Chapter 5. Enclosure Optimization Function

Background

The synthesis of the enclosure parameters using "family curves" technique was given in Chapter 4. However, it is always recommended to confirm the results of the design by applying an optimization process to the enclosure parameters found in Chapter 4. During the optimization, parameters of the enclosure are varied accordingly to the method's algorithm and the error function is calculated for every set of parameters. The error is considered to be any difference between a reference target frequency response function and the frequency response calculated for the current set of enclosure parameters. There are a number of optimization methods available for applications such as minimization of the error function. The method adopted in this program was first described by Rosenbrock in 1960. The method lends itself to a computer application. For a detailed description of the method the user is referred to [18]. The algorithm attempts to minimize the error by adjusting the parameters of the enclosure.

There are six target reference functions for a sealed enclosure:

1. Chebyshev, 2-nd order, 0.5 dB ripple,
2. Chebyshev, 2-nd order, 1.0 dB ripple,
3. Chebyshev, 2-nd order, 2.0 dB ripple,
4. Chebyshev, 2-nd order, 3.0 dB ripple,
5. Bessel, 2-nd order and
6. Butterworth, 2-nd order.

There are also 13 target reference functions for a vented enclosure:

1. Chebyshev, 3-rd order, 0.5 dB ripple,
2. Chebyshev, 3-rd order, 1.0 dB ripple,
3. Chebyshev, 3-rd order, 2.0 dB ripple,
4. Chebyshev, 3-rd order, 3.0 dB ripple,
5. Chebyshev, 4-th order, 0.5 dB ripple,
6. Chebyshev, 4-th order, 1.0 dB ripple,
7. Chebyshev, 4-th order, 2.0 dB ripple,
8. Chebyshev, 4-th order, 3.0 dB ripple,
9. Bessel, 3-rd order,
10. Bessel, 4-th order,
11. Butterworth, 3-rd order.
12. Butterworth, 4-th order and
13. Quasi-Butterworth (QB3) 3-th order.

And finally, there are 3 types of target alignments for Band-Pass Type 2 enclosure:

1. Narrow (Chebyshev type)
2. Medium (Chebyshev type)
3. Wide (Butterworth type)

The target response is selected from a dialog box invoked by pressing "Optimize Sealed", "Optimize Vented" or “Optimize BP2” buttons. The dialog box will also offer some pre-calculated parameters of the enclosure being optimized (or default values, if no driver file has been loaded). The proposed values for the 3-dB cut-off frequency, enclosure tuning (vented) and enclosure volume, were calculated for a given driver, but user may edit any of them. The "Reference" button on the dialog box should be used for plotting the reference curve only.

Optimization Strategy

Generally, optimization is a "curve fitting" process, which attempts to obtain minimum error between the amplitude response of the selected enclosure and required target function. Should the 3-dB cut-off frequency of the target response be selected badly, the global error at the end of the optimization process will be large. The proposed values presented to the user in the dialog should be considered as a good starting point for optimization. However, the reference curve should still be moved around on the frequency axis to check if a better fit can be achieved for a given driver. This is exactly what the Optimization tool offers.

The algorithm will perform 30 optimizations using 30 target responses with different 3-dB cut-off frequencies. The cut-off frequencies will be selected as 80 to 180% of the "Proposed F[3dB]" parameter editable from the dialog box eg: the first target reference curve will have its 3-dB cut-off frequency calculated as ("Proposed F[3dB]) * 0.8, the second curve: ("Proposed F[3dB]) * 0.9, and so on till the 10-th curve, having the 3-dB frequency equal to ("Proposed F[3dB]) * 1.8. The emphasis on the higher cut-off frequencies are advocated, as it generally leads to smaller enclosures. Selecting the "Proposed F[3dB]" too low, may become a source of significant errors. When the optimization process is completed, the **lowest Global Error** is highlighted by the program and the enclosure parameters (Qb, Vb and Fb, in case of a vented enclosures) are transferred to the driver's data file space.

