Multi-Sub Optimizer Tutorial

Introduction

Multi-Sub Optimizer (MSO) is free software that optimizes the low-frequency response of an audio system having multiple subwoofers. It optimizes the integration of the subwoofers with one another and with the main speakers. It is able to perform this optimization at multiple listening positions simultaneously. It does this by using individual gain, delay, and equalization (EQ) adjustments for each sub. Because of this individual sub adjustments, it can:

- Control the interaction between the subs.
- Control the interaction between the subs and main speakers.

The technique used by MSO is different than the conventional approach of tackling room mode effects by using shared EQ for all subs.

Conventional Equalization for Room Mode Effects

When you place subwoofers and main speakers in a room and the measure their frequency response, room modes in the modal region (typically 200 Hz and below, depending on room dimensions) cause large peaks and dips in the measured frequency response. A typical way to tackle this problem is to use a digital signal processing (DSP) device that provides parametric EQ for the subwoofers. You might apply the same EQ to all subwoofers in order to flatten the measured response at the main listening position (MLP). In a home theater application, you'd typically adjust the subwoofer distance and level settings in the AVR or preamp/processor for best integration of the subs and main speakers. After each such sub distance and level adjustment, you'd make a new measurement to determine if the result is good enough. In a more sophisticated approach using a DSP device, you might set individual delays for each subwoofer. You might then calculate these delays based on the relative distances of each sub from the main listening position and keep them at their calculated value. This step alone can make a significant improvement.

Problems with the Conventional Approach

At the specific frequencies of the room modes, the frequency response may have peaks at some listening positions and dips at others. Unless you're very lucky, flattening the response at the main listening position can make it worse at others. Also, when integrating the main speakers and subs, each new adjustment of subwoofer distance and level requires a corresponding measurement to determine if the integration of main speakers and subs is good enough. That can become very time consuming.

The Advantage of Using Individual Subwoofer EQ

The earliest known effective attempt to simultaneously fix frequency response errors at multiple listening positions can be found in the 1995 Master's thesis of Bruno Korst-Fagundes. He assumed multiple speakers with a mono source signal and didn't specifically mention subwoofers, but his concept applies to equally well to subs. He split the mono signal into separate EQ for each speaker and found that if the number of speakers is equal to the number of listening positions at which their frequency response is measured, it's possible in theory to get perfectly flat response of the combined speaker outputs at multiple listening positions simultaneously. His approach works by solving a set of simultaneous linear equations at each frequency, based on measurements from each speaker to each listening position. The solution to each system of equations at a given frequency yields the required gain and phase of each sub's DSP filter at that frequency. A high-order finite-impulse-response (FIR) filter having the calculated gain and phase response at each frequency is then designed for each sub. This approach requires special-purpose FIR filter hardware and has some practical problems related to the need for impractically high filter gains at some frequencies. The practical need to limit these gains places a limit on how flat the combined subwoofer responses can be in practice. JBL used a variation of this approach on a product called the BassQ.

Earl Geddes has some proprietary software designed under the assumption that a commonly-available type of DSP device having infinite-impulse-response (IIR) filters will be used. These IIR filters are simple compared to the FIR filters used in products like the BassQ. They emulate the behavior of analog filters. An approach that determines the best possible result with hardware that's commonly available and low in cost, like that used by Dr. Geddes, makes a lot of practical sense. Not much is known about his proprietary software, but his video about multiple subwoofers suggests it's doing something similar to what MSO is doing: trying to get the flattest combined response of subs and main speakers at multiple seating positions. The idea for MSO was inspired by that video.

Harman also has a patented system called Sound Field Management (SFM) that works by minimizing a metric called the mean spatial variance (MSV). The goal of SFM is to minimize frequency response *variation* of the combined sub responses (the MSV) across seating positions *without regard to the flatness of the response*. A single separate PEQ, gain and delay per subwoofer are adjusted to minimize the MSV. Then EQ that's common to all subs is performed in a second, separate step to flatten response. Finally, integration with the mains is performed in a third step. MSO does not work in this way.

MSO bases its calculations on the response *flatness* at multiple listening positions, so its reduction of seat-to-seat frequency response variation is only an indirect (but significant) result of this approach. The optimization of response flatness at multiple seating positions and integration of subs and main speakers are all done in one step in order to maximize the usage of the limited EQ resources available in low-cost DSP units.

Tutorial: Creating An Example Project

To perform the tutorial, download tutorial_files.zip to the folder of your choice and unzip it, ensuring that the unzip operation preserves the folders within the zip file. The tutorial contains the folders **Data**, **Project** and **Sample Projects**. The **Data** folder contains the measurement text files you'll be importing, and the **Project** folder is empty. The **Project** folder is where you'll save the MSO project file (.msop file), which is a binary file containing all the information about your project. The **Sample Projects** folder contains projects that have progressed in various stages and whose data on such items as optimized filter parameters matches up with the illustrations in this tutorial. Before looking at the example, we'll have a brief look at the main window of MSO as shown below.

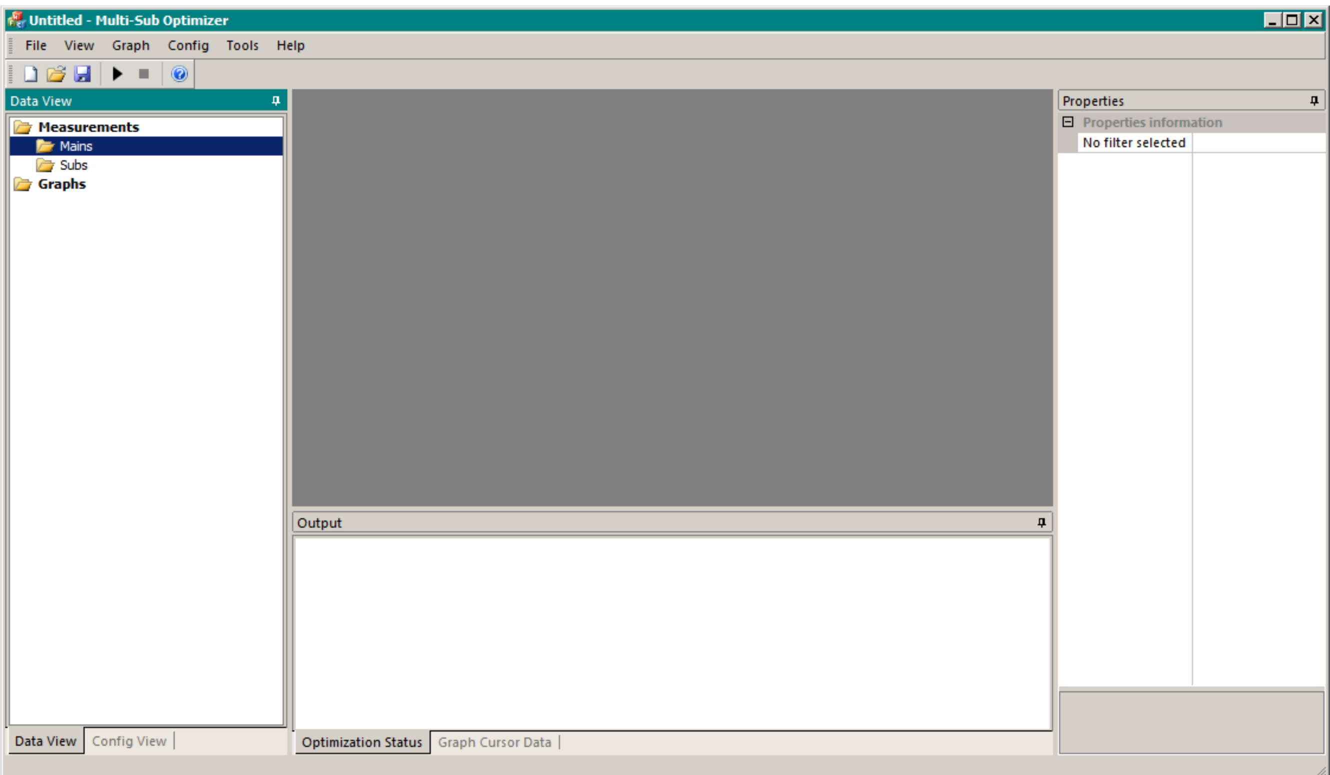


Figure 1: MSO Main Window

You'll see a typical menu and a small toolbar. The left window pane contains two tabs labeled **Data View** and **Config View.** The **Data View** is for displaying which text files you've imported, and allows you to create and manipulate graphs and their traces. In the **Config View**, you can define filter channels, add filters to them, associate measurements with them and other activities. Both **Data View** and **Config View** are tree views whose nodes, if shown as a folder icon, represent categories of data, and if shown as a document-like icon, represent data added explicitly or implicitly by you. At the bottom in the center is the **Output** window. It displays various status items such as optimization status if an optimization is being run, and cursor data values if you are tracing a curve on a graph. At the top in the center is an empty area where graphs and text windows will be shown after you create them. On the right side of the main window is the **Properties** window, also called the **Properties** grid. When you define filters to be used for EQ, their parameter values and upper and lower limits will be shown there, where you can modify them if needed.

Click on the **Data View** tab at the lower left of the main window and try hovering the mouse over the text labeled **Mains** (under **Measurements**), or its icon. You'll see a yellow "tool tip" pop up. The tool tip provides a hint that you can obtain a context menu when you right-click on this node. It also gives a list of some of the menu options. Right-click on this node and you'll see a context menu with only one choice: **Import Mains Measurements**. Using this menu, you can import some data. One good way to explore the user interface of MSO is to hover the mouse over various nodes in the **Data View** and **Config View** trees. If a tool tip appears, there is a context menu associated with that node. By right-clicking a node that shows a tool tip, you can see what menu options are associated with that node. For the tool tip to appear, the mouse must be on the text or icon of the corresponding node. If the mouse is hovered to the right of the node's text, no tool tip will be shown.

A Note About The Project

This project, whose data was provided by Jag768, uses the multi-sub technique recommended by Earl Geddes. In the Geddes arrangement, the main speakers have no high-pass filter. In addition, the sub measurements were performed without a low-pass filter. For this project, individual low-pass filters will be added for each separate subwoofer filter channel using an external DSP, and these low-pass filters will in general have different cutoff frequencies. This is different from a typical home theater application in which the measurements are performed with the chosen crossover already in place and bass management enables. In such a case, no low-pass filter would be added via an external EQ, and typically only PEQ, delay and gain would be used in MSO for each subwoofer filter channel.

Importing Data

After choosing the **Import Mains Measurements** menu selection, you'll get a standard Windows **File Open** dialog with the default extension set to **.frd**. Navigate to the folder where you downloaded the tutorial and select the **Data** sub-folder. There you'll see the **.frd** files for the tutorial. Resize the dialog if necessary to see all of the files. You'll notice that the provider of these files, Jag768, has helpfully given them names that allow identification of which sub or main speaker is being measured, and what the listening position is. There are four files of mains measurements to import: **Pos1_mains.frd**, **Pos2_mains.frd**, **Pos3_mains.frd** and **Pos4_mains.frd**, corresponding to four listening positions. Select all four by pressing **Ctrl** and left-clicking to select each one in turn. Click the **Open** button of the dialog to import the files. There is a short delay while the software checks the text files for errors and converts the text to numeric data. You will then see four icons under **Mains**, displaying the names of the four imported main speaker measurement files as shown below.

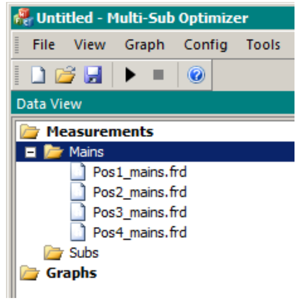
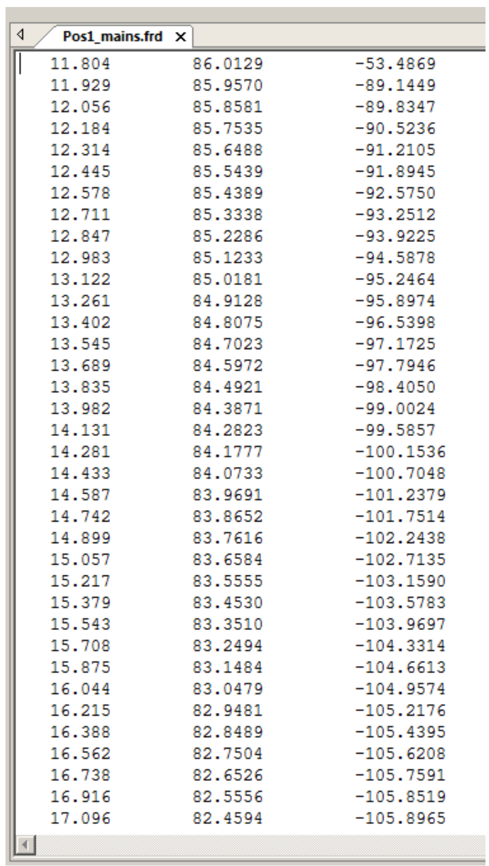


Figure 2: Data View after importing mains measurements

If you hover over one of these file names, you'll see a tool tip indicating that there is a context menu associated with the imported data. Right-click on one of the file names and choose **Show Imported Text**. This will create a tabbed window showing the text you imported. This is illustrated below.


Pos1_mains.frd

11.804	86.0129	-53.4869
11.929	85.9570	-89.1449
12.056	85.8581	-89.8347
12.184	85.7535	-90.5236
12.314	85.6488	-91.2105
12.445	85.5439	-91.8945
12.578	85.4389	-92.5750
12.711	85.3338	-93.2512
12.847	85.2286	-93.9225
12.983	85.1233	-94.5878
13.122	85.0181	-95.2464
13.261	84.9128	-95.8974
13.402	84.8075	-96.5398
13.545	84.7023	-97.1725
13.689	84.5972	-97.7946
13.835	84.4921	-98.4050
13.982	84.3871	-99.0024
14.131	84.2823	-99.5857
14.281	84.1777	-100.1536
14.433	84.0733	-100.7048
14.587	83.9691	-101.2379
14.742	83.8652	-101.7514
14.899	83.7616	-102.2438
15.057	83.6584	-102.7135
15.217	83.5555	-103.1590
15.379	83.4530	-103.5783
15.543	83.3510	-103.9697
15.708	83.2494	-104.3314
15.875	83.1484	-104.6613
16.044	83.0479	-104.9574
16.215	82.9481	-105.2176
16.388	82.8489	-105.4395
16.562	82.7504	-105.6208
16.738	82.6526	-105.7591
16.916	82.5556	-105.8519
17.096	82.4594	-105.8965

Figure 3: Imported measurement in text form

The **.frd** format is very simple. The first column contains the frequency in Hz, the second the SPL in dB, and the third the phase in degrees. The columns can be separated by spaces or tabs. Not present in this example are comment lines, which are recommended. Comment lines can help by reminding you of information such as which speaker and listening position you measured. The description of this format on the FRD Consortium web page specifies that comment lines begin with the “*” character. MSO allows comment lines to begin with many different characters, so it's not critical that they begin with the “*” character. If MSO determines the line is not data, it treats the line as a comment and preserves it. However, you should avoid beginning comment lines with characters such as “+”, “-”, “.”, “,” or the digits 0 through 9 to prevent them from being mistaken as numeric data. If you are using Room EQ Wizard (REW), you can create the **.frd** files by using REW's **File, Export, Measurement as Text** menu sequence. If you have comments in REW's comment field for the measurement, which is recommended, these will be imported by MSO as-is without error. There is no need to edit these files in any way prior to importing them if REW is used to generate them, provided you use the REW menu selection mentioned above to generate the **.frd** files. If you are using REW in a country that uses the comma as the decimal separator, REW will export the text in that format. MSO will sense the decimal separator when importing and will import the data accordingly. The need to interpret commas as decimal separators in countries using this convention means that commas must not be used to separate data columns – only spaces or tabs.

