Earendel

Earendel (Eärendil) is a character in Tolkien's works, the name however goes even more back in history in Norse mythology, then as Aurvandill.
The name is said to mean 'Rising star'.

Lately the Hubble telescope spotted WHL0137-LS which was nicknamed Earendel.

The star is 28 billion light-years away and is the earliest known star. The star saw its youth when the universe, as we know it today, was still a baby.

This loudspeaker project is named Earendel to celebrate that art, myths and science has transformed the human from hunter-gatherers to a species that is always in search for what may lie just around the corner. All that in just a blink of an eye in the history of the universe.

The Earendel is a three-way ”double D'Appolito” system with SEAS drivers for the mid-bass to tweeter frequency region and Peerless long stroke drivers for the subwoofer.

The "double D'Appolito" refers to that a normal D'Appolito typically has two bass/midrange units, one located above the tweeter and one below. This design is however built with an extra part of speakers to be able to handle the relatively low crossover frequency to the subwoofer. The outer pair is decoupled towards higher frequencies and the inner pair is slightly decoupled towards lower frequencies, the purpose is to limit comb filtering.

The Subwoofer is a 12" long throw subwoofer from the Peerless XLS series. A passive radiator design is used, where an extra 500g weight is added to reach a low resonance frequency.

The loudspeaker units in this design are thus:

- Subwoofer : Peerless XLS 830500
- Bass/mid : SEAS W15CY001 and CA18RLY
- Treble : SEAS T25CF002 Millennium + a no-name backfiring tweeter

All driver units are recycled from the Nangijala dipole loudspeakers, built ca 2011.

The total weight including drivers and subwoofer plate amps is 45kg and the total height is 130cm, i.e. a barely acceptable spouse admittance factor. The subwoofer and the bass/mid-treble cabinets are built separately to make the whole thing movable without getting a strained back as reward.

The subwoofer plate amp allegedly delivers 700W peak power. The power amplifier is a 6ch Rotel amplifier rated at 90W/8ohm per channel. Two amplifiers per channel is bridge-coupled for a 180W power for the bass/mid speakers.

The crossovers are 2 MiniDSP 2x4 units, one for each channel. The crossovers are configured as a combo of phase-linear FIR for the bass/mid-treble and normal causal bi-quad filters for the lower frequency range. This means that the speakers are phase linear from ~200Hz and up. The frequency response from 20Hz and up.

The following section describe the loudspeaker as detailed as possible. The loudspeaker design is done in LspCAD 6 with the accompanying justMLS tool for the measurements. The building plans are not available in an acceptable shape however as the author drew them up with the traditional analogue tools pen, paper and ruler, with some help from a calculator for the trigonometry.
The cabinets are made from 18mm staff glued beechwood that is internally braced for stability, pictures at end of this document shows part of the building process.

Bass/mid cabinet

The bass/mid cabinet is designed for the following drivers

- D1a, D1b : SEAS W15CY001
- D2a, D2b : SEAS CA18RLY

The inner volume in the cabinet is split into two parts. The D1 drivers use 17l while the D2 drivers use 38l. The whole LspCAD 6 model including the analogue circuits that do the above-mentioned de-coupling is shown in Figure 1.

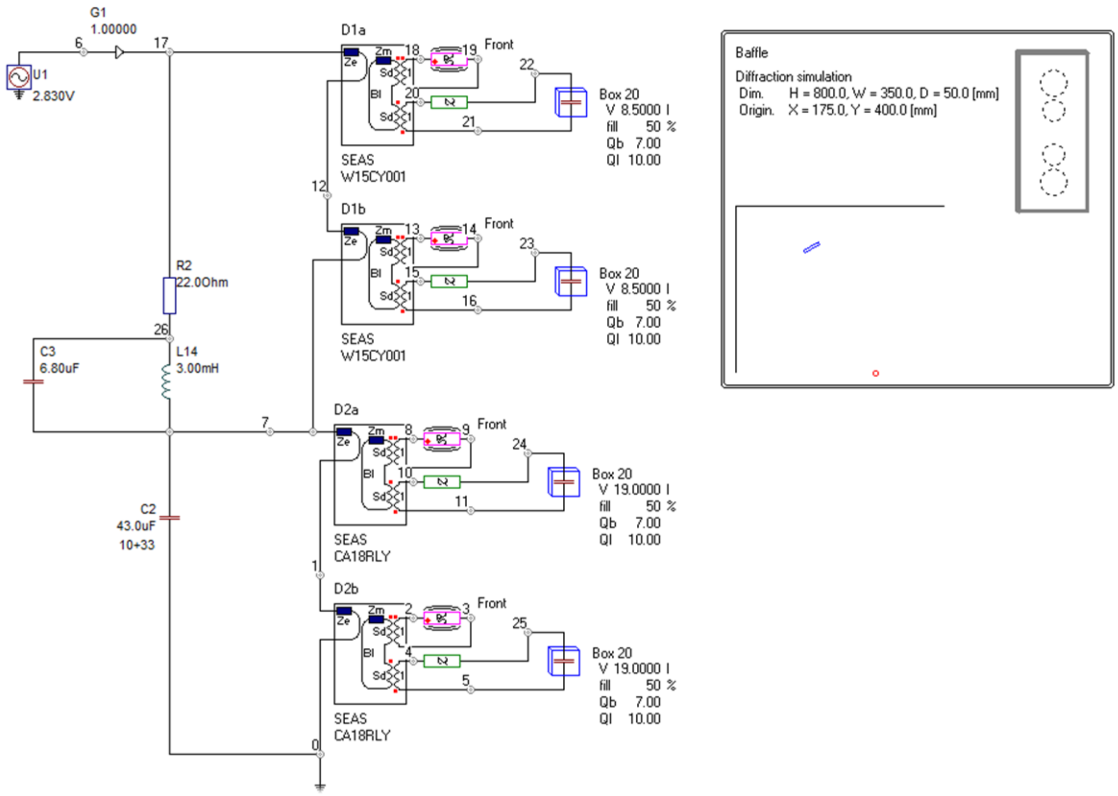


Figure 1 LspCAD model for bass/mid cabinet

The modelled frequency response is shown in Figure 2.

