A Tubular Tuning Method for Vented Enclosures*

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Computer-generated tables greatly simplify the selection of vent dimensions for a vented loudspeaker enclosure. Fine adjustment of vent length may be guided by a simple partial derivative expression relating resonance frequency to vent length.

INTRODUCTION: The required vent dimensions for a vented loudspeaker enclosure are usually found either by solving a set of equations or by using carefully constructed nomograms or charts based on these equations. The basic calculations may also be carried out effortlessly using a digital computer.

Once a computer is programmed to design vents, it can readily provide an enormous number of solutions at low cost and print these out in tabular format. This note describes the construction and use of such a set of tables. These provide an accurate and easy to use discrete tabular equivalent to the nomogram or chart.

VENT DESIGN RELATIONSHIPS

The resonance frequency of a Helmholtz resonator [1, p. 193] is given by

\[ f_B = \frac{c}{2\pi} \left( \frac{S_v}{L_{VE} V_B} \right)^{1/2} \]  

(1)

where

- \( f_B \) resonance frequency in Hz
- \( c \) velocity of sound in air (= 343 m/s)
- \( S_v \) vent cross-sectional area
- \( L_{VE} \) vent effective length
- \( V_B \) net internal volume of resonator or enclosure.

This relationship is based on the assumption that only a minimal amount of enclosure filling is used.

Solving for the ratio \( S_v / L_{VE} \) in Eq. (1) yields

\[ \frac{S_v}{L_{VE}} = V_B \left( 2\pi f_B / c \right)^2 = \text{ALPHA} \]  

(2)

which is recognized as the reciprocal of Thiele’s Eq. (61) [2, p. 391]. This equation is used to generate “ALPHA tables” as described in the Appendix. These tables relate the variables \( f_B \) (Hz), \( V_B \) (cubic inches or cubic feet), and ALPHA (inches, or inches squared per inch).

The expression for effective vent length [1, p. 194] is

\[ L_{VE} = L_V + L_{VC} = L_V + 0.825 (S_v)^{1/2} \]  

(3)

where

- \( L_V \) actual physical length of vent
- \( L_{VC} \) total inner plus outer vent end correction (assuming one end flanged and the other end unflanged).

Substituting Eq. (3) into (2) and solving for \( L_V \) gives

\[ L_V = \frac{S_v}{\text{ALPHA}} - 0.825 (S_v)^{1/2} \]  

(4)

This equation can be rewritten for the special case of a square vent of side \( D \) yielding

\[ L_V = D/2 \frac{\text{ALPHA}}{2} - 0.825 \]  

(5)

The “D table” described in the Appendix uses Eq. (5) to relate the variables \( D, L_V \), and ALPHA (all in inches). \( D \) is used here for convenience. Circular or rectangular vents of area \( S_v = D^2 \) provide equivalent tuning.

VENT CONSTRAINTS

A wide variety of combinations of \( D \) and \( L_V \) can provide a required value of ALPHA. The allowable or useful combinations for a given system are determined by observing practical restrictions on both \( L_V \) and \( D \).

Thiele [2, pp. 390-391] points out that vent length must be restricted to a small fraction of a wavelength at the loudspeaker resonance frequency. The vent length is also restricted in practice by the available enclosure depth.

Small [3, p. 440] suggests a lower limit on vent area to minimize vent turbulence and windage noises, given by

\[ S_v \leq 0.8 f_B V_D \]  

(6)

where \( V_D \) is the peak displacement volume of the driver diaphragm (effective diaphragm area times peak linear displacement) and all variables in this expression are in SI units (meters, hertz).

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PROJECT NOTES/ENGINEERING BRIEFS

BASIC VENT DESIGN PROCEDURE

The basic process of designing a vent using the above relationships is thus.

1) Given: \( V_n, f_n \).
2) Calculate: \( \text{ALPHA} \) from Eq. (2). (Look this up in the ALPHA table.)
3) Choose: \( L_v \) or \( D \).
4) Calculate: \( D \) or \( L_v \) from Eq. (5). (See D table.)
5) Repeat the last two steps if necessary to find an acceptable combination of \( L_v \) and \( D \).

