Avalon Clone with Accuton CELL Series (Part 1)

XEN Audio

June 2013

Background

About 2 years ago, we came across the excellent website of Marc Heijligers on his Avalon Clone Build. It is very unfortunate that the website is no longer available, but the documentation of the development and the build was a perfect piece of technical reporting.

Early 2012, we talked to Joachim Gerhard about this, and he introduced us to the then brand new CELL series of Accuton, and they were also for Joachim interesting enough that he promised to help us with designing a version of the Avalon Clone based on them. I immediately jumped at the opportunity. Aside from the opportunity to a pair of reference-class speakers, I would not want to miss the opportunity of seeing at close proximity a top speaker designer at work. We must have been the first to order these chassis, as they took more than 6 months to deliver, very untypical for a German manufacturer.

I also told a friend about these chassis. Being a professor of mechatronics at a top European university and one of the top experts in the field, he went as far as downloading the geometry of the voice coil motor and having it simulated. The result confirmed a very impressive field uniformity in the air gap of better than 2% over the entire operation range. The new man at Accuton knows what he is doing.

For this built, we chose the C25-6-158 ceramic tweeter, and C90-6-724 mid-range. The new bass unit AS190-4-251 was not then available, and we were offered a C220-6-227 which is similar to the C220-6-221, but has neodymium magnets.

Enclosure

Making the enclosure took us more than half a year. The basic geometry was based on the Avalon Clone that was published by Tony Gee. The enclosure of the bass unit is a bass reflex of 50 litres with a reflex pipe of 70mm diameter and 210mm length. We had a discussion with Joachim as to where to place the bass reflex pipe. Instead of using down firing, Joachim suggested to put it co-axial, directly behind the bass chassis. For the mid-range, we built two different enclosure types, a vented sphere of 6 litres a la B&W Nautilus, and a "venturi" vented cone that was conceived by Joachim. We have to admit that we were a bit sceptical about the venturi, but as you will see we were proven totally wrong. The tweeter is a sealed unit, so only an opening of the correct diameter on the front baffle is required.

Different to conventional chassis, the mid-range and the tweeter has an expandable O-Ring mounting to the enclosure, which requires a solid cylindrical bore with the correct diameter. For the prototype we were milling this from solid MDF using a precision template to set the correct diameter. In the final version, a sleeve made from aluminium will be used for each chassis. The bass unit is just standard mounting flange with wood screws. So those were easy.

Preparation

When the prototype enclosures were ready, we test mounted the chassis and did some preliminary measurements ourselves. The chassis had been run-in for some 40 hours at normal music level, using a standard crossover I have lying around. This is only to ensure the tweeter and mid-range would not get damaged due to excessive load.

The measurement of the tweeter agreed essentially to that from the manufacturer. In any case, other than choosing the crossover frequency and the filter type, there is little one could do to influence its performance. The bass unit we could only measure near field, and then at the reflex pipe. The results corresponded reasonably to the design values. In case of the mid-range, it is worth noting that while the vented sphere extended some 50Hz lower than the venturi, it also showed a resonance at about 800Hz, probably due to standing waves inside the sphere. The vents in both the sphere and the venturi also showed another resonance at 50Hz and 80Hz respectively, well below the cross-over frequency. The 10-kHz cone break-up of the mid-range also resembled that published by Accuton.

After our rough measurements, we made up two minimalistic first-order crossovers at 300Hz and 3kHz and ran the chassis for another 80 hours. Even though far from optimum, the sound quality was already so obvious compared to anything else we had before.

Crossover Design with Joachim Gerhard

(All intellectual properties of the crossover design remain under the ownership of Joachim Gerhard)

After the first measurements and cross over design attempt ourselves, we travelled some 500km to meet up with Joachim Gerhard for proper measurement and for the design of the crossover.

Joachim showed us some current development of his own. For example, he showed us a small speaker called “Small Wonder”. It was a two-way based reflex, with a mid-range the size of Alpair 6 or smaller. The enclosure was smaller than our AP6 bass reflex, but the bass it produced was just amazing. The chassis is a custom production for him with extra-long strokes, and you can really see the piston going in and out at least 6mm. He also had a few prototype speakers based on the CELL mid-range in closed box. Those had already been published at DIYA earlier.

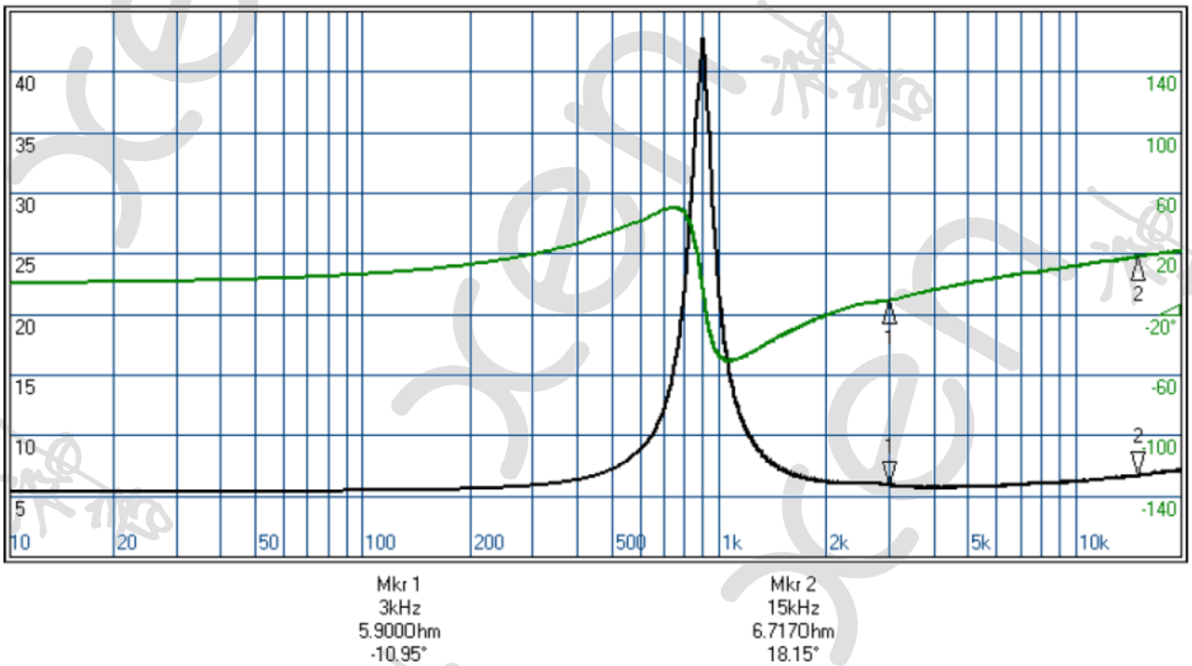
Impedance Measurement

The software used for the measurement is commercially available, and uses sweep sine rather than pulses as excitation. It has a long, self-calibrating routine which automatically corrects for the non-linearities of the ADCs and the DACs of the USB external soundcard. Not very user friendly, but Joachim thinks highly of the actual measurement methods, so the not-so-optimal user interface becomes bearable.

