ALPEQO Lite – V.1.0.2

User Guide

Alango Parametric EQ Optimization (ALPEQO) system is a software solution designed to address the problem of loudspeaker frequency response optimization for mass produced consumer audio products. ***ALPEQO™*** is designed to be easily integrated into an existing production line quality control testing station thus streamlining the final stages of the manufacturing process by allowing the combination of the testing and calibration tasks.

1. Introduction

Consumer audio electronics are typically subject to various standards or manufacturing requirements that dictate the acceptance criteria for the product's many performance aspects. One such aspect is the loudspeaker's frequency response.

In a mass production setting, consistently meeting the loudspeaker frequency response requirements over the entire production run requires not only careful selection of the loudspeaker components and proper acoustic design but also tight control over the manufacturing tolerances. All of which may lead to increased manufacturing costs.

The problem is further aggravated by the inherent manufacturing tolerances of the loudspeaker components themselves which require, in many cases, manual sorting of the components into different batches based on their deviation from the original frequency response specification. This fact further increases manufacturing time and costs and reduces the overall production yield.

Since most modern audio electronic devices contain a DSP or a microcontroller with some DSP capabilities, it is logical to seek a software solution to the problem in the form of digital equalization. This approach does not increase the part count for the final product and the filtering task can be performed at low computational cost using efficient digital filter structures making it suitable for most modern low-cost microcontrollers. However, the problem of selecting the optimal filter parameters for the equalizer remains.

Since the task of selecting the optimal filter parameters must be carried out for each individual unit on the production line based on the actual performance of the unit, it must be automated and ideally, combined with the quality control tests for efficiency. ***ALPEQO™*** provides the solution to this exact problem.

2. Problem to Solve

The problem of finding appropriate filter parameters for the equalizer can be defined as follows:

Given the loudspeaker's **measured frequency response** $\boldsymbol{A}(\boldsymbol{f})$, the **target frequency response** $\boldsymbol{D}(\boldsymbol{f})$ and a **tolerance** $\boldsymbol{E}(\boldsymbol{f})$, the goal is to find the optimal parameters for a set of $\boldsymbol{n}$ filters so that their **combined frequency response** $\boldsymbol{H}(\boldsymbol{f})$ satisfies:

$$|\boldsymbol{D}(\boldsymbol{f}) - [\boldsymbol{A}(\boldsymbol{f}) + \boldsymbol{H}(\boldsymbol{f})]| \leq \boldsymbol{E}(\boldsymbol{f})$$

where all quantities are specified in *decibels*.

By defining the **target filter frequency response** $\boldsymbol{T}(\boldsymbol{f}) = \boldsymbol{D}(\boldsymbol{f}) - \boldsymbol{A}(\boldsymbol{f})$ and the **combined filter frequency response model** $\boldsymbol{H_t}(\boldsymbol{f}, \boldsymbol{\beta})$ ***ALPEQO™*** treats the filter design process as a nonlinear optimization problem, where the goal is to find the parameter vector $\boldsymbol{\beta}$ that minimizes some "norm" of the difference $\boldsymbol{T}(\boldsymbol{f}) - \boldsymbol{H_t}(\boldsymbol{f}, \boldsymbol{\beta})$. Thus, our task is to find a set of filters parameters $\boldsymbol{\beta}$ that satisfy the **tolerance constraint** $|\boldsymbol{D}(\boldsymbol{f}) - [\boldsymbol{A}(\boldsymbol{f}) + \boldsymbol{H}(\boldsymbol{f})]| \leq \boldsymbol{E}(\boldsymbol{f})$ for $\boldsymbol{H}(\boldsymbol{f}) = \boldsymbol{H_t}(\boldsymbol{f}, \boldsymbol{\beta})$.

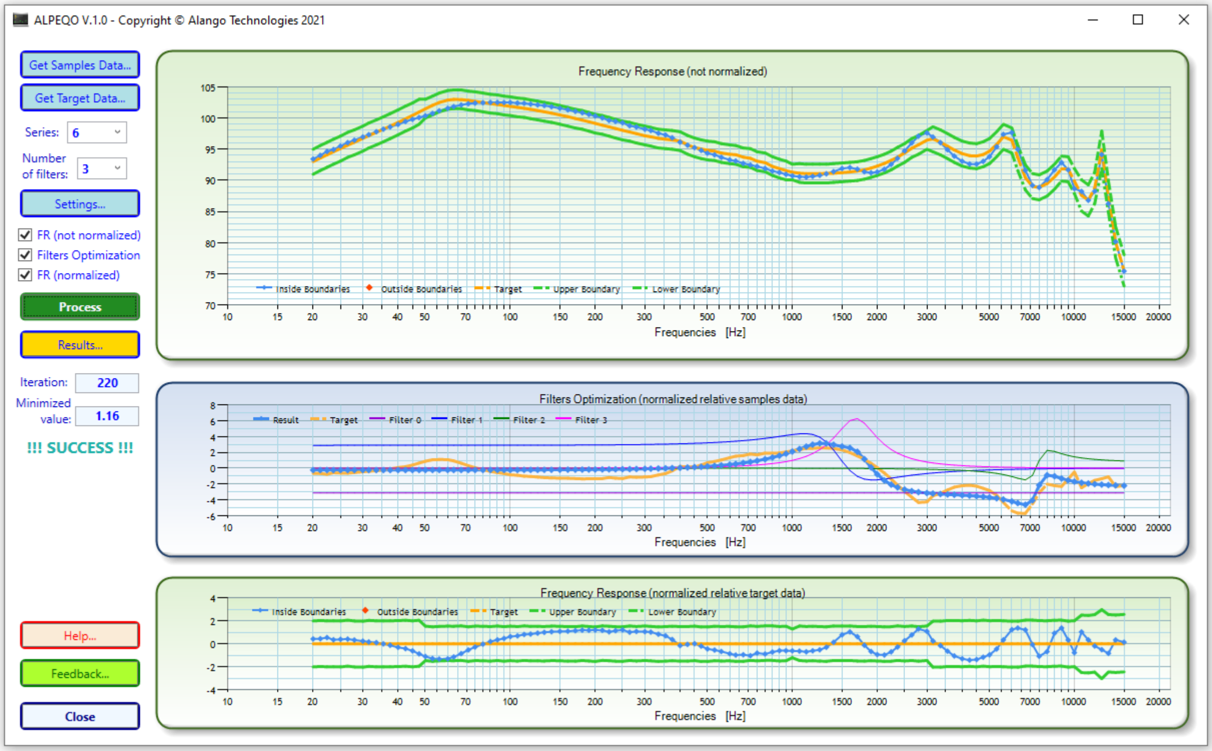
Further details regarding the **combined filter frequency response model** $\boldsymbol{H_t}(\boldsymbol{f}, \boldsymbol{\beta})$ are presented in section 3.6.

3. ALPEQO Lite Application

3.1. Main window

Alpeqo Lite is the Windows application for solving the problem described in section 1 and section 2. The main window of this application is shown below (see ***Figure 1***).

Figure 1



At the left part of the main window, you can see main controls (Buttons, Combo boxes, Checkboxes and Textboxes) to drive the application. At the right part of the main window, three charts are located – the "*Frequency Response (not normalized)*" chart at the top, "*Frequency Response (normalized relative target data)*" chart at the bottom, and "*Filters Optimization (normalized relative samples data)*" in the middle.

Figure 1 demonstrates these three charts after an optimization task is finished.

The upper chart shows how well the *non-normalized*, compensated frequency response (dotted blue curve) approximates the target frequency response (bold yellow curve).

This chart also illustrates whether the resulting frequency response curve falls within the upper and lower boundaries (bold green curves).

The middle chart shows how well the *combined filter* frequency response (dotted blue curve) approximates the target filter frequency response (thick yellow curve).

Additionally, the curves for separate filter stages and global gain used for this approximation (blue, green, magenta and purple curves) are presented.

The bottom chart reveals the compensated frequency response (bold blue curve) difference from the target frequency response (bold yellow line). Note how in this chart, the frequency responses are *normalized* in such a way that target frequency response looks like a horizontal straight line.

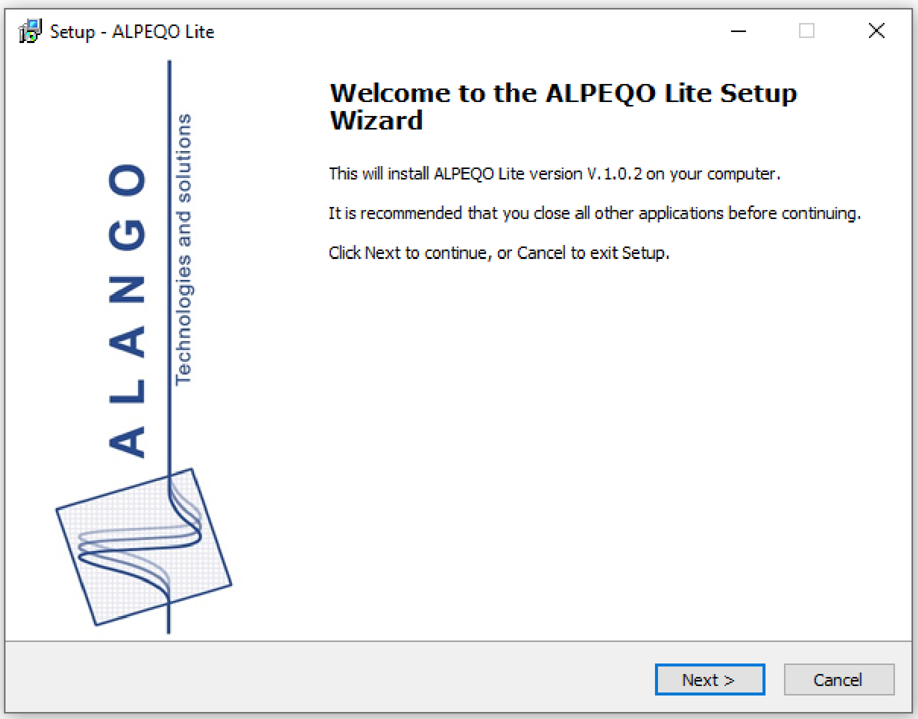
Similar to the upper chart, the bottom chart illustrates whether the resulting frequency response falls within the upper and lower boundaries (bold green curves) – which is the goal of our optimization problem (see section 2).