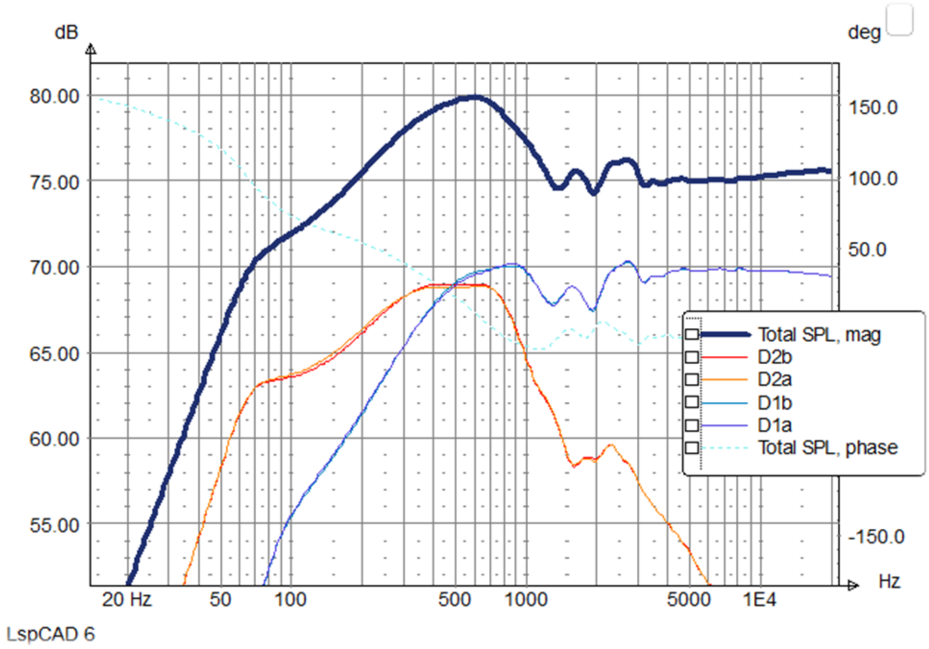


Figure 2 Modelled frequency response

The model addresses diffraction but does not consider the impact of the inductance on the frequency response as this does not make sense for bass/mid units that rely on controlled break-up of the cone to extend the frequency response. The graph clearly shows the result of the decoupling components.

Subwoofer cabinet

The subwoofer cabinet is largely adapted to fit with the overall design. I would have been preferred with a few litres extra but in the end it set was set to 36l. The subwoofer is a Peerless 830500.
An extra 400g weight is added to the passive radiator to extend the resonance frequency down to 19Hz. The priority with this project has been to reproduce the low end notes. High output has been of lesser importance. The resulting frequency response is shown in Figure 4. Unlike the cabinet model for the bass/mid, the impact of loudspeaker inductance is accounted for in this case. While subwoofer have cone break up modes too they don't occur at frequencies of interest in this case give that the crossover frequency is set to be around 100Hz

