Designing a closed box loudspeaker

In the following text it is assumed that we chose a speaker element with parameters, Q_{ts}, f_S, V_{AS}. Then we design a suitable box by choosing its volume, V_B, so as to get desired characteristics.

1. Decide system Q, or loudspeaker characteristics, by choosing Q_{tc} (this affects resonance frequency, f_B):

$$0{,}5 \le Q_{tc} \le 1 \text{ , ideal interval } 0{,}6 \le Q_{tc} \le 0{,}9$$

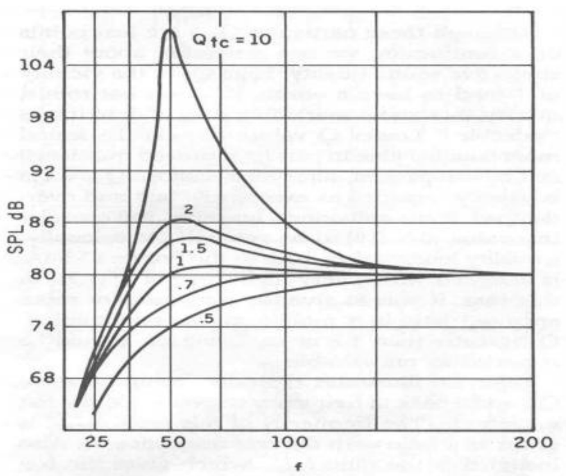

Figure 1. Qtc is a measure of system damping. Qtc = $\frac{1}{\sqrt{2}}$ ≈ 0.707 yields lowest f3 and most even frequency characteristic

A. At lower frequencies where the wavelength is larger than the largest room dimensions the whole room will be pressurized by the speaker diaphragm outside of the box in the same way as inside the box. This is called *room gain* or *room lift* and will give a sound pressure increase of max 9 dB for the lowest frequencies. *Room gain* requires that the room is relatively leak free with all doors closed and not leaking, no large windows ("the base leaks out through the window"). The smaller and less leaky the room is the closer to 9 dB you will get.

The largest dimension x, of a rectangular room is a diagonal from corner to corner.

$$x = \sqrt{a^2+b^2+c^2}\text{, a, b, c are the rooms length, width and height}$$

If the room is relatively free from leakage we get an increase of sound pressure for

$$f < \frac{c}{x} = \frac{340}{x}\,Hz$$

Example. Two rooms measure 2.5*4*5 respectively 2.5*3,5*4 meter. This yield $X = \sqrt{2{,}5^2+4^2+5^2} = 6.87$ respectively 5.87 m. Combining yields $f < \frac{340}{6{,}87} =$ 50 Hz and 58 Hz respectively. We see that for normal rooms we may get a sound pressure increase in the interval 0-9 dB for frequencies under 50-60 Hz.

B. If a loudspeaker diaphragm is less than circa 1/16 wave length from a rigid area (floor, wall, ceiling) sound pressure will rise by 3dB because the space it radiates into is halved compared to the space with no rigid area. We talk about a half space or 2π sr (steradians). If it is close to two rigid orthogonal surfaces, for example on the floor against a wall (π sr) we get 6 dB rise, and if the loudspeaker stands in a corner (π/2 sr), the rise is 9 dB.

Taken together these effects can give a rise of 18 dB and can thus dramatically change the perceived characteristics of the loudspeaker in a listening room compared to calculated or characteristics measured in an echo free heavily damped room, figure 2.

Figure 2 shows that at low frequencies, when *room gain* and radiation into π- or π/2 space contribute largely, it is preferable to choose a small Qtc. If we disregard *room gain* in figure 2, open doors, large windows, etc, we see that f3 is lowered from 60 Hz to 26-27 Hz due to three rigid surfaces only.