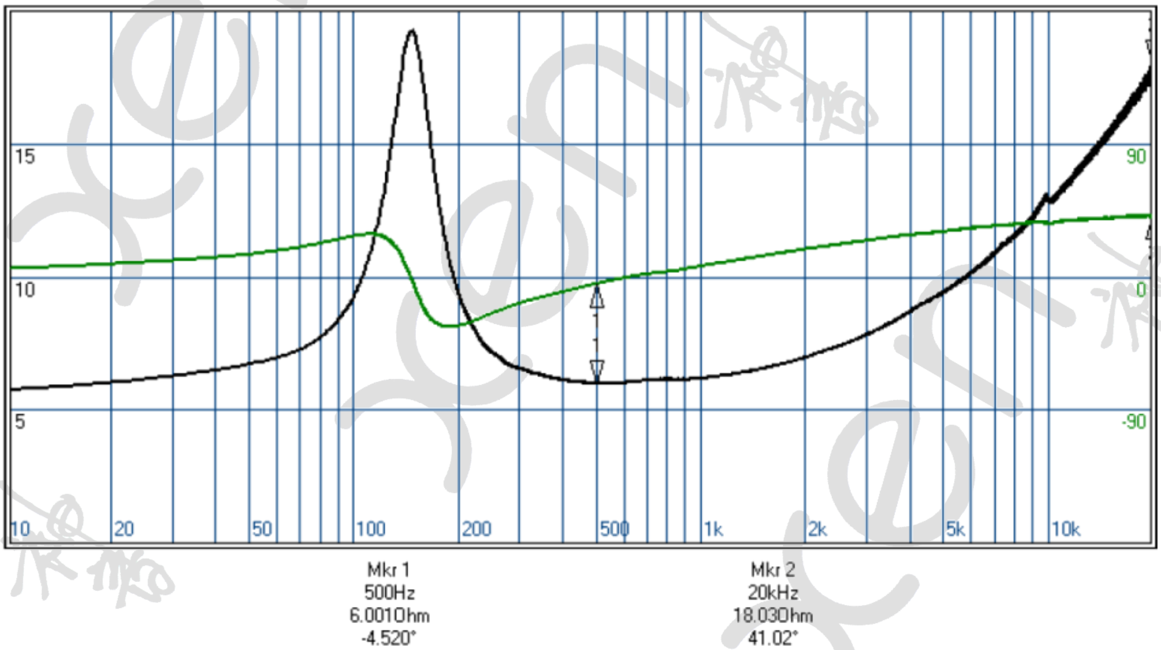
After a couple of hours setting up the speakers and measurement software, we started measurement. The speaker was placed on a pedestal about 50cm high. The first thing he did was to measure the impedance of each chassis using a 10R resistor in series at the amplifier output. For the mid-range, we could observe the same resonance of the sphere compared to the venturi. So we decided to proceed with the venturi, even though that resonance can be damped. No damping is always better than damping or notching. And the venturi was surprisingly free of resonances even without any stuffing at all.

As reported elsewhere, the exit opening at the back of the mid-range chassis had another pipe resonance around 1kHz, but this was removed by plugging the hole with egg-tray-shaped acoustic foam, with the “fingers” pointing towards but not touching the membrane. The opening of the venturi produce yet another resonance at 80Hz as already mentioned, and this disappeared as we plugged the hole by hand. But Joachim preferred a vented enclosure as they would sound more open in his experience. So we plugged the hole again with the same acoustic foam, which did the trick again. There was a very small spike left at about 2kHz which was barely visible. But being a perfectionist, Joachim removed those as well with loosely packed real sheep wool inside the venturi. One could have honestly left the venturi unstuffed, and the response would still have looked near-perfect.

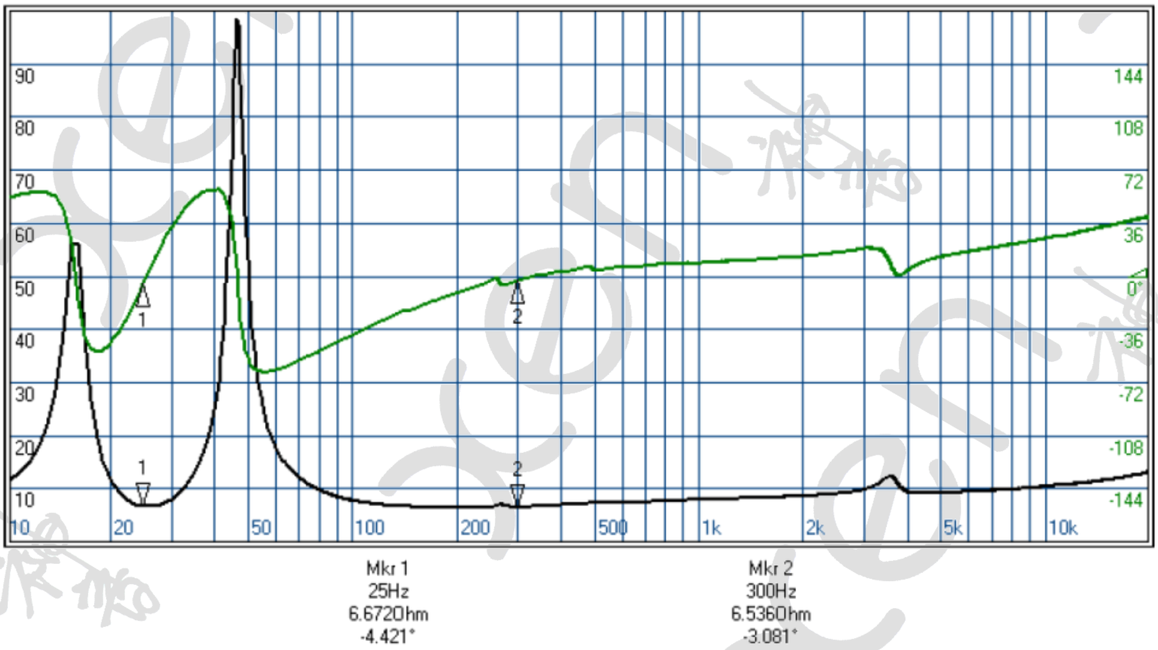
The tweeter is closed with no enclosure as such, so nothing needed tuning but just an impedance measurement. The bass impedance was also measured, and although the peak of the chassis was not of matched height as that of the reflex pipe, Joachim wanted to leave it as it was. He said that only if the bass would be too dry that we should trim the length a bit shorter. I have listened to this for more than 80 hours, and I can live with this comfortably as it is. There was a small resonance due to the longitudinal reflections inside the bass reflex box. So some packing for the bass reflex should be considered. It was lined with 10mm random-woven felt at the time of testing.



