Linearteam technical paper

About the ports and differences between various equations and design software calculations

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Chapter 1

Introduction

This document is mostly a rewrite to LaTeX environment from previous MS Word document, mainly due to the fact that I was not satisfied with the typographical quality of the final document, especially regarding formulas. Some results have been written in more compactly. Also, LaTeX helps me to write better documents, since the time is spent in writing content and logical structure, not fiddling around with actual layout, which I hate do all the time I use MS Word.

Differing port lengths between various calculation formulas and design software has caused some confusion, especially among beginners. In this document, I'll examine various port tuning formulas and show the causes for differing results. I have experimentally calculated these values for various design software.

Small reminder of "advanced simulations" found in other software: Simulation can look advanced, but it can go terribly wrong anyway (so called snake-oil remedy, particulary known among cryptologists: The bad cipher can look random, but doesn't really bear any true cryptanalysis). That is particulary true for nonlinear simulation. It is based upon guessing, if there is no input for nonlinearity info.

Classic Thiele-Small parameters don't tell anything about what happens after linearity assumption is no longer valid. They are small-signal parameters which change with operating point. You can make guesses, but whether it is absolutely correct is very questionable anyway. For good non- linearity simulations, the parameters should be given in polynomial or at least in table form, to see how to change them when driver has different excursion.

Please feel free to send any corrections, additions, feedback and suggestions about this document.

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Chapter 2

Differences between various formulas

2.1   List of symbols

A_v, S_v	inside area of the port
c	speed of sound in air
D_v, d	port inside diameter
f_b	tuning frequency of the port
j	Imaginary unit, $\sqrt{-1}$
k	end correction factor
L_v, l	physical length of the port
L_t	acoustic length of the port, including end correction
N_p	number of the ports in box
NFR	Normalized Flare Rate. Dimensionless ratio of port length to flare double radius
ω_b	angular tuning frequency of the port
p	atmosphere air pressure
R	inside radius of the port
RH	relative humidity
ρ	air density
T	temperature
V, V_b	box net volume
X_C	capacitive reactance
X_L	inductive reactance

2.2   The basic formula of the Helmholtz resonator

In order to understand the theory behind the loudspeaker ports, we must first develop a theory behind the Helmholtz resonator.

The Helmholtz resonator is just like the electrical LC-resonator. Acoustical inductance comes from air mass in the port and acoustical capacitance comes from compliance of the air in the box.

Electrical analogy here is that *current* in inductor resists changes by generating *voltage* same way than moving slug of air resists changes to velocity by creating a *force*. Likewise, capacitor resists of changing the voltage by creating a *current*. Same way container filled with pressurised air resists changing of *pressure* by creating a *air flow*, called *volume velocity*. Summary of the analogies can be found in table 2.1.

The basic assumption in electroacoustic equivalent circuits is that pressure is reasonable uniform across the whole volume and port.

Table 2.1: Electrical analogies for acoustical quantities.

Electrical quantity	Acoustical quantity
Current	Volume velocity
Voltage	Pressure
Inductance	Mass
Capacitance	Compliance

Resonance is defined by the condition when inductive and capacitive reactances in the circuit cancel each other out so that circuit looks purely resistive from outside. The formula for the resonant frequency of the electrical LC-resonator can be derived as follows:

$$
\begin{aligned}
& jX_L - jX_C = 0 \\
\Leftrightarrow\ & j\omega L - j\frac{1}{\omega C} = 0 \\
\Leftrightarrow\ & j\omega L = j\frac{1}{\omega C} \\
\Leftrightarrow\ & \omega^2 = \frac{1}{LC} \\
\Leftrightarrow\ & f = \frac{1}{2\pi\sqrt{LC}}
\end{aligned}
\tag{2.1}
$$

The formula for acoustical inductance (i.e. a tube) is

$$
L_a = \frac{\rho l_t}{S_v}
\tag{2.2}
$$

and for acoustical capacitance (i.e. a closed box) is

$$
C_a = \frac{V_b}{\rho c^2}
\tag{2.3}
$$

By marking $L = L_a$ and $C = C_a$ and by substituting (2.2) and (2.3) into (2.1) we get

$$
f = \frac{1}{2\pi\sqrt{\frac{\rho l_t}{S_v}\frac{V_b}{\rho c^2}}} = \frac{1}{2\pi\sqrt{\frac{l_t V_b}{S_v c^2}}} = \frac{\sqrt{S_v c^2}}{2\pi\sqrt{l_t V_b}} = \frac{c}{2\pi}\sqrt{\frac{S_v}{l_t V_b}}
\tag{2.4}
$$

By noting that if we have multiple ports, the cross-section area is multiplied by number of ports and when acoustical length is related to the physical length of the port, the correction factor called end correction comes into play. The end correction means that port is effectively longer than its physical length. This excess length comes from radiation impedance reactance, or to put it more simply, port air moves surrounding air also in addition to the internal port air mass.