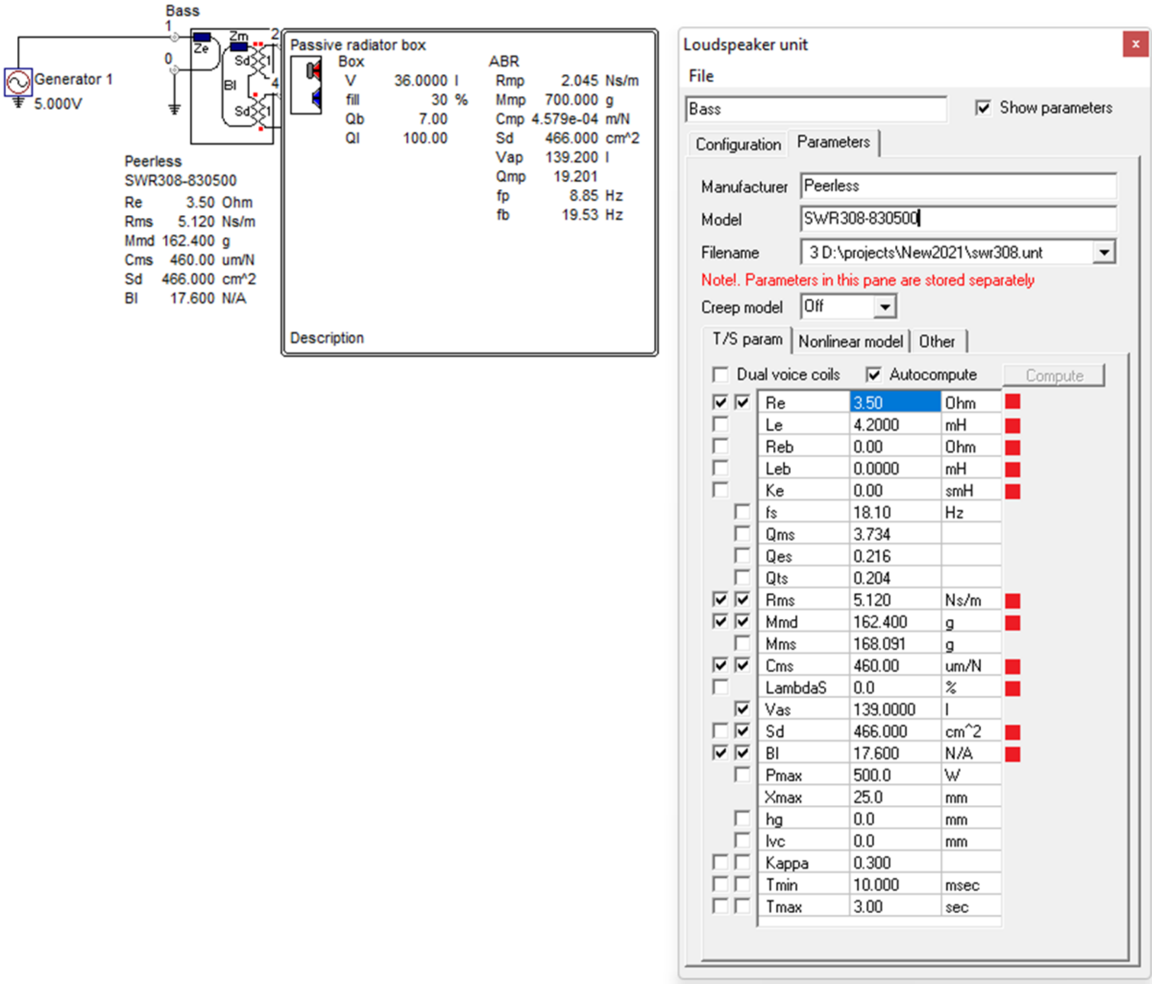


Figure 3 Cabinet model for subwoofer

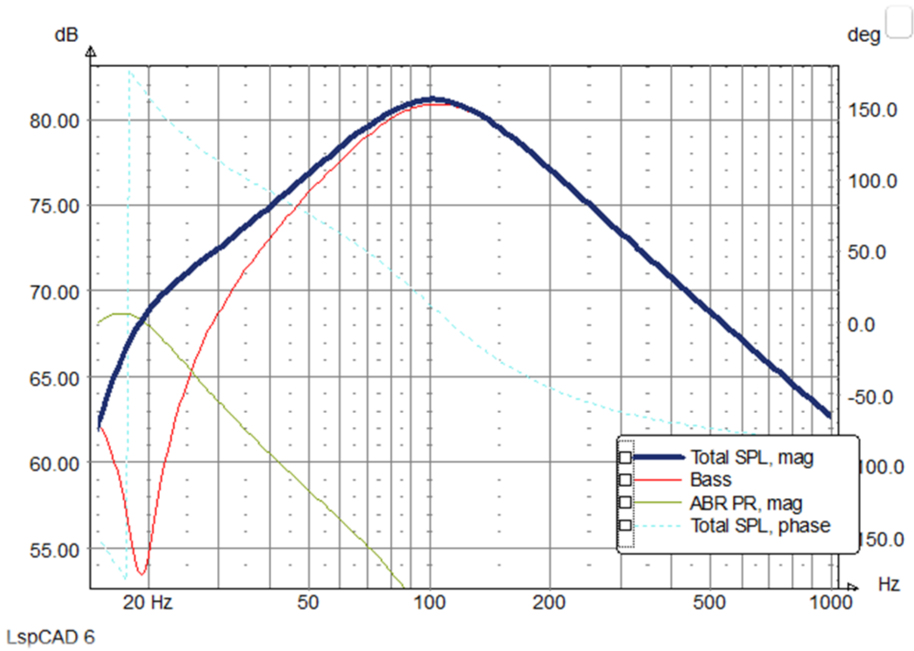


Figure 4 Frequency response for subwoofer

Crossovers

The crossover is designed around MiniDSP 2x4 HD. This device has, besides support for BiQuad filters also support for FIR filters with a maximum of 4096 tabs per device that can be distributed across all output channels. Two devices are used, one for each channel. The routing is done as in Figure 5.

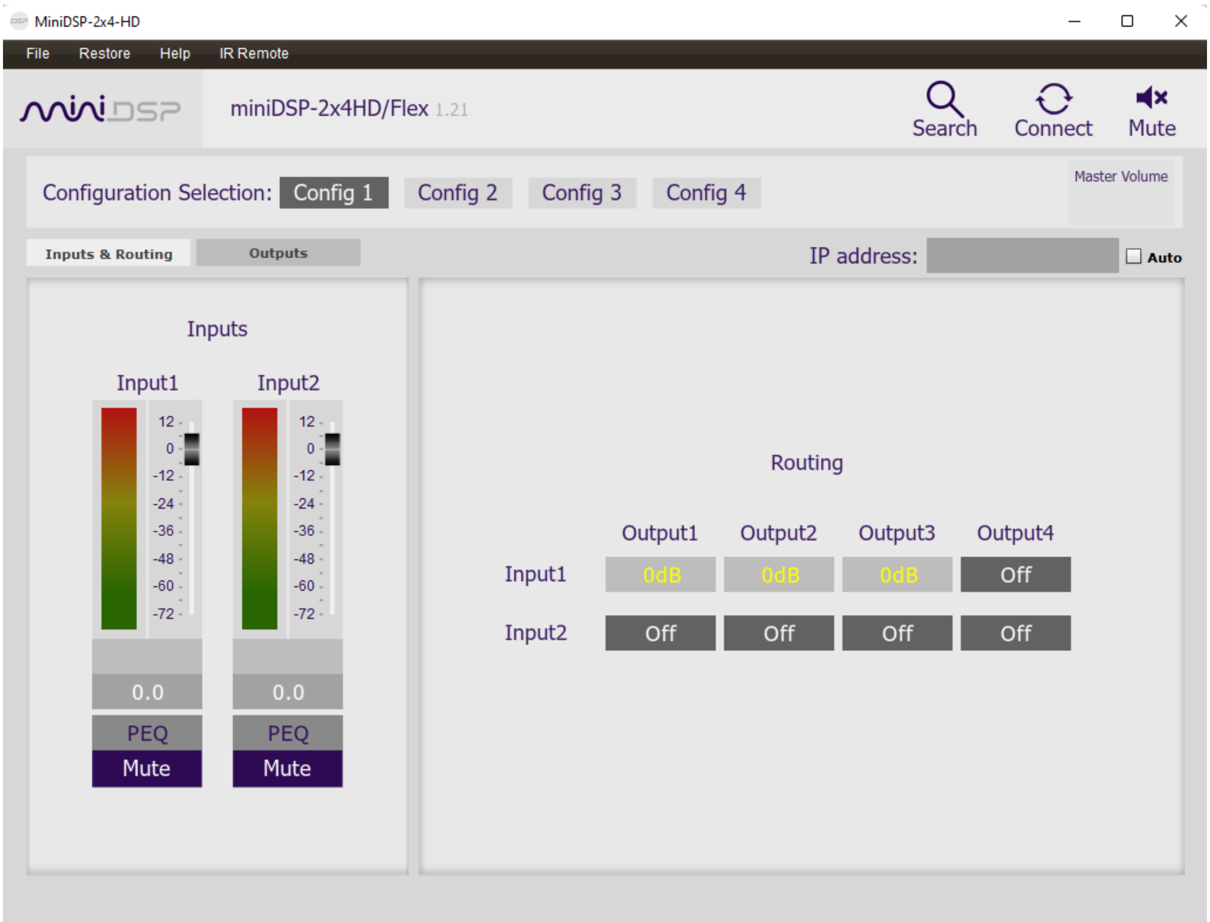


Figure 5 MiniDSP 2x4 HD routing

As FIR filters are of increasing interest because of the ability to offer phase linear crossovers, it is tempting to try and use it altogether and skip these causal BiQuad filters. This is however not without complications. A 100Hz crossover point requires a considerable amount of filter taps, and in addition the resulting delay would become so large that it becomes difficult to time-align the loudspeakers in a home cinema system.

A compromise is thus used, the crossover between the subwoofer and the bass/mid is a traditional crossover, while the crossover between the bass/mid and the treble is a FIR filter. In addition, it is of interest to equalize the artifacts in the loudspeaker frequency response.

Measurement

Firstly, it is necessary to measure the loudspeakers individually when mounted in the cabinet, here be dragons … Measurements in house in a living room is nearly impossible as the measurement time windows need to be really short to avoid the impact of reflections from floor, ceiling and walls. The best alternative is to bring all 45kg of loudspeaker outside on one sunny day. If you have been in north Sweden in the summers you'll realize that for instance midsummer, which is holiday numero uno, offers everything between +5 C and rain (on rare occasions even snow), and +25 C. So, it takes careful planning to do a measurement campaign outside. Also consider that 80-90dB MLS noise can make neighbours upset after a while. Measurements were done but they were not perfect, something that may affect the end result. Come next summer, the author promises to annoy the neighbours again. After all drivers are measured it is important to verify that they are aligned properly. The details are not shown here but examples can be found in the document http://www.ijdata.com/LspCAD%206%20tutorial.pdf .

It was tried to measure the subwoofer with a ground plane measurement, but it was nearly impossible to get credible results, so in the end it was decided to use the modelled response for the subwoofer in the crossover design.

Design

The frequency response for the treble unit is shown in Figure 6. Note that a coupling capacitor of 15uF is used for the tweeter, this to protect the tweeter in case accidents happen, like for instance that all crossovers are bypassed.

