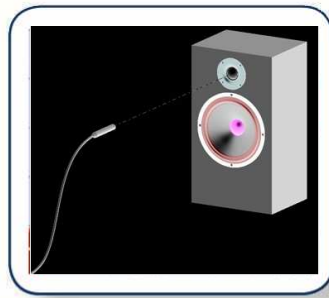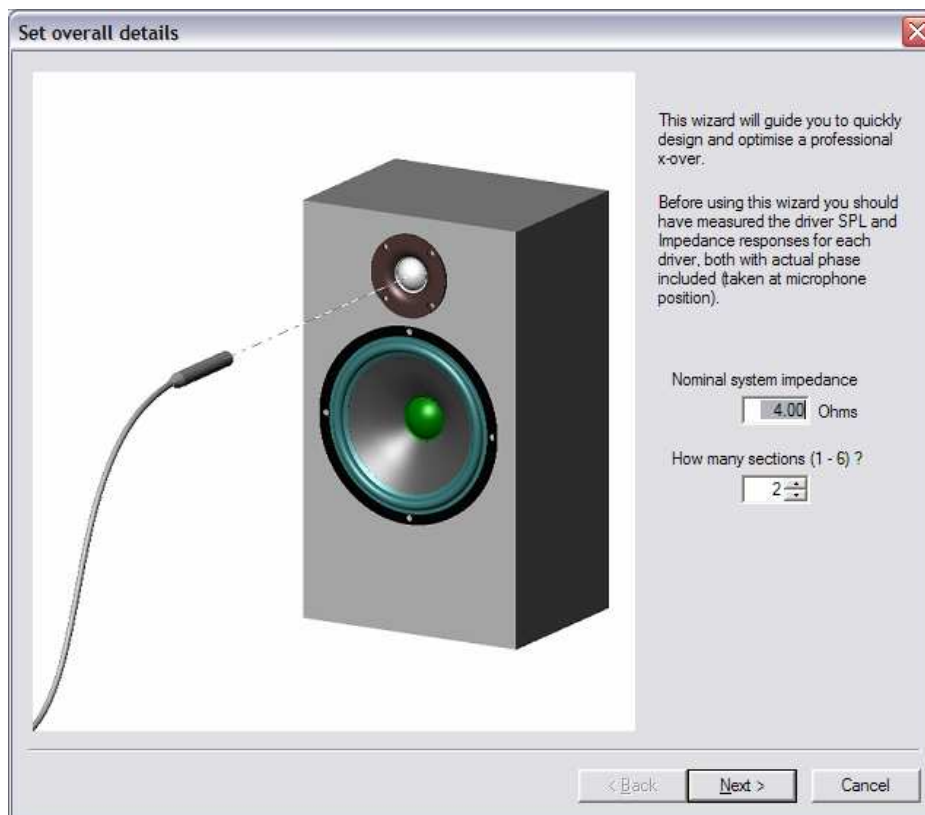# FINE X-over™

X-over Design

Tutorial

In this tutorial we show several examples of simple and advanced X-over designs, using FINE X-over.

In the first example we create the x-over for two drivers we have previously measured in our cabinet. Press New to get the Wizard, which will guide you to design the best possible x-over for your system.

Figure 1. Wizard Start

We have the option to import measured files from FINELab (.lab) and FINECone (.FSIM) and a number of systems like MLSSA, LMS, CALSOD, Sound-check etc. Here we use MLSSA files as *.FRQ and *.TXT.

The two drivers are measured in the cabinet as shown on the sketch. We have placed the microphone in the listening position (usually in line with the tweeter) and in the preferred 2-3m distance. Then we have measured the woofer response and also exported as *.txt files (Actual + BODE Plot in MLSSA). The tweeter is done the same way, with the microphone in the SAME position. Finally we measured the impedance from 20-20kHz for both drivers

Choose the nominal system impedance, normally 4 or 8 ohms (mostly determined by the woofer) even 1 ohm or 0.5 ohm is possible. This is used for initial x-over calculations and for minimum impedance calculation. We will set the nominal impedance to 4 ohms (min impedance is therefore 4 ohms-20% =3.2 ohms). We choose 2 sections (2-way) as we have two drivers.

Press Next. Open SPL to load the file you had previously measured: SKO130-SPL.txt, and Open Imp. to load the impedance file SKO130-Imp.FRQ, see Figure 3. You can click the file to preview and check that you have selected the correct curve (Fig. 2).

Note the vertical line ——Target level. This is the level we want to optimise the system to. You can drag the line up/down by the left mouse button, or overwrite the number (90.3 dB). We have chosen the flat level above 200Hz for the woofer, because this is close to the maximum level we expect to get out of the total system. We will consider off-axis SPL files later.
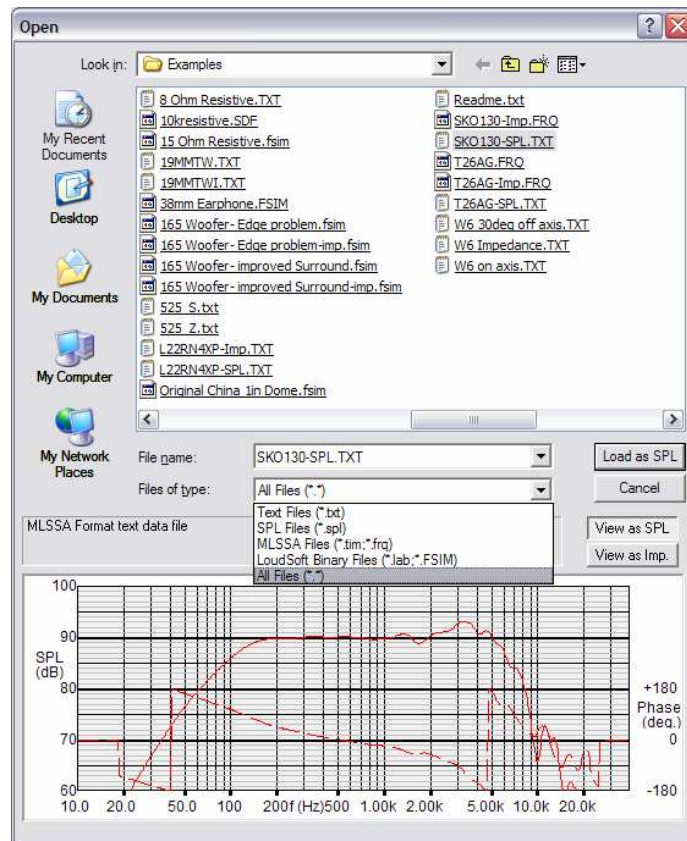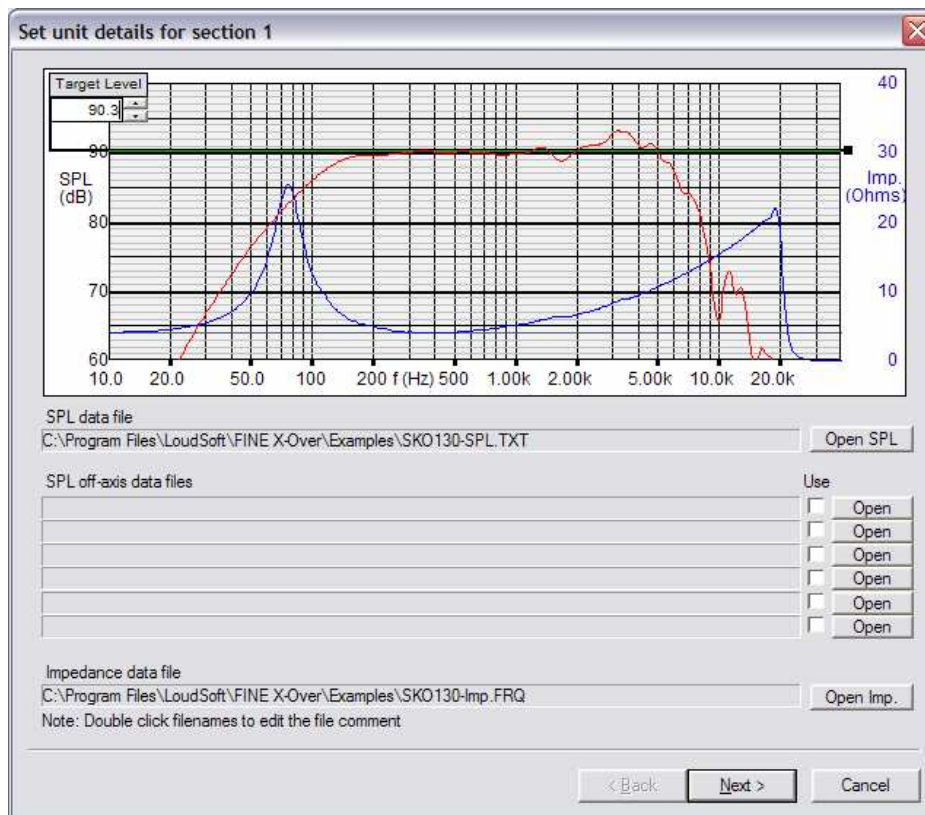
Figure 2. File Preview

Figure 3. File load

Press next to load the tweeter the same way. This time we use the measured T26AG.frq file directly without exporting to txt-format. Let us keep the 90.3dB target level also for the tweeter.
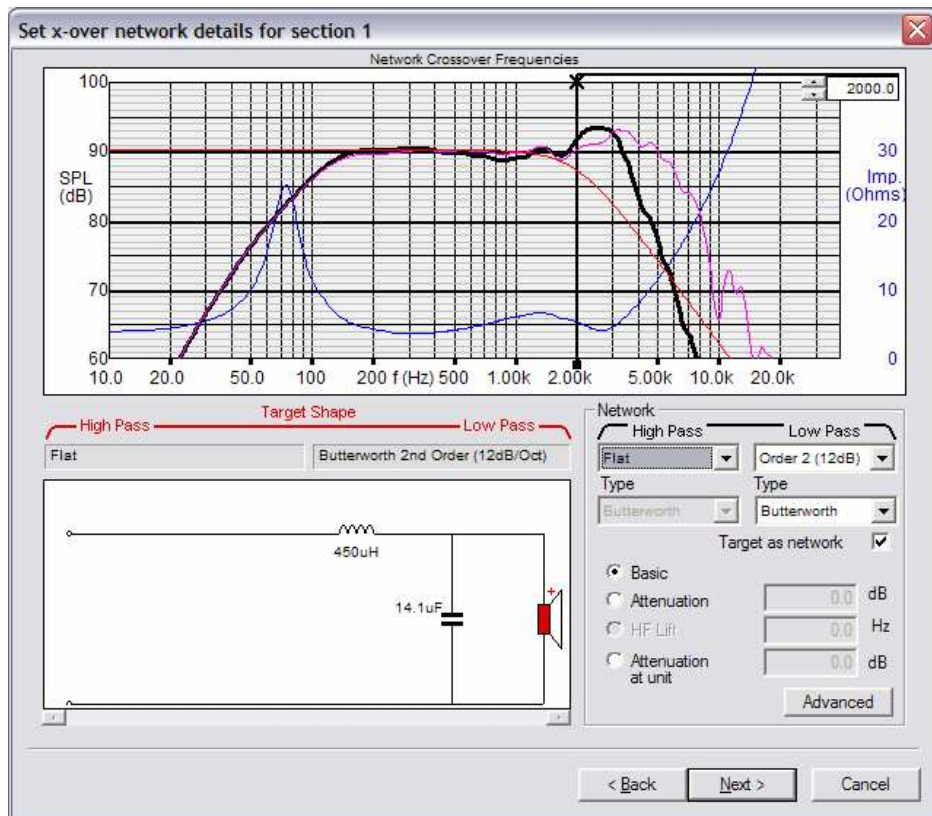
Figure 4. Target response