Tweeter



Mid-Range



Bass

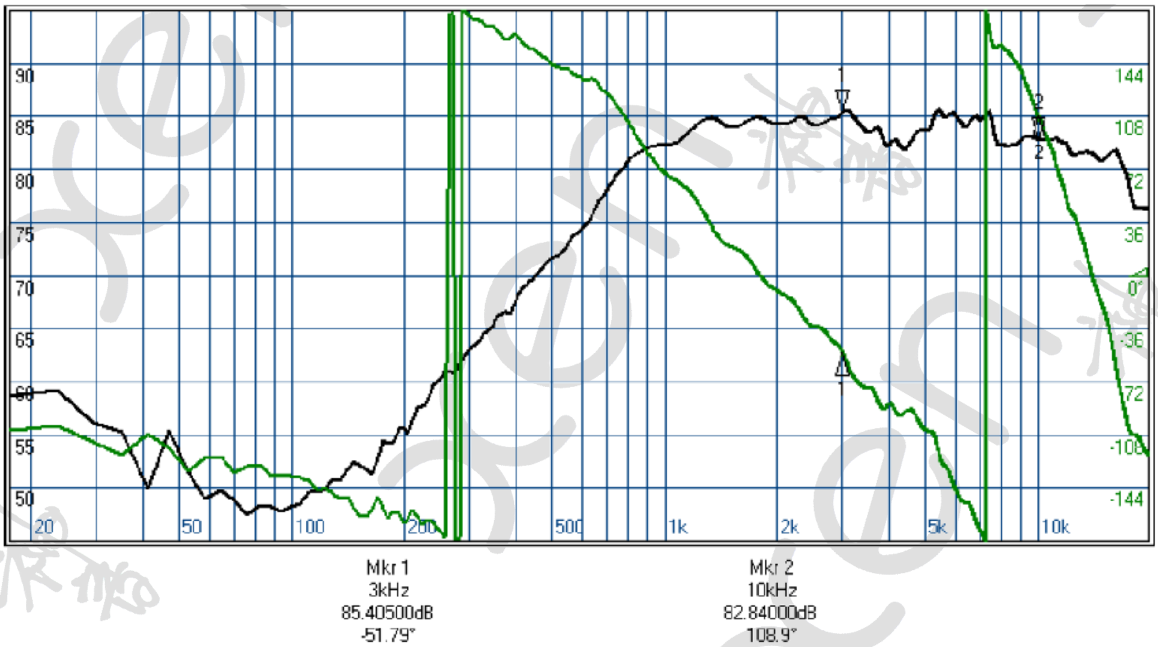
SPL Measurement

The impedance measurement was backed up by near-field SPL measurements using a calibrated wide-band microphone to make sure all the resonances were either dealt with or taken note of. It is worth noting that the drop of about 5dB of the tweeter above 10kHz as measured by us was less noticeable in Joachim's measurement. We presumed that this was due to his better calibrated microphone. Joachim also did not attempt to use SPL for the bass reflex tuning, relying purely on the impedance measurement of the bass unit.

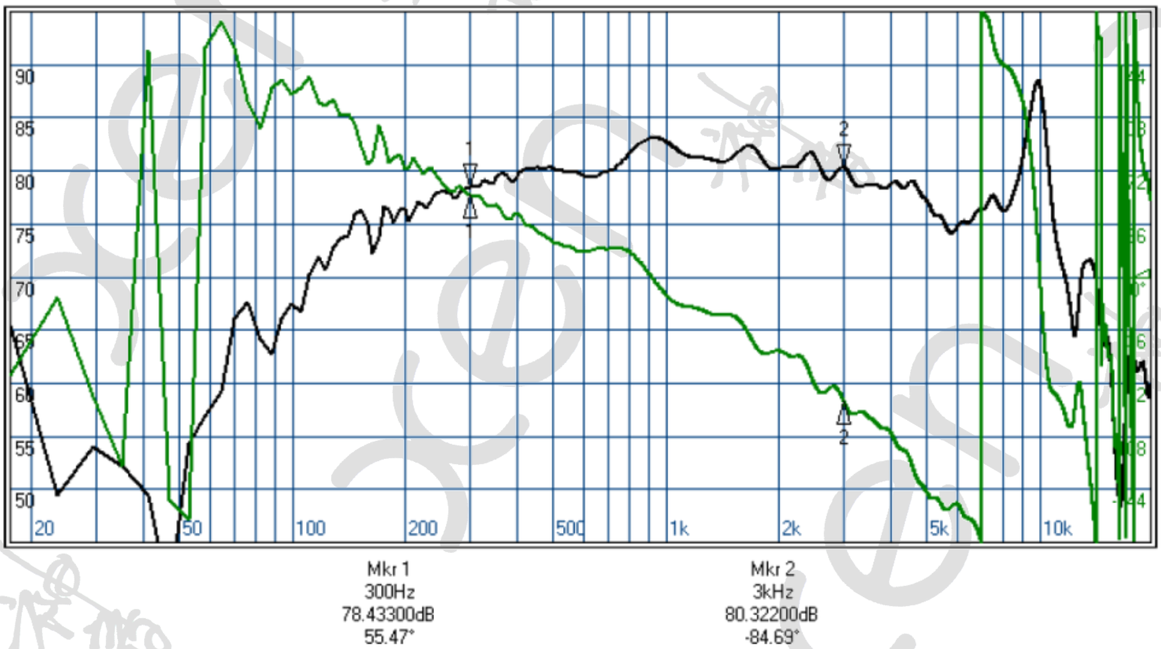
The next step was to measure the far field response. The microphone was placed some 75cm away from the chassis, and the time delay for a pulse response was measured. The time delay of the mid-range was found to be 40µs ahead of the tweeter, so the mid-range was used as reference and its time delay applied to all 3 chassis. The speaker was slightly rotated off axis, to find the best compromise for a flat response for the tweeter. This is then defined as the reference measurement axis. The SPL response of all 3 chassis was then measured with the microphone at this same position (vertical level in line with the tweeter).

After these, the reference measurements for impedance and SPL for all 3 chassis in their respective optimised enclosures were obtained and these were exported to separate software for cross-over design.

