Vented-Box Loudspeaker Design with a Given Driver

(From the book *Introduction to Electroacoustics and Audio Amplifier Design, Second Edition - Revised Printing* by W. Marshall Leach, Jr., published by Kendall/Hunt, © 2001.)

The vented-box design procedure for a given driver requires a knowledge of the driver parameters f_S, Q_{TS}, and V_{AS}. A value for Q_L must be assumed. The rule of thumb that is commonly used is to assume the value $Q_L = 7$ for the initial design. After the required box volume is determined, it can be assumed that the value for Q_L is correct if the box volume is in the medium range, i.e. 2 to 3 cubic feet. For smaller volumes, a larger value of Q_L should be assumed and the design procedure repeated. For larger volumes, a smaller value of Q_L should be assumed and the design procedure repeated.

Vented-box design charts for $Q_L = \infty$, 20, 10, 7, 5, and 3 are given in Figs. 1 through 6. The procedure for using these charts is as follows:

1. On the left ordinate of the appropriate chart, locate the value of Q_{TS} for the driver. Draw a horizontal line through this value which intersects the Q_{TS} curve on the chart. Draw a vertical line through this intersection that cuts the abscissa.

2. Read the value of the box compliance ratio α from the intersection of the vertical line with the abscissa. Calculate the required box volume $V_{AB} = V_{AS}/\alpha$.

3. Read the value of the Helmholtz tuning ratio $h = f_B/f_S$ from the right ordinate corresponding to the point that the vertical line in step 1 crosses the h curve on the chart. Calculate the Helmholtz frequency $f_B = h f_S$.

4. Read the value $q = f_\ell/f_S$ from the right ordinate corresponding to the point that the vertical line in step 1 crosses the q curve on the chart. Calculate the system lower half-power or -3 dB cutoff frequency $f_\ell = q f_S$.

5. For a vent or port of cross section S_P, calculate its length from the formula

$$L_P = \left(\frac{c}{2\pi f_B}\right)^2 \frac{S_P}{V_{AB}} - 1.463\sqrt{\frac{S_P}{\pi}} \tag{1}$$

