PROJECT NOTES / ENGINEERING BRIEFS

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

$$f_B = \frac{c}{2\pi}\left[S_V/(L_{\mathrm{VE}}\, V_B) \right]^{1/2} \tag{1}$$

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

$$S_V/L_{\mathrm{VE}} = V_B\,(2\pi f_B/c)^2 = \mathrm{ALPHA} \tag{2}$$

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

$$L_{\mathrm{VE}} = L_V + L_{\mathrm{VC}} = L_V + 0.825\,(S_V)^{1/2} \tag{3}$$

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

$$L_V = S_V/\mathrm{ALPHA} - 0.825\,(S_V)^{1/2}. \tag{4}$$

This equation can be rewritten for the special case of a square vent of side $D = S_V{}^{1/2}$ yielding

$$L_V = D^2/\mathrm{ALPHA} - 0.825D. \tag{5}$$

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

$$S_V \leqq 0.8\, f_B\, V_D \tag{6}$$

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).

* This Project Note was a section of the paper "The Vented Loudspeaker Cabinet: A Restatement," presented May 5, 1972, at the 42nd Convention of the Audio Engineering Society, Los Angeles.

BASIC VENT DESIGN PROCEDURE

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

1) Given: V_B, f_B.

2) Calculate: 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 $\pm$ 5% of the desired value. This accuracy is seldom good enough. The sensitivity functions for the variation of f_B [4] show that the Thiele alignments [2] are fairly sensitive to errors in f_B, 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_B and L_V, taken from Eq. (1), is quite useful in correcting the vent length:

$$\partial f_B / \partial L_V = - f_B/(2L_{VE}) \approx - f_B/(2L_V). \tag{7}$$

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

$$\triangle L_V = - \triangle f_B \frac{2L_V}{f_B} \tag{8}$$

where

$\triangle L_V$ required change in vent length in inches (negative value means reduced length)

$\triangle f_B$ $f_{\text{required}} - f_{\text{actual}}$

L_V, f_B values for present vent length.

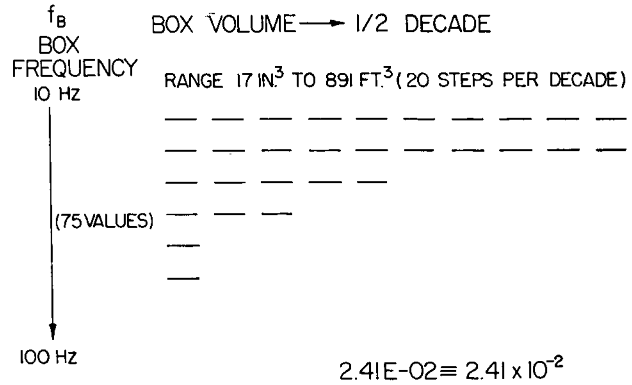

Fig. 1. Skeleton setup of ALPHA table. Values of vent cross-sectional area to effective length ratio are listed as a function of box resonance frequency and volume.

This correction process is usually quite accurate; it saves time compared to trial-and-error trimming.

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: $V_B = 7.8$ ft³, $f_B = 25.0$ Hz.
Look up: ALPHA $= 1.80$ in²/in (On ALPHA table 6, Fig. 2).
Choose: $L_V = 10$ in.
Look up: $D = 5.01$ in (on D table 9, Fig. 4).

Therefore the final vent dimensions are approximately 5 in by 5 in (or 5⅝-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_B of 22 Hz, the amount of vent length to remove can be calculated by applying Eq. (8):

$$\triangle L_V = -3 \times \frac{2 \times 12}{22} = -3.27 \text{ in.}$$

******************** ALPHA TABLE NO. 6 FOR CABINET TUNING ********************
BOX VOLUMES FROM 3.162 TO 8.911 CUBIC FEET OR 5.46E 03 TO 1.54E 04 CUB INCHES.
VOLUME (ACROSS) ALPHA=(PORT AREA)/(PORT EFFECTIVE LENGTH) IN SQUARE INCHES PER INCH.