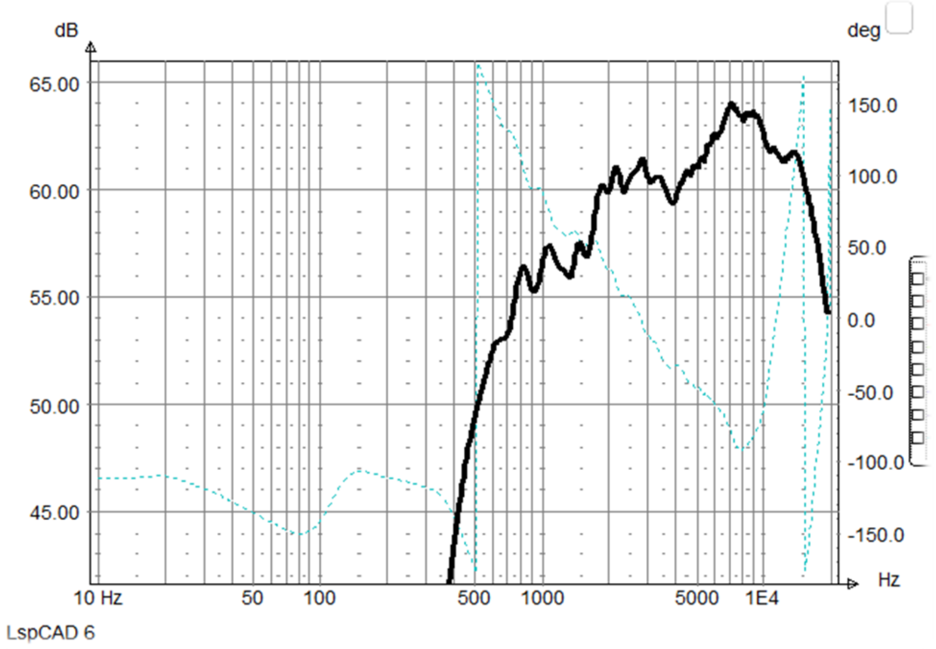
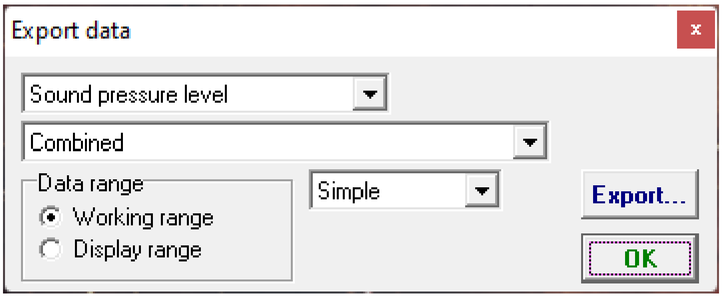


Figure 6 Treble unit, with 15uF coupling capacitor

It is obvious that the tweeter has some irregularities that could be equalized. Therefore, the response completely without any digital filters is exported, this time for a limited frequency range.



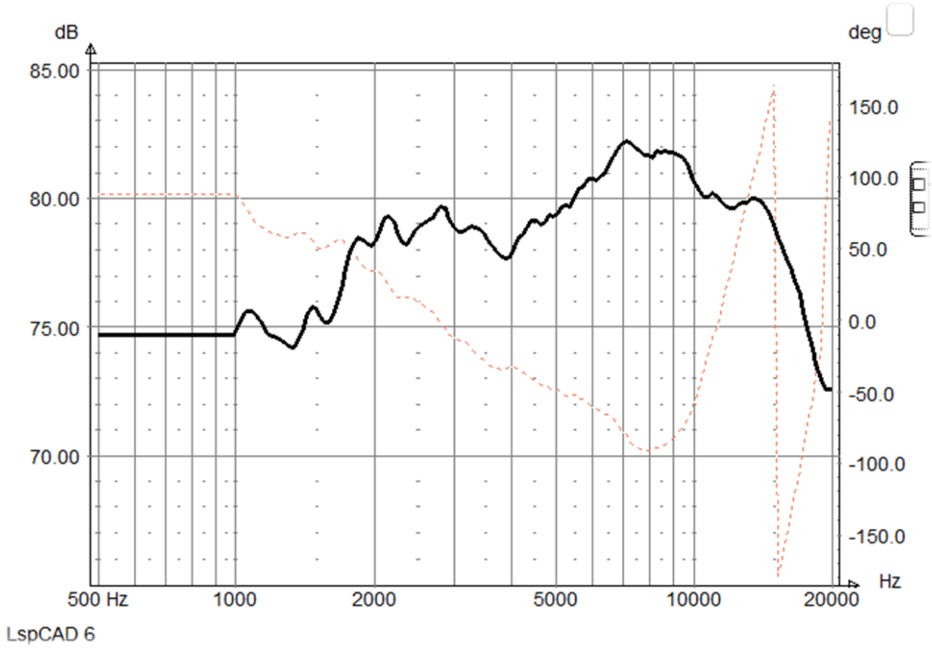


Figure 7 Frequency response for equalization, limited to range 1000-20000Hz

This is used for the equalization of the response in the FIR filter design in LspCAD.

For the bass/mid the joint response for the four drivers without crossovers look like Figure 8.

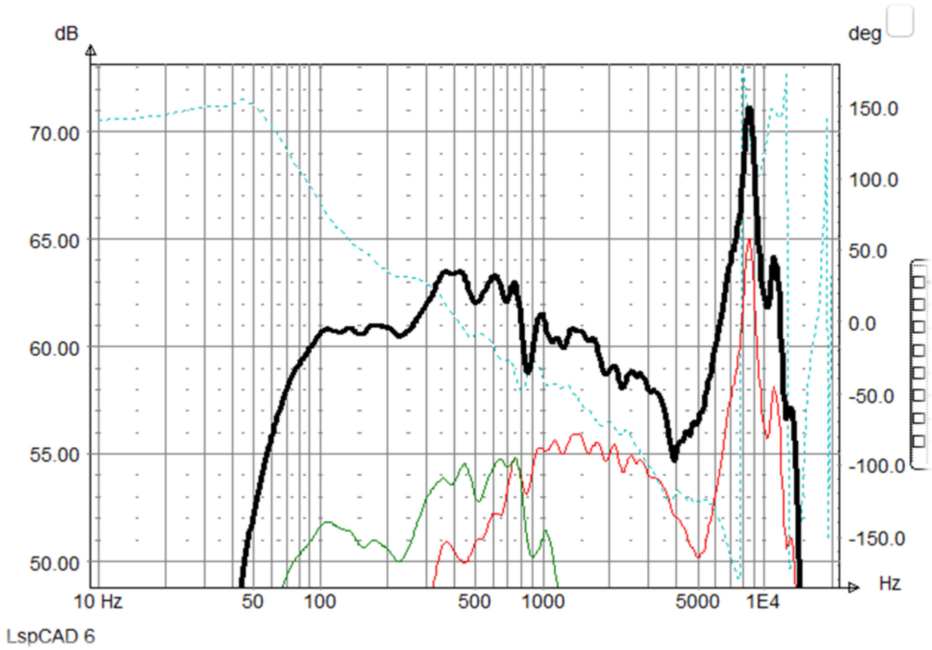


Figure 8 Bass/mid response without crossovers

Also in this case, a frequency range limited equalization response is calculated and shown in Figure 9.

