

At these frequencies, reduced power output generally occurs. In general, the upper frequency limit for operation of a horn should be chosen sufficiently low so that troubles from transverse standing waves are avoided.

9.12. Materials. The material from which a horn is constructed is very important. If the side walls of the horn resonate mechanically at one or more frequencies in the range of operation, "dips" in the power-output curve will occur. Undamped thin metal is the least desirable material because the horn from which it is made will resonate violently at fairly low frequencies. Heavy metals, covered on the outside with thick mastic material so that mechanical resonances are damped, are much better. A concrete or plaster horn 1 or 2 in. in thickness is best because of its weight and internal damping.

Plywood is commonly used in the construction of large horns. Although it is not as satisfactory as concrete, it gives satisfactory results if its thickness exceeds $\frac{3}{4}$ in. and if it is braced with wooden pieces glued on at frequent, irregular intervals.

Example 9.3. A horn combination consisting of two horns, one for radiating low frequencies and the other for radiating high frequencies, is required. It is desired that the frequency response be flat between 70 and 6000 cps and that the horn combination be designed to fit into an average-sized living room. The system will be used for reproducing high-fidelity music in the home. The maximum acoustic powers to be radiated in six frequency regions are estimated as follows:⁵

Frequency range	Power level, db re 10^{-13} watt
70-250	102
250-400	102
400-1000	102
1000-2200	99
2200-3000	96
3000-8000	96

Solution for Low-frequency Horn. We shall select the exponential horn as the best compromise shape of horn for our use. Because the lowest frequency at which good radiation is desired is 70 cps, we choose the mouth area from Eq. (9.16).

$$\text{Mouth area } S_M = \frac{\lambda^2}{4\pi} = \frac{c^2}{4\pi f^2} = 1.93 \text{ m}^2 = 20.8 \text{ ft}^2$$

Twenty square feet is probably too large a mouth area for the living room of most homes, so that a compromise in design is necessary.

Let us choose arbitrarily a mouth area of about 10 ft^2 , that is, 0.93 m^2 . This corresponds to the bell opening shown in Fig. 9.10c. We see from this chart that below $f = 2f_c$ there will be two resonances that are not desirable, but they are fairly well damped.

Let us design for a cutoff frequency of

$$f_c = 60 \text{ cps}$$

⁵ H. F. Hopkins and N. R. Stryker, A Proposed Loudness-efficiency Rating for Loudspeakers and the Determination of System Power Requirements for Enclosures, *Proc. IRE*, **36**: 315-335 (1948).

The flare constant m equals [see Eq. (9.28)]

$$m = \frac{4\pi f_c}{c} = \frac{4\pi 60}{344.8} = 2.18 \text{ m}^{-1}$$

Let us choose a 12-in. direct-radiator unit with an effective diameter of 0.25 m as the driver. The effective area of this driver unit is

$$S_D = \pi(0.125)^2 = 0.049 \text{ m}^2$$

Assume the other constants to be as follows:

$$R_g = R_E = 6 \text{ ohms} \\ Bl = 15 \text{ webers/m}$$

From Example 9.2, it appears that for maximum efficiency S_D/S_T should equal 2. However, to keep the length down, let us make

$$\frac{S_D}{S_T} = 1$$

Then,

$$r_{MT} = \frac{S_T}{\rho_0 c S_D^2} = \frac{1}{(406)(0.049)} = 0.05 \text{ mks mechanical mohms}$$

Let us calculate the reference PAE. Assume in Fig. 9.4b that $r_{MB} \gg r_{MT}$. From Eq. (9.7),

$$\text{PAE} = \frac{(400)(6)(0.05)(15)^2}{[(15^2)(0.05) + (12)(2)]^2} = 22\%$$

As a trial, let us make $S_D/S_T = 2.0$. Then $r_{MT} = 0.025$, and $\text{PAE} = 24\%$. Finally, let $S_T/S_D = 2$. Then, $r_{MT} = 0.1$, and $\text{PAE} = 15.8\%$.