CU. FT. =		3.16E 00	3.55E 00	3.98E 00	4.47E 00	5.01E 00	5.62E 00	6.31E 00	7.08E 00	7.94E 00	8.91E 00
CU. IN. =		5.46E 03	6.13E 03	6.88E 03	7.72E 03	8.66E 03	9.72E 03	1.09E 04	1.22E 04	1.37E 04	1.54E 04
F-BOX HZ (DOWN)											
10.00	*	1.18E-01	1.32E-01	1.48E-01	1.67E-01	1.87E-01	2.10E-01	2.35E-01	2.64E-01	2.96E-01	3.32E-01
21.77	*	5.59E-01	6.27E-01	7.04E-01	7.89E-01	8.86E-01	9.94E-01	1.12E 00	1.25E 00	1.40E 00	1.58E 00
22.46	*	5.95E-01	6.67E-01	7.49E-01	8.40E-01	9.43E-01	1.06E 00	1.19E 00	1.33E 00	1.49E 00	1.68E 00
23.17	*	6.33E-01	7.10E-01	7.97E-01	8.94E-01	1.00E 00	1.13E 00	1.26E 00	1.42E 00	1.59E 00	1.78E 00
23.90	*	6.74E-01	7.56E-01	8.48E-01	9.52E-01	1.07E 00	1.20E 00	1.34E 00	1.51E 00	1.69E 00	1.90E 00
24.65	*	7.17E-01	8.04E-01	9.03E-01	1.01E 00	1.14E 00	1.27E 00	1.43E 00	1.60E 00	$\boxed{1.80E\ 00}$	2.02E 00
25.43	*	7.63E-01	8.56E-01	9.60E-01	1.08E 00	1.21E 00	1.36E 00	1.52E 00	1.71E 00	1.92E 00	2.15E 00
26.24	*	8.12E-01	9.11E-01	1.02E 00	1.15E 00	1.29E 00	1.44E 00	1.62E 00	1.82E 00	2.04E 00	2.29E 00
27.07	*	8.64E-01	9.69E-01	1.09E 00	1.22E 00	1.37E 00	1.54E 00	1.72E 00	1.93E 00	2.17E 00	2.44E 00
27.92	*	9.20E-01	1.03E 00	1.16E 00	1.30E 00	1.46E 00	1.64E 00	1.83E 00	2.06E 00	2.31E 00	2.59E 00
28.80	*	9.79E-01	1.10E 00	1.23E 00	1.38E 00	1.55E 00	1.74E 00	1.95E 00	2.19E 00	2.46E 00	2.76E 00
100.00	*	1.18E 01	1.32E 01	1.48E 01	1.67E 01	1.87E 01	2.10E 01	2.35E 01	2.64E 01	2.96E 01	3.32E 01

Fig. 2. A portion of ALPHA table 6 which covers box frequencies 10 Hz-100 Hz, box volumes 3.16-8.91 ft.³

D TABLE NO. 9 FOR CABINET TUNING

ALPHA VALUES FROM 1.00E 00 TO 2.82E 00 SQUARE INCHES PER INCH.
ALPHA (ACROSS) D=SIDE DIMENSION OF SQUARE PORT CROSS-SECTION IN INCHES.