Enclosure Optimization

The optimization process uses the data provided by the enclosure design screen. The “Enclosure Optimization” screen allows for several parameters to be edited - depending on the enclosure type. Generally, drivers with a Qt-factor greater then 0.5, should be used in sealed boxes or for Chebyshev alignments. Drivers with the Qt as high as 0.9-1.0 may also be tested with Chebyshev 4th order, 3dB ripple alignments. The optimization routines will find it difficult to produce the "optimally flat alignment" (Butterworth 4th order) with this type of driver in a vented enclosure. You may find, that the final Q-factor of the enclosure (Qb) has to be as low as 2.0 in order to reduce the humps in the frequency response. The efficiency of the system will be reduced as well. To start the optimization process, you needs to select the desired tab (click on the "Sealed", "Vented" or “BP2 TABs), depending on the designed enclosure and then select the desired action by pressing one of the three dialog box buttons. Optimization process is invoked by pressing the "**Optimize"** button and after a few moments, a message window will indicate the process is completed. **“Abort**” button simply aborts the process and **“Reference**” button plots the reference enclosure curve. Optimized values for the example vented enclosure are shown on Fig 5.1:

Vb = 175 liters   Fb = 25.3 Hz   Qb = 74.4   F3db = 25.4 Hz.

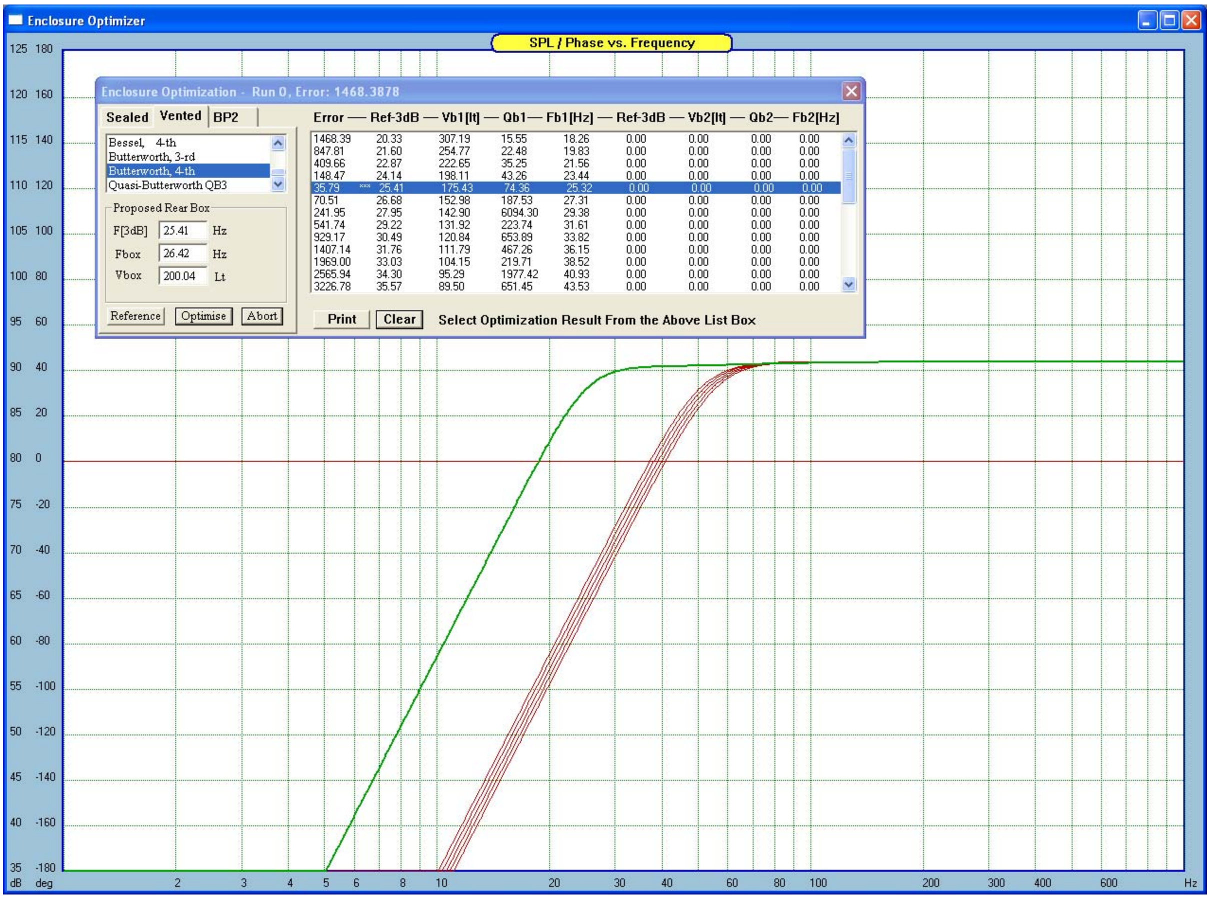

Fig 5.1 Optimized vented enclosure parameters