Now is the time to select the x-over type and Target frequency response. Figure 4 shows the first section - woofer (LF). We may chose Butterworth (Linkwitz-Riley, Chebyshev and Bessel are also possible) type and 1st Order (6dB/Oct) up to 4th Order (24dB/Oct). The black vertical x-line shows the chosen x-over frequency, and we have selected 2nd order (12dB/Oct) Butterworth at 2000Hz. You can drag the X-line by the left mouse button, while observing the filtered section response change.
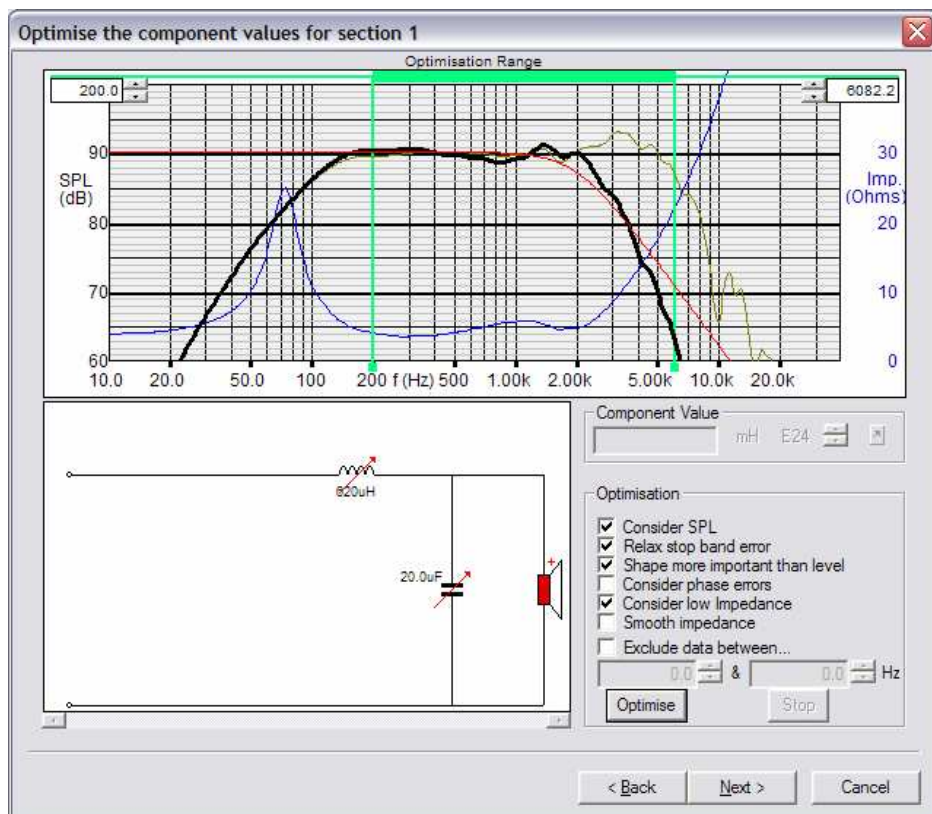

Figure 5. Optimise section 1

The next screen is the 1st (woofer) section Optimiser, Fig 5. Let us optimise the x-over components to the target 2nd order Low Pass response (red———), while keeping a minimum impedance of 4 ohms -20%=3.2 ohms (according to the common IEC 60268-5 standard). We observe that the inductor (L) and capacitor (C) already are marked for optimisation, by the red arrows.

The chosen optimising range is shown between the two green lines, which can be dragged as before. It is important select the start at 200 Hz above the woofer resonance where the response is almost flat (if the first green line is too low the optimisation gets bad). The upper limit is set by default to two times the x-over frequency (=4000 Hz), which we drag to 6082.2 Hz to include the top end.

Observe the Optimisation settings on the right side: "Consider SPL" and "Relax stop band error" are selected by default. We could select "Shape more important than level" because that may help the optimiser to find a good response at a higher SPL level. Further "Consider low impedance" is set to avoid getting lower than minimum impedance.

Now we press "Optimise" and see the optimised response in a few seconds.
The next screen Fig. 6 shows the target response for the 2nd (tweeter) section with the already chosen x-over frequency (2000 Hz) marked. We have chosen attenuation (3 dB by resistors), because the tweeter sensitivity is above the target.
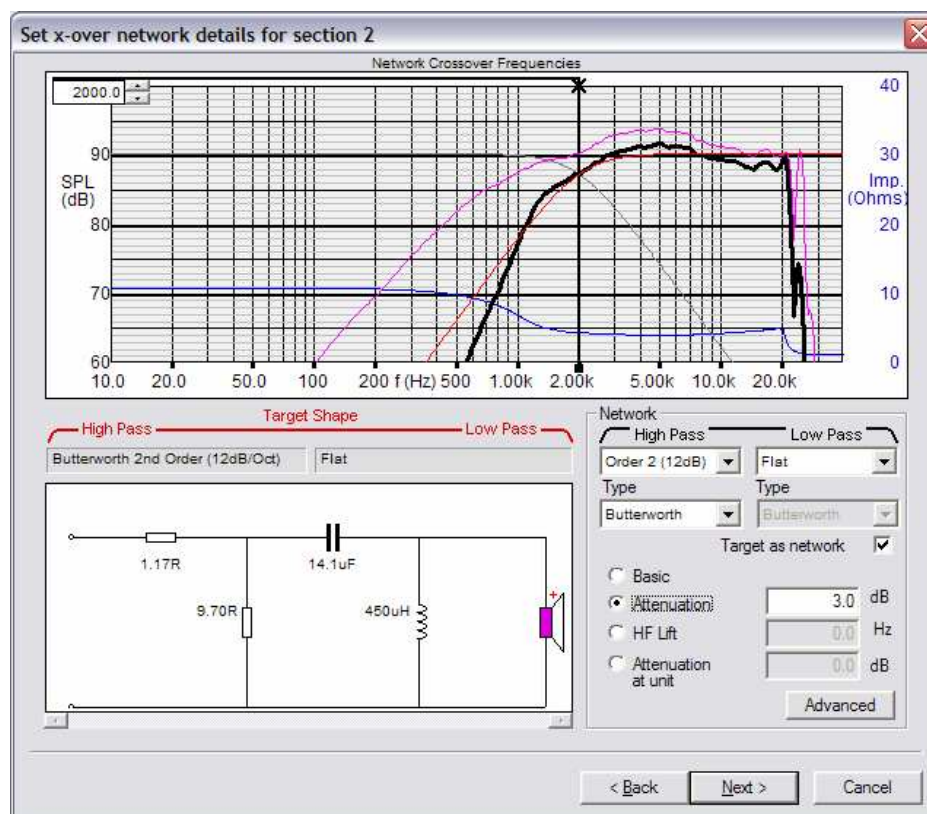

Figure 6. Target tweeter response

Fig. 7 shows the HF (Tweeter) optimising range is set from 1000 to almost 20 kHz, because we want to include the top end response without exceeding the limit in the impedance response at 20 kHz,

If you want to keep any of the components as a fixed value, just double click and the red arrow (=variable) is removed.

After pressing "Optimise" we see the optimised HF/ Tweeter response is quite close to the target. The Wizard is now finished.

See the total response in the main window with the optimised sections. This response is quite flat already, however we should use the System Optimisation to obtain an even better total response.
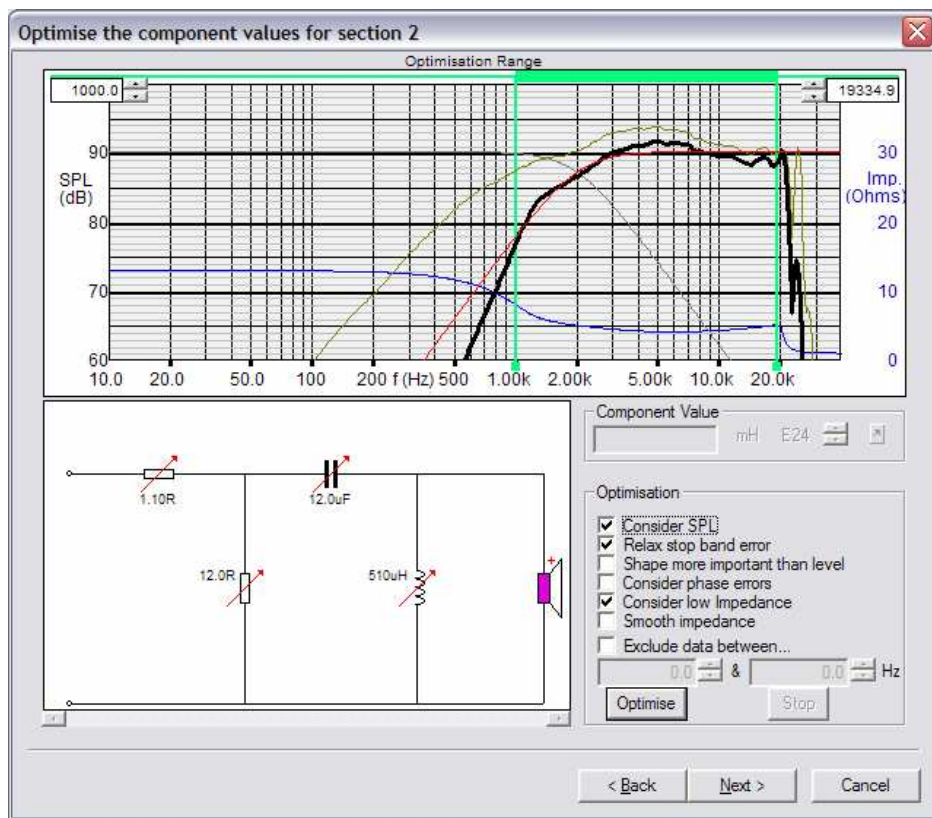
Figure 7. Optimised HF section

The optimisation range is set as the "flat" part of the total response. However we have deselected "Shape more important than level" because we are interested in the absolute best and flattest response.

The final optimised response in Fig. 8, is flat within +/-1.0 dB from 150-20kHz. The minimum impedance is above the limit (3.2 ohms) 20-20kHz. The resistor of 1Mohm is redundant and can safely be removed.