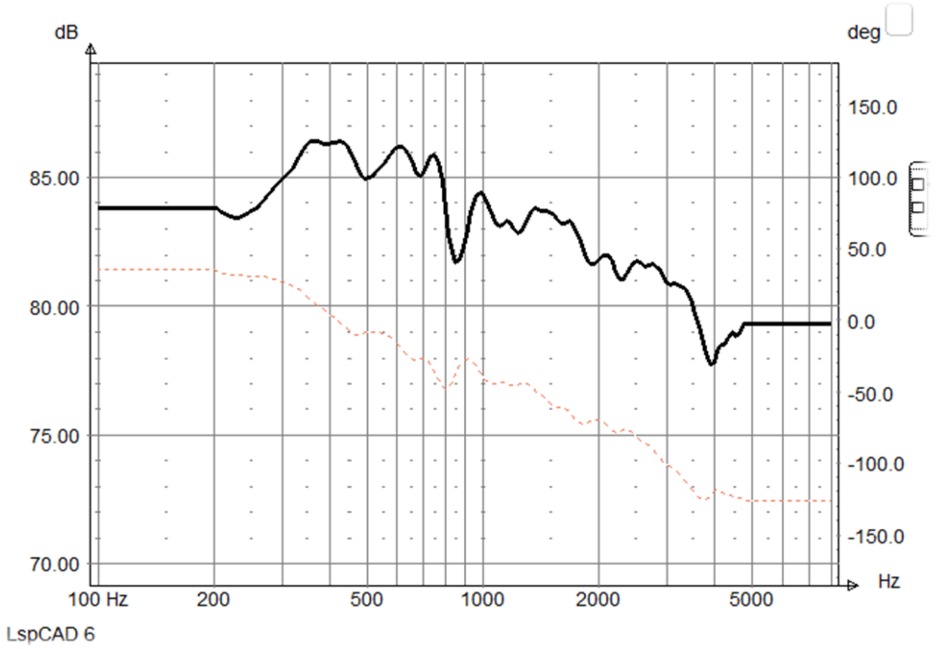


Figure 9 Equalization response for bass/mid, limited to range 200-5000Hz

The task is now to create a crossover between the bass/mid and the treble with FIR filters. Also, at the same time it is desired to equalize the frequency responses of the drivers. The treble is first designed using the analogue filter design block in LspCAD 6. As the target platform runs at 96000Hz, this frequency is also selected in the filter block. The cut-off is set to 2500Hz and 1024 points is selected (yes it says 1025 but it is 1024..). The equalization response mentioned above is imported and the **Subtract** and **Mag-Phase** options are selected, this means that the equalization response is inverted both in terms of magnitude and phase. This generally rates a response that is non-causal, the trick is here to utilize the windowing that is applied to the FIR filter design to limit problematic pre-ringing.

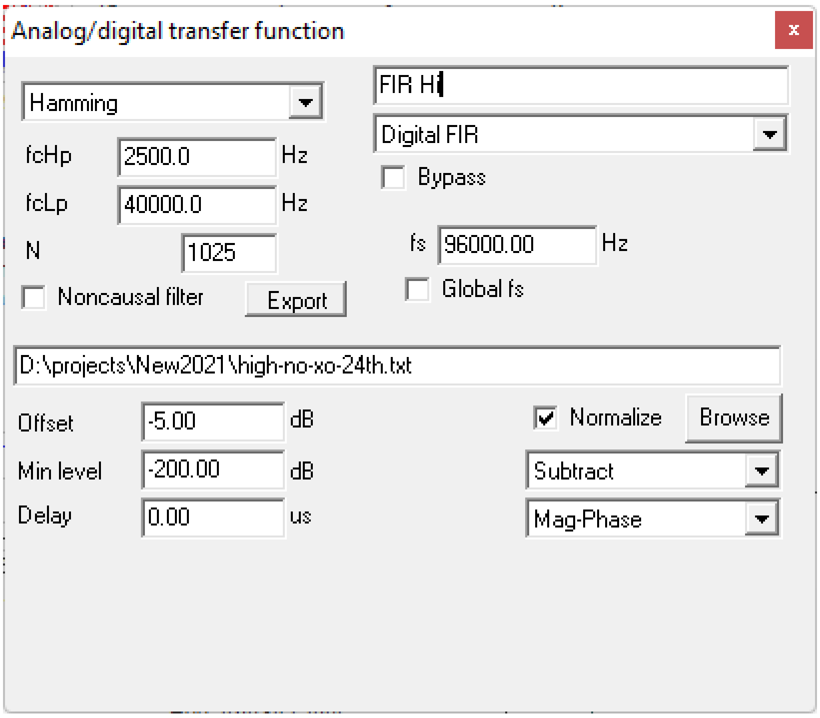


Figure 10 Filter block for FIR filter design with equalization

Typically the **Normalize** checkbox is selected and optionally the Offset may need to be adjusted to make the resulting passband gain close to unity. The FIR filter coefficients are exported with the **Export** button. Note that the MiniDSP requires .bin format (32 bit floating point).

The resulting tweeter response now becomes like Figure 11. Note that the phase response is flat in the pass band.

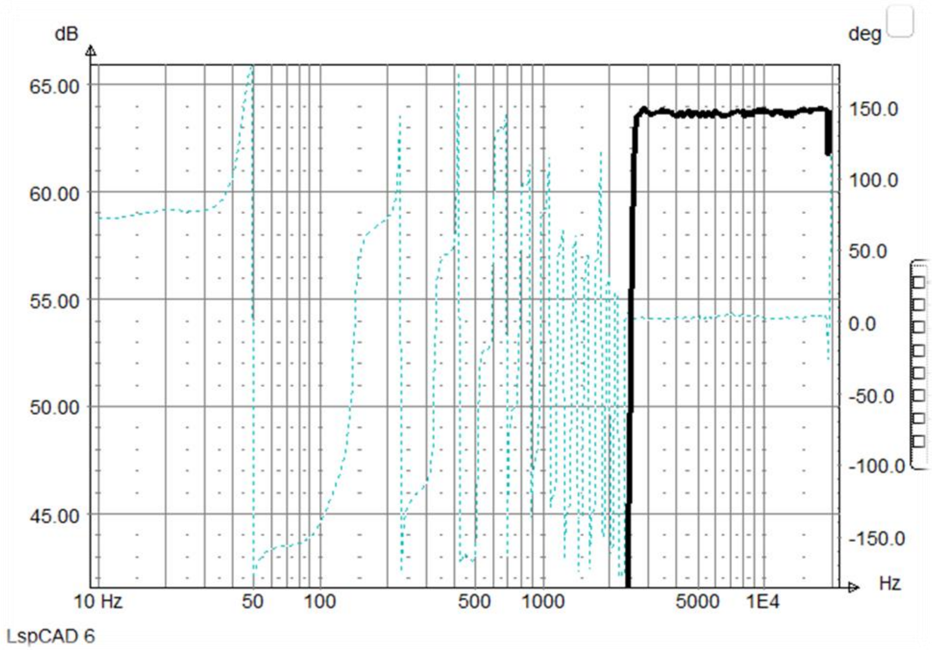


Figure 11 Tweeter response with 2500Hz cut off and equalization

A similar procedure is repeated for the bass/mid and the resulting response without highpass filter for the crossover to the subwoofer is like Figure 12. The response shows a bit more ripple in this case, the reason is that 1024 taps is a bit too few. 2048 taps gives less ripple but the resulting delay then increases.