Now you can import the sub measurements. A second way to import measurements uses the main menu. Choose **File, Import Sub Measurements** from the main menu. This will show the same **File Open** dialog that we used to import the mains data, but it will now open in the same folder (directory) used before. The easiest way to select the sub measurement files is to select the first file by clicking on it, then press **Shift** and click the last file. This will select all of the files. Then press **Ctrl** and left-click on the four mains measurement files (**Pos1_mains.frd**, **Pos2_mains.frd**, **Pos3_mains.frd** and **Pos4_mains.frd**) to deselect them so that only sub measurement files are selected. Click the **Open** button on the dialog to import the files. There is a delay while the software performs error checking and converts the text of the files to numeric data. Each file name will appear as an icon under the **Subs** category in the **Data View**.

If you again right-click on the name of one of the imported files, you can look at the other options on the context menu as shown below.

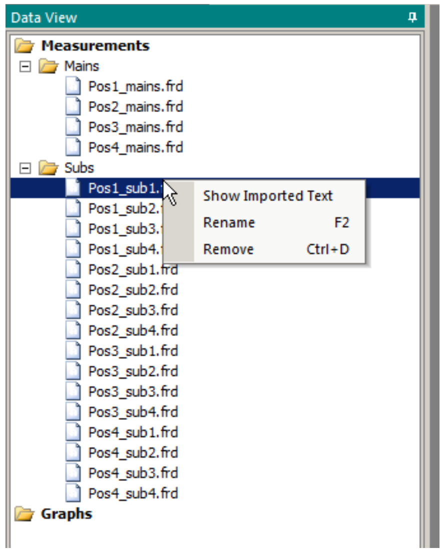


Figure 4: Context menu for imported measurements

Show Imported Text has already been illustrated. You can rename the measurement from this context menu by choosing **Rename** or by pressing **F2**. You can give measurements any name, but the name should be short, yet contain information about which speaker or sub was being measured and what the listening position was. If you chose file names carefully, you probably won't need to rename them. You might want to remove the "**.frd**" at the end of the measurement name for clarity. Also, once you import the measurements, they become part of the project and are saved with it when you choose **File, Save** from the main menu. These files need not be present on disk after they are imported. The other option on this context menu is **Remove**. If you accidentally import **Mains** data into the **Subs** category or vice versa, you can use **Remove** to remove the problem measurement from the project. **Ctrl+D** and **Delete** also cause the selected measurement to be removed from the project. This operation doesn't affect the original text files on disk. You can then re-import the data to the correct data category as needed in the event of an error.

Trying Out Graphs

Since you now have imported data, you're in a position to take a preliminary look at graphs. You won't see all the possibilities with graphs just yet, but you can get a good first idea of how to use them by creating some simple ones with the data you now have available. You can create Graphs in two ways:

- From the main menu, choose **Graph, New Graph**.
- In the **Data View** tab, right-click on the tree node named **Graphs** and choose **New Graph** from the context menu.

This will cause the **Graph Properties** dialog to be launched as shown below.

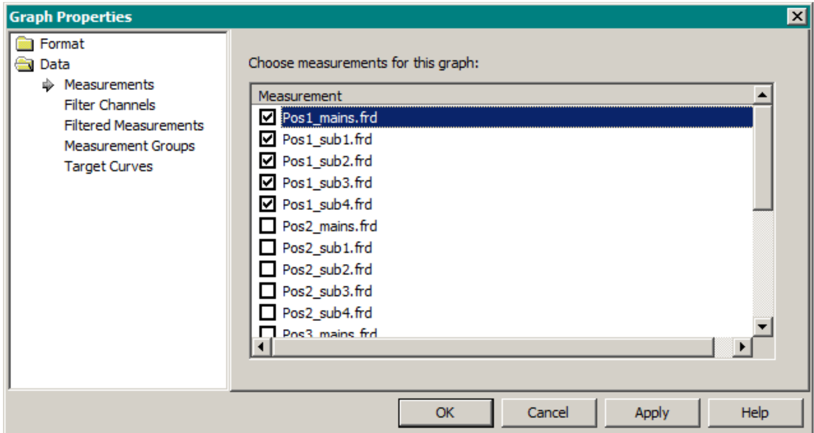


Figure 5: Graph Properties dialog – Measurements page

You use this dialog both for creating new graphs as well as modifying existing ones. The dialog has a tree view on the left, which allows you to select different categories of options to change. Initially, the **Data** category is active, and the item underneath that, **Measurements**, is shown. You can plot four other types of data, but since you only have imported measurements at this point, only those are available. You'll see the other data types when you create them later in this tutorial. When you select **Measurements**, the pane on the right of the dialog shows all the measurements you previously imported. For this graph, choose the first five measurements (**Pos1_mains.frd**, **Pos1_sub1.frd**, **Pos1_sub2.frd**, **Pos1_sub3.frd** and **Pos1_sub4.frd**) as shown above by clicking on the checkboxes in the measurement list. These are all the measurements at position 1, which is the main listening position. After selecting them, do not press the **OK** button at this time. Instead, press **Apply**. The graph will immediately display the changes you've made, while still keeping the dialog box open if further changes are required. If you accidentally press **OK**, this will close the dialog box. To get the dialog box back, simply right-click the graph and choose **Graph Properties** from the context menu. In the tree view on the left side of the **Graph Properties** dialog, click **Format**. This will display the format options. Click **Axes**. The dialog box will be as shown below.

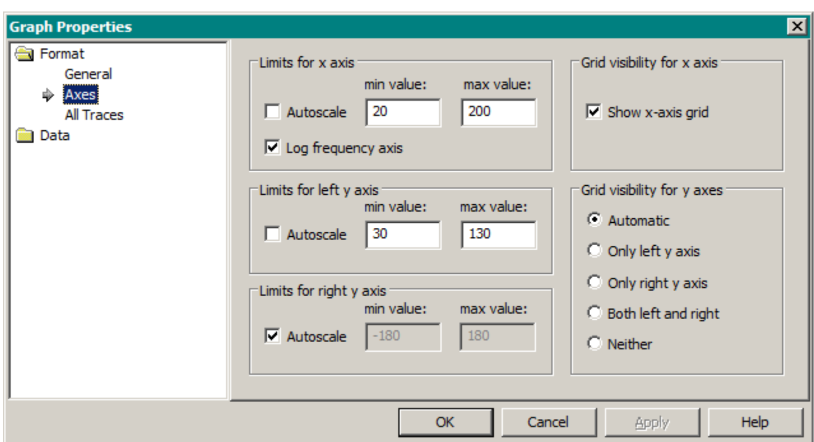


Figure 6: Graph Properties dialog – Axes page

Notice that the default x-axis scaling is manual and the default y-axis scaling is automatic. You can change the y axis scaling to manual by unchecking **Autoscale** under **Limits for left y axis**,. Type in **30** to the **min value** edit box, and **130** to the **max value** edit box as shown above. Press **Apply** to see your changes. After you click the **Apply** button, it will be grayed out as shown above.

One useful feature of graphs is the data cursor. First, close the **Graph Properties** dialog by clicking on **OK** if you haven't yet done so. Next, right-click on the graph to show its context menu. Choose **Show Data Cursor**. This will cause the data cursor to appear as a vertical line, with the mouse cursor, now in the shape of a double-ended arrow, positioned on the data cursor as shown below.

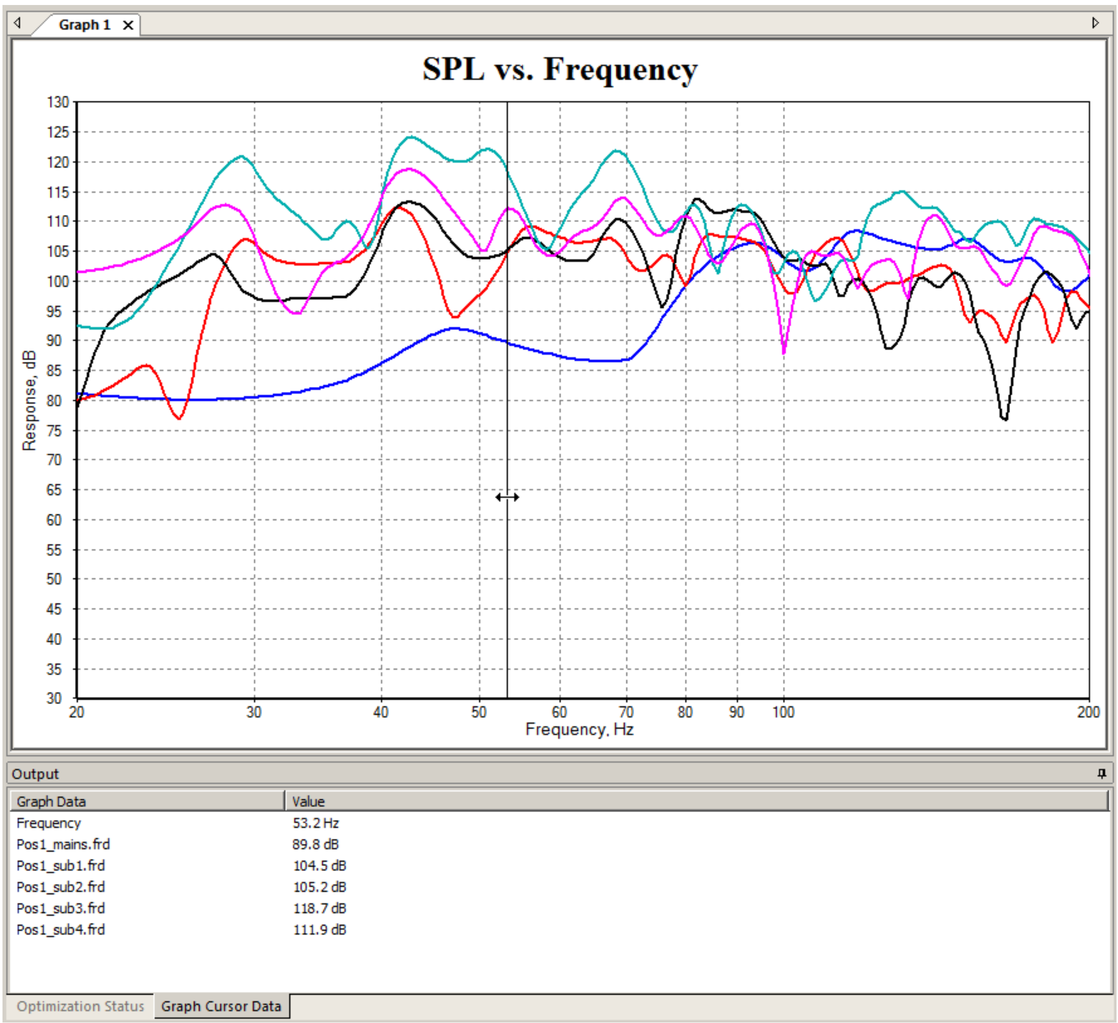


Figure 7: Tracing graph data with the data cursor

This special mouse cursor indicates that you can use the left mouse button to drag the data cursor to the desired frequency and examine the trace data values. In the **Output** window, the **Graph Cursor Data** tab has been automatically activated, and the frequency at the cursor position, along with the SPL values of all of the traces at that frequency are shown. These values automatically update as you drag the data cursor. If you release the left mouse button and move it away from the data cursor, the mouse cursor goes back to its original shape. If you move the mouse cursor close enough to the data cursor, it will turn into a double-ended arrow and you can drag the data cursor again. To hide the data cursor, right-click on the graph and choose **Hide Data Cursor** from the context menu.

Adding Filter Channels

MSO does not have preconfigured setups for specific DSP hardware. Instead, you tell MSO how many filter channels your hardware has by adding filter channels in the **Config View**. To add filter channels, click the **Config View** tab at the lower left of the main window and locate the **Subwoofer Channels** folder icon. Right-click on it and choose **Add Filter Channel** from the context menu. This will create a new filter channel called **Sub Channel 1**. Repeat this process three more times to create the filter channels **Sub Channel 2, Sub Channel 3 and Sub Channel 4**. You have just created four subwoofer channels, one for each of four subwoofers. You set up the filters you want by adding filters to each of these channels. Before you do that though, you need to add a channel for the main speakers, even though you may not be using MSO to EQ the mains. The reason for this will be explained shortly. Right-click the **Mains Channels** node and choose **Add Filter Channel** from the context menu. This will create a new filter channel for the main speakers called **Mains Channel 1**. When done, the results should appear as below.

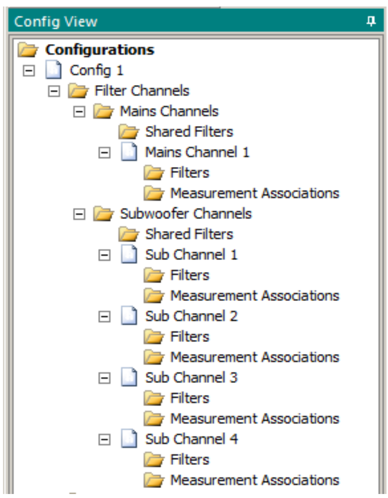


Figure 8: Filter channels added

Adding Filters to Filter Channels

Now you'll add a parametric EQ to **Sub Channel 1**. Click the **Filters** folder icon under **Sub Channel 1**. Right-click and choose **Add Parametric EQ**. You'll see a new icon labeled **FL1:Parametric EQ** under **Filters**, which is under **Sub Channel 1**. Click on **FL1: Parametric EQ** to select it.

When a filter is selected in this way, the **Properties** window on the right side of the main window will show information about the filter, its parameter values, and the upper and lower limits of permissible values of each parameter. This is illustrated below.

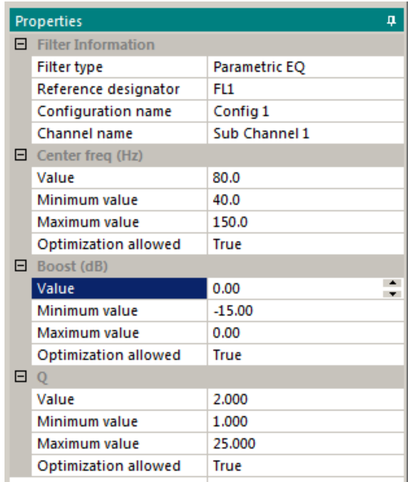


Figure 9: Properties window

The first group of properties is **Filter Information**. You can't alter any of the **Filter Information** values as their purpose is just to identify the filter, its type, and other information about it. Below **Filter Information** are the parameters, their names, values, and the upper and lower limits of those values. Only the information in the right column can be changed. You can change the values themselves in the right column by editing them as you would in a spreadsheet. In addition, when you click in the right column of the **Value** field, a spin control with up and down arrows appears, allowing you to tune the value by pressing either of these two arrows.

The **Optimization allowed** field controls whether the optimizer is permitted to alter the value of the parameter. If set to **False**, the parameter will retain the value set in the **Properties** window and won't be changed by the optimizer.

Notice the **Maximum value** field of the **Boost (dB)** parameter has a value of 0 dB to disallow boosting. This is only an initial maximum value as a safety feature for some DSP hardware that might have dynamic range problems when boosting is done. You can manually edit the maximum value of the boost to be up to 15 dB, which is likely to be much more than you'd ever want to use. You can also set the default minimum and maximum values of newly-created filters of all types. You'll look at that next.

Setting Default Filter Parameter Limits

MSO is initially set up with default values for the minimum and maximum parameter limits. These limits prevent the optimizer from adjusting parameters to values that are either impractical or beyond the capability of your DSP hardware. You can change these limits using the **Application Options** dialog. From the main menu, choose **Tools**, **Application Options**. The **Application Options** dialog will be shown as below.