The basic Helmholtz resonator tuning formula without any numerical approximate constants is the mother of all these port design equations:

$$
f_b = \frac{c}{2\pi}\sqrt{\frac{S_v n_p}{V_b(L_v + k2\sqrt{\frac{S_v}{\pi}})}} \Leftrightarrow L_v = \frac{c^2}{(2\pi)^2}\frac{S_v n_p}{f_b^2 V_b} - k2\sqrt{\frac{S_v}{\pi}}
\tag{2.5}
$$

Using relation for circular port,

$$S_v = \frac{d_v^2 \pi}{4} \tag{2.6}$$

the port tuning equation (2.5) can be rewritten as

$$f_b = \frac{c}{2\pi} \sqrt{\frac{d_v^2 \pi}{4 V_b (L_v + d_v k)}} \Leftrightarrow L_v = \frac{c^2}{(2\pi)^2} \frac{d_v^2 \pi n_p}{4 f_b^2 V_b} - k d_v = \frac{c^2}{16 \pi^2} \frac{d_v^2 n_p}{f_b^2 V_b} - k d_v \tag{2.7}$$

where c is the speed of sound in meters/per second, V_b is the volume of the box in cubic meters and and S_v is the cross-section area of the port in square meters. It is possible to use imperial units but then all lengths must be of same unit i.e. inches. That implies that one must use cubic inches for volumes if length is inches.

The "standard" end corrections are: 0.425 for flanged end and 0.307 for free end. Typical k for end correction is 0.732 (one flanged and one free end).

2.3   Some common formulas

The various occurences of the port tuning formula are as follows:

1. The one used by Vance Dickason:

$$L_v = \frac{1.463 \times 10^7 R^2}{f_b^2 V_b} - 1.463 R \tag{2.8}$$

Where L_v is length in inches, F_b is tuning frequency in Hz, V_b is box volume in cubic inches and R is radius of the vent in inches. This could be written to use diameter d in place of the port radius:

$$L_v = \frac{1.463 \times 10^7 d^2}{4 f_b^2 V_b} - \frac{1.463}{2} d \tag{2.9}$$

2. The one used by A. N. Thiele (Loudspeakers in vented boxes, part I):

$$V_b = \frac{1.84 \times 10^8 S_v}{\omega_b^2 L_v} = \frac{1.84 \times 10^8 S_v}{(2\pi)^2 f_b^2 L_v} \Leftrightarrow L_v = \frac{1.84 \times 10^8 S_v}{(2\pi)^2 f_b^2 V_b} \tag{2.10}$$

V_b is the box volume in cubic inches, S_v is the vent area in square inches and f_b is the port tuning frequency in Hz. Note that Thiele's equation doesn't include the end correction. He mentions that L_v is the effective length of the vent which includes its actual length together with an end correction.

3. The one mentioned in JL Audio's "Port Basics"-tutorial):

$$F_b = 0.159 \sqrt{\frac{A_v 1.84 \times 10^8}{V_b (L_v + 0.823 \sqrt{A_v})}} \Leftrightarrow L_v = \frac{0.159^2 \times 1.84 \times 10^8 A_v}{f_b^2 V_b} - 0.823 \sqrt{A_v} \tag{2.11}$$

This formula is particulary interesting, because of the explanation about using multiple ports on enclosure. JL Audio's tutorial claims that the port length must be different when using

multiple ports even if the total area of the ports is same than single port. While this is of course true, but reason is not friction in ports (although it increases also), but simply because end correction of the port is determined by single port.

When calculating port using this formula, one should use the method recommended by JL audio (dividing the box volume by the number of the ports). Only then the end correction part will be correct. Alternatively, use A_v of the single vent in the "end correction part". The corrected equation for arbitary number of the ports N_p is

$$F_b = 0.159\sqrt{\frac{A_v N_p 1.84 \times 10^8}{V_b(L_v + 0.823\sqrt{A_v})}} \Leftrightarrow L_v = \frac{0.159^2 \times 1.84 \times 10^8 A_v N_p}{f_b^2 V_b} - 0.823\sqrt{A_v} \quad (2.12)$$

4. The one mentioned in the subwoofer DIY pages at http://www.diysubwoofers.org/portcal.htm:

$$L_v = \frac{23562.5 D_v^2 N_p}{f_b^2 V_b} - kD_v \quad (2.13)$$

Units used are $[L_v]$=cm, $[D_v]$=cm and $[V_b]$=litres.