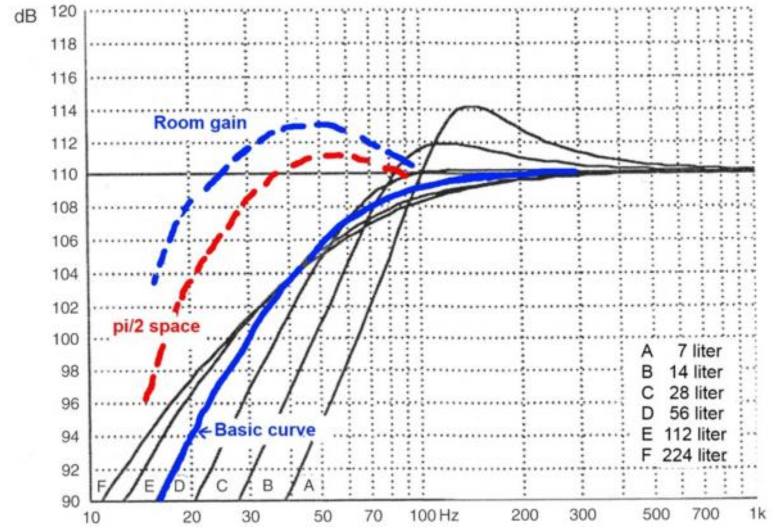

Figure 2. Frequency curves for a speaker element ($f_s = 20Hz$) in different boxes. To "basic curve", which corresponds to Qtc ≈ 0,7-0,8, has been added contributions from three hard surfaces that give max 9 dB, and room gain chosen to be 5 db @ 20Hz with a drop off of 5 dB/octave (original diagram from Newell & Holland, Loudspeakers..., ISBN 0-2405-2014-9, and data from Colloms, High Performance Loudspeakers, ISBN 0-470-09430-3)

2. Now we investigate what speaker element to pick by trying different elements that have specific Q_{ts}, f_s och V_{AS}. Calculate

$$\alpha = \left(\frac{Q_{tc}}{Q_{ts}}\right)^2 - 1 = \frac{V_{AS}}{V_B}$$

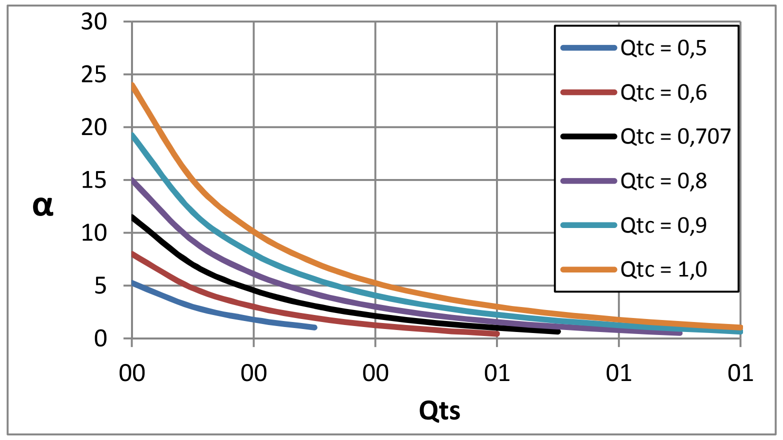

Figure 3. α as a function of Qts and Qtc

3. Calculate box volume. Large α yield small box.

$$V_B = \frac{V_{AS}}{\alpha}$$

4. Calculate system resonance frequency

$$f_B = \frac{Q_{tc}}{Q_{ts}} f_S$$

Small Q_{ts} gives large f_B. It is best not to pick to small a value for Q_{ts}.

5. Calculate the frequency for which sound pressure has fallen 3 dB.

$$f_3 = \left|\left(\frac{1}{2Q_{tc}^2}-1\right) + \sqrt{\left(\frac{1}{2Q_{tc}^2}-1\right)^2+1}\,\right|^{\frac{1}{2}} \cdot f_B$$

$$f_3 = f(Q_{tc}) \cdot f_b = f(Q_{tc}) \cdot \frac{Q_{tc}}{Q_{ts}} f_S$$

An interesting function is $f(Q_{tc}) \cdot Q_{tc}$, with minimum for $Q_{tc} \approx 0{,}7$. Line 4 in the table.