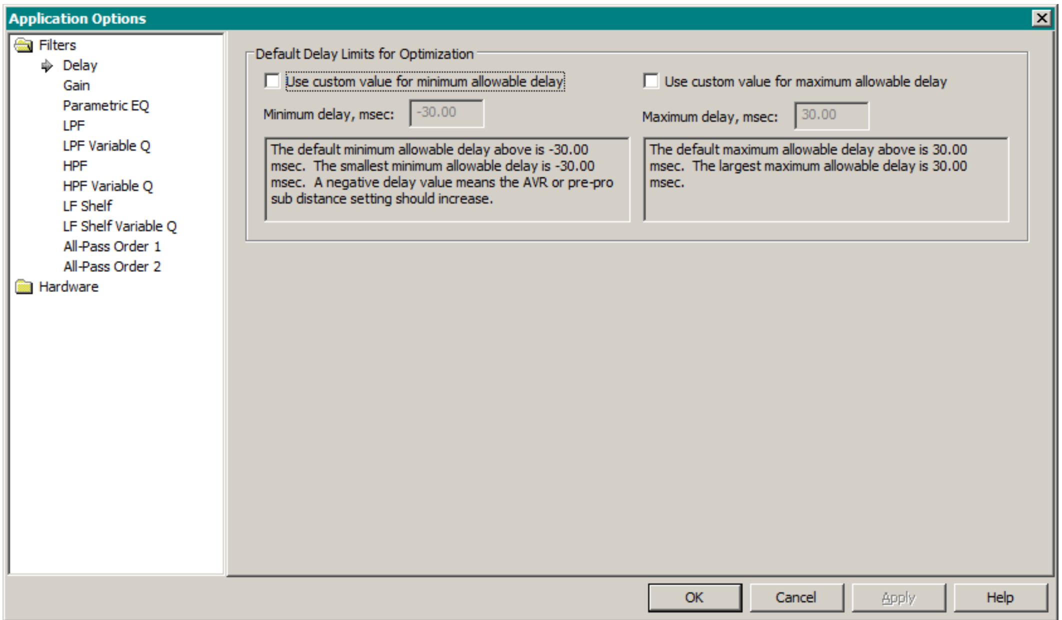


Figure 10: Application Options dialog

Assume the DSP being used has a maximum delay of 15 milliseconds. Check the **Use custom value for minimum allowable delay** checkbox and enter **0** into the **Minimum delay, msec** edit control. Check the **Use custom value for maximum allowable delay** checkbox and enter **15** into the **Maximum delay, msec** edit control. Now all newly-created delay blocks will have these limits for the delay. You can override the limits manually after the delay block is added, by using values as low as -30 milliseconds for the lower limit and as high as 30 milliseconds for the upper limit. A negative delay means that the delay should be reduced relative to the as-measured condition, which means increasing the sub distance in your AVR from what it was when the measurement was performed.

You can configure custom minimum and maximum values for each of the parameters of other filter types too, but for this tutorial you'll keep all of them at the default values except the minimum and maximum delays. These values will stay in effect for all projects, not just the current one. Changes you made to the default minimum and maximum delays affects only newly-created delay blocks.

A Second Look at Graphs

You can demonstrate the tuning feature by making another graph. From the main menu, choose **Graph**, **New Graph**. Under the **Data** category, choose **Filter Channels**. The five filter channels you defined now appear in the list. However, only one of them, **Sub Channel 1**, has any filters in it. Check the checkbox of only **Sub Channel 1** from the list as shown below.

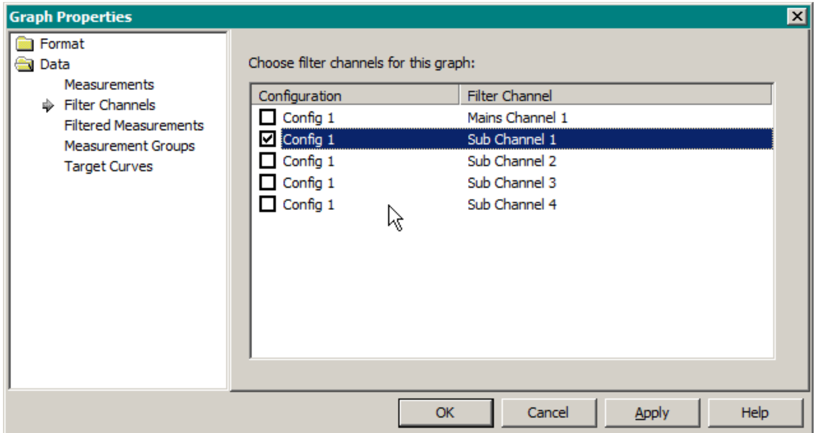


Figure 11: Choosing filter channels to plot

Press **Apply**. Under **Format**, **General**, change the graph title from **SPL vs. Frequency** to **Sub Channel 1 Response vs. Frequency**. Under **Format**, **Axes**, disable autoscaling of the left y axis and enter **-20** for its lower limit and **20** for its upper limit. Press **Apply**. The frequency response of **Sub Channel 1** is shown, but it's just a flat line because the PEQ boost is set to its initial value of 0 dB. If the properties of the parametric EQ **FL1** are not shown in the properties window, go to the **Config View** and select **FL1:Parametric EQ**. In the **Properties** window, locate the **Boost (dB)** parameter and click the mouse on the right column of the **Value** field. The spin control should appear as in Figure 9 above. Press and hold the left mouse button down with the mouse cursor over the down arrow of the spin control while observing the graph. You might have to wait a few seconds because the initial changes happen slowly, but you should see the filter response of the graph change as you tune the **Boost (dB)** parameter. When it has reached its minimum value of -15 dB, the graph should look as below. This assumes the center frequency and Q of **FL1** are set to their default values of 80 Hz and 2.0 respectively.

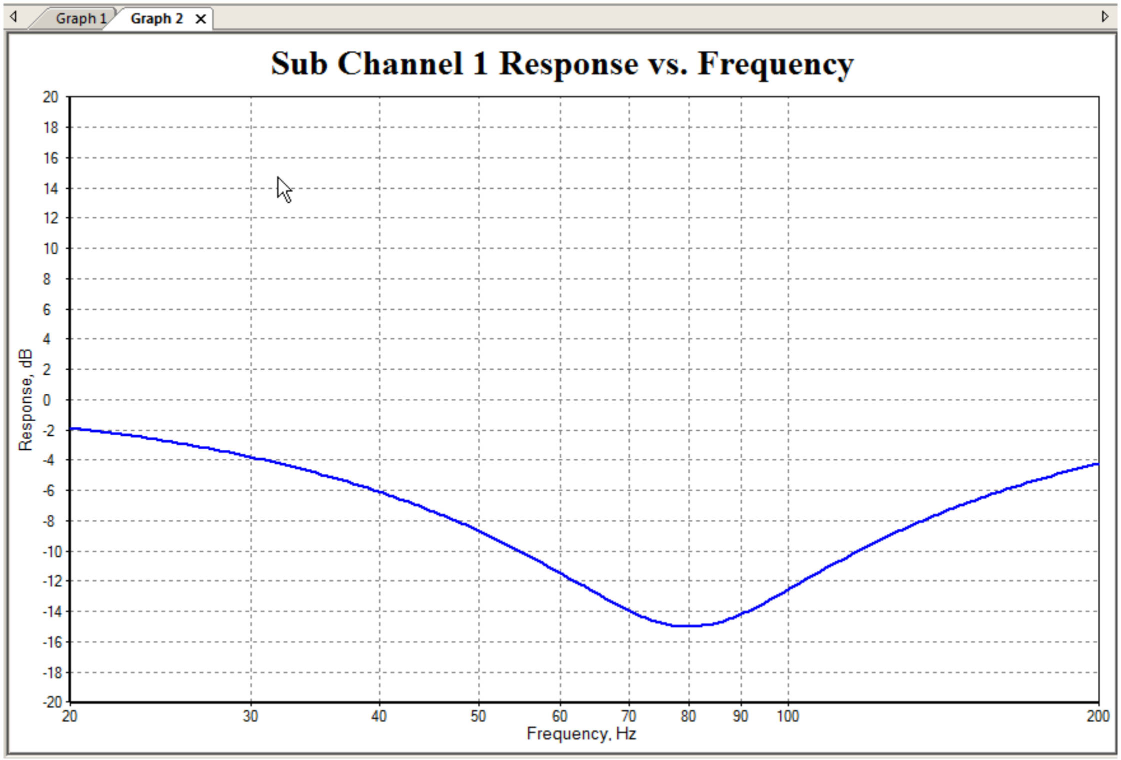


Figure 12: Parametric EQ response vs. frequency with 15 dB cut

For now, set **FL1** back to 0 dB boost. To do this, just enter the text into the right column of the **Value** field of the **Boost (dB)** parameter. You must press **Enter** for the change to be finalized. When the change takes effect, the text display of the value turns to bold. The graph of the response of **Sub Channel 1** should once again be a flat line at 0 dB.

Assume that each of the four sub channels will contain the following filters:

- Four PEQ filters
- One 24 dB/oct Linkwitz-Riley low-pass filter
- One delay block
- One gain block

The channel for the main speakers will have no filters, delays or gain blocks of any kind.

Add filters to each of the four sub channels you've defined so its configuration matches that above. For each sub channel, add the PEQs first, then the low-pass filter, then the delay, then the gain block, beginning with **Sub Channel 1**. Then move on to the next sub channel. Performing the steps in that order will ensure that the reference designators (e.g. FL1, FL2 etc.) match up with the illustrations in this document. The 24 dB/oct Linkwitz-Riley low-pass filter is added using the **Advanced** sub-menu of the context menu for adding filters and is named “LPF Linkwitz-Riley 24 dB/oct” . If you accidentally add the wrong type of filter, just select it and press the **Delete** key to remove it.

Saving Your Work

Now would be a good time to save what you've done. Choose **File**, **Save** from the main menu or press **Ctrl+S**. Navigate to the tutorial's **Project** folder and save your file as **tutorial_1**. MSO will automatically add a **.msop** extension to the file. A file with a **.msop** extension is an MSO project.

Associating Measurements With Filter Channels

To perform an optimization, MSO needs information about which imported measurements are associated with which sub or main speaker. Since each independent Sub or main speaker is associated with an individual filter channel, you accomplish this by associating measurements with filter channels. The following assumptions apply:

- All main speaker measurements are associated with **Mains Channel 1**
- All Sub 1 measurements are associated with **Sub Channel 1**
- All Sub 2 measurements are associated with **Sub Channel 2**
- All Sub 3 measurements are associated with **Sub Channel 3**
- All Sub 4 measurements are associated with **Sub Channel 4**

To associate the main speaker measurements with **Mains Channel 1**, select the **Measurement Associations** icon under **Mains Channel 1**. Right-click and choose **Associate Measurements** from the context menu. All the main speaker measurements are shown in the dialog. Check all of them and click **OK**. You will now see four icons corresponding to the four main speaker measurements (that is, the main speakers at four listening positions) under **Measurement Associations**, which in turn is under **Mains Channel 1**. This is illustrated below.

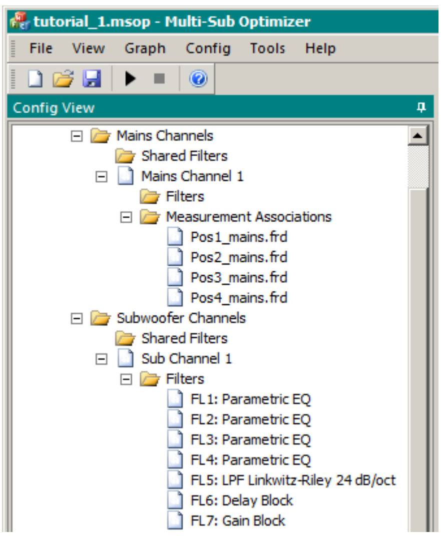


Figure 13: Associating main speaker measurements with their filter channel

Next, associate the Sub 1 measurements with **Sub Channel 1**. Right-clicking on **Measurement Associations** under **Sub Channel 1** and choosing **Associate Measurements** gives the following dialog box:

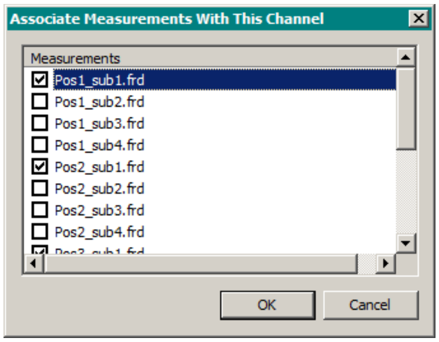


Figure 14: Measurement association for subs

There should be a total of four measurements involving Sub 1, showing up as every fifth measurement. Select the four measurements ending in **_sub1.frd** and press **OK**. Repeat this process for each of the three remaining sub channels. Each time you invoke the **Associate Measurements** dialog for a sub channel, the measurements you previously associated with a channel will have been removed from the list. A measurement cannot be associated with more than one channel. When done, the **Config View** should look something like this (**Filters** nodes have been collapsed for clarity):

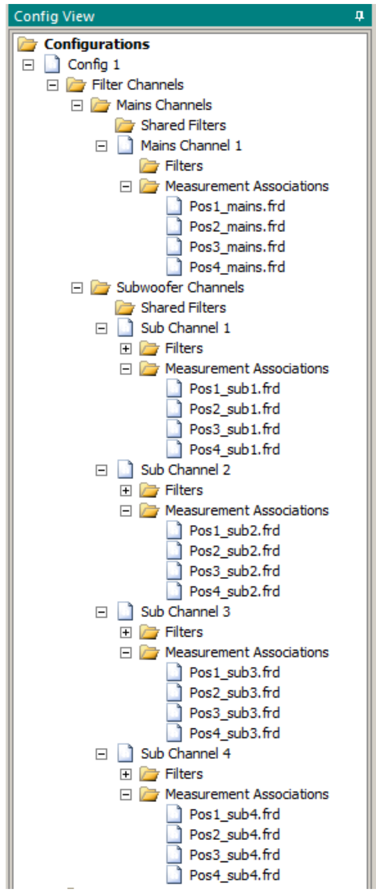


Figure 15: All measurement associations complete

A Third Look at Graphs

Now that you've associated measurements with filter channels, you can look at another type of graph trace.

From the main menu, choose **Graph**, **New Graph**. This launches the **Graph Properties** dialog. The property page for **Data**, under **Measurements,** is the default when the dialog launches. On this page, check the checkbox for the measurement named **Pos1_sub1.frd** as shown below.

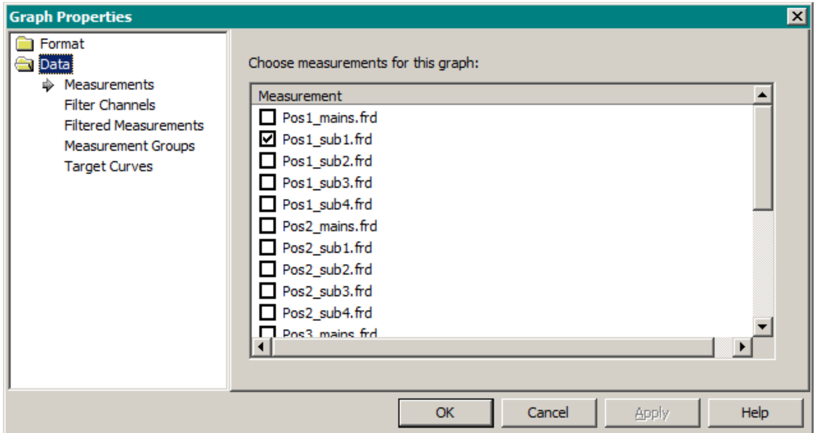


Figure 16: Plotting an unfiltered measurement

Next, choose **Filtered Measurements** as shown below.