Further details regarding the use of the **Alpeqo Lite** are presented in section 3.3.

3.2. Install/Uninstall

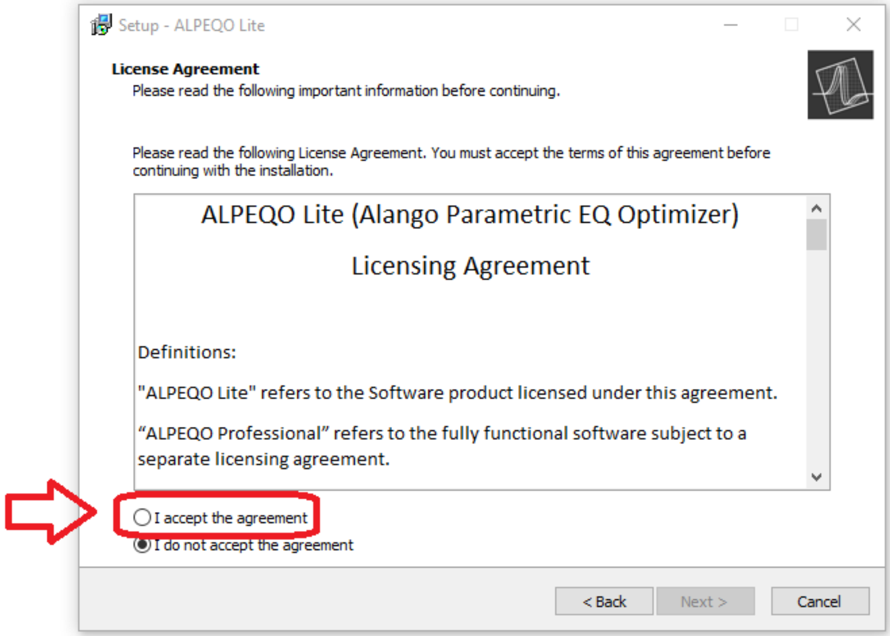
To install **Alpeqo Lite** V.1.0.2 simply run the setup file **ALPEQO Lite V.1.0.2.exe** and follow the on-screen instructions.

Figure 2



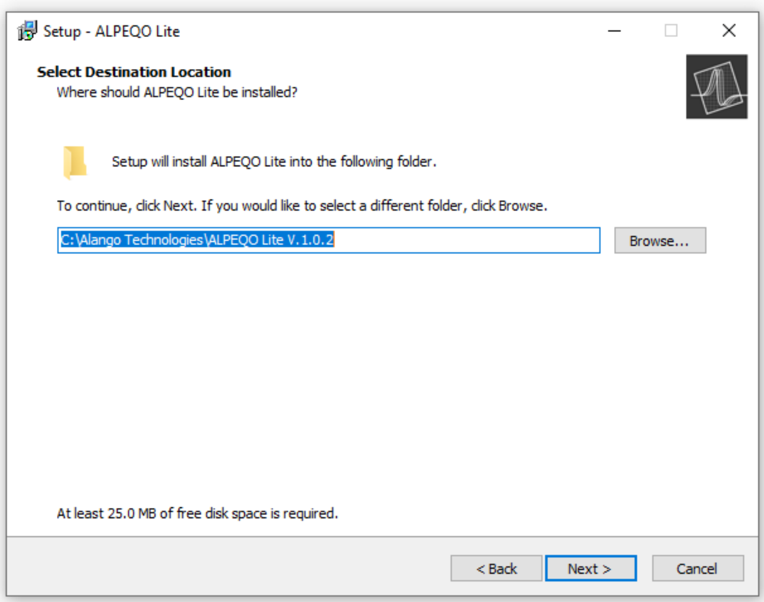
After the **Welcome** dialog read, review, and accept the **End-User License Agreement** by clicking the **Accept** radio button and click the **Next** button.

Figure 3



On the next screen, **Select Destination Location** for the installation of **Alpeqo Lite** and click **Next**.

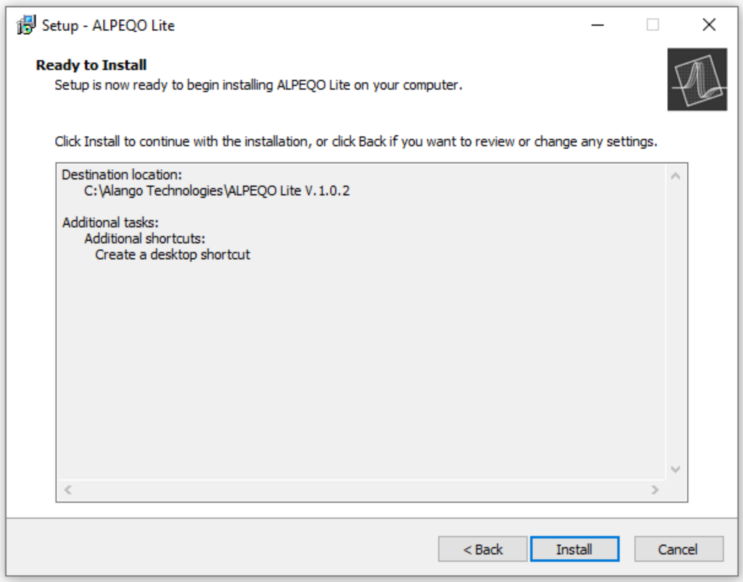
Figure 4



On the next screen, the **Select Additional Tasks** dialog lets you choose whether to create a desktop icon for the **Alpeqo Lite.**

Finally, the **Ready to Install** dialog (***Figure 5***) summarizes the installation choices made in the previous screens. If you are happy with your selection, click the **Install** button to start the installation process.

Figure 5



At the end of the installation process, the **Information** dialog will display the contents of the **ReadMe** file (see ***Figure 6***)

Figure 6

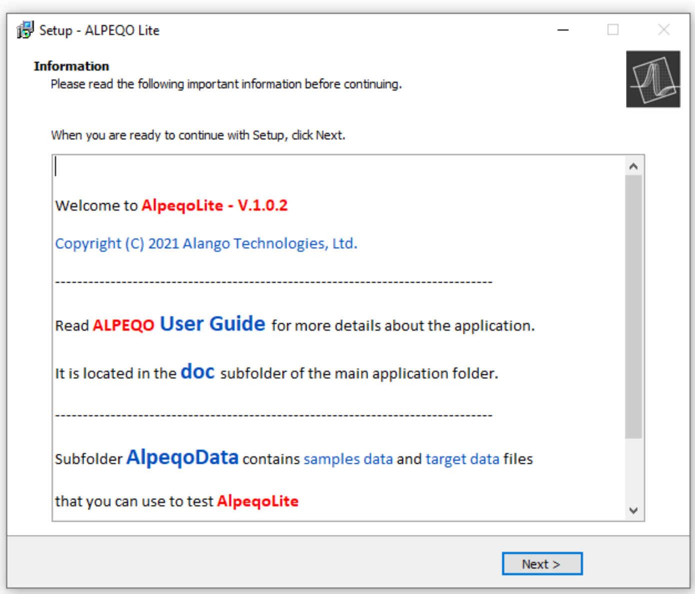
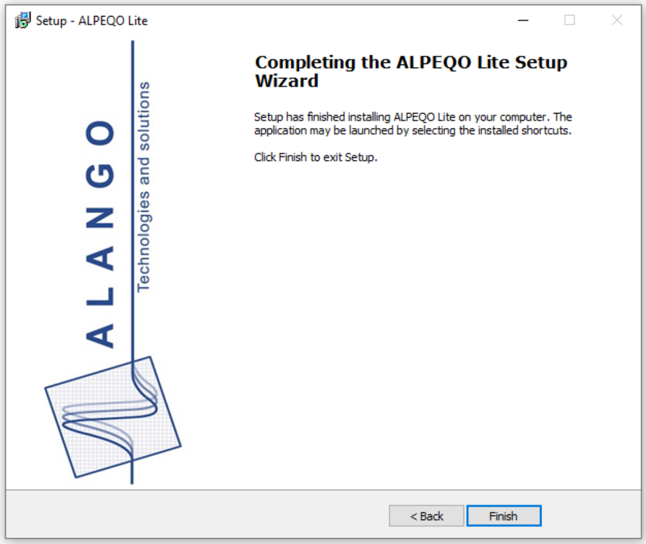


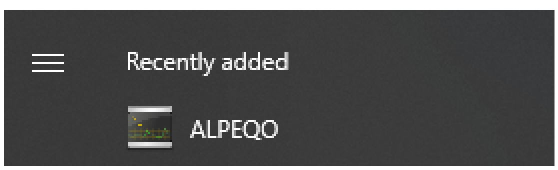
Figure 7



Click **Finish** button to finish installation.

After installation is finished you have the **ALPEQO** icon 

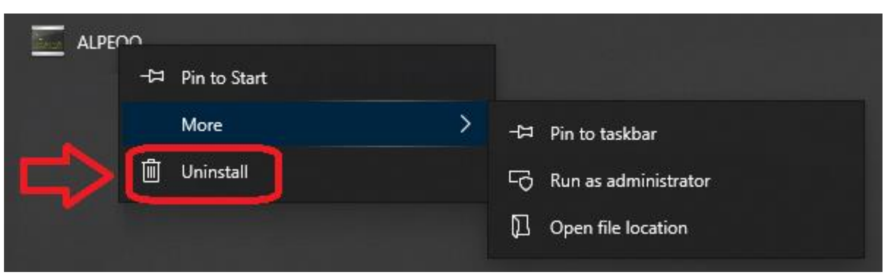
on your **desktop**,

and **ALPEQO** item 

among the **Recently added** items of the Windows **Startup menu**.