The selection of the vent area is an important consideration. For a given f_B, it can be seen from Eq. (1) that the vent length increases as its area is increased. As a general rule, the vent area should be chosen as large as possible to minimize noise caused by turbulent air flow. If the area is too large, however, the vent will extend too far into the enclosure and might have its unflanged end too close to the back wall. Ideally, the vent should extend to about one-half the depth of the box. In the event that it is too long to fit in the enclosure, an elbow shaped vent can be used. Round PVC tubing makes a good vent material. To increase the vent area, two or more equal length vent tubes can be used. In this case, the length is calculated as if the tubes are a single tube having a cross-sectional area equal to the total area of all the tubes. There is only one Helmholtz frequency when multiple vents are used.
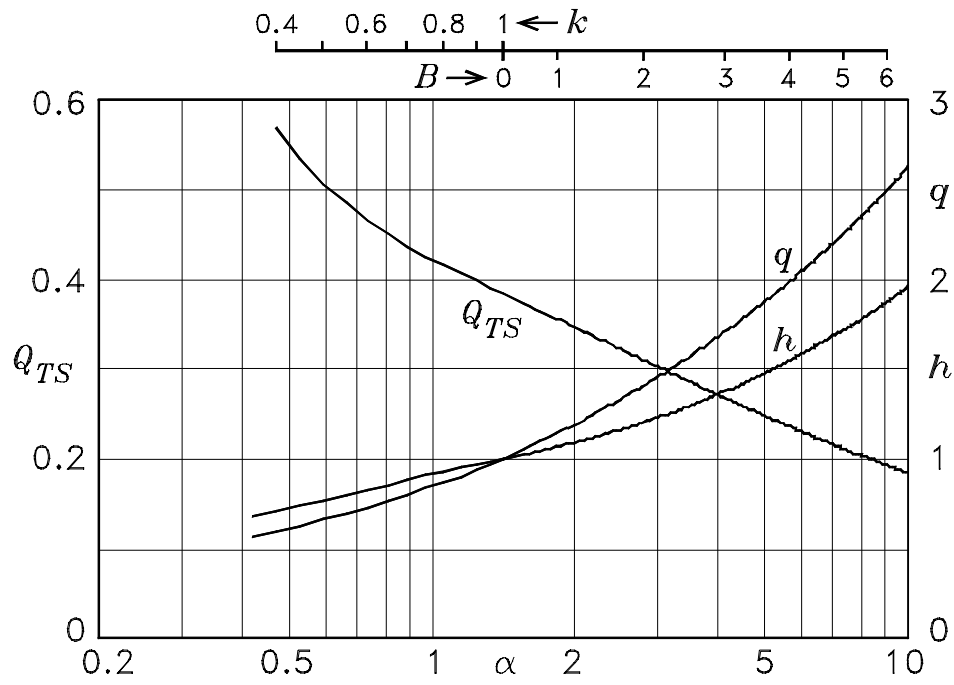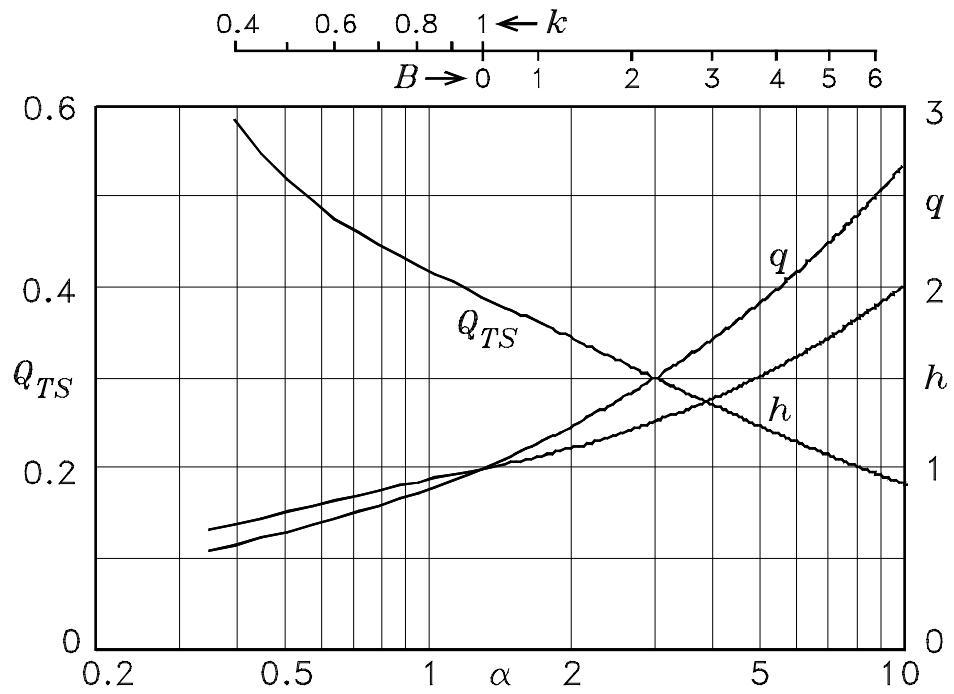
Figure 1: Vented-box alignment chart for $Q_L = \infty$.
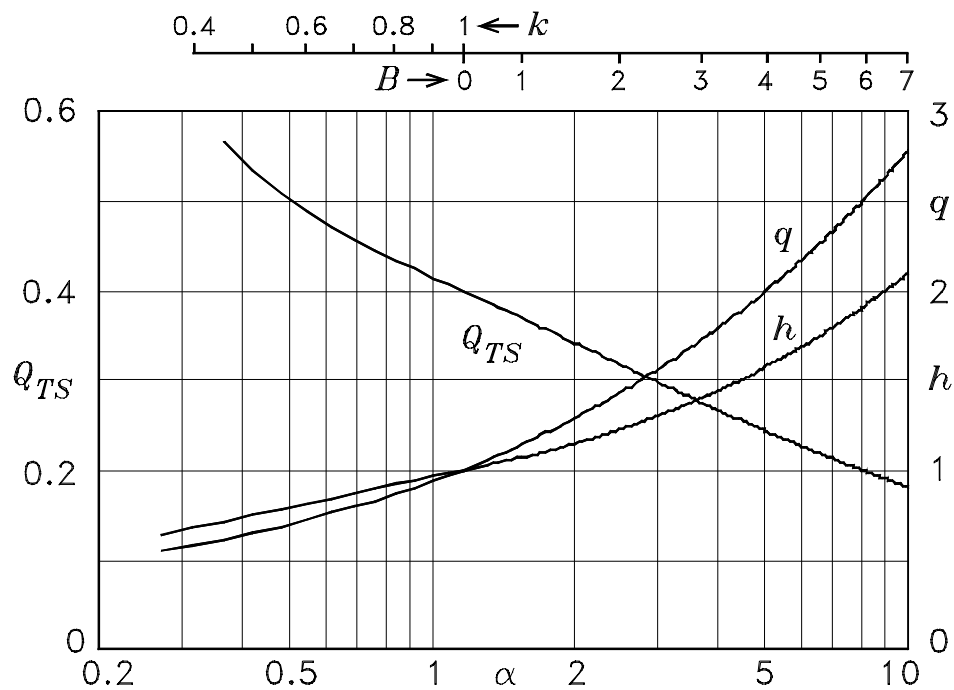