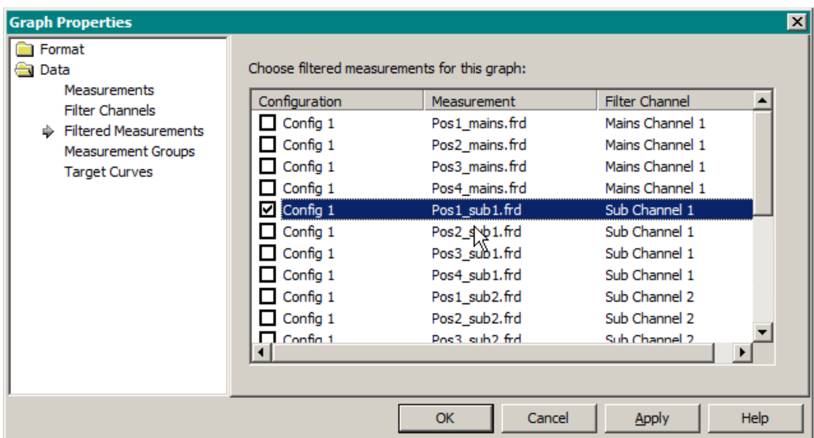


Figure 17: Plotting a filtered measurement

Check the checkbox for the measurement named **Pos1_sub1.frd** as shown above. Press **Apply**. This shows two traces, the unfiltered and filtered **Pos1_sub1.frd** measurement of Sub 1 at the main listening position (position 1). The dialog shows that **Sub Channel 1** performs the filtering. Choose **Format**, **General**, and on the resulting property page, check the **Show legend** checkbox. Choose **Axes** under **Format**, disable autoscale for the left y axis, and set its lower and upper limits to **60** and **120** respectively. Click **OK**. The filtered measurement shows the effect of the 24 dB/oct Linkwitz-Riley low-pass filter in **Sub Channel 1** on the **Pos1_sub1.frd** measurement. The default cutoff frequency of newly-created low-pass filters is 80 Hz, so activating the data cursor and setting it as close as possible to 80 Hz should show a 6 dB difference between the filtered and unfiltered **Pos1_sub1.frd** measurement as shown below.

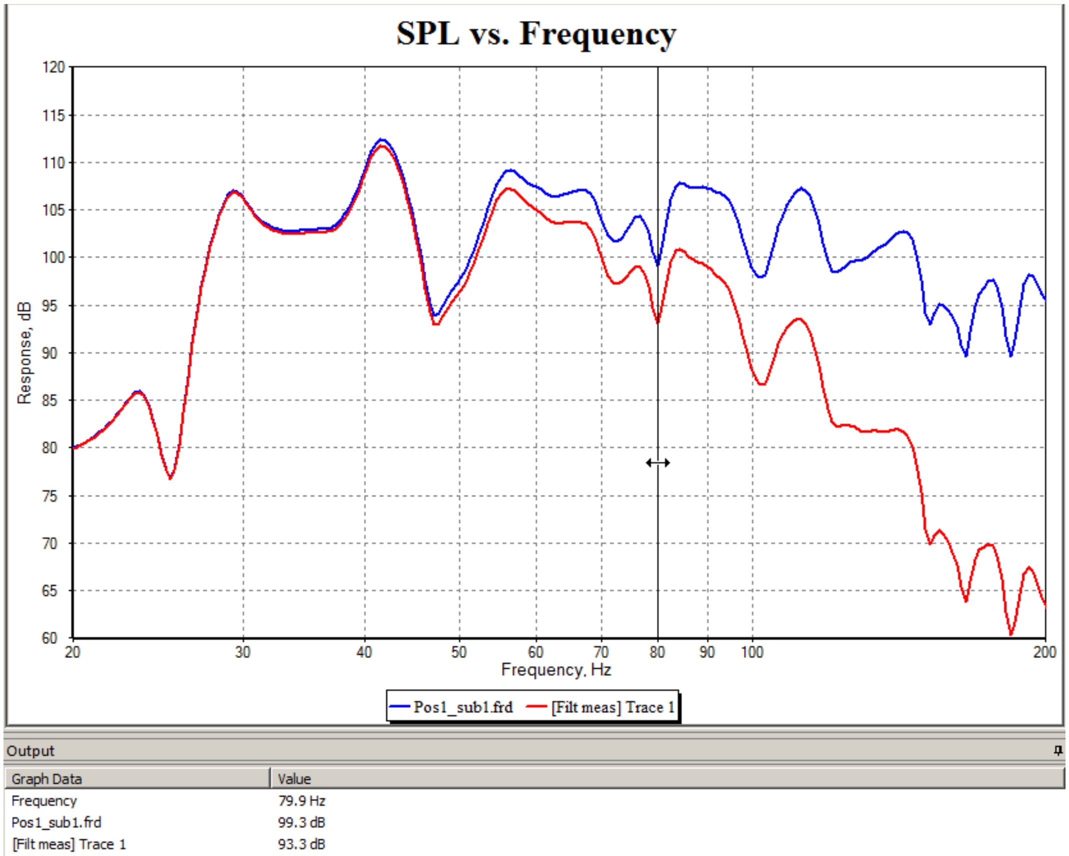


Figure 18: A plot of filtered and unfiltered measurements

Measurement Groups

So far, you've seen how to plot measurements, filter channel frequency responses and filtered measurements. But one piece of the puzzle is still missing: how do you plot the combined output of multiple subs and main speakers at a given listening position? This is done using *measurement groups*. A measurement group is a collection of filtered measurements that are added together (properly taking phase into account) to form a single combined response. To plot the combined outputs of **Sub 1**, **Sub 2**, **Sub 3**, **Sub 4** and main speakers at each of the four listening positions, you'll need to define four measurement groups, one for each listening position. Measurement groups are also used by the automatic optimizer. If you define these four measurement groups, the optimizer will adjust the filter parameters to simultaneously make the frequency response of each group as flat as possible.

To define a measurement group, activate the **Config View** tab at the lower left of the main window. Scroll down to the bottom, where you'll see a folder icon named **Measurement Groups**. Right-click on this icon and choose **Add Measurement Group** from the context menu. For the first group, you'll choose all the measurements from position 1 as shown below.

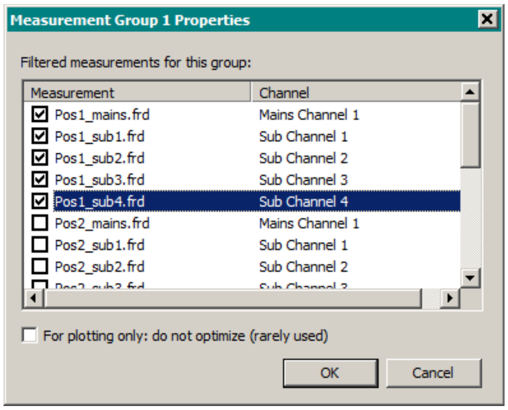


Figure 19: Defining a measurement group

Click **OK**. In the **Config View**, a new icon is created under **Measurement Groups** called **Measurement Group 1**. This name isn't very descriptive, but you can easily change it. Select **Measurement Group 1** and press **F2**. This allows editing the name in place. Since position 1 is the main listening position, call it **MLP** as shown below.

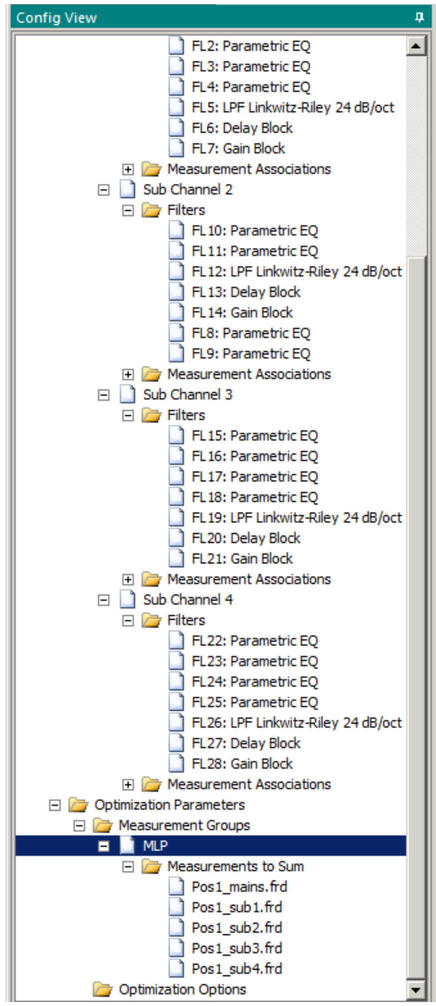


Figure 20: First measurement group defined

Create three more measurement groups, choosing all measurements in position 2 for the first, position 3 for the second and position 4 for the third. Rename these groups **Pos 2**, **Pos 3** and **Pos 4** respectively. The result should look as below.

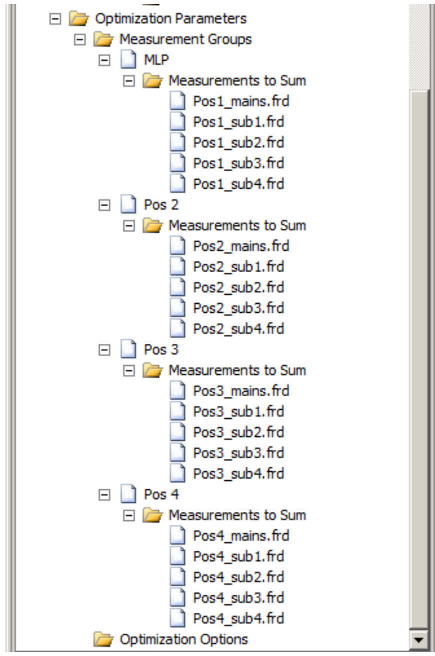


Figure 21: All measurement groups defined

A Fourth Look at Graphs

Now that all the measurement groups are defined, you can plot them on a graph. Select the **Data View** tab at the lower left of the main window. You created several graphs earlier in the tutorial, but these were only for demonstration purposes, so they can be deleted. To delete a graph, select its icon (named e.g. **Graph 1**, **Graph 2** etc.) in the **Data View** and press the **Delete** key. Repeat this action for all existing graphs unless you're sure you want to keep them.

Create a new graph, and under **Data** in the **Graph Properties** dialog, select **Measurement Groups**. The four measurement groups you created are shown in the dialog as below.

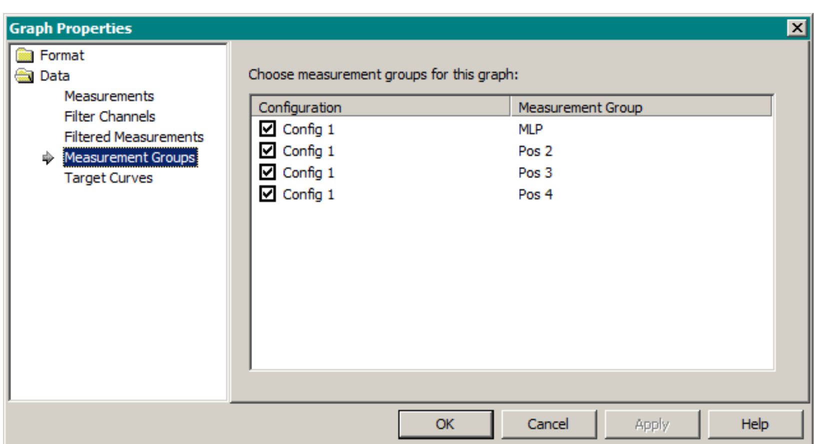


Figure 22: Plotting measurement groups

Check the checkboxes of all four of them and click **Apply**. Under **Format**, select **General**. Change the graph title from **SPL vs. Frequency** to **Combined Response SPL vs. Frequency**. Check the **Show legend** checkbox. Under **Format**, select **Axes** and disable autoscaling for the left y axis. Set the lower limit of the left y axis to **50** and its upper limit to **125**. Click **OK**.

You'll notice the trace names are automatically generated, but these names aren't descriptive of their actual meaning. In the **Data View**, you can expand the tree nodes of each trace to see its constituent parts. Both the names of graphs and their traces can be changed. When you change a trace name, the new name will show up in the graph's legend. When you change a graph name, the new name will show up in the tab of the graph window. Before renaming, the trace display in the Data View looks as below.

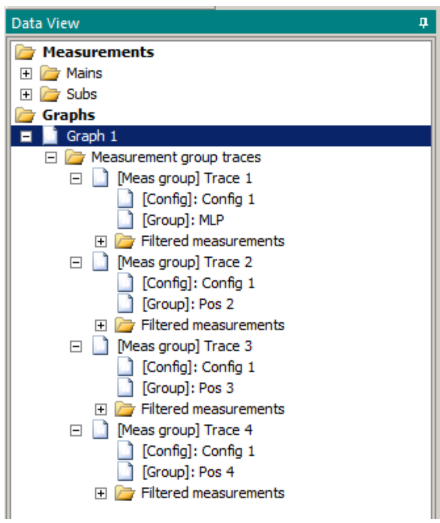


Figure 23: Graph and trace names before renaming

You rename graphs and their traces by selecting their associated node in the tree, pressing **F2**, and entering new text into the edit control that appears. Rename the graph from **Graph 1** to **Combined Responses**. Rename each trace to the name of the measurement group that it displays (that is, **[Meas group] Trace 1** will be renamed to **MLP** and so on for the other traces). When this is done, the **Data View** will look as below.

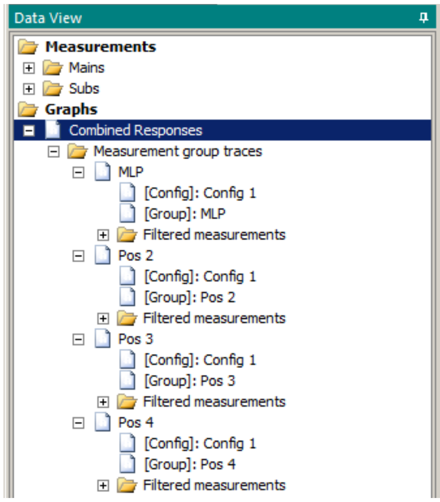


Figure 24: Graph and trace names after renaming

The graph legend now shows the new trace names, which are more descriptive of what's being plotted. The tab at the top of the graph window now reads **Combined Responses** and the legend entries now match the trace names.

Another problem is that the traces are all on top of one another. It would be better to separate them to make them easier to see. To do this, you'll add display offsets to three of the four traces. Right-click the graph and choose **Trace Properties**. This opens up the Trace Properties dialog as shown below.

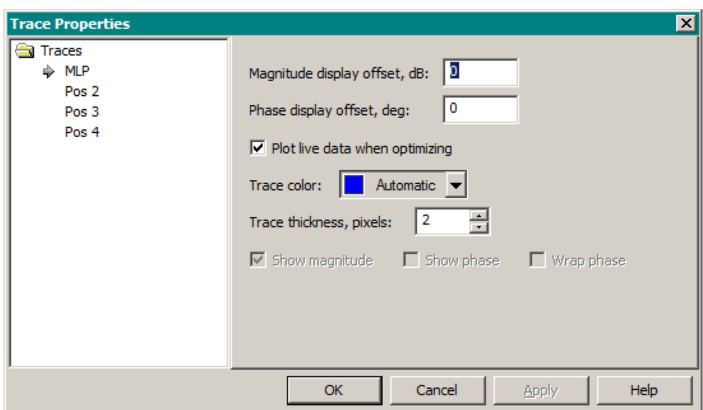


Figure 25: Trace properties dialog

The new trace names you chose also show up here. The edit control labeled **Magnitude display offset, dB** is used to enter the desired offset. For **MLP**, leave the display offset at **0**. Set the **Pos 2**, **Pos 3** and **Pos 4** offsets to **-15**, **-30** and **-45** dB respectively and click **Apply**. Before closing this dialog box, notice the **Plot live data when optimizing** option. When this option is checked and an optimization is running, the trace will be animated, updating continuously with the best solution currently found. It is strongly suggested to leave this option in the default checked state.