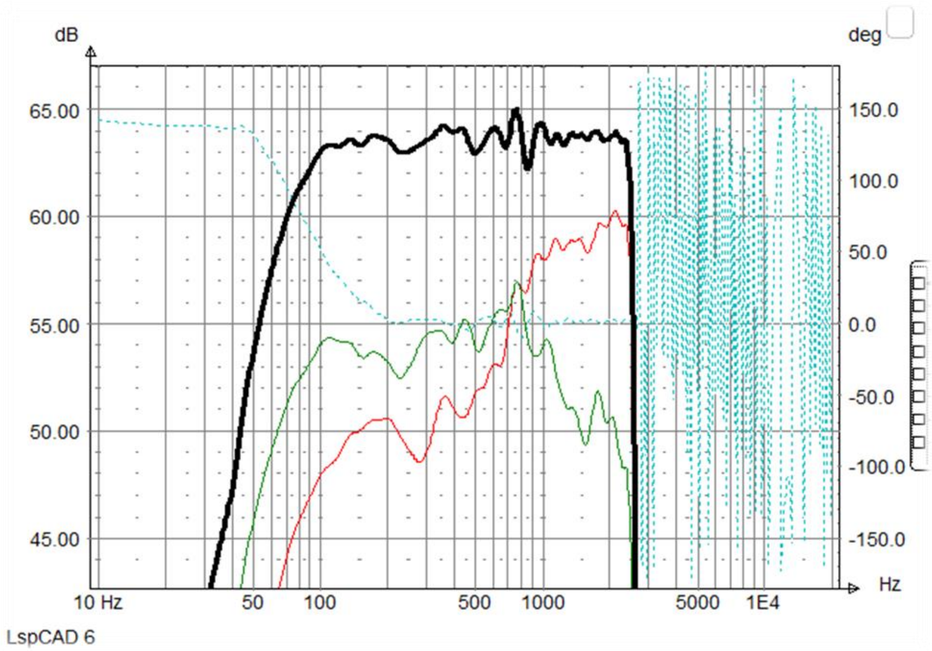


Figure 12 Bass/mid response with 2500Hz cut off and equalization from 200Hz and up

Finally, the subwoofer and bass/mid need to be yanked together. After some optimization, the resulting response becomes like Figure 13.

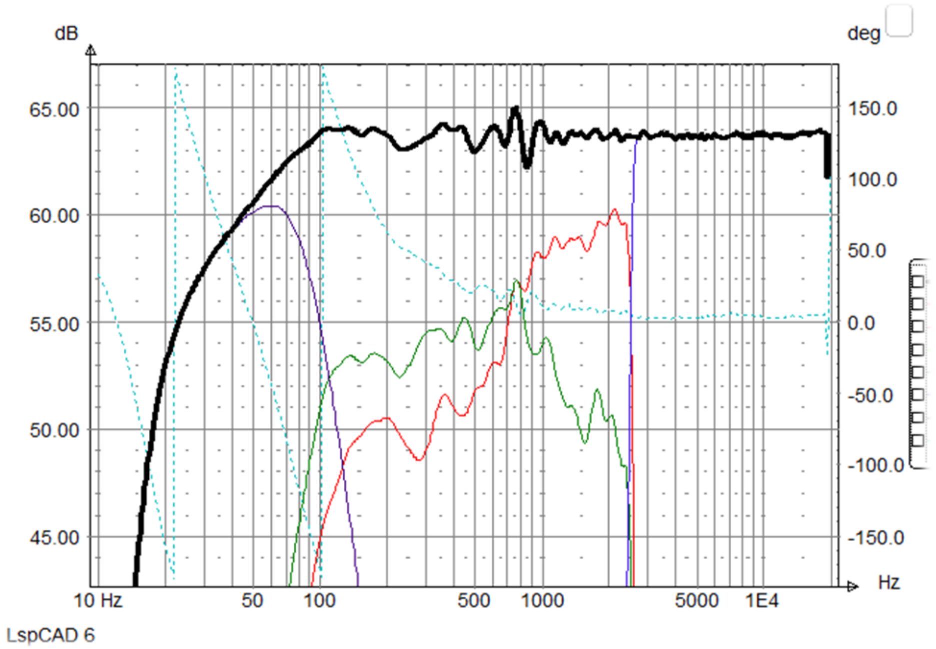


Figure 13 Resulting frequency response

An equalization is added to lift the subwoofer at very low frequencies and a 18Hz HP filter is added to avoid over excursion at subsonic frequencies. The subwoofer response drops with ~6dB/octave below 100Hz, this has turned out to work fine in the author's living room as it reduces issues with extreme low bass boominess. The resulting filter is shown in Figure 14. Note the extra 5ms delay for the subwoofer to align properly with the bass/mid and treble.