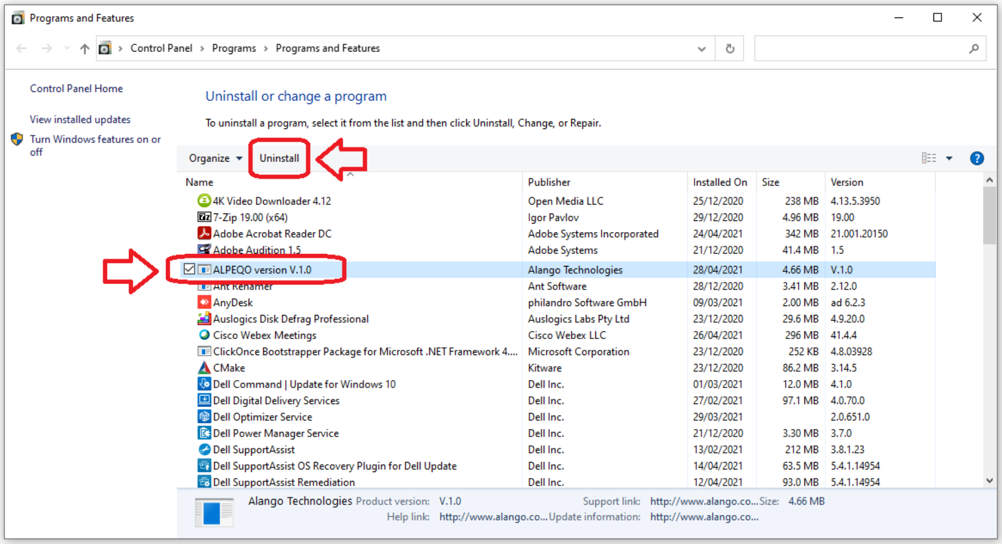
Additionally, the same menu item can be found under the letter **A** in the Windows **Start menu**.

Figure 8



Were you decide to uninstall **Alpeqo Lite**, click the **Uninstall** item from the Windows **Startup menu**. (see **Figure 8**). Thus, you launch standard Windows uninstall tool. You just need to select **ALPEQO** item in the list of installed programs and then click **Uninstall** button at the top.

Figure 9



3.3. Start using Alpeqo Lite

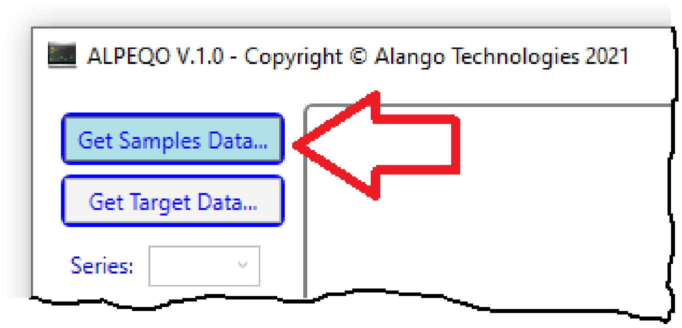
To launch **Alpeqo Lite** you can either use corresponding desktop icon or use **ALPEQO** item from the Windows **Startup menu**.

After the launch of **Alpeqo Lite** you receive the main window of the application with empty chart frames:

Figure 10

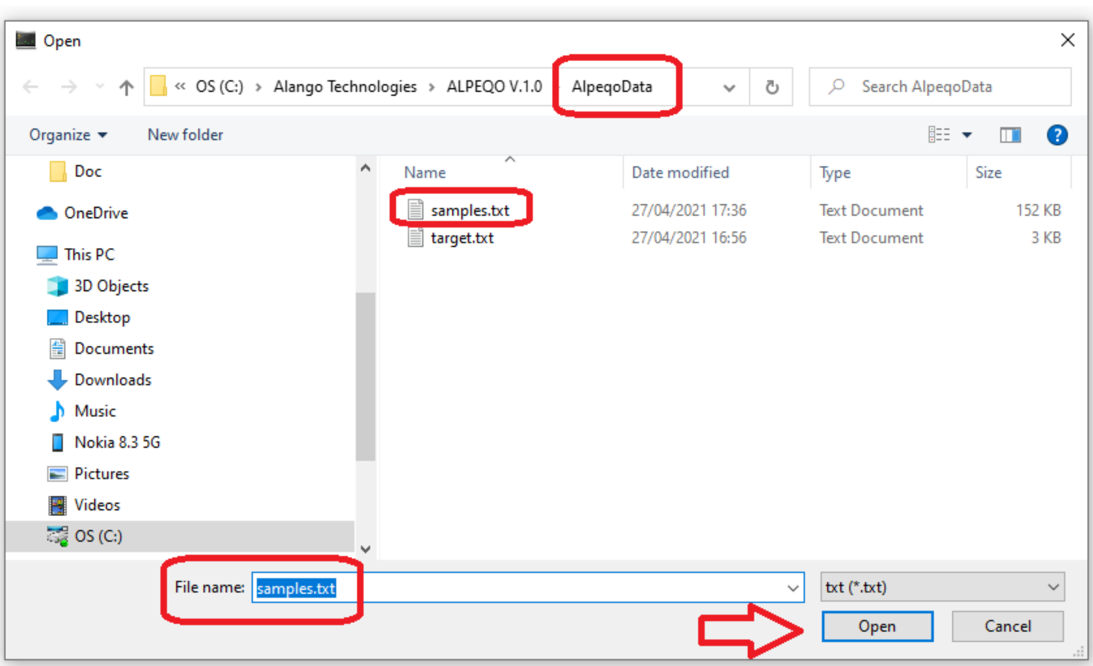
At the left of the main window all of the controls will be disabled except the bottom three buttons ("*Help*", "*Feedback*", and "*Close*") and the top button "*Get Samples Data*". Start your session by clicking the "Get Samples Data" button:

Figure 11



This will open an **Open File** dialog where you can select the *samples data* file. The default example file is *samples.txt* from the **AlpeqoData** subfolder of the **Alpeqo Lite** folder:

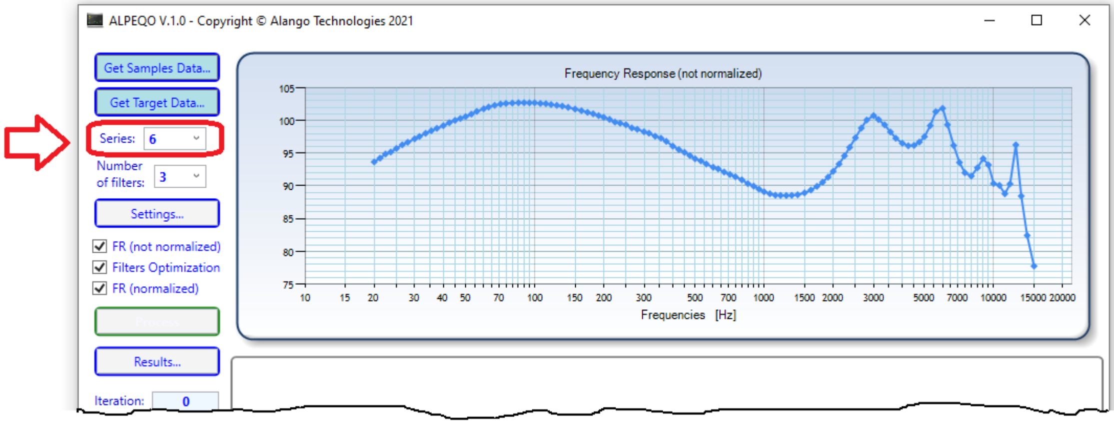
Figure 12



The example file contains 199 samples of some frequency response data (see section 3.9, describing the structure of this file).

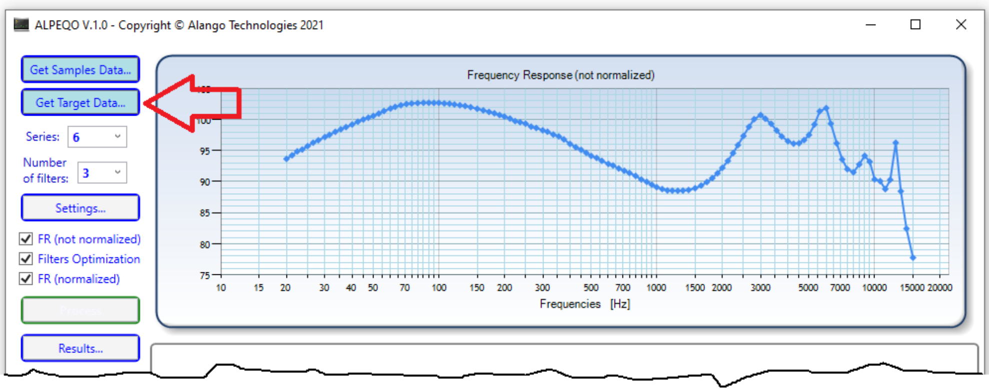
After loading the sample data file, you can see the "*Frequency Response (not normalized)*" chart of one of the samples series. The series selection can be changed via the **Series** Combo box (see ***Figure 13***).

Figure 13



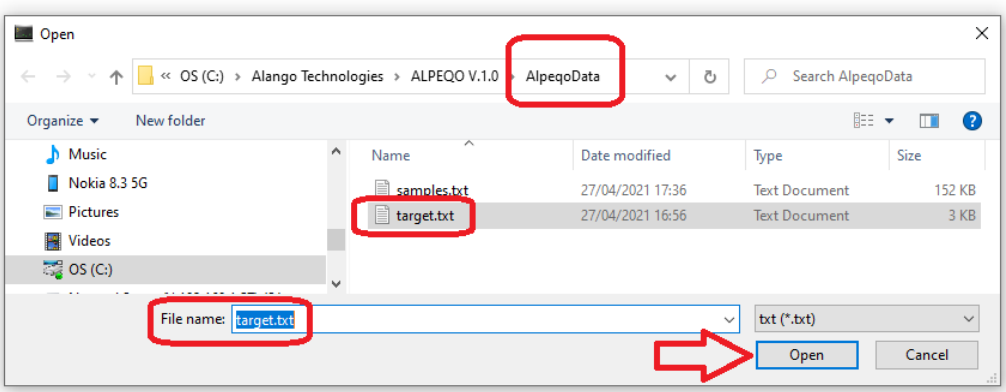
After loading the sample data file, the "*Get Target Data*" button will be enabled (see ***Figure 14***).