You can monitor the progress of the optimization process. Two parameters, relating to the progress are displayed: Current Global Error and Number of Trials. Examining the results one can observe, that the enclosure designed using the "family curve" approach has very similar parameters to the optimized box. The user should also be aware that the error function the program is trying to minimize, may have one or more local minimum. It may happen, that the algorithm will never find a global minimum, so it is recommended to monitor the value of the global error displayed on the screen. Should the error increase steadily, the process should be aborted by clicking on the "Abort" button.

The discussion here was limited to a woofer installed in a vented enclosure. However, the user would follow the same steps designing either sealed or vented boxes for a midrange or upper bass driver. The "Erase" button clears the plotting area. The complete discussion on the numerical optimization methods is beyond the scope of this manual. For the more difficult drivers, (driver with a Qt> 0.5 installed in vented enclosure) the user should try a few different starting set of parameters. The algorithm may be able to find a lower F3db cut-off frequency and flatter frequency response for a higher allowed Qb.

The user is referred to [12], [18], [19], [20] and [21]. Fig 5.2 shows a woofer driver (test301.wfr) optimized for a sealed enclosure with Qb=10.0. Driver's low Qt forced the resulting small enclosure. Fig 5.3 shows the same woofer optimized for a vented enclosure, but for Chebyshev 4-th, 0.5 dB ripple. Please note quite large box and NO losses proposed by the algorithm. Fig 5.4 shows three examples of the reference curves for BP2 enclosure.