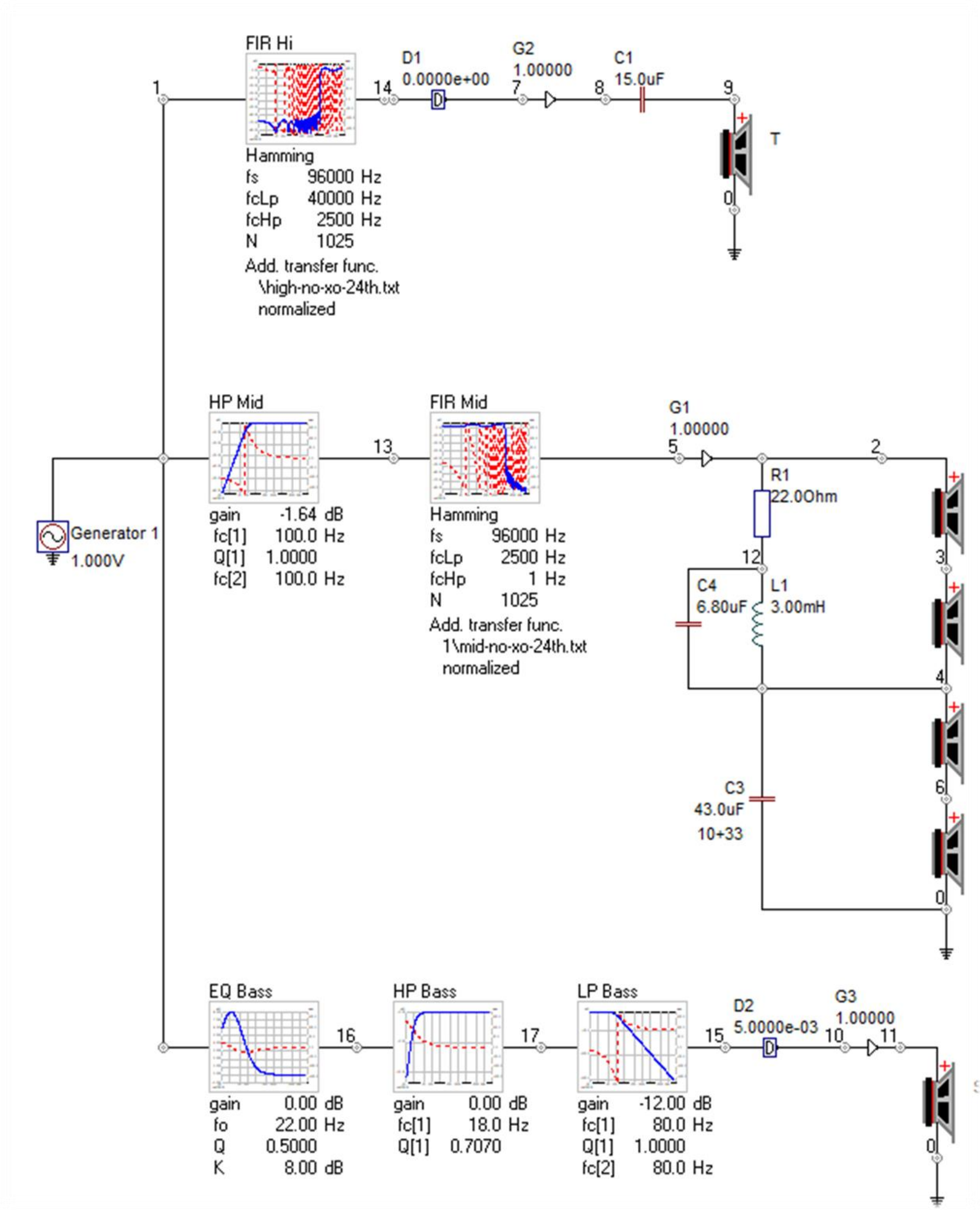


Figure 14 LspCAD 6 filter schematic

The transfer function for each of the loudspeaker units is shown in Figure 15

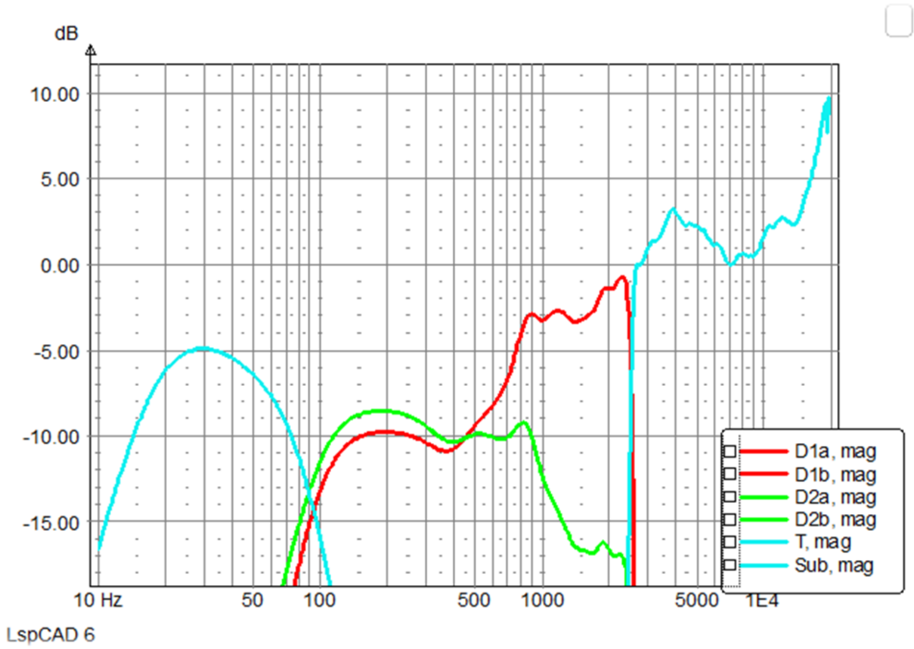


Figure 15 Transfer functions

Control measurements

Measurements are done in-house to see if the results meet the simulated response

The first measurement is with a 5ms time window, 80cm from the speaker, at tweeter height.

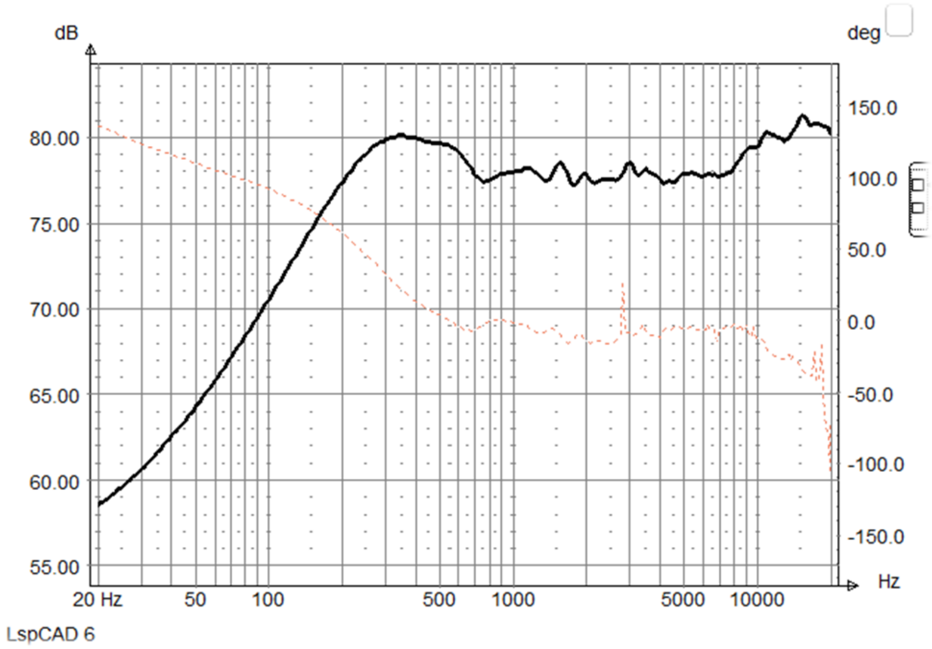


Figure 16 5ms time window 80cm distance

This result does not match the simulated result for the same distance. It is likely that the initial measurements done outdoors were not properly done. In any case the measured response look quite OK and the phase response above 500Hz is nearly flat as expected.