Figure 14



Click the "*Get Target Data*" button to open an **Open File** dialog where you can select the *target data* file. The default example file is *target.txt* from the **AlpeqoData** subfolder of the **Alpeqo Lite** folder:

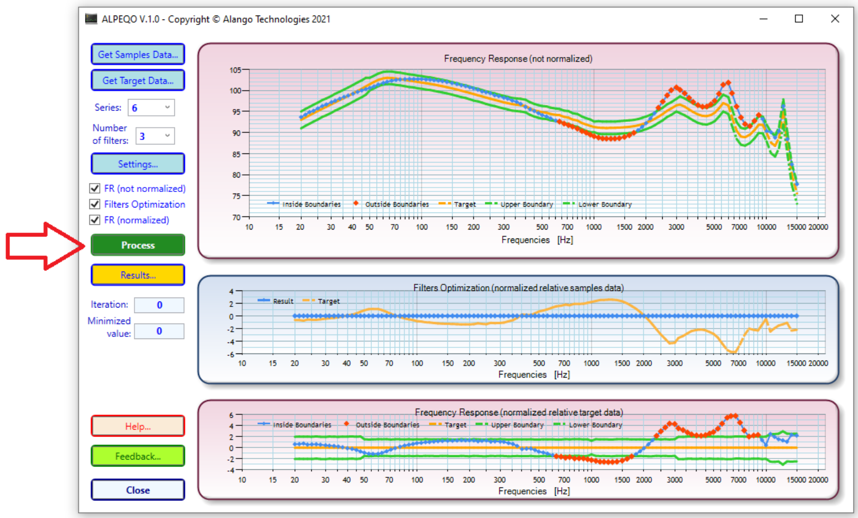
Figure 15



The *target data* file contains target frequency response data and upper and lower boundaries data (see section 3.10, describing the structure of this file).

After loading the target data file, you can see two more charts – "*Filters Optimization (normalized relatives samples data)*" and "*Frequency Response (normalized relative target data)*". The upper chart will be updated as well (compare ***Figure 14*** and ***Figure 16***) to reflect the selected target data.

Figure 16



After selecting the sample and target data, you can click the **Process** button (dark green button – see ***Figure 16***) to start the filter fitting task (this is described in detail in section 3.5).

3.4. User controls

Series combo box.

Allows choice of the sample data series from the collection of data series that are loaded from a sample data file (see ***Figure 13***).

Number of filters combo box.

Allows setting the desired number of filters to be used for correction of the frequency response data. The minimum number of filters is 3, the maximum number is 7. More details about filters are presented in section 3.6.

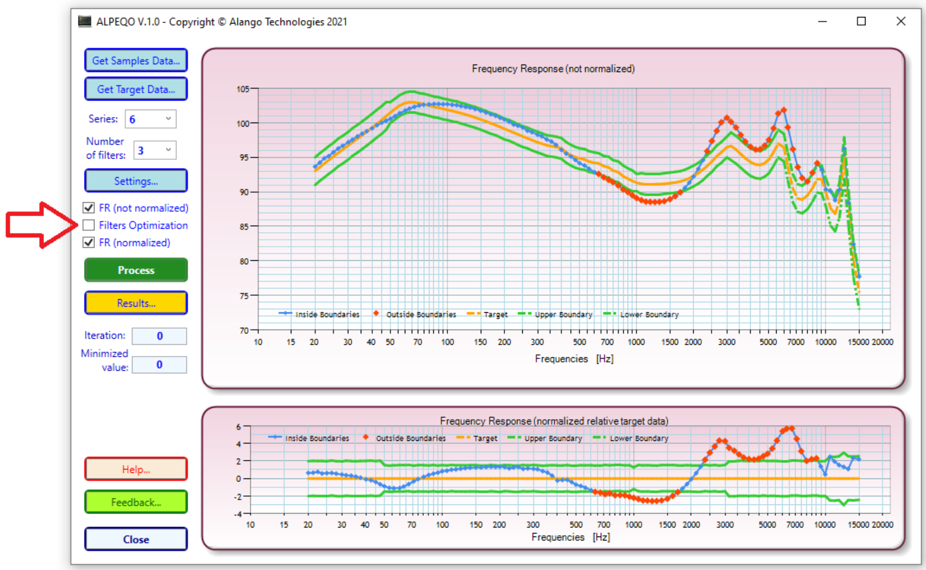
Settings button.

Opens the **Settings dialog** that allows you setting all the parameters of the application (see section 3.7 for more details).

Plot visibility checkboxes.

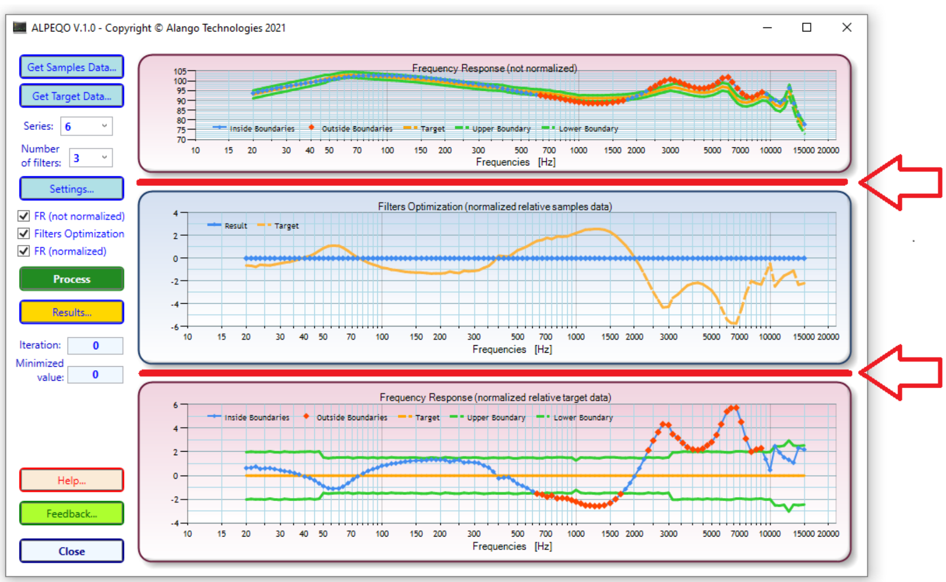
Those checkboxes control the visibility of the three charts located on the right part of the main window. This is useful when only some of the charts are of particular interest. For instance, ***Figure 17*** illustrates how the filters optimization chart is hidden to allow more space for the other two charts.

Figure 17



Additionally, the charts are resizable by dragging the split-bars located in the spaces between them as illustrated by the following figure.

Figure 18



When hovering the mouse pointer over the split-bars it will change the mouse cursor to the up/down arrow ⇕ to indicate the location of the split-bars.

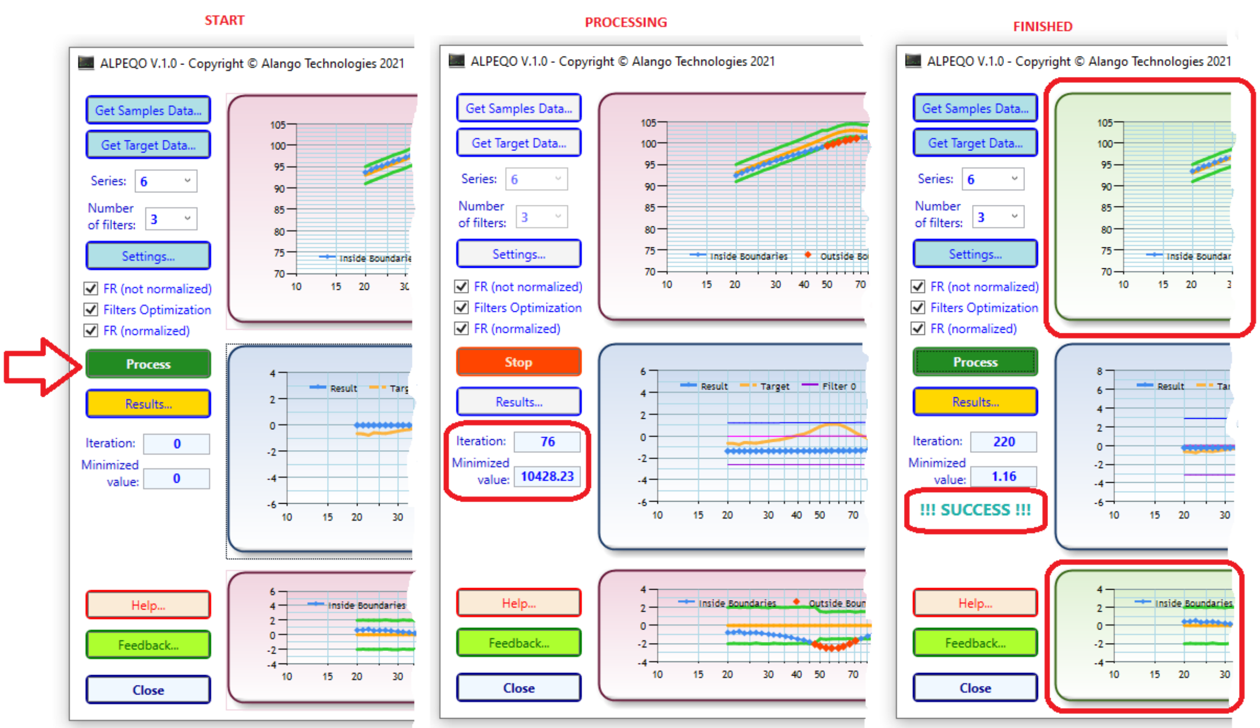
Click left mouse button and move this cursor up or down to change the height proportion between the adjacent charts.

3.5. Data processing

To start a filter fitting task, click the dark green **Process** button (see ***Figure 16*** above).

The **Process** button will become the **Stop** button which can now be used to interrupt the filter fitting task. When the process is finished, the button will again return to its initial state:

Figure 19



Normally, however, a fitting task completes within a few seconds, so there would be no need to use the **Stop** button.

If the process is concluded with a successful fit, a **"!!! SUCCCESS !!!"** message is displayed and the background of the upper and bottom charts changes to light green (see the right part of the ***Figure 19***).

If the process is not successful in fitting the filters to the desired response, a **"!!! FAILED !!!"** message is displayed instead, and the background of the upper and bottom charts remains light red (see ***Figure 20***).

Throughout the duration of the fitting process (see the middle part of the ***Figure 19***) you can see the current iteration number and the residuals norm, which is to be minimized during the EQ optimization process.