5. The one used in Finland by Pekka Tuomela in Finnish audio-magazine "HIFI-lehti":

$$L_v = \frac{22700 d^2}{f_b^2 V_b} - 0.8 D_v \quad (2.14)$$

The units are the same than those of diysubwoofers.org.

6. There is a "newer" equation, the one represented by Alex Salvatti, Doug Button and Allan Devantier. It has ability to calculate flared ports. The formula is:

$$f_b = \frac{c}{2\pi}\sqrt{\frac{A_{\text{eff}}}{L_{\text{eff}} V_b}} \quad (2.15)$$

Where

$$A_{\text{eff}} = \left[1 + 0.576\underbrace{\left(\frac{L_v}{2r_{\text{fit}}}\right)}_{\text{NFR}}\right] A_{\text{min}} \quad (2.16)$$

and

$$L_{\text{eff}} = L_v + D_{\text{min}} \quad (2.17)$$

NFR is abbreviation for Normalized Flare Rate. NFR is zero for standard straight port, and one for maximally radiused port. A_{min} is minimum port area, e.g. the area of the circle where the flared port is narrowest. The coefficient of 0.576 comes from experimental work done fitting the increase of port area to flare rate.

By combining these to one single equation, we get

$$f_b = \frac{c}{2\pi}\sqrt{\frac{(1+0.576NFR)A_{\min}}{(L_v D_{\min})V_b}} \tag{2.18}$$

or by terms of L_v,

$$L_v = \frac{c^2}{16\pi}\frac{(1+0.576NFR)D_{\min}}{V_b f_b^2} - D_{\min} \tag{2.19}$$

Comparing the equations, one can see that there are basically three parts in them:

1. The numerical constant, which includes the speed of sound and other numerical constants rolled into one.

2. The part containing physical properties, the box volume, port area, diameter or radius, tuning frequency and number of the ports, optionally.

3. The end correction part, which subtracts the end correction from the acoustical length of the port.

One can see by comparing equations (2.8)-(2.14) and (2.19), that the varying part is the numerical constant part. Let's examine equations (2.8)-(2.14) for which value is actually used for speed of sound, and end correction.

This speed, using environmental values of temperature +20°C, air pressure 101325 Pa and relative humidity 30%, is about 343,68 m/s. This is standard setup in WinISD. I'll use form $L_v = \ldots$ of (2.7). Defining following unit conversion factor, 1 in = 0.0254 m is useful.

2.4   The effect of the ambient temperature to port tuning

The calculated port length is proportional to square of the speed of sound, as can be seen from (2.7). The speed of sound is proportional to square root of temperature. The resulting effect is that the port length has approximately linear dependancy on the absolute temperature.

If the temperature changes from -30 °C to +30 °C (60 Kelvins), the port length is increased by factor of

$$\frac{T_1}{T_0} = 1 + \frac{\Delta T}{T_0} = 1 + \frac{60\text{K}}{243.15\text{K}} \approx 1.2468 \tag{2.20}$$

Port length is changed 25%. If port is 1 meters long, this means 20 centimeters of change. That is a quite big change. In case 1, difference between largest and smallest figure is about 43 millimeters. This corresponds changing temperature variable of WinISD from 8.3 °C to 28.7 °C, about 20 °C.

2.5   Determining values of c and k from various port formulas

1. Dickason's equation:

   By marking equations (2.8) and (2.7) equal we get

$$\frac{1.463 \times 10^7 d^2}{4 f_b^2 V_b} = \underbrace{\frac{1}{0.0254}}_{\text{m to in}} \frac{c^2}{(2\pi)^2} \frac{d^2 \pi}{4 f_b^2 V_b} \overbrace{\underbrace{\frac{0.0254^2}{0.0254^3}}_{\text{in}^3 \text{ to m}^3}}^{\text{in to m}} \tag{2.21}$$

and then solving for c we get

$$c = \sqrt{\frac{1.463 \times 10^7 \, 0.0254^3 \, 0.0254 \, 16\pi}{4 \, 0.0254^2}} = \sqrt{1.463 \times 10^7 \, 0.254^2 \, 4\pi} \approx 344, 40 \frac{\text{m}}{\text{s}} \tag{2.22}$$

For the end correction part, $1.463/2 = 0.7315$ is close to 0.732.

2. Thiele's equation:

   Just like before, comparing equations (2.10) and (2.7). I have excluded the end correction, to match the original equation.