**Figure 8. Final optimised response w. acoustical and Impedance Phase**
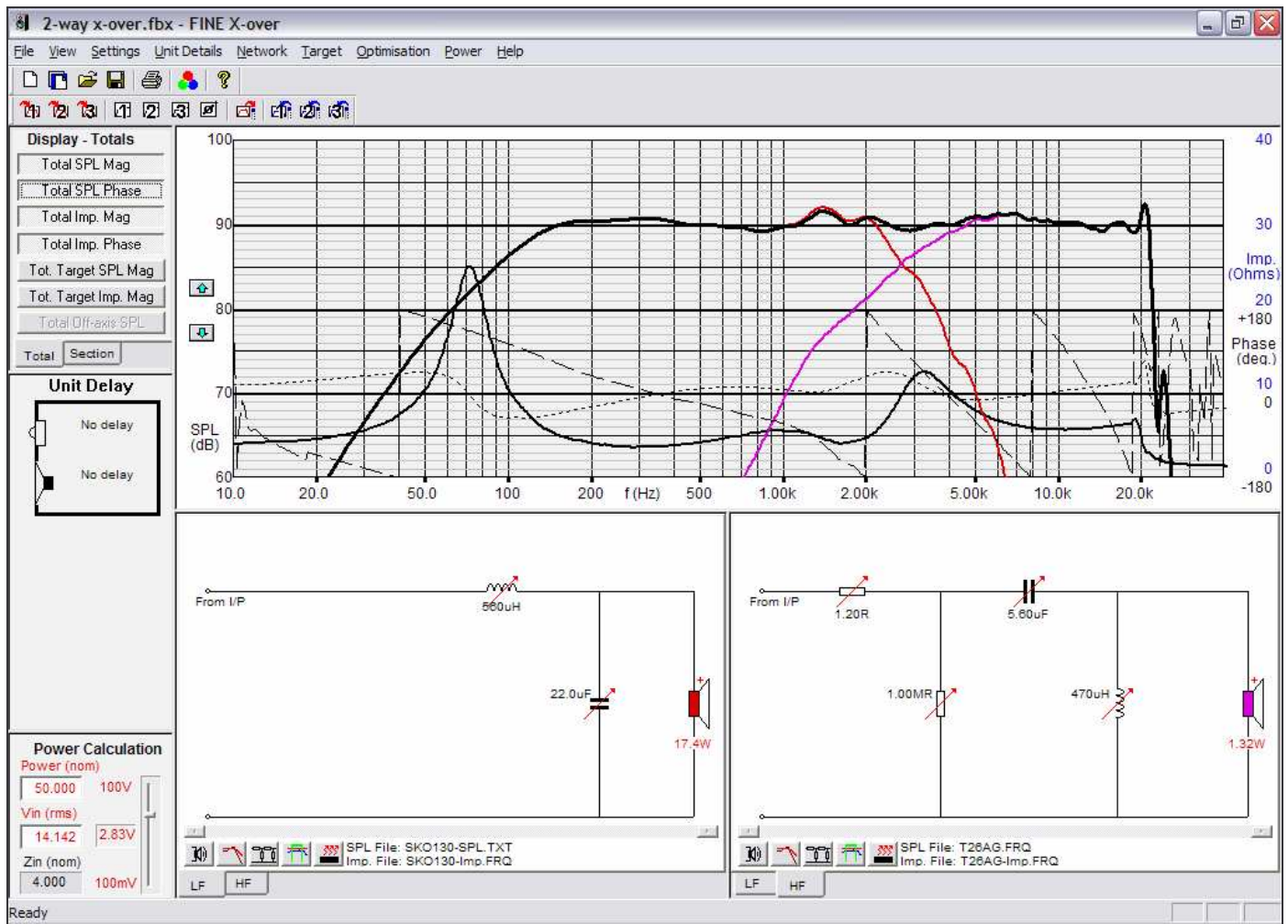
The power in the woofer (LF) and tweeter (HF) is shown under the driver symbols with red numbers, 17.4W and 1.32W respectively, for 50W RMS input (IEC 60268-1: Simulated Music).

Note you can always change component values by clicking (left mouse button), and you will get the edit menu shown in the lower right corner. Change (standard E24/E12...) values by rolling the mouse wheel up/down or use the arrow keys in menu or keyboard.

Press Total SPL Phase and Total Imp Phase to view the acoustical and electrical phase responses, see Fig. 8. The acoustical phase (-----) is quite linear and the electrical phase (……) is well behaved within +/- 45deg up to 20 kHz.

You may save the total response for later in user memory or as a file using the button bar:
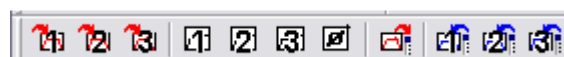
Import of FSIM files from FINECone

The new versions of FINE-programs can both export and import responses in the new compressed FSIM format. In other words it is possible to simulate and solve response problems without having to build any samples.

The next Fig. 9 shows the imported woofer simulation from FINECone of a bad 165mm woofer with a big dip at 1300Hz. This dip cannot be avoided with the x-over, also because the tweeter cannot go so low without getting too high power. (>2.26W)
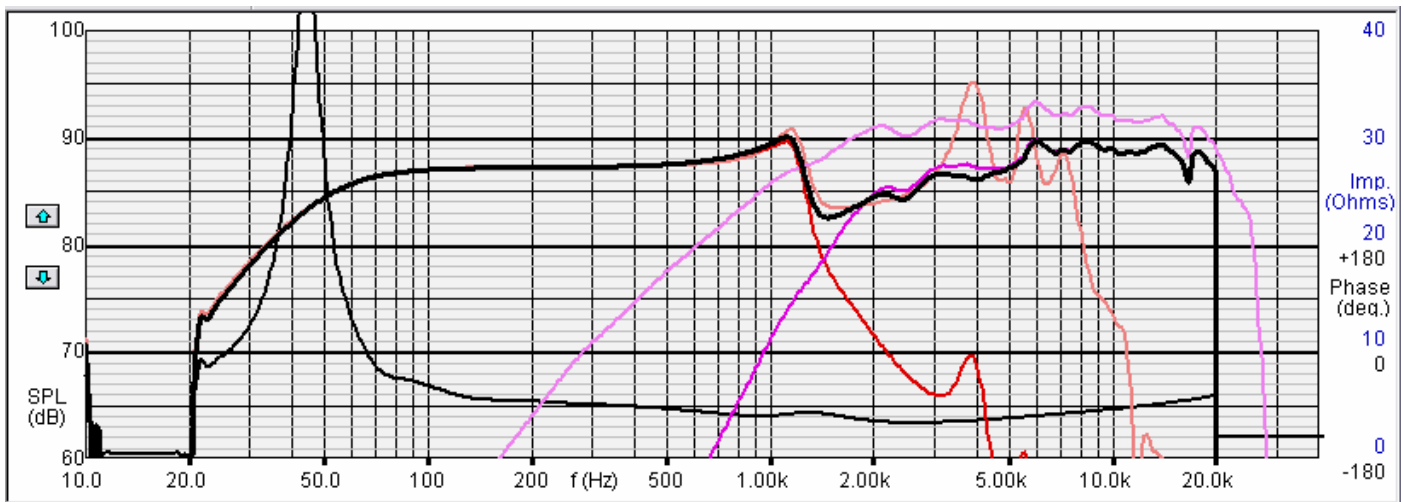

Figure 9. FINECone 165woofer response imported into FINE X-over as FSIM

FINECone was used to simulate a solution to the bad woofer response, and the improved woofer response was imported into FINE X-over, see Fig. 10. Now a good response can be achieved with a suitable X-over.

In addition we have simulated the effect of the **Baffle** on the response by the 72.1uF//2.2 ohms in series. The cabinet front baffle will lower the response level up to the actual frequency (1004 Hz), indicated by the grey pointer. (The grey response is without baffle simulation)
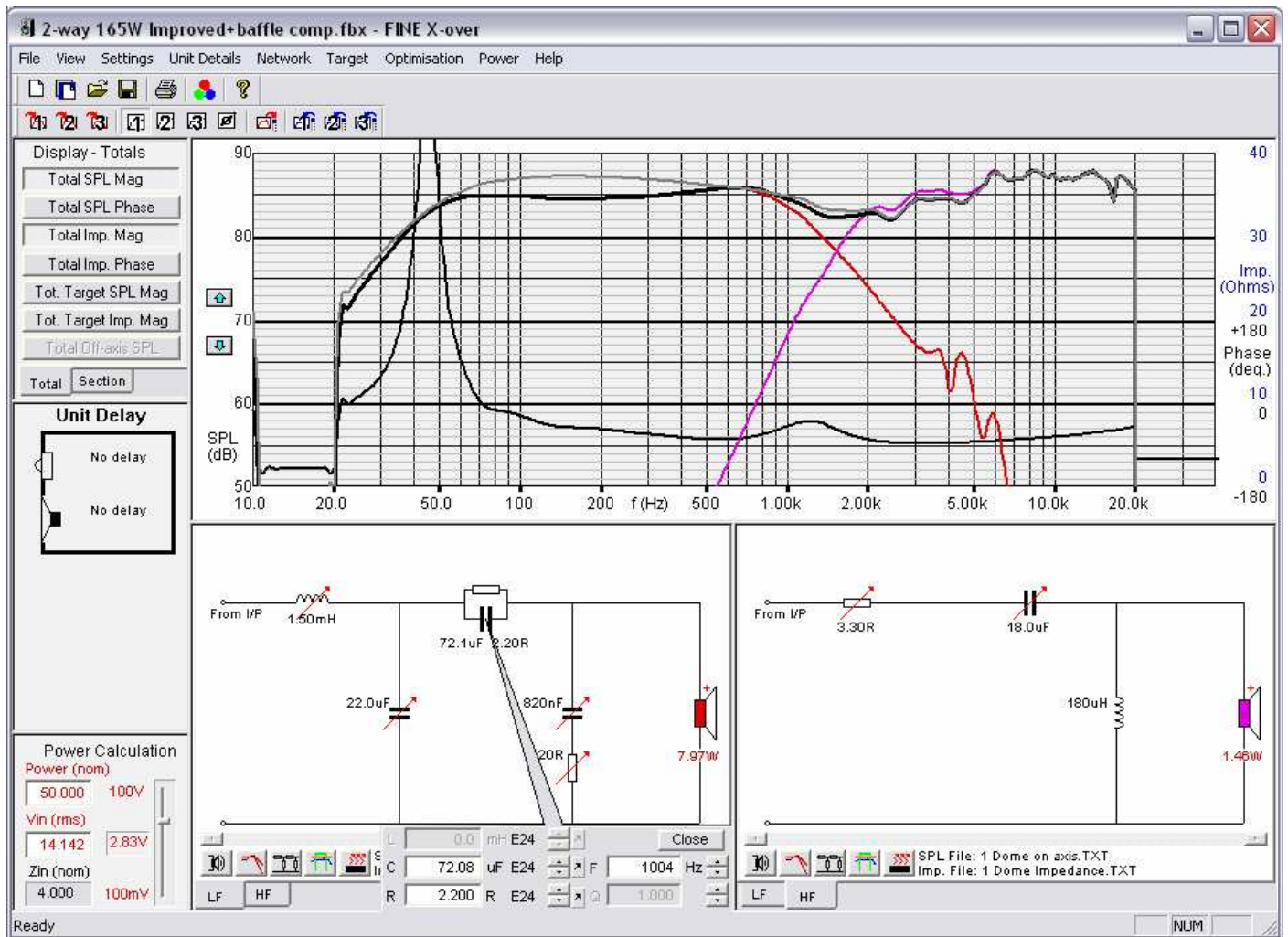
Figure 10. Simulated solution imported from FINECone + baffle simulation