Additionally, the charts are animated and illustrate the fitting process by showing how the frequency response and filter curves change over time as the filter parameter approximation is improved. The fitting process stops once the optimization goal is reached and the frequency response curve lies within the lower and upper boundaries or, once the predefined limits of the fitting task (such as maximal number of iterations) are reached.

If at the end of the fitting process, the corrected frequency response curve does not fully fit within the boundaries, then the process failed. The offending regions of the frequency response curve will be marked with red dots as illustrated on the next figure:

Figure 20

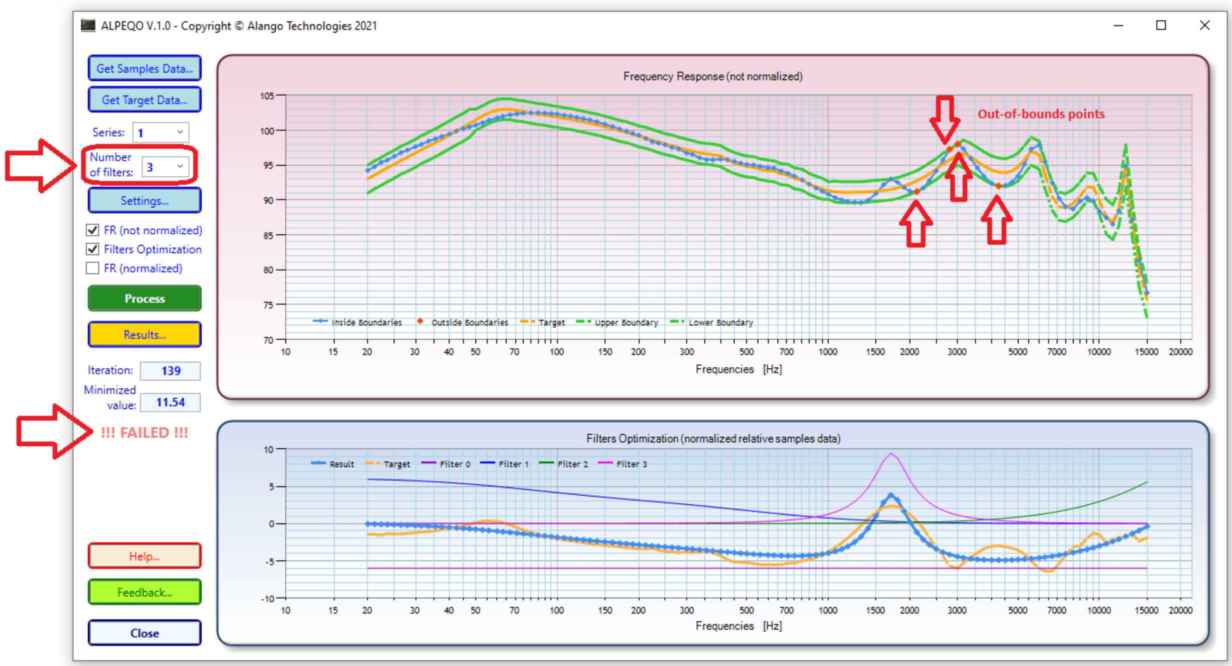
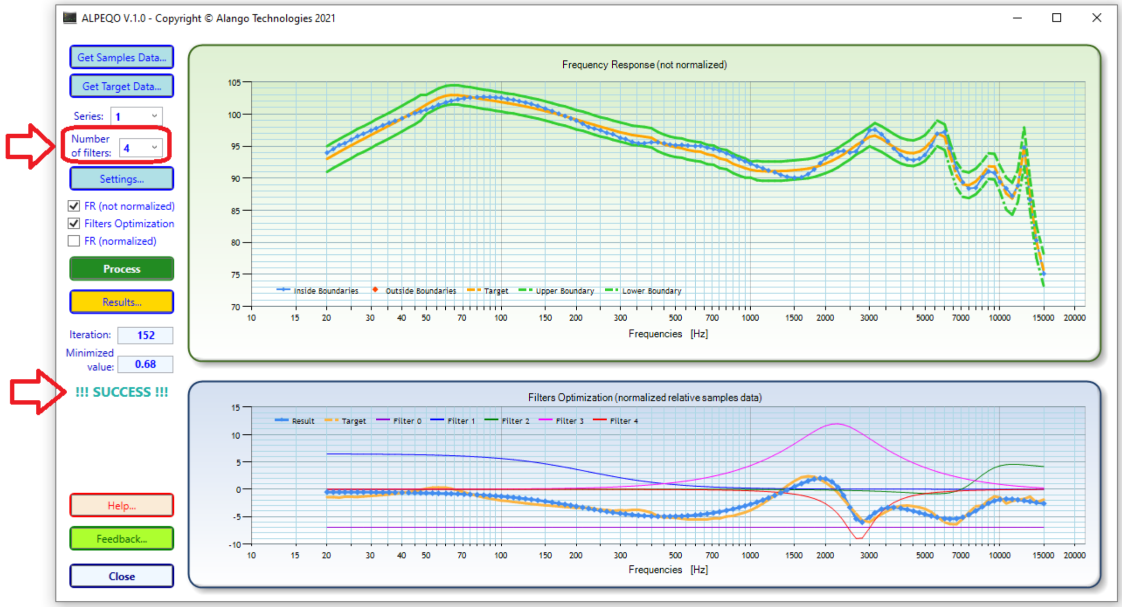


Figure 20 demonstrates a failed fitting process using only **3** filters. However, increasing the filter count to **4** and repeating the process will result in a successful fit as illustrated by ***Figure 21***.

Figure 21



To summarize, working with **Alpeqo Lite** is quite straightforward:

- Load some samples data file.
- Load corresponding target data file.
- Select the sample series set you wish to process.
- Set the number of filters you wish to use.
- Click **Process** button and wait for the fitting task to complete.
- If the fitting process failed, increase the number of filters and repeat.

When the fitting process is successfully completed, the parameters of the optimized filters will be presented in the **Results** dialog (see section 3.8).

Additional control over the fitting process parameters is achieved via the **Settings** dialog described in section 3.7.

3.6. EQ Filters

As defined in section 2, our task is to find a set of filters parameters $\boldsymbol{\beta}$ that satisfy for $\boldsymbol{H}(\boldsymbol{f}) = \boldsymbol{H}_t(\boldsymbol{f}, \boldsymbol{\beta})$ the **tolerance constraint**:

$$|\boldsymbol{D}(\boldsymbol{f}) - [\boldsymbol{A}(\boldsymbol{f}) + \boldsymbol{H}(\boldsymbol{f})]| \leq \boldsymbol{E}(\boldsymbol{f}),$$

where $\boldsymbol{E}(\boldsymbol{f})$ is the given **tolerance**, $\boldsymbol{D}(\boldsymbol{f})$ is the given **target frequency response**, $\boldsymbol{A}(\boldsymbol{f})$ is the **measured frequency response**, and $\boldsymbol{H}(\boldsymbol{f})$ is the **combined frequency response**

$$H(f) = H_0(\beta) + \sum H_k(f, \beta) ,$$

where H_0, H_1, ..., H_n – are the functions from the given **set of filters**.

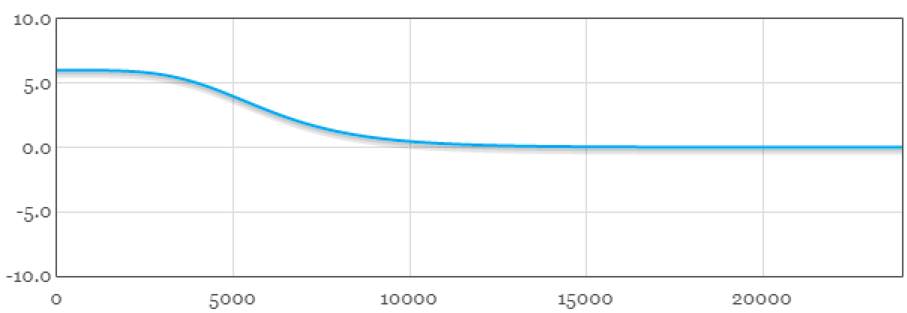
The individual frequency response of each filter is derived from its respective transfer function as described throughout the remainder of this section.

Alpeqo Lite uses 3 types of filters: **low-shelf**, **high-shelf**, and **bell filters** of the 2nd order with their respective frequency responses defined by 3 parameters: G_k - gain, C_k - center frequency and Q_k – quality factor. Additionally, as a special case, filter 0 is used only as a global gain and is therefore frequency independent.

Low-shelf filter

This type of filter is used in position 1. Its frequency response resembles a "shelf" in the low end of the spectrum. For instance, setting G_1 = 6 (dB), C_1 = 5000 (Hz), and Q_1 = 2.5, the filter H_1 has the following frequency response:

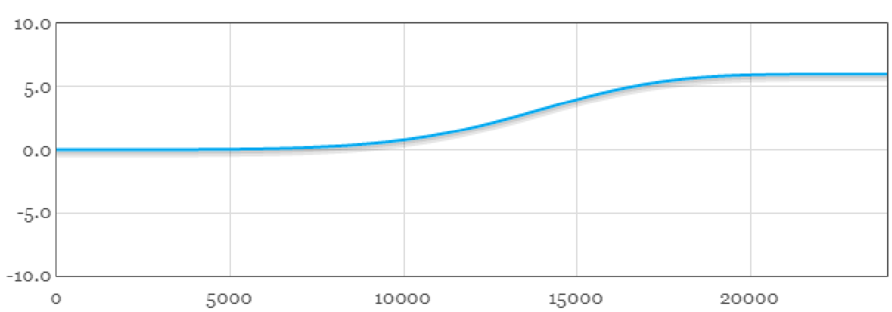
Figure 22



High-shelf filter

This type of filter is similar to the low-shelf filter and is used in position 2. Its frequency response resembles a "shelf" in the high end of the spectrum. For example, setting G_1 = 6 (dB), C_1 = 15000 (Hz), and Q_1 = 2.5 results in the following frequency response:

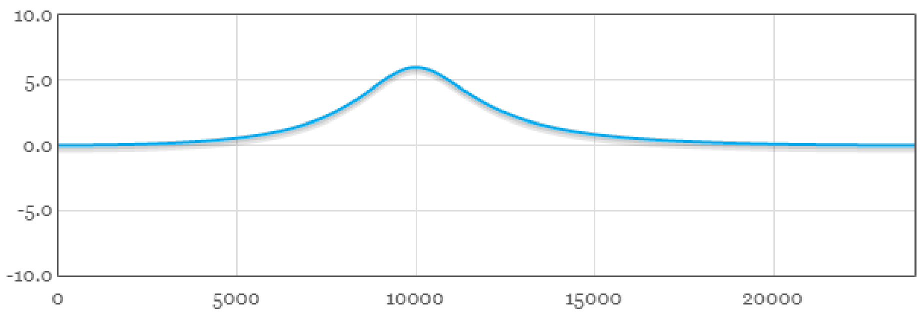
Figure 23



Bell filter

This type of filter is used in positions 3 through 7. Its frequency response resembles a "bell" in the spectrum. For instance, setting $\boldsymbol{G_1}$ = 6 (dB), $\boldsymbol{C_1}$ = 10000 (Hz), and $\boldsymbol{Q_1}$ = 2.5 results in the following frequency response:

Figure 24



All of the filters mentioned above are modeled as **biquad filters** having the transfer function:

$$H(z) = \frac{b_0 + b_1 \cdot z^{-1} + b_2 \cdot z^{-2}}{a_0 + a_1 \cdot z^{-1} + a_2 \cdot z^{-2}}$$

To keep the DC gain at unity, the filter coefficients a_i, b_i are typically normalized such that $a_0 = 1$:

$$H(z) = \frac{\left(\frac{b_0}{a_0}\right) + \left(\frac{b_1}{a_0}\right) \cdot z^{-1} + \left(\frac{b_2}{a_0}\right) \cdot z^{-2}}{1 + \left(\frac{a_1}{a_0}\right) \cdot z^{-1} + \left(\frac{a_2}{a_0}\right) \cdot z^{-2}}$$

This form naturally lends itself to the typical **direct form 1** implementation:

$$\begin{aligned} y[n] = & \left(\frac{b_0}{a_0}\right) \cdot x[n] + \left(\frac{b_1}{a_0}\right) \cdot x[n-1] + \left(\frac{b_2}{a_0}\right) \cdot x[n-2] \\ & - \left(\frac{a_1}{a_0}\right) \cdot y[n-1] - \left(\frac{a_2}{a_0}\right) \cdot y[n-2] \end{aligned}$$

We don't explicitly use these filters in our EQ optimization process, but we use functions $\boldsymbol{H(z)}$ defined above.

The **DF1** filter is not explicitly used in the optimization process but is rather shown here for completeness. Instead, the filter transfer functions $\boldsymbol{H(z)}$ are used.

Noting that $\boldsymbol{H(z)}$ is a complex function of a complex argument $\boldsymbol{z}$, it is necessary to establish the relation between the real and complex frequency representations by defining the substitution $\boldsymbol{z = e^{sT} = e^{\frac{2i\pi f}{F_s}}}$ where $\boldsymbol{i}$ is the imaginary unit, $\boldsymbol{f}$ is a real frequency and $\boldsymbol{F_s}$ is the sampling rate.

The frequency response can then be obtained by taking the absolute value of $\boldsymbol{H(z)}$ for a given frequency and converting the result to decibels:

$$\boldsymbol{H(f) = 20\log_{10}|H(z)|}$$

Which is exactly the frequency response used for the optimization process as defined at the beginning of this section and illustrated for the various filter types for their respective coefficients sets. ***(Figures 22-24).***

The coefficients $\boldsymbol{a_i}$, $\boldsymbol{b_i}$ of a given filter are in turn defined by the filter parameters $\boldsymbol{G_k}$, $\boldsymbol{C_k}$ and $\boldsymbol{Q_k}$.

To get the explicit formulae for $\boldsymbol{H(f)}$ it is necessary to define some intermediate variables:

Let $\boldsymbol{A = 10^{\frac{G_k}{40}}}$, where $\boldsymbol{G_k}$ is the **gain parameter** of filter $\boldsymbol{k}$.
Let $\boldsymbol{\omega_0 = \frac{2\pi C_k}{F_s}}$, where $\boldsymbol{C_k}$ is the **center frequency** of filter $\boldsymbol{k}$ and $\boldsymbol{F_s}$ is the sampling rate.
Let $\boldsymbol{\alpha = \frac{\sin\omega_0}{2Q_k}}$, where $\boldsymbol{Q_k}$ is the **quality factor** of filter $\boldsymbol{k}$.

Now for **low shelf** filter (see ***Figure 22***) we have:

$$
\begin{aligned}
a_0 &= (A+1) + (A-1)\cdot\cos(\omega_0) + 2\cdot\sqrt{A}\cdot\alpha \\
a_1 &= -2\cdot((A-1) + (A+1)\cdot\cos(\omega_0)) \\
a_2 &= (A+1) + (A-1)\cdot\cos(\omega_0) - 2\cdot\sqrt{A}\cdot\alpha \\
b_0 &= A\cdot((A+1) - (A-1)\cdot\cos(\omega_0) + 2\cdot\sqrt{A}\cdot\alpha) \\
b_1 &= 2\cdot A\cdot((A-1) - (A+1)\cdot\cos(\omega_0)) \\
b_2 &= A\cdot((A+1) - (A-1)\cdot\cos(\omega_0) - 2\cdot\sqrt{A}\cdot\alpha)
\end{aligned}
$$

For **high shelf** filter (see ***Figure 23***) we have:

$$
\begin{aligned}
a_0 &= (A+1) - (A-1)\cdot\cos(\omega_0) + 2\cdot\sqrt{A}\cdot\alpha \\
a_1 &= 2\cdot((A-1) - (A+1)\cdot\cos(\omega_0)) \\
a_2 &= (A+1) - (A-1)\cdot\cos(\omega_0) - 2\cdot\sqrt{A}\cdot\alpha \\
b_0 &= A\cdot((A+1) + (A-1)\cdot\cos(\omega_0) + 2\cdot\sqrt{A}\cdot\alpha) \\
b_1 &= -2\cdot A\cdot((A-1) + (A+1)\cdot\cos(\omega_0)) \\
b_2 &= A\cdot((A+1) + (A-1)\cdot\cos(\omega_0) - 2\cdot\sqrt{A}\cdot\alpha)
\end{aligned}
$$

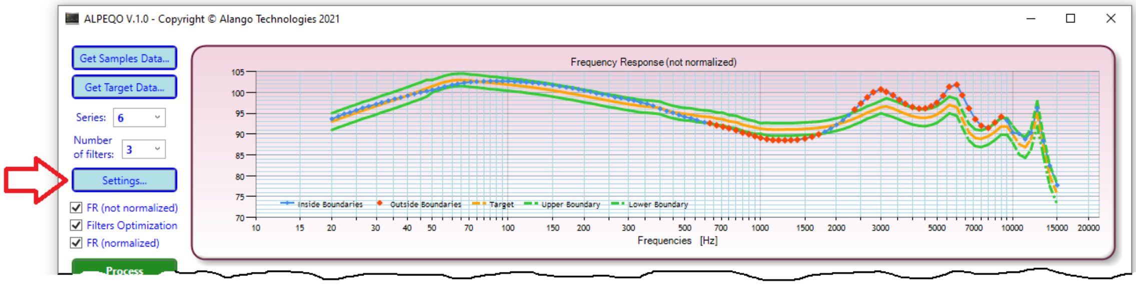
And for **bell** filter (see ***Figure 24***) we have:

$$
\begin{aligned}
a_0 &= 1 + \frac{\alpha}{A} & \qquad b_0 &= 1 + \alpha\cdot A \\
a_1 &= -2\cdot\cos(\omega_0) & \qquad b_1 &= -2\cdot\cos(\omega_0) \\
a_2 &= 1 - \frac{\alpha}{A} & \qquad b_2 &= 1 - \alpha\cdot A
\end{aligned}
$$

3.7. Settings dialog

The settings dialog allows to define configuration of the filter set, initial parameters and parameter limits, and the global optimization procedure settings.

Figure 25

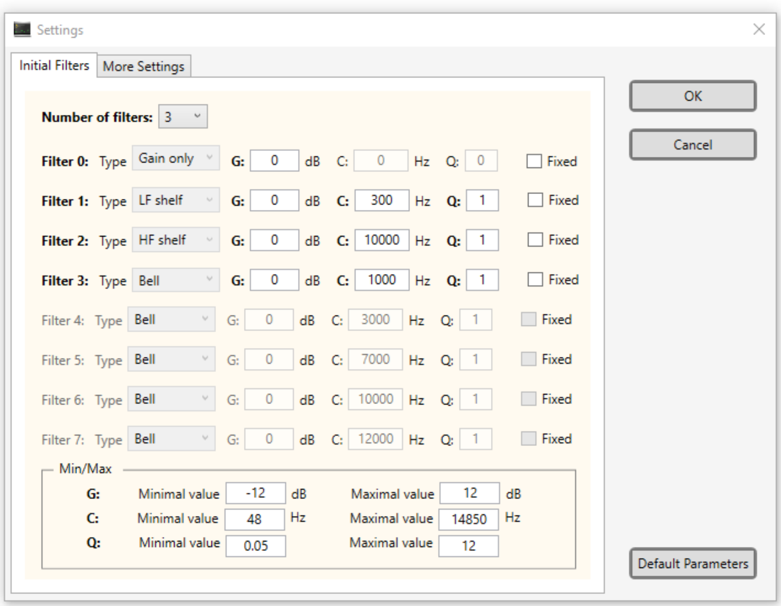


The settings dialog has two tabs – Initial Filters and More Settings and is accessible by clicking the "**Settings...**" button in the main window (see ***Figure 25*** above).

3.7.1. Initial filters

ALPEQO™ uses an iterative process to solve the problem described in section 2. At the beginning of this process, it is necessary to define the initial conditions for the problem which is the initial set of filter parameters. ***Figure 26*** illustrates the default values of the $\boldsymbol{G_k}$, $\boldsymbol{C_k}$ and $\boldsymbol{Q_k}$ parameters for the default selection of 3 filters.

Figure 26



The **Number of filters** combo box allows setting the desired number of filters to be used for correction of the frequency response data. This is similar to the homonymous combo box located in the main window.