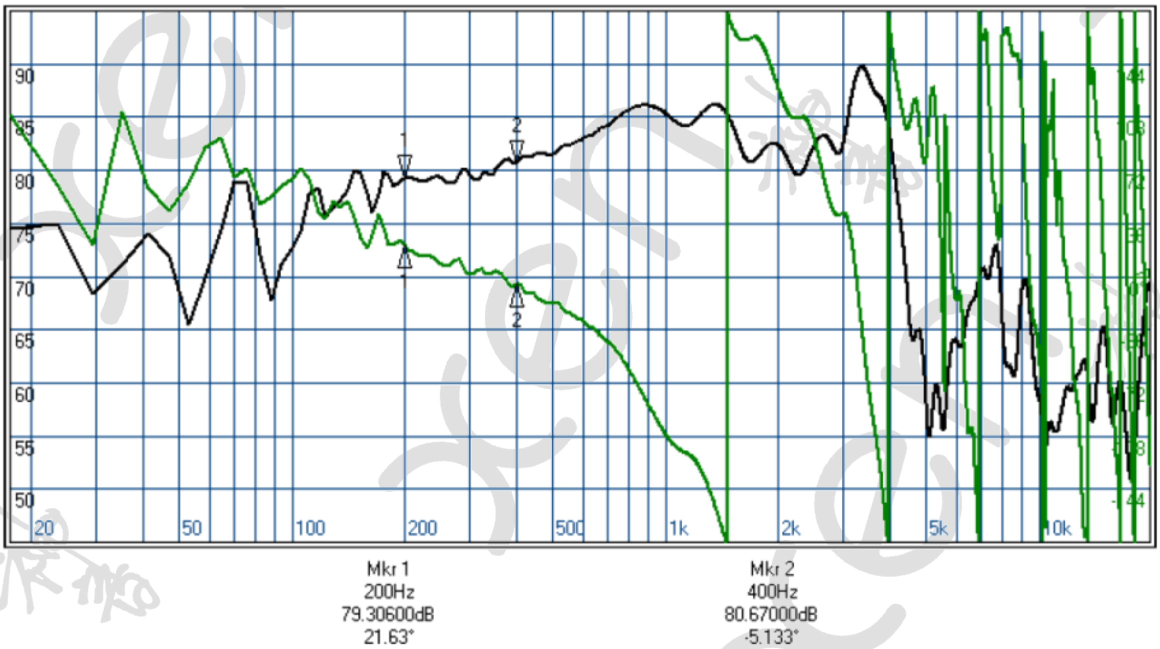
Joachim also proposed to reduce the front baffle tilt angle from 9° to 5° or 6° to time align the tweeter and the mid-range. Also we should reduce the vertical distance between the two to something like 15mm between the peripheries.



Tweeter

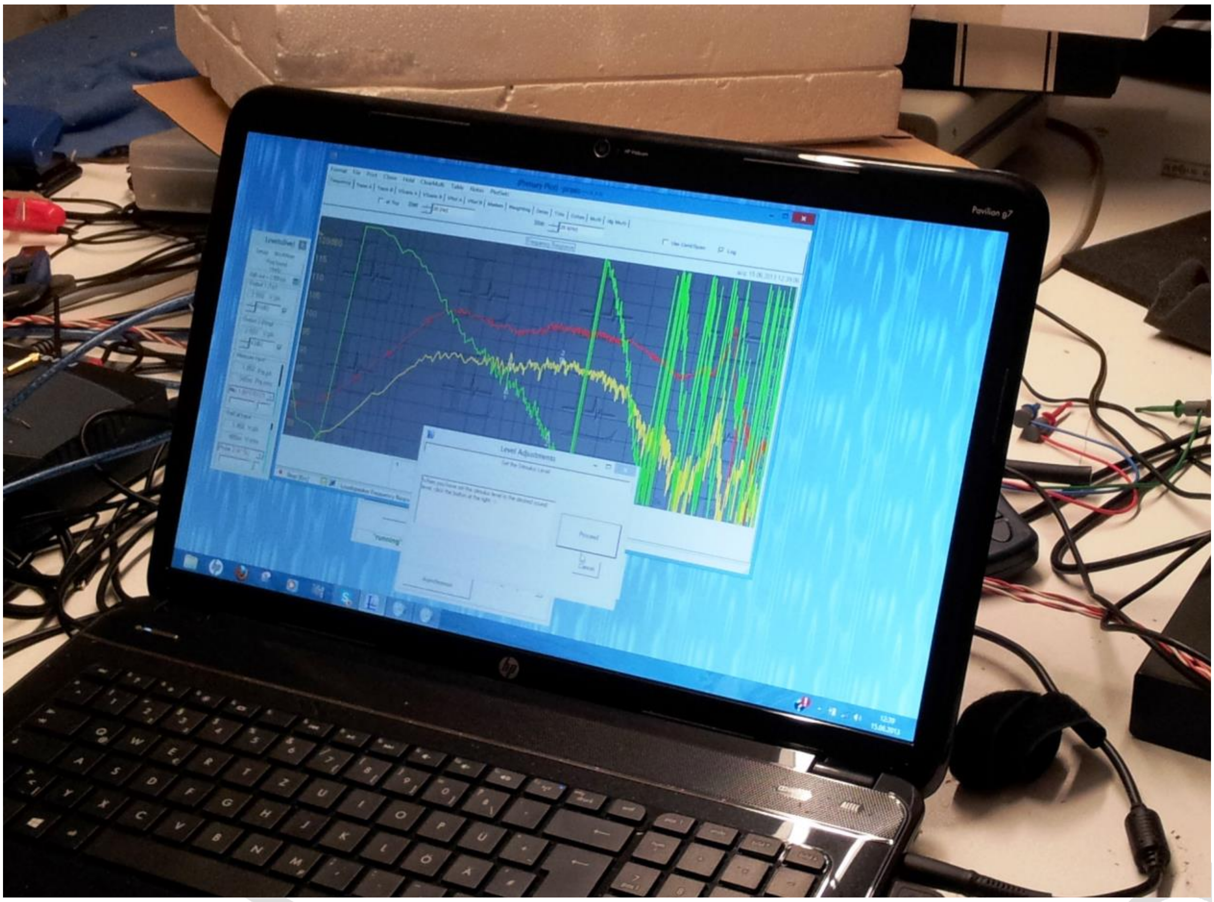


Mid-Range



90
85
80
75
70
65
60
55
50
20
50
100
200
500
1k
2k
5k
10k
Mkr 1
200Hz
79.30600dB
21.63°
Mkr 2
400Hz
80.67000dB
-5.133°