Off-axis Response Examples

To achieve the highest quality speaker system design it is recommended to measure and optimise both the on-axis as well as off-axis responses. This is possible in FINE X-over, see the following 2-way speaker system in the next Fig. 11.
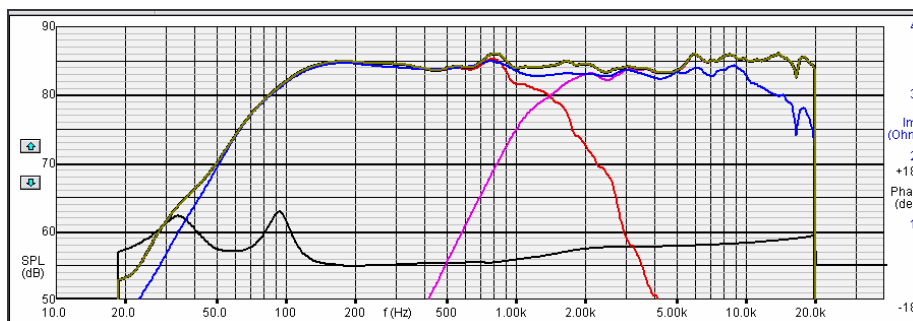

Figure 11. On and Off-axis curves calculated with X-over

The blue curve is the 30 degree off-axis response calculated with the same filter components as the on-axis response. Note that the peak at 6 kHz is hardly visible on the blue curve.

Recent Research in Acoustics has shown that it is most important to keep the off-axis responses smooth and controlled. Therefore it is interesting to optimise the off-axis curve(s) while keeping the on-axis curve in control. That is what we will do in the next example.
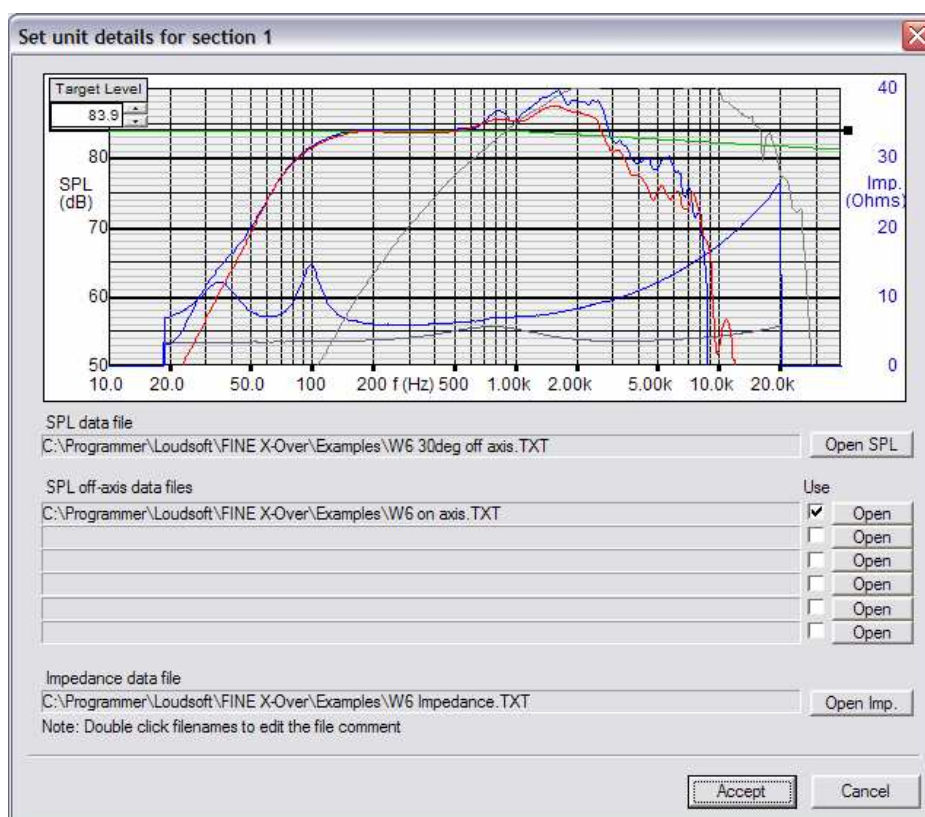

Figure 12. On and Off-axis curve import

In the curve import screen (Fig. 12) we do a little trick and import the OFF-axis curve first and secondly the on-axis response (which is normally used for the off-axis). We may even import up to 6 off-axis responses

However the off-axis response should not be flat as normal, but rather sloping gently downwards towards the high frequencies.

Go to the main menu and find "Target" and "System Target" in the drop-down box. Here we will modify the target (Fig. 13) to have a -0.5dB/oct slope starting at 1000 Hz.
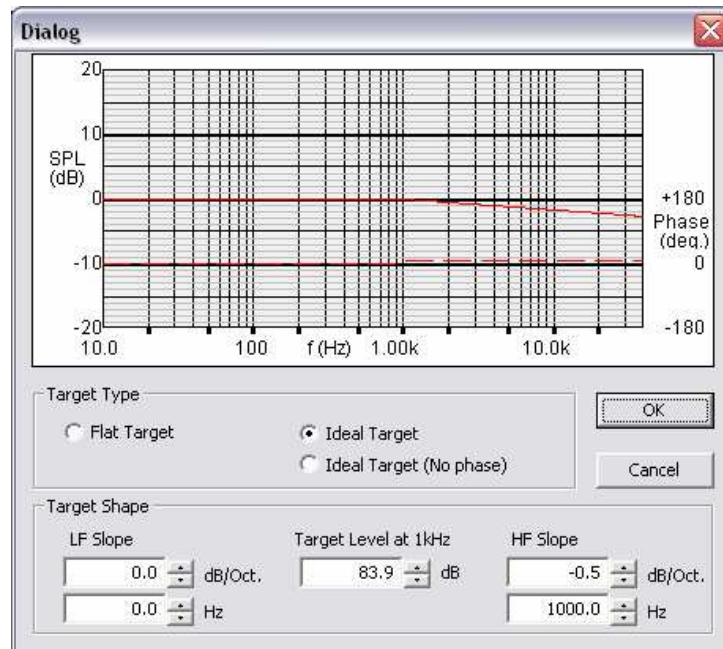

Figure 13. Sloping Target setting

Now we are able to optimise the **off-axis** response to the new sloping target, see Fig. 14. The off-axis response is now smooth and well-controlled
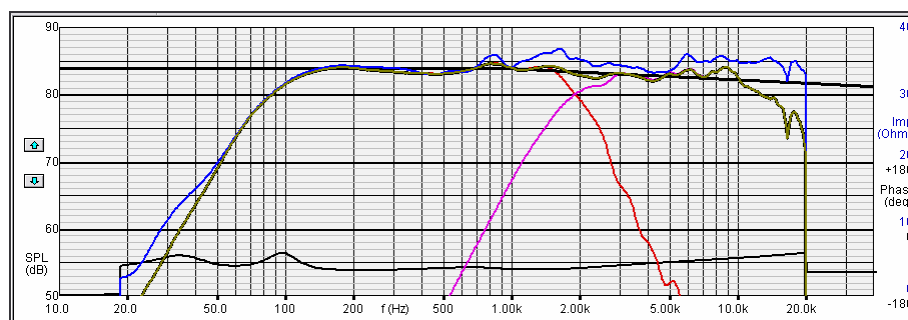

**Figure 14. X-over Optimised to sloping Off-axis Target**

3-way X-over

In the next example we will design a more advanced 3-way x-over using the two previous drivers as midrange and tweeter and add a new driver as woofer. The new woofer is 8 ohms impedance but the two others are 4 and 6 ohms impedance. We will therefore aim at a nominal 4 ohms impedance system. We want to design our system with minimum impedance of 3.2 ohms to protect the amplifier.
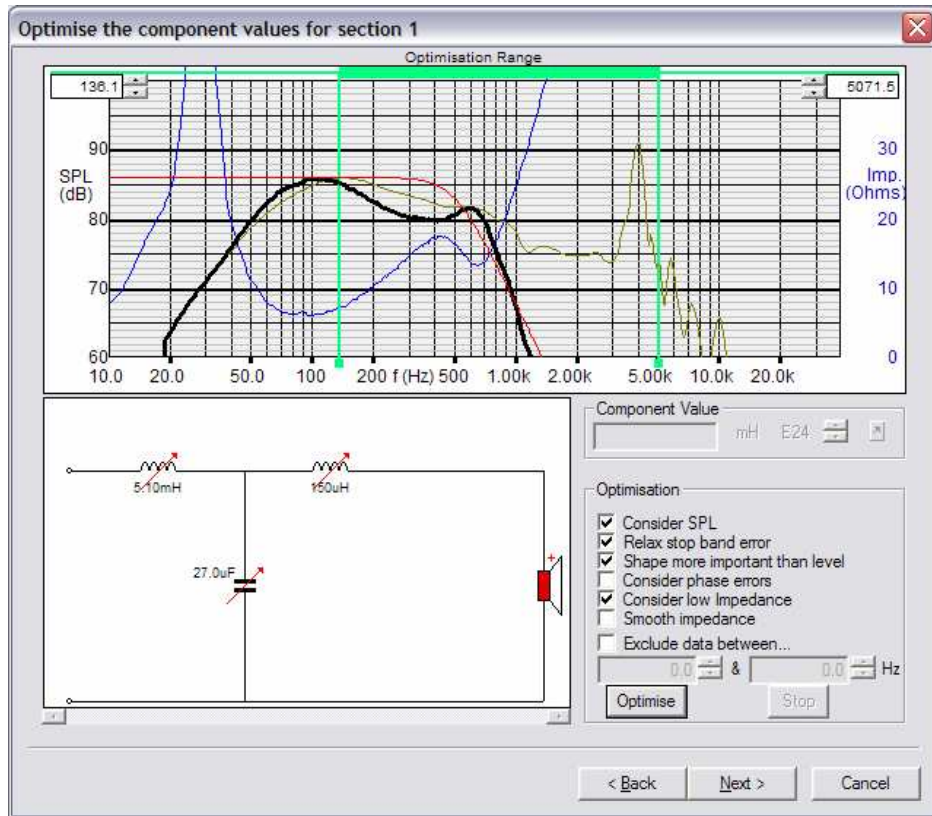
Figure 15. Woofer response without compensation