ENCLOSURE TUNING ACCURACY

It has been the author's experience that no matter how carefully and accurately the vent dimensions are calculated, the designer is fortunate if the cabinet resonance frequency obtained is within ±5% of the desired value. This accuracy is seldom good enough. The sensitivity functions for the variation of \( f_n \) [4] show that the Thiele alignments [2] are fairly sensitive to errors in \( f_n \), especially for the Chebyshev alignments. The author usually adds a correction factor of between 10 and 20 percent to the computed vent length so that the vent can be experimentally shortened to make the cabinet resonance frequency correct. The following partial derivative relating \( f_n \) and \( L_v \), taken from Eq. (1), is quite useful in correcting the vent length:

\[
\frac{df_n}{dL_v} = \frac{-f_n}{2L_v} \quad \text{(7)}
\]

Thus if the extra length allowance results in low tuning as expected, the amount by which the vent must be shortened to provide correct tuning may be calculated as

\[
\Delta L_v = -\frac{2L_v}{f_n} \Delta f_n \quad \text{(8)}
\]

where

- \( \Delta L_v \) required change in vent length in inches (negative value means reduced length)
- \( \Delta f_n \) \( f_n \) required \( f_n \) actual
- \( L_v, f_n \) values for present vent length.

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**Fig. 1.** Skeleton setup of ALPHA table. Values of vent cross-sectional area to effective length ratio are listed as a function of box resonance frequency and volume. This correction process is usually quite accurate; it saves time compared to trial-and-error trimming.

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**A COMPLETE DESIGN EXAMPLE**

Tune a cabinet (about 18" deep) of 7.8 ft³ net internal volume to a resonance frequency of 25.0 Hz.

Given: \( V_n = 7.8 \text{ ft}^3, f_n = 25.0 \text{ Hz.} \)

Look up: \( \text{ALPHA} = 1.80 \text{ in}^3/\text{in} \) (On ALPHA table 6, Fig. 2).

Choose: \( L_v = 10 \text{ in}. \)

Look up: \( D = 5.01 \text{ in} \) (on D table 9, Fig. 4).

Therefore the final vent dimensions are approximately 5 in by 5 in (or 5%-in diameter) and, allowing for 20% excess in length, 12 in deep. Note that the numerically closest table entries were taken in each look-up operation without any interpolation.

The cabinet is now tuned using these calculated dimensions and the actual box resonance frequency measured as suggested in the Appendix. Assuming a measured \( f_n \) of 22 Hz, the amount of vent length to remove can be calculated by applying Eq. (8):

\[
\Delta L_v = -3 \times 2 \times 12 = -3.27 \text{ in.}
\]

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**Fig. 2.** A portion of ALPHA table 6 which covers box frequencies 10 Hz-100 Hz, box volumes 3.16-8.91 ft³.
Fig. 3. Skeleton setup of the desired box resonance frequency method of table formulation is presented, and portions of simple look-up operations. These tables are too lengthy portion of one of the ALPHA tables yielded required values of ALPHA and the net internal cabinet volume \( V_B \). Ten ALPHA tables span box volume ranging from 17 to 891 in. with step factors of 1.122 (20 steps per decade) and resonance frequencies ranging from 10 Hz to 100 Hz with step factors of 1.032 (75 steps per decade). A skeleton setup of an ALPHA table is shown in Fig. 1, while a portion of one of the actual tables (no. 6) is shown in Fig. 2.

\[
D = \frac{S_{16}}{V_B} \quad \text{for a vent of square cross-section, given the value of} \quad \text{ALPHA and the actual length of the vent} \quad L_V. \quad \text{They may also be used to find} \quad L_V \quad \text{given} \quad \text{ALPHA and} \quad D. \quad \text{Sixteen} \quad D \text{tables cover ALPHA values ranging from} \quad 0.0001 \quad \text{to 8910 with step factors of} \quad 1.122 \quad \text{(20 steps per decade), and} \quad L_V \text{values ranging from zero to 37 in steps of} \quad 0.5 \quad \text{in. A skeleton setup of a} \quad D \text{table is shown in Fig. 3, and portion of one of the actual} \quad D \text{tables (no. 9) in Fig. 4.}
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Measurement of \( f_b \)

Benson [5, p. 471] derives a measurement method of the true value of \( f_b \) which is essentially independent of voltage coil inductance. He develops an equation for \( f_b \) written in terms of \( f_L, f_H, \) and \( f_C \) (the impedance peak frequencies) as shown

\[
f_b = (f_C^2 + f_L^2 - f_H^2)^{1/2} \quad (9)
\]

where

\( f_L, f_H \) frequencies of higher and lower peaks of the magnitude of the driving point impedance of the driver mounted in the vented enclosure.

\( f_C \) frequency of peak of the magnitude of the driving point impedance when the vent is completely sealed and covered up (resonance frequency of closed-box system in the same box volume).

REFERENCES


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\text{Note: Mr. Keele's biography appeared in the January/February 1973 issue.}
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