Q_{tc}	$f(Q_{tc})$	$f(Q_{tc}) \cdot Q_{tc}$
0.5	1.554	0.777
0.6	1.209	0.725
0.707	1	0.707
0.8	0.897	0.718
0.9	0.829	0.747
1	0.786	0.786
1.1	0.757	0.832
1.2	0.736	0.883

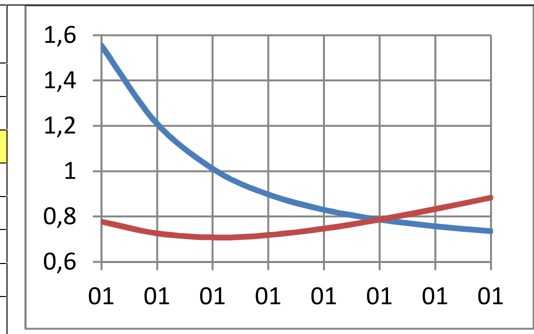

Figure 4. f(Qtc) (blue line) and f(Qtc)*Qtc (red line) as a function of Qtc

It is apparent from figure 4 that picking a Qtc in the interval 0,6-0,8 yield the lowest f_3. If we now use an element with Qts in the interval 0,3-0,5 we will get a moderately large box (Qts closer to 0,3) and a good base response with low f3 (Qts closer to 0,5), figure 5.

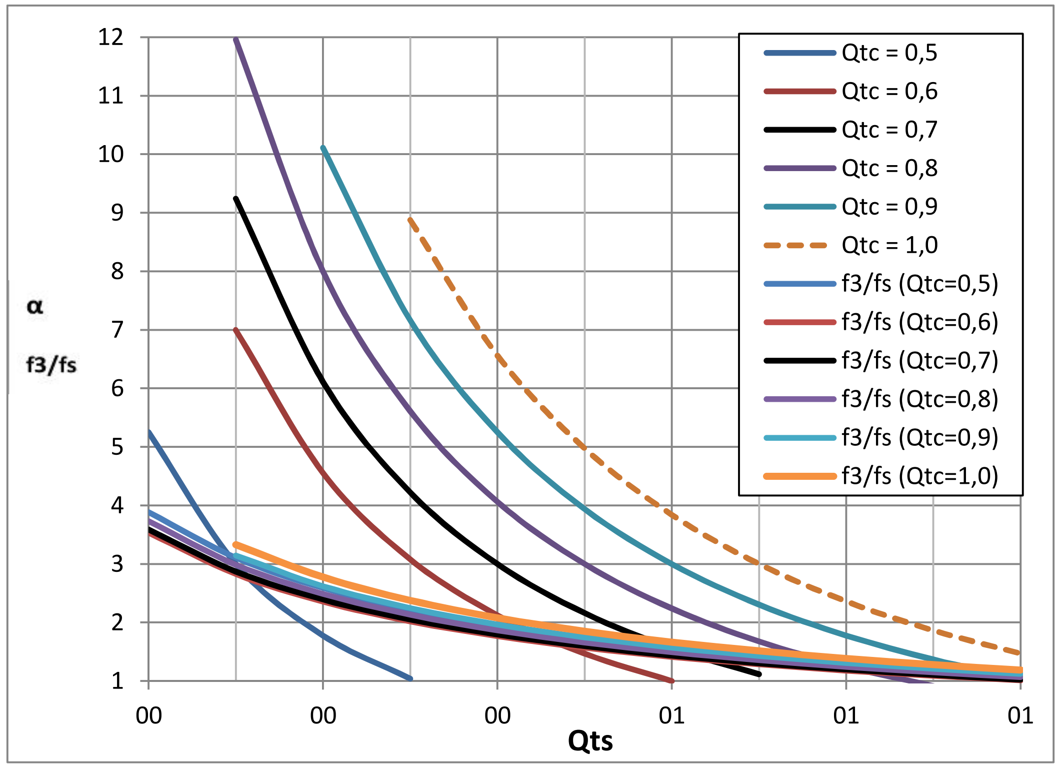

Figure 5. α = V_{AS}/V_B and f3/fs (curves close together) as functions of Qts and Qtc

Comments

It is apparent from figure 5 that a suitable speaker element for a closed box design should have

- ❑ $\mathbf{Q_{ts}}$ in the interval 0,3-0,5
- ❑ $\mathbf{f_S}$ as low as possible
- ❑ $\mathbf{V_{AS}}$ should not be to large depending on selection of Q_{ts}. Small Q_{ts} put less demand on small V_{AS} than if Q_{ts} is larger, see figure 5.

References: Small, Richard. H., *Closed-box Loudspeaker Systems Part I & II*, JAES Vol 20, no10, pp798-808, Dec 1972, & JAES Vol 21, no 1, pp11-18; Feb 1973; Newell & Holland, Loudspeakers..., ISBN 0-2405-2014-9; Colloms, High Performance Loudspeakers, ISBN 0-470-09430-3.

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