   Using same method, we get

$$\frac{1.84 \times 10^8 S_v}{(2\pi)^2 f_b^2 V_b} = \underbrace{\frac{1}{0.0254}}_{\text{m to in}} \frac{c^2}{(2\pi)^2} \frac{S_v}{f_b^2 V_b} \overbrace{\underbrace{\frac{0.0254^2}{0.0254^3}}_{\text{in}^3 \text{ to m}^3}}^{\text{in}^2 \text{ to m}^2} \tag{2.23}$$

   solving for c gives us

$$c = \sqrt{1.84 \times 10^8 \, 0.254^2} \approx 344, 54 \frac{\text{m}}{\text{s}} \tag{2.24}$$

   This equation has no end correction (but Thiele discusses this separately), so I will not dig into this any further.

3. JL Audio's equation:

   Equation (2.11) has same form than Thiele's, but now there is factor of $1/(2\pi)^2$ converted to numerical approximation. This causes some additional inaccuracy.

   By equating (2.11) and (2.7) with imperial to metric conversion factors, noting that $A_v = S_v$ and setting two equations equal we get for speed of sound dependent part:

$$\frac{0.159^2 \, 1.84 \times 10^8 S_v}{f_b^2 V_b} = \underbrace{\frac{1}{0.0254}}_{\text{m to in}} \frac{c^2}{(2\pi)^2} \frac{S_v}{f_b^2 V_b} \overbrace{\underbrace{\frac{0.0254^2}{0.0254^3}}_{\text{in}^3 \text{ to m}^3}}^{\text{in}^2 \text{ to m}^2} \tag{2.25}$$

   Assuming all errors become from sound velocity, the sound velocity is

$$c = \sqrt{0.159^2 \, 1.84 \times 10^8 (2\pi)^2 (0.0254)^2} \approx 344, 21 \frac{\text{m}}{\text{s}} \tag{2.26}$$

So there is neglible change compared to Thiele's equation. For the end correction factors and again noting that $A_v = S_v$, solving for k gives

$$0.823\sqrt{S_v} = 2k\sqrt{\frac{S_v}{\pi}} \Leftrightarrow k = \frac{0.832\sqrt{\pi}}{2} \approx 0.729 \tag{2.27}$$

There is again some change to 0.732 which is a standard value. However, it is further off than Dickason's figure.

4. Diysubwoofers.org equation:

Equating (2.13) with (2.7) and applying the unit conversion factors gives us

$$\frac{23562.5D_v^2N_p}{F_b^2V_b} = \underbrace{\frac{1}{0.01}}_{\text{m to cm}} \frac{c^2}{(2\pi)^2} \overbrace{\underbrace{\frac{(0.01)^2}{0.001}}_{\text{l to m}^3}}^{\text{cm}^2 \text{ to m}^2} \frac{d_v^2\pi n_p}{4f_b^2V_b} \tag{2.28}$$

and solving for c gives us

$$c = \sqrt{\frac{23562.5(2\pi)^24}{10\pi}} \approx 344,15\frac{\text{m}}{\text{s}} \tag{2.29}$$

This is also very close to previous formulas. Because k is specified separately, there is no need to analyze that part.

5. Pekka Tuomela's equation:

Equating (2.14) with (2.7) and applying the unit conversion factors gives us

$$\frac{22700d_v^2n_p}{f_b^2V_b} = \underbrace{\frac{1}{0.01}}_{\text{m to cm}} \frac{c^2}{(2\pi)^2} \overbrace{\underbrace{\frac{(0.01)^2}{0.001}}_{\text{l to m}^3}}^{\text{cm}^2 \text{ to m}^2} \frac{d_v^2\pi n_p}{4f_b^2V_b} \tag{2.30}$$

and solving for c we get

$$c = \sqrt{\frac{22700(2\pi)^24}{10\pi}} \approx 337,79\frac{\text{m}}{\text{s}} \tag{2.31}$$

This is considerably less than the other formulas have. It seems that us Finns like listening in cold environments . WinISD's temperature variable has to reduce to $10,73°C$ to achieve this velocity.

2.6   Summary of calculated values

Table 2.2: Summary of the calculated values for c and k of various formulas.

Equation provider	Speed of sound c/m/s	End correction value k
Vance Dickason, Loudspeaker design cookbook	344.40	0.7315
A. N. Thiele, Loudspeaker in vented boxes, Part II	344.54	N/A
JL Audio tutorial, ”Port basics”	344.21	0.729
Brian Steele, Diysubwoofers.org web page	344.15	N/A
Pekka Tuomela, Hifi-lehti	337.79	0.8
WinISD pro 0.50, standard setup	343.68	0.732

Chapter 3

Differences between software packages

For WinISD case, there is no need for any secrecy, the port length is calculated using (2.7). The c is shown in "plot" tab. I think all software authors should tell what is going "under the hood". That way, user has better knowledge what are the weaknesses.