Figure 2: Vented-box alignment chart for $Q_L = 20$.

Figure 3: Vented-box alignment chart for $Q_L = 10$.
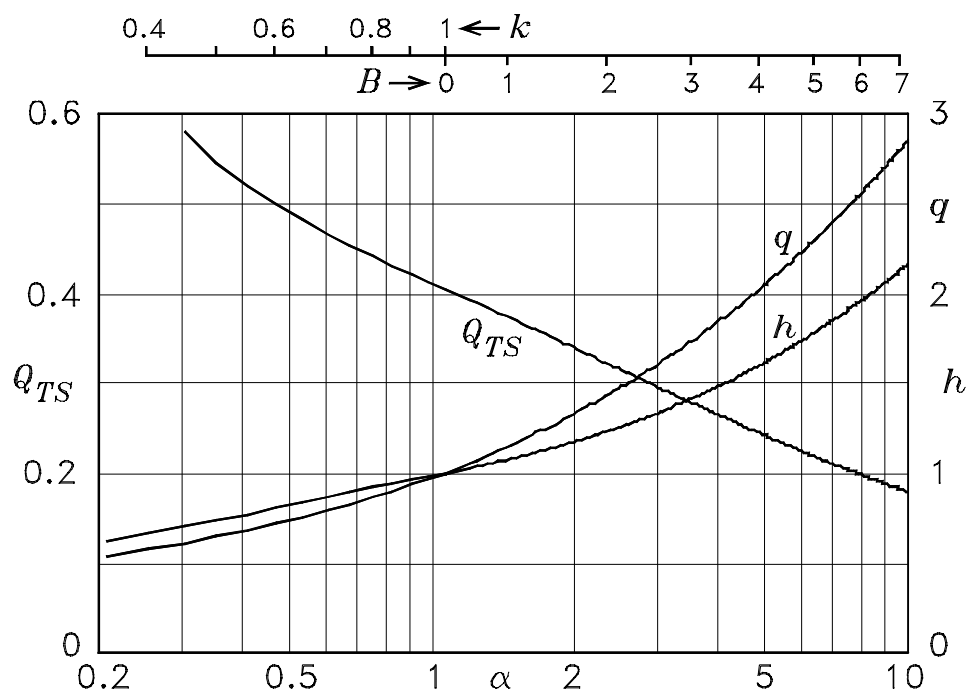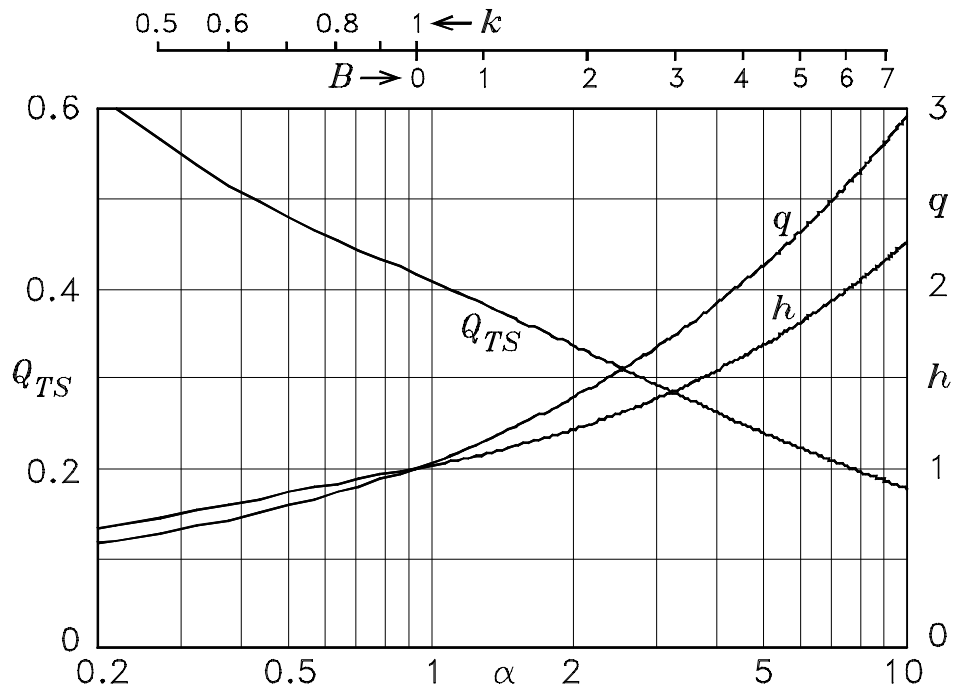