Fig. 15 shows the response (——) of the woofer (SEAS L22RN4X/P), having a downward slope and a large peak at 4 kHz. We have chosen the target SPL at 86 dB due to the lower sensitivity, and x-over frequency of 500 Hz. The optimised response with a 3rd order-18dB/oct Butterworth filter is also shown (note that we have dragged the optimisation range to include the large peak). However the optimised section response is far from the red target (——), and we need to do something to improve this x-over. We could select a 4th order (24dB/oct) or special x-over, but let us instead investigate the cause of the bad response.
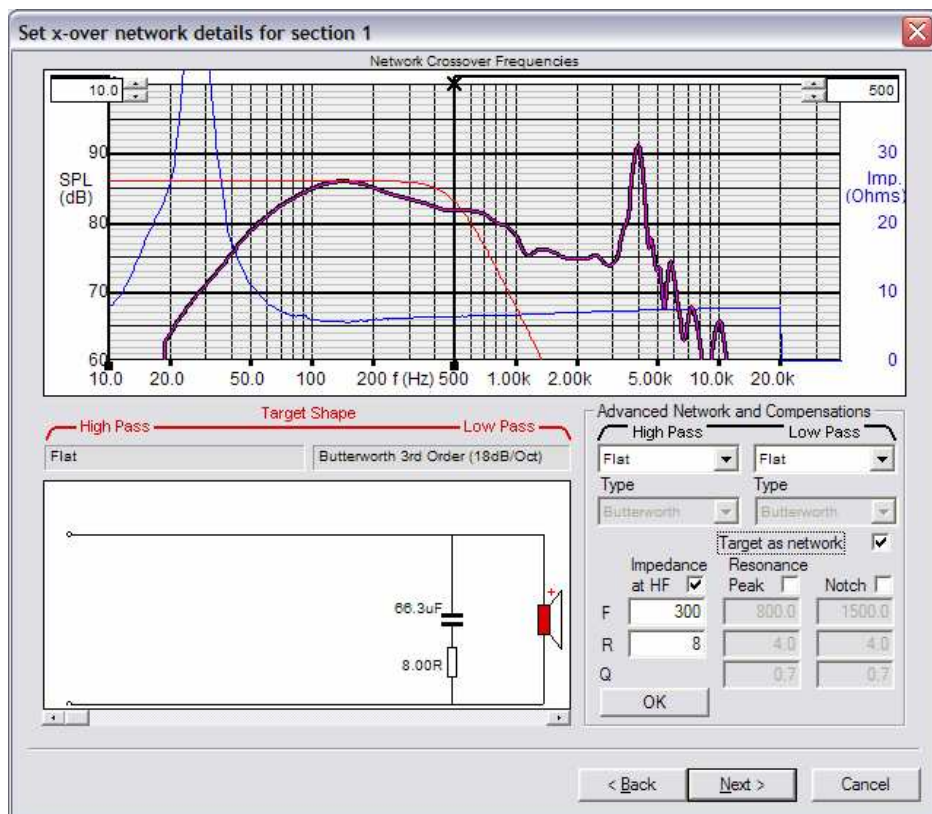
Figure 16. Woofer (Impedance) compensations

The SEAS L22RN4X/P woofer has a long voice coil and very high impedance above 500 Hz. This is the reason why the three x-over components are not really effective. Luckily we have another option, namely to compensate for the impedance rise with a capacitor and a resistor, see Fig 16.

In order to view the driver impedance without x-over components, we can select a flat target (= no x-over). Press the "Advanced" button.

Here we can choose 3 kinds of compensations:

1) Impedance at HF
2) Resonance peak
3) Notch (filter)

all indicated by the small sketches. The first will compensate for the impedance rise towards high frequencies, the second will compensate for the woofer resonance Fs and the last is a tuneable notch filter.

For this application we can use both the first and last, but we have chosen the first impedance compensation, because it only needs two components. We have initially set F to 300 Hz (frequency where the imp has increased by about 3 dB), after trying a couple of other values we set R to 8 ohms and get the nice flat impedance curve, which is shown in blue (Fig. 16).

The new optimised woofer response is shown in Fig. 17, and is now following the red target really well, while keeping above minimum impedance.
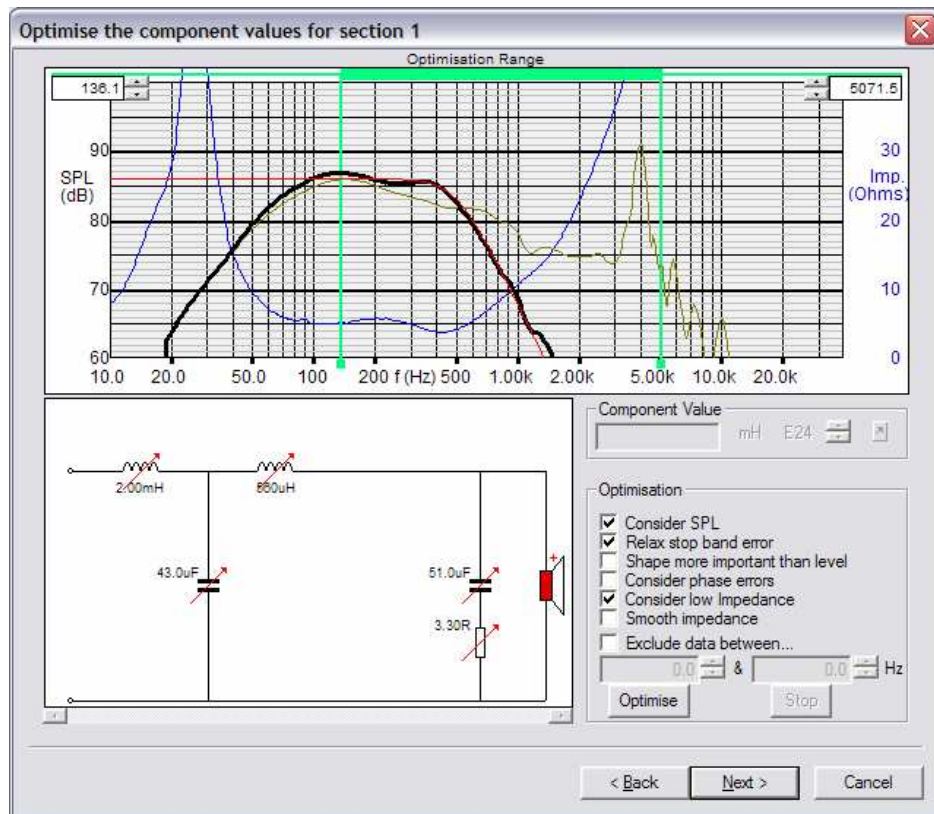
Figure 17. Optimised Woofer section with compensation

Moving to the next driver section, we want to use the SKO130 now as midrange. Therefore we need to choose two x-over frequencies to form the necessary band-pass filter, see Fig. 18. The lower (x-over freq.) is already chosen at 500 Hz and we select the upper above 4000 Hz, to relieve the tweeter for the low frequencies.
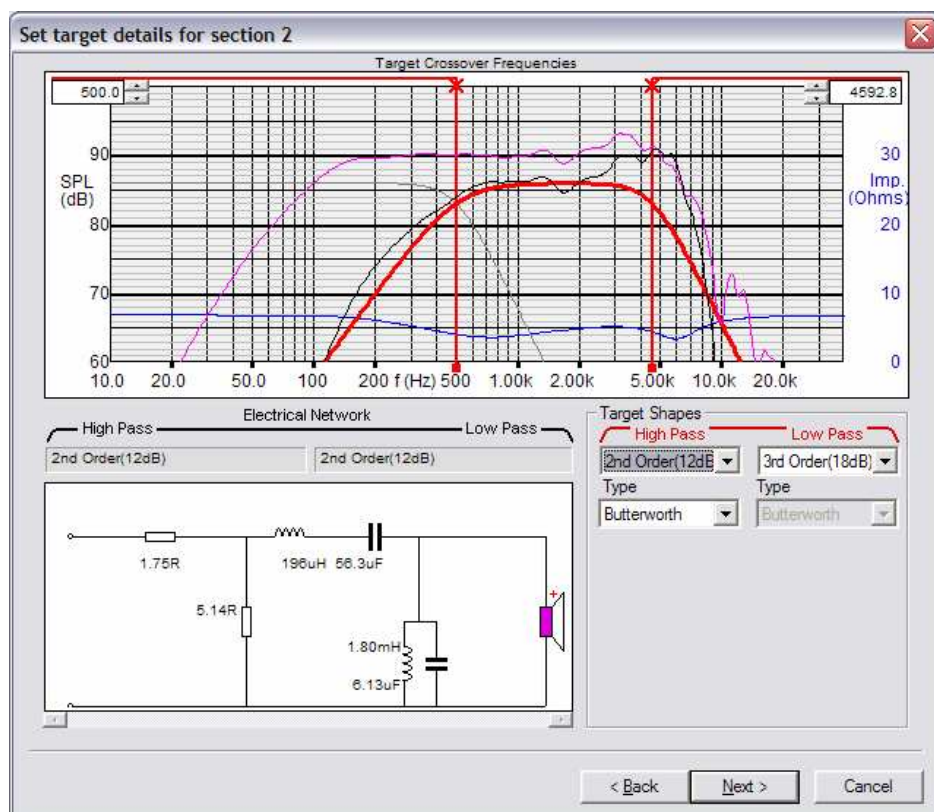

Figure 18. Midrange variable Target setup

This time the attenuator option has been selected as we need to lower the output from the more sensitive midrange to match the target SPL of the woofer (86dB). The attenuation is set to 5 dB, but this is actually not so important, because the optimiser will find the best setting also for the attenuator components.

Fig. 18 also shows that it is possible to specify for instance a **3rd order target** with a 2nd order network because "Target as Network" has been deselected.