3.1 Constants c and k for different design software

The method for extracting the calculation constants hidden inside the software is described in this chapter.

Previous technique is applicable to software also. You can't really see what calculation equations are used in the particular software. If we can assume that software in question uses same formula with different constants, we can solve two unknowns using pair of linear equations.

By marking

$$x = \frac{c^2}{(2\pi)^2} \tag{3.1}$$

and

$$a_1 = \frac{d_{v1}^2 \pi n_{p1}}{4 f_{b1}^2 V_{b1}} \tag{3.2}$$

$$a_2 = \frac{d_{v2}^2 \pi n_{p1}}{4 f_{b1}^2 V_{b1}} \tag{3.3}$$

we get following pair of equations:

$$\begin{cases} l_{v1} = a_1 x - k d_{v1} \\ l_{v2} = a_2 x - k d_{v2} \end{cases} \tag{3.4}$$

The velocity of the sound is then calculatable using

$$c = 2\pi\sqrt{x} \tag{3.5}$$

Now, if we calculate using any software package two different combinations of ports, we can get values for x and k. However, the results should be verified with second pair of cases. By comparing results from first and second case pair, we can estimate, if the equation used in the software in question is really representable by this form.

I have choosen arbitarily combinations ($n_p = 1$ in all cases) shown in table 3.1 for testing.

Table 3.1: Test cases for program port calculation evaluation.

Case	D_v/mm	V_b/litres	F_b/Hz	Value of constant $a(\times 10^{-4})$	WinISD pro reference port length/mm
1	100.0	100.0	20.0	1.96349540849	514.3
2	82.0	30.0	40.0	1.10021192722	269.2
3	85.0	50.0	35.0	0.926449262131	215.0
4	70.0	85.0	18.0	1.39740413967	366.9

For convenience, I have included reference values calculated with WinISD, using standard environmental setup ($T = 20°C$, $p = 101325$ Pa, $RH =30\%$). One possible difficulty is that the port length is expressed rather coarsely for this purpose, so values obtained are not most accurate, but they enable to make some conclusions, especially when two groups 1&2 and 3&4 are compared.

3.1.1 TermPro version 1.07

Table 3.2: TermPro 1.07 port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	TermPro port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	512.0	514.3
2	82.0	30.0	40.0	267.9	269.2
3	85.0	50.0	35.0	213.9	215.0
4	70.0	85.0	18.0	365.3	366.9

Solving unknowns from cases 1 & 2 from table 3.2, we get the following set of equations:

$$\begin{cases} 1.96349540849 \cdot 10^{-4}x_1 - 100 \cdot 10^{-3}k_1 = 512.0 \cdot 10^{-3} \\ 1.10021192722 \cdot 10^{-4}x_1 - 82 \cdot 10^{-3}k_1 = 267.9 \cdot 10^{-3} \end{cases}$$

Solving x_1 and k_1 and applying equation (3.5) we get:

$$\begin{cases} x_1 \approx 2980.067 \Rightarrow c_1 = 2\pi\sqrt{x} = 2\pi\sqrt{2980.067} \approx 343\frac{m}{s} \\ k_1 \approx 0.7313 \end{cases}$$

To verify obtained results, let's calculate these from cases 3 & 4:

$$\begin{cases} 0.926449262131 \cdot 10^{-4}x_2 - 85 \cdot 10^{-3}k_2 = 213.9 \cdot 10^{-3} \\ 1.39740413967 \cdot 10^{-4}x_2 - 70 \cdot 10^{-3}k_2 = 365.3 \cdot 10^{-3} \end{cases}$$

Solving this equation pair gives us

$$\begin{cases} x_2 \approx 2981.30 \Rightarrow c_2 = 2\pi\sqrt{x} = 2\pi\sqrt{2981.30} \approx 343.07\frac{m}{s} \\ k_2 \approx 0.7330 \end{cases}$$

Averaging results for cases, we get 343.0 m/s for c and 0.732 for end correction k. So TermPro probably uses sound velocity of 343 m/s and end correction of 0.732. This can be achieved with WinISD by reducing temperature to 18.88 °C. It yields to 343 m/s as sound velocity on otherwise standard environmental setup.

Please note that this version of TermPro seems to calculate multiple ports wrong, probably SW author has not understood how end correction really works. It just calculates sum of area of all ports, and then calculates length using this area like a single port. This is not correct, because end correction is determined by the single port. Error is not huge, though, when total change in frequency response is considered.