Figure 4: Vented-box alignment chart for $Q_L = 7$.

3

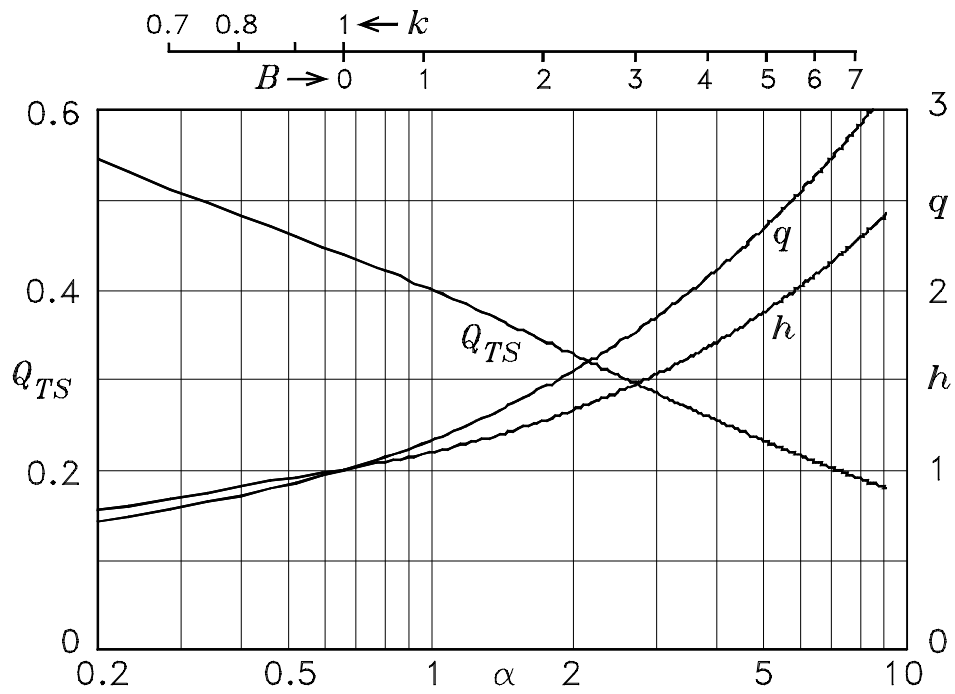Figure 5: Vented-box alignment chart for $Q_L = 5$.

Figure 6: Vented-box alignment chart for $Q_L = 3$.

4

After a system is designed and built, the Helmholtz frequency can be measured by connecting the system to the parameter measurement test set described in *Introduction to Electroacoustics and Audio Amplifier Design*. At the Helmholtz frequency, the system exhibits a null in its input impedance so that the voice-coil voltage exhibits a null. Often, it will be found that the measured frequency will not correspond to the desired frequency. There is a simple procedure which can be used to tune the port length. Cut the port 20% longer than the value predicted by Eq. (1). Denote this length by L'_P. Measure the Helmholtz frequency for this length. Denote this by f'_B (which is less than f_B). The amount which L'_P must be reduced to make the Helmholtz frequency increase from f'_B to f_B is given by

$$\Delta L_P = L'_P - L_P = \left(\frac{c}{2\pi}\right)^2 \frac{S_P}{V_{AB}} \left[\frac{1}{f'^2_B} - \frac{1}{f^2_B}\right] \tag{2}$$

Example 1 *A driver has the parameters $Q_{TS} = 0.3$, $f_S = 28$ Hz, $V_{AS} = 6$ feet³, and $R_E = 7\ \Omega$. The inductor in the crossover network has the dc resistance $R_g = 1\ \Omega$ that is in series with the woofer. Design a vented-box enclosure for the driver.*