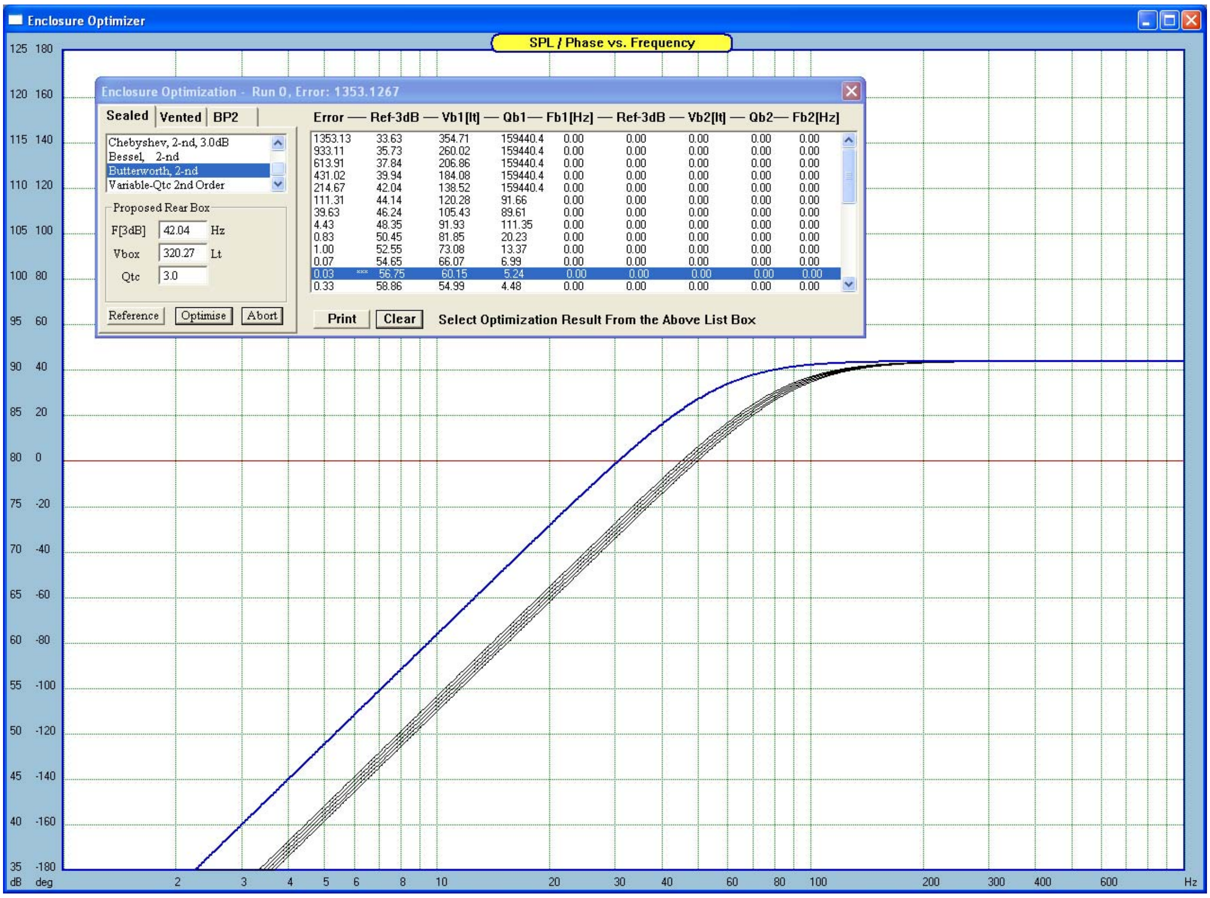

Fig 5.2 Optimized sealed enclosure parameters

As the optimization process steps-through the alignments, the list box on the right-hand side of the box gets filled with optimization results. For a sealed enclosure the results would show:

1. Error – This is a measure of how close the current SPL curve matches the target curve. The smaller the error the better match was accomplished.
2. Ref 3dB – This is the current 3dB cut-off frequency of the target curve.
3. Vb1 – Current rear enclosure volume.
4. Qb1 – Current rear enclosure Q-factor.