3.1.2   WinSpeakerz Demo 2.5.0

Table 3.3: WinSpeakerz Demo 2.5.0 port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	WinSpeakerz port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	519	514.3
2	82.0	30.0	40.0	272	269.2
3	85.0	50.0	35.0	217	215.0
4	70.0	85.0	18.0	370	366.9

Again, by using same techniques we get for cases 1 and 2

$$\begin{cases} x_1 \approx 3012.23 \Rightarrow c_1 \approx 344.8 \frac{\text{m}}{\text{s}} \\ k_1 \approx 0.7313 \end{cases}$$

To verify results, calculating these from cases 3 and 4, we get:

$$\begin{cases} x_2 \approx 3015.14 \Rightarrow c_2 \approx 345.01 \frac{\text{m}}{\text{s}} \\ k_2 \approx 0.7334 \end{cases}$$

There, we can see that sound velocity is probably 345 m/s and end correction is 0.732.

3.1.3   LspCAD demo 5.20

Table 3.4: lspCAD 5.20 port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	lspCAD port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	490	514.3
2	82.0	30.0	40.0	251	269.2
3	85.0	50.0	35.0	201	215.0
4	70.0	85.0	18.0	344	366.9

Again, by using same techniques we get for cases 1 and 2

$$\begin{cases} x_1 \approx 2957.71 \Rightarrow c_1 \approx 341.7 \frac{\text{m}}{\text{s}} \\ k_1 \approx 0.9074 \end{cases}$$

To verify results, calculating these from cases 3 and 4, we get:

$$\begin{cases} x_2 \approx 3814.01 \Rightarrow c_2 \approx 333.25\frac{m}{s} \\ k_2 \approx 0.7013 \end{cases}$$

These values dont match very well. What's happening here? It is clear that something "adjustment" is done here. Probably Q_p[1] is calculated internally, and then the port length is adjusted correspondingly, or port volume is subtracted from internal box volume. Which is the case, it is not in my knowledge. LspCAD manual doesnt tell either.

By matching the impedance curves on the LspCAD and WinISD, we get following values for Q_p:

1. Q_p=35.3

2. Q_p=50.0

3. Q_p=45.0

4. Q_p=23.0

Lower the Q_p, lower the actual tuning frequency. Even this don't explain fully, why the values are different. Something "heavy magic" is going on here.

3.1.4   Loudspeaker Lab 2.20 Demo

Table 3.5: Loudspeaker Lab 2.20 Demo port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	Loudspeaker Lab port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	515.4	514.3
2	82.0	30.0	40.0	269.8	269.2
3	85.0	50.0	35.0	215.5	215.0
4	70.0	85.0	18.0	367.6	366.9

This program has settable environment temperature. It was set to 20 °C, as has WinISD. Again, by using same techniques we get for cases 1 and 2

$$\begin{cases} x_1 \approx 2997.483 \Rightarrow c_1 \approx 344.0\frac{m}{s} \\ k_1 \approx 0.7315 \end{cases}$$

To verify results, calculating these from cases 3 and 4, we get:

$$\begin{cases} x_2 \approx 2996.779 \Rightarrow c_2 \approx 344.0\frac{m}{s} \\ k_2 \approx 0.7310 \end{cases}$$

3.1.5   JBL Speakershop 1.0

This program has settable environment parameters for air density and speed of sound. They were set to WinISD standard values.

Again, by using same techniques we get for cases 1 and 2

$$\begin{cases} x_1 \approx 3222.28106 \Rightarrow c_1 \approx 356.67\frac{m}{s} \\ k_1 \approx 1.00000007 \end{cases}$$

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[1]Q_p tells how good the port is, or higher number means less friction (resistance) on the port.

Table 3.6: JBL Speakershop 1.0 port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	JBL Speakershop port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	532.6934	514.3
2	82.0	30.0	40.0	272.5192	269.2
3	85.0	50.0	35.0	213.528	215.0
4	70.0	85.0	18.0	380.2829	366.9

To verify results, calculating these from cases 3 and 4, we get:

$$\begin{cases} x_2 \approx 3222.28111 \Rightarrow c_2 \approx 356.67\frac{m}{s} \\ k_2 \approx 0.999999995 \end{cases}$$

This gives high confidence of calculated values of speed of sound and end correction. Funnily enough, the program seems not to use specified environmental values for port calculations. End correction is a bit high side.