Bass



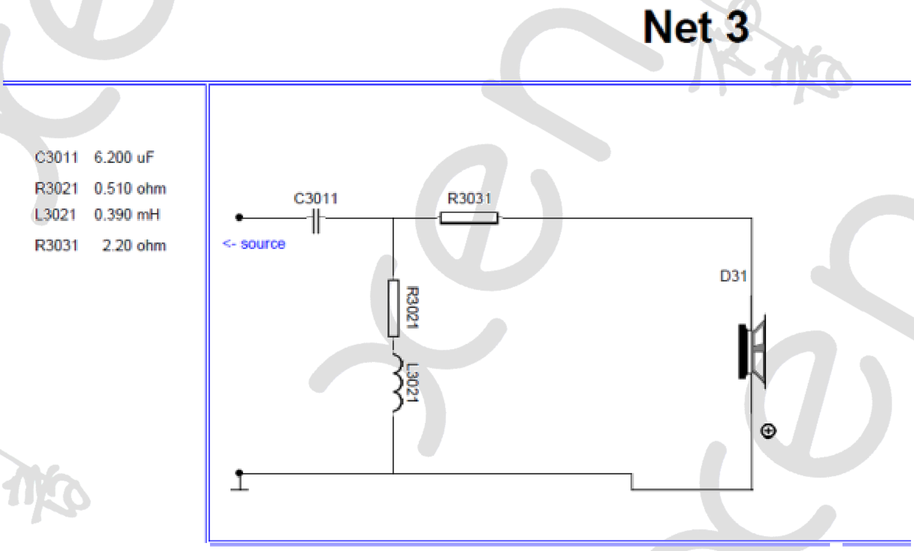
Cross-Over Design

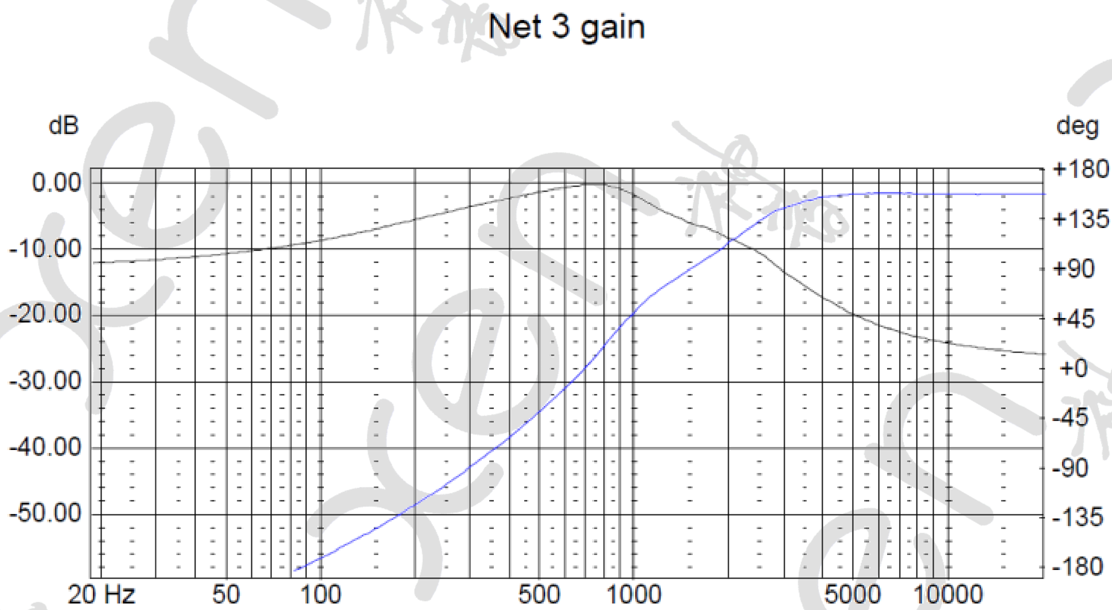
Cross-over design is an art as there are infinite numbers of possible solutions, and each one has its own sonic signature. It is also where the signature of one designer differs from another. Joachim has 40 years' experience in this, and the speed with which he juggled different parameters was simply amazing to watch.

He started off with the mid-range, first flattening its impedance peak at around 150Hz with a RLC notch. Then he used another notch to remove the 10kHz cone break-out of the mid-range membrane. A RC Zoebel was then used to flatten the impedance rise at HF. Crossover to the bass was chosen at 270Hz, around which the bass chassis had the most favourable gain / phase behaviour. Crossover with the tweeter was then set at 2700Hz. He preferred to use 2nd order Linkwitz for a 3-way application like ours. The Accuton membranes were known to be very fragile and could even fracture under normal usage, so first order crossover should be avoided. The disadvantage of the LR2 is of course that the bass and the tweeter have to be phase inverted. Since the mid-range in the venturi already had a natural 1st order drop below 300Hz, the electronic filter only needed to be of first order.

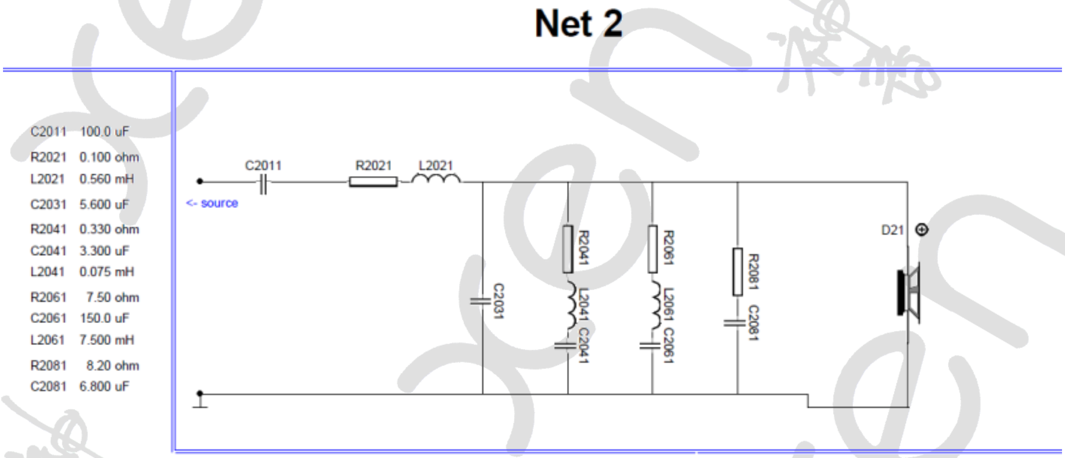
The result of half an hours' CAD design can be seen below :