SQ. IN/IN= / L INCHES (DOWN)		1.00E 00	1.12E 00	1.26E 00	1.41E 00	1.58E 00	1.78E 00	2.00E 00	2.24E 00	2.51E 00	2.82E 00
0.0	*	8.25E-01	9.26E-01	1.04E 00	1.17E 00	1.31E 00	1.47E 00	1.65E 00	1.85E 00	2.07E 00	2.33E 00
7.5	*	3.18E 00	3.40E 00	3.64E 00	3.89E 00	4.16E 00	4.46E 00	4.78E 00	5.12E 00	5.50E 00	5.90E 00
8.0	*	3.27E 00	3.49E 00	3.74E 00	3.99E 00	4.27E 00	4.58E 00	4.90E 00	5.26E 00	5.64E 00	6.05E 00
8.5	*	3.36E 00	3.59E 00	3.83E 00	4.10E 00	4.38E 00	4.69E 00	5.02E 00	5.38E 00	5.77E 00	6.19E 00
9.0	*	3.44E 00	3.67E 00	3.93E 00	4.20E 00	4.49E 00	4.80E 00	5.14E 00	5.51E 00	5.90E 00	6.33E 00
9.5	*	3.52E 00	3.76E 00	4.02E 00	4.29E 00	4.59E 00	4.91E 00	5.25E 00	5.63E 00	6.03E 00	6.47E 00
10.0	*	3.60E 00	3.84E 00	4.11E 00	4.39E 00	4.69E 00	5.01E 00	5.37E 00	5.74E 00	6.15E 00	6.60E 00
10.5	*	3.68E 00	3.93E 00	4.19E 00	4.48E 00	4.79E 00	5.12E 00	5.47E 00	5.86E 00	6.28E 00	6.73E 00
11.0	*	3.75E 00	4.01E 00	4.28E 00	4.57E 00	4.88E 00	5.22E 00	5.58E 00	5.97E 00	6.39E 00	6.85E 00
11.5	*	3.83E 00	4.08E 00	4.36E 00	4.65E 00	4.97E 00	5.31E 00	5.68E 00	6.08E 00	6.51E 00	6.97E 00
12.0	*	3.90E 00	4.16E 00	4.44E 00	4.74E 00	5.06E 00	5.41E 00	5.78E 00	6.19E 00	6.62E 00	7.09E 00
37.0	*	6.51E 00	6.92E 00	7.36E 00	7.84E 00	8.34E 00	8.88E 00	9.45E 00	1.01E 01	1.07E 01	1.14E 01

Fig. 4. A portion of *D* table 9 which covers ALPHA values from 1.00 to 2.82 and vent length of 0.0 to 37.0 in.

This calculation shows that the desired cabinet resonance frequency should be obtained by removing 3¼ in from the duct length.

CONCLUSION

The author has used a computer to compile a set of tables which reduce the vent design problem to two simple look-up operations. These tables are too lengthy for complete publication in the *Journal*. However, the method of table formulation is presented, and portions of the tables are shown to illustrate their use. Copies of the complete table set may be obtained for the cost of printing by writing directly to the author.

APPENDIX

Alpha Tables

The ALPHA tables yield required values of ALPHA $= S_V/L_{VE}$ (in inches or inches squared per inch) given the desired box resonance frequency f_B and the net internal cabinet volume V_B. Ten ALPHA tables span box volumes ranging from 17 in^3 to 891 ft^3 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.

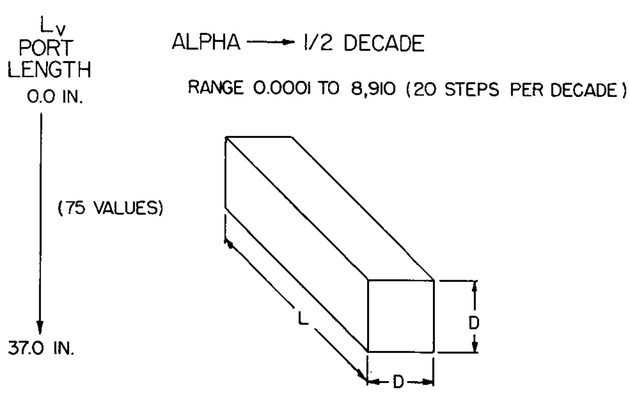

Fig. 3. Skeleton setup of *D* table. Values of square vent dimension are listed as a function of actual port length and ALPHA.

D Tables

The D tables give values of the side dimension $D = S_V^{1/2}$ for a vent of square cross-section, given the value of ALPHA and the actual length of the vent L_V. They may also be used to find L_V given ALPHA and D. Sixteen D tables cover ALPHA values ranging from 0.0001 to 8910 with step factors of 1.122 (20 steps per decade), and L_V values ranging from zero to 37 in in steps of 0.5 in. A skeleton setup of a D table is shown in Fig. 3, and portion of one of the actual D tables (no. 9) in Fig. 4.

Measurement of f_B

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

$$f_B = (f_L^2 + f_H^2 - f_C^2)^{1/2} \tag{9}$$

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