3.1.6   Blaubox (version unknown)

Table 3.7: Blaubox port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	Blaubox port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	515.874	514.3
2	82.0	30.0	40.0	269.494	269.2
3	85.0	50.0	35.0	214.63	215.0
4	70.0	85.0	18.0	368.3	366.9

This program has settable environment parameters for air density and speed of sound. They were set to WinISD standard values.

Again, by using same techniques we get for cases 1 and 2

$$\begin{cases} x_1 \approx 3011.11 \Rightarrow c_1 \approx 344.78\frac{m}{s} \\ k_1 \approx 0.754 \end{cases}$$

To verify results, calculating these from cases 3 and 4, we get:

$$\begin{cases} x_2 \approx 3019.10 \Rightarrow c_2 \approx 345.24\frac{m}{s} \\ k_2 \approx 0.766 \end{cases}$$

Sound velocity is probably here 345 m/s and end correction, about 0.76.

3.1.7   Autosound Technical Magazine BassBoxDesigner © A.Karhu java applet

Again, by using same techniques we get for cases 1 and 2

$$\begin{cases} x_1 \approx 2999.994 \Rightarrow c \approx 344.144\frac{m}{s} \\ k_1 \approx 0.7325 \end{cases}$$

Table 3.8: ASTM BBD port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	ASTM BBD port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	515.8	514.3
2	82.0	30.0	40.0	270.0	269.2
3	85.0	50.0	35.0	215.7	215.0
4	70.0	85.0	18.0	367.9	366.9

To verify results, calculating these from cases 3 and 4, we get:

$$\begin{cases} x_2 \approx 2998.911 \Rightarrow c \approx 344.08\frac{m}{s} \\ k_2 \approx 0.731 \end{cases}$$

Sound velocity is probably here 344 m/s and end correction, about 0.732.

3.1.8 DOS BoxModel v1.2 © Robert M. Bullock III

Environment settings of this program are set to T=20.0 °Cand P=760 mmHg, which are equivalent to the WinISD pro 0.50a default values.

Table 3.9: DOS BoxModel v1.2 port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	DOS BoxModel port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	513.1	514.3
2	82.0	30.0	40.0	268.5	269.2
3	85.0	50.0	35.0	214.4	215.0
4	70.0	85.0	18.0	366.0	366.9

Again, by using same techniques we get for cases 1 and 2

$$\begin{cases} x_1 \approx 2985.990 \Rightarrow c_1 \approx 343.34\frac{m}{s} \\ k_1 \approx 0.73198 \end{cases}$$

To verify results, calculating these from cases 3 and 4, we get:

$$\begin{cases} x_2 \approx 2985.838 \Rightarrow c_2 \approx 343.33\frac{m}{s} \\ k_2 \approx 0.732 \end{cases}$$

Sound velocity is probably here 343.3 m/s and end correction 0.732.

3.1.9 Audua Speaker Workshop 1.05

Again, by using same techniques we get for cases 1 and 2

$$\begin{cases} x_1 \approx 3004.309 \Rightarrow c_1 \approx 344.39\frac{m}{s} \\ k_1 \approx 0.730 \end{cases}$$

To verify results, calculating these from cases 3 and 4, we get:

$$\begin{cases} x_2 \approx 3003.454 \Rightarrow c_2 \approx 344.34\frac{m}{s} \\ k_2 \approx 0.730 \end{cases}$$

Sound velocity is probably here 343.4 m/s and end correction 0.730.

Table 3.10: Audua Speaker Workshop 1.05 port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	Audua Speaker Workshop port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	516.8	514.3
2	82.0	30.0	40.0	270.6	269.2
3	85.0	50.0	35.0	216.2	215.0
4	70.0	85.0	18.0	368.6	366.9

3.1.10   BassBox Pro v6.0.20

Table 3.11: BassBox Pro 6.0 port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	BassBox Pro port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	510.055137565835	514.3
2	82.0	30.0	40.0	259.83422874939	269.2
3	85.0	50.0	35.0	202.846424092288	215.0
4	70.0	85.0	18.0	364.171412356223	366.9

This software has user configurable values for c and ρ. I set them to WinISD standard values for testing, i.e. 343,68 m/s for c and 1,2 kg/m^3 for the speed of sound. Enough precision for this purpose.

Again, by using same techniques we get for cases 1 and 2

$$\begin{cases} x_1 \approx 3106.9853 \Rightarrow c_1 \approx 350.2\frac{\text{m}}{\text{s}} \\ k_1 \approx 1.0000 \end{cases}$$

To verify results, calculating these from cases 3 and 4, we get:

$$\begin{cases} x_2 \approx 3106.9853 \Rightarrow c_2 \approx 350.2\frac{\text{m}}{\text{s}} \\ k_2 \approx 1.0000 \end{cases}$$

The resulting sound velocity is 350.2 m/s and end correction 1.0000. Something funny happens here, since the calculated values don't match with inputted ones. Probably it is due to box volume compensation or some other similar gimmick. The port length calculation seems to obey the standard formula, however. The end correction is same than in JBL SpeakerShop, probably due to that SpeakerShop is a custom version of the BassBox early version.