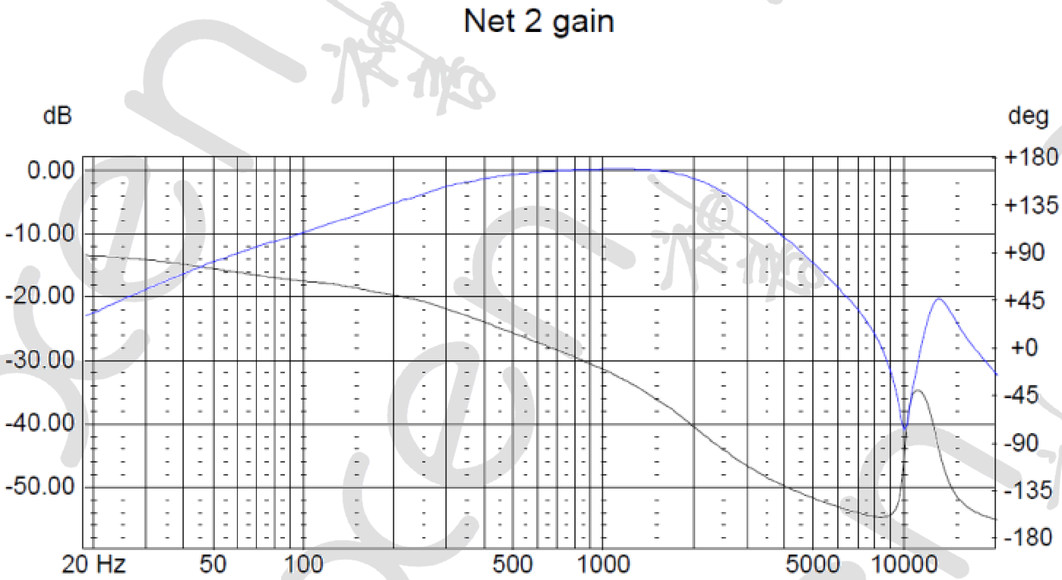
1) **Crossover Tweeter**



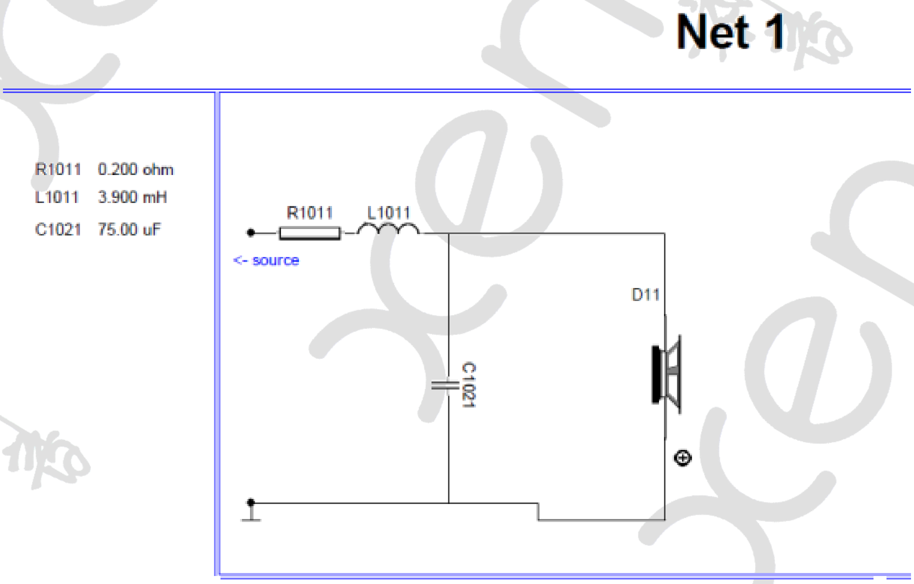


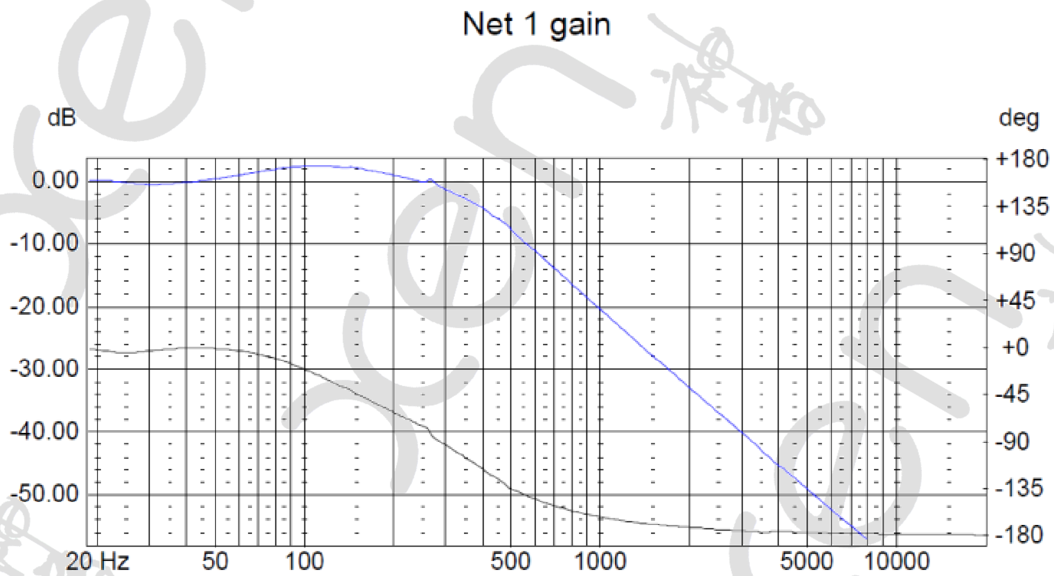
2) Crossover Mid-Range



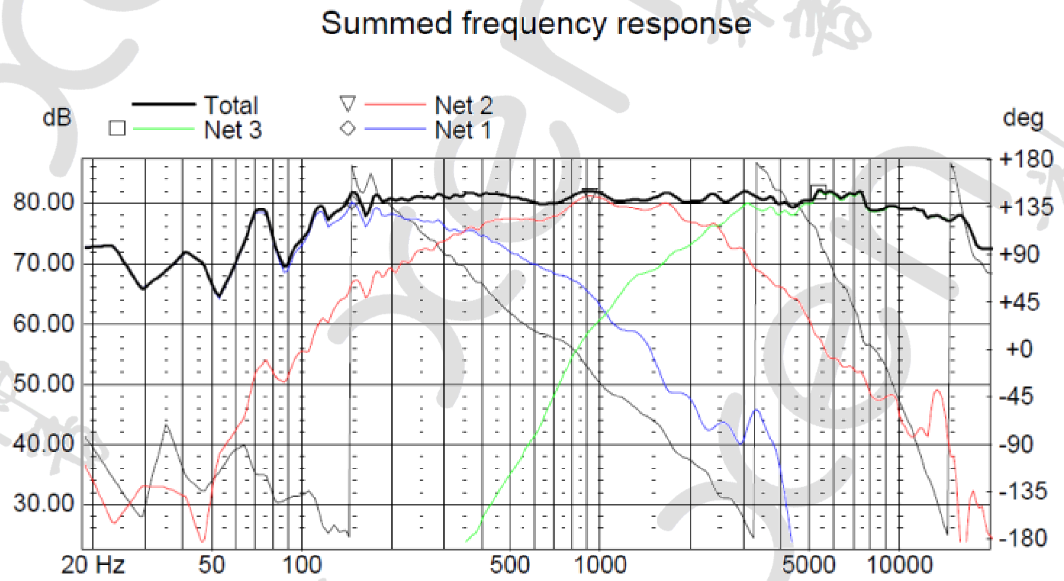


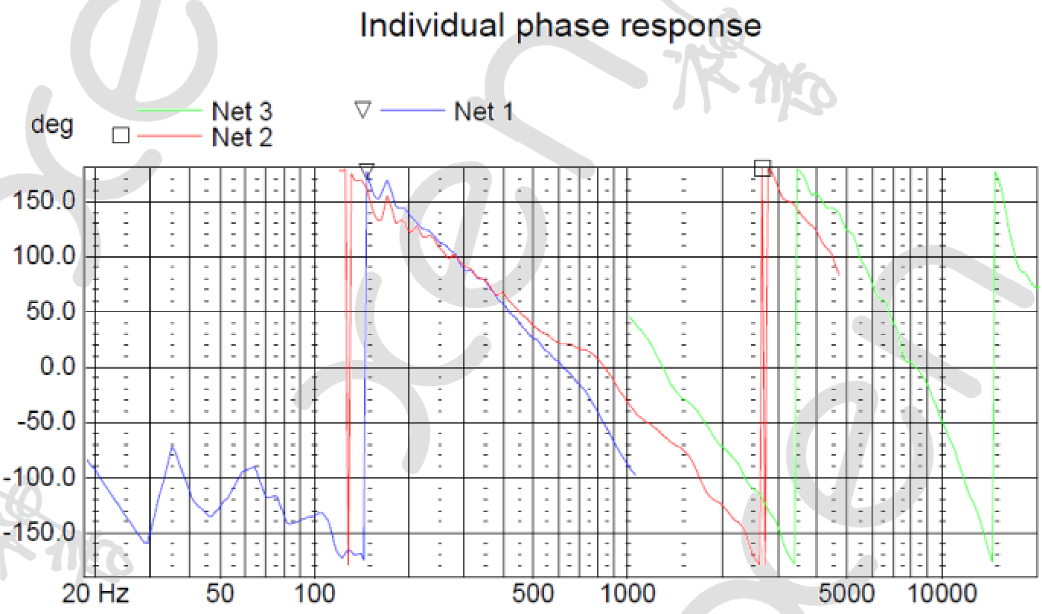
3) **Crossover Bass**



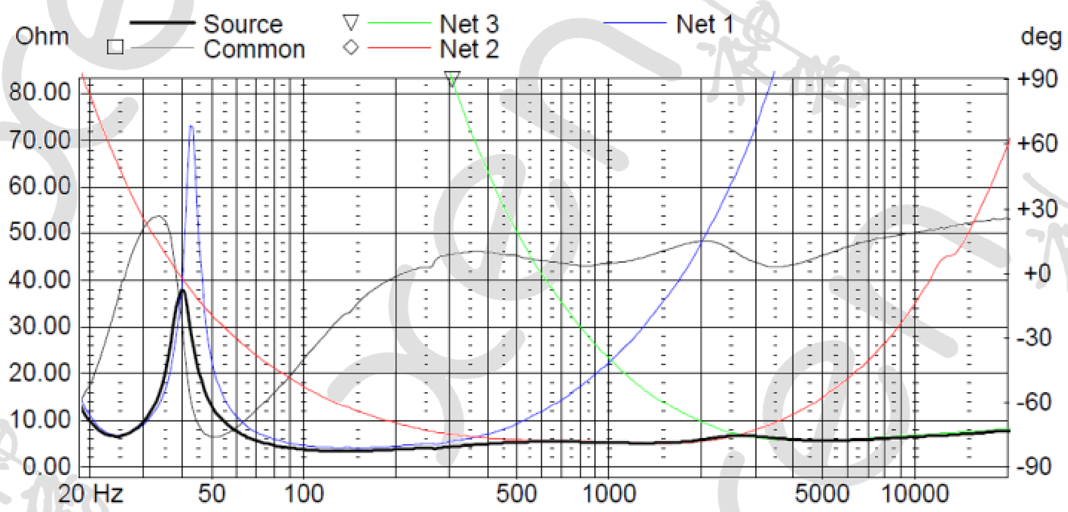


4) Overall response

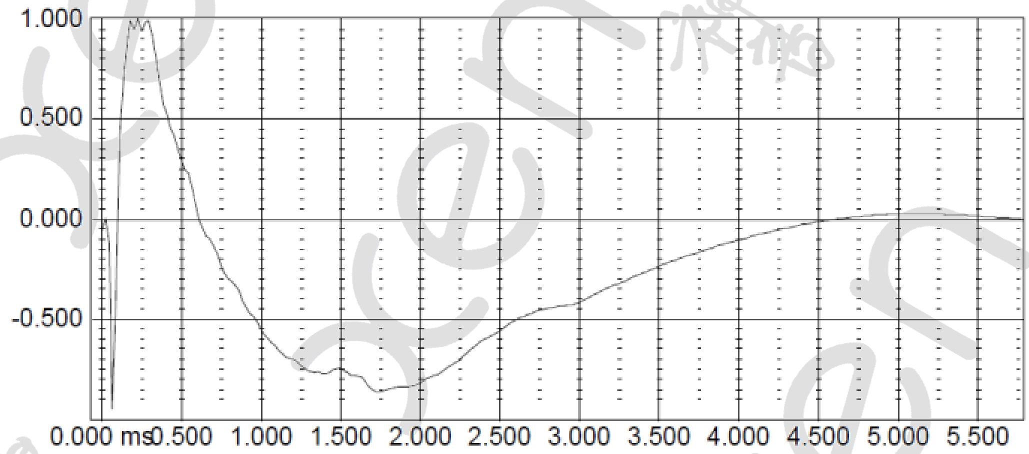




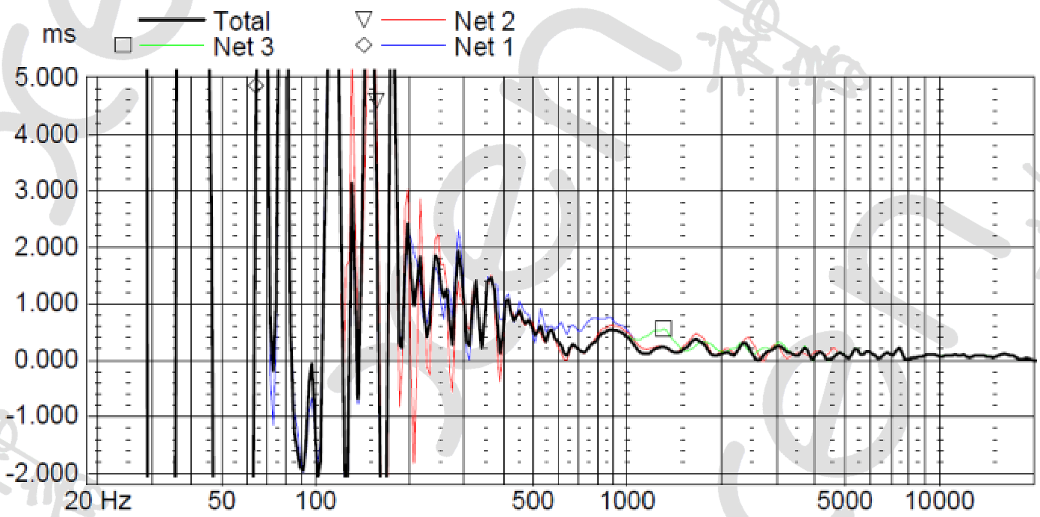
Input impedance



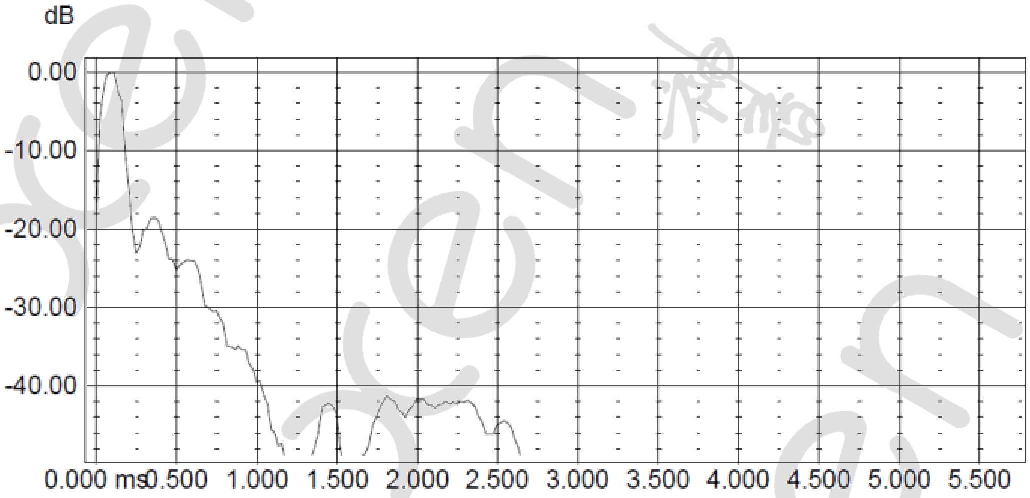
Step response



Group delay



Energy-time response



It is worth mentioning that the frequency response of the overall impedance of the passive crossover is flat from 100Hz onwards. Even though it is a low-ish 4 ohms, this is not a result of the crossover design but rather a function of the drivers. This is because the electrical impedance of the crossover is constant, and thus we see more or less the Re impedance of the drivers. According to Joachim, any crossover that does not present a constant impedance stores energy in the crossover. In this design, Joachim found a unique combination of flat impedance and flat amplitude response WITHOUT putting anything in parallel with the OUTSIDE of the crossover.

And most modern-day power amplifier would have no problem handling that impedance.

Choice of Crossover Components