After making these changes, the Combined Responses graph should look as below.

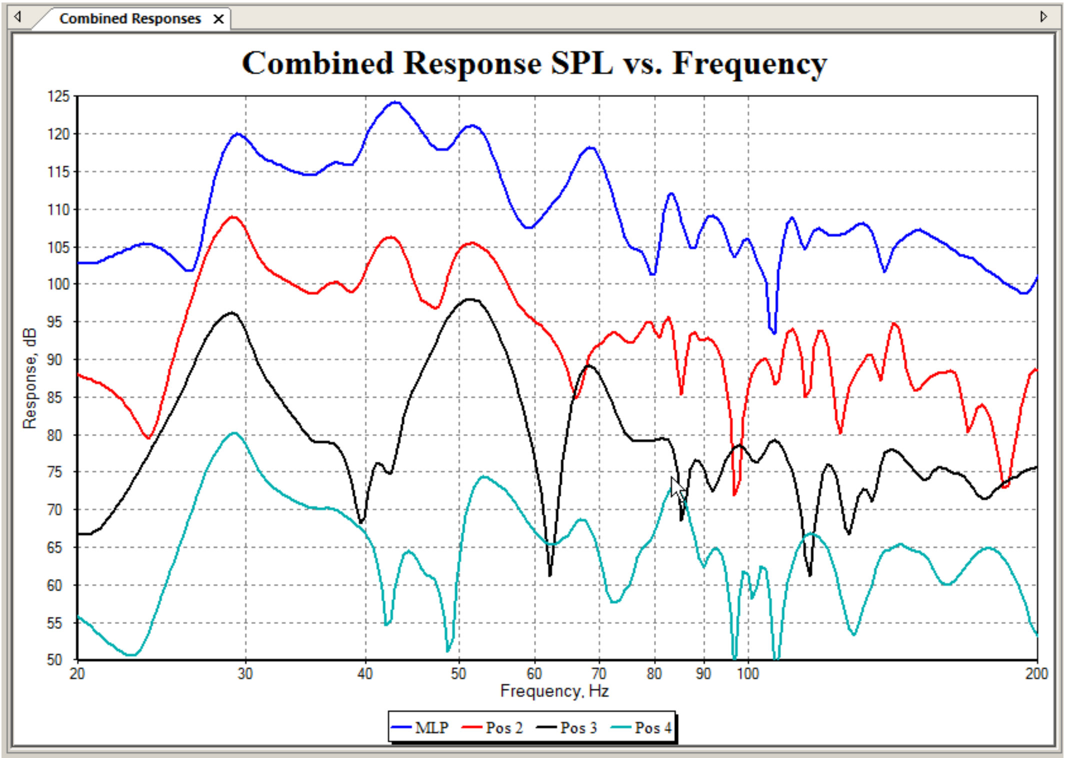


Figure 26: Combined responses after entry of display offsets

Many problems exist in the data of Figure 26, especially in position 3, which has a big peak at about 51 Hz, followed by a suckout at about 62 Hz. Simply applying EQ to make the response flat at the main listening position would still leave many problems at the other positions. This is the kind of problem that MSO's optimization was designed to solve.

Setting Up the Optimization

Before running an optimization, some setup is required. You must consider the upper and lower limits of filter parameter values and set the optimization options.

Filter Parameter Limits

For this tutorial, you'll use the default parameter limits for all filters. For other applications, some experimentation may be needed.

Optimization Options

You set the optimization options by choosing **Tools**, **Optimization Options** from the main menu. A folder representing the configuration name is shown on the left of the **Optimization Options** dialog, with **Criteria** selected. Set the options as shown below.

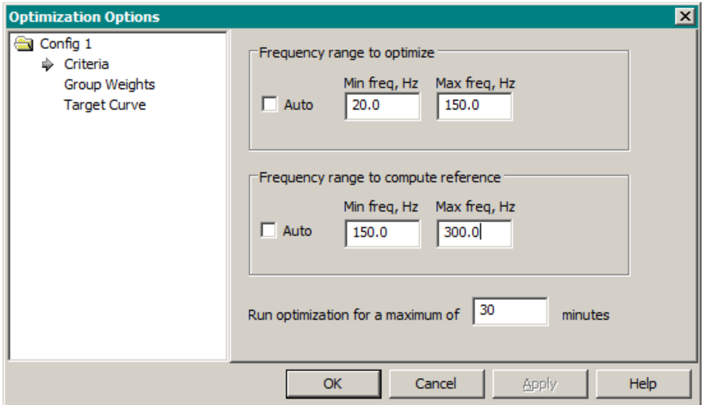


Figure 27: Optimization Options Criteria page

MSO only optimizes the flatness of the combined sub and main speaker responses over the frequency range specified in **Frequency range to optimize**. Uncheck the Auto checkbox and enter **20** and **150** for the minimum and maximum frequencies respectively. **Frequency range to compute reference** needs some explanation. MSO optimizes response flatness by minimizing the sum of the squares of the differences in dB between the response value at each frequency and a reference value. For each listening position, the reference value is computed by taking the average over frequency of its frequency response values in dB over the **Frequency range to compute reference** above. This reference frequency range should be at the high end of the frequency band, where the response is nominally constant with frequency and not affected much by the filters being used. Using a reference frequency range of 150-300 Hz is a good rule of thumb. You could think of the optimization as “lining up” the response at each listening position from 20 Hz to 150 Hz with its corresponding average response from 150 Hz to 300 Hz while also trying to make the response from 20 Hz to 150 Hz as flat as possible.

Set **Run optimization for a maximum of...** to 30 minutes. This seems like a long time, but the optimizer has a lot of work to do, and the problem solved by MSO has no closed-form mathematical solution. Each sub channel has fifteen adjustable parameters (four PEQs with three parameters each, one delay, one gain and one LPF). Considering all four channels, that's a total of sixty adjustable parameters. When running an optimization, the status is shown and you can stop it at any time. The running status and the appearance of the graph gives an idea about the best solution the optimizer has found thus far, and you can stop early if need be. When the optimization stops, either automatically or manually, you are prompted for whether you want to keep or discard the modifications made.

Next, select **Group Weights** in the left-hand portion of the **Optimization Options** dialog. Weighting allows you to “score” errors higher for, say, the MLP than the other listening positions. On the **Group Weights** property page, set the weights for positions 2, 3 and 4 to 0.75 as shown below.

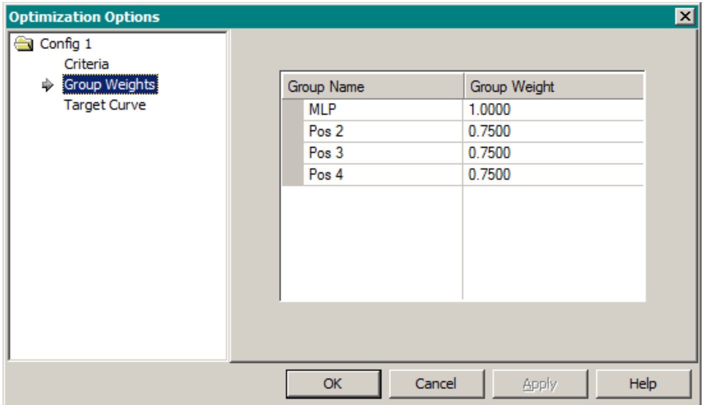


Figure 28: Assigning error weights to different listening positions

For this weighting, an error of (1 / 0.75) dB = 1.33 dB in positions 2, 3 and 4 counts the same toward the total error as a 1 dB error at the MLP. This will tend to make the frequency response at the MLP slightly flatter than the other positions.

For now, you won't use the **Target Curve** option, so the project is ready for optimization.

Running the Optimization

Before running the optimization, save the project using **Ctrl+S**. Then using **File**, **Save As**, save it again under the new name **tutorial_2.msop**. By performing the optimization on **tutorial_2.msop** and keeping **tutorial_1.msop** in its non-optimized state, you'll be able to do a "before and after" comparison between the two. Later in the tutorial, you'll see a better way to do such comparisons. Also, make sure the **Combined Responses** graph is currently displayed. If it is not, select the **Data View** tab, right-click on the **Combined Responses** graph icon and choose **Show Graph**.

To run the optimization, press the **Start Optimization** button on the toolbar or choose **Config**, **Optimize** from the main menu. As the optimization runs, you'll see the **Combined Responses** graph continuously update with the newest solution found. It may appear to get stuck on a solution that isn't as good as what you'd like, but often giving it 20 minutes or so to explore the space of possible solutions can show surprising improvements in the result, even late into the process. Your results may vary because of MSO's use of a random number generator within the optimizer, but you should expect to see something like the results shown below, given that you've run the optimizer long enough.

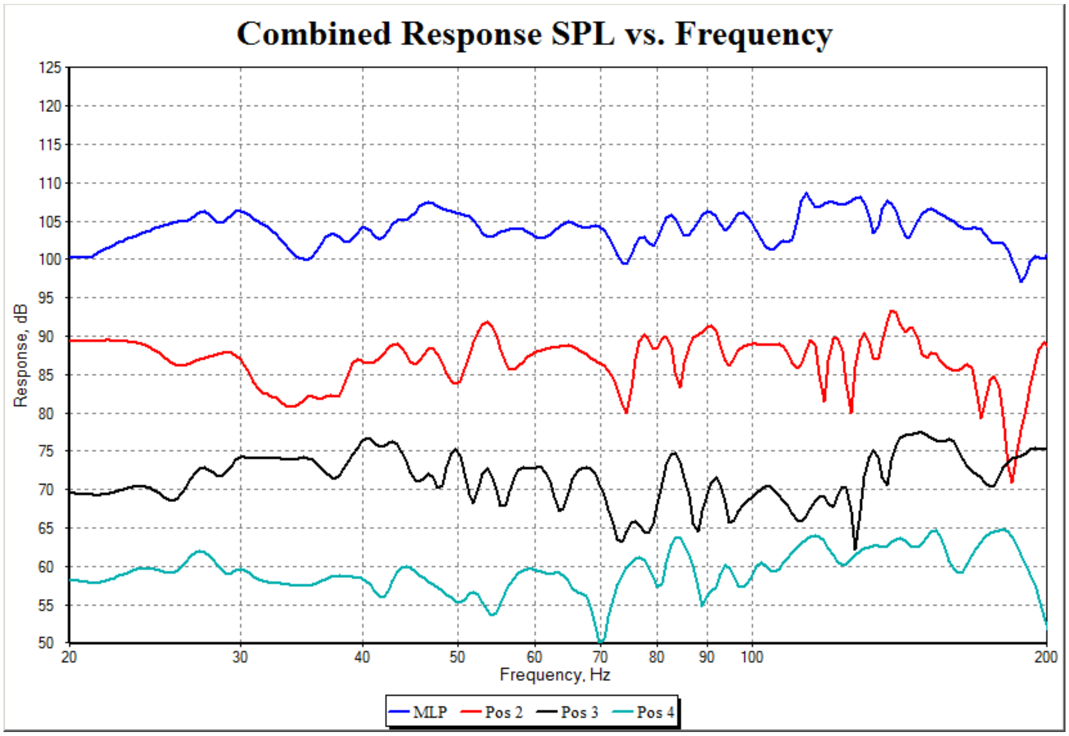


Figure 29: Combined responses after optimization

Compare this with the combined responses before optimization, repeated for clarity below.

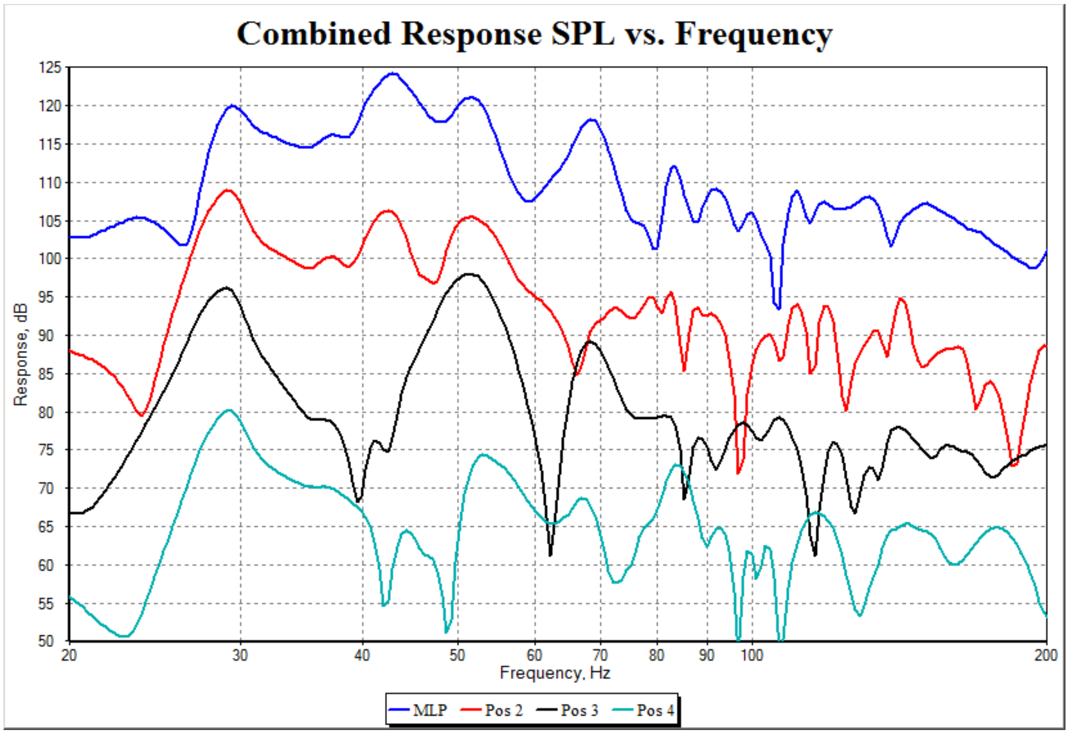


Figure 30: Combined responses before optimization

Running the optimization has provided a substantial improvement, both to flatness and seat-to-seat consistency of responses.

Getting Information About the DSP Filters

To find out what the filter responses look like, you'll create a graph to plot them. Since your results may be different from the results above, open the **tutorial_2_prefab.msop** in the **Sample Projects** sub-folder of the tutorial to ensure your results match the tutorial. Then, use **File**, **Save As** to save it as **tutorial_2.msop**, overwriting the **tutorial_2.msop** you created earlier.

Create a new graph, then in **Data**, **Filter Channels** in the **Graph Properties** dialog, check the checkboxes for all four subwoofer channels (but not the mains channel, which has no filters). Press **Apply**. In **Format**, **General**, change the graph title to **Filter Responses vs. Frequency**. Check the **Show legend** checkbox. In **Format**, **Axes**, disable autoscale for the left y axis and set its lower and upper limits to **-65** and **5** respectively. Press **Apply** to make sure the axis values are correct, then press **OK** to close the dialog. Rename the graph from **Graph 2** to **Filter Responses**. Rename the **[Filt chan] Trace 1**, **[Filt chan] Trace 2**, **[Filt chan] Trace 3**, **and [Filt chan] Trace 4** traces to **Sub Chan 1**, **Sub Chan 2**, **Sub Chan 3**, and **Sub Chan 4** respectively. The new graph should look as below.