After extending the optimisation range to 6000 Hz, we get the optimised band-pass response, see Fig. 19. We have used the default optimise settings, however we have deselected "Shape more important than level" to aim for the best absolute band-pass response.
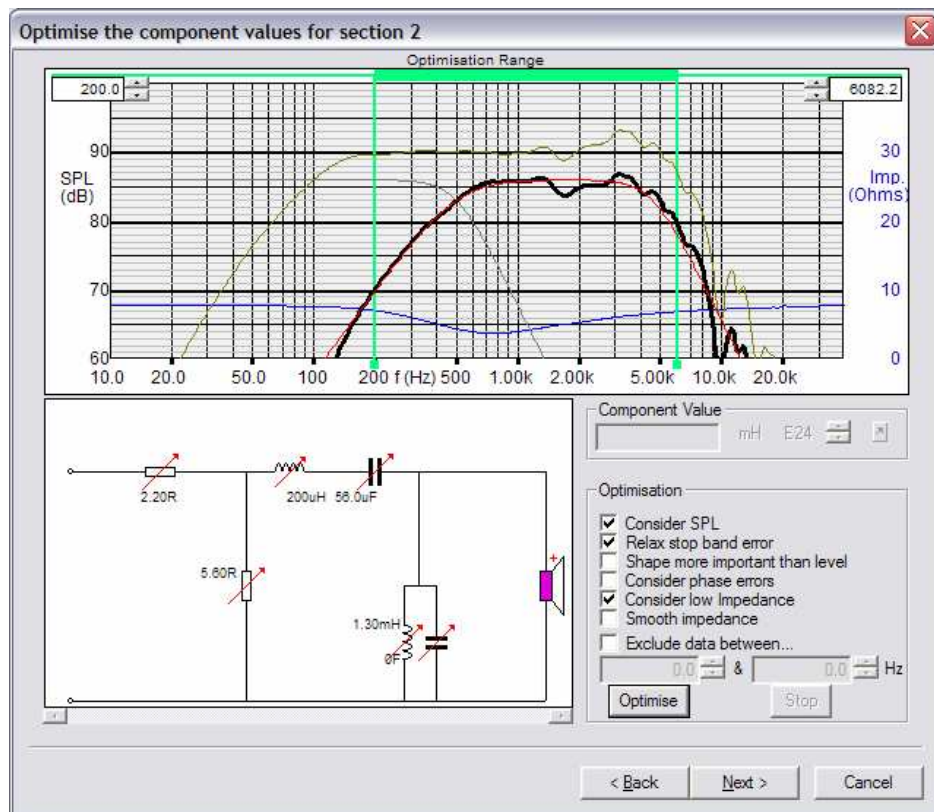
Figure 19. Optimised band-pass for midrange

The tweeter section is optimised like the first 2-way x-over, except that we have chosen a 3rd order target. We need an attenuator like in the midrange case due to the lower sensitivity of the woofer. We use 6 dB attenuation and optimise without "Shape more important than level" set. The optimised tweeter section is shown as Fig. 20.
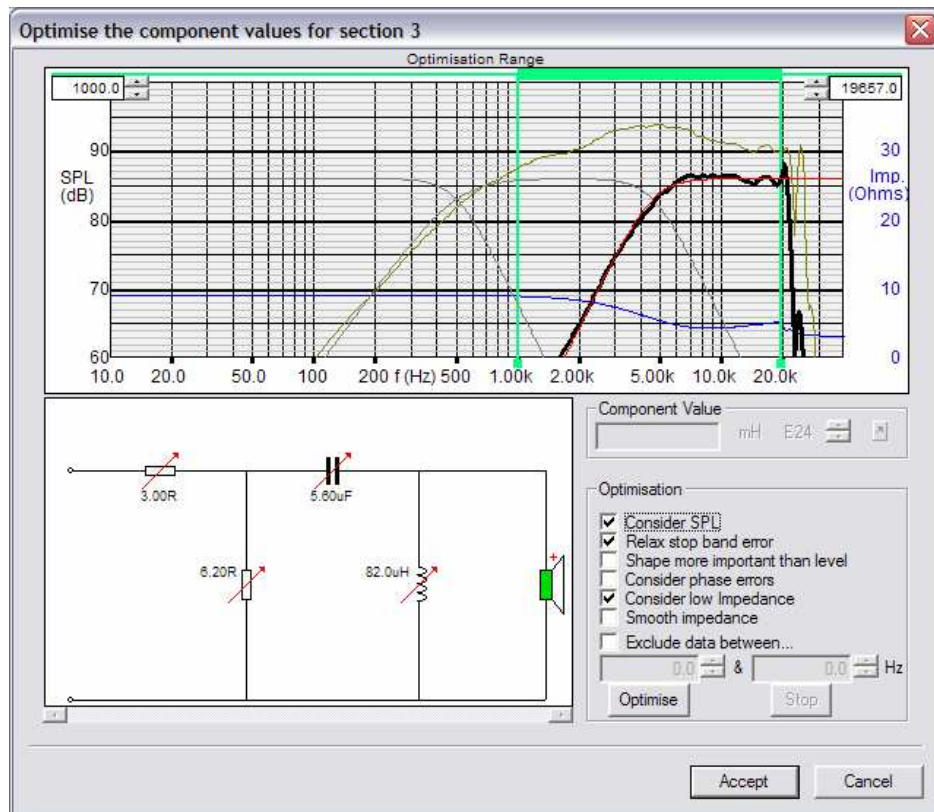
Figure 20. Optimised tweeter section

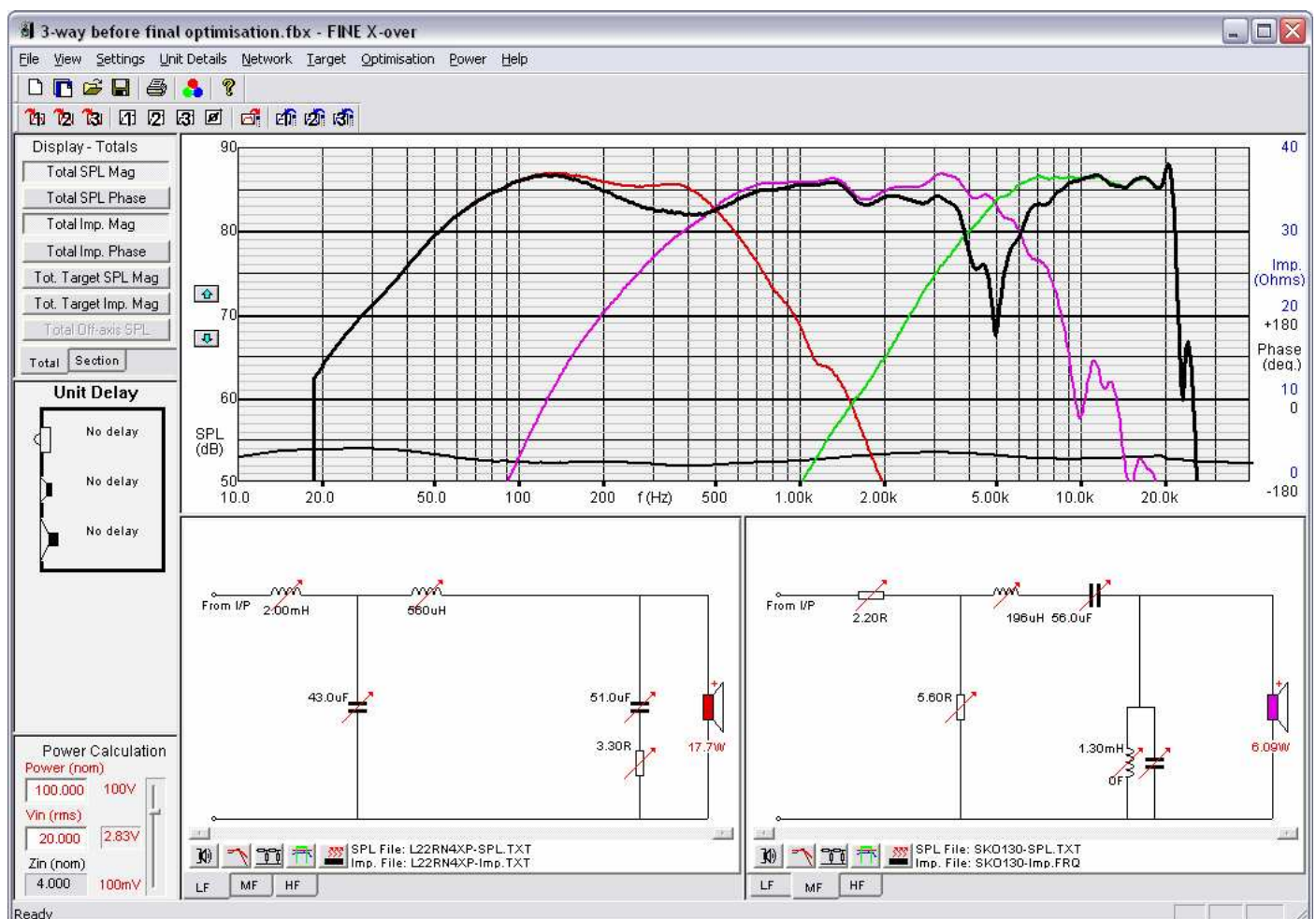We have now finished the Wizard and it is time to view the total response, see Fig. 21.

Figure 21. Total system response with problem

This response is not really good, maybe to our surprise. But when we check the driver responses we see the midrange and tweeter are reaching well together. The reason for the two drivers not summing together is that they are acoustically out of phase.

There are basically two ways to change the acoustical phase between drivers: A) To invert the + and – terminals or B) Move the drivers physically (Delay). First we try A and later B.

A) Midrange inverted

We can easily change the electrical phase of the midrange (+ and – terminals) by clicking on the midrange driver symbol and set a mark for "Phase Invert" for the midrange (Fig.22).

**Figure 22. Driver Phase setting**

The response is now without the dips at 400 and 5000Hz, but still not flat. We may optimise the total system response at once, however there is a big risk for the optimiser to end up with a strange X-over, because there may be too many components to optimise.

Therefore we need to guide the optimiser by selecting only few components to optimise. The rule is "better few than many". In the 1st woofer section, we have fixed the two capacitors by double-clicking to remove the red variable arrow, since this will also keep the impedance compensation circuit (C+R).

The midrange section components are changed to allow an earlier cut off. This includes the parallel capacitor, which is now fixed to 16 uF (was 0). These changes were done by clicking on one component and quickly rolling through all available values (here E24 range) using the mouse wheel, while watching the curves change simultaneously on the screen (see Fig. 23). The midrange is the most difficult to design and therefore all other components were left as variable for the optimiser.

