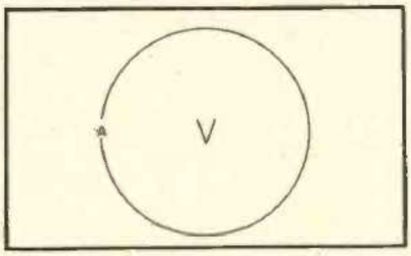

Fig. 3. Basic diagram of Helmholtz resonator.

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 system, 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:

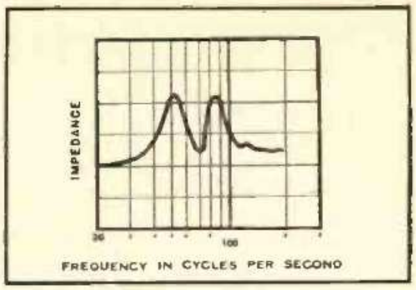

Fig. 2. Impedance curve of the speaker mounted in the cabinet of Fig. 1.

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

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:

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

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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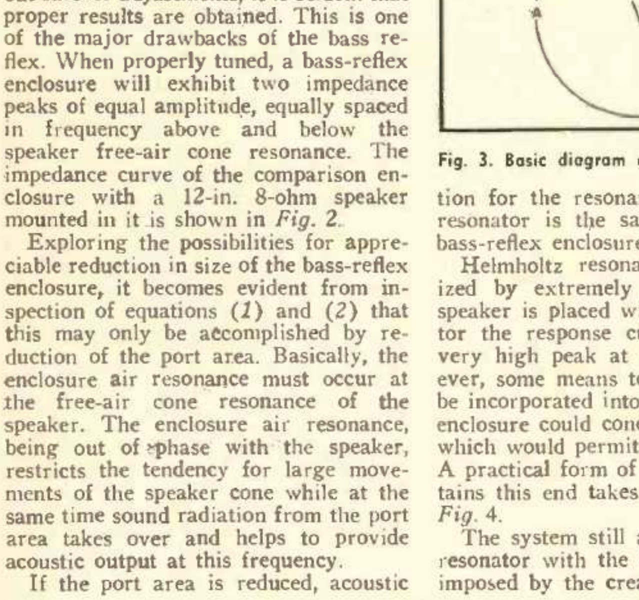

Fig. 4. Front and sectional views of R-J speaker enclosure.