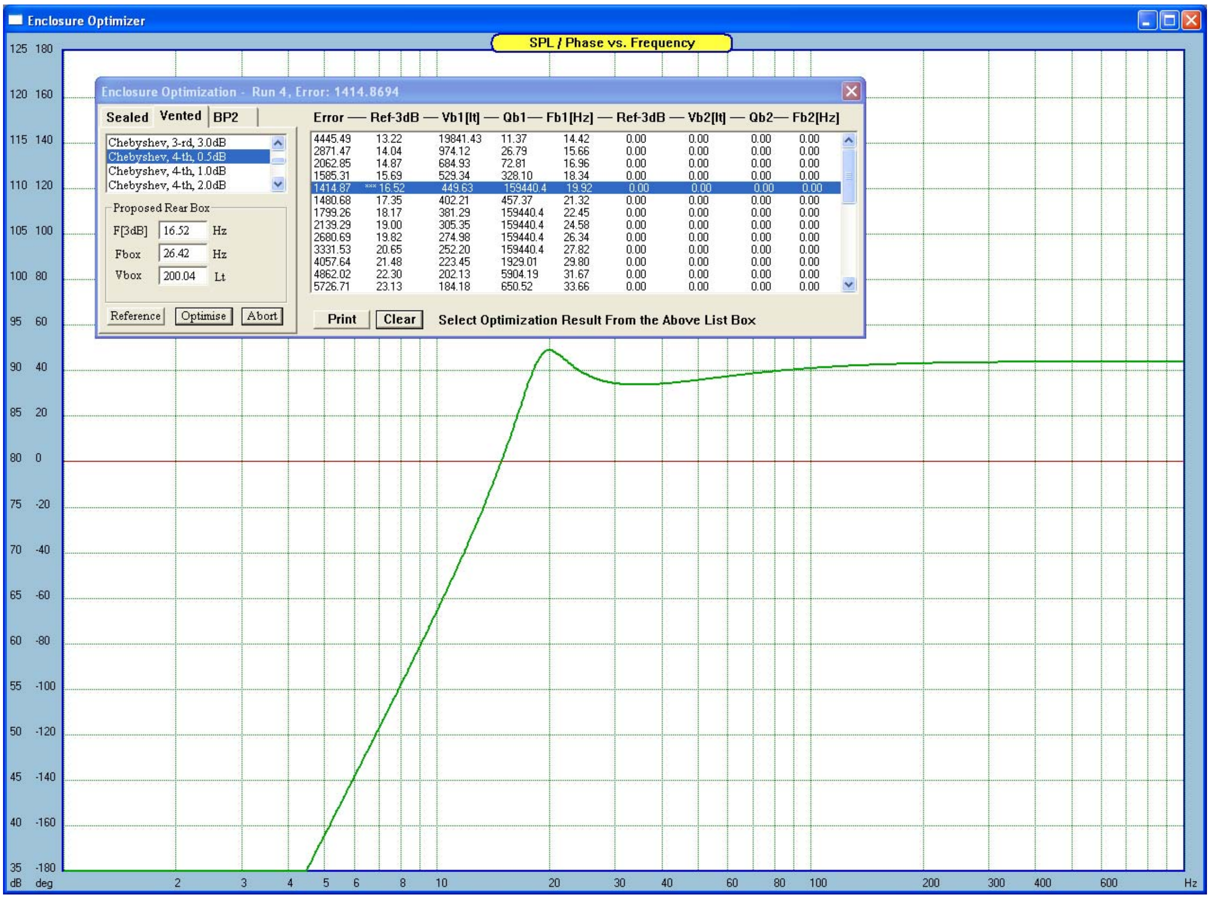

Fig 5.3 Optimized vented enclosure parameters for Chebyshev, 0.5dB ripple

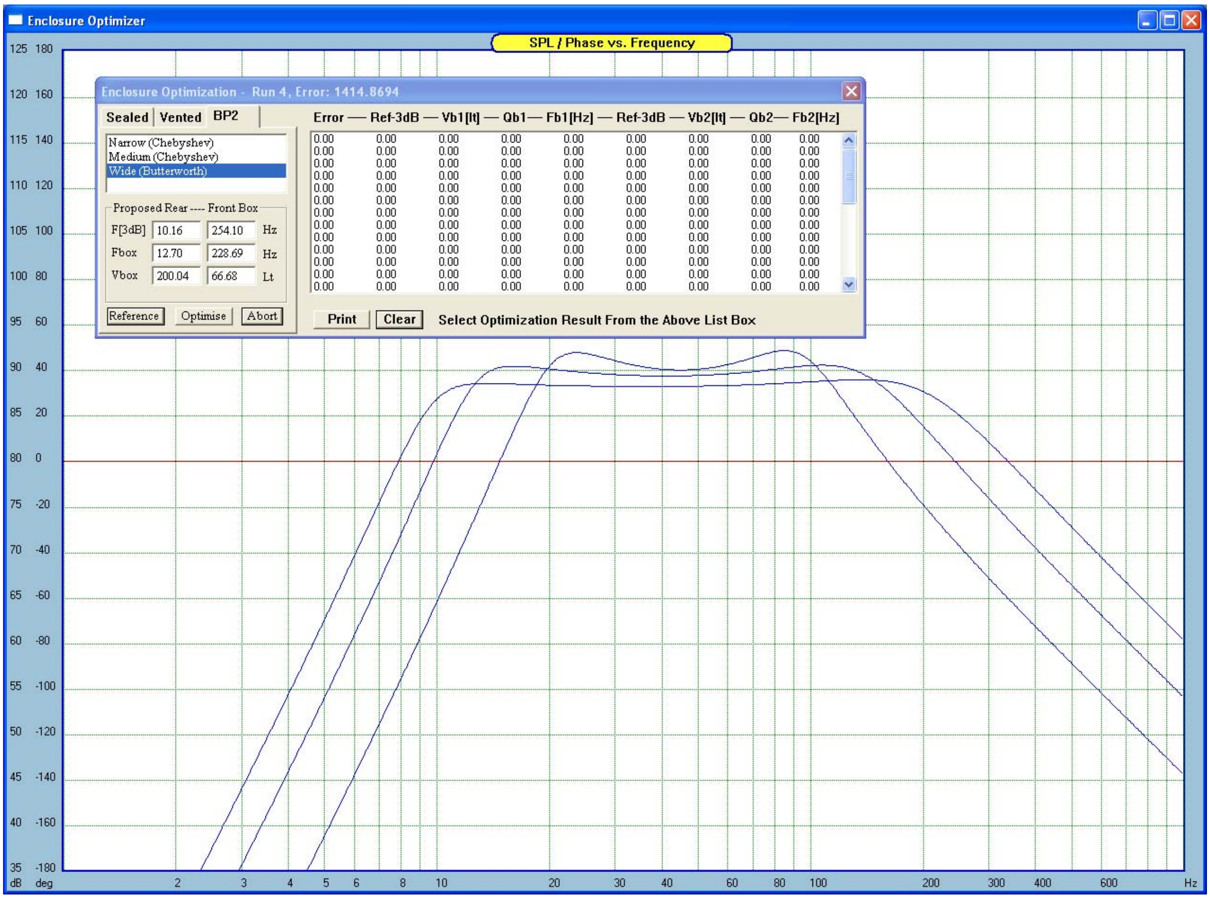

Fig 5.4 Example of the target curves for BP2 enclosure

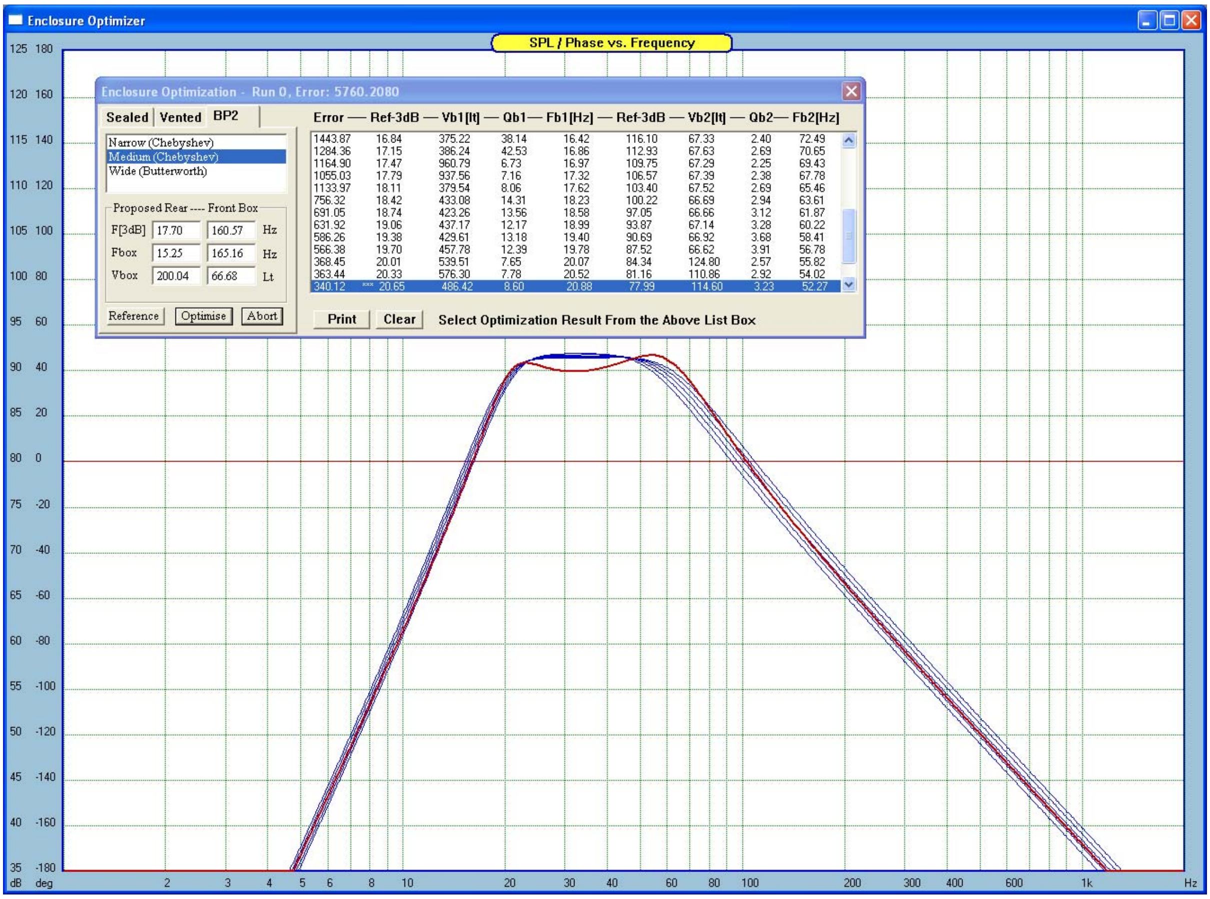

Fig 5.5 Example of BP2 optimization

Sealed enclosure can also be defined in terms of the total, or system Q-factor, Qtc. Should you decide to optimize your sealed enclosure for a particular Q-factor, you need to enter its value in the Qtc data field on the "Sealed" TAB.

The list box can handle maximum 30 entries, so there is that many alignments for the algorithm to try. Consecutive optimization results are listed in the box for your review and resulting parameters are transferred to the driver's data space when you click on the line showing the desired parameters. Please use scrolling tab to move other results into view area. When you click on any of the lines, you will also see the resulting SPL displayed on the screen.

Enclosures can be optimized for several parameters. Even the simplest, sealed box, has at least two "degrees of freedom":