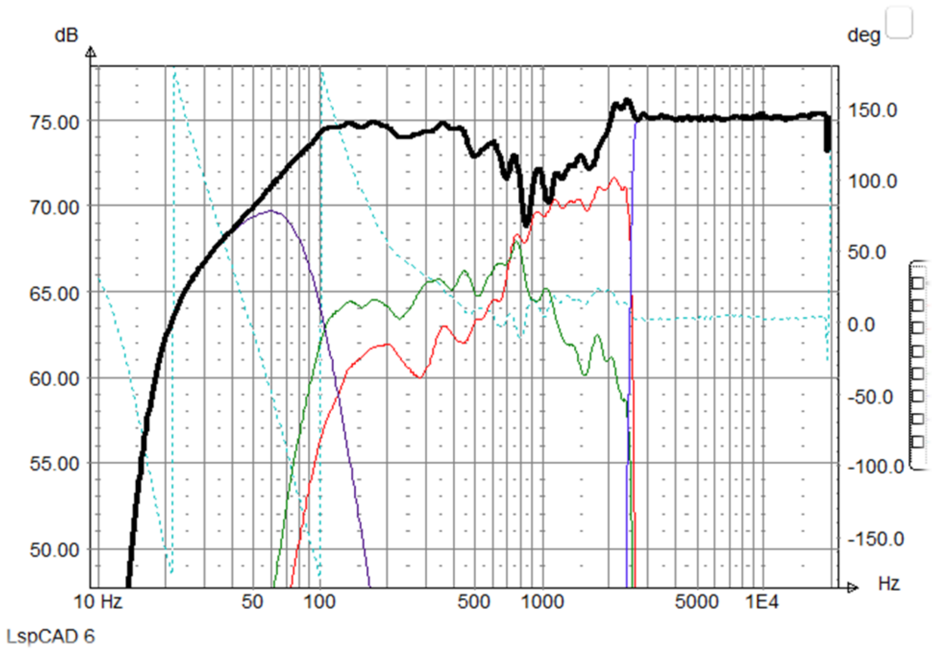


Figure 17 Simulated response at 80cm distance

A Measurement with a 40ms time window is shown in Figure 18. The extra rise towards low frequencies is due more in room reflections. The reason to the extra rise above 10kHz is unknown.

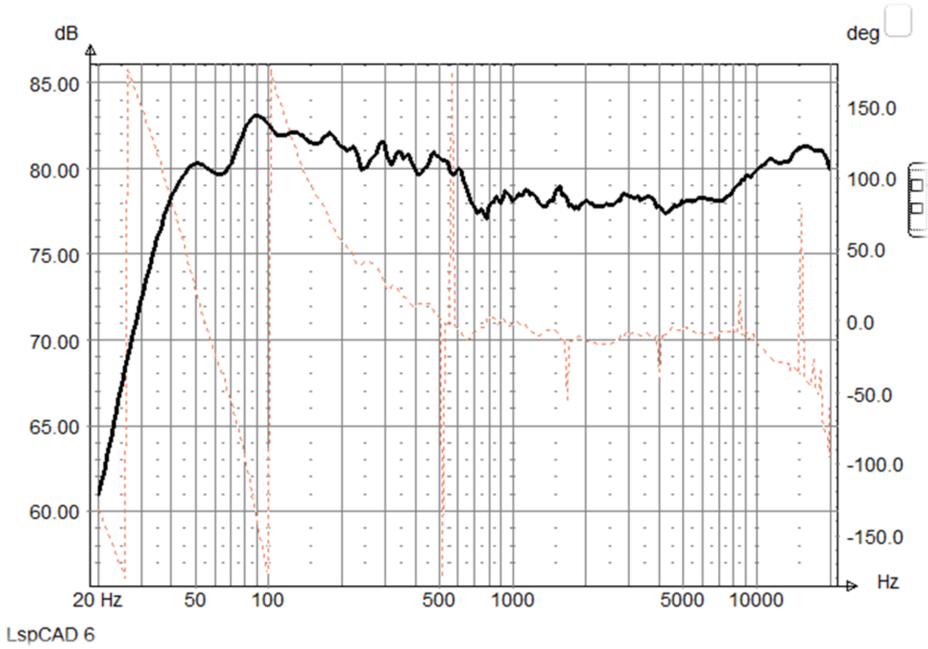


Figure 18 50ms time window 80cm distance

Finally, a measurement at 300cm distance with a 40ms time window. The response is here so cluttered up by reflections from hard surfaces

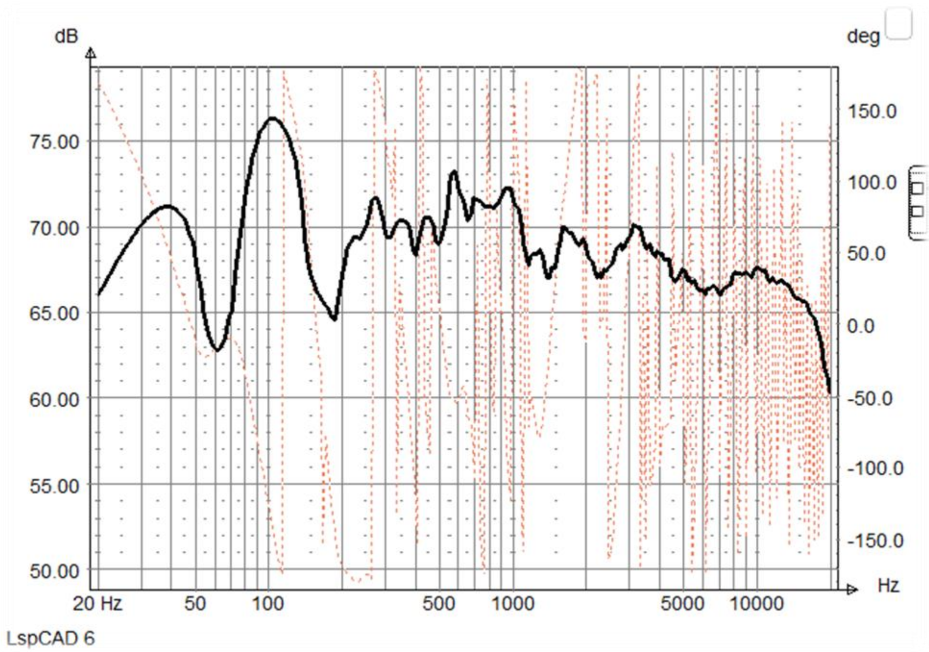


Figure 19 40ms time window and 300cm distance

Pictures








Excel

The Nangijala, open baffle speakers, built ca 2007 (left). The speaker units were recycled for use in the new Earendel (right)