Solution. In order to account for R_g, we need the electrical quality factor Q_{ES} of the driver. Because this is not given, the value of Q_{MS} must be estimated and then Q_{ES} calculated. Let us assume that $Q_{MS} \simeq 4$. Thus we have

$$Q_{ES} = \frac{Q_{MS}Q_{TS}}{Q_{MS} - Q_{TS}} = 0.324 \tag{3}$$

Q_{ES} and Q_{TS} with R_g in series with the driver are

$$Q'_{ES} = Q_{ES}\left(1 + \frac{R_g}{R_E}\right) = 0.371 \qquad Q'_{TS} = \frac{Q'_{ES}Q_{MS}}{Q'_{ES} + Q_{MS}} = 0.339 \tag{4}$$

From the $Q_L = 7$ design chart, we have $\alpha = 2$, $h = 1.2$, and $f_3/f_S = 1.3$. Thus $V_{AB} = V_{AS}/\alpha = 3$ feet³, $f_B = hf_S = 33.6$ Hz, and $f_\ell = qf_S = 36.4$ Hz. Let us assume a vent tube that has a circular cross section with a diameter of 3 inches. The length of the vent is given by

$$L_P = \left[\frac{1131}{2\pi 33.6}\right]^2 \frac{\pi (1.5/12)^2}{3} - 1.463\,(1.5/12) = 0.2867 \text{ foot or } 3.441 \text{ inches} \tag{5}$$

System Verification

To verify a system design, any crossover network must be disconnected. The frequencies f_L, f_B, and f_H shown in Fig. 7 must be measured. At these frequencies, the voice-coil impedance is real and is labeled R_L, R_B, and R_H in the figure. The value of R_B must also be measured. These can be determined by the techniques described in *Introduction to Electroacoustics and Audio Amplifier Design*. The frequencies f_L, f_B, and f_H are most easily determined as the frequencies where the phase crosses zero. However, enclosure losses and the voice-coil inductance can perturb the phase more than the magnitude, so that it is preferable to determine f_L and f_H at the maximum impedance and f_B at the minimum. From these measurements, the driver resonance frequency f_{SB} for the air load mass presented

by the enclosure, the compliance ratio α, and the vent tuning ratio h can be calculated from the relations

$$f_{SB} = \frac{f_L f_H}{f_B} \qquad a = \left[\left(\frac{f_B}{f_L}\right)^2 - 1\right]\left[1 - \left(\frac{f_B}{f_H}\right)^2\right] \qquad h = \frac{f_B}{f_{SB}} \tag{6}$$
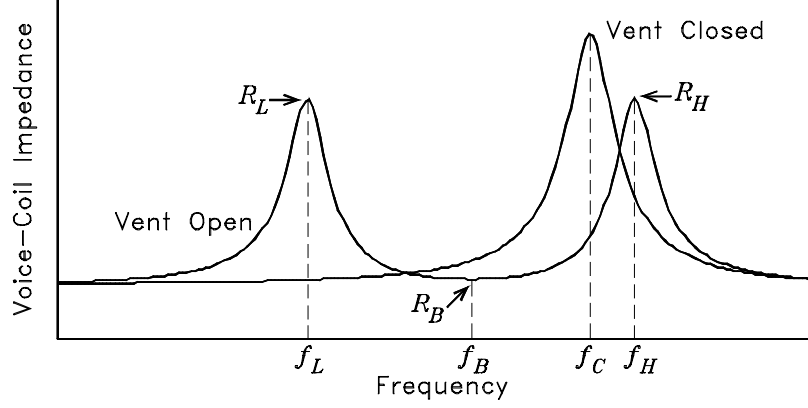

Figure 7: $|Z_{VC}|$ versus frequency with the vent open and the vent closed.

To determine the box quality factor Q_L, the driver voice-coil resistance R_E, its resonance frequency f_S, and its quality factors Q_{ES} and Q_{MS} must be known. First, adjust the quality factors for the air load mass presented by the enclosure using the relations $Q'_{ES} = Q_{ES} \times f_S/f_{SB}$ and $Q'_{MS} = Q_{MS} \times f_S/f_{SB}$. The box quality factor is given by

$$Q_L = \frac{h}{\alpha}\left[\frac{R_E}{Q'_{ES}(R_B - R_E)} - \frac{1}{Q'_{MS}}\right] \tag{7}$$