3.1.11   UniBox v4.07

UniBox is a MS Excel-based spreadsheet application that is very respectable work, considering the typical use of MS Excel. MS Excel is definitely not oriented for scientific/engineering applications.

Like in BassBox, this software has user configurable values for c and ρ. I set them to WinISD standard values for testing, i.e. 343,68 m/s for c and 1,2 kg/m^3 for the air density ρ.

Again, by using same techniques we get for cases 1 and 2

$$\begin{cases} x_1 \approx 2940.9186 \Rightarrow c_1 \approx 340.7\frac{\text{m}}{\text{s}} \\ k_1 \approx 0.7325 \end{cases}$$

To verify results, calculating these from cases 3 and 4, we get:

Table 3.12: UniBox 4.07 port length results compared to WinISD pro 0.50a.

Case	D_v/mm	V_b/litres	F_b/Hz	UniBox port length/mm	WinISD pro reference port length/mm
1	100.0	100.0	20.0	504.2	514.3
2	82.0	30.0	40.0	263.5	269.2
3	85.0	50.0	35.0	210.2	215.0
4	70.0	85.0	18.0	359.7	366.9

$$\begin{cases} x_2 \approx 2941.0563 \Rightarrow c_2 \approx 340.7\frac{\text{m}}{\text{s}} \\ k_2 \approx 0.7326 \end{cases}$$

The sound velocity c is consistently 340.7 m/s and end correction with one flushed end is about 0.733.

3.2 Summary of software packages

Table 3.13: Summary of calculated port lengths in millimeters in various design software.

Software	Case 1	Case 2	Case 3	Case 4
WinISD pro 0.50a	514.3	269.2	215.0	366.9
TermPro 1.07	512.0	267.9	213.9	365.3
WinSpeakerz Demo 2.5.0	519	272	217	370
LSPCad Demo 5.20	490	251	201	344
Loudspeaker LAB demo 2.20	515.4	269.8	215.5	367.6
JBL SpeakerShop 1.0	532.6934	272.5192	213.528	380.2829
BlauBox	515.874	269.494	214.63	368.3
ASTM BBD	515.8	270.0	215.7	367.9
DOS BoxModel	513.1	268.5	214.4	366.9
Audua Speaker Workshop 1.05	516.8	270.6	216.2	368.6
BassBox Pro v6.0.20	510.0551	259.8342	202.8464	364.1714
Unibox 4.07	504.2	263.5	210.2	359.7

Table 3.14: Table 9. Summary of sound velocities and end corrections in various design software

Software	Speed of sound c (m/s)	End correction factor k
WinISD pro 0.50a	343.68	0.732
TermPro 1.07	343	0.732
WinSpeakerz Demo 2.5.0	345	0.732
LSPCad Demo 5.20	N/A	N/A
Loudspeaker LAB demo 2.20	344.0	0.732
JBL SpeakerShop 1.0	356.67	1.000
BlauBox	345	0.760
ASTM BBD	344	0.732
DOS BoxModel	343.3	0.732
Audua Speaker Workshop 1.05	343.4	0.730
BassBox Pro v6.0.20	350.2	1.000
Unibox 4.07	340.7	0.733

3.3 Discussion

Most of the "manual" formulas represented here produce identical results for all practical purposes. There is no any significant difference among them. Some software seems not to use directly the given data (or the classic tuning formula derived here). That is readily obvious from the results obtained.

From the calculated values, it can be said, that most enclosure design software use the same formula, but each software author has specific taste of what is considered as "correct" speed of sound. As mentioned in Claus Futtrup's excellent Driver Parameter Calculator manual, the speed of sound is not very trivial topic.

In car-fi environment, the environment temperature variations may be extremely high, I can see that span of some 60°C is not unusual. That changes tunings quite a bit. It is very much larger change than differences between different software.

WinISD is the only software in comparison which lets user to specify the temperature, humidity and ambient air pressure where to perform the port calculation.

Unless I receive a good scientific basis why LspCAD calculates port obviously very different way than rest of the software, I am somewhat sceptic. It is probably more relevant to discuss, whether the environment conditions are correct, when port length is calculated.

The correct port length is not exact science, and none of the tested software produces any more correct results than the others, considering all the nonidealities found in practical boxbuilding.