It is seen that the ratio of the throat and diaphragm areas may be made equal with little loss of efficiency, thereby making our horn of reasonably short length. The length of our horn is found, from Eq. (9.17),

$$e^{mx} = \frac{0.93}{0.049} = 19$$

or

$$mx = 2.94 \\ x = \frac{2.94}{2.18} = 1.35 \text{ m} = 4.4 \text{ ft}$$

The intensities for a horn with a throat area of 0.049 m^2 are as follows, assuming uniform pressure distribution:

Frequency	Power, watts	Watts/cm ² at throat
70-250	1.58×10^{-3}	3.22×10^{-6}
250-400	1.58×10^{-3}	3.22×10^{-6}
400-1000	1.58×10^{-3}	3.22×10^{-6}
1000-2200	7.94×10^{-4}	1.62×10^{-6}
2200-3000	4×10^{-4}	8.16×10^{-7}
3000-8000	4×10^{-4}	8.16×10^{-7}

Let us set the upper limit of operation at 600 cps. Then $f/f_c = 10$. Extrapolation of the line for 10 in Fig. 9.12 to 3.22×10^{-6} shows that the per cent second-harmonic distortion in the horn will be about 0.02 per cent, which is negligible. In fact, the power level could be increased 30 db before the distortion would become as large as 1 per cent.

This calculation would seem to indicate that the low-frequency unit could be operated successfully above 600 cps. However, it seems from experience that for psychological reasons the changeover from the low-frequency to the high-frequency horn should occur at a frequency below 600 cps for best auditory results.

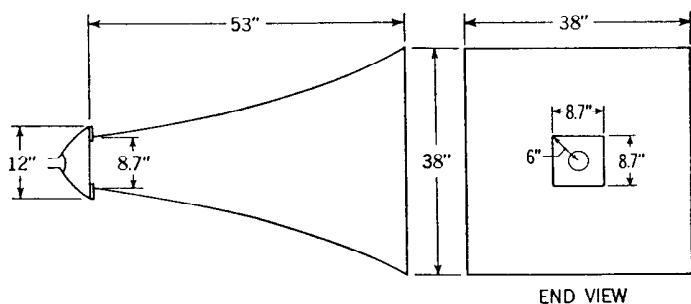


FIG. 9.17. Plans for a simple straight exponential horn with a cutoff frequency of 60 cps, a throat area of 0.049 m^2 , and a mouth area of 0.93 m^2 .

Let us see what value the total compliance in the driving-unit circuit ought to have if it is to balance out the mass reactance of the horn at frequencies below the diaphragm resonance frequency. From Eqs. (9.12), (9.13), and (9.23),

$$C_{M2} = \frac{S_T^2}{S_D^2} C_{MT} = \frac{2S_T}{S_D^2 \rho_0 c^2 m} = \frac{2S_T}{S_D^2 \gamma P_0 m}$$

$$C_{M2} = \frac{2}{(1.4)(0.049) \times 10^5 (2.18)} = 1.34 \times 10^{-4} \text{ m/newton}$$

The quantity C_{M2} includes the combined compliance of the loudspeaker and the enclosure behind it. Reference to Fig. 8.5d shows that this is a reasonable value of compliance to expect from a loudspeaker of this diameter. In case the compliance is not correct, we can vary the size of the throat, or even m somewhat, in order to achieve the desired value for C_{M2} .

Two possible horns for our design are the straight square horn shown in Fig. 9.17 or the folded horn of the Klipsch type⁶ shown in Fig. 9.18. If the straight horn is used, it will probably be necessary to put it partially above the ceiling or below the floor in order to make its presence nonobjectionable in the room.

Solution for High-frequency Horn. As a cutoff frequency, let us choose

$$f_c = 300 \text{ cps}$$

We shall use an electrical crossover network of 500 cps, which will make effective use of both horns and is a good choice of frequency from the standpoint of the psychology of listening.