Before the choice of crossover components are made, it is logical to understand their functionality first. Also, even though Joachim designed a purely passive crossover, we made the conscious decision right from the start to use line-level crossover between bass and mid-range. So some adaption would be necessary.

Tweeter

For the tweeter, C3011 and L3021 forms a 2nd order HP filter at 3.24kHz. R3031 is used to balance the SPL between the tweeter and the mid-range. This can be varied from 1.5 to 2.2 ohm according to listening impressions. Otherwise it will remain as is, a purely passive crossover.

As the crossover is in the signal path and is HF, it is important to use good components. The following choice was made together with Joachim :

C3011	Mundorf EVO oil 5.6µF // 0,56µF // Polystyrol 10nF 160V
L3021	Mundorf CFC-16 0.39mH
R3031	First test with normal wire-wound to decide final value, then Mundorf Supreme Wire-wound

Mid-Range

C2011 and the impedance of the chassis forms a 1st order (electrical) HP at around 275Hz. Since an active crossover is to be used between mid-range and bass, this is no longer needed. The line-level crossover takes the form of a simple C-R of 33n/17.5k followed by a simple buffer such as a JFET source follower.

L2061, C2061 and R2061 are for the impedance correction for the fundamental resonance of the Cell midrange in the damped Venturi. If that impedance would not be flat, the roll-off by C2011 would become bumpy. In an active midrange-bass crossover, this impedance correction of the fundamental resonance of the midrange is not necessary as the varying impedance is taken care of by the damping factor of the power amplifier. Hence they are left out.