The capacitor in the tweeter section was fixed, in order to keep the nice tweeter response. Finally we select "System Optimisation" from 150-15 kHz with "Consider Low Impedance" checked, to get the flattest response while keeping the impedance above the minimum 3.2 ohms.
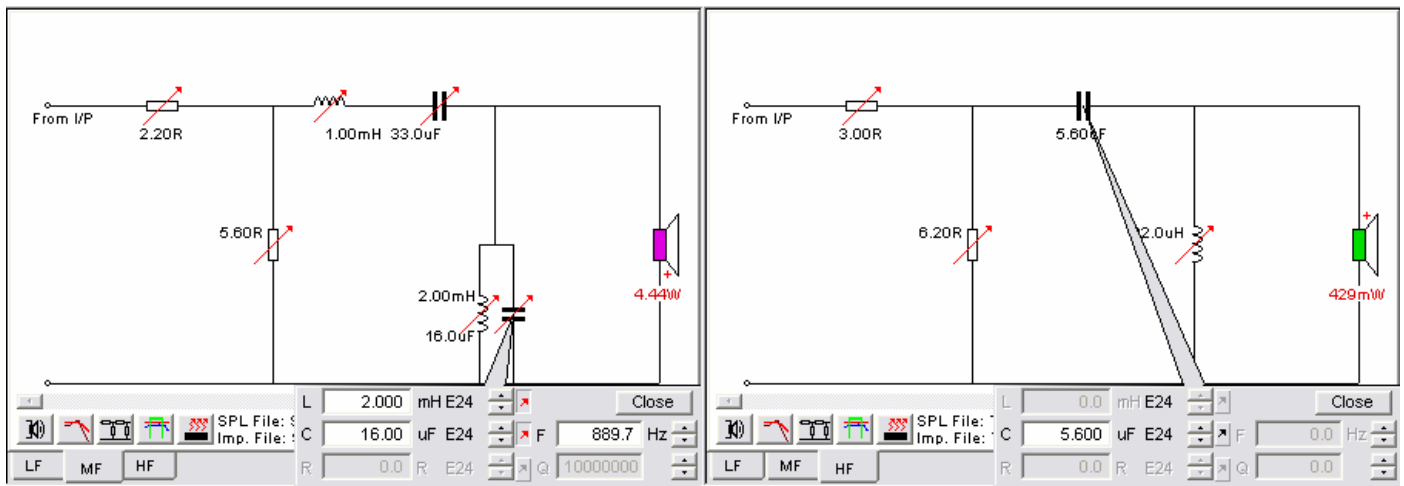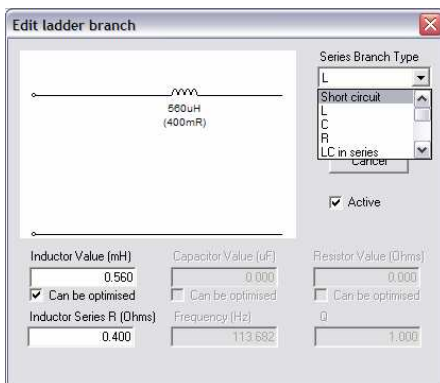
Figure 23. Component adjusting before final Optimisation

The final response is quite flat, within +/- 1dB from 90 Hz to 20 kHz. The total impedance is above the required minimum impedance of 3.2 0hms (10-20000 Hz).

We have further simplified the X-over as follows. The second inductance in section 1 (woofer) is just 0.56 mH and may be omitted. By right-clicking on the component we get a menu where we can de-activate the inductor, Fig. 24.

We see that the change is less than 1 dB, so we select "Short circuit" under "Series Branch Type". Likewise we decide to omit the parallel resistors in section 2 and 3 (Mid + TW).

Interestingly we began with a 3rd order (18dB/oct) filter for the woofer but left out a component, so 2nd order (12dB/Oct) was enough.

Figure 24. Right-click menu

Up to this point we have assumed the inductors being ideal i.e. without resistance (RL). Now we want to include a resistance of 0.4 ohms in all inductors. Right-click the inductor for section 1 (2.0mH) and get the component branch edit for the inductor (L) Fig. 24. The Inductor Series RL is entered as 0.4 ohms. The upper right "series Branch Type" also displays some of the possibilities to insert up to 3 other components in various ways. This includes "Short circuit" and "Open circuit" which can be used to remove components.

All the above changes were done and fine-tuned in Fig.25 by using System Optimisation again.
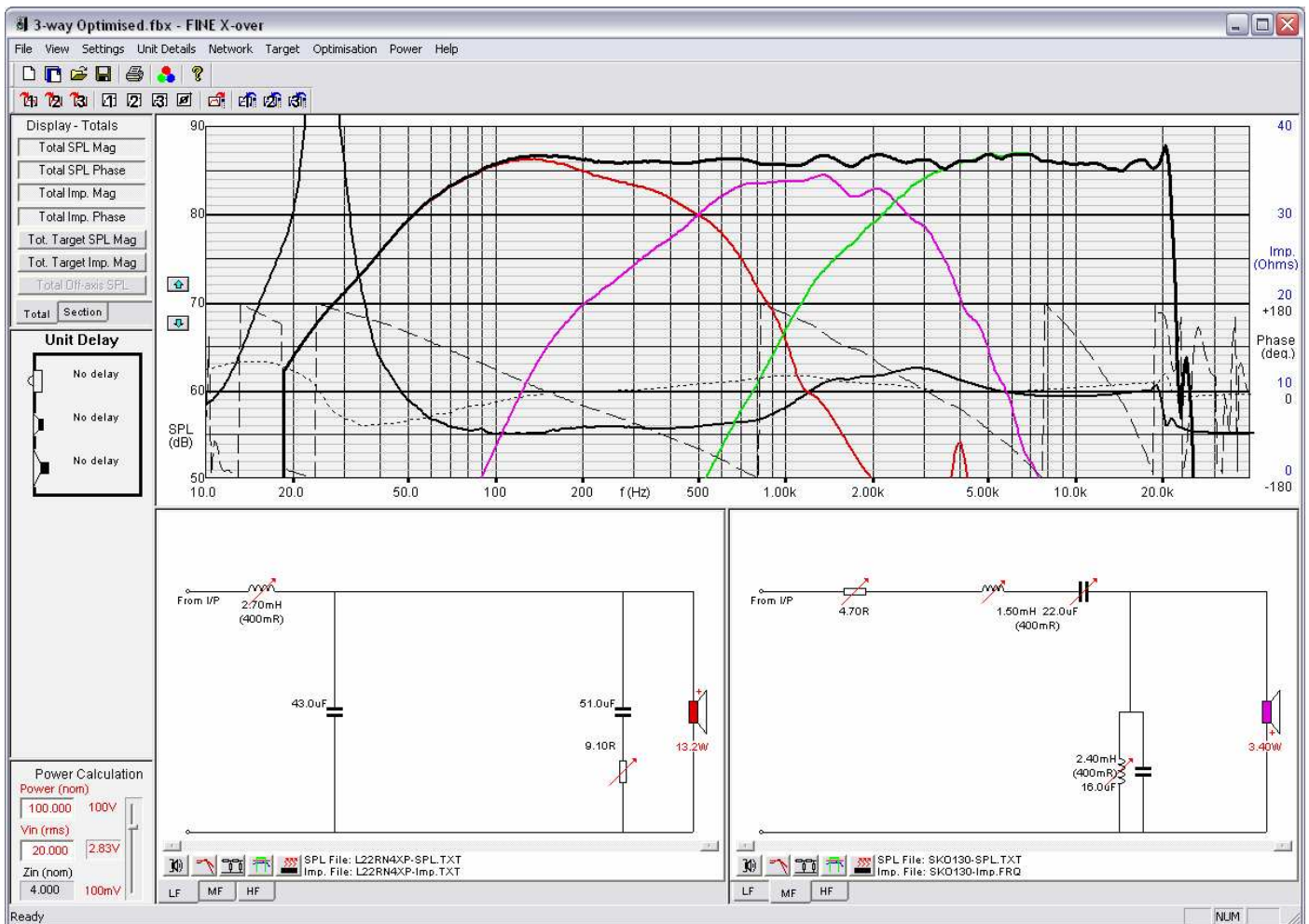
Figure 25. Final optimised 3-way X-over

B) Midrange and Tweeter with Delay

Instead of inverting the terminal of the midrange we can simulate changes to the driver positions by introducing delay, see Fig. 26. By clicking and rolling with the mouse wheel the user can simulate +/- movements of the driver recessed in or protruding from the baffle.

It is possible to find the best position by observing the acoustical phase of the individual drivers.
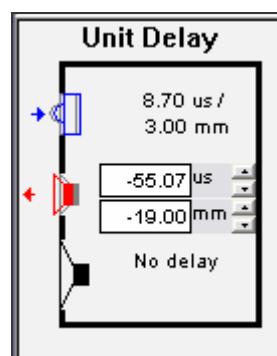

Figure 26. Driver Delay

The resulting response with all drivers in (electrical) phase is shown in Fig. 27. The driver responses are actually improved and the midrange is working better.
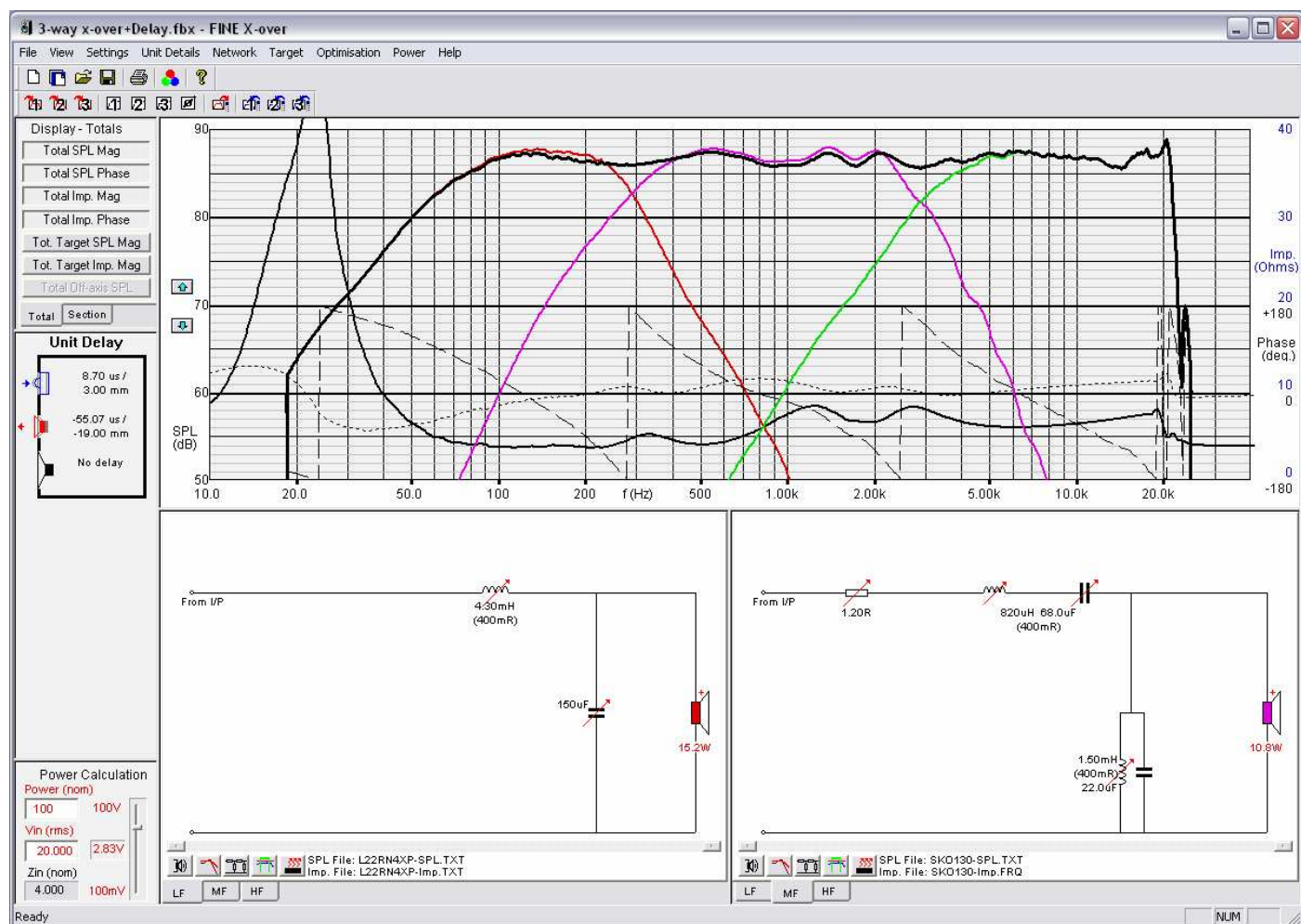

Figure 27. 3-way x-over with Midrange and Tweeter Delay

2.5-way X-over

In a multiple woofer design the engineer often want to have all woofers working together at low frequencies but only use one of the drivers to extend up to the midrange or tweeter.