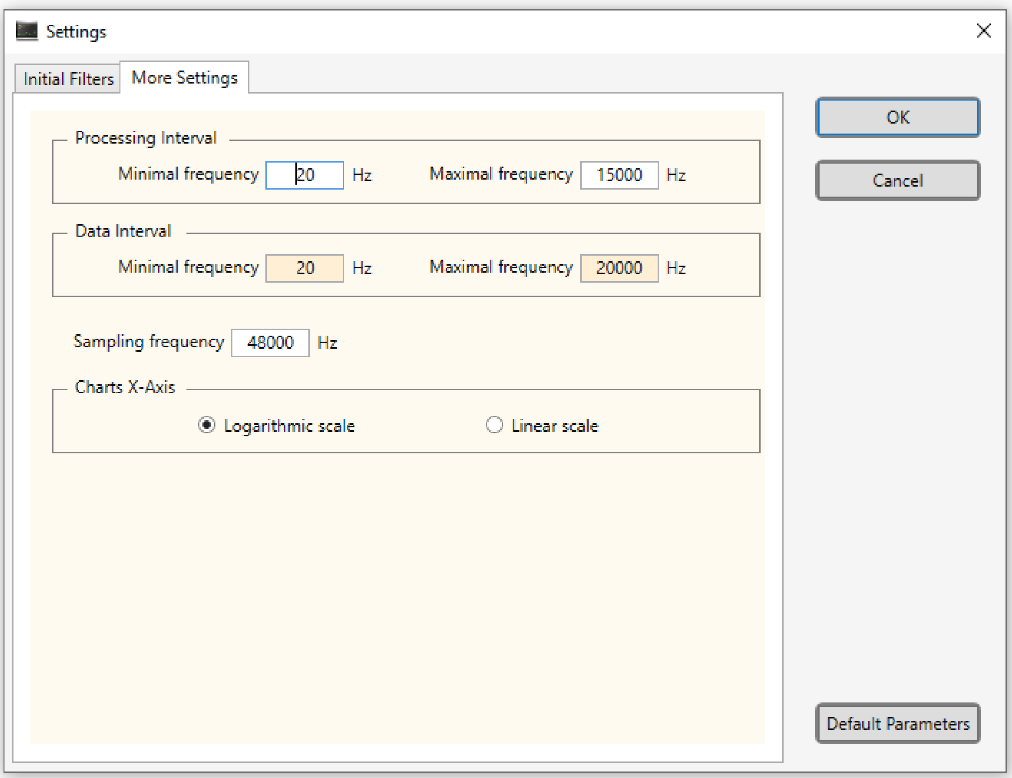
For each filter, the initial $\boldsymbol{G_k}$, $\boldsymbol{C_k}$ and $\boldsymbol{Q_k}$ parameters can be defined in the corresponding fields in the middle section of the dialog. Additionally, the "Fixed" checkbox allows fixing the corresponding filter to its initial state.

The range of parameters $\boldsymbol{G_k}$, $\boldsymbol{C_k}$ and $\boldsymbol{Q_k}$ is controlled by **Min/Max** values defined in the bottom section of the dialog.

3.7.2. More Settings

In the **More Settings** tab, you can set some additional parameters:

Figure 27



The **processing interval** defines the frequency range within which the optimization is performed. Any data outside this frequency range is ignored for the purposes of the optimization procedure.

The **data interval** indicates the actual frequency range obtained from the data files.

The **sampling frequency** field defines F_s described in section 3.6. Note that the sampling frequency must be greater than twice the maximal frequency of the processing interval.

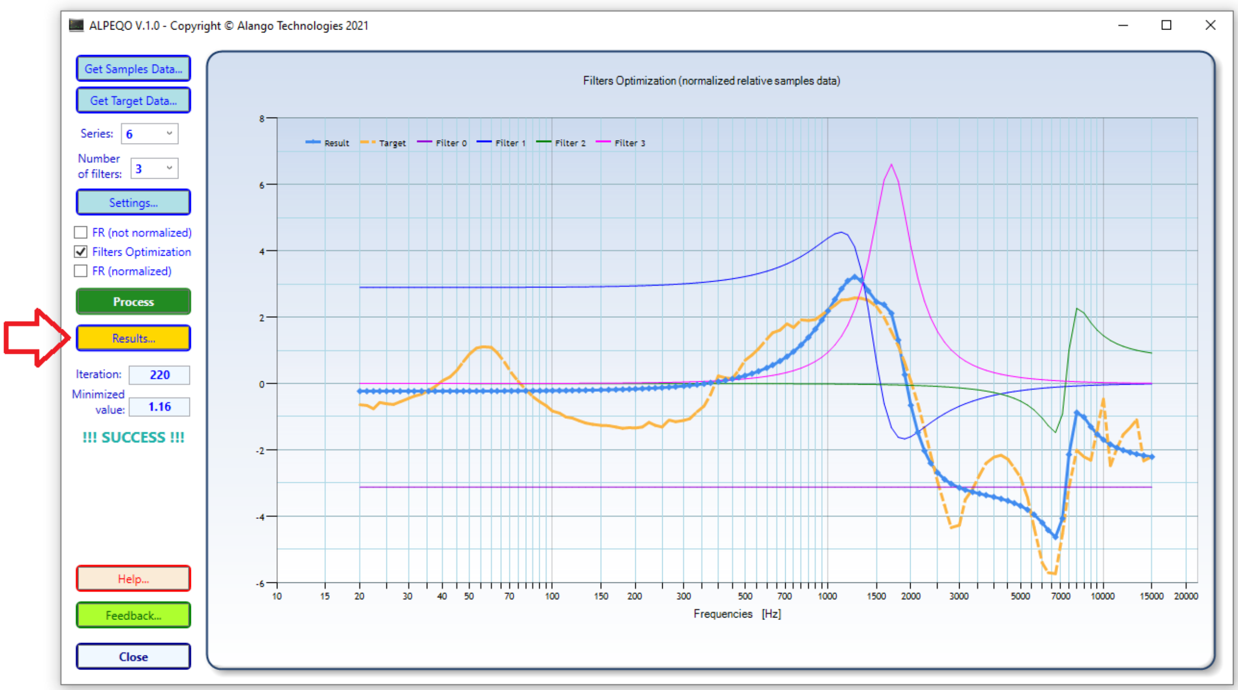
The **Charts X-Axis** radio buttons define the type of scale used for frequency axis in the main window charts. The scale can be set to either *logarithmic* or *linear* modes.

If at any time, it is necessary to restore the default settings, it can be easily done by clicking the **Default Parameters** button at the right bottom corner of the dialog.

3.8. Results dialog

When the optimization process is finished, the middle chart illustrates the optimization results. The individual frequency response of each filter and their combined frequency response are shown overlaying the normalized target frequency response.

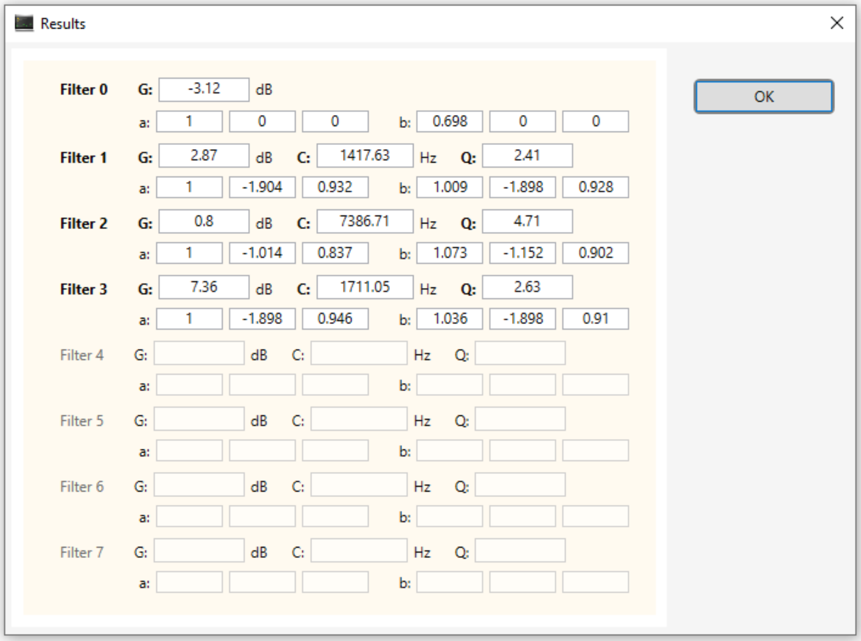
Figure 28



While this presentation is convenient to visually analyze the resulting filters and the quality of the fit, it is typically desirable to have the corresponding filter parameters or even the filter coefficients used by each of the resulting filters.

As illustrated by ***Figure 29***, this information can be easily obtained from the **Results** dialog which is accessible from the main window by clicking the yellow "**Results...**" button (see ***Figure 28***).

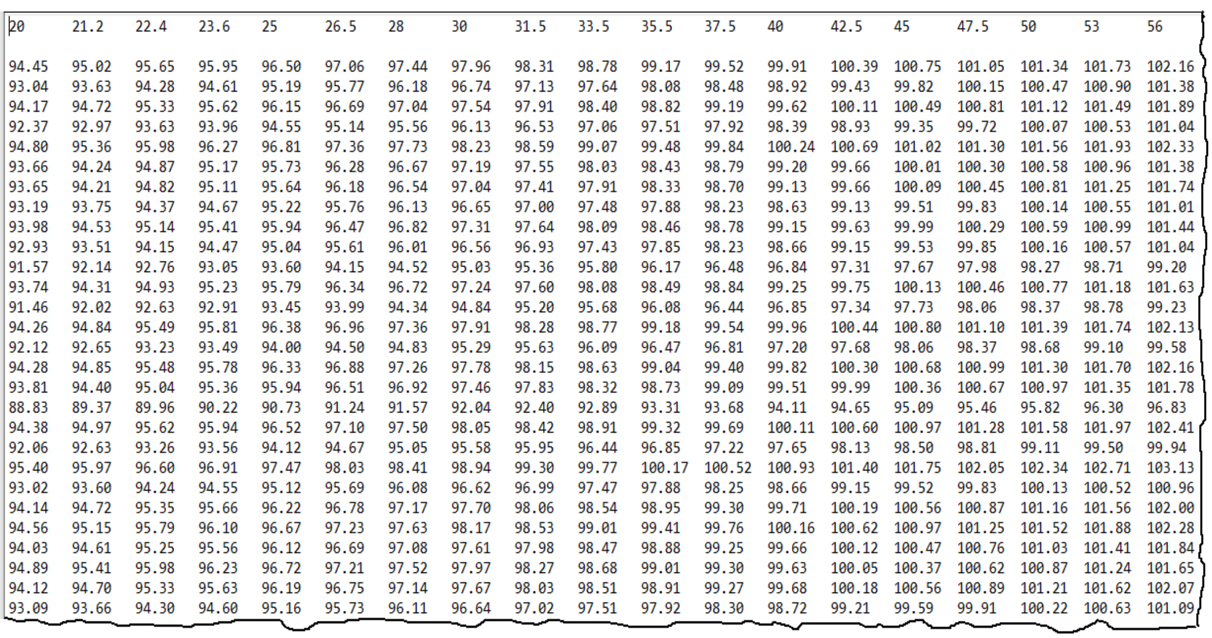
Figure 29



3.9. Samples data file

The samples data file is the text file that contains the measured frequency response data. An example sample data file "samples.txt" can be found in the **AlpeqoData** subfolder of the **Alpeqo Lite** installation directory. The content of the file is illustrated by ***Figure 30***:

Figure 30



20	21.2	22.4	23.6	25	26.5	28	30	31.5	33.5	35.5	37.5	40	42.5	45	47.5	50	53	56
94.45	95.02	95.65	95.95	96.50	97.06	97.44	97.96	98.31	98.78	99.17	99.52	99.91	100.39	100.75	101.05	101.34	101.73	102.16
93.04	93.63	94.28	94.61	95.19	95.77	96.18	96.74	97.13	97.64	98.08	98.48	98.92	99.43	99.82	100.15	100.47	100.90	101.38
94.17	94.72	95.33	95.62	96.15	96.69	97.04	97.54	97.91	98.40	98.82	99.19	99.62	100.11	100.49	100.81	101.12	101.49	101.89
92.37	92.97	93.63	93.96	94.55	95.14	95.56	96.13	96.53	97.06	97.51	97.92	98.39	98.93	99.35	99.72	100.07	100.53	101.04
94.80	95.36	95.98	96.27	96.81	97.36	97.73	98.23	98.59	99.07	99.48	99.84	100.24	100.69	101.02	101.30	101.56	101.93	102.33
93.66	94.24	94.87	95.17	95.73	96.28	96.67	97.19	97.55	98.03	98.43	98.79	99.20	99.66	100.01	100.30	100.58	100.96	101.38
93.65	94.21	94.82	95.11	95.64	96.18	96.54	97.04	97.41	97.91	98.33	98.70	99.13	99.66	100.09	100.45	100.81	101.25	101.74
93.19	93.75	94.37	94.67	95.22	95.76	96.13	96.65	97.00	97.48	97.88	98.23	98.63	99.13	99.51	99.83	100.14	100.55	101.01
93.98	94.53	95.14	95.41	95.94	96.47	96.82	97.31	97.64	98.09	98.46	98.78	99.15	99.63	99.99	100.29	100.59	100.99	101.44
92.93	93.51	94.15	94.47	95.04	95.61	96.01	96.56	96.93	97.43	97.85	98.23	98.66	99.15	99.53	99.85	100.16	100.57	101.04
91.57	92.14	92.76	93.05	93.60	94.15	94.52	95.03	95.36	95.80	96.17	96.48	96.84	97.31	97.67	97.98	98.27	98.71	99.20
93.74	94.31	94.93	95.23	95.79	96.34	96.72	97.24	97.60	98.08	98.49	98.84	99.25	99.75	100.13	100.46	100.77	101.18	101.63
91.46	92.02	92.63	92.91	93.45	93.99	94.34	94.84	95.20	95.68	96.08	96.44	96.85	97.34	97.73	98.06	98.37	98.78	99.23
94.26	94.84	95.49	95.81	96.38	96.96	97.36	97.91	98.28	98.77	99.18	99.54	99.96	100.44	100.80	101.10	101.39	101.74	102.13
92.12	92.65	93.23	93.49	94.00	94.50	94.83	95.29	95.63	96.09	96.47	96.81	97.20	97.68	98.06	98.37	98.68	99.10	99.58
94.28	94.85	95.48	95.78	96.33	96.88	97.26	97.78	98.15	98.63	99.04	99.40	99.82	100.30	100.68	100.99	101.30	101.70	102.16
93.81	94.40	95.04	95.36	95.94	96.51	96.92	97.46	97.83	98.32	98.73	99.09	99.51	99.99	100.36	100.67	100.97	101.35	101.78
88.83	89.37	89.96	90.22	90.73	91.24	91.57	92.04	92.40	92.89	93.31	93.68	94.11	94.65	95.09	95.46	95.82	96.30	96.83
94.38	94.97	95.62	95.94	96.52	97.10	97.50	98.05	98.42	98.91	99.32	99.69	100.11	100.60	100.97	101.28	101.58	101.97	102.41
92.06	92.63	93.26	93.56	94.12	94.67	95.05	95.58	95.95	96.44	96.85	97.22	97.65	98.13	98.50	98.81	99.11	99.50	99.94
95.40	95.97	96.60	96.91	97.47	98.03	98.41	98.94	99.30	99.77	100.17	100.52	100.93	101.40	101.75	102.05	102.34	102.71	103.13
93.02	93.60	94.24	94.55	95.12	95.69	96.08	96.62	96.99	97.47	97.88	98.25	98.66	99.15	99.52	99.83	100.13	100.52	100.96
94.14	94.72	95.35	95.66	96.22	96.78	97.17	97.70	98.06	98.54	98.95	99.30	99.71	100.19	100.56	100.87	101.16	101.56	102.00
94.56	95.15	95.79	96.10	96.67	97.23	97.63	98.17	98.53	99.01	99.41	99.76	100.16	100.62	100.97	101.25	101.52	101.88	102.28
94.03	94.61	95.25	95.56	96.12	96.69	97.08	97.61	97.98	98.47	98.88	99.25	99.66	100.12	100.47	100.76	101.03	101.41	101.84
94.89	95.41	95.98	96.23	96.72	97.21	97.52	97.97	98.27	98.68	99.01	99.30	99.63	100.05	100.37	100.62	100.87	101.24	101.65
94.12	94.70	95.33	95.63	96.19	96.75	97.14	97.67	98.03	98.51	98.91	99.27	99.68	100.18	100.56	100.89	101.21	101.62	102.07
93.09	93.66	94.30	94.60	95.16	95.73	96.11	96.64	97.02	97.51	97.92	98.30	98.72	99.21	99.59	99.91	100.22	100.63	101.09

The file is structured according to the following set of rules:

- Empty lines (or lines containing only whitespaces) are ignored.
- Numerical values are separated by tabs, spaces, or commas (or any combination thereof).
- The first non-empty line lists the frequency points at which the measurements are taken. The frequency points must be listed in non-decreasing order.
- The following non-empty lines contain frequency response data measured in decibels. Each line must have the same number of values as the number of frequency points defined by the first non-empty line. The position of each value must correspond to its respective frequency.

3.10. Target data file

The target data file is the text file that contains the target frequency response data and bounds. An example target data file “target.txt” can be found in the **AlpeqoData** subfolder of the **Alpeqo Lite** installation directory. The content of the file is illustrated by ***Figure 31***:

Figure 31

```
20     21.2   22.4   23.6   25     26.5   28     30     31.5   33.5   35.5   37.5   40     42.5   45     47.5   50     53     56

93.02  93.58  94.11  94.6   95.12  95.65  96.12  96.74  97.17  97.71  98.22  98.7   99.29  99.86  100.41 100.96 101.47 102.03 102.49
95     95.6   96.1   96.6   97.1   97.7   98.1   98.7   99.2   99.7   100.2  100.7  101.3  101.9  102.4  103    103    103.5  104
91     91.6   92.1   92.6   93.1   93.7   94.1   94.7   95.2   95.7   96.2   96.7   97.3   97.9   98.4   99     100    100.5  101
```

The file is structured according to the following set of rules:

- Empty lines (or lines containing only whitespaces) are ignored.
- Numerical values are separated by tabs, spaces, or commas (or any combination thereof).
- The first non-empty line contains frequencies.
- The first non-empty line lists the frequency points at which the target frequency response and its bounds are defined.
- The frequency points must be listed in non-decreasing order and match the frequency points defined in the samples data file.
- The next non-empty lines contain the target frequency response, the upper bound of the frequency response and the lower bound of the frequency response in this exact order. Each line must have the same number of values as the number of frequency points defined by the first non-empty line. The position of each value must correspond to its respective frequency.

3.11. Configuration file

The configuration file, "**workspace.txt**" stores the **Alpeqo Lite** settings when the application is closed. The file is loaded again on the next start of **Alpeqo Lite** and all workspace settings are restored.

While it is possible to manually modify this file in any text editor, it is not an advisable practice. In order to avoid mistakes it is better to use Settings dialog of **Alpeqo Lite**.

The configuration file **workspace.txt** has the following structure (see ***Figure 32***):

- The first 3 lines toggle the visibility of the 3 charts in the main window and correspond to the 3 checkboxes located immediately below the "Settings..." button.
- Line 4 defines the type of the X axis scale as described in section 3.7.2.
- Line 5 defines the sampling frequency as described in section 3.7.2.
- Line 6 defines the samples data series index and corresponds to the "Series" combo box in the main window.
- Lines 7, 8 define the processing interval as described in section 3.7.2.
- Line 9 defines the number of filters (excluding filter 0) used for the optimization process.
- Lines 10, 11 define the gain limits for the filters.
- Lines 12-18 define the starting center frequencies of the filters.
- Lines 19, 20 define quality factor limits for the filters.

Figure 32

```
upper_chart     Show
middle_chart    Show
down_chart      Show
x_axis_scale    Logarithmic
sampling_frequency      48000.000000
samples_data_index      6
min_processing_frequency        20.000000
max_processing_frequency        15000.000000
number_of_filters       3
min_gain        -12.000000
max_gain        12.000000
c1      300.000000
c2      10000.000000
c3      1000.000000
c4      3000.000000
c5      7000.000000
c6      10000.000000
c7      12000.000000
q_min   0.050000
q_max   12.000000
```