L2021 and C2031 forms a 2nd order (electrical) LP filter at 2840Hz to crossover with the tweeter. So again good quality components should be used :

L2021	Mundorf CFC-14 0.56mH
C2031	Mundorf EVO oil 5.6µF // Polystyrol 10nF 160V

R2081 and C2081 are for impedance correction for the inductance of the Cell so that the impedance curve is flat in the mid-range treble. Again this is HF in shunt and hence the following components are chosen :

R2081	Isabellenhütte PBH 8R2
C2031	Mundorf EVO oil 6.8µF // Polystyrol 10nF 160V

Then L2041, C2041 and R2041 forms a notch at 10kHz to suppress the 10kHz cone break-out.

L2041	Mundorf L50 0.075mH, DCR 0.34 (modified from 0.1mH, epoxy impregnated)
C2041	Mundorf EVO oil 3.3µF
R2041	replaced by DCR of L2041

Bass

L1011 & C1021 forms a (electrical) 2nd order LP filter at 295Hz. However C1021 is in parallel with the impedance of the chassis, which is about 6.3R around the crossover frequency. Simulations show that this is best simulated by a 2^{nd} order Linkwitz Riley of Q 0.866, rather than Q 0.5. The Sallen-Key LP filter uses R's of 11.5k and C's of 27n / 80n.

No crossover components at power level are required for the bass at all. This, together with the elimination of the HP components for the mid-range, means that all the high value components of the passive 3-way crossover, which are both bulky and expensive, can be avoided altogether.

(to be continued)