The following example is exactly that, which we call a 2.5-way system design. We have used L22RN4XP woofer in the first section. The second woofer SKO130 input is taken from the first woofer terminals,
see Fig. 28, where you select the LF input by one click.

The frequency response shows that the two woofers work nicely together at low frequencies and the second (purple) woofer response extend well up to the tweeter.
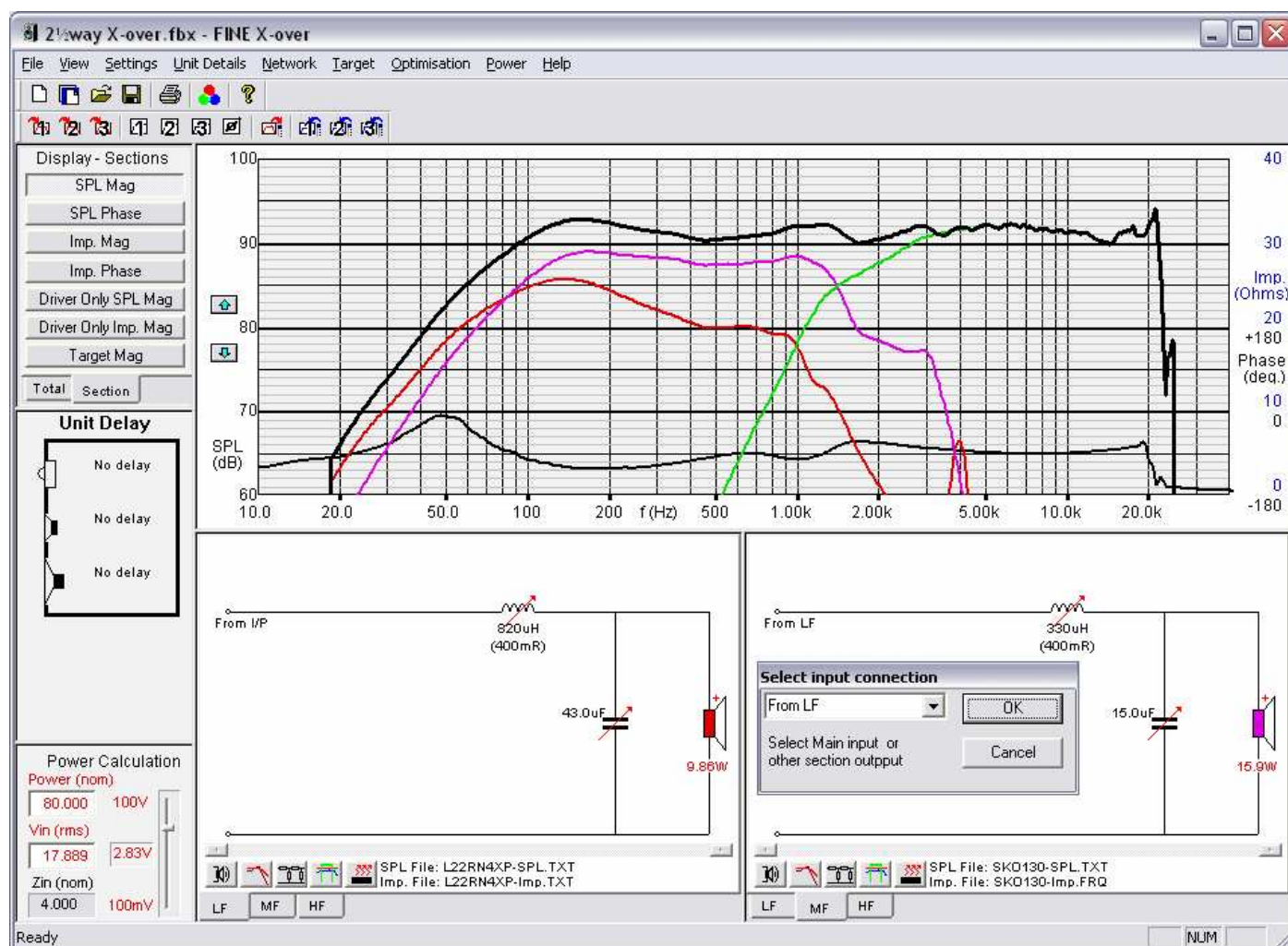

Figure 28. 2.5way X-over (Tapped woofer)

Power in Drivers and Components

Finally we may inspect the component and driver power in all the x-over sections. Press the button ![button] to display the Power in section 2 (Midrange) of the 3-way X-over (Fig. 29):

Here is the real power calculated for the resistive components and the driver. The input is 100W (RMS) in nominal 4 ohms, with a power spectrum per IEC 60268-1, to simulate "normal" music.

The power for the driver is 3.83W , which seems little. However the impedance of the driver is higher than 4 ohms over most of the spectrum, the x-over frequency is 500 Hz, and the power is reduced due to the IEC 60268-1 spectrum.

Note that the power in the serial inductor is 326mW, which is due to the 0.4 ohms RL. The power in the attenuation resistor is 3.83W. The power in the resistors and coils can be rather high and is therefore quite important!
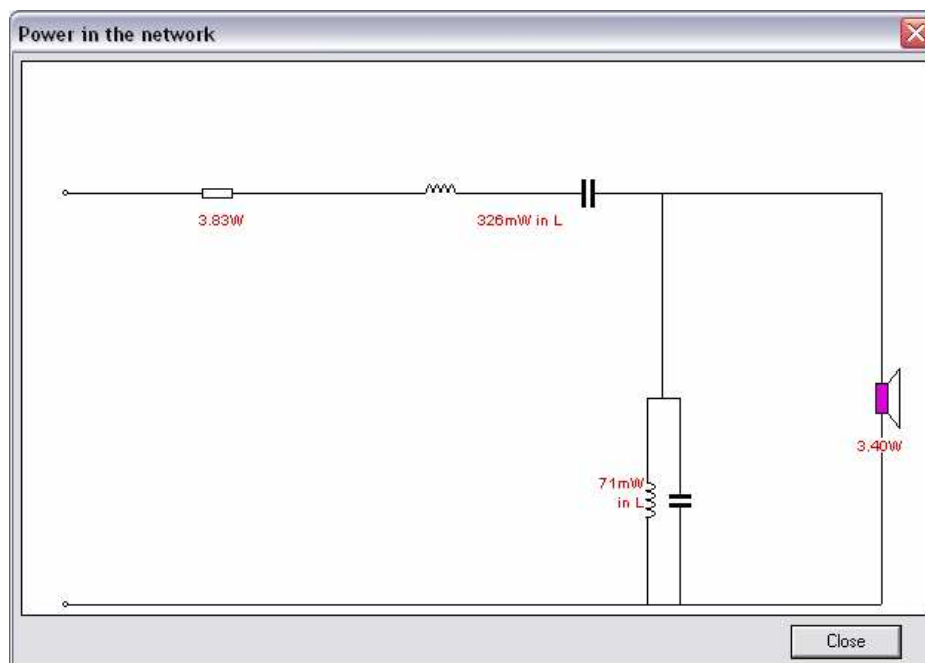
Figure 29. Real Power in 3-way section 2 (Midrange)
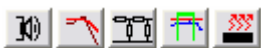
The above section buttons provide fast access to:
1. Response Input
2. Target
3. Network
4. Optimise
5. Power Analysis

Finally we may go into "Settings" to enter the tab: Component Adjustments (Fig. 30). Here we can set which range of standard components we want. First was used the E24 range, which is the most accurate. Selecting E12 or maybe 5% will use less accurate and therefore less expensive components. However new simulations may be necessary to optimise for the best response.
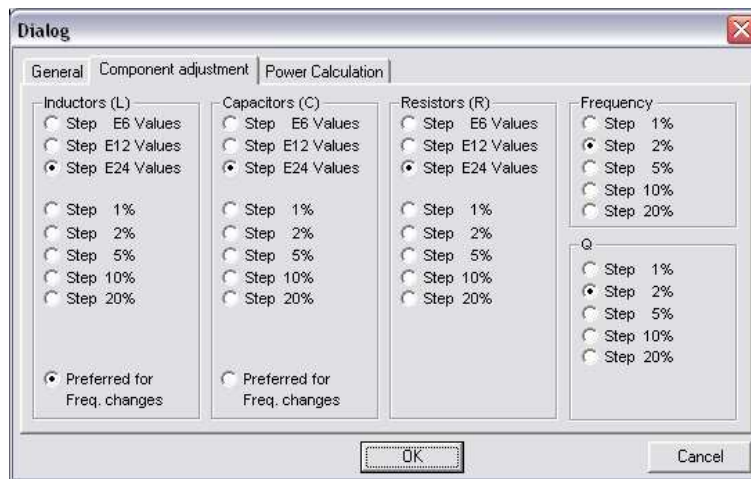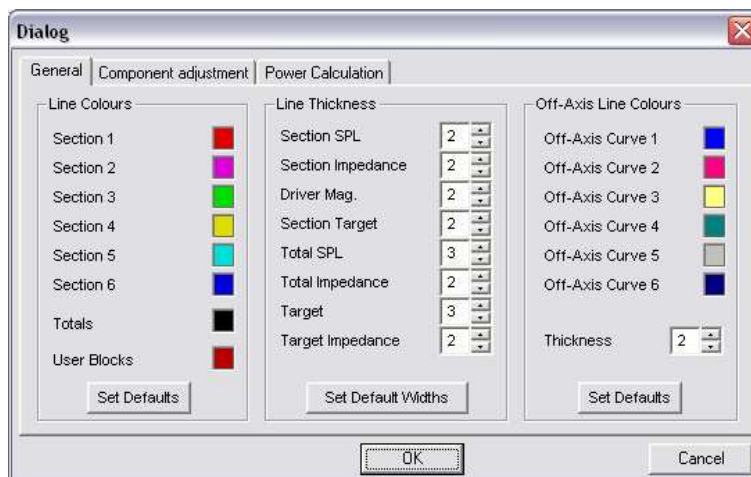
Figure 30. Component Adjustment Settings

Figure 31. Colour Settings

LOUDSOFT
www.loudsoft.com

Agern Alle 3 – 2970 Horsholm – Denmark
Tel: (+45) 4582 6291 - Fax (+45) 4582 7242