1. **System Q-factor, Qtc**. This would be a good choice if you were interested in a particular Qtc parameter and associated time-domain response of this second-order circuit. Different type of music is often said to sound better for a particular Qtc factor. For instance, orchestral or symphonic music may sound better with a sealed enclosure with Qtc = 0.7. On the other hand, rock or disco music may prefer Qtc = 1.5 at a particular frequency.

2. **Lowest F3dB.** Here you may be interested in getting out the most of your loudspeaker. It is assumed here, that the flattest SPL is also desired. This optimization would provide you with the most extended low-frequency end.

Vented enclosure optimization would typically revolve around the lowest F3dB. However QB3 target may also be desired, as it provides sensible compromise between the good impulse response of the sealed box and better bass extension of the vented enclosure.

When optimizing for the lowest 3dB parameter, the optimization algorithm moves the target's 3dB frequency starting from the low end and progressing to the high-end of the bass range. Typical result of the optimization process for a sealed and vented enclosure will result in a bunch of results that start with a high Error, then exhibit a minimum Error value then continue into high Error area again.

The low-end high Error is the result of the driver not being able to reproduce bass frequencies well below its resonant frequency. Then the Error begins to drop and reaches minimum. This is where the size of the enclosure becomes proportional to Vas of the driver. The high-end Error is the result of the driver being too compliant (Vas too high) for the requested target F3dB in this frequency range. Here, the algorithm will try to smooth the ever increasing humps on the SPL curve by increasing box damping (reducing Qb1). However a limit is reached sooner rather than later, and the Error begins to creep up again. Somewhere in the middle is you optimal alignment for the given driver. Remember Thiele's rule-of-thumb for maximally flat alignment for a vented box: Vb=Vas, Qtc=0.38, F3dB=Fs.