The flare constant is [see Eq. (9.28)]

$$m = \frac{4\pi f_c}{c} = \frac{4\pi 300}{344.8} = 10.9 \text{ m}^{-1}$$

⁶ P. W. Klipsch, A Low-frequency Horn of Small Dimensions, *J. Acoust. Soc. Amer.*, **13**: 137-144 (1941).

Let us assume that the driver unit is the one discussed in Example 9-1. For this, $S_T = 3.14 \times 10^{-4} \text{ m}^2$.

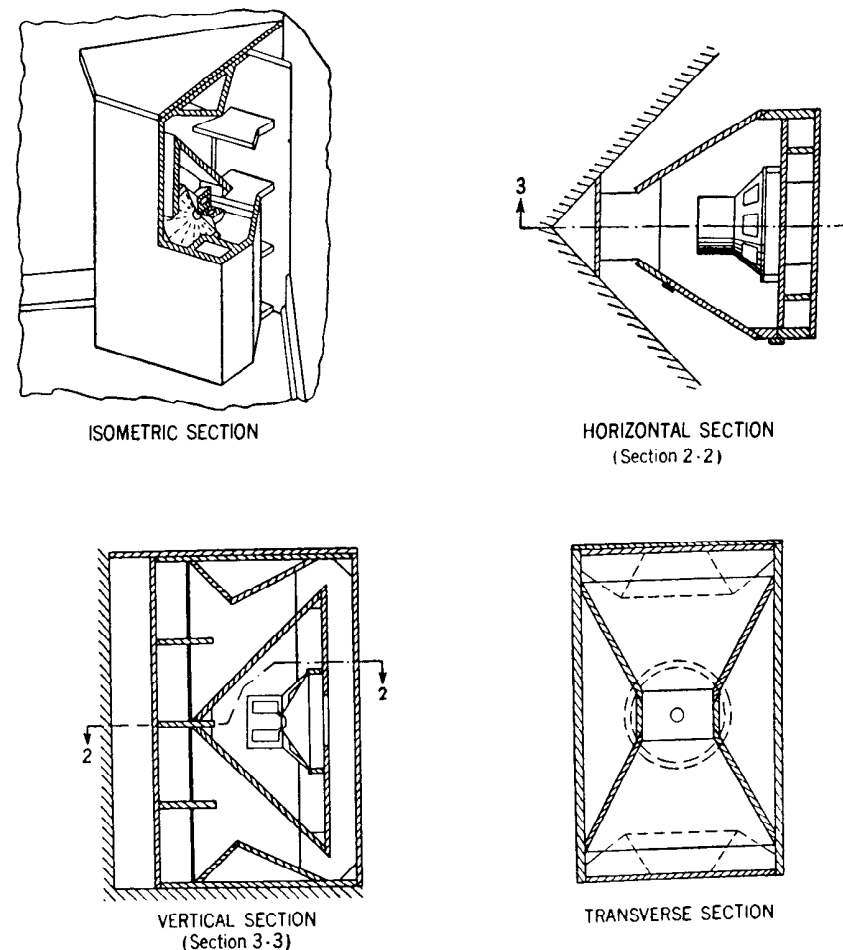


FIG. 9.18. Sketches for a Klipsch type of folded exponential horn. This particular horn is about 40 in. high and has smooth response below 200 cps.

The horn should radiate sound well at 400 cps, so that the mouth-opening area should be, if possible, greater than that given by Eq. (9.16),

$$S_M = \frac{c^2}{4\pi f^2} = \frac{(344.8)^2}{4\pi(400)^2} = 0.0591 \text{ m}^2$$

$$= 91.5 \text{ in.}^2$$

As we learned in Chap. 4, in order to get a wide directivity pattern, say $\pm 30^\circ$ over a wide range of frequencies, the horn should have a curved mouth. Let us select a design that is about 6 in. in height and has a circular curved mouth with an arc length of 30 in. The mouth area for these dimensions is 180 in.^2 , or 0.1163 m^2 , which is double that called for above.