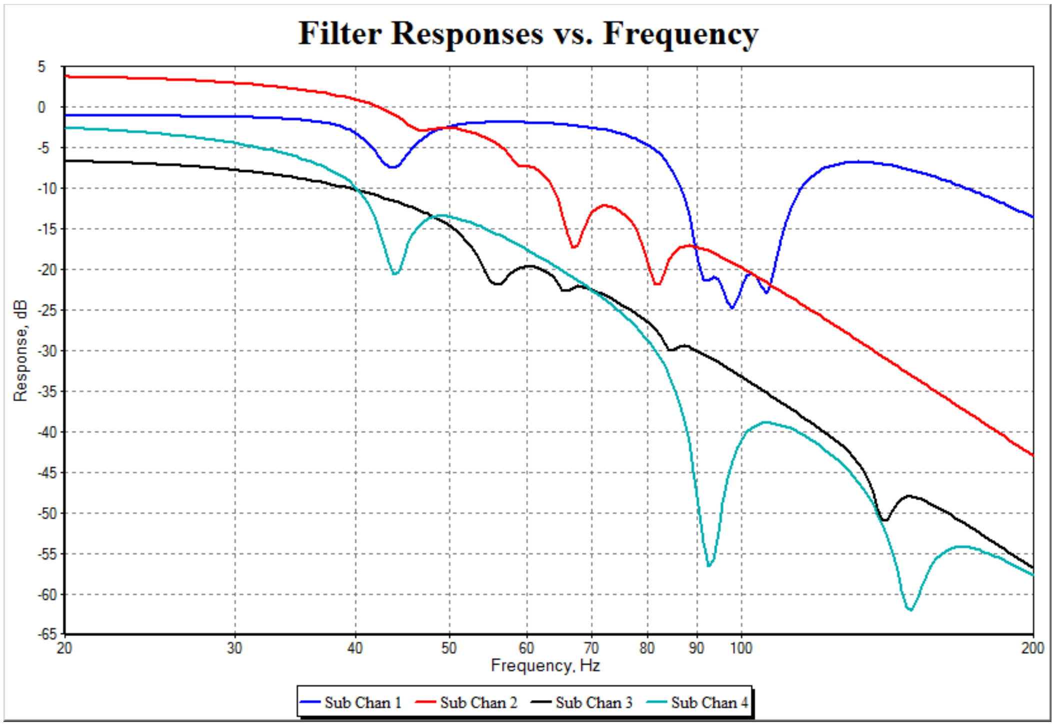


Figure 31: Filter channel responses after optimization

Filter Reports

You could determine the filter parameter values by selecting each one and looking in the **Properties** window, but using the filter report feature is easier and quicker. To see the filter report, activate the **Config View** and right-click on the **Config 1** icon just underneath the topmost **Configurations** icon. Select **Show Filter Report** from the context window. This will open up a tabbed text window with the information you'll need to enter into the software of your DSP. If there are many filters, such as in this project, this could get tedious.

Biquad Information

Some DSP vendors, such as miniDSP, support a special text format which allows you to copy and paste all the parameter values for an entire filter channel into the software to configure all the filters in that channel at once. MSO supports the miniDSP format, but you'll need to enable it in the application options. Select **Tools**, **Application Options** from the main menu. On the left side of the **Application Options** dialog, select **Hardware** and **Filter Reports**. Check the checkbox labeled **Include biquad information in filter reports**. This activates the **Sample rate** selection radio buttons. Be sure to choose the sample rate used by the actual hardware. For the purposes of the tutorial, choose **48 kHz**. In the **Config 1 filters** text view containing the filter report, right-click and choose **Refresh** from the context menu. This will cause the filter report to be updated with the biquad information. Pressing Page Down a few times will take you to the part of the filter report containing the information about the biquads and other related information. The portion for Sub Channel 1 should look as below.

```
Sub Channel 1:
FL1: Parametric EQ (biquad1)
FL2: Parametric EQ (biquad2)
FL3: Parametric EQ (biquad3)
FL4: Parametric EQ (biquad4)
FL5: LPF Linkwitz-Riley 24 dB/oct (biquad5, biquad6)
biquad1,
b0=0.999289245870467,
b1=-1.997957246800862,
b2=0.998811046390038,
a1=1.997957246800862,
a2=-0.998100292260505,
biquad2,
b0=0.998818991406365,
b1=-1.996962910604257,
b2=0.998307607188862,
a1=1.996962910604257,
a2=-0.997126598595227,
biquad3,
b0=0.998746233369988,
b1=-1.996741429491683,
b2=0.998189334211126,
a1=1.996741429491683,
a2=-0.996935567581113,
biquad4,
b0=0.999748065657730,
b1=-1.998989646925358,
b2=0.999274155844187,
a1=1.998989646925358,
a2=-0.999022221501918,
biquad5,
b0=0.000095059903807,
b1=0.000190119807613,
b2=0.000095059903807,
a1=1.972233747669657,
a2=-0.972613987284884,
biquad6,
b0=0.000095059903807,
b1=0.000190119807613,
b2=0.000095059903807,
a1=1.972233747669657,
a2=-0.972613987284884
```

You can highlight the text of a channel (biquad1-biquad6) and press **Ctrl+C** to copy it to the clipboard. You can then paste it into the miniDSP software to configure the appropriate channel. See the miniDSP documentation for more information.

Additional Topics

Earlier in the tutorial, in order to compare the results before and after optimization, you saved the project as **tutorial_1.msop** before optimizing, and obtained the graph of Figure 30. After optimization, you saved the project as **tutorial_2.msop** and obtained the graph of Figure 29. This kind of comparison can be done within a single project using the **Configurations** feature.

Configurations

The **Configurations** feature allows for optimizing using different types of filters, different filter parameters and so on. Save the current project and open up the **tutorial_1.msop**. Save it as **tutorial_3.msop** so you can still go back to the original if you make a mistake. Select the name of the configuration, **Config 1**, and press **F2**. Rename the configuration to **Original**. Right-click on **Original** and choose **Clone Configuration**. This will create an exact copy of the configuration named **Config 2**. Rename **Config 2** to **Optimized**. After collapsing the tree structure of both **Original** and **Optimized**, the result should look as below.

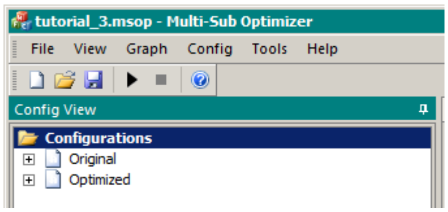


Figure 32: Cloning a configuration

The **Original** configuration should be kept as-is to enable performance comparison before and after optimization. To protect it, you can lock all the parameters of all the filters in the configuration. Select the topmost node of the **Original** configuration as shown above in Figure 32. Right-click and choose **Lock All Filter Parameters of this Configuration** from the context menu. This will set the **Optimization allowed** property of all parameters of all filters in **Original** to **False**. Verify that this is the case by expanding the **Original** node. The icons for all the filters in the **Original** configuration will now be a dark gray color, indicating that the optimizer will not adjust any of their parameters.

Press the **Start optimization** button on the toolbar. A dialog box pops up, asking you to specify which configuration you want to optimize. This dialog only pops up when there is more than one configuration present. Select **Original** and click **OK**. You should get the message **The configuration named “Original” has no optimizable parameters**. Since this project originated with the **tutorial_1.msop** that was saved prior to running the optimization, you'll need to run the optimization again to optimize the filter parameters for the **Optimized** configuration. However, since you just created the **Optimized** configuration by cloning the **Original** configuration, there are not yet any graphs associated with the new **Optimized** configuration. You'll do that next.

Activate the **Data View** by clicking on the **Data View** tab at the lower left of the main window.

Rename the **Combined Responses** graph by clicking on the **Combined Responses** text under **Graphs** and pressing **F2**. Rename it to **Combined Responses (Original)**. Right-click on **Graphs** and choose **New Graph…** to create a new graph. Under **Data** in the **Graph Properties** dialog, select **Measurement Groups**. On the right side of this dialog, check the checkboxes of the four measurement groups associated with the configuration named **Optimized**. The **Graph Properties** dialog should appear as below.

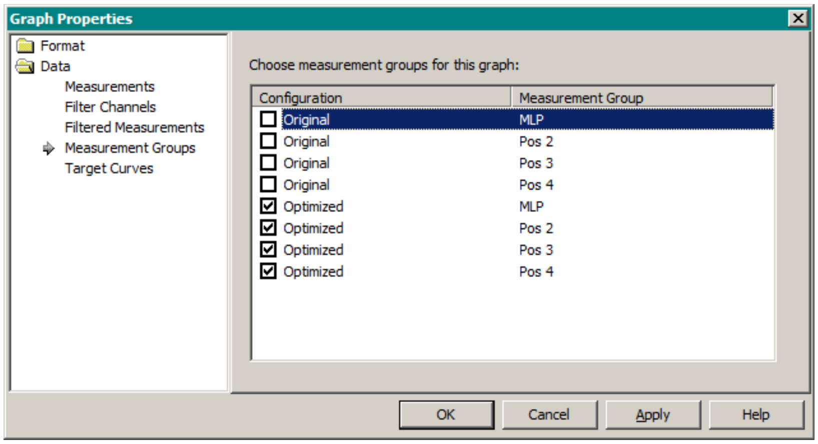


Figure 33: Choosing data to plot for the new configuration

Under **Format**, choose **General**. Change the graph title to **Optimized Combined Response SPL vs. Frequency** and check the **Show legend** checkbox. Under **Format**, choose **Axes**. Uncheck the **Autoscale** checkbox for the left y axis and set the **min value** and **max value** to **50** and **125** respectively. Click **OK**. In the **Data View**, rename the newly-created **Graph 2** to **Combined Responses (Optimized)**.

The graph names now properly reflect their content, but you should still rename the graph traces. Before doing that, expand the nodes in the tree that contain the trace names so they look as below.

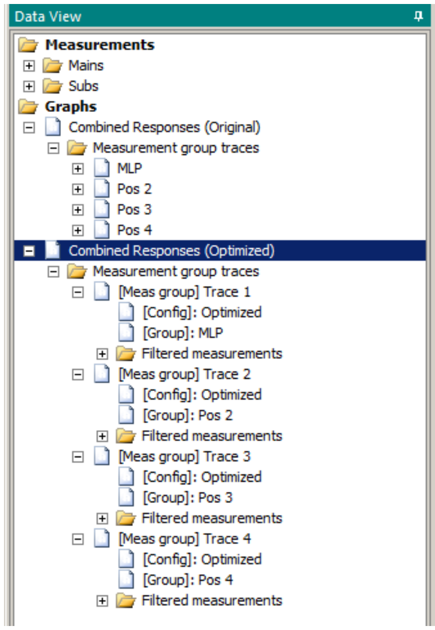


Figure 34: Trace names before renaming

For consistency with the previous graph, name each trace the same as its group name. This means **[Meas group] Trace 1**, **[Meas group] Trace 2**, **[Meas group] Trace 3** and **[Meas group] Trace 4** get renamed to **MLP**, **Pos 2**, **Pos 3** and **Pos 4** respectively. After renaming, the **Data View** should look as below.

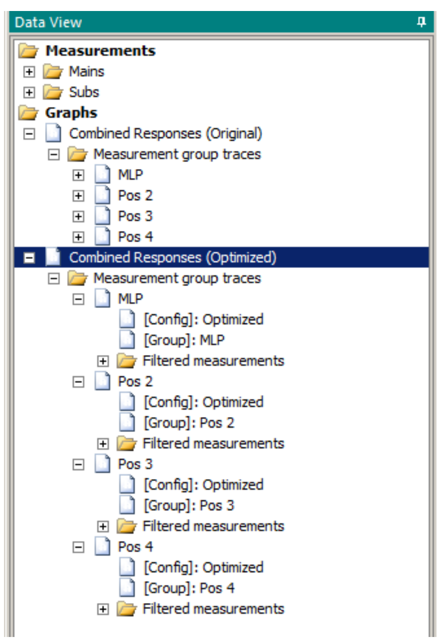


Figure 35: Trace names after renaming

You'll also notice that the trace names in the graph's legend have changed, and match up with what you entered in the **Data View**.

You'll need to add display offsets to the traces to make them more easily distinguishable. Right click on the graph and choose **Trace Properties…** from the context menu. Set the **Magnitude display offset, dB** of the **MLP**, **Pos 2**, **Pos 3** and **Pos 4** traces to **0**, **-15**, **-30** and **-45** respectively. Click **OK**. The graphs named **Combined Responses (Original)** and **Combined Responses (Optimized)** should now look the same. To avoid confusion, close the **Combined Responses (Original)** graph window if it is open, so that only the **Combined Responses (Optimized)** graph is shown.

Now is a good time to save your work, so press **Ctrl+S** to save or choose **File**, **Save** from the main menu to save the project.

Press the **Start optimization** button on the toolbar again, but this time choose **Optimized** as the configuration. In the dialog, you can either click **OK** or double-click the configuration name to start the optimization. This is a complex optimization, so let it run for the full 30 minutes to ensure the best results.

Since the optimizer uses a random number generator in its optimization algorithm, the results vary somewhat from one equally long optimization run to another. Because of this, , open the **tutorial_3_prefab.msop** in the **Sample Projects** sub-folder of the tutorial to ensure your results match the tutorial. Then, use **File**, **Save As** to save it as **tutorial_3.msop**, overwriting the **tutorial_3.msop** you created earlier.

As an exercise on your own, try out what you learned earlier in **Getting Information About the DSP Filters** to create a graph named **Optimized Filter Responses** showing the frequency responses of the **Sub 1**, **Sub 2**, **Sub 3** and **Sub 4** channels of the **Optimized** configuration. Choose manual scaling for the y axis and name the traces **Sub 1**, **Sub 2**, **Sub 3** and **Sub 4**. You can also try the step of doing a filter report for the **Optimized** configuration. That exercise has been worked out and can be found in the **tutorial_4_prefab.msop** in the **Sample Projects** sub-folder of the tutorial.

Supplying Information About Your AVR

MSO allows you to enter information about your AVR or preamp/processor, which enables MSO to incorporate the AVR's distance and gain adjustment capability into the overall calculation of gain and delay parameters. For instance, if the optimum delay of some sub channel is negative, this is unrealizable in DSP circuitry, but can easily be accommodated in the AVR by increasing its distance setting relative to the as-measured condition and adjusting the other sub delays accordingly..

To enter your AVR information, choose **Tools**, **Application Options** from the main menu, then select **Hardware** in the Application Options dialog. Check the **System uses AVR or pre/pro with sub out** checkbox. The dialog will appear as below.

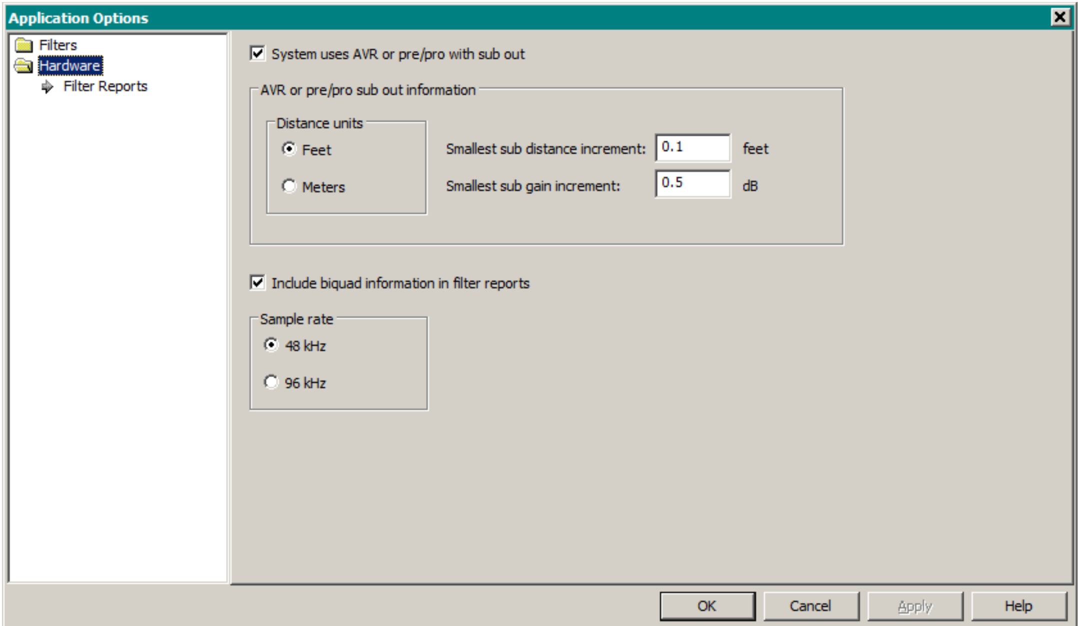


Figure 36: Configuring the AVR settings

Enter the appropriate distance units and increment, along with the sub out gain step in dB (usually 0.5 dB). The actual distance settings of the AVR usually depend on both its make and model as well as its setup options. For this reason, it makes sense to double-check the AVR's setup before entering the data here.

Getting Additional AVR Settings From the Filter Report

Entering AVR information into the Application Options enables an additional feature in the filter reports. To see this, open up **tutorial_4_prefab.msop** and save it as **tutorial_4.msop**. Select the top-most node of the **Optimized** configuration and choose **Show Filter Report**. Scrolling down to the bottom of the report reveals additional information as follows.

```
Final gain and delay/distance settings:
Increase AVR sub out trim gain by 1.5 dB
Sub Channel 1 gain: -5.6301 dB
Sub Channel 2 gain: -0.0673176 dB
Sub Channel 3 gain: -14.0948 dB
Sub Channel 4 gain: -4.23466 dB
Decrease AVR sub out distance by 3 feet
Sub Channel 1 delay: 12.346 msec
Sub Channel 2 delay: 4.53837 msec
Sub Channel 3 delay: 4.46217 msec
Sub Channel 4 delay: 0.0462191 msec
```

MSO configures the gain of each DSP channel to be 0.0 dB or less, to prevent the possibility of internal digital overload. In addition, the imprecision of the 0.5 dB gain step of the AVR is made up for by adjusting the individual channel gains, which are assumed to have a finer gain step size than that of the AVR. A similar situation holds for the delay. If negative delays are present in the delay blocks, they will be absorbed into the AVR setting by means of an increase in the sub distance. In this case, no negative delays are present, so the sub distance undergoes a net decrease.

Improving Response Flatness at the Main Listening Position

The corrected responses of Figure 29 show improved frequency response flatness for all listening positions compared to the uncorrected responses of Figure 30. Yet the response at the main listening position may not be as flat as you would like it to be. Since one side effect of adjusting the individual channel EQs is to reduce the seat-to-seat variation in frequency response, altering these individual EQ settings is not a good way to flatten the response at the main listening position any further. Instead, a better idea is to keep the existing individual channel EQs and add shared filters that affect the responses of all subs simultaneously so that the seat-to-seat variation of the frequency response is not affected. Keep in mind that in doing so, the flatness of the frequency response at positions other than the main listening position may be degraded relative to Figure 29, as was mentioned earlier in the tutorial when discussing the pitfalls of shared EQ. However, should you choose to use this technique, MSO gives you the needed tools.

To perform this task, you'll clone the **Optimized** configuration of **tutorial_4.msop**. Open up **tutorial_4.msop** and in the **Config View**, select the root node of the **Optimized** configuration (the node labeled "Optimized" just underneath **Configurations**). Right-click and choose **Clone Configuration** from the context menu. This will create a new configuration called **Config 3**. Rename it to **MLP Cleanup**. Right-click on **MLP Cleanup** and choose **Lock All Filter Parameters of this Configuration**. This will prevent the optimizer from changing the individual subwoofer EQ settings. You'll see that the icons for all the filters in this channel are dark gray in color. You'll want to add some shared sub filters and run a new optimization on **MLP Cleanup** so that only the parameters of these shared filters are adjusted.

Using Plot-Only Measurement Groups

Before adding shared sub filters, the optimization parameters must be changed so that only the **MLP** response is optimized for flatness, and not any of the other listening positions. One way to do this would be to remove all the measurement groups except **MLP**. However, this would have the undesired side effect of disallowing the ability to graph the frequency responses of the other three listening positions, at least while the optimization is being run. To solve this problem, you can instead make all the measurement groups not associated with the **MLP** into *plot-only measurement groups*. Such measurement groups can be plotted, but are not used as optimization criteria.

Locate the measurement groups of the **MLP Cleanup** configuration. Select the **Pos 2** measurement group, right-click on it and choose **Properties** from the context menu. In the resulting dialog box, check the checkbox labeled **For plotting only: do not optimize**. Click **OK**. The icon for the **Pos 2** measurement group will turn gray, indicating it is a plot-only group. Repeat the process for the **Pos 3** and **Pos 4** measurement groups. The measurement groups for **MLP Cleanup** should look as below.

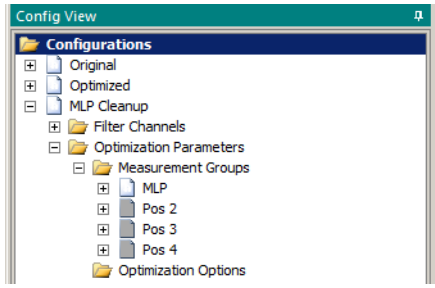


Figure 37: After making non-MLP measurement groups plot-only

Using the Rearrange Gains and Rearrange Delays Features

In the next section, you'll be adding some PEQ filters to the **Shared Filters** of the **Subwoofer Channels**. These filters will only affect the subs, not the main speakers. In addition to altering the frequency response magnitude of the combined sub outputs, they will also change the phase of this frequency response. Since the main speakers aren't affected by this change, it follows that the shared PEQs will change the relative phase between mains and subs from the previously-optimized condition. To fix this, you'll need a shared delay. Likewise, the PEQs you'll use will be limited to response cuts, not boost. It's reasonable to expect that because of these response cuts, a shared gain boost will be needed for the subs to get the best flatness of the combined response of subs and main speakers. Taking delay as an example, you can see that the configuration of delays in the four sub channels of the **MLP Cleanup** configuration looks conceptually as below.

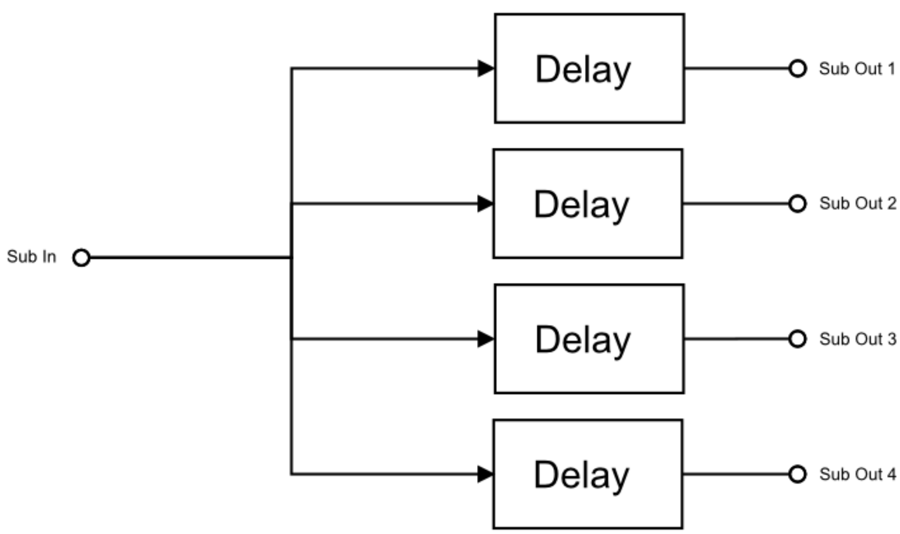


Figure 38: Delay configuration before rearrange

We'd like to add a shared delay, making the new configuration as below.

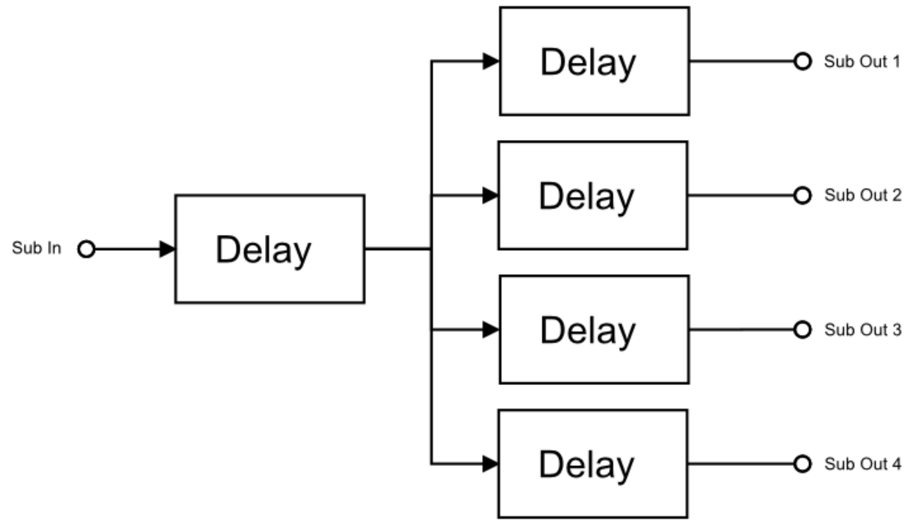


Figure 39: Disallowed delay configuration

The delay configuration of Figure 39 is conceptually correct, but disallowed in MSO. This is discussed in the MSO Reference. Briefly, if the configuration of Figure 39 were allowed, it would be possible to set the **Optimization allowed** property of all five delays to **True**. This would have the effect of causing the optimizer to explore an infinite space of redundant solutions when an optimization is run. The optimizer would “chase its tail” so to speak. To prevent this, a delay configuration similar to the figure below must be used.

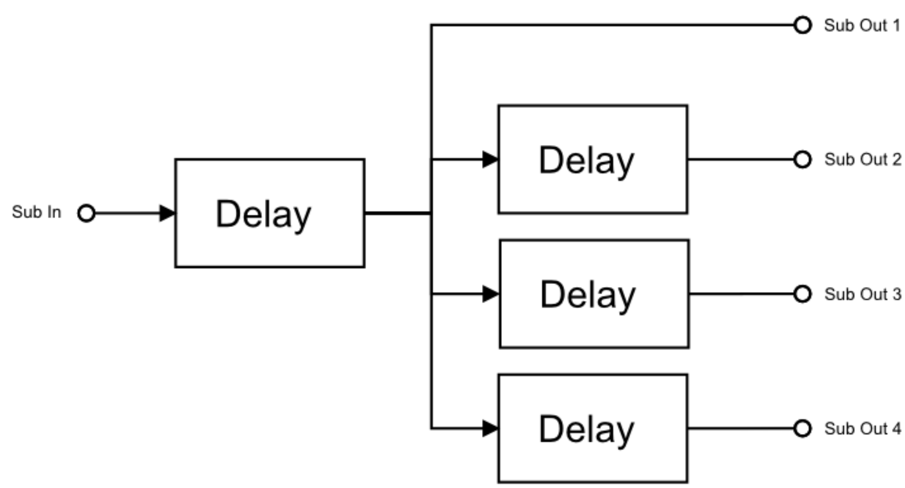


Figure 40: An allowed delay configuration using a shared delay

In practice, it's not necessary for the channel without delay to be the first one as in the figure above. The individual channel with the smallest delay in Figure 38 ends up with no delay in the configuration of Figure 40. It should be clear that in going from the configuration of Figure 38 to that of Figure 40 to set up the project to optimize the **MLP** response flatness would involve some tedious calculations and shuffling of the delay blocks. An exactly analogous procedure would have to be done with the gain blocks too. MSO can do this in one step for each of the gain and delay configurations via the **Rearrange Delays** and **Rearrange Gains** commands respectively.

Locate the **Subwoofer Channels** node under the **MLP Cleanup** configuration. Observe that there are initially no shared filters of any kind. Right-click this node and select **Rearrange Delays** from the context menu. You'll notice that there is now a delay block under **Shared Filters**, and the delay block of **Sub Channel 4** is now gone. All the delays have been recalculated to give a net delay for each sub channel that is exactly equivalent to the previous condition.

Right-click on the **Subwoofer Channels** node and choose **Rearrange Gains** from the context menu. A gain block appears under **Shared Filters**, and the gain block of **Sub Channel 2** is now gone.

These shared gain and delay blocks were not newly created, but are existing blocks that have been relocated to the **Shared Filters** and had their **Value** parameters suitably altered. Since all filter parameters were previously locked (that is, the **Optimization allowed** properties of all their parameters were set to **False**), the shared gain and delay blocks retain this setting and will need to be unlocked. This can be seen via the gray color of the icons for FL14 and FL27. The fastest way to unlock the shared gain and delay blocks is to right-click on the **Shared Filters** node and choose **Unlock Shared Sub Filter Parameters** from the context menu. You can verify that the change took place by observing that the color of the corresponding filter icons is now white. The **MLP Cleanup** configuration should now look as below. The individual sub channel nodes have been collapsed for clarity.

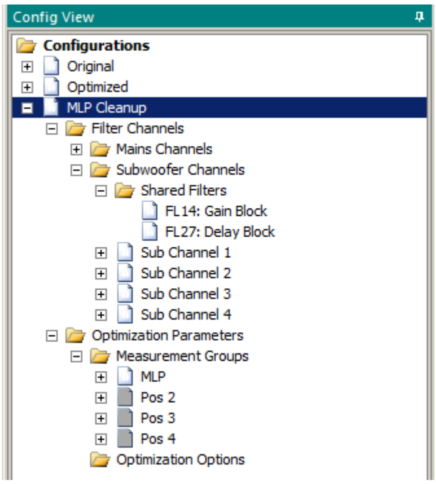


Figure 41: After rearranging delays and gains

Successive applications of the **Rearrange Delays** command just toggle between the delay configurations of Figure 38 and Figure 40. **Rearrange Gains** behaves similarly.

Using Shared Sub Filters, Delays and Gains

Now that you have shared gain and delay blocks, you can add the shared PEQ filters. In the **MLP Cleanup** configuration, right-click the **Shared Filters** node under **Subwoofer Channels**. Choose **Add Parametric EQ** from the context menu. Repeat this operation until six shared PEQs have been added.

Tweaking the Optimization Options

Since the previous optimization has flattened the frequency response well, it can be beneficial to alter the frequency range over which the level reference is computed for the next optimization. You'll change those options next.

From the main menu, choose **Tools**, **Optimization Options**, then choose **MLP Cleanup**. In **Criteria**, change **Frequency range to compute reference**, specifying a minimum frequency of 25 Hz and a maximum frequency of 200 Hz. Click **OK**.

Making a Graph for the New Configuration

Using what you learned before about making graphs, create a new graph whose traces are the four measurement groups of the **MLP Cleanup** configuration. Set the graph title to "MLP Cleanup Combined Response SPL vs. Frequency" and enable the legend. Set the y-axis to manual scaling with minimum and maximum values of 45 dB and 120 dB respectively. Set the graph name in the **Data View** to "MLP Cleanup Combined Responses" and make each trace name the same as its corresponding measurement group name. The graph information should show up in the **Data View** as below.

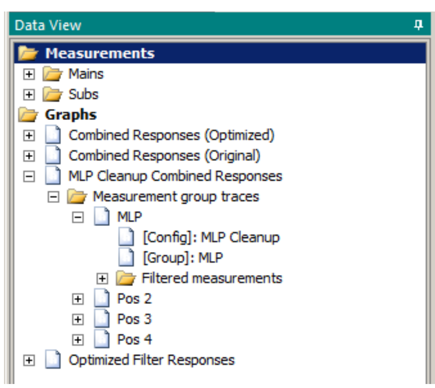


Figure 42: Graph settings for final MLP cleanup

Save your results as **tutorial_5.msop**, then run the optimization, saving the results again afterward. The results of the optimization are shown below, and can be found in the MSO project **tutorial_5_prefab.msop**.

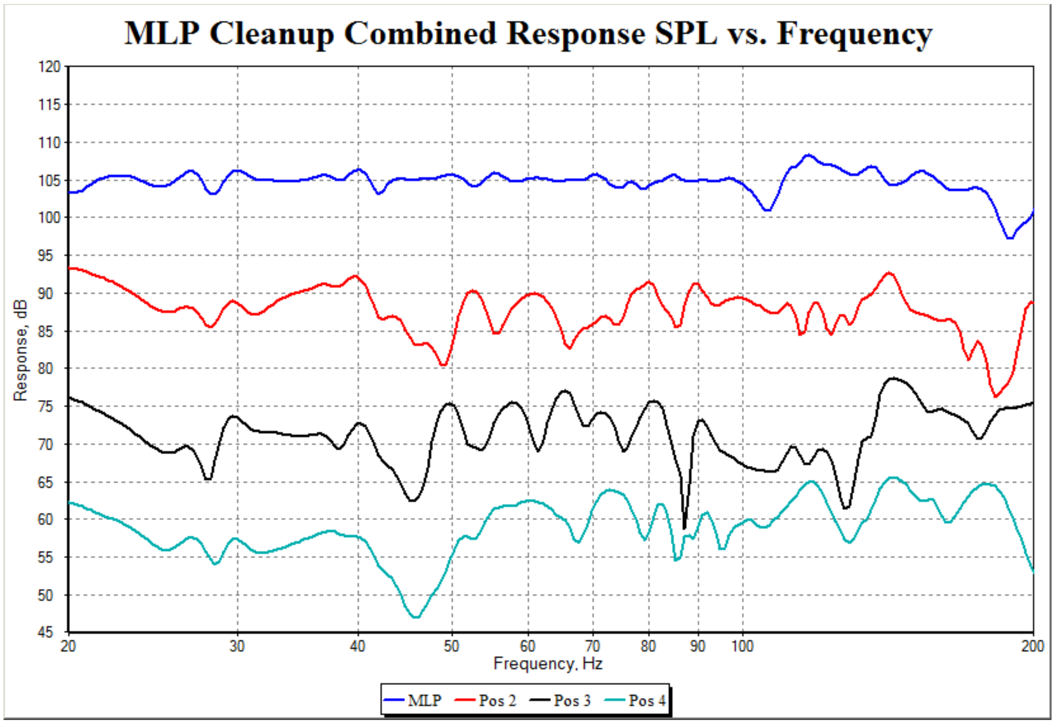


Figure 43: Optimization results of MLP cleanup

Summary of Results

A graph of the frequency response data before any optimization is repeated below, showing large deviations from flat response and large seat-to-seat variation.

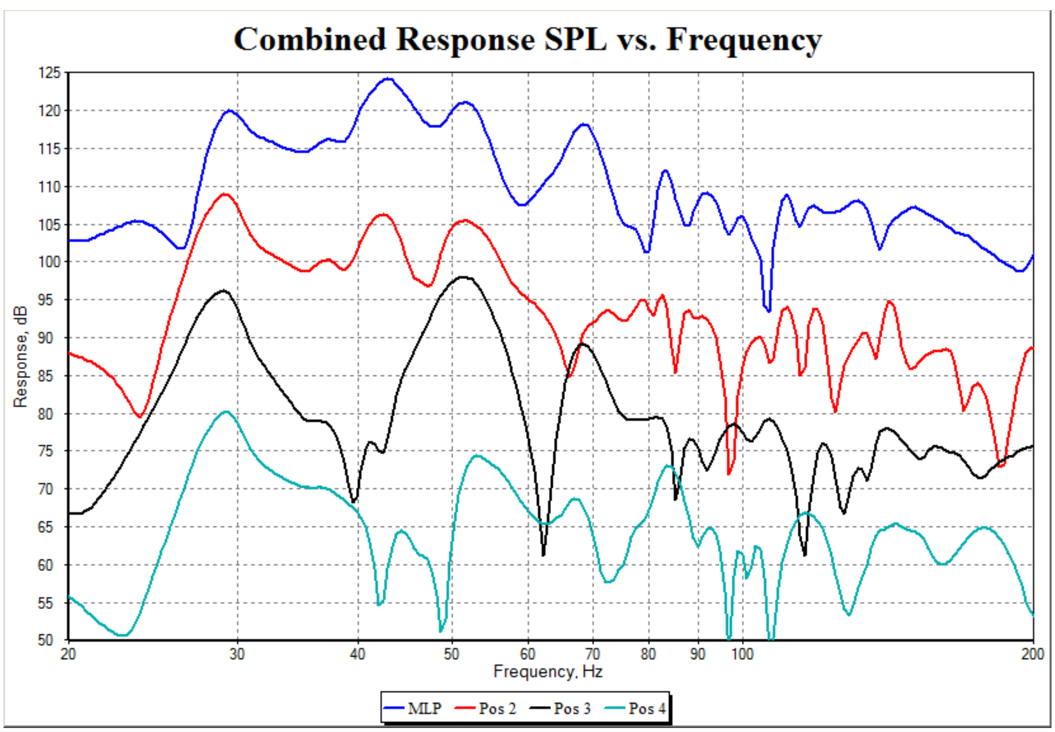


Figure 44: Combined responses before optimization

The results after the first optimization as performed in the **tutorial_4_prefab.msop** in the **Sample Projects** sub-folder of the tutorial are shown below.

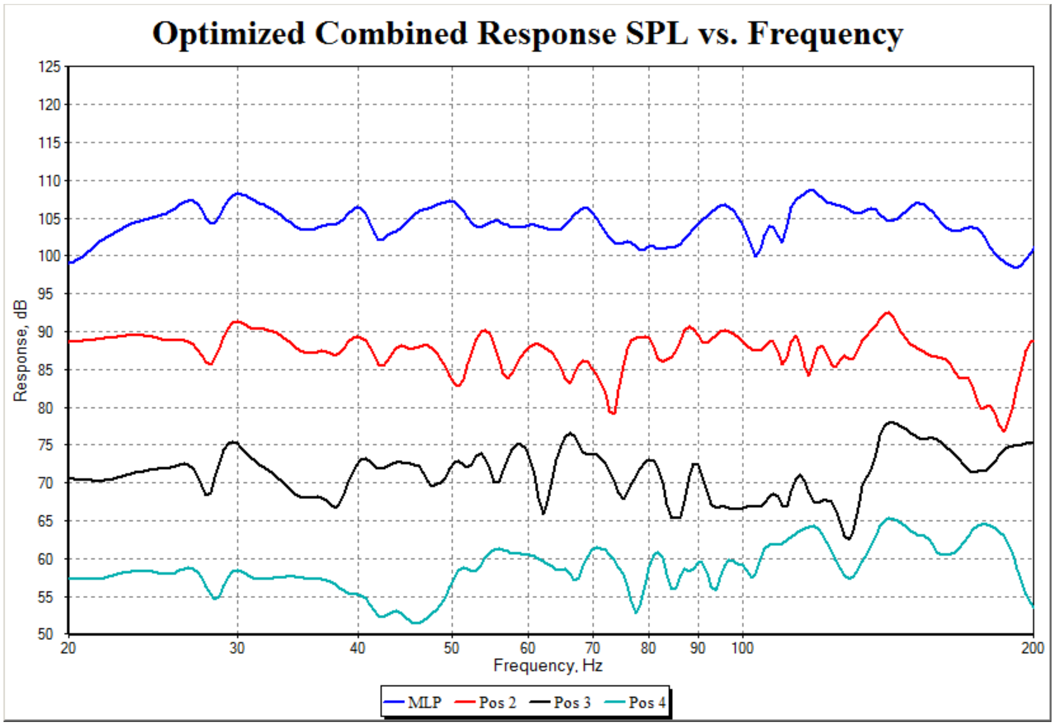


Figure 45: Combined responses after first optimization

You can see clear improvements in both overall flatness and response variation from seat to seat.

The filter responses to achieve this result are shown below.

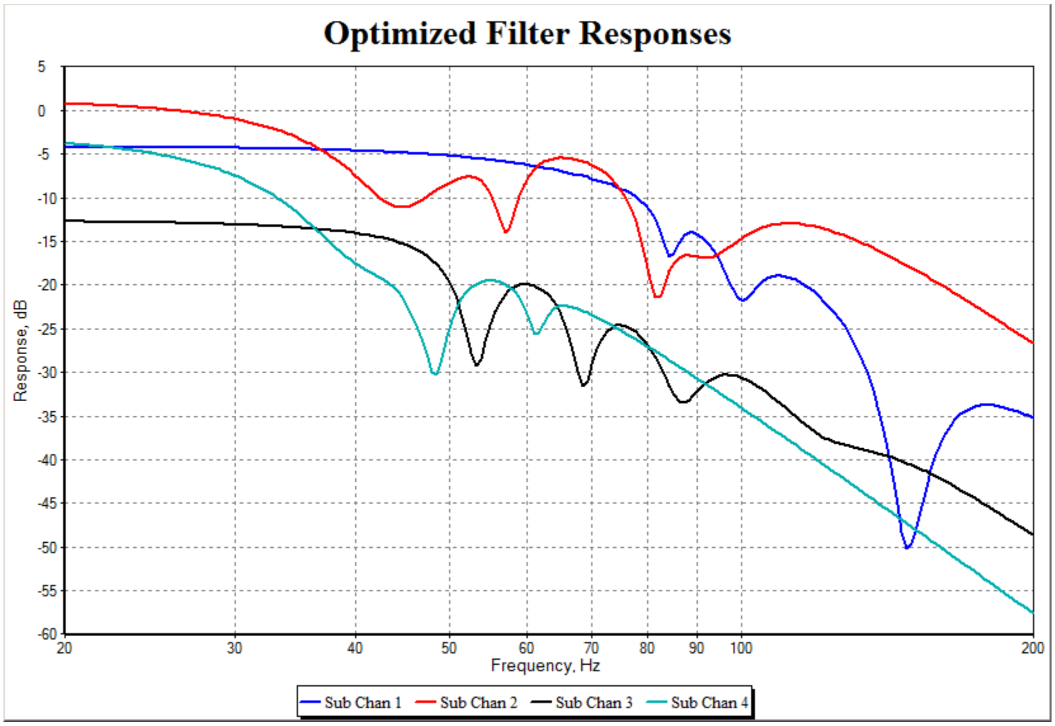


Figure 46: Filter responses after first optimization

No boosting is done in any of the PEQ filters.

Next, the MLP response was made as flat as possible using the following steps.

- Clone the **Optimized** configuration, renaming it **MLP Cleanup**.
- Lock all the filter parameters of the **MLP Cleanup** configuration.
- Use **Rearrange Gains** and **Rearrange Delays** to make a shared delay block and gain block available in the **MLP Cleanup** configuration.
- Unlock the parameters of just the shared gain and delay blocks.
- Add six PEQ filters to the **Shared Filters** of the **Subwoofer Channels** of **MLP Cleanup**.
- Make all measurement groups except the MLP plot-only in **MLP Cleanup**.
- Re-run the optimization.

This gives the results shown below.

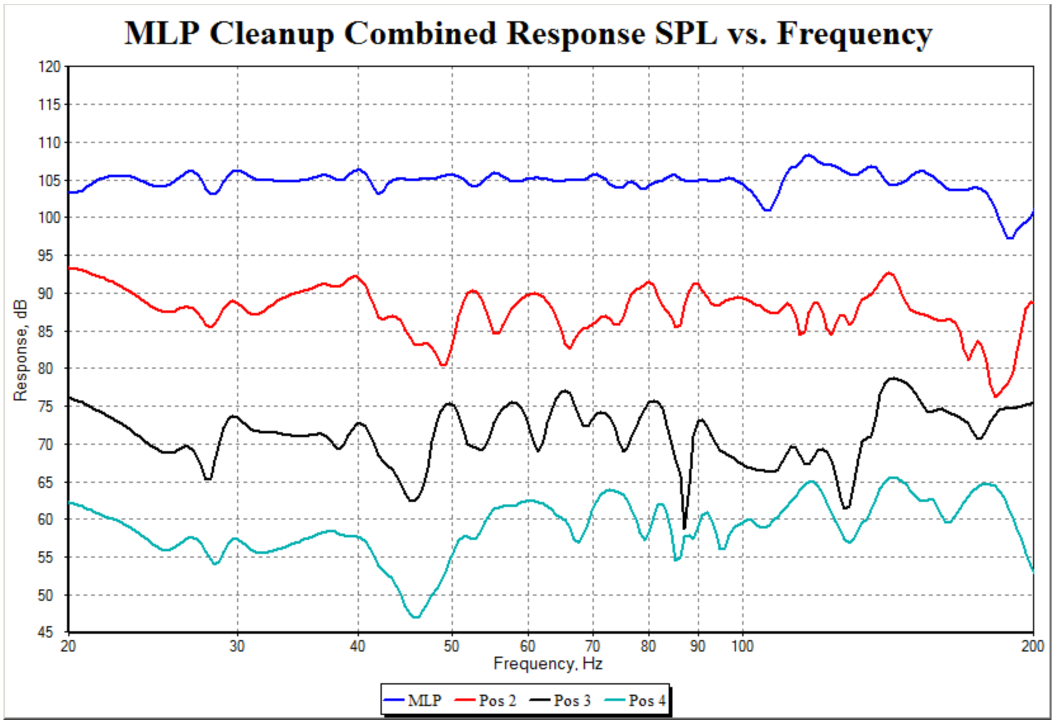


Figure 47: Optimization results of MLP cleanup

It is interesting to compare the final gain and delay settings of the first optimization and the final one. After the first optimization, the following results were obtained.

```
Final gain and delay/distance settings:
Increase AVR sub out trim gain by 1.5 dB
Sub Channel 1 gain: -5.6301 dB
Sub Channel 2 gain: -0.0673176 dB
Sub Channel 3 gain: -14.0948 dB
Sub Channel 4 gain: -4.23466 dB
Decrease AVR sub out distance by 3 feet
Sub Channel 1 delay: 12.346 msec
Sub Channel 2 delay: 4.53837 msec
Sub Channel 3 delay: 4.46217 msec
Sub Channel 4 delay: 0.0462191 msec
```

Here are the results after the final optimization.

```
Final gain and delay/distance settings:
Increase AVR sub out trim gain by 9.5 dB
Sub Channel 1 gain: -5.89511 dB
Sub Channel 2 gain: -0.332327 dB
Sub Channel 3 gain: -14.3598 dB
Sub Channel 4 gain: -4.49967 dB
Increase AVR sub out distance by 12.4 feet
Sub Channel 1 delay: 12.3516 msec
Sub Channel 2 delay: 4.54393 msec
Sub Channel 3 delay: 4.46773 msec
Sub Channel 4 delay: 0.0517806 msec
```

The AVR sub out gain of the final optimization is 8 dB higher than the first one. The AVR sub distance of the final optimization is a surprising 15.4 feet greater than the first optimization. This is probably due to the added phase shift of the shared PEQ filters used in the final optimization.

It's not completely clear whether the final effort to flatten the MLP was worth the side effects. Though the final MLP response is much flatter than in the first optimization, the listening positions other than the